Baffinland Iron Mines Corporation–Mary River Project

2018 Passive Acoustic Monitoring Program

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Executive Summary

The Mary River Project (the Project), an iron ore mining project owned by Baffinland Iron Mines Corporation (Baffinland), located in the Qikiqtani region of Nunavut, opened in 2015 with high shipping activity occurring during the open water season. Commercial shipping operations associated with the Project overlap with established summering grounds for the Eclipse Sound narwhal summer stock during the open-water season.

The 2018 Passive Acoustic Monitoring Program was developed by JASCO Applied Sciences (JASCO), in collaboration with Golder Associates Ltd. (Golder) and Baffinland, to evaluate potential Project-related effects to marine mammals from shipping noise. The main objective of this program was to document ambient underwater noise levels and identify marine mammal (notably narwhal) presence at five acoustic monitoring stations in Milne Inlet from 04 August to 28 September 2018. A secondary objective was to evaluate Project-shipping noise levels in relation to established marine mammal acoustic thresholds for injury and disturbance.

Five marine acoustic recorders were deployed in the vicinity of the Mary River Project shipping activities in southern Milne Inlet, Nunavut, between 4 Aug and 28 Sep 2018 (56 days) to characterize the baseline noise conditions near the Project site and to monitor marine mammal acoustic occurrence.

The underwater soundscape and its noise contributors were quantified. Sound exposure levels were similar at AMAR−1, −2, −4, and −5, with lower levels at AMAR−3 where the recorder was located in a more protected embayment. The primary contributor to the soundscape throughout the recording period was shipping; however, wind and waves also contributed to the soundscape at each station.

Sounds from three species of marine mammals were identified acoustically in the data. Narwhals were detected across all stations between 9 Aug and 24 Sep 2018. Narwhal whistle and click detections at the northern station (AMAR−5) were more limited than at other stations, likely reflecting a north-south distribution of narwhal in the Bruce Head study area. Narwhal acoustical presence was higher at stations in the southern part of the study area. Killer whales were manually detected on two days (31 Aug and 1 Sep 2018) at all stations. This short period of killer whale calls is consistent with the migratory behaviour of the species in the study area. Sporadic detections of ringed seal vocalizations indicate their presence in the area.

This study provides information on the occurrence of narwhals in the vicinity of the Mary River Project in southern Milne Inlet. Our findings suggest that the anthropogenic sounds (vessel noise) did not approach the National Marine Fisheries Service (NMFS, 2018) thresholds for possible injury to marine mammal hearing. The exceedances of 120 dB re 1 µPa (a threshold recommended by National Oceanic and Atmospheric Administration (NOAA) for disturbance of cetaceans) were rare at all stations. At AMAR−1, the station with the highest sound levels, and one of the stations with the highest narwhal whistles detections, the 120 dB threshold was exceeded 2.4% of the time. At AMAR−3, the station furthest from the shipping route and with the lowest sound levels, the 120 dB threshold was exceeded 0.5% of the time.

Listening range reduction (LRR) is the fractional decrease in the available listening range for marine animals. The largest LRR occurrences were associated with ambient noise, such as wind and rain, rather than vessels for the narwhal whistle and click frequencies, especially at AMAR−3; but ambient noise did not cause LRR for burst pulses. The effects from vessel noise were greater at AMAR-1 than AMAR-3, as expected. At AMAR-1, there was greater than 90% LRR for whistles during 4.3% of the time when vessels were detected, for burst pulse calls during 0.9% of the time that vessels were detected, and for clicks during 10.2% of the time when vessels were detected. At AMAR-3, there was greater than 90% LRR for whistles during 0.2% of the time when vessels were detected and for clicks during 1.9% of the time when vessels were detected. Vessels did not impact the listening range for burst pulse calls at AMAR-3.

The measurements from this study were compared with predicted underwater sound footprints for transiting ore carriers, generated through numerical modelling in support of the Mary River Project Phase 2 Proposal. The model estimates often exceeded the levels measured in this study at the AMAR locations. This was predominantly due to the fact that the vessel source level applied in the model exceeded the measured vessel source levels by as much as 15 dB. Measured and modelled underwater sound levels were in good agreement for a vessel with a source levels that matched the modelled surrogate. The measurements were between 1 and 10 dB of the modelled levels, depending on range and aspect from the transiting vessel.

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ᓄᓘᔮᒃ ᐅᔭᖅᓂᐊᕐᕕᒃ, ᓴᕕᖃᔭᒃᓴᓂᒃ ᐅᔭᖅᓂᐊᖅᑐᑦ ᓇᖕᒥᓂᕆᔭᐅᔪᖅ ᐸᕕᓐᓛᓐᑦ ᓴᕕᖃᔭᒃᓴᓂᒃ ᐅᔭᖅᓂᐊᖅᑎᑦ ᑯᐊᐳᕆᓴᓐ, ᑕᐅᕙᓃᑦᑐᖅ ᕿᑭᖅᑕᓂ ᓄᓇᕗᒻᒥ, ᒪᑐᐃᓚᐅᖅᑐᖅ 2015 ᐅᓄᖅᑐᓂᒃ ᐅᒥᐊᕐᔪᐊᖃᖅᑎᓪᓗᒍ ᐃᖏᕐᕋᔪᑦ ᓯᑯᑲᖏᑎᓪᓗᒍ ᐃᒪᖓ ᐊᐅᔭᒃᑯᑦ. ᑮᓇᐅᔭᓕᐅᕈᑕᐅᔪᑦ ᐅᒥᐊᕐᔪᐊᑦ ᐅᓯᑲᖅᑕᖅᑐᑦ ᐱᓕᕆᔪᑦ ᑖᒃᑯᓄᖓ ᐅᔭᖅᓂᐊᕐᕕᒃ ᐸᕐᔭᒡᓘᑎᓯᒪᖕᒪᑦ ᐊᐅᔭᖃᕐᕕᐅᕙᒃᑐᓄᑦ ᑕᓯᐅᔭᖅ ᑑᒑᓕᑦ ᕿᓚᓗᒐᐃᑦ ᐊᐅᔭᖃᑦᑕᕐᒪᑕ ᓯᑯᖃᖅᑎᓇᒍ ᐊᐅᔭᒃᑯᑦ.

ᑕᐃᑲᓂ 2018 ᓂᐱᖏᓐᓂᒃ ᖃᐅᔨᓴᓚᐅᖅᑐᑦ ᓴᕿᑕᐅᓯᒪᓪᓗᓂ ᔮᓐᑯ ᖃᐅᔨᓴᖅᑎᒻᒪᕇᑦ, ᐃᑲᔪᖃᑎᒌᓪᓗᒋᑦ ᒎᓪᓗ ᐱᓇᓱᐊᖃᑎᒌᑦ ᑎᒥᖓ ᐊᒻᒪᓗ ᐸᕕᓐᓛᓐᑦ, ᖃᐅᔨᓇᓱᑦᑎᐊᖅᓱᒋᑦ ᐅᔭᖅᓂᐊᕐᕕᒃ-ᐱᓯᒪᔪᓂᑦ ᐊᒃᑐᐃᒐᔭᕐᒪᖔᑕ ᐳᐃᔨᓂᒃ ᐅᒥᐊᕐᔪᐊᑦ ᐅᓯᑲᖅᑕᖅᑐᑦ ᓂᐱᖏᓐᓂᑦ.

ᐅᓇ ᑐᑭᓕᐅᕈᑕᐅᕙᓪᓕᐊᔪᖅ ᐱᓕᕆᑎᑦᑎᔾᔪᑕᐅᔪᖅ ᑎᑎᕋᖅᑕᐅᓗᑎᒃ ᐊᓯᐊᓂᑦ ᐃᒫᓂ ᓂᐹᕿᔪᑦ ᓂᐱᓖᑦ ᐊᒻᒪᓗ ᓇᓗᓇᐃᕐᓗᒋᑦ ᐳᐃᔨᑦ (ᐱᓗᐊᖅᑐᒥᒃ ᑑᒑᓕᑦ ᕿᓚᓗᒐᐃᑦ) ᐱᑕᖃᕐᒪᖔᑕ ᑕᓪᓕᒪᓂ ᓂᐱᓕᐅᕐᕕᐅᔪᑦ ᓈᓚᒡᕕᐅᔪᑦ ᕿᑦᖑᐊᓂ ᐱᒋᐊᖅᓱᑎᒃ 04 ᐋᒍᓯ ᑎᑭᓪᓗᒍ 28 ᓯᑎᐱᕆ 2018. ᐱᖃᑖ ᑐᑭᓕᐅᕈᑕᐅᕙᓪᓕᐊᔪᖅ ᖃᐅᔨᓇᓱᑦᑎᐊᕐᓗᒋᑦ ᐅᔭᖅᓂᐊᕐᕕᒃ-ᐅᓯᑲᖅᑕᖅᑐᑦ ᓂᐱᖏᑦ ᐳᐃᔨᑦ ᐃᓂᒥᖕᓂ ᐋᓂᖅᓯᒪᓂᕈᑎᒃ ᐊᒻᒪᓗ ᐸᒡᕕᔭᐅᒍᑎᒃ.

ᑕᓪᓕᒪᑦ ᑕᕆᐅᕐᒥ ᓂᐱᓕᐅᕈᑎᑦ ᐃᖃᖓᓂ ᓂᐱᖃᖅᑐᓂᒃ ᐃᒫᖅᑕᐅᓚᐅᖅᑐᑦ ᖃᓂᒋᔭᖓᓂ ᓄᓘᔮᒃ ᐅᔭᖅᓂᐊᕐᕕᒃ ᐅᓯᑲᖅᑕᕐᕕᐅᔪᑦ ᖃᓄᐃᓕᐅᕐᕕᐅᔪᓂ ᓂᒋᐊᓂ ᕿᑦᖑᐊᑕ, ᓄᓇᕗᑦ, ᐊᕙᑖᓂ 4 ᐋᒍᓯ ᐊᒻᒪᓗ 28 ᓯᑎᐱᕆ 2018 (56 ᐅᓪᓗᓄᑦ) ᓴᕿᑦᑎᐊᖅᓱᒋᑦ ᓇᒧᑦ ᑎᑭᐅᑎᓯᒪᓂᖏ ᑭᓪᓕᖓᓂ ᓂᐱᖃᖅᑐᑦ ᖃᓂᒋᔭᖓᓂ ᐅᔭᖅᓂᐊᕐᕕᒃ ᐊᒻᒪᓗ ᒥᐊᓂᕆᓪᓗᒋᑦ ᐳᐃᔨᑦ ᓂᐱᖃᖅᑐᑦ.

ᐃᒪᐅᑉ ᐃᓗᐊᓂ ᐊᖅᑲᐅᒪᔪᑦ ᓂᐃᖏ ᐊᒻᒪᓗ ᓂᐱᖃᖅᑎᑦᑎᔪᑦ ᖃᐅᔨᔭᒃᓴᐅᓕᓚᐅᖅᑐᑦ. ᓂᐱᖏᑦ ᓇᒧᖔᓯᒪᖕᒪᖔᑕ ᐊᕙᑖᓂ ᐊᔾᔨᒋᓪᓗᒋᑦ ᑕᐃᑲᓂᑦᑕᐅᖅ ᐃᒫᓂ ᓂᐱᓕᐅᕈᑎᑦ−1, −2, −4, ᐊᒻᒪᓗ −5 ᐊᒻᒪᓗ ᓂᐱᑭᓐᓇᖅᓴᐃᑦ ᑕᐃᑲᓂ ᐃᒫᓂ ᓂᐱᓕᐅᕈᑎᖃᖅᑐᓂ - 3 ᑕᐃᑲᓂᓗ ᓂᐱᓕᐅᕈᑎᖓᑕ ᐃᓂᖓ ᓴᐳᒻᒥᔭᐅᕕᑦᑎᐊᕙᒃ ᕿᓚᓗᒐᓄᑦ. ᑕᐃᒪᓐᓇᐅᑎᑦᑎᒋᐊᕐᕕᖏ ᓂᐱᓕᕆᓂᕐᒧᑦ ᓇᐅᒃᑯᑐᐃᓐᓇᖅ ᓂᐱᓕᐅᖅᓯᒪᕕᒋᓪᓗᒋᑦ ᑕᐃᑲᓂ ᐅᒥᐊᕐᔪᐊᑦ ᐅᓯᑲᖅᑕᖅᑎᓪᓗᒋᑦ; ᑕᐃᒪᓐᓇᐅᒐᓗᐊᖅᑎᓪᓗᒍ, ᐊᓄᕆᐅᑉ ᓂᐱᖓ ᐊᒻᒪᓗ ᒪᓪᓕᖅᑐᑉ ᓂᐱᖓ ᑕᒫᓃᖅᑲᓯᐅᑎᓯᒪᔪᑦ ᐊᑐᓂ ᖃᐅᔨᓴᕐᕕᐅᔪᓂ.

ᓂᐱᖏᑦ ᐱᖓᓱᑦ ᐆᒪᔪᑦ ᐳᐃᔨᑦ ᓇᓗᓇᐃᖅᑕᐅᓚᐅᖅᑐᖅ ᓂᐱᓕᐅᖅᓯᒪᔪᓂ ᖃᐅᔨᓴᕈᑎᑖᓂᑦ. ᑑᒑᓕᑦ ᕿᓚᓗᒐᐃᑦ ᐱᑕᖃᓚᐅᖅᑐᑦ ᓇᓂᑐᐃᓐᓇᖅ ᑕᒪᐃᓐᓂ ᖃᐅᔨᓴᕐᕕᐅᔪᓂ ᓂᐱᓕᐅᕈᑎᖃᖅᑐᓂ ᐊᕙᑖᓂ 9 ᐋᒍᓯ ᐊᒻᒪᓗ 24 ᓯᑎᐱᕆ 2018. ᐋᖅᓱᐃᑦ ᓴᖅᑭᔮᓚᐅᖅᑐᑦ ᑕᑯᔭᒃᓴᐅᓪᓗᑎᒃ ᒪᕐᕉᖕᓄᑦ ᐅᓪᓗᓄᑦ (31 ᐋᒍᓯ ᐊᒻᒪᓗ 1 ᓯᑎᐱᕆ 2018) ᑕᒪᐃᓐᓂ ᖃᐅᔨᓴᕐᕕᐅᔪᓕᒫᓂ. ᐅᓇ ᕿᓚᒥᐅᔪᒥᒃ ᐋᖅᓱᒃᑕᖅᑲᔩᖅ ᒪᓕᑦᑎᐊᖅᑐᖅ ᓇᒧᖓᐅᓂᖏ ᖃᓄᐃᓕᐅᕈᓯᖏᑦ ᐆᒪᔪᑦ ᑕᐅᕙᓂ ᐃᓕᑕᐅᓇᓱᒃᑐᓂ ᓄᓇᖓᓂ. ᐱᑕᖃᓚᐅᖅᐸᓪᓗᑎᒃ ᓇᑦᑏᑦ ᓂᐱᖃᖅᑐᑦ ᖃᐅᔨᓇᖅᓯᓚᐅᕆᓪᓗᑎᒃ ᐱᑕᖃᓂᖏᓐᓂᒃ ᑕᐅᕙᓂ ᓄᓇᖓᓂ. ᑑᒑᓕᑦ ᕿᓚᓗᒐᐃᑦ ᐅᕕᖕᖏᐊᕋᖅᑐᑦ ᐊᒻᒪᓗ ᑭᓕᑭᓕᒃ ᑐᓴᖅᓴᐅᔪᑦ ᐅᐊᖕᓇᖓᓂ ᓂᐱᓕᐅᕈᑎᖃᖅᑐᓂᒃ ᖃᐅᔨᓴᕐᕕᐅᔪᓂ (ᐃᒫᓂ ᓂᐱᓕᐅᕈᑎ-5) ᖃᑦᔫᓇᐅᕙᓪᓗᑎᒃ ᐊᓯᖏᓐᓂ ᓂᐱᓕᐅᕈᑎᖃᕐᕕᐅᔪᓂ, ᑕᐃᒪᓗ ᓇᓗᓇᐃᓚᐅᖅᑐᑦ ᐅᐊᖕᓇᖓᓂ-ᓂᒋᐊᓂ ᑕᒫᓃᑦᑐᑦ. ᑑᒑᓕᑦ ᕿᓚᓗᒐᐃᑦ ᓂᐱᖃᓚᐅᖅᑐᑦ ᐳᖅᑐᓂᖅᓴᐅᔪᓃᑦᑐᓂ ᓂᐱᓕᐅᕈᑎᓂ ᓂᒋᐊᓂ ᐃᓚᖓᑕ ᐃᓕᑕᐅᓇᓱᒡᕕᐅᔪᑦ ᓄᓇᖓᓂ.

ᐅᓇ ᐃᓕᑕᐅᓇᓱᒃᑐᖅ ᖃᐅᔨᒪᑎᑦᑎᔪᖅ ᐱᑕᖃᖅᑎᓪᓗᒋᑦ ᑑᒑᓕᑦ ᕿᓚᓗᒐᐃᑦ ᖃᓂᒋᔭᖓᓂ ᓄᓘᔮᖕᓂ ᐅᔭᖅᓂᐊᖅᑐᑦ ᓂᒋᐊᓂ ᕿᑦᖑᐊᑕ. ᓇᓂᓯᓯᒪᔪᒍᑦ ᐃᓱᒪᓕᕈᑎᒃᓴᓂᒃ ᐅᑯᐊ ᓂᐱᖏᑦ ᐅᒥᐊᕐᔪᐊᑦ ᑎᑭᐅᑎᓯᒪᓐᖏᑦᑐᑦ ᑕᒪᑐᒧᖓ ᑲᓇᑕᒥ ᑕᕆᐅᕐᒥ ᐃᖃᓗᒐᓱᒃᑐᓕᕆᔨᒃᑯᑦ ᐱᔭᑦᑎᕋᖅᑎᑦ 2018 ᓇᔪᖅᑕᐅᔪᓄᑦ ᐃᒪᖓ ᐳᐃᔨᑦ ᑐᓵᔪᓐᓇᖅᑐᖏᓐᓂᑦ ᓯᕗᐃᒐᓴᕐᓂᖅᐸᑕ. ᐅᖓᑖᓃᓗᐊᖅᑐᖅ 120 dB re 1 μPa (ᑑᓴᔪᓐᓇᕈᑎᖏᑦ ᓱᕋᐃᓕᓴᓂᖏᑦᑐᑦ ᐊᑐᓕᖅᑯᓴᐅᔪᑦ ᑲᓇᑕᒥ ᐃᒪᕕᓕᕆᔨᒃᑯᑦ ᐊᒻᒪᓗ ᓯᓚᒥ ᐊᓂᕐᓂᖅᑲᓐᖏᑦᑐᒥ ᐊᐅᓚᑦᓯᔨᑦ ᓇᒧᒃᓯᓕᒪᓂᖏ ᐃᒪᕐᒥᐅᑕᐃᑦ) ᑕᒪᐃᓐᓂ ᓴᕿᒪᔭᐅᖏᑦᑐᑦ ᑕᒪᐃᓐᓂ ᐃᒻᒥᒃ ᐊᐅᓚᔪᖅ ᐃᒫᓂ ᓂᐱᓕᐅᕈᑎ−1 (ᐃᓚᖓᑦ ᖃᐅᔨᓴᕐᕕᒃ ᕿᓚᓗᖃᑦᑑᔪᖅ ᐅᕕᖏᐊᕋᖅᑐᓂᒃ ᖃᐅᔨᕕᐅᕙᒃᑐᖅ) ᐊᒻᒪᓗ ᐃᒻᒥᒃ ᐊᐅᓚᔪᖅ ᐃᒫᓂ ᓂᐱᓕᐅᕈᑎ−3 (ᖃᐅᔨᓴᕐᕕᒃ ᐊᑦᑎᒌᖑᔪᖅ ᓂᐱᖃᖅᑐᖃᓗᐊᓐᖏᓂᖕᒪᓗ). ᑐᓴᓪᓚᕐᒍ ᓂᐱᓕᐅᖅᓯᒪᔪᓐᓇᖅᑐᖅ ᐊᑦᑎᒃᓯᓯᒪᔫᖅᑐᖅ ᐃᓚᖓᒍ ᐊᑐᐃᓐᓇᐅᔪᖃᖅᑲᖕᓂ ᓈᓚᖕᓂᐊᕐᓗᒋᑦ ᐳᐃᔨᑦ.

ᐅᓇ ᑕᑭᒑᖅ ᑐᓴᓪᓚᕐᓗᒋᑦ ᓂᐱᓕᐅᖅᓯᒪᔪᓐᓇᖅᑐᖅ ᐃᓚᖏᓐᓇᓪᓚᓂ ᓂᐱᓕᐅᖅᓯᒪᑎᓐᓂᖅᑕᐅᓂᖅᓴᖅᑐᖅ ᓈᓚᓪᓚᕐᓗᒋᑦ ᖃᓂᒋᔭᖅᓴᖅᑐᓐᓇᖅᑐᑦ ᓂᐹᕿᔪᑦ, ᓲᕐᓗ ᐊᓄᕆ ᐊᒻᒪᓗ ᒪᕐᑯᒃ, ᑐᓴᓇᕐᓂᑦ ᐅᒥᐊᕐᔪᐊᑦ ᑑᓚᖕᓇᓐᓇᑦ ᐅᕕᖏᐊᖅᑐᑦ ᐊᒻᒪᓗ ᑭᓕᒃᑭᓕᒃ-ᓂᓕᐊᔪᑦ, ᐱᓗᐊᖅᑐᒥᒃ ᑕᐃᑲᓂ ᐃᒻᒥᒃ ᐊᐅᓚᔪᖅ ᐃᒫᓂ ᓂᐱᓕᐅᕈᑎ−3; ᑭᓯᐊᓂ ᓯᓚᑖᓂᑦ ᓂᐹᕿᔪᑦ ᐊᒃᑐᐃᒐᑎᒃ ᑐᓴᓪᓚᕐᓗᒋᑦ ᓂᐱᓕᐅᖅᓯᒪᔪᓐᓇᖅᑐᑦ ᓱᕋᐅᑎᔭᐅᒐᓴᕐᓂᖕᒍᑦ ᑎᑦᓂᖅᑕᐅᓂᖅᓴᖅᑐᖅ. ᐅᒥᐊᕐᔪᐊᑦ ᑐᓵᖏᑦᑎᑦᑎᒍᓐᓇᖅᑐᑦ ᐅᕕᖏᐊᕐᑐᓂ ᑳᒃᑯᓇᓪᓚ ᑎᑭᓯᕐᓂᖏᑦ ᐊᒻᒪᓗ ᑭᓕᒃᑭᓕᒃ ᓂᐱᖏᑦ, ᐊᒻᒪᓗ ᐊᒃᑐᐃᓂᖅᓴᐅᓂᖓ ᑕᐃᑲᓂ ᐃᒫᓂ ᓂᐱᓕᐅᕈᑎ-1 ᑳᒃᑯᓇᓪᓚ ᐃᒻᒥᒃ ᐊᐅᓚᔪᖅ ᐃᒫᓂ ᓂᐱᓕᐅᕈᑎ-3, ᓂᕆᐅᓇᓚᐅᖅᑐᖅ ᑕᒪᓇᐃᓐᓂᐊᖅᑐᖅ.

1. Introduction

The Mary River Project (the Project), an iron ore mining project owned by Baffinland Iron Mines Corporation (Baffinland), located in the Qikiqtani region of Nunavut, opened in 2015 with shipping activity occurring during the open water season. Commercial shipping operations associated with the Project overlap with established summering grounds for the Eclipse Sound narwhal summer stock during the open-water season.

Project Certificate No. 005, amended by the Nunavut Impact Review Board (NIRB) on 27 May 2014, authorizes the Company to mine up to 22.2 million tonnes per annum (Mtpa) of iron ore from Deposit No. 1. Of this 22.2 Mtpa, the Company is currently authorized to transport 18 Mtpa of ore by rail to Steensby Port for year-round shipping through the Southern Shipping Route (via Foxe Basin and Hudson Strait), and 4.2 Mtpa of ore by truck to Milne Port for open water shipping through the Northern Shipping Route using chartered ore carrier vessels. The Northern Shipping Route encompasses Milne Inlet, Eclipse Sound, Pond Inlet, and adjacent water bodies. A Production Increase to ship 6.0 Mtpa from Milne Port was approved by the Nunavut Impact Review Board (NIRB) for implementation during 2018 and 2019.

Primary concerns identified along the Project's Northern Shipping Route include potential disturbance effects on narwhal from shipping noise during the open-water season that may lead to changes in narwhal distribution, abundance, migration patterns, and subsequent availability of narwhal for harvesting by local communities.

In accordance with existing Terms and Conditions of Project Certificate (PC) #005, Baffinland is responsible for the establishment and implementation of environmental effects monitoring (EEM) studies that are conducted over a defined time period with the following objectives:

- Assess the accuracy of effects predictions in the FEIS (BIM 2012) and Addendum 1 (BIM 2013).
- Assess the effectiveness of Project mitigation measures.
- Verify compliance of the Project with regulatory requirements, Project permits, standards and policies.
- Identify unforeseen adverse effects and provide early warnings of undesirable changes in the environment.
- 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 or MEWG) with respect to:
    - Potential adjustments to existing monitoring protocols or monitoring framework to allow for the most scientifically defensible synthesis, analysis and interpretation of data.
    - Project management decisions requiring modification of operational practices where and when necessary.

The 2018 Passive Acoustic Monitoring Program was developed by JASCO Applied Sciences (JASCO), in collaboration with Golder Associates Ltd. (Golder) and Baffinland, to evaluate potential Project-related effects to marine mammals from shipping noise. The Passive Acoustic Monitoring Program was designed to verify the following predictions made in the 2012 FEIS and the 2013 FEIS Addendum.

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

The Passive Acoustic Monitoring Program was designed to address monitoring requirements outlined in the following PC 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”.

JASCO was contracted by Golder to undertake an underwater noise monitoring program along the Northern Shipping Route. The objectives of the Passive Acoustic Monitoring (PAM) Program were to measure ambient noise levels, to compare *in-situ* sound levels relative to modelled sound levels, to determine marine mammal species (notably narwhal) presence in the Bruce Head region of the Northern Shipping Route, to evaluate Project shipping noise levels in relation to established marine mammal acoustic thresholds for injury and onset of disturbance, and to collect recordings that could be used to evaluate vessel noise signatures and potential changes in narwhal vocal behaviour in relation to shipping. This last component is being analyzed separately as part of a collaboration between Baffinland, Golder, JASCO and the University of New Brunswick (UNB)’s marine mammal acoustic laboratory. Results will be presented separately for this component once these analyses are complete.

1.1. Soniferous Marine Life and Acoustic Monitoring

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

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

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

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

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

Marine mammals are the primary biological contributors to the underwater soundscape. Marine mammals, and cetaceans in particular, rely almost exclusively on sound for navigating, foraging, breeding, and communicating (Clark 1990, Edds-Walton 1997, Tyack and Clark 2000). Although species differ widely in their vocal behaviour, most can be reasonably expected to produce sounds on a regular basis. Passive acoustic monitoring is therefore increasingly preferred as a cost-effective and efficient survey method. 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.

Knowledge of the acoustic signals of the marine mammals expected in the study area varies across species. These sounds can be split into two broad categories: Tonal signals, including baleen whale moans and odontocete whistles, and echolocation clicks produced by all odontocetes mainly for foraging and navigating. While the signals of most species have been described to some extent, these descriptions are not always sufficient for reliable, systematic identification, let alone to design automated acoustic signal detectors to process large datasets (Table 2).

The acoustic monitoring program was performed with autonomous acoustic recording systems deployed on the seabed for 2 months (4 Aug to 28 Sep 2018) at five stations across Milne Inlet (Figure 1).

Table 2. Acoustic signals used for identification and automated detection of the species expected in Milne Inlet and supporting references. 'NA' indicates that no automated detector was available for a species.

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

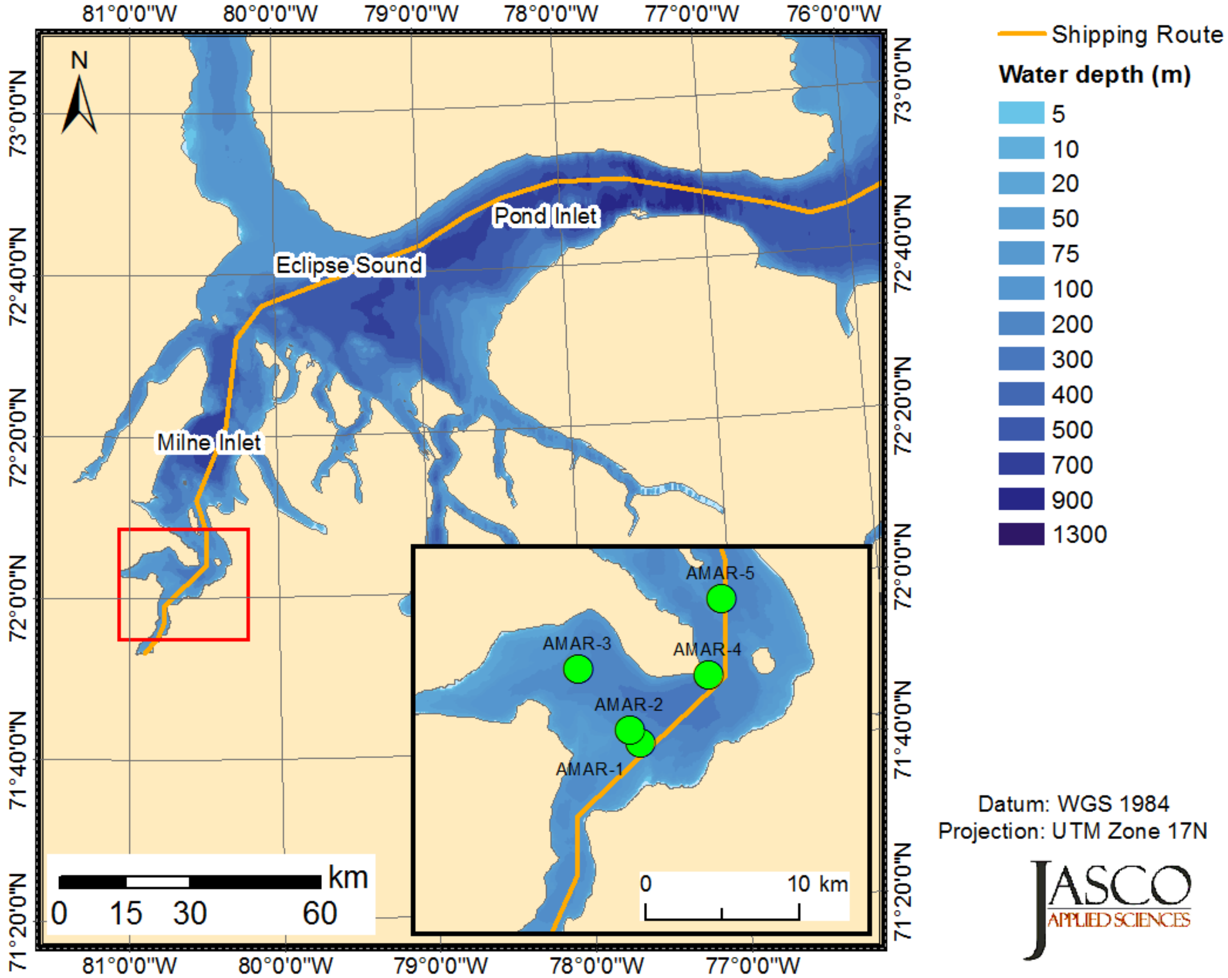

Figure 1. Acoustic monitoring area and recorder stations across Milne Inlet (Autonomous recorders in green).

1.2. 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 noise is known to be an important contributor to near-shore soundscapes (Deane 2000). In polar regions, sea ice can produce loud sounds that are often the main contributor of acoustic energy in the local soundscape, particularly during ice formation and break up (Milne and Ganton 1964). 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 (Figure 2). Kim and Conrad (2016) reported that in the area, below 1000 Hz, moderate winds (~6 m/s) typical of the site contributed to average ambient sound levels of ~94 dB re 1 µPa.

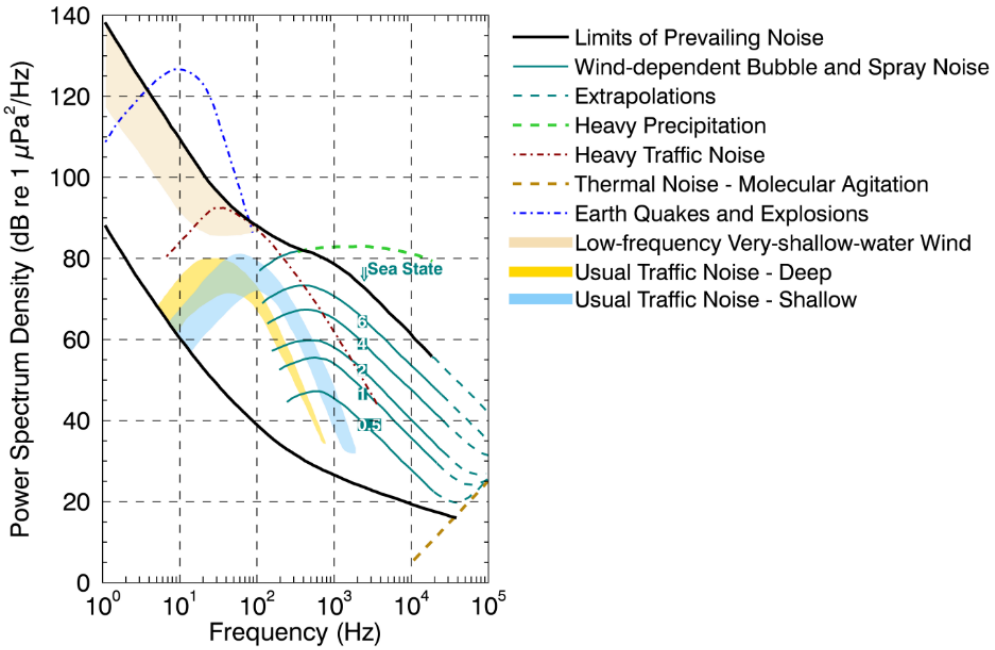

Figure 2. Wenz curves (NRC 2003), adapted from (Wenz 1962), describing pressure spectral density levels of marine ambient noise from weather, wind, geologic activity, and commercial shipping.

1.3. Anthropogenic Contributors to the Soundscape

Anthropogenic (human-generated) sound can be a by-product of vessel operations, such as engine noise radiating through vessel hulls and cavitating propulsion systems, or it can be a product of active acoustic data collection, with seismic surveys, military sonar, and depth sounding as main contributors. The contribution of anthropogenic sources to the ocean soundscape has increased steadily over the past several decades. This increase is largely driven by greater maritime shipping and oil and gas exploration globally (Hildebrand 2009). The extent of seismic survey sounds has increased significantly following the expansion of oil and gas exploration into deep water, and seismic sounds can now be detected across ocean basins (Nieukirk et al. 2004). The main anthropogenic contributor to the total sound field in the present study was vessel traffic associated with the transport of iron ore.

1.3.1. Vessel Traffic

Pond Inlet has experienced the largest increase in marine vessel activity in Nunavut in recent decades. This increase is mainly attributable to increases in tourism vessels, bulk carriers, and tanker traffic related to the Mary River mine (Dawson et al. 2018). Vessel traffic, both from vessels associated with transporting the iron ore and support vessels (tugs, ice breakers, research vessels, etc.), contributed to the soundscape. These vessels generally follow the main shipping lane that passes through the study area (Figure 3).

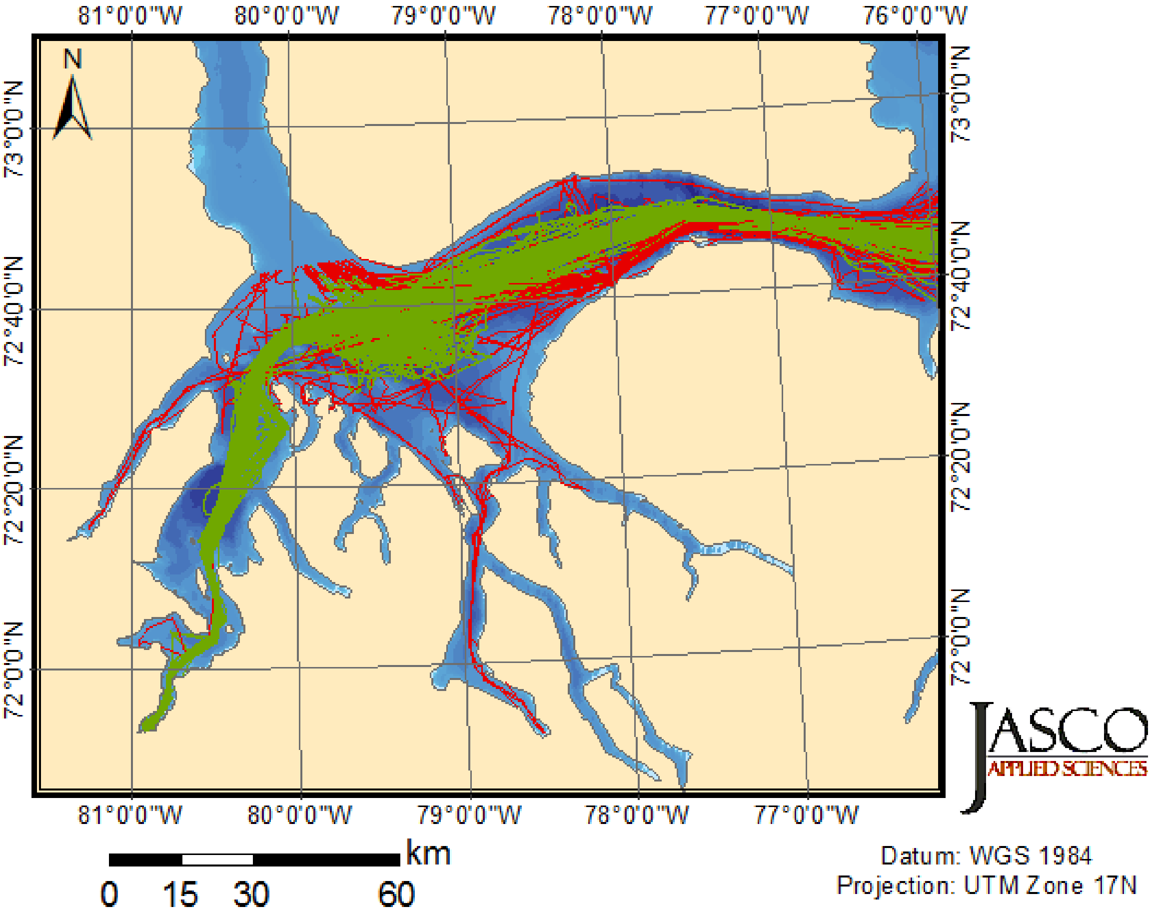

Figure 3. Vessel traffic travelling along the Northern Shipping Route during the 2018 recording period; both Project-related vessels (green) and non-Project related vessels (red). Automatic Identification System (AIS) data acquired from ground-based stations at Bruce Head and Pond Inlet, as well as AIS data collected by satellites (ExactEarth archive).

2. Methods

2.1. Acoustic Data Acquisition

2.1.1. Recording configuration and duration

Underwater sound was recorded with Autonomous Multichannel Acoustic Recorders (G3 AMARs, JASCO; Figure 4). Each AMAR was fitted with an M36 omnidirectional hydrophone (GeoSpectrum Technologies Inc., −165 ± 3 dB re 1 V/µPa sensitivity). The devices were calibrated to within 1 dB. The AMAR hydrophones were protected by a hydrophone cage, which was covered with a shroud to minimize noise artifacts from water flow. The AMARs recorded continuously on a duty cycle at 64 000 samples per second with a 6 dB gain for a recording bandwidth of 10 Hz to 32 kHz during 14 min, and then at 250 000 samples per second for a recording bandwidth of 10 Hz to 125 kHz during 1 min.

Figure 4. The Autonomous Multichannel Acoustic Recorder (in the middle of the mooring - AMAR G3; JASCO) used to measure underwater sound in and near Milne Inlet.

2.1.2. Monitoring stations

AMARs were deployed at 5 stations (Figure 1) between 4 Aug and 28 Sep 2018 (Table 3) from the *Ocean Raynald T.* (Figure 5). All AMARs were retrieved as planned from the same vessel using acoustic releases. All AMARs recorded as planned from deployment until retrieval, for a recording duration of 56 days per AMAR. Figure 6 provides details about the mooring design. Table 4 provides distances between the stations.

Figure 5. Vessel *Ocean Raynald T*. used for both deployment and retrieval.

Table 3. Operation period, location, and depth of the AMARs deployed.

Station	Latitude	Longitude	Depth (m)	Deployment	Retrieval	Duration (days)
AMAR-1	72.02772	−80.64588	209	4 Aug 2018	28 Sep 2018	56
AMAR-2	72.03550	−80.66560	205	4 Aug 2018	28 Sep 2018	56
AMAR-3	72.07155	−80.76305	201	4 Aug 2018	28 Sep 2018	56
AMAR-4	72.06772	−80.51567	225	4 Aug 2018	28 Sep 2018	56
AMAR-5	72.11210	−80.49042	245	4 Aug 2018	28 Sep 2018	56

Table 4. Distances between stations.

Station	AMAR-1	AMAR-2	AMAR-3	AMAR-4	AMAR-5
AMAR-1					
AMAR-2	1.102 km				
AMAR-3	6.339 km	5.237 km			
AMAR-4	6.325 km	6.288 km	8.514 km		
AMAR-5	10.826 km	10.455 km	10.397 km	5.028 km	

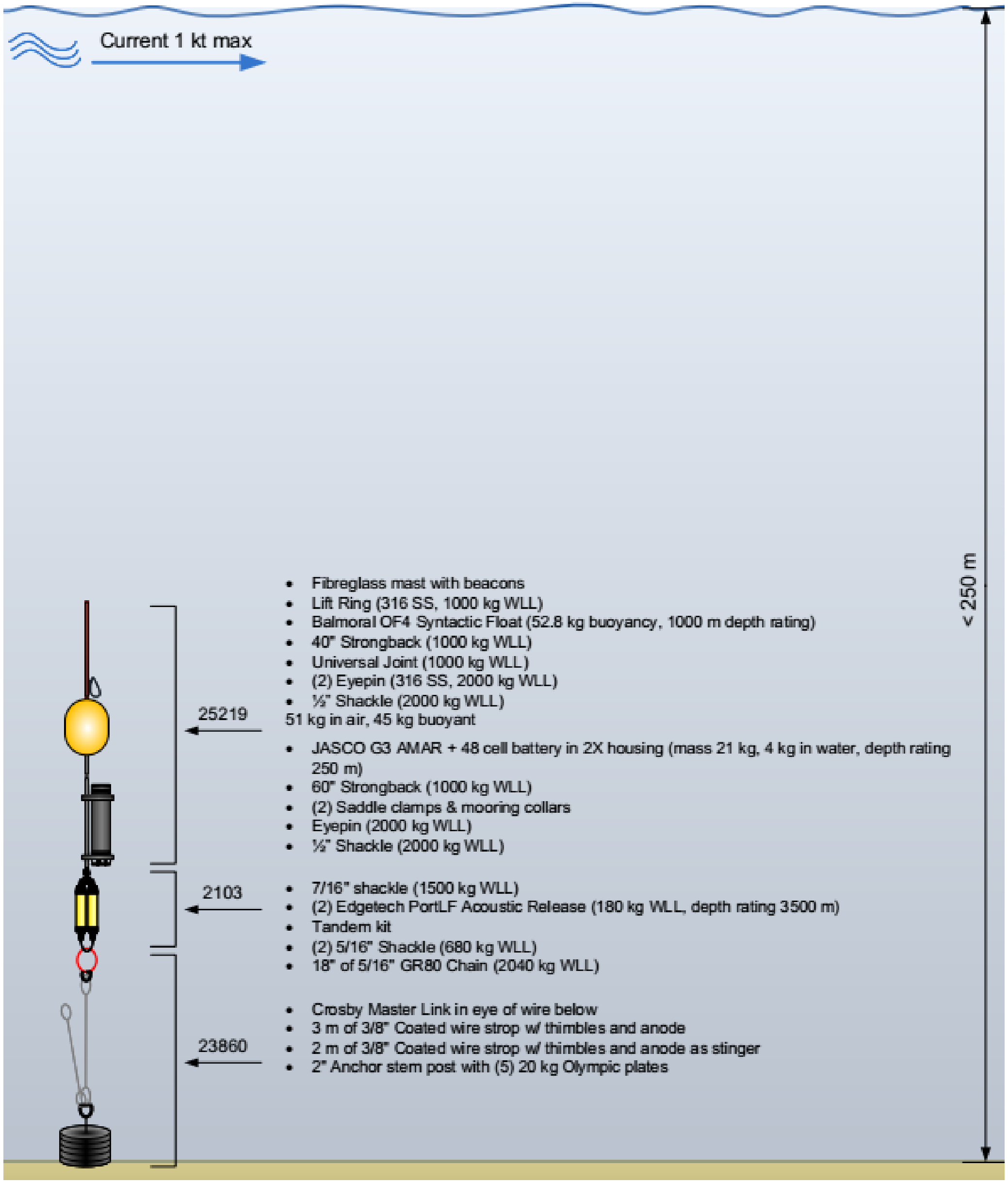

Figure 6. Mooring design with one AMAR attached to an anchor. Hydrophone was 3 m above the seafloor. This configuration was used at all stations.

2.2. Automated Data Analysis

Collectively 4.6 TB of acoustic data was collected during this study: 936 GB on AMAR−1, 936 GB on AMAR−2, 939 GB on AMAR−3, 935 GB on AMAR−4, and 942 GB on AMAR−5. Automated analysis of total ocean noise and sounds from vessels and marine mammal vocalizations was performed. Appendix A outlines the stages of the analyses.

2.2.1. Total Ocean noise and time series analysis

Ambient noise levels at each station were examined to document the local underwater sound conditions. In Section 3.1, ambient noise levels are presented as:

- Statistical distribution of SPL (L_p) in each 1/3-octave-band. The boxes of the statistical distributions indicate the first (L_{25}), second (L_{50}), and third (L_{75}) quartiles. The whiskers indicate the maximum and minimum range of the data. The solid line indicates the mean SPL, or L_{mean}, in each 1/3-octave-band.
- Spectral density level percentiles: Histograms of each frequency bin per 1 min of data. The L_{eq}, L_5, L_{25}, L_{50}, L_{75}, and L_{95} percentiles are plotted. The L_5 percentile curve is the frequency-dependent level exceeded by 5% of the 1 min averages. Equivalently, 95% of the 1 min spectral levels are above the 95th percentile curve. This approach, which is standard, leads to lower percentiles representing higher sound levels.
- Broadband and approximate-decade-band SPL over time: The levels are defined for the 10 Hz to 16 kHz (broadband), and 10–100 Hz, 100 Hz to 1 kHz, and 1–10 kHz decade frequency bands.
- Spectrograms: Ambient noise at each station was analyzed by Hamming-windowed fast Fourier transforms (FFTs), with 1 Hz resolution and 50% window overlap. The 120 FFTs performed with these settings are averaged to yield 1 min average spectra.
- Daily sound exposure levels (SEL; $L_{E,24h}$): The SEL represents the total sound energy received over a 24 hour period. It has become the standard metric for evaluating the probability of temporary or permanent hearing threshold shift. Long-term exposure to sound impacts an animal more severely if the sounds are within its most sensitive hearing frequency range. Therefore, during SEL analysis recorded sounds are typically filtered by the animal’s auditory frequency weighting function before integrating to obtain SEL. For this analysis the 10 Hz and above SEL were computed as well as the SEL weighted by the marine mammal auditory filters (Appendix C) (NMFS 2018). The SEL thresholds for possible hearing impacts from sound on marine mammals are provided in Table AE-1 of NMFS (2018).

The 50th percentile (median of 1 min spectral averages) can be compared to the Wenz ambient noise curves (Figure 2) (Wenz 1962), which show the variability of ambient spectral levels off the U.S. Pacific coast as a function of frequency of measurements for a range of weather, vessel traffic, and geologic conditions. The Wenz curve levels are generalized and are used for approximate comparisons only.

The 1 min averaged, 1 Hz spectral density levels are summed over the 1/3-octave and decade bands to calculate the 1 min averaged broadband levels (dB re 1 μPa). They are presented with the density levels. Table A-1 lists the 1/3-octave-band frequencies. Table A-2 lists the decade-band frequencies. Weather conditions throughout the recording periods were also gathered to inform the discussion on the factors driving noise levels and influencing marine mammal detections. Wind data was collected in 2018 from Baffinland’s permanent meteorological station located at Milne Port at 71.886°N and 80.885°W. Detailed description of acoustic metrics and 1/3-octave-band analysis can be found in Appendices A.1 and A.2.

2.2.2. Vessel noise detection

Vessels were detected in two steps:

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

Vessel detections were defined by three criteria:

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

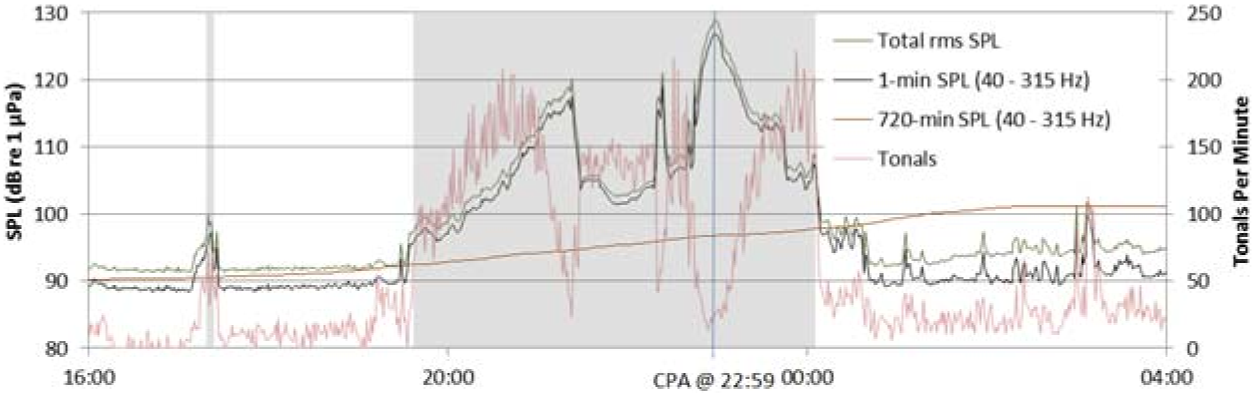

Figure 7. Example of broadband and 40–315 Hz band SPL, as well as the number of tonals detected per minute as a ship approached a recorder, stopped, and then departed. The shaded area is the period of shipping detection. Fewer tonals are detected at the ship's closest point of approach (CPA) at 22:59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

2.2.3. Marine Mammal Detection Overview

We used a combination of automated detectors and manual review by an experienced analyst to determine the presence of sounds produced by marine mammals (notably narwhal). First, automated detectors identified acoustic signals potentially produced by odontocetes, mysticetes, and pinnipeds. For the species of interest (narwhal) no species-specific and effective detector was available; thus, generic marine mammal call detectors were used (see sections 2.2.3.1 and 2.2.3.2). Whistle detections and clicks detections were manually reviewed (validated) within a subset of the dataset, results of each detector were critically reviewed, and the output of detectors were restricted where necessary to provide the most accurate description of narwhal presence. Where detector results were found to be unreliable (detector precision <0.75, see section 2.2.3.3), only the validated results are presented.

In this report, the term detector is used to describe automated algorithms that combine detection and classification steps. A detection refers to an acoustic signal that has been flagged as a sound of interest based on spectral features and subsequently classified based on similarities to several templates in a library of marine mammal signals.

Marine mammal species other than narwhals found during the manual validation of detector results are presented as well.

2.2.3.1. Click detection

Odontocete clicks are high-frequency impulses ranging from 5 to over 150 kHz (Au et al. 1999, Møhl et al. 2000). We applied an automated click detector to the 250 kilosamples per second (ksps) data (audio bandwidth up to 125 kHz for ~1 min of every 15 min) to identify clicks from beluga whale and narwhal. This detector is based on zero-crossings in the acoustic time series. Zero-crossings are the rapid oscillations of a click's pressure waveform above and below the signal's normal level (e.g., Figure A-4). Zero-crossing-based features of detected events are then compared to templates of known clicks for classification (see Appendix A.3.1 for details).

2.2.3.2. 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 and delphinids whistles). The signals of some pinniped species, such as bearded seal trills, have also have tonal components. Baleen whale and pinniped tonal acoustic signals range predominantly between 15 Hz and 4 kHz (Berchok et al. 2006, Risch et al. 2007), thus detectors for these species were applied to the 64 ksps data (audio bandwidth up to 32 kHz for ~14 min every 15 min) and to the 250 kilosamples per second (ksps) data (audio bandwidth up to 125 kHz for ~1 min of every 15 min). The tonal signal detector identified continuous contours of elevated energy and classified them against a library of marine mammal signals (see Appendix A.3.2 for details).

2.2.3.3. Validation of Automated Detectors

Automated detectors are developed with training data files containing a range of vocalization types and background noise conditions. Training files cannot cover the full range of possible vocalization types and noise conditions; therefore, a selection of files was manually validated to check each detector's performance for a specific station and timeframe, to determine how best to refine the detector results, or to decide if it is necessary to rely only on manually validated results of narwhal occurrence. Details of the file selection and validation process can be found in Appendix A.3.

To determine the performance of each detector and any necessary thresholds, the automated and validated results were input to a maximum likelihood estimation algorithm that maximizes the probability of detection and minimizes the number of false alarms using the 'F-score' (see Appendix A.3.2 for details). It also estimates the precision (P) and recall (R) of the detector. P represents the proportion of files with detections that are true positives. A P value of 0.9 means that 90% of the files with detections truly contain the targeted signal, but 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 detector. An R value of 0.8 means that 80% of files known to contain a target signal had automated detections, but it does not indicate how many files with detections were incorrect. An F-score is a combined measure of P and R where an F-score of 1 indicates perfect performance–all events are detected with no false alarms.

The algorithm determines a detector threshold for each species, at every station, that maximizes the F-score. Resulting thresholds, Ps, and Rs are presented in Section 3.3 and in further detail in Appendix B.

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

The occurrence of narwhals (both validated and automated) was plotted using JASCO's Ark software as time series showing presence/absence by hour over each day for the recording period. Marine mammal occurrence is also presented as spatial plots for each station.

3. Results

3.1. Ambient Noise Measurements

3.1.1. Total sound levels

This section presents the total sound levels from the data sets. We present the results in four ways:

1. **Band-level plots**: These strip charts show the averaged received sound levels as a function of time within a given frequency band. We show the total sound level (10 Hz to 16 kHz) and the decade bands for 10–32000 Hz, 10–100 Hz, 100–1000 Hz, 1000–10000 Hz, and 10–32 kHz. The 10–100 Hz band is associated with large shipping vessels, seismic surveys, and mooring noise. The 100–1000 Hz band is generally associated with wind and wave noise, but can include ringed and bearded seals, walrus, bowhead whale, pulse calls produced by narwhal, nearby vessels, dynamic positioning sound and seismic surveys. Sounds above 1000 Hz include ringed and bearded seals, walrus, bowhead whale, killer whale, beluga and narwhal whistles and clicks, and wind and wave noise and close-range human sources (Figures 8 to 12).
2. **Long-term Spectral Averages (LTSAs)**: Color plots showing power spectral density levels as a function of time (*x* axis) and frequency (*y* axis). The LTSAs are excellent summaries of the temporal and frequency variability in the data.
3. **Distribution of 1/3-octave-band SPL**: These box-and-whisker plots show the average and extreme sound levels in each 1/3-octave-band. As discussed in Appendix 0,1/3-octave-bands represent the hearing bands of many mammals. They are often used as the bandwidths for expressing the source level of broadband sounds such as shipping and seismic surveys. The distribution of 1/3-octave sound levels can be used as the noise floor for modelling the detection of vessels or marine mammal vocalizations.
4. **Power Spectral Densities (PSDs)**: These plots show the statistical sound levels in 1 Hz frequency bins. These levels can be directly compared to the Wenz curves (Figure 2). We also plot the spectral probability density (Merchant et al. 2013) to assess whether the distribution is multi-modal.

The LTSAs and Band-Level plots for all five stations are shown in Figure 8 through Figure 12 and fine scale weekly plots are in Appendix D. As expected, sound levels were highest in the shipping lanes (AMAR−1, −4, and −5; Table 5) and lowest at AMAR−3 (Table 5), which was sheltered in a bay outside of the shipping lanes (Koluktoo Bay). There was a mean SPL difference of almost 8 dB re 1 µPa between the sheltered bay and the shipping lane stations. AMAR−1 and −2 were ~1 km apart, with a maximum broadband SPL measured at 148 and 140 dB re 1 µPa, respectively (Table 5). Engine sound from vessels and wind and wave action were present throughout the recording period, indicated by the horizontal and vertical lines labelled in the spectrograms (Figures 8 to 12). In addition, narwhal pulsed calls and whistles contributed to the 100–5000 Hz frequency band. The vessel sounds represented in the 10–100 Hz band was on average 8 to 10 dB higher throughout the shipping lane stations. The wind and wave sounds contributing to the 100–1000 Hz band was 6 to 8 dB higher at shipping lane stations compared to AMAR-3. Bands +1 kHz differed by a maximum of 5 dB.

The PSD plots (Figure 13) showed consistency throughout the percentiles at each station, with slightly elevated levels at the shipping lane stations.

Table 5. Broadband SPL values for stations AMAR−1 to −5.

Station	Min. broadband SPL (dB re 1 µPa)	Max. broadband SPL (dB re 1 µPa)	Mean broadband SPL (dB re 1 µPa)
AMAR−1	79.6	148	114.8
AMAR−2	79	140	110.9
AMAR−3	79.7	133.1	105.3
AMAR−4	79.5	143.8	111.6
AMAR−5	79.3	145.6	112.6

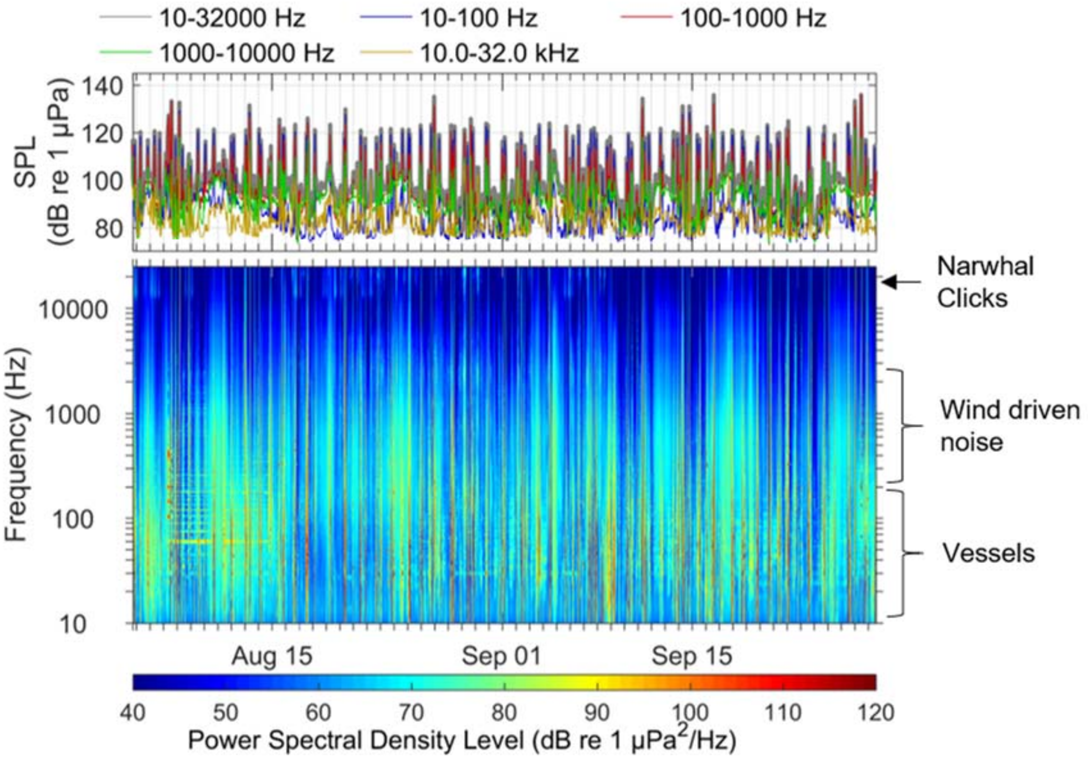

Figure 8. AMAR−1: Spectrogram (bottom) and in-band SPL (top) for underwater sound.

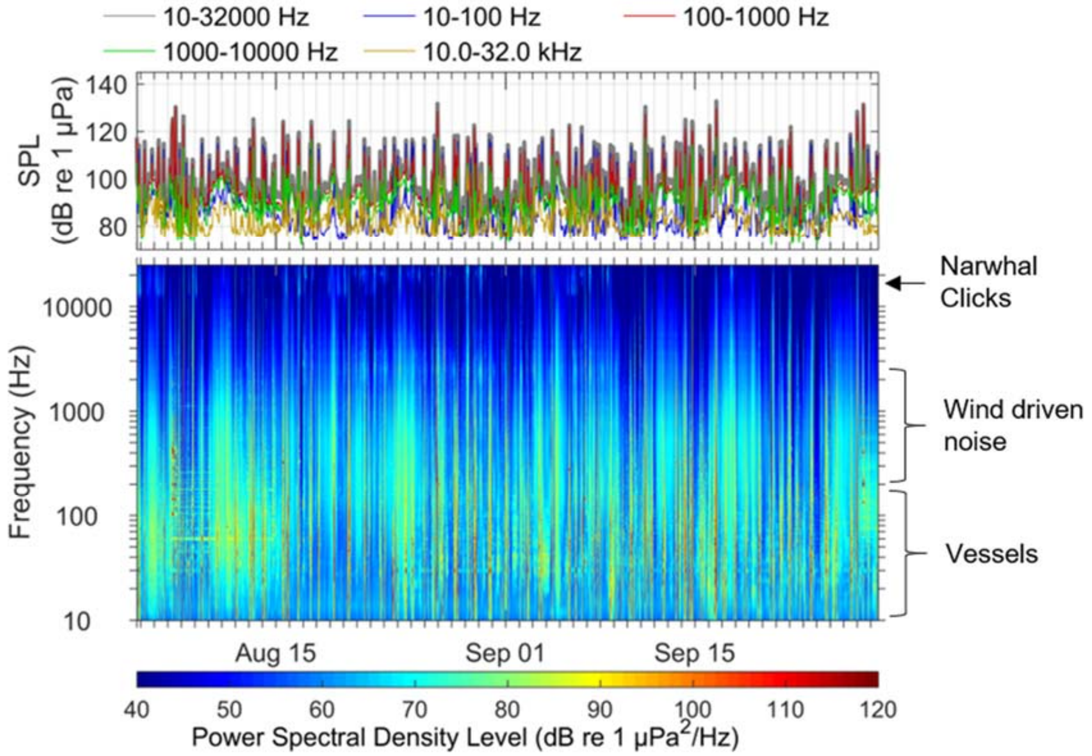

Figure 9. AMAR−2: Spectrogram (bottom) and in-band SPL (top) for underwater sound.

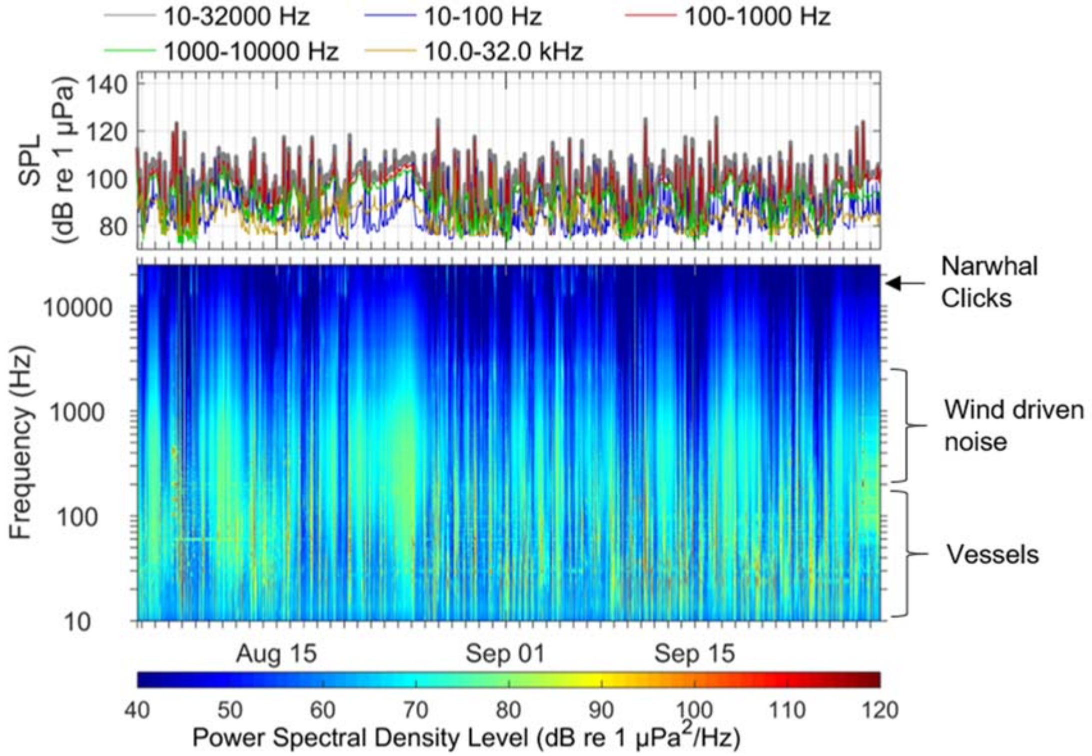

Figure 10. AMAR−3: Spectrogram (bottom) and in-band SPL (top) for underwater sound.

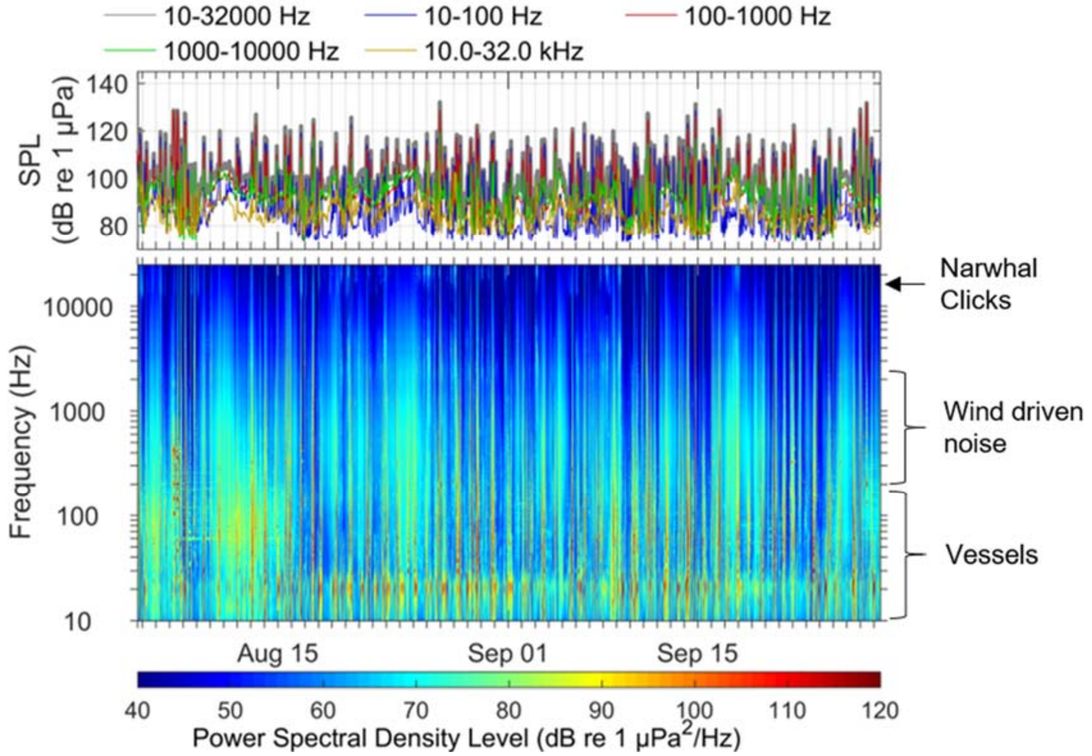

Figure 11. AMAR−4: Spectrogram (bottom) and in-band SPL (top) for underwater sound.

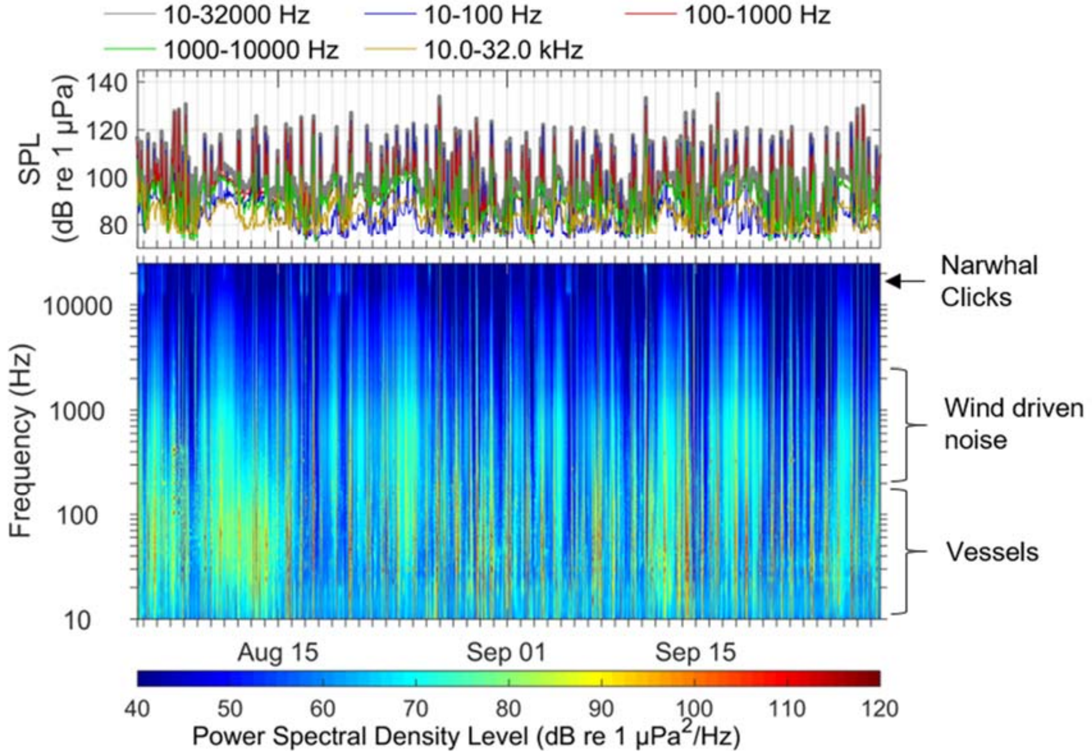

Figure 12. AMAR−5: Spectrogram (bottom) and in-band SPL (top) for underwater sound.

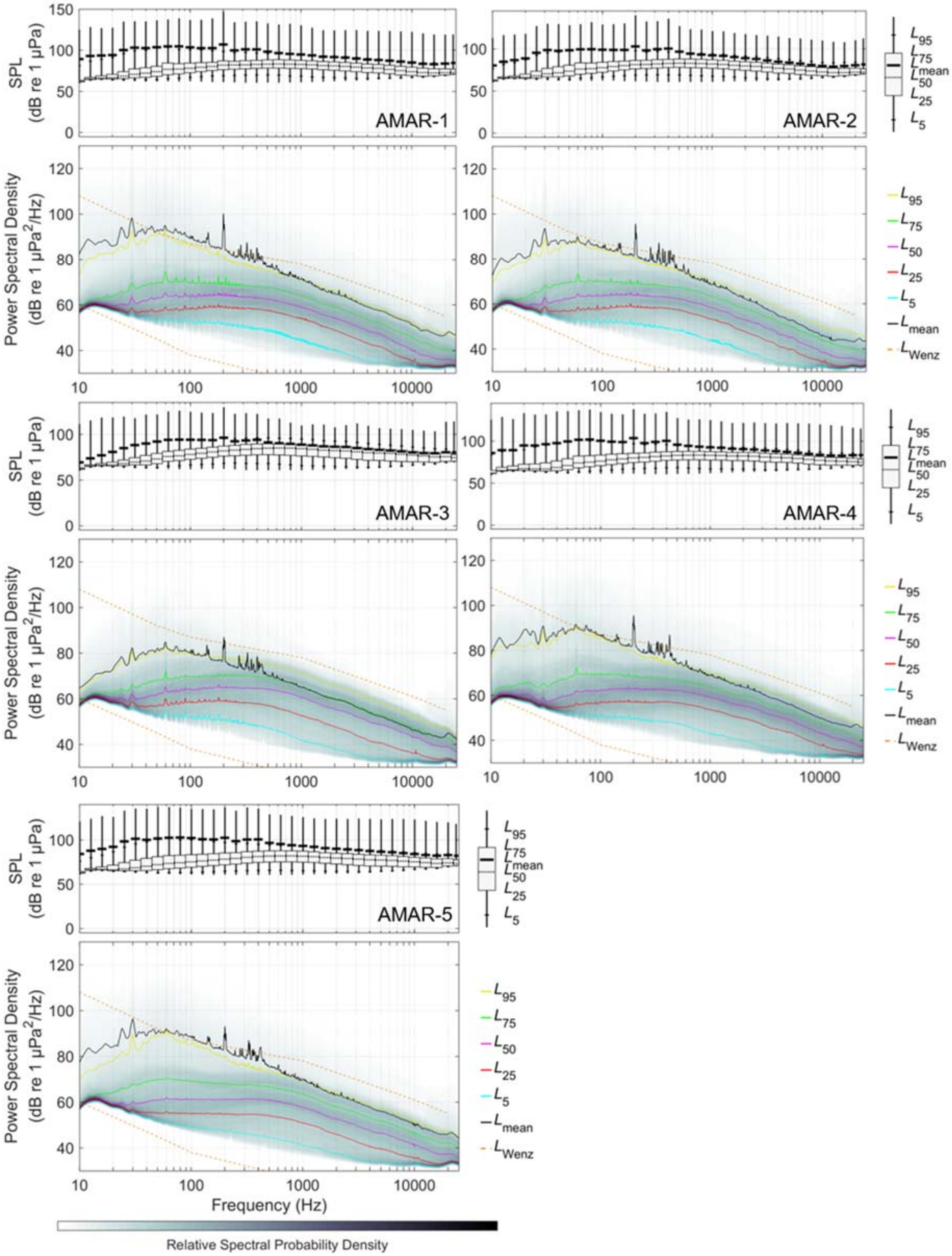

Figure 13. Stations for AMAR−1 (top left), AMAR−2 (top right), AMAR−3 (middle left), AMAR−4 (middle right), and AMAR−5 (bottom): Exceedance percentiles and mean of 1/3-octave-band SPL and exceedance percentiles and probability density (grayscale) of 1-min power spectral density levels compared to the limits of prevailing noise (Wenz 1962). L_{Mean} is the arithmetic mean (ISO 18405 2017).

3.1.2. Daily SEL levels

The 24 h SEL metric is the standard measure of possible injury from long-term exposure to man-made sound (Southall et al. 2007, NMFS 2018). The sound levels measured at the recorders (Figure 14) were below levels that could lead to a temporary reduction or permanent loss in hearing sensitivity (Temporary Threshold Shift: TTS and Permanent Threshold Shift: PTS). Thresholds (SEL_{cum}): 153 dB re 1 µPa²·s for high-frequency cetaceans, 178 dB re 1 µPa²·s for mid-frequency cetaceans, 179 dB re 1 µPa²·s for low-frequency cetaceans, 181 dB re 1 µPa²·s for phocid pinnipeds, and 199 dB re 1 µPa²·s for otariid pinnipeds. Sound exposure levels were similar at AMAR−1, −2, −4, and −5, with lower levels at AMAR−3 where the recorder was located in a more protected embayment.

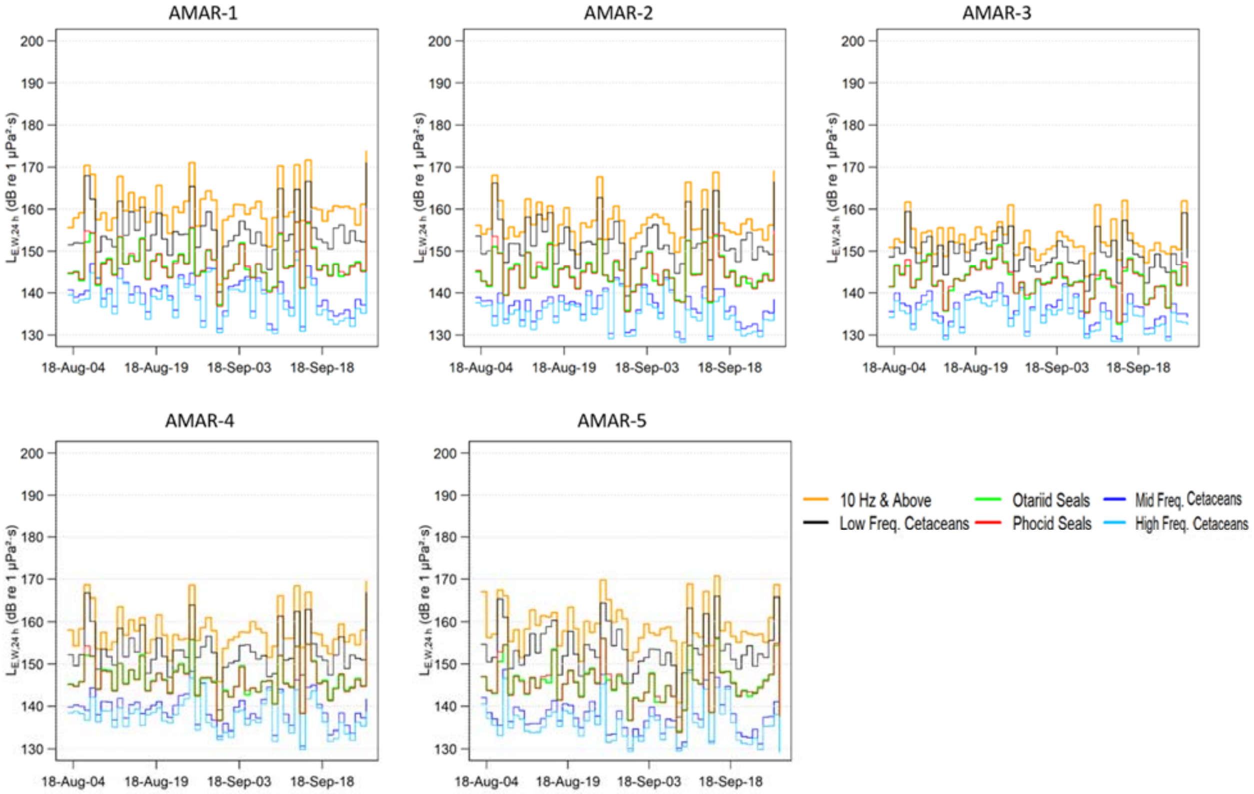

Figure 14. AMAR−1 to −5: The staircase plot shows the daily sound exposure levels, weighted for the NMFS (2018) marine mammal hearing.

3.2. Vessel Detections

Vessels were detected using the automated detection algorithm described in Section 2.2.2. Vessel detections denote closest points of approach (CPA) to the recorder, by hour. All stations had high detection counts throughout the recording period (Figure 15), with some periods of fewer detections lasting a few days, but detections received at all times of day. The furthest northerly stations near Bruce Head (AMAR−4 and −5) had fewer detections throughout September.

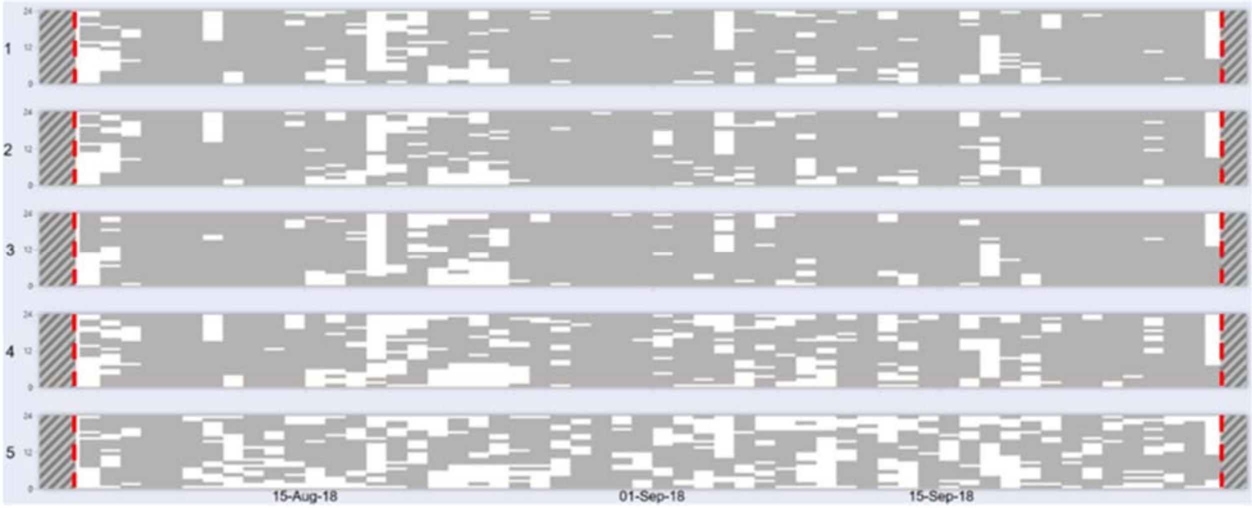

Figure 15. Vessel detections each hour (vertical axis) for each date (horizontal axis) at the five stations. The red dashed lines indicate AMAR deployment and retrieval dates.

In Figure 16, the spectrogram of a vessel passing AMAR−4 illustrates the Lloyd's mirror, or bathtub pattern, as a vessel passes the recorder. This pattern is caused by constructive and destructive interference between direct and reflected paths of sound.

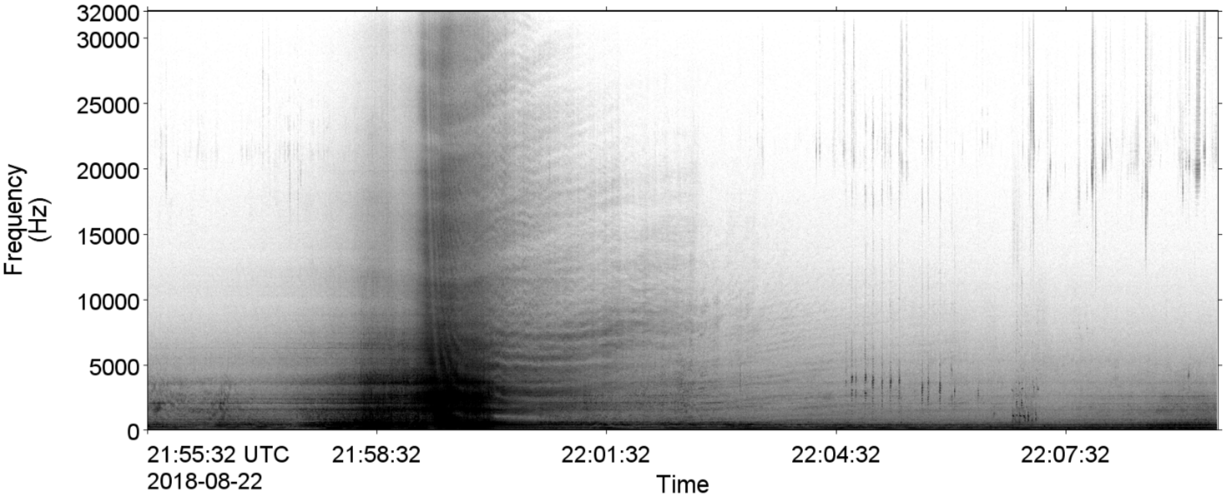

Figure 16. Spectrogram of a vessel (left) passing AMAR−4 and narwhal clicks (right) on 22 Aug 2018 (2 Hz frequency resolution, 0.128 time window, 0.032 time step, Hamming window).

3.3. Narwhal detections

The acoustic presence of narwhal was identified automatically by JASCO's detectors (Section 2.2.3) and validated via the manual review of 0.5% of the low- and high-frequency datasets, which represents 300 sound files, or 2.5 h worth of 1-min 250 ksps sounds files and 35 h worth of 14-min 64 ksps sound files.

Detector performance varied across call types (whistles and clicks) and stations. Detector precision was generally high for all stations for whistle detector and most stations for click detector scoring above the minimum precision of 0.75 threshold (Appendix B). Detector recall values were lower than precision (Appendix B). This is partly by design because the detection count threshold is based on maximizing the F-score, which is itself biased towards precision (Appendix B).

The two main kind of communicative sounds narwhals are known to produce are whistles (tonal sounds) and clicks (pulsed sounds) (Ford and Fisher 1978). Whistles classified as narwhal are narrow-band, frequency-modulated sounds between 300 Hz and 10 kHz (Ford and Fisher 1978). Narwhals emit clicks with peak frequencies from 5 to 48 kHz and bandwidths that can extend above 100 kHz (Miller et al. 1995). Narwhal clicks have been characterized in two (low- and high-) or three (low-, mid-, and high-) categories according to their peak frequency (<10; ~10-20; >20 kHz; Stafford et al. 2012) and by their emission rate: slow rate (click train or echolocation clicks, 2–30 clicks/s) and fast rate (burst or buzz or pulse, 40–400 clicks/s) (Møhl et al. 1990, Miller et al. 1995, Stafford et al. 2012).

Because of the overlap in vocal repertoires of the two Monodontid species (narwhals and beluga whales) expected in the study area (Stephenson and Hartwig 2010), the whistle detector and the click detector were unable to distinguish whistles and clicks, respectively, by species. Due to the higher probability of narwhal presence in the area, we have assumed that the results from whistle and click detectors are actually "narwhal".

Narwhal whistles (Figure 17) were found at all stations over the recording period (Figure 18), mostly from mid-August to early-September. AMAR−5 had the fewest narwhal whistle detections.

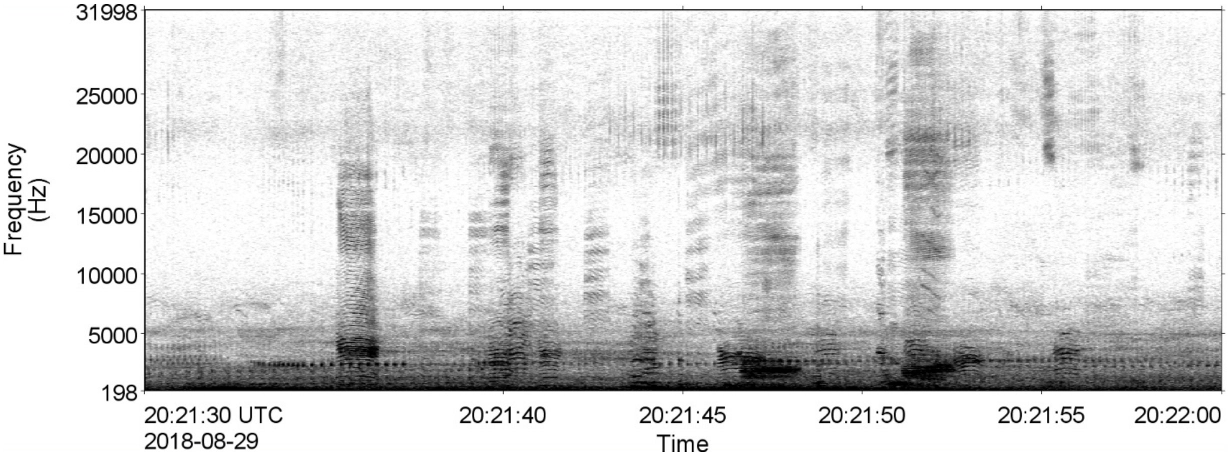

Figure 17. Spectrogram of narwhal pulse calls and whistles recorded at AMAR−3 on 29 Aug 2018 (2 Hz frequency resolution, 0.128 time window, 0.032 time step, Hamming window).

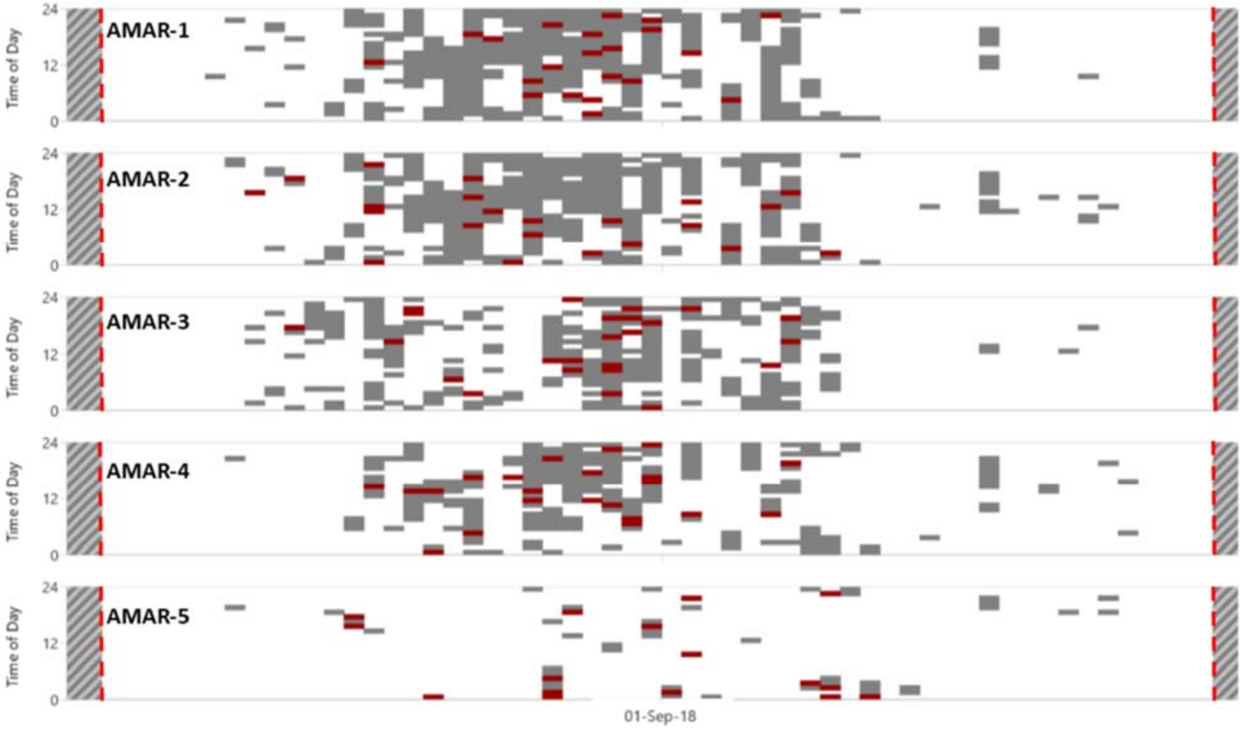

Figure 18. Daily and hourly occurrence of detected narwhal whistles recorded at AMAR−1, AMAR−2, AMAR−3, AMAR−4 and AMAR−5 from 9 Aug to 24 Sep 2018. Grey dots indicate automated detections. Red dots indicate manually validated results. The red dashed lines indicate AMAR deployment and retrieval dates.

Narwhal clicks (Figure 19 and 20) were found at all stations throughout all the recording periods (Figure 21). AMAR−5 had the fewest narwhal click detections.

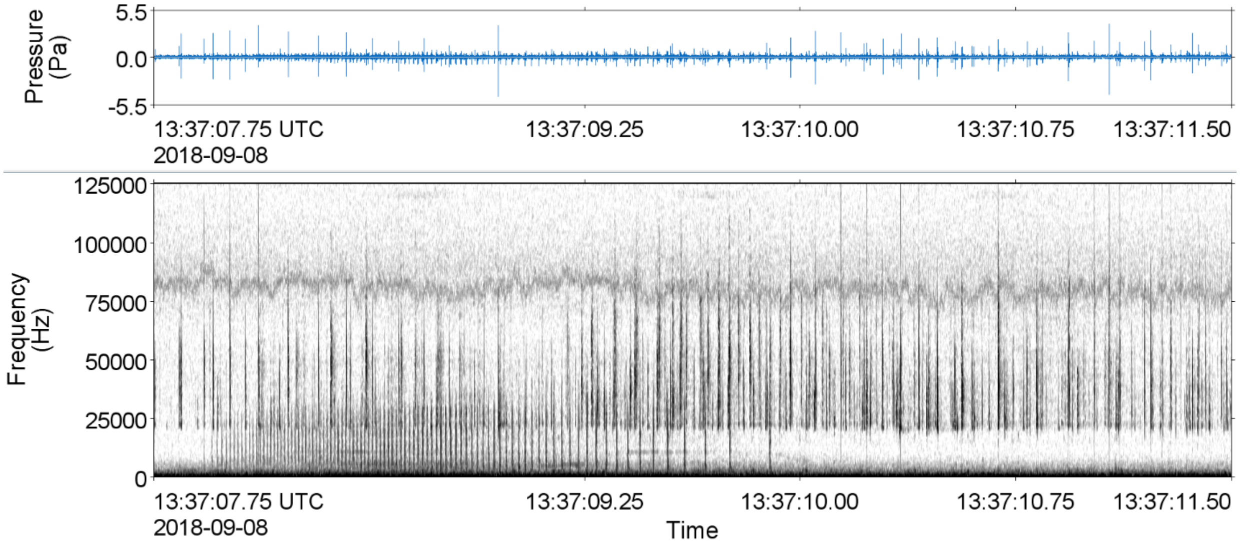

Figure 19. Spectrogram of narwhal high and mid clicks recorded at AMAR−1 on 8 Sep 2018 (122 Hz frequency resolution, 0.001 time window, 0.0005 time step, Hamming window).

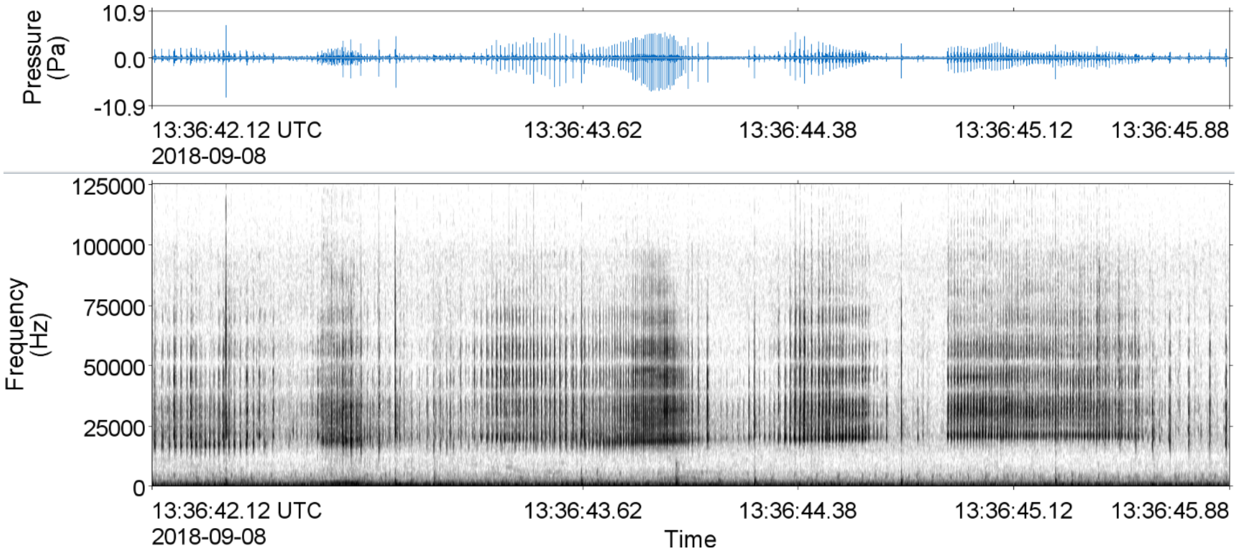

Figure 20. Spectrogram of narwhal high clicks recorded at AMAR−2 on 8 Sep 2018 (122 Hz frequency resolution, 0.001 time window, 0.0005 time step, Hamming window).

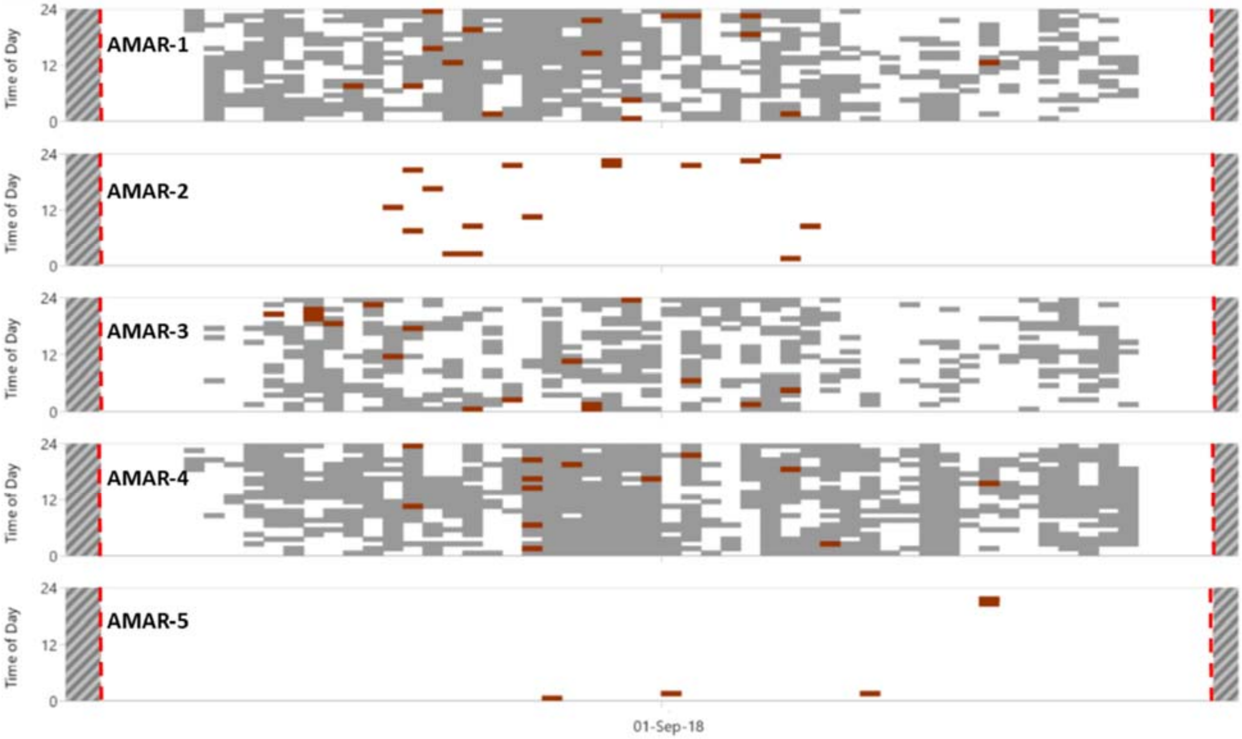

Figure 21. Daily and hourly occurrence of detected narwhal clicks recorded at AMAR−1, AMAR−2, AMAR−3, AMAR−4 and AMAR−5 from 4 Aug to 28 Sep 2018. Grey dots indicate automated detections. Red dots indicate manually validated results. The red dashed lines indicate AMAR deployment and retrieval dates. Manually identified signals are shown if the detector's precision was below 0.75 (AMAR−2 and AMAR−5).

3.4. Other marine mammal detections

3.4.1. Killer whale

Killer whale calls were potentially identified (during the manual review of 0.5% of the datasets; see Section 3.3) between 31 Au and 1 Sep 2018 at all stations (examples of killer whale calls in Figures 22 and 23). This short of period for killer whale calls is consistent with the sporadic occurrences of this species in the study area during the open water season.

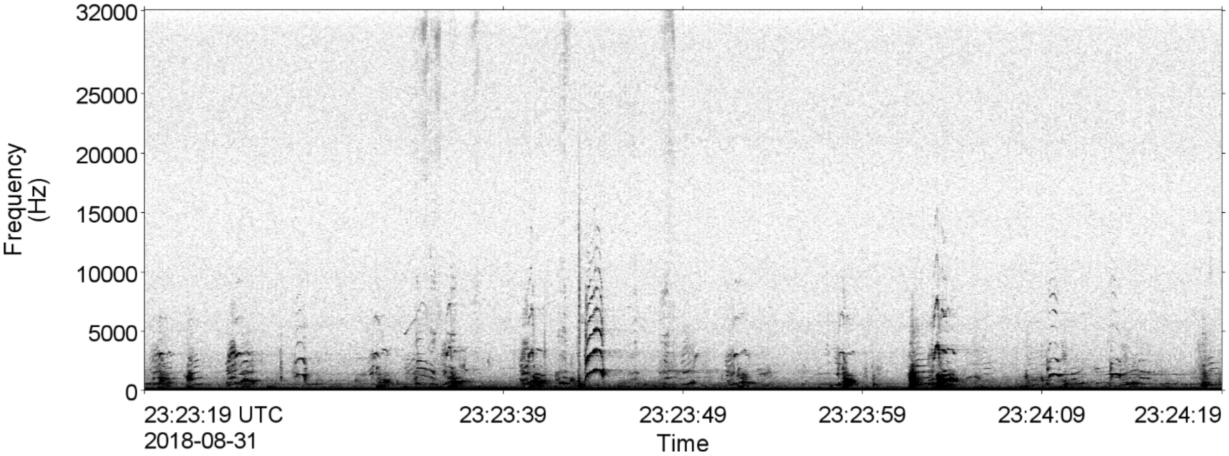

Figure 22. Spectrogram of killer whale and narwhal calls recorded at AMAR−1 on 31 Aug 2018 (2 Hz frequency resolution, 0.128 time window, 0.032 time step, Hamming window).

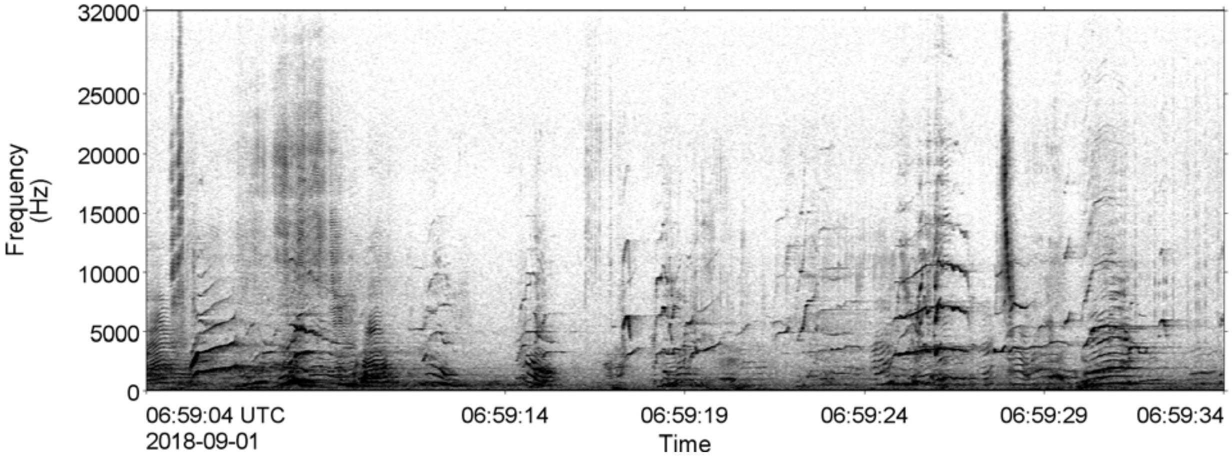

Figure 23. Spectrogram of killer whale and narwhal calls recorded at AMAR−5 on 1 Sep 2018 (2 Hz frequency resolution, 0.128 time window, 0.032 time step, Hamming window).

3.4.2. Ringed seal

While no detectors effectively identified ringed seal acoustic signals, potential ringed seal calls were identified during the manual review of 0.5% of the datasets at AMAR−1 (24 and 25 Aug), AMAR−2 (22 Aug), and AMAR−5 (15 Sep). Ringed seal vocalizations were chirps and barks (e.g., Figures 24 and 25) (Stirling 1973, Jones et al. 2014).

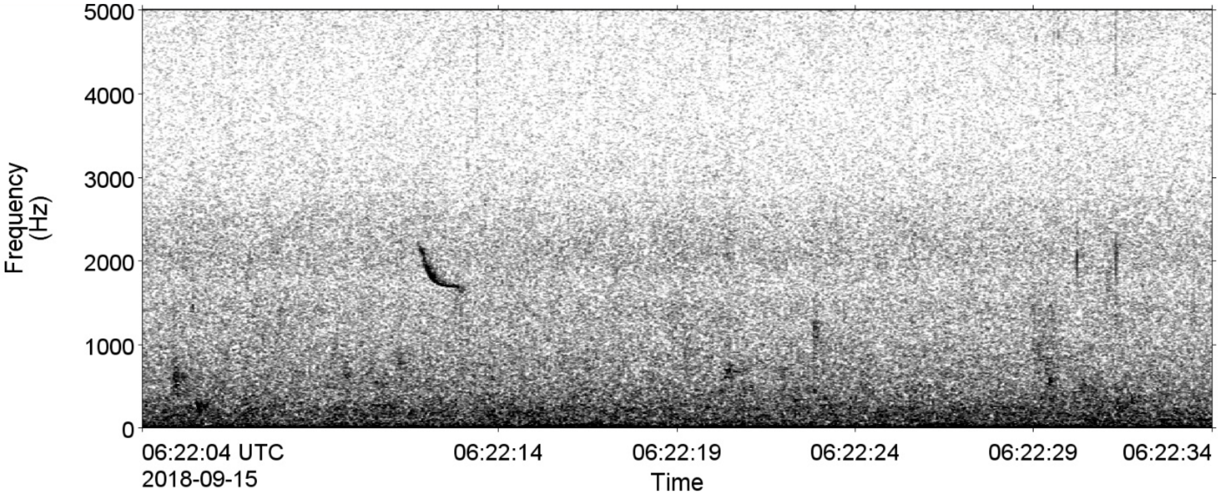

Figure 24. Spectrogram of a potential ringed seal descending chirp recorded at AMAR−5 on 15 Sep 2018 (2 Hz frequency resolution, 0.128 time window, 0.032 time step, Hamming window).

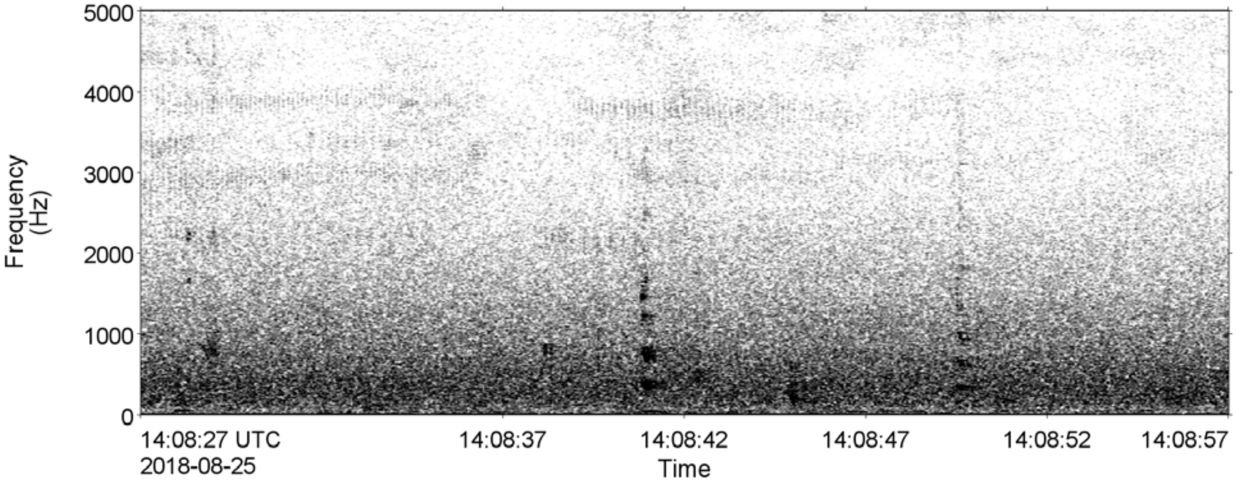

Figure 25. Spectrogram of potential ringed seal barks recorded at AMAR−1 on 25 Aug 2018 (2 Hz frequency resolution, 0.128 time window, 0.032 time step, Hamming window).

4. Discussion and Conclusion

4.1. Ambient Noise and Vessel Measurements

Acoustic levels in the ocean are influenced by sounds produced by wind, waves, ice-cracking events, geological seismic events, biological sources, and human activities. The acoustic levels were assessed at all five stations in this study. Sound exposure levels were similar at AMAR−1, −2, −4, and −5, with lower levels at AMAR−3, where the recorder was located in a more protected embayment. The maximum distance between recorders was ~11 km between AMAR−1 and −5 (Table 4). The primary contributor to the soundscape throughout the recording period was shipping (Figure 15). However, anthropogenic sounds did not reach the NMFS (2018) thresholds for possible injury to marine mammal hearing. Wind and waves also contributed to the soundscape at each station.

For sound levels below the thresholds for possible injury to hearing, it is possible to investigate the effects of sound on marine life using the percentage of time that the broadband sound levels exceed published thresholds for disturbance, as well as the percentage of time that the listening space was reduced due to high sound levels from vessels. For continuous sound sources like vessels, NOAA (1998) recommended 120 dB re 1 µPa as a threshold for disturbance onset of cetaceans, based on deflections of migrating bowheads around industrial activities in the arctic (Richardson et al. 1985). This threshold was incorporated into the recovery strategy for beluga whales in the St. Lawrence Estuary (https://bit.ly/2RUbDeN). The empirical distribution functions for AMAR−1 (with the highest sound levels, and one of the stations with the highest narwhal whistles detections) and AMAR−3 (station with the lowest sound levels) are shown in Figure 26 to assess the probability of sound levels exceeding 120 dB re 1 µPa. To generate these figures, the 1-minute sound pressure level data (10–30 000 Hz) were sorted from smallest to largest, and then the total number of minutes that were greater than a sound pressure level shown on the x-axis was computed and shown as a percentage on the y-axis. As an example of interpreting these figures, all minutes of data at AMAR−1 had an SPL greater than 80 dB re 1 µPa and less than 145 dB re 1 µPa. The exceedances of 120 dB re 1 µPa were rare at both stations. At AMAR−1 (station on the shipping corridor with the highest recorded sound levels), 2.4% of the data exceeded 120 dB re 1 µPa and only 0.5% exceeded the threshold at AMAR−3 (station furthest from shipping corridor with the lowest recorded sound levels).

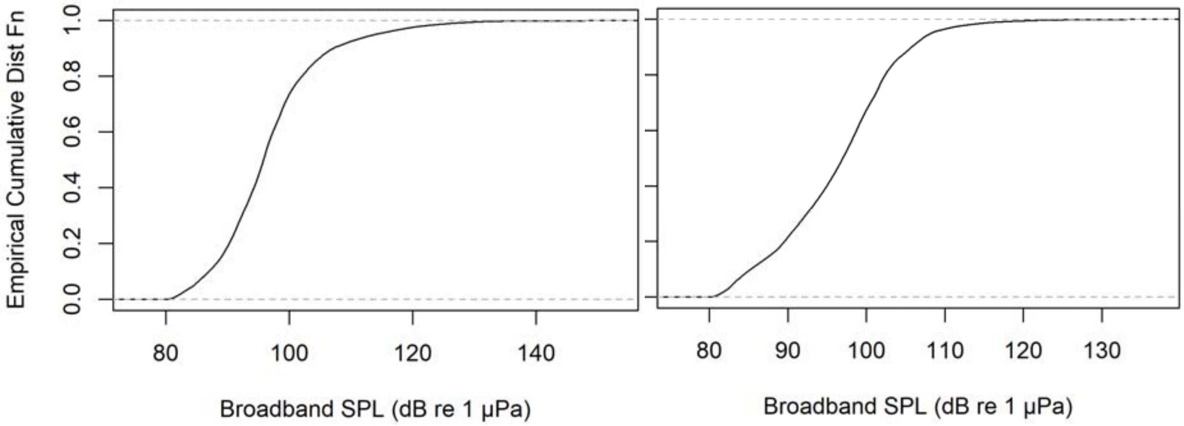

Figure 26. Empirical cumulative distribution functions for (left) AMAR−1 and (right) AMAR−3.

Listening range reduction (LRR) is the fractional decrease in the available listening range for marine animals (similar to listening space reduction, Pine et al. 2018, 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. (2018), modified to remove the factor of 2). In Equation 1, NL_2 is the sound pressure level with the masking noise present, NL_1 is the sound pressure level without the masking present, and N is the geometric spreading coefficient for the acoustic propagation environment. The sound pressure levels are computed for 1/3-octave-bands that are representative of the important listening frequencies for animals of interest.

$$LRR = 100 * \left(1 - 10^{\frac{NL_2 - NL_1}{N}}\right) \tag{1}$$

LRR was computed for a typical recording location (AMAR−1) as well as the quietest location (AMAR−3). At each location, the LRR was determined for whistles using 5 kHz as a typical frequency (mean frequency; Marcoux et al. 2012), and for clicks using 25 kHz as a representative frequency (25 kHz is the maximum 1/3-octave available for data sampled at 64 kHz; narwhal mid-frequency clicks have a mean frequency of ~10 kHz (Stafford et al. 2012); high-frequency clicks have a centre frequency of 53 kHz; (Rasmussen et al. 2015)) (Figure 27). The data were divided into periods with and without vessel detections (see Figure 7). The normal listening space was determined using the maximum of the mid-frequency cetacean audiogram (see Table A-9 in Finneran 2015) or the median 1-minute sound pressure level without vessels in each of the 1/3-octave-bands of interest as the baseline hearing threshold. The geometric spreading coefficient was set to a nominal value of 15. The analysis was performed for each 1 dB of increased 1/3-octave-band SPL above the normal condition. As a result of the choices made in determining the LRR, the 0% change condition in Figure 27 is at least 50%, but may be higher than 50% if the median ambient sound level in the 1/3-octave-band is lower than the animal's audiogram sensitivity at that frequency, as is the case at 1 kHz. The results show that the largest LRR occurrences were associated with ambient noise such as wind and rain rather than vessels for the narwhal whistle and click frequencies, especially at AMAR−3.

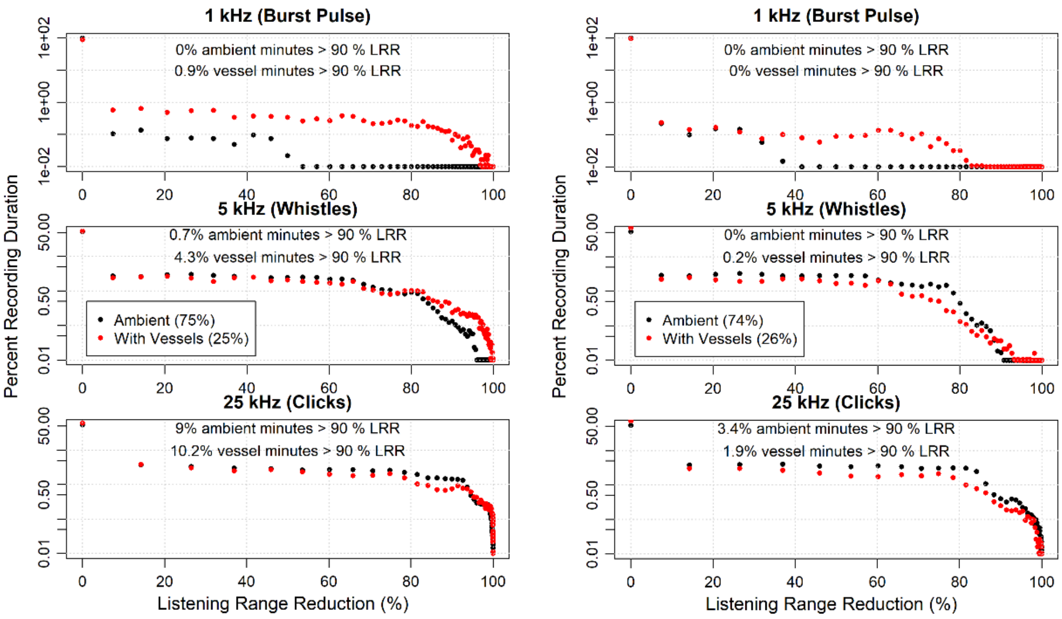

Figure 27. Listening range reduction (LRR) in Milne-Inlet for narwhal: (Left) AMAR−1 and (right) AMAR−3. For each station, the top figure shows the LRR for the 1 kHz 1/3-octave band which is representative of burst pulses, the middle figure shows the LRR for the 5 kHz 1/3-octave-band which is representative of listening for whistles, and the bottom figure shows the LRR for 25 kHz which is representative for clicks. The black dots show the distribution of LRR for ambient data only, while the red dots show the distribution of LRR for minutes with vessel detections. The y-axis is logarithmic to better view the rare high LRR events.

To compare the reductions in listening range, a 90% reduction was selected as the threshold for a significant reduction. Greater than 90% LRR for whistles occurred during 4.3% and 0.2% of the recordings containing vessel noise at AMAR-1 and AMAR-3, respectively (Figure 27). For clicks, greater than 90% LRR occurred during 10.2% of recordings containing vessel noise at AMAR-1 and 1.9% at AMAR-3 (Figure 27).

4.2. Model-Measurement Comparison

In support of the Mary River Project Phase 2 Proposal, JASCO modelled underwater sounds generated by ore carriers transiting along the northern shipping route (Quijano et al. 2018). Sounds from transiting vessels were modelled for locations at Milne Port, near Koluktoo Bay, in Milne Inlet and Eclipse Sound, and near Pond Inlet. The AMARs from the 2018 acoustic monitoring study were nearest to the Koluktoo Bay model location (Figure 28). Sounds from Postpanamax ore carriers transiting near Koluktoo Bay were modelled to a level of 120 dB re 1 µPa at distances as far as 10 km from the vessels (Figure E-7 in Quijano et al. 2018). In support of the present study, we conducted a brief analysis to compare those modelled estimates with the received sound levels measured on the AMARs from the 2018 acoustic monitoring. We used time-stamped vessel positions from the AIS records to determine times when ore carriers were nearest to the Koluktoo Bay model location, then compared the modelled and measured sound levels at the AMAR locations for those times. We examined the measured sound levels for 31 vessels as they transited along the shipping route near the model location.

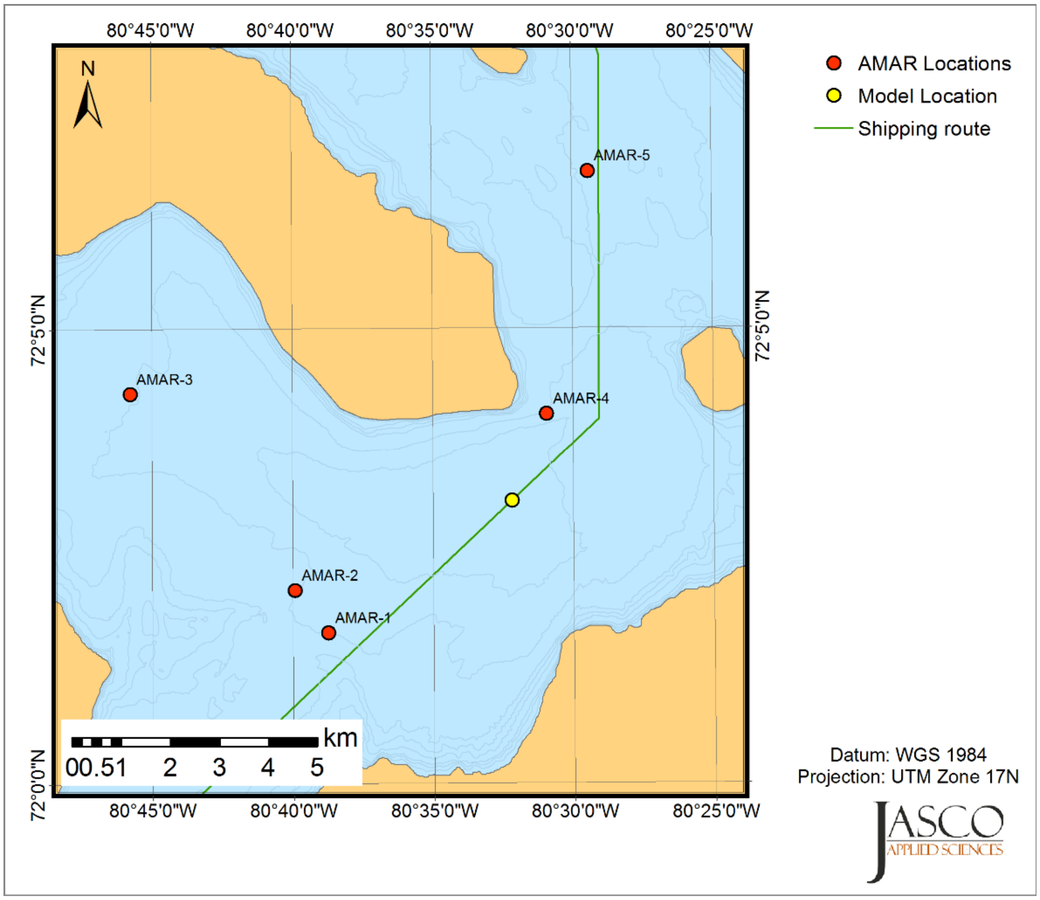

Figure 28. AMAR locations where measurements were collected in 2018 (red) and the Koluktoo Bay model location (yellow).

The measured levels were not directly comparable to the model outputs presented in Quijano et al (2018) because the modelled sound level contours were generated by selecting the maximum sound level over all depths at each range (this is a precautionary modelling approach applied because underwater sound levels typically vary with depth). Other features of the acoustic modelling approach that could effect the comparison between the model and measured data include the following:

- The source level input to the model: For the model, we selected the 90th percentile from empirical measurements of transiting bulkers as a conservative surrogate for the Postpanamax ore carriers.
- The assumed vessel speed: We modelled a Postpanamax ore carrier transiting at 9 knots, but the vessels considered in the present analysis were transiting at speeds between 5.5 and 9 knots.
- The assumed environment: We selected conservative parameters to characterize the bathymetry, sound speed profile, and the seafloor geoacoustics – all of which effect the modelled sound transmission.

Correcting only for the receiver depths (that is, comparing the measured levels with the levels modelled at the AMAR hydrophone depths), the modelled levels exceeded the measured levels by between 1 and 24 dB across vessels and across AMAR locations (11–16 dB across AMARs when averaged over all considered vessels).

To investigate whether this disagreement between the model and the data could be largely attributed to the surrogate source level input to the model, we estimated vessel-specific source levels. To this end, we selected time periods when the vessels passed nearest to AMARs 1 and 2. The received levels at those time instances were then back-propagated, on a 1/3-octave band basis, to derive a source level approximation for each of the vessels. In this step, we also adjusted the source level to correspond to a speed of 9 knots following the approach in Quijano et al (2018). The broadband vessel-specific source levels thus derived differed by between 0 and 15 dB from the surrogate broadband source level of 187 dB re 1 µPa; with the measured source levels being lower than the surrogate source level in all but two instances for the vessels considered in this analysis. Simply adjusting the broadband source level by these amounts yielded model-measurement differences across AMARs between 6 and 10 dB when averaged over vessels.

Examining the derived 1/3-octave-band source levels for each vessel also revealed small differences in the frequency distribution of the sounds, which would also affect the frequency-dependent sound propagation. Using the measurement-derived vessel-specific source levels, we re-ran the model from the model location to the individual AMAR locations to compare modelled and measured levels for each considered vessel. Figure 29 shows this comparison for a vessel (the *Nordpol*) that had a derived broadband source level equal to the modelled surrogate. Figure 30 shows the comparison for the vessel with the lowest derived broadband source level (the *Golden Opal*), which was 15 dB less than the modelled surrogate. These two vessels represent the extremes of the discrepancies with of the modelled and measured source levels.

In each plot in Figure 30, the green line shows the originally-modelled maximum-over-depth received sound level, the red line is the originally modelled received sound level at the AMAR depth, and the black line is the modelled received sound level at the AMAR depth computed using the vessel-specific, measurement-derived source level. Green stars at 4621 m (AMAR-1), 4796 m (AMAR-2), 8089 m (AMAR-3), 1915 m (AMAR-4), and 6909 m (AMAR-5) show the measured sound levels for the corresponding times.

The modelled levels at AMAR-1 and AMAR-2 (both at nearly 5 km range from the model location) were within 3-4 dB higher than the measured levels at those locations. At AMAR-3 (8 km from the model location), the model overestimated the measured level by 9 dB for the *Nordpol* and 3 dB for the *Golden Opal*. In general, the model consistently overestimated sound levels at AMAR-4 and AMAR-5 (approximately 2 km and 7 km from the model location, respectively) by a larger degree compared to levels measured at the same locations.

To further validate the accuracy of the modelled transmission loss versus range, we selected a few examples where vessels passed broadside to a transect extending from the shipping route into Koluktoo Bay, and inline with AMAR-1, AMAR-2, and AMAR-3. We ran the model using the appropriate measurement-derived source levels. Excellent agreement (Figure 31) between the model (solid lines) and the measured sound levels (stars) indicates that the model accurately represents the sound transmission into Koluktoo Bay.

The consistent overestimation of sound levels at AMAR-4 and AMAR-5 suggests that there may be a spatial dependence of the environment or a propagation effect that is not accounted for in the model. This could be due to inaccuracies in the assumed bathymetry or to a north-south gradient of the geoacoustic properties of the seafloor, for example. This has not been investigated further at this time, as it would require a more sophisticated model sensitivity investigation, which is beyond the scope of this summary analysis.

Other factors that have not been thoroughly investigated in this summary analysis, but that are expected to be important factors impacting the underwater sound field, include the horizontal directivity of the vessel sounds, differences in sounds for inbound versus outbound vessel transits, and sound level dependence on vessel draft. Further, and more detailed, investigation would be required to quantify these factors. Some research in this regard is currently being undertaken in part by a graduate student at University of New Brunswick.

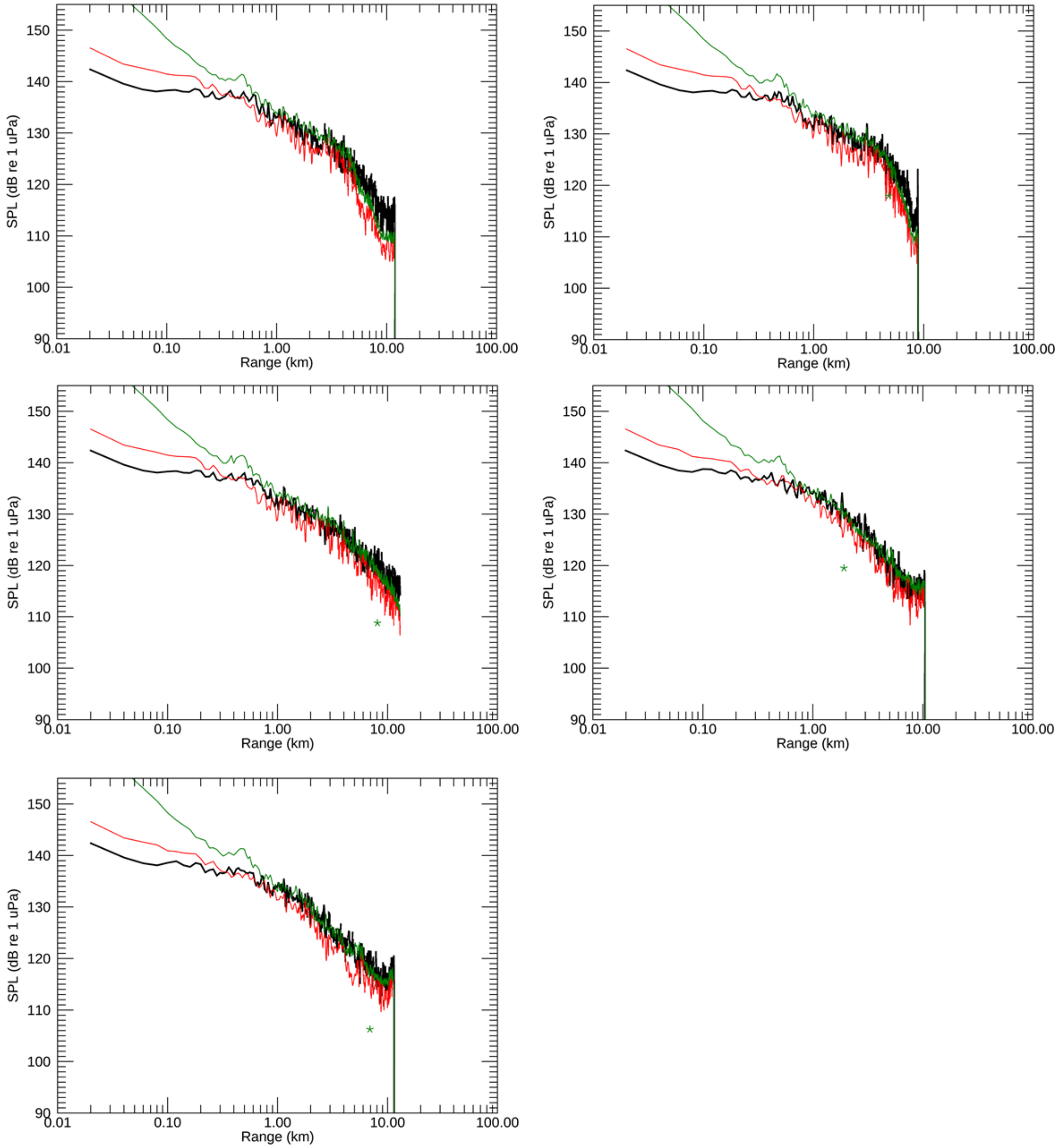

Figure 29. Measured levels (green stars) at AMAR-1 (top left), AMAR-2 (top right), AMAR-3 (middle left), AMAR-4 (middle right), and AMAR-5 (bottom left) for the *Nordpol* transiting near Koluktoo Bay. Predicted sound levels modelled using a surrogate source level and maximizing over depth (green line), modelled using a surrogate source level and output at the AMAR depth (red line), and modelled using the measurement-derived source level and output at the AMAR depth (black line).

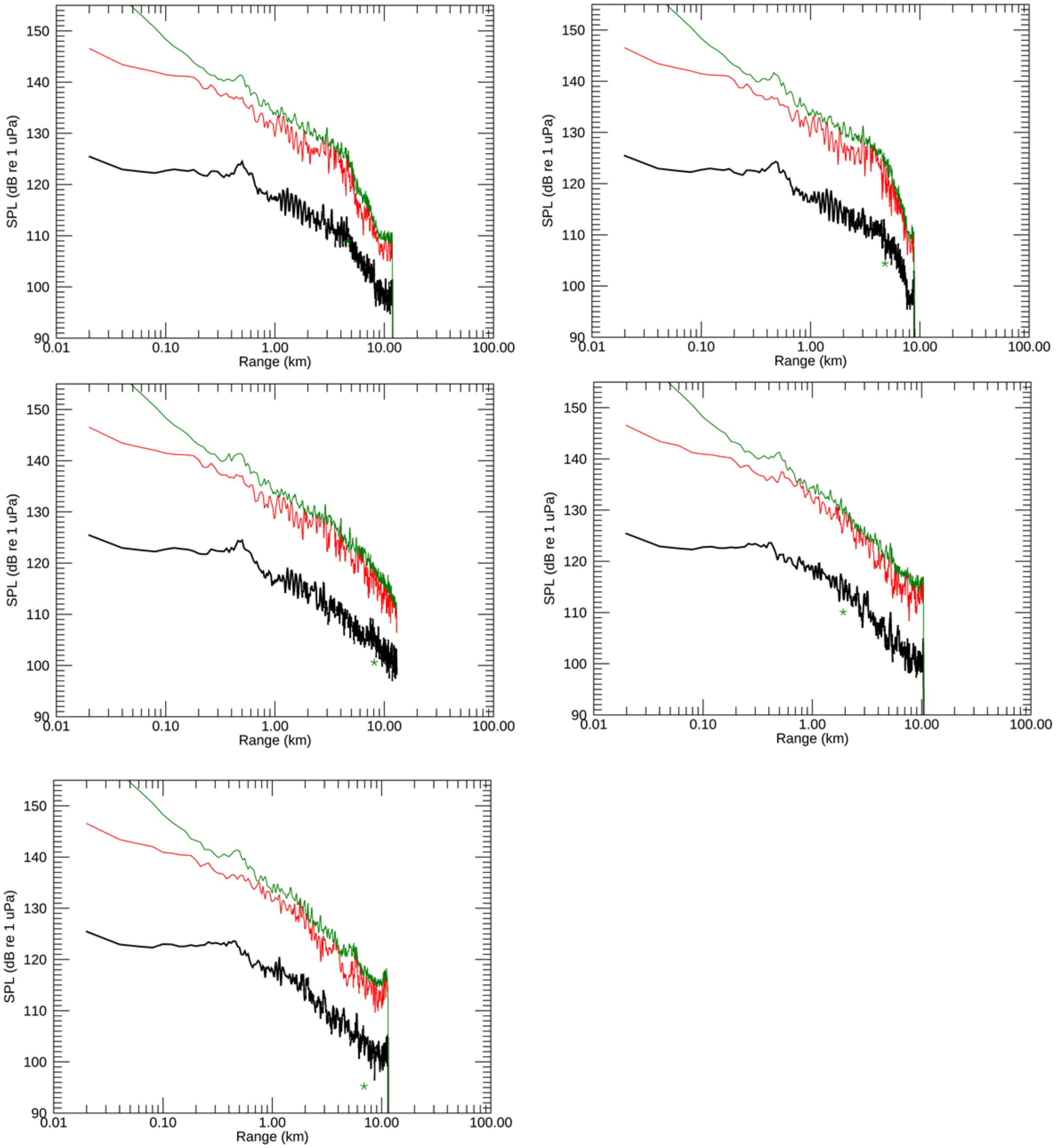

Figure 30. Measured levels (green stars) at AMAR-1 (top left), AMAR-2 (top right), AMAR-3 (middle left), AMAR-4 (middle right), and AMAR-5 (bottom left) for the *Golden Opal* transiting near Koluktoo Bay. Predicted sound levels modelled using a surrogate source level and maximizing over depth (green line), modelled using a surrogate source level and output at the AMAR depth (red line), and modelled using the measurement-derived source level and output at the AMAR depth (black line).

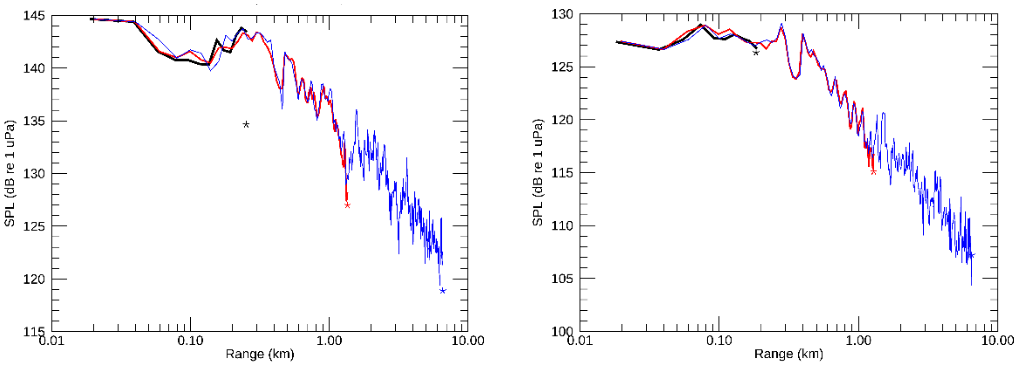

Figure 31. Modelled (solid lines) and measured (stars) sound levels for a transect from the shipping route into Koluktoo Bay passing AMAR-1 (black), AMAR-2 (red) and AMAR-3 (blue). Examples shown for the Nordpol (left) and the Golden Opal (right).

4.3. Marine Mammals

The marine mammal acoustic detection results presented in this report provide an index of acoustic occurrence for each species. Although they can be used to describe the relative abundance of a species across the study area, many factors influence the detectability of the targeted signals. While acoustic detection does indicate presence, an absence of detections does not necessarily indicate absence of animals; that can be due to lack of vocalizations by individuals near the acoustic recorders, masking of signals by environmental or anthropogenic noise sources, or a combination of these factors.

4.3.1. Narwhal

Narwhals were detected across all stations between 9 Aug and 24 Sep 2018. Narwhal whistle and click detections at the northern station (AMAR−5) was more limited than at other stations, likely reflecting habitat selection. Southern stations, AMAR−1 and −2, had the most whistle detections, which is consistent with visual observations in previous years (Smith et al. 2017). The arrival and departure time of narwhals from their summering areas is variable and depends on ice conditions. Narwhals typically arrive in Milne Inlet in late July as the ice breaks up, and they depart for their wintering area in Baffin Bay in September before ice forms (Finley and Gibb 1982, Dietz et al. 2001, Watt et al. 2012, Watt et al. 2016). The acoustic presence of narwhals in the area supports previous research (Marcoux et al. 2009, 2012).

4.3.2. Killer whale

During the open-water season, notably during late summer, killer whales enter bays and inlets in the eastern Canadian Arctic in pursuit of prey, such as narwhal, beluga whales, bowhead whales, and seals (Reeves 1988, Higdon et al. 2012). A killer whale tracked for 90 days remained in the eastern Canadian Arctic (Admiralty and Prince Regent Inlets) from mid-August until early October, when locations overlapped marine mammal prey species' aggregations (Matthews et al. 2011). The results presented here are based on manual review and, therefore, underestimate the acoustic occurrence of this species. Nevertheless, the temporal overlap between acoustic results and the detections of potential killer whale prey (narwhals) is consistent with some previous killer whale observations (presence around Pond Inlet peaks in July and August, but have been seen there as late as October; reported inMatthews et al. 2011).

4.3.3. Ringed seal

Ringed seals (*Pusa hispida*) are abundant throughout Nunavut waters and occur year-round along the coast. In spring, a high density of breeding adults occurs on stable, land-fast ice in areas with good snow cover, whereas non-breeders tend to be found at the floe edge or in the moving pack ice (Yurkowski et al. 2018). The middle of Milne Inlet, as well as the southern Milne Inlet northward, are ringed seal hotspots (Yurkowski et al. 2018). Manual (sporadic) detections of ringed seal vocalizations confirm their presence in the area. The results presented here are based on manual review and, therefore, underestimate the acoustic occurrence of this species.

The environmental, anthropogenic, and noise-related factors that may influence detection patterns at each station should be investigated further.

4.4. Recommendations

A passive acoustic monitoring program is proposed in 2019 that would be undertaken in concert with the Bruce Head visual-based behavioural monitoring program conducted at Bruce Head (shore-based monitoring station) to evaluate whether the frequency, intensity, and duration of different narwhal call types is modified in the presence of large vessel traffic (in relation to visually recorded behavioural changes). A collaborative study between Golder, JASCO, the University of New Brunswick and Baffinland is being undertaken in 2019 to address this identified data gap.

5. Acknowledgements

The authors would like to acknowledge Julien Delarue and Christopher Whitt of JASCO and Golder team members for their assistance deploying and retrieving the acoustic recorders, as well as the JASCO equipment team for their expert preparation and handling of the gear. The crew of the *Ocean Raynald T.*, contributed to the logistical and operational success of the deployment and retrieval cruises.

Glossary

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) (ISO 2017).

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 noise
All-encompassing sound at a given place, usually a composite of sound from many sources near and far (ANSI S1.1-1994 R2004), e.g., shipping vessels, seismic activity, precipitation, sea ice movement, wave action, and biological activity.

Auditory frequency weighting (auditory weighting function, frequency-weighting function)
The process of band-pass filtering sounds to reduce the importance of inaudible or less-audible frequencies for individual species or groups of species of aquatic mammals (ISO 2017). One example is M-weighting introduced by Southall et al. (2007) to describe "Generalized frequency weightings for various functional hearing groups of marine mammals, allowing for their functional bandwidths and appropriate in characterizing auditory effects of strong sounds".

background noise
Total of all sources of interference in a system used for the production, detection, measurement, or recording of a signal, independent of the presence of the signal (ANSI S1.1-1994 R2004). Ambient noise 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/ASA S1.13-2005 R2010).

bar
Unit of pressure equal to 100 kPa, which is approximately equal to the atmospheric pressure on Earth at sea level. 1 bar is equal to 10^6 Pa or 10^{11} μPa.

box-and-whisker plot
A plot that illustrates the centre, spread, and overall range of data from a visual 5-number summary. The ends of the box are the upper and lower quartiles (25th and 75th percentiles). The horizontal line inside the box is the median (50th percentile). The whiskers and points extend outside the box to the highest and lowest observations, where the points correspond to outlier observations (i.e., observations that fall more than 1.5 × IQR beyond the upper and lower quartiles, where IQR is the interquartile range).

broadband sound level
The total sound pressure level measured over a specified frequency range. If the frequency range is unspecified, it refers to the entire measured frequency range.

cavitation
A rapid formation and collapse of vapor cavities (i.e., bubbles or voids) in water, most often caused by a rapid change in pressure. Fast-spinning vessel propellers typically cause cavitation, which creates a lot of noise.

cetacean
Any animal in the order Cetacea. These are aquatic, mostly marine mammals and include whales, dolphins, and porpoises.

continuous sound
A sound whose sound pressure level remains above ambient sound during the observation period (ANSI/ASA S1.13-2005 R2010). A sound that gradually varies in intensity with time, for example, sound from a marine vessel.

decade
Logarithmic frequency interval whose upper bound is ten times larger than its lower bound (ISO 2006).

decidecade
One tenth of a decade (ISO 2017). 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".

decibel (dB)
One-tenth of a bel. Unit of level when the base of the logarithm is the tenth root of ten, and the quantities concerned are proportional to power (ANSI S1.1-1994 R2004).

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

fast-average sound pressure level
The time-averaged sound pressure levels calculated over the duration of a pulse (e.g., 90%-energy time window), using the leaky time integrator from Plomp and Bouman (1959) and a time constant of 125 ms. Typically used only for pulsed sounds.

fast Fourier transform (FFT)
A computationally efficiently algorithm for computing the discrete Fourier transform.

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
Groups of marine mammal species with similar hearing ranges. Commonly defined functional hearing groups include low-, mid-, and high-frequency cetaceans, pinnipeds in water, and pinnipeds in air.

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

hertz (Hz)
A unit of frequency defined as one cycle per second.

high-frequency (HF) cetacean
The functional cetacean hearing group that represents those odontocetes (toothed whales) specialized for hearing high frequencies.

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

impulsive sound
Sound that is typically brief and intermittent with rapid (within a few seconds) rise time and decay back to ambient levels (NOAA 2013, ANSI S12.7-1986 R2006). For example, seismic airguns and impact pile driving.

Listening reduction range (LRR)
Fractional decrease in the range over which marine animals can detect a sound.

low-frequency (LF) cetacean
The functional cetacean hearing group that represents mysticetes (baleen whales) specialized for hearing low frequencies.

masking
Obscuring of sounds of interest by sounds at similar frequencies.

mean-square sound pressure spectral density
Distribution as a function of frequency of the mean-square sound pressure per unit bandwidth (usually 1 Hz) of a sound having a continuous spectrum (ANSI S1.1-1994 R2004). Unit: $\mu Pa^2/Hz$.

median
The 50th percentile of a statistical distribution.

mid-frequency (MF) cetacean
The functional cetacean hearing group that represents those odontocetes (toothed whales) specialized for mid-frequency hearing.

mysticete
Mysticeti, a suborder of cetaceans, use their baleen plates, rather than teeth, to filter food from water. They are not known to echolocate, but they use sound for communication. Members of this group include all baleen whales, including rorquals (Balaenopteridae), right whales (Balaenidae), and grey whales (*Eschrichtius robustus*).

non-impulsive sound
Sound that is broadband, narrowband or tonal, brief or prolonged, continuous or intermittent, and typically does not have a high peak pressure with rapid rise time (typically only small fluctuations in decibel level) that impulsive signals have (ANSI/ASA S3.20-1995 R2008). For example, marine vessels, aircraft, machinery, construction, and vibratory pile driving (NIOSH 1998, NOAA 2015).

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, narwhals, 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.

otariid pinnipeds in water (OPW)
The functional pinniped hearing group that represents eared seals under water.

peak pressure level (PK)
The maximum instantaneous sound pressure level, in a stated frequency band, within a stated period. Also called zero-to-peak pressure level. Unit: decibel (dB).

peak-to-peak pressure level (PK-PK)
The difference between the maximum and minimum instantaneous pressure levels. Unit: decibel (dB).

percentile level, exceedance
The sound level exceeded *n* % of the time during a measurement.

permanent threshold shift (PTS)
A permanent 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)
The functional pinniped hearing group that represents true/earless seals under water.

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 hydrostatic pressure caused by a sound wave. Also called overpressure. Unit: pascal (Pa). Symbol: p.

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 (RL)
The sound level measured (or that would be measured) at a defined location.

rms
root-mean-square.

sound
A time-varying pressure disturbance generated by mechanical vibration waves travelling through a fluid medium such as air or water.

sound exposure
Time integral of squared, instantaneous frequency-weighted sound pressure over a stated time interval or event. Unit: pascal-squared second ($Pa^2 \cdot s$) (ANSI S1.1-1994 R2004).

sound exposure level (SEL)
A cumulative measure related to the sound energy in one or more pulses. Unit: dB re 1 $\mu Pa^2 \cdot s$. SEL is expressed over the summation period (e.g., per-pulse SEL [for airguns], single-strike SEL [for pile drivers], 24-hour SEL).

sound exposure spectral density
Distribution as a function of frequency of the time-integrated squared sound pressure per unit bandwidth of a sound having a continuous spectrum (ANSI S1.1-1994 R2004). Unit: $\mu Pa^2 \cdot s/Hz$.

sound field
Region containing sound waves (ANSI S1.1-1994 R2004).

sound intensity
Sound energy flowing through a unit area perpendicular to the direction of propagation per unit time.

sound pressure level (SPL)
The decibel ratio of the time-mean-square sound pressure, in a stated frequency band, to the square of the reference sound pressure (ANSI S1.1-1994 R2004).

For sound in water, the reference sound pressure is one micropascal (p_0 = 1 μPa) and the unit for SPL is dB re 1 μPa^2:

$$L_p = 10 \log_{10}(p^2/p_0^2) = 20 \log_{10}(p/p_0)$$

Unless otherwise stated, SPL refers to the root-mean-square (rms) pressure level. See also 90% sound pressure level and fast-average sound pressure level. Non-rectangular time window functions may be applied during calculation of the rms value, in which case the SPL unit should identify the window type.

sound speed profile
The speed of sound in the water column as a function of depth below the water surface.

source level (SL)
The sound level measured in the far-field and scaled back to a standard reference distance of 1 metre from the acoustic centre of the source. Unit: dB re 1 μPa·m (pressure level) or dB re 1 $\mu Pa^2 \cdot s \cdot m$ (exposure level).

spectral density level
The decibel level ($10 \cdot \log_{10}$) of the spectral density of a given parameter such as SPL or SEL, for which the units are dB re 1 $\mu Pa^2/Hz$ and dB re 1 $\mu Pa^2 \cdot s/Hz$, respectively.

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)
Temporary loss of hearing sensitivity caused by excessive noise exposure.

Literature Cited

[BIM] Baffinland Iron Mines Corporation. 2012. *Mary River Project: Final Environmental Impact Statement. Popular Summary*. 22 pp. http://www.baffinland.com/wp-content/uploads/2012/06/POP_Eng_sm.pdf.

[BIM] Baffinland Iron Mines Corporation. 2013. *Early revenue phase – addendum to final environmental impact statement. Mary River Project final environmental impact statement*. Volume 1-10. Unpublished report by BIM submitted to the Nunavut Impact Review Board.

[COSEWIC] Committee on the Status of Endangered Wildlife in Canada. 2004. *COSEWIC assessment and update status report on the beluga whale Delphinapterus leucas in Canada*. Ottawa, ON, Canada. ix + 70 pp. https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/cosewic/sr_beluga_whale_e.pdf.

[COSEWIC] Committee on the Status of Endangered Wildlife in Canada. 2008a. *COSEWIC assessment and update status report on the narwhal Monodon monoceros in Canada*. Ottawa, ON, Canada. 25 pp. https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/cosewic/sr_narwhal_e.pdf.

[COSEWIC] Committee on the Status of Endangered Wildlife in Canada. 2008b. *COSEWIC assessment and update status report on the Killer Whale Orcinus orca, Southern Resident population, Northern Resident population, West Coast Transient population, Offshore population and Northwest Atlantic / Eastern Arctic population, in Canada. Committee on the Status of Endangered Wildlife in Canada*. Ottawa, ON, Canada. viii + 65 pp. https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/cosewic/sr_killer_whale_0809_e.pdf.

[COSEWIC] Committee on the Status of Endangered Wildlife in Canada. 2009. *COSEWIC assessment and update status report on the Bowhead Whale Balaena mysticetus, Bering-Chukchi-Beaufort population and Eastern Canada-West Greenland population, in Canada*. Ottawa, ON, Canada. vii + 49 pp. https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/cosewic/sr_bowhead_whale_0809_e.pdf.

[COSEWIC] Committee on the Status of Endangered Wildlife in Canada. 2017. *COSEWIC assessment and status report on the Atlantic Walrus Odobenus rosmarus rosmarus, High Arctic population, Central-Low Arctic population and Nova Scotia-Newfoundland-Gulf of St. Lawrence population in Canada*. Ottawa, ON, Canada. xxi + 89 pp. https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/cosewic/sr_Atlantic%20Walrus_2017_e.pdf.

[ISO] International Organization for Standardization. 2006. *ISO 80000-3:2006. Quantities and Units – Part 3: Space and time*. https://www.iso.org/standard/31888.html.

[ISO] International Organization for Standardization. 2017. *ISO 18405:2017. Underwater acoustics – Terminology*. Geneva. https://www.iso.org/standard/62406.html.

[NIOSH] National Institute for Occupational Safety and Health. 1998. *Criteria for a recommended standard: Occupational noise exposure. Revised Criteria*. Document Number 98-126. U.S. Department of Health and Human Services, NIOSH, Cincinnati, OH, USA. 122 pp. https://www.cdc.gov/niosh/docs/98-126/pdfs/98-126.pdf.

[NMFS] National Marine Fisheries Service (U.S.). 2018. *2018 Revision to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts*. U.S. Department of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-59. 167 pp. https://www.fisheries.noaa.gov/webdam/download/75962998.

[NOAA] National Oceanic and Atmospheric Administration (U.S.). 1998. Incidental taking of marine mammals; Acoustic harassment. *Federal Register* 63(143): 40103.

[NOAA] National Oceanic and Atmospheric Administration (U.S.). 2013. *Draft guidance for assessing the effects of anthropogenic sound on marine mammals: Acoustic threshold levels for onset of permanent and temporary threshold shifts*. National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and NMFS Office of Protected Resources, Silver Spring, MD, USA. 76 pp.

[NOAA] National Oceanic and Atmospheric Administration (U.S.). 2015. *Draft guidance for assessing the effects of anthropogenic sound on marine mammal hearing: Underwater acoustic threshold levels for onset of permanent and temporary threshold shifts*. NMFS Office of Protected Resources, Silver Spring, MD, USA. 180 pp.

[NRC] National Research Council (U.S.). 2003. *Ocean Noise and Marine Mammals*. National Research Council (U.S.), Ocean Studies Board, Committee on Potential Impacts of Ambient Noise in the Ocean on Marine Mammals. The National Academies Press, Washington, DC, USA. http://www.nap.edu/openbook.php?record_id=10564.

ANSI S12.7-1986. R2006. *American National Standard Methods for Measurements of Impulsive Noise*. American National Standards Institute, NY, USA.

ANSI S1.1-1994. R2004. *American National Standard Acoustical Terminology*. American National Standards Institute, NY, USA.

ANSI/ASA S1.13-2005. R2010. *American National Standard Measurement of Sound Pressure Levels in Air*. American National Standards Institute and Acoustical Society of America, NY, USA.

ANSI/ASA S3.20-1995. R2008. *American National Standard Bioacoustical Terminology*. American National Standards Institute and Acoustical Society of America, NY, USA.

Arveson, P.T. and D.J. Vendittis. 2000. Radiated noise characteristics of a modern cargo ship. *Journal of the Acoustical Society of America* 107(1): 118-129. https://doi.org/10.1121/1.428344.

Au, W.W.L., R.A. Kastelein, T. Rippe, and N.M. Schooneman. 1999. Transmission beam pattern and echolocation signals of a harbor porpoise (*Phocoena phocoena*). *Journal of the Acoustical Society of America* 106(6): 3699-3705. https://doi.org/10.1121/1.428221.

Berchok, C.L., D.L. Bradley, and T.B. Gabrielson. 2006. St. Lawrence blue whale vocalizations revisited: Characterization of calls detected from 1998 to 2001. *Journal of the Acoustical Society of America* 120(4): 2340-2354. https://doi.org/10.1121/1.2335676.

Campbell, R.R., D.B. Yurick, and N.B. Snow. 1988. Predation on narwhals, Monodon monoceros, by killer whales, *Orcinus orca*, in the eastern Canadian arctic. *Canadian Field-Naturalist* 102(4): 689–696.

Clark, C.W. and J.H. Johnson. 1984. The sounds of the bowhead whale, *Balaena mysticetus*, during the spring migrations of 1979 and 1980. *Canadian Journal of Zoology* 62(7): 1436-1441. https://doi.org/10.1139/z84-206.

Clark, C.W. 1990. Acoustic behaviour of mysticete whales. *In* Thomas, J. and R.A. Kastelein (eds.). *Sensory Abilities of Cetaceans*. Springer, Boston, MA. pp 571-583. https://doi.org/10.1007/978-1-4899-0858-2_40.

Dawson, J., L. Pizzolato, S.E. Howell, L. Copland, and M.E. Johnston. 2018. Temporal and Spatial Patterns of Ship Traffic in the Canadian Arctic from 1990 to 2015. *Arctic* 71(1): 15-26. https://doi.org/10.14430/arctic4698.

Deane, G.B. 2000. Long time-base observations of surf noise. *Journal of the Acoustical Society of America* 107(2): 758-770. https://doi.org/10.1121/1.428259.

Deecke, V.B., J.K.B. Ford, and P.J.B. Slater. 2005. The vocal behaviour of mammal-eating killer whales: Communicating with costly calls. *Animal Behaviour* 69(2): 395-405. https://doi.org/10.1016/j.anbehav.2004.04.014.

Delarue, J., M. Laurinolli, and B. Martin. 2009. Bowhead whale (*Balaena mysticetus*) songs in the Chukchi Sea between October 2007 and May 2008. *Journal of the Acoustical Society of America* 126(6): 3319-3328. https://doi.org/10.1121/1.3257201.

Dietz, R., M.P. Heide-Jørgensen, P.R. Richard, and M. Acquarone. 2001. Summer and fall movements of narwhals (*Monodon monoceros*) from northeastern Baffin Island towards northern Davis Strait. *Arctic* 54: 244-261. https://www.jstor.org/stable/40512344.

Edds-Walton, P.L. 1997. Acoustic communication signals of mysticetes whales. *Bioacoustics* 8(1-2): 47-60. https://doi.org/10.1080/09524622.2008.9753759.

Finley, K.J. and E.J. Gibb. 1982. Summer diet of the narwhal (*Monodon monoceros*) in Pond Inlet, northern Baffin Island. *Canadian Journal of Zoology* 60(12): 3353-3363. https://doi.org/10.1139/z82-424.

Finneran, J.J. 2015. *Auditory weighting functions and TTS/PTS exposure functions for cetaceans and marine carnivores*. Technical report by SSC Pacific, San Diego, CA, USA.

Finneran, J.J. 2016. *Auditory weighting functions and TTS/PTS exposure functions for marine mammals exposed to underwater noise*. Technical Report for Space and Naval Warfare Systems Center Pacific, San Diego, CA, USA. 49 pp. http://www.dtic.mil/dtic/tr/fulltext/u2/1026445.pdf.

Ford, J.K.B. and H.D. Fisher. 1978. Underwater acoustic signals of the narwhal (*Monodon monoceros*). *Canadian Journal of Zoology* 56(4): 552-560. https://doi.org/10.1139/z78-079.

Ford, J.K.B., L.M. Nichol, and D.M. Cavanagh. 1986. *Preliminary assessment of the value of underwater vocalizations in population studies of narwhals in the Canadian Arctic*. Report by West Coast Whale Research Foundation for World Wildlife Fund Canada. vii + 44 pp.

Ford, J.K.B. 1989. Acoustic behaviour of resident killer whales (*Orcinus orca*) off Vancouver Island, British Columbia. *Canadian Journal of Zoology* 67(3): 727-745. https://doi.org/10.1139/z89-105.

Garland, E.C., M. Castellote, and C.L. Berchok. 2015. Beluga whale (*Delphinapterus leucas*) vocalizations and call classification from the eastern Beaufort Sea population. *Journal of the Acoustical Society of America* 137(6): 3054-3067. https://doi.org/10.1121/1.4919338.

Golder Associates Ltd. 2018. *Bruce Head Shore-based Monitoring Program: 2014-2017 Integrated Report*. Document Number 1663724-081-R-Rev0-12000.

Golder Associates Ltd. 2019. *2017 Narwhal Tagging Study - Technical Report (DRAFT)*. Document Number 1663724-082-R-RevB. Draft Report in Progress.

Higdon, J.W., D.D.W. Hauser, and S.H. Ferguson. 2012. Killer whales (Orcinus orca) in the Canadian Arctic: Distribution, prey items, group sizes, and seasonality. *Marine Mammal Science* 28(2): E93-E109. https://doi.org/10.1111/j.1748-7692.2011.00489.x.

Hildebrand, J.A. 2009. Anthropogenic and natural sources of ambient noise in the ocean. *Marine Ecology Progress Series* 395: 5-20. https://doi.org/10.3354/meps08353.

Jason Prno Consulting Services Ltd. 2017. *Results of Community Workshops Conducted for Baffinland Iron Mines Corporation's Phase 2 Proposal*. Report prepared for Baffinland Iron Mines Corporation.

Jones, J., E. Roth, M. Mahoney, C. Zeller, C. Jackson, K. Kitka, I. Sia, S. Wiggins, J. Hildebrand, et al. 2011. *Seasonal presence of ringed (Pusa hispida), ribbon (Histrophoca fasciata), and bearded seal (Erignathus barbatus) vocalizations in the Chukchi Sea, north of Barrow, Alaska*. *Alaska Marine Science Symposium*, Anchorage, AK.

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

Karlsen, J., A. Bisther, C. Lydersen, T. Haug, and K.M. Kovacs. 2002. Summer vocalisations of adult male white whales (*Delphinapterus leucas*) in Svalbard, Norway. *Polar Biology* 25(11): 808-817. https://doi.org/10.1007/s00300-002-0415-6.

Kim, K.H. and A.C. Conrad. 2016. *Acoustic Monitoring Near Koluktoo Bay, Milne Inlet, August–October 2015* Report Number 522-2. Report by Greeneridge Sciences Inc. for Baffinland Iron Mines Corporation. x + 69 pp.

Kowarski, K.A., J. Delarue, B. Martin, and B. Gaudet. In preparation. Tackling large, multi-species passive acoustic monitoring programs: A method for determining cetacean occurrence.

Marcoux, M., M. Auger-Méthé, and M.M. Humphries. 2009. Encounter frequencies and grouping patterns of narwhals in Koluktoo Bay, Baffin Island. *Polar Biology* 32(12): 1705-1716. https://doi.org/10.1007/s00300-009-0670-x.

Marcoux, M., M. Auger-Méthé, and M.M. Humphries. 2012. Variability and context specificity of narwhal (*Monodon monoceros*) whistles and pulsed calls. *Marine Mammal Science* 28(4): 649-665. https://doi.org/10.1111/j.1748-7692.2011.00514.x.

Matthews, C.J.D., S.P. Luque, S.D. Petersen, R.D. Andrews, and S.H. Ferguson. 2011. Satellite tracking of a killer whale (*Orcinus orca*) in the eastern Canadian Arctic documents ice avoidance and rapid, long-distance movement into the North Atlantic. *Polar Biology* 34(7): 1091-1096. https://doi.org/10.1007/s00300-010-0958-x.

Merchant, N.D., T.R. Barton, P.M. Thompson, E. Pirotta, D.T. Dakin, and J. Dorocicz. 2013. Spectral probability density as a tool for ambient noise analysis. *Journal of the Acoustical Society of America* 133(4): EL262-EL267. https://doi.org/10.1121/1.4794934.

Miller, K.M., J. Pristed, B. Møhl, and A. Surlykke. 1995. The click-sounds of narwhals (*Monodon monoceros*) in Inglefield Bay, Northwest Greenland. *Society for Marine Mammalogy* 11(4): 491-502. https://doi.org/10.1111/j.1748-7692.1995.tb00672.x.

Milne, A.R. and J.H. Ganton. 1964. Ambient Noise under Arctic-Sea Ice. *Journal of the Acoustical Society of America* 36(5): 855-863. https://doi.org/10.1121/1.1919103.

Møhl, B., A. Surlykke, and L.A. Miller. 1990. High Intensity Narwhal Clicks. *In* Thomas, J.A. and R.A. Kastelein (eds.). *Sensory Abilities of Cetaceans: Laboratory and Field Evidence*. Springer, Boston, MA, USA. pp 295-303. https://doi.org/10.1007/978-1-4899-0858-2_18.

Møhl, B., M. Wahlberg, P.T. Madsen, L.A. Miller, and A. Surlykke. 2000. Sperm whale clicks: Directionality and source level revisited. *Journal of the Acoustical Society of America* 107(1): 638-648. https://doi.org/10.1121/1.428329.

Mouy, X., M.M. Zykov, and S.B. Martin. 2011. Two-dimensional localization of walruses in shallow water using a ray-tracing model. *Journal of the Acoustical Society of America* 129(4): 2574-2574. https://doi.org/10.1121/1.3588495.

Nedwell, J.R. and A.W. Turnpenny. 1998. The use of a generic frequency weighting scale in estimating environmental effect. *Workshop on Seismics and Marine Mammals*. 23–25 Jun 1998, London, UK.

Nedwell, J.R., A.W. Turnpenny, J. Lovell, S.J. Parvin, R. Workman, and J.A.L. Spinks. 2007. *A validation of the* dB_{ht} *as a measure of the behavioural and auditory effects of underwater noise*. Document Number 534R1231 Report prepared by Subacoustech Ltd. for the UK Department of Business, Enterprise and Regulatory Reform under Project No. RDCZ/011/0004. http://www.subacoustech.com/wp-content/uploads/534R1231.pdf.

Nieukirk, S.L., K.M. Stafford, D.K. Mellinger, R.P. Dziak, and C.G. Fox. 2004. Low-frequency whale and seismic airgun sounds recorded in the mid-Atlantic Ocean. *Journal of the Acoustical Society of America* 115(4): 1832-1843. https://doi.org/10.1121/1.1675816.

Pine, M.K., D.E. Hannay, S.J. Insley, W.D. Halliday, and F. Juanes. 2018. Assessing vessel slowdown for reducing auditory masking for marine mammals and fish of the western Canadian Arctic. *Marine Pollution Bulletin* 135: 290-302. https://doi.org/10.1016/j.marpolbul.2018.07.031.

Plomp, R. and M.A. Bouman. 1959. Relation between Hearing Threshold and Duration for Tone Pulses. *Journal of the Acoustical Society of America* 31(6): 749-758. https://doi.org/10.1121/1.1907781.

Quijano, J.E., C. O'Neill, and M.E. Austin. 2018. *Underwater Noise Assessment for the Mary River Project - Phase 2 Proposal: Construction and operation activities in Milne Port and along the Northern Shipping Route*. Document Number 01621, Version 1.0. Technical report by JASCO Applied Sciences for Golder Associates Ltd.

Rasmussen, M.H., J.C. Koblitz, and K.L. Laidre. 2015. Buzzes and High-frequency clicks recorded from narwhals (Monodon monoceros) at their wintering ground. *Aquatic Mammals* 41(2): 256-264. http://dx.doi.org/10.1578/AM.41.3.2015.256.

Reeves, R.R. 1988. Distribution and seasonality of killer whales in the eastern Canadian Arctic. *Rit Fiskideildar* 11: 136-160.

Richardson, W.J., M.A. Fraker, B. Würsig, and R.S. Wells. 1985. Behaviour of Bowhead Whales Balaena mysticetus summering in the Beaufort Sea: Reactions to industrial activities. *Biological Conservation* 32(3): 195-230. https://doi.org/10.1016/0006-3207(85)90111-9.

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

Ross, D. 1976. *Mechanics of Underwater Noise*. Pergamon Press, New York.

Smith, H.R., J.R. Brandon, P. Abgrall, M. Fitzgerald, R.E. Elliott, and V.D. Moulton. 2015. *Shore-based monitoring of narwhals and vessels at Bruce Head, Milne Inlet, 30 July – 8 September 2014*. Report Number FA0013-2. Report by LGL Limited for Baffinland Iron Mines Corporation. 73 p + appendices.

Smith, H.R., V.D. Moulton, S. Raborn, P. Abgrall, R.E. Elliott, and M. Fitzgerald. 2017. *Shore-based monitoring of narwhals and vessels at Bruce Head, Milne Inlet, 2016*. Report Number FA0089-1. Report by LGL Limited for Baffinland Iron Mines Corporation. 87 p. + appendices. https://www.baffinland.com/downloadocs/fa0089---bruce-head-narwhal-2016-final-reportopt_2017-10-08-33.pdf.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, Jr., D. Kastak, D.R. Ketten, J.H. Miller, et al. 2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. *Aquatic Mammals* 33(4): 411-521. https://doi.org/10.1080/09524622.2008.9753846.

Stafford, K.M., K.L. Laidre, and M.P. Heide-Jorgensen. 2012. First acoustic recordings of narwhals (*Monodon monoceros*) in winter. *Marine Mammal Science* 28(2): E197-E207. https://doi.org/10.1111/j.1748-7692.2011.00500.x.

Stephenson, S.A. and L. Hartwig. 2010. The arctic marine workshop. *Canadian Manuscript Report of Fisheries and Aquatic Sciences* 2934: 76.

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

Stirling, I., W. Calvert, and C. Spencer. 1987. Evidence of stereotyped underwater vocalizations of male Atlantic walruses (*Odobenus rosmarus rosmarus*). *Canadian Journal of Zoology* 65(9): 2311-2321. https://doi.org/10.1139/z87-348.

Terhune, J.M. 1994. Geographical variation of harp seal underwater vocalizations. *Canadian Journal of Zoology* 72(5): 892-897. https://doi.org/10.1139/z94-121.

Thomas, T., P. Abgrall, S.W. Raborn, H. Smith, R.E. Elliott, and V.D. Moulton. 2014. *Narwhals and shipping: shore-based study at Bruce Head, Milne Inlet, August 2013. Final*. Report Number TA8286-2. Report by LGL Limited for Baffinland Iron Mines Corporation. 60 p + appendices.

Thomas, T.A., S. Raborn, R.E. Elliott, and V.D. Moulton. 2015. *Marine mammal aerial surveys in Eclipse Sound, Milne Inlet, Navy Board Inlet, and Pond Inlet, 1 August – 22 October 2014*. Report Number FA0024-2. Report by LGL Limited for Baffinland Iron Mines Corporation, King City, ON, Canada. 70 pp.

Thomas, T.A., S. Raborn, R.E. Elliott, and V.D. Moulton. 2016. *Marine mammal aerial surveys in Eclipse Sound, Milne Inlet and Pond Inlet, 1 August – 17 September 2015*. Report Number FA0059-3. Report by LGL Limited for Baffinland Iron Mines Corporation. 76 p. + appendices, King City, ON, Canada. 70 pp. https://www.baffinland.com/downloadocs/1663724-002-r-rev0-golder-peer-review-marine-mammals-aerial-survey-31mar..._2017-09-58-09.pdf.

Tyack, P.L. and C.W. Clark. 2000. Communication and acoustic behavior of dolphins and whales. *In Hearing by whales and dolphins*. Springer, New York. pp 156-224.

Watt, C.A., J. Orr, B. LeBlanc, P. Richard, and S.H. Ferguson. 2012. *Satellite tracking of narwhals (Monodon monoceros) from Admiralty Inlet (2009) and Eclipse Sound (2010–2011)*. Volume 46. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/046. iii + 17 pp.

Watt, C.A., J.R. Orr, and S.H. Ferguson. 2016. Spatial distribution of narwhal (*Monodon monoceros*) diving for Canadian populations helps identify important seasonal foraging areas. *Canadian Journal of Zoology* 95(1): 41-50. https://doi.org/10.1139/cjz-2016-0178.

Wenz, G.M. 1962. Acoustic Ambient Noise in the Ocean: Spectra and Sources. *Journal of the Acoustical Society of America* 34(12): 1936-1956. https://doi.org/10.1121/1.1909155.

Yurkowski, D.J., B.G. Young, J.B. Dunn, and S.H. Ferguson. 2018. Spring distribution of ringed seals (*Pusa hispida*) in Eclipse Sound and Milne Inlet, Nunavut: Implications for potential ice-breaking activities. *Arctic Science*: 1-8. https://doi.org/10.1139/as-2018-0020.

Appendix A. Acoustic Data Analysis Methods

The data sampled at 64 kilosamples per second (ksps) was processed for ambient sound analysis, vessel noise detection, and detection of all marine mammal calls except clicks. Click and whistle detections were performed on the data sampled at 375 ksps. This section describes the ambient, vessel, and marine mammal detection algorithms employed (Figure A-1).

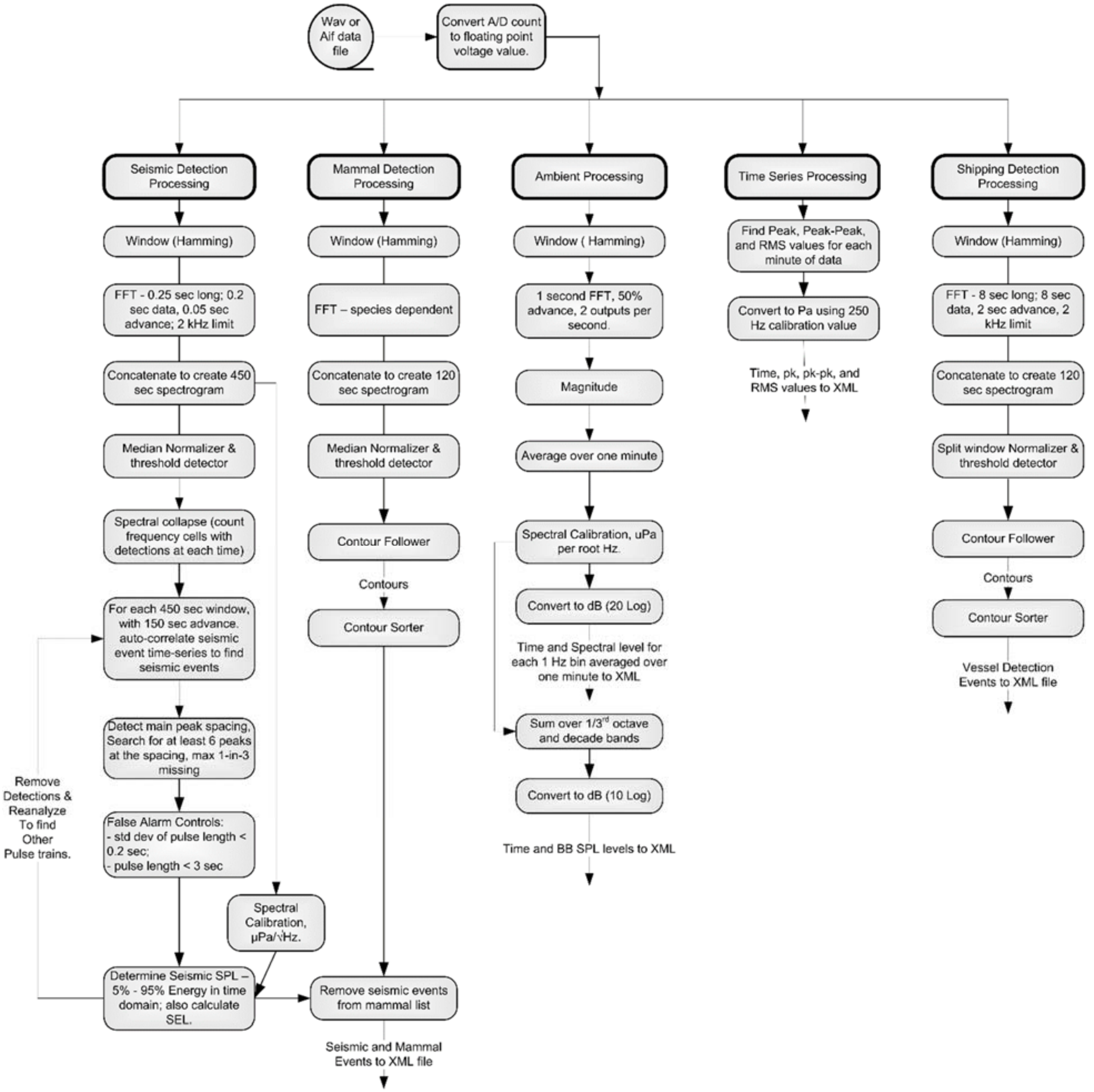

Figure A-1. Major stages of the automated acoustic analysis process performed with JASCO's custom software suite.

A.1. Total Ambient Sound Levels

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

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

$$\mathrm{PK} = L_{\mathrm{p,pk}} = 10\log_{10}\frac{\max|p^2(t)|}{p_0^2} \tag{A-1}$$

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

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

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

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

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

$$\mathrm{SEL} = L_{\mathrm{E}} = 10\log_{10}\left[\int_T p^2(t)\,dt\Big/T_0 p_0^2\right] \tag{A-3}$$

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

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

$$L_{\mathrm{E},N} = 10\log_{10}\sum_{i=1}^{N}10^{\frac{L_{E,i}}{10}} \tag{A-4}$$

To compute the SPL(T_{90}) and SEL of acoustic events in the presence of high levels of background noise, equations A-5 and A-6 are modified to subtract the background noise contribution:

$$\mathrm{SPL}(\mathrm{T}_{90}) = L_{\mathrm{p90}} = 10\log_{10}\left[\frac{1}{T_{90}}\int_{T_{90}}\left(p^2(t)-\overline{n^2}\right)dt\Big/p_0^2\right] \tag{A-5}$$

$$L_{\mathrm{E}} = 10\log_{10}\left[\int_{T}\left(p^2(t)-\overline{n^2}\right)dt\Big/T_0p_0^2\right] \tag{A-6}$$

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

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

$$L_{\mathrm{p}} = L_{\mathrm{E}} - 10\log_{10}(T) \tag{A-7}$$

$$L_{\mathrm{p90}} = L_{\mathrm{E}} - 10\log_{10}(T_{90}) - 0.458 \tag{A-8}$$

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

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

$$L_{\mathrm{eq}} = 10\log_{10}\left[\frac{1}{T}\int_{T}p^2(t)\,dt\Big/p_0^2\right] \tag{A-9}$$

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

A.2. One-Third-Octave-Band Analysis

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

Because animals perceive exponential increases in frequency rather than linear increases, analyzing a sound spectrum with passbands that increase exponentially in size better approximates real-world scenarios. In underwater acoustics, a spectrum is commonly split into 1/3-octave-bands, which are one-third of an octave wide; each octave represents a doubling in sound frequency. A very similar measure is to logarithmically divide each frequency decade into 10 passbands, which are commonly misnamed the 1/3-octave-bands rather than deci-decades; we use this naming in the report. The centre frequency of the ith 1/3-octave-band, $f_{\mathrm{c}}(i)$, is defined as:

$$f_{\mathrm{c}}(i) = 10^{\frac{i}{10}}, \tag{A-10}$$

and the low (f_{lo}) and high (f_{hi}) frequency limits of the ith 1/3-octave-band are defined as:

$$f_{\mathrm{lo},i} = 10^{\frac{-1}{20}} f_{\mathrm{c}}(i) \quad \text{and} \quad f_{\mathrm{hi},i} = 10^{\frac{1}{20}} f_{\mathrm{c}}(i) \tag{A-11}$$

The 1/3-octave-bands become wider with increasing frequency, and on a logarithmic scale the bands appear equally spaced (Figure A-2).

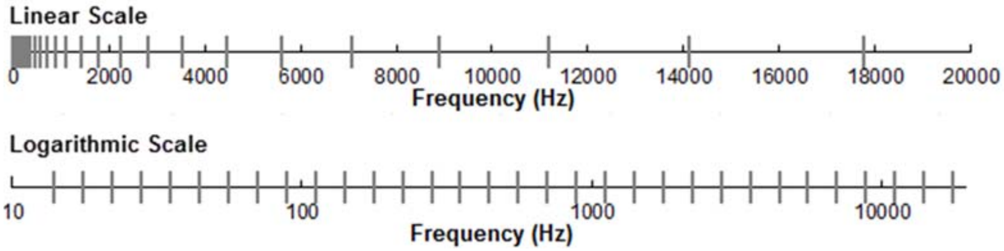

Figure A-2. One-third-octave frequency bands (vertical lines) shown on a linear frequency scale and a logarithmic scale.

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

$$L_{\mathrm{p},i} = 10 \log_{10} \int_{f_{\mathrm{lo},i}}^{f_{\mathrm{hi},i}} S(f)\, df \tag{A-12}$$

Summing the sound pressure level of all the 1/3-octave-bands yields the broadband sound pressure level:

$$\text{Broadband SPL} = 10 \log_{10} \sum_{i} 10^{\frac{L_{\mathrm{p},i}}{10}} \tag{A-13}$$

Figure A-3 shows an example of how the 1/3-octave-band sound pressure levels compare to the power spectrum of an ambient noise signal. Because the 1/3-octave-bands are wider with increasing frequency, the 1/3-octave-band SPL is higher than the power spectrum, especially at higher frequencies. 1/3-octave-band analysis is applied to both continuous and impulsive noise sources. For impulsive sources, the 1/3-octave-band SEL is typically reported.

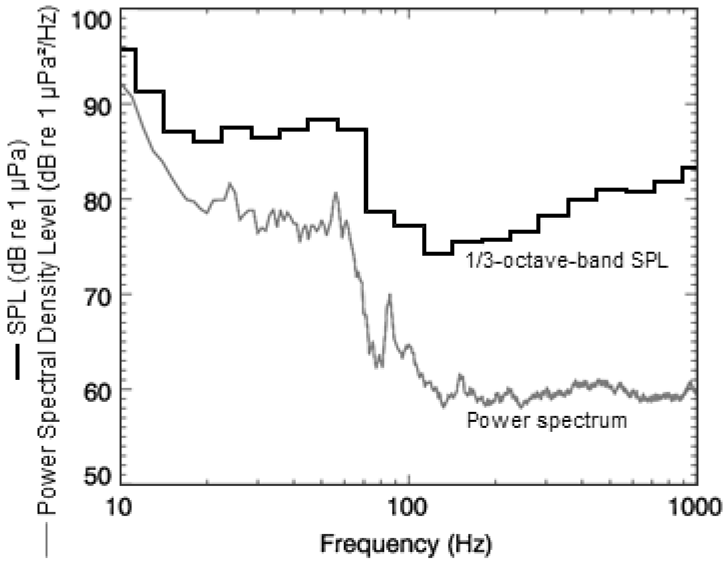

Figure A-3. A power spectrum and the corresponding 1/3-octave-band sound pressure levels of example ambient noise shown on a logarithmic frequency scale. Because the 1/3-octave-bands are wider with increasing frequency, the 1/3-octave-band SPL is higher than the power spectrum.

Table A-1. One-third-octave-band frequencies (Hz).

Band	Lower frequency	Nominal centre frequency	Upper frequency
1	8.9	10	11.2
2	11.6	13	14.6
3	14.3	16	17.9
4	17.8	20	22.4
5	22.3	25	28.0
6	28.5	32	35.9
7	35.6	40	44.9
8	45.0	51	57.2
9	57.0	64	71.8
10	72.0	81	90.9
11	90.9	102	114.4
12	114.1	128	143.7
13	143.4	161	180.7
14	180.8	203	227.9
15	228.0	256	287.4
16	287.7	323	362.6
17	362.7	406	455.7
18	456.1	512	574.7
19	574.6	645	723.9
20	724.2	813	912.6
21	912.3	1024	1149
22	1,150	1,290	1,447
23	1,448	1,625	1,824
24	1,824	2,048	2,297
25	2,298	2,580	2,896
26	2,896	3,251	3,649
27	3,649	4,096	4,597
28	4,598	5,161	5,793
29	5,793	6,502	7,298
30	7,298	8,192	9,195
31	9,195	10,321	11,585
32	11,585	13,004	14,597

Table A-2. Decade-band 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

A.3. Marine Mammal Detections

JASCO applied automated analysis techniques to the acoustic data. Automated detectors were employed to detect (if present) impulsive clicks and tonal whistles of narwhal and killer whale, and tonal moans of mysticetes including bowhead whales.

A.3.1. Automated click detectors

Odontocete clicks were detected by the following steps (Figure A-4):

1. The raw data was high-pass filtered to remove all energy below 8 kHz. This removed most energy from other sources such as shrimp, vessels, wind, and cetacean tonal calls, while allowing the energy from all marine mammal click types to pass.
2. The filtered samples were summed to create a 0.5 ms rms time series. Most marine mammal clicks have a 0.1–1 ms duration.
3. Possible click events were identified with a Teager-Kaiser energy detector.
4. The maximum peak signal within 1 ms of the detected peak was found in the high-pass filtered data.
5. The high-pass filtered data was searched backwards and forwards to find the time span where the local data maxima were within 12 dB of the maximum peak. The algorithm allowed two zero-crossings to occur where the local peak was not within 12 dB of the maximum before stopping the search. This defined the time window of the detected click.
6. The classification parameters were 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 were computed. The slope parameter helps to identify beaked whale clicks, as beaked whale clicks increase in frequency (upsweep).
7. The Mahalanobis distance between the extracted classification parameters and the templates of known click types was computed. The covariance matrices for the known click types, computed from thousands of manually identified clicks for each species, were stored in an external file. Each click was classified as a type with the minimum Mahalanobis distance, unless none of them were less than the specified distance threshold.

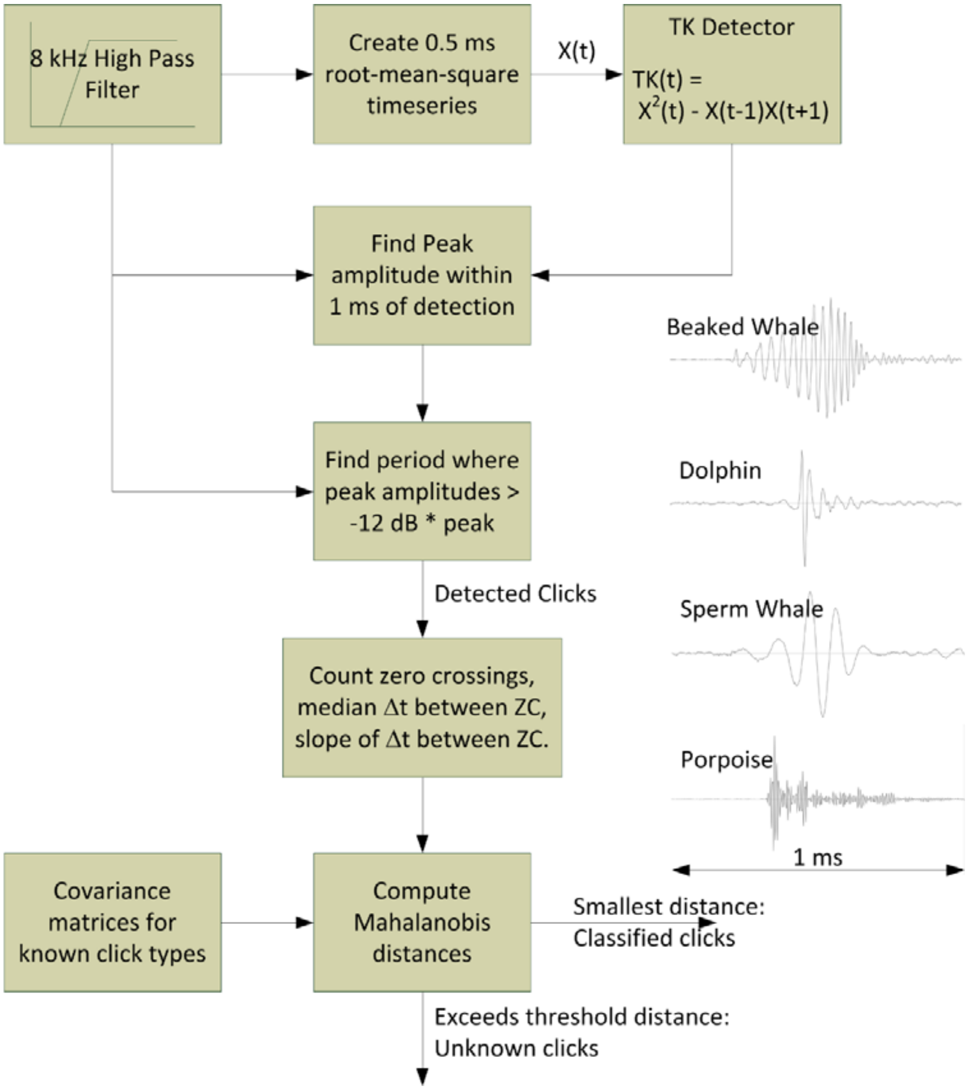

Figure A-4. The click detector/classifier and a 1-ms time-series of four click types.

A.3.2. Cetacean tonal call detection

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

1. 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 A-3) were created.
2. Adjacent bins were joined, and contours were created via a contour-following algorithm (Figure A-5).
3. A sorting algorithm determined if the contours match the definition of a marine mammal vocalization (Table A-4).

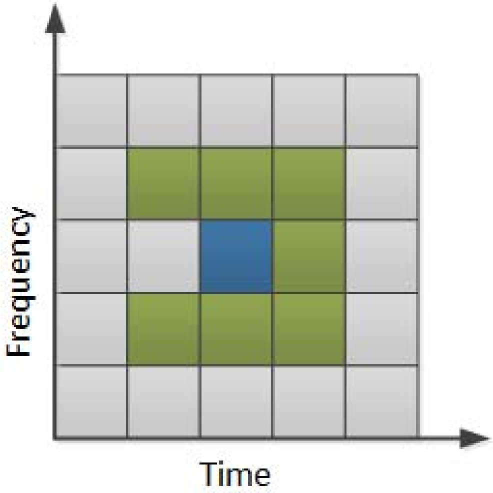

Figure A-5. Illustration of the search area used to connect spectrogram bins. The blue square represents a bin of the binary spectrogram equalling 1 and the green squares represent the potential bins it could be connected to. The algorithm advances from left to right so grey cells left of the test cell need not be checked.

Table A-3. Fast Fourier Transform (FFT) and detection window settings 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.

Possible species	Vocalization	FFT			Detection window (s)	Detection threshold
		Resolution (Hz)	Frame length (s)	Timestep (s)		
Narwhals	Whistle	64	0.015	0.005	5	3
Killer whales	Whistle	16	0.03	0.015	5	3
Bowhead whales	Moan	4	0.2	0.05	5	3

Table A-4. A sample of vocalization sorter definitions for the tonal vocalizations of cetacean species expected in the area.

Possible species	Vocalization	Frequency (Hz)	Duration (s)	Bandwidth (Hz)	Other detection parameters
Narwhals	Whistle	4,000–20,000	0.3–3	>700	Maximum instantaneous bandwidth = 5,000 Hz
Killer whales	Whistle	1,000–10,000	0.5–5	>300	Minimum frequency <5,000 Hz
Bowhead whales	Moan	100–700	0.5–5	>50	Maximum instantaneous bandwidth = 200 Hz

A.3.3. Validation of automated detectors

A.3.3.1. Selecting Data for Manual Validation

To standardize the file selection process, we developed an algorithm that automatically selects a sample of files for review. The sample size *N* is set based on the amount of time allocated to the review effort. *N* = 0.5% of acoustic data was applied in the present report.

Kowarski et al. (In preparation) compared the results of 0.5, 1, and 2.5% analysis for two baleen whale and two beaked whale species occurrences. They found that the occurrence results were identical for most of the analyzed data sets. When results differed between validation efforts, 0.5% analysis always resulted in a more conservative outcome.

The algorithm selects files to manually review based on the following criteria:

1. All species targeted by a detector whose performance needs to be assessed must be represented within a minimum of 10 files (unless fewer than 10 files have detections).
2. The sample should not include more than one file per day unless *N* is greater than the number of recording days or the “minimum 10 files per species” rule dictates that more than one file per day be reviewed.
3. Select files containing low, medium, and high numbers of detected species. Files with no detected species are excluded from the pool of eligible files. Files are selected such that the proportion of each species count bin within the sample matches the per-file species count distribution in the whole data set.
4. Select files with low, medium, and high numbers of detections per file for each species. The number of detections per file is split into low (but at least one), medium, and high bins, which corresponded to the lower, middle, and upper third percentile of the range, respectively. Files with no detection for each species will appear among those with detections of other species, allowing us to evaluate false negatives. We choose to slightly oversample the high detection counts (40% of files compared with 30% from the medium and low bins) to avoid biasing the threshold high. The three files with the highest detection counts are automatically included in those selected from the high bins for the same reason.

We score the goodness of fit of a sample of files according to how well it conforms to the “preferred” distribution of detections, as determined by the initial distribution and the preferred final sampling. A lower score implies a better fit. To score the goodness of fit, we perform the following step for a selected sample of files:

1. Determine the diversity (species count per file) proportions (Pc) of the selected sample of files, and calculate a diversity score based on how much the current proportions differ from the original diversity proportions (Po).

   DiversityScore = average(abs(Pc[i]–Po[i]))

2. For each species, determine the proportion of files (C) that have detection counts in the low/medium/high original species count distributions. Files with no detections are not included in the calculation for each species (0-detection files for a species will unavoidably be included in files selected for other species).

   PerSpeciesScore[i] = abs(C_{low}–0.3) + abs(C_{medium}–0.3) + abs(C_{high}–0.4)

   DetectionScore = average(PerSpeciesScore[1..n]), where n is the number of species

   FitScore = (DiversityScore + DetectionScore)/2

A.3.3.2. Detector Performance Calculation and Optimization

All files selected for manual validation were reviewed by one 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 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, the analyst would consult 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 raw 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 validated versus 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. The following restrictions were applied to our detector results:

1. If a species was automatically detected at a station, but was never manually validated, all automated detections at that station were considered false and the station was not included in the results as the species was considered absent.
2. If a species was automatically detected over a specific timeframe, but manual validation revealed all detections to be falsely triggered by another sound source or species, all automated detections during that time at that station were excluded.

In phase 2, the performance of the detectors was calculated based on the phase 1 restrictions and optimized for each species using a threshold, defined as the number of detections per file at and above which detections of species were considered valid. This was completed for each station as automated detectors perform differently depending on factors, such as the species diversity of the area or human activity, which vary in space and time.

To determine the performance of each 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 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.

P is the classifier's precision, representing the proportion of files with detections that are true positives. A *P* value of 0.9 means that 90% of the files with detections truly contain that species, but says nothing about whether all files containing acoustic signals from the species were identified. *R* is the classifier's recall, representing the proportion of files containing the species of interest that are identified by the detector. An *R* value of 0.8 means that 80% of all files containing acoustic signals from the species of interest also contained automated detections, but says nothing about how many files with detections were incorrect. Thus, a perfect detector would have *P* and *R* values equal to 1. The algorithm determines a detector threshold for each species, at every station, for both years, that maximizes the F-score. Appendix B presents resulting thresholds, *P*s, and *R*s.

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 (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.

Appendix B. Detector Performance

B.1. Narwhal Whistles

Table B-1. Performance of the automated narwhal detector for each station including the Threshold implemented, the resulting detector Precision (P) and Recall (R), the number of files included in the calculation (# Files; excluding any files where an analyst was uncertain of species presence), the number of files in the calculation containing an annotation for this species/ vocalization type (# Annotation files), and the number of files in the calculation containing automated narwhal whistle detections (# Detection files).

Station	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
AMAR-1	1	0.94	0.76	30	21	17
AMAR-2	1	0.88	0.64	30	22	16
AMAR-3	1	1.00	0.44	30	25	11
AMAR-4	1	1.00	0.65	30	23	15
AMAR-5	1	0.80	0.44	30	18	10

B.2. Narwhal Clicks

Table B-2. Performance of the automated narwhal detector for each station including the Threshold implemented, the resulting detector Precision (P) and Recall (R), the number of files included in the calculation (# Files; excluding any files where an analyst was uncertain of species presence), the number of files in the calculation containing an annotation for this species/ vocalization type (# Annotation files), and the number of files in the calculation containing automated narwhal click detections (# Detection files).

Station	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
AMAR-1	2	0.78	0.93	30	15	26
AMAR-2	1	0.65	1.00	30	17	26
AMAR-3	2	0.94	0.94	30	18	26
AMAR-4	9	0.93	1.00	30	14	26
AMAR-5	10	0.50	1.00	30	6	26

Appendix C. Marine Mammal Auditory Frequency Weighting

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).

C.1.1. Southall et al. (2007) Weighting Functions

Auditory weighting functions for marine mammals—called M-weighting functions—were proposed by Southall et al. (2007). These M-weighting functions are applied in a similar way as A-weighting for noise level assessments for humans. Functions were defined for five hearing groups of marine mammals:

- Low-frequency (LF) cetaceans—mysticetes (baleen whales)–estimated auditory bandwidth between 7 Hz and 22 kHz
- Mid-frequency (MF) cetaceans—some odontocetes (toothed whales) specialized for using mid frequencies–estimated auditory bandwidth between 150 Hz and 160 kHz
- High-frequency (HF) cetaceans—odontocetes specialized for using high-frequencies–estimated auditory bandwidth between 200 Hz and 180 kHz
- Pinnipeds in water (Pw)—seals, sea lions, and walrus
- Pinnipeds in air (not addressed here)

The M-weighting functions have unity gain (0 dB) through the passband and their high and low frequency roll-offs are approximately –12 dB per octave. The amplitude response in the frequency domain of each M-weighting function is defined by:

$$G(f) = -20\log_{10}\left[\left(1+\frac{a^2}{f^2}\right)\left(1+\frac{f^2}{b^2}\right)\right] \tag{C-1}$$

where $G(f)$ is the weighting function amplitude (in dB) at the frequency f (in Hz), and a and b are the estimated lower and upper hearing limits, respectively, which control the roll-off and passband of the weighting function. The parameters a and b are defined uniquely for each hearing group (Table C-1). Figure C-1 shows the auditory weighting functions recommended by Southall et al. (2007).

Table C-1. Parameters for the auditory weighting functions recommended by Southall et al. (2007).

Functional hearing group	a (Hz)	b (Hz)
Low-frequency cetaceans	7	22,000
Mid-frequency cetaceans	150	160,000
High-frequency cetaceans	200	180,000
Pinnipeds in water	75	75,000

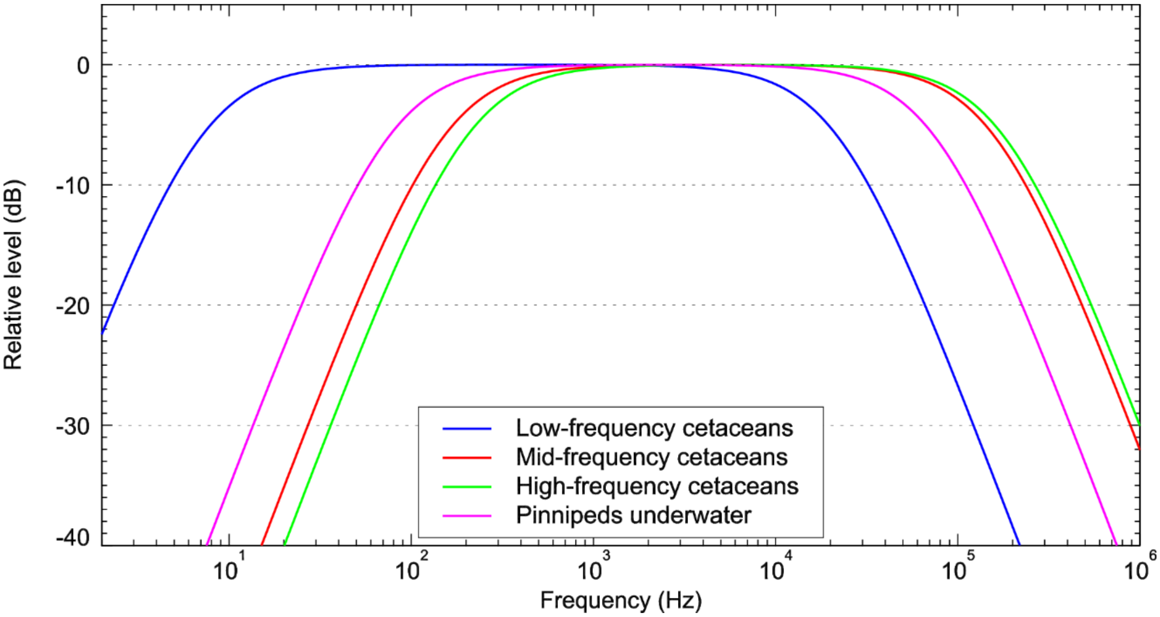

Figure C-1. Auditory weighting functions for the functional marine mammal hearing groups as recommended by Southall et al. (2007).

C.1.2. NMFS (2018) weighting functions

In 2015, a U.S. Navy technical report by Finneran (2015) recommended new auditory weighting functions. The auditory weighting functions for marine mammals are applied in a similar way as A-weighting for noise level assessments for humans. The new frequency-weighting functions are expressed as:

$$G(f) = K + 10\log_{10}\left\{\frac{(f/f_1)^{2a}}{[1+(f/f_1)^2]^a[1+(f/f_2)^2]^b}\right\} \tag{C-2}$$

Finneran (2015) proposed five functional hearing groups for marine mammals in water: low-, mid- and high-frequency cetaceans (LF, MF, and HF cetaceans, respectively), 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 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 recommended by NMFS (2018).

Functional hearing group	***a***	***b***	f_1 (Hz)	f_2 (Hz)	K (dB)
Low-frequency cetaceans	1.0	2	200	19,000	0.13
Mid-frequency cetaceans	1.6	2	8,800	110,000	1.20
High-frequency cetaceans	1.8	2	12,000	140,000	1.36
Phocid pinnipeds in water	1.0	2	1,900	30,000	0.75
Otariid pinnipeds in water	2.0	2	940	25,000	0.64

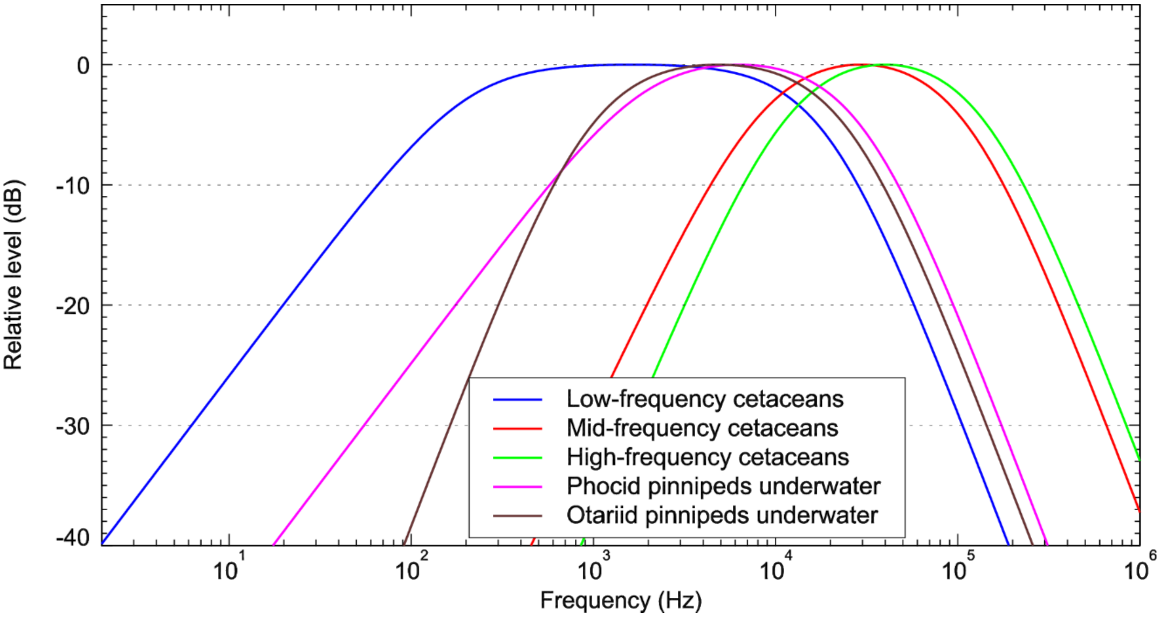

Figure C-2. Auditory weighting functions for the functional marine mammal hearing groups as recommended by NMFS (2018).

Appendix D. Weekly LTSA and Band-level Plots

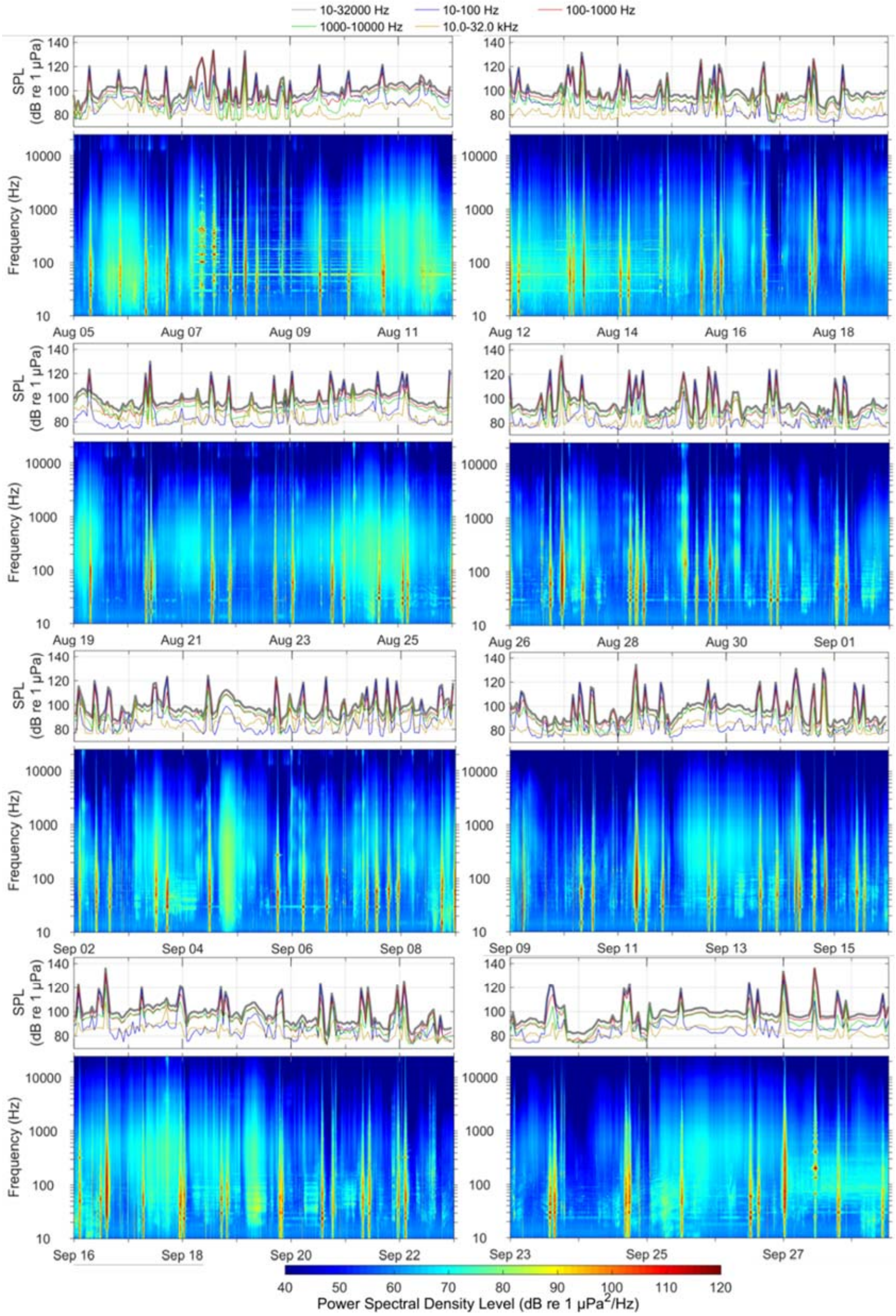

Figure D-1. Weekly plots for AMAR−1: Spectrogram (bottom) and in-band SPL (top) for underwater sound.

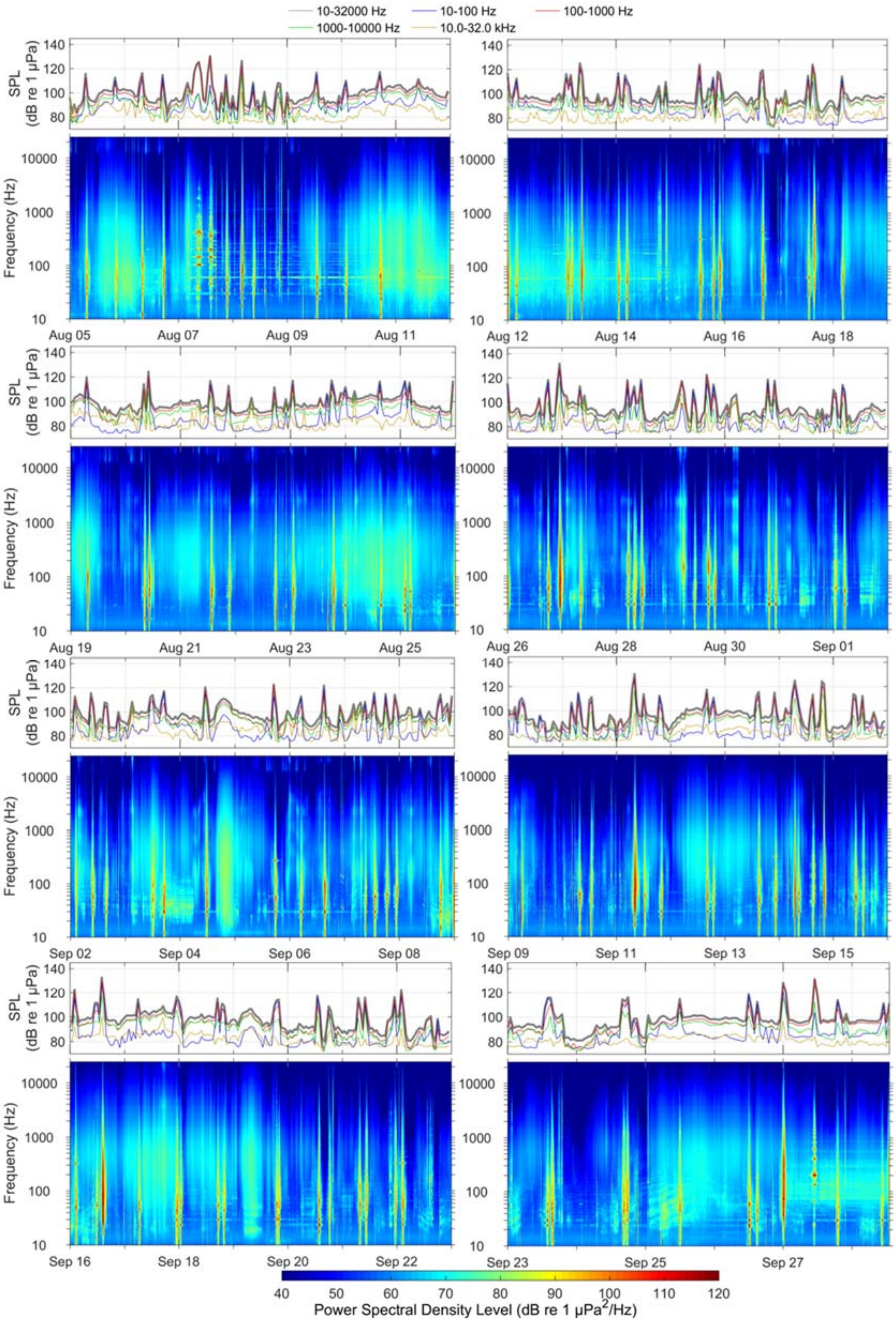

Figure D-2. Weekly plots for AMAR−2: Spectrogram (bottom) and in-band SPL (top) for underwater sound.

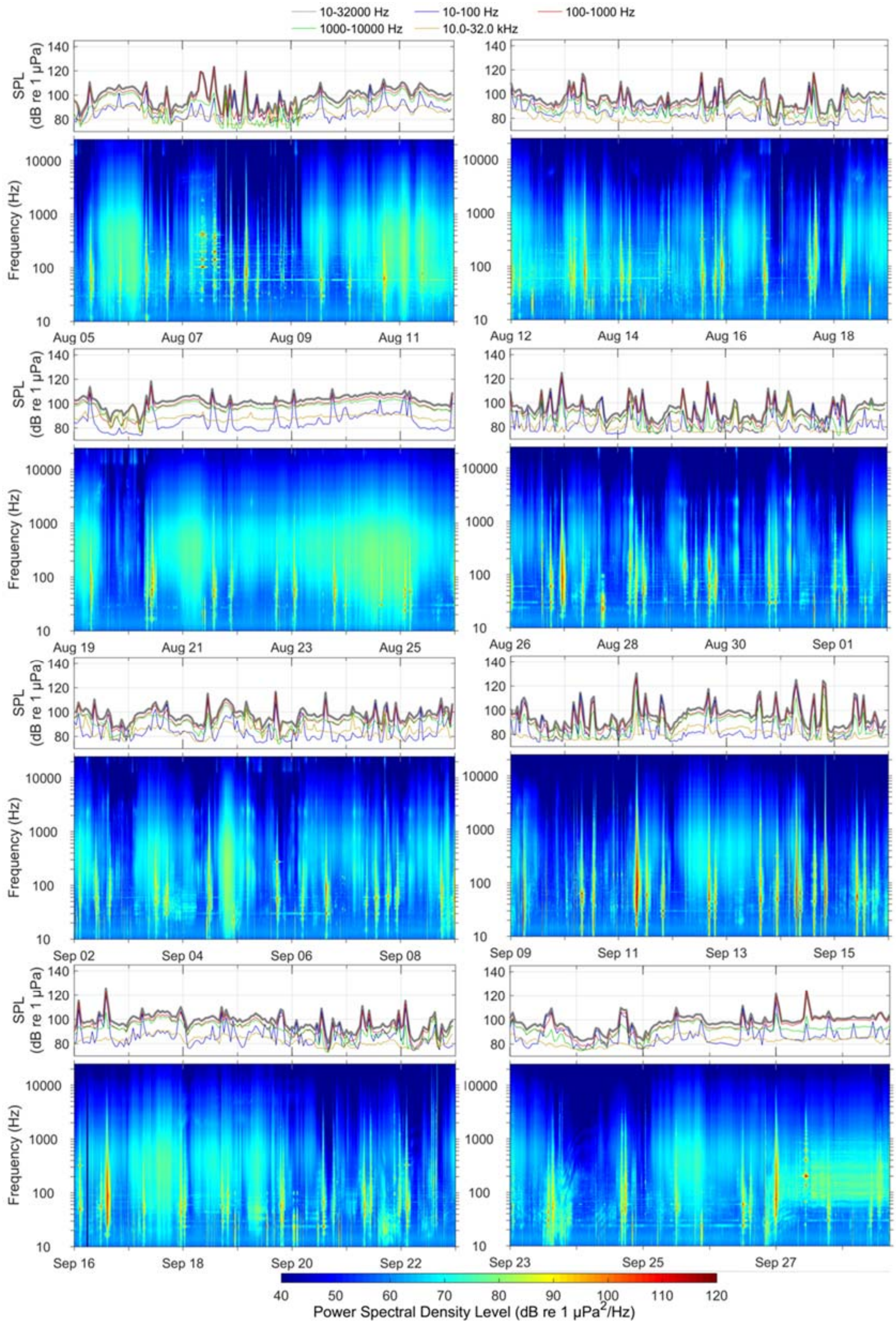

Figure D-3. Weekly plots for AMAR−3: Spectrogram (bottom) and in-band SPL (top) for underwater sound.

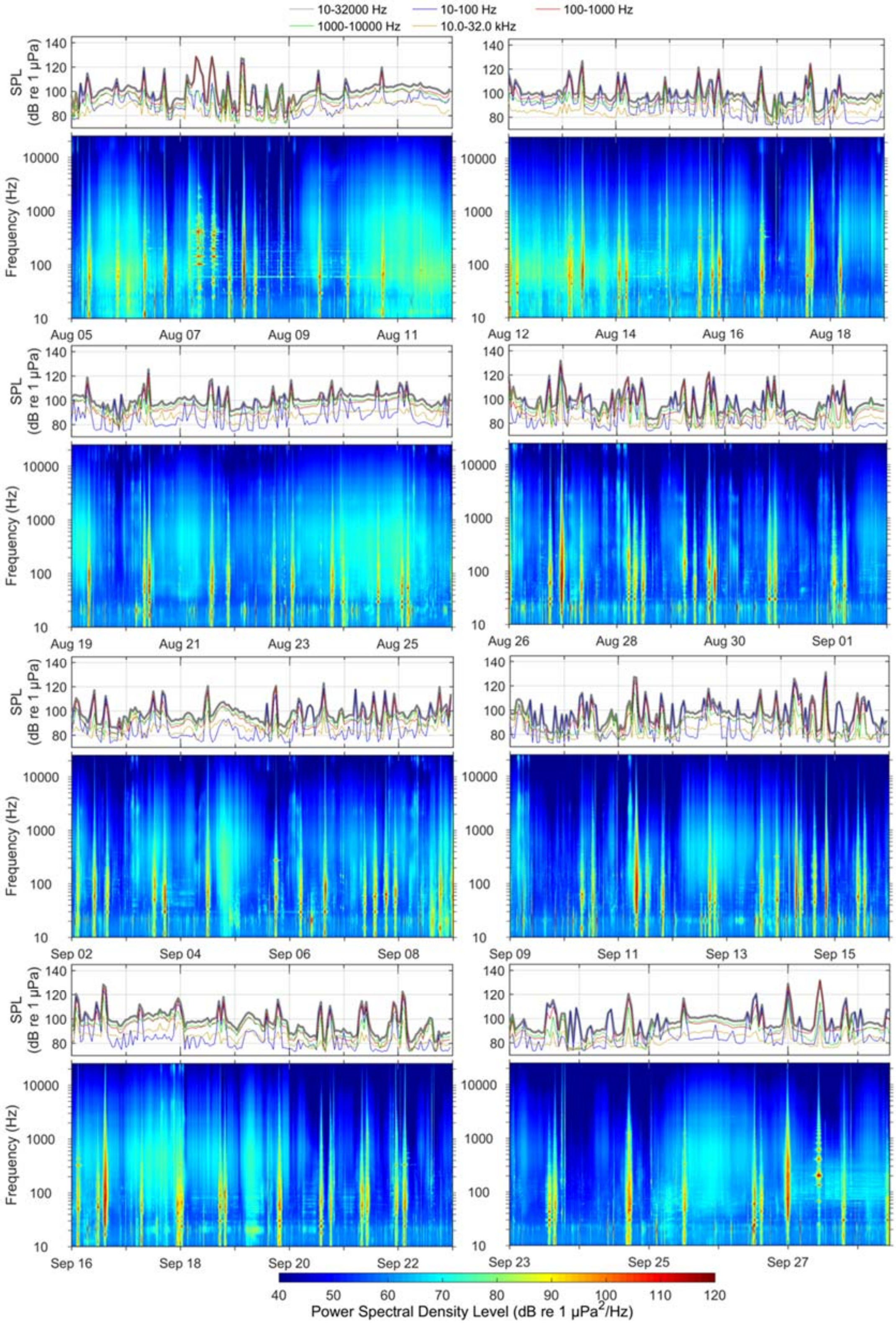

Figure D-4. Weekly plots for AMAR−4: Spectrogram (bottom) and in-band SPL (top) for underwater sound.

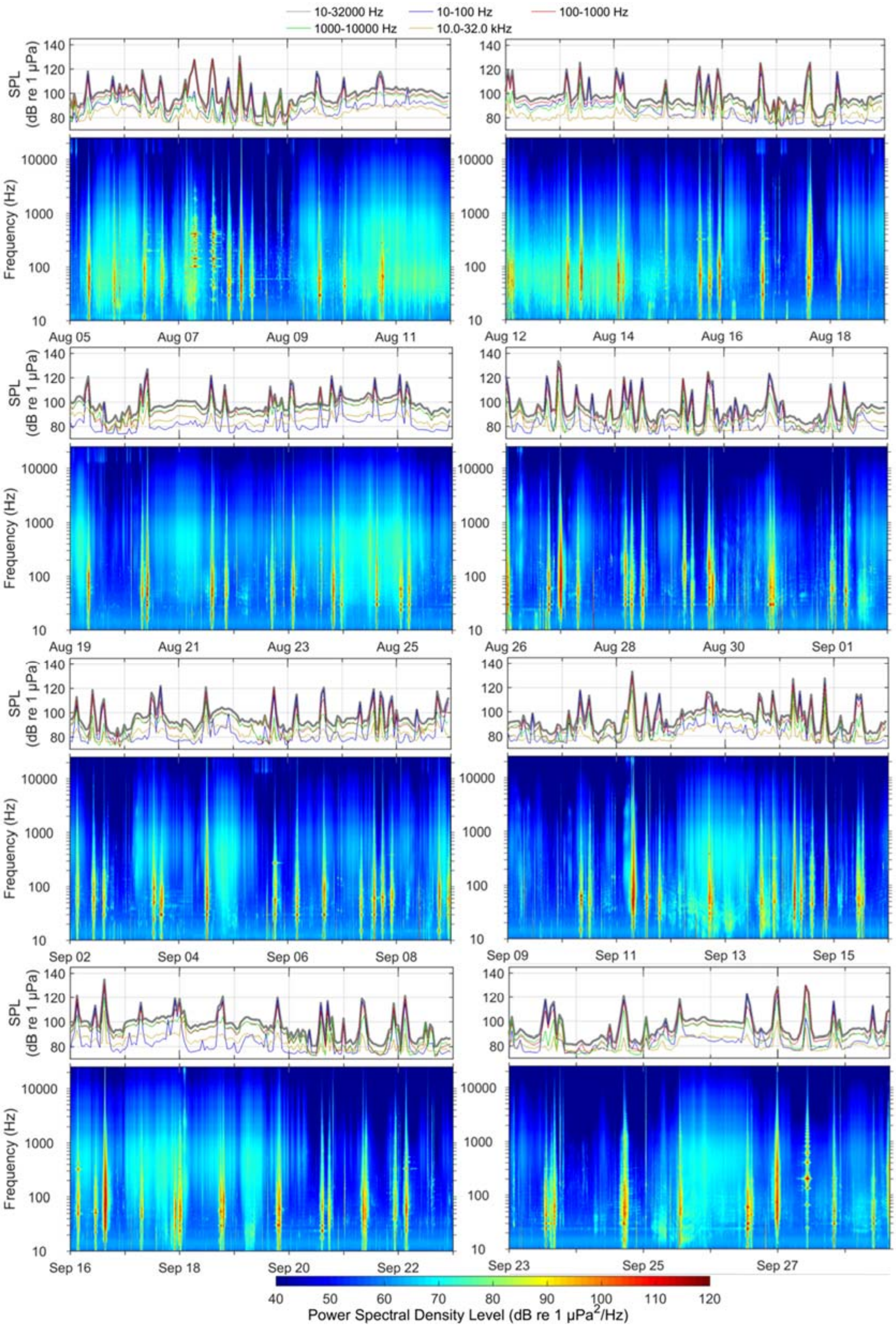

Figure D-5. Weekly plots for AMAR−5: Spectrogram (bottom) and in-band SPL (top) for underwater sound.

Name: Laura Watkinson

Agency / Organization: DFO Science

Date of Comment Submission: April 2, 2019

#	Document Name	Section Reference	Comment	Baffinland Response
1	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Page 19, Figure 16:	DFO Science found Figure 16 to be very useful and informative. DFO Science requests that each of the panels be provided separately so that they are larger.	As requested by DFO Science, each of the panels has been provided separately so that they are larger.
2	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Page 20, Figure 17:	DFO Science requests that L_{mean} in the bottom panels be defined.	L_{Mean} is the arithmetic mean (ISO 18405-2017). See caption of Figure 13.
3	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Page 24, Figure 22:	DFO Science notes that the red dashed lines that indicates AMAR deployment and retrieval dates is very difficult to distinguish in the figure (either difficult to see or missing or it is the section dashed in grey). DFO Science requests that the red dashed line be made more pronounced.	As suggested by DFO Science, the red dashed line has been adjusted so that it is more pronounced in the figure.

#	Document Name	Section Reference	Comment	Baffinland Response
4	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Page 28, Figure 30:	The report states “*As a result of the choices made in determining the LSR, the 0% change condition in Figure 31 is at least 50% for all cases. The results show that the largest LSR occurrences were associated with ambient noise such as wind and rain rather than vessels for the Narwhal whistle and click frequencies, especially at AMAR−3. Based on these assessments it appears that the shipping activity could have disturbed the Narwhal or seriously impacted their listening space at most 1% of the recording period*”. This figure also means that in 50% of the time, there is a reduction in the listening space. DFO Science requests that BIM provide the formula that they used to calculate the Listening Space Reduction. Without this formula, DFO Science cannot adequately interpret and assess the analysis conducted. This is an important analysis and the results presented are hard to interpret without all the information.	The report has been revised to include the formula used to calculate LSR (note, now referred to as Listening Range Reduction or LRR).

Name: Parks Canada – Natural Resource Conservation Branch (via Jacquie Bastick)

Agency / Organization: Parks Canada

Date of Comment Submission: March 29, 2019

#	Document Name	Section Reference	Comment	Baffinland Response
1	*2018 Passive Acoustic Monitoring Report*	4. Discussion and Conclusion	Results are not compared back to the thresholds established by Baffinland (FEIS 2013). These thresholds should be restated in each report (e.g.: in an appendix) and all results should be related back to them as well as compared (e.g.: trends) to all previous monitoring data.	The PAM program does not evaluate changes to narwhal abundance that would be tied to potential long-term displacement or abandonment effects by narwhal, or changes at their population level (which are the indicators identified in the FEIS and FEIS Addendum). More specifically, the two relevant indicator thresholds established in the FEIS (Baffinland 2012) and the FEIS Addendum (Baffinland 2013) are: • ≥10 % of narwhals in the Regional Study Area (RSA) exhibit strong disturbance and avoidance reactions that lead to (seasonal) abandonment of areas identified as important habitat. • ≥10 % of the population in the Local study area (LSA) exposed to these continuous sound levels. The primary objectives of the Passive Acoustic Monitoring

#	Document Name	Section Reference	Comment	Baffinland Response
				(PAM) Program were to measure ambient sound levels, to compare in-situ sound levels relative to modelled sound levels, to determine species presence in this part of the RSA, to evaluate the period of time in which the disturbance onset threshold would be exceeded, and to collect recordings that could be used to evaluate vessel noise signatures and potential changes in narwhal vocal behaviour in relation to shipping. This last component is being analyzed separately as part of a collaboration between Baffinland, Golder, JASCO and the University of New Brunswick (UNB)'s marine mammal acoustic laboratory. Final results of this work will be available in 2020. Final results from these studies will be available in Q3 2020, with preliminary results available as early as Q4 2019. Figure 26 assesses the probability of sound levels exceeding the disturbance onset threshold of 120 sB re 1 µPa at two stations (AMAR-1, one of the stations with the highest narwhal whistles detections; and AMAR-3, the station with the lowest sound exposure levels). The exceedances of 120 dB re 1 µPa were rare at both stations. At AMAR−1 (station closest to the shipping lane that recorded the highest SELs of all 5 stations), 2.4% of the data exceeded 120 dB re 1 µPa and only 0.5%

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				exceeded the threshold at AMAR−3 (station furthest from the shipping lane that recorded the lowest SELs of all 5 stations).
2	*2018 Passive Acoustic Monitoring Report*	4.1 Discussion and Conclusion	There is minimal discussion of narwhal call masking or if cessation of narwhal calls occurs due to vessel noise. Is the analysis of listening space reduction intended to incorporate these responses?	This was outside the scope of this report. Two students at UNB are currently looking at narwhal vocal behaviour in relation to vessel traffic and associated noise in more detail. Final results from these studies will be available in Q3 2020, with preliminary results available as early as Q4 2019.
3	*2018 Passive Acoustic Monitoring Report*	1.2 Ambient Sound Levels	It is stated that sea ice is often a main contributor to the acoustic landscape in the Arctic and that narwhals arrive in Milne Inlet generally as ice conditions allow. What is the evidence and/or baseline soundscape data to support this statement? This information should be part of the baseline for monitoring change in soundscape over time, and assessing impacts of noise to marine mammals from shipping. Early in the acoustic monitoring period, was ice still present in the area?	As mentioned in the report: "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 (Milne and Ganton 1964)." The timing of narwhal arrival and departure to/from their summering areas is variable and dependent on ice conditions (Dietz et al. 2001). Early in the acoustic monitoring period, sea ice was absent or rare in the study area, so no sea ice noise was detected by the hydrophones. This program focused on open water conditions. In 2019, two automated acoustic recorders will be

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			And if so was any of this noise detected by the hydrophones?	deployed under the sea ice, one in Eclipse Sound and the other near Pond Inlet. Acoustic recordings from these deployments will monitor the soundscape during the early shoulder season, including the sounds of ice break-up. <u>References</u>: Milne, A.R. and J.H. Ganton. 1964. Ambient Noise under Arctic-Sea Ice. *Journal of the Acoustical Society of America* 36(5): 855-863 Dietz, R., Heide-Jørgensen, M. P., Richard, P. R., & Acquarone, M. (2001). Summer and fall movements of narwhals (*Monodon monoceros*) from northeastern Baffin Island towards northern Davis Strait. *Arctic*, 244-261.
4	*2018 Passive Acoustic Monitoring Report*	3.3 Narwhal Detections	It is stated that 0.5% of the acoustic datasets were manually reviewed for analysis. Is there a specific reason that this threshold was selected?	The amount of data required for validation depends on the size of the dataset, the aim of the research, and the amount of effort allocated (time, budget and analyst availability). Kowarski et al. (in preparation) compared the results of 0.5%, 1% and 2.5% analysis for two baleen whale and two beaked whale species. They found that the occurrence results are identical for most of the analyzed datasets. When results differed between validation effort, 0.5% analysis always resulted in a more conservative outcome.

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Agency / Organization: Qikiqtani Inuit Association

Date of Comment Submission: 31 March 2019

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1	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	General	QIA notes that this report is unprotected, allowing copying/pasting, which facilitates the review (like the terrestrial reports and unlike most other draft reports submitted to the MEWG).	No response required.
2	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	General	A significant volume of vessel noise signature data was collected but not analyzed and reported. This information should be included in the report (also see next comment).	The scope for this data summary report did not include a detailed analysis of vessel noise signatures. Recorded vessel sound levels are being investigated more thoroughly as part of two M.Sc. student graduate thesis programs through the University of New Brunswick. Final results from these studies will be available in Q3 2020, with preliminary results available as early as Q4 2019.

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3	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 1, Executive Summary	It seems strange to consider evaluating Project-shipping noise levels a secondary objective, as it's just as important to monitoring and assessment as documenting marine mammal presence and ambient noise levels.	The objectives of the Passive Acoustic Monitoring (PAM) Program were to measure ambient noise levels, to compare in-situ sound levels relative to modelled sound levels, to determine species presence in this part of the Regional Study Area (RSA), to evaluate the period of time in which the disturbance onset threshold would be exceeded, and to collect recordings that could be used to evaluate vessel noise signatures and potential changes in narwhal vocal behaviour in relation to shipping. This last component is being analyzed separately as part of a collaboration between Baffinland, Golder, JASCO and the University of New Brunswick (UNB)'s marine mammal acoustic laboratory. Final results from this study will be available in Q3 2020, with preliminary results available as early as Q4 2019.
4	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 1, Executive Summary (and pg. 29, s. 4.2.1. Narwhals)	"Narwhal whistle and click detections at the northern station (AMAR-5) were more limited than at other stations, likely reflecting habitat selection." What evidence is there to support habitat selection as the explanatory factor here?	Previous studies have reported that narwhal tended to be more spatially restricted to the southern portion (e.g. strata) of the Bruce Head study area (Thomas et al. 2013; Smith et al. 2015). The sentence has been revised to read: "Narwhal whistle and click detections at the northern station (AMAR-5) were more limited than at other stations, likely reflecting a north-south distribution of narwhal in the Bruce Head study area."

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5	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 1, Executive Summary (and pg. 30, s. 4.2.3. Ringed seals)	"Sporadic detections of ringed seal vocalizations confirm their presence in the area." Year-round ringed seal presence in this area has long been confirmed.	The sentence has been revised to read: "Sporadic detections of ringed seal vocalizations indicate their presence in the area."
6	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 2, s. 1. Introduction	Calling the putative Eclipse Sound narwhal summer stock a "summering herd" is confusing given the use of "herd" to define aggregations in other monitoring programs.	Comment noted. Revised the text to read: "Commercial shipping operations associated with the Project overlap with established summering grounds for the Eclipse Sound narwhal summer stock during the open-water season".
7	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 3, s. 1. Introduction	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". No PAM devices were deployed in Eclipse Sound and Pond Inlet, and there was limited effort there in 2018 (some SBO monitoring). Acoustic monitoring should be	Acoustic recorders will be deployed in two additional locations for the 2019 field season, one in Eclipse Sound and one near Pond Inlet (corresponding with acoustic modelling locations for the FEIS Addendum for Phase 2).

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			expanded to these areas, as per Condition requirements.	
8	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 3, s. 1. Introduction	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)." No EWI are yet defined. How can this PAM program contribute to their development?	Concurrent visual and acoustic data need to be collected to help further inform development of Early Warning Indicators (EWI). This is planned as part of the 2019 Bruce Head Shore-based Monitoring Program.
9	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 3, s. 1.1. Soniferous Marine Life and Acoustic Monitoring	"Four cetacean (bowhead whale (Figure 1), narwhal, beluga whale and killer whale) and four pinniped (ringed seal, bearded seals, harp seal, and walrus) species may be found in or near the study area (Table 1)." Other species are known to occur within the RSA (e.g., sperm whale, hooded seal).	To our knowledge, sperm whale have only been identified near Pond Inlet, but have not been observed near Bruce Head. Comment noted on hooded seal. In any case, text has been revised to now read: "Five cetacean (bowhead whale, narwhal, beluga whale, killer whale and sperm whale) and five pinniped (ringed seal, bearded seal, harp seal, hooded seal and walrus) species may be found in or near the study area (Table 1)".

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10	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 3, s. 1.1. Soniferous Marine Life and Acoustic Monitoring	"On the contrary, walrus have been reported outside the study area (Figure 4), and killer whale (Figure 8) travel widely and their distribution records are scarce." Neither of these statements are accurate - walrus have been documented within Milne Inlet (including by BIMC consultants), and there are numerous published records of killer whale distribution and occurrence in the region.	This sentence has been deleted. The previous sentence has been revised to read: "The presence of pinnipeds (ringed seal, bearded seal, harp seal, walrus) and cetaceans, such as bowhead whales, beluga whales, narwhal, and killer whales, has been previously reported in at least part of the study area (Ford et al. 1986, Campbell et al. 1988, COSEWIC 2004, COSEWIC 2008a, COSEWIC 2008b, COSEWIC 2009, Marcoux et al. 2009, Stephenson and Hartwig 2010, Thomas et al. 2014, Smith et al. 2015, COSEWIC 2017)" References: [COSEWIC] Committee on the Status of Endangered Wildlife in Canada. 2004. *COSEWIC assessment and update status report on the beluga whale Delphinapterus leucas in Canada*. Ottawa, ON, Canada. ix + 70 pp. https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/cosewic/sr_beluga_whale_e.pdf. [COSEWIC] Committee on the Status of Endangered Wildlife in Canada. 2008a. *COSEWIC assessment and update status report on the Killer Whale Orcinus orca, Southern Resident population, Northern Resident population, West Coast Transient population,*

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				Offshore population and Northwest Atlantic / Eastern Arctic population, in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa, ON, Canada. viii + 65 pp. https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/cosewic/sr_killer_whale_0809_e.pdf. [COSEWIC] Committee on the Status of Endangered Wildlife in Canada. 2008b. *COSEWIC assessment and update status report on the narwhal Monodon monoceros in Canada*. Ottawa, ON, Canada. 25 pp. https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/cosewic/sr_narwhal_e.pdf. [COSEWIC] Committee on the Status of Endangered Wildlife in Canada. 2009. *COSEWIC assessment and update status report on the Bowhead Whale Balaena mysticetus, Bering-Chukchi-Beaufort population and Eastern Canada-West Greenland population, in Canada*. Ottawa, ON, Canada. vii + 49 pp. https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/c

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				osewic/sr_bowhead_whale_0809_e.pdf. [COSEWIC] Committee on the Status of Endangered Wildlife in Canada. 2017. *COSEWIC assessment and status report on the Atlantic Walrus Odobenus rosmarus rosmarus, High Arctic population, Central-Low Arctic population and Nova Scotia-Newfoundland-Gulf of St. Lawrence population in Canada*. Ottawa, ON, Canada. xxi + 89 pp. https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/cosewic/sr_Atlantic%20Walrus_2017_e.pdf. Marcoux, M., M. Auger-Méthé, and M.M. Humphries. 2009. Encounter frequencies and grouping patterns of narwhals in Koluktoo Bay, Baffin Island. *Polar Biology* 32(12): 1705-1716. https://doi.org/10.1007/s00300-009-0670-x. Smith, H.R., J.R. Brandon, P. Abgrall, M. Fitzgerald, R.E. Elliott, and V.D. Moulton. 2015. *Shore-based monitoring of narwhals and vessels at Bruce Head, Milne Inlet, 30 July – 8 September 2014*. FA0013-2. Report by LGL Limited for Baffinland Iron Mines

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				Corporation. 73 p + appendices. Stephenson, S.A. and L. Hartwig. 2010. The arctic marine workshop. *Canadian Manuscript Report of Fisheries and Aquatic Sciences* 2934: 76. Thomas, T., P. Abgrall, S.W. Raborn, H. Smith, R.E. Elliott, and V.D. Moulton. 2014. *Narwhals and shipping: shore-based study at Bruce Head, Milne Inlet, August 2013. Final*. TA8286-2. Report by LGL Limited for Baffinland Iron Mines Corporation. 60 p + appendices.
11	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 4, Table 1, s. 1.1. Soniferous Marine Life and Acoustic Monitoring	There is no recognized "Nunavut, Arctic Ocean population" of Atlantic walrus. The COSEWIC assessment in 2017 considered two extant "Designatable Units" (i.e., populations) - the High Arctic population and Central-Low Arctic population (in addition to the extinct Nova Scotia-Newfoundland-Gulf of St. Lawrence population). The High Arctic population is found within the RSA (and Project-vessels could interact with animals from the Central-Low Arctic population in southern Baffin Bay and in Davis Strait).	This was a typo – author erroneously used the range value instead of the population value. Text has been revised accordingly.

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12	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 4-8, Figures 1-8, s. 1.1. Soniferous Marine Life and Acoustic Monitoring	These maps showing Arctic-wide distribution are not needed for this report and simply take up space that could be better used discussing acoustics, marine mammal communication, and results (including vessel noise signatures). Some of them are accurate/misleading without the context included in the original source (e.g., areas where bearded seals are "absent"). If range maps are going to be included (they aren't necessary), better (i.e., more accurate) species-specific sources should be used (e.g., COSEWIC reports, US assessments for ice seals).	As suggested, maps have been removed.
13	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 8-9 incl. Table 2., , s. 1.1. Soniferous Marine Life and Acoustic Monitoring	Stafford et al. (2012) collected narwhal vocalization data in winter in the pack ice off West Greenland, in comparison to other studies on the acoustic repertoire of narwhals which were conducted in summer ice-free waters and close to shore (e.g., Watkins et al. 1971; Ford and Fisher 1978; Møhl et al. 1990; Miller et al. 1995; Shapiro 2006; Marcoux et al. 2012). Do vocalizations differ during the winter period, and if so, how? Any differences in summer and winter vocal repertoire could influence the efficiency and accuracy of automated detection. In addition, data from Ford and Fisher (1978) and Stafford et al. (2012) were recorded using a single hydrophone, and the use of multi hydrophone arrays has been shown to provide more detailed and additional measures of biosonar properties (e.g., see Discussion in Koblitz et al. 2016; also noted in	Stafford et al. (2012) mentioned that more tonal calls were recorded during the winter, as compared to the summer recordings by Watkins et al. (1971). The authors also found that the echolocation clicks were the most commonly recorded signal. Seasonal variation of the vocal repertoire or vocalization characteristics (e.g, minimum frequency, maximum frequency, frequency range, duration etc) is still poorly understood. For example, Rasmussen et al. (1995) reported that during the winter (Northwest Greenland) inter-click interval (ICI) in the buzz phase was decreasing down to a minimum of 3.2 ms; Miller et al. (1995) reported during the summer (Northwest Greenland) an ICI of 2.5 ms. Whistle and click detectors used in this report were "generic" and the manual verification process allowed for validation of whistle

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			Golder's draft report on the 2017 tagging study). How do the vocal repertoire data collected via a single hydrophone (e.g., Stafford et al. 2012; Rasmussen et al. 2015) compare to those collected using an array (e.g., Koblitz et al. 2016)? How sensitive might the automatic detection algorithm be to the properties (and source information) used? <u>References</u> Ford, J.K.B., and Fisher, H.D. 1978. Underwater acoustic signals of narwhal (Monodon monoceros). Canadian Journal of Zoology 56(4): 552-560. Koblitz, J.C., Stilz, P., Rasmussen, M.H., and Laidre, K.L. 2016. Highly directional sonar beam of narwhals (Monodon monoceros) measured with a vertical 16 hydrophone array. PLoS ONE 11(11): e0162069. Marcoux, M., Auger-Methe, M., and Humphries, M.M. 2012. Variability and context specificity of narwhal (Monodon monoceros) whistles and pulsed calls. Marine Mammal Science 28(4): 649-665. Miller, L.A., Pristed, J., Møhl, B., and Surlykke, A. 1995. The click-sounds of narwhals (Monodon-Monoceros) in Inglefield Bay, Northwest Greenland. Marine Mammal Science 11(4): 491-502. Møhl, B., Surlykke, A., and Miller, L.A. 1990. High intensity narwhal clicks. Pages 295-303 in: Thomas, J.A., and Kastelein, R.A., eds.	and click detections produced by narwhals. Both in winter and summer, narwhal produce a variety of sounds including echolocation click trains, burst pulses, and frequency modulated, tonal whistles. We assumed that the efficiency and accuracy of automated detection were not influenced. Collecting passive acoustic data on multiple channels (array) makes it possible to detect, localize and track vocalizing marine mammals. It can also allow for more detailed and additional measures of the biosonar properties of the clicks. However, the vocal repertoire data collected by an array versus a single hydrophone will be similar. <u>References:</u> Miller, L.A., Pristed, J., Møhl, B., and Surlykke, A. 1995. The click-sounds of narwhals (Monodon-Monoceros) in Inglefield Bay, Northwest Greenland. Marine Mammal Science 11(4): 491-502. Rasmussen, M.H., Koblitz, J.C., and Laidre, K.L. 2015. Buzzes and high frequency broad band clicks recorded from narwhals (Monodon monoceros) at their wintering feeding ground. Aquatic Mammals 41(3): 256-264. Stafford, K.M., K.L. Laidre, and M.P. Heide-Jorgensen. 2012. First acoustic recordings of narwhals (*Monodon monoceros*) in winter. Marine Mammal Science 28(2):

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			Sensory abilities of cetaceans. Plenum Press, New York, NY. Rasmussen, M.H., Koblitz, J.C., and Laidre, K.L. 2015. Buzzes and high frequency broad band clicks recorded from narwhals (Monodon monoceros) at their wintering feeding ground. Aquatic Mammals 41(3): 256-264. Shapiro, A.D. 2006. Preliminary evidence for signature vocalizations among free-ranging narwhals (Monodon monoceros). The Journal of the Acoustical Society of America 120: 1695-1705. Stafford, K.M., Laidre, K.L., and Heide-Jorgensen, M.P. 2012. First acoustic recordings of narwhals (Monodon monoceros) in winter. Marine Mammal Science 28(2): E197–E207. Watkins, W.A., Schevill, W.E., and Ray, C. 1971. Underwater sounds of Monodon (Narwhal). The Journal of the Acoustical Society of America 49(2): 595-599.	E197-E207. https://doi.org/10.1111/j.1748-7692.2011.00500.x Watkins, W.A., Schevill, W.E., and Ray, C. 1971. Underwater sounds of Monodon (Narwhal). The Journal of the Acoustical Society of America 49(2): 595-599.
14	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 10, s. 1.2. Ambient Sound Levels	What data are available from previous monitoring (Greeneridge) on ambient sound levels in the local area?	From previous monitoring programs (Greeneridge), we have information on wind-generated noise. Report has been revised to include the following information: “Kim and Conrad (2016) reported that in the area, below 1000 Hz, moderate winds (~6 m/s) typical of the site contributed to average ambient sound levels of ~94 dB re 1 µPa.” Reference

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				Kim, K.H., and A.C. Conrad. 2016. *Acoustic Monitoring Near Koluktoo Bay, Milne Inlet, August–October 2015*. Greeneridge Rep. 522-2. Rep. from Greeneridge Sciences Inc. (Santa Barbara, CA) for Baffinland Iron Mines Corporation (Oakville, ON). x + 69 p.
15	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 10, s. 1.3. Anthropogenic Contributors to the Soundscape	"The main anthropogenic contributor to ambient noise in the present study was vessel traffic associated with the transport of iron ore." Anthropogenic noise is ambient noise? Ambient noise is usually considered to be analogous to background noise, or the background sound pressure level at a given location as a reference level to an intrusive sound source. Should Project-related shipping activity not be considered intrusive, instead of background?	This sentence has been revised to read: "The main anthropogenic contributor to the total sound field in the present study was vessel traffic associated with the transport of iron ore."
16	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 11,s. 1.3.1. Vessel Traffic	Figure 11 - data sources for vessel traffic map?	Data sources have been added to the report, including Automatic Identification System (AIS) data acquired from ground-based stations at Bruce Head and Pond Inlet, as well as AIS data collected by satellites (ExactEarth archive)".

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17	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 12, s. 2.1.1. Recording configuration and duration	It isn't clear from the description on how recorders were programmed. Did they record on one duty cycle for 14 minutes, the other for 1 minute, and then repeat (i.e., continuous recording)? Or did they record 15 minutes and then shut off for a specified time before starting the 15 minutes again? If the latter, how often did the 15-minute recording session occur?	Sentence in the report has been revised to read: "The AMARs recorded continuously on a duty cycle at 64 000 samples per second with a 6 dB gain for a recording bandwidth of 10 Hz to 32 kHz during 14 min, and then at 250 000 samples per second for a recording bandwidth of 10 Hz to 125 kHz during 1 min"
18	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 13, s. 2.1.2. Monitoring stations	"All AMARs recorded as planned from deployment until retrieval, for an average recording duration of 56 days." Yes, the average of 56 times 5 is 56, but with all deployments starting and ending at the same time, why report an average? It's meaningless. All devices were deployed for 56 days with the same start and end dates.	Sentence in the report has been revised to read: "All AMARs were retrieved as planned from the same vessel using acoustic releases. All AMARs recorded as planned from deployment until retrieval, for a recording duration of 56 days per AMAR".
19	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 15, s. 2.2. Automated Data Analysis	"The AMARs collected approximately 800 GB of acoustic data during this study." Should report actual total and amount per device.	As suggested, the following statement has been added to the report: "Collectively 4.6 TB of acoustic data was collected during this study: 936 GB on AMAR−1, 936 GB on AMAR−2, 939 GB on AMAR−3, 935 GB on AMAR−4, and 942 GB on AMAR−5."
20	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 15, s. 2.2.1. Total Ocean noise and time series analysis	"Ambient noise levels at each station were examined to document the local baseline underwater sound conditions." Previous sections identified vessel noise as a contributor to ambient noise. Is this the case for the analyses described here? A "baseline" should exclude Project-related activities.	Sentence in the report has been revised to read: "Ambient noise levels at each station were examined to document the local underwater sound conditions."

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21	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 15, s. 2.2.1. Total Ocean noise and time series analysis	"... Wenz ambient noise curves (Figure 10) (Wenz 1962), which show the variability of ambient spectral levels off the U.S. Pacific coast as a function of frequency of measurements for a range of weather, vessel traffic, and geologic conditions. The Wenz curve levels are generalized and are used for approximate comparisons only." Why not compare against ambient noise data for the specific region, using already available data?	The Wenz curves are the reference against which other environments are normally compared as a benchmark of the typical limits of prevailing noise. The Wenz curves are generalized and are used for an approximate comparison to identify any anomalous trends that deviate from expected ambient ocean conditions. It is standard practice to perform this type of generalized comparison.
22	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 15, s. 2.2.1. Total Ocean noise and time series analysis	"Weather conditions throughout the recording periods were also gathered to inform the discussion on the factors driving noise levels and influencing marine mammal detections." What is/are the source(s) for weather data?	Sources for weather data have been added to the report, as per the following: "Wind data was collected in 2018 from Baffinland's permanent meteorological station located at Milne Port at 71.886°N and 80.885°W."
23	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 16, 2.2.2. Vessel noise detection	Were any sensitivity analyses conducted to determine efficiency and accuracy of automated detection of vessels? Manual review was conducted for marine mammal detections (s. 2.2.3), was this not done for vessels?	No, the vessel detector is sufficiently reliable that we typically do not, and there is no intent to do so during future reporting efforts.

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24	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 16, 2.2.3. Marine Mammal Detection Overview	“For the species of interest (narwhals) no effective detector was available. Whistle detections and clicks detections were manually reviewed (validated) within a sample of the dataset, results of each detector were critically reviewed, and the output of detectors were restricted where necessary to provide the most accurate description of narwhal presence. Where detector results were found to be unreliable, only the validated results are presented.” This seems to contradict Table 2 (pg. 9), which states that whistles and clicks were used for automatic detection of narwhals. Or was automatic detection attempted but deemed to be not effective? Please clarify. If the latter, would additional detail on narwhal vocal repertoires (see comment 13) improve efficiency?	Whistle and click detectors used in this report were “generic” and the manual verification process allowed for validatation of whistle and click detections produced by narwhals. There were not enough quality examples in the recordings of whistles and clicks produced by narwhal to develop and train a robust automated narwhal detector for these call types. Using recordings collected in 2018 in addition to the 2017 data should allow for the development (and training) of an automated whistle detector, click detector and a pulse call detector for narwhal.
25	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 18, s. 3.1.1. Total sound levels	The description of the frequency bands in the band-level plots would benefit from the use of example species that occur in the Project area, e.g., which band is most associated with narwhal?	As suggested, we use species that occur in the Project area. The text in the report has been revised to read: “The 10–100 Hz band is associated with large shipping vessels, seismic surveys, and mooring noise. The 100–1000 Hz band is generally associated with wind and wave noise, but can include sounds from ringed and bearded seals, walrus, bowhead whale, pulse calls produced by narwhal, nearby vessels, dynamic positioning sound and seismic surveys. Sounds above 1000 Hz include ringed and bearded seal, walrus, bowhead whale, killer whale, beluga and narwhal whistles and clicks, and

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				wind and wave noise and close-range human sources”.
26	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 22, s. 3.2. Vessel Detections	Figure 19 shows vessel detections as present/absent, but it would be useful to see a figure that shows the number of vessels detected per hour.	This would require significant additional effort and is beyond the scope of this report. This is being investigated as part of two M.Sc. student graduate thesis programs through the University of New Brunswick. Final results from these studies will be available in Q3 2020, with preliminary results available as early as Q4 2019.
27	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 22, s. 3.2. Vessel Detections	Are vessel detections larger vessels only? Information on smaller vessels is important for monitoring (local hunters, gunshots, etc.).	Figure 15 shows the hours where tonal sounds were present. These sounds are generated by both large and small vessels. Extracting information on the size of vessel is possible but would require significant additional effort and is beyond the scope of this report.
28	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 23, s. 3.3. Narwhal detections	“The acoustic presence of narwhals was identified automatically by JASCO’s detectors (Section 2.2.3) and validated via the manual review of 0.5% of the low- and high-frequency datasets…” What is the justification for using less than 1% of the data for manual review?	The amount of data required for validation depends on the size of the dataset and the aim of the research. Kowarski et al. (in preparation) compared the results of 0.5% ,1% and 2.5 % analysis for two baleen whale and two beaked whale species. They found that the occurrence results are identical for most of the analyzed datasets. When results differed between validation effort, 0.5% analysis

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				always resulted in a more conservative outcome.
29	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 24-25, s. 3.3. Narwhal detections	Figures 22 and 23 show daily and hourly occurrence of detected narwhal whistles and clicks, respectively. Grey indicates automated detections, and red indicates manually validated results. Are the manually validated results only for samples that had automatic detections, or were samples checked for false negatives as well?	The manually validated results were performed for samples that had automatic detections as well as samples without automatic detections.
30	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 26, s. 3.4.1. Killer whale Pg. 30, 4.2.2. Killer whales Pg. A-7 to A-9, A.3. Marine Mammal Detections	"Killer whale calls were potentially identified (during the manual review of 0.5% of the datasets; see Section 3.3) between 31 Au[g] and 1 Sep 2018 at all stations..." Why did the automatic detection process not identify killer whale vocalizations? “The results presented here are based on manual review and, therefore, underestimate the acoustic occurrence of this species.” Effective monitoring of killer whale occurrence is needed given their influence on narwhal movements and behaviour. It is therefore important to understand why the automated detection was not identifying their presence. Golder	The automatic detection process identified whistle presence. The manual review allowed distinction between narwhal whistles and killer whale whistles. As previously noted, the whistle detector was generic due to the lack of good narwhal sound examples that were available at the time of this analysis. The scope of this project was narwhal focused and all data could not reasonably be manually verified for killer whale presence during this analysis. We are investigating using these data, and data from 2017, for development and training of species-specific automated detectors for future analyses. That

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			noted the importance of this in the 2017 narwhal tagging study draft report (pg. 12, s. 2.5.2): "Understanding confounding effects such as the presence of predators in a system is important when assessing movement behaviour of cetaceans in relation to vessel traffic. Killer whales, for example, are well known to prey on narwhal and may affect narwhal space patterns..." QIA agrees with this statement and supports additional effort to identify killer whale detections. "Automated detectors were employed to detect (if present) impulsive clicks and tonal whistles of narwhal and killer whale… Automated detection failed to identify killer whale vocalizations. Are the parameters used (e.g., Tables A-3, A-4; pg. A-9) not accurately describing the vocal behaviour of this species in the north Baffin region?	was not possible prior to this analysis.
31	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 26, s. 3.4.1. Killer whale	"However, we do not exclude that those acoustic signals could have actually been produced by bowhead whales." How are the acoustic characteristics of the two similar? What can be done to confirm species ID? An understanding of killer whale presence is needed to better understand narwhal movements in relation to stressors, and bowhead distribution is relevant to monitoring and mitigation of impacts from vessel noise and collision risk. Effective	We removed this sentence. Both bowhead and killer whale have been sighted in the area. However, acoustic characteristics are more similar to killer whale calls.

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			monitoring requires accurate species ID.	
32	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 28, s. 4.1. Ambient Noise and Vessel	"The empirical distribution functions for AMAR−1 (one of the stations with the highest narwhal whistles detections) and AMAR−3 (station with the lowest sound exposure levels) are shown in Figure 30 to assess the probability of sound levels exceeding 120 dB re 1 µPa." These plots, and the method used to produce them, are not clear to me, and additional explanation would be helpful for people who are not acousticians. Wouldn't it be more useful to plot a time series and show the actual times when sound levels exceeded 120 dB re 1 µPa?	The text in the report has been revised to read: "To generate these figures, the 1-minute sound pressure level data (10–30 000 Hz) were sorted from smallest to largest, and then the total number of minutes that were greater than a sound pressure level shown on the x-axis was computed and shown as a percentage on the y-axis. As an example of interpreting these figures, all minutes of data at AMAR−1 had an SPL greater than 80 dB re 1 µPa and less than 145 dB re 1 µPa. The exceedances of 120 dB re 1 µPa were rare at both stations. At AMAR−1 (station on the shipping corridor with the highest recorded sound levels), 2.4% of the data exceeded 120 dB re 1 µPa and only 0.5% exceeded the threshold at AMAR−3 (station furthest from shipping corridor with the lowest recorded sound levels)."

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33	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 28, s. 4.1. Ambient Noise and Vessel	At each location, the LSR was determined for whistles using 5 kHz as a typical frequency, and for clicks using 31.5 kHz as typical frequency (Figure 31). How do the "typical" frequencies compare with range of frequencies used? Are other frequencies of whistles and clicks important for narwhal communication?	This information has been added to the revised report as follows (noting that LSR is now referred to in the revised report as Listening Range Reduction or LRR): “At each location, the LRR was determined for whistles using 5 kHz as a typical frequency (mean frequency; Marcoux et al. 2012), and for clicks using 25 kHz as a representative frequency (25 kHz is the maximum 1/3 octave available for data sampled at 64 kHz; narwhal mid-frequency clicks have a mean frequency of ~10 kHz (Stafford et al. 2012); high-frequency clicks have a centre frequency of 53 kHz; (Rasmussen et al. 2015)” Additional details of the LRR computation have been added to the report as well.
34	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 28, s. 4.1. Ambient Noise and Vessel	For LSR, “[t]he data were divided into periods with and without vessel detections (see Figure 15).” What about vessel numbers versus just presence/absence? How do increasing numbers of vessels affect LSR (and empirical distribution functions)?	The figures show minimal difference between times with and without vessels. There is not enough vessel data to assess the effects of multiple vessels.

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35	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 28, s. 4.1. Ambient Noise and Vessel	Re: LSR, what is "normal condition"? No vessels, but what for ambient noise sources? How is ambient defined (as it varies with weather, etc.)?	As mentioned in the text: "The normal listening space was determined using the maximum of the mid-frequency cetacean audiogram (see Table A-9 in Finneran 2015) or the median 1-minute sound pressure level without vessels in each of the 1/3-octave-bands of interest as the baseline hearing threshold."
36	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 29, s. 4.1. Ambient Noise and Vessel	"Based on these assessments it appears that the shipping activity could have disturbed the narwhal or seriously impacted their listening space at most 1% of the recording period." Is this based on a complete analysis of a continuous data set (i.e., data recorded over 100% of the deployment period [or on a different duty cycle?], and all data analyzed)?	This sentence was revisited following a more thorough analysis of the entire dataset. The exceedances of 120 dB re 1 µPa (a threshold recommended by National Oceanic and Atmospheric Administration (NOAA) for disturbance of cetaceans) were rare at all stations. At AMAR−1,with the highest sound levels, and one of the stations with the highest narwhal whistles detections, the 120 dB threshold was exceeded 2.4% of the time. At AMAR−3, the station furthest from the shipping route and with the lowest sound levels, the 120 dB threshold was exceeded 0.5% of the time. Analysis of Listening Range Reduction was conducted for the entire datasets recorded at AMAR-1 and AMAR-3, in consideration of three different narwhal call types. At AMAR-1, there was greater than 90% LRR for whistles during 4.3% of the time when vessels were detected, for clicks during 10.2% of the time when vessels were detected, and for burst pulses during 0.9% of the time when

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				vessels were detected. At AMAR-3, there was greater than 90% LRR for whistles during 0.2% of the time when vessels were detected and for clicks during 1.9% of the time when vessels were detected. Burst pulse detection ranges were never affected when vessels were detected.
37	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. 32, Glossary	Ambient noise is defined as "[a]ll-encompassing sound at a given place, usually a composite of sound from many sources near and far (ANSI S1.1-1994 R2004), e.g., shipping vessels, seismic activity, precipitation, sea ice movement, wave action, and biological activity. Background noise is defined as the "[t]otal of all sources of interference in a system used for the production, detection, measurement, or recording of a signal, independent of the presence of the signal (ANSI S1.1-1994 R2004). Ambient noise detected, measured, or recorded with a signal is part of the background noise." Is vessel noise considered ambient noise but not background noise? Or is vessel noise also considered to be background noise? The baseline condition should be with no shipping, and Project-shipping adds to the background noise?	For our purposes, ambient and background are the same. They represent the sound that remains after all automatically detectable sources are excluded. Detectable vessels are neither ambient nor background.

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38	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. A-1, Appendix A. Acoustic Data Analysis Methods	“The data sampled at 32 kilosamples per second (ksps) was processed for ambient sound analysis, vessel noise detection, and detection of all marine mammal calls except clicks. Click and whistle detections were performed on the data sampled at 375 ksps. This section describes the ambient, vessel, and marine mammal detection algorithms employed (Figure A-1).” So whistles were processed at both sampling rates?	Yes, whistles were processed at both sampling rates.
39	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. A-3, s. A.2. One-Third-Octave-Band Analysis	Wenz curves “represent typical deep ocean sound levels (Figure 10) (Wenz 1962). This splitting of the spectrum into passbands of a constant width of 1 Hz, however, does not represent how animals perceive sound.” If Wenz curves "represent typical deep ocean sound levels", how applicable are there to the conditions in a narrow (and much shallower than deep ocean) inlet like Milne Inlet?	These are the standard reference curves – they are provided for comparative purposes. The Wenz curves are the reference against which environments are normally compared as a benchmark of the typical limits of prevailing noise. The Wenz curves are generalized and are used for an approximate comparison to identify any anomalous trends that deviate from expected ambient ocean conditions. It is standard practice to perform this type of generalized comparison.
40	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. A-10, s. A.3.3.1. Selecting Data for Manual Validation	“To standardize the file selection process, we developed an algorithm that automatically selects a sample of files for review. The sample size N is set based on the amount of time allocated to the review effort. N = 0.5% of acoustic data was applied in the present report.” No justification (statistical, etc.) for choice of sample size, which is low.	The amount of data required for validation depends on the size of the dataset and the aim of the research. As stated in the report, Kowarski et al. (in preparation) compared the results of 0.5%, 1% and 2.5% analysis for 2 baleen whale and 2 beaked whale species. They found that the occurrence results are identical for most of the analyzed datasets. When results differed between validation effort, 0.5% analysis always resulted in a more conservative outcome.

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41	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. A-10, s. A.3.3.1. Selecting Data for Manual Validation	"Files with no detected species are excluded from the pool of eligible files." Why not examine for false negatives? “Files with no detection for each species will appear among those with detections of other species, allowing us to evaluate false negatives.” How many files were examined? Is this how killer whale and ringed seals were detected?	False negatives were examined. Only files with no detected species were excluded from the pool of eligible files. Because we used different detectors for different call types, some of the files have detections for one call type but not for other(s). We examined those files for false negatives. It is not our standard protocol to review files with no detections at all for false negatives. 0.5% of the files were examined. Yes, killer whale and ringed seals were found during the manual verification.
42	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. A-11, s. A.3.3.2. Detector Performance Calculation and Optimization	“All files selected for manual validation were reviewed by one 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.” So files were examined for all species in Table 2 (pg. 9)? Harp seal, bowhead whale, walrus, etc?	The primary objective of this report was to document ambient underwater noise levels and identify marine mammal presence with a focus on narwhal. Therefore, files selected for manual validation (narwhal presence) were also examined for the presence of other marine mammal species.
43	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. A-11, s. A.3.3.2. Detector Performance Calculation and Optimization	“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.” What proportion, if any, were classified this way in 2018?	None of the reviewed files contained an uncertain or unknown sound. This was included to clarify what protocol would be followed.

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44	2018 Passive Acoustic Monitoring Program draft report (file name "2018 PAM Report DRAFT FOR MEWG Review.pdf")	Pg. B-1, Appendix B. Detector Performance, s. B.1. Narwhal Whistles	Table B-1 - Why was recall so much lower at AMAR-3 and AMAR-5 for narwhal whistles?	A low recall translates into missing detections. The detector could miss an entire string of detections because of low signal-to-noise-ratio (SNR) or individual detections within a detection bout. For example, faint, distant, acoustic signals are generally missed.