Baffinland Iron Mines Corporation – Mary River Project

2021 Underwater Acoustic Monitoring Program (Open-Water Season) Final Report

JASCO Applied Sciences (Canada) Ltd

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ᓄᓘᔭᖕᓂ ᐱᓕᕆᐊᖅ (ᐱᓕᕆᐊᖅ) ᐊᐅᓚᓂᖃᖅᑐᑦ ᓄᓇᐅᑉ ᖄᖓᓂ ᐅᔭᕋᖕᓂᐊᖅᓱᑎᒃ ᓴᕕᒃᓴᓂᒃ ᓇᖕᒥᓂᖁᑎᒋᔭᐅᓪᓗᓂ ᐹᕝᕙᓐᓛᓐ ᓴᕕᒃᓴᓂᒃ ᐅᔭᕋᖕᓂᐊᕐᑏᑦ ᑯᐊᐳᕇᓴᓐᓚᑦ (ᐹᕝᕙᓐᓛᓐ). ᐱᓕᕆᐊᖅ ᐃᓂᖃᖅᑐᖅ ᕿᑭᖅᑕᓂ ᓄᓇᖁᑎᖏᓐᓂ ᐅᐊᖕᓇᖓᓂ ᕿᑭᖅᑖᓘᑉ ᕿᑭᖅᑕᖓᓂ, ᓄᓇᕗᒻᒥ. ᐊᐅᓚᓂᖃᖅᑐᖅ ᐅᔭᕋᖕᓂᐊᕐᕕᒃ ᐊᒃᑐᐊᔪᖅ ᑐᓚᒃᑕᕐᕕᖕᒧᑦ ᖁᖑᐊᓄᑦ (ᖁᖑᐊᓂ ᑐᓚᒃᑕᕐᕕᒃ) ᐊᑐᖅᖢᒍ 100 ᑭᓛᒥᑕᓂᒃ ᑕᑭᓂᓕᒃ ᖁᖑᐊᓄᑦ ᐊᖅᑯᑎᑯᑖᒃ, ᓴᕕᒃᓴᖅ ᐅᓯᓕᖅᓱᖅᑕᐅᓚᐅᖅᖢᓂ ᐊᐅᓪᓚᖅᑎᑕᒃᓴᐅᓪᓗᑎᒃ ᐅᑭᐅᖅᑕᖅᑑᑦ ᐅᒥᐊᔪᐊᒃᑯᑦ ᐊᖅᑯᑖᒎᑦ ᓵᑕᖅᑕᐅᕙᒃᑐᑎᒎᑦ ᓴᕕᒃᓴᓂᒃ ᐅᓯᔫᒃᓴᒃᑯᑦ ᐅᒥᐊᔪᐊᒃᑯᑦ. ᖃᐅᑕᒫᑦ ᐊᐅᓪᓚᖅᑎᑦᑎᖃᑦᑕᕐᓃᑦ ᐱᓕᕆᐊᓃᑦ ᐊᒃᑐᐊᔪᑦ ᐱᓕᕆᐊᒧᑦ ᑐᔾᔭᐱᒃᓯᒪᔪᑦ ᐋᖅᑭᒃᑕᐅᓯᒪᔪᑎᒍᑦ ᐊᐅᔭᒃᑯᑦ ᓇᔪᒪᐅᕙᒃᑐᖅ ᑕᓯᐅᔭᒥ ᑐᓵᓕᖕᓂᑦ ᐊᐅᔭᖅᓯᐅᕕᐅᕙᒃᑐᒥ.

ᐅᒥᐊᔪᐊᒥᖔᖅᑐᑦ ᓂᐲᑦ ᐸᕝᕚᓵᕆᓂᖅᑐᐃᓐᓇᕆᐊᖅᑐᑦ ᑑᓚᓕᖕᓂᒃ, ᐊᒻᒪᓗ ᐱᒻᒪᕆᐅᓪᓗᓂ ᖃᐅᔨᓴᕐᓗᒋᑦ ᑕᐃᒪᐃᑦᑐᑦ ᐊᒃᑐᐃᓐᓂᑦ ᐊᓯᔾᔩᓇᔭᕐᒪᖔᑕ ᑑᓚᓖᑦ ᓇᓃᖅᑕᕐᓂᖏᓐᓂᒃ, ᐱᑕᖃᕐᓂᖏᓐᓂᒃ ᐅᕝᕙᓘᓐᓃᑦ ᑖᒃᓯᐊᖅᑎᓪᓗᒋᑦ ᐊᖅᑯᑎᒋᕙᒃᑕᖏᓐᓂᒃ. ᒪᓕᒃᖢᑎᒃ ᑕᐃᒎᓯᕐᓂᒃ ᐊᒻᒪᓗ ᒪᓕᒃᑕᐅᔭᕆᐊᓕᖕᓂᒃ ᐅᔭᕋᖕᓂᐊᕈᓐᓇᐅᑎᐅᑉ ᓇᐃᓴᐅᑖ 005-ᒥᒃ, ᐹᕝᕙᓐᓛᓐᑯᑦ ᐱᓕᕆᐊᒃᓴᖃᖅᑐᑦ ᐋᖅᑭᒃᓯᖢᑎᒃ ᐊᒻᒪᓗ ᐊᑐᓕᖅᑎᑦᑎᓗᑎᒃ ᐊᕙᑎᒧᑦ ᐊᒃᑐᐃᓂᕐᓄᑦ ᖃᐅᔨᓴᖅᐸᓪᓕᐊᖏᓐᓇᕈᑐᑎᓂᒃ (EEM) ᖃᐅᔨᓴᕈᑎᓂᒃ ᓇᓗᓇᐃᔭᐃᔦᓐᓇᖅᑐᓂᒃ ᓂᕆᐅᒋᔭᐅᒻᒥᑦᑐᓂᒃ ᐊᒃᑐᐃᓂᕐᓗᖕᓂᕐᓂᒃ, ᐊᑐᐃᓐᓇᕈᐃᔦᓐᓇᕐᓗᑎᒃ ᐅᔾᔨᖅᓱᖅᓵᓕᓂᕐᓗᒃ ᐊᓯᔾᔨᕈᑕᐅᓗᐊᒻᒥᑦᑐᓂᒃ ᐊᕙᑎᒧᑦ, ᐊᒻᒪᓗ ᐱᐅᓯᒋᐊᕐᓗᒋᑦ ᑐᑭᓯᐅᒪᓂᖏᑦ ᓄᓇᓕᖕᓂ ᐊᕙᑎᒧᑦ ᑲᔪᓯᓂᐅᕙᒃᑐᓂᒃ ᐱᓕᕆᐊᒥᖔᑐᐃᓐᓇᕆᐊᓕᖕᓂᓪᓗ ᑕᐃᒪᐃᓕᖅᑎᑕᐅᔪᑦ-ᐊᒃᑐᐃᓃᑦ ᐱᐅᓯᐅᕙᒃᑐᑦ. ᑖᓐᓇ ᐅᓂᒃᑳᖅ ᓇᓗᓇᐃᔭᐃᔪᖅ ᐱᓕᕆᔾᔪᓯᕐᓂᒃ ᐊᒻᒪᓗ ᖃᐅᔨᓴᐅᔪᓂᒃ ᓂᐱᖃᐃᓐᓇᖅᑐᓂᒃ ᖃᐅᔨᓴᖅᐸᓪᓕᐊᖏᓐᓇᕐᓂᖅ (PAM) ᖃᐅᔨᓴᕐᓂᕐᓂᒃ ᐱᓕᕆᐊᖑᓯᒪᔪᑦ ᐃᓚᒋᔭᐅᖁᓪᓗᒋᑦ ᑕᒪᒃᑯᓄᖓ ᐊᕙᑎᒧᑦ ᐊᒃᑐᐃᓂᕐᓄᑦ ᖃᐅᔨᓴᖅᐸᓪᓕᐊᖏᓐᓇᖅᑕᐅᔭᕆᐊᓕᖕᓄᑦ.

ᑖᓐᓇ 2021-ᒥ ᓂᐱᖃᐃᓐᓇᖅᑐᓂᒃ ᖃᐅᔨᓴᖅᐸᓪᓕᐊᖏᓐᓇᕐᓂᖅ (PAM) ᐱᕙᓪᓕᐊᑎᑕᐅᓚᐅᖅᑐᑦ ᔮᔅᑰ ᐊᑐᖅᓯᒪᔪᓂᒃ ᖃᐅᔨᓴᖅᑐᓕᕆᓂᕐᒥᒃ (ᔮᔅᑰ), ᐱᓕᕆᖃᑎᖃᖅᖢᑎᒃ ᒎᓗ ᐱᓕᕆᖃᑎᒌᑦ ᓕᒥᑎᑦᑯᓐᓂᒃ (ᒎᓗ) ᐊᒻᒪᓗ ᐹᕝᕙᓐᓛᓐᑯᓐᓂᒃ, ᖃᐅᔨᓴᖁᓪᓗᒋᑦ ᐱᑕᖃᓕᑐᐃᓐᓇᕆᐊᓐᓂᒃ ᐱᓕᕆᐊᒧᑦ-ᐊᒃᑐᐊᔪᑦ ᐊᒃᑐᐃᓃᑦ ᑕᕆᐅᒥ ᐳᐃᔩᓄᑦ ᐅᒥᐊᔪᐊᒃᑯᑦ ᓂᐱᓂᑦ. ᑐᖂᓚᓪᓗᐊᑕᖓ ᑕᒪᑐᒪ ᐱᓕᕆᐊᑉ ᑎᑎᕋᖅᑕᐅᓯᒪᓕᖁᓪᓗᒋᑦ ᐊᕕᒃᑐᖅᓱᒋᑦ ᐊᓂᖅᓵᖅᐸᒃᑕᑦᑎᓐᓂᒃ ᐊᒻᒪᓗ ᐃᓄᖕᓂ ᐱᓕᕆᐊᖑᔪᑦ ᐃᒫᓂ ᓂᐱᖅᑯᖅᑐᓕᕆᓐᓂᖏᑦ ᓂᐱᓕᐅᖅᑕᐅᓯᒪᔪᑦ 2021-ᒥ ᐱᖓᓱᓂ ᓂᐱᓄᑦ ᖃᐅᔨᓴᖅᐸᓪᓕᐊᖏᓐᓇᕐᓂᕐᒧᑦ ᐃᓂᐅᔪᓂᒃ; ᐊᑕᐅᓯᖅ ᐃᓂᖃᖅᑐᑦ ᑕᐅᕗᓇ ᐅᑭᐅᖅᑕᖅᑐᒥ ᐅᒥᐊᔪᐊᑦ ᐊᖅᑯᑖᓂ ᐃᑐᕝᕕᓕᖕᒥᒃ (ᐃᑐᕝᕕᓕᒃ) ᖁᖑᐊᓂ, ᐊᑕᐅᓯᖅ ᖃᓂᒋᔭᖓ ᐹᕝᕙᓐᓛᓐᑯᑦ ᑭᓴᖅᓯᒪᕝᕕᒋᕙᒃᑕᖓᓂ ᐃᒥᓕᖕᒥ (ᐃᒥᓕᒃ), ᐊᑕᐅᓯᖅᓗ ᐃᒪᐃᓐᓇᖕᒥ ᖃᓂᒋᔭᖓ ᒥᑦᑎᒪᑕᓕᐅᑉ (ᒥᑦᑎᒪᑕᓕᒃ), ᐅᒥᐊᕐᓴᓕᓂ ᑐᓚᒃᑕᕝᕕ ᓴᓇᔭᐅᓚᐅᖅᑎᓪᓗᒍ. ᐊᑕᖏᖅᓱᒋᑦ ᐱᖓᓱᑦ ᐋᖅᑭᒃᑕᐅᓚᐅᖅᑐᑦ ᐱᒋᐊᕐᓂᖓᓂᒃ ᐋᒡᒋᓯ ᐊᒻᒪᓗ ᐲᖅᑕᐅᓪᓗᑎᒃ ᕿᑎᐊᓂ ᓯᑎᐱᕆᐅᑉ 2021-ᒥ, ᐊᒻᒪᓗ ᓂᐱᓕᐅᓈᓐᓇᓚᐅᖅᑐᑦ.

ᑐᕿᓚᓇᔭᐅᒃᑳᓂᖅᑐᑦ ᐱᓕᕆᐊᒥᑦ ᐃᒪᐃᑦᑑᔪᑦ: ᓂᐱᖏᑦ ᓇᓗᓇᐃᔭᖅᓱᒋᑦ ᑕᓇᐅᒥ ᐳᐃᔨᑦ ᐆᒪᔪᑦ ᐊᔾᔨᒌᖏᑦᑐᑦ (ᐱᓗᐊᖅᑐᒥᒃ ᑑᓚᓖᑦ) ᐱᑕᖃᖅᑐᑦ ᑕᐅᕗᓇ ᐅᑭᐅᖅᑕᖅᑐᒥ ᐅᒥᐊᔪᐊᑦ ᐊᖅᑯᑖᒍᑦ 20211-ᒥ; ᖃᐅᔨᓴᖅᓱᒋᑦ ᐱᓕᕆᐊᒥᑦ-ᐅᒥᐊᔪᐊᓂᑦ ᓂᐱᖅᑯᖅᑐᓂᒃ ᐊᑦᑐᐊᔪᑦ ᐋᖅᑭᒃᑕᐅᓯᒪᔪᑎᒍᑦ ᑕᓇᐅᒥ ᐳᐃᔨᑦ ᓂᐱᓄᑦ ᖃᖓᐃᓐᓇᓕᐅᕐᓂᑕ ᑭᓪᓕᕐᒪᐅᓂᖓᓄᑦ ᐊᓂᖏᓐᓂᒃ ᐸᑦᓴᓴᐃᓂᕐᒧᑦ ᐊᒻᒪᓗ ᖃᓄᐃᓂᖅᓴᐅᖕᒪᖔᑕ ᖃᐅᔨᓴᖅᑕᐅᓯᒪᔪᑦ ᓂᐱᖅᑯᖅᑐᓕᓇᑦ ᐅᒥᐊᕐᓂᐊ ᐱᓕᕆᐊᒍᑦ ᐋᖅᑭᒃᑕᐅᓯᒪᔪᑦ ᒥᒃᓴᐅᓴᐃᓇᕐᑎᖑᒧ ᒥᒃᓴᐅᓴᐅᑎᒥᑦ ᐊᑐᖅᑕᐅᓯᒪᔪᒥᒃ ᐊᕙᑎᒧᑦ ᐊᒃᑐᐃᓂᕐᓄᑦ ᖃᐅᔨᓴᕈᑎᓂ; ᐊᒻᒪᓗ ᒥᒃᓴᐅᓴᐅᑎᒥᑦ ᓂᕈᑐᓂᕐᓯ ᑐᓴᕝᕕᐅᔪᓇᖅᑐᑦ ᒥᒃᒥᐊᕐᒃᑐᒍ (LRR) ᐊᒃᑐᐊᔪᑦ ᐱᓕᕆᐊᑉ ᐅᒥᐊᔪᐊᖕᒥᑐᑦ ᐊᓂᖅᓵᖅᐸᒃᑕᑦᑎᖕᓂ ᓂᐱᖅᑯᖅᑐᓕᓇᖕᓂᖕᒥᓂ.

ᓂᐱᓕᐅᖅᑕᐅᔪᑐᒃᑖᑦ ᓂᐱᓕᐅᖅᑕᐅᓚᐅᖅᑐᑦ ᓯᑯᖃᖏᑎᓪᓗᒍ ᐅᒥᐊᖅᓴᐅᓇᐅᑎᓪᓗᒍ. ᓂᐱᓕᐅᖅᓯᖃᑦᑕᓂᑦ ᐅᖓᓯᒃᑐᒃᑯᑦ ᓂᐱᖅᑯᖅᑐᓕᓇᐅᓂᑦ (ᖃᐅᔨᓴᐅᒥ ᐊᑕᐅᓯᖅ ᑎᑦᑕᖅ ᐊᑐᖅᑕᐅᓚᔪᑉᑐᓂ) ᐃᒪᐃᑦᑐᑉᐅᖅᑐᑦ 112.4, 115.1, ᐊᒻᒪᓗ 109.8 dB re 1 µPa ᐃᑐᕕᓕᖕᒥ, ᒥᑦᑎᒪᑕᓕᖕᒥ ᐊᒻᒪᓗ ᐃᒥᓕᖕᓂ, ᐱᑦᑐᒥᑦ (ᓂᐱᖅᑯᖅᑐᓗᐊᒻᒥᑦᑐᑦ ᖁᕙᕝᕙᓯᓕᓂᑦ ᐃᒪᐃᓕᖓᓚᐅᖅᑐᑦ 98.2, 101.7, ᐊᒻᒪᓗ 97.2 dB re 1 µPa). ᓂᐱᖅᑯᖅᑐᓕᓂᒃᑎᑦᑎᓂᖏᑦ ᐅᖓᑕᐅᔅᓚᐅᖏᑦᑐᑦ ᖁᓗᐃᓪᓕᔪᖃᖅᑳᖅᑎᓇᒍ

ᑭᒡᓕᐅᔪᓂᒃ ᐊᑐᓂ ᐃᓂᐅᔪᓂᒃ; 2.5%-ᖑᔪᑦ ᑖᒃᑯᓇᓂ 46 ᐅᓪᓗᑦ ᓂᐱᓕᕆᐅᕆᓂᕐᓂ ᐃᓗᕕᓕᖕᒥ, 1.7%–ᖑᔪᑦ 39 ᐅᓪᓗᑦ ᓂᐱᓕᐅᖅᑐᑦ ᒥᑦᑎᒪᑕᓕᖕᒥ, ᐊᒻᒪᓗ 0.6%-ᖑᔪᑦ 43 ᐅᓪᓗᑦ ᓂᐱᓕᐅᕆᑎᓪᓗᒋᑦ ᐃᒥᓕᖕᒥ.

ᖃᖓᓂᓴᑐᖃᑦ ᓂᐱᖅᑯᖅᑐᓕᓅᖕᓂᕐᒧᑦ, ᓂᐱᓕᐅᖅᑕᐅᓯᒪᔪᑦ ᐃᓗᕕᓕᖕᒥ 2018-ᒥᓂᑦ, ᖃᓄᐃᓐᓂᖅᓴᐅᖕᒪᖕᓛᑕ ᖃᐅᔨᒋᐊᖅᑕᐅᓚᐅᖅᑐᑦ 2021-ᒥ ᑎᑎᖅᑲᖁᑎᑖᕆᔭᐅᔪᓄᑦ ᕿᓂᖅᓱᑎᒃ ᖃᓄᐃᓕᖓᕙᖕᓂᖕᒋᓐᓂᒃ ᓂᐱᖅᑯᖅᑐᓯᕙᓪᓕᐊᑎᓪᓗᒋᑦ ᐊᓂᒍᖅᐸᓪᓕᐊᔪᒥ. ᓴᙱᓂᖕᒋᓐᓄᑦ ᖃᐅᔨᓴᕈᑏᑦ ᓴᖑᖓᓕᓅᑦ ᖃᓄᐃᓐᓂᖅᓴᐅᓂᖕᒋᓐᓄᑦ ᕿᒥᕐᕈᔭᐅᓚᐅᖅᑐᑦ ᐊᕌᒍᓄᑦ, ᐱᔭᐅᙱᑦᑐᑐᐊᖑᓪᓗᓂ 2019 ᓂᐱᖅᑯᖅᑐᓕᓅᑦ ᓂᐱᖅᑯᖅᑐᓂᖅᓴᐅᓚᐅᕐᓂᖕᒋᓐᓄᑦ 2-5 ᑕᓯᐳᒥᒃ (dB) ᑖᒃᑯᓇᓂ ᓂᐱᐊᕐᔫᓚᔪᒃᑐᓂ.

ᓂᐹᑦ ᐱᖓᓱᓂᑦ ᑕᕆᐅᒥ ᐳᐃᔾᔪᓂᑦ ᐊᔾᔨᒌᙱᑦᑐᓂᑦ ᐆᒪᔪᓂᑦ (ᐊᕐᕈᒃ, ᕿᓚᓗᒐᖅ ᖃᕋᖅᑕᖅ, ᕿᓚᓗᒐᖅ ᑑᒑᓕᒃ) ᓇᓗᓇᐃᖅᑕᐅᓯᒪᔪᑦ ᑕᐃᑲᓂ ᓂᐱᓄᑦ ᑎᑎᖅᑲᕐᑯᑎᓂ, ᖄᒃᑲᓐᓂᖓᒍᑦ ᑲᖐᒋᔭᐅᔪᑦ ᓂᐹᑦ ᑕᓕᕈᓕᖕᓂᒃ. ᑑᒑᓖᑦ ᓂᐱᖏᑦ ᓂᐱᓕᐅᖅᑕᐅᓚᐅᖅᑐᑦ ᐃᓗᕕᓕᖕᒥ ᐊᒻᒪ ᐃᒥᓕᖕᓂ ᑭᓯᐊᓂ ᒥᑦᑎᒪᑕᓕᖕᒥᐅᙱᑦᑐᑦ. ᖃᖓᒃᑰᓂᖓ ᑑᒑᓕᖕᓄᑦ ᓂᐱᓂᒃ ᑐᓴᕐᓂᖅ ᐃᓗᕕᓕᖕᒥ ᒪᓕᑐᐃᓐᓇᓚᐅᖅᑐᖅ ᓂᐱᓕᐅᖅᑕᐅᓚᐅᖅᓯᒪᔪᓂᒃ 2018-ᒥᓂᑦ, ᐅᓄᕐᓂᖏᑦ ᓂᐹᑦ ᐅᓄᙱᓐᓂᖅᓴᐅᓚᐅᖅᑐᑦ ᐅᔾᔨᕆᔭᐅᖃᑦᑕᖅᓯᒪᔪᒃᑯᑦ ᐅᓄᖅᑑᓪᓗᐊᖅᑎᓪᓗᒋᑦ ᖃᐅᔨᔭᐅᔪᑦ 2019-ᒥ. ᑕᒪᓐᓇ ᒪᓕᑐᐃᓐᓇᖅᑐᑦ ᖃᐅᔨᔭᐅᔪᓂᒃ ᐸᕙᓃᓐᑯᑦ ᑲᖓᑕᕗᒃᑯᑦ ᖃᐅᔨᓴᕐᓂᕆᓚᐅᖅᑕᖓᓂᒃ, ᓂᐱᓕᐅᕆᓚᐅᖅᑎᓪᓗᒋᑦ ᐅᓄᙱᓐᓂᖅᓴᓂᒃ ᑑᒑᓕᖕᓂᒃ ᓄᓇᓂ ᐊᕕᒃᑐᖅᓯᒪᔪᓂ ᖃᐅᔨᓴᕐᕕᐅᔪᓂ 2020-ᒥ ᐊᒻᒪᓗ 2021-ᒥ ᖃᓄᐃᓐᓂᖅᓴᐅᓂᖕᒋᑦ ᑕᑯᓪᓗᒋᑦ 2019-ᒥ. ᑐᙵᕕᒋᓪᓗᒋᑦ ᑕᒪᒃᑯᐊ, ᑕᐃᒪᐃᙱᑦᑐᒃᓴᐅᔪᑦ ᑖᒃᑯᐊ ᓇᐃᓴᐅᑏᑦ ᓂᐱᓄᑦ ᑐᓴᖅᑕᐅᔪᓄᑦ ᑕᐃᒪᐃᓕᖅᓯᒪᔪᑦ ᐊᓯᔾᔨᖅᓯᒪᓂᖕᒋᓐᓄᑦ ᓂᐱᖃᖅᑐᓄᑦ ᐃᓕᖅᑯᓯᕆᕙᒃᑕᖕᒋᓐᓄᑦ 2022-2021-ᒥ ᑕᑯᓪᓗᒋᑦ ᖃᓄᐃᓐᓂᖅᓴᐅᓚᐅᕐᓂᖕᒋᑦ 2019-ᒥ, ᑭᓂᐊᓯᓕ ᑕᐃᒪᐃᑦᑐᒃᓴᐅᔪᑦ ᑑᒑᓖᑦ ᐱᑕᖃᙱᓐᓂᖅᓴᐅᓚᐅᕐᓂᖕᒋᓐᓄᑦ 2021-ᒥ ᓂᐱᓕᐅᖅᑕᐅᑎᓪᓗᒋᑦ. ᓯᕗᓪᓕᖅᐹᑦᑎᐊᒥ 2021-ᒥ ᖃᕋᖅᑕᑦ ᕿᓚᓗᒐᑦ ᓂᐱᖏᑦ ᑐᓴᖅᑕᐅᓚᐅᖅᑐᑦ ᐊᒻᒪᓗ ᐅᒃᐱᕐᓇᑦᑎᐊᖅᓱᑎᒃ ᓇᓗᓇᐃᖅᑕᐅᓯᒪᔪᑦ ᑖᒃᑯᐊ ᐱᓕᕆᔾᔪᓯᖕᒋᓐᓂᒃ ᔫᓐ ᐊᑕᖏᖅᓱᑎᒃ (2021), ᓇᓗᓇᐃᖅᓯᓪᓗᑎᒃ ᖃᕋᖅᑕᑦ ᕿᓚᓗᒐᑦ ᑕᐅᕝᕙᖕᒐᓚᐅᖃᑦᑕᕐᓂᖕᒋᓐᓂᒃ ᓄᓇᐅᔪᒧᑦ ᑖᒃᑯᓇᓂ ᐅᕝᕙᓘᓐᓃᑦ ᖃᓂᒋᔭᖕᒋᓐᓂᒃ ᑑᒑᓖᑦ. ᐊᕐᕕᑦ ᓂᐱᖏᑦ ᑐᓴᖅᑕᐅᓚᐅᖅᑐᑦ (ᐊᒻᒪ ᐊᒡᒐᒃᑯᑦ ᓇᓗᓇᐃᖅᑕᐅᓪᓗᓂ) ᐃᓛᓐᓂᒃᑯᑦ ᐃᓗᕕᓕᖕᒥ ᓯᒡᔭᖓᓂ ᖃᐅᔨᓴᖅᐸᓪᓕᐊᖕᒋᓐᓇᕐᓂᕐᒧᑦ ᐱᓕᕆᐊᓂ. ᐃᓚᖏᑦ ᓂᐹᑦ ᒪᓕᒃᑐᑦ ᓂᐱᖃᖅᑎᑕᐅᔪᑦ ᐅᒡᔪᖕᓂᒃ ᐊᒻᒪᓗ ᓇᑦᑎᕐᓂᒃ ᑐᓴᖅᑕᐅᖃᑦᑕᓚᐅᕐᔪᑦ ᓂᐱᓕᐅᖅᓯᒪᔪᑎᒍᑦ.

ᐅᒥᐊᕐᔪᐊᑦ ᓂᐱᖃᓚᐅᖅᑐᑦ 30%, 36%, ᐊᒻᒪᓗ 32% ᑲᑎᓪᓗᒃᑖᖅᓱᒋᑦ ᓂᐱᓕᐅᖅᑕᐅᔪᓂ ᐃᓗᕕᓕᖕᒥ, ᒥᑦᑎᒪᑕᓕᖕᒥ, ᐊᒻᒪᓗ ᐃᒥᓕᖕᓂᒃ, ᐊᒃᑐᐊᔪᑦ. ᐃᖕᖏᓐᓇᖅ ᓇᓗᓇᐃᒃᑯᑕᓕᕆᔾᔪᑎ (AIS) ᓂᐱᓕᐊᖕᒋᑦ ᓇᓗᓇᐃᖅᓯᓯᒪᔪᑦ ᐊᑕᖏᖅᓱᒋᑦ ᐅᒥᐊᕐᔪᐊᑦ ᐃᖕᒋᕐᕋᔪᑦ ᖃᐅᔨᔭᐅᔪᑦ ᐃᓗᕕᓕᖕᒥ ᐊᒻᒪᓗᓗ ᐃᒥᓕᓂ ᓂᐱᓕᐅᖅᑕᐅᔪᑦ ᐱᓕᕆᐊᒍᑦ ᐊᒃᑐᐊᓚᐅᖅᑐᑦ, ᑕᒪᒃᑯᐊᓕ ᒥᑦᑎᒪᑕᓕᖕᒥ ᓂᐱᓕᐅᕈᑏᑦ ᑐᓴᖃᑦᑕᓪᓗᐊᑕᓚᐅᖅᑐᑦ ᐱᓕᕆᐊᒥᖕᓛᙱᑦᑐᓂᒃ ᐅᒥᐊᕐᔪᐊᓂᒃ. ᑐᓴᕐᕕᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᑯᕆᐊᕐᑯᓪᓗᒍ (LRR) - ᓂᐱᑭᒡᓕᕚᓪᓕᐊᕐᔪᒃᑎᑦᑎᓃᑦ ᐊᑐᐃᓐᓇᐅᔪᓄᑦ ᑑᓴᕝᕕᐅᔪᓐᓇᖅᑐᓄᑦ ᑕᕆᐅᒥ ᐳᐃᔨᓄᑦ – ᖃᕆᓴᐅᔭᒃᑯᑦ ᐋᖅᑭᒃᑕᐅᓯᒪᓚᐅᖅᑐᑦ ᐊᑐᓂ ᓂᐱᓕᐅᖅᓯᕝᕕᐅᔪᓂ ᐱᖓᓱᓄᑦ ᕿᔾᔭᓕᕐᓄᑦ, ᐊᑐᓂ ᑭᒡᓕᖅᑐᐃᓪᓗᑎᒃ ᐊᔾᔨᒌᙱᑦᑐᓂᒃ ᑐᓵᓃᑦ ᐱᓕᖃᐅᓯᖕᒋᓐᓂᒃ; 1 khz (ᑭᒡᓕᖅᑐᐃᔪᖅ ᑑᓵᓃᑦ ᓂᐱᖃᖅᑎᑦᑎᓚᐅᑲᖃᑦᑕᕐᓂᖕᒋᓐᓂᒃ), 5 kHz (ᑭᒡᓕᖅᑐᐃᔪᖅ ᐅᕕᙱᐊᖅᑕᖕᒋᓐᓂᒃ ᐊᒻᒪᓗ ᑲᓯᐊᐸᓪᓚᑦᑎᑎᑦᑎᓂᖕᒋᓐᓂᒃ) ᐊᒻᒪᓗ 25 kHz (ᑭᒡᓕᖅᑐᐃᔪ ᑲᓯᑦᑎᑦᑎᐊᕐᔪᖕᓃᑦ ᐊᒻᒪᓗ ᓂᐱᖅᑯᖅᑐᓂᖅᓴᐃᑦ ᓂᓪᓕᐊᔭᖕᒋᑦ). ᑖᒃᑯᐊ ᑐᓴᕐᕕᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᑯᕆᐊᕐᑯᓪᓗᒋᑦ (LRR) ᓴᖅᑭᓯᒪᔪᖅ ᐊᑐᓂ ᐱᖓᓱᑦ ᕿᔮᓕᓂ ᓇᐃᓈᖅᓯᒪᔪᑦ ᐃᒪᓐᓇ:

1 kHz (ᓂᐱᖃᖅᑎᑦᑎᓚᐅᑲᖃᑦᑕᕐᓂᖕᒋᓐᓂᒃ):

ᓂᐱᖅᑯᖅᑐᓂᖅᓴᐃᑦ 50%-ᒥᒃ ᓂᐱᓄᑦ 1 kHz ᑐᓴᖅᑕᐅᔪᑦ ᐊᑐᖅᑎᓪᓗᒋᑦ 5.1%, 8.8%, ᐊᒻᒪᓗ 4.7% ᐊᑐᖅᑕᐅᑎᓪᓗᒋ ᐅᒥᐊᕐᔪᐊᑦ ᑑᓴᔭᐅᑎᓪᓗᒋᑦ (ᓱᕐᓗ 1.5%, 3.2%, ᐊᒻᒪᓗ 1.5% ᓂᐱᓕᐅᖅᓯᕝᕕᐅᔪᒥ) ᐃᓗᕕᓕᖕᒥ, ᒥᑦᑎᒪᑕᓕᖕᒥ, ᐊᒻᒪᓗ ᐃᒥᓕᖕᓂ ᓂᐱᓕᐅᕈᑎᓂ, ᐊᒃᑐᐊᔪᑦ. ᓂᐱᖃᐃᓐᓇᖅᑐᑦ ᓈᒻᒪᒋᔭᐅᔪᒥᒃ ᑐᓴᕐᕕᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᑯᕆᐊᕐᑯᓪᓗᒋᑦ (LRR) ᐃᒪᐃᑎᓪᓗᒍ 1 kHz ᓇᓕᐊᖕᓂᑐᐃᓐᓇᖅ ᓂᐱᓕᐅᕐᑯᖕᓂ, ᐱᔾᔪᑎᒋᓪᓗᒋᑦ ᑑᓴᓂᕐᒧᑦ ᖃᓄᐃᓪᓕᔪᖃᖅᑳᖅᑎᓐᓇᒍ ᑭᒡᓕᐅᔪᓂᒃ ᑑᒑᓕᖕᓄᑦ ᐃᒪᐃᓐᓇᑎᕆᐅᑎᓪᓗᒍ 1 kHz ᖁᕝᕙᓯᖕᓂᖅᓴᐅᔪᖅ ᑐᓴᖅᑕᐅᖕᒋᓐᓇᐅᔭᓚᔪᒃᑐᑦ ᖁᕝᕙᓯᓕᓅᖕᒋᓐᓂᒃ ᓇᓕᐊᖕᓂᑐᐃᓐᓇᖅ ᕿᔾᔭᓪᓗᓕᕐᓂ.

5 kHz (ᐅᕙᖕᕿᐊᖅᑕᖕᕿᓐᓂᒃ/ᑲᓱᐊᐸᓚᑦᑎᑎᑦᑎᓂᖕᕿᓐᓂᒃ):

ᓂᐱᖅᑯᖅᑐᓂᖅᓴᖅ 50%-ᒥᒃ ᑕᒪᑐᒧᖕᒐ ᑐᓴᕐᕙᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᓯᕿᐊᕐᑯᓪᓗᒋᑦ (LRR) ᓂᐲᑦ 5 kHz ᑐᓴᖅᑕᐅᔪᑦ ᐊᑐᖅᑎᓪᓗᒋᑦ 22.2%, 29.6% ᐊᒻᒪᓗ 33.9% ᓂᐱᓕᐅᕐᕙᐅᑎᓪᓗᒋᑦ ᐅᒥᐊᕐᔪᐊᖅ ᑐᓴᖅᑕᐅᓪᓗᑎᒃ (ᓲᕐᓗ 6.7%, 10.7%, ᐊᒻᒪᓗ 10.8% ᓂᐱᓕᐅᕐᓇᐅᔪᒥ) ᐃᓗᕙᓕᖕᒥ, ᒥᑦᑎᒪᑕᓕᖕᒥ ᐊᒻᒪᓗ ᐃᒥᓕᖕᒥ ᓂᐱᓕᐅᕈᑎᓂ, ᐊᒃᑐᐊᔪᑦ. ᓂᐱᖃᐃᓐᓇᖅᑐᑦ ᓴᖅᑭᓯᒪᔪᑦ ᓂᐱᖅᑯᖅᑐᓂᖅᓴᐅᓪᓗᓂ 50%-ᒥᒃ ᑕᒪᑐᒧᖕᒐ ᑐᓴᕐᕙᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᓯᕿᐊᕐᑯᓪᓗᒋᑦ (LRR) ᓂᐱᓄᑦ 5 kHz–ᒥ ᐊᑐᖅᑎᓪᓗᒋᑦ 21.5%, 31.1% ᐊᒻᒪᓗ 31.2% ᓂᐱᓕᐅᕐᕙᐅᔪᒥ ᐅᒥᐊᕐᔪᐊᑦ ᓂᐱᖃᙱᓗᑎᒃ ᐃᓗᕙᓕᖕᒥ, ᒥᑦᑎᒪᑕᓕᖕᒥ, ᐊᒻᒪᓗ ᐃᒥᓕᖕᒥ ᓂᐱᓕᐅᕈᑎᓂᑦ, ᐊᒃᑐᐊᔪᑦ.

25 kHz (ᑲᓱᑦᑎᑦᑎᐊᕐᔪᖕᓃᑦ/ᓂᐱᖅᑯᖅᑐᓂᖅᓴᐃᑦ ᓂᓪᓕᐊᔭᖕᒋᑦ).

ᓂᐱᖅᑯᖅᑐᓂᖅᓴᐃᑦ 50%-ᒥᒃ ᑐᓴᕐᕙᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᓯᕿᐊᕐᑯᓪᓗᒋᑦ (LRR) ᓂᐱᓄᑦ ᐃᒪᐃᑎᓪᓗᒋᑦ 25 kHz ᑐᓴᖅᓴᐅᔪᑦ ᐊᑐᖅᑕᐅᑎᓪᓗᒋᑦ 14.5%, 19.5% ᐊᒻᒪᓗ 29.5% ᐱᕙᖃᖅᑎᓪᓗᒋᑦ ᐅᒥᐊᕐᔪᐊᖅ ᑐᓴᖅᑕᐅᑎᓪᓗᒋᑦ (ᓲᕐᓗ 4.4%, 7.0%, ᐊᒻᒪᓗ 9.4% ᓂᐱᓕᐅᕐᕙᐅᔪᓂ) ᐃᓗᕙᓕᖕᒥ, ᒥᑦᑎᒪᑕᓕᖕᒥ, ᐃᒥᓕᖕᒥ ᓂᐱᓕᐅᕈᑎᓂ, ᐊᒃᑐᐊᔪᑦ. ᓂᐱᖃᐃᓐᓇᖅᑐᑦ ᑐᓴᖅᑕᐅᔪᑦ ᓂᐱᖅᑯᖅᑐᓂᖅᓴᐅᓪᓗᑎᒃ 50%-ᒥᒃ ᑐᓴᕐᕙᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᓯᕿᐊᕐᑯᓪᓗᒋᑦ (LRR) ᓂᐱᓄᑦ ᐊᑐᖅᑎᓪᓗᒋᑦ 25 kHz ᐱᓕᕆᑎᓪᓗᒋᑦ 14.3%, 29.8% ᐊᒻᒪᓗ 31.2% ᓂᐱᓕᐅᕐᕙᐅᔪᓂᖅ ᐅᒥᐊᕐᔪᐊᑦ ᓂᐱᖃᖅᑎᓐᓇᒋᑦ ᐃᓗᕙᓕᖕᒥ, ᒥᑦᑎᒪᑕᓕᖕᒥ, ᐊᒻᒪᓗ ᐃᒥᓕᖕᒥ ᓂᐱᓕᐅᕈᑎᓄᑦ, ᐊᒃᑐᐊᔪᑦ.

Executive Summary

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

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

The 2021 PAM Program was developed by JASCO Applied Sciences (JASCO), in collaboration with Golder Associates Ltd. (Golder) and Baffinland, to evaluate potential Project-related effects to marine mammals from shipping noise. The main objective of this program was to document and characterize ambient and anthropogenic underwater noise levels recorded in 2021 at three acoustic monitoring stations: one at located along the Northern Shipping Route at Iluvilik (Bruce Head) in Milne Inlet, one near Baffinland's anchorage location at Imilik (Ragged Island), and one offshore of the community of Mittimatalik (Pond Inlet), where a small craft harbour was being constructed. All three recorders were deployed at the beginning of August and were retrieved in mid-September 2021, and recorded continuously.

Additional objectives of the program were: to acoustically identify marine mammal species (notably narwhal) present along the Northern Shipping Route in 2021; to evaluate Project-shipping noise levels in relation to established marine mammal acoustic thresholds for injury and disturbance and to compare measured sound levels from shipping activities to modelled estimates used for environmental effects assessment; and to estimate the extent of listening range reduction (LRR) associated with Project vessels relative to ambient noise levels.

All recordings were made during the open-water shipping period. Mean broadband sound levels (one-minute averaged) were 112.4, 115.1, and 109.8 dB re 1 µPa at Bruce Head, Pond Inlet, and Ragged Island, respectively (median levels were 98.2, 101.7, and 97.2 dB re 1 µPa). Sound exposure levels never exceeded thresholds for acoustic injury (temporary or permanent hearing loss) at any recording location. The one-minute averaged SPL occasionally exceeded the 120 dB re 1 µPa marine mammal disturbance threshold at each station; for 2.5 % of the 46 days of recording at Bruce Head, 1.7 % of the 39 days of recording at Pond Inlet, and 0.6 % of the 43 days of recording at Ragged Island.

Historical mean sound levels, recorded at Bruce Head since 2018, were compared with 2021 data to look for trends of increasing levels over time. The mean power spectral density curves were comparable across years, with the exception of 2019 when sound levels were louder by 2-5 dB over most frequencies.

Sounds from three marine mammal species (bowhead, beluga, and narwhal) were identified in the acoustic data, in addition to suspected sounds from pinnipeds. Narwhal vocalizations were recorded at Bruce Head and Ragged Island but not at Pond Inlet. Though the timing for narwhal acoustic detections at Bruce Head was consistent with recordings since 2018, the number of acoustic detections were lower

compared to an apparent peak number of detections in 2019. This is consistent with the results of Baffinland's aerial survey program, which recorded lower numbers of narwhal in the RSA in 2020 and 2021 compared to 2019. Based on this, it is not likely that the number of acoustic detections are a result of changed acoustic behaviour in 2020-2021 compared to 2019, but rather a result of less narwhal being in the system at the time of the 2021 recordings. For the first time in 2021 beluga whale acoustic detections were confidently identified following the methodology of Zahn et al. (2021), indicating that beluga were occasionally present in the region amongst or near narwhal. Bowhead whale vocalizations were acoustically detected (and manually validated) occasionally at the Bruce Head and Ragged Island recorders, which is consistent with visual observations made during the 2021 Bruce Head shore-based monitoring program. Some acoustic signals consistent with those produced by bearded seals and ringed seals were also detected throughout the recordings.

Vessels were acoustically detected on 30%, 36% and 32% of the total recordings at Bruce Head, Pond Inlet, and Ragged Island, respectively. Automated Identification System (AIS) records indicate that all vessel traffic detected on the Bruce Head and Ragged Island recorders were Project related, while the Pond Inlet recorder mainly experienced noise from non-Project vessels. Listening range reduction (LRR)—the fractional decrease in the available listening range for marine animals—was computed at each recording station for three frequencies, each representative of different narwhal vocalization types: 1 khz (representative of narwhal burst pulses), 5 kHz (representative of whistles and knock trains) and 25 kHz (representative of clicks and high-frequency buzzes). The LRR results for each of the three frequencies are summarized as follows:

1 kHz (burst pulses):

Greater than 50% LRR for sound at 1 kHz occurred during 5.1%, 8.8%, and 4.7% of the time when vessels were detected (i.e. 1.5%, 3.2%, and 1.5% of the recording period) at the Bruce Head, Pond Inlet, and Ragged Island recorders, respectively. Ambient noise did not cause appreciable LRR at 1 kHz at any recording station, given the hearing threshold for a narwhal at 1 kHz is higher than the median ambient sound level at this specific frequency.

5 kHz (whistles/knock trains):

Greater than 50% LRR for sound at 5 kHz occurred during 22.2%, 29.6% and 33.9% of the time when vessels were detected (i.e 6.7%, 10.7%, and 10.8% of the recording period) at the Bruce Head, Pond Inlet, and Ragged Island recorders, respectively. Ambient noise resulted in greater than 50% LRR for sound at 5 kHz during 21.5%, 31.1% and 31.2% of the recording period without vessel noise at the Bruce Head, Pond Inlet, and Ragged Island recorders, respectively.

25 kHz (clicks / high frequency buzzes):

Greater than 50% LRR for sound at 25 kHz occurred during 14.5%, 19.5% and 29.5% of the time when vessels were detected (i.e. 4.4%, 7.0%, and 9.4% of the recording period) at the Bruce Head, Pond Inlet, and Ragged Island recorders, respectively. Ambient noise resulted in greater than 50% LRR for sound at 25 kHz during 14.3%, 29.8% and 31.2% of the recording period without vessel noise at the Bruce Head, Pond Inlet, and Ragged Island recorders, respectively.

1. Introduction

Underwater sound level measurements were collected at locations in Milne Inlet and Eclipse Sound during JASCO Applied Sciences' (JASCO) 2021 Passive Acoustic Monitoring (PAM) program, developed in collaboration with Golder Associates Ltd. (Golder) and Baffinland Iron Mines Corporation (Baffinland), to evaluate potential Project-related effects to marine mammals from shipping noise associated with Baffinland's Mary River Project. The data were analyzed to document the spatial and temporal variability of recorded underwater sounds, to document marine mammal vocalization occurrence (primarily focused on narwhal), and to quantify the degree to which noise from Project vessels contributed to the underwater sound field.

Acoustic monitoring, using Autonomous Multichannel Acoustic Recorders (AMARs; JASCO Applied Sciences), commenced in August and concluded in mid-September 2021. One recorder was deployed at Iluvilik (Bruce Head), one at the anchorage location at Imilik (Ragged Island), and one near Mittimatalik (Pond Inlet) approximately 1 km from the location of the Small Craft Harbour (SCH) construction project.

1.1. Project Context

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

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

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

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

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

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

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

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

1.2. Study Objectives

The objectives of the 2021 Open-Water Season PAM Program were the following:

- Measure and report ambient noise levels at a location along the Northern Shipping Route, in Milne Inlet (Figure 1),
- Compare in-situ sound levels relative to modelled sound levels,
- Determine marine mammal species (notably narwhal) acoustic presence along the Northern Shipping Route,
- Evaluate Project shipping noise levels in relation to established marine mammal acoustic thresholds for injury and onset of disturbance,
- Estimate the extent of listening range reduction (LRR) associated with Project vessel transits along the Northern Shipping Route relative to ambient noise levels.
- Characterize sound at the anchorage location near Ragged Island.
- Characterize sound recorded near to the Pond Inlet Small Craft Harbour construction activities.

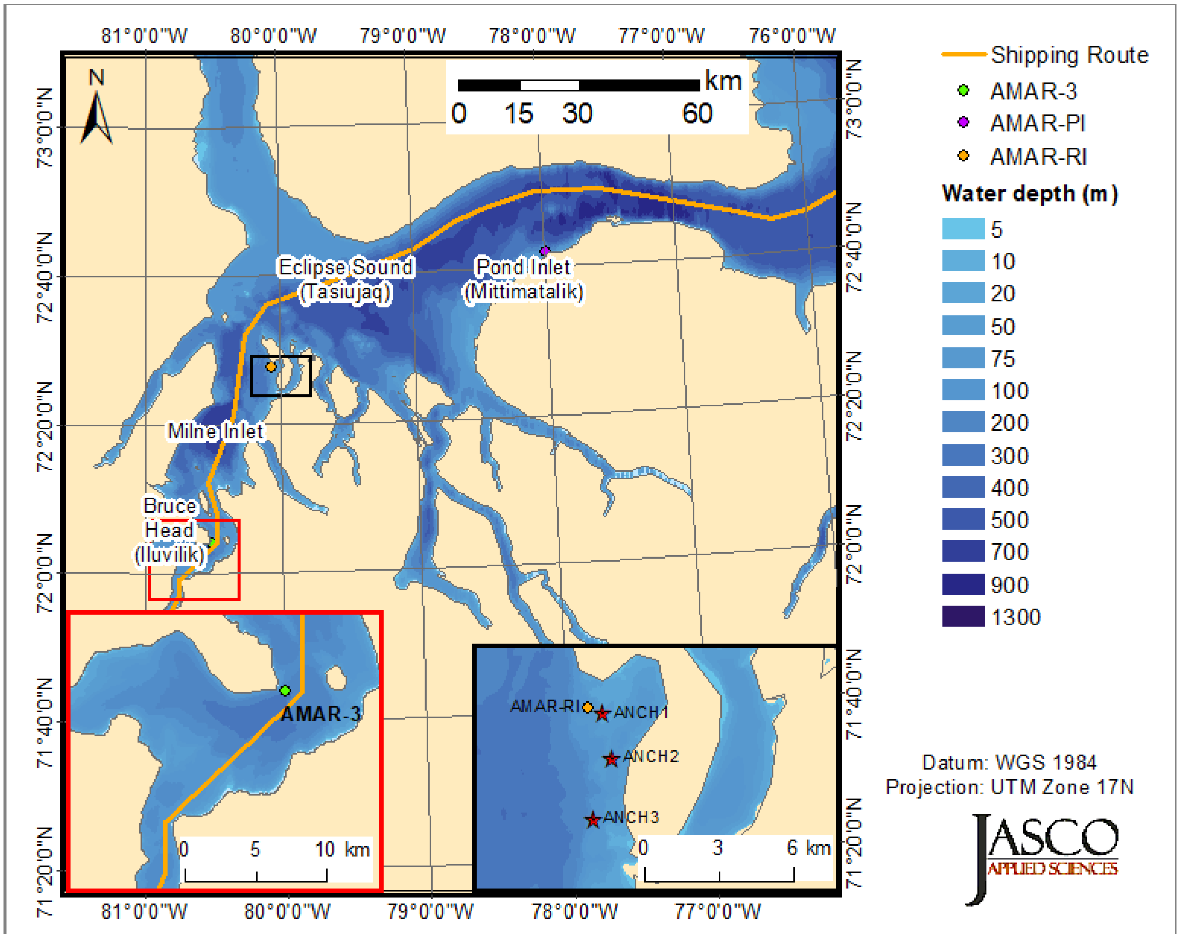

Figure 1. Acoustic monitoring area and locations of recorder stations along the Northern Shipping Route, at Bruce Head (red insert: AMAR–3), Ragged Island (black insert: AMAR–RI), and Pond Inlet (AMAR–PI). Red stars denote Baffinland's three anchorage locations at Ragged Island (ANCH 1, ANCH 2, and ANCH 3).

1.3. Ambient Sound Levels

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

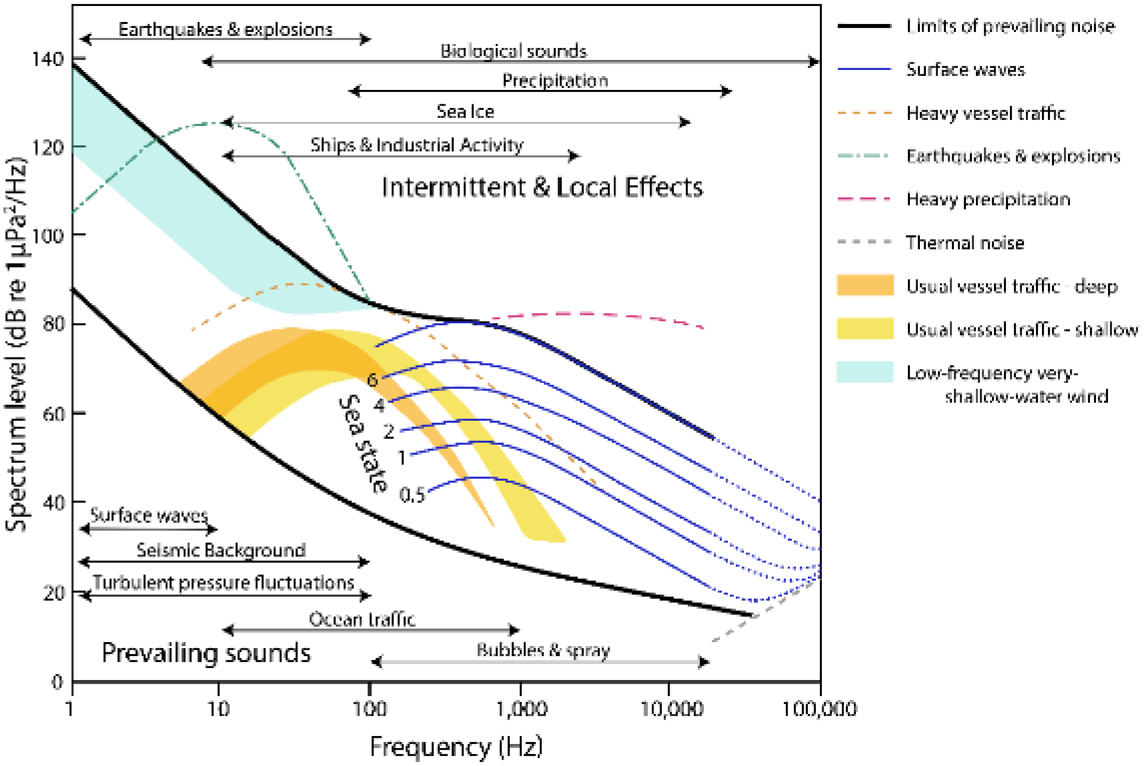

Figure 2. Wenz curves. While the often cited Wenz curves show sea state dependent spectra only above 200 Hz, with a peak at ~500 Hz, Wenz showed measurements at lower frequencies (Wenz 1962). Spectrum levels exhibit a local minimum at ~100–200 Hz and rise for frequencies less than 100 Hz.

1.4. Biological Contributors to the Marine Soundscape

Five cetacean (bowhead whales, narwhals, beluga whales, killer whales, and sperm whales) and five pinniped (ringed seals, bearded seals, harp seals, hooded seals, and walrus) species may be found in or near the Project area (Table 1). Current knowledge on marine mammal presence and distribution in Milne Inlet is largely derived from traditional knowledge (Jason Prno Consulting Services Ltd. 2017) and scientific survey data (Thomas et al. 2015, 2016, Golder Associates Ltd. 2018, 2019, 2020) as reported in the 2010 Arctic Marine Workshop (Stephenson and Hartwig 2010) and from research activities (Yurkowski et al. 2018).

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

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

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

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

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

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

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

Species	Sound Production Frequency Range (kHz)[1]	Identification signal	Automated detection signal	Reference
Bowhead whales	0.02 (moan) – 6 (warble)	Moan	Moan	Clark and Johnson (1984) Delarue et al. (2009)
Beluga whales	0.1 – 21 (whistle, pulsed call) 40 – 120 (echolocation)	Whistle	Whistle	Karlsen et al. (2002) Garland et al. (2015)
Narwhal	0.3 (whistle, pulsed call) – 24 (pulsed call) 53 (echolocation mean)	Whistle, click, buzz, knock	Whistle, click, buzz knock	Stafford et al. (2012) Ford and Fisher (1978) (Walmsley et al. 2020)
Killer whales	0.1 (click burst) – 75 (ultrasonic whistles) 22 – 80 (echolocation)	Whistle, pulsed vocalization	Tonal signal <6 kHz	Ford (1989) Deecke et al. (2005)
Sperm whales	0.4 (squeal) – 9 (coda) 3 – 26 (echolocation)	Click	Click	(Watkins 1980)
Ringed seals	0.4 (howl) – 0.7 (howl)	Grunt, yelp, bark	Grunt	Stirling et al. (1987) Jones et al. (2011)
Bearded seals	0.08 (groan) – 22 (moan)	Trill	Trill	Risch et al. (2007)
Harp seals	0.1 - 10	Grunt, yelp, bark	Grunt	Terhune (1994)
Walrus	0.2 (rasp) – 20 (knock)	Grunt, knock, bells	Grunt, bells	Stirling et al. (1987) Mouy et al. (2011)

1 (Southall et al. 2019)

1.5. Anthropogenic Contributors to the Soundscape

The main anthropogenic (human-generated) contributor to the total sound field in the study area was vessel traffic. This sound is a by-product of vessel operations, including engine sound radiating through vessel hulls and cavitating propellers. Project vessels, both those associated with transporting the iron ore (i.e., ore carriers) and support vessels (tugs, icebreakers, fuel tankers, and cargo vessels.), contribute to the soundscape. These vessels generally follow the nominal shipping lane (the Northern Shipping Route) that passes through the Project area (Figure 3). Other non-Project vessels that transited through the area in 2021 included cargo, fishing, passenger, and search and rescue vessels as well as service ships, tankers, and tugs. Small boats are also frequently in the study area and are a relevant source of anthropogenic noise (Hermannsen et al. 2019, Wilson et al. 2022), which has not been well characterized in the study area because these boats typically do not have AIS.

Ore carriers heading to Milne Port also called at anchorages at Ragged Island (ANCH1, ANCH 2, and ANCH3, Figure 1) while awaiting availability at the ore dock to allow them to approach the Port. The main sources of noise from the vessels on anchor were sounds from generators and pumps, and engine noise if the vessel's engine was running. Vessels were on anchor at either one or both of the anchorages on 34 out of the 43 recording days (Figure 4).

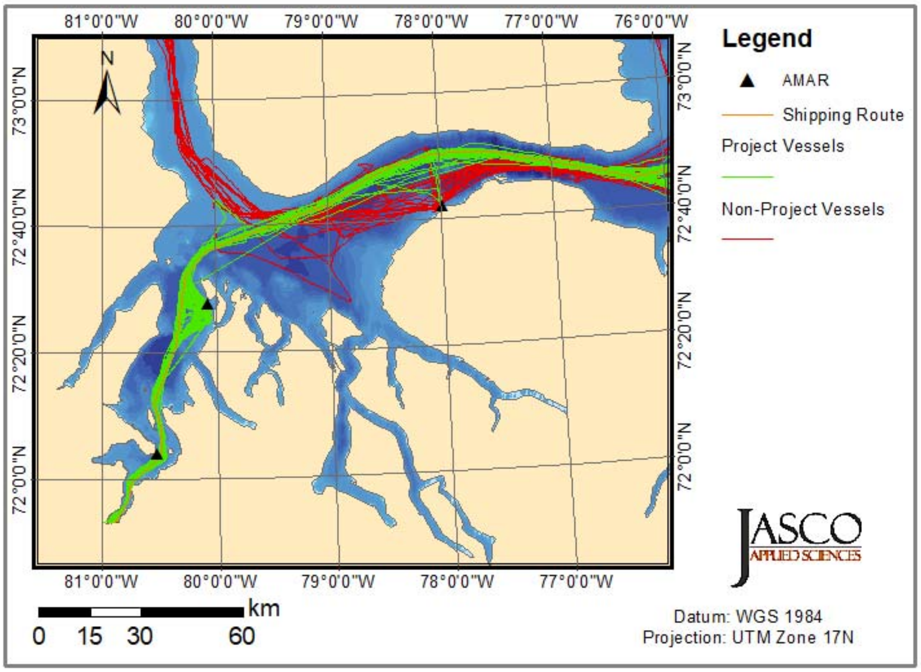

Figure 3. Vessel traffic travelling along the Northern Shipping Route during the 2021 recording period; both Project-related vessels (green) and non-Project related vessels (red) are displayed. Automatic Identification System (AIS) vessel tracking data was acquired from ground-based stations at Bruce Head and Pond Inlet, as well as AIS data collected by satellites (exactEarth 2020).

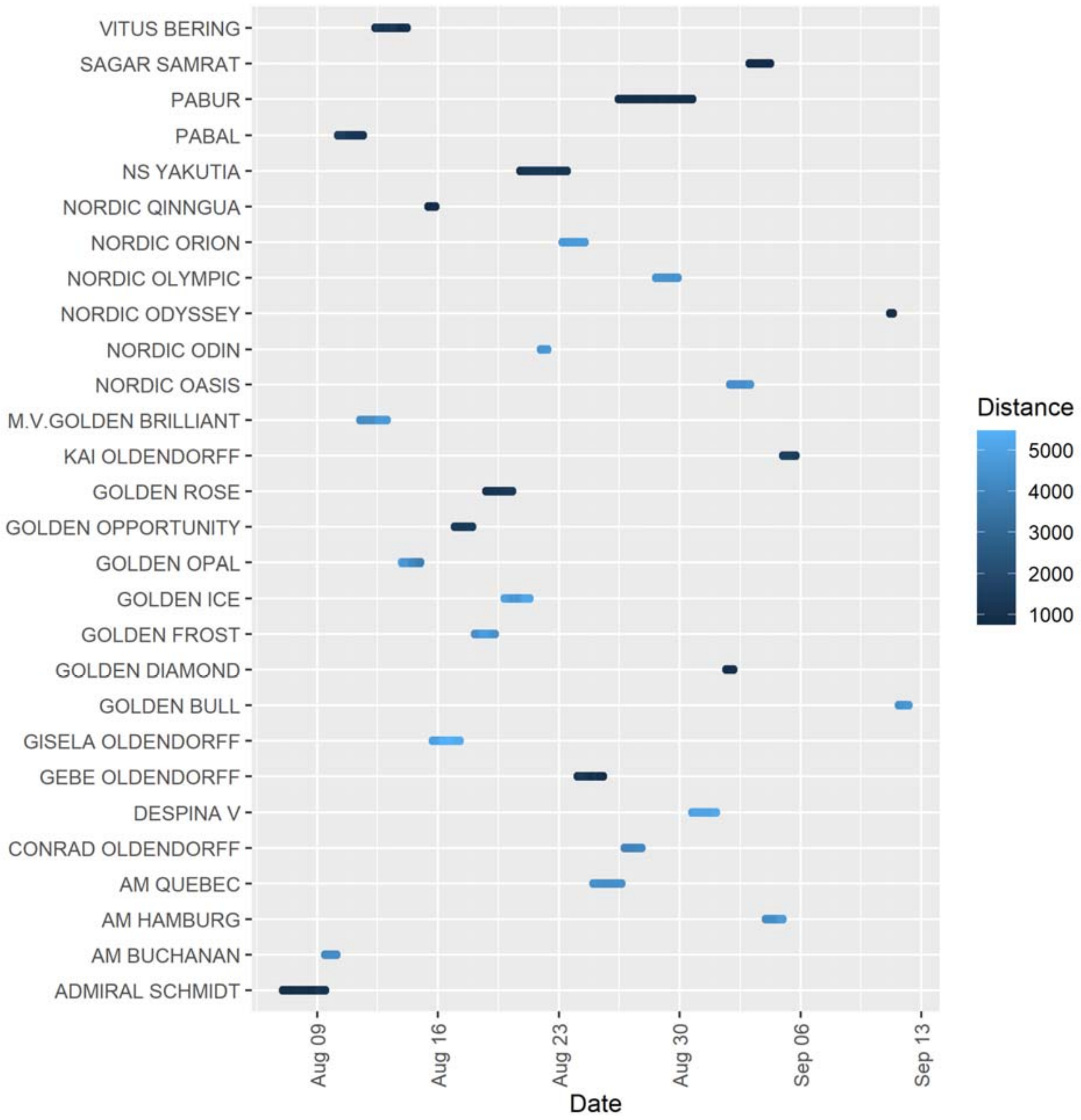

Figure 4 Schedule of when AIS data indicated that vessels were On Anchor at Ragged Island. Color coded according to distance from the acoustic recording location: dark blue shading indicates vessels were at ANCH 1 and light blue shading indicates vessels were at ANCH 3.

2. Methods

2.1. Acoustic Data Acquisition

Underwater sound was recorded with three Autonomous Multichannel Acoustic Recorders (AMARs, JASCO; Figure 5). AMARs were each fitted with a M36 omnidirectional hydrophone (GeoSpectrum Technologies Inc., −165 ± 3 dB re 1 V/µPa sensitivity). All devices were calibrated to within 1 dB using a pistonphone calibrator (Appendix A). The AMAR hydrophones were protected by a hydrophone cage, which was covered with a shroud to minimize noise artifacts from water flow. The recorders had a duty cycle, sampling alternately at 64 kHz for 14 minutes and 512 kHz for 1 minute.

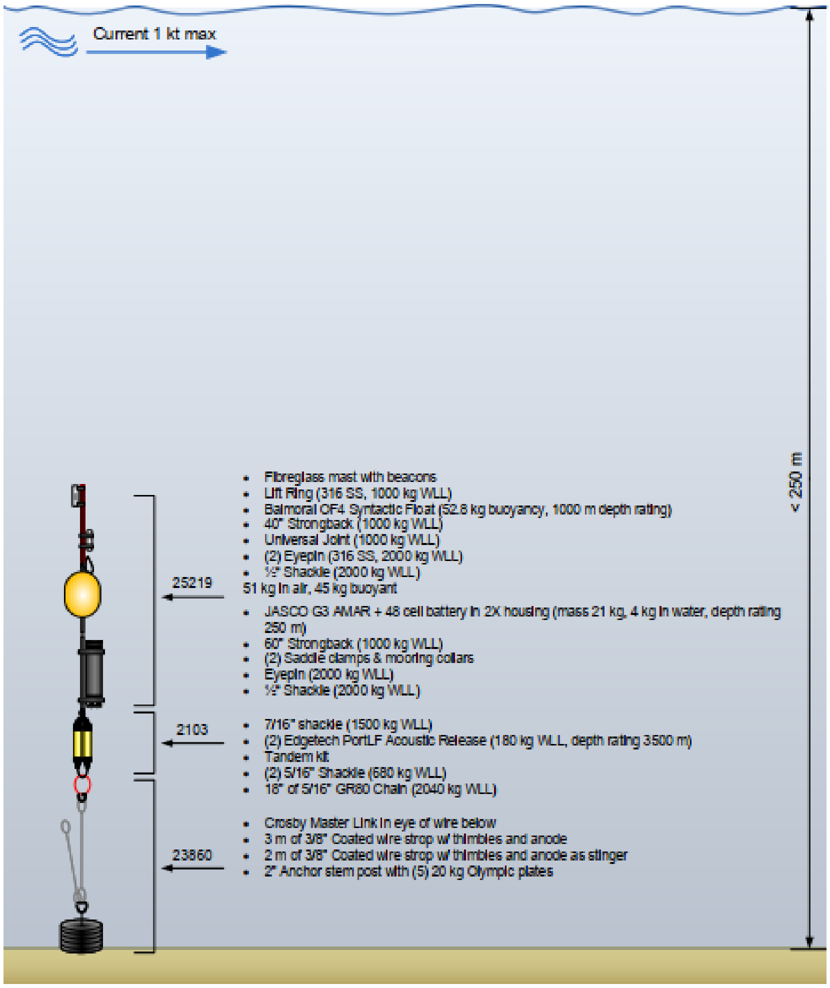

Figure 5. The Autonomous Multichannel Acoustic Recorder (AMAR) used to measure underwater sound.

2.1.1. Deployment Locations

AMARs were deployed at three locations in summer 2021 (Table 3, Figure 1), near Pond Inlet, Ragged Island, and Bruce Head. All AMARs recorded for approximately 6 weeks, from late- July/early-August through to mid-September. Deployment details are provided in Table 3. The Bruce Head and Ragged Island recorders were deployed from Baffinland's Research Vessel (Figure 7) while the Pond Inlet recorder was deployed from the *MSV Botnica* (Figure 6). All recorders were retrieved from the *Botnica*.

The Ragged Island AMAR was nominally 1.1 km from the location that Baffinland identifies as ANCH 1 and nominally 4.6 km from Baffinland's ANCH 3 (Figure 1, black inset).

Table 3. Operation period and location of the Autonomous Multichannel Acoustic Recorders (AMARs) deployed for the 2021 PAM program.

2021 Stations	Latitude	Longitude	Water depth (m)	Start date/ Time	Stop date/ Time	Recording duration (days)
Bruce Head AMAR-3	72.06715°N	-80.5172°W	238	30 Jul 2021 16:16:22	13 Sep 2021 12:59:15	46
Ragged Island AMAR-RI	72.46352°N	-80.0701°W	131	2 Aug 2021 12:13:55	13 Sep 2021 18:40:00	43
Pond Inlet AMAR-PI	72.70773°N	-77.9828°W	123	7 Aug 2021 18:38:01	14 Sep 2021 15:52:00	39

Figure 6. Vessel *MSV Botnica* used for deployment of Pond Inlet recorder and retrieval of all recorders.

Figure 7. BIM Research Vessel used for Bruce Head and Ragged Island AMAR deployments.

2.1.2. Sound Level Analysis

The collected data span 1.5 months at each of the three stations at 10–32,000 Hz and 10–343,750 Hz. The goal of the sound level analysis is to present this expansive data in a manner that documents the baseline underwater sound conditions in the RSA to make comparisons between stations, over time, and with external factors that change sound levels such as weather and human activities.

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

2.1.3. Vessel Noise Detection

Constant, narrowband tones produced by a vessel’s propulsion system and other rotating machinery (Arveson and Vendittis 2000) were detected by analyzing the recorded data using a 0.125 Hz resolution spectrogram of the data (8 seconds of data, 2 second advance, Hann window). A split window normalizer was used to find frequencies that exceeded their local background by at least a factor of 3. For each minute of data, the number of tones that lasted at least 20 seconds as well as the decidecade sound pressure levels were passed to the next stage of analysis. In the second stage of analysis, the energy in the 40–315 Hz decidecade bands was summed to define a shipping band SPL since this band contains most sound energy produced by mid-sized to large vessels. Background estimates of the shipping band

SPL and broadband SPL were then compared to their median values over the 720-minute window, centered on the current time. Vessel detections are defined by three criteria depicted in Figure 8:

- The SPL in the shipping band is at least 3 dB above the 720-minute median.
- The average number of tonals over all 11-minute window centered on the analysis time was at least 0.5, and at least one minute had 3 or more tones.
- The shipping band SPL in within 12 dB of the broadband SPL, indicating that shipping is a substantial part of the recorded soundscape.

All minutes that met these criteria were identified has having shipping present. When there were at least 5 minutes that met these criteria, a shipping event was identified. The shipping detection window was then extended by a 10 minute window before and after the event as it is likely that shipping energy is also present in those minutes. The minute with the maximum shipping band SPL was identified as the time of the CPA.

The same detector approach was also employed to detect the presence of smaller commercial or recreational boats. For boat detection a boating band SPL of 315-2000 Hz was used instead of the 40-315 Hz shipping band which is better matched to the frequencies emitted from boats' propellers. Since boats often pass by much faster than large vessels, the minimum detection duration is reduced from 5 minutes to 2 minutes, and a 5-minute average of the number of tonals was computed instead of 11-minutes. Since large vessels tend to be much louder than smaller boats, so if both are present at the same time masking of the small boat noise is possible.

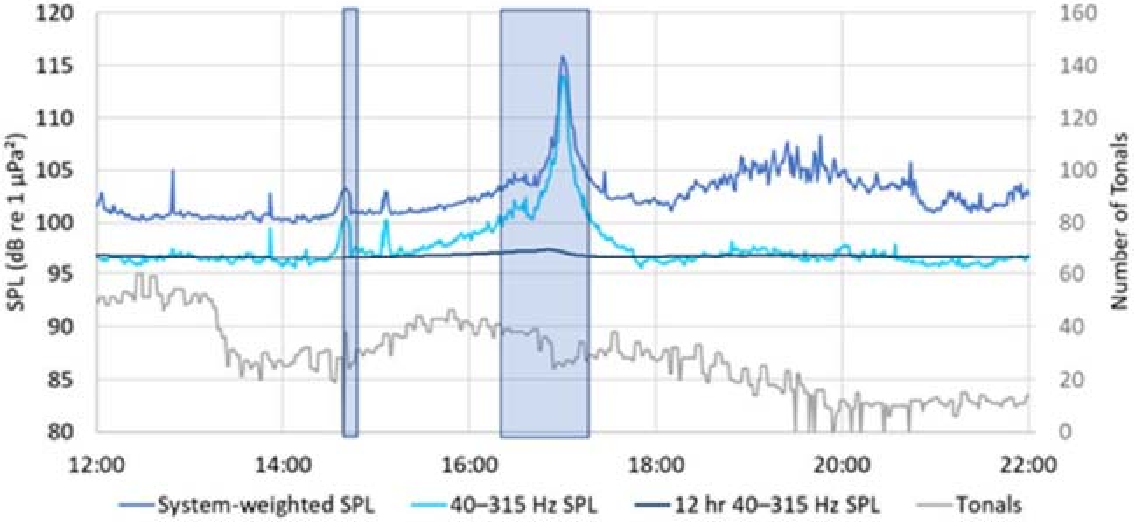

Figure 8. Example of broadband and 40–315 Hz band sound pressure level (SPL), as well as the number of tonals detected per minute as a ship approached a recorder, stopped, and then departed. These data are example only, and were not recorded in the regional study area. The shaded area is the period of shipping detection. Fewer tonals are detected at the ship's closest point of approach (CPA) at 17:00 because of masking by broadband cavitation noise and due to Doppler shift that affects the tone frequencies.

2.2. Listening Range Reduction Calculations

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

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

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

LRR was calculated for three frequencies representative of five types of narwhal vocalizations, for all three AMAR locations in the regional study area. LRR was calculated at each AMAR station using the same methodology outlined in the 2018 Bruce Head Passive Acoustic Monitoring report (Frouin-Mouy et al. 2019), as follows. At each location, LRR was determined for narwhal low-frequency buzzes (or burst pulses) using 1 kHz as the representative frequency, for whistles and knock trains using 5 kHz as a representative frequency (mean frequency; Marcoux et al. 2012), and for clicks and high-frequency buzzes using 25 kHz as a representative frequency (25 kHz is the maximum decidecade band available for data sampled at 64 kHz; narwhal mid-frequency clicks have a mean frequency of ~10 kHz (Stafford et al. 2012); high-frequency clicks have a centre frequency of 53 kHz; (Rasmussen et al. 2015)). The data were divided into periods with and without vessel detections. The normal listening range was determined using the maximum of the mid-frequency cetacean audiogram (see Table A-9 in Finneran 2015) or the median 1-minute SPL without vessels in each of the decidecade bands of interest as the baseline hearing threshold (Table 4). The geometric spreading coefficient was set to a nominal value of 15. The analysis was performed for each 1 dB of increased decidecade band SPL above the normal condition.

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

Band center frequency (kHz)	Decidecade band baseline ambient level (dB re 1 µPa)			Hearing threshold for mid-frequency cetaceans* (dB re 1 µPa)
	Pond Inlet	Ragged Island	Bruce Head	
1	87.7	83.4	84.6	96.7
5	80.9	78.8	83.2	74.1
25	76.2	74.1	77.6	57.2

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

2.3. Marine Mammal Detection Overview

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

2.3.1. Automated Click Detection

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

2.3.2. Automated Tonal Signal Detection

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

2.3.3. Evaluating Automated Detector Performance

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

To determine the performance of the automated detectors at each station per acoustic file (14 min files sampled at 64 kHz and 1 min files sampled at 512 kHz), the automated and manual results (excluding files where an analyst indicated uncertainty in species occurrence) were fed into an algorithm that calculates precision (*P*), recall (*R*), and Matthew's Correlation Coefficient (MCC) (see Appendix C.4 for formulas). *P* represents the proportion of files with detections that are true positives. A *P* value of 0.90 means that 90% of the files with automated detections truly contain the targeted signal, but it does not indicate whether all files containing acoustic signals from the species were identified. *R* represents the proportion of files containing the signal of interest that were identified by the automated detector. An *R* value of 0.90 means that 90% of files known to contain a target signal had automated detections, but it says nothing about how many files with automated detections were incorrect. An MCC is a combined measure of *P* and *R*, where an MCC of 1.00 indicates perfect performance–all events were correctly automatically detected. The algorithm determines a per file automated detector threshold (the number of automated detections per file where automated detections were considered valid, bounded by a minimum and maximum) that maximizes the MCC.

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

The occurrence of each species (both validated and automated, or validated only where appropriate) was plotted using JASCO's Ark software as time series showing presence/absence by hour over each day of the recording period. Automated detector performance metrics are provided in Appendix F and should be considered when interpreting results.

2.3.4. Differentiating Between Narwhal and Beluga Clicks

The clicks produced by beluga and narwhal share many features, and therefore the ability to differentiate between the species (manually or automatically) based on these signals was limited in previous PAM reports (Frouin-Mouy and Maxner 2018, Frouin-Mouy et al. 2020). Previously, acoustic detection of narwhal by JASCO has been largely based on their tonal signals and validated by any visual sighting data collected throughout the recording period. These methods were inherently limited, particularly given that these animals commonly produce only clicks, without any tonal calls to allow for species identification.

During the analysis of the present data set, Zahn et al. (2021) produced a valuable article entitled '*Acoustic differentiation and classification of wild belugas and narwhals using echolocation clicks*'. We investigated previous JASCO truth data sets of narwhal and beluga to see if the findings of Zahn et al. (2021) could be replicated. The analysis is summarized in Appendix D. The analysis showed that the findings of Zahn et al. (2021) align closely with the archived data, suggesting that the recommendations from the paper for methods to differentiate between these species based on clicks may be valid and applicable for the present bottom mounted recorder data.

Based on these findings, the following protocols were applied for differentiating between the clicks of narwhal and beluga in the present data during manual analysis. If the -3 dB frequency maximum of a click is:

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

These methods were applied to the Bruce Head 2021 station where odontocete clicks were identified.

3. Results

3.1. Ambient Noise Measurements

3.1.1. Total Ocean Sound Levels

Total ocean sound levels are presented as:

- **Band-level plots:** These strip charts show the averaged received sound pressure levels as a function of time within a given frequency band. We show the total sound levels (across the entire recorded bandwidth from 10 to 32,000 Hz or 256000 Hz) and the levels in the decade bands of 10–100, 100–1000, 1000–10,000, 10,000–100,000 Hz, and 100–1000 kHz depending on the recording bandwidth. The 10–100 Hz band is associated with fin, sei, and blue whales, large shipping vessels, flow and mooring noise, and seismic survey pulses. Sounds within the 100–1000 Hz band are generally associated with the physical environment such as wind and wave conditions but can also include both biological and anthropogenic sources such as minke, right, and humpback whales, fish, nearby vessels, and pile driving. Sounds above 1000 Hz include high-frequency components of humpback whale sounds, odontocete whistles and echolocation signals, wind- and wave-generated sounds, and sounds from human sources at close range including pile driving, vessels, seismic surveys, and sonars.
- **Long-term Spectral Averages (LTSAs)**: These color plots show power spectral density levels as a function of time (*x*-axis) and frequency (*y*-axis). The frequency axis uses a logarithmic scale, which provides equal vertical space for each decade increase in frequency and allows the reader to equally see the contributions of low and high-frequency sound sources. The LTSAs are excellent summaries of the temporal and frequency variability in the data.
- **Decidecade box-and-whisker plots**: In these figures, the ‘boxes’ represent the middle 50% of the range of sound pressure levels measured, so that the bottom of the box is the sound level 25th percentile (L_{25}) of the recorded levels, the bar in the middle of the box is the median (L_{50}), and the top of the box is the level that exceeded 75% of the data (L_{75}). The whiskers indicate the maximum and minimum range of the data.
- **Spectral density level percentiles**: The decidecade box-and-whisker plots are representations of the histogram of each band’s sound pressure levels. The power spectral density data have too many frequency bins for a similar presentation. Instead, colored lines are drawn to represent the L_{eq}, L_5, L_{25}, L_{50}, L_{75}, and L_{95} percentiles of the histograms. Shading is provided underneath these lines to provide an indication of the relative probability distribution. It is common to compare the power spectral densities to the results from Wenz (1962), which documented the variability of ambient spectral levels off the US Pacific coast as a function of frequency of measurements for a range of weather, vessel traffic, and geologic conditions. The Wenz levels are appropriate for approximate comparisons only since the data were collected in deep water, largely before an increase in low-frequency sound levels (Andrew et al. 2011).
- **Daily sound exposure levels (SEL; $L_{E,24h}$)**: The SEL represents the total sound energy received over a 24 h period, computed as the linear sum of all 1-minute values for each day. It has become the standard metric for evaluating the probability of temporary or permanent hearing threshold shift. Long-term exposure to sound impacts an animal more severely if the sounds are within its most sensitive hearing frequency range. Therefore, during SEL analysis recorded sounds are typically

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

- **Cumulative Distribution Functions (CDFs):** Empirical distribution functions quantify the proportion of data that exceeded a given SPL. To obtain these, the broadband (10–30 000 Hz) 1-minute SPL data were sorted from smallest to largest, and then the total number of minutes that were greater than a given sound pressure level were computed as a percentage of the recording duration. These plots can be interpreted in two ways: the y-axis on these plots give the percent of the data that were below the corresponding x-axis value, and the integral of the y-axis values for all data to the right of a given x-axis value provides the exceedance value for that SPL.

The recorded broadband sound levels are summarized in Table 5. The spectrogram and band-level plots for all stations (left panels of Figures 9–11) provide an overview of the sound variability in time and frequency presenting an overview of presence and level of contribution from different sources. Short-term events appear as vertical stripes on the spectrograms and spikes on the band level plots. Long-term events affect (increasing or decreasing accordingly) the band level over the event period and appear in the spectrograms as horizontal bands of colour. The percentile figures (right panels of Figures 9–11) show boxplots by decidecade band (top panels) and power spectral density by percentile. Spikes in the percentiles can be indicative of longer-term trends or major events in specific frequency bands. Cumulative distribution functions for each recorder are plotted in Figure 12.

The recording periods at all three locations began after the breakup of ice had occurred in late July and the shipping season had begun. The dominant anthropogenic contribution to the ambient soundscape was from vessel noise (Project-related and non Project-related), most notably at the Pond Inlet site. The recorder at Pond Inlet also received sound from construction activities at the small craft harbour, though the specific contribution of these sounds could not be well characterized or distinguished from vessel noise because no details about the construction activity schedule and operations have been made public. Recorded sounds levels were highest at the Pond Inlet station across all frequency bands.

An example of vessel noise near Bruce Head is shown in Figure 13. The Bruce Head site was the closest to the northern shipping route. The sound levels received were consistent throughout the deployment period, with a few multi-day louder periods in August associated with periods of high wind (Appendix G), and regular short-duration spikes of noise from passing vessels. The Bruce Head recorder was also deployed in approximately twice the water depth of Pond Inlet or Ragged Island, which would make the other two recorders slightly more susceptible to increased sound levels from surface sounds corresponding with increased sound levels at the lowest frequencies.

As shown in Figure 3, both the Pond Inlet and Ragged Island recording sites received a high volume of vessel traffic. Pond Inlet was subject to predominantly non-Project vessel traffic (red tracks in Figure 3), although a few cargo and fuel vessels that service the Project also made scheduled stops in Pond Inlet (unrelated to the Project). Nearly daily presence of Project ore carriers occurred at the Ragged Island anchorages (green tracks in Figure 3). Figure 14 shows an example of the intermittent vessel related sounds at Ragged Island; the noise from vessels on anchor is explored in more detail in Section 3.4. For both these sites, vessels often remained close to the recorder for a sustained period, versus at Bruce Head where most vessels transited over the recorder with shorter durations of noise exposure.

Table 5 Broadband, unweighted, sound pressure level (SPL, dB re 1 µPa) values at each recorder station.

Station	Minimum	Maximum	Mean	Median
Bruce Head	79.6	137.4	112.4	98.2
Pond Inlet	81.0	148.9	115.1	101.7
Ragged Island	79.9	145.6	109.8	97.2

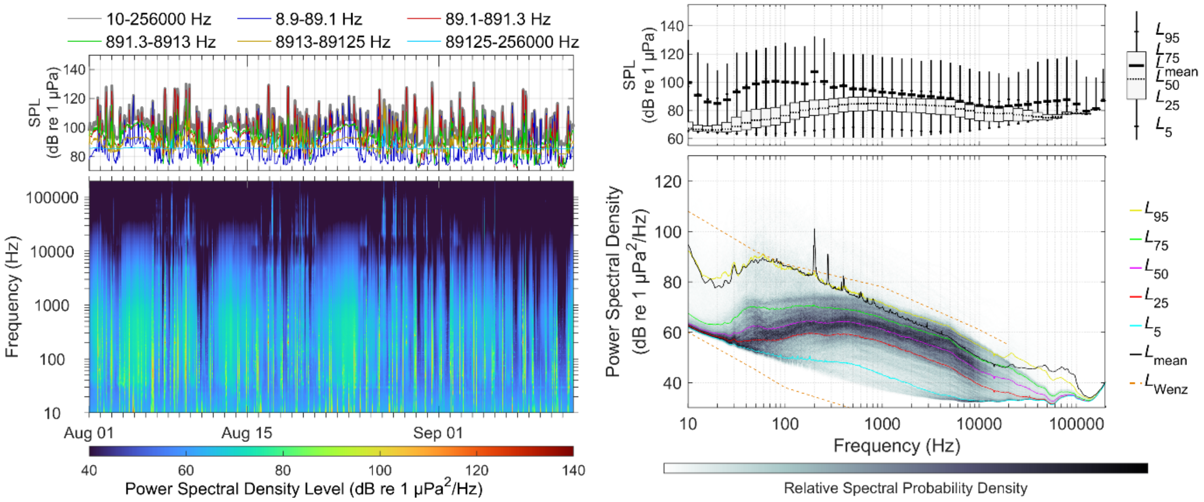

Figure 9. Bruce Head: (left) In-band sound pressure level (SPL) and spectrogram of underwater sound. (Right) Exceedance percentiles and mean of decidecade-band SPL and exceedance percentiles and probability density (grayscale) of 1-min power spectrum density (PSD) levels compared to the limits of prevailing noise (Wenz 1962). The recordings occurred from August to September 2021.

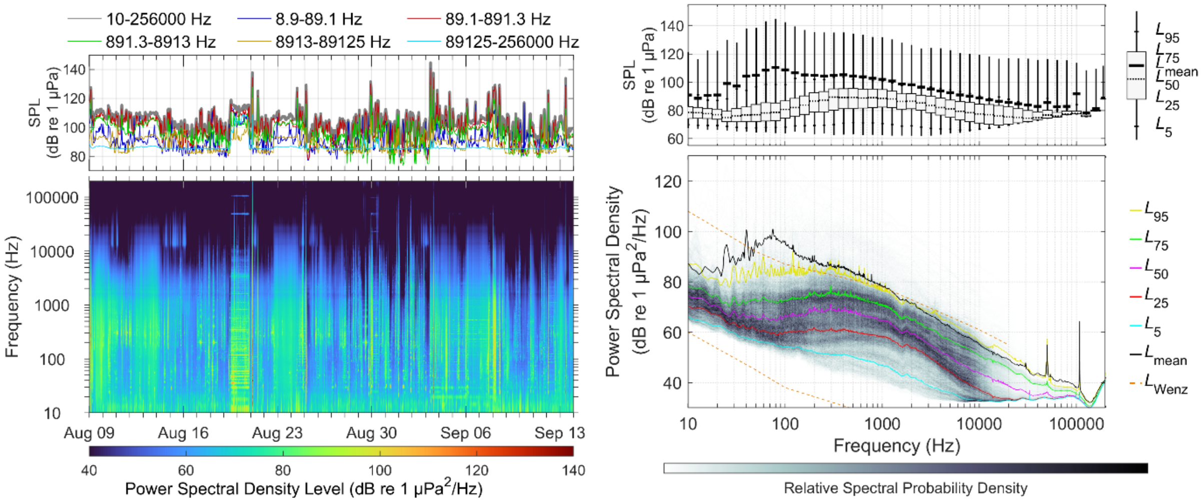

Figure 10. Pond Inlet: (left) In-band sound pressure level (SPL) and spectrogram of underwater sound. (Right) Exceedance percentiles and mean of decidecade-band SPL and exceedance percentiles and probability density (grayscale) of 1-min power spectrum density (PSD) levels compared to the limits of prevailing noise (Wenz 1962). The recordings occurred from August to September 2021.

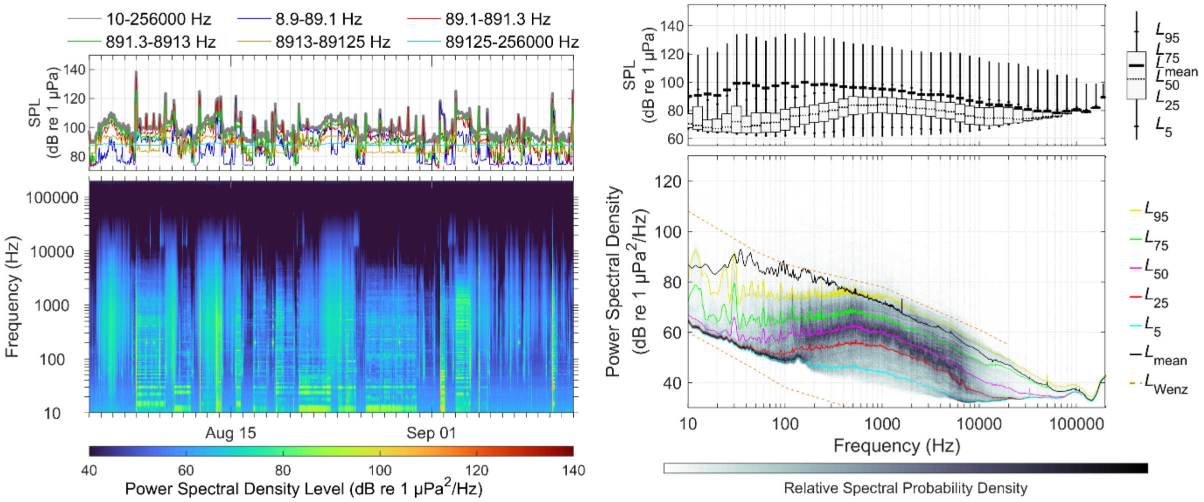

Figure 11. Ragged Island: (left) In-band sound pressure level (SPL) and spectrogram of underwater sound. (Right) Exceedance percentiles and mean of decidecade-band SPL and exceedance percentiles and probability density (grayscale) of 1-min power spectrum density (PSD) levels compared to the limits of prevailing noise (Wenz 1962). The recordings occurred from August to September 2021.

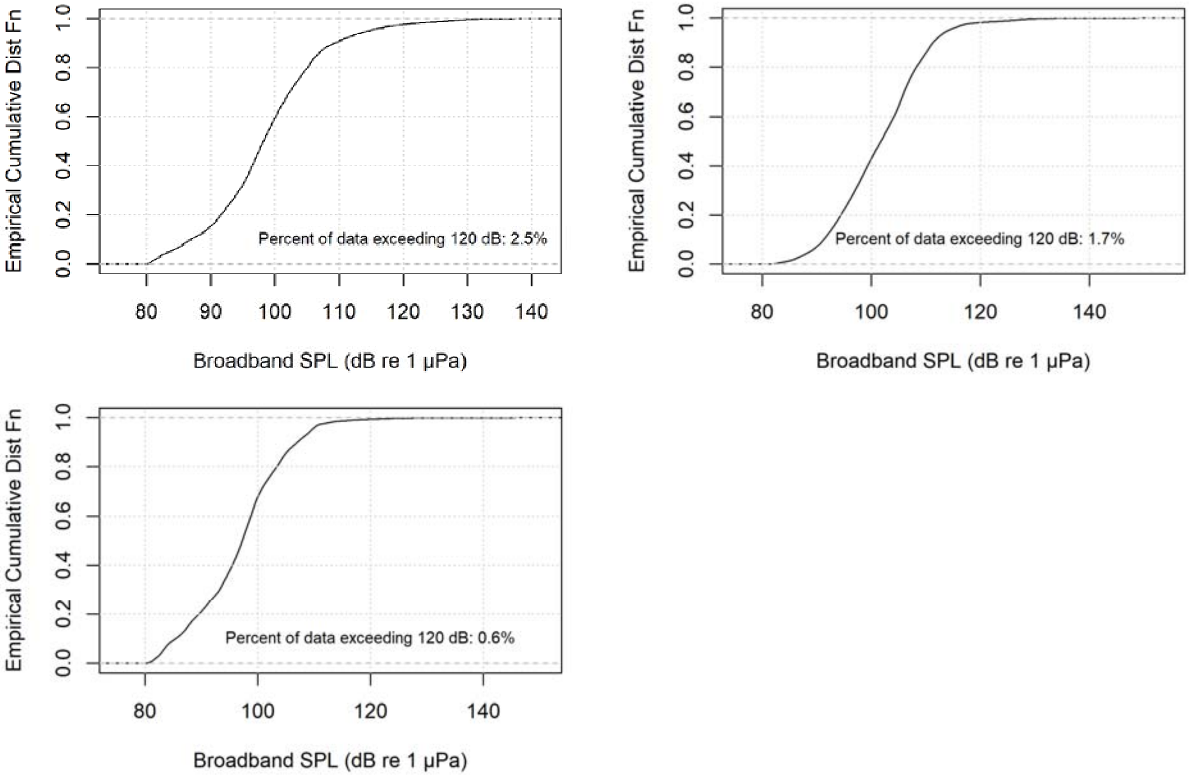

Figure 12 Empirical cumulative distribution functions for broadband SPL recorded at (top, left) Bruce Head, (top, right) Pond Inlet, and (bottom, left) Ragged Island.

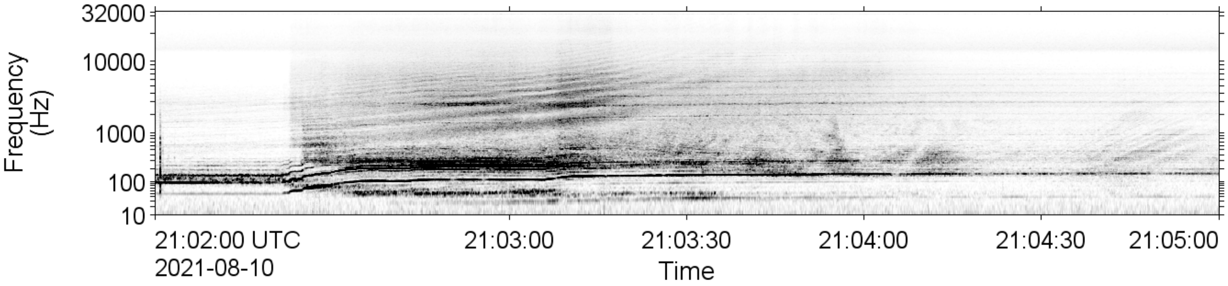

Figure 13. Bruce Head: Example of vessel crossing at the station.

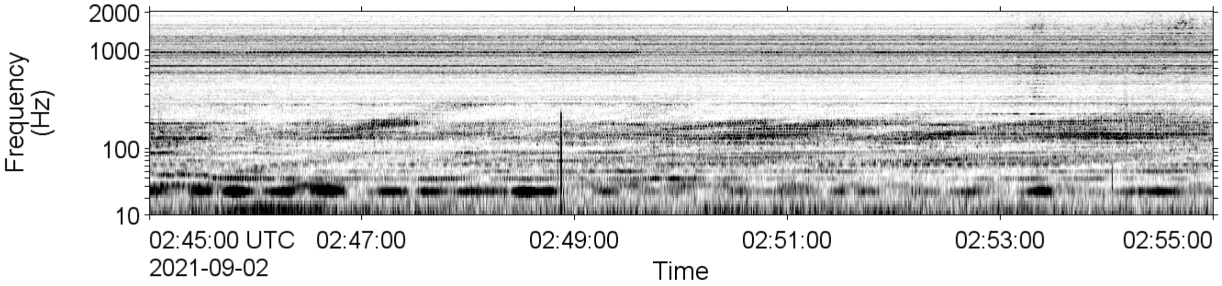

Figure 14. Ragged Island: Example of intermittent vessel noise at the station.

3.2. Daily Sound Exposure Levels

The perception of underwater sound depends on the hearing sensitivity of the receiving animal in the frequency bands of the sound. Hearing sensitivity in animals varies with frequency, the hearing sensitivity curve (audiogram) usually follows a U-shaped curve (where there is a central frequency band of optimal hearing sensitivity and reduced hearing sensitivity at higher and lower frequencies). The hearing sensitivity frequency range differs between species, meaning that different species will perceive underwater sound differently, depending on the frequency content of the sound. Auditory frequency weighting functions for different functional hearing groups (see Appendix G) are applied to reflect an animal's ability to hear a sound and to de-emphasize frequencies animals do not hear well relative to the frequency band of best sensitivity. Figure 15 shows the difference between perceived daily sound exposure by low-, mid-, and high-frequency cetaceans and pinnipeds (otariid and phocid). All daily sound exposure levels recorded during this study were below the thresholds for temporary or permanent hearing threshold shifts (i.e., hearing loss) for each functional hearing group (Southall et al. 2019). There were no threshold exceedances for any of the three stations during the deployment period.

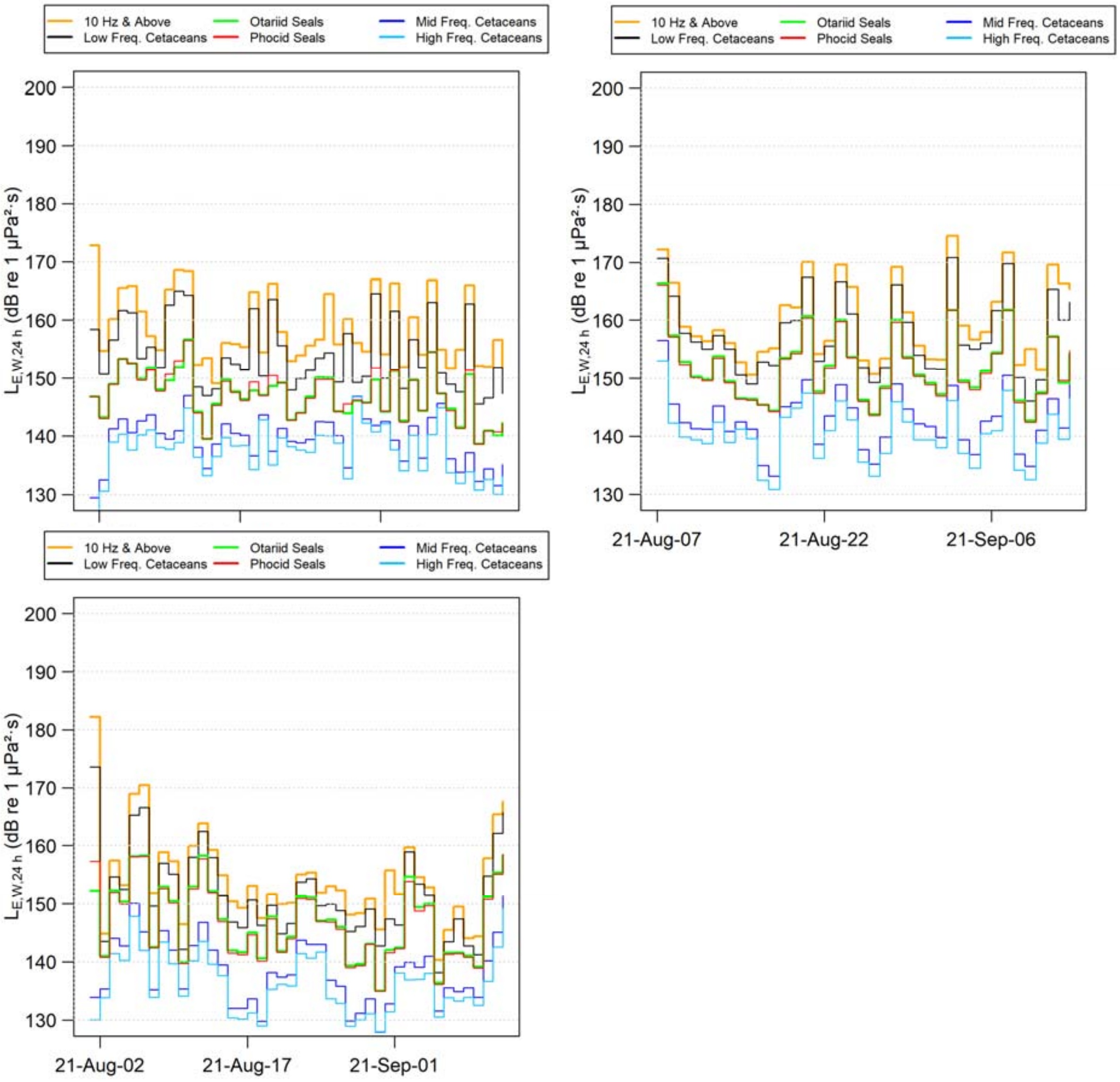

Figure 15. Daily sound exposure level (SEL) at (top, left) Bruce Head, (top, right) Pond Inlet, and (bottom, left) Ragged Island.

3.3. Vessel Detections

Recording for all three stations started while the shipping season was already underway. Vessels were detected for multiple hours daily until the end of each station's deployment. Vessel detections by hour are shown in Figures 16–18 for large vessels and smaller boats, where large vessels are the dominant occurrence. These plots indicate simply vessel presence and do not reflect the recorded sound level at these times. It is shown in Section 4.2 that the vessel noise exceeded levels that could cause behavioural disturbance for less than one hour per day. Results showing the proportion of narwhal listening range reduction caused by vessel noise, relative to ambient noise, are provided in Section 3.5.

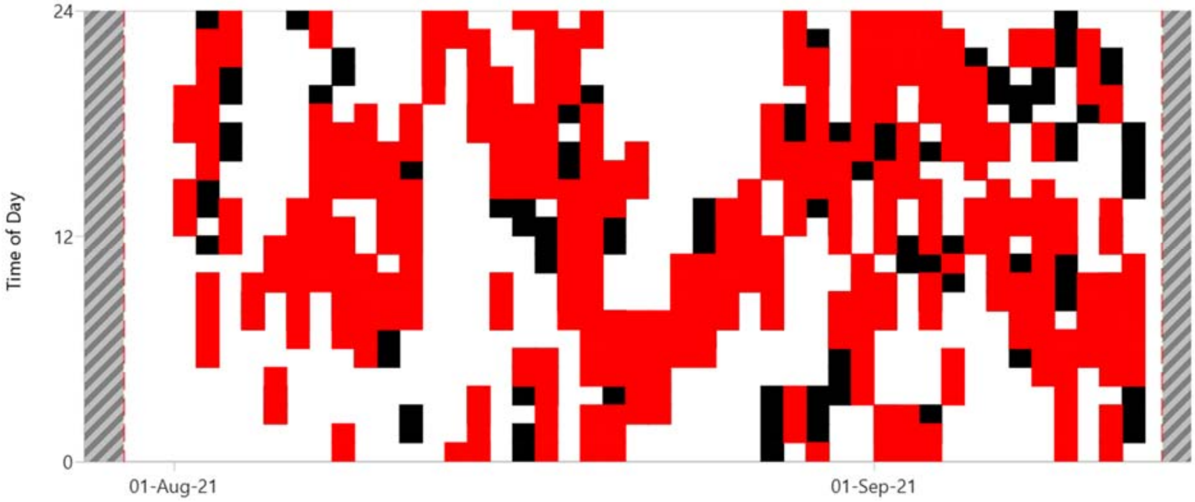

Figure 16. Bruce Head: Vessel detections by hour. Large vessels are red, smaller boats in black. Shaded regions represent pre and post deployment.

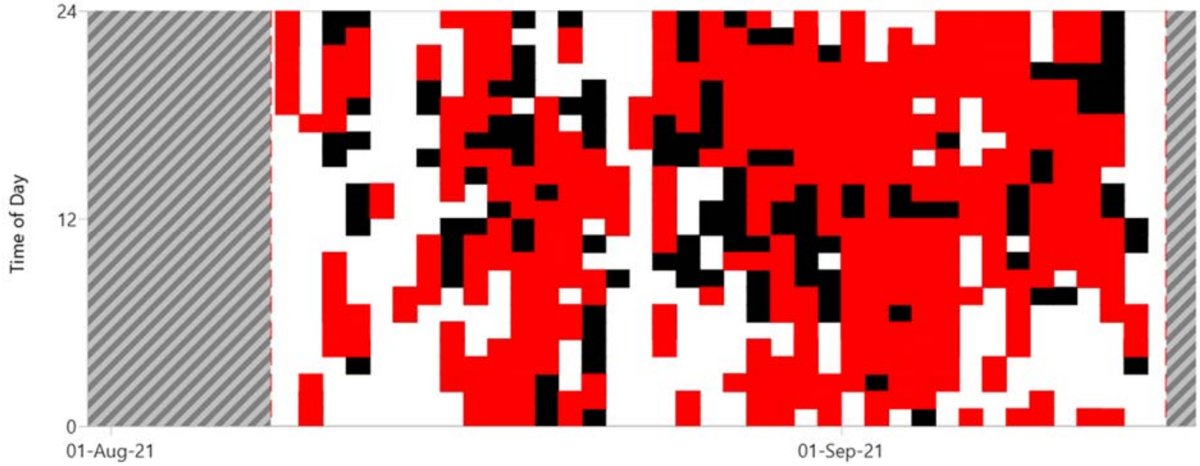

Figure 17. Pond Inlet: Vessel detections by hour. Large vessels are red, smaller boats in black. Shaded regions represent pre and post deployment.

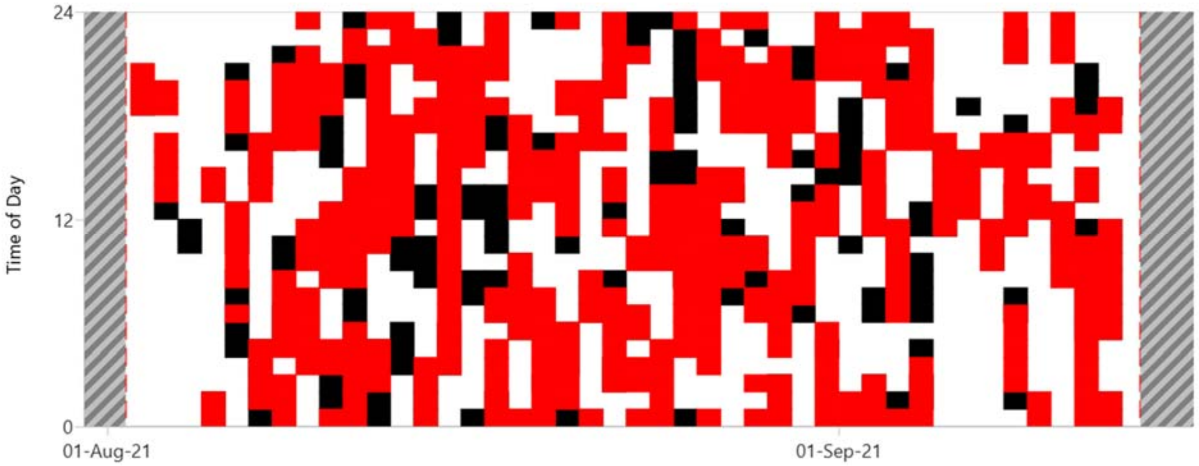

Figure 18. Ragged Island: Vessel detections by hour. Large vessels are red, smaller boats in black. Shaded regions represent pre and post deployment.

3.4. Sound Levels at Ragged Island Anchorage Location

During the 43-day recording period, 13 ore carriers were at the Ragged Island anchorage ANCH 1, nominally 1.1 km from AMAR-RI, and 15 ore carriers were at ANCH 3, nominally 4.6 km from AMAR-RI. Vessels remained on anchor for durations between 3 hours and 4 days, with an average duration of 31 hours.

Recorded broadband sound levels (ANCH 1, Figure 20; ANCH 3 Figure 21) varied considerably while the vessels were on anchor in most instances. This is perhaps due to changing loading conditions on the vessel's generators as the recorded sounds were tonal and consistent with that from generators used to supply the ship power. Some of the recordings contained low-frequency (< 100 Hz) engine noise with elevated sound levels at those times, but there was no evidence of blade, shaft, or rudder motion, confirming that the vessels were stationary with the engine running at idle.

No vessels were on anchor between 07 Sep and 10 Sep and no Project vessels approached the anchorages on those dates. The distribution of sound levels recorded on those days, when Project vessels were absent, was computed for comparison (Figure 22). As expected, the mean broadband SPL recorded when vessels were on anchor exceeded the mean broadband SPL recorded on the days when no vessels were present for 25 out of the 28 recorded vessels.

Figure 23 has spectrogram plots, showing the frequency distribution of sound levels for three example conditions: during a quieter time with vessels on anchor (when the *Golden Opportunity* was at ANCH 1 and the *Gisela Oldendorff* was at ANCH 3 on 17 Aug), during a noisier time with vessels on anchor (when the *Nordic Odyssey* was at ANCH 1 on 11 Sep with its engine running but idle), and during a time with no vessels nearby (on 08 Sep). Sounds from the vessels on anchor occurred mainly below 3 kHz which is within the hearing range of pinnipeds and low-frequency cetaceans such as bowheads, but is at the lower range of sensitivity for narwhal and below their range of best hearing (i.e. low frequency engine noise from the anchored vessels is below the frequency range that narwhal can hear). Section 3.5 presents Listening Range Reduction calculations for this recording, as a measure of the potential impact that the noise from the anchored vessels could have had on the ability of narwhal to communicate or use sound for life functions.

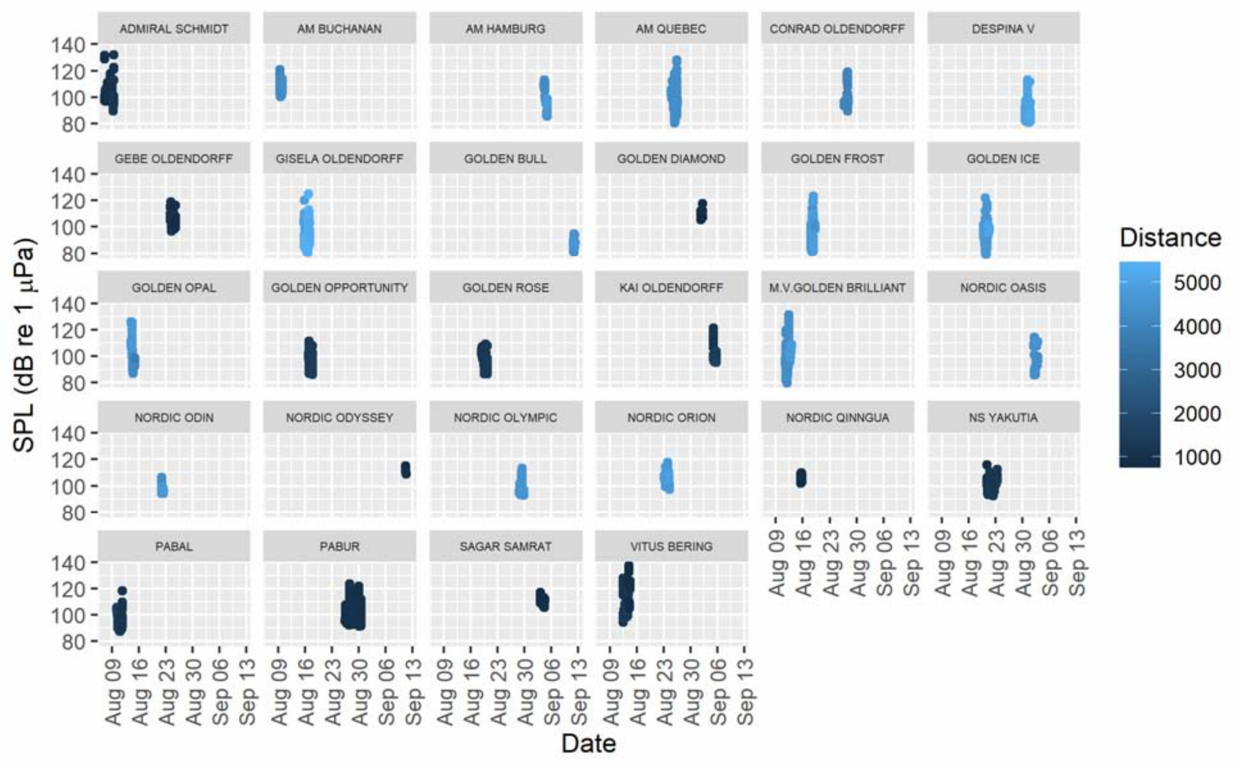

Figure 19 Ragged Island: Recorded sound levels (broadband, 1-second SPL) when AIS records indicated vessels were On Anchor. Colour shading indicates distance between the vessel and AMAR-RI: vessels at ANCH 1 are dark blue and those at ANCH 3 are light blue.

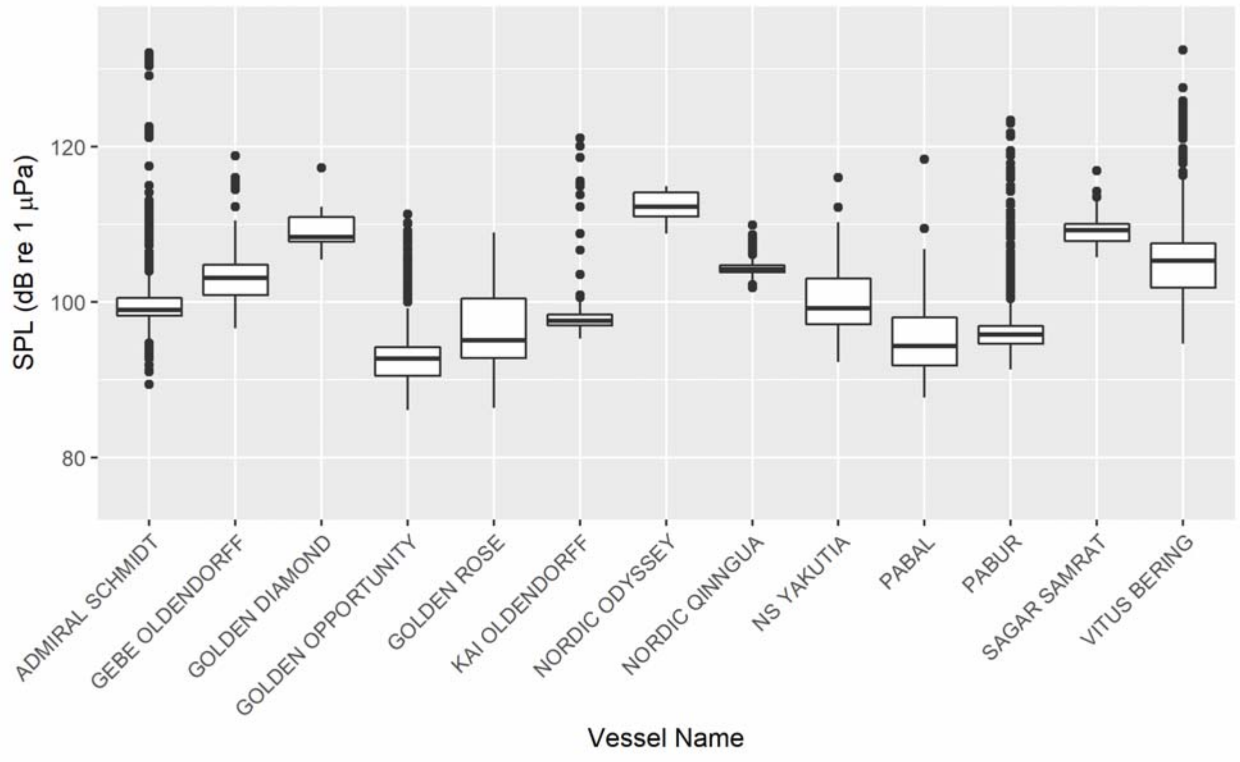

Figure 20 Anchorage 1: Distribution of recorded sound levels (broadband, 1-second SPL) when AIS records indicated vessels were On Anchor.

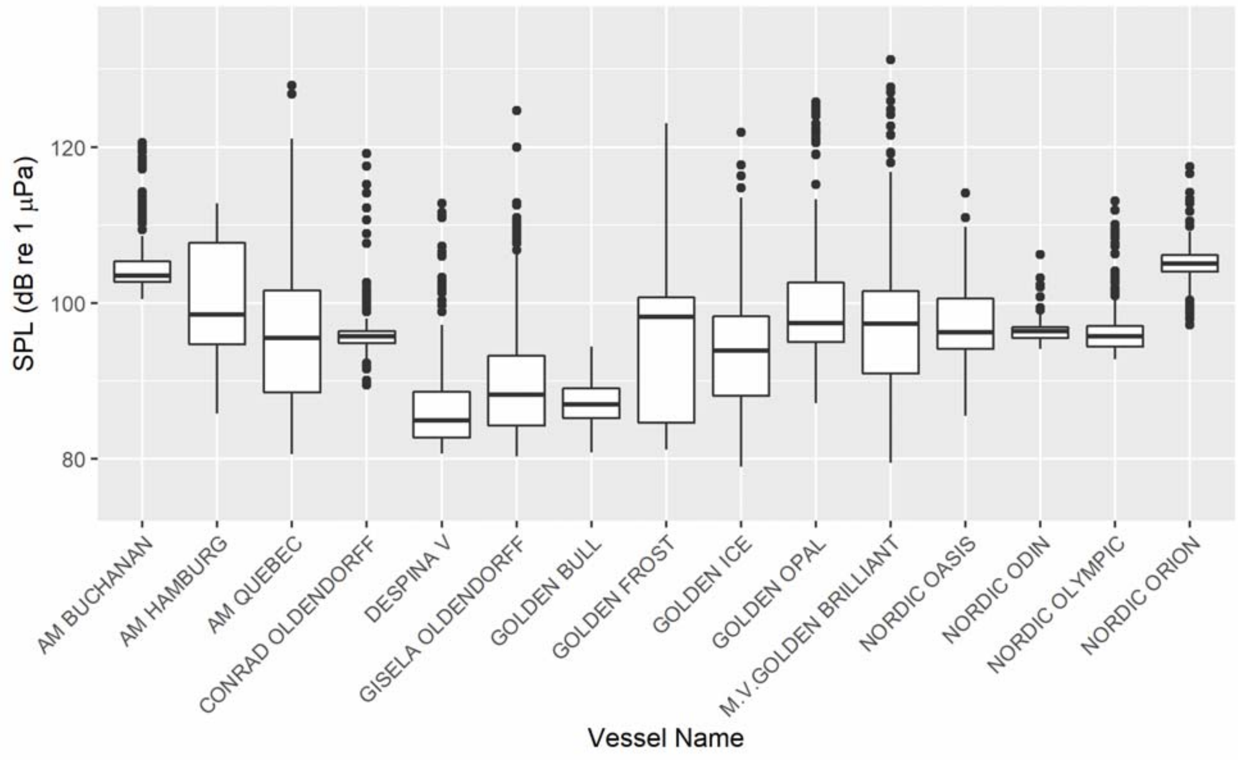

Figure 21 Anchorage 3: Distribution of recorded sound levels (broadband, 1-second SPL) when AIS records indicated vessels were On Anchor.

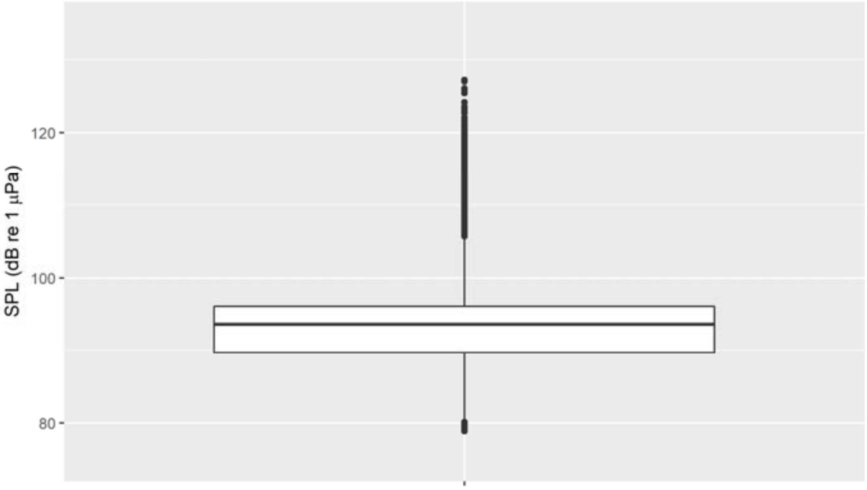

Figure 22 Distribution of recorded sound levels when AIS records indicated that no vessels were On Anchor at any of the Ragged Island anchorages.

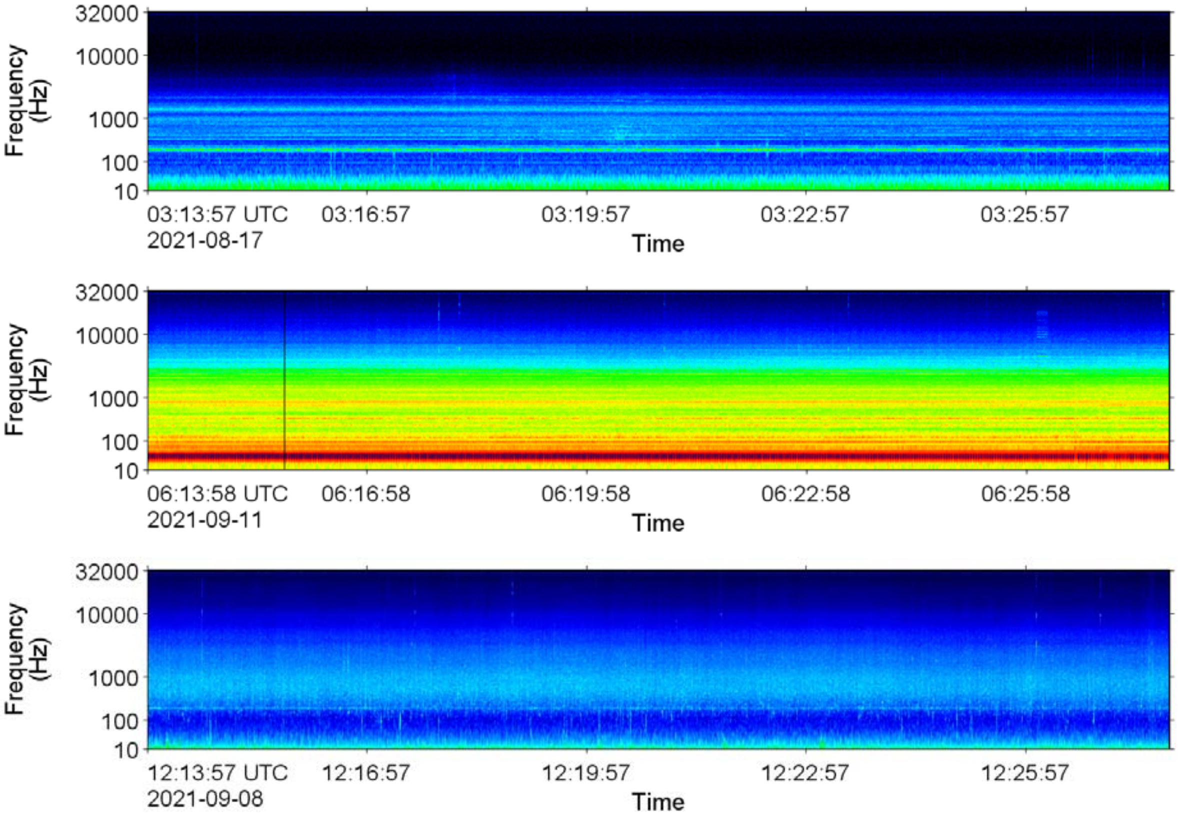

Figure 23 Example spectrograms of sounds recorded at Ragged Island during (top) a time with low sound levels while the *Golden Opportunity* was at Anchorage 1 and *Gisela Oldendorff* was at Anchorage 3 on 17 Aug, (middle) a time with elevated sound levels when the *Nordic Odyssey* was at Anchorage 1 on 11 Sep, and (bottom) a randomly selected time on 08 Sep when there were no vessels in the area. (2 Hz frequency resolution, 0.128 s time window, 0.032 s time step, Hamming window, 14 min of data).

3.5. Listening Range Reduction

Listening Range Reduction (LRR) was calculated (Table 6) for reductions in listening range of at least 50% and 90% (>50% and >90% LRR), for each recorder location and for all narwhal vocalization types (clicks, high-frequency buzzes, whistles, knocks, and burst pulse or low-frequency buzzes). Figure 24 presents LRR results for recordings at Pond Inlet, Ragged Island, and Bruce Head during the 2021 recording period, showing the amount of LRR at each location during times with and without vessel noise detections computed relative to the median ambient noise level. Figure 25 shows the % LRR at each location as a function of time. The time scale presented in Figure 25 gives the impression that high percentages of LRR occur frequently throughout the recordings, however examining the data over the course of a single day we see that high percentages of LRR occur for at most a few hours each day. As examples, plots of % LRR from Bruce Head are provided for a day with low ambient sound levels (11 Sep, Figure 26), a day with some periods of elevated ambient sound levels (28 Aug, Figure 27), and for a day when ambient levels were elevated due to high wind (24 Aug, Figure 29).

Table 6. Percent of total recording minutes associated with >50% and >90% listening range reduction (LRR) at each acoustic recorder location during the 2021 acoustic monitoring period.

Recorder		1 kHz (Burst Pulses)		5 kHz (Whistles and Knock Trains)		25 kHz (Clicks and High-Frequency Buzz)	
		>50 % LRR	>90 % LRR	>50 % LRR	>90 % LRR	>50 % LRR	>90 % LRR
Bruce Head	Ambient noise data	0.0	0.0	21.5	0.1	14.3	1.5
	Data with vessels detected	5.1	0.5	22.2	2.1	14.5	1.9
Pond Inlet	Ambient noise data	1.3	0.0	31.1	1.8	29.8	0.6
	Data with vessels detected	8.8	2.9	29.8	4.9	19.5	2.0
Ragged Island	Ambient noise data	0.4	0.0	31.2	2.3	31.2	0.6
	Data with vessels detected	4.7	0.5	33.9	5.8	29.5	1.4

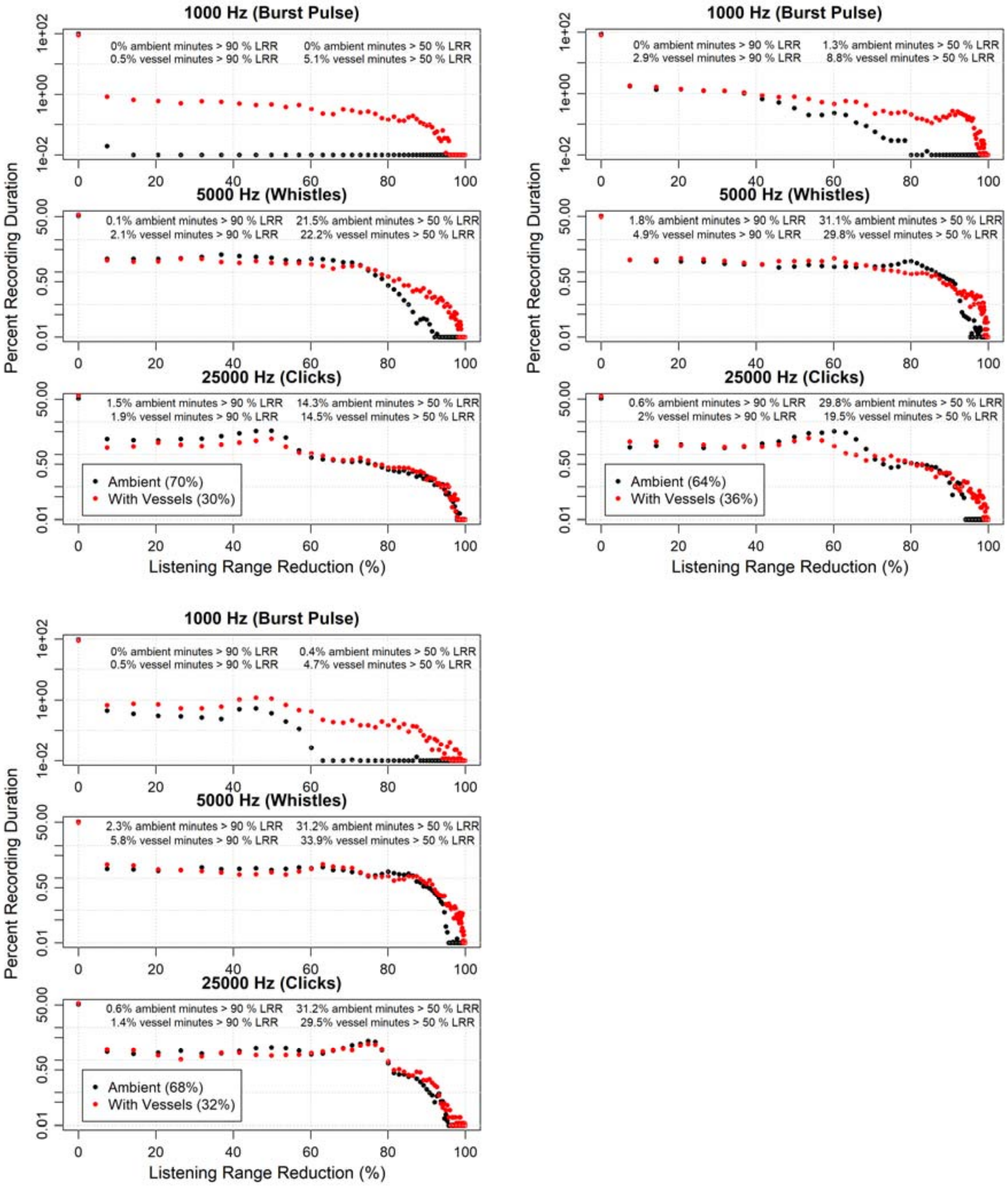

Figure 24 Listening range reduction (LRR) for the three considered frequencies at (left, top) Bruce Head, (right, top) Pond Inlet, and (left, bottom) Ragged Island. For each station, the top figure shows LRR for the 1 kHz decidecade band, which is representative of burst pulses, the middle figure shows LRR for the 5 kHz decidecade band, which is representative of listening for whistles and knocks, and the bottom figure shows LRR for 25 kHz which is representative of clicks and high-frequency buzzes. The black dots show the distribution of LRR for ambient noise data only (no vessels), while the red dots show the distribution of LRR for recordings with vessels detected (vessels + ambient noise). The y-axis is logarithmic to better illustrate the rare high LRR events.

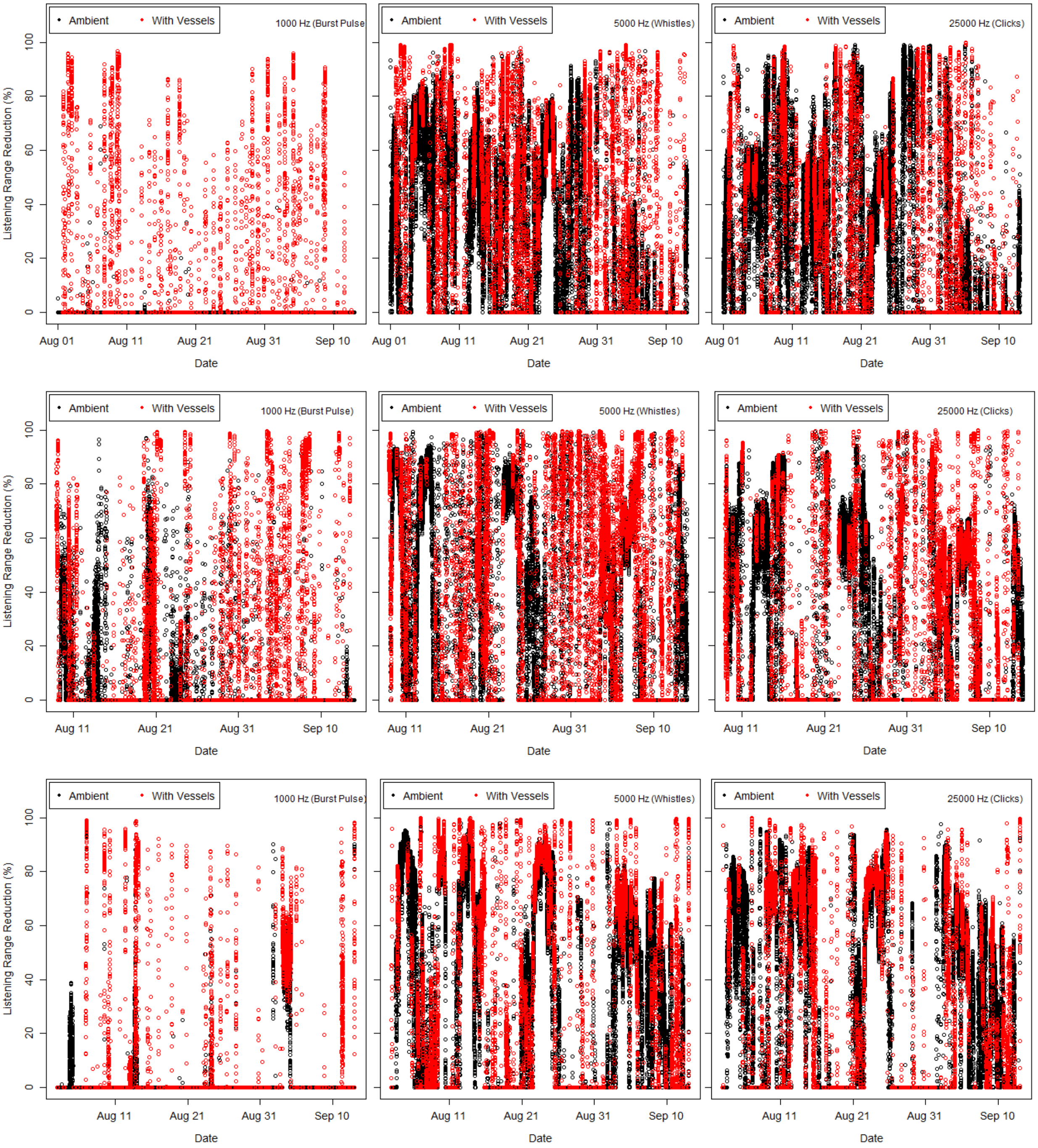

Figure 25 Listening Range Reduction over time for the three considered frequencies at (top row) Bruce Head, (middle row) Pond Inlet, and (bottom row) Ragged Island. For each station, the left figure shows LRR for the 1 kHz decidecade band, which is representative of burst pulses, the middle figure shows LRR for the 5 kHz decidecade band, which is representative of listening for whistles and knocks, and the right figure shows LRR for 25 kHz which is representative of clicks and high-frequency buzzes. The black dots show the distribution of LRR for ambient noise data only (no vessels), while the red dots show the distribution of LRR for recordings with vessels detected (vessels + ambient noise).

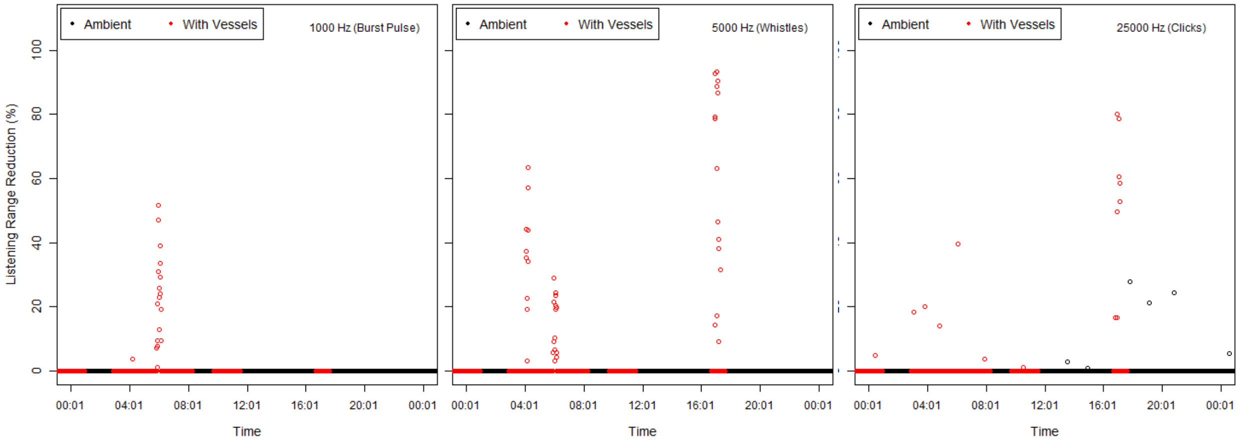

Figure 26 11 Sep: Listening Range Reduction over time for a day with low ambient noise levels at Bruce Head. The left figure shows LRR for the 1 kHz decidecade band, which is representative of burst pulses, the middle figure shows LRR for the 5 kHz decidecade band, which is representative of listening for whistles and knocks, and the right figure shows LRR for 25 kHz which is representative of clicks and high-frequency buzzes. The black dots show the distribution of LRR for ambient noise data only (no vessels), while the red dots show the distribution of LRR for recordings with vessels detected (vessels + ambient noise).

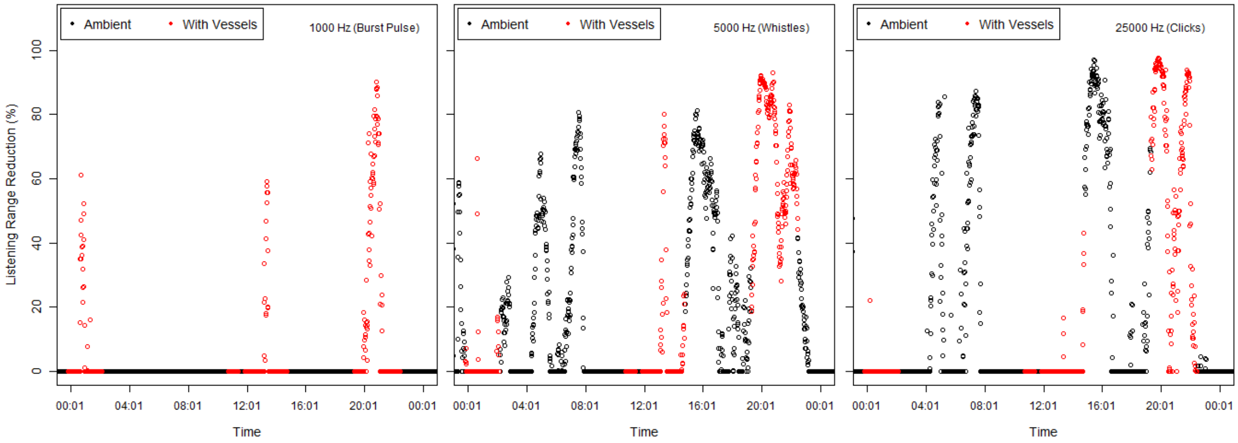

Figure 27 28 Aug: Listening Range Reduction over time for a day with some periods with elevated ambient noise levels at Bruce Head. The left figure shows LRR for the 1 kHz decidecade band, which is representative of burst pulses, the middle figure shows LRR for the 5 kHz decidecade band, which is representative of listening for whistles and knocks, and the right figure shows LRR for 25 kHz which is representative of clicks and high-frequency buzzes. The black dots show the distribution of LRR for ambient noise data only (no vessels), while the red dots show the distribution of LRR for recordings with vessels detected (vessels + ambient noise).

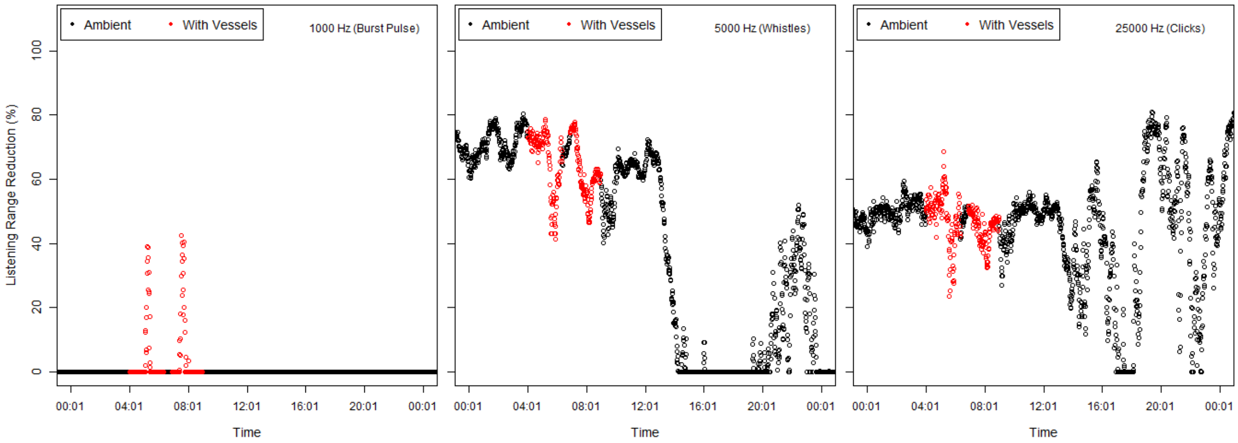

Figure 28 24 Aug: Listening Range Reduction over time for a day with elevated ambient noise levels at Bruce Head. The left figure shows LRR for the 1 kHz decidecade band, which is representative of burst pulses, the middle figure shows LRR for the 5 kHz decidecade band, which is representative of listening for whistles and knocks, and the right figure shows LRR for 25 kHz which is representative of clicks and high-frequency buzzes. The black dots show the distribution of LRR for ambient noise data only (no vessels), while the red dots show the distribution of LRR for recordings with vessels detected (vessels + ambient noise).

3.6. Marine Mammal Detections

The acoustic presence of marine mammals was identified automatically by JASCO's detectors and validated via the manual review of 3% of the data (see Section 2.3), which represents 712 sound files, or ~89 h of data (83.1 h worth of 1-min 512 kHz sound files and 5.9 h worth of 14-min 64 kHz sound files). Both the detectors and analysts found acoustic signals of beluga, bowhead, and narwhal. In addition to these species, signals potentially produced by bearded seals and ringed seals were detected. For each confirmed species, exemplar vocalizations and occurrence through the recording period are provided below along with the Precision and Recall values of automated detectors. Detailed automated detector results can be found in Appendix F.

3.6.1. Beluga Whales

Odontocete clicks were only manually confirmed at Bruce Head in 2021; therefore, the method described in Section 2.3.4 to differentiate between narwhal and beluga during manual analysis was applied to these data. In all acoustic files where beluga were detected, narwhal were also suspected of being present. Clicks suspected of being produced by beluga resided at higher frequencies than those of narwhal (Figure 29). In a few instances, the occurrence of many whistles further suggests that beluga resided amongst the narwhal on occasion (Figure 29).

Beluga detections occurred infrequently throughout the recording period in summer 2021 at Bruce Head (Figure 30). Three predominant periods of detection were evident: 6–10 Aug, 17–21 Aug, and 27–31 Aug 2021 (Figure 30).

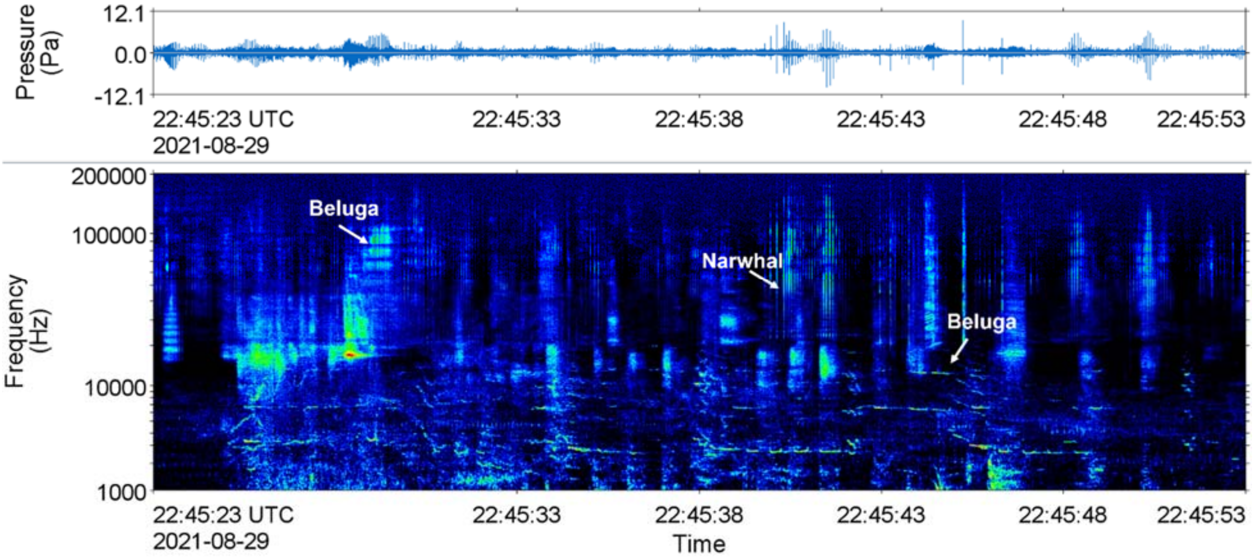

Figure 29. (Top) Waveform and (bottom) spectrogram of clicks and whistles believed to be produced by narwhal and beluga, as labelled. Data were recorded on 29 Aug 2021 at Bruce Head (4 Hz frequency resolution, 0.05 s time window, 0.01 s time step, Hamming window, normalized across time, 30 s of data).

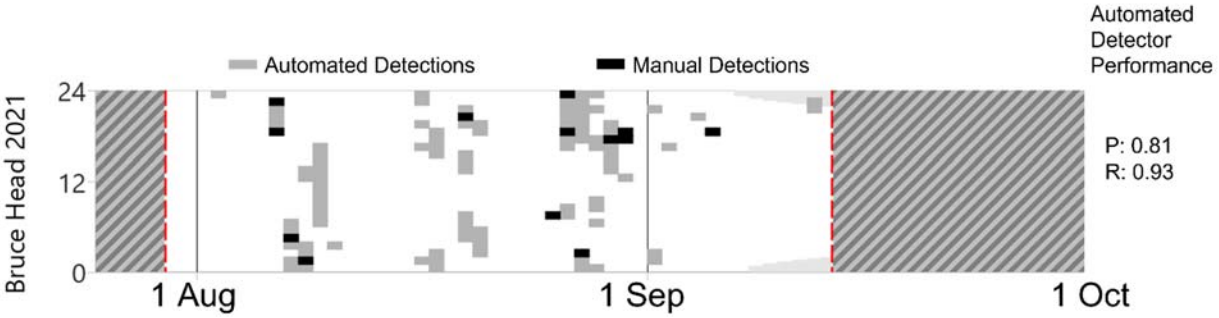

Figure 30. Hours per day with beluga click detections. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. The grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the UDB click detector.

3.6.2. Bowhead Whales

Bowhead whale moans (Figure 31) were rarely detected during manual analysis. Only two days were confirmed with bowhead whale vocalizations at Bruce Head and two days at Ragged Island (Figure 32). These few manual detections were insufficient to determine automated detector performance, but considering the hundreds of files manually reviewed, we are confident that this species was indeed vocally rare in the data.

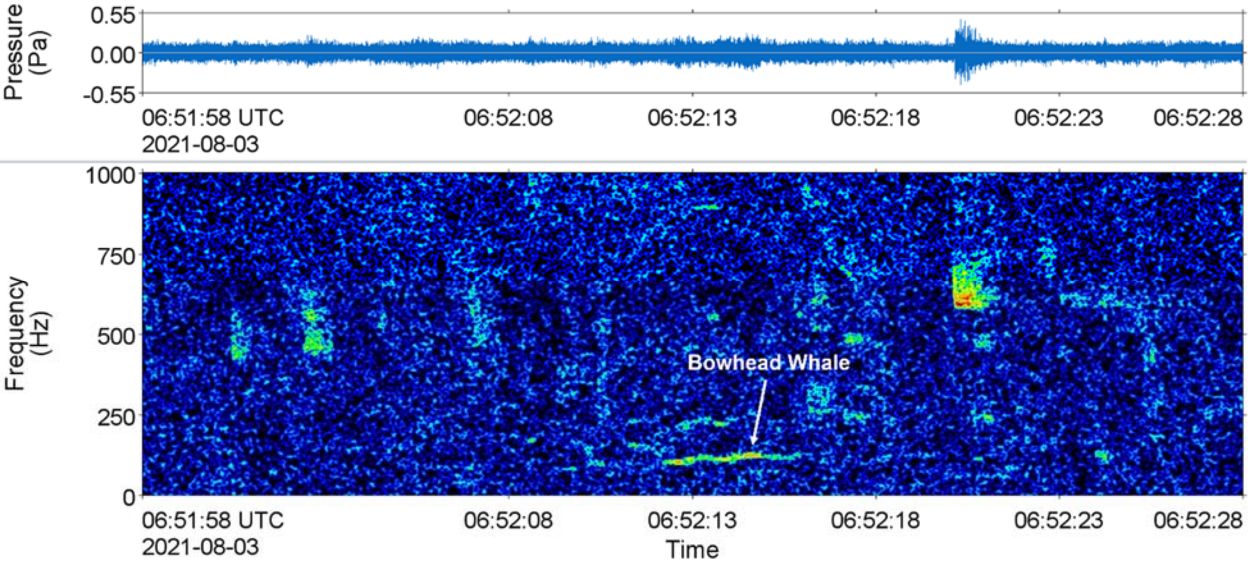

Figure 31. (Top) Waveform and (bottom) spectrogram of a bowhead whale moan recorded on 3 Aug 2021 at Bruce Head (2 Hz frequency resolution, 0.2 s time window, 0.02 s time step, Hanning window, normalized across time, 30 s of data).

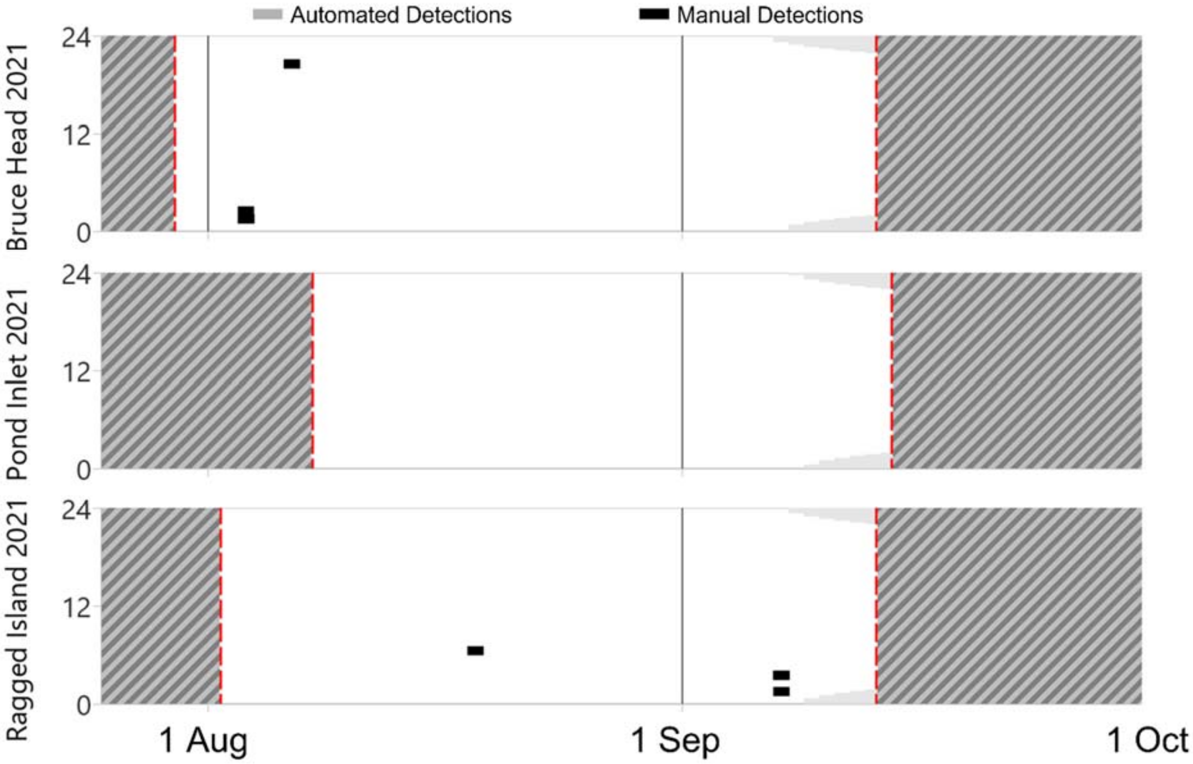

Figure 32. Hours per day with bowhead whale moan detections at each station through the recording period. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included along right side. The grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data.

3.6.3. Narwhal

Narwhal vocalizations identified during manual analysis included clicks (and click trains), high-frequency buzzes, low-frequency buzzes, knock trains, and whistles (Figure 33). Narwhal detections were common at Bruce Head, less frequent at Ragged Island, and absent from Pond Inlet (Figures 34–39). This is consistent with Baffinland's aerial survey distribution data. As with beluga whale clicks at Bruce Head (Figure 30), narwhal vocalizations were most commonly detected during three periods: 6–10 Aug, 17–21 Aug, and 27 Aug to 5 Sep 2021 (Figures 34–39). High-frequency vocalizations (clicks, click trains, high-frequency buzzes), likely associated with foraging, were only confirmed at Bruce Head (Figures 34–39). These detections correspond with expected seasonal distribution and habitat use in the RSA for this species (QIA 2018).

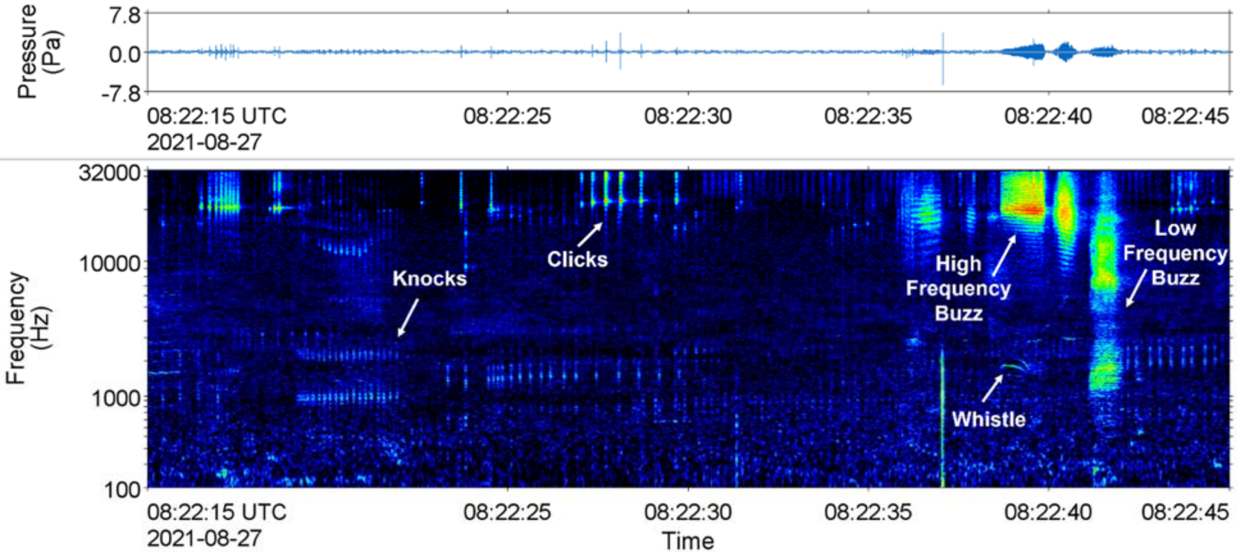

Figure 33. (Top) Waveform and (bottom) spectrogram of narwhal vocalizations recorded on 27 Aug 2021 at Bruce Head (2 Hz frequency resolution, 0.125 s time window, 0.03125 s time step, Hamming window, normalized across time, 30 s of data).

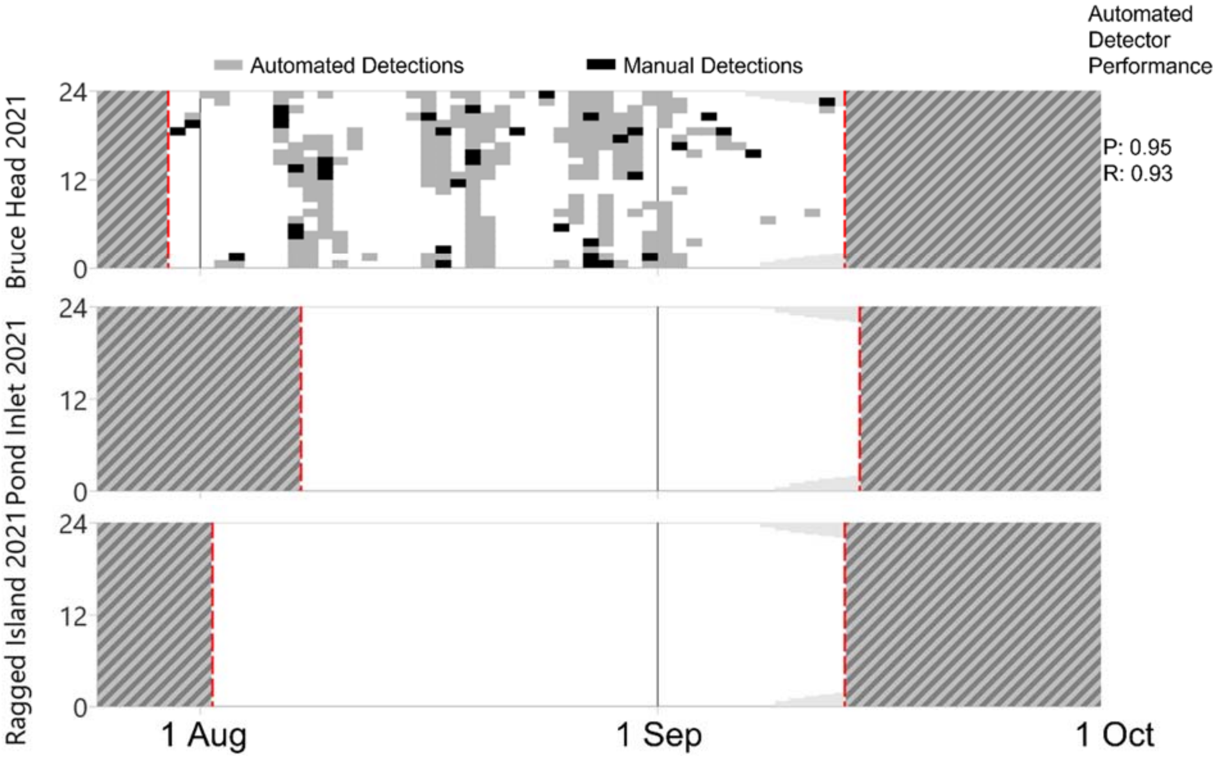

Figure 34. Hours per day with narwhal high-frequency buzz detections at each station through the recording period. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. The grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the Narwhal HFbuzz detector.

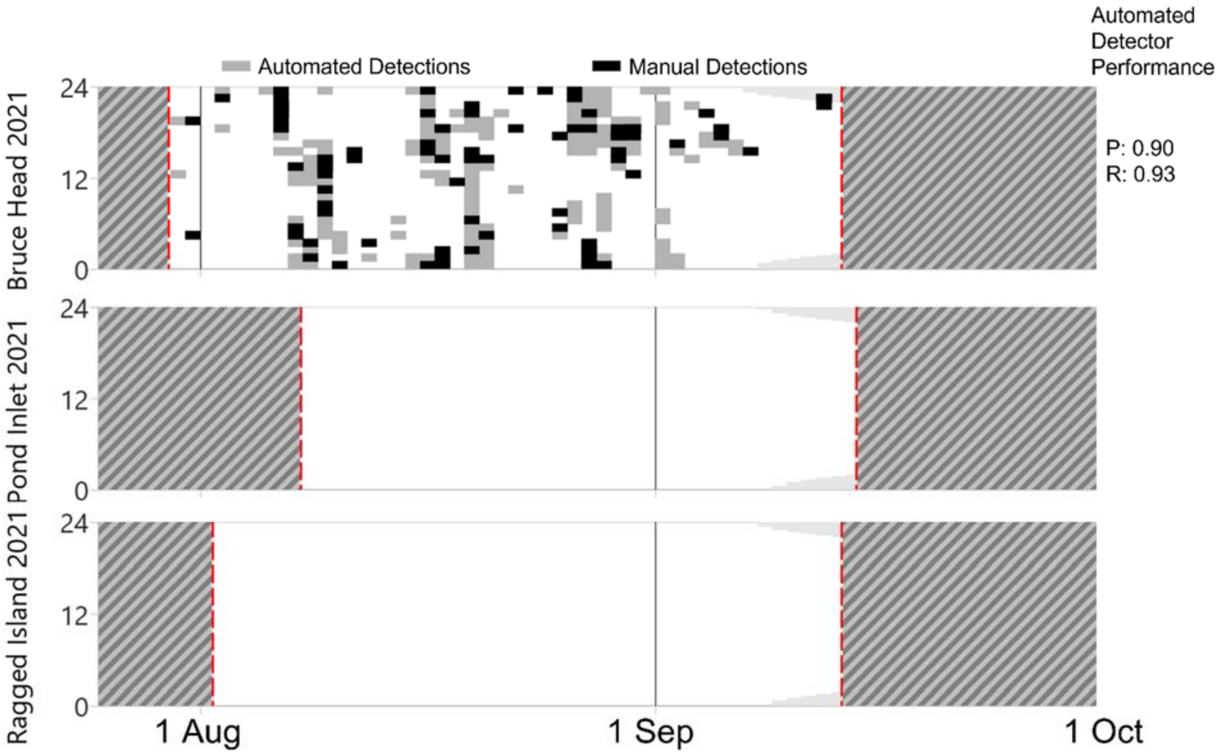

Figure 35. Hours per day with narwhal click detections at each station through the recording period. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. The grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the narwhal click detector.

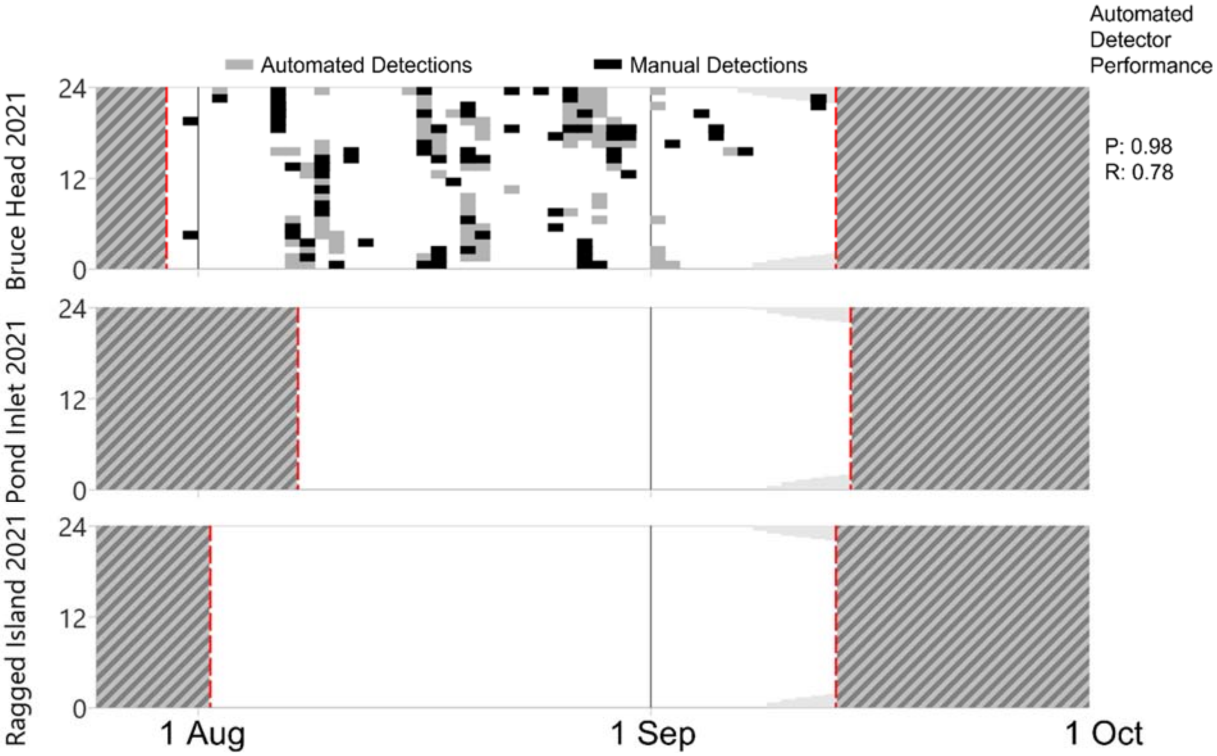

Figure 36. Hours per day with narwhal click train detections at each station through the recording period. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. The grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the narwhal click train detector.

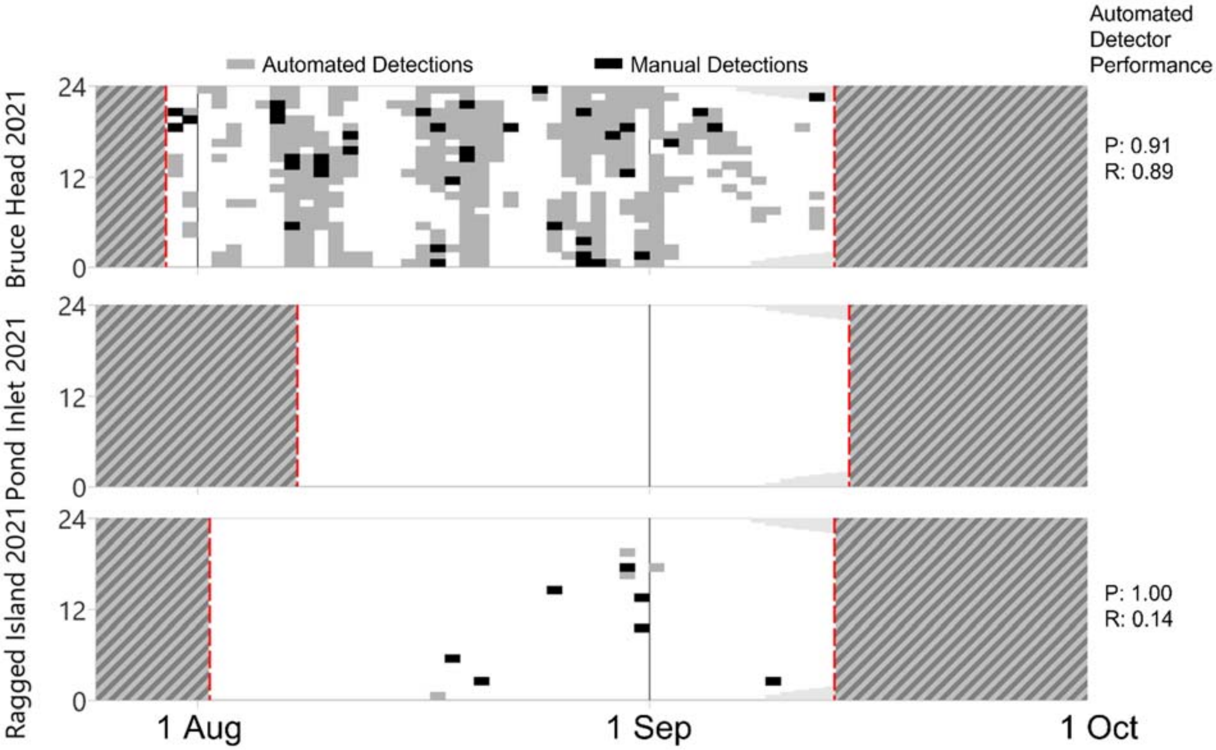

Figure 37. Hours per day with narwhal low-frequency buzz detections at each station through the recording period. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. The grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the Narwhal_LFbuzz detector.

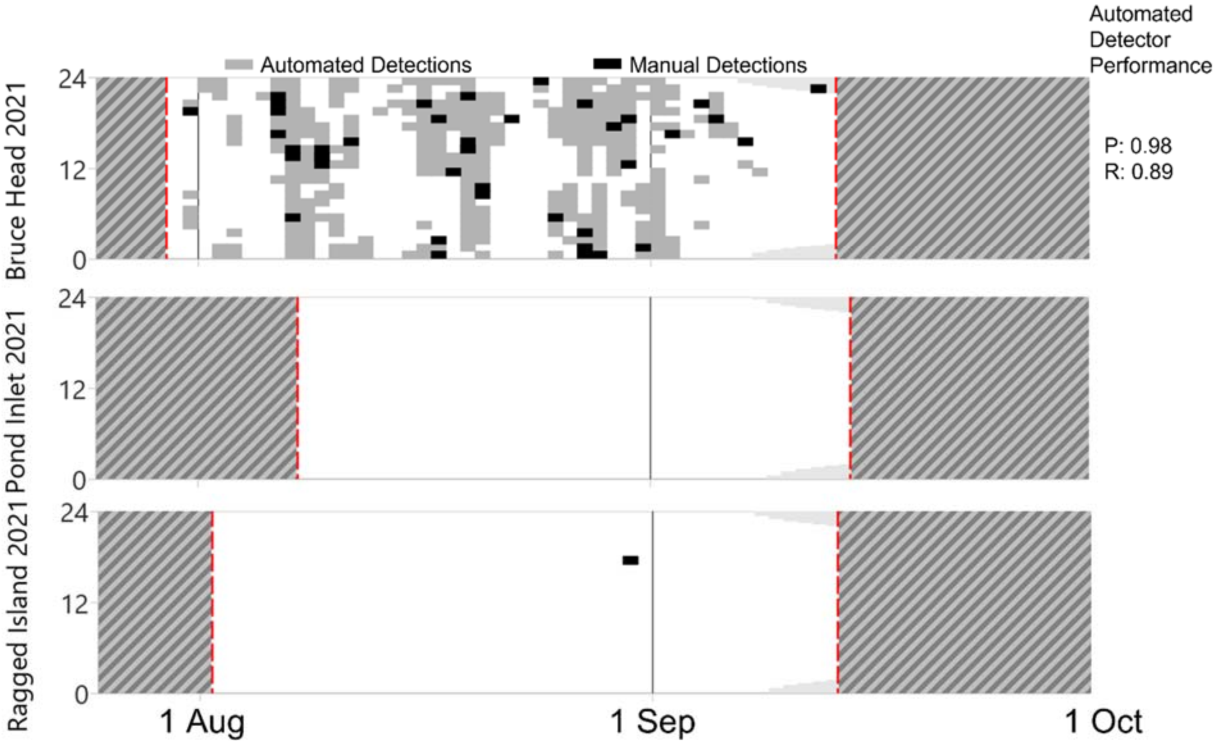

Figure 38. Hours per day with narwhal whistle detections at each station through the recording period. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. The grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the Narwhal_Whistle detector.

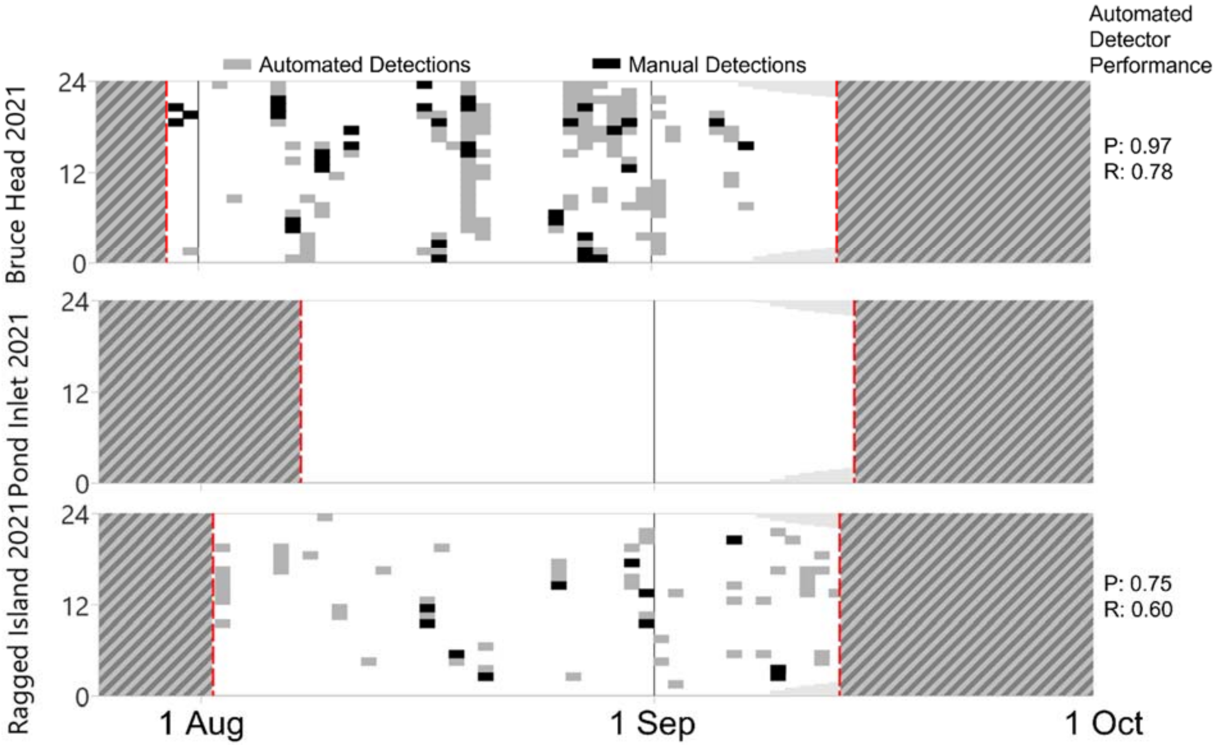

Figure 39. Hours per day with narwhal knock train detections at each station through the recording period. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. The grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the NarwhalKnockTrain detector.

3.6.4. Pinnipeds

While pinniped vocalizations were never unequivocally confirmed in the acoustic data, analysts occasionally identified acoustic signals similar to those produced by bearded seals (Figure 40) and ringed seals (Figure 41). In these instances, analysts could never rule out that the sounds were produced by narwhal and/or bowhead whales, both of whose wide vocal repertoires span many frequencies and durations, overlapping with the properties of pinniped signals.

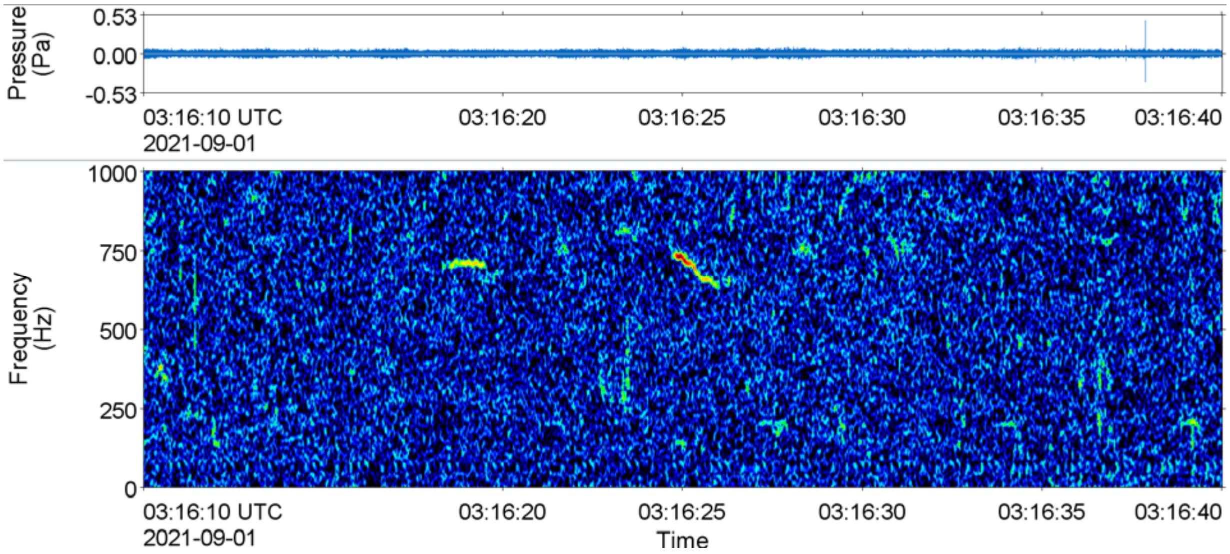

Figure 40. (Top) Waveform and (bottom) spectrogram of a potential bearded seal trill recorded on 1 Sep 2021 at Ragged Island (2 Hz frequency resolution, 0.128 s time window, 0.032 s time step, Hamming window, normalized across time, 30 s of data).

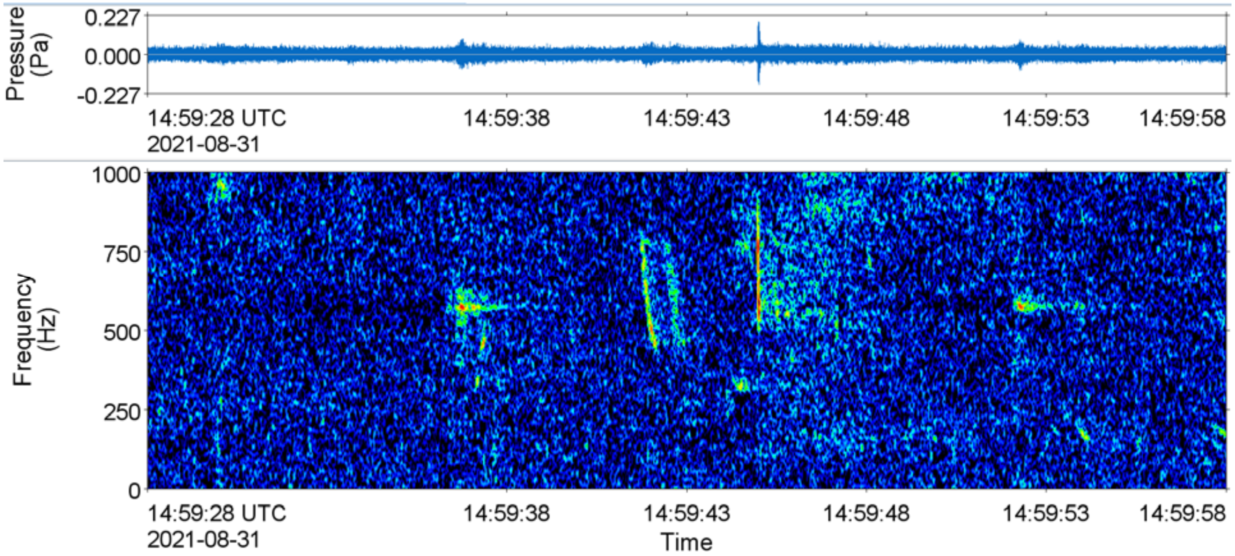

Figure 41. (Top) Waveform and (bottom) spectrogram of a potential ringed seal vocalization recorded on 31 Aug 2021 at Ragged Island (2 Hz frequency resolution, 0.128 s time window, 0.032 s time step, Hamming window, normalized across time, 30 s of data).

4. Discussion and Conclusion

4.1. Listening Range Reduction

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

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

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

4.2. Vessel Contribution to Soundscape

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

Measured underwater sound levels from the recording stations were analyzed to determine the amount of time that broadband sound levels exceeded the disturbance onset threshold of 120 dB re 1 µPa (Table 7, Figure 42). As shown in Section 3.1, the broadband SPL exceeded 120 dB re 1 µPa for 2.5% of the 46-day recording duration at Bruce Head, 1.7% of the 39-day recording duration at Pond Inlet, and 0.6% of the 43-day recording duration at Ragged Island. On average, received sound levels at the AMAR locations exceeded the disturbance threshold of 120 dB re 1 µPa for less than one hour per day (averaged over acoustic recording days). Table 7 also shows the maximum number of hours in a day during which the SPL exceeded the 120 dB re 1 µPa threshold; 2.6 hours per day at Bruce Head, 5.3 hours at Pond Inlet, and less than 1.2 hours at Ragged Island.

Table 7. Average and maximum daily exposure durations for disturbance (120 dB re 1 µPa) for each recorder during the 2021 acoustic monitoring period.

Recorder		Time per shipping season day with SPL > 120 dB (hours [minutes])	
		Average	Maximum
Bruce Head	All recorded data	0.4 [23.3]	2.6 [155.0]
	Only data with vessels detected	0.3 [21.0]	2.6 [155.0]
Pond Inlet	All recorded data	0.2 [15.0]	5.3 [316.0]
	Only data with vessels detected	0.2 [14.9]	5.3 [316.0]
Ragged Island	All recorded data	0.1 [5.3]	1.2 [70.0]
	Only data with vessels detected	0.0 [2.9]	0.8 [46.0]

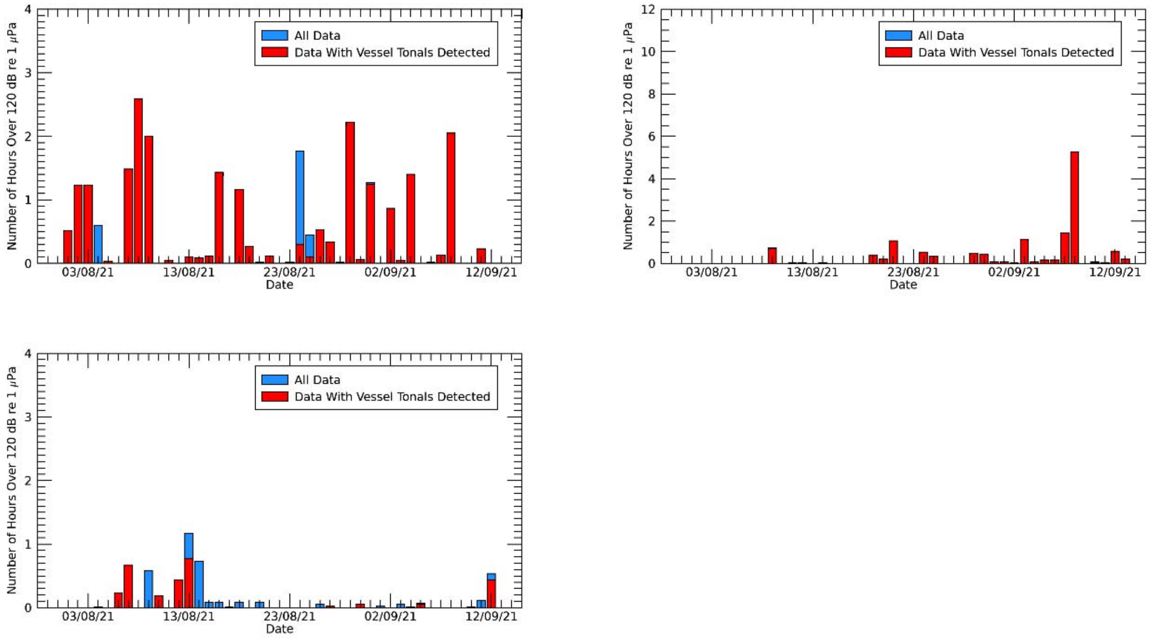

Figure 42. Hours per day with recorded sound pressure level (SPL) exceeding 120 dB re 1 µPa at (top left) Bruce Head, (top right) Pond Inlet, and (bottom left) Ragged Island.

4.3. Ambient Sound Levels at Bruce Head 2018–2021

The Bruce Head station was generally consistent in mean ambient sound levels across all years of study by JASCO (2018–2021, Figure 43). All years experienced peaks in the mean percentile in the 100–300 Hz range, attributed to vessel traffic from the shipping lane. Levels were louder by 2–5 dB re 1µPa^2/Hz over most frequencies in 2019 compared to other years. But overall, sound levels were very similar between years and remained within the Wenz limits except for a few shipping tonal bands. Despite increased ore carrier transits since 2018, there was not a corresponding increase of the mean ambient sound levels at most frequencies.

One notable difference between the curves is the peak from the 2020 recording period slightly above 10 kHz. This was caused by one minute of communications with the transponder on the recorder on the day prior to retrieval of the recorder in 2020 and is not a result of Project shipping. This spike does not affect the mean broadband SPL value.

Underwater acoustic recordings were also collected by Baffinland in 2014 (Kim and Conrad 2015) at a location (72.0660° N, 80.5121° W) approximately 245 m southeast of the Bruce Head recorder location, with water depth 291 m, and in 2015 at a location (72.0645° N, 80.4877° W) approximately 1 km southeast of the Bruce Head recorder location, with water depth 300 m (Kim and Conrad 2016). Those data were recorded on an ASAR Model C (Greeneridge Sciences, Inc.) with an HTI-92-WB hydrophone, at a sample rate of 48 kHz. System gains for that data analysis were obtained from manufacturer specifications. These data are included in Figure 43 and Table 8 for comparison with the data collected from 2018 – 2021. Mean sound levels between 100 Hz and 300 Hz were approximately 2-3 dB lower in 2014 and 2015 compared to later years, which is thought to be a result of increased vessel traffic in later years. The median sound levels, however, are consistent over years (Figure 43, right). As seen in Figures 9 through 11, the mean sound levels track the 95th percentile of the data, indicating that the median levels are the result of infrequent events with elevated sound levels, that do not dominantly affect the overall soundscape. Several large spikes in this frequency range are present in 2018 through 2021 (notably at 200 Hz), that are consistent with tonal noise from the icebreaker MSV Botnica, which did not visit Milne Port in 2014 and 2015. These spikes are not evident in the median spectral density curves indicating that the spikes are attributable to a few, short duration events, but are not a chronic component of the soundscape. Conversely, in 2014 and 2015 mean sound levels between approximately 2 and 6 kHz exceeded by several dB the mean levels from later years, with the exception of 2019. Elevated levels at this frequency range are thought to be caused by periods of elevated narwhal social calling based on the 2019 narwhal detection results. Similarly, in 2018 and 2019 elevated levels of the mean are noted at 20 kHz, which may be caused by increased narwhal vocal presence in those years. Mean sound levels were comparable over years at other frequencies and the median levels were comparable at all frequencies (discrepancies below 20 Hz are due to the use of different hydrophones in 2014-2015 compared to later years).

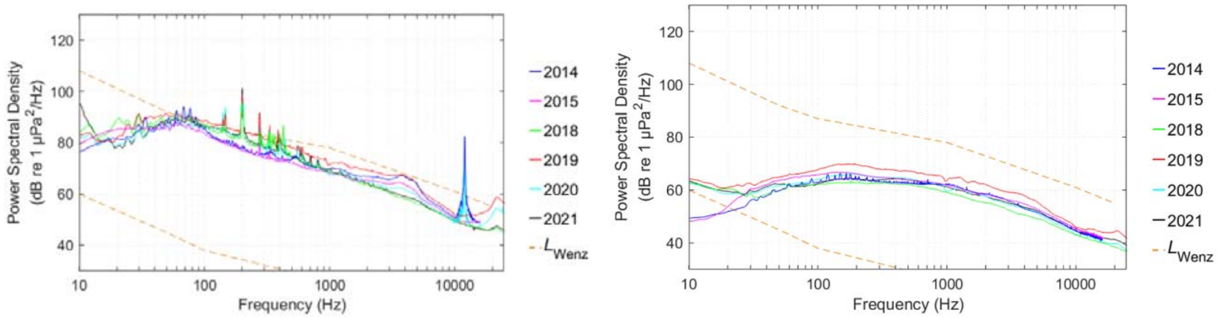

Figure 43. Multi-year comparison of power spectral density (PSD) levels at Bruce Head. Data from 2014 and 2015 were recorded with an ASAR Model C (Greeneridge Sciences) with an HTI-92-WB hydrophone, analyzed using manufacturer calibrations, with bandwidth 10 Hz to 23.5 kHz. Data from 2018 – 2021 were recorded with an AMAR-G4 (JASCO Applied Sciences) with a GeoSpectrum M36-V35-100 hydrophone, end-to-end system calibration performed at deployment, with a bandwidth of 10 Hz to 32 kHz. (left) mean, (right) median.

Table 8 Broadband sound pressure level (dB re 1 µPa) recorded at Bruce Head, 2014-2021.

	2014[1]	2015[1]	2018[2]	2019[2]	2020[2]	2021[2]
Mean	109.6	107.2	111.6	113.8	111.8	112.4
Median	96.1	96.6	95.8	102.1	98.0	98.2

[1] ASAR Model C (Greeneridge Sciences) with HTI-92-WB hydrophone, bandwidth 10 Hz to 23.5 kHz, manufacturer calibrated.
[2] AMAR-G4 (JASCO Applied Sciences) with GeoSpectrum M36-V35-100 hydrophone, bandwidth 10 Hz to 32 kHz, end-to-end calibration performed at deployment.

4.4. Marine Mammal Presence

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

In addition to the 2021 monitoring program, the discussion provides a summary of marine mammal acoustic occurrence since 2018 at Bruce Head, an area that has been acoustically monitored near-consistently over four consecutive summers (see previous JASCO reports and Appendix E). Automated detector performance for this multi-year summary is included in Appendix F. When considering these multi-year results, it must be considered that the amount of manual analysis performed, the automated detectors used, and the automated detector performance sometimes varied across monitoring years (Appendices E and F). Regardless, methods have been sufficiently consistent to allow the general trends in multi-year occurrence to be compared and considered reliable.

The discussion emphasizes those species confirmed to be acoustically present in the 2021 data (bowhead whales, narwhal, and beluga), but there is also discussion of species that were present at Bruce Head in previous recording years (killer whale) and species for which there is some evidence suggesting that they were present (bearded and ringed seals).

4.4.1. Beluga Whales

Beluga whales are generally associated with Subarctic and Arctic waters. They often occur in inshore and shallow waters (Richard et al. 2001). Beluga whales are known to occur in the monitoring area, though not as regularly as narwhal. Beluga whales generally vocalize abundantly, with whistles representing a large portion of their vocal repertoire (Garland et al. 2015). In contrast, while the narwhal repertoire includes whistles, they are less common than their other sounds such as buzzes and knock trains (Ford and Fisher 1978). In previous monitoring years, if recordings did not have many whistles typical of beluga whales and lacked signals typical of narwhal, we were unable to confidently detect beluga. This often resulted in few instances where beluga presence could be confidently confirmed, in an acoustically narwhal-dominant data set. Given new information provided by Zahn et al. (2021), attempts to distinguish beluga clicks amongst those of narwhal in the 2021 data set (see Section 2.3.4) were pursued. A similar analysis would be valuable in historic Bruce Head data to observe any multi-year trends. These new analysis techniques indicate that beluga are occasionally present in the region amongst or near the narwhal.

4.4.2. Bowhead Whales

The acoustic occurrence of bowhead whales in the data is unsurprising given that the range of the Eastern Canada-West Greenland (ECWG) bowhead whale population (COSEWIC 2009) overlaps with the present monitoring area (Heide-Jørgensen et al. 2008, Wiig et al. 2010). Although bowhead whales do not leave Arctic waters, they do follow annual migration patterns. The ECWG population aggregates in several areas in winter: in Hudson Strait, in the Davis Strait-southern Baffin Bay, and in and near Disko Bay. Whales tagged in Cumberland Sound in spring were found to circumnavigate Baffin Island. Both Inuit observations and tag data indicates that from May to July bowhead whales move northward from the Cumberland Sound to Pond Inlet (COSEWIC 2009). The animals then summer in northern Baffin Island and the northeast coast which includes the present study area from May to August (COSEWIC 2009).

The rare acoustic occurrence of bowhead whales at the Bruce Head and Ragged Island 2021 recorders through August and September 2021 likely reflects that most animals had already vacated the area and continued their migration by this time. This conclusion is strengthened by the fact that bowhead whales are vocally active year-round (Clark et al. 2015). This trend in rare acoustic occurrence of bowhead whales at Bruce Head in the late summer was similarly found in previous recording years (Figure 44).

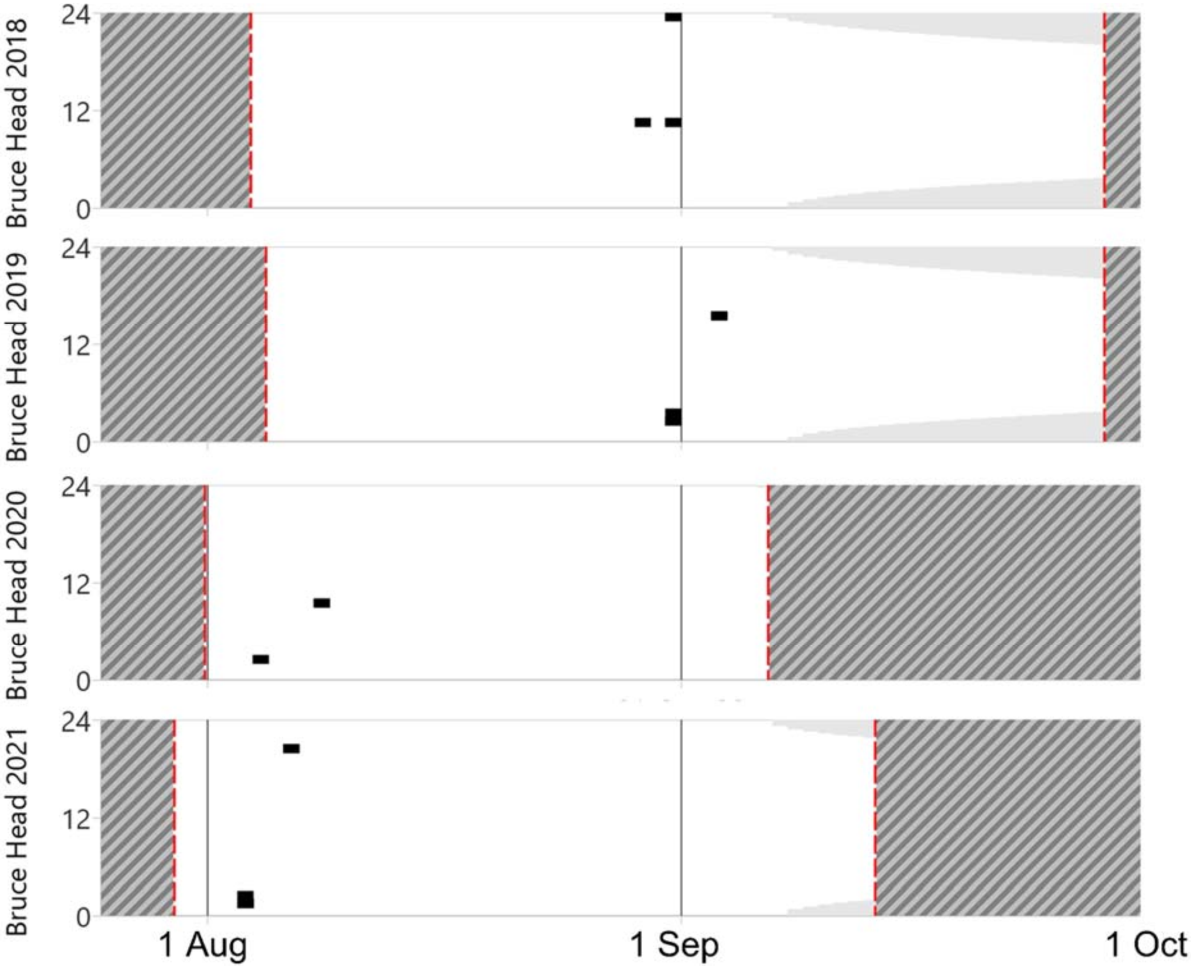

Figure 44. Hours per day with bowhead whale manual (black) and automated (grey) detections. The grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the UDB click detector.

4.4.3. Narwhal

The acoustic occurrence of narwhal in the data was expected, as this Arctic species is hunted in the monitoring region and is known to spend the summer aggregated in bays and fjords around Baffin Island, Hudson Bay, Lancaster Sound, and the northeast coast of Greenland. In winter, they aggregate in dense pack ice in the middle of Baffin Bay and Davis Strait as well as in Disko Bay and near the entrance of the Hudson Strait, with relatively short migratory movements between summer and winter grounds (COSEWIC 2004b). Uncorrected estimates put the population between 45,000–50,000 in the Canadian Arctic (COSEWIC 2004b).

In 2021, narwhal acoustic detections were more common further south in the Inlet in August and September, with a complete absence of detections at Pond Inlet. Hunters have observed that since the 1960s, narwhal have become less common near Pond Inlet, instead preferentially travelling down the middle of the inlet, potentially to avoid hunters, motorboats, and snowmobiles near the community (COSEWIC 2004b).

During summer at Bruce Head, acoustic detections suggest some variation in narwhal acoustic occurrence from 2018–2021 (Figures 45 to 50). There were fewer hours with acoustic occurrence in 2018 compared to 2019, with most detections between mid-August and mid-September 2018. In contrast, in 2019, hours with narwhal acoustic occurrence were spread throughout the entire recording period with few recording days lacking acoustic detections. Subsequent recording years saw a reduction in narwhal acoustic detections compared to 2019. This apparent peak in narwhal in 2019 was similarly observed during visual monitoring, suggesting that acoustic programs can be used to observe relative trends in animal density. In both 2020 and 2021, narwhal acoustic occurrence at Bruce Head occurred in three waves through the summer. Future work should explore what, if any, environmental variables, or prey movements may be associated with these trends.

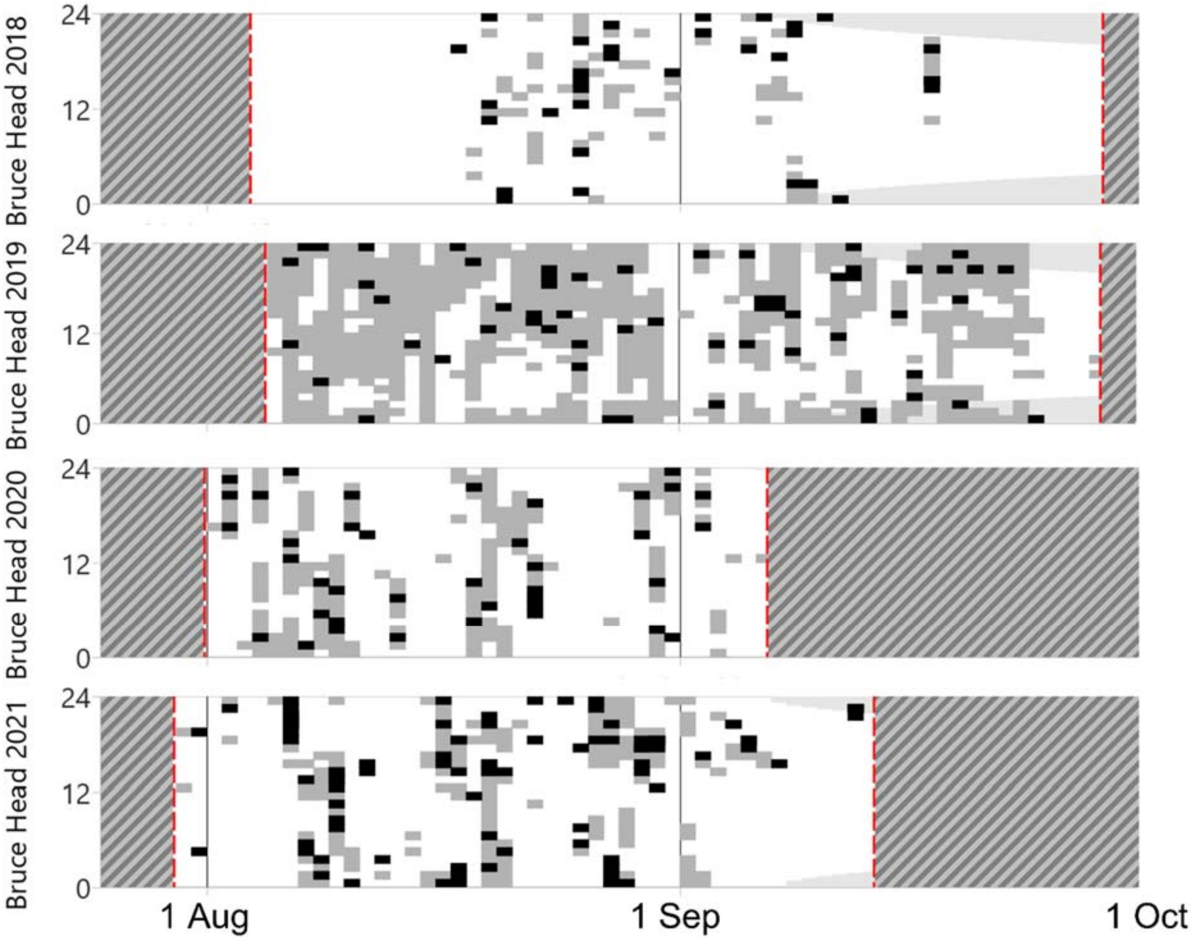

Figure 45. Hours per day with narwhal click manual (black) and automated (grey) detections. The grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the UDB click detector.

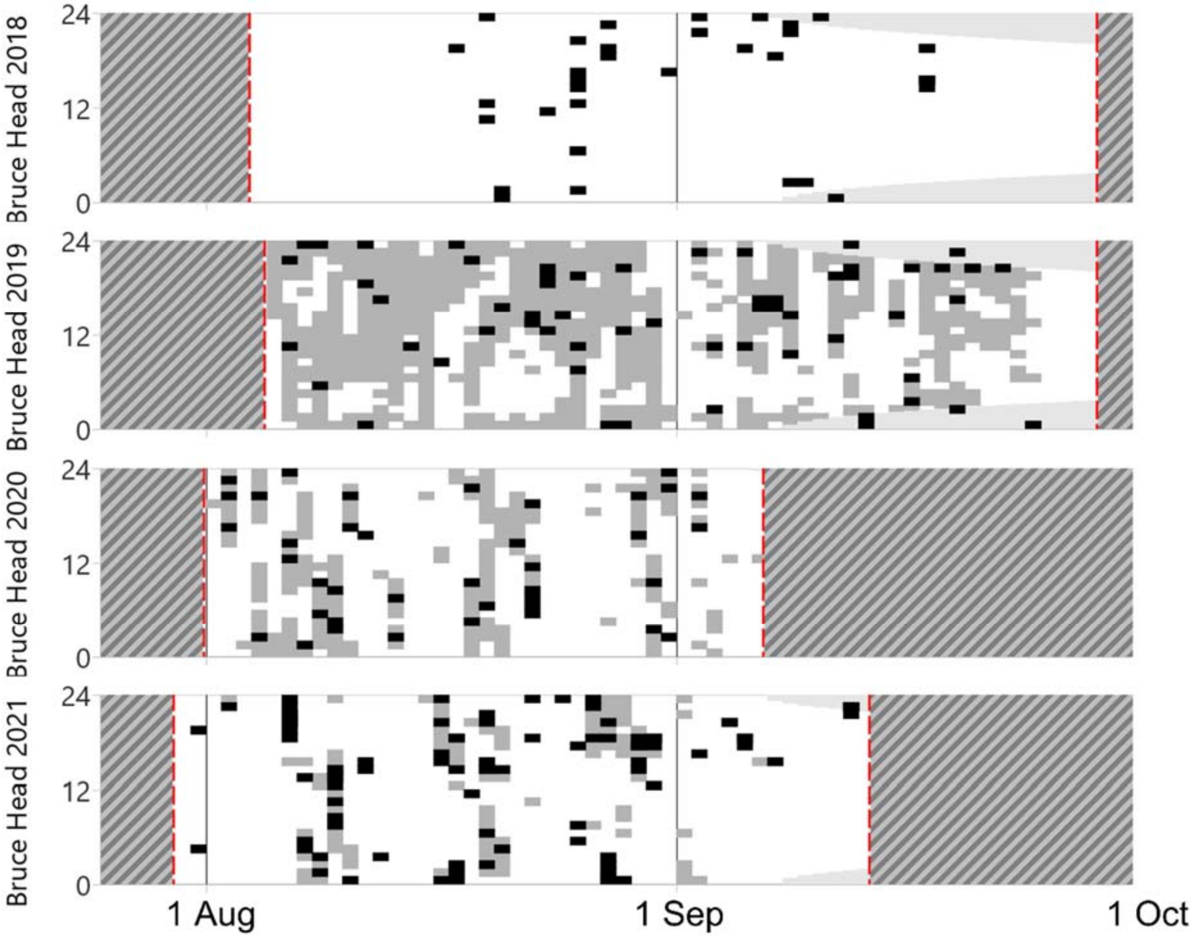

Figure 46. Hours per day with narwhal click train manual (black) and automated (grey) detections. The grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the UDB click detector.

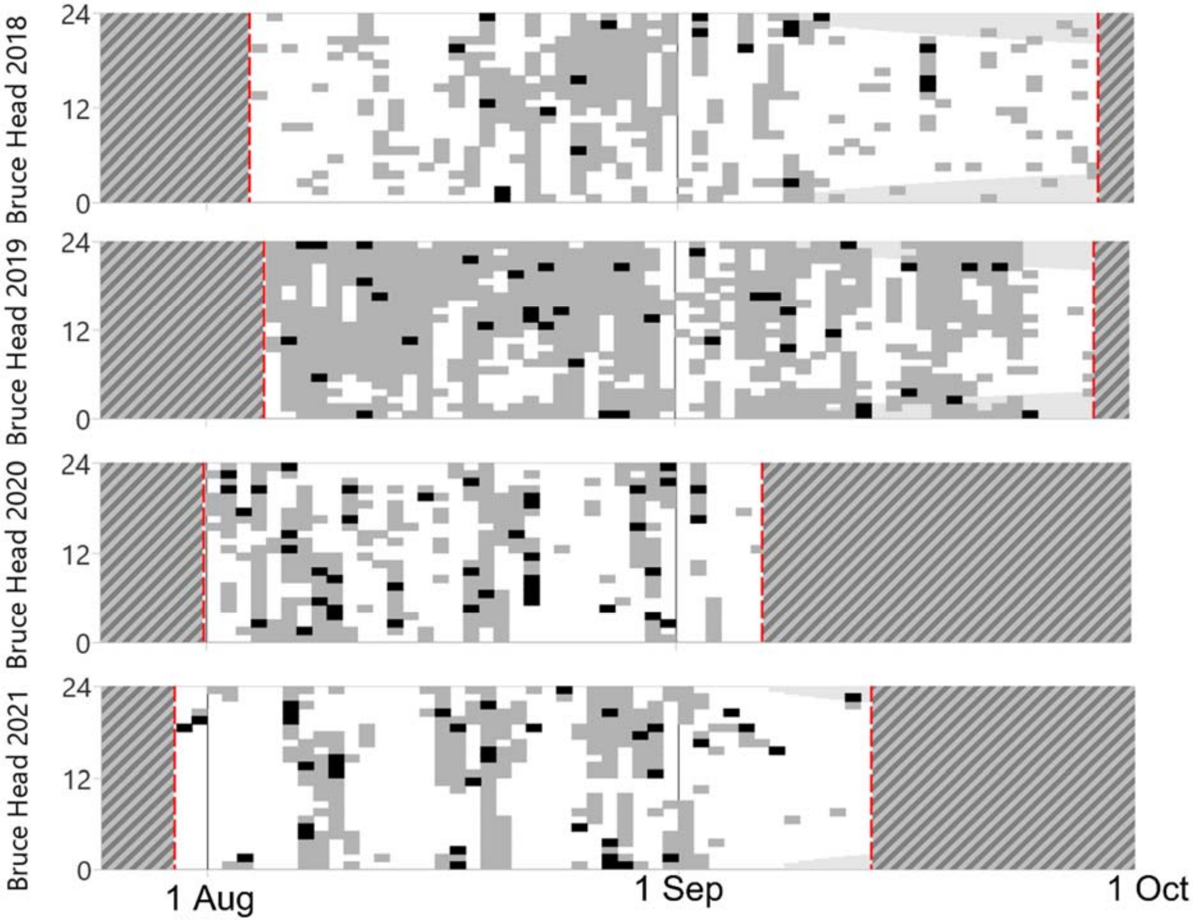

Figure 47. Hours per day with narwhal high-frequency buzz manual (black) and automated (grey) detections. The grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the UDB click detector.

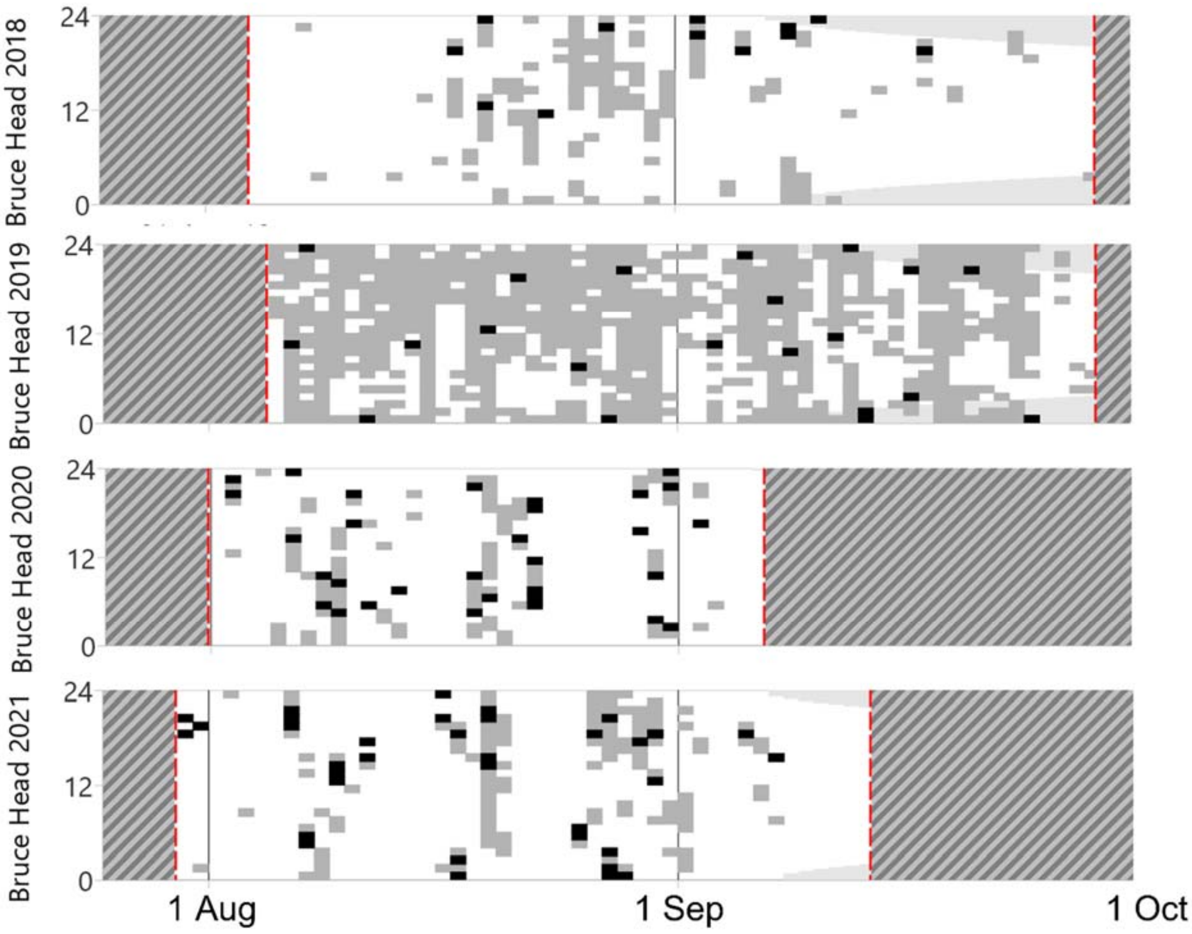

Figure 48. Hours per day with narwhal knock manual (black) and automated (grey) detections. The grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the UDB click detector.

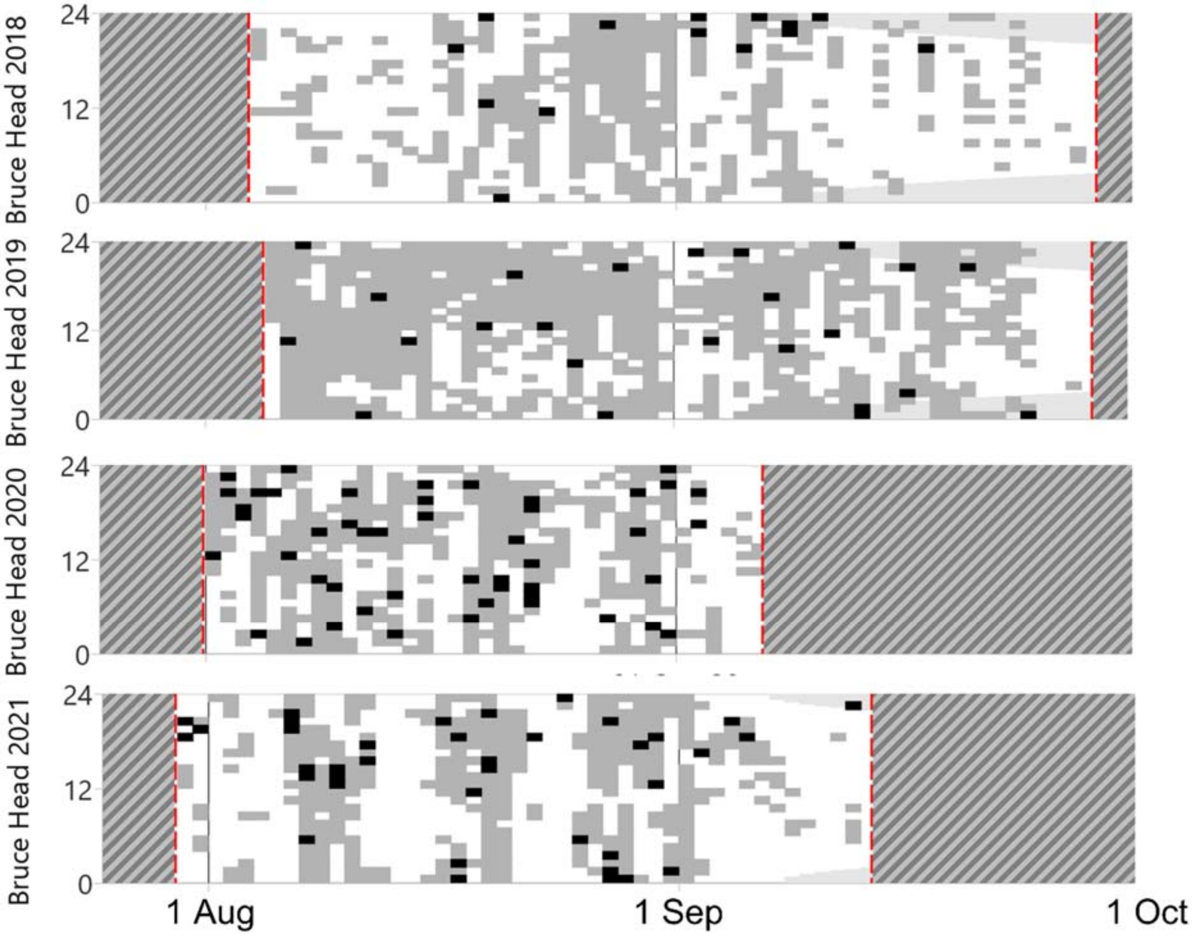

Figure 49. Hours per day with narwhal low-frequency buzz manual (black) and automated (grey) detections. The grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the UDB click detector.

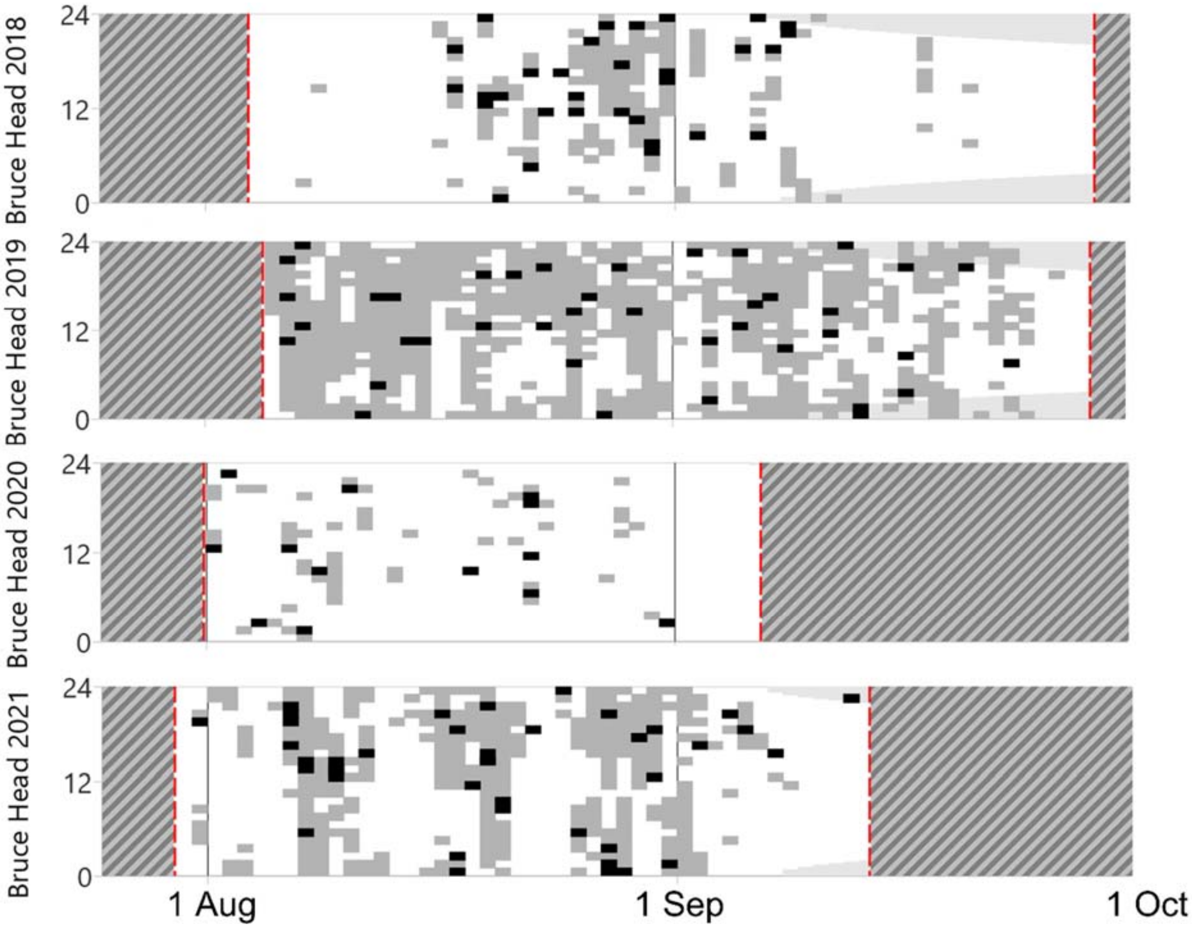

Figure 50. Hours per day with narwhal whistle manual (black) and automated (grey) detections. The grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the UDB click detector.

4.4.4. Killer Whales

Killer whales are found in all the world's oceans and share the sperm whale's distinction of having the largest range of any non-human mammal (Whitehead 2002). Killer whale sightings in the eastern Canadian Arctic are widely distributed, with the highest reported numbers in Lancaster Sound, which includes the Project area (Higdon et al. 2012). The killer whale population size in the eastern Canadian Arctic is unknown but believed to be small. Group sizes of up to 100 animals have been observed, although typical group sizes are lower and vary according to prey type, which include bowhead whales, monodontids, and seals (Higdon et al. 2012, Lefort et al. 2020). Prey preferences of killer whales in eastern Canada is unknown, and whether prey specialization even exists here is unclear (Lawson and Stevens 2013). Mammal-eating killer whales in the north Pacific tend to be more acoustically cryptic than their fish-eating counterparts (Barrett-Lennard et al. 1996). As a result, the acoustic foraging behaviour of killer whales in the Arctic should be considered when assessing the acoustic occurrence of that species.

There were no acoustic detections of killer whales in the 2021 data set, but they were infrequently detected in 2019 and 2020 at Bruce Head (Figure 51). These limited acoustic detections are consistent with the presumably small (although likely increasing) population size and its potentially vocally cryptic behaviour.

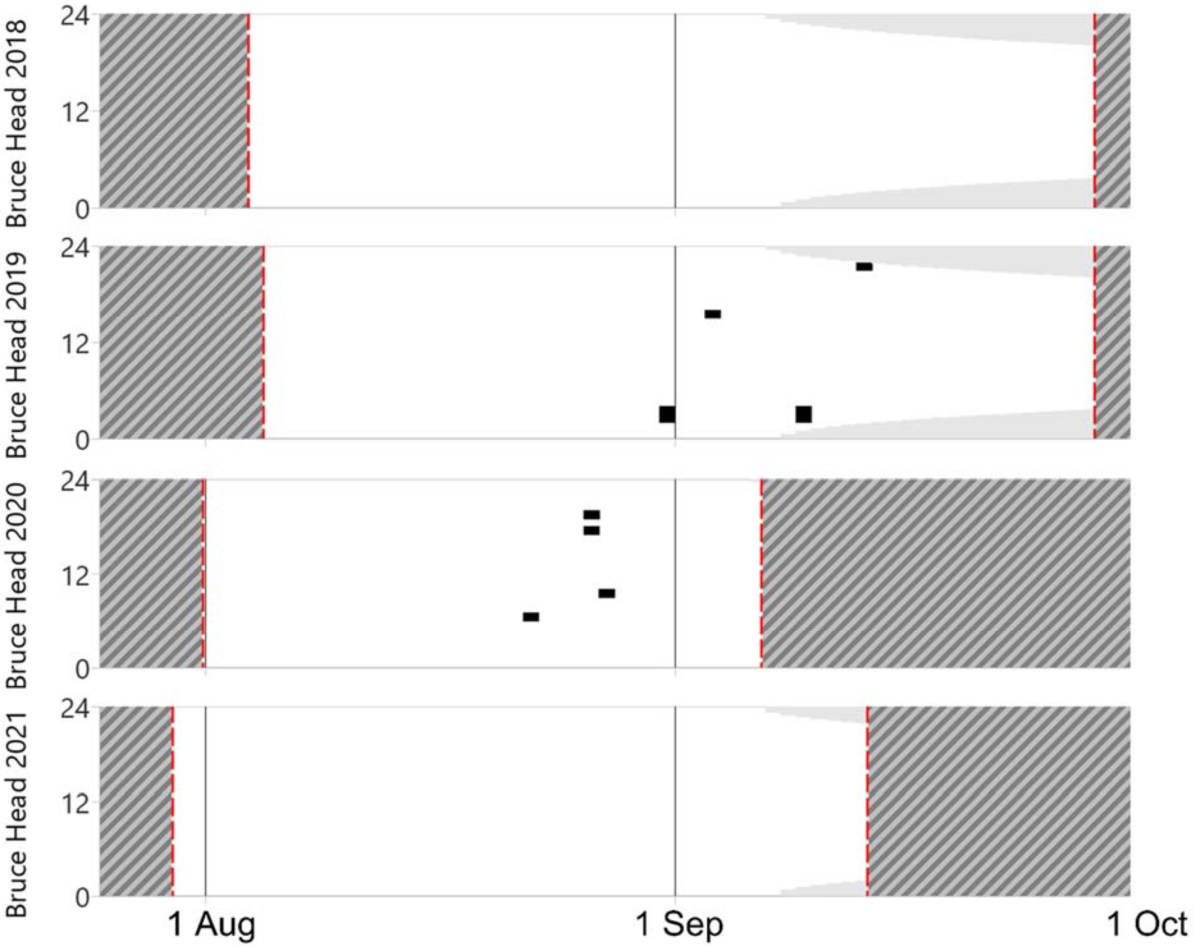

Figure 51. Hours per day with killer whale manual (black) and automated (grey) detections. The grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the UDB click detector.

4.4.5. Pinnipeds

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

4.5. Summary

The results of the 2021 PAM program contained in this report are consistent with results from previous PAM programs conducted by JASCO in the RSA since 2018. This analysis included the first detailed look at noise from vessels on anchor at the Ragged Island anchorage location. Sound levels recorded between 1 and 5 km from the anchored vessels were elevated above ambient sound levels (recorded on days when no vessels were on anchor) but rarely exceeded the 120 dB threshold for marine mammal disturbance, for only 0.6% of the 43 day recording period.

Marine mammal vocalizations were detected throughout the recordings from three marine mammal species: bowhead whales, narwhal, and beluga, as well as suspected detections of pinnipeds. Patterns in marine mammal acoustic detections were consistent with JASCO's prior acoustic monitoring results, noting a decreased acoustic occurrence of narwhal in 2020 and 2021. This is consistent with the results of Baffinland's aerial survey program, which recorded lower numbers of narwhal in the RSA in 2020 and 2021 compared to 2019. Based on this, it is not likely that the number of acoustic detections are a result of changed acoustic behaviour in 2020-2021 compared to 2019, but rather a result of less narwhal being in the system at the time of the 2021 recordings.

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

Acknowledgements

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Glossary

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

1/3-octave

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

1/3-octave-band

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

ambient sound

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

audiogram

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

auditory frequency weighting

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

auditory frequency weighting function

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

background noise

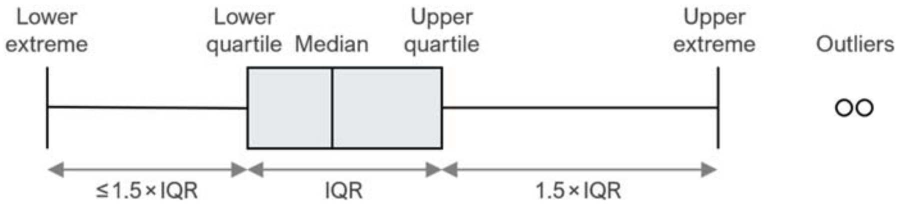
Combination of ambient sound, acoustic self-noise, and sonar reverberation. Ambient sound detected, measured, or recorded with a signal is part of the background noise.

bandwidth

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

box-and-whisker plot

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



broadband level

The total level measured over a specified frequency range.

cetacean

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

continuous sound

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

critical band

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

decade

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

decidecade

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

decidecade band

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

decibel (dB)

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

delphinid

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

duty cycle

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

Fourier transform (or Fourier synthesis)

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

frequency

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

hearing group

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

hearing threshold

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

hertz (Hz)

A unit of frequency defined as one cycle per second.

high-frequency (HF) cetacean

See hearing group.

hydrophone

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

impulsive sound

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

low-frequency (LF) cetacean

See hearing group.

masking

Obscuring of sounds of interest by sounds at similar frequencies.

median

The 50th percentile of a statistical distribution.

mid-frequency (MF) cetacean

See hearing group.

mysticete

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

octave

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

odontocete

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

otariid

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

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

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

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

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

peak-to-peak pressure

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

percentile level

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

permanent threshold shift (PTS)

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

phocid

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

phocid pinnipeds in water (PPW)

See hearing group.

pinniped

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

pressure, acoustic

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

pressure, hydrostatic

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

received level

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

reference values

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

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

rms

abbreviation for root-mean-square.

sound

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

sound exposure

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

sound exposure level

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

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

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

sound field

Region containing sound waves.

sound pressure level (rms sound pressure level)

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

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

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

source level (SL)

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

spectrogram

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

spectrum

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

temporary threshold shift (TTS)

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

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Appendix A. Calibration

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

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

Appendix B. Acoustic Data Analysis Methods

The data sampled at 64 or 512 kHz was processed for ambient sound analysis, vessel noise detection, and detection of all marine mammal vocalizations. This section describes the ambient, vessel, and marine mammal detection algorithms employed (Figure B-1).

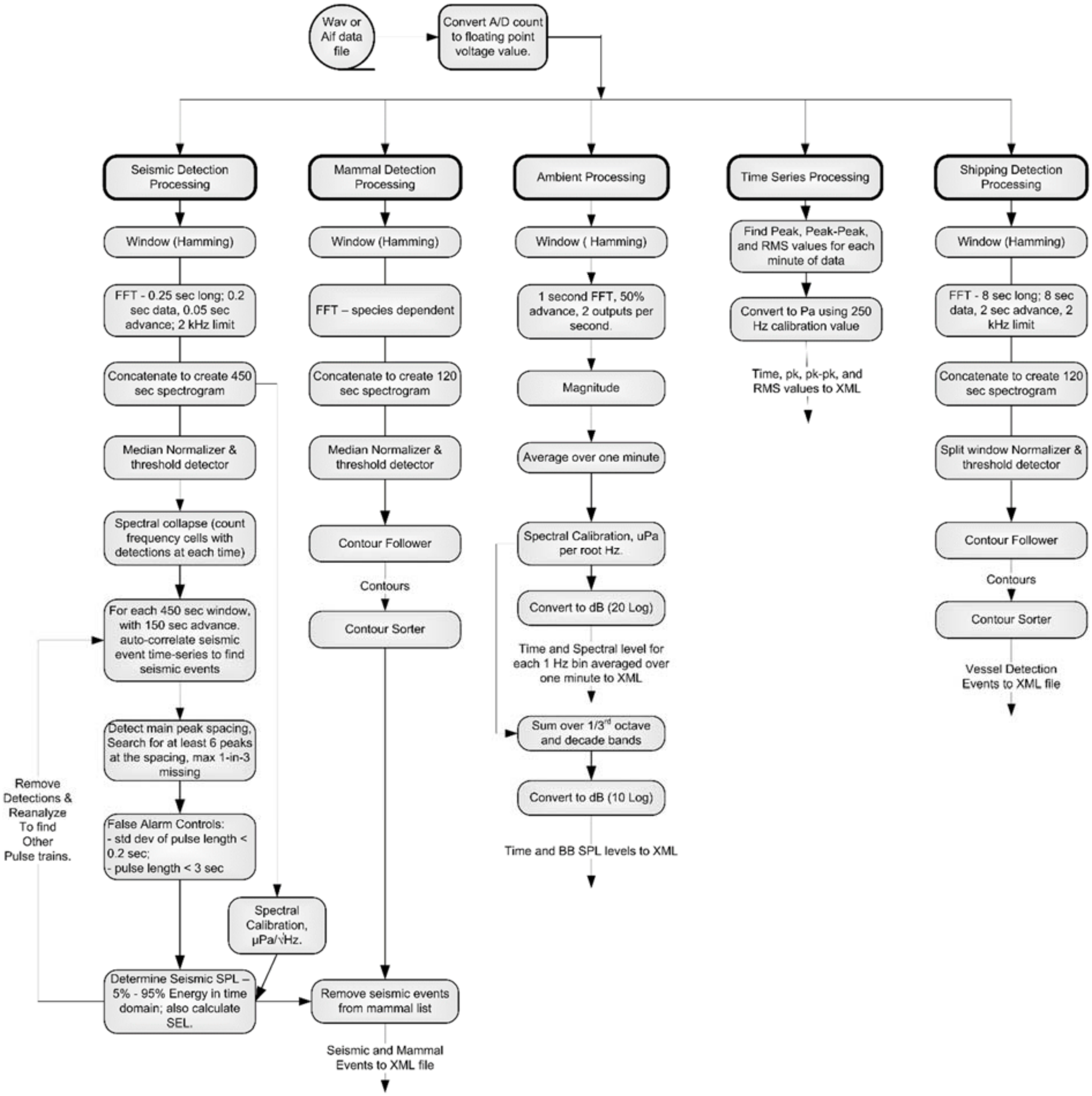

Figure B-1. Major stages of the automated acoustic analysis process performed with JASCO's custom software suite.

B.1. Total Ambient Sound Levels

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$L_p = L_E - 10\log_{10}(T) \quad \text{(B-8)}$$

$$L_{p90} = L_E - 10\log_{10}(T_{90}) - 0.458 \quad \text{(B-9)}$$

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

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

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

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

B.2. Decidecade Band Analysis

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

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

$$f_{\mathrm{c}}(i) = 10^{\frac{i}{10}}\,\mathrm{kHz} \tag{B-1}$$

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

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

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

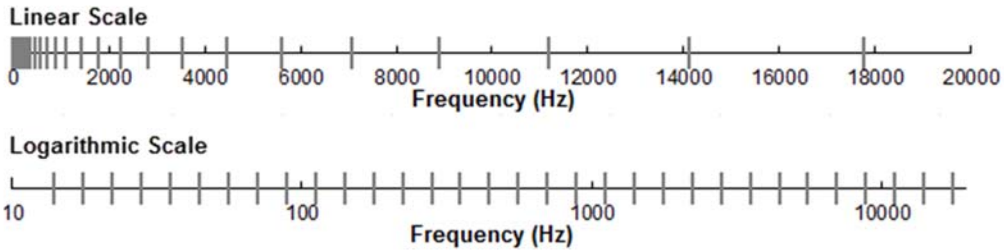

Figure B-2. Decidecade frequency bands (vertical lines) shown on a linear frequency scale and a logarithmic scale.

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

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

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

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

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

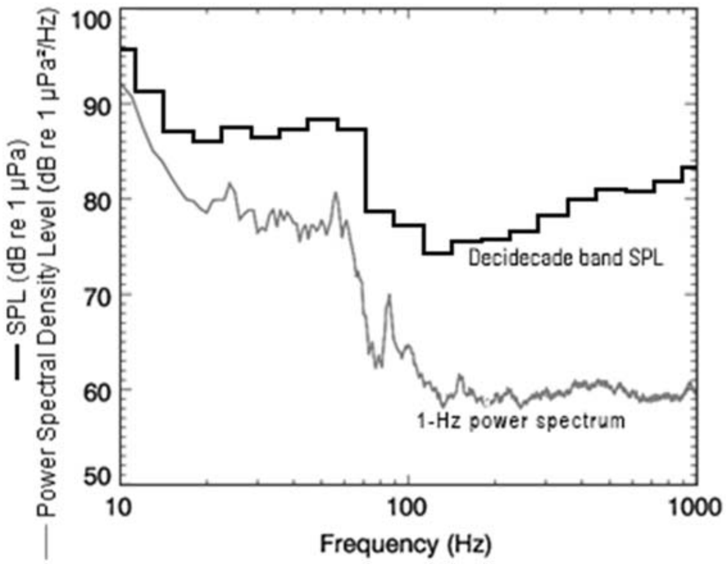

Figure B-3. Sound pressure spectral density levels and the corresponding decidecade band sound pressure levels of example ambient sound shown on a logarithmic frequency scale. Because the decidecade bands are wider with increasing frequency, the 1/3-octave-band SPL is higher than the power spectrum.

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

Band	Lower frequency	Nominal centre frequency	Upper frequency
10	8.9	10.0	11.2
11	11.2	12.6	14.1
12	14.1	15.8	17.8
13	17.8	20.0	22.4
14	22.4	25.1	28.2
15	28.2	31.6	35.5
16	35.5	39.8	44.7
17	44.7	50.1	56.2
18	56.2	63.1	70.8
19	70.8	79.4	89.1
20	89.1	100.0	112.2
21	112	126	141
22	141	158	178
23	178	200	224
24	224	251	282
25	282	316	355
26	355	398	447
27	447	501	562
28	562	631	708
29	708	794	891
30	891	1000	1122
31	1122	1259	1413
32	1413	1585	1778
33	1778	1995	2239
34	2239	2512	2818
35	2818	3162	3548
36	3548	3981	4467
37	4467	5012	5623
38	5623	6310	7079
39	7079	7943	8913
40	8913	10000	11220
41	11220	12589	14125

Band	Lower frequency	Nominal centre frequency	Upper frequency
10	8.9	10.0	11.2
11	11.2	12.6	14.1
12	14.1	15.8	17.8
13	17.8	20.0	22.4
14	22.4	25.1	28.2
15	28.2	31.6	35.5
16	35.5	39.8	44.7
17	44.7	50.1	56.2
26	355	398	447
27	447	501	562
28	562	631	708
29	708	794	891
30	891	1000	1122
31	1122	1259	1413
32	1413	1585	1778
33	1778	1995	2239

18	56.2	63.1	70.8
19	70.8	79.4	89.1
20	89.1	100.0	112.2
21	112	126	141
22	141	158	178
23	178	200	224
24	224	251	282
25	282	316	355
34	2239	2512	2818
35	2818	3162	3548
36	3548	3981	4467
37	4467	5012	5623
38	5623	6310	7079
39	7079	7943	8913
40	8913	10000	11220
41	11220	12589	14125

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

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

Appendix C. Marine Mammal Detection Methodology

C.1. Automated Click Detector for Odontocetes

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

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

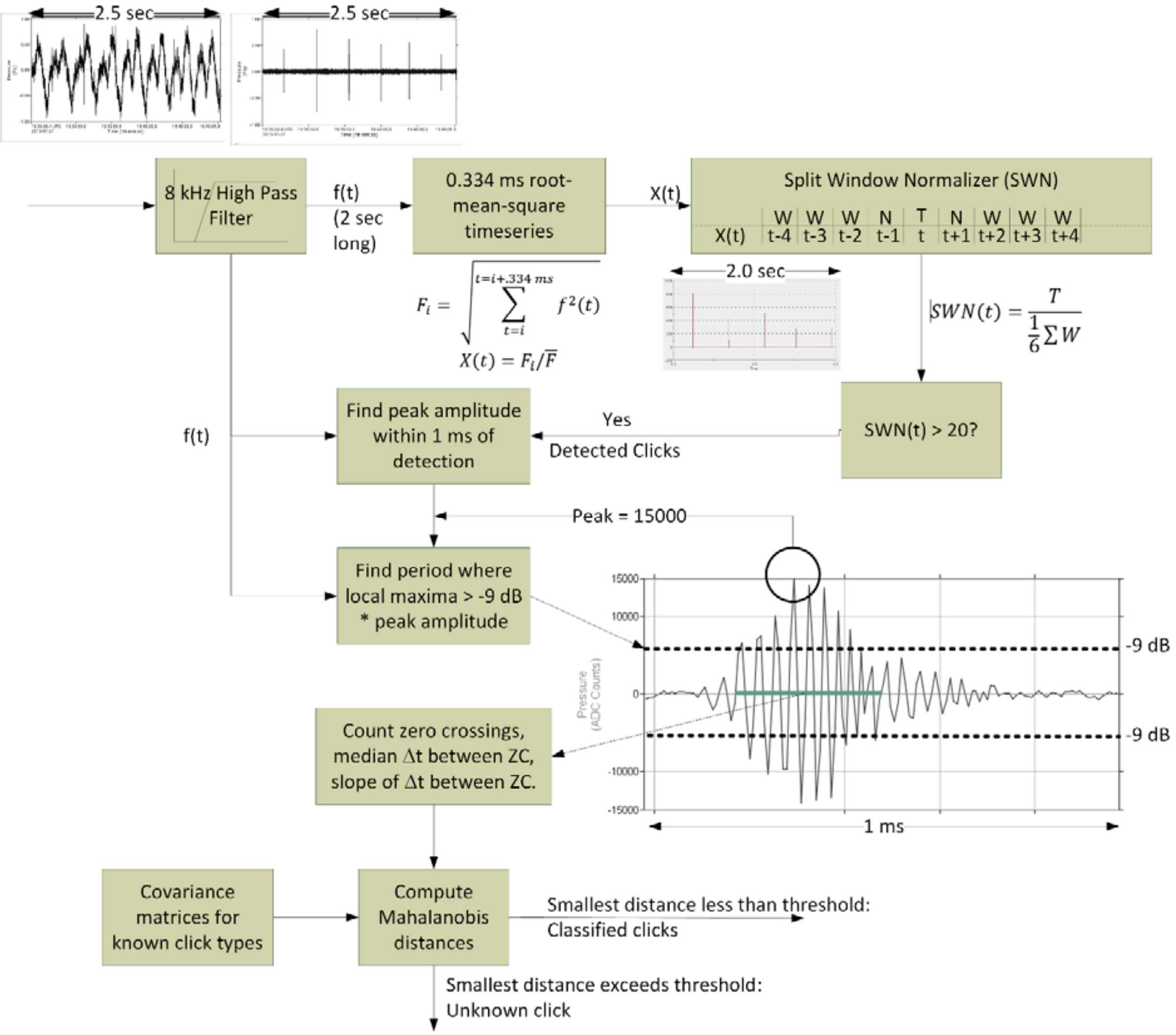

Figure C-1. The automated click detector/classifier block diagram.

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

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

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

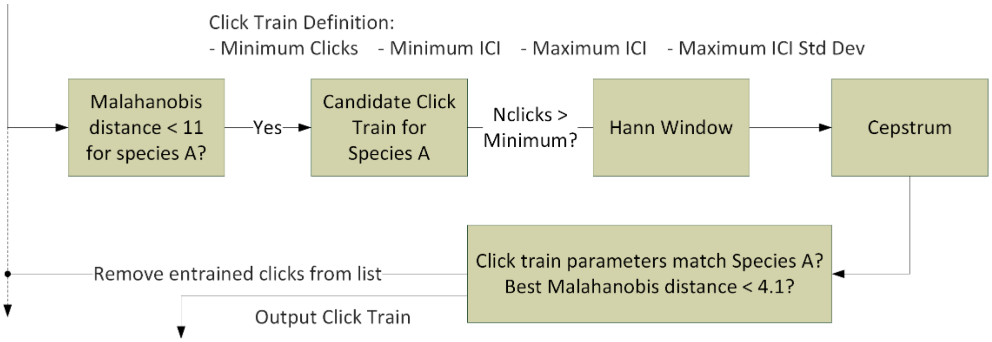

Figure C-2. The click train automated detector/classifier block diagram.

C.2. Automated Tonal Signal Detection

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

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

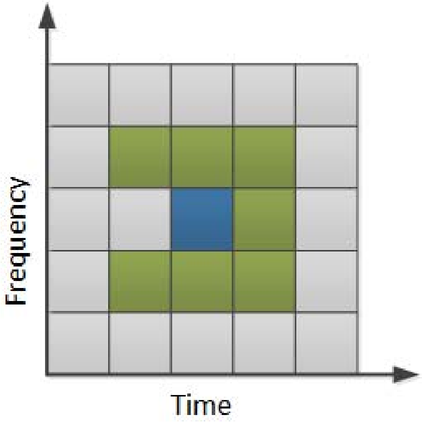

Figure C-3. Illustration of the search area used to connect spectrogram bins. The blue square represents a bin of the binary spectrogram equalling 1 and the green squares represent the potential bins it could be connected to. The algorithm advances from left to right so grey cells left of the test cell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

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

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

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

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

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

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

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

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

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

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

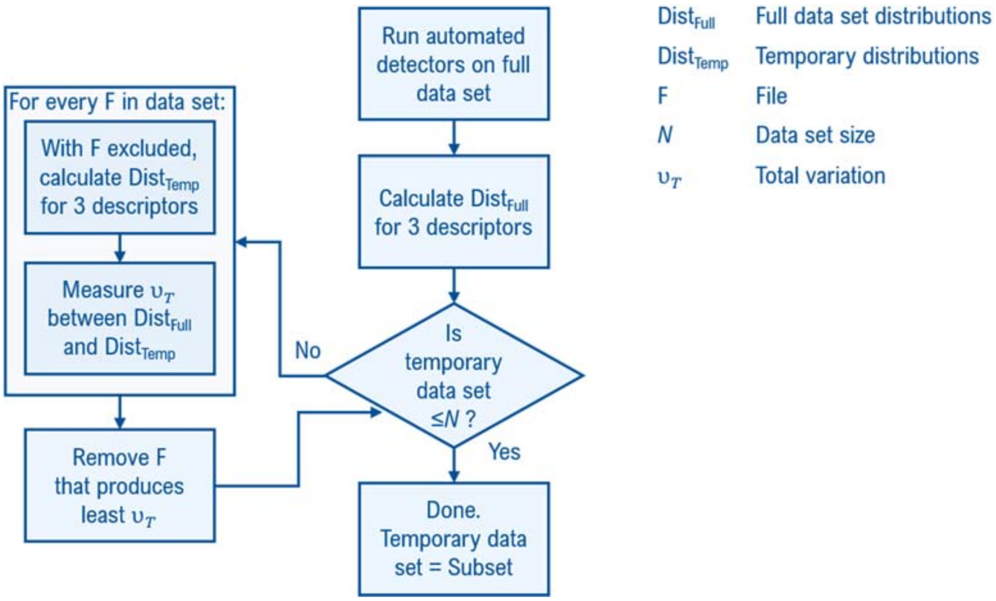

Figure C-4. Automated Data Selection for Validation (ADSV) process based on Figure 1 from Kowarski et al. (2021).

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

C.4. Automated Detector Performance Calculation and Optimization

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

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

In phase 2, the performance of the automated detectors was calculated and optimized for each species using a threshold, defined as the range of the number of automated detections per file within which detections of species were considered valid (bounded by a minimum and maximum).

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

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

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

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

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

Appendix D. Differentiating Between Narwhal and Beluga Clicks

An effort was made to validate the findings of Zahn et al. (2021) and develop a method for differentiating between narwhal and beluga clicks during manual analysis. Narwhal and beluga whale 'truth' data from JASCO's archive was used. Truth data are recordings where we could be reasonably certain of the species present. For narwhal truth data, we used five files from 2018 Milne Inlet data when sightings indicated only narwhal were present. For beluga truth data, we used four files from a beluga whale nursery in the Gulf of St. Lawrence, where narwhal are almost entirely absent. In each truth file, 8–20 clicks were annotated for a total of 58 narwhal click annotations and 41 beluga click annotations. Characteristics of the click annotations were extracted using JASCO's Ark and PAMlab software and then compared to the same characteristics presented in Zahn et al. (2021). Three parameters are presented and compared in Table D-1 and Figure D-1. These parameters are presented because Zahn et al. (2021) indicated they, among others, may be useful. Our click characteristic values closely matched that of the publication but had greater variability with more overlap between the two species. Based on these findings, we applied a manual analysis protocol to the present data set that is noted in red in Figure D-1 and specified in Section 2.3.4.

With more time, we would like to investigate further and consider using fmin_3dB as the indicator during manual analysis (high importance suggested in paper). Furthermore, in future work JASCO will be updating its formula for calculating click parameters. The beluga truth data should be used to inform further developing the beluga click automated detector.

Table D-1. The mean (minimum-maximum) of three click characteristics of narwhal and beluga calculated from JASCO's data and presented in Zahn et al. (2021). JASCO data N = 5 files for narwhal and N = 4 files for beluga.

Source of data	Beluga			Narwhal		
	fmax_3dB	centerHz_10dB	centerHz_3db	fmax_3dB	centerHz_10dB	centerHz_3db
JASCO	74.9 (62.3–89.7)	72.3 (60.5–84.5)	69.7 (58.7–84.7)	44.1 (27.3–64.3)	41.7 (26.4–61.7)	39.2 (24.7–56.4)
Zahn et al. (2021)	74.2 (54.3–103.3)	70.2 (53.1–93.6)	69.6 (52.2 to 95.7)	47.1 (29.6–66.6)	46.2 (28.1–65.5)	43.8 (28.1–58.9)

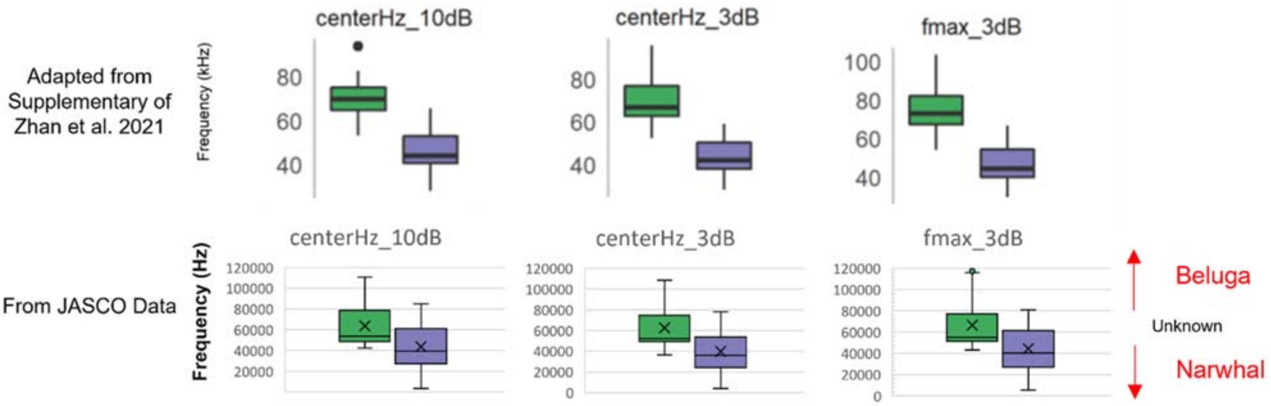

Figure D-1. Boxplots of three click characteristics of narwhal (purple) and beluga (green) calculated from JASCO's data and presented in Zahn et al. (2021). JASCO data N = 58 clicks for narwhal and N = 41 files for beluga. On the right is the definitions for differentiating the clicks of these species in the present data set.

Appendix E. Previous Programs

Details of previous Bruce Head recording years can be found in earlier JASCO reports and are summarized here for reference alongside the 2021 recordings (Table E-1). Bruce Head has been a consistent recording station since 2018, though in 2018 it was called AMAR-4 and in 2019 it was called AMAR3. The level of manual analysis effort varied across program years with only 0.5% of recordings manually reviewed in 2018 and 2019 and 3% manually reviewed in subsequent years (Table E-1).

Table E-1. Operation period and location of the Autonomous Multichannel Acoustic Recorders (AMARs) deployed for the 2018, 2019, 2020 and 2021 Passive Acoustic Monitoring (PAM) program included in this report.

Station	Year	Latitude	Longitude	Water depth (m)	Start date	Stop date	Recording duration (days)	Manual analysis effort (%)
Bruce Head	2018	72.06768°N	−80.5158°W	225	4 Aug 2018	28 Sep 2018	56	0.5
	2019	72.06717°N	−80.5181°W	223.5	5 Aug 2019	28 Sep 2019	55	0.5
	2020	72.06727°N	−80.5182°W	225	1 Aug 2020	6 Sep 2020	35	3
	2021	72.06715°N	-80.5172°W	238	30 Jul 2021	13 Sep 2021	46	3
Ragged Island	2021	72.46352°N	-80.0701°W	131	2 Aug 2021	13 Sep 2021	43	3
Pond Inlet	2021	72.70773°N	-77.9828°W	123	7 Aug 2021	14 Sep 2021	39	3

Appendix F. Marine Mammal Automated Detector Performance Results

Automated detector performance is provided for the 2021 data presented in Section 3.5 and for all recording years of Bruce Head presented in Section 4.4. Automated detectors that triggered on species' vocalizations confirmed to occur in the data during manual analysis are included in Table F-1. These detectors had performance metrics that varied across species, vocalization types, and stations (Table F-1). Automated detectors targeting stereotyped acoustic signals or those that are unique in spectral content, such as narwhal high-frequency buzzes, outperformed detectors aimed at finding acoustic signals with greater inter-specific overlap in spectral content, such as the moans of bowhead whales. Where there was sufficient data to calculate automated detector performance metrics, the precision and recall was generally high (Table F-1). Automated detector results deemed reliable and refined to incorporate the classification threshold and exclusion periods are presented in Section 3.5.

Table F-1. The per-file performance of automated detectors by station including the detection-per-file threshold implemented, the resulting Precision (P) and Recall (R), the number of files in the validation sample (# Files), the number of files in the sample containing an annotation (# A) and automated detections (# D) of the relevant species. 2018 and 2019 performance metrics are based on manual analysis of 0.5% of the recording data while 2020–2021 are based on 3% analysis. For 2018–2020, the threshold is a minimum while in 2021 it is bounded by a minimum and maximum. 'NA' denotes values that performance could not be calculated due to an insufficient number of TP, FN, and FP files to calculate the P and R, or a lack of validated signals.

Species signal (Detector)	Station-yyyy	File duration	Threshold	P	R	MCC	# Files	# A	# D
Beluga click HF (UDB.Click)	Bruce Head-2021	1	16–518	0.81	0.93	0.84	96	14	31
Bowhead moans (MFMoanLow)	Bruce Head-2018	14	NA	NA	NA	NA	NA	3	NA
	Bruce Head-2019	14	NA	NA	NA	NA	NA	3	NA
	Bruce Head-2020	14	NA	NA	NA	NA	106	2	9
	Bruce Head-2021	14	1–2	0.20	0.75	0.34	102	4	30
	Pond Inlet-2021	14	NA	NA	NA	NA	NA	0	NA
	Ragged Island-2021	14	6–7	0	0	-0.01	109	2	19
Killer whale tonal calls (WhistleHigh)	Bruce Head-2018	14	NA	NA	NA	NA	NA	0	NA
	Bruce Head-2019	14	NA	NA	NA	NA	NA	8	NA
	Bruce Head-2020	14	1	0.06	0.60	0.07	106	5	48
	Bruce Head-2021	14	NA	NA	NA	NA	NA	0	NA
	Pond Inlet-2021	14	NA	NA	NA	NA	NA	0	NA
	Ragged Island-2021	14	NA	NA	NA	NA	NA	0	NA
Narwhal click (narwhal click)	Bruce Head-2018*	1	9	0.93	1.00	30	14	26	9
	Bruce Head-2019	1	14	1.00	1.00	1.00	27	25	26
	Bruce Head-2020	1	12	0.96	0.96	0.82	105	77	86
	Bruce Head-2021	1	4–2618	0.90	0.93	0.81	127	69	84
	Pond Inlet-2021	1	NA	NA	NA	NA	NA	0	NA
	Ragged Island-2021	1	NA	NA	NA	NA	NA	0	NA
Narwhal click trains (narwhal click train)	Bruce Head-2018	1	NA	NA	NA	NA	NA	NA	NA
	Bruce Head-2019	1	1	1.00	1.00	1.00	27	25	25

Species signal (Detector)	Station-yyyy	File duration	Threshold	P	R	MCC	# Files	# A	# D
	Bruce Head-2020	1	1	0.96	0.94	0.81	105	77	75
	Bruce Head-2021	1	5–237	0.98	0.78	0.77	127	69	62
	Pond Inlet-2021	1	NA	NA	NA	NA	NA	0	NA
	Ragged Island-2021	1	NA	NA	NA	NA	NA	0	NA
Narwhal low-frequency buzz (Narwhal_LFbuzz)	Bruce Head-2018	14	1	1.00	0.79	0.80	28	14	11
	Bruce Head-2019	14	1	1.00	0.63	27	24	15	1
	Bruce Head-2020	14	1	0.74	0.87	0.58	106	52	61
	Bruce Head-2021	14	1–59	0.91	0.89	0.84	114	46	45
	Pond Inlet-2021	14	NA	NA	NA	NA	NA	0	NA
	Ragged Island-2021	14	34–46	1.00	0.14	0.37	107	7	43
Narwhal high-frequency buzz (Narwhal_HFbuzz)	Bruce Head-2018	14	10	1.00	0.82	0.84	28	11	15
	Bruce Head-2019	14	1	0.94	0.89	27	18	17	1
	Bruce Head-2020	14	2	0.96	0.98	0.94	106	46	48
	Bruce Head-2021	14	2–273	0.95	0.93	0.91	113	44	44
	Pond Inlet-2021	14	NA	NA	NA	NA	NA	0	NA
	Ragged Island-2021	14	NA	NA	NA	NA	NA	0	NA
Narwhal knocks (NarwhalKnockTrain)	Bruce Head-2018	14	12	1.00	0.85	0.86	28	13	13
	Bruce Head-2019	14	1	1.00	0.62	27	21	13	1
	Bruce Head-2020	14	11	0.85	0.85	0.77	106	33	41
	Bruce Head-2021	14	5–177	0.97	0.78	0.82	115	36	43
	Pond Inlet-2021	14	NA	NA	NA	NA	NA	0	NA
	Ragged Island-2021	14	2–6	0.75	0.6	0.64	108	10	15
Narwhal tonal calls (Narwhal_Whistle)	Bruce Head-2018	14	3	1.00	0.44	0.57	28	9	3
	Bruce Head-2019	14	1	1.00	0.50	27	24	12	1
	Bruce Head-2020	14	12	0.64	0.64	0.56	106	14	50
	Bruce Head-2021	14	1–35	0.98	0.89	0.89	109	46	42
	Pond Inlet-2021	14	NA	NA	NA	NA	NA	0	NA
	Ragged Island-2021	14	NA	NA	NA	NA	NA	1	NA

* Bruce Head 2018 Narwhal click detector was different from subsequent years.

Appendix G. Auditory Frequency Weighting Functions

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

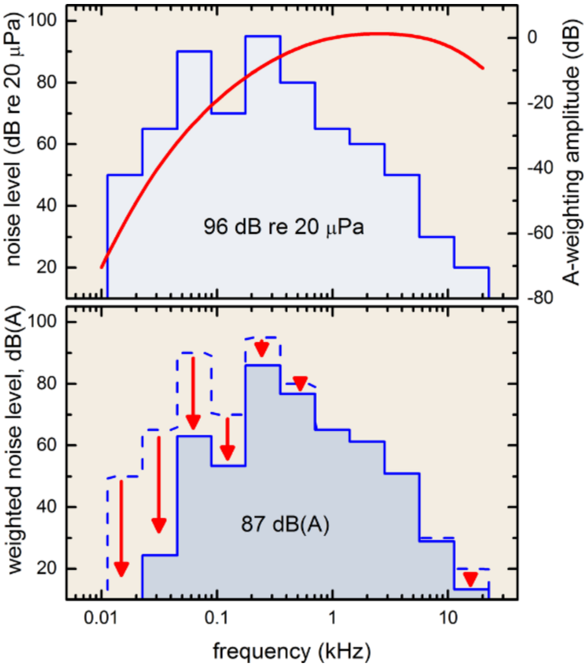

Figure G-1. Application of an auditory weighting function. Blue line shows a hypothetical, octave-band sound pressure spectrum in air, with a total sound pressure level (integrated over all octave-bands) of 96 dB re 20 µPa (This example uses in air-noise levels; therefore, a different reference pressure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

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

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

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

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

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

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

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

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

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

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

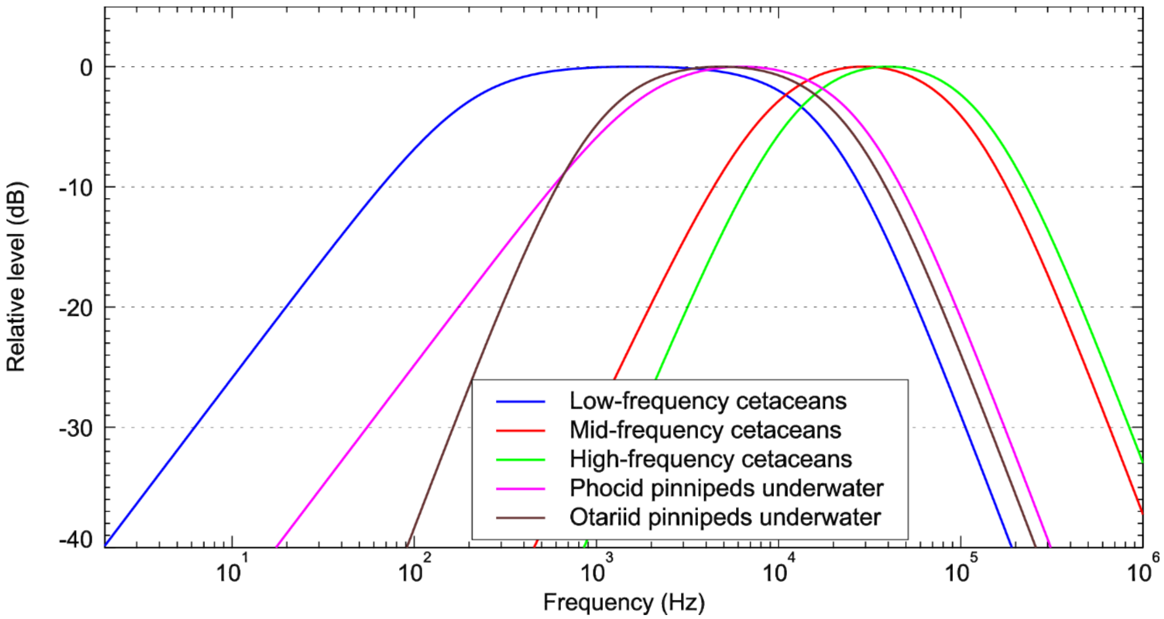

Figure G-2. Auditory weighting functions for functional marine mammal hearing groups as recommended by NMFS (2018).

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

Figure G-3. Marine mammal auditory injury (permanent threshold shift, PTS and temporary threshold shift, TTS) sound exposure level (SEL) thresholds based on NMFS (2018) for non-impulsive sound sources, in dB re 1 µPa²·s.

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

Appendix H. Wind speed data at Pond Inlet

Records of wind speed recorded at Pond Inlet were obtained from Environment and Climate Change Canada climatological records ([Hourly Data Report for August 01, 2021 - Climate - Environment and Climate Change Canada (weather.gc.ca)](), accessed 03 March 2022).

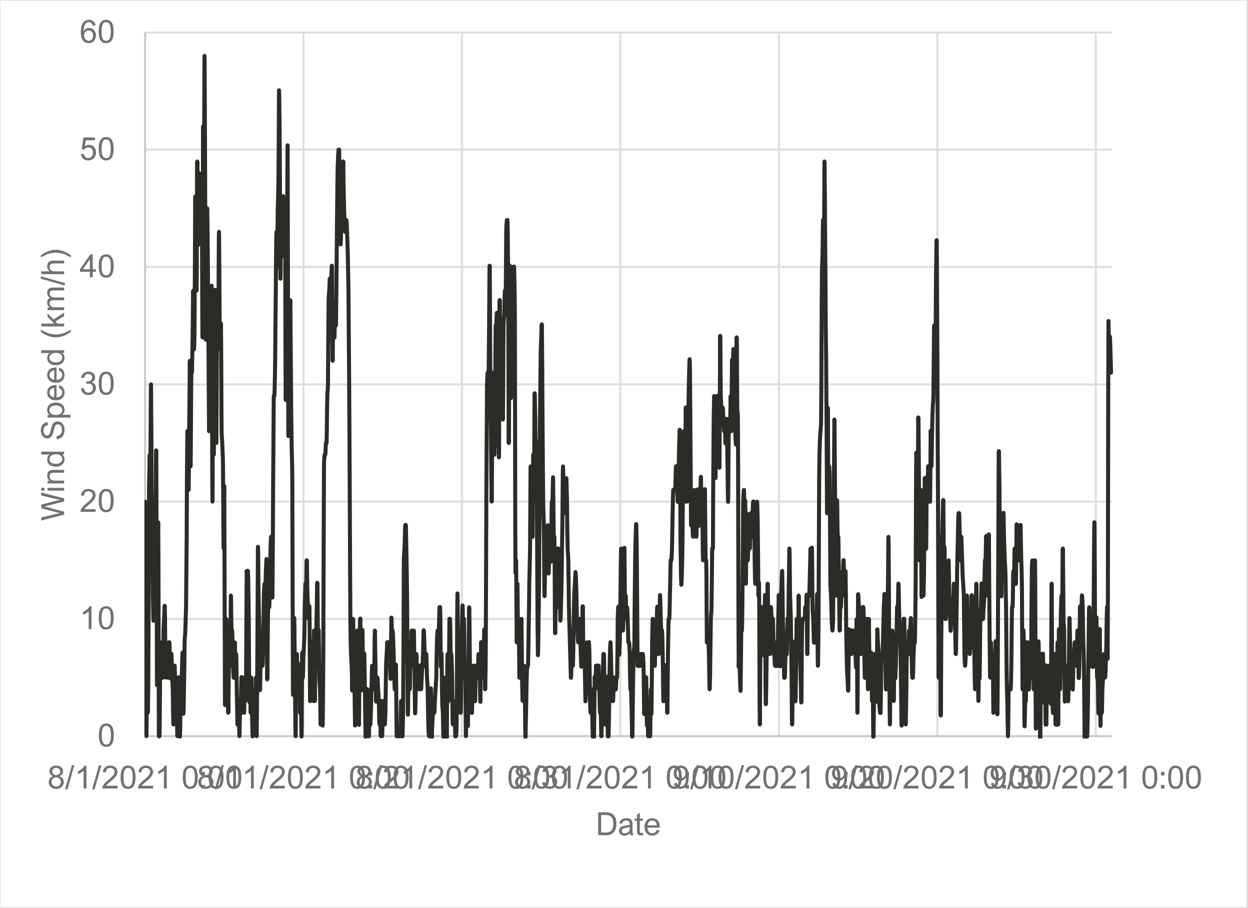

Figure H-1. Wind speed data recorded at Pond Inlet, Environment and Climate Change Canada.

Appendix I. Marine Environment Working Group Comments

I.1. DFO

Reviewer Agency/Organization:	*DFO*
Reviewers:	Marianne *Marcoux, Kimberly Howland, Joclyn Paulic, Daniel Coombs, Edyta Ratajczyk*
Document(s) Reviewed:	2021 Underwater Acoustic Monitoring Program (Open-Water Season)
Date Review Completed	

Comment No.:	*DFO-6*
Section Reference:	2.1.1. Deployment Locations
Comment:	

Issue:
All of the AMARs were deployed in relatively shallow water and/or close to land.

Clarification:
Could you comment on how this bias affect your results?

Recommendation:
-Please provide a section with the limitation of the study and explain how it might change the results
-For future acoustic monitoring studies, consider moving the AMAR to a deeper more open area.

Baffinland Response:

The water depths at Baffinland’s acoustic recording locations (~ 120 – 240 m) are not what would typically be considered as “shallow water” from an acoustic perspective and no significant limitations associated with recordings in these water depths are expected. Prior modelling results indicate that sound propagation distances within the regional study area are dominantly affected by the geography, with sound levels within 5-10 km of a vessel being fairly consistent at locations in Milne Inlet and western Eclipse Sound despite differences of water depth at the modelled sites.

In 2021, each recorder location was chosen for a specific objective:

- Bruce Head – this location was chosen for consistency over years with the recording location used by Baffinland since 2014, allowing for year over year comparisons at a consistent location.

This location is also within the Behavioural Study Area of the Bruce Head Monitoring Program, providing potential for combined analysis of acoustic and behavioural observation data as possible, and is in a location where large numbers of narwhal have historically been sighted.

- Ragged Island – this location was chosen due to its proximity to the anchorage locations at Ragged Island, specifically to characterize noise in that area based on feedback and concerns from Pond Inlet community members.
- Pond Inlet – this location was chosen for its proximity to the small craft harbour construction at Pond Inlet. The purpose for this recorder was not to characterize vessel noise associated with Baffinland's activities. Its purpose was to characterize noise from the small craft harbour construction activities.

Given these intended objectives, there is no bias or limitation associated with the recorder locations or water depths at these locations.

In August 2022, two floe edge monitoring acoustic recorders will be retrieved which were deployed at the end of the 2021 monitoring season, in water depths of 630 m and 674 m. These devices recorded data from Sep 15 through Oct 15, 2021 and will record from Jul 7 through Aug 6, 2022. These are the deepest recording locations at which Baffinland has collected acoustic recordings since 2014. These data will allow for an analysis to confirm whether water depth at the receiver has an effect on the recorded sound levels in comparison to sound levels recorded near Bruce Head. A more fulsome response to this question can be provided after those data are analyzed. However, as previously stated, water depth at the recording locations is not expected to result in any strong bias or limitation of results of Baffinland's underwater noise monitoring to date.

Characteristics of the sound at the eastern floe edge recorder location are expected to be different from recordings from other locations in western Eclipse Sound and in Milne Inlet, since the eastern floe edge location is exposed to the open waters of Baffin Bay whereas the other locations are in more protected waters. But data from the western floe edge recorder location are expected to be consistent with previous results from western Eclipse Sound.

Comment No.:	*DFO-7*
Section Reference:	3.5. Listening Range Reduction
Comment:	

Issue:
The results on Listening Range Reduction are difficult to interpret. It would be helpful to see a comparison between the years of the study

Recommendation:
Consider adding a multi-year comparison for the Listening Range Reduction results.

Baffinland Response:

A multi-year comparison of Listening Range Reduction results will be provided in future monitoring reports.

Comment No.:	*DFO-8*
Section Reference:	4.2. Vessel Contribution to Soundscape
Comment:	

Recommendation:
Please provide a section that compares the results of the report to results in Jones 2021 and Tervo et al., 2021.

Jones (2021) Underwater soundscape and radiated noise from ships in Eclipse Sound, NE Canadian Arctic. Marine Physical Laboratory Technical Memorandum Number: MPLTM651. Report prepared for the Nunavut Impact Review Board (NIRB) and submitted to the NIRB by Oceans North on January 18, 2021

Tervo, Blackwell, Ditlevsen, Conrad, Samson, Garde, Hansen and Peter (Nov 2021) Narwhals react to ship noise and airgun pulses embedded in background noise. Biol. Lett. 17: 20210220. https://doi.org/10.1098/rsbl.2021.0220

Baffinland Response:

Results in Jones (2021) are not directly comparable to results from Baffinland's acoustic monitoring to date, since the data were collected and analyzed using different analysis methodologies, using different recording devices, and in different locations. Nevertheless, broadband median levels reported by Jones (2021) for July and August at Milne Inlet are consistent with Baffinland's median sound levels at Bruce Head as reported in the 2021 monitoring report, when accounting for bandwidth. It is important to note that the Jones (2021) data only characterize sound between 20 Hz and 4 kHz, they do not capture the full frequency range of the measurements collected by Baffinland (10 Hz to 32 kHz) so they will underestimate the total sound field. Median spectral density levels between the two studies are also comparable, as are Baffinland's mean spectral density data comparable to Jones (2021) 90th percentile spectral density data at Milne Inlet. The fact that the mean sound levels track with the upper end of the recorded sound level distribution indicates that the mean is driven by infrequent events with elevated sound levels (i.e., vessel passages that are of short duration).

Jones' recordings at the Pond Inlet location are expected to differ from data recorded in western Eclipse Sound and in Milne Inlet due to exposure to the open waters of Baffin Bay (see response to DFO 06); differences between Jones' Milne Inlet and Pond Inlet locations are evident in their report. The data from Jones (2021) would be best compared to data from the floe edge recorders, that will be retrieved in August 2022. As such, this requested comparison with Jones (2021) is best saved for the analysis of the floe edge recorder data and there would be little value in adding this comparison to the 2021 Passive Acoustic Monitoring report. Comparisons between the floe edge recordings and Jones (2021) are subject to the same caveats re: differences in equipment (i.e. hydrophones and recording devices) and analysis methodology.

With regards to Tervo et. al. (2021), that paper focuses mainly on narwhal reactions to airgun sounds. Airguns generate high intensity, impulsive noise that is not comparable to the low intensity non-impulsive sound from vessels. As such, narwhal reactions to these two sources of noise are not expected to be the same. Heide-Jorgensen et al (2021) provides more details of the study in question, and that paper does allude to similar narwhal responses to the seismic vessel when the airguns were not active also. JASCO understands from communication with the authors that a subsequent paper by Tervo et. al. is forthcoming that will provide more details about narwhal responses during exposure to the airguns and to the seismic vessel alone (with a multi-beam sonar in use). It is our understanding that no trials were conducted with only vessel noise prior to any exposure to airgun noise, which may have biased the results. Nevertheless, inclusion of any discussion of results from this study is best reserved until detailed results of responses to narwhal to the vessel without airguns are available.

Heide-Jørgensen MP, Blackwell SB, Tervo OM, Samson AL, Garde E, Hansen RG, Ngô MC, Conrad AS, Trinhammer P, Schmidt HC, Sinding M-HS, Williams TM and Ditlevsen S (2021) Behavioral Response Study on Seismic Airgun and Vessel Exposures in Narwhals. Front. Mar. Sci. 8:658173. doi: 10.3389/fmars.2021.658173

I.2. Parks Canada

Reviewer Agency/Organization:	*Parks Canada Agency*
Reviewers:	*Allison Stoddart, Jordan Hoffman, Chantal Vis*
Document(s) Reviewed:	*2021 Underwater Acoustic Monitoring Program (Open-water Season)*
Date Review Completed	*2022-05-17*

Comment No.:	PCA-05
Section Reference:	2021 Underwater Acoustic Monitoring Program (Open-Water Season), Page 30, Section 3.5 ‘Results: Listening Range Reduction’
Comment:	

We recommend that inter-annual comparisons of Listening Range Reduction for ambient and vessel noise be presented in future acoustic monitoring reports.

Baffinland Response:

Interannual comparisons of Listening Range Reduction for ambient and vessel noise will be presented in future acoustic monitoring reports.

I.3. Oceans North

Reviewer Agency/Organization:	*Oceans North*
Reviewers:	*Dr. Kristin Westdal, Dr. Josh Jones, & Amanda Joynt*
Document(s) Reviewed:	*Open Water Acoustic Monitoring 2021*
Date Review Completed	*2022-05-27*

Comment No.:	ON-5
Section Reference:	P001348-011; Document 02633 v1.0 pp. D-3 Appendix E Table E-1

Comment:

Issue:

Data table only goes back to 2018, but long-term effects of increased shipping are a subject of both the past project, the existing project certificate, and the Phase 2 Development Proposal.

Recommendation:

Please provide a table updated to include all acoustic data collected by BIMC to date. These data are needed to understand long-term changes in underwater sound levels and the occurrence of underwater noise from ships.

Baffinland Response:

Figure 43 and Table 8 in the 2021 Underwater Acoustic Monitoring Program Report (Open-water Season) have been updated to included data collected by Greeneridge Sciences in 2014 and 2015. There is excellent agreement in the data across years. Mean sound levels between approximately 100 and 400 Hz were elevated by a few dB in years with greater numbers of Project vessel transits, as expected. There is also a prominent tone at 200 Hz in data from 2018 – 2021 that is likely attributable to the icebreaker MSV *Botnica*, which did not visit the regional study area in 2014 and 2015. Spectral density levels at frequencies between approximately 3 and 6 kHz and frequencies around 20 kHz were higher in some years than others and are thought to indicate times with high vocal presence of narwhal social calls and higher frequency vocalizations, respectively. Since these are mean levels, and they track with the high end of the sound level distribution, these variations are the result of intermittent, short duration, high intensity events (e.g. vessel transits near the recorder) but do not reflect persistent or chronic changes of the soundscape. Chronic changes to the soundscape are better characterized by looking at the median levels across years so these have also been added to the above-referenced table and figure. The median sound levels are very consistent across years at all frequencies. Variability at frequencies below 20 Hz, between data collected in 2014-2015 compared to those collected since 2018, are due to different sensitivity responses of the different hydrophones used to collect the data. The updated table and figure are copied below for reference.

Table 8 Broadband (10-24 kHz 2014-2015, 10-32 kHz 2018-2021) sound pressure level (SPL) measured at Bruce Head for Baffinland between 2014 and 2021 (no data were collected in 2016 or 2017).

	2014	2015	2018	2019	2020	2021
Mean	109.6	107.2	111.6	113.8	111.8	112.4
Median	96.1	96.6	95.8	102.1	98.0	98.2

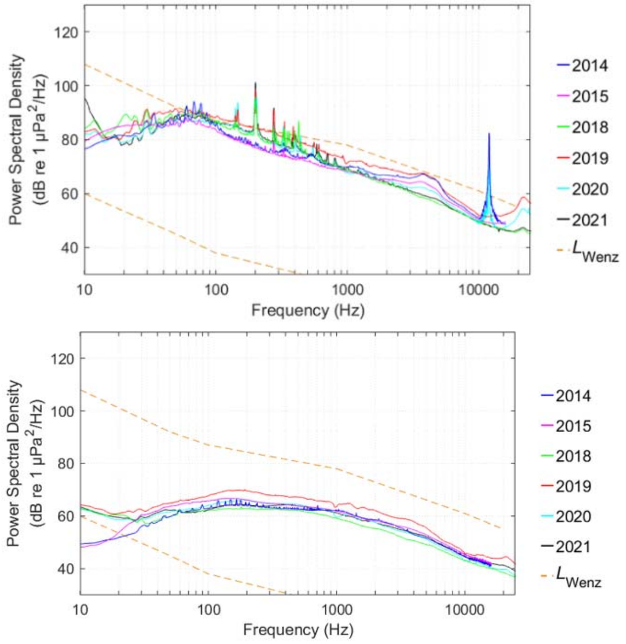

Figure 43 Power spectral densities recorded at Bruce Head between 2014 and 2021 (no data collected in 2016 and 2017); (left) mean over recording period (right) median over recording period.

Comment No.:	ON-6
Section Reference:	P001348-011; Document 02633 v1.0 pp. 12 Table 3
Comment:	

Issue:
Was permission obtained for deployment of the acoustic recording device at location AMAR-PI, approximately 1 km from the community of Pond Inlet? When was the mooring deployed? When was it recovered? Research, including deployments of acoustic recording devices, without community support in this region makes it harder for the research community to obtain authorization from the relevant authorities, including local HTO's.

Recommendation:
Please provide documentation of authorization to deploy AMAR-PI along with dates of the deployment and recovery of this mooring.

Baffinland Response:

Each year, Baffinland obtains a Nunavut Research Institute (NRI) scientific license to support marine environmental monitoring requirements related to NIRB Project Certificate 005. In accordance with existing terms and conditions of Project Certificate No. 005, Baffinland is responsible for establishing and implementing environmental effects monitoring (EEM) studies. The Acoustic Monitoring Program specifically aimed to address monitoring requirements outlined in the following Project Certificate No. 005 terms and conditions:

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

> *3. A monitoring and mitigation plan is to be developed, and approved by Fisheries and Oceans Canada prior to the commencement of blasting in marine areas".*

In addition, Baffinland engaged specifically with the Mittimatalik Hunters and Trappers Organization (MHTO) regarding the proposed deployment and locations of all acoustic recorders through several means:

- Letter from Golder Associates to MHTO dated May 26, 2021 ("Letter of Support for Baffinland's 2021 Marine Monitoring Programs")
- Discussion during May 28, 2021 meeting with MHTO and the Hamlet of Pond Inlet (slide decks 4 a and 4b presented during the meeting)
- Presentation materials from a meeting of the Marine Environment Working Group (MEWG; of which the MHTO is a member) on June 29, 2021
- Memo dated July 14, 2021 delivered by email and in printed copy from Baffinland to MHTO ("2021/2022 Passive Acoustic Monitoring Program Acoustic Recorder Locations")

No feedback or engagement on this topic was received from the (MHTO) and no objections were communicated to Baffinland.

Comment No.:	ON-7
Section Reference:	P001348-011; Document 02633 v1.0 pp. 25 Figures 16 and 17
Comment:	

Issue:
Vessel detection methods illustrated in Figure 8 (p.14) indicate that the "system weighted" and 40-315 Hz sound pressure level (SPL) are elevated by the approaching ship for a period of 1 hour prior to and 30 minutes after the window of vessel detection shown. Figures 16 and 17 (p. 25) show the total periods of vessel detections at each recording location. Are vessels not detectable outside of the plotted ship detection times using the proponent's methods for acoustic detection?

Recommendation:
Please clarify how the received level thresholds for automated vessel detection were selected. Do the periods between automated vessel detections plotted in figures 16 and 17 contain underwater noise from project ships that could be detected by the proponent if the detection criteria were different? Does the proponent suggest that time in between automated vessel detections in figures 16 and 17 is free from underwater radiated noise from ships?

Baffinland Response:

The data in Figure 8 (p 14) are for illustrative purposes only, to demonstrate the methodology. Those data were not recorded as part of this monitoring program and are purely an example.

The thresholds for automated vessel detection are based on a large collection of empirical data of many types of vessels, collected in multiple different environments. The thresholds are selected to yield consistent and reliable, automated, confirmation of vessel presence. The thresholds are targeted to identify times when vessel noise is a substantial contributor to the soundscape. As a buffer, the algorithm expands the detection window by 10 minutes on either end, to account for periods with lower level vessel noise contributions. Outside of that expanded window, marine mammals are not likely to be able to perceive the difference between the very low level vessel noise and the background.

It is worth noting that the use of an automated detector allows for efficient and expedient processing of multiple months of data from multiple recorders. It is not feasible to perform manual identification of the start and end of each vessel transit given the volumes of data recorded each year. Automated detection methods are required, and JASCO’s vessel detection algorithm is appropriate for this purpose. The algorithm has been extensively benchmarked against a large database of measurements. A student at Dalhousie University is currently investigating the detector performance with variations of the detector thresholds. To date, that work indicates that the default thresholds yield optimal detector performance for a variety of conditions.

Comment No.:	ON-8
Section Reference:	P001348-011; Document 02633 v1.0 pp. 20, 21 Figures 9-11
Comment:	

Issue:
Underwater sound level percentiles for the recording periods plotted in Figures 9-11 differ substantially from the levels represented as ‘normal’ in the Wenz curves (Figure 2), especially below 100 Hz and above 10 kHz. From Figures 9-11, it appears that the percentile levels converge toward a single level and that the natural sound levels may not be recorded or represented in the plot.

Recommendation:
Please explain the lack of natural variability in recorded sound levels below 100 Hz and above 10 kHz. Why are the levels in these frequency ranges different from the environmental sound levels predicted from general patterns in ocean underwater sound as depicted in the Wenz curves (Figure 2)?

Baffinland Response:

At the top end of the frequency spectrum (i.e., at frequencies greater than 10 kHz) the acoustic recordings are limited by the noise floor of the hydrophones. Oceans North will note from these figures that it is only the lower 25th percentile of the data that are affected by this, the remaining portion of the data is accurately characterized by the high quality recordings. Similarly, below approximately 50 Hz, the recordings are limited by the low frequency roll-off of the hydrophones. Again, only the lower 25th percentile of the data are affected. The recordings are more than adequate and appropriate for characterizing the majority of the variability of the acoustic environment in the regional study area

(RSA). These are the highest quality recordings available for these very low levels of noise.

Comment No.:	ON-9
Section Reference:	P001348-011; Document 02633 v1.0 pp. 15, 31 Table 4
Comment:	

Issue:
Baffinland has estimated that the narwhal hearing threshold at 25 kHz is 57 dB (Table 4). This level appears to be unmeasurable using the proponent's acoustic recording devices, as do natural ambient levels of sound at this frequency range (see comment above). As a result of the higher apparent recording system noise levels, the proponent estimates that listening range reduction does not occur in the frequencies narwhal use for echolocation.

Recommendation:
Improve noise characteristics of acoustic recording or otherwise develop a method to measure natural levels of sound at frequencies above 10 kHz so these levels can be appropriately incorporated into evaluation of the effect of underwater noise from project ships on acoustic communication space and listening space of narwhals in the project impact area. Otherwise, please make clear in annual reporting what the limitations of the recording devices are at these frequencies and how those limitation influence the estimation of project noise impacts to marine mammal communication.

Baffinland Response:

For initial clarification, Baffinland has not estimated that listening range reduction (LRR) does not occur in frequencies that narwhal use for echolocation. The results in Section 3.5 clearly indicate that > 50% LRR was calculated to occur in the 25 kHz decidecade band during between 14% and 30% of the recordings containing vessel noise, depending on recording location (>90% LRR occurred during between 1.4% and 2% of the recordings containing vessel noise).

The LRR calculations are computed relative to the median measured sound level. The measured median sound level is accurately characterized in this analysis and is not affected by the hydrophone noise floor at 25 kHz (please see response to ON-08). This hydrophone noise floor limitation does result in over-estimation of at most 25% of the recorded sound levels, which can affect the LRR results. But what this means, in fact, is that Baffinland over predicts the amount of LRR by using a minimum received level of 72 dB (the minimum measurable decidecade band level at 25 kHz) rather than 57 dB (the narwhal hearing threshold).

Oceans North is correct in that a decidecade band level of 57 dB at 25 kHz is not measurable with the acoustic recording configuration used by Baffinland. The limitation is not the recording device (the AMAR spectral noise floor is ~15 dB re 1 µPa^2/Hz at 10 kHz); it is a limitation of the hydrophone sensitivity at those frequencies. The hydrophone has an equivalent electronic noise floor of ~30 dB re 1 µPa^2/Hz. The performance of the recording devices used by Baffinland far exceed those of any other recording devices. There is one model of hydrophone that could provide superior performance compared to the hydrophone that Baffinland has used, however those hydrophones have very high power requirements and would preclude the ability to perform long duration recordings. The cost-benefit to making this change is not justified because the recording devices are already more than adequate to accurately characterize at least 75% (or more) of the variability of the sound levels, and to fully characterize the range of vessel sounds.