Baffinland Iron Mines Corporation – Mary River Project

2019 Passive Acoustic Monitoring Program – Final Report

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ᐅᒥᐊᖅᔪᐊᓂᑦ ᓂᐱᖃᖅᑐᖅ ᐃᓂᒋᔭᐅᔪᒥᑦ ᐃᓗᐃᓯᕆᓂᖃᕈᓐᓇᖅᑐᖅ ᑑᕌᓕᖕᓄᑦ, ᐊᒻᒪᓗ ᐱᒻᒪᕆᐅᔪᖅ ᖃᒥᕐᕈᓗᒋᑦ ᐊᑐᖅᓯᓂᐅᔪᖅ ᐊᓯᐊᓐᖑᖅᑎᑦᑎᖕᒪᖕᒑᑦ ᓇᒧᖕᒐᐅᖃᑦᑕᕐᓂᖏᓐᓂᒃ ᑑᒐᓕᑦ, ᐊᒥᓱᓂᖏᓐᓂᒃ, ᐅᕝᕙᓘᓐᓃᑦ ᐅᑎᖅᑕᖃᑦᑕᕐᓂᖏᓐᓄᑦ ᐊᑐᖅᓯᓗᑎᒃ ᒪᖃᐃᑕᐅᔪᖕᓇᕐᓂᖏᓐᓄᑦ ᒪᓂᒪᓂᖏᓐᓂᒃ ᓄᓇᓕᖕᒥᐅᓄᑦ. ᒪᓕᒃᓱᒋᑦ ᓴᖅᑭᑕᐅᓯᒪᔪᑦ ᑐᑭᐅᔪᑦ ᐊᒻᒪᓗ ᖃᐅᔨᓴᕐᓂᐊᖅᑐᓂᑦ ᐱᓕᕆᐊᕐᒧᑦ ᓇᓗᓇᐃᒃᑯᑕᖅ ᓈᓴᐅᑎᓕᒃ 005-ᒥᑦ, ᐹᕙᓛᓐᑯᑦ ᓴᖅᑭᑎᑦᓯᕆᐊᖃᖅᑐᑦ ᐊᒻᒪᓗ ᐊᑐᓕᖅᑎᓪᓗᒍ ᐊᕙᑎᒥᒃ ᖃᐅᔨᒋᐊᕈᓕᖅᑎᑦᑎᓂᕐᓄᑦ ᖃᐅᔨᓴᐃᓂᕐᒥᒃ (EEM) ᖃᐅᔨᓂᐊᕐᓗᑎᒃ ᖃᐅᔨᒪᓇᓐᖏᑦᑐᓂᒃ ᐊᖏᔪᒥᒃ ᐊᑐᖅᓯᓂᐅᔪᑦ, ᖃᐅᔨᑎᑦᑎᓯᓕᓗᑎᒃ ᓈᒻᒪᖏᑦᑐᓂᒃ ᐊᓯᐊᓐᖑᖅᓯᓂᐅᔪᓂᒃ ᐊᕙᑎᒧᑦ ᐊᒻᒪᓗ ᐱᐅᓯᕆᐊᕐᓗᒋᑦ ᑐᑭᓯᐊᔭᐅᓂᖏᑦ ᖃᓂᑦᑐᒥᑦ ᐊᕙᑎᒧᑦ ᐱᕙᓪᓕᐊᓂᐅᔪᑦ ᐊᒻᒪᓗ ᐱᓕᕆᐊᕐᒥᓐᓂᕈᓐᓇᖅᑐᓂᒃ ᐱᔪᓂᒃ-ᐊᒻᒪᓗ-ᐊᑐᖅᓯᔪᓂᒃ ᐱᓕᕆᖅᑎᕆᓂᐅᔪᓂᒃ. ᑖᓐᓇ ᐅᓂᒃᑳᖅ ᓇᓗᓇᐃᔭᐃᔪᖅ ᐊᑐᖅᑕᐅᔪᓂᒃ ᐊᒻᒪᓗ ᖃᐅᔨᓴᕐᓂᐅᔪᓂᒃ ᓂᐱᖃᕐᓂᕐᒧᑦ ᖃᐅᔨᓴᐃᓂᐅᓗᐅᖅᑐᒥᑦ ᐱᓕᕆᐊᕆᓂᐊᕐᓗᒋᑦ ᐊᕙᑎ ᐊᑐᖅᑕᐅᓂᖓᓄᑦ ᖃᐅᔨᓴᐃᓂᕐᒧᑦ ᐱᔭᕆᐊᖃᖅᑐᑦ.

2019 ᓂᐱᖃᕐᓂᕐᒧᑦ ᖃᐅᔨᓴᐃᓂᖅ ᐱᓕᕆᐊᖑᓗᐅᖅᑐᖅ JASCO ᐊᑐᖅᑕᐅᔪᑦ ᓯᓇᑐᐃᓐᓇᓕᕆᔩᑯᓐᓄᑦ (JASCO), ᐱᓕᕆᖃᑎᖃᕐᓗᒋᑦ ᒨᑐ ᑲᑐᔾᔨᖃᑎᒌᒃᑯᑦ (ᒨᑐᒃᑯᑦ) ᐊᒻᒪᓗ ᐹᕙᓛᓐᑯᑦ, ᕿᒥᕐᕈᓂᐊᕐᓗᒍ ᐱᓕᕆᐊᕐᒥᑦ-ᐱᔪᓂᒃ ᐊᑐᖅᓯᓂᐅᔪᙱᑦᑐᑦ ᑕᕆᐅᕐᒥᐅᑕᓄᑦ ᐅᒥᐊᖅᔪᐊᑦ ᓂᐱᖃᕐᓂᖏᓐᓄᑦ. ᐱᔾᔪᑎᒋᓗᐊᕐᑕᖓ ᐱᓕᕆᐊᕆᔭᐅᔪᒧᑦ ᑎᑎᕋᐃᓂᐊᕐᓗᓂ ᐃᒪᐅᑉ ᐃᓗᐊᓂᑦ ᓂᐱᖃᓐᓂᑦ ᖃᐅᔨᓴᕐᓗᒋᑦ ᓇᓃᓂᕆᔭᖏᑦ ᑕᓪᓕᒪᐅᔪᓂᒃ ᓂᐱᖃᕐᓂᕐᒧᑦ ᖃᐅᔨᓴᐃᕝᕙᐅᔪᓂᑦ (ᐊᐅᔭᖅ<ᓪᓕᐊᓕᕝᕕᖓᒍᑦ ᒪᕐᕉᓐᓂᑦ ᖃᐅᔨᓴᐃᕝᕙᖕᓂᑦ ᐅᒥᐊᖅᔪᐊᑦ ᐊᑉᖁᑎᒋᖃᑦᑕᖅᑕᖏᓐᓂᑦ ᑕᓯᐅᔭᕐᒥᑦ ᐊᒻᒪᓗ ᕿᙳᐊᓂᑦ ᐅᐊᖕᓇᖕᓂᑦ; ᐊᒻᒪᓗ ᐊᐅᔭᐅᑎᓪᓗᒍ ᓯᑕᒪᓂᑦ ᐃᓂᐅᔪᓂᑦ ᕿᙳᐊᓂᑦ (ᐅᐊᖕᓇᖅ ᐊᒻᒪᓗ ᓂᒋᖅ). ᑐᓪᓕᐊ ᐱᔾᔪᑎᒋᔭᐅᔪᖅ ᖃᐅᔨᓗᓂ ᑕᕆᐅᕐᒥᐅᑕᐃᑦ ᓂᕆᐅᓐᑦ ᑕᐃᒪᐅᖃᑦᑕᖅᑐᑦ (ᐱᓗᐊᖅᑐᒥᑦ ᑑᒑᓕᑦ) ᕿᙳᐊᓂᑦ ᓂᒋᐊᓂᑦ. ᑭᖑᓪᓕᖅᐹᒃᑯᖕᒐᔪᖅ ᐱᔾᔪᑎᒋᔭᐅᔪᖅ ᕿᒥᕐᕈᓗᒍ ᐱᓕᕆᐊᕐᒥᑦ-ᐅᒥᐊᖅᔪᐊᓂᑦ ᖃᓄᐃᒻᒪᑦ ᓂᐱᖃᕐᓂᐅᔪᖅ ᑕᕆᐅᕐᒥᐅᑕᓄᑦ ᓂᐱᖃᕐᓂᕐᒧᑦ ᑎᑭᐅᑎᓯᒪᔭᕆᐊᓕᖕᓄᑦ ᐋᓂᖅᑕᐅᓂᖏᓐᓄᑦ ᐊᒻᒪᓗ ᐃᓗᐃᓰᖅᑕᐅᓂᖏᓐᓄᑦ ᐊᒻᒪᓗ ᖃᐅᓈᓂᖅᓴᐅᔪᓕᕆᓗᓂ ᖃᐅᔨᓂᐊᕐᓗᒍ ᓂᐱᖃᕐᓂᐅᔪᓂᒃ ᐅᒥᐊᖅᔪᐊᑦ ᑎᑭᑎᑕᐅᖃᑦᑕᖅᑐᓂᖏᓐᓄᑦ ᐊᐅᔭᐅᑎᓪᓗᒍ ᐋᖅᑭᐅᒪᔪᓄᑦ ᓇᓚᐅᑦᑖᖅᑕᐅᔪᓄᑦ ᐊᑐᖅᑕᐅᖃᑦᑕᖅᑐᑦ ᐊᕙᑎᒥᒃ ᐊᑐᖅᓯᓂᐅᔪᓂᒃ ᖃᐅᔨᓴᐃᓂᕐᒧᑦ.

ᑲᑎᖅᓱᕆᑦ ᑕᓪᓕᒪᐃᑦ ᐃᒪᐅᑉ ᐃᓗᐊᓂᑦ ᓂᐱᓕᐅᕈᑏᑦ ᐃᓕᔭᐅᓚᐅᖅᑐᑦ. AMAR–RI ᓂᐱᓕᐅᕈᑏᑦ ᐅᐊᖕᓇᖕᒐᓂᑦ ᕿᙳᐊᓂᑦ (ᐃᒥᓕᖕᓂᑦ) ᐊᒻᒪᓗ AMAR–BI ᑕᓯᐅᔭᕐᒥᑦ (ᖃᓂᑕᖕᒐᓂᑦ ᐊᑭᐊᓂᑦ) ᐃᓕᔭᐅᐸᓗᑎᒃ ᐊᑯᓂᖕᒐᓂᑦ ᔪᓚᐃᑦ 20/21 ᐊᒻᒪᓗ ᐊᒋᓕᕈᓯᕝ 4, 2019-ᒥᑦ; ᐊᓂᑎᑦᑕᐅᓯᒪᓚᐅᖅᑐᑦ ᓂᐱᓕᐅᕆᐊᕐᓂᐊᕐᓗᑎᒃ ᓯᑉᑎᑉᕙ 7, 2019-ᒥᑦ. AMAR–RI ᐱᔭᐅᓚᐅᖅᑐᑦ ᐃᓕᔭᒃᑲᓂᖅᓱᑎᓪᓗ ᓂᐱᓕᐅᕆᓂᐊᕐᓗᑎᒃ ᐊᑯᓂᖕᒐᓂᑦ ᐊᒋᓕᕈᓯᕝ 4 ᐊᒻᒪᓗ ᐊᒥᒐᐃᔭᕝ 29, 2019. ᐱᖕᒐᓱᑦ ᐃᓂᐅᔪᑦ ᕿᙳᐊ ᓂᒋᐊᓂᑦ ᐃᓕᔭᐅᓚᐅᖅᑐᑦ ᐊᑯᓂᖕᒐᓂᑦ ᐊᒋᓕᕈᓯᕝ 5 ᐊᒻᒪᓗ ᐊᒥᒐᐃᔭᕝ 28, 2019-ᒥᑦ. AMAR-1 ᐃᓂᐅᔫᒥᓚᐅᖅᑐᖅ ᐅᒥᐊᖅᔪᐊᓄᑦ ᐊᑉᖁᑎᒋᔭᐅᔪᒥᑦ ᑳ (Koluktoo Bay) ᐹᖕᒐᓂᑦ. AMAR-2 ᑳ (Koluktoo Bay)-ᒦᓚᐅᖅᑐᖅ, 6 ᑭᓛᒥᑕᓄᑦ ᐅᖕᒐᓯᒃᑎᒋᔪᒥᑦ ᐱᖕᒐᖕᓇᖕᒐᓂᑦ ᐅᒥᐊᖅᔪᐊᑦ ᐊᑉᖁᑎᖏᓐᓂᑦ. AMAR-3 ᐅᒥᐊᖅᔪᐊᑦ ᐊᑉᖁᑎᖕᒐᓂᑦ ᐅᑯᓂᖕᒐᓂᑦ ᕿᑭᖅᑕᑕᓇᖅ ᐊᒻᒪᓗ ᐃᓗᕕᓕᐅᑉ, 6 ᑭᓛᒥᑕᓄᑦ ᐅᖕᒐᓯᒃᑎᒋᔪᒥᑦ ᐅᐊᖕᓇᖕᒐᓂᑦ AMAR-1. ᓂᐱᓕᐅᕝᕕᐅᔪᓄᒃᑖᑦ ᓂᐱᐅᓃᓐᓇᓚᐅᖅᑐᑦ ᐃᓕᔭᐅᖕᒪᑕᒥᑦ ᐱᔭᐅᖕᒪᑕᒧᑦ, ᓂᐱᐅᓕᕆᓃᑦ 28-ᓄᑦ ᐅᐸᓅᓚᐅᖅᑐᑦ ᐊᑐᓂ ᓂᐱᓕᐅᕝᕕᖕᓂᑦ AMAR-B1-ᒥᑦ ᐊᒻᒪᓗ AMAR-RI-ᒥᑦ (ᓯᕗᓪᓕᖅᐹᑦ ᓂᐱᓕᐅᕐᓂᑦ), 55 ᐅᐸᓄᑦ ᐊᑐᓂ ᓂᐱᓕᐅᕝᕕᐅᔪᓂᑦ ᓂᒋᐊᓂᑦ ᕿᙳᐊ, ᐊᒻᒪᓗ 57 ᐅᐸᓄᑦ ᑐᓕᐊᓂᑦ ᓂᐱᓕᐅᕆᓇᒥᑦ AMAR-RI-ᒥᑦ.

ᖃᐅᔨᓴᕐᓂᐅᔪᑦ ᖃᐅᔨᓴᐃᓂᕐᒥᑦ ᐅᒥᐊᖅᔪᐊᑦ ᐃᖏᕋᔭᕆᐊᖏᖅᑎᓪᓗᒋᑦ (ᓯᑉᑎᑦ 7-ᒥᑦ ᐊᒋᓕᕈᓯᕝ 4, 2019-ᒥᑦ) ᐊᑭᐊᓂᑦ ᐊᒻᒪᓗ ᐃᒥᓕᖕᒥᑦ ᓂᐱᓕᐅᕝᕕᐅᔪᓄᑦ (AMAR-BI ᐊᒻᒪᓗ AMAR-RI) ᐊᖏᓪᓕᒋᕙᓪᓕᐊᓚᐅᖅᑐᑦ ᖃᐹᕐᖃᑦᑕᕐᓂᖏᓐᓄᑦ ᐊᑖᓂᑦ 1000 Hz-ᒧᑦ ᑕᖅᑭᐅᑉ ᐅᖕᒑᓄᑦ ᑕᒪᐋᓂᑦ ᓂᐱᓕᐅᕝᕕᐅᔪᓂᑦ. ᐊᖏᓪᓕᒋᕙᓪᓕᕐᓂᖅ ᐱᔾᔪᑕᐅᒐᓚᐅᖅᑐᖅ ᐅᒥᐊᖅᔪᐊᑦ ᐃᖏᕋᔭᕐᓂᖏᓐᓄᑦ (ᐃᓚᖏᑦ ᐱᓕᕆᐊᑉ ᐅᒥᐊᖅᔪᐊᖏᑦ ᐃᓚᖏᓪᓗ ᐱᔾᔪᑎᖃᖅᑐᑦ ᐊᐅᔭᖏᕐᓂᖕᒐᓄᑦ) ᐊᒻᒪᓗ ᓯᓚ ᐱᔾᔪᑎᕐᓗᒍ ᐊᒻᒪᓗ ᑕᕐᔪᕐᓂᒥᑦ ᓂᐱᐅᔪᑦ ᐃᓂᐅᔪᓂᑦ ᓯᑯᑕᖅᑐᐃᓐᓇᖅᓯᒪᓕᖅᑐᖅ. ᐃᒥᓕᖕᓂᑦ ᓂᐱᓕᐅᕈᑎ ᖁᑎᓛᓂᒃ ᓂᐱᖃᓚᐅᖅᑐᖅ ᐊᑭᐊᓂᐅᖕᒐᓂᑦ, ᐱᔾᔪᑕᐅᔪᒃᓴᐅᔪᖅ ᖃᓇᓂᖅᓴᐅᓂᖕᒐᓄᑦ ᐅᒥᐊᖅᔪᐊᑦ ᐊᑉᖁᑎᖕᒐᓂᑦ ᐊᒻᒪᓗ ᐃᑲᓐᓂᖅᓴᒥᑦ ᐃᓕᔭᐅᓯᒪᖕᒪᑦ (120 ᒦᑕᓂᒃ ᐃᒥᓕᖕᓂᑦ 330 ᒦᑕᐅᐸᓂ ᐊᑭᐊᓂᑦ); ᐃᒥᓕᖕᓂᑦ ᓂᐱᓕᐅᕈᑎ ᐅᒥᐊᖅᔪᐊᓄᑦ ᐊᑉᖁᓯᖅᑕᐅᑲᑦᑕᕐᓂᖅᓴᐅᔪᖅ, ᑯᕕᓂᖅᓄᑦ, ᐊᒻᒪᓗ ᖄᖕᒐᓂᑦ ᓂᐱᖃᕐᓂᐅᔪᓄᑦ. ᓂᐱᖃᕐᓂᐅᔪᑦ ᐅᖕᒐᑕᐅᑎᓪᓗᐅᖏᑦᑐᑦ ᑎᑭᐅᑎᓯᒪᔭᕆᐊᓕᖕᓄᑦ ᓂᐱᖃᕐᓂᕐᒧᑦ ᐋᓂᖅᓯᓂᕐᒧᑦ (ᑑᓴᔪᓐᓃᖅᓯᒪᓕᐅᕆᓪᓚᕐᓂᕐᒧᑦ ᑑᓴᔪᓐᓃᓪᓗᐊᕐᓂᕐᓄᑦ) ᓇᓕᑐᐃᓐᓇᖏᓐᓂᑦ ᓂᐱᓕᐅᕝᕕᖕᒍᑦ, ᖃᐅᔨᑐᓂᖕᒐ ᐊᑐᖅᑐ ᑲᓇᑕᒥᑦ ᑕᕆᐅᒥᑦ ᐊᒻᒪᓗ ᓯᓚᒥᑦ ᐊᐅᓚᑦᑎᔨᒃᑯᑦ (NOAA) ᒪᓕᒃᑕᐅᔪᒃᓴᖏᑦ ᖃᐅᔨᓴᐃᓂᐊᕐᓗᓂ ᓂᐱᖃᕐᓂᕐᒧᑦ ᐊᑐᖅᓯᓂᐅᔪᑦ ᑕᕆᐅᕐᒥᐅᑕᓄᑦ, ᓂᕐᔪᑎᓄᑦ ᐱᓕᕆᐊᑉ ᖃᓂᖕᒐᓃᑦᑐᓄᑦ. ᓂᐱᖃᕐᓂᐅᑉ ᓴᙱᓂᖓ (SPL) ᐅᖕᒐᑕᐅᑎᑦᑎᓚᐅᖅᓯᒪᖏᑦᑐᖅ 120 dB re 1 µPa-ᒥᑦ (ᑎᑭᐅᑎᓂᖅ ᐊᑐᖅᑯᔭᐅᔪᖅ

NOAA-ᑯᓐᓄᑦ ᐃᓘᐃᓯᓇᓂᕐᒧᑦ ᑕᕆᐅᕐᒥᐅᑕᓂᒃ) ᓂᐱᓕᐅᕆᓂᓘᑉᑖᒥᑦ; 1.9%-ᑐᐃᓐᓇᐃᑦ ᑲᑎᕐᓗᒋᑦ 28 ᐅᑉᓗᓂᒃ ᓂᐱᓕᐅᕆᓂᕐᒧᑦ AMAR-R1-ᒥᑦ ᐊᒻᒪᓗ 1.4% ᐊᔾᔨᖏᑦ ᑲᑎᕐᓗᒋᑦ ᓂᐱᓕᐅᕆᓃᑦ (28 ᐅᑉᓗᐃᑦ) AMAR-B1-ᒥᑦ.

ᐊᐅᔭᐅᑎᓪᓗᒍ ᓂᐱᓕᕆᓂᖅ (ᐊᑯᓪᓕᕈᕐᕕᒃ 4-ᒥᑦ ᐊᒥᕋᐃᔭᕐᕕᒃ 28, 2019-ᒧᑦ), ᐱᖕᒐᓱᑦ ᓂᐱᓕᐅᕆᖅᕖᑦ ᕿᙱᒍᐊ ᓂᕆᐊᓂᑦ 200 ᒦᑕᓪᓗᐊᓂᑦ ᐃᑎᓂᕐᒦᓚᐅᖅᑐᑦ. AMAR-1 ᐊᒻᒪᓗ AMAR-3 ᖁᑦᑎᖕᓂᖅᓴᓂᒃ ᓂᐱᖃᓚᐅᖅᑐᑦ 30-300 Hz-ᒦᑦᑐᓂᑦ, ᐱᔾᔪᑎᖃᖅᑐᖅ ᖃᓐᓂᖅᓴᐅᓂᖏᓐᓄᑦ ᐅᒥᐊᕐᔪᐊᑦ ᐊᑉᕐᑯᑎᖏᓐᓂᑦ. ᑕᒪᕐᒥᒃ ᐱᖕᒐᓱᑦ ᓂᐱᓕᐅᕐᕖᑦ ᕿᙱᒍᐊ ᓂᕆᐊᓂᑦ ᖁᑦᑎᒃᓯᓯᒪᓂᖃᓚᐅᖅᑐᑦ ᐳᓴᕐᑎᒃᑯᑦ ᖃᓂᑕᖕᒐᓂᑦ 20 kHz ᐱᔾᔪᑕᐅᑉᓗᑎᒃ ᑑᓛᓖᑦ ᓂᑉᓕᐊᓂᖏᑦ (AMAR-RI ᑕᒃᖃᐅᑎᑦᑎᓚᐅᖏᑦᑐᖅ ᖁᑦᑎᒃᓯᓯᒪᔪᓂᑦ ᖃᓂᑕᖕᒐᓃᑦᑐᓂᒃ 20 kHz). ᓂᐱᖃᕐᓂᖅ ᐅᖕᒐᑕᐅᑦᑎᓂᖃᓚᐅᖏᑕᐃᓐᓇᖅᑐᖅ ᑎᑭᐅᑎᓂᐅᔪᓄᑦ ᓂᐱᖃᕐᓂᕐᒧᑦ ᐋᓐᓂᖅᓯᓂᕐᒧᑦ (ᑑᓴᔪᖕᓃᖅᓯᒪᓚᐅᐱᓪᓚᖕᓂᕐᒧᑦ ᑐᓴᔪᖕᓂᒻᒪᕆᒃᑲᓂᓘᓐᓃᑦ) ᓇᓕᐊᖕᓂᑐᐃᓐᓇᖅ ᓂᐱᓕᐅᕆᕞᖃᖅᑐᓂᑦ, ᐊᑐᖅᓗᒋᑦ ᐊᑐᕐᑯᔭᐅᔪᑦ NOAA-ᑯᑦ ᒪᓕᕐᑯᔨᓂᖏᑦ ᖃᐅᔨᓴᐃᓂᕐᒧᑦ ᓂᐱᖃᕐᓂᕐᒧᑦ ᐊᒃᑐᖅᓯᓂᐅᔪᓂᒃ ᑕᕆᐅᕐᒥᐅᑕᓄᑦ, ᓂᕐᔪᑎᓄᑦ ᑕᐃᒪᐅᖃᑦᑕᖅᑐᑦ ᐱᓕᕆᐊᑉ ᖃᓂᑕᖕᒐᓂᑦ. ᐊᑕᐅᓯᖅ ᒥᓂᑦ-ᒥᑦ ᐊᒥᓱᑦ ᑲᑎᕐᓗᒋ SPL ᐅᖕᒐᑕᐅᑦᑎᑦᑎᐊᓚᐅᖏᑦᑐᖅ 120 dB re 1 μPa-ᒥᑦ ᑕᕆᐅᕐᒥᐅᑕᓂᒃ ᐃᓘᐃᓯᓇᓂᕐᒧᑦ ᑎᑭᐅᑎᓂᕐᒥᒃ ᓇᓕᑐᐃᓐᓇᖏᓐᓂᑦ ᓂᐱᓕᐅᕆᕝᕕᐅᔪᓂᑦ. ᐅᖕᒐᑕᐅᑦᑎᓃᑦ ᐊᑕᓯᕐᒥᓗᐊᖑᖃᑦᑕᓚᐅᖅᑐᖅ ᐱᖕᒐᓲᔪᓂᑦ ᓂᐱᓕᐅᕆᕝᕕᖕᓂᑦ ᕿᙱᒍᐊ ᓂᕆᐊᓂᑦ (AMAR-1, ᐅᒥᐊᕐᔪᐊᑦ ᐊᑉᕐᑯᑎᕆᖃᑦᑕᖅᑕᖕᒐᓃᑦᑐᖅ) 3%-ᖑᔪᖅ 55 ᐅᑉᓗᓄᑦ (ᑲᑎᕐᓗᒋᑦ ᓂᐱᓕᐅᕆᓃᑦ) ᐊᒻᒪᓗ ᓂᐱᖃᓗᐊᖏᓛᖑᔪᖅ (0.8% 55 ᐅᑉᓗᓂᒃ ᓂᐱᓕᐅᕆᓂᕐᓄᑦ) AMAR-2 (ᐃᓗᐊᓂᑦ ᖄ (Koluktoo Bay) ᐊᒻᒪᓗ ᐅᖕᒐᓯᕐᓚᐅᔭᖅᓗᓂ ᐅᒥᐊᕐᔪᐊᓄᑦ ᐊᑉᕐᑯᑎᒋᔭᐅᖃᑦᑕᖅᑐᒥᑦ.

ᐱᖕᒐᓱᓂᑦ ᑕᕆᐅᕐᒥᐅᑕᐃᑦ ᓂᐱᖏᑦ ᐃᓕᑕᕆᔭᐅᓚᐅᖅᑐᑦ ᓂᐱᓕᐅᖅᑕᐅᓯᒪᔪᓂᑦ. ᑑᓛᓖᑦ ᓂᑉᓕᐊᓂᖏᑦ ᓂᐱᓕᐅᕐᕕᓘᑉᑖᓂᓚᐅᖅᑐᑦ ᐊᑯᓪᓕᕈᕐᕕᒃ ᐱᒋᐊᓵᖅᑎᓪᓗᒍ ᐊᒥᕋᐃᔭᕐᕕᐅᑉ ᓄᙳᐊᓄᑦ. ᖃᑉᓯᐊᕐᔪᐃᑦ ᐊᕐᕖᑦ ᓂᑉᓕᐊᔪᑦ ᖃᐅᔨᔭᐅᓚᐅᖅᑐᑦ (ᐊᒻᒪᓗ ᐱᓕᕆᐊᕆᑉᓗᒋᑦ ᓇᓗᓇᐃᖅᑕᐅᑉᓗᓂ) ᐊᑯᓐᓂᖏᓐᓂᑦ ᐊᑯᓪᓕᕈᕐᕕᒃ 12 ᐊᒻᒪᓗ ᐊᒥᕋᐃᔭᕐᕕᒃ 4, 2019-ᒥᑦ ᒪᕐᕈᖕᓂᑦ ᐱᖕᒐᓲᔪᓂᑦ ᓂᐱᓕᐅᕆᕝᕕᖕᓂᑦ ᕿᙱᒍᐊ ᓂᕆᐊᓂᑦ, ᑕᒪᓐᓇ ᐊᔾᔨᒋᔭᖕᒐ ᐅᓂᑉᑲᖑᓚᐅᖅᑐᒥᑦ ᖃᐅᔨᔭᐅᔪᑦ ᐊᕐᕖᑦ ᐊᑯᓪᓕᕈᕐᕕᖕᒥᑦ ᐊᒻᒪᓗ ᐊᒥᕋᐃᔭᕐᕕᒃ ᐱᕆᐊᓖᖅᑎᓪᓗᒍ ᐃᓗᕕᓕᖕᒥᑦ. ᖃᑉᓯᐊᕐᔪᐃᑦ ᐋᕐᓗᐃᑦ ᓂᑉᓕᐊᔪᑦ ᖃᐅᔨᔭᐅᓚᐅᖅᑐᑦ (ᐊᒻᒪᓗ ᐱᓕᕆᐊᕆᑉᓗᒋᑦ ᓇᓗᓇᐃᖅᑕᐅᑉᓗᓂ) ᐊᑯᓐᓂᖓᓂ ᐊᑯᓪᓕᕈᕐᕕᒃ 31 ᐊᒻᒪᓗ ᐊᒥᕋᐃᔭᕐᕕᒃ 16, 2019-ᒥᑦ ᑕᒪᐃᓐᓂᑦ ᓂᐱᓕᐅᕐᕕᐅᔪᓂᑦ. ᑕᒪᓐᓇ ᓇᐃᑦᑑᔪᒥᑦ ᐋᕐᓗᐃᑦ ᓂᑉᓕᐊᓂᖏᑦ ᐊᔾᔨᒋᔭᖏᑦ ᐅᑎᖅᑕᖃᑦᑕᕐᓂᖏᓐᓄᑦ ᐃᓕᖅᑯᓯᖏᑦ ᖃᐅᔨᓴᐃᖅᕕᐅᔪᒥᑦ.

ᑐᓴᔭᐅᔪᖕᓇᕐᓂᖏᓐᓂᒃ ᒥᒃᓴᕆᐊᖅᑐᖅ - ᐃᓚᖓ ᒥᒃᓴᕆᐊᕐᓂᐅᔪᖅ ᒪᓂᒪᔪᓂᑦ ᑐᓴᔭᐅᔪᖕᓇᕐᓂᐅᔪᒥᑦ ᑕᕆᐅᕐᒥᐅᑕᐃᑦ - ᖃᐅᔨᔭᐅᓚᐅᖅᑐᖅ ᑑᓛᓕᖕᓄᑦ ᑕᓪᓕᒪᓘᑉᑖᓂᑦ ᓂᐱᓕᐅᕆᕝᕕᐅᔪᓂᑦ ᖃᓂᑦᑐᒥᑦ ᖃᐅᔨᓴᐃᕝᕕᐅᔪᒥᑦ. ᐅᒥᐊᕐᔪᐊᑦ ᓂᐱᖏᑦ ᖃᐅᔨᔭᐅᓚᐅᖅᑐᑦ 33%-ᖑᔪᓂᑦ ᑲᑎᕐᓗᒋᑦ ᓂᐱᓕᐅᖅᑕᐅᔪᓂᑦ AMAR-RI-ᒥᑦ ᐊᐅᔭᖅᑎᓪᓗᒍ (163-ᓂᑦ 493-ᖑᔪᓂᑦ ᐃᑲᕐᕋᐃᑦ) ᐊᒻᒪᓗ 29%-ᖑᔪᓂᑦ ᑲᑎᕐᓗᒋᑦ ᓂᐱᓕᐅᖅᑕᐅᔪᓂᑦ ᑕᐃᑲᓐᓂᑦᑕᐃᓐᓇᖅ ᓂᐱᓕᐅᕐᕕᐅᔪᒥᑦ ᐊᐅᔭᐅᑎᓪᓗᒍ (390-ᓂᑦ 1,345-ᖑᔪᓂᑦ ᐃᑲᕐᕋᐃᑦ). ᐅᒥᐊᕐᔪᐊᑦ ᓂᐱᖏᑦ ᖃᐅᔨᔭᐅᓚᐅᖅᑐᑦ 20%-ᖑᔪᓂᑦ ᑲᑎᕐᓗᒋᑦ ᓂᐱᓕᐅᖅᑕᐅᔪᓂᑦ (259-ᓂᑦ 1,297-ᖑᔪᓂᑦ ᐃᑲᕐᕋᐃᑦ) AMAR-1-ᒥᑦ, ᐊᒻᒪᓗ 15%-ᖑᔪᓂᑦ ᑲᑎᕐᓗᒋᑦ ᓂᐱᓕᐅᖅᑕᐅᔪᓂᑦ AMAR-2 (ᖄ-ᒥᑦ (Koluktoo Bay)) ᐊᐅᔭᐅᑎᓪᓗᒍ (195-ᓂᑦ 1,297-ᖑᔪᓂᑦ ᐃᑲᕐᕋᐃᑦ).

ᓂᐱᖃᕐᓂᕐᒧᑦ 1 kHz -ᒥᑦ (ᖃᑉᔫᖅᑕᕋᔪᖕᓂᖕᒐᓃᑦᑐᖅ ᑑᓛᓕᖕᓄᑦ ᐊᑦᑎᖕᓂᖅᓴᐅᑉᓗᓂ ᓂᐱᖏᑦ), ᐊᖏᓂᖅᓴᐅᓚᐅᖅᑐᖅ 50% LRR-ᒥᑦ 4.1% ᓂᐱᓕᐅᖅᑕᐅᓯᒪᔪᓂᑦ ᐅᒥᐊᕐᔪᐊᖅᐸᓗᒃᑲᑦᑕᖅᓱᑎᒃ AMAR-RI-ᒥᑦ ᐊᐅᔮᖅᑎᓪᓗᒍ, ᐊᒻᒪᓗ 3.3% ᓂᐱᓕᐅᖅᓯᒪᔪᑦ ᐅᒥᐊᕐᔪᐊᖅᐸᓗᒃᓱᑎᒃ ᐊᑕᐅᑦᑎᒃᑯᑦ ᑖᒃᑯᓂᑦᑕᐃᓐᓇᖅ ᓂᐱᓕᐅᖅᓯᒪᔪᒥᑦ ᐊᐅᔭᐅᑎᓪᓗᒍ. ᐊᖏᓂᖅᓴᐅᓚᐅᖅᑐᖅ 50% LRR-ᒥᑦ ᑖᑉᓯᒧᙵ ᓂᐱᒧᑦ ᑕᐃᒪᐅᖃᑦᑕᖅᓱᓂ 10%-ᒥᒃ ᓂᐱᓕᐅᕆᑎᓪᓗᒋᑦ AMAR-1-ᒥᑦ, ᐊᒻᒪᓗ 3.3%-ᒥᑦ AMAR-2-ᒥᑦ. ᐊᐅᔭᐅᑎᓪᓗᒍ, ᓂᐱᖃᕐᓂᖅ ᐊᑦᑎᖕᓂᖅᓴᐅᖕᒪᑦ ᑑᓛᓖᑦ ᑐᓴᓂᖏᓐᓂᑦ ᓂᐱᖃᕐᓂᐅᔪᒥᑦ, ᓂᐱᖃᕐᓂᐅᔪᖅ LRR-ᒥᑦ ᐊᖏᓂᖅᓴᐅᓚᐅᖅᑐᖅ 50%-ᒥᑦ ᓂᐱᖃᕐᓂᐅᔪᒧᑦ 0.1%, 0.9% ᐊᒻᒪᓗ 0.2%-ᑐᐃᓐᓇᐅᑉᓗᑎᒃ AMAR-RI-ᒥᑦ, AMAR-1, ᐊᒻᒪᓗ AMAR-2-ᒥᑦ. ᐊᖏᓂᖅᓴᐅᓚᐅᖅᑐᖅ 50%-ᒥᑦ ᓂᐱᖃᕐᓂᐅᔪᒧᑦ 5 kHz-ᒥᑦ (ᖃᑉᔫᖅᑕᕋᔪᖕᓂᖕᒐᓃᑦᑐᖅ ᑑᓛᓖᑦ ᐅᕖᖏᐊᖅᑐᕐᓂᖏᑦ ᐊᒻᒪᓗ ᓄᓇᒃᑰᕈᑎᕐᔪᐊᖅᐸᓗᒃ) ᑕᐃᒪᐅᖃᑦᑕᓚᐅᖅᑐᖅ 48.7% ᓂᐱᓕᐅᖅᑕᐅᓯᒪᔪᓂᑦ ᐅᒥᐊᕐᔪᐊᖅᐸᓗᒃᑲᑦᑕᖅᓱᑎᒃ AMAR-RI-ᒥᑦ ᐊᐅᔭᐅᑎᓪᓗᒍ. ᐊᐅᔭᐅᑎᓪᓗᒍ ᐊᖏᓂᖅᓴᐅᓚᐅᖅᑐᖅ 50%-ᒥᑦ ᓂᐱᖃᕐᓂᐅᔪᒧᑦ 5 kHz-ᒥᑦ 14.7%-ᒥᑦ ᓂᐱᓕᐅᖅᑕᐅᓯᒪᔪᓂᑦ ᐅᒥᐊᕐᔪᐊᖅᐸᓗᒃᓱᑎᒃ AMAR-RI-ᒥᑦ, 27%-ᖑᔪᑦ ᓂᐱᓕᐅᖅᑕᐅᓯᒪᔪᓂᑦ ᐅᒥᐊᕐᔪᐊᖅᐸᓗᒃᑲᑦᑕᖅᓱᑎᒃ AMAR-1-ᒥᑦ ᐊᒻᒪᓗ 9.6% ᓂᐱᓕᐅᖅᑕᐅᓯᒪᔪᓂᑦ ᐅᒥᐊᕐᔪᐊᖅᐸᓗᒃᑲᑦᑕᖅᓱᑎᒃ AMAR-2-ᒥᑦ. ᓂᐱᖃᕐᓂᖅ ᐊᖏᓂᖅᓴᐅᓚᐅᖅᑐᖅ 50% LRR-ᒥᑦ 24.5% ᓂᐱᓕᐅᖅᑕᐅᓯᒪᔪᓄᑦ ᐅᒥᐊᕐᔪᐊᖅᐸᓘᖏᕐᓱᑎᒃ AMAR-RI-ᒥᑦ ᐊᐅᔮᖅᑎᓪᓗᒍ, ᐊᒻᒪᓗ 15.5%, 29.3%, ᐊᒻᒪᓗ 14.7% ᐅᒥᐊᕐᔪᐊᖅᐸᓘᖏᕐᓱᑎᒃ AMAR-RI-ᒥᑦ, AMAR-1, ᐊᒻᒪᓗ AMAR-2-ᒥᑦ, ᐊᐅᔭᐅᑎᓪᓗᒍ. ᓂᐱᖃᕐᓂᐅᔪᒧᑦ 25 kHz-ᒥᑦ (ᖃᑉᔫᖅᑕᕋᔪᖕᓂᖕᒐᓃᑦᑐᖅ ᑑᓛᓕᒃᐸᓗᒃᑐᓄᑦ ᐊᒻᒪᓗ ᖁᑦᑎᖕᓂᖅᓴᐅᑉᓗᓂ ᓂᑉᓕᐊᓂᕐᒥᑦ), ᐊᖏᓂᖅᓴᐅᓚᐅᖅᑐᖅ 50% LRR-ᒥᑦ 50.8%-ᖏᓐᓂᑦ ᓂᐱᓕᐅᖅᑕᐅᓯᒪᔪᓂᑦ ᐅᒥᐊᕐᔪᐊᖅᐸᓗᒃᓱᑎᒃ AMAR-RI-ᒥᑦ ᐊᐅᔮᖅᑎᓪᓗᒍ, ᐊᒻᒪᓗ 24.4-ᒥᑦ 32.6, ᐊᒻᒪᓗ 33%-ᒥᑦ ᓂᐱᓕᐅᖅᑕᐅᔪᓂᑦ ᐅᒥᐊᕐᔪᐊᖅᐸᓗᒃᓱᑎᒃ AMAR-RI-ᒥᑦ, AMAR-1, ᐊᒻᒪᓗ AMAR-2-ᒥᑦ ᐊᐅᔭᐅᑎᓪᓗᒍ. ᓂᐱᖃᕐᓂᖅ ᐊᖏᓂᖅᓴᐅᓚᐅᖅᑐᖅ 50% LLR-ᒥᑦ 25 kHz-ᒥᑦ 36.7% ᓂᐱᓕᐅᖅᑕᐅᓯᒪᔪᓂᑦ ᐅᒥᐊᕐᔪᐊᖅᐸᓘᖏᕐᓱᑎᒃ AMAR-RI-ᒥᑦ ᐊᐅᔮᖅᑎᓪᓗᒍ, ᐊᒻᒪᓗ 32-ᒧᑦ, 45.9, ᐊᒻᒪᓗ 45.6%-ᒧᑦ ᓂᐱᓕᐅᖅᑕᐅᓯᒪᔪᓂᑦ ᐅᒥᐊᕐᔪᐊᖅᐸᓘᖏᕐᓱᑎᒃ AMAR-RI-ᒥᑦ, AMAR-1, ᐊᒻᒪᓗ AMAR-2-ᒥᑦ, ᐊᐅᔭᐅᑎᓪᓗᒍ. ᖃᓄᐃᖕᒐᓂᐅᔪᑦ ᓇᓗᓇᐃᖅᓯᔪᑦ ᓂᐱᖃᕐᓂᖅ ᐊᒃᑐᖅᓯᔪᖅ ᑐᓴᓂᖏᓐᓄᑦ ᑑᓛᓖᑦ ᐊᔾᔨᕐᓚᖕᒐᓂᒃ ᖃᓄᑎᒋᐅᓂᖕᒐᓄᑦ ᐅᒥᐊᕐᔪᐊᖅᐸᓗᖕᓄᑦ, ᐊᒻᒪᓗ ᐊᔾᔨᕐᓕᕆᔭᖕᒐ ᐊᖏᓂᖅᓴᐅᔪᕐᔫᓐᓃᑦ ᐃᓚᖏᓐᓄᑦ ᐅᒥᐊᕐᔪᐊᖅᐸᓗᒃᑎᓪᓗᒍ. ᓈᓴᐅᑎᐅᔪᑦ >90% LRR-ᒧᑦ ᐃᓚᐅᔪᑦ ᑖᕙᓂ ᐅᓂᑉᑳᒥᑦ.

ᓯᑯᓂᒃ ᓯᕐᑯᑉᑎᓇᔾᔪᑎᓂᑦ ᓂᐱᖃᕐᓂᐅᔪᓄᑦ ᓇᓚᐅᑦᑖᖅᑕᐅᔪᑦ (ᐱᓗᐊᖅᑐᒥᑦ, ᓂᐱᖃᕐᓂᕐᔪᐊᓄᑦ) ᐱᓕᕆᐊᖑᓚᐅᖅᑐᑦ ᐆᒃᑐᕋᖅᑕᐅᔪᓂᑦ

ᓯᑯᒥᑦ ᓯᕐᑯᑉᑎᕆᔾᔪᑦ MSV *Botnica*-ᒥᑦ ᐊᐅᓛᖅᑎᓪᓗᒍ ᖄᖏᕐᒪᒋᑦ ᐃᒪᐅᑉ ᐃᓗᐊᓃᑦᑐᑦ ᓂᐱᓕᐅᕈᑏᑦ, ᐱᖃᑎᒋᔭᐅᑉᓗᑎᒃ ᐱᖃᑎᒋᔭᐅᙱᔅᓱᑎᒡᓗ ᐅᔭᕋᒃᑕᖅᑕᐅᔪᓂᒃ ᐅᓯᔪᓂᒃ ᐅᒥᐊᕐᔪᐊᓄᑦ. ᐊᒥᓲᙱᓐᓂᖅᓴᐅᓚᐅᖅᑐᑦ ᓯᑯᒥᒃ ᓯᕐᑯᑉᑎᕆᔪᑦ 2019-ᒥᑦ, ᐅᒥᐊᕐᔪᐊᑦ ᐃᒪᒃᑯᑦ ᐅᓗᕆᐊᓇᙱᓐᓂᖅᓴᒃᑰᕈᒪᓚᐅᕐᒪᑕ. ᑕᐃᒪᓐᓇᒧᑦ, ᓯᑯᒥᑦ ᓯᕐᑯᑉᑎᕆᔪᓗᒃᑖᑦ ᐃᖏᕐᕋᔪᑦ ᖃᓂᑕᖏᓐᓂᑦ ᓂᐱᓕᐅᕈᑎᖃᖅᑐᐃᑦ ᐊᐅᔭᒃᑰᓚᐅᖅᑐᑦ. ᓂᐱᑐᓂᖃᖅᑐᑦ, ᐊᒻᒪᓗ ᐱᔭᐅᔪᑦ ᓂᐱᖃᕐᓂᐅᔪᓂᒃ ᐃᓚᒋᔭᐅᑉᓗᓂ ᖃᑉᓯᐊᕐᔪᖕᓂᑦ ᐅᒥᐊᕐᔪᐊᕐᓂᑦ, ᖃᓄᐃᓐᓂᖅᓴᐅᔪᖏᓐᓅᓚᐅᖅᑕᕗᑦ ᐋᖅᑭᐅᒪᔪᓄᑦ ᓇᓚᐃᑦᑖᖅᑕᐅᔪᑦ ᐊᕙᑎᒥᒃ ᖃᐅᔨᓴᐃᓂᕐᒧᑦ ᓯᑯᒥᒃ ᓯᕐᑯᑉᑎᕆᓂᖃᖅᑎᓪᓗᒋᑦ ᐹᕕᓐᓛᓐᑯᑦ ᑐᒃᓯᕋᐅᑎᖓᑦ ᑐᓪᓕᐊ ᐱᓕᕆᐊᕐᒧᑦ ᐊᖏᒡᓕᒋᐊᖅᓯᔪᒪᓂᕐᒧᑦ ᓄᓘᔾᔭᓂᑦ. ᓂᐱᖃᓗᐊᕐᓂᕐᒨᖓᔪᑦ, ᐊᑐᖅᑕᐅᔪᑦ ᓇᓚᐅᑦᑖᕆᓂᕐᒧᑦ ᓯᓚᒧᑦ ᑎᑭᐅᑎᓂᖏᑦ ᐃᒪᐅᑉ ᐃᓗᐊᓂᑦ ᓂᐱᖃᕐᓂᐅᔪᓂᑦ ᓯᑯᒥᒃ ᓯᕐᑯᑉᑎᕆᔪᓂᑦ ᑐᓪᓕᐊ ᐱᓕᕆᐊᕐᒧᑦ ᐊᕙᑎᒥᒃ ᖃᐅᔨᓴᐃᓂᕐᒧᑦ, ᐱᑕᖃᓗᐊᓚᐅᖏᑦᑐᖅ ᐆᒃᑐᕋᖅᑕᐅᔪᑦ ᑲᑎᑕᐅᔪᓂᑦ ᐊᐅᔮᖅᑎᓪᓗᒍ 2019-ᒥᑦ MSV *Botnica* ᐊᐅᓛᓚᐅᕐᒪᑦ ᐊᐅᔭᐅᑎᓪᓗᒍ; ᑭᓯᐊᓂ, ᐋᖅᑭᐅᒪᔪᖅ ᐅᖓᑎᓗᐊᖓᓄᑦ ᓇᓚᐅᑦᑖᓚᐅᖅᑐᖅ ᐊᑯᓂᐅᔪᒧᑦ ᐊᒻᒪᓗ ᓯᓚᒧᑦ ᑎᑭᐅᑎᓂᖏᑦ ᐃᒪᐅᑉ ᐃᓗᐊᓂᑦ ᓂᐱᖃᕐᓂᐅᔪᓂᑦ, ᖃᓄᐃᓐᓂᖅᓴᐅᔪᖏᓐᓅᖅᑕᐅᖕᒪᑕ ᐆᒃᑐᕋᖅᑕᐅᓯᒪᔪᓄᑦ ᓂᐱᖃᕐᓂᕐᒥᒃ ᐱᔭᐅᔪᓂᒃ ᐊᑯᓂᐅᓂᖅᓴᐅᔪᓄᑦ.

Executive Summary

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

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

The 2019 Passive Acoustic Monitoring Program was developed by JASCO Applied Sciences (JASCO), in collaboration with Golder Associates Ltd. (Golder) and Baffinland, to evaluate potential Project-related effects to marine mammals from shipping noise. The main objective of this program was to document ambient underwater noise levels at five acoustic monitoring stations (during the early shoulder season at two stations along the shipping route in Eclipse Sound and Milne Inlet North; and during the open water season at four stations in Milne Inlet (North and South). A secondary objective was to identify marine mammal presence (notably narwhal) at Milne Inlet South. The final objective was to evaluate Project-shipping noise levels in relation to established marine mammal acoustic thresholds for injury and disturbance and to compare measured sound levels from shipping activities during the shoulder season to modelled estimates used for environmental effects assessment.

A total of five underwater sound recorders (Autonomous Multichannel Acoustic Recorders, AMARs) were deployed as recording stations. AMAR−RI in North Milne Inlet (at Ragged Island) and AMAR−BI in Eclipse Sound (near Bylot Island) were deployed between 20/21 May and 4 Aug 2019; they were programmed to start recording underwater sounds on 7 Jul 2019. AMAR-RI was retrieved and redeployed to record between 4 Aug and 29 Sep 2019. Three stations in Milne Inlet South were deployed between 5 Aug and 28 Sep 2019. AMAR-1 was located on the shipping lane at the entrance of Koluktoo Bay. AMAR-2 was located in Koluktoo Bay, approximately 6 km west of the nominal shipping lane. AMAR-3 was located on the shipping lane between Poirier Island and Bruce Head, approximately 6 km north of AMAR-1. All stations continued recording from deployment until retrieval, for a recording duration of 28 days per station at AMAR-BI and AMAR-RI (first recording period), 55 days per station at Milne Inlet South, and 57 days for the second recording period at AMAR-RI.

The results of the ambient analysis for the early shoulder season (7 Jul to 4 Aug 2019) for the Bylot Island and Ragged Island recording stations (AMAR-BI and AMAR-RI) showed an increase in frequencies below 1000 Hz over the month of recording for both stations. This increase is largely attributed to the increase in vessel traffic (some of which is from the Project and some of which is related to the start of the open water season) and weather and wave induced noise at these locations due to decreasing ice presence. The Ragged Island recorder had overall higher sound levels than Bylot Island, likely due to it being closer to the shipping lanes and its shallower deployment location (120 m at Ragged Island compared to 330 m at Bylot Island); the Ragged Island station would have been exposed to a greater amount of vessel, flow, and surface sounds. Sound exposure levels never exceeded thresholds for acoustic injury (temporary or permanent hearing loss) at either recording location, based on criterion from the National Oceanic and Atmospheric Administration (NOAA) guidance for assessing acoustic impacts to marine mammals, for the species that occur in the Project Area. The sound pressure level (SPL) rarely exceeded 120 dB re 1 µPa (a threshold recommended by NOAA for disturbance of cetaceans) throughout the recording period; only for 1.9% of the total 28 day recording duration at AMAR-RI and 1.4% of the same total recording duration (28 days) at AMAR-BI.

During the open water season recording period (4 Aug to 28 Sep 2019), the three stations at Milne Inlet South were in approximately 200 m water depth. AMAR-1 and AMAR-3 had higher sound levels in the 30–300 Hz range, which is attributed to their closer proximity to the shipping lane. All three stations in Milne Inlet South had elevated percentile levels near 20 kHz that are attributed to the presence of narwhal echolocation clicks (AMAR-RI did not show elevated percentile levels near 20 kHz). Sound exposure levels never exceeded thresholds for acoustic injury (temporary or permanent hearing loss) at any recording location, based on criterion from NOAA guidance for assessing acoustic impacts to marine mammals, for the species that occur in the Project Area. The one-minute averaged SPL rarely exceeded the 120 dB re 1 µPa marine mammal disturbance threshold at any station. Such exceedances occurred most frequently at one of the three stations at Milne Inlet South (AMAR-1, located on the shipping lane) for 3% of the 55 days (total recording duration) and the least frequently (0.8% of the 55 day recording) at AMAR-2 (located inside Koluktoo Bay and away from the nominal shipping corridor).

Sounds from three marine mammal species were identified in the acoustic data. Narwhal vocalizations were found at all stations mainly from early August to late September. A few bowhead whale vocalizations were detected (and manually validated) between 12 Aug and 4 Sep 2019 at two of the three stations at Milne Inlet South, which is consistent with previously reported observations of bowhead whales in August and early September at Bruce Head. A few killer whale vocalizations were detected (and manually validated) between 31 Aug and 16 Sep 2019 at all stations. This short period of killer whale vocalizations is consistent with the migratory behaviour of this species in the study area.

Listening range reduction (LRR)—the fractional decrease in the available listening range for marine animals—was computed for narwhal at all five recording stations in the regional study area. Vessels were acoustically detected on 33% of the total recordings at AMAR-RI during the early shoulder season (163 out of 493 hours) and on 29% of the total recordings at the same station during the open water season (390 out of 1,345 hours). Vessels were acoustically detected on 20% of the total recordings (259 out of 1,297 hours) at AMAR-1, and on 15% of the total recordings at AMAR-2 (in Koluktoo Bay) during the open water season (195 out of 1297 hours).

For sound at 1 kHz (a frequency component of narwhal low-frequency buzzes), greater than 50% LRR occurred during 4.1% of recordings containing vessel noise at AMAR-RI during the early shoulder season, and 3.3% of recordings containing vessel noise at the same station during the open water season. Greater than 50% LRR for this frequency occurred during 10% of the recording period at the AMAR-1, and 3.3% at AMAR-2. During the open water season, since the median ambient sound level is lower than the narwhal hearing threshold at this frequency, ambient sounds resulted in LRR of greater than 50% for this frequency during only 0.1%, 0.9%, and 0.2% at AMAR-RI, AMAR-1, and AMAR-2, respectively. Greater than 50% LRR for sound at 5 kHz (a frequency component of narwhal whistles and knock trains) occurred during 48.7% of the recordings containing vessel noise at AMAR-RI during the shoulder season. During the open water season, greater than 50% LRR occurred at 5 kHz during 14.7% of the recordings containing vessel noise at AMAR-RI, 27% of the recordings containing vessel noise at AMAR-1, and 9.6% of the recording containing vessel noise at AMAR-2. Ambient noise resulted in greater than 50% LRR at 5 kHz for 24.5% of the recordings without vessel noise at AMAR-RI in the early shoulder season, and for 15.5%, 29.3%, and 14.7% of the recordings without vessel noise at AMAR-RI, AMAR-1, and AMAR-2, respectively, during the open water season. For sound at a frequency of 25 kHz (a frequency component of narwhal clicks and high-frequency buzzes), greater than 50% LRR occurred during 50.8% of recordings containing vessel noise at AMAR-RI during the early shoulder season, and during 24.4, 32.6, and 33% of recordings with vessel noise from AMAR-RI, AMAR-1, and AMAR-2 during the open water season. Ambient noise resulted in greater than 50% LRR at 25 kHz for 36.7% of the recordings without vessel noise at AMAR-RI in the early shoulder season, and for 32, 45.9, and 45.6% of the recordings without vessel noise at AMAR-RI, AMAR-1, and AMAR-2, respectively, during the open water season. These results indicate that ambient noise affects the listening range of narwhal at similar severity levels as vessel noise, and for similar or greater proportions of time as vessel noise. Corresponding values for >90% LRR are also provided in this report.

Icebreaker source level estimates (specifically, radiated noise levels) were computed from measurements of the icebreaker MSV *Botnica* as it transited past the underwater recorders, with and without ore carriers in escort. There was limited active icebreaking in 2019, as the vessels preferentially transited through safer open water conditions where possible. As such, all icebreaker transits near to the acoustic recorders occurred in open water conditions. Radiated noise levels, and received sound levels as a function of range from the vessels, were compared with modelled estimates computed for an environmental assessment of icebreaking activities conducted as part of Baffinland's Proposal for a Phase 2 expansion of the Mary River Project. Modelled radiated noise levels, used for estimating the spatial extent of underwater sounds from icebreaking activities in the Phase 2 environmental assessment, slightly under-represented the measurements collected in the early shoulder season of 2019 as MSV *Botnica* transited in open water conditions; however, the model overestimated the long-range propagation and the spatial extent of these generated underwater sounds, when compared to measured received sound levels at longer ranges.

1. Introduction

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.

To date, Baffinland has been operating in the Early Revenue Phase (ERP) of the Project, which includes shipping ore via Milne Port between July and October. Shipping of ore from Milne Port began in 2015 with the ERP and is expected to continue for the life of the Project (20+ years).

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, and provide early warnings of undesirable changes in the environment.
- Improve understanding of local environmental processes and potential Project-related cause-and-effect relationships.
- Provide feedback to the applicable regulators (e.g., NIRB) and advisory bodies (e.g., Marine Environmental Working Group (MEWG)) with respect to:
    - Potential adjustments to existing monitoring protocols or monitoring framework to allow for the most scientifically defensible synthesis, analysis, and interpretation of data.
    - Project management decisions requiring modifying operational practices where and when necessary.

This report presents the results of the 2019 Passive Acoustic Monitoring (PAM) Program 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, including possible changes in narwhal distribution, abundance, or migration patterns that could affect their availability for harvesting by local communities. In 2019, acoustic monitoring using acoustic recorders commenced during the early shoulder season and concluded at the end of the 2019 open water season. For the purposes of this report, the early “shoulder” season is the period at the front end of the shipping season when icebreaker activities occurred along the Northern Shipping Route. In 2019, this occurred between 17 and 29 Jul. The term “open water” season is used in the report to define the period when the ocean was mainly clear of heavy ice and no icebreaking activities occurred. In 2019, the open water season occurred between 30 Jul and 4 Oct, followed by a late shoulder season from 5 through 28 Oct when ice began to return to the area and icebreaker activities resumed along the Northern Shipping Route. Two acoustic recorders were deployed at the end of the open water season to record sounds through the late shoulder season. Those data are not included in this report.

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 was also specifically designed 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".*

The objectives of the 2019 PAM program were the following:

- Measure and report the ambient noise levels in representative areas along the Northern Shipping Route, including Milne Inlet (North and South) and in Eclipse Sound (Figure 1),
- Compare in-situ sound levels relative to modelled sound levels used for the environmental assessment of Baffinland's proposed Phase 2 expansion,
- Measure icebreaker noise emission levels and compare them with predicted emission levels used for the environmental assessment of Baffinland's proposed Phase 2 expansion,
- Determine marine mammal species (notably narwhal) acoustic presence in the Bruce Head region of 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 vessel transits along the Northern Shipping Route relative to ambient noise conditions, and
- Collect recordings that could be used to evaluate vessel noise signatures and potential changes in narwhal vocal behaviour in relation to shipping.

This last component is being analyzed separately as part of a collaboration between Baffinland, Golder, JASCO, and the marine mammal acoustic laboratory at the University of New Brunswick (UNB). Results will be presented in a separate report when those analyses are complete.

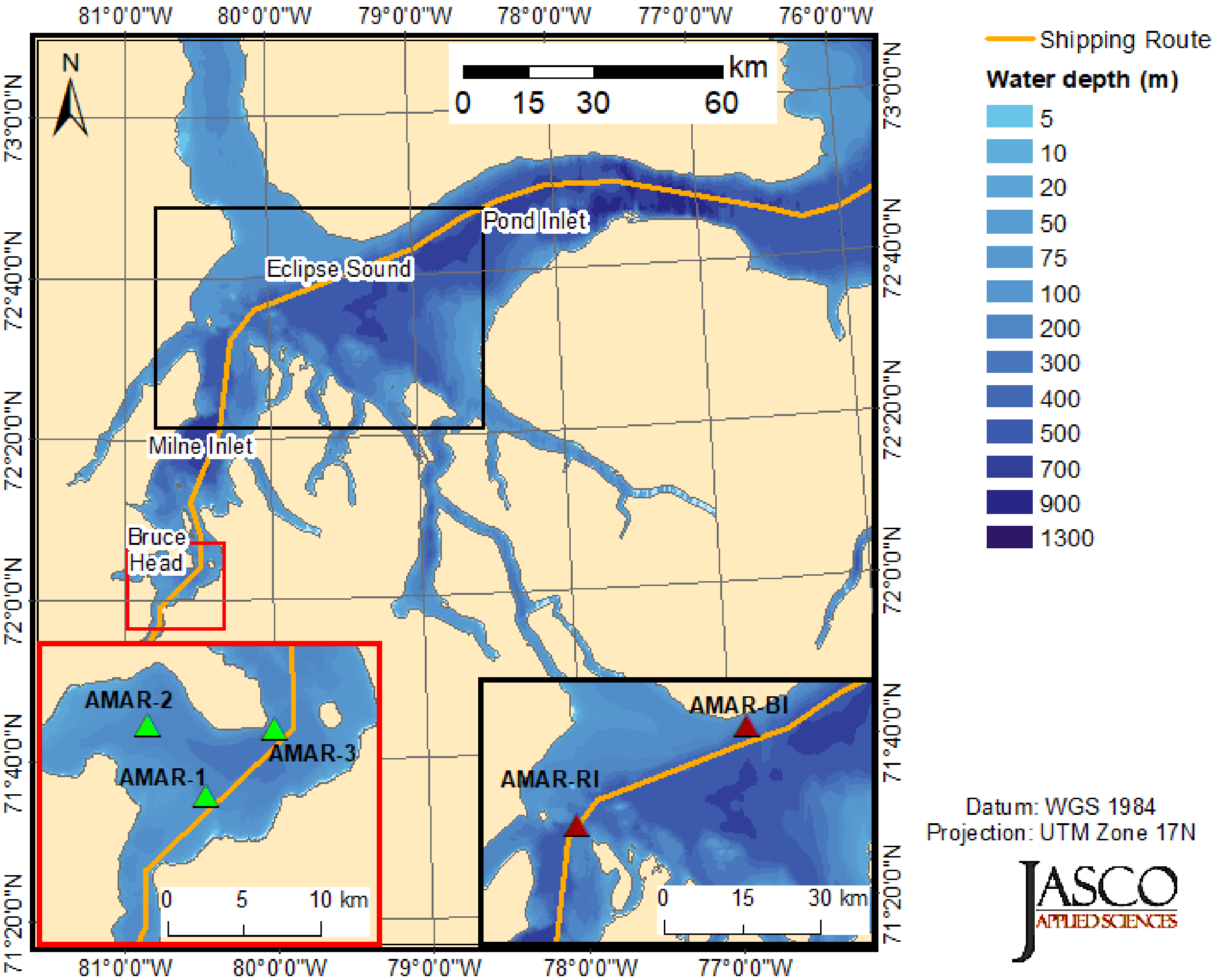


Figure 1. Acoustic monitoring area and locations of recorder stations along the Northern Shipping Route, including Milne Inlet South (red insert: AMAR–1, AMAR –2, and AMAR –3), Milne Inlet North (black insert: AMAR–RI), and Eclipse Sound (black insert: AMAR–BI).

1.1. 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 2017). The typical frequencies and spectral levels of natural and human-produced noise are shown on Wenz curves (Wenz 1962) (Figure 2), which show the variability of ambient spectral levels off the US Pacific coast as a function of frequency 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.

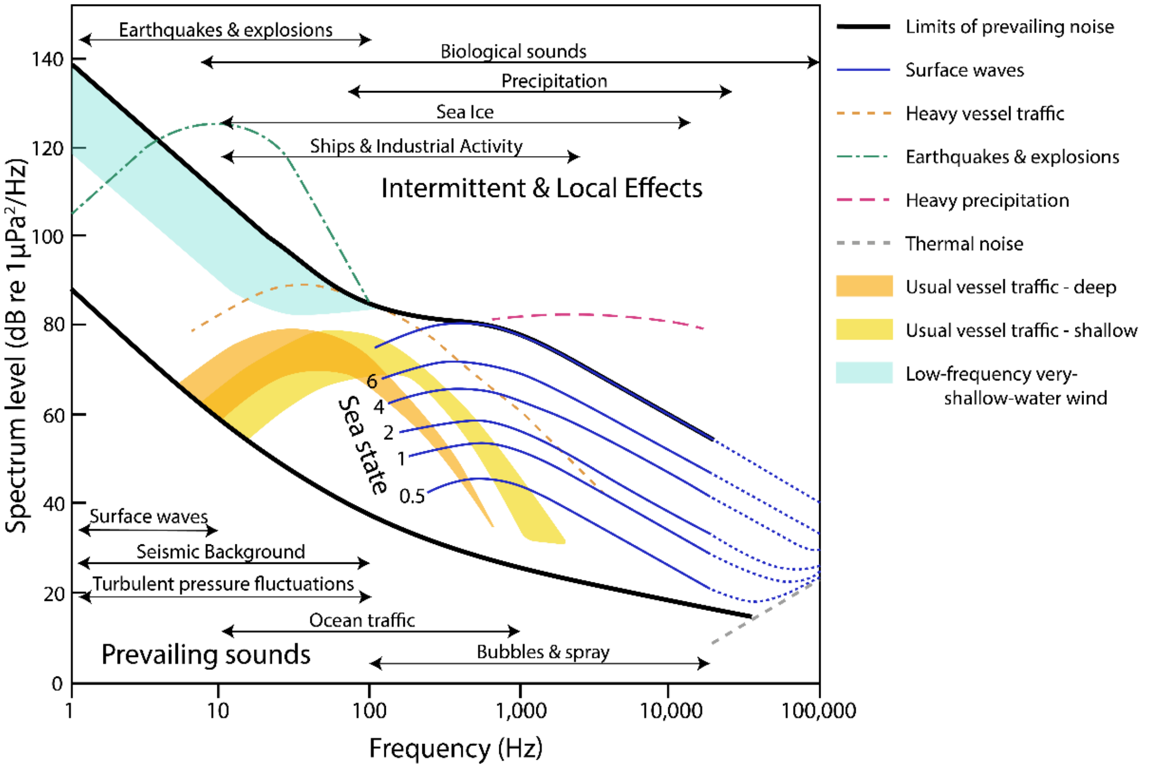


Figure 2. While the often cited “Wenz curves” show sea state dependent spectra only above 200 Hz, with a peak at ~500 Hz, Wenz showed measurements at lower frequencies (Wenz 1962). Spectrum levels exhibit a local minimum at ~100–200 Hz and rise for *f* <100 Hz.

1.2. Biological Contributors to the Marine Soundscape

Five cetacean species (bowhead whales, narwhals, beluga whales, killer whales, and sperm whales) and five pinniped species (ringed seals, bearded seals, harp seals, hooded seals, and walrus) 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, 2019b) 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]	No status[1,*]
Beluga whales	*Delphinapterus leucas*	Special concern[2]	No status[2]
Narwhals	*Monodon monoceros*	Special concern	No status*
Killer whales	*Orcinus orca*	Special concern[3]	No status[3,*]
Sperm whales	*Physeter macrocephalus*	Not at risk	Not listed
Pinnipeds			
Ringed seals	*Phoca hispida*	Special concern	No status
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, 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. In this report, the focus is on determining the general vocal presence, or absence, of marine mammal species (notably narwhal).

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 or tonal signals including baleen whale moans and odontocete whistles, and echolocation clicks produced by all odontocetes mainly for foraging and navigating. While the signals of most species in the Project area have been described to some extent, these are generally understudied and 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. 'NA' indicates that no automated detector was available for a species.

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

1.3. Anthropogenic Contributors to the Soundscape

Anthropogenic (human-generated) sound can be a by-product of vessel operations, such as engine sound radiating through vessel hulls and cavitating propellers, or it can be a product of active acoustic data collection, with seismic surveys, military sonar, and depth sounding being the main contributors. Marine construction projects often involve nearshore blasting and pile driving that can produce high levels of impulsive-type noise. The contribution of anthropogenic sources to the ocean soundscape has increased from the 1950s to 2010, largely driven by greater maritime shipping traffic (Ross 1976, Andrew et al. 2011). Recent trends suggest that global sound levels are leveling off or potentially decreasing in some areas (Andrew et al. 2011, Miksis-Olds and Nichols 2016). The main anthropogenic contributor to the total sound field in the present study was vessel traffic associated with the transport of iron ore.

1.3.1. Vessel Traffic

Project vessels, both those associated with transporting 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). During the 2019 shipping season, there were 231 one-way transits of Project related vessels, 177 of which occurred while the AMARs were deployed and recording acoustic data (Table 3).

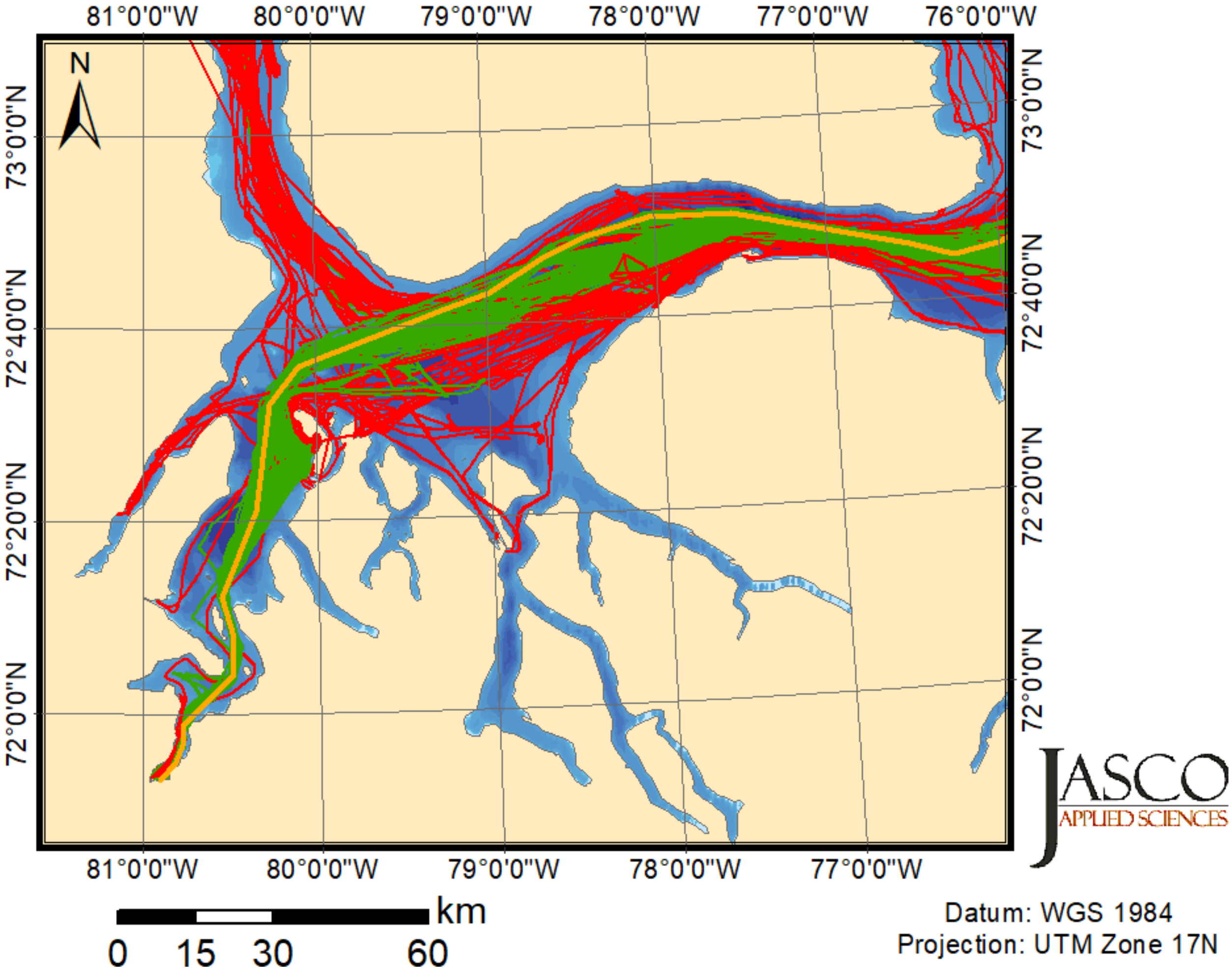


Figure 3. Vessel traffic travelling along the Northern Shipping Route (orange line) during the 2019 recording period; both Project-related vessels (green) and non-Project related vessels (red) are displayed, based on Automatic Identification System (AIS) vessel tracking data acquired from ground-based stations at Bruce Head and Pond Inlet, as well as AIS data collected by satellites (exactEarth 2020).

Table 3 Numbers of one-way transits for Project vessels during the 2019 shipping season.

Project Vessel Type	Number of one-way transits in 2019 shipping season	Number of one-way transits recorded by AMARs during 2019 shipping season
Ore carrier	164	131
Cargo / Supply	28	24
Tanker	10	9
Tug	6	4
Icebreaker	21	7
TOTAL	231	177

2. Methods

2.1. Acoustic Data Acquisition

2.1.1. Recording Configuration and Duration

Underwater sound was recorded with Autonomous Multichannel Acoustic Recorders–Generation 3 (AMAR G3, JASCO; Figure 4). Each AMAR was fitted with an M36-V35-100 omnidirectional hydrophone (GeoSpectrum Technologies Inc., −165 ± 3 dB re 1 V/µPa sensitivity). Because icebreaking was anticipated to generate high-amplitude sounds, the two AMARs deployed for the early shoulder season were also equipped with a second hydrophone, an M36-V0-100 omnidirectional hydrophone (GeoSpectrum Technologies Inc., −200 ± 3 dB re 1 V/µPa sensitivity) for wider dynamic range of recording. All devices were calibrated to within 1 dB using a pistonphone calibrator. The AMAR hydrophones were protected by a hydrophone cage, which was covered with a shroud to minimize noise artifacts from water flow. The AMARs recorded continuously on a duty cycle at 64,000 samples per second with a 6 dB gain for a recording bandwidth of 10 Hz to 32 kHz during 14 min, and then at 687,500 samples per second for a recording bandwidth of 10 Hz to 343.75 kHz during 1 min.

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

2.1.2. AMAR Recording Stations

AMARs were deployed at a total of five recording stations (see locations in Figure 1 and Table 4). AMAR−RI in Milne Inlet North and AMAR−BI in Eclipse Sound were deployed through the ice (Figure 5) on 20/21 May 2019 (the exact recorder locations were dictated by the depth limitations of the recorder pressure housings and the local bathymetry). These recorders were set with a delayed start to record underwater sounds between 7 Jul and 4 Aug 2019, at which time they were retrieved from the icebreaker MSV *Botnica* (Figure 6). AMAR–1, –2, and –3 in Milne Inlet South were deployed from MSV *Botnica* and recorded underwater sounds between 5 Aug and 28 Sep 2019. AMAR–RI in Milne Inlet North was retrieved and redeployed from MSV *Botnica* on 4 Aug and recorded underwater sounds until its retrieval on 29 Sep 2019.

All AMARs were retrieved from MSV *Botnica* using acoustic releases. All AMARs recorded as planned from deployment (or delayed recording start) until retrieval, for a recording duration of 28 days per AMAR (Eclipse Sound and Milne Inlet North – first recording period), 55 days per AMAR (Milne Inlet South), and 57 days for the second deployment at Milne Inlet North. Figure 7 provides details of the mooring design.

Figure 5. Through-ice AMAR deployment in Eclipse Sound in May 2019, supported by Tagak Outfitters (Photo: Ben Widdowson).

Figure 6. Vessel MSV *Botnica* used for both deployment and retrieval.

Table 4. Operation period, location, and depth of the Autonomous Multichannel Acoustic Recorders (AMARs) deployed in and near Milne Inlet (North and South) and in Eclipse Sound.

Station	Latitude	Longitude	Depth (m)	Deployment	Recording start	Retrieval	Recording duration (days)
AMAR-1	72.02756	−80.64772	190	5 Aug 2019	5 Aug 2019	28 Sep 2019	55
AMAR-2	72.07000	−80.75969	202.5	5 Aug 2019	5 Aug 2019	28 Sep 2019	55
AMAR-3	72.06717	−80.51808	223.5	5 Aug 2019	5 Aug 2019	28 Sep 2019	55
AMAR-RI	72.55747	−80.20761	120	20 May 2019	7 Jul 2019	4 Aug 2019	28
AMAR-RI	72.55803	−80.20856	121.5	4 Aug 2019	4 Aug 2019	29 Sep 2019	57
AMAR-BI	72.72328	−79.21328	330	21 May 2019	7 Jul 2019	4 Aug 2019	28

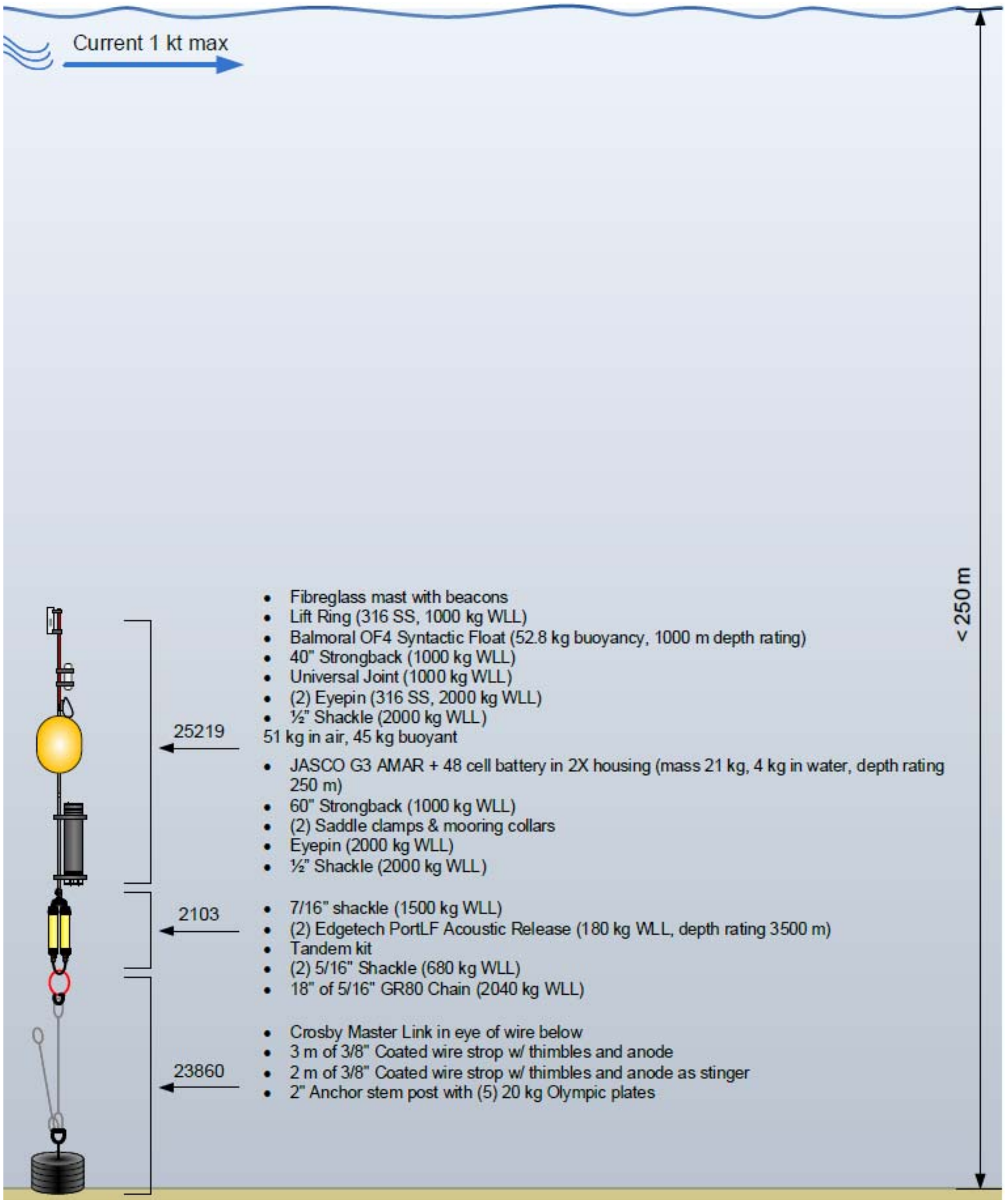


Figure 7. Mooring design with one Autonomous Multichannel Acoustic Recorder (AMAR) attached to an anchor. The hydrophone was 3 m above the seafloor. This configuration was used at all stations.

2.2. Automated Data Analysis

A total of 5.78 TB of acoustic data was collected during this study: 1.0 TB on AMAR–RI (first deployment), 1.0 TB on AMAR–BI, 1.26 TB on AMAR−1, 1.26 TB on AMAR−2, 1.26 TB on AMAR−3, and 1.26 TB on AMAR–RI (second deployment). Automated analysis of total ocean noise and sounds from vessels and marine mammal vocalizations was performed. Appendix B outlines the stages of the analyses.

2.2.1. Total Ocean Noise and Time Series Analysis

Ambient noise levels at each station were examined to document the local underwater sound conditions. Appendix A presents detailed descriptions of acoustic metrics and 1/3-octave-band analysis. In Section 3.1, ambient noise levels are presented as:

- Statistical distribution of sound pressure levels (SPL; L_p) in each 1/3-octave-band. The boxes of the statistical distributions indicate the first (L_{25}), second (L_{50}), and third (L_{75}) quartiles. The whiskers indicate the maximum and minimum range of the data. The solid line indicates the mean SPL, L_{mean}, in each 1/3-octave-band.
- Spectral density level percentiles: Histograms of each frequency bin per 1 min of data. The 1 min averaged, 1 Hz spectral density levels are summed over the 1/3-octave and decade bands to calculate the 1 min averaged broadband levels (dB re 1 µPa). They are presented with the density levels. Table A-1 lists the 1/3-octave-band frequencies. Table A-2 lists the decade-band frequencies. The L_{eq}, L_5, L_{25}, L_{50}, L_{75}, and L_{95} percentiles are plotted. The L_5 percentile curve is the frequency-dependent level exceeded by 5% of the 1 min averages. Equivalently, 95% of the 1 min spectral levels are above the 95th percentile curve. This approach, which is standard, leads to lower percentiles representing higher sound levels. The 50th percentile (median of 1 min spectral averages) can be compared to the Wenz ambient noise curves (Figure 2) (Wenz 1962).
- Broadband and approximate-decade-band SPL over time: The levels are defined for the 10 Hz to 25 kHz (broadband), and 10–100 Hz, 100 Hz to 1 kHz, and 1–10 kHz decade frequency bands.
- Spectrograms: Ambient noise at each station was analyzed by Hamming-windowed fast Fourier transforms (FFTs), with 1 Hz resolution and 50% window overlap. The 120 FFTs performed with these settings are averaged to yield 1 min average spectra.
- Daily sound exposure levels (SEL; $L_{E,24h}$): The SEL represents the total sound energy received over a 24-hour period. It has become a standard metric for evaluating the probability of temporary or permanent hearing threshold shift, much like the 8-hour accumulation period used for human workplace noise assessments. 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 unweighted SEL (10 Hz and above) were computed as well as the SEL weighted by the marine mammal auditory filters (AppendixA.3) (NMFS 2018). The 24-hour SEL metric is a standard measure of possible injury from long-term exposure to man-made sound (Southall et al. 2007, NMFS 2018). The SEL thresholds for possible hearing impacts from sound on marine mammals are provided in Table AE-1 of NMFS (2018). Thresholds for either temporary reduction or permanent loss in hearing sensitivity (Temporary Threshold Shift: TTS and Permanent Threshold Shift: PTS) have been determined. Note that these frequency weighting functions and hearing impact thresholds are consistent with those in Southall et al. (2019), though the latter use different nomenclature for the hearing group names. For each hearing group, the resulting weighted TTS onset thresholds are:
    - 153 dB re 1 µPa²·s for high-frequency cetaceans,

  - 178 dB re 1 µPa²·s for mid-frequency cetaceans,
  - 179 dB re 1 µPa²·s for low-frequency cetaceans,
  - 181 dB re 1 µPa²·s for phocid pinnipeds (underwater), and
  - 199 dB re 1 µPa²·s for otariid pinnipeds (underwater).

2.2.2. Vessel Noise Detection

Vessels were detected in two steps:

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

Vessel detections were defined by three criteria:

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

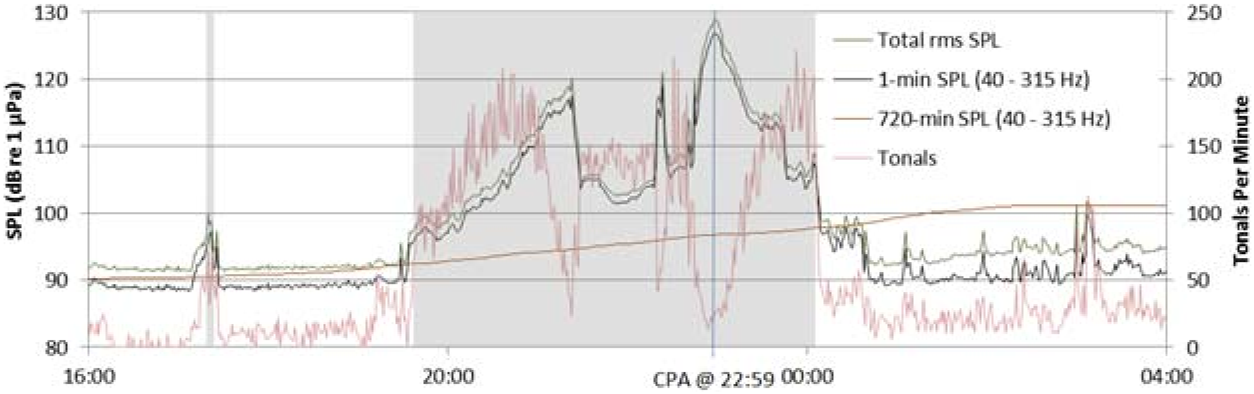


Figure 8. Example of broadband and 40–315 Hz band sound pressure level (SPL), as well as the number of tonals detected per minute as a ship approached a recorder, stopped, and then departed. The shaded area is the period of shipping detection. Fewer tonals are detected at the ship's closest point of approach (CPA) at 22:59 because of masking by broadband cavitation noise and due to Doppler shift that affects the tone frequencies and causes the detector to lose track of them.

2.2.3. Marine Mammal Detection Overview

The presence of sounds produced by marine mammals (notably narwhals) was determined using a combination of automated detectors and manual review by several experienced analysts. First, automated detectors identified acoustic signals potentially produced by odontocetes, mysticetes, and pinnipeds. There was no available specialized detector available for narwhal; thus, generic marine mammal vocalization detectors were modified and applied for this work (see Sections 2.2.3.1 and 2.2.3.2). Whistle detections and clicks detections made by the automated detectors were manually reviewed (validated) for a subset of the data set. Where detector results were found to be unreliable (detector precision <0.75, see Section 2.2.3.4), only the validated results are presented. Marine mammal species other than narwhals found during the manual validation of detector results are also presented.

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

2.2.3.1. *Click Detection*

Odontocete clicks are high-frequency impulses ranging from 5 to over 150 kHz (Au et al. 1999, Møhl et al. 2000). An automated click detector was applied to the 250 kHz sampled data (audio bandwidth up to 125 kHz for ~1 min every 15 min) to identify clicks from beluga whales and narwhals. This detector is based on zero-crossings in the acoustic time series. Zero-crossings are the rapid oscillations of a click’s pressure waveform above and below the signal’s normal level (e.g., see Figure B-1). Zero-crossing-based features of detected events are then compared to templates of known clicks for classification (see Appendix B.1.1 for details).

2.2.3.2. Tonal Signal Detection

Tonal signals are narrowband signals, often with harmonics, produced by many species across a range of taxa (e.g., baleen whale moans and delphinids whistles). The signals of some pinniped species, such as bearded seal trills, have also have tonal components with time-varying frequency. Baleen whale and pinniped tonal acoustic signals range predominantly between 15 Hz and 4 kHz (Berchok et al. 2006, Risch et al. 2007), thus detectors for these species were applied to the 64 ksps data (audio bandwidth up to 32 kHz for ~14 min every 15 min) and to the 250 kilosamples per second (ksps) data (audio bandwidth up to 125 kHz for ~1 min every 15 min). The tonal signal detector identified continuous contours of elevated energy and classified them against a library of marine mammal signals (see Appendix B.1.2 for details).

2.2.3.3. Narwhal-specific Vocalization Detection

Vocalization-specific automated detectors were developed for five types of narwhal-produced sounds: echolocation clicks, high-frequency buzzes, low-frequency buzzes, whistles, and knocks. Echolocation clicks are characterized by a sound energy from above 32 kHz down to ~10 kHz. High-frequency buzzes are defined as the prey capture buzz that results from a very high echolocation click rate. Low-frequency buzzes are made up of a series of short duration pulses that are given in rapid succession, with frequencies ranging from ~6 up to 24 kHz. Knocks are characterized as individual, impulsive broadband sounds that often are given in a short series. Whistles are continuous pure-tone signals with overtones These automated detectors were developed and optimized to detect every vocalization, rather than at least one vocalization per acoustic file, which is more typical of most presence/absence analysis. To achieve this goal, every narwhal vocalization in an acoustic file was fully annotated by a manual analyst to generate a truth data set. Acoustic files for the truth data set were selected to capture all vocalization types of interest, with an attempt to collect at least 10 files for each vocalization type, five of which contained high quality (e.g., high signal-to-noise ratio) vocalizations for training, and five of variable quality for testing. Also included were files where each vocalization type was absent but other acoustical signals, such as those from vessels, were present. This was done to evaluate false detection performance. When possible, the truth data spanned time of day, day of year, and locations, while using information regarding the occurrence of narwhal in the region (see Appendix B.1.3 for details).

2.2.3.4. Validation of Automated Detectors

Automated detectors are developed with training data files containing a range of vocalization types and background noise conditions. Training files cannot cover all possible vocalization types and noise conditions; therefore, a selection of files is manually validated to check each detector's performance for a specific station and timeframe, to determine how best to refine the detector results, or to decide if it is necessary to rely only on manually validated results of narwhal occurrence. Details of the file selection and validation process can be found in Appendix B.1.

To determine the performance of each detector and any necessary thresholds, the automated and validated results were input to a maximum likelihood estimation algorithm that maximizes the probability of detection and minimizes the number of false alarms using the 'F-score' (see Appendix B.1.2 for details). It also estimates the precision (P) and recall (R) of the detector. P represents the proportion of files with detections that are true positives. A P value of 0.9 means that 90% of the files with detections truly contain the targeted signal, but does not indicate whether all files containing acoustic signals from the species were identified. R represents the proportion of files containing the signal of interest that were identified by the detector. An R value of 0.8 means that 80% of files known to contain a target signal had automated detections, but it does not indicate how many files with detections were incorrect. An F-score is a combined measure of P and R where an F-score of 1 indicates perfect performance–all events are detected with no false alarms.

The algorithm determines a detector threshold for each species, at every station, that maximizes the F-score. Resulting thresholds, *P*s, and *R*s are presented in Section 3.3 and in further detail in Appendix C.

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

The occurrence of narwhals (both validated and automated) was plotted using JASCO's Ark software as time series showing presence/absence by hour over each day for the recording period. Marine mammal occurrence is also presented as spatial plots for each station. Both for the killer whale and bowhead whale detectors, the number of detections were too few to characterize the detector performance. Instead, only manual annotations were used.

2.3. Vessel Sound Level Analysis

Sound levels of the icebreaker MSV *Botnica* were determined by analyzing data recorded as it sailed over AMAR-RI and AMAR-BI during the early shoulder season. Vessel positions were obtained from Baffinland's shore-based AIS stations installed at Bruce Head and Pond Inlet. Recording times were accounted for clock drift (8–11 s) that occurred during the measurement period and then correlated with vessel position times from the AIS records. The data were visualized in Global Mapper (www.bluemarblegeo.com) to determine the tracks with the closest point of approach of MSV *Botnica* to the AMARs, with the greatest distances from the accompanying ore carriers. Five suitable tracks past AMAR–BI were analyzed (Table 5) to characterize the sound levels emitted by MSV *Botnica* while it was transiting in open water. MSV *Botnica* did not transit directly over either recorder during the early shoulder season in ice conditions that would have required the vessel to actively break ice. The nearest icebreaking recording was collected while MSV *Botnica* was breaking ice several kilometres away from AMAR–RI. During this time, the ore carriers were nearer to the AMAR and thus dominated those recordings, precluding them from this analysis.

Received sound levels during these open water transits were computed in 1-second, Hann-weighted time windows with 50% overlap. Due to the closest point of approach (CPA) being less than the water depth at the recorder position (330 m), radiated noise levels (RNL) were computed from received levels using a spherical spreading transmission loss assumption, i.e., 20 log *r*, where *r* represents slant range in metres from the ship to the hydrophone. The slant range between the vessel and the hydrophone was computed using AIS data, AMAR deployed location, estimated hydrophone depth based on the mooring design, and an assumed source depth of 5.46 m (computed using 0.7 times the MSV *Botnica* draft of 7.8 m).

Table 5. MSV *Botnica* open water transits recorded on AMAR–BI used to derive radiated noise level estimates. Dates and times are in UTC.

Transit #	Date	Time of closest point of approach	Nearest horizontal range to AMAR (m)	Speed (kn)	Course heading (°)	Escorted vessels* and respective ranges from AMAR during *Botnica* closest point of approach
1	18 Jul 2019	09:45	<70	8.7	250.4	*Nordic Odin* (1 km), *Nordic Oasis* (4.2 km), *Ocean Taiga* (6.4 km)
2	19 Jul 2019	06:39	<120	8.3	71.3	None
3	20 Jul 2019	13:33	<64	8.4	250	*NS Yakutia* (1.6 km), *NS Energy* (3.9 km)
4	22 Jul 2019	15:36	<43	8	250.6	*Sagar Samrat* (2.7 km), *Nordic Oshima* (4.4 km), *Nordic Odyssey* (6.2 km)
5	23 Jul 2019	23:44	<82	8.2	65.4	*NS Yakutia* (1.4 km), *NS Energy* (3.3 km)

* *Nordic Odin, Nordic Oasis, NS Yakutia, NS Energy, Sagar Samrat*, and *Nordic Oshima* are ore carriers. *Ocean Taiga* is a Project-related tug.

2.4. 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. 2018a), 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. (2018b), 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 1/3-octave-bands that are representative of the important listening frequencies for animals of interest.

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

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 under natural ambient conditions (i.e., representing the proportional reduction in distance at which a signal of interest can be heard, in the presence of noise). LRR does not provide absolute areas or volumes of space. However, a benefit of the LRR method is that it does not rely on source levels of the sounds of interest, which is often unknown. Instead, the method depends only on the transmission loss.

LRR was calculated for three frequencies representative of five types of narwhal vocalizations, for all five 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). At each location, LRR was determined for narwhal low-frequency buzzes (or burst pulses) using 1 kHz as the representative frequency, for whistles and knock trains using 5 kHz as a representative frequency (mean frequency; Marcoux et al. 2012), and for clicks and high-frequency buzzes using 25 kHz as a representative frequency (25 kHz is the maximum 1/3-octave available for data sampled at 64 kHz; narwhal mid-frequency clicks have a mean frequency of ~10 kHz (Stafford et al. 2012); high-frequency clicks have a centre frequency of 53 kHz; (Rasmussen et al. 2015)). The data were divided into periods with and without vessel detections. The normal listening range was determined using the maximum of the mid-frequency cetacean audiogram (see Table A-9 in Finneran 2015) or the median 1-minute SPL without vessels in each of the 1/3-octave-bands of interest as the baseline hearing threshold (Table 6). The geometric spreading coefficient was set to a nominal value of 15. The analysis was performed for each 1 dB of increased 1/3-octave-band SPL above the normal condition.

Table 6 Parameters used to determine the normal condition, NL_1, in calculations of LRR.

1/3-ocatve Band Center Frequency (kHz)	1/3-ocatve Band Median Baseline Ambient Level						MF Cetacean Hearing Threshold*
	Early Shoulder Season		Open Water Season				
	AMAR-RI	AMAR-BI	AMAR-1	AMAR-2	AMAR-3	AMAR-RI	
1	78.7	83.9	88.7	90.4	87.5	83.5	96.7
5	78.4	82.2	86.2	86.3	86.0	81.3	74.1
25	72.6	74.6	82.7	81.2	79.8	76.4	57.2

*from Finneran 2016, Equation A-9 and Table A-3

3. Results

Ambient noise and vessel detections along the Northern Shipping Route were quantified at Milne Inlet (North and South) and in Eclipse Sound, as described in Section 3.1 and 3.2. Three species of cetaceans were identified in Milne Inlet South through the marine mammal sound detection analysis: narwhals, killer whales, and bowhead whales. These results are provided in Sections 3.3 and 3.4. Section 3.5 contains the sound level characterization of the icebreaker MSV *Botnica* from recordings collected during the early shoulder season. Results of LRR computations are in Section 3.6

3.1. Ambient Noise Measurements

3.1.1. Ambient Sound levels

This section presents sound level statistics derived from the five AMAR data sets using the following formats:

1. **Band-level plots**: These strip charts show the 1-hour averaged received SPL as a function of time within a given frequency band for the nominal decade bands: 10–100 Hz, 100–1000 Hz, 1000–10000 Hz, and broadband 10–25 kHz. The 10–100 Hz band largely represents noise from large shipping vessels or seismic surveys. It can also include contaminating noise generated by movement of the acoustic mooring. The 100–1000 Hz band contains substantial shipping noise but it is often also influenced by wind and wave noise. It can include sounds produce by ringed and bearded seals, walrus, bowhead whale, and pulse vocalizations of narwhal. Sounds above 1000 Hz can include sounds made by ringed seals, bearded seals, walrus, bowhead whales, killer whales, beluga whales, narwhal whistles and clicks, wind and wave noise, and close-range ships (Figures 14 to 17).
2. **Long-term Spectral Averages (LTSAs)**: Color plots, also known as spectrograms, showing 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. We used 1 second fast-Fourier transform was applied, with 50% overlap. A 1 minute resolution was obtained by averaging 120 of the 1-second samples. The LTSAs provide a good overview of the temporal and frequency variability in the data.
3. **Distribution of 1/3-octave-band SPL**: These box-and-whisker plots show average and extreme sound levels in each 1/3-octave-band. One-third octave-bands represent approximately the critical bandwidth of hearing bands of many mammals (see Appendix A). They are often used as bandwidths for expressing the source level of broadband sounds such as shipping and seismic surveys. The distribution of 1/3-octave-band SPL can be used as the noise floor for predicting the ability of marine mammals to detect important sounds such as other marine mammal vocalizations.
4. **Power Spectral Densities (PSDs)**: These plots show the spectral distributions in two formats: first, the percentile power spectra (SPL in 1 Hz frequency bands versus frequency). These levels can be directly compared to the Wenz curves (Figure 2). The second plot format shows the spectral probability density (Merchant et al. 2013) that indicates the distribution of spectral levels over time. This format can illustrate when distributions are multi-modal – i.e., have more than one common spectral shape characteristic, such as a calm-wind condition and high-wind condition or a vessel present condition.
5. **Cumulative Distribution Functions:** 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.

3.1.1.1. Early Shoulder Season

The results of the ambient analyses for the early shoulder season (7 Jul to 4 Aug 2019) are shown in Table 7 and Figures 9–11 for the Bylot Island (BI) and Ragged Island (RI) AMAR recording stations. Weekly plots of each result type appear in Appendix D. Both AMAR stations showed an increase in SPL for frequencies under 1000 Hz over the month of recording. This increase is largely attributed to the increase in vessel traffic, weather, and wave induced noise at these locations due to decreasing ice presence and the beginning of the shipping season. The two AMAR stations were located near the main shipping route into Milne Inlet North and Eclipse Sound. The Ragged Island station (AMAR–RI), showed increased SPL in the 10–30 Hz range at regular intervals corresponding with the peak flow times of the tidal cycle. During deployment, the field team noticed high tidal velocities at this location. Figure 13 shows a short-term spectrogram of the low frequencies during one of the time periods of higher sound levels and demonstrates a current-induced vibration of the mooring that was recorded by the hydrophone. These elevated levels did not occur during the second (open water) recording period at this station or any other station. This indicates that the cause was likely a subtlety of the mooring component connections, in combination with the deployment location and flow speeds. The Ragged Island recorder had overall higher sound levels than the Bylot Island recorder, likely due to AMAR–RI's shallower deployment location (120 m at Ragged Island compared to 330 m at Bylot Island). AMAR–RI would have been exposed to a greater amount of vessel, flow, and surface sounds. Curves showing empirical distribution functions, or SPL exceedance percentages, are shown in Figure 12. These show that 98.1% and 98.6% of the data were below 120 dB re 1 µPa at AMAR-RI and AMAR-BI, respectively. Or, recorded levels at these locations exceeded 120 dB re 1 µPa for only 1.9% and 1.4% of the recording periods.

Table 7. Broadband sound pressure level (SPL) values for Milne Inlet North (AMAR−RI) and Eclipse Sound (AMAR–BI) during early shoulder season shipping.

Station	Min. broadband SPL (dB re 1 µPa)	Max. broadband SPL (dB re 1 µPa)	Mean broadband SPL (dB re 1 µPa)
AMAR−RI	80.2	151.3	102.2
AMAR−BI	83.9	141.7	99.7

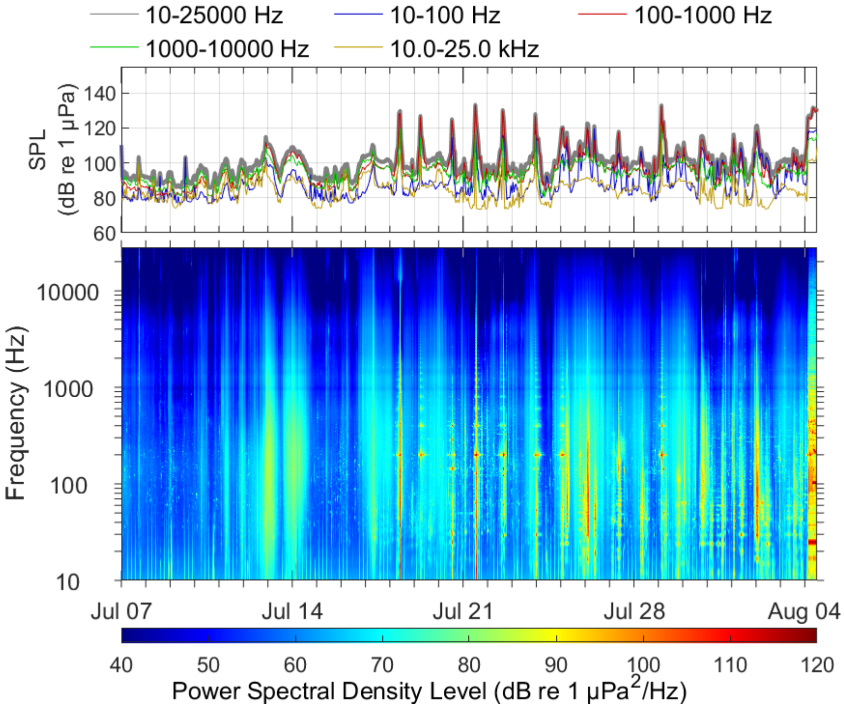


Figure 9. AMAR–BI: (Bottom) spectrogram and (top) in-band sound pressure level (SPL). Vessel transits associated with the Mary River Mine commenced on 17 Jul 2019. Sharp peaks in the SPL time series indicate vessel transits past the recorder.

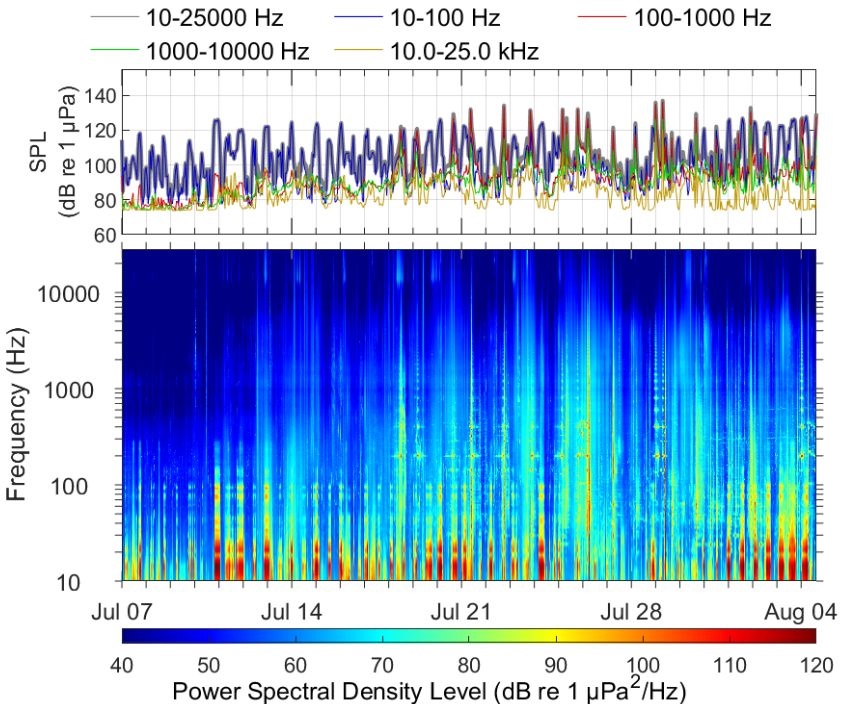


Figure 10. AMAR–RI (first deployment): (Bottom) spectrogram and (top) in-band sound pressure level (SPL). Vessel transits associated with the Mary River Mine commenced on 17 Jul 2019. Sharp peaks in the SPL time series that indicate vessel transits past the recorder are most identifiable in the 1000–10000 Hz band that is less impacted by flow noise at this recorder that is dominant in the 10–100 Hz band.

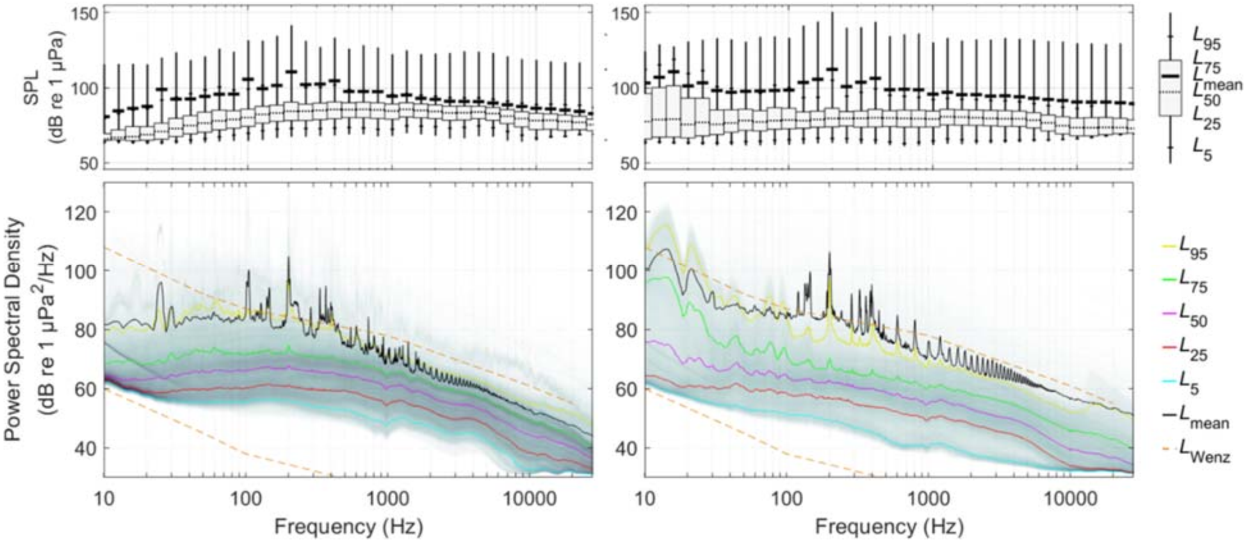


Figure 11. Stations for (left) AMAR−BI and (right) AMAR−RI (first deployment): Percentiles and mean of 1/3-octave-band sound pressure level (SPL) and percentiles and spectral probability density (grayscale) of 1-min power spectral density levels (bin width: 1 Hz) compared to the limits of prevailing noise (Wenz 1962). L_{mean} is the arithmetic mean (ISO 2017).

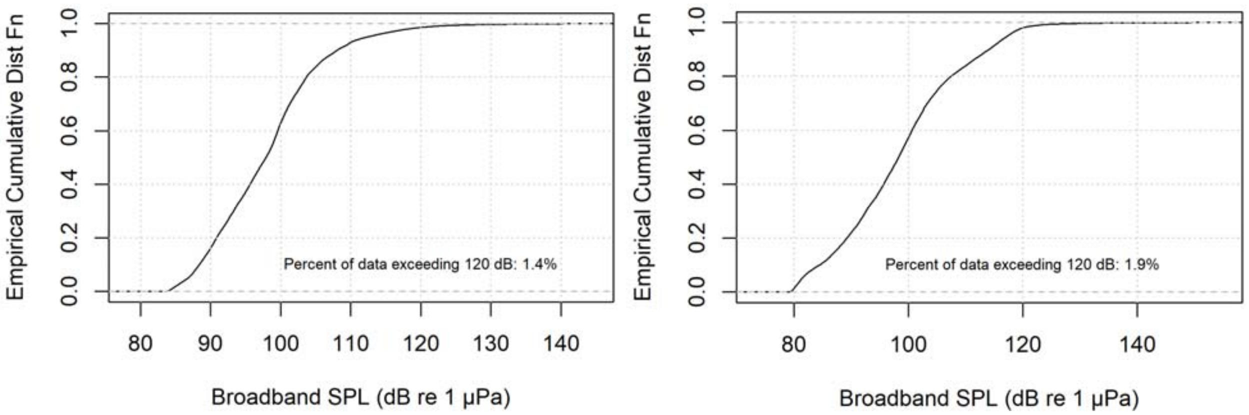


Figure 12. Empirical cumulative distribution functions for (left) AMAR−BI and (right) AMAR−RI (first deployment).

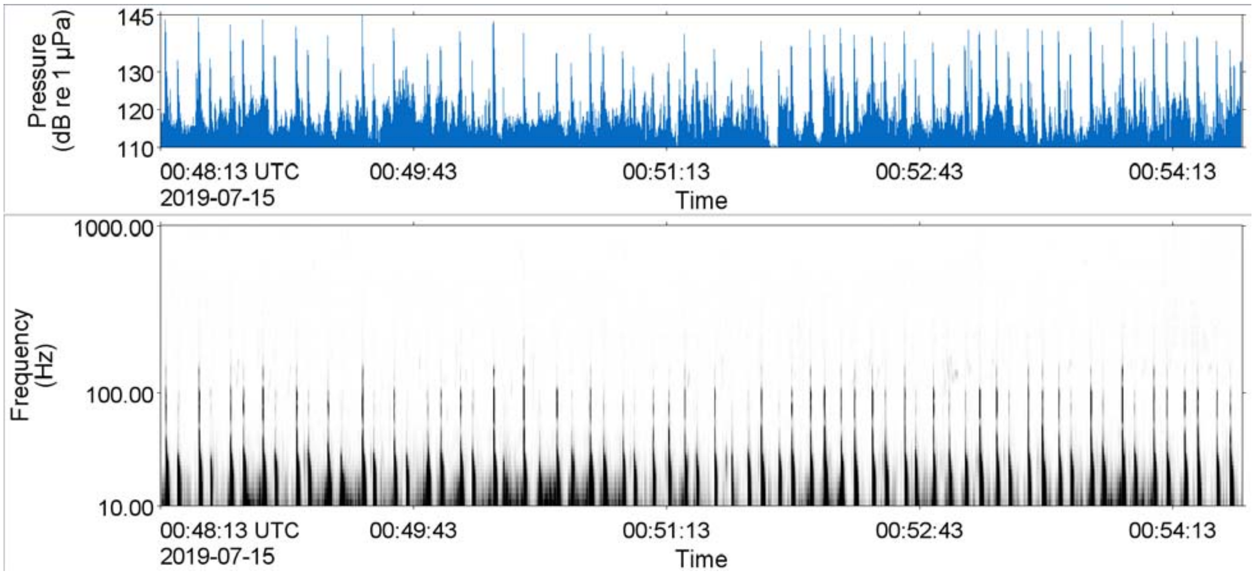


Figure 13. Example of elevated low-frequency sound recorded at AMAR-RI (Ragged Island).

3.1.1.2. Open Water Season

The LTSAs and band-level plots for the four AMAR stations deployed during the open water period are shown in Table 8 and Figures 14 through 17, and the corresponding finer-scale weekly plots are provided in Appendix D. For this recording period, the Ragged Island station (AMAR–RI) was redeployed at the same location as the early shoulder season. The Bylot Island station (AMAR–BI) was not redeployed during the open water season. However, three additional AMARs were deployed near Bruce Head, within Milne Inlet South. AMAR–1 and –3 were deployed on the nominal shipping lane, and AMAR–2 was deployed at the entrance of Koluktoo Bay. AMAR–1, –2, and –3 were in approximately 200 m water depth.

AMAR–1 and –3 recorded higher sound levels in the 30–300 Hz range, which is attributed to their closer proximity to vessel traffic (Figure 18). AMAR–1, –2, and –3 had elevated percentile levels near 20 kHz (Figure 18) that are attributed to the presence of narwhal echolocation clicks (Figures 14, 15, and 16). AMAR-RI did not show elevated percentile levels near 20 kHz (Figure 18), clicks were not acoustically detected at this station (Figure 17). Empirical distribution function curves showing SPL exceedance percentages are shown in Figure 19. These plots illustrate that exceedances of 120 dB re 1 µPa were rare at all stations. Recorded SPL exceeded 120 dB re 1 µPa for 3% of the recording period at AMAR-1 (the highest percentage of all AMAR recording locations), located on the nominal shipping route, and for only 0.8% of the recording period at AMAR-2 located in the entrance to Koluktoo Bay.

Table 8. Broadband sound pressure level (SPL) values for Milne Inlet South (AMAR−1 to −3) and Milne Inlet North (AMAR–RI) during open water season shipping.

Station	Min. broadband SPL (dB re 1 µPa)	Max. broadband SPL (dB re 1 µPa)	Mean broadband SPL (dB re 1 µPa)
AMAR−1	80.7	150.2	103.3
AMAR−2	82.1	153.9	103.6
AMAR−3	80.1	145.2	102.7
AMAR−RI	80.3	154.1	98.2

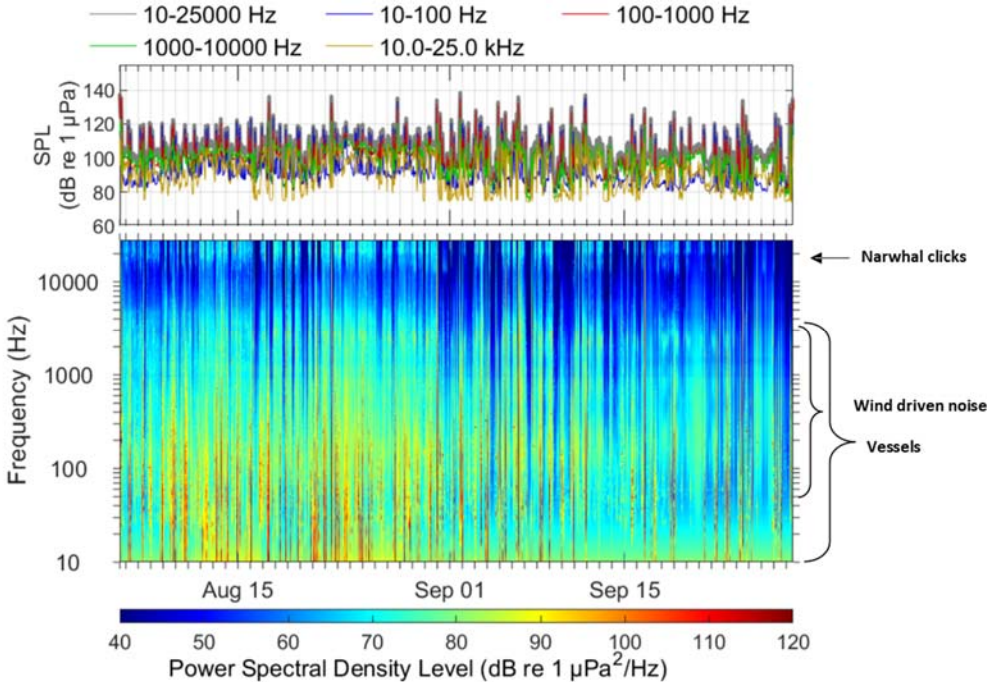


Figure 14. AMAR−1: (Bottom) spectrogram and (top) in-band sound pressure level (SPL).

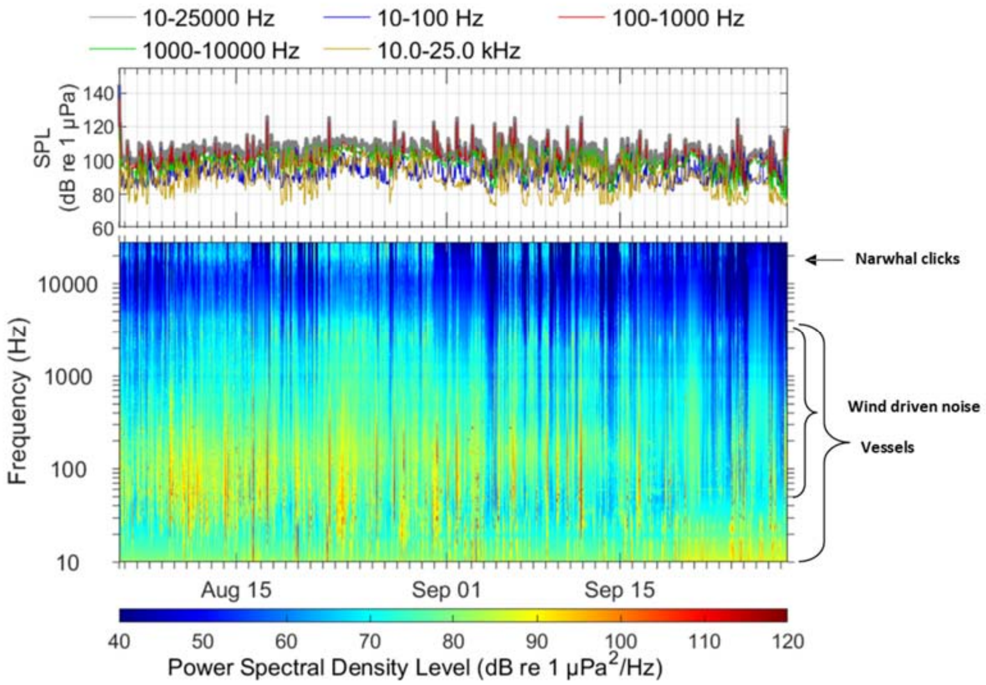


Figure 15. AMAR−2: (Bottom) spectrogram and (top) in-band sound pressure level (SPL).

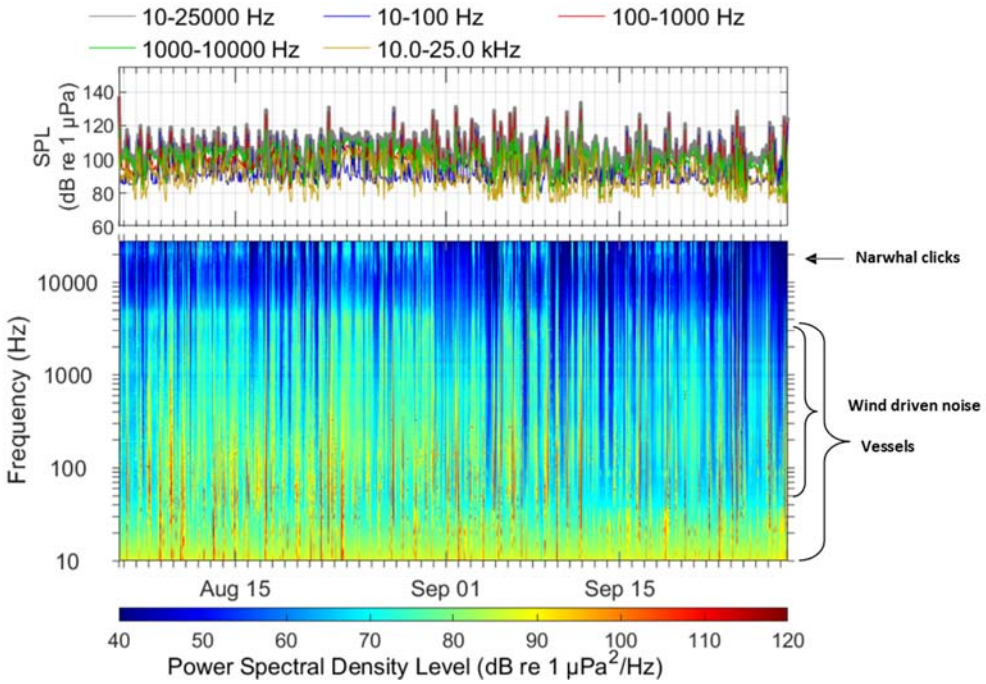


Figure 16. AMAR−3: (Bottom) spectrogram and (top) in-band sound pressure level (SPL) underwater sound.

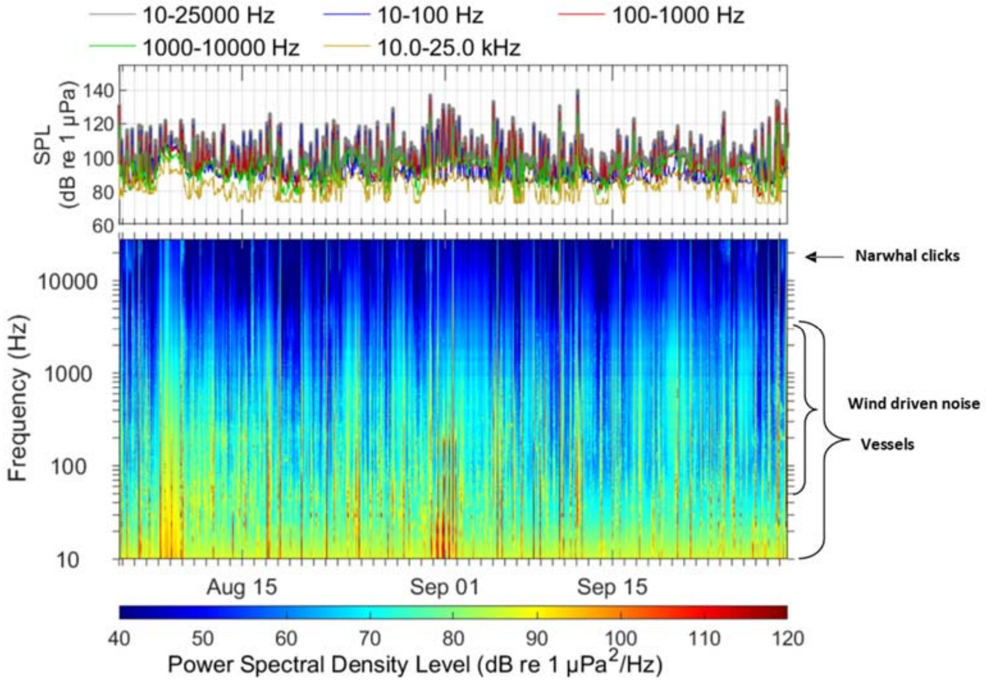


Figure 17. AMAR−RI: (Bottom) spectrogram and (top) in-band sound pressure level (SPL).

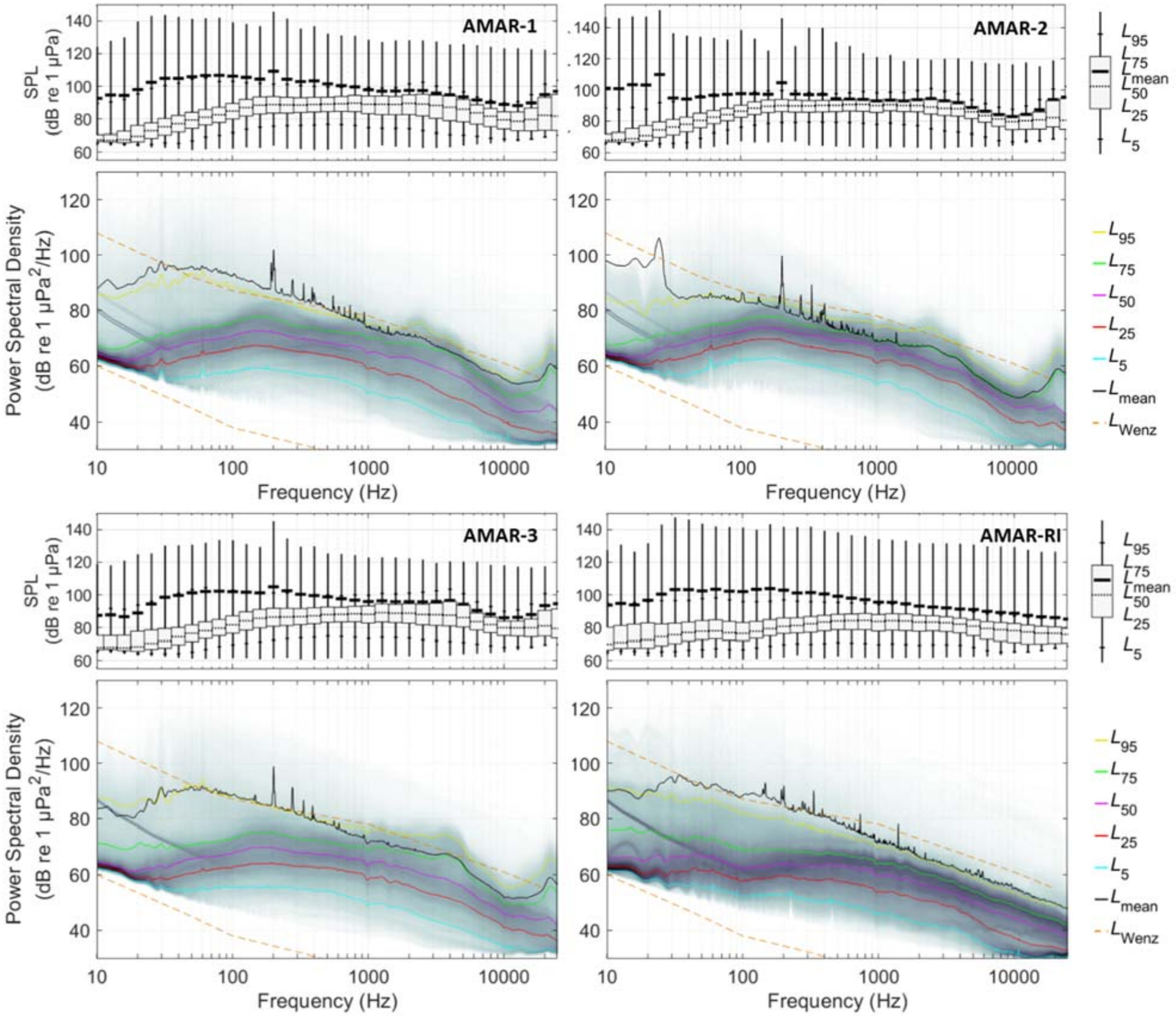


Figure 18. Stations for AMAR−1 (top left), AMAR −2 (top right), AMAR −3 (bottom left), and AMAR −RI (bottom right): Percentiles and mean of 1/3-octave-band SPL and percentiles and probability density (grayscale) of 1-min power spectral density levels compared to the limits of prevailing noise (Wenz 1962). L_{mean} is the arithmetic mean (ISO 18405 2017).

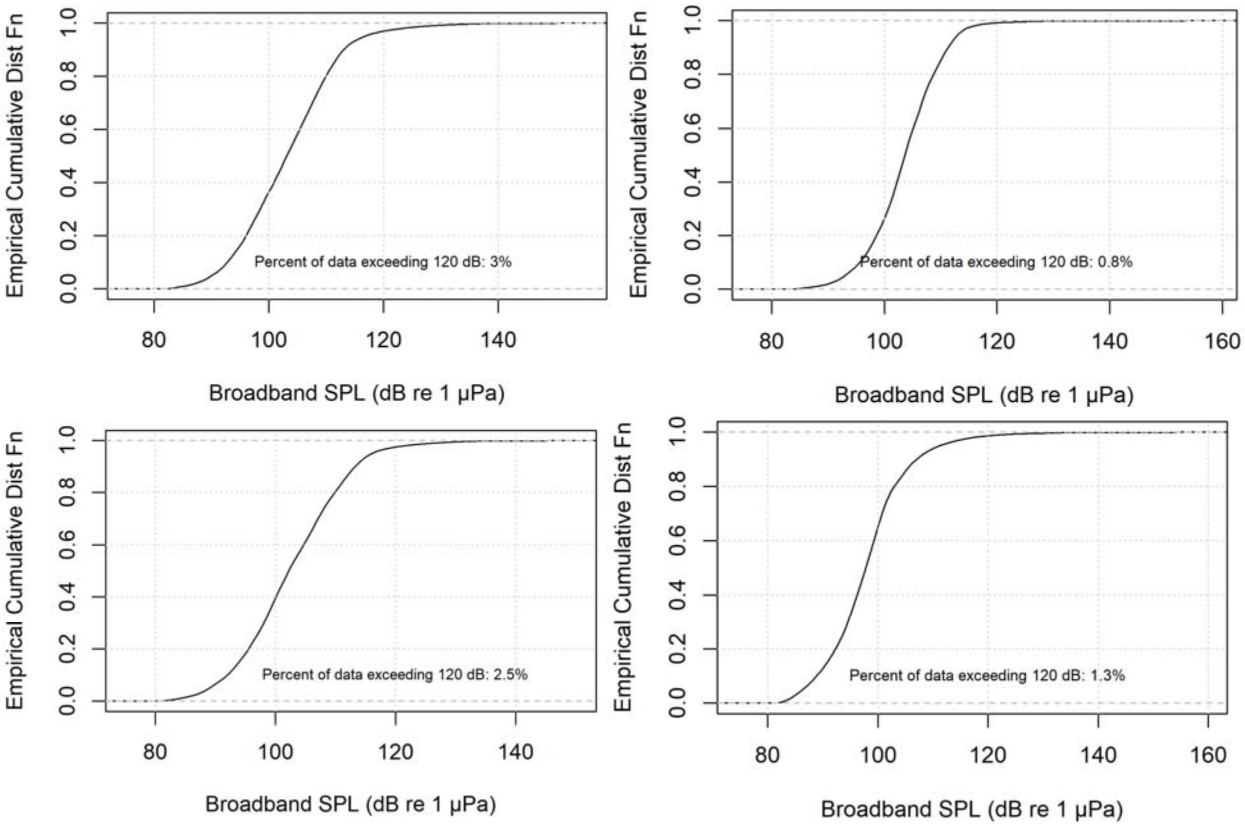


Figure 19. Empirical cumulative distribution functions for (top left) AMAR−1, (top right) AMAR−2, (bottom left) AMAR−3, and AMAR-RI (bottom right).

3.1.2. Daily Sound Exposure Levels (SEL)

3.1.2.1. Early Shoulder Season

Statistical distributions of the daily unweighted sound exposure level (SEL) recorded between 7 Jul and 4 Aug 2019 on the Bylot Island and Ragged Island AMARs are presented in Figure 20. SEL values plotted in black represent total SEL (ambient + vessel noise), while SEL data plotted in gold represent periods when only vessels were present in the recordings. Also shown is a statistical distribution of the number of hours per day in which vessels were detected on each AMAR (for any portion of that hour), and of the number of vessel passes detected per day on each AMAR. This summary includes all vessels recorded on the AMARs and may include vessels that were not associated with Baffinland's operations. Project-related vessels did not begin shipping until 17 Jul, evident in these plots as increases in the daily SEL, and the mean SPL are noted at both locations after this date, along with an increase of the proportional contribution of sounds from vessels after this date. Figures 21 and 22 illustrate the daily unweighted SEL and the mean sound pressure level (SPL, L_{mean}) each day measured at the Bylot Island and Ragged Island AMARs, respectively.

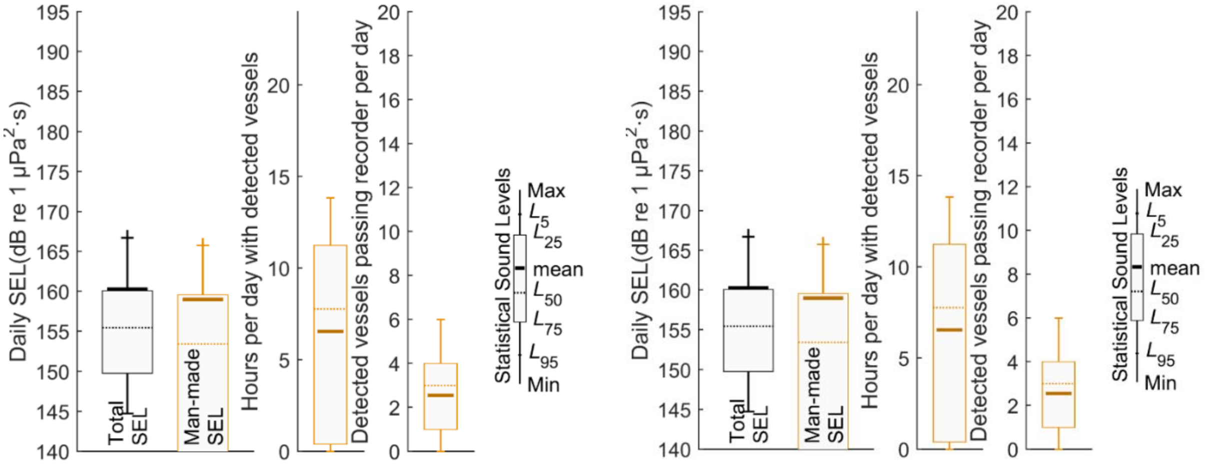


Figure 20. (Left) AMAR–BI and (right) AMAR–RI (first deployment): Statistical distribution of the sound exposure level (SEL), summary SEL statistics for periods when vessels were detected, hours per day that vessels were detected, and the number of vessels detected per day between 7 Jul and 4 Aug 2019.

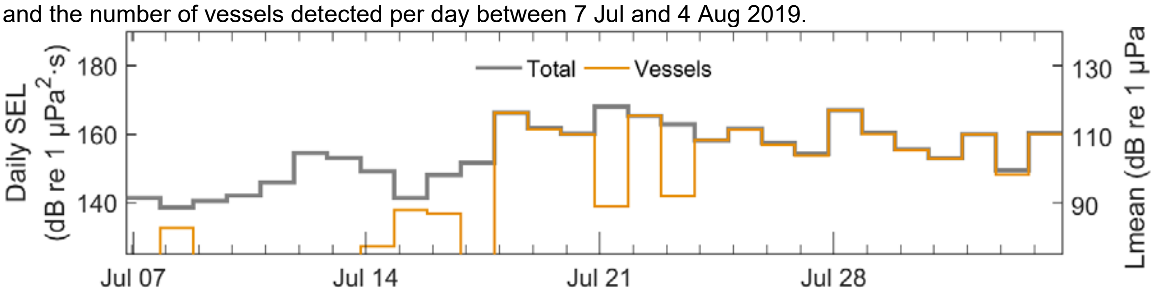


Figure 21. AMAR–BI: Daily sound exposure level (SEL; left axis) and daily mean sound pressure level (SPL; right axis) for data recorded between 7 Jul and 4 Aug 2019.

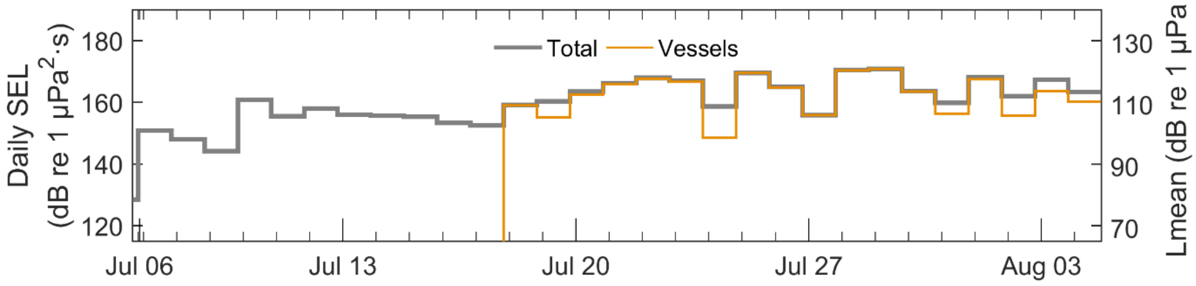


Figure 22. AMAR–RI: Daily sound exposure level (SEL; left axis) and daily mean sound pressure level (SPL; right axis) for data recorded between 7 Jul and 4 Aug 2019.

Levels were often higher at Ragged Island than Bylot Island, particularly for broadband SEL, which is attributed to better sound propagation in the shallower waters at the Ragged Island AMAR recording station. There were a few days with elevated daily SEL at both stations, such as at the start of the Project shipping season on 17 Jul. Another example occurred 26 Jul 2019 when there were multiple Project vessel transits along the Northern Shipping Route. Both stations were located on the same shipping route, and on 26 Jul an increase in hourly SPL occurred at Bylot Island approximately 1 hour before Ragged Island. AIS records indicated that the icebreaker MSV *Botnica* escorted the oil and chemical tanker *Sarah Desgagnes* toward Milne Port on that day. On the same day, the bulk carrier *Nordic Oshima* transited past the recorders after departing from Milne Port. Figure 24 shows an example spectrogram from 26 Jul 2019 with noise from MSV *Botnica* escorting the *Sarah Desgagnes*.

Frequency-weighted daily SEL values were calculated for the five marine mammal functional hearing groups using the approach described in the US National Marine Fisheries Services (NMFS 2018) guidance for assessing acoustic impacts. These levels are presented in Figure 23. None of the thresholds for either permanent or temporary hearing threshold shift (PTS and TTS) were exceeded throughout the recordings at either location for any of the marine mammals that occur in the Project area.

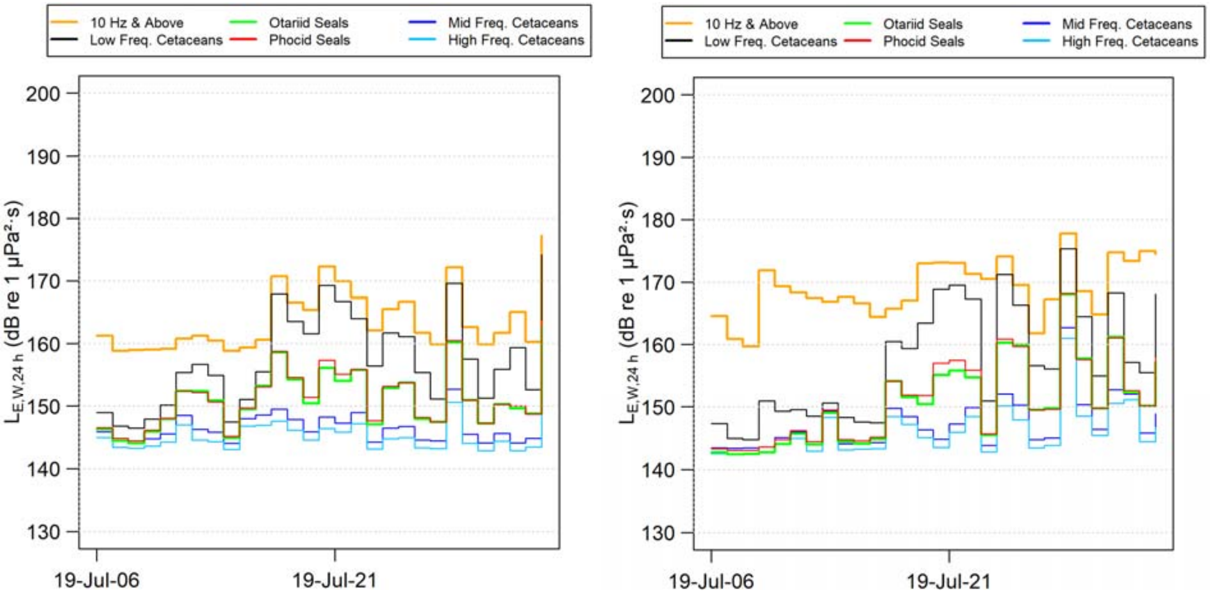


Figure 23. (left) AMAR–BI and (right) AMAR –RI: The staircase plot shows the daily sound exposure levels (SEL), weighted for marine mammal hearing using the NMFS (2018) functions.

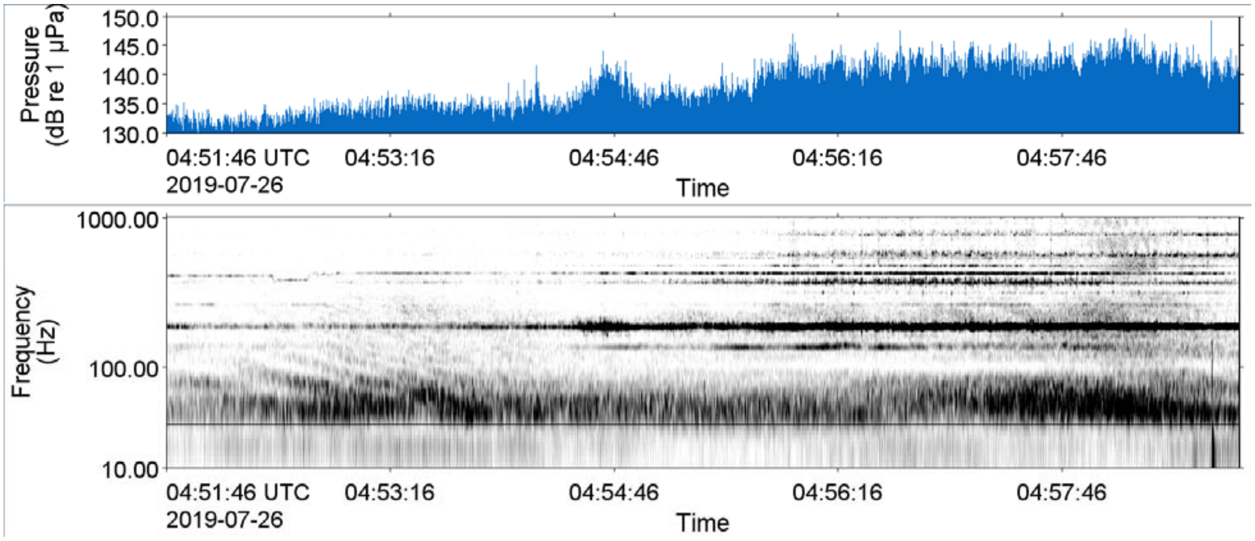


Figure 24. Noise recorded on AMAR-RI as the icebreaker MSV *Botnica* transited past, while escorting oil tanker *Sarah Desgagnes* on 26 Jul 2019. The vessels passed within approximately 700 m of the recorder at this time.

3.1.2.2. Open Water Season

Figure 25 presents the statistical distributions of the daily unweighted SEL recorded on the Bruce Head and Ragged Island AMARs between 4 Aug and 28 Sep 2019. This summary includes all recorded data and may include sound from vessels that are not associated with Baffinland's operations. Figures 26 through 29 illustrate the daily unweighted SEL and the mean SPL (L_{mean}) per day for AMAR–1, –2, –3, and –RI, respectively.

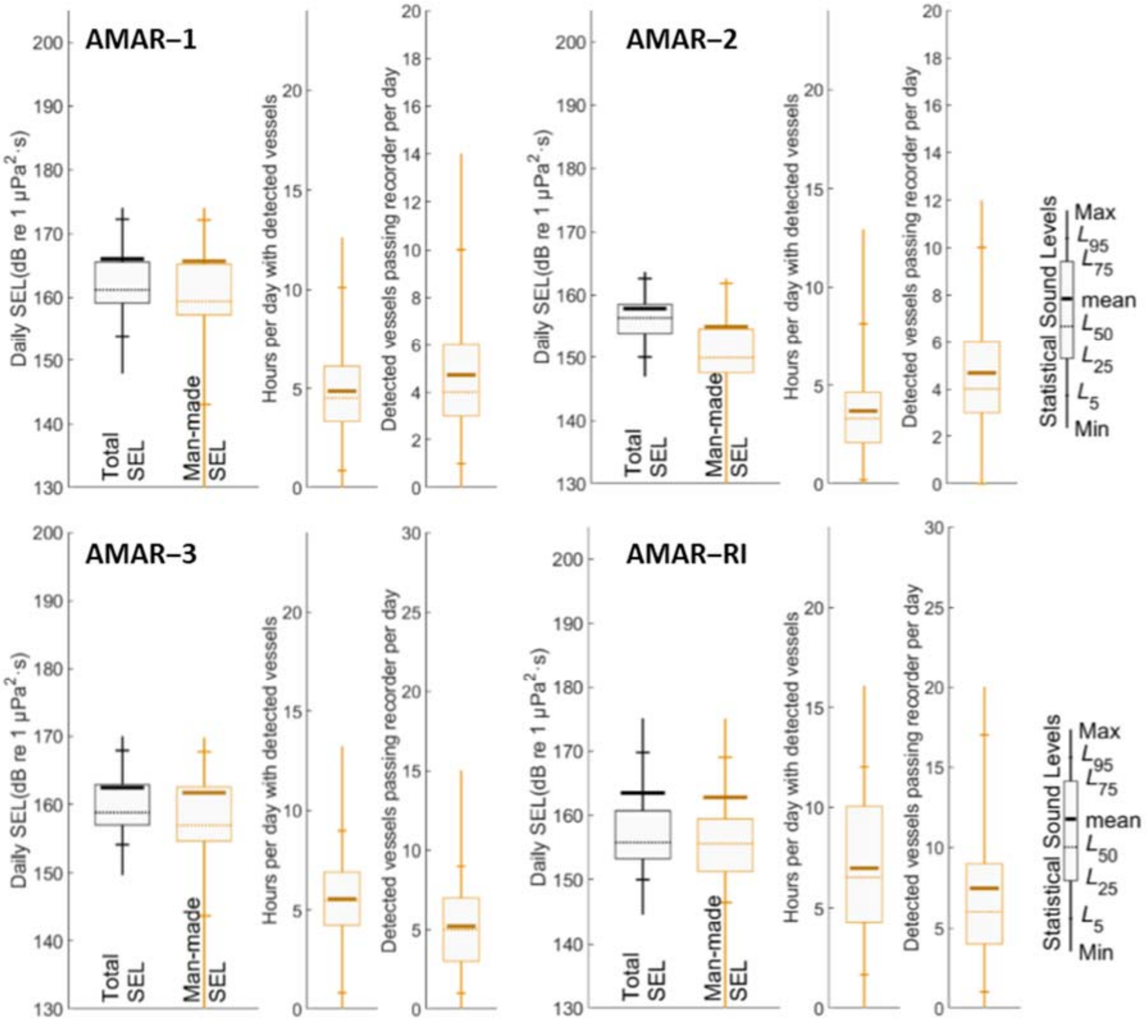


Figure 25. Statistical distribution (at each recording station) of the sound exposure level (SEL), summary SEL statistics for periods when vessels were detected, hours per day that vessels were detected, and the number of vessels detected per day between 4 Aug and 28 Sep 2019.

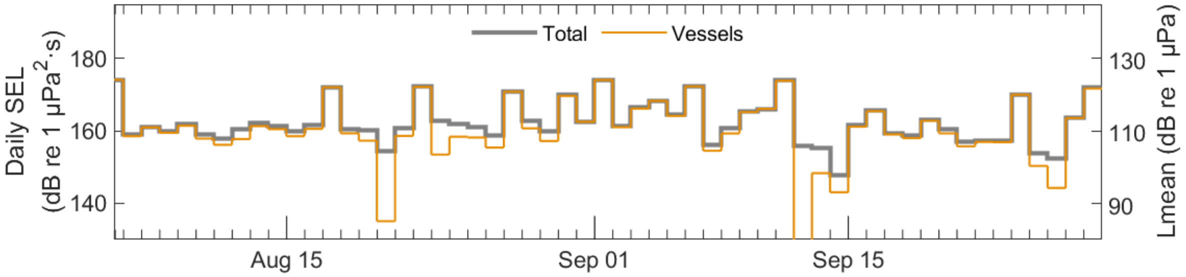


Figure 26. AMAR–1: Daily sound exposure level (SEL; left axis) and daily mean sound pressure level (SPL; right axis) for data recorded between 4 Aug and 28 Sep 2019.

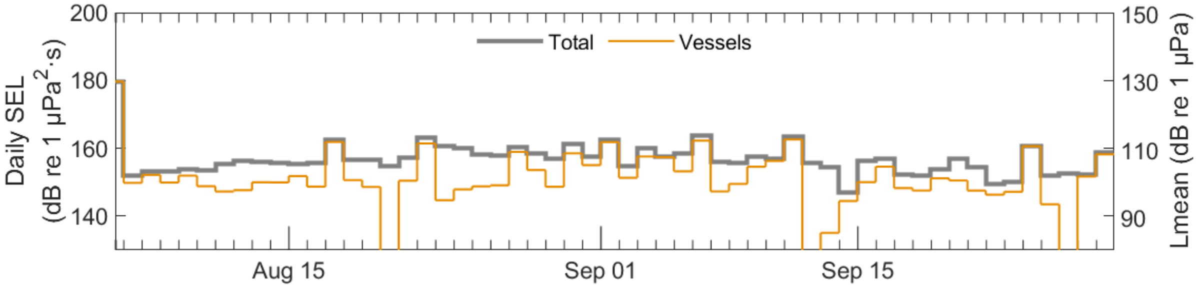


Figure 27. AMAR–2: Daily sound exposure level (SEL; left axis) and daily mean sound pressure level (SPL; right axis) for data recorded between 4 Aug and 28 Sep 2019.

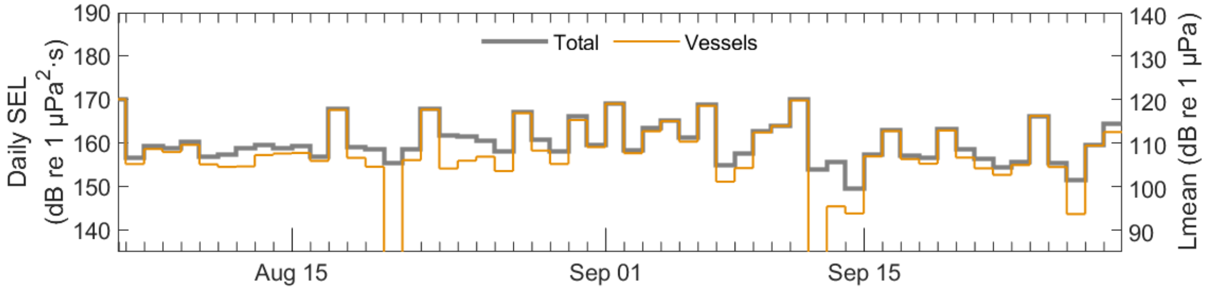


Figure 28. AMAR–3: Daily sound exposure level (SEL; left axis) and daily mean sound pressure level (SPL; right axis for data recorded between 4 Aug and 28 Sep 2019.

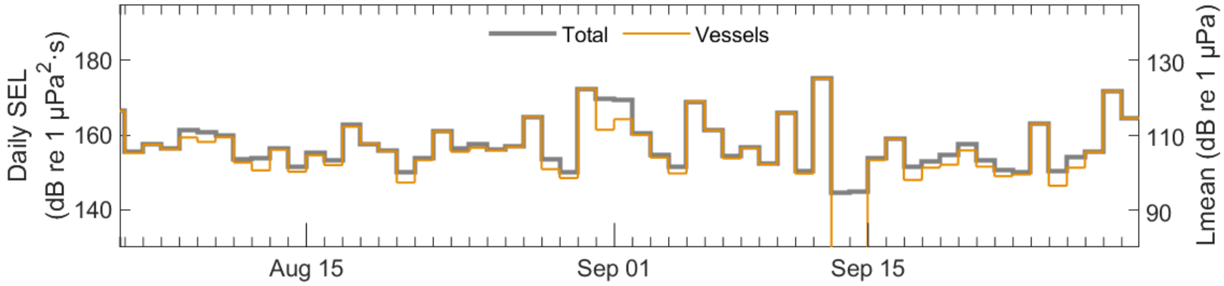


Figure 29. AMAR–RI: Daily sound exposure level (SEL; left axis) and daily mean sound pressure level (SPL; right axis for data recorded between 4 Aug and 28 Sep 2019.

Frequency-weighted daily SEL values were calculated for the five marine mammal functional hearing groups according to the definitions in the US National Marine Fisheries Services (NMFS 2018) guidance for assessing acoustic impacts and are show in Figure 30. At all recording locations, sound levels were below the acoustic thresholds for a temporary reduction (TTS) or permanent loss in hearing sensitivity (PTS) for any of the marine mammals that occur in the Project area.

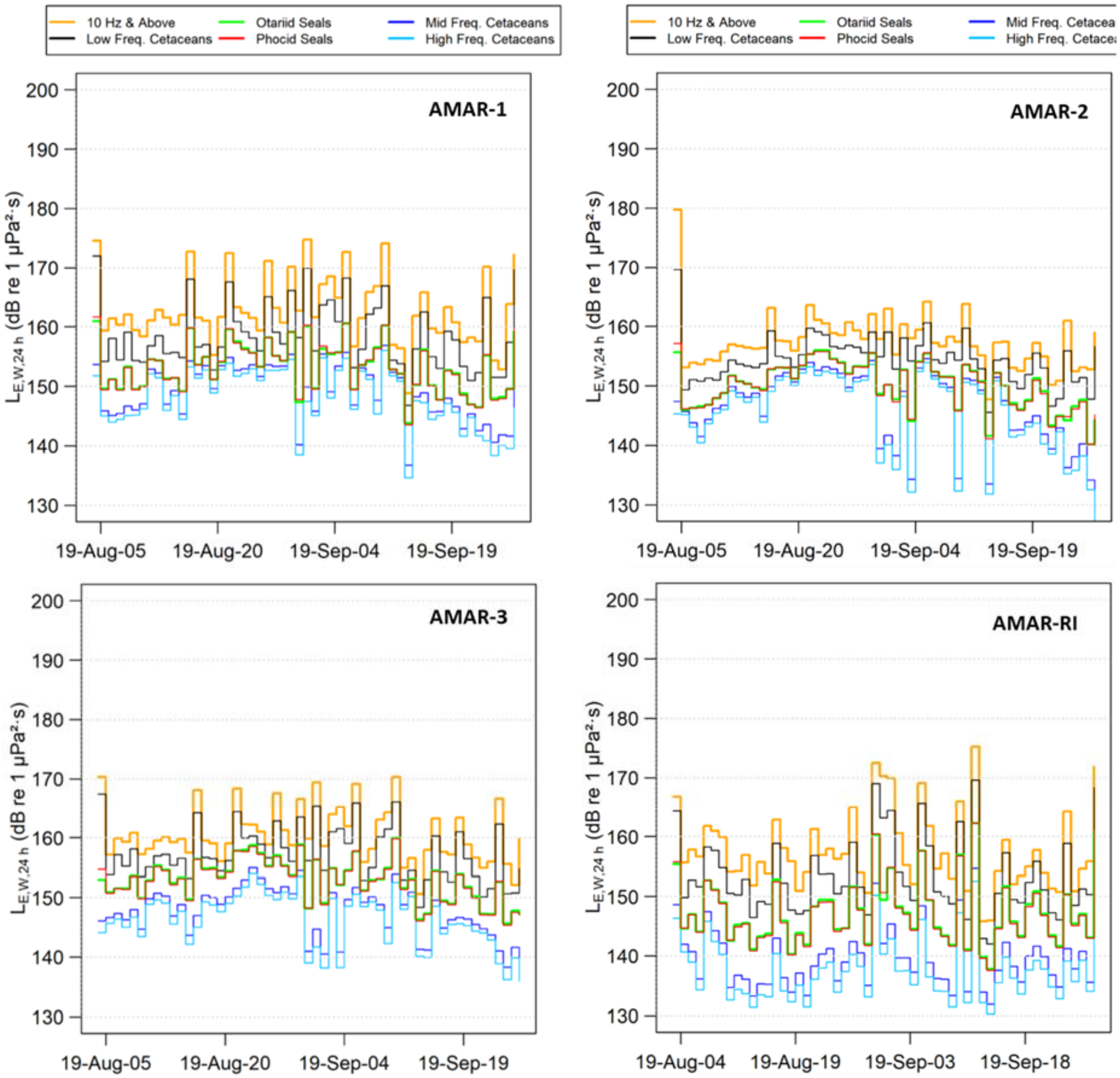


Figure 30. AMAR−1 to −RI: The staircase plot shows the daily sound exposure levels (SEL), weighted for marine mammal hearing using the NMFS (2018) functions.

3.2. Vessel Detections

Vessels were detected using the automated detection algorithm described in Section 2.2.2. The vessel detections denote the acoustic presence of a vessel, by hour, as identified by the automated detection algorithm discussed in Section 2.2.2. All stations had high vessel detection counts throughout the recording period (Figure 31), with some periods of fewer detections lasting a few days. Very few vessels were detected in the first half of July, prior to the start of Project-related shipping on 17 Jul. Detections were made relatively uniformly across all times of day. The station near Ragged Island (AMAR-RI) had more detections than stations in and near Milne Inlet South (AMAR−1 to −3) throughout September (Figure 31).

During the early shoulder season, vessels (Project and non-Project related) were acoustically detected in 33% of the early shoulder season recordings at AMAR-RI (163 out of 493 hours) and in 37% of the early shoulder season recordings at AMAR-BI (182 out of 493 hours) (Table 9). During the open water season, the proportion of the recordings with vessels acoustically detected (Project and non-Project related) ranged between 15% of the total recordings at AMAR-2 (195 of 1297 hours) and 29% of the total recordings at AMAR-RI (390 of 1345 hours) (Table 11).

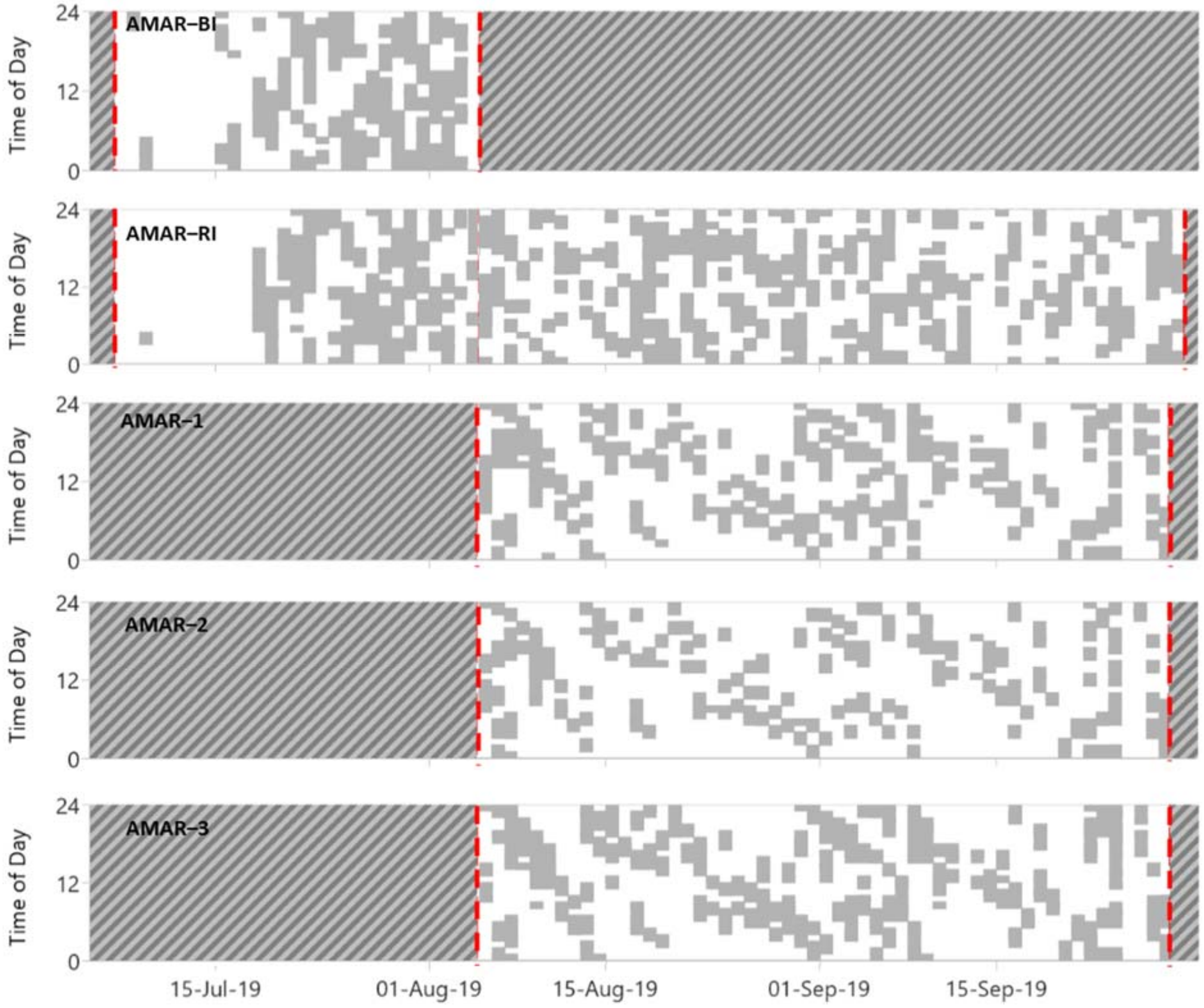


Figure 31. Vessel detections each hour (vertical axis) for each date (horizontal axis) at the five stations during the early shoulder season and the open water season. The red dashed lines indicate AMAR deployment (or recording start) and retrieval dates.

Table 9 Early shoulder season: Proportion of acoustic recordings between 17 Jul and 5 Aug 2019 with vessel detections.

Station	Recording duration (h)	Hours with vessel detections (h)	Percentage of recording with vessel detections (%)
AMAR-BI	493	182	37
AMAR-RI	493	163	33

Table 10 Open water season: Proportion of acoustic recordings between 5 Aug and 28 Sep 2019 with vessel detections.

Station	Recording duration (h)	Hours with vessel detections (h)	Percentage of recording with vessel detections (%)
AMAR-1	1297	259	20
AMAR-2	1297	195	15
AMAR-3	1300	299	23
AMAR-RI	1345	390	29

3.3. Narwhal Detections at Bruce Head – Open Water Season

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

Narwhal vocalizations were identified by JASCO's automated detectors (Section 2.2.3) and validated via manual review of 0.5% of the low- and high-frequency data sets The manually-reviewed data represent 156 sound files, or 1.3 h worth of 1 min 687.5 kHz sounds files and 18.2 h worth of 14 min 64 kHz sound files.

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

Because of the overlap in vocal repertoires of the two Monodontid species (narwhals and beluga whales) with potential to frequent in the Project area (Stephenson and Hartwig 2010), the whistle and the click detectors were unable to distinguish these vocalizations by species. However, due to the higher probability of narwhal presence in the Project area (e.g., only a single beluga whale was observed during the 5-week visual observation program at Bruce Head in 2019), all whistle and click vocalizations detected on the AMARs were attributed to “narwhal”.

Generic detector performance varied across vocalization types (whistles and clicks) and AMAR stations. Detector precision was high for AMAR–1 and AMAR–2 for the whistle detector and AMAR–2 and AMAR–3 for the click detector scoring above the minimum precision of a 0.75 threshold (Appendix C). Detector precision could not be calculated for AMAR–1 because all files reviewed were found to either have a confirmed or a potential narwhal click. For AMAR–1, we assumed a threshold (=1) identical to the two other stations.

Narwhal (generic) whistles (Figure 32) were found at all stations over the recording period (Figure 33), mostly from early August to late September.

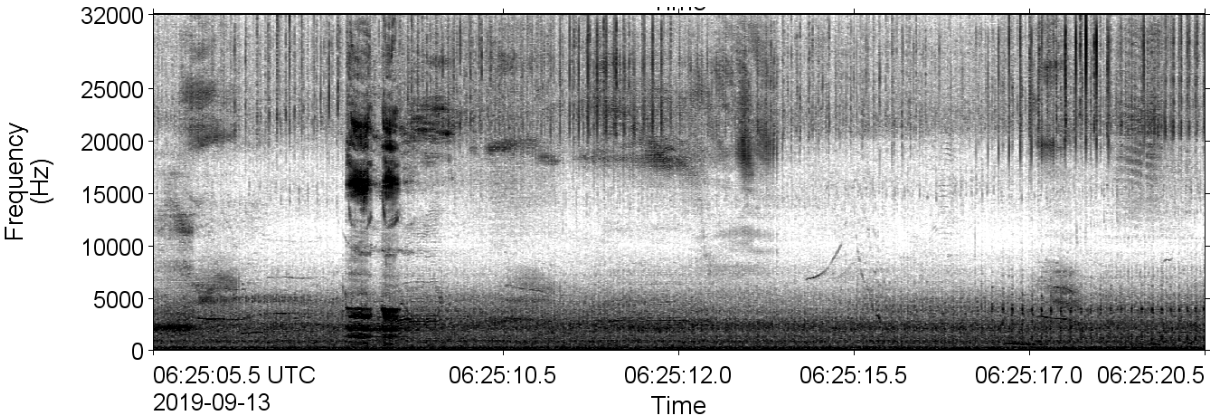


Figure 32. Spectrogram of narwhal pulse vocalizations and whistles recorded at AMAR−3 on 13 Sep 2019 (2 Hz frequency resolution, 0.05 time window, 0.01 time step, Hamming window).

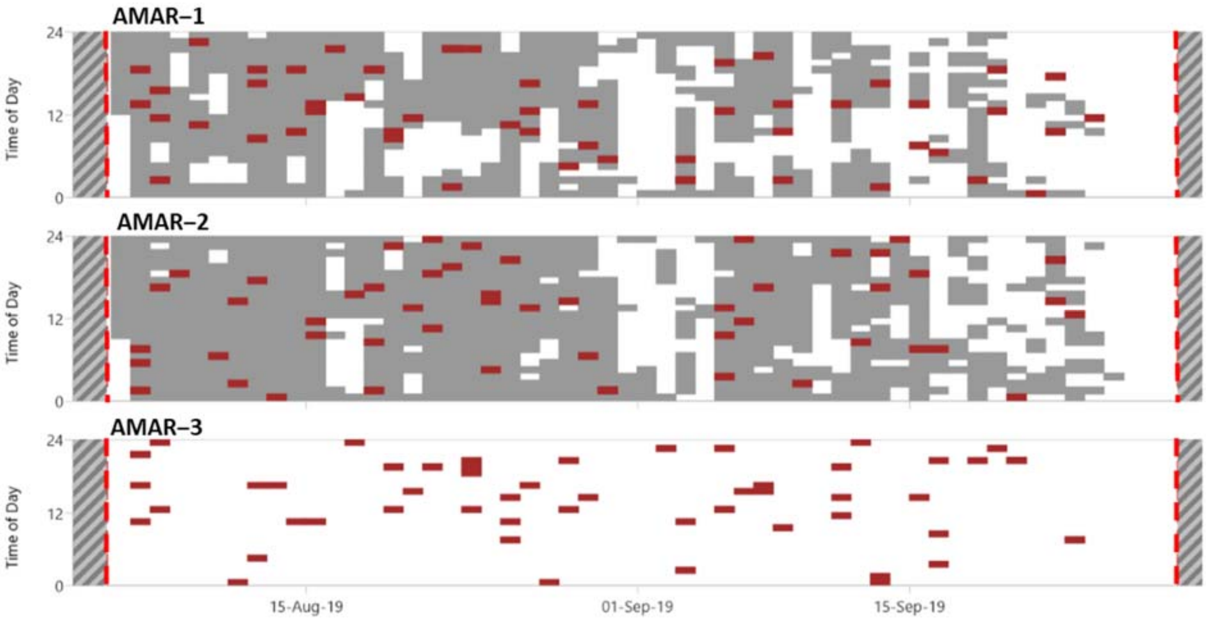


Figure 33. Daily and hourly occurrence of detected narwhal (generic) whistles recorded at AMAR−1, AMAR−2, and AMAR−3 from 5 Aug to 28 Sep 2019. Grey dots indicate automated detections. Red dots indicate manually validated results. The red dashed lines indicate AMAR deployment and retrieval dates. Only manually identified signals are shown if the detector's precision was below 0.75 (AMAR−3).

Narwhal (generic) clicks (Figure 34) were found at all stations and throughout all recording periods (Figure 35), most occurring from early August to late September. AMAR−1 and AMAR −2 had similar number of narwhal click detections, and AMAR−3 had fewer.

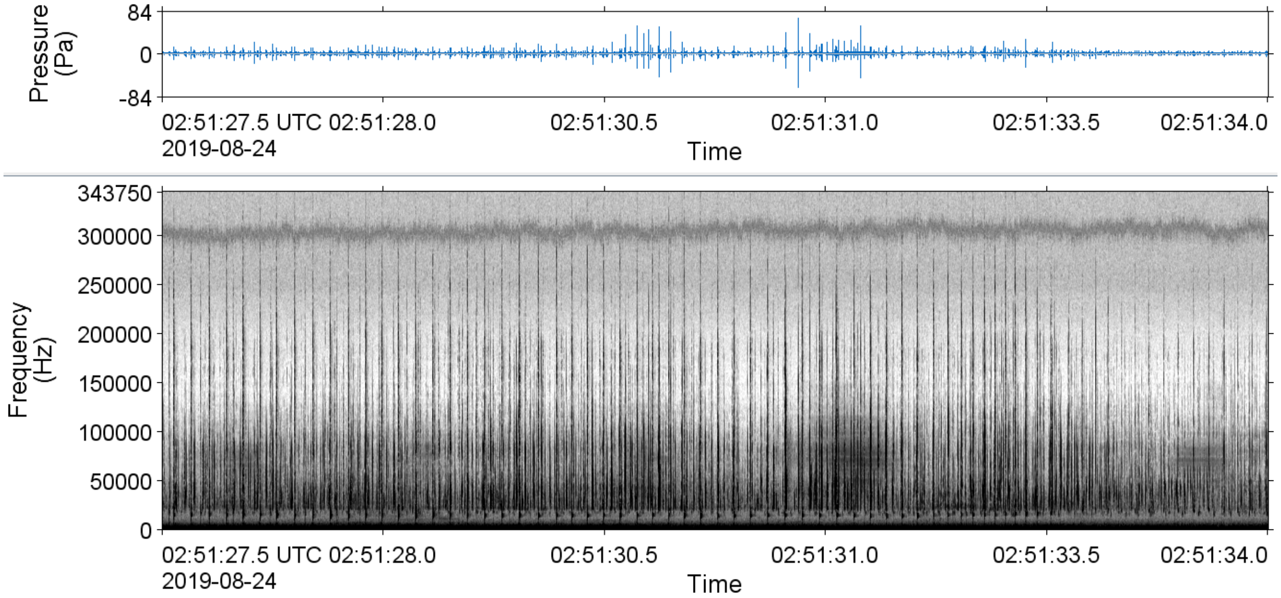


Figure 34. Waveform (top) and spectrogram (bottom) of narwhal clicks recorded at AMAR−1 on 24 Aug 2019 (UTC) (84 Hz frequency resolution, 0.001 time window, 0.0005 time step, Hamming window).

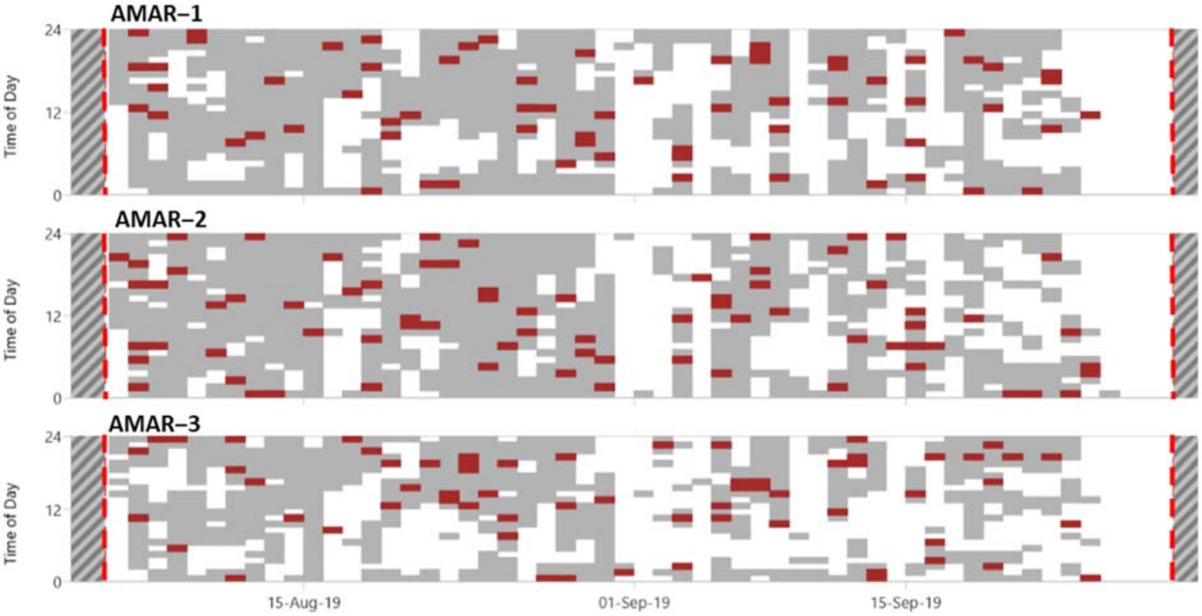


Figure 35. Daily and hourly occurrence of detected narwhal (generic) clicks recorded at AMAR−1, AMAR−2 and AMAR−3 from 5 Aug to 28 Sep 2019. Grey dots indicate automated detections. Red dots indicate manually validated results. The red dashed lines indicate AMAR deployment and retrieval dates.

Vocalization-specific detectors were used for this study. Echolocation clicks (Figure 36), low-frequency buzzes (Figure 37), high-frequency buzzes (Figure 38), knocks (Figure 39), and (vocalization-specific) whistles (Figure 40) were detected at all AMAR stations throughout the recording periods.

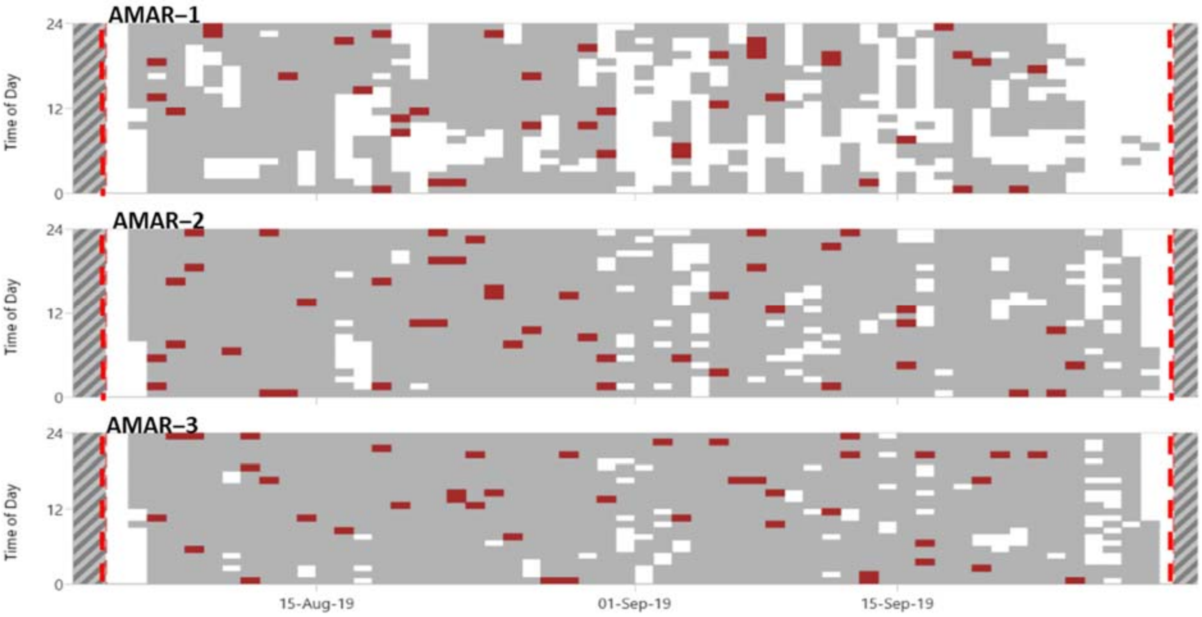


Figure 36. Daily and hourly occurrence of detected narwhal echolocation clicks recorded at AMAR−1, AMAR−2, and AMAR−3 from 5 Aug to 28 Sep 2019. Grey dots indicate automated detections. Red dots indicate manually validated results. The red dashed lines indicate AMAR deployment and retrieval dates.

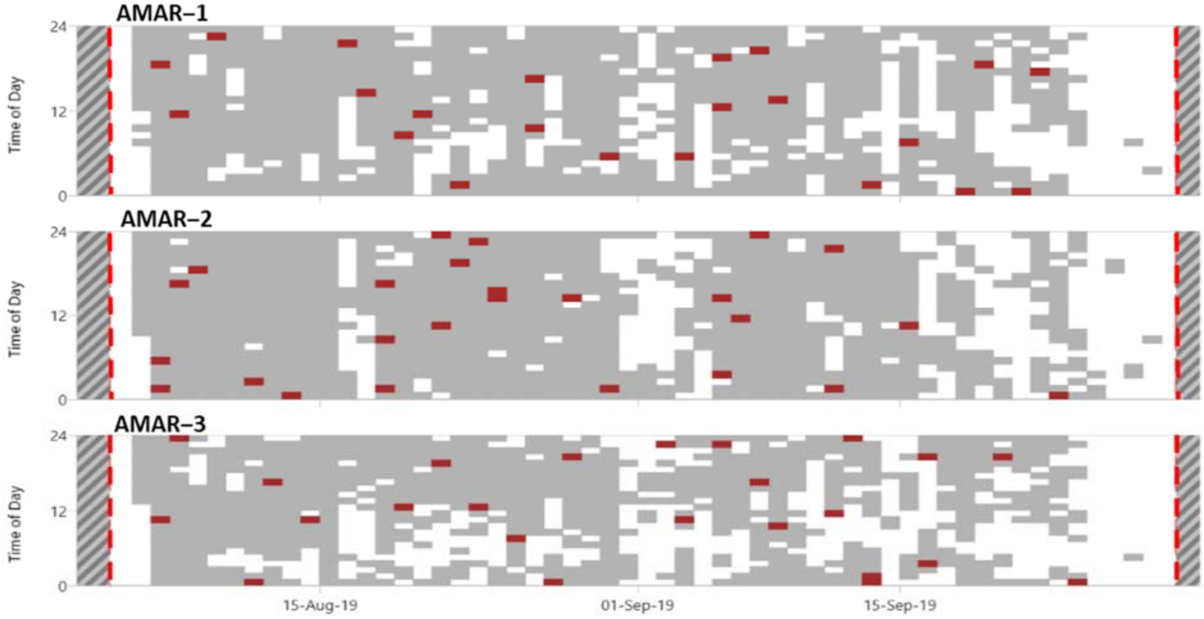


Figure 37. Daily and hourly occurrence of detected narwhal low-frequency buzzes recorded at AMAR−1, AMAR−2, and AMAR−3 from 5 Aug to 28 Sep 2019. Grey dots indicate automated detections. Red dots indicate manually validated results. The red dashed lines indicate AMAR deployment and retrieval dates.

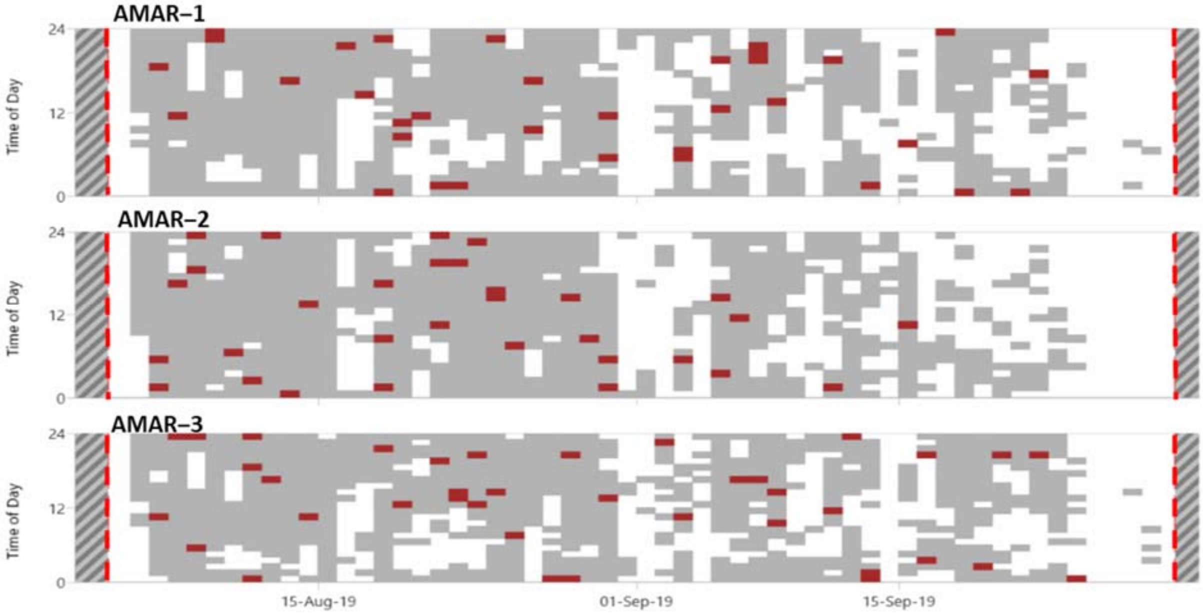


Figure 38. Daily and hourly occurrence of detected narwhal high-frequency buzzes recorded at AMAR−1, AMAR−2, and AMAR−3 from 5 Aug to 28 Sep 2019. Grey dots indicate automated detections. Red dots indicate manually validated results. The red dashed lines indicate AMAR deployment and retrieval dates.

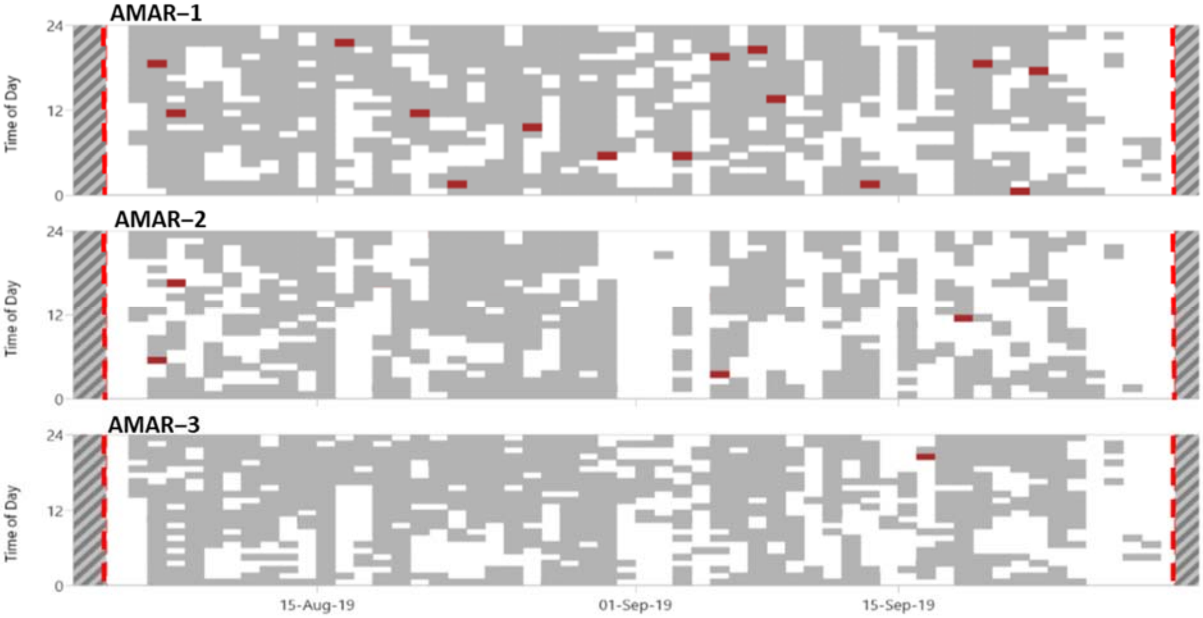


Figure 39. Daily and hourly occurrence of detected narwhal knocks recorded at AMAR−1, AMAR−2, and AMAR−3 from 5 Aug to 28 Sep 2019. Grey dots indicate automated detections. Red dots indicate manually validated results. The red dashed lines indicate AMAR deployment and retrieval dates.

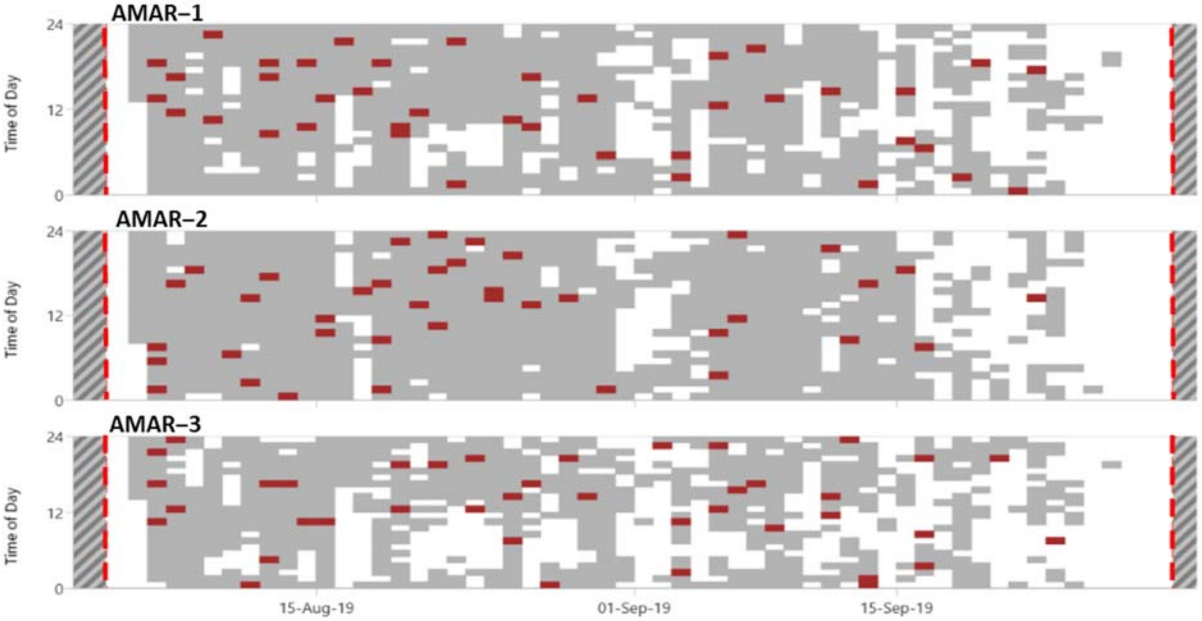


Figure 40. Daily and hourly occurrence of detected narwhal (vocalization-specific) whistles recorded at AMAR−1, AMAR−2, and AMAR−3 from 5 Aug to 28 Sep 2019. Grey dots indicate automated detections. Red dots indicate manually validated results. The red dashed lines indicate AMAR deployment and retrieval dates.

3.4. Other Marine Mammal Detections at Bruce Head – Open Water Season

3.4.1. Bowhead Whales

Bowhead whale vocalizations were manually found only on six occasions in the recordings collected from the Bruce Head AMAR stations during the open water season. Examples of bowhead whale vocalizations are shown in Figures 41 and 42 for AMAR–1 and AMAR–3, respectively. Due to the low number of manual detections, they could not be used for the detector performance characterization.

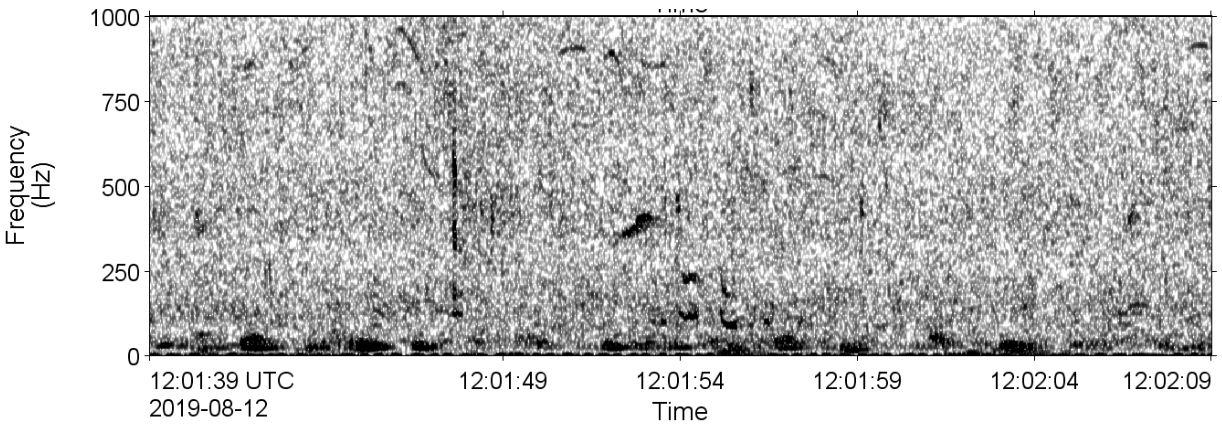


Figure 41. Spectrogram of bowhead vocalizations recorded at AMAR−1 on 12 Aug 2019 (UTC) (2 Hz frequency resolution, 0.128 time window, 0.032 time step, Hamming window).

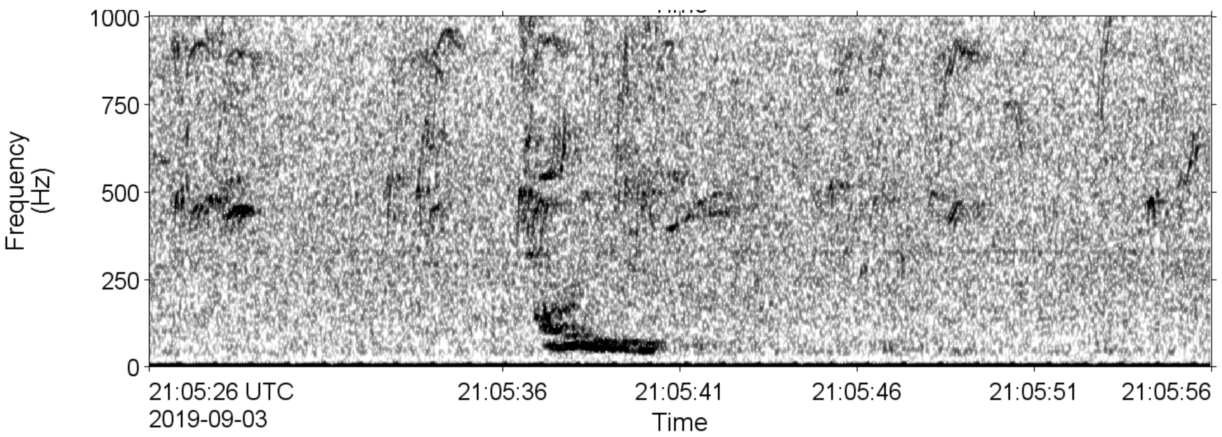


Figure 42. Spectrogram of bowhead vocalizations recorded at AMAR−3 on 3 Sep 2019 (UTC) (2 Hz frequency resolution, 0.128 time window, 0.032 time step, Hamming window).

3.4.2. Killer Whales

Killer whale vocalizations were manually found only on eighteen occasions in the recordings collected from the Bruce Head AMAR stations during the open water season. Examples of killer whale vocalizations are shown in Figures 43 through 45 for each of the respective AMAR stations at Bruce Head. Due to the low number of manual detections, performance of the automated detector could not be undertaken for this species.

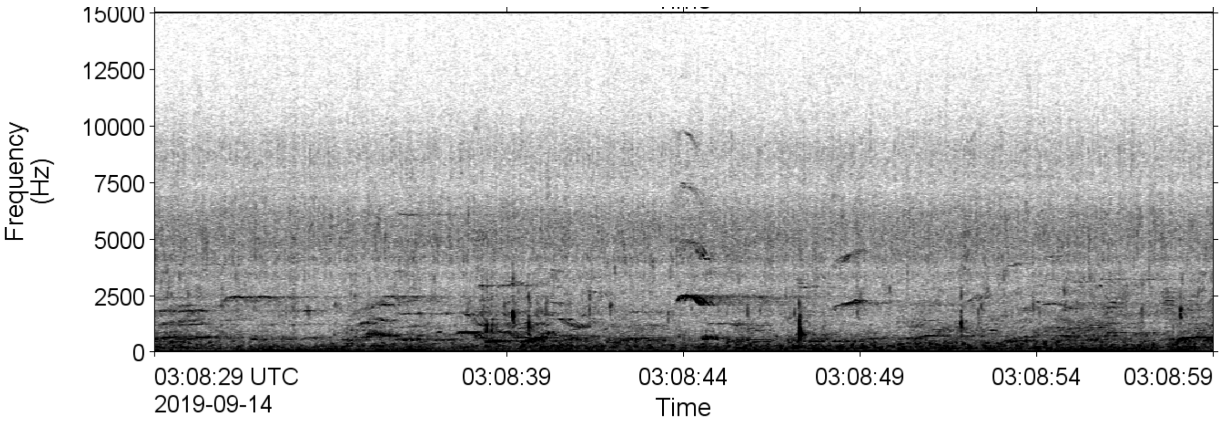


Figure 43. Spectrogram of killer whale whistles recorded at AMAR−1 on 16 Sep 2019 (UTC) (2 Hz frequency resolution, 0.05 time window, 0.01 time step, Hamming window).

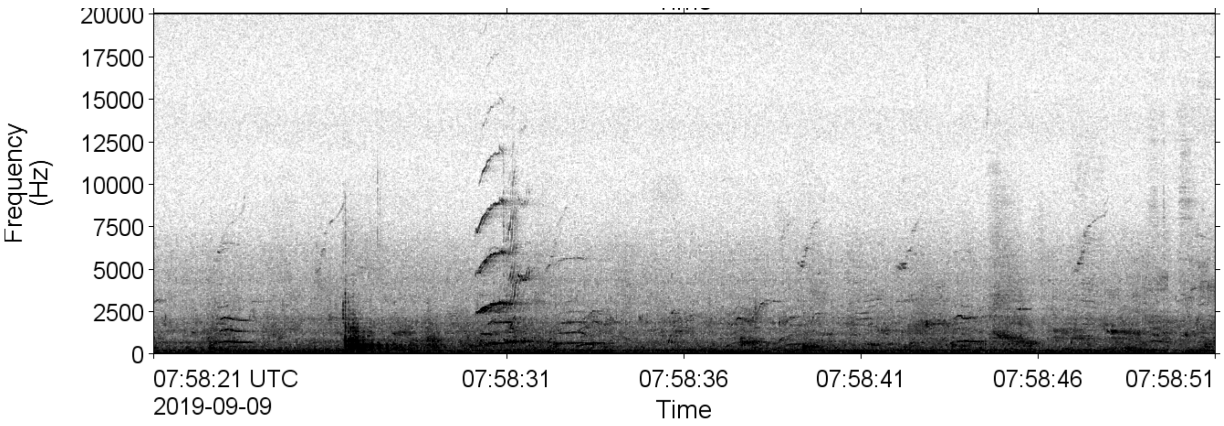


Figure 44. Spectrogram of killer whale whistles recorded at AMAR−2 on 9 Sep 2019 (UTC) (2 Hz frequency resolution, 0.05 time window, 0.01 time step, Hamming window).

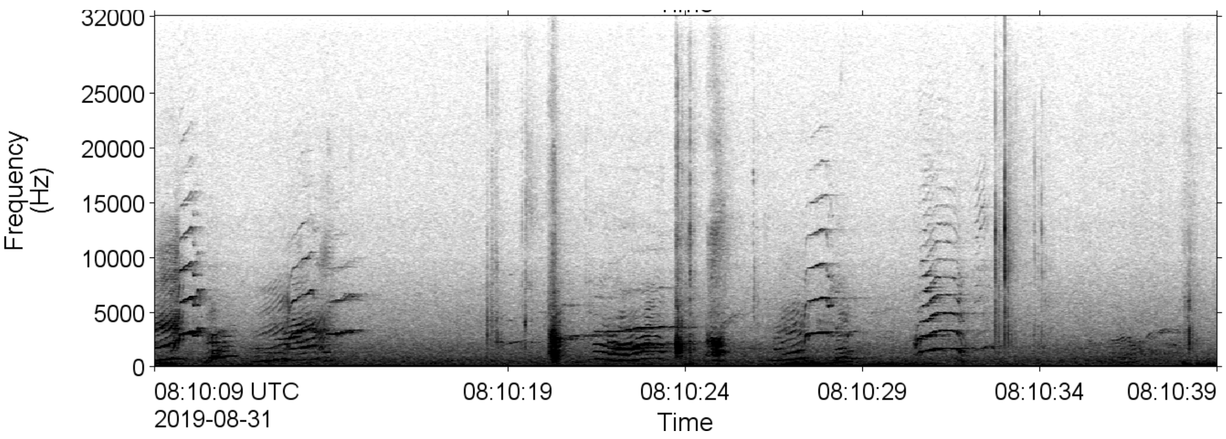


Figure 45. Spectrogram of killer whale whistles recorded at AMAR−3 on 31 Aug 2019 (UTC) (2 Hz frequency resolution, 0.05 time window, 0.01 time step, Hamming window).

3.5. Shoulder Season Vessel Measurements

Recordings made during the early shoulder season were used to derive a source level estimate for the icebreaker MSV *Botnica*. Specifically, we calculated radiated noise levels from five transits of the icebreaker MSV *Botnica* with one or more ore carriers in escort (see Section 2.3). The lowest and highest radiated noise levels are plotted in Figure 46 (Track #3 and Track #4, respectively). For comparison, Figure 46 also shows the levels of a single icebreaker transiting in open water at 9 knots that were applied for acoustic modelling that was carried out in support of the *Effects Assessment of Icebreaker Operations During the Shoulder Shipping Season for Baffinland's Phase 2 Proposal* (Golder Associates Ltd. 2019a, their Appendix B). Measurement-derived radiated noise levels for MSV *Botnica* transiting in open water at 8 knots were between 2 and 7 dB higher than those assumed in the acoustic modelling. It is possible that noise from the ore carriers under escort contributed to the estimates presented for MSV *Botnica*, but this is expected to be minimal given the separation distance from the ore carriers to the AMAR (minimum of 1 km) while MSV *Botnica* was at its closest point of approach.

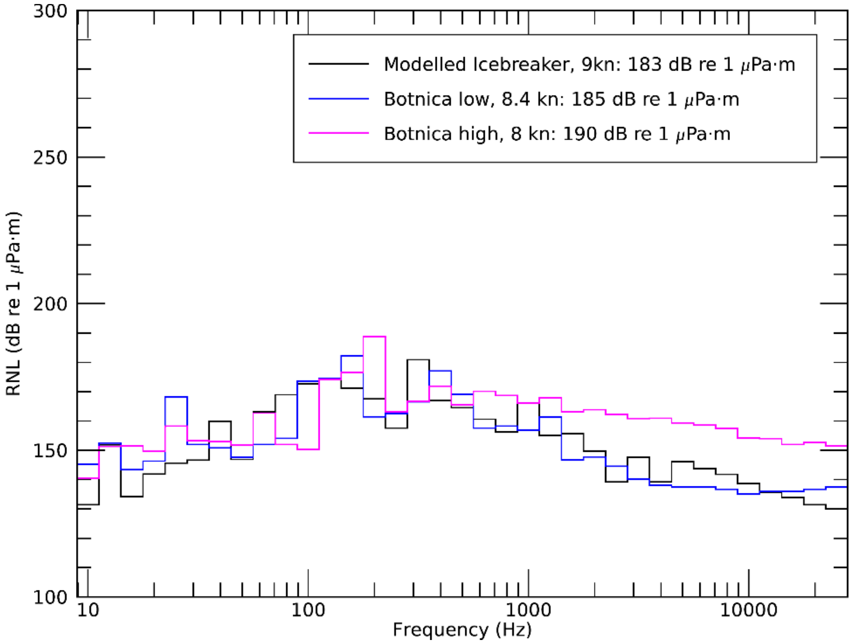


Figure 46 The loudest (magenta) and quietest (blue) measurement-derived radiated noise levels for the icebreaker MSV *Botnica* transiting in open water, while escorting one or more ore carriers along the Northern Shipping Route in 2019, with estimated radiated noise levels used for acoustic modelling of a generic icebreaker transiting in open water at 9 knots (black).

3.6. Listening Range Reduction

LRR was calculated (Table 11) for reductions in listening range of at least 50% and 90% (>50% LRR and >90% LRR), for all five recorder locations and for all narwhal vocalization types (clicks, high-frequency buzzes, whistles, knocks, and burst pulse or low-frequency buzzes). Figure 47 presents LRR results for AMARs deployed during the early shoulder season, and Figure 48 presents results for AMARs deployed during the open water season. For discussion purposes, a general overview is provided below for three representative recorder locations relative to the 50% LRR metric. Corresponding values for 90% LRR are provided in Table 11.

3.6.1. AMAR-RI

AMAR-RI was located directly on the nominal shipping route in Milne Inlet North adjacent to the Ragged Island anchorage locations. Vessel noise was most common at this recorder location, with vessels acoustically detected on 33% of the early shoulder season recording (163 out of 493 hours) and on 29% of the open water season recording (390 out of 1,345 hours). Greater than 50% LRR occurred most frequently at AMAR-RI during the early shoulder season. A summary of the LRR calculations for each of the three considered frequencies, with a relative comparison to ambient noise (i.e., data with no vessels present) is as follows:

1 kHz (burst pulses)

During the early shoulder season, greater than 50% LRR for sound at 1 kHz (a frequency component of narwhal burst pulses) occurred during 4.1% of the time vessels were detected acoustically on the recording (7 of 163 hours). This means that 96% of the time when vessel noise was detectable in the shoulder season at AMAR-RI, a stationary narwhal would be able to detect a sound at 1 kHz to distances over half of their full detection range, and 4% of the time when vessel noise was detectable in the shoulder season at this location, their detection range at this frequency would be reduced by at least half. Because the hearing threshold for narwhal at 1 kHz is higher than the median ambient sound level at this frequency, ambient noise did not cause appreciable LRR for this vocalization type during any of the early shoulder season recording (0 of 521 hours without vessels detected). Overall, vessel noise resulted in greater than 50% LRR for sound at 1kHz for 1% of the total recording period during the early shoulder season (7 of 493 hours).

During the open water season, greater than 50% LRR occurred for sound at 1 kHz during 3.3% of the time vessels were detected on the recording (13 of 390 hours). Ambient noise caused greater than 50% LRR for sound at 1 kHz during 0.1% of the recordings when no vessels were detected acoustically (1 of 955 hours). Overall, ambient noise caused greater than 50% LRR for sound at 1 kHz for 0.07% of the total open water recording period (1 of 1,345 hours), while vessel noise caused greater than 50% LRR for sound at 1 kHz for 1% of the open water recording period (13 of 1,345 hours).

5 kHz (whistles and knock trains)

During the early shoulder season, greater than 50% LRR occurred for sound at 5 kHz (a frequency component of narwhal whistles and knock trains) during 48.7% of the time vessels were detected acoustically on the recording at AMAR-RI (79 of 163 hours). In comparison, ambient noise during the early shoulder season resulted in greater than 50% LRR for sound at 5 kHz during 24.5% of the recordings when no vessels were detected (80 of 330 hours). Overall, both ambient noise and vessels resulted in greater than 50% LRR for sound at 5 kHz for 16% of the total shoulder season recording period (80 of 493 hours from ambient noise and 79 of 493 hours from vessel noise).

During the open water season, greater than 50% LRR occurred for sound at 5 kHz during 14.7% of the time vessels were detected on the recording at AMAR-RI (57 of 390 hours). Ambient noise resulted in greater than 50% LRR for sound at 5 kHz during 15.5% of the recordings when no vessels were detected acoustically (148 of 955 hours). Overall, ambient noise resulted in greater than 50% LRR for sound at 5 kHz for 11% of the total open water recording period (148 of 1,345 hours), while vessel noise resulted in greater than 50% LRR for sound at 5 kHz for 4.2% of the total open water recording period (57 of 1,345 hours).

25 kHz (clicks and high-frequency buzzes)

During the early shoulder season, greater than 50% LRR occurred for sound at 25 kHz (a frequency component of narwhal clicks and high-frequency buzzes) during 50.8% of the time vessels were detected acoustically on the recording at AMAR-RI (83 of 163 hours). During this same period, ambient noise resulted in greater than 50% LRR for sound at 25 kHz during 36.7% of the recordings when no vessels were detected (121 of 330 hours). Overall, greater than 50% LRR occurred for sound at 25 kHz for 41% of the total recording period during the early shoulder season; 25% of this was related to ambient noise (121 of 493 hours) and 12% of this was related to vessel noise (83 of 493 hours).

During the open water season, greater than 50% LRR occurred for sound at 25 kHz during 24% of the time vessels were detected on the recording (94 of 390 hours). Ambient noise resulted in greater than 50% LRR for sound at 25 kHz during 32% of the recordings when no vessels were detected acoustically (306 of 955 hours). Overall, greater than 50% LRR occurred for sound at 25 kHz for 37% of the total recording period during the open water season; 23% of this was related to ambient noise (306 of 1,345 hours) and 14% of this was related to vessel noise (191 of 1,345 hours).

3.6.2. AMAR–1

AMAR–1 was located directly on the nominal shipping route in Milne Inlet South, adjacent to the entrance to Koluktoo Bay. It was only deployed during the open water season. Vessels were acoustically detected on 20% of the recording (259 out of 1,297 hours). A summary of the LRR for each of the three considered frequencies, with a relative comparison to ambient noise (i.e., no vessels present) is as follows.

1 kHz (burst pulses)

During the open water season, greater than 50% LRR for sound for 1 kHz (a frequency component of narwhal burst pulses) occurred during 10.1% of the time vessels were detected on the recording (26 of 259 hours). Ambient noise resulted in greater than 50% LRR for sound at 1 kHz during 0.9% of the recordings when no vessels were detected acoustically (9 of 1,038 hours). Overall, ambient noise resulted in greater than 50% LRR for sound at 1 kHz for 0.7% of the total open water recording period (9 of 1,297 hours), while vessel noise resulted in greater than 50% LRR for sound at 1 kHz for 2% of the open water recording period (26 of 1,297 hours).

5 kHz (whistles and knock trains)

During the open water season, greater than 50% LRR for sound at 5 kHz (a frequency component of narwhal whistles and knock trains) occurred during 27% of the time vessels were detected on the recording (70 of 259 hours). Ambient noise resulted in greater than 50% LRR for sound at 5 kHz during 29% of the recordings when no vessels were detected acoustically (301 of 1,038 hours). Overall, ambient noise resulted in greater than 50% LRR for sound at 5 kHz for 23% of the total open water recording period (301 of 1,297 hours), while vessel noise resulted in greater than 50% LRR for sound at 5 kHz for 5% of the total open water recording period (70 of 1,297 hours).

25 kHz (clicks and high-frequency buzzes)

During the open water season, greater than 50% LRR for sound at 25 kHz (a frequency component of narwhal clicks and high-frequency buzzes) occurred during 32.6% of the time vessels were detected on the recording (85 of 259 hours). Ambient noise resulted in greater than 50% LRR for sound at 25 kHz during 45.9% of the recordings when no vessels were detected acoustically (476 of 1,038 hours). Overall, ambient noise resulted in greater than 50% LRR for sound at 25 kHz for 37% of the total open water recording period (476 of 1,297 hours), while vessel noise resulted in a 50% LRR for clicks for 7% of the total open water recording period (85 of 1,297 hours).

3.6.3. AMAR–2

AMAR–2 was located in Koluktoo Bay, approximately 6 km west of the nominal shipping route in Milne Inlet South. AMAR–2 was only deployed during the open water season. Vessels were acoustically detected in 15% of the recording (195 out of 1,297 hours). A summary of the LRR for each of the three considered frequencies, with a relative comparison to ambient noise (i.e., no vessels present) is as follows:

1 kHz (burst pulses)

During the open water season, greater than 50% LRR for sound at 1 kHz occurred during 3.3% of the time vessels were detected on the recording (6 of 195 hours). Ambient noise resulted in greater than 50% LRR for sound at 1 kHz during 0.2% of the recordings when no vessels were detected acoustically (2 of 1,102 hours). Overall, ambient noise resulted in greater than 50% LRR for sound at 1 kHz for 0.1% of the total open water recording period (2 of 1,297 hours), while vessel noise resulted in greater than 50% LRR for sound at 1 kHz for 0.4% of the open water recording period (6 of 1,297 hours).

5 kHz (whistles and knock trains)

During the open water season, greater than 50% LRR occurred for sound at 5 kHz (a frequency component of narwhal whistles and knock trains) during 9.6% of the time vessels were detected on the recording (19 of 195 hours). Ambient noise resulted in greater than 50% LRR for sound at 5 kHz during 14.7% of the recordings when no vessels were detected acoustically (162 of 1,102 hours). Overall, ambient noise resulted in greater than 50% LRR for sound at 5 kHz for 12% of the total open water recording period (162 of 1,297 hours), while vessel noise resulted in greater than 50% LRR for sound at 5 kHz for 1% of the total open water recording period (19 of 1,297 hours).

25 kHz (clicks and high-frequency buzzes)

During the open water season, greater than 50% LRR for sound at 25 kHz (a frequency component of narwhal clicks and high-frequency buzzes) occurred during 33% of the time vessels were detected on the recording (64 of 195 hours). Ambient noise resulted in greater than 50% LRR for sound at 25 kHz during 45.6% of the recordings when no vessels were detected acoustically (502 of 1,102 hours). Overall, ambient noise resulted in greater than 50% LRR for sound at 25 kHz for 39% of the total open water recording period (502 of 1,297 hours), while vessel noise resulted in greater than 50% LRR for sound at 25 kHz for 5% of the total open water recording period (64 of 1,297 hours).

Table 11. Percent of time associated with >50% and >90% listening range reduction (LRR) at each acoustic recorder location during the 2019 early shoulder and open water shipping seasons.

Recorder		**1 kHz**		**5 kHz**		**25 kHz**	
		>50 % LRR	>90 % LRR	>50 % LRR	>90 % LRR	>50 % LRR	>90 % LRR
Early shoulder season deployments (7 Jul to 4 Aug)							
AMAR–BI	Ambient noise data	0.2	0	21.0	0.3	30.5	8.4
	Data with vessels detected	1.8	0.3	22.4	1.3	30.4	6.3
AMAR–RI	Ambient noise data	0	0	24.5	0.8	36.7	16.9
	Data with vessels detected	4.1	0.9	48.7	5.1	50.8	26.3
Open water season deployments (5 Aug to 28 Sep)							
AMAR–1	Ambient noise data	0.9	0	29.3	0.1	45.9	36.4
	Data with vessels detected	10.1	2.1	27	3.0	32.6	22.9
AMAR–2	Ambient noise data	0.2	0	14.7	0	45.6	37.7
	Data with vessels detected	3.3	0.1	9.6	0.2	33.0	26.3
AMAR–3	Ambient noise data	0.8	0	33.0	3.1	42.0	33.2
	Data with vessels detected	8.1	1.2	34.0	4.6	37.0	25.7
AMAR–RI	Ambient noise data	0.1	0	15.5	0.2	31.7	6.2
	Data with vessels detected	3.3	0.8	14.7	2.0	24.4	6.2

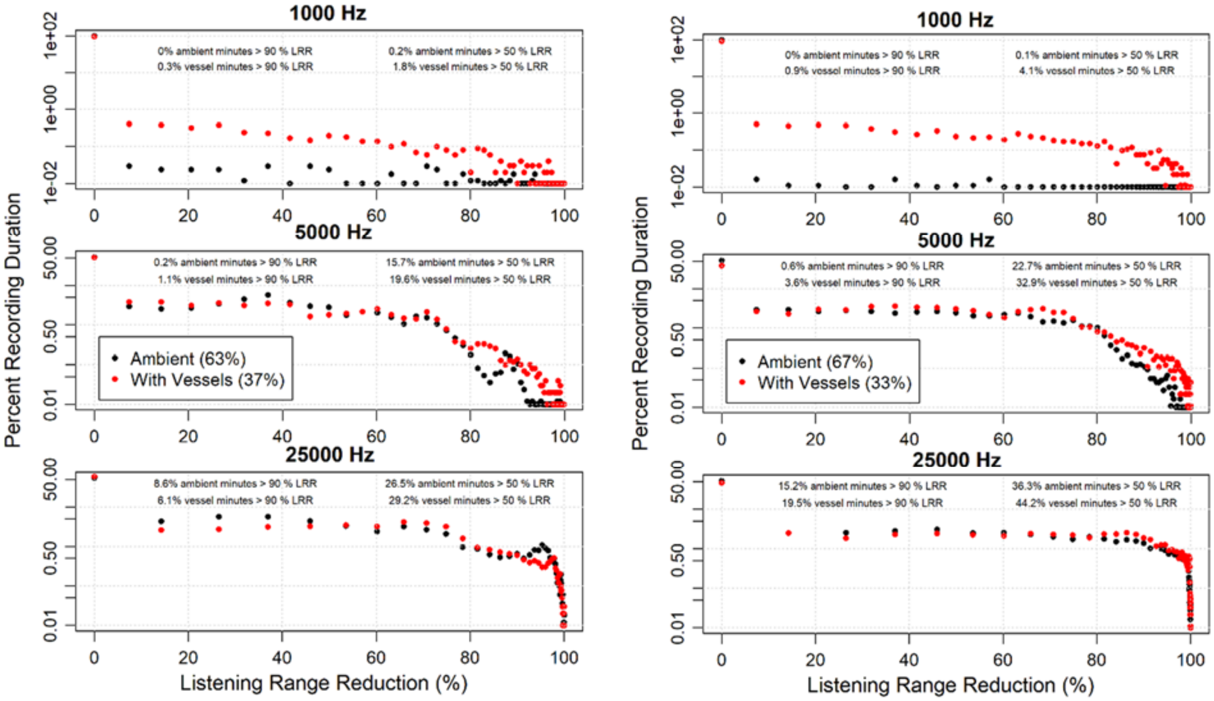
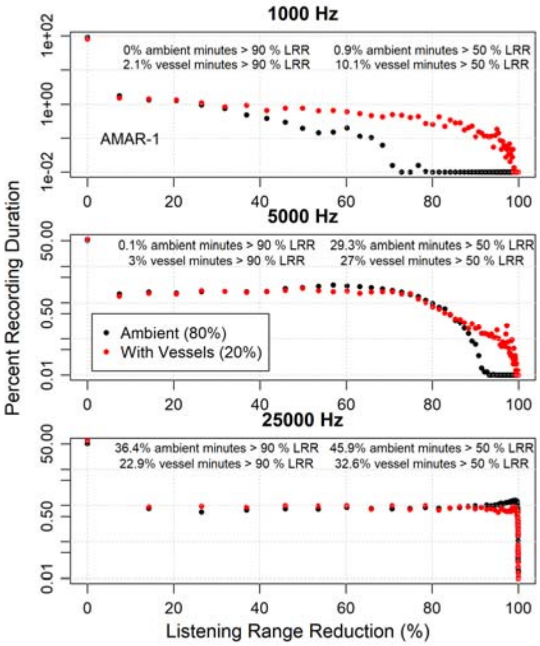
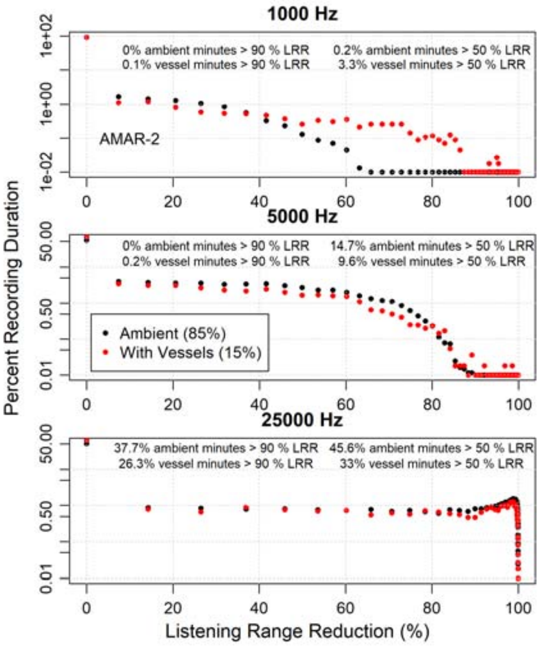
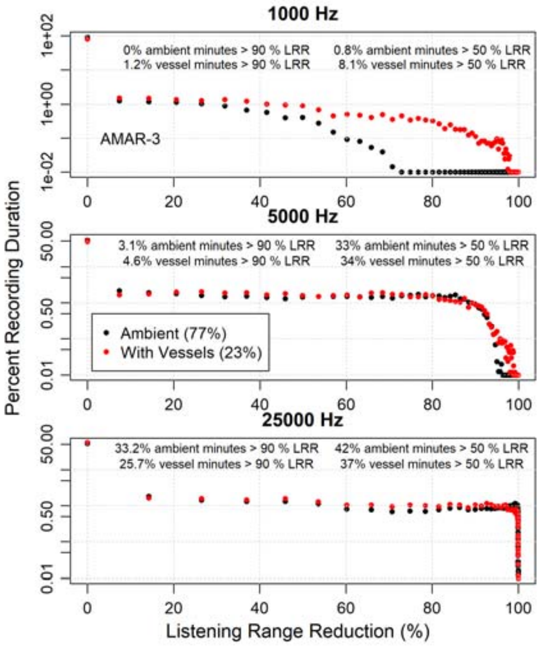


Figure 47. Listening range reduction (LRR) during the early shoulder season for the three considered frequencies at AMAR−BI (left) and AMAR–RI (right). For each station, the top figure shows LRR for the 1 kHz 1/3-octave-band, which is representative of burst pulses, the middle figure shows LRR for the 5 kHz 1/3-octave-band, which is representative of listening for whistles and knocks, and the bottom figure shows LRR for 25 kHz which is representative of clicks and high-frequency buzzes. The black dots show the distribution of LRR for ambient data only, while the red dots show the distribution of LRR for minutes with vessel detections. 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.


1000 Hz
0% ambient minutes > 90 % LRR
2.1% vessel minutes > 90 % LRR
0.9% ambient minutes > 50 % LRR
10.1% vessel minutes > 50 % LRR
AMAR-1
5000 Hz
0.1% ambient minutes > 90 % LRR
3% vessel minutes > 90 % LRR
29.3% ambient minutes > 50 % LRR
27% vessel minutes > 50 % LRR
Ambient (80%)
With Vessels (20%)
25000 Hz
36.4% ambient minutes > 90 % LRR
22.9% vessel minutes > 90 % LRR
45.9% ambient minutes > 50 % LRR
32.6% vessel minutes > 50 % LRR
Percent Recording Duration
Listening Range Reduction (%)


1000 Hz
0% ambient minutes > 90 % LRR
0.1% vessel minutes > 90 % LRR
0.2% ambient minutes > 50 % LRR
3.3% vessel minutes > 50 % LRR
AMAR-2
5000 Hz
0% ambient minutes > 90 % LRR
0.2% vessel minutes > 90 % LRR
14.7% ambient minutes > 50 % LRR
9.6% vessel minutes > 50 % LRR
Ambient (85%)
With Vessels (15%)
25000 Hz
37.7% ambient minutes > 90 % LRR
26.3% vessel minutes > 90 % LRR
45.6% ambient minutes > 50 % LRR
33% vessel minutes > 50 % LRR
Percent Recording Duration
Listening Range Reduction (%)


1000 Hz
0% ambient minutes > 90 % LRR
1.2% vessel minutes > 90 % LRR
0.8% ambient minutes > 50 % LRR
8.1% vessel minutes > 50 % LRR
AMAR-3
5000 Hz
3.1% ambient minutes > 90 % LRR
4.6% vessel minutes > 90 % LRR
33% ambient minutes > 50 % LRR
34% vessel minutes > 50 % LRR
Ambient (77%)
With Vessels (23%)
25000 Hz
33.2% ambient minutes > 90 % LRR
25.7% vessel minutes > 90 % LRR
42% ambient minutes > 50 % LRR
37% vessel minutes > 50 % LRR
Percent Recording Duration
Listening Range Reduction (%)

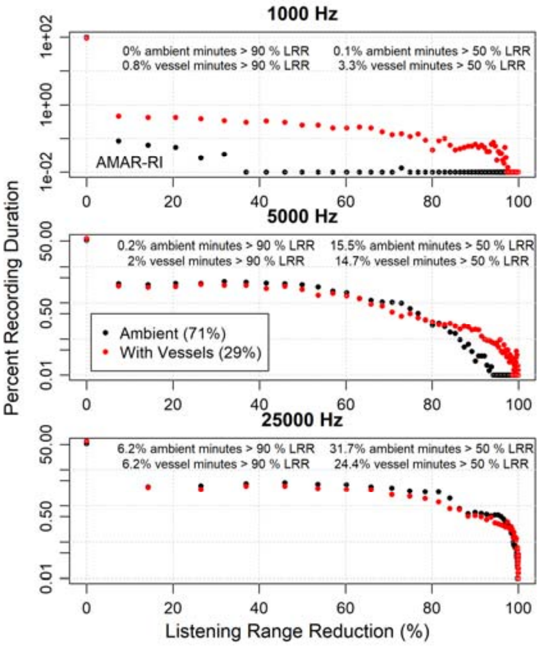

1000 Hz
0% ambient minutes > 90 % LRR
0.8% vessel minutes > 90 % LRR
0.1% ambient minutes > 50 % LRR
3.3% vessel minutes > 50 % LRR
AMAR-RI
5000 Hz
0.2% ambient minutes > 90 % LRR
2% vessel minutes > 90 % LRR
15.5% ambient minutes > 50 % LRR
14.7% vessel minutes > 50 % LRR
Ambient (71%)
With Vessels (29%)
25000 Hz
6.2% ambient minutes > 90 % LRR
6.2% vessel minutes > 90 % LRR
31.7% ambient minutes > 50 % LRR
24.4% vessel minutes > 50 % LRR
Percent Recording Duration
Listening Range Reduction (%)

Figure 48. Listening range reduction (LRR) during the open water season for the three considered frequencies at each station. For each station, the top figure shows LRR for the 1 kHz 1/3-octave-band, which is representative of burst pulses, the middle figure shows LRR for the 5 kHz 1/3-octave-band, which is representative of listening for whistles and knocks, and the bottom figure shows LRR for 25 kHz which is representative for clicks and high-frequency buzzes. The black dots show the distribution of LRR for ambient data only, while the red dots show the distribution of LRR for minutes with vessel detections. The 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.

4. Summary and Discussion

4.1. Ambient Noise and Vessel Noise

All sound levels measured in this study were below the thresholds for auditory injury for all marine mammals species that occur in the study area. Nevertheless, vessel noise has the potential to result in disturbance or acoustic masking effects on marine mammals. We investigated potential acoustic disturbance using the criterion of NOAA (1998), which is based on minimum sound levels observed to produce deflections of migrating bowhead whales near industrial activities in the arctic (Richardson et al. 1985). This criterion, defined as when broadband SPL exceeds 120 dB re 1 µPa, is the current disturbance threshold used by NOAA for assessing disturbance to marine mammals by continuous-type sounds such as vessel noise. The 120 dB re 1 µPa threshold is considered appropriate for assessing vessel noise impacts on marine mammals, and it has been incorporated into the recovery strategy for beluga whales in the St. Lawrence Estuary (https://bit.ly/2RUbDeN).

Measured underwater sound levels from the recording stations were analyzed to determine the amount of time that broadband sound levels exceeded the disturbance onset threshold of 120 dB re 1 µPa over the early shoulder and open water seasons (Table 12, Figure 49). The one-minute averaged SPL rarely exceeded the 120 dB re 1 µPa threshold at any of the stations. As was shown in Section 3.1.1, during the early shoulder season, the SPL exceeded 120 dB re 1 µPa for 1.9% of the total recording duration (28 days) at Ragged Island (AMAR–RI) and 1.4% of the same total recording duration (28 days) at Bylot Island (AMAR–BI). During the open water season, the proportion of time that underwater sound levels exceeded the 120 dB threshold ranged from 0.8% for the recorder in Koluktoo Bay (AMAR–2, 55-day recording) to 3% for the recorder directly on the shipping lane in Milne Inlet South (AMAR–1, 55-day recording). 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.

Table 12. Average and maximum daily exposure durations for disturbance (120 dB re 1 µPa) for each recorder during the 2019 early shoulder and open water shipping seasons.

Recorder		Average time per day with SPL > 120 dB (hours [minutes])	Maximum time per day with SPL > 120 dB (hours [minutes])
AMAR–BI	All recorded data	0.2 [12.6]	8.6 [516.0]
	Only data with vessels detected	0.2 [12.6]	8.6 [516.0]
AMAR–RI (first deployment)	All recorded data	1.3 [77.3]	10.6 [637.0]
	Only data with vessels detected	0.7 [41.1]	7.1 [427.0]
AMAR–1	All recorded data	0.4 [23.6]	2.3 [136.0]
	Only data with vessels detected	0.1 [8.1]	0.8 [47.0]
AMAR–2	All recorded data	0.1 [6.3]	1.4 [82.0]
	Only data with vessels detected	0.0 [2.1]	0.5 [28.0]
AMAR–3	All recorded data	0.3 [19.4]	2.4 [145.0]
	Only data with vessels detected	0.1 [6.8]	0.9 [52.0]
AMAR–RI (second deployment)	All recorded data	0.2 [10.9]	3.1 [184.0]
	Only data with vessels detected	0.1 [3.1]	0.7 [43.0]

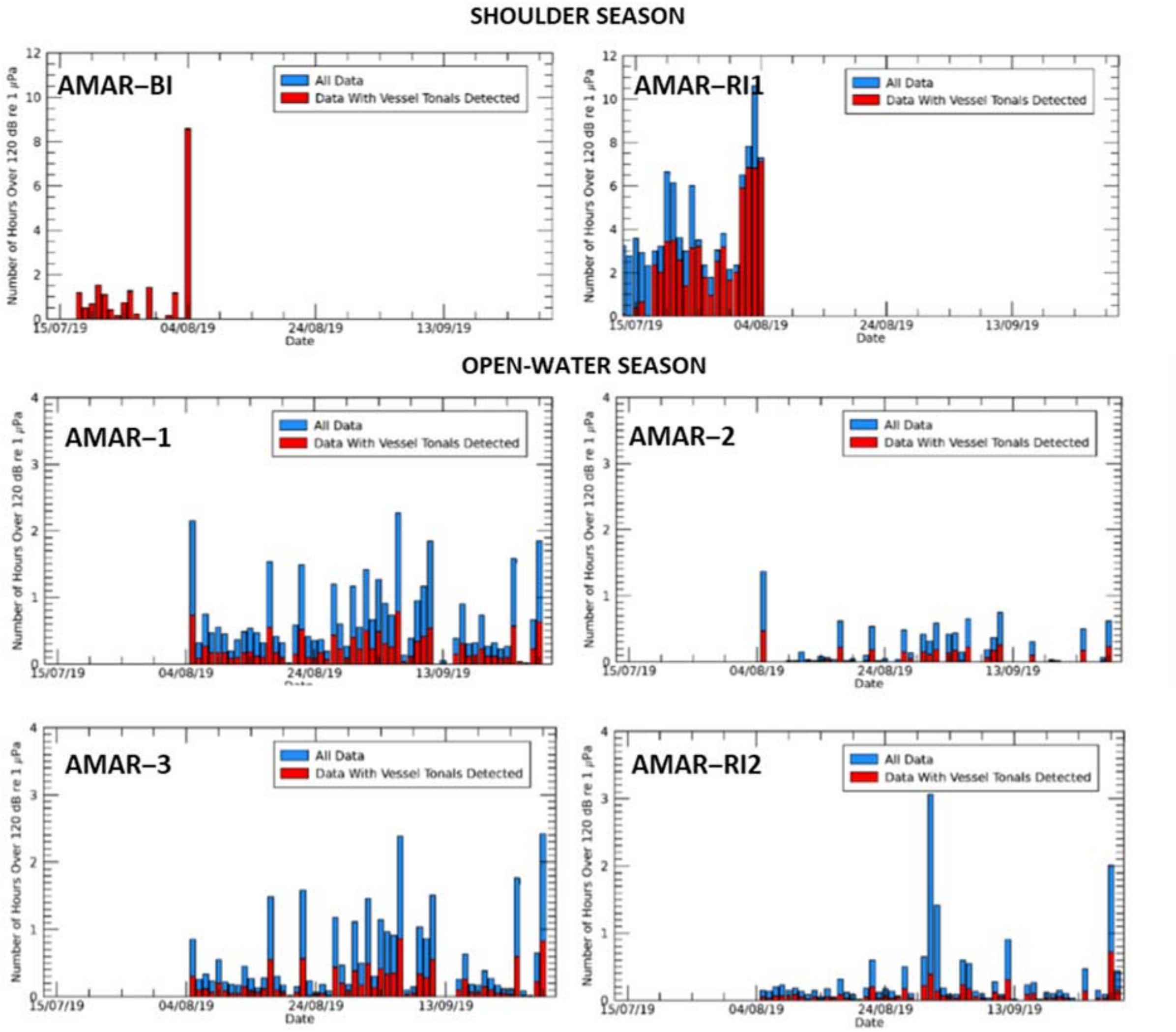


Figure 49. Hours per day with recorded sound pressure level (SPL) exceeding 120 dB re 1 µPa during shoulder season (AMAR−BI and AMAR−RI) and during open season (AMAR−1, AMAR−2, AMAR−3, and AMAR−RI).

4.2. Measurement – Model Comparisons

Measurement-derived source levels (specifically, radiated noise levels) for MSV *Botnica* transiting in open water at 8 knots exceeded those assumed in the acoustic modelling of an icebreaker transiting at 9 knots in open water that was carried out in support of an effects assessment of icebreaking activities (Golder Associates Ltd. 2019a). This means that the modelled sound footprints were based on slightly under-representative source level estimates for open water conditions. Unfortunately, a similar comparison cannot be made for an icebreaker transiting through ice; those model estimates were based on a different surrogate source, and we did not collect usable measurements of MSV *Botnica* breaking ice in 2019.

To assess the accuracy of the acoustic modelling estimates with respect to the propagation of sound from a transiting icebreaker, we determined the total amount of time during which received sound levels exceed 120 dB re 1 µPa for each of the five analyzed icebreaker transits (Table 13). This was done by counting the number of 1 min windows with SPL exceeding 120 dB within 2 hours on either side of MSV *Botnica*'s closest point of approach to AMAR–BI during the five analyzed transits. Acoustic modelling predicted that sound at an SPL of 120 dB re 1 µPa from a single icebreaker is transiting at 9 knots in open water would extend to a distance of 6.2 km in Eclipse Sound (5.3 km near Pond Inlet). The distance to 120 dB re 1 µPa for an icebreaker transiting with two ore carriers in escort was modelled to be 25.9 km in Eclipse Sound (16.3 km near Pond Inlet). Based on these modelling results, a stationary animal in Eclipse Sound would be likely to experience sounds at an SPL of 120 dB re 1 µPa for 3.1 hours as the vessel convoy transited past it (or for 0.7 hours as an icebreaker transited past alone). The modelled estimates exceed the measured durations shown in Table 13, indicating that the sound propagation calculations incorporated in the model are quite conservative, despite the under-estimation of the radiated noise levels.

Table 13. Total times that sound levels were greater than 120 dB re 1 µPa during five icebreaker transits past AMAR–BI.

Transit #	Escorted vessels* and respective ranges from AMAR during Botnica closest point of approach	Time ≥ 120 dB SPL (hours [minutes])
1	*Nordic Odin* (1 km), *Nordic Oasis* (4.2 km), *Ocean Taiga* (6.4 km)	1.3 [75]
2	None	0.5 [33]
3	*NS Yakutia* (1.6 km), *NS Energy* (3.9 km)	0.7 [43]
4	*Sagar Samrat* (2.7 km), *Nordic Oshima* (4.4 km), *Nordic Odyssey* (6.2 km)	1.2 [69]
5	*NS Yakutia* (1.4 km), *NS Energy* (3.3 km)	0.6 [37]

* *Nordic Odin, Nordic Oasis, NS Yakutia, NS Energy, Sagar Samrat*, *Nordic Oshima,* and *Nordic Odyssey* are ore carriers. *Ocean Taiga* is a Project-related tug.

4.3. Listening Range Reduction

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

Results demonstrate that both ambient and vessel noise sources can result in LRR, at different contributing levels depending on the vocalization type of interest. The listening range for sound at 25 kHz (representative of narwhal clicks and high-frequency buzzes) was more affected, by both vessel noise and ambient noise, than sound at 1 kHz (a representation frequency for burst pulses). The potential consequence is a reduced range at which the listener (narwhal) can detect potential prey. At frequencies consistent with narwhal clicks, knocks, and whistles, vessel noise resulted in LRR similar to what narwhal experience from ambient noise sources (e.g., wind, waves, rain). A small seasonal effect is present for both vocalization types, with vessel noise slightly more influential than ambient noise sources during the early shoulder season (particularly at Ragged Island), and ambient noise sources slightly more influential than vessel noise during the open water season. Burst pulses were the least susceptible vocalization type to LRR due to vessel noise, with a 90%LRR occurring ≤1% of the time during the early shoulder season, and ≤2.1% of the time during the open water season. 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,

Although DFO Science has expressed concern that the acceptable risk threshold for LRR for narwhal has not been scientifically demonstrated by Baffinland, it is well known that currently there are no established regulatory thresholds under any jurisdiction that would aid in the determination of significance of acoustic masking effects on narwhal. As described in (Hemmera 2019), (Erbe et al. 2016) characterize acoustic masking as a complex phenomenon. Masking levels can be variable and dependent on the physiological and anatomical characteristics, and activity, of the sender and receiver, the levels of ambient noise and the degree of habituation of the individuals, as well as any anti-masking strategies employed. There is no vocalization masking model developed in the literature that is narwhal-specific and no research is available on the hearing ability (i.e., audiogram) of narwhal (Erbe et al. 2016). More research is needed to understand the process and biological significance of masking, as well as the risk of masking by various anthropogenic activities, before masking can be incorporated into regulation strategies or approaches for mitigation (Erbe et al. 2016).

4.4. Marine Mammal Presence

4.4.1. Narwhals

Narwhals were detected on all AMAR stations over the recording period, and primarily from early August to late September. Narwhal click detections at the Bruce Head station (AMAR−3) were more limited than at the two other stations (AMAR−1 and AMAR−2). The arrival and departure times of narwhals from their summering areas is variable and depends on ice conditions. Narwhals typically arrive in Milne Inlet in late July as the ice breaks up, and they depart for their wintering area in Baffin Bay in September before ice forms (Finley and Gibb 1982, Dietz et al. 2001, Watt et al. 2012, Watt et al. 2016). The acoustic presence of narwhals in the area supports previous research (Marcoux et al. 2009, 2012). Recently, it was demonstrated that narwhals produce at least two kind of vocal sequences, consisting of “paired” patterns and “burst pulse series” (Walmsley et al. 2020). Both types of vocal sequences were present in the AMAR recordings collected near Bruce Head (Figures 50 and 51).

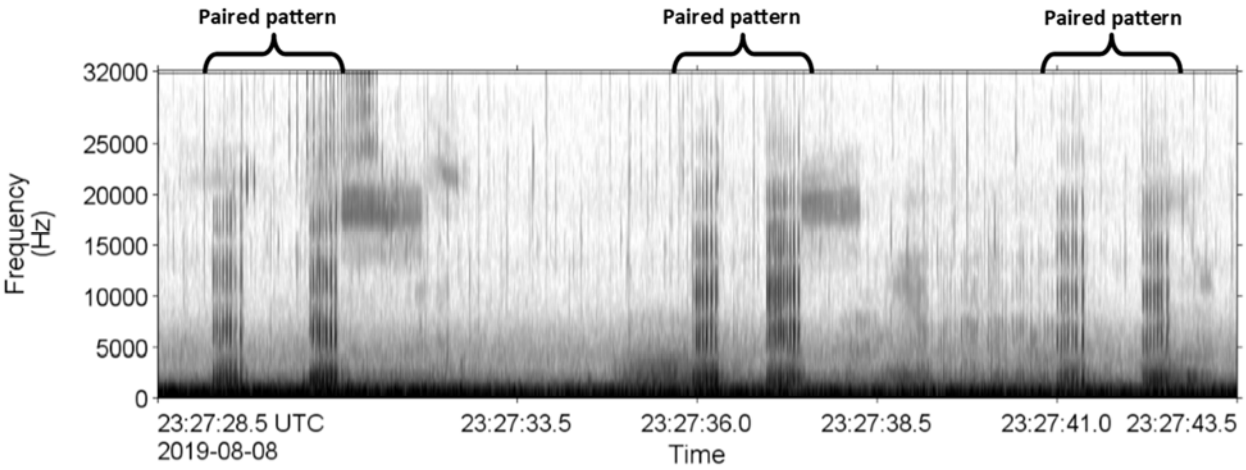


Figure 50. Spectrogram of narwhal “paired” patterns recorded at AMAR−2 on 8 Aug 2019 (UTC) (84 Hz frequency resolution, 0.001 time window, 0.0005 time step, Hamming window).

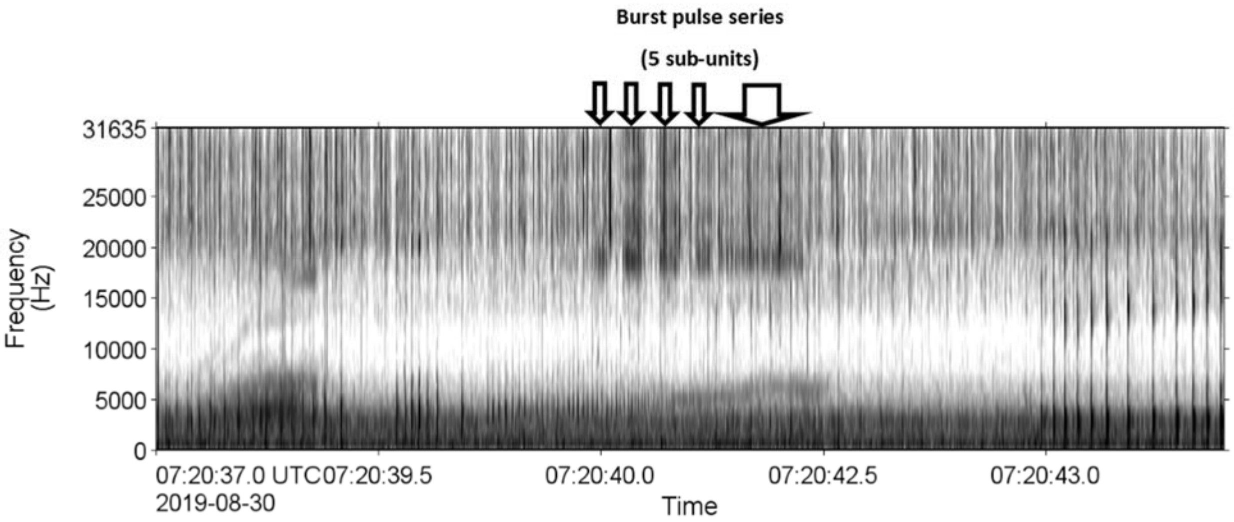


Figure 51. Spectrogram of narwhal “burst pulse series” recorded at AMAR−2 on 30 Aug 2019 (UTC) (84 Hz frequency resolution, 0.001 time window, 0.0005 time step, Hamming window).

4.4.2. Bowhead Whales

Bowhead whales depart Disko Bay (West Greenland) in mid to late May and move northwest, crossing Baffin Bay and reaching Bylot Island between late May and July (Heide-Jørgensen et al. 2003, Heide-Jørgensen et al. 2012, Laidre and Heide-Jørgensen 2012). In this study, bowhead whales were acoustically identified between 12 Aug and 4 Sep 2019 at AMAR–1 and AMAR–3. The results presented here are based on only few detections (and manual validation) and, therefore, might underestimate the acoustic occurrence of this species (the main focus of this report was on narwhal acoustic presence). Nevertheless, our results are consistent with a previous publication; Marcoux et al. (2009) reported some observations of bowhead whales in August and early September at Bruce Head.

4.4.3. Killer Whales

During the open water season, notably during late summer, killer whales enter bays and inlets in the eastern Canadian Arctic in pursuit of prey, such as narwhal, beluga whales, bowhead whales, and seals (Reeves 1988, Higdon et al. 2012). A killer whale tracked for 90 days remained in the eastern Canadian Arctic (Admiralty and Prince Regent Inlets) from mid-August until early October, when locations overlapped marine mammal prey species' aggregations (Matthews et al. 2011). The results presented here are based on few detections (and manual validation) and, therefore, might underestimate the acoustic occurrence of this species (the main focus of this report was on narwhal acoustic presence). Nevertheless, the temporal overlap between acoustic results and the detections of potential killer whale prey (narwhals) is consistent with some previous killer whale observations (presence around Pond Inlet peaks in July and August, but have been observed there as late as October; as reported in Matthews et al. 2011). This short period of detections for killer whale vocalizations is consistent with the sporadic occurrences of this species in the Project area during the open water season. Killer whales in the Eastern Canadian Arctic are understudied, and their basic ecology and distribution is poorly known. Recently, Sportelli (2019) provided the first description of the vocal repertoire (pulsed vocalizations) of killer whales present in Eclipse Sound and Milne Inlet. Eleven stereotypic vocalization types have been described, which includes some vocalizations similar to the ones illustrated in Figures 43 to 45.

4.5. Recommendations

A passive acoustic monitoring program is proposed in 2020 that would be undertaken in concert with the Bruce Head visual-based behavioural monitoring program conducted at Bruce Head (shore-based monitoring station) for continued documenting of ambient underwater noise levels along the shipping corridor, monitoring of marine mammal presence along the shipping corridor near Bruce Head and in Koluktoo Bay, and further comparison of measured (actual) ship noise levels to estimated ship noise levels determined through underwater noise modelling. Moreover, two acoustic recorders deployed near Ragged Island and Bylot Island at the end of the open water season 2019 will record sounds through the 2019 late shoulder season and through the 2020 early shoulder season (scheduled to start recording sounds on July 12, 2020), to document ambient underwater noise levels along the shipping corridor during both late and early shoulder seasons, and allowing further comparison of measured (actual) ship noise levels to estimated ship noise levels determined through underwater noise modelling.

5. Acknowledgements

The authors would like to acknowledge Emily Maxner, Jason Hines, and Eric Lumsden of JASCO and Golder team members for their assistance deploying and retrieving the acoustic recorders, as well as the manual analysts, and the JASCO equipment team for their expert preparation and handling of the gear. Tagak Outfitters were instrumental in supporting the through-ice deployment of the early shoulder season acoustic recorders. The crew of MSV *Botnica*, contributed to the logistical and operational success of the open water season deployment and retrieval cruises.

Glossary

1/3-octave
One third of an octave. Note: A one-third octave is approximately equal to one decidecade (1/3 oct ≈ 1.003 ddec; ISO 2017).

1/3-octave-band
Frequency band whose bandwidth is one one-third octave. Note: The bandwidth of a one-third octave-band increases with increasing centre frequency.

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

audiogram
A graph of hearing threshold level (sound pressure levels) as a function of frequency, which describes the hearing sensitivity of an animal over its hearing range.

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

background noise
Total of all sources of interference in a system used for the production, detection, measurement, or recording of a signal, independent of the presence of the signal (ANSI S1.1-1994 R2004). For example, background noise comprises all sounds that an animal must contend with when trying to detect a sound of interest, such as the vocalization of another animal. Ambient noise detected, measured, or recorded with a signal is part of the background noise.

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

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

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

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

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

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 2006).

decidecade
One tenth of a decade (ISO 2017). Note: An alternative name for decidecade (symbol ddec) is "one-tenth decade". A decidecade is approximately equal to one third of an octave (1 ddec ≈ 0.3322 oct) and for this reason is sometimes referred to as a "one-third octave".

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

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

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.

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

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

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

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

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

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

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

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

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

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

median
The 50th percentile of a statistical distribution.

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

mysticete
Mysticeti, a suborder of cetaceans, use their baleen plates, rather than teeth, to filter food from water. They are not known to echolocate, but they use sound for communication. Members of this group include 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, narwhals, dolphins, and porpoises.

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

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

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

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

permanent threshold shift (PTS)
A permanent loss of hearing sensitivity caused by excessive noise exposure. PTS is considered auditory injury.

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

phocid pinnipeds in water (PPW)
The functional pinniped hearing group that represents true/earless seals under water.

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

pressure, acoustic
The deviation from the ambient hydrostatic pressure caused by a sound wave. Also called overpressure. Unit: pascal (Pa). Symbol: *p*.

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

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

rms
root-mean-square.

signature
Pressure signal generated by a source.

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

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

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

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

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

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

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

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

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

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

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

temporary threshold shift (TTS)
Temporary loss of hearing sensitivity caused by excessive noise exposure.

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Appendix A. Metrics for Quantifying Underwater Sounds

A.1. Acoustic Metrics

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. This appendix provides specific definitions of relevant metrics used in this report. Where possible the ANSI and ISO standard definitions and symbols for sound metrics are followed, but these standards are not always consistent.

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

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

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

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

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

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

The sound exposure level (SEL or L_E, dB re 1 $\mu\mathrm{Pa}^2\cdot\mathrm{s}$) 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):

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

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

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

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

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

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

$$L_E = 10\log_{10}\left[\int_T\left(p^2(t)-\overline{n^2}\right)dt\Big/T_0p_0^2\right] \tag{A-7}$$

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

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

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

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

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

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

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

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

A.2. One-Third Octave Band Analysis

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

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

$$f_{\mathrm{c}}(i) = 10^{\frac{i}{10}}, \tag{11}$$

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

$$f_{\mathrm{lo},i} = 10^{\frac{-1}{20}} f_{\mathrm{c}}(i) \quad \text{and} \quad f_{\mathrm{hi},i} = 10^{\frac{1}{20}} f_{\mathrm{c}}(i) \tag{A-12}$$

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

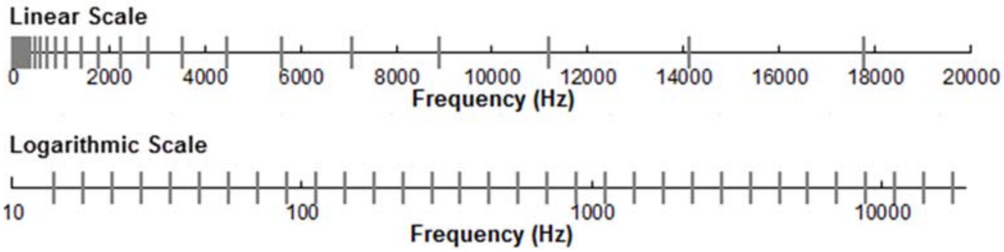

Figure A-1. One-third octave-band frequency bands (vertical lines) shown on a linear frequency scale and a logarithmic scale.

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

$$L_{\mathrm{p},i} = 10 \log_{10} \int_{f_{\mathrm{lo},i}}^{f_{\mathrm{hi},i}} S(f)\, df \tag{A-13}$$

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

$$\text{Broadband SPL} = 10 \log_{10} \sum_{i} 10^{\frac{L_{\mathrm{p},i}}{10}} \tag{A-14}$$

Figure A-2 shows an example of how the 1/3-octave-band sound pressure levels compare to the power spectrum of an ambient noise signal. Because the 1/3-octave-bands are wider with increasing frequency, the 1/3-octave-band SPL is higher than the power spectrum, especially at higher frequencies. 1/3-octave-band analysis is applied to both continuous and impulsive noise sources. For impulsive sources, the 1/3-octave-band SEL is typically reported.

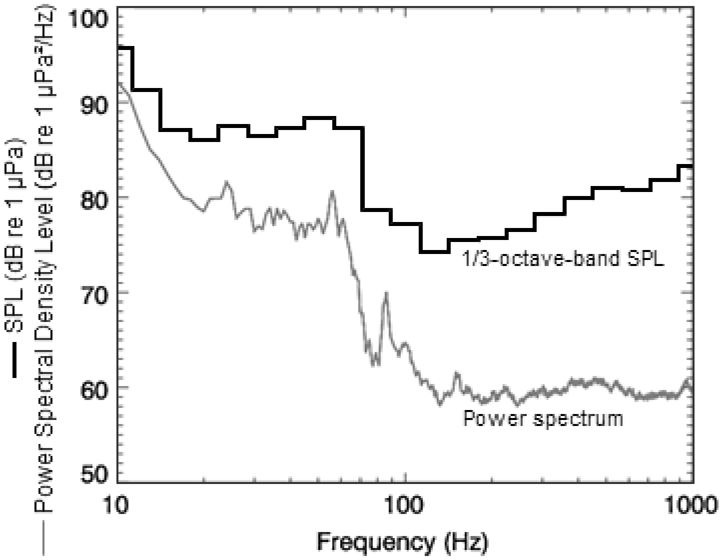

Figure A-2. A power spectrum and the corresponding 1/3-octave-band sound pressure levels of example ambient noise shown on a logarithmic frequency scale. Because the 1/3-octave-bands are wider with increasing frequency, the 1/3-octave-band SPL is higher than the power spectrum.

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

Band	Lower frequency	Nominal centre frequency	Upper frequency
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

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

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

A.3. Marine Mammal Auditory Frequency Weighting

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

A.3.1. Southall et al. (2007) Weighting Functions

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

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

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

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

where $G(f)$ is the weighting function amplitude (in dB) at the frequency f (in Hz), and a and b are the estimated lower and upper hearing limits, respectively, which control the roll-off and passband of the weighting function. The parameters a and b are defined uniquely for each hearing group (Table A-3). Figure A-3 shows the auditory weighting functions recommended by Southall et al. (2007).

Table A-3. Parameters for the auditory weighting functions recommended by Southall et al. (2007).

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

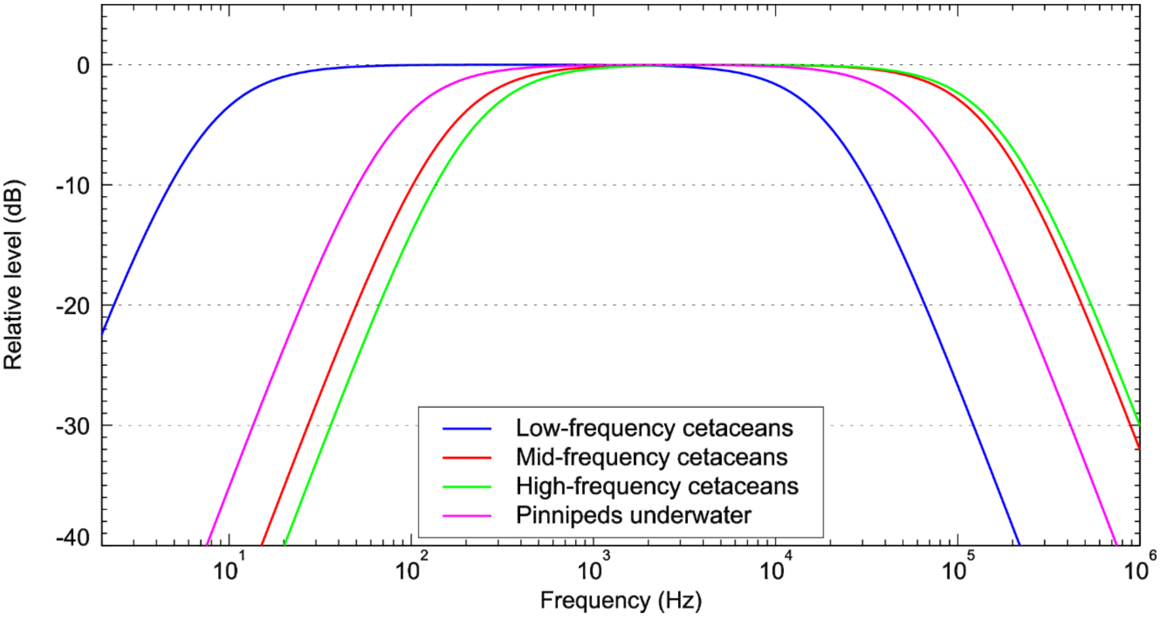

Figure A-3. Auditory weighting functions for the functional marine mammal hearing groups as recommended by Southall et al. (2007).

A.3.2. NMFS (2018) Weighting Functions

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

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

Finneran (2015) proposed five functional hearing groups for marine mammals in water: low-, mid- and high-frequency cetaceans (LF, MF, and HF cetaceans, respectively), phocid pinnipeds, and otariid pinnipeds. The parameters for these frequency-weighting functions were further modified the following year (Finneran 2016) and were adopted in NOAA's technical guidance that assesses noise impacts on marine mammals (NMFS 2018). Table A-4 lists the frequency-weighting parameters for each hearing group. Figure A-4 shows the resulting frequency-weighting curves.

Table A-4. Parameters for the auditory weighting functions recommended by NMFS (2018).

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

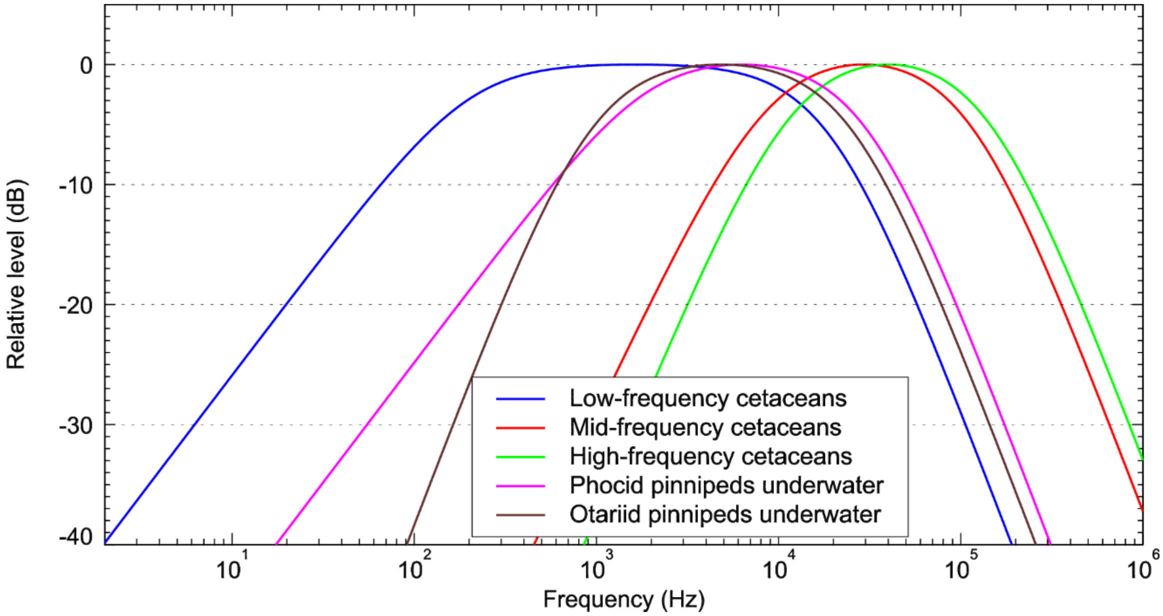

Figure A-4. Auditory weighting functions for the functional marine mammal hearing groups as recommended by NMFS (2018).

Appendix B. Acoustic Data Analysis Methods

B.1. Marine Mammal Detections

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

B.1.1. Automated Click Detectors

Odontocete clicks were detected by the following steps (Figure B-1):

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

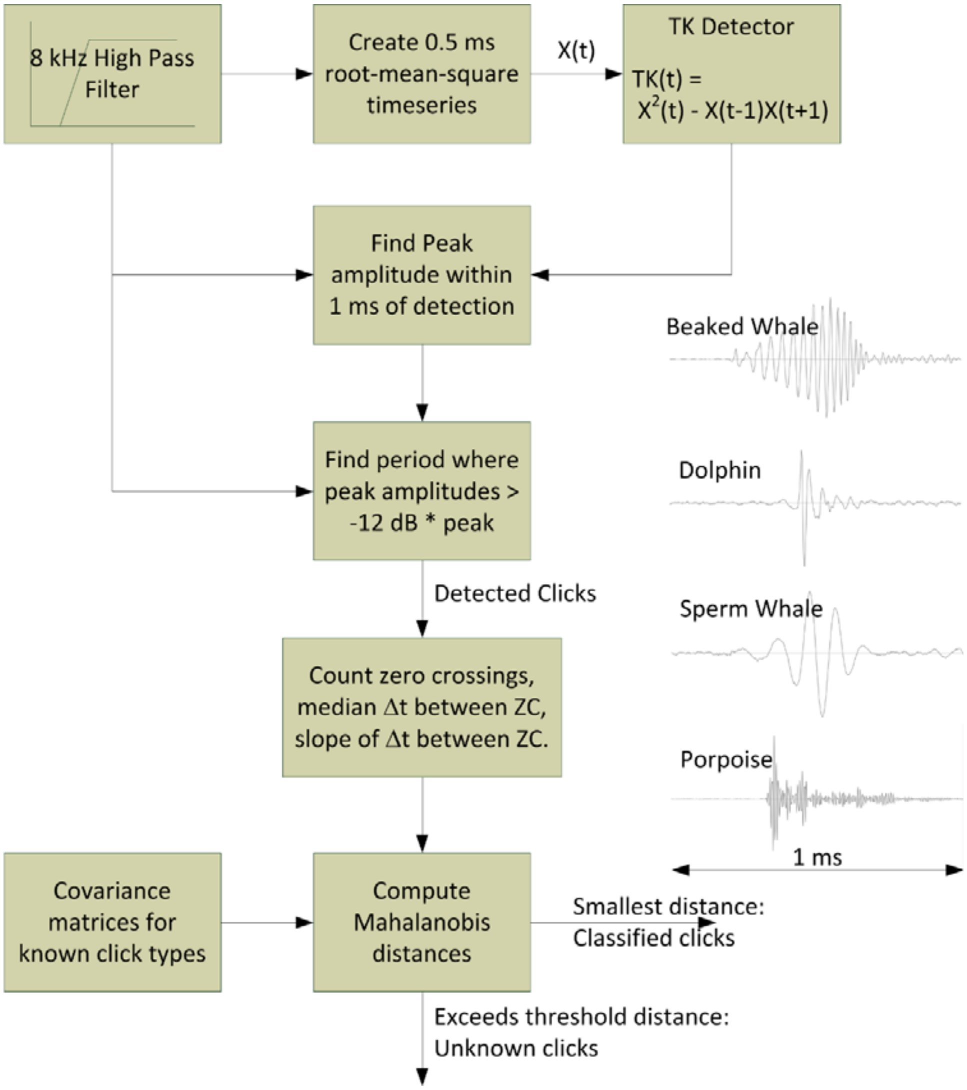

Figure B-1. The click detector/classifier and a 1-ms time-series of four click types.

B.1.2. Cetacean Tonal Vocalization Detection

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

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

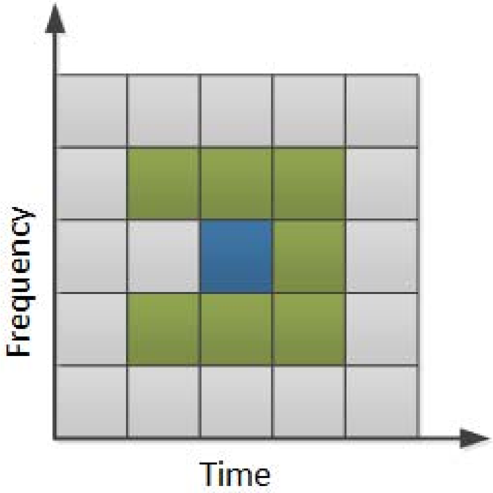

Figure B-2. Illustration of the search area used to connect spectrogram bins. The blue square represents a bin of the binary spectrogram equalling 1 and the green squares represent the potential bins it could be connected to. The algorithm advances from left to right so grey cells left of the test cell need not be checked.

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

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

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

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

B.1.3. Narwhal-Specific Vocalization Detection

32 acoustic files were identified and fully annotated for automated detector purposes, where many files could appropriately be used for developing more than one automated detector vocalization type. Analysis resulted in 1433 annotations created by an experienced analyst: 195 echolocation click trains, 79 high-frequency buzz trains, 679 low-frequency buzz trains, 57 whistles, 294 knock trains, and 51 "other" vocalizations where the analyst was uncertain on vocalization assignment.

The echolocation click detector used JASCO's pre-existing click detector (see Section 2.2.3.1 and Appendix B.1.1). Click zero-crossing parameters were extracted from the truth data set and then used to create and optimize a narwhal-specific click detector.

The detectors for high-frequency buzz, low-frequency buzz, and whistles were created by optimizing JASCO's contour detector software (see Section 2.2.3.2 and Appendix B.1.2). Within PAMlab, analysts altered the automated detector parameters to include as many true automated detections as possible, while minimizing false positives for each automated vocalization type detector. A summary of parameters used are included in Tables B-3 and B-4.

The knock train detector implemented a novel approach that used the contour detector (see Section 2.2.3.2 and Appendix B.1.2) and subsequently linked knocks into trains. The detector was optimized for narwhal knock trains with parameters summarized in Tables B-3 and B-4. This detector operated in two phases:

1. All candidate knocks were isolated from the recordings using a contour detector tuned to detect short energy pulses between 1 and 8 kHz between 5 and 40 ms in duration, and
2. Pulses were combined into trains whenever an interrupted sequence of 6 to 100 pulses was found, spaced 30 to 500 ms apart, and where subsequent gaps varied by no more than 20%. Trains were capped at 30 s.

Table B-3. Fast Fourier Transform (FFT) and detection window settings used to detect narwhal vocalizations in the data. Values are based on JASCO's experience and empirical evaluation on a variety of data sets.

Vocalization	**FFT**			**Detection window (s)**	**Detection threshold**
	Resolution (Hz)	Frame length (s)	Timestep (s)		
High-frequency buzz	64	0.01	0.005	5	2.5
Low-frequency buzz	16	0.03	0.015	5	2
Whistle	4	0.05	0.01	5	3.5
Knock train	64	0.01	0.005	40	2

Table B-4. A sample of vocalization sorter definitions for narwhal vocalizations.

Vocalization	**Frequency (Hz)**	**Duration (s)**	**Bandwidth (Hz)**
High-frequency buzz	14,000–100,000	0.1–10	>3000
Low-frequency buzz	1,000–10,000	0.5–5	>1000
Whistle	1,000–20,000	0.5–5	>20
Knock train	1,000–8,000	0.5–30	NA

B.1.4. Validation of Automated Detectors

B.1.4.1. Selecting Data for Manual Validation

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

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

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

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

The goodness of fit of a sample of files was scored according to how well it conforms to the “preferred” distribution of detections, as determined by the initial distribution and the preferred final sampling. A lower score implies a better fit. To score the goodness of fit, the following steps are performed for a selected sample of files:

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

   $\mathrm{DiversityScore} = \mathrm{average}(\mathrm{abs}(Pc[i]–Po[i]))$

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

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

   $\mathrm{DetectionScore} = \mathrm{average}(\mathrm{PerSpeciesScore}[1..n])$, where n is the number of species

   $\mathrm{FitScore} = (\mathrm{DiversityScore} + \mathrm{DetectionScore})/2$

B.1.4.2. Detector Performance Calculation and Optimization

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

In phase 1, the validated versus detector results were plotted as time series and critically reviewed to determine when and where automated detections should be excluded. Questionable detections that overlap with the detection period of other species were scrutinized. By restricting detections spatially and/or temporally where appropriate, the reliability of the results is maximized. The following restrictions were applied to our detector results:

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

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

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

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

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

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

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

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

Appendix C. Detector Performance

C.1. Narwhal Whistles (generic)

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

Station	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
AMAR−1	4	0.82	1.00	19	14	18
AMAR−2	1	0.81	0.81	24	16	16
AMAR−3	2	0.56	0.77	27	13	19

C.2. Narwhal Clicks (generic)

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

Station	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
AMAR−1	-	-	-	26	26	23
AMAR−2	1	1.00	0.92	27	24	22
AMAR−3	1	1.00	1.00	27	25	25

For Station AMAR–1, performance could not be calculated because there were no files reviewed that were not found to either have a narwhal click or have a potential narwhal click.

C.3. Narwhal Echolocation Clicks

Table C-3. Performance of the automated narwhal echolocation clicks detector for each station including the Threshold implemented, the resulting detector Precision (P) and Recall (R), the number of files included in the calculation (# Files; excluding any files where an analyst was uncertain of species presence), the number of files in the calculation containing an annotation for this species/ vocalization type (# Annotation files), and the number of files in the calculation containing automated narwhal echolocation click detections (# Detection files).

Station	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
AMAR−1	111	1	1	27	20	21
AMAR−2	1	1	1	27	23	23
AMAR−3	1	1	0.95	27	22	21

C.4. Narwhal High-Frequency Buzzes

Table C-4. Performance of the automated narwhal high-frequency buzzes detector for each station including the Threshold implemented, the resulting detector Precision (P) and Recall (R), the number of files included in the calculation (# Files; excluding any files where an analyst was uncertain of species presence), the number of files in the calculation containing an annotation for this species/ vocalization type (# Annotation files), and the number of files in the calculation containing automated narwhal high-frequency buzz detections (# Detection files).

Station	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
AMAR-1	4	1	0.86	27	14	18
AMAR-2	5	0.82	0.90	27	10	16
AMAR-3	1	0.94	0.89	27	18	17

C.5. Narwhal Low-Frequency Buzzes

Table C-5. Performance of the automated narwhal low-frequency buzzes detector for each station including the Threshold implemented, the resulting detector Precision (P) and Recall (R), the number of files included in the calculation (# Files; excluding any files where an analyst was uncertain of species presence), the number of files in the calculation containing an annotation for this species/ vocalization type (# Annotation files), and the number of files in the calculation containing automated narwhal low-frequency buzz detections (# Detection files).

Station	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
AMAR-1	1	1	0.70	27	23	16
AMAR-2	1	0.95	0.82	27	22	19
AMAR-3	1	1	0.63	27	24	15

C.6. Narwhal Knocks

Table C-6. Performance of the automated narwhal knocks detector for each station including the Threshold implemented, the resulting detector Precision (P) and Recall (R), the number of files included in the calculation (# Files; excluding any files where an analyst was uncertain of species presence), the number of files in the calculation containing an annotation for this species/ vocalization type (# Annotation files), and the number of files in the calculation containing automated narwhal knock detections (# Detection files).

Station	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
AMAR-1	1	0.86	0.75	27	16	14
AMAR-2	7	0.92	0.73	27	15	13
AMAR-3	1	1	0.62	27	21	13

C.7. Narwhal Whistles

Table C-7. Performance of the automated narwhal whistles detector for each station including the Threshold implemented, the resulting detector Precision (P) and Recall (R), the number of files included in the calculation (# Files; excluding any files where an analyst was uncertain of species presence), the number of files in the calculation containing an annotation for this species/ vocalization type (# Annotation files), and the number of files in the calculation containing automated narwhal whistle detections (# Detection files).

Station	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
AMAR−1	1	1	0.64	27	22	14
AMAR−2	1	0.90	0.90	27	19	19
AMAR−3	1	1	0.50	27	24	12

Appendix D. Weekly LTSA and Band-level Plots

D.1. AMAR-BI

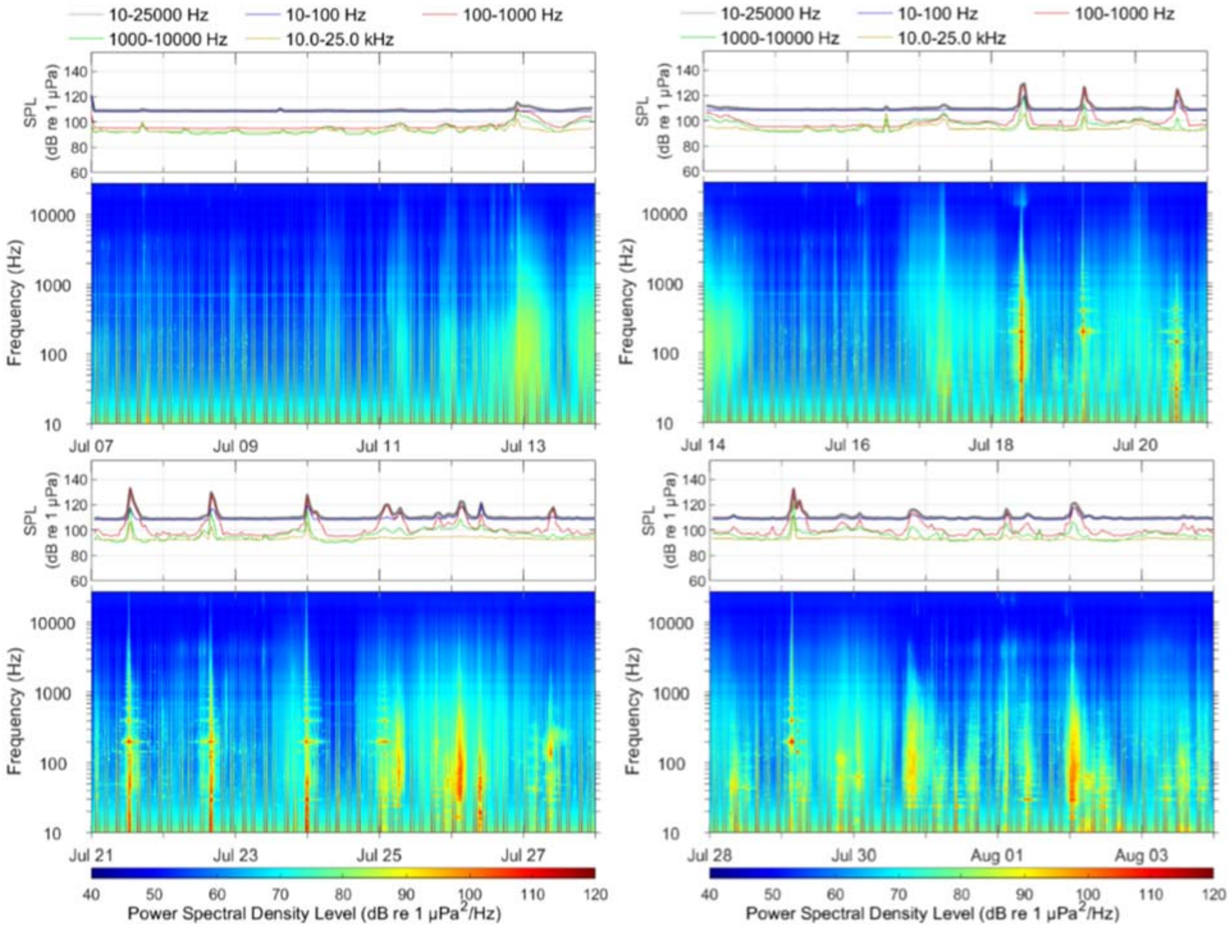

Figure D-1. Weekly plots for AMAR−BI: (Bottom) spectrogram and (top) in-band sound pressure level (SPL) for underwater sound

D.2. AMAR-RI (Shoulder Season)

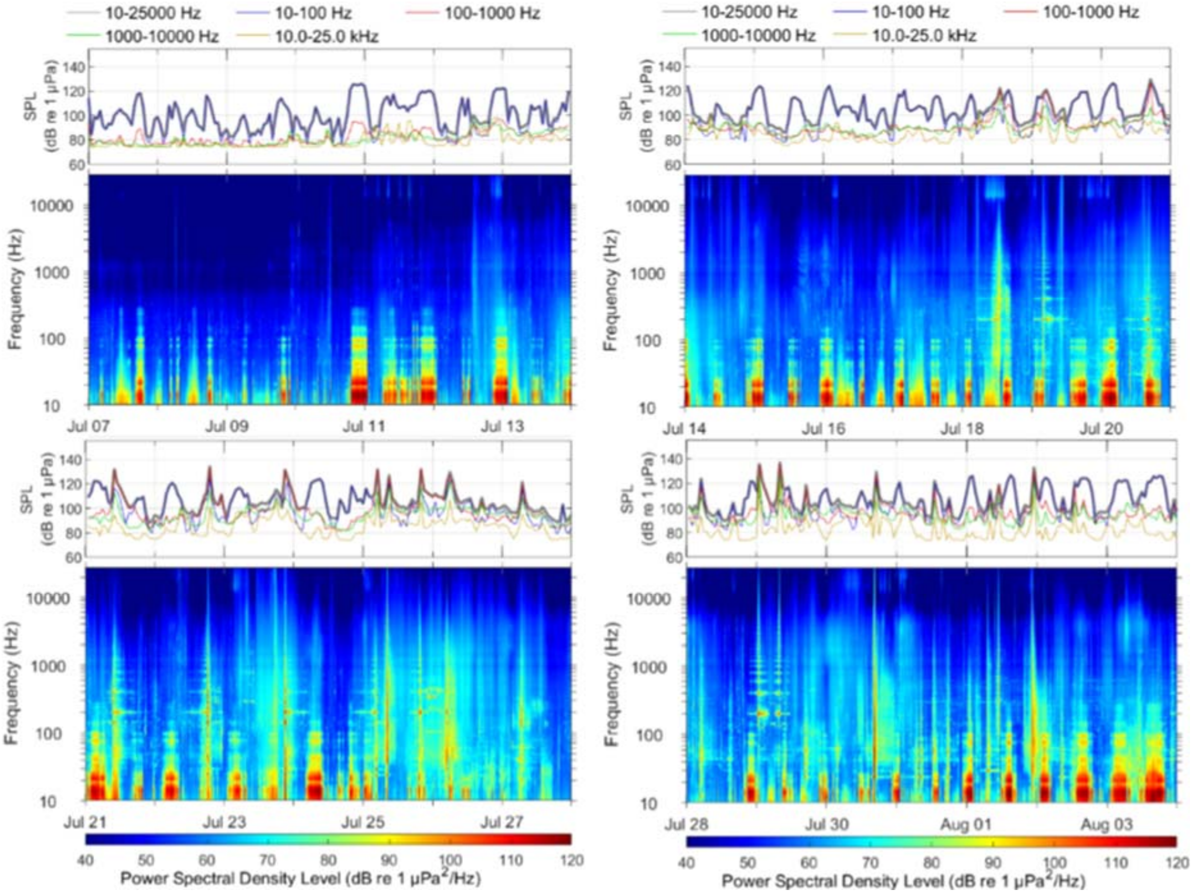

Figure D-2. Weekly plots for AMAR−RI: (Bottom) spectrogram and (top) in-band sound pressure level (SPL).

D.3. AMAR–1

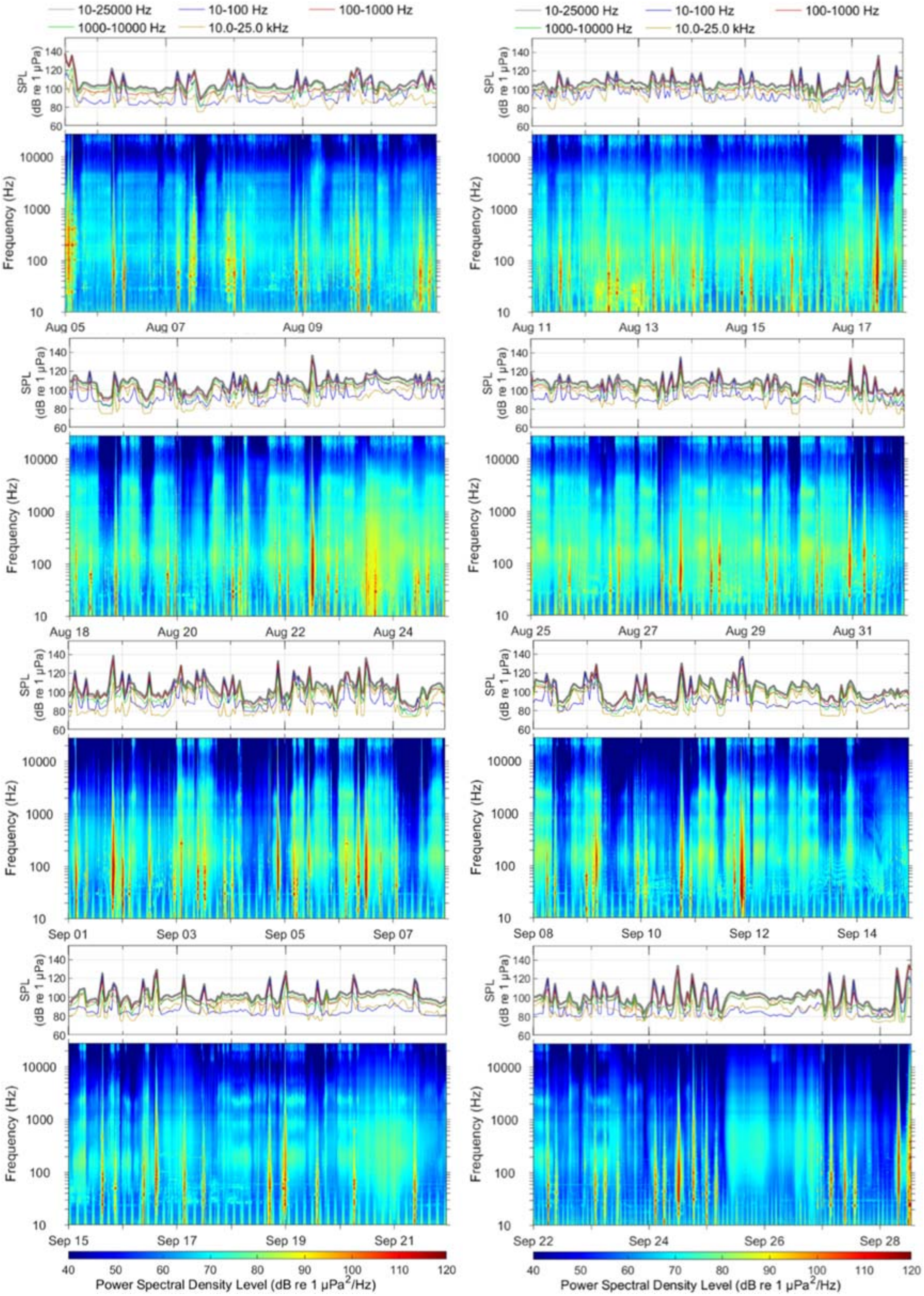

Figure D-3. Weekly plots for AMAR−1: (Bottom) spectrogram and (top) in-band sound pressure level (SPL).

D.4. AMAR–2

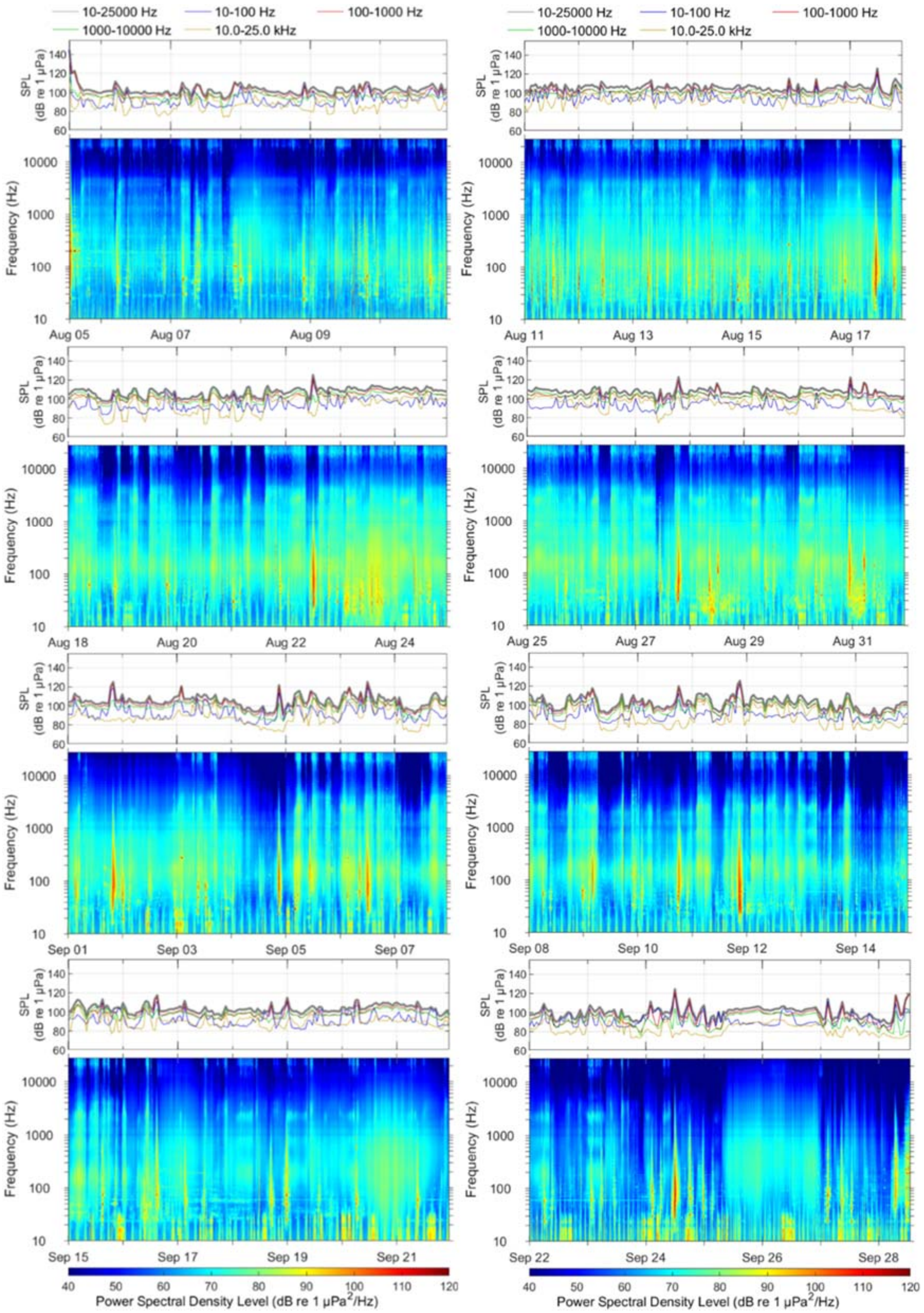

Figure D-4. Weekly plots for AMAR−2: (Bottom) spectrogram and (top) in-band sound pressure level (SPL).

D.5. AMAR–3

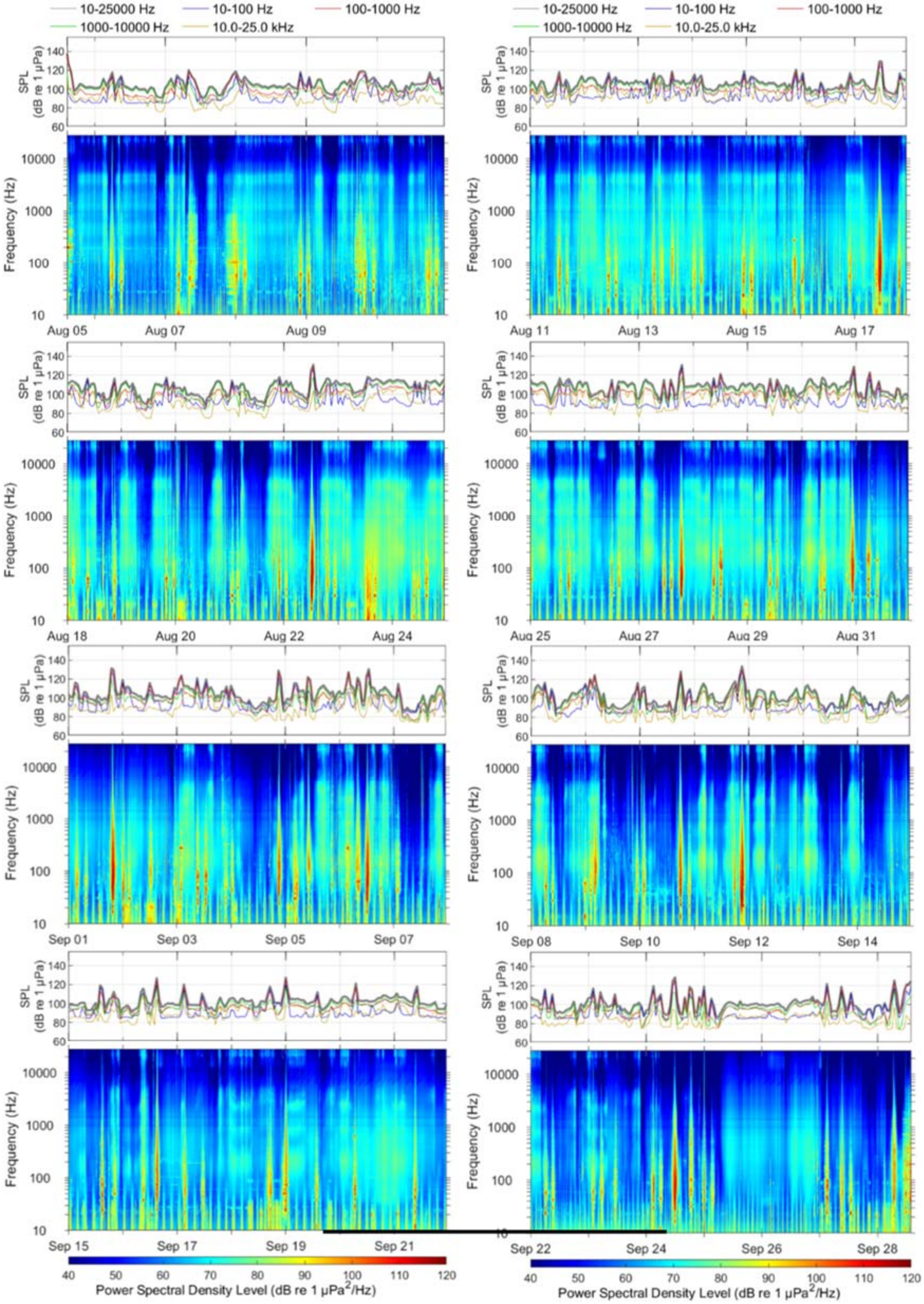

Figure D-5. Weekly plots for AMAR−3: (Bottom) spectrogram and (top) in-band sound pressure level (SPL).

D.6. AMAR-RI (Open Water Season)

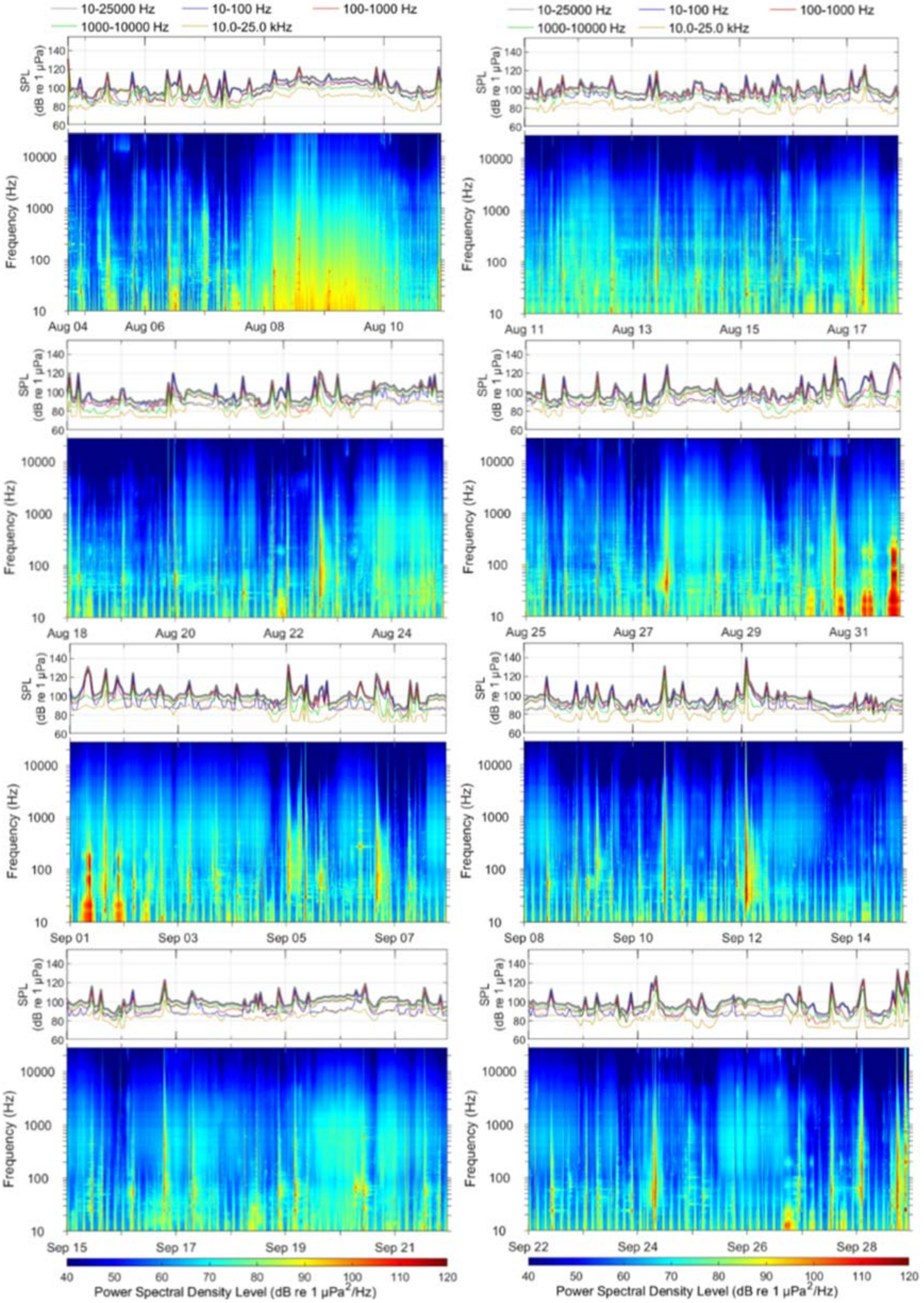

Figure D-6. Weekly plots for AMAR−RI (second deployment): (Bottom) spectrogram and (top) in-band sound pressure level (SPL).

Appendix E. Responses to Comments from Marine Environmental Working Group Members

E.1. Fisheries and Oceans Canada and Parks Canada

Name: Marianne Marcoux, Jacquie Bastick

Agency / Organization: DFO and PCA

Date of Comment Submission: June 15th, 2020

#	Document Name	Section Reference	Comment	Baffinland Response
1	2019 Passive Acoustic Monitoring Program	General comments	It would be useful that the results from the different monitoring programs related to marine mammals get interpreted and integrated together. The different monitoring programs were designed to complement each other and their results should feed into each other. In addition, they are all part of the same adaptive management and mitigation plan.	Comment noted. The various programs undertaken by Baffinland are designed to obtain a comprehensive understanding of narwhal response to vessel traffic. A Technical Memorandum entitled “Summary of Results for the 2019 Marine Mammal Monitoring Programs” was submitted to DFO in May 2020 and incorporated an integrated summary of the results of all the marine mammal monitoring programs.
2	2019 Passive Acoustic Monitoring Program	Executive Summary	It should be clearly noted that heavy ice breaking activities did not take place in 2019 and that it was not possible to compare measured levels of noise emitted by the MSV Botnica breaking ice to the predictions of the models provided in the original assessment.	The following sentences have been added to the Executive Summary: “There was limited active icebreaking in 2019, as the vessels preferentially transited through safer open water conditions where possible. As such, all icebreaker transits near to the acoustic recorders occurred in open water conditions.”
3	2019 Passive Acoustic Monitoring Program	2.2.3.3. Narwhal-specific Vocalization Detection	Could you provide a description of what knock trains are in the context of this report?	Knock train is a typo. It, actually, refers to the name of the knock detector (pulse train detector) developed for this specific Project. The report should refer to knock (instead of knock train) in this context. The sentence has been modified and can be read as:

#	Document Name	Section Reference	Comment	Baffinland Response
				"Vocalization-specific automated detectors were developed for five types of narwhal-produced sounds: echolocation clicks, high-frequency buzzes, low-frequency buzzes, whistles, and knocks".
4	2019 Passive Acoustic Monitoring Program	2.3. Vessel Sound Level Analysis	It would be useful to provide the ice concentrations that relate to each transit/recording in table 4.	As indicated in the Table Caption, each of these transits occurred in open water conditions.
5	2019 Passive Acoustic Monitoring Program	4.2. Measurement – Model Comparisons	JASCO stated: "The modelled estimates exceed the measured durations shown in Table 11, indicating that the sound propagation calculations incorporated in the model are quite conservative, despite the under-estimation of the radiated noise levels." Does this statement take into account that the Botnica transited at 8 knot (not 9 knot as modelled)?	Yes. The estimated radiated noise levels for the Botnica at 8 knots were louder than those assumed in the modelling for the Botnica transiting in open water at 9 knots. If the measurements were corrected (i.e. increased) for an assumed transit speed of 9 knots, the measured levels would even further exceed those used in the model. The measurements indicate that a louder source resulted in shorter exposure durations compared to what was estimated through modelling for a quieter source. One would expect a louder source to result in longer exposure durations. This indicates that the model is underestimating the amount of sound transmission loss in the environment. In other words, this shows that the model has overestimated the distances over which the sound travels, resulting in a conservative estimation of the exposure durations.
6	2019 Passive Acoustic Monitoring Program	4.5. Recommendations	This is an interesting report. It will be important to continue the Passive Acoustic Monitoring program to capture variation in environmental conditions such as sea ice concentration, especially since recordings made in 2019 did not capture heavy icebreaking conditions.	Passive Acoustic Monitoring has been extended for another year. As mentioned in the Introduction, two acoustic recorders were deployed at the end of the open water season in 2019 to record sounds through the late shoulder season. These hydrophones, deployed near to Ragged Island and Bylot Island, will also record sounds through the early shoulder season (recording started on July 12, 2020). During summer 2020, another hydrophone will be

#	Document Name	Section Reference	Comment	Baffinland Response
				deployed at Bruce Head to record sounds during the open water season.
7	2019 Passive Acoustic Monitoring Program	4.5. Recommendations	It is not clear if AMAR-R1 and AMAR-B1 will be redeployed in future years. Can you clarify? Are there plans to deploy AMAR in other locations? For example, it would be interesting to compare model predictions to recording levels in Milne Inlet.	Constraints for the 2020 field season limited the 2020 open-water acoustic monitoring program to a single AMAR deployed off Bruce Head. The anticipated scope for future acoustic monitoring programs is not known at this time.
8	2019 Passive Acoustic Monitoring Program	4.5. Recommendations	AMARs were retrieved on September 28-29, 2019. What are the plans to monitor noise levels at the fall shoulder season? Will some of the AMAR be deployed over winter? It is important to monitor noise levels in the fall while narwhals migrate out of the area.	As stated previously, and as mentioned in the Introduction, two acoustic recorders were deployed at the end of the open water season in 2019 to record sounds through the late (fall) shoulder season. These hydrophones, deployed near to Ragged Island and Bylot Island, will also record sounds through the early shoulder season (recording will start on July 12, 2020 and continue until the batteries are depleted). The following sentence has been added at the end of Recommendations in Section 4.5 : “Moreover, two acoustic recorders deployed near Ragged Island and Bylot Island at the end of the 2019 open water season will record sounds through the 2019 late shoulder season and through the 2020 early shoulder season (scheduled to start recording sounds on July 12, 2020), to document ambient underwater noise levels along the shipping corridor during both late and early shoulder seasons, and allowing further comparison of measured (actual) ship noise levels to estimated ship noise levels

#	Document Name	Section Reference	Comment	Baffinland Response
				determined through underwater noise modelling.”
9	2019 Passive Acoustic Monitoring Program	4.5. Recommendations	Given that this report indicates that 50% LRR occurs prevalently when the icebreaker was present, the mitigation measures proposed for icebreaking during the shoulder season (as detailed in Assessment of Icebreaking Operations during Shipping Shoulder Seasons on Marine Biophysical Valued Ecosystem Components 1663724-102-R-Rev1-30000) should also apply during the open water season.	The icebreaker remains at anchor at Milne Port during the open water season and does not escort vessels along the shipping lane during this time. It is not clear which results in the report indicate to DFO and PCA that 50% LRR occurs prevalently when the icebreaker was present. 50% LRR was in fact more prevalent during the open water season recordings compared to the early shoulder season recordings.

E.2. Oceans North

Name: Amanda Joynt

Agency / Organization: Oceans North

Date of Comment Submission: June 13, 2020

These comments refer to an independent analysis with the title of: Underwater Radiated Noise from Ships in Eclipse Sound, 2018-2019 (Jones 2020). The figures and tables from this analysis is provided with these comments. A full copy of the analysis will be provided when it is in its final version.

#	Document Name	Section Reference	Comment	Baffinland Response
1	Draft 2019 Passive Acoustic Monitoring Program Report	Section 2.4	When evaluating auditory masking in marine mammals resulting from man-made noise, a common approach is to estimate the loss of area within which effective hearing of acoustic signals can occur. For example, Listening Space Reduction (LSR) has been employed in several published studies evaluating acoustic masking in Arctic marine mammals (e.g. Hannay *et al.,* 2016; Mathews *et al.*, 2016; Pine *et al.*, 2018). “Listening range reduction” (LRR) has been introduced by the proponent for the purpose of this effects assessment. It is estimated by modifying the published LSR equation to give the change in radius (i.e. range from the listener) rather than area. For example, a 50% and 90% reduction of ‘listening range’ yields a 75% and 99% reduction in listening space, respectively. A simplified diagrammatic example has been included in these comments (Figs. 1 below). Evaluating masking in this way may understate the effect of ship noise and makes comparison with	The report presents the calculation of Listening Range Reduction (LRR) rather than Listening Space Reduction (LSR) because the LRR result speaks more directly to the issue of concern, which is the distance over which narwhal will be able to detect calls. It is more intuitive to consider the distance over which a vocalization could be detected rather than to think about ‘listening space’, or the volume within which a narwhal could communicate. The effects are not understated because we are explicit that we are calculating LRR, and we point out that it is a modified version of the LSR calculation. The fundamental concept underlying the calculation of LRR is the same as that used to calculate LSR and the equation is derived in exactly the same manner – we are not introducing a novel approach compared to that which has been presented in the cited references. The same method is applied with a simple manipulation of the equation to yield the more intuitive output of communication range rather than communication space. The output yields an equivalent assessment of the impact of noise on communication. LRR has been applied in more recent published works, e.g. Pine et al, 2020.

#	Document Name	Section Reference	Comment	Baffinland Response
			previous published research more difficult. Section 2.4 suggests that Listening Range Reduction is more 'intuitive.' Please clarify why this measurement was created and why the more common method consistent with previous published literature, Listening Space Reduction, is not being applied. Please provide results in context of LSR or make clear the difference in the results produced by this novel method of masking estimation when compared to previously published studies elsewhere.	Pine, M., K.A. Nikolich, B. Martin, C. Morris, and F. Juanes. 2020. Assessing auditory masking for management of underwater anthropogenic noise. Journal of the Acoustical Society of America 147: 3408-3417.
2	Draft 2019 Passive Acoustic Monitoring Program Report	Section 2.4 p.18 Eqn. 1 (Listening range reduction) Section 2.2.1 p.26 (sound spectrum level percentile plots; Fig 18) Section 1.0, pg. 5. Objective of the Report: "Estimate the extent of listening range reduction (LRR) associated with vessel transits along the Northern Shipping Route relative to ambient noise conditions"	Listening Space Reduction is a function of the change in noise added by the ship (NL_2; Sect2.4 Eqn.1) over some reference level of 'background' noise (NL_1; Sect2.4 Eqn.1). Estimates of LSR are sensitive to the difference (NL_2-NL_1). For example, a 10 dB increase in noise is the difference between LRR 50% and LRR 90% (*i.e.* LSR75% and LSR99%; Fig 1 below). NL_1 is defined (Sect. 2.4 p.18) from "the maximum of the mid-frequency cetacean audiogram (see Table A-9 in Finneran 2015) or the median 1-minute SPL without vessels in each of the 1/3-octave-bands of interest. Please provide the actual dB values used	A Table has been added to the report (Table 5) which contains the baseline and audiogram levels requested. For each AMAR, we apply a single fixed value for NL_1. Using the median ambient level to define NL_1 gives a conservative assessment of the extent of LRR that occurs in the presence of vessel noise relative to that under natural ambient conditions. Oceans North correctly states that our calculations will overestimate the degree of LRR for noisier ambient sound conditions. However, as the calculations provide a more conservative assessment of potential effects, we do not agree that the calculations should be repeated for different baseline ambient sound levels (i.e. for quiet and loud conditions).

#	Document Name	Section Reference	Comment	Baffinland Response
			to define NL_1 for each recording site. These values should include the median 1-minute SPL without vessels and the specific values used from the mid-frequency cetacean audiogram for each of the 1/3rd octave bands assessed. Using a single background noise reference level that is lower than actual noise levels about half the time (50th percentile) may result in assuming a larger value for NL_2-NL_1 more often than occurred relative to noise levels at the time of each ship transit. This overestimation of LSR levels may especially occur during the months of Sept and Oct with higher average background noise levels caused by increased wind-driven surface noise in the frequency bands of interest. Again, a single averaged reference noise level does not account for these relatively 'noisy' periods and may make it more difficult to identify LSR caused by ship transits vs. natural noise when ships are not present. Please provide evaluation of LSR under different noise conditions. For example, Pine *et al.*, (2018) estimate LSR for container ship transits under 'noisy' and 'quiet' ambient noise conditions. Without this, we may often overestimate LSR occurring due to the addition of ship noise and	An alternative approach to calculating LRR during vessel transits, that would allow us to consider varying background sound conditions, would be to calculate a variable NL_1 based on the ambient sound levels from a time period just before and/or just after the vessel transit occurred. However, that approach would not allow us to investigate the range of LRR for fluctuating environmental conditions and for conditions with vessel noise in a consistent way. Furthermore, at 1 kHz the value for NL_1 is the MFC composite audiogram level. This value is higher than even the 90th percentile ambient sound level at all locations, so the analysis for the 1/3-ocatve band centered at 1 kHz would be unchanged under consideration of different ambient sound conditions. We calculate LRR separately for data collected when no vessels are detected (i.e. normal environmental conditions) and for data collected when vessels are detected, to allow us to examine and compare the range of LRR effects under normal environmental conditions versus conditions with vessel noise, relative to a common median baseline level. The classification of periods with and without vessel detections is not a function of the distance between the vessel and the recorder; it is dependent on the characteristics of the received sounds. The distances between the vessels and the AMARs at these times is variable and dependent on the vessel and ambient sounds at the time. Periods that contain shipping noise are identified using JASCO's vessel noise detector, which is

#	Document Name	Section Reference	Comment	Baffinland Response
			it's difficult to understand what the range of LSR effects may be under normal environmental conditions. An example of two general cargo vessel transits with LSR estimated using median and 90th percentile background noise is provided in Fig 5 below (adapted from Jones, 2020). What steps are taken to avoid long-range ship noise entering 'background' noise periods used to estimate ambient noise for NL_1 in LSR calculations? How far are the ships away during background noise periods? As defined in this report, it is not clear that recording periods 'without ships' do not include <200 Hz noise from ships, propagating over large distances.	described in Section 2.2.2 of the report. The vessel noise detector looks for tonal sounds within the shipping frequency range (40 Hz to 315 Hz) that are within a specified threshold. Periods flagged as containing vessels are those with 5 or more tonals (0.125 Hz bandwidth), that exceed by 3 dB the median sound level in the shipping frequency band (computed over a 12 hour window centered on the tonal) and that are within 8 dB of the broadband SPL in that window. It is possible that periods flagged as being absent of vessel detections could contain some low-level, long-range sound produced by vessels. The ambient soundscape is commonly defined to consist of both natural sources (wind, waves, rain, biologic sounds, seismic events, etc) and anthropogenic sources such as long-range vessel noise. Our analysis is consistent with this definition.
3	Draft 2019 Passive Acoustic Monitoring Program Report	Figure 24, page 30.	What are the characteristics of underwater noise levels recorded by the proponent from all project-related vessels (e.g. bulk carrier, general cargo, tanker, tug)? For reference and as an example, Table 1 below (from Jones 2020) includes some noise measurements for 4 common types of project-related vessel. The noise levels reported should be accompanied by some context regarding ship characteristics wherever possible.	Detailed analysis of individual sound signatures for each Project vessel was beyond the scope of this data summary report. Rather, in this analysis, we consider the total noise from all vessels which is appropriate for considering the total vessel noise contribution to the soundscape. Analysis of these data is ongoing to determine more refined characterization of individual vessels and these results will be provided as they become available. A graduate student from the University of New Brunswick is also undertaking a more detailed analysis of the received sound levels for individual transits of all

#	Document Name	Section Reference	Comment	Baffinland Response
				project vessels and a comparison of the relative sound levels from each. Results from those studies will be available in 2021.
4	Draft 2019 Passive Acoustic Monitoring Program Report	Table 11	Model results for ranges to lower broadband received sound pressure levels SPL_{BB} than 120 dB have been requested by DFO (e.g. 110, 115 dB). What are the distances to transiting ships when measured received levels were > 110dB for each of the project vessel types? Modelled versus measured ranges should be included in this report for each different project-related ship type. There should be a table showing these ranges in the report. An example of two transits of project-related general cargo vessels is provided in Figures 2-4 below (figures adapted from Jones, 2020) .	There is no scientific justification for computing distances to received sound levels lower than 120 dB re 1 µPa. JASCO does not see value in including these distances in this data summary report.
5	Draft 2019 Passive Acoustic Monitoring Program Report	1.0, pg. 5. Objective of the Report: "Estimate the extent of listening range reduction (LRR) associated with vessel transits along the Northern Shipping Route relative to ambient noise conditions"	The number of transits and how many vessels travelled within the project area is not clear. Periods when vessels were detected does not translate easily into transits and therefore needs context provided by other data such as AIS messages. This helps to understand the relationship between ship type and received level and to better evaluate cumulative impacts of ship noise.	The following text has been added to Section 1.3.1 of the report, to provide context around the number of transits (by type of vessel) that occurred while the AMARs were deployed and recording data: "During the 2019 shipping season, there were 231 one-way transits of Project related vessels, 177 of which occurred while AMARs were deployed and recording acoustic data (Table 3).". Table 3 has been added to the report, which breaks down the one-way transits by Project vessel type.

#	Document Name	Section Reference	Comment	Baffinland Response
			We cannot estimate Phase 1 or proposed Phase 2 impacts without understanding the current and proposed number of transits and types of ships. To estimate impacts, especially if Phase 2 goes forward, the number and type of ship transits should be determined ahead of time as much as possible.	
6	Draft 2019 Passive Acoustic Monitoring Program Report	Sect 3.1.2.1 Figures 20 and 25.	What is the definition of “detected vessels passing the recorder” (Sect 3.1.2.1 p.28 Fig 20, 25)? Is it a period when multiple vessels were present or is it one individual transit of one vessel? To evaluate the relationship between number of vessel transits daily and reported noise levels it would be helpful to have an understanding of the degree to which multiple vessel transits are included in each ‘detection’.	The vessel detector is described in Section 2.2.2. The vessel detector can identify distinct vessel events if the vessels’ closest points of approach are separated by at least 30 minutes. Vessels whose passages are more closely spaced would be considered a single vessel detection event.
7	Draft 2019 Passive Acoustic Monitoring Program Report	Figure 18 (p.26)	Low-frequency ambient noise median sound spectrum levels below 100 Hz are > 10 dB less than reported for other areas of the Arctic with similar depth (e.g. AMAR-3 and AMAR-BI compared to Roth *et al.*, 2012). What is the explanation for this divergence from expected ambient noise level? This is important to understand as, for example, a systematic underestimate of $\mathrm{SPL_{BB}}$ 120 dB occurrence or overestimate of LSR (LRR) for low frequencies (e.g. ringed seal, bowhead whale) could result from the undermeasurement of	The low-frequency (< 100 Hz) median sound spectral data are not unexpected. Some examples of underwater acoustic recordings from the Arctic that show similar trends of low frequency sound spectral levels include those from: Frouin-Mouy et al, 2016; Insley et al 2017; Kim and Conrad 2015 and 2016; and O’Neill 2016. Frouin-Mouy, H., J. MacDonnell, J. Delarue, X. Mouy, B. Martin, and D. Hannay. 2016. Northeastern Chukchi Sea Joint Acoustic Monitoring Program 2014–2015. Document #01214. Technical report by JASCO Applied Sciences for Shell Exploration & Production Company.

#	Document Name	Section Reference	Comment	Baffinland Response
			noise levels in these frequencies.	Insley, S.J. and W.D. Halliday, and T. deJ. 2017. Seasonal Patterns in Ocean Ambient Noise near Sachs Harbour, Northwest Territores. Arctic. 70(3), p239-248. https://doi.org/10.14430/arctic4662 Kim, K.H., and A.C. Conrad. 2015. Acoustic Monitoring Near Koluktoo Bay, Milne Inlet, July–September 2014. Greeneridge Rep. 511-2. Rep. from Greeneridge Sciences Inc. (Santa Barbara, CA) for Baffinland Iron Mines Corporation (Oakville, ON). viii + 56 p. Kim, K.H., and A.C. Conrad. 2016. Acoustic Monitoring Near Koluktoo Bay, Milne Inlet, August–October 2015. Greeneridge Rep. 522-2. Rep. from Greeneridge Sciences Inc. (Santa Barbara, CA) for Baffinland Iron Mines Corporation (Oakville, ON). x + 69 p. O’Neill, C. 2016. Oceanography and Underwater Acoustics in Resolute Bay, Nunavut: 2012-2015. Master’s Thesis. University of Victoria.

E.3. Qikiqtani Inuit Association

Name: Jeff W. Higdon

Agency / Organization: Qikiqtani Inuit Association

Date of Comment Submission: 12 June 2020

#	Document Name	Section Reference	Comment	Baffinland Response
1	Baffinland Iron Mines Corporation – Mary River Project 2019 Passive Acoustic Monitoring Program – Draft Report	Executive Summary	The Executive Summary should be translated to Inuktitut prior to finalizing the report.	The Executive Summary will be translated into Inuktitut with the final version of the report.
2	Baffinland Iron Mines Corporation – Mary River Project 2019 Passive Acoustic Monitoring Program – Draft Report	General	We would like to see a greater integration of results from the different monitoring programs. For example, the tagging study identified narwhal reactions at various distances from vessels, and the PAM data could be used to estimate received sound levels at these distances for the vessels in question.	Additional analysis is being undertaken to investigate the relationship between the tagging study and estimated underwater received sound levels. These results will be reported separately once available.
3	Baffinland Iron Mines Corporation – Mary River Project 2019 Passive Acoustic Monitoring Program – Draft Report	1.2. Biological Contributors to the Marine Soundscape, p. 9 - Table 2	Bearded seal trills were used as an automated detection signal, but there is no information in the Results on whether any calls were detected. Were the marine mammal detection algorithms run on the shoulder season recordings?	The automated detector for bearded seals detected some acoustic signals; however, no actual bearded seal calls were identified during the manual review. The results section focuses only on detected marine mammal species. The marine mammal detection algorithms were not run on the shoulder season recordings as the primary purpose for those recorders was to characterize the noise from the icebreaker.

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4	Baffinland Iron Mines Corporation – Mary River Project 2019 Passive Acoustic Monitoring Program – Draft Report	1.2. Biological Contributors to the Marine Soundscape, p. 9 - Table 2 (also 2.2.3., B.1.2)	Table 2 says there was no automated detector for bowhead whales (“N/A”), but Tables B-1 and B-2 (App. B.1.2) list detection window settings and vocalization sorter definitions. S. 2.2.3 (p. 15) also states that “automated detectors identified acoustic signals potentially produced by… mysticetes...” Was a sorting algorithm used or were all bowhead detections manual?	There was no “species-specific” automated detector for bowhead whales. We used a combination of Low/Mid-Frequency Moan detectors (generic contour detector) which can detect acoustic signals potentially produced by mysticetes. For clarification, we added in Table 2 that the automated detection signal was a “Low/Mid-Frequency Moan”.
5	Baffinland Iron Mines Corporation – Mary River Project 2019 Passive Acoustic Monitoring Program – Draft Report	2.2.1. Total Ocean Noise and Time Series Analysis, p. 15	“Weather conditions throughout the recording periods were also gathered to inform the discussion on the factors driving natural noise levels and hence influencing the ability to detect marine mammal sounds, which can be partially masked during periods of high wind and wave noise.” More information on weather conditions (wind events, rain, etc.) and the relationship with ambient noise and narwhal detections (influence on foraging behaviour, for example) would be useful.	The weather data collected by the meteorological station located at Milne Port did not show any relationship with narwhal detections. However, it should be noted that the weather at Milne Port can be different than the conditions at the different AMAR locations. This paragraph has been removed because weather data specific to the AMAR locations was not available.
6	Baffinland Iron Mines Corporation – Mary River Project 2019 Passive Acoustic Monitoring Program – Draft Report	3.1.1.1. Early Shoulder Season, p. 20	“Ragged Island station (AMAR–RI) showed increased SPL in the 10–30 Hz range at regular intervals corresponding with the peak flow times of the tidal cycle.” Given the influence of tides on ambient noise levels (and narwhal behaviour), further exploration of relationships with tide could be considered.	We cannot separate true ambient acoustic noise from tidally-induced system noise (i.e flow noise and mooring self-noise); narwhal would not experience the latter as it is specific to the mooring. From these data, we cannot quantify the tidally-induced increase in ambient noise that would be relevant to narwhal behaviour.

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7	Baffinland Iron Mines Corporation – Mary River Project 2019 Passive Acoustic Monitoring Program – Draft Report	3.1.1.2. Open Water Season, p. 23	In Figures 14 through 17, vessel noise overlaps with wind driven noise in the spectrogram. What is the relative contribution of the two different sources to the SPL in the relevant bands?	We cannot distinguish the relative contributions of these two sources at the frequencies where they overlap.
8	Baffinland Iron Mines Corporation – Mary River Project 2019 Passive Acoustic Monitoring Program – Draft Report	3.1.2.1. Early Shoulder Season, p. 28	"This summary includes all vessels recorded on the AMARs and may include vessels that were not associated with Baffinland's operations." It is important to consider all vessels, as they all contribute to the soundscape, but the Automatic Identification System data could be used to determine which vessels are company-chartered and which are not.	As the automated vessel detector used to generate these summary plots cannot interpret the AIS data, or distinguish Project from non-Project vessels, this distinction is not made in our soundscape summary analysis. We appreciate this comment from QIA and can consider attempting to segregate Project and non-Project vessels in future analyses and reports. For example, analysis is ongoing to characterize the sound output from individual Project vessels based on recordings to date.
9	Baffinland Iron Mines Corporation – Mary River Project 2019 Passive Acoustic Monitoring Program – Draft Report	3.1.2.1. Early Shoulder Season, p. 28; 3.1.2.2. Open Water Season, p. 33	Re: Figures 23 (S. 3.1.2.1, p. 28) and 30 (S. 3.1.2.2, p. 33), does the otariid weighting function apply to Atlantic walrus? It could be removed from these figures if not, since no otariids are present.	Otariid group (as described in NMFS 2018) includes both otariids and other non-phocid marine carnivores (walruses, otters and polar bears).
10	Baffinland Iron Mines Corporation – Mary River Project 2019 Passive Acoustic Monitoring Program – Draft Report	3.3. Narwhal Detections at Bruce Head – Open Water Season, pp. 35-40	Narwhal clicks and buzzes are associated with foraging, are there any relationships between detection frequency and time of day, tide cycles, sea state, etc?	Figure 36 (echolocation clicks) and Figure 38 (high-frequency buzzes) do not seem to support any relationship between detection and time of day or tide cycles. Students from the University of New Brunswick are also doing a more detailed analysis and results from those studies will be available in 2021.

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11	Baffinland Iron Mines Corporation – Mary River Project 2019 Passive Acoustic Monitoring Program – Draft Report	3.4. Other Marine Mammal Detections at Bruce Head – Open Water Season, p. 40-42	How many total detections for bowhead whales and killer whales?	We manually found bowhead whale calls and killer whale calls only on six and eighteen occasions, respectively, in the recordings collected from the Bruce Head AMAR stations during the open water season. In order to avoid any confusion or misunderstanding between automated detections and manual verifications we rephrased our sentences, which can now be read as: “Bowhead whale vocalizations were manually found only on six occasions in the recordings collected from the Bruce Head AMAR stations during the open water season. Examples of bowhead whale vocalizations are shown in Figures 41 and 42 for AMAR–1 and AMAR–3, respectively. Due to the low number of manual detections, they could not be used for the detector performance characterization. “ “Killer whale vocalizations were manually found only on eighteen occasions in the recordings collected from the Bruce Head AMAR stations during the open water season. Examples of killer whale vocalizations are shown in Figures 43 through 45 for each of the respective AMAR stations at Bruce Head. Due to the low number of manual detections, performance of the automated detector could not be undertaken for this species.”.
12	Baffinland Iron Mines Corporation – Mary River Project 2019 Passive Acoustic Monitoring Program – Draft Report	3.5. Shoulder Season Vessel Measurements, p. 42 (also 4.2. Measurement – Model Comparisons, p. 50)	The text says MSV Botnica was travelling at 8 knots, and the Figure 46 caption says the model estimates were for the vessel at 9 knots. How much of an effect would this slight reduction in speed have on measured noise?	This difference in speed could result in an estimated difference of 3 dB to the overall, broadband sound level (based on empirical data), i.e. a vessel transiting at 8 knots would be expected to be 3 dB quieter than one travelling at 9 knots. The Botnica was travelling slower than the modelled speed.

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13	Baffinland Iron Mines Corporation – Mary River Project 2019 Passive Acoustic Monitoring Program – Draft Report	4.1. Ambient Noise and Vessel Noise, pp. 49-50	Table 10 reports the average and maximum only, it would be useful to see more summary statistics such as median, range (a statistical summary of the data in Figure 49).	The purpose for this analysis was to compare the time when measured sound levels exceeded 120 dB re 1 µPa in a day relative to the durations derived from model estimates. The maximum values are adequate to verify that the model yields conservative estimates of the worst case scenario. Average values were also shown to provide further context.
14	Baffinland Iron Mines Corporation – Mary River Project 2019 Passive Acoustic Monitoring Program – Draft Report	4.3. Listening Range Reduction, p. 51-52 (also 3.6. Listening Range Reduction, pp. 43-48)	“The listening range for sound at 25 kHz (representative of narwhal clicks and high-frequency buzzes) was more affected, by both vessel noise and ambient noise, than sound at 1 kHz...” What are the potential biological impacts of these reductions in listening space for narwhal foraging?	The listening range for sound at 25 kHz (representative of narwhal clicks and high-frequency buzzes) was more affected, by both vessel noise and ambient noise, than sound at 1 kHz (a representative frequency for burst pulses). The potential consequence is a reduced range at which the listener (narwhal) can detect potential prey for a small percentage of time. This range was reduced by more than half during a maximum of 14% of the open water recording period, and 12% of the early shoulder season recording period in 2019.