Underwater Acoustic Monitoring

Baffinland Iron Mines Shoulder Season Shipping 2019–2020

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ᐃᒪᐅᑉ ᐃᓗᐊᓂᑦ ᑐᓴᖅᓴᐅᓃᑦ ᓇᓃᓐᓂᕆᔭᖏᑦ ᓂᐱᓕᐅᖅᑕᐅᓚᐅᖅᑐᑦ ᒪᕐᕉᖕᓂᑦ ᐃᓂᐅᔪᓂᑦ ᐅᐊᖕᓇᖅᐸᓯᖕᒥᑦ ᐅᒥᐊᕐᔪᐊᓄᑦ ᐊᑉᑯᑎᒋᔭᐅᔪᒥᑦ ᐱᔾᔪᑎᖃᖅᑐᓂᒃ ᐹᕝᕚᓖᓐᑯᑦ ᓴᕝᕙᔭᒃᓴᓄᑦ ᐅᔭᕋᒃᑕᕆᐊᖓᓂᑦ ᓄᓘᔭᓂᑦ. ᐊᑕᐅᓯᖅ ᐃᒪᐅᑉ ᐃᓗᐊᓂᑦ ᑐᓴᖅᓴᐅᔪᓂᒃ ᓂᐱᓕᐅᕈᑎ ᑕᓯᐅᔭᕐᒥᑦ ᐃᓕᔭᐅᓯᒪᓚᐅᖅᑐᖅ, ᖃᓂᑕᖓᓂᑦ ᓂᒋᖅᐸᓯᖓᓂᑦ ᐱᖓᓇᖅᐸᓯᖓᑕ ᐃᓱᐊᓂᑦ ᐊᑭᐊᓂᑦ, ᐱᖃᑖᓗ ᐅᐊᖕᓇᖅᐸᓯᖓᓂᑦ ᕿᓐᒍᐊᓂᑦ ᖃᓂᑕᖓᓂᑦ ᐃᒥᓖᑦ. ᓂᐱᓕᐅᕈᑏᑦ ᐃᓕᔭᐅᓚᐅᖅᑐᑦ ᐊᒥᕋᐃᔭᕝᕕᒃ (ᓯᑎᐱᕆ) 29, 2019-ᒥᑦ ᐆᒃᑐᕋᕐᓂᐊᕐᓗᒋᑦ ᐃᒪᐅᑉ ᓂᐱᖃᕐᓂᖓ ᓯᑯᒥᑦ ᓯᕐᑯᕐᑎᓇᔩᖅ ᐅᒥᐊᕐᔪᐊᕐᒥᑦ MSV *Botnica* 2019-ᒥᑦ ᓄᖑᐸᓪᓕᐊᓂᖓᓂᑦ ᐅᒥᐊᕐᔪᐊᑦ ᑎᑭᖅᑲᑦᑕᕐᓂᕆᔭᖏᓐᓂᑦ. ᐹᑐᓖᖏᑦ ᐊᑯᓂᐅᓂᖅᓴᖅ ᐊᔪᖏᓐᓂᐊᕐᓗᑎᒃ, ᓂᐱᓕᐅᕈᑏᑦ ᐋᖅᑭᒃᑕᐅᓯᒪᓚᐅᖅᑐᑦ ᓄᖃᖅᑕᕐᓂᐊᕐᓗᑎᒃ ᐅᑭᐅᒃᑯᑦ, ᐅᑭᐅᓖᑦ (ᐅᒃᑑᐱᕆ) 12, 2019-ᒥᑦ ᓴᖅᑭᑦ (ᔪᓚᐃ) 17, 2020-ᒧᑦ. ᐃᒪᐅᑉ ᐃᓗᐊᓂᑦ ᓂᐱᖃᕐᓂᖅ ᖃᐅᔨᓴᖅᑕᐅᓚᐅᖅᑐᖅ ᑲᑎᖕᓂᒥᑦ 17 ᐊᑕᐅᓯᕐᒧᑦ ᐅᕐᓂᒃᑕᐅᔪᒧᑦ ᐃᖏᕐᕋᓂᖓᑕ MSV *Botnica* ᑕᓯᐅᔭᕐᒥᑦ (8-ᖑᔪᑦ 2019-ᒥᑦ ᓄᖑᐸᓪᓕᐊᓂᖓᓂᑦ ᐅᒥᐊᕐᔪᐊᑦ ᑎᑭᖅᑲᑦᑕᕐᓂᕆᔭᖏᓐᓂᑦ ᐊᒻᒪᓗ 9-ᖑᔪᑦ 2020 ᐅᒥᐊᕐᔪᐊᑦ ᑎᑭᖅᑲᓪᓚᕐᓂᖏᓐᓂᑦ) ᐊᒻᒪᓗ 18 ᐊᑕᐅᓯᕐᒧᑦ ᐅᕐᓂᒃᑕᐅᔪᒧᑦ ᐃᖏᕐᕋᓂᖓᑕ ᐅᐊᖕᓇᖅᐸᓯᖓᓂᑦ ᕿᓐᒍᐊᓂᑦ (7-ᖑᐸᓗᑎᒃ 2019-ᒥᑦ ᓄᖑᐸᓪᓕᐊᓂᖓᓂᑦ ᐅᒥᐊᕐᔪᐊᑦ ᑎᑭᖅᑲᑦᑕᕐᓂᕆᔭᖏᓐᓂᑦ ᐊᒻᒪᓗ 11-ᖑᔪᑦ 2020-ᒥᑦ ᐅᒥᐊᕐᔪᐊᑦ ᑎᑭᖅᑲᓪᓚᕐᓂᖏᓐᓂᑦ). ᐃᖏᕐᕋᔭᒃᑐᓗᒃᑖᑦ ᓂᐱᓕᐅᖅᑕᐅᓚᐅᖅᑐᑦ 2019-ᒥᑦ ᐊᐅᔭᐅᑎᓪᓗᒍ (ᓯᑯᑕᖃᓚᐅᖏᑦᑐᖅ ᑲᑎᓯᒪᔪᓂᒃ). ᐃᖏᕐᕋᔭᒃᑐᑦ 2020-ᒥᑦ ᐊᐅᔭᒃᑰᓚᐅᖅᑐᖅ ᓯᑯᖃᖅᑎᓪᓗᒍᓗ, ᓯᑯᐃᑦ ᑲᑎᓯᒪᔪᑦ ᐊᑯᓐᓂᖏᓐᓂᐅᓚᐅᖅᑐᑦ 0/10 ᐊᒻᒪᓗ 9/10. ᖃᐅᔨᓴᐃᓂᕐᒥᑦ ᐃᖏᕐᕋᔭᒃᑐᓂᑦ, ᓯᑯᒥᑦ ᓯᕐᑯᕐᑎᓇᔩᖅ MSV *Botnica* ᐅᒥᐊᕐᔪᐊᑑᐸᓗᓂ ᐅᕝᕙᓘᓐᓃᑦ ᐊᑕᐅᓯᕐᒥᑦ ᓯᑕᒪᓄᑦ ᐊᓯᖏᓐᓂᒃ ᐅᒥᐊᕐᔪᐊᑦ ᐃᓚᒋᔭᐅᐸᓗᑎᒃ (ᐅᔭᕋᒃᑕᖅᑕᐅᔪᓂᒃ ᐅᓯᔪᑦ ᐊᒻᒪᓗ ᓯᑲᐅᑦ).

ᓈᓴᐅᓯᕆᔾᔪᑎᖃᓚᐅᖅᑐᑦ ᐃᒪᐅᑉ ᐃᓗᐊᓂ ᓂᐱᐅᑉ ᓴᙱᓂᖏᑦᑕ ᓇᓐᓂᕆᔭᖏᓐᓂᒃ (SPL) ᓂᐱᓕᐅᕆᕝᕕᐅᔪᓂᑦ ᐊᑐᓂ ᖃᐅᔨᓴᖅᑕᐅᔪᐃᑦ ᓯᑯᓂᒃ ᓯᕐᑯᕐᑎᓇᔩᑦ ᐃᖏᕐᕋᕝᕕᒋᔭᖏᓐᓂᑦ, ᐊᓯᖏᓐᓂᒃ ᐅᒥᐊᕐᔪᐊᖃᑎᖃᕐᓗᓂ ᐊᒥᐅᔪᐊᑑᐸᓗᑎᒡᓗᓐᓃᑦ. ᐆᒃᑐᕋᖅᑕᐅᔪᑦ ᓇᓚᐅᑦᑖᓚᐅᖅᑐᒧᑦ ᒪᕐᕉᒃ ᒥᐊᑎᓇᒃᓯ-ᓂᑦ (metrics) ᐅᒥᐊᕐᔪᐊᑦ ᓂᐱᖃᖅᑎᑦᑎᓂᖏᓐᓂᑦ, ᐃᒪᐅᑉ ᐃᓗᐊᓂᑦ ᓂᐱᖃᕐᓃᑦ ᓇᓃᓐᓂᕆᔭᖏᑦ ᐊᒻᒪᓗ ᒫᓄᐴᓪ-ᒥᑦ (monopole) ᐱᔪᓂᒃ, ᐊᑐᓂ ᐃᖏᕐᕋᔭᖕᓂᕆᔭᖓᓂᑦ MSV *Botnica.* ᓈᓴᐅᓯᕆᓚᐅᕐᒥᔪᑦ 90-ᒋᔭᖓᓂᑦ ᐳᓭᑕᐃᓪ-ᒥᑦ (percentile) ᐅᖓᓯᖕᓂᕐᒧᑦ MSV *Botnica*-ᒥᑦ ᓂᐱᖃᕐᓂᖏᑦ ᓇᓐᓂᕆᔭᖓᑦ ᐅᖓᑕᐅᑦᑎᐸᓗᑎᒃ 120 dB re 1 µPa-ᒥᑦ, ᑕᐃᒪᓐᓇᐃᓚᔪᒃᑑᐸᓗᓂ ᖃᐅᔨᓴᐃᐸᓗᓂ ᑕᕆᐅᕐᒥᐅᑕᓂᒃ ᓂᕐᔪᑏᑦ ᐱᖁᓯᕆᔭᖏᓐᓂᒃ ᐃᓗᐃᓵᖅᑕᐅᒍᑎᒃ ᐅᒥᐊᕐᔪᐊᓂᒃ ᓂᐱᖃᕐᓂᐅᔪᓂᑦ. ᑭᖑᓪᓕᖅᐹᖅ, ᓈᓴᐅᓯᕆᓚᐅᖅᑕᕆᑦ ᑲᑎᖕᓂᒥᑦ ᐊᒃᑐᖅᑕᐅᓯᒪᓂᕐᒧᑦ ᐊᑯᓂᐅᑎᒋᔪᑦ ᓂᐱᖃᕐᓂᖏᑦ ᓇᓐᓂᕆᔭᖓᑦ 120 dB re 1 µPa-ᒦᖅᑎᒃ ᖃᖏᐅᑎᐸᓗᑎᒡᓗᓐᓃᑦ ᓂᐱᓕᐅᕆᕝᕕᐅᔪᓂ ᐊᑐᓂ ᐃᖏᕐᕋᓂᕆᔭᐅᔪᓂᑦ.

ᐆᒃᑐᕋᐃᓐᓂᑦ ᐱᔭᐅᓚᐅᖅᑐᑦ ᒫᓄᐴᓪ-ᒥᑦ (monopole) ᐱᔪᓂᒃ 20 dB-ᓂᒃ ᐊᑦᑎᖑᓂᖅᓴᐅᓚᐅᖅᑐᖅ ᐃᓱᒪᒋᔭᐅᔪᓂᑦ ᓂᐱᖃᕐᓂᕐᒧᑦ ᐋᖅᑭᒃᓯᐃᓐᓂᑦ ᐃᖏᕐᕋᔭᒃᑐᓄᑦ ᓯᑯᐃᑦ ᑲᑎᓯᒪᔪᓂᑦ 3/10-ᖑᐸᓗᑎᒃ ᐊᒻᒪᓗ 10/10-ᖑᐸᓗᑎᒃ. ᑭᓯᐊᓂ ᑕᐃᑲᐅᑯᐊ ᐱᔭᐅᔪᑦ ᐃᖏᕐᕋᔪᓄᑦ ᐊᐅᔭᒃᑯᑦ ᖁᑦᑎᖕᓂᖅᓴᐅᕚᓪᓕᔪᓚᐅᖅᑐᑦ ᓇᓚᐅᑦᑖᖅᑕᐅᔪᓂᑦ ᐆᒃᑐᕋᐃᓂᕐᓄᑦ. ᐅᖓᓯᒃᑎᒋᓂᖏᑦ 120 dB-ᒧᑦ ᐊᑯᓂᐅᓂᖅᓴᐅᖃᑦᑕᓚᐅᖅᑐᑦ ᑐᓄᐊᓂᑦ ᐅᒥᐊᕐᔪᐊᑦ ᑕᐅᑐᙱᖕᒍᑎᑦ ᐆᒃᑐᕋᖅᑕᐅᔪᑦ ᐅᒥᐊᕐᔪᐊᑦ ᓵᖓᓃᑦᑐᑦ. ᐅᖓᓯᒃᑎᒋᓂᖏᑦ ᐱᔭᐅᓚᐅᖅᑐᑦ ᐆᒃᑐᕋᖅᑕᐅᔪᓂᑦ ᑭᖑᓂᐊᒍᑦ ᐅᒥᐊᕐᔪᐊᑦ 50-80%-ᓗᐊᓂᒃ ᓇᐃᓐᓂᖅᓴᐅᔪᑦ ᐆᒃᑐᕋᐃᓂᕐᒧᑦ ᓇᓚᐅᑦᑖᖅᑕᐅᔪᓂᑦ ᓯᑯᓂᒃ ᑲᑎᓯᒪᔪᖃᖅᑐᓂᒃ 3/10-ᖑᔪᓄᑦ ᐊᒻᒪᓗ 10/10-ᖑᔪᓄᑦ ᐊᒻᒪᓗ 55%-ᒧᑦ ᑎᑭᓪᓗᒋᑦ ᓇᐃᓐᓂᖅᓴᐅᔪᑦ ᐃᖏᕐᕋᔪᓄᑦ ᐊᐅᔭᒃᑯᑦ, ᐃᓚᖏᑦ ᐅᒥᐊᕐᔪᐊᑑᐸᓗᑎᒃ ᐃᖏᕐᕋᔪᒧᑦ ᓯᑯᓂᑦ ᓯᕐᑯᕐᑎᓇᔩᑦ ᐊᐅᔭᒃᑯᑦ ᐅᖓᓯᖕᓂᐅᔪᓂᒃ ᐱᓚᐅᖅᑐᑦ ᑭᖑᓂᐊᒍᑦ ᐊᔾᔨᐸᓗᓂᐅᒃ ᐅᕝᕙᓘᓐᓃᑦ ᐅᖓᑕᐅᑦᑎᐸᓗᑎᒃ ᐋᖅᑭᐅᒪᔪᓄᑦ ᓇᓚᐅᑦᑖᖅᑕᐅᔪᑦ.

ᐊᖏᓘᒃᑯᑦ ᐊᒃᑐᖅᑕᐅᓯᒪᔪᑦ ᐊᑯᓂᐅᑎᒋᔪᒧᑦ 1.08 ᐃᑲᕐᕋᐅᓚᐅᖅᑐᑦ (65.3 ᒥᓂᑦᖑᔪᑦ) MSV *Botnica* ᐃᖏᕐᕋᑎᓪᓗᒍ 9/10 ᓯᑯᓕᖏᑦ ᓴᖅᑭᑦ 22, 2020-ᒥᑦ ᐊᓯᖏᓐᓂᒃ ᐅᒥᐊᕐᔪᐊᖅᑕᖃᕐᒥᑎᓪᓗᒍ ᓇᑉᐱᖅᓯᖅᑎᕆᐸᓗᓂ 7.3 knots-ᓂᒃ. ᖃᓄᐃᖓᓂᐅᔪᑦ ᑕᑯᒃᓴᐅᑎᑦᑎᔪᑦ, MSV *Botnica* ᖃᑯᑎᒃᑯᑦ ᓂᐱᖅᑯᖅᑐᖃᑦᑕᓚᐅᖅᑐᖅ ᐃᖏᕐᕋᑎᓪᓗᒍ ᓯᑯᒃᑯᑦ, ᓇᐃᑦᑑᖃᑦᑕᓚᐅᖅᑐᑦ ᐊᒻᒪᓗ ᖁᑎᒃᑰᖃᑦᑕᖅᐸᑎᒃ. ᑎᑭᐅᑎᓂᖓ ᐊᒻᒪᓗ ᐊᑯᓂᐅᑎᒋᓂᖓ ᖁᓛᓂᑦ ᐅᖃᐅᓯᐅᔪᖅ 120 dB-ᒧᑦ ᑎᑭᐅᑎᓂᖅ ᐊᖏᓪᓕᒋᐊᕌᕐᔪᖃᑦᑕᖅᑐᖅ ᒥᑭᔪᒥᒃ ᐅᒥᐊᕐᔪᖅᑕᖃᒃᑲᓂᓕᕋᖓᑦ ᐃᖏᕐᕋᔪᓂᑦ, ᐊᒻᒪᓗ ᐆᒃᑐᕋᖅᑕᐅᔪᑦ MSV *Botnica* ᐃᖏᕐᕋᑎᓪᓗᒍ ᐅᒥᐊᕐᔪᐊᓛᓪᓗᓂ ᐊᔾᔨᖏᓐᓂᑦᑐᑦ ᐃᒪᕐᒥᑦ ᖃᓄᐃᓐᓂᐅᔪᓂᑦ (ᓲᕐᓗ ᐊᔾᔨᖏᓐᓂᑦᑕᖏᑦ ᓯᑯᐃᑦ ᑲᑎᓯᒪᔪᓄᑦ ᐊᒻᒪᓗ ᓇᑭᖕᓴᕐᓂᐅᑉ).

ᖃᓄᐃᖓᓂᐅᔪᑦ ᖃᓄᐃᓐᓂᖅᓴᐅᓂᖏᓐᓃᖅᑕᐅᓚᐅᖅᑐᑦ ᐊᖏᕈᒪᔪᓄᑦ ᓇᓚᐅᑦᑖᖅᑕᐅᔪᓄᑦ ᓈᓴᐅᓯᓐᓯᔭᐅᓚᐅᖅᑐᑦ ᐃᓚᒋᐅᑉᐸᓗᓂ ᖃᐅᔨᓴᐃᓂᕐᒧᑦ ᓯᑯᒥᑦ ᓯᕗᓐᓂᖅᑐᒥᑦ ᐅᒥᐊᕐᔪᐊᑦ ᐊᐅᓚᖅᑎᓪᓗᑎᑦ ᐸᕝᕙᓪᓕᕈᓐᓄᑦ (ᒍᓪᓗᑐ ᑲᑐᔾᔭᑎᕆᑦ 2019). ᖃᓄᐃᖓᓂᐅᔪᑦ ᓇᓗᓇᐃᓚᐅᖅᑐᑦ ᐃᓱᒪᒋᔭᐅᔪᑦ ᐊᑐᖅᑕᐅᓚᐅᖅᑐᑦ ᓂᐱᖃᕐᓂᕐᒧᑦ ᐊᖏᕈᒪᔪᓄᑦ ᐅᖓᑕᓗᐊᖓᓂᑦ ᓇᓚᐅᑦᑖᕆᓂᖃᓚᐅᖅᑐᑦ ᓯᓚᔪᓂᒃ ᓂᐱᖃᕐᓂᕐᒧᑦ ᓇᓃᓐᓂᐅᔪᓄᑦ, ᐊᑐᖅᑕᐅᓲᑦ ᐊᖏᒃᑕᐅᓯᒪᓚᐅᕐᒪᑦ ᓇᓚᐅᑦᑖᕆᓂᕐᒧᑦ ᐊᖏᒃᑕᐅᖅᑲᖅᑕᐅᓚᐅᖅᑐᒧᑦ. ᖃᓄᐃᖓᓂᑦ ᑕᑯᒃᓴᐅᑎᑦᑎᓚᐅᖅᑐᑦ ᐆᒃᑐᕋᖅᑕᐅᔪᑦ ᐊᑐᓂ ᐃᖏᕐᕋᔾᔪᑎᖏᓐᓂᑦ ᐊᒃᑐᖅᑕᐅᓯᒪᔪᑦ ᐅᖓᑕᐅᑎᑦᑐᑦ 120 db re 1 µPa-ᒧᑦ 80-90%-ᓗᐊᓂᒃ ᐊᑦᑎᖑᓂᖅᓴᐅᓚᐅᖅᑐᑦ ᓇᓚᐅᑦᑖᖅᑕᐅᔪᓂᑦ ᓯᑯᒥᑦ ᓯᕗᓐᓂᖅᑐᖅ ᐅᒥᐊᕐᔪᐊᖏᑦ ᐃᖏᕐᕋᔪᖅ ᓯᑯᓕᖏᑦ ᐊᑯᓂᖏᓐᓃᑦᑐᓂᒃ 3/10 ᐊᒻᒪᓗ 9/10 ᑲᑎᓯᒪᔪᓂᑦ ᐊᒻᒪᓗ 60%-ᓗᐊᓂᒃ ᐊᑦᑎᖑᓂᖅᓴᐅᐸᓗᓂ ᓇᓚᐅᑦᑖᖅᑕᐅᔪᓂᒃ ᐊᒃᑐᖅᑕᐅᓯᒪᔪᓄᑦ ᐊᑯᓂᐅᑎᒋᓂᖏᓐᓄᑦ ᓯᑯᒥᑦ ᓯᕗᓐᓂᖅᑐᑦ ᐅᒥᐊᕐᔪᐊᑦ ᐊᒪᐃᓐᓇᕐᒥᑎᓪᓗᒍ.

Executive Summary

Underwater sound levels were recorded at two locations along the Northern Shipping Route associated with Baffinland Iron Mine's Mary River mine. One underwater acoustic recorder was located in Eclipse Sound, near the southwest end of Bylot Island, and the other was in northern Milne Inlet near Ragged Island. The recorders were deployed on 29 Sep 2019 to measure underwater noise from the icebreaker MSV *Botnica* during 2019 late 'shoulder season' shipping. To extend their battery life, the recorders were programmed to stop recording through the winter, from 12 Oct 2019 to 17 Jul 2020, so they could continue to record noise from icebreaker transits during the 2020 'early shoulder' season. Underwater noise was analyzed for a total of 17 one-way transits of the MSV *Botnica* in Eclipse Sound (8 in the 2019 late shoulder season and 9 in the 2020 early shoulder season) and 18 one-way transits in northern Milne Inlet (7 in the 2019 late shoulder season and 11 in the 2020 early shoulder season). All transits recorded in 2019 occurred in open-water conditions (0/10 ice concentration).Transits in 2020 included open-water and ice-covered conditions, with ice concentrations between 0/10 and 9/10. During the analyzed transits, the icebreaker MSV *Botnica* either transited alone or with 1 to 4 other vessels in escort (ore carriers and tugs).

We calculated the underwater sound pressure levels (SPL) at the recorder locations during each of the analyzed icebreaker transits, with and without vessels under escort. From these measurements we estimated two standard metrics of vessel noise emissions, the underwater radiated noise levels and monopole source levels, for each transit of the MSV *Botnica*. We also computed the 90th percentile distance from the MSV *Botnica* at which sound levels exceeded 120 dB re 1 µPa, which is a common threshold for assessing marine mammal behavioural disturbance from shipping noise. Finally, we computed the total exposure durations during which sound levels were at or above the 120 dB re 1 µPa threshold at the recorder locations for each transit.

Measurement derived monopole source levels were 20 dB lower than those assumed in the acoustic modelling for transits in ice concentrations of 3/10 and 10/10. But those derived for transits in open water were slightly higher than the estimate assumed for modelling. The distances to 120 dB were longer behind the vessels compared to those measured in front of the vessels. Distances derived from measurements collected aft of the vessels were approximately 50-80% shorter than the model estimates for ice concentrations between 3/10 and 10/10 and up to 55% shorter for transits in open water conditions, though some transits of the icebreaker on its own in open water yielded distances in the aft aspect that matched or exceeded the model estimates.

The maximum exposure duration was 1.08 hours (65.3 minutes) when the MSV *Botnica* was transiting through 9/10 ice concentration on 22 July 2020 with no vessels in escort at a speed of 7.3 knots. The results show that, although the MSV *Botnica* occasionally generated high intensity sound while transiting through ice, these periods were brief and intermittent. The extent and duration of ensonification above the 120 dB threshold increased by a small amount when additional vessels were added to the convoy, and when ice concentration increased, but not by amounts that exceeded the variability between measurements of the MSV *Botnica* travelling on its own in varying conditions (i.e. for different ice concentrations and at different speeds).

The results of this analysis were compared with modelling estimates that were calculated as part of the Assessment of Icebreaking Operations for Baffinland (Golder Associates 2019). The results confirmed that the assumptions used in the acoustic modelling led to overestimates of the real sound levels, as conservatism had been designed into the original modelling assessment. Results demonstrated that the measured per-transit noise exposure periods exceeding 120 dB re 1 µPa were approximately 80-90% lower than predicted estimates for an icebreaker transiting in ice between 3/10 and 9/10 concentration and at least 60% lower than the predicted exposure durations when the icebreaker was in open water.

1. Introduction

Underwater sound level measurements were collected at locations in Milne Inlet and Eclipse Sound as part of JASCO Applied Sciences' (JASCO) 2019 and 2020 Passive Acoustic Monitoring (PAM) programs conducted for Baffinland Iron Mine Corporation's (Baffinland's) Mary River Project. Data were collected using JASCO's Autonomous Multichannel Acoustic Recorders (AMARs). These data were analyzed previously to document the spatial and temporal variability of the recorded underwater sounds, to document marine mammal vocalization occurrence (primarily focused on narwhal), and to quantify the degree to which noise from Project vessels contributed to the underwater sound field (Frouin-Mouy et al. 2020). Measurements were collected both during the open water season and during the 'shoulder season', that is, the times on either end of the open water season when there is no landfast ice but ice conditions remain between 1/10 to 9/10 concentration along the Northern Shipping Route. This report focuses exclusively on the underwater sound levels recorded during shipping activities in the 2019 late shoulder season (October 2019) and 2020 early shoulder season (July 2020), with a specific objective to characterize the underwater noise generated during icebreaker transits and compare these results to numerical model predictions.

In 2019, Golder Associates Ltd. (Golder) prepared an environmental effects assessment of the potential impacts to the marine environment from Baffinland's shoulder season shipping and icebreaking, in relation to Baffinland's Phase 2 Development Proposal (Golder Associates 2019). Underwater noise was one of the assessed effects and the assessment is also relevant to current Project shipping in the shoulder seasons. To inform Golder's assessment, JASCO estimated the extent of ensonification during icebreaking through numerical modelling (Quijano et al. 2019). Subsequently, JASCO collected the underwater noise measurements detailed in this report to verify the predictions from that acoustic modelling assessment, and to quantify the degree of conservatism in the modelling.

This present analysis involved processing acoustic data from AMAR-RI, a recorder located near Ragged Island in northern Milne Inlet, and AMAR-BI, located near Bylot Island in Eclipse Sound, both located on the nominal shipping route (Figure 1). Late shoulder season data analyzed in this report were recorded from 1 to 17 Oct 2019 and early shoulder season data were recorded from 21 Jul to 01 Aug 2020. For each icebreaker transit, analysis was performed for a segment of data recorded within 1 hour before and after the icebreaker MSV *Botnica*'s closest point of approach (CPA) to the acoustic recorder. The data were analyzed to estimate radiated sound levels from the icebreaker, in varying ice conditions from open water to 9/10 ice concentration, and the distances from the icebreaker where sound levels exceeded the sound pressure level (SPL) threshold of 120 dB re 1 µPa, which is a threshold used to indicate noise levels at which there is a potential for marine mammal behavioural disturbance ([NMFS] National Marine Fisheries Service 2013). We also computed the total amount of time during each icebreaker transit when the SPL exceeded this threshold. Some of the analyzed transits included those during which the MSV *Botnica* escorted between 1 and 4 other vessels to or from Milne Port. This analysis considered the combined noise from all vessels in each convoy.

In accordance with existing terms and conditions of Project Certificate No. 005, Baffinland is responsible to conduct acoustic monitoring, toward the objective of preventing impacts to marine mammals from Project shipping activities. This acoustic monitoring study contributes toward the following objectives from the Project Certificate Terms and Conditions:

- Assess the accuracy of effects predictions in the Final Environmental Impact Statement (FEIS; BIM 2012) and Addendum 1 (BIM 2013) with respect to disturbance effects from ships noise on marine mammals.
- Assess the effectiveness of Project mitigation measures to minimizing impacts to marine mammals from Project shipping activities.
- Facilitate assessment of the potential short term, long term, and cumulative effects of vessel noise on marine mammals and marine mammal populations.
- Improve understanding of local environmental processes and potential Project-related cause-and-effect relationships.

This report describes the methods that were used to collect and analyze the data (Section 2), presents the results of the analysis (Section 3), and provides a brief summary and discussion of the results (Section 4).

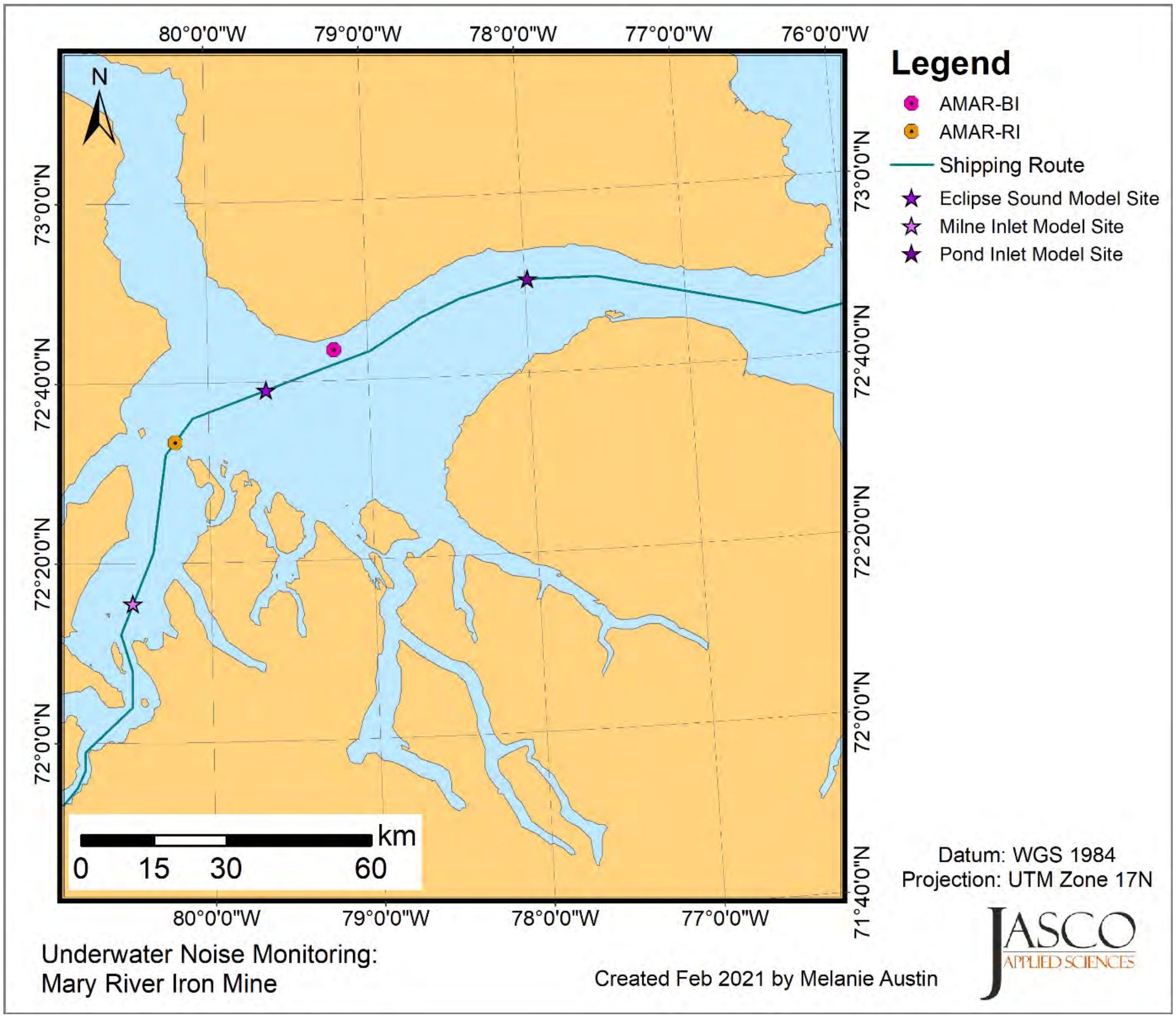

Figure 1. Acoustic monitoring locations along the Northern Shipping Route (AMAR–BI and AMAR–RI) and modelled sites where sound level estimates were computed for the Icebreaker Environmental Assessment (Quijano et al. 2019).

1.1. Transit Details

The first transit of the icebreaker MSV *Botnica* during the 2019 late shoulder season occurred on 5 Oct 2019. The AMARs recorded underwater noise during all transits between that date and 17 Oct 2019, when they were pre-programmed to power down for winter. During the 2019 late shoulder season, all MSV *Botnica* transits occurred in open water. The AMARs were pre-programmed to 'wake' and start recording again on 12 Jul 2020. They recorded through to 5 Sep 2020, thus capturing all MSV *Botnica* transits during 2020 early shoulder season between 21 Jul and 1 Aug 2020. MSV *Botnica* did not transit directly over either recorder during the 2019 later shoulder season in ice conditions that would have required the vessel to actively break ice, so only open-water transit data are available in that time. During the 2020 early shoulder season, noise levels of the MSV *Botnica* were recorded for transits in ice concentrations between 0 and 9/10ths. Details for all analyzed transits for AMAR-BI are summarized in Table 1 and for AMAR-RI in Table 2.

Table 1. AMAR-BI: MSV *Botnica* transits recorded in Eclipse Sound during 2019 late shoulder season and 2020 early shoulder season. Dates and times are in UTC.

Date	**Botnica CPA time**	**Direction**	**Ice concentration at AMAR**	***Botnica* speed (kn)**	**Vessels in convoy**			
					Name	Vessel type	Distance from *Botnica* (km)	Speed (kn)
2019 Oct 05	21:49:12	Outbound	0/10	5.9	None			
2019 Oct 08	23:52:33	Inbound	0/10	8.4	None			
2019 Oct 10	23:06:30	Outbound	0/10	7.8	*Sagar Samrat*	Ore carrier	3.9	8.6
2019 Oct 12	13:38:42	Inbound	0/10	6.2	None			
2019 Oct 13	04:59:09	Outbound	0/10	8.6	*Arkadia*	Ore carrier	4.1	8.2
2019 Oct 14	21:02:07	Inbound	0/10	6.2	None			
2019 Oct 15	15:11:02	Outbound	0/10	8.4	*Nordic Odin*	Ore carrier	6.4	8.0
2019 Oct 17	18:49:07	Inbound	0/10	8.1	None			
2020 Jul 21	16:47:58	Inbound	9/10	5.4	*Nordic Oasis*	Ore carrier	0.73	5.9
					Nordic Oshima	Ore carrier	2.1	7.0
					Ocean Raynald T	Tug	2.7	5.9
					Ocean Taiga	Tug	2.4	8.2
2020 Jul 22	14:08:05	Outbound	9/10	7.3	None			
2020 Jul 23	19:07:25	Inbound	2/10	5.9	*Nordic Odyssey*	Ore carrier	0.74	5.8
					Nordic Olympic	Ore carrier	2.1	5.5
2020 Jul 24	23:04:17	Outbound	8/10	5.3	*Nordic Oasis*	Ore carrier	1.2	4.6
					Nordic Oshima	Ore carrier	2.2	4.8
2020 Jul 26	23:27:08	Outbound	8/10	4.2	*Nordic Odyssey*	Ore carrier	1.4	5.1
					Nordic Olympic	Ore carrier	2.7	5.3
2020 Jul 29	00:42:27	Outbound	0/10	8.8	*Nordic Odin*	Ore carrier	1.5	8.6
					Admiral Schmidt	Ore carrier	3.3	8.6
2020 Jul 30	07:09:56	Inbound	0/10	8.3	*NS Yakutia*	Ore carrier	2.8	8.5
					Golden Brilliant	Ore carrier	9.9	8.9
2020 Jul 30	23:46:22	Outbound	0/10	8.6	*Gisela Oldendorff*	Ore carrier	2.6	8.1
2020 Aug 01	01:55:18	Inbound	0/10	8.5	*Golden Ruby*	Ore carrier	6.5	8.7
					*NS Yakutia**	Ore carrier	6.6	8.6
					Rio Tamara	Ore carrier	2.8	8.9

*NS Yakutia was actually Outbound from Port, but passed the AMAR at the same time as the incoming convoy of MSV Botnica with Golden Ruby and Rio Tamara.

Table 2. AMAR-RI: MSV *Botnica* transits recorded in northern Milne Inlet during 2019 late shoulder season and 2020 early shoulder season. Dates and times are in UTC.

Date	Botnica CPA time	Direction	Ice concentration at AMAR	*Botnica* speed (kn)	Vessels in convoy			
					Name	Vessel type	Distance from *Botnica* (km)	Speed (kn)
2019 Oct 05	18:42:10	Outbound	0/10	7	None			
2019 Oct 09	02:23:05	Inbound	0/10	8.5	None			
2019 Oct 10	20:27:57	Outbound	0/10	8	*Sagar Samrat*	Ore carrier	2.9	7.5
2019 Oct 12	16:29:23	Inbound	0/10	5.7	None			
2019 Oct 13	02:30:32	Outbound	0/10	8.6	*Arkadia*	Ore carrier	2.6	8.3
2019 Oct 15	00:19:10	Inbound	0/10	6.1	None			
2019 Oct 17	21:35:05	Inbound	0/10	8.6	None			
2020 Jul 22	11:04:03	Outbound	9/10	6.6	None			
2020 Jul 23	23:14:48	Inbound	2/10	7.1	*Nordic Odyssey*	Ore carrier	0.74	6.4
					Nordic Olympic	Ore Carrier	2.1	6.1
2020 Jul 24	19:16:14	Outbound	8/10	4.6	*Nordic Oasis*	Ore carrier	1.0	4.1
					Nordic Oshima	Ore carrier	2.1	4.2
2020 Jul 26	04:59:11	Inbound	5/10	8.1	*Admiral Schmidt*	Ore carrier	2.9	8.6
					Nordic Odin	Ore Carrier	2.0	8.1
2020 Jul 26	20:19:37	Outbound	5/10	7.5	*Nordic Odyssey*	Ore carrier	2.8	5.4
					Nordic Olympic	Ore carrier	1.6	5.7
2020 Jul 28	06:32:33	Inbound	0/10	8.0	*Vitus Bering*	Ore carrier	3.5	9
					Gisela Oldendorff	Ore carrier	2.5	6.3
2020 Jul 28	21:54:23	Outbound	0/10	8.8	*Nordic Odin*	Ore carrier	1.3	8.7
					Admiral Schmidt	Ore carrier	3.7	8.4
2020 Jul 30	09:53:39	Inbound	0/10	7.8	*NS Yakutia*	Ore carrier	4.0	8.2
					Golden Brilliant	Ore carrier	9.2	6.8
2020 Jul 30	21:16:17	Outbound	0/10	8.4	*Gisela Oldendorff*	Ore carrier	2.1	8.6
2020 Aug 01	04:20:59	Inbound	0/10	8.8	*Rio Tamara*	Ore carrier	1.3	8.0
					Golden Ruby	Ore carrier	6.3	8.5

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 2). Each AMAR was fitted with an M36-V35-100 omnidirectional hydrophone (GeoSpectrum Technologies Inc., −165 ± 3 dB re 1 V/µPa sensitivity). All devices were calibrated to within 1 dB using a pistonphone calibrator in JASCO's laboratory before shipping, and in the field immediately before deployment and upon retrieval. 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 at 64,000 samples per second with a 6 dB gain for a recording bandwidth of 10 Hz to 32 kHz. The recorders were programmed to power off from 17 Oct 2019 until 12 Jul 2020.

Figure 2. The Autonomous Multichannel Acoustic Recorder – Generation 3 (AMAR G3; JASCO) positioned in the middle of the mooring. AMARs were used to measure underwater sound.

2.1.2. AMAR Recording Stations

The AMARs were deployed at two recording stations, AMAR-BI in Eclipse Sound and AMAR-RI in northern Milne Inlet (see locations in Figure 1 and Table 3). Both recorders were deployed on 29 Sep 2019 from the MSV *Botnica* (Figure 3, left) and were retrieved on 5 Sep 2020 from Baffinland's research vessel (Figure 3, right). Both AMARs recorded as planned from their delayed recording start of 1 Oct 2019 until retrieval, including a period of dormancy from 17 Oct 2019 to 12 Jul 2020, for a recording duration of 17 days in the 2019 late shoulder season and 18 days in the 2020 early shoulder season. Figure 4 provides details of the mooring design.

Figure 3. Vessel MSV *Botnica* used for AMAR deployment (left). AMAR retrieval from Baffinland's research vessel (right).

Table 3. Operation period, location, and depth of the Autonomous Multichannel Acoustic Recorders (AMARs).

Station	Latitude	Longitude	Depth (m)	Deployment	Retrieval
AMAR-BI	72°43'26.7"N	79°12'50"W	297	2019 Sep 29	2020 Sep 05
AMAR-RI	72°33'26.7"N	80°12'25.4"W	91		

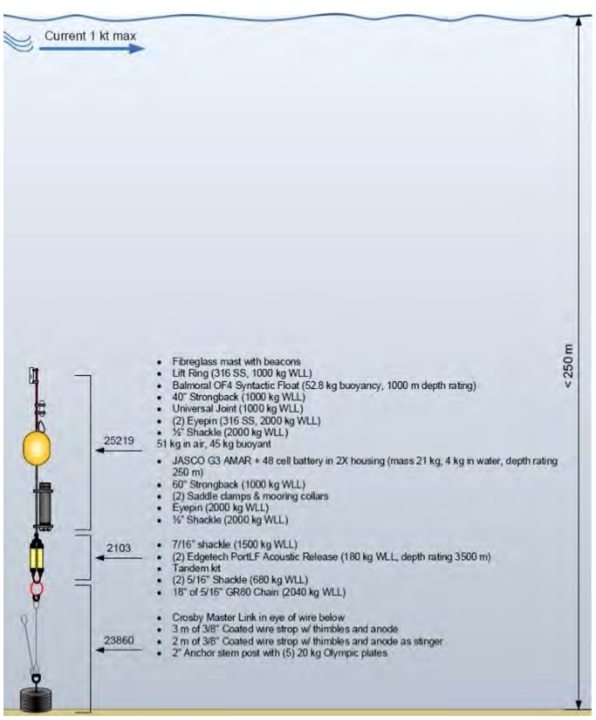

Figure 4. Mooring with one Autonomous Multichannel Acoustic Recorder (AMAR) attached to an anchor (JASCO Mooring Design 208). The hydrophone was 3 m above the seafloor. This configuration was used at both stations.

2.2. Vessel Sound Level Analysis

Sound levels of the icebreaker MSV *Botnica* were determined by analyzing data recorded as the vessel sailed over AMAR-RI and AMAR-BI during the 2019 late shoulder season and 2020 early shoulder season. Time-stamped vessel positions were obtained from Automated Identification System (AIS) records (exactEarth 2020) and correlated with the acoustic recording times. Ice concentrations were obtained from Ship Board Observer logs for 2019 and from daily ice charts from the Canadian Ice Service (2020), validated by logs from vessel master's where available. Underwater noise was analyzed for a total of 17 one-way transits of the *Botnica* at AMAR-BI (8 in the 2019 late shoulder season and 9 in the 2020 early shoulder season) and 18 one-way transits at AMAR-RI (7 in the 2019 late shoulder season and 11 in the 2020 early shoulder season). Analyzed transits included a combination of solo transits of the MSV *Botnica* and transits with the MSV *Botnica* escorting between 1 to 4 Project vessels (ore carriers and tugs), as documented in Tables 1 and 2.

Acoustic data were first analyzed using JASCO's ShipSound automated noise emission measurement system that combines underwater acoustic recordings, AIS records, and acoustic propagation loss calculations to derive sound source signatures for individual vessels. ShipSound identifies vessels that traverse a predefined transit area and then automatically extracts the corresponding acoustic data for analysis. It uses a vessel's speed together with a cepstral analysis of the Lloyd's mirror pattern (an interference pattern caused by sound reflecting from the sea surface) to determine the timing and location of closest point of approach (CPA) of the vessel's acoustic centre. Following the ANSI/ASA S12.64 Standard (ANSI/ASA 2009), data windows for individual vessel transits are defined as the period over which the acoustic centre is within ±30° of the CPA. Time-stamped vessel track data from AIS records (obtained from exactEarth) were used to determine distances between the vessels and the AMAR and to obtain other relevant vessel information (class, speed, length, course over ground, etc.).

ShipSound automatically determines the data window and processes the acoustic data in 1-second periods, stepped in 0.5-second intervals. Spectrum measurements (i.e., sound levels as a function of frequency) are calculated using 1-second fast Fourier transforms (FFTs), shaded using a Hann window with 1 Hz frequency resolution. A higher frequency resolution of 0.125 Hz using a Hamming window is also implemented to compute the spectrum up to 500 Hz.

ShipSound calculates two kinds of vessel source levels from the data window: Monopole Source Level (MSL) and Radiated Noise Level (RNL). MSL is equal to the measured sound pressure level scaled according to a numerical acoustic propagation loss (PL) model that accounts for the effect of the local environment on sound propagation (i.e., sea-surface reflection, water column refraction and absorption, and bottom loss). MSL is the value used in most acoustic models. The RNL is equal to the measured sound pressure level, back-propagated according to geometric spreading loss based on the distance between a source and the hydrophone to yield an effective noise emission level for the vessel. RNL is the source level calculation method specified by the ANSI standard. The ShipSound software applies the ANSI/ASA S12.64 Grade-A method for back-propagation distance (ANSI/ASA 2009): it determines the instantaneous vessel range (R) in metres from the measurement hydrophone for each 1-second step within the data window. The RNL back propagation method of $20 \times \mathrm{Log}_{10}(R)$ is applied to the spectra of each step separately. As part of the scaling for sound transmission loss between the vessel and the hydrophone, the attenuation of acoustic energy by molecular absorption in seawater was also considered, even though this is not specified by ANSI/ASA S12.64. This volumetric sound absorption is quantified by an absorption coefficient that depends on water temperature, salinity, and depth as well as the sound frequency. In general, the absorption coefficient increases with the square of the sound frequency. The absorption coefficient for seawater is computed in ShipSound using the formulae of François and Garrison (1982a, 1982b). Accounting for absorption is necessary when the CPA distances are not controlled.

ShipSound also calculates background noise in each frequency band. Measured band levels are accepted if they exceed the background levels by 3 dB or more. Band levels are corrected if they exceed background levels by 3–10 dB but are rejected if they are less than 3 dB above background. Adjusted and rejected band levels are flagged in the database. A quality control review process is undertaken whereby measurements are then either Accepted or Rejected, dependent on how many frequency bands were rejected due to background noise contamination and whether the dominant frequency bands required adjustment. Measurements were also rejected if: other vessels were within six times the CPA for the MSV *Botnica*, the MSV *Botnica*'s speed fluctuated by more than three knots within the data window, or the MSV *Botnica* did not follow a relatively straight path. For this analysis, we did not reject measurements when other vessels occurred within six times the CPA for vessel convoys. Instead, these results were flagged to indicate that the resulting RNL and MSL values could be affected by the presence of nearby vessels.

Sound levels in Section 3 are presented using the following data presentation formats:

- SPL over time: The levels are defined for broadband frequency range (1 to 25 kHz) and for the following decade bands: 10–100 Hz (Decade A), 100 Hz to 1 kHz (Decade B), 1–10 kHz (Decade C), and 10-25 kHz (Decade D).
- Spectrograms: 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.

2.3. Sound Level Versus Range Analysis

Received SPLs during each icebreaker transit were computed in 1-second, Hann-weighted, time windows with 50% overlap. These time-stamped SPL data were compared to the distance of each vessel from the AMAR at the respective times. We computed the distances in the forward and aft directions (i.e., measured as the MSV *Botnica* approached the AMAR and as the vessels moved away from the AMAR, respectively) where the measured SPL was at or above 120 dB re 1 µPa. To do this, we plotted the SPL data as a function of range and fit an empirical propagation loss curve by minimizing (in the least-squares sense) the difference between the trend line and the measured level-distance samples. To provide a conservative estimate, the best-fit line was shifted upward so that the trend line exceeded 90% of the SPL data. The distance to 120 dB re 1 µPa was obtained from this 90% fit. For this analysis, we included data from a time window of between 45 minutes to 1 hour before and after the time of the CPA of the MSV *Botnica* to the AMAR. This analysis approach considers the composite noise from all vessels in the convoys. Because there was overlap of the noise fields from the vessels, the linear regression model gave a reasonable estimate of the 120 dB distances. Two examples are shown in Figure 5; the one on the left for a transit of the MSV *Botnica* with no vessels in escort and one on the right for the MSV *Botnica* with 4 vessels in escort.

We also determined the total amount of time during which received sound levels exceeded 120 dB re 1 µPa for each of the analyzed icebreaker transits. This was done by counting the number of 1 second samples with SPL exceeding 120 dB when the MSV *Botnica* was within 20 km of the AMAR.

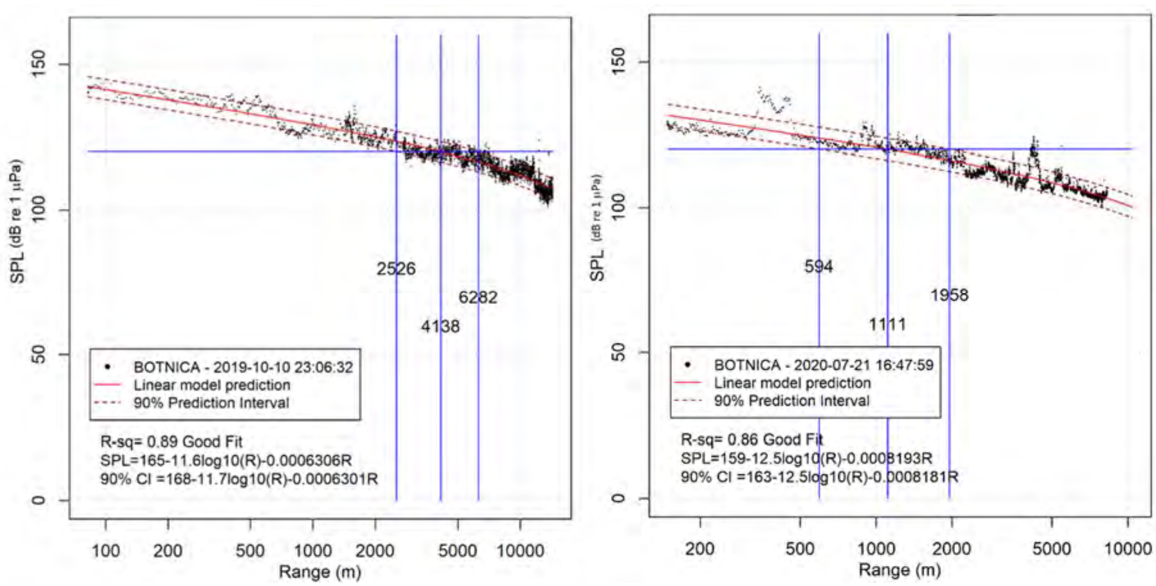

Figure 5. Example plots of the sound pressure level (SPL) versus range curve fitting approach used to determine the distances from the ship that correspond with an SPL of 120 dB re 1 Pa. The example on the left is for data recorded on AMAR-BI on 10 Oct 2019 while the MSV *Botnica* approached the recorder (i.e., in the forward aspect) with no vessels in escort and 0/10 ice concentration. The example on the right is for data recorded on AMAR-BI on 21 Jul 2020 while the MSV *Botnica* approached the AMAR with 4 vessels in escort, in 9/10 ice concentration.

3. Results

3.1. Sound level measurements

The analyzed icebreaker data included transits with the MSV *Botnica* escorting up to 4 vessels (2 ore carriers and 2 tugs) to and from Milne Port. Ice conditions during the transits varied between 0/10 concentration and 9/10 concentration. The accompanying vessels were ore carriers, with the exception of the first day of shipping in 2020, when the MSV *Botnica* escorted 2 ore carriers and 2 tugs into Milne Port in one transit.

Figure 6 is a plot of the broadband SPL as a function of time recorded at AMAR-BI while the MSV *Botnica* transited toward Milne Port while escorting the 2 ore carriers and 2 tugs on 21 Jul 2020, with 9/10 ice concentration. The plot includes data recorded 1 hour before the CPA of the MSV *Botnica* and 1 hour after. On the right hand axis, Figure 6 also shows the distances between each vessel and the AMAR through time.

Figure 7 is a spectrogram plot showing the noise levels as a function of frequency and time during this transit. The noise footprints of the successive vessels overlap with each other and are not obviously distinguishable. The SPL remains elevated above 120 dB re 1 µPa from shortly before the passing of the MSV *Botnica* at 16:47 through to the transit of the tug *Ocean Raynald T* past the AMAR at 17:02, the last vessel in the convoy. There were occasional spikes in the time record, where the SPL increased by approximately 10 dB. These excursions of the SPL align with times in the spectrogram where the characteristic tonal structure of the noise emitted by the MSV *Botnica* was evident (examples outlined in the Figure), indicating that these spikes are attributable to the MSV *Botnica*. This tonal structure of the noise output by the MSV *Botnica* is discussed further in Section 0, these are periods when the MSV *Botnica* engines were interpreted to be operating at full power for brief times.

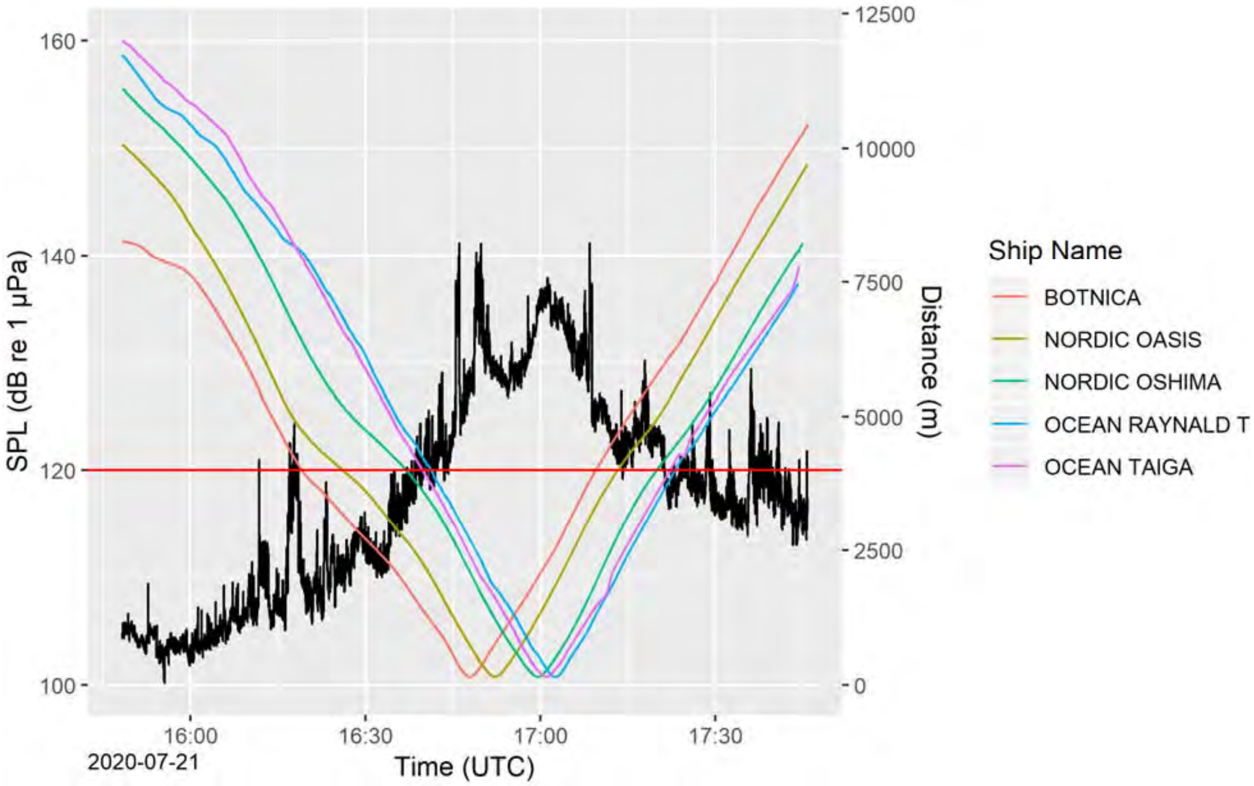

Figure 6. AMAR-BI: Sound pressure level (SPL; left axis) as a function of time (black curve) recorded while MSV *Botnica* transited through Eclipse Sound toward Milne Port, with 4 vessels in escort and 9/10 ice concentration. The distances (right axis) between the vessels and the AMAR are plotted as colored lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

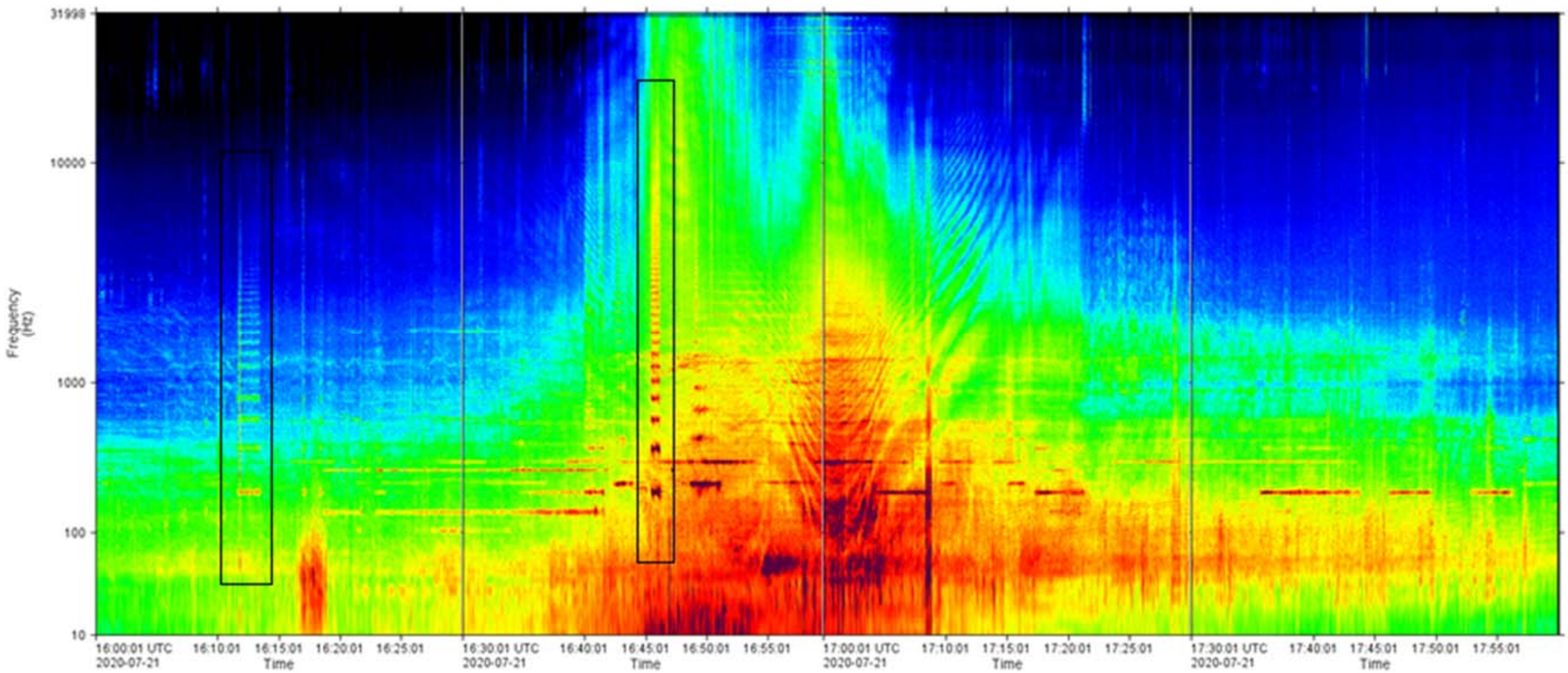

Figure 7. Spectrogram of sound intensity versus time and acoustic frequency from the recording on AMAR-BI: MSV *Botnica* with 4 vessels in escort, transiting in Eclipse Sound toward Milne Port on 21 Jul 2020 in conditions with 9/10 ice concentration. The MSV *Botnica* is the first vessel to pass the recorder, two examples of the tonal nature of its noise are outlined in black.

By comparison, Figure 8 is a plot showing the SPL (and distance between the MSV *Botnica* and the AMAR) as a function of time as the MSV *Botnica* transited through northern Milne Inlet and past AMAR-RI in 9/10 ice concentration, but with no vessels in escort. There was a narrower main peak of the SPL curve, as the MSV *Botnica* passed by the AMAR with its CPA to the AMAR at 11:04. The SPL is above 120 dB re 1 µPa for a total of 17 minutes during this transit. In comparison, the main peak in the curve in Figure 7 was broader as it encompassed the noise from all five vessels in that transit. The SPL exceeded 120 dB re 1 µPa for a total of 47 minutes during that transit. Figure 9 is a similar plot of the MSV *Botnica* with no vessels in escort, but when there was no ice present. In this case, there is only one main peak of the SPL, when the MSV *Botnica* passed the AMAR at 18:42, and the SPL exceeded 120 dB re 1 µPa for 12 minutes. Equivalent plots for every analyzed transit can be found in Appendix B.

Figure 10 and Figure 11 are high resolution spectrogram plots for these two transits generated from the 1-second averaged SPL data. There was low frequency mooring noise below 100 Hz in the first half of the transit through 9/10 ice concentration in Figure 10, indicating that this is a time of elevated low frequency background noise conditions that are not attributable to the MSV *Botnica* and could be caused by current flow This noise is not present in the later part of that transit. During this transit, there were longer and more frequent periods when many tones were evident (horizontal bands of noise at discrete frequencies, with regular spacing). These occurred at the harmonics of the engine rotation rates and the propeller blade rates (see Section 0). The louder tones indicate times when the MSV *Botnica* engines were working harder and the tones shifted in frequency as the MSV *Botnica*'s operating conditions changed. There were intermittent bursts of high intensity noise even when the MSV *Botnica* was not at the CPA. For example, one of these occurs just before 12:00 on 22 Jul 2020, which is after the low frequency mooring noise abated. In contrast, the tones occurred at consistent frequencies during the transit with no ice present on 05 Oct 2019 and were loudest when the MSV *Botnica* was at the CPA for that transit. This indicates that the MSV *Botnica* was more frequently changing engine power during the transit in 9/10 ice concentration than while transiting through low ice concentration.

Figure 12 is a plot comparing these two transits (i.e. for the MSV *Botnica* with no vessels in escort while transiting through 9/10 ice on the left compared to when transiting through 0/10 ice on the right). The figure includes spectrogram plots generated from 1-minute averaged SPL data in the bottom panels, and 1-minute averaged SPL for different decade band levels in the top panels. Similar plots for all analyzed icebreaker transits can be found in Appendix C. The band level plots are a useful way to characterize the noise distribution with frequency.

During the transit in 9/10 ice concentration, there was increased noise but this was mostly due to the elevated low frequency background noise then. Focussing on the data immediately surrounding the CPA, where the MSV *Botnica* was the dominant noise contributor (11:04 for the plot on the left and 18:42 for the plot on the right), there was notably more noise for the transit with 9/10 ice concentration at frequencies above 1 kHz. This is apparent from the elevated levels in Decade C and D during that time, shown in the upper panels of Figure 12.

Tables 4 through 11 summarize the computed radiated noise levels (RNLs), monopole source levels (MSLs), the 90th percentile distance between the MSV *Botnica* and the AMAR where the SPL exceeded 120 dB re 1 µPa, and the total amount of time in which that SPL threshold was exceeded for each analyzed icebreaker transit. The distances to 120 dB were longer behind the vessels compared to those measured in front of the vessels, indicating that there is more noise generated in the stern, or aft, aspect compared to the forward.

These results, and the plots in Appendix B, indicate that the extent and duration of ensonification above the 120 dB threshold increases by a small amount when additional vessels are added to the convoy, but not by amounts that exceed the variability between measurements of the MSV *Botnica* on its own in varying conditions (i.e. in different ice conditions or when travelling at different speeds). These results vary depending on the following factors: the spatial distribution of the vessels in the convoy, the speed of travel, the ice concentration, the sea state, and the vessel draft (also related to the vessel load) during the transits. A detailed noise correlation analysis of these factors was not within the scope of this report.

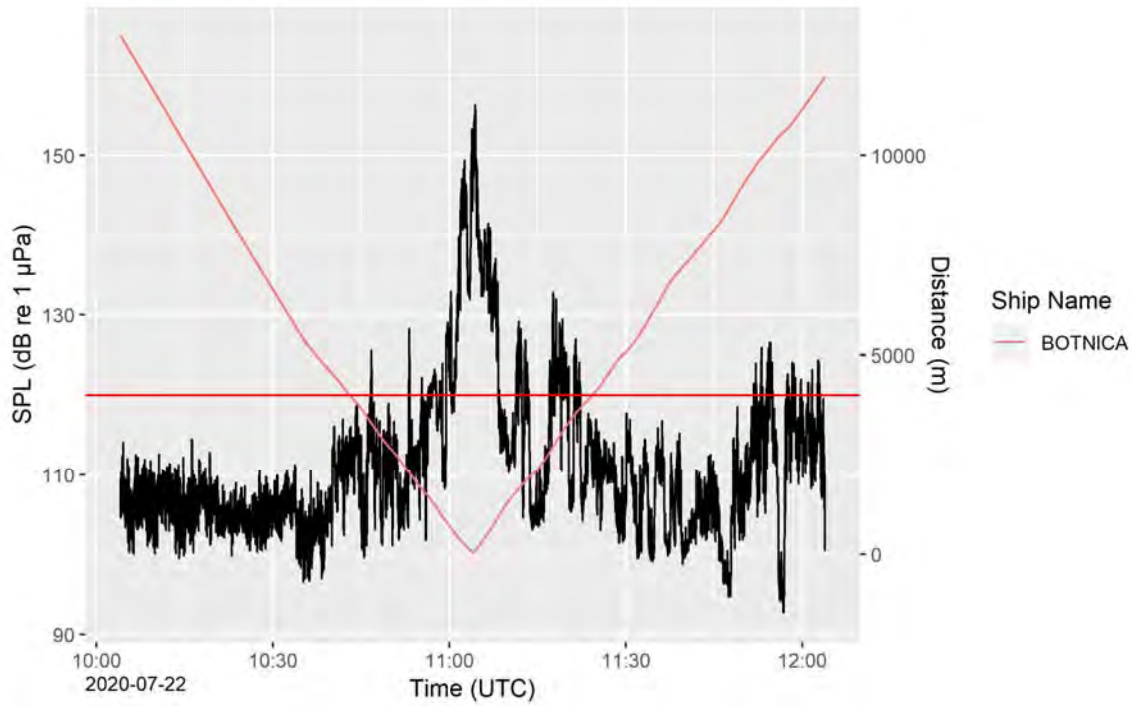

Figure 8. AMAR-RI: Sound pressure level (SPL; left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound toward Milne Port, with no vessels in escort and 9/10 ice concentration at a speed of 6.6. knots. The distances (right axis) between the vessel and the AMAR are plotted in pink. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

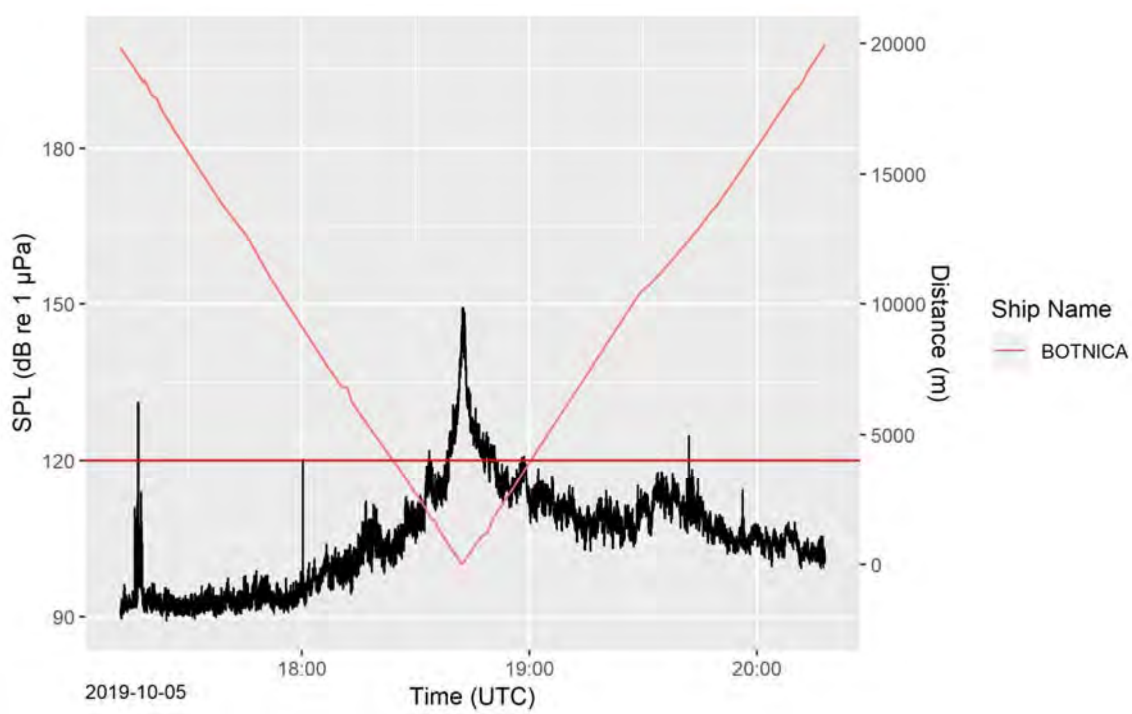

Figure 9. AMAR-RI: Sound pressure level (SPL; left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound toward Milne Port, with no vessels in escort and 0/10 ice concentration at a speed of 7 knots. The distances (right axis) between the vessel and the AMAR are plotted in pink. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

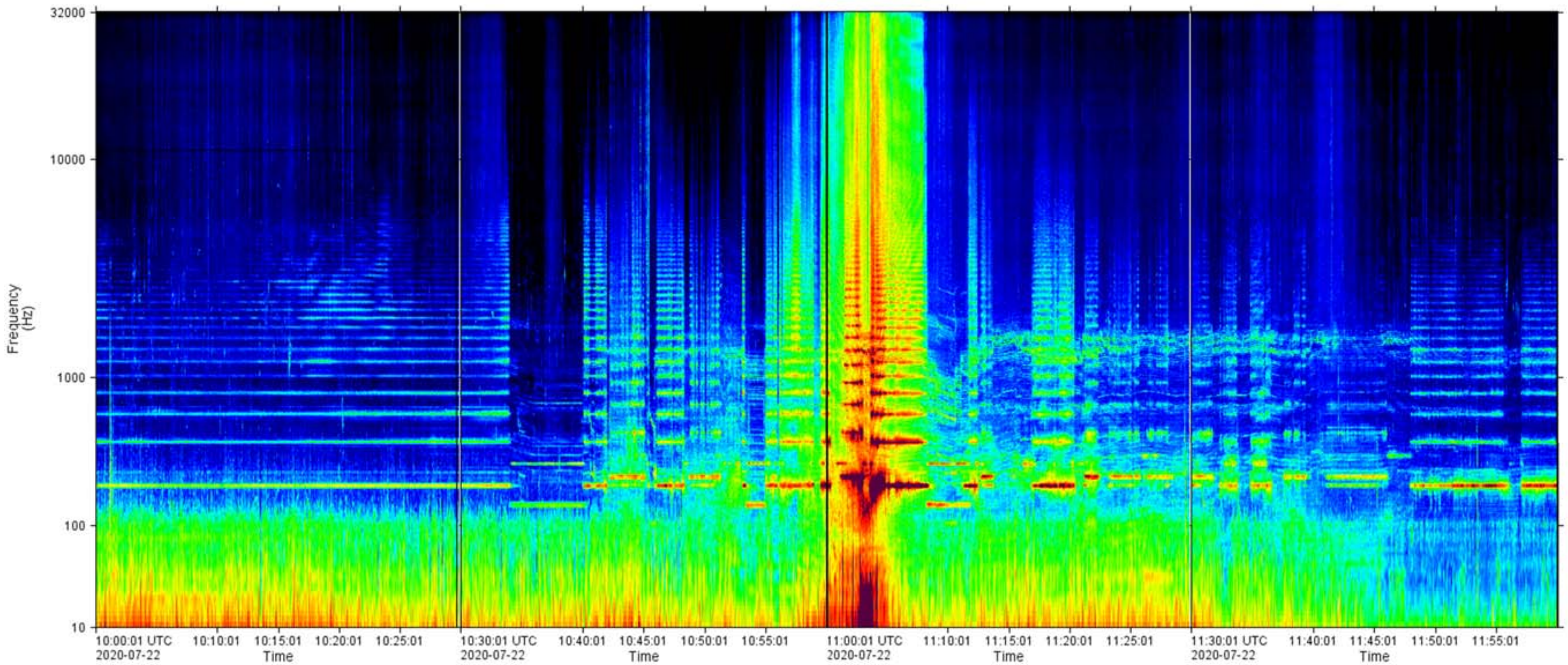

Figure 10. AMAR-RI: Spectrogram of noise for MSV *Botnica* with no vessels in escort, transiting in Eclipse Sound leaving Milne Port on 22 Jul 2020 in conditions with 9/10 ice concentration.

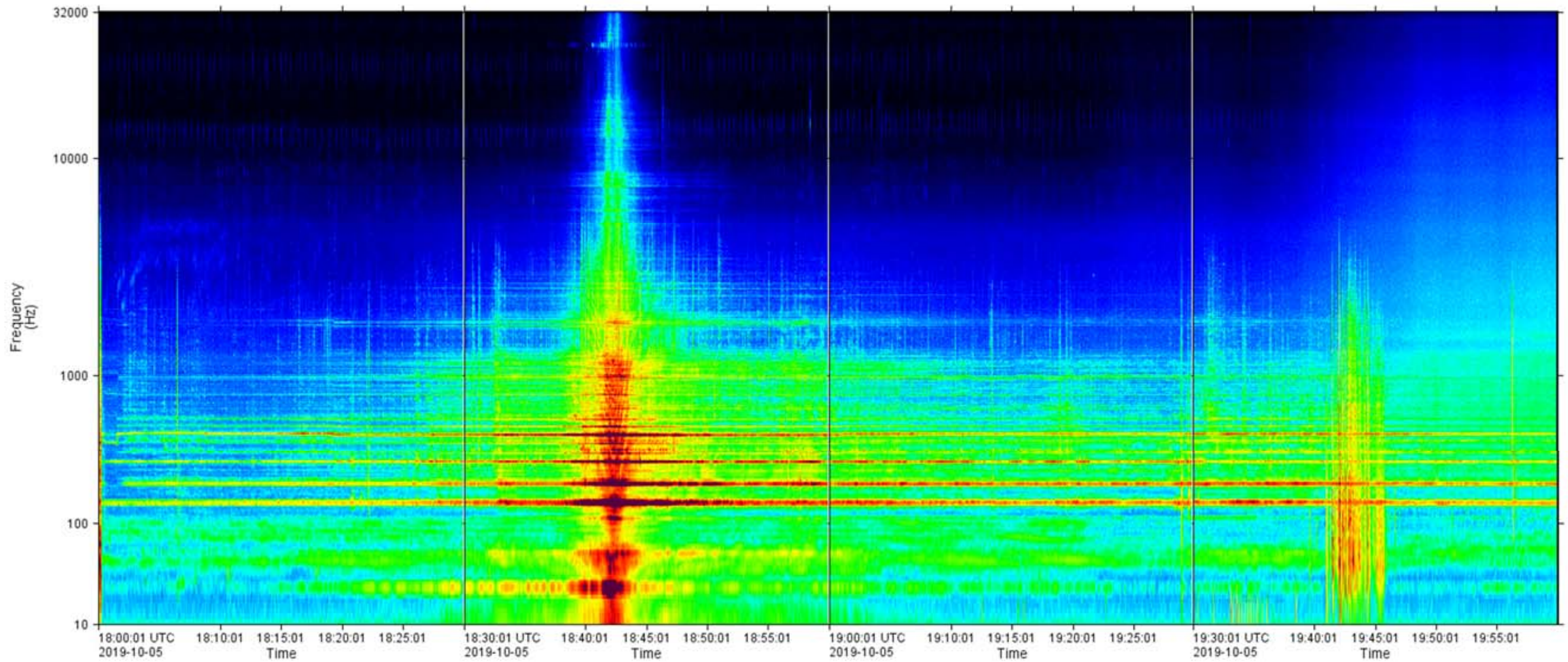

Figure 11. AMAR-RI: Spectrogram of noise for MSV *Botnica* with no vessels in escort, transiting in Eclipse Sound leaving Milne Port on 22 Jul 2020 in conditions with 0/10 ice concentration.

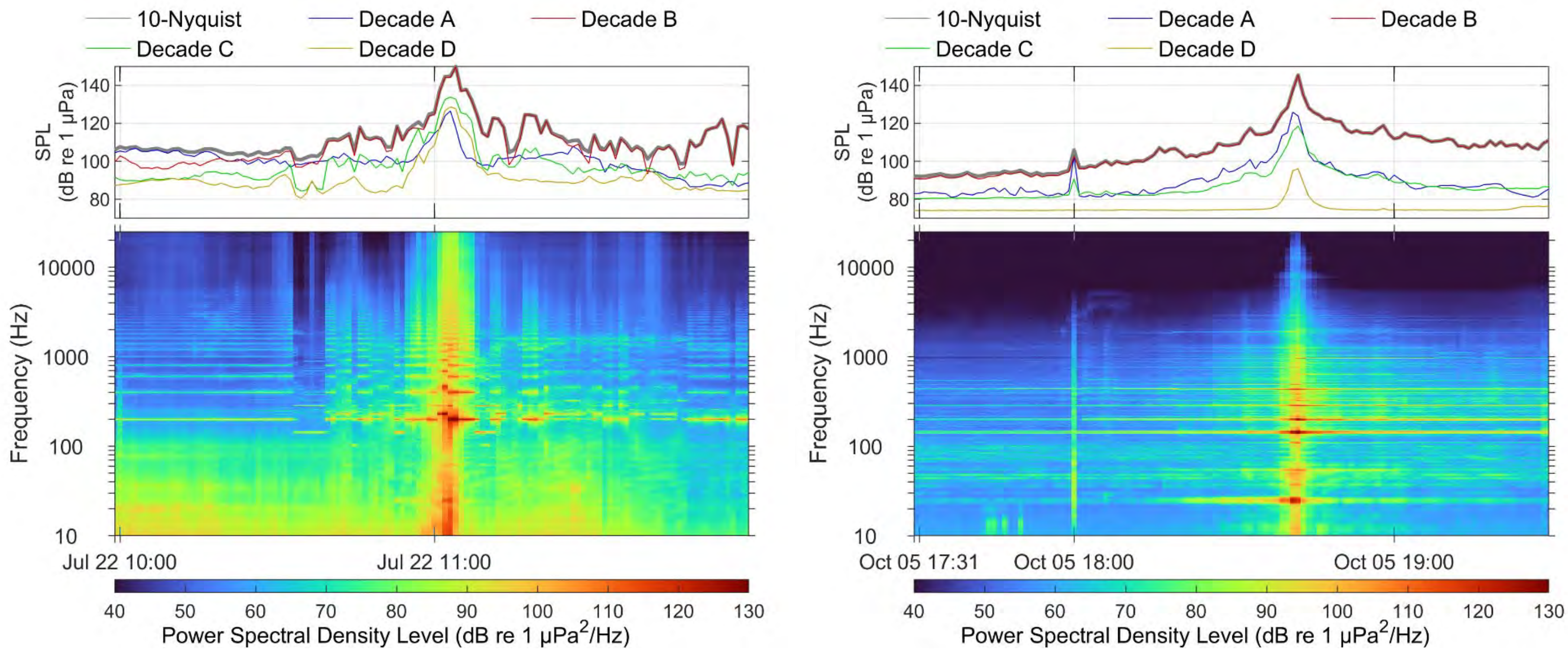

Figure 12 AMAR-RI: Spectrogram (bottom panels) and decade band levels (top panels) for data recorded while *Botnica* transited with no vessels in escort on (left) 22 Jul 2020 with 9/10 ice concentration and (right) 5 Oct 2019 with 0/10 ice concentration.

Table 4. AMAR-BI: MSV *Botnica* with no vessels in escort. Sound level details for transits during 2019 late shoulder season and 2020 early shoulder season.

Date	CPA time (UTC)	Direction	Ice concentration	Horizontal Range to AMAR at CPA (m)	*Botnica* RNL (dB re 1 µPa)	*Botnica* MSL (dB re 1 µPa)	*Botnica* speed (kn)	Range from *Botnica* to 120 dB (km)		Time > 120 dB (minutes)
								Forward	Aft	
2019 Oct 05	21:49:12	Outbound	0/10	2	181.9	179.9	5.9	2.2	N/A*	33.9
2019 Oct 08	23:52:33	Inbound	0/10	71	187.3	185.0	8.4	2.7	14.9	43.3
2019 Oct 12	13:38:42	Inbound	0/10	44	N/A	N/A	6.2	2.2	14.0	44.5
2019 Oct 14	21:02:07	Inbound	0/10	61	185.2	183.1	6.2	2.8	20.1	45.2
2019 Oct 17	18:49:07	Inbound	0/10	45	184.8	182.5	8.1	1.8	5.6	17.8
2020 Jul 22	14:08:05	Outbound	9/10	82	191.2	190.3	7.3	5.1	20.3	65.3

* The *Nordic Odin* was near the AMAR and prevented determination of the 120 dB distance for the *Botnica* with no vessels in escort.

Table 5. AMAR-BI: MSV *Botnica* with 1 vessel in escort. Sound level details for transits during 2019 late shoulder season and 2020 early shoulder season.

Date	CPA time (UTC)	Direction	Ice concentration	Horizontal Range to AMAR at CPA (m)	*Botnica* RNL (dB re 1 µPa)	*Botnica* MSL (dB re 1 µPa)	*Botnica* speed (kn)	Range from *Botnica* to 120 dB (km)		Time > 120 dB (minutes)
								Forward	Aft	
2019 Oct 10	23:06:30	Outbound	0/10	82	190.1*	188.3*	7.8	6.3	11.5	51.0
2019 Oct 13	04:59:09	Outbound	0/10	60	187.8	185.8	8.6	6.1	15.4	51.2
2019 Oct 15	15:11:02	Outbound	0/10	73	190.2	188.2	8.4	5.0	14.0	44.8
2020 Jul 30	23:46:22	Outbound	0/10	453	183.5*	182.3*	8.6	2.4	8.8	21.7

* Noise from the vessels under escort influenced this measurement.

Table 6. AMAR-BI: MSV *Botnica* transits with 2 vessels in escort. Sound level details for transits during 2019 late shoulder season and 2020 early shoulder season.

Date	CPA time (UTC)	Direction	Ice concentration	Horizontal Range to AMAR at CPA (m)	*Botnica* RNL (dB re 1 µPa)	*Botnica* MSL (dB re 1 µPa)	*Botnica* speed (kn)	Range from *Botnica* to 120 dB (km)		Time > 120 dB (minutes)
								Forward	Aft	
2020 Jul 23	19:07:25	Inbound	2/10	140	185.4*	183.6*	5.9	2.2	6.3	30.8
2020 Jul 24	23:04:17	Outbound	8/10	112	183.3*	181.1*	5.3	1.2	6.8	36.1
2020 Jul 26	23:27:08	Outbound	8/10	94	173.5*	171.9*	4.2	3.7	6.9	46.0
2020 Jul 29	00:42:27	Outbound	0/10	58	187.1*	185.0*	8.8	5.9	10.4	38.6
2020 Jul 30	07:09:56	Inbound	0/10	153	185.8	184.0	8.3	1.8	7.8	21.7

* Noise from the vessels under escort influenced this measurement.

Table 7. AMAR-BI: MSV *Botnica* transits with 3 vessels in escort. Sound level details for transits during 2019 late shoulder season and 2020 early shoulder season.

Date	CPA time (UTC)	Direction	Ice concentration	Horizontal Range to AMAR at CPA (m)	*Botnica* RNL (dB re 1 µPa)	*Botnica* MSL (dB re 1 µPa)	*Botnica* speed (kn)	Range from *Botnica* to 120 dB (km)		Time > 120 dB (minutes)
								Forward	Aft	
2020 Aug 01	01:55:18	Inbound	0/10	826	172.3*	170.6*	8.5	4.0	11.7	40.8

* Noise from the vessels under escort influenced this measurement.

Table 8. AMAR-BI: MSV *Botnica* transits with 4 vessels in escort. Sound level details for transits during 2019 late shoulder season and 2020 early shoulder season.

Date	CPA time (UTC)	Direction	Ice concentration	Horizontal Range to AMAR at CPA (m)	*Botnica* RNL (dB re 1 µPa)	*Botnica* MSL (dB re 1 µPa)	*Botnica* speed (kn)	Range from *Botnica* to 120 dB (km)		Time > 120 dB (minutes)
								Forward	Aft	
2020 Jul 21	16:47:58	Inbound	9/10	149	175.0*	173.6*	5.4	2.0	9.8	46.9

* Noise from the vessels under escort influenced this measurement.

Table 9. AMAR-RI: MSV *Botnica* with no vessels in escort. Sound level details for transits during 2019 late shoulder season and 2020 early shoulder season.

Date	CPA time (UTC)	Direction	Ice concentration	Horizontal Range to AMAR at CPA (m)	*Botnica* RNL (dB re 1 µPa)	*Botnica* MSL (dB re 1 µPa)	*Botnica* speed (kn)	Range from *Botnica* to 120 dB (km)		Time > 120 dB (minutes)
								Forward	Aft	
2019 Oct 05	18:42:10	Outbound	0/10	29	187.3	185.2	7	1.2	2.3	12.0
2019 Oct 09	02:23:05	Inbound	0/10	36	191.0	189.7	8.5	2.9	3.6	20.5
2019 Oct 12	16:29:23	Inbound	0/10	48	185.8	185.0	5.7	1.3	2.0	11.8
2019 Oct 15	00:19:10	Inbound	0/10	28	192.4	190.3	6.1	4.8	3.0	33.2*
2019 Oct 17	21:35:05	Inbound	0/10	100	188.0	187.5	8.6	1.3	2.4	10.2
2020 Jul 22	11:04:03	Outbound	9/10	56	190.4	189.0	6.6	1.7	3.4	17.3

* The MSV Botnica stopped moving toward the end of this transit, and this transit is considered anomalous.

Table 10. AMAR-RI: MSV *Botnica* with 1 vessel in escort. Sound level details for transits during 2019 late shoulder season and 2020 early shoulder season.

Date	CPA time (UTC)	Direction	Ice concentration	Horizontal Range to AMAR at CPA (m)	*Botnica* RNL (dB re 1 µPa)	*Botnica* MSL (dB re 1 µPa)	*Botnica* speed (kn)	Range from *Botnica* to 120 dB (km)		Time > 120 dB (minutes)
								Forward	Aft	
2019 Oct 10	20:27:57	Outbound	0/10	42	189.3	187.7	8	1.5	11.4	23.6
2019 Oct 13	02:30:32	Outbound	0/10	19	189.4	187.6	8.6	2.8	19.5	31.6
2020 Jul 30	21:16:17	Outbound	0/10	67	191.2	190	8.4	N/A†	N/A†	N/A†

* Noise from the vessels under escort influenced this measurement.
† Background sounds were elevated at this time by mooring noise, which precluded determination of this value.

Table 11. AMAR-RI: MSV *Botnica* transits with 2 vessels in escort. Sound level details for transits during 2019 late shoulder season and 2020 early shoulder season.

Date	CPA time (UTC)	Direction	Ice concentration	Horizontal Range to AMAR at CPA (m)	*Botnica* RNL (dB re 1 µPa)	*Botnica* MSL (dB re 1 µPa)	*Botnica* speed (kn)	Range from *Botnica* to 120 dB (km)		Time > 120 dB (minutes)
								Forward	Aft	
2020 Jul 23	23:14:48	Inbound	2/10	111	181.2*	180.0*	7.1	1.3	6.7	22.5
2020 Jul 24	19:16:14	Outbound	8/10	175	189.0*	185.9*	4.6	1.8	5.2	32.0
2020 Jul 26	04:59:11	Inbound	5/10	59	192.2	192.4	8.1	11	6.5	31.4
2020 Jul 26	20:19:37	Outbound	5/10	150	192.3*	191.9*	7.5	2.0	N/A†	N/A†
2020 Jul 28	06:32:33	Inbound	0/10	8	193.5	191.1	8.0	N/A†	N/A†	N/A†
2020 Jul 28	21:54:23	Outbound	0/10	363	184.8*	183.2*	8.8	N/A†	8.0	N/A†
2020 Jul 30	09:53:39	Inbound	0/10	100	189.9	188.9	7.8	3.0	11.8	36.3
2020 Aug 01	04:20:59	Inbound	0/10	73	189.7	187.8	8.8	3.6	6.3	27.3

* Noise from the vessels under escort influenced this measurement.
† Background sounds were elevated at this time by mooring noise, which precluded determination of this value.

3.2. Comparison of measurements to modelled estimates

The purpose of this analysis was to characterize the underwater noise generated during icebreaker transits, and to compare the results with acoustic modelling estimates provided in Quijano et al. (2019). The acoustic modelling estimates are summarized as follows:

- Single Icebreaker with no vessels in escort:
  - The distance to an SPL of 120 dB re 1 µPa from a single icebreaker transiting at 9 knots in open water would extend to 6.2 km in Eclipse Sound, 5.3 km near Pond Inlet, and 5.6 km in Milne Inlet.
  - These distances were modelled to be 40.5 km, 26.9 km, and 26.5 km in 10/10 ice concentration, respectively, and 33.2, 20.1, and 22.2 km in 3/10 ice concentration.
- Single icebreaker with 1 ore carrier in escort:
  - The distance to 120 dB re 1 µPa for an icebreaker transiting with 1 ore carrier in escort was modelled to be 18.6 km in Eclipse Sound, 11.2 km near Pond Inlet, and 13.3 km in Milne Inlet when transiting in open water.
  - These modelled distances were 40.4, 27.2, and 26.3 km in 10/10 ice concentration or 34.9, 22.3, and 23.2 km in 3/10 ice concentration.
- Single icebreaker with 2 ore carriers in escort:
  - The distance to 120 dB re 1 µPa for an icebreaker transiting with 2 ore carriers in escort was modelled to be 25.9 km in Eclipse Sound, 16.3 km near Pond Inlet, and 15.2 km in Milne Inlet.
  - These distances were 40.3, 27.6, and 26.1 km in 10/10 ice concentration and 37.3, 25.0, and 23.6 km in 3/10 ice concentration.

The modelled MSL for the icebreaker was 210 dB re 1 µPa while transiting in 10/10 ice concentration at 4. 6knots, 208 dB re 1 µPa while transiting in 3/10 ice concentration at 9 knots, and 183 dB re 1 µPa in open water at 9 knots. The measurements yielded MSL estimates of approximately 190 dB re 1 µPa while transiting at approximately 7 knots in 9/10 ice concentration, and between 183 and 190 dB re 1 µPa while transiting in open water at variable speeds. The measured MSL is therefore 20 dB lower than the modelled MSL for an icebreaker transiting through 9/10 ice concentration and slightly higher than the modelled MSL for an icebreaker in open water.

Note that the modelled distances were computed relative to the centroid of the vessel distribution for convoys with more than 1 vessel. During the actual measured transits, the vessels in convoy travelled at slightly different, and variable, speeds so it was not feasible to compute the distance to 120 dB relative to a dynamic centroid position from the acoustic measurements. Instead, the distances derived from the measurements are given relative to the AIS reported position of the MSV *Botnica*. During the measured transits, the vessels were separated by at least 1 km (Table 1 and 2) but 500 m separation between vessels was assumed for the modelling. The modelled distances are, therefore, not directly comparable to the 120 dB distances provided in this report and this difference of the centroid results in an offset of up to 500 m between the modelled and the measured distances. The modelling also assumed that the ore carriers would be Cape Size ore carriers, but the vessels measured in 2020 were not this large. Nevertheless, in the modelling the icebreaker was shown to be the dominant noise source and the size of ore carrier would have had a minimal effect on the model estimates. Finally, the transit speeds assumed in the modelling generally overestimated the actual transit speeds during the measurements by roughly 1 to 3 knots. Lower sound levels would be expected for vessels travelling at slower speeds. The exposure duration would also be expected to be longer for a vessel travelling at slower speed, though this relationship is complicated by the corresponding decrease in sound level. As such, the comparisons that follow have not been adjusted for transit speed differences between the modelled scenarios and actual transit speeds.

These caveats about differences between the model and the measurement conditions notwithstanding, the distances to 120 dB re 1 µPa aft of the vessels resulting from the measurements were approximately 50-83% shorter than the model estimates for ice concentrations between 3/10 and 10/10 and up to 55% shorter for transits in open water conditions (measured sound travelled to further aft of the vessels compared to in front, so the larger aft distances were used for this model comparison). However, some transits of the icebreaker on its own in open water yielded distances in the aft aspect that matched or exceeded the model estimates although, in these cases, the sound level does drop below 120 dB at intermediate distances between the vessel and the 90th percentile measured distance. In these cases, the overall exposure durations were less than predicted through modelling.

We have also compared the measured and modelled durations of exposure at an SPL of 120 dB re 1 µPa for each transit. Based on the modelling results, a stationary animal in Eclipse Sound would be likely to experience sounds at an SPL of 120 dB re 1 µPa for the periods indicated in Table 12, ranging between 0.7 and 9.5 hours, dependent on transit scenario and ice concentration. The modelled estimates exceed all of the measured durations shown in Section 3 (summarized in Table 13), indicating that the sound propagation calculations incorporated in the model are conservative. The measured per-transit noise exposure periods exceeding 120 dB re 1 µPa were approximately 80-90% lower than modelling estimates when the icebreaker was transiting through ice with concentration between 3/10 and 9/10, and > 60% lower than modelled estimates when the icebreaker was traveling in open water, except for the case of the icebreaker transiting through open water with no vessels in escort.

Table 12. Modelled distance to the 120 dB disturbance onset threshold and total exposure period >120 dB re 1 uPa per icebreaker transit for two different icebreaker escort scenarios in various ice concentrations in Eclipse Sound (Quijano et al. 2019).

Icebreaker Transit Scenario	Vessel Speed (knots)	Ice Concentration	Range (R95%) to 120 dB disturbance threshold (km)	Total exposure period >120 dB per transit (hours)
1 icebreaker	4.6	10/10	40.5	9.5
	9	3/10	33.2	4.0
	9	0/10	6.2	0.7
1 icebreaker + 1 capesize carrier	4.6	10/10	40.4	9.5
	9	3/10	34.9	4.2
	9	0/10	18.6	2.2
1 icebreaker + 2 capesize carriers	4.6	10/10	40.3	9.5
	9	3/10	37.3	4.5
	9	0/10	25.9	3.1

Table 13 Total exposure period > 120 dB re 1 µPa per icebreaker transit in various conditions based on AMAR recordings from the 2019 later should season and 2020 early shoulder season shipping activities.

Icebreaker Transit Scenario	Spread of Vessel Speeds (knots)	Ice Concentration	Spread of Ranges (R95%) to 120 dB disturbance threshold (km) from Aft	Spread of the total exposure duration > 120 dB per transit (hours)
1 icebreaker	6.6 - 7.3	9/10	3.4 – 20.3	0.28 - 1.08
	N/A	3/10	N/A	N/A
	5.8 – 8.4	0/10	2.0 – 20.1	0.17 – 0.75
1 icebreaker + 1 ore carrier	N/A	9/10	N/A	N/A
	N/A	3/10	N/A	N/A
	7.8 – 8.6	0/10	8.8 – 19.5	0.36 – 0.85
1 icebreaker + 2 ore carriers	4.2 – 5.3	8/10	5.2 – 6.9	0.53 – 0.77
	5.9 – 8.1	2/10 – 5/10	6.3 – 6.5	0.37 - 0.52
	7.8 – 8.8	0/10	6.3 – 11.8	0.37 – 0.64

4. Discussion and Conclusion

The underwater noise emissions of the icebreaker MSV *Botnica* exhibit many strong tones that are atypical of other vessel classes. This is thought to be due to an unusual engine configuration on the MSV *Botnica*, consisting of 12 main diesel engines and 4 stroke diesel secondary power generators. The blade rates in the sound signature are loud with many harmonics. These features make the MSV *Botnica* noise easily distinguishable from that of the other vessels monitored.

The exposure periods based on the measurements analyzed in this report are consistent with those based on measurements from the 2019 early shoulder season (Section 4.2 in Frouin-Mouy et al. (2020)) for icebreaker transits that occurred in open water conditions. Although the modelling predicted much longer propagation distances and greater exposure durations for transits through 9/10 ice concentration compared to those in open water, the measurements did not reflect this same degree of variability with changing ice conditions. This is thought to be because the assumed source levels used for the modelling are representative of the times when the icebreaker is actively interacting with ice. Intermittent bursts of noise from the MSV *Botnica* noted in the measurements can exceed the nominal sound levels by approximately 10 dB (see for example Figure 6). The measurements indicate that these periods of high intensity noise typically occur in short bursts, lasting on the order of minutes or less. Modelling predictions assumed this high intensity noise to be consistent for the entire transit. This conservative assumption lead to overly precautionary predictions of the exposure durations, as has been shown in this report.

Although the MSL for the icebreaker transiting in open water was slightly underestimated in the modelling, the resulting distances to 120 dB predicted by the model overestimated, for the most part, those derived from acoustic measurements. This indicates that the sound propagation model overestimated the distances over which the sounds travel due to conservative assumptions of the environmental conditions (water column sound speed and seafloor geoacoustic parameters) input to the model.

The duration calculations presented in this report can be used to estimate cumulative noise exposure from multiple transits on marine mammals by multiplying the computed per-transit exposure durations by expected numbers of daily transits with convoys of between 0 and 4 vessels with an icebreaker in Eclipse Sound. This contributes toward the objective from the Project Certificate Terms and Conditions to “Facilitate assessment of the potential short term, long term, and cumulative effects of vessel noise on marine mammals and marine mammal populations.”.

With respect to the objective of assessing the accuracy of Baffinland’s effects predictions of disturbance effects from Project shipping in the shoulder season on marine mammals, these results support assumptions that acoustic modelling estimates are conservative and over-representative of measured or actual sound exposure durations. Results demonstrated that the measured per-transit noise exposure periods exceeding 120 dB re 1 µPa were approximately 80-90% lower than modelling estimates when the icebreaker was actively breaking ice (3/10 to 9/10), and > 60% lower than modelled estimates when the icebreaker was traveling in open water. This means that in reality there will be longer periods, or a greater proportion of the day, during which narwhal would not be exposed to sounds from shoulder season shipping at levels with the potential to elicit behavioural disturbance. As such, mitigation measures that have been put into place (namely, transit restrictions to limit the number icebreaker transits in 24 hours when ice concentrations are greater than 3/10) are expected to be more than adequate to effectively mitigate impacts from icebreaking on narwhal behaviour and distribution, by providing long periods in the day when narwhal would not be disturbed by Project icebreaking noise.

5. Acknowledgements

The authors would like to acknowledge Héloïse Frouin-Mouy and Eric Lumsden of JASCO and Golder team members for their assistance deploying and retrieving the acoustic recorders, as well as the JASCO equipment team for their expert preparation and handling of the gear. The crew of MSV *Botnica*, contributed to the logistical and operational success of the deployment of the AMARs and the 2020 Golder Marine Environmental Effects Program team, and vessel operator Mike Hann, assisted with the retrieval from Baffinland's research vessel.

Glossary

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

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

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 R2004).

ensonified
Exposed to sound.

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.

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

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

monopole source level (MSL)
A source level that has been calculated using an acoustic model that accounts for the effects of the sea-surface, in-water propagation, and seabed on propagation loss, assuming a point-like (monopole) sound source. Also see radiated noise level.

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

radiated noise level (RNL)
A source level that has been calculated assuming sound pressure decays geometrically with distance from the source, with no influence of the sea-surface and seabed. Also see **monopole source level**.

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

rms
root-mean-square.

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

sound field
Region containing sound waves (ANSI 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 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. 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.

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

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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 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:

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

where $g(t)$ is an optional time weighting function. In many cases, the start time of the integration is marched forward in small time steps to produce a time-varying SPL function. For short acoustic events, such as sonar pulses and marine mammal vocalizations, it is important to choose an appropriate time window that matches the duration of the signal.

A.2. Frequency 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. This splitting of the spectrum into passbands of a constant width of 1 Hz, however, does not represent how animals perceive sound.

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

$$f_c(i) = 10^{\frac{i}{10}}, \tag{2}$$

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

$$f_{lo,i} = 10^{\frac{-1}{20}} f_c(i) \quad \text{and} \quad f_{hi,i} = 10^{\frac{1}{20}} f_c(i) \tag{A-3}$$

The decidecade bands become wider with increasing frequency, and on a logarithmic scale the bands appear equally spaced.

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

$$L_{\mathrm{p},i} = 10\log_{10}\int_{f_{\mathrm{lo},i}}^{f_{\mathrm{hi},i}} S(f)\,df \tag{A-4}$$

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

$$\text{Broadband SPL} = 10\log_{10}\sum_i 10^{\frac{L_{\mathrm{p},i}}{10}} \tag{A-5}$$

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

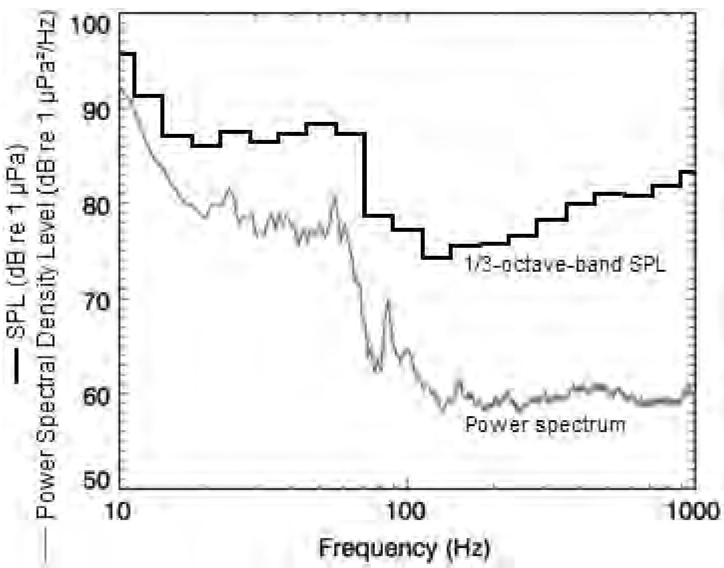


Figure A-1. Sound pressure spectral density levels and the corresponding 1/3-octave-band sound pressure levels of example ambient noise shown on a logarithmic frequency scale.

Appendix B. Broadband Received Levels per Transit

B.1. AMAR-BI

B.1.1. No vessels in escort

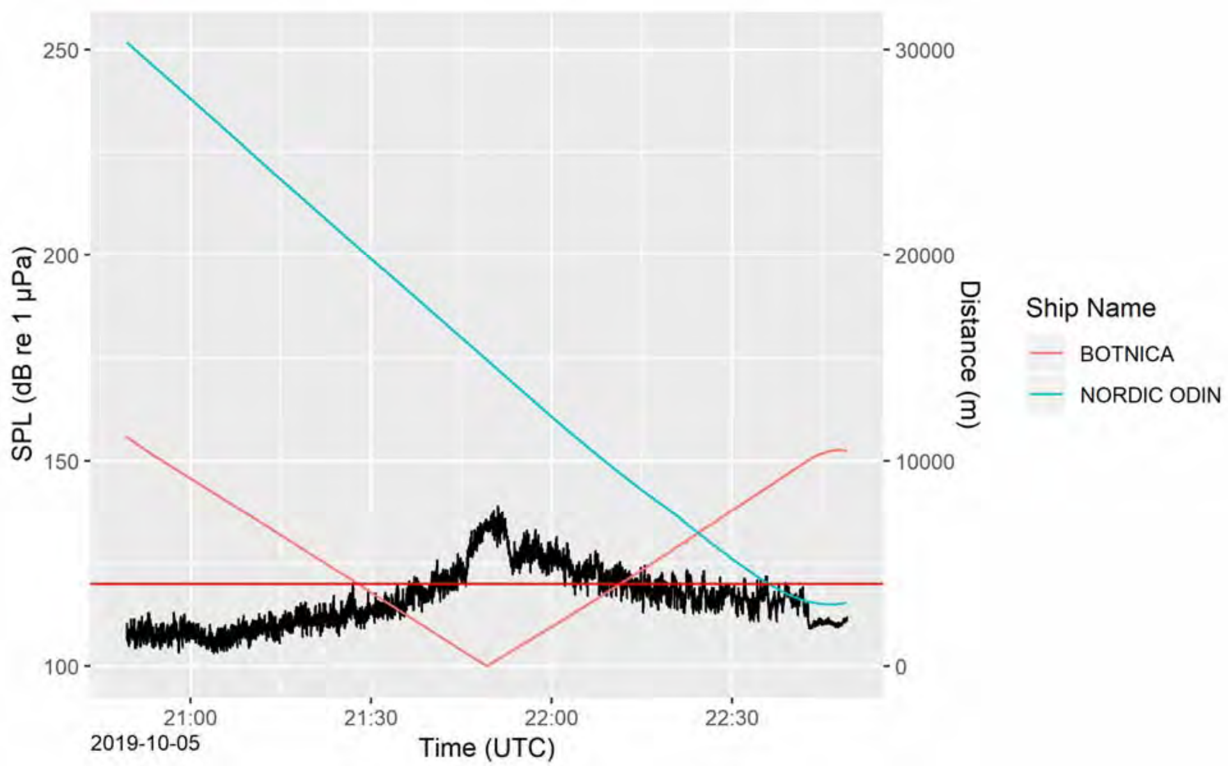


Figure B-1. AMAR-BI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 5 Oct 2019 leaving Milne Port, with no vessels in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

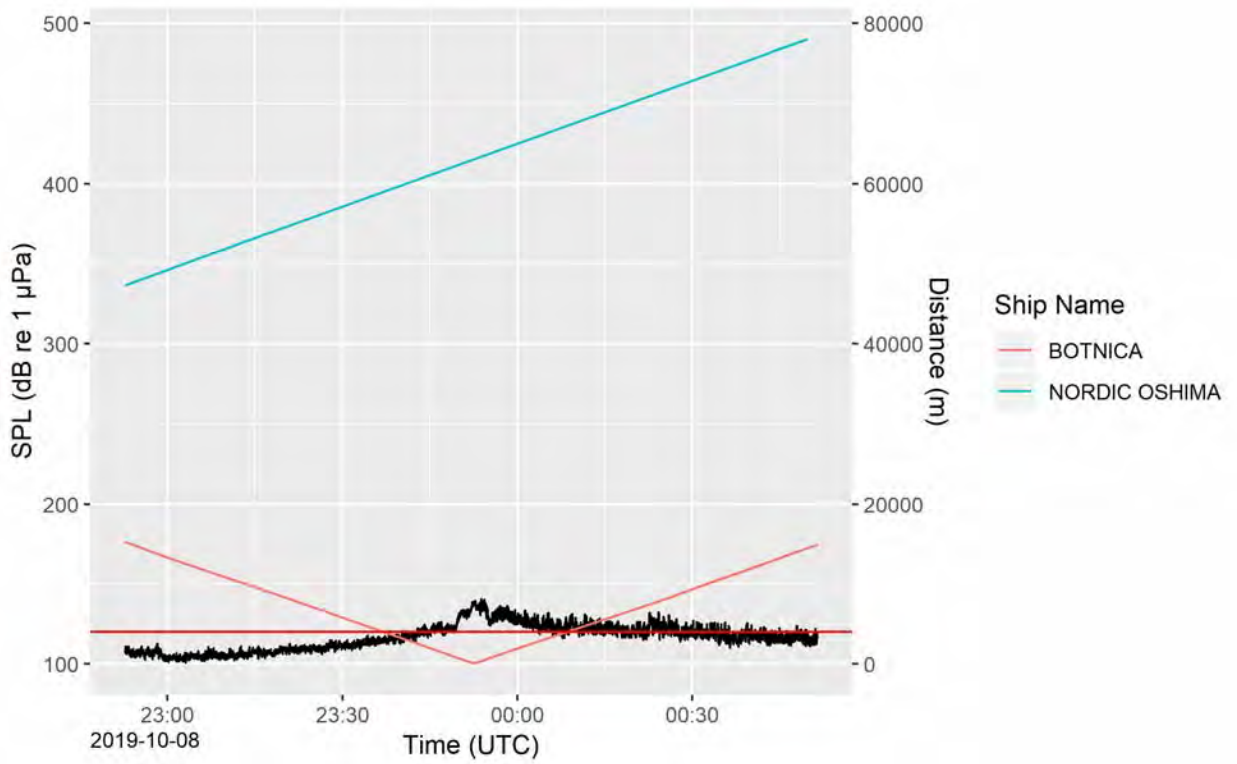


Figure B-2. AMAR-BI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 8 Oct 2019 coming to Milne Port, with no vessels in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

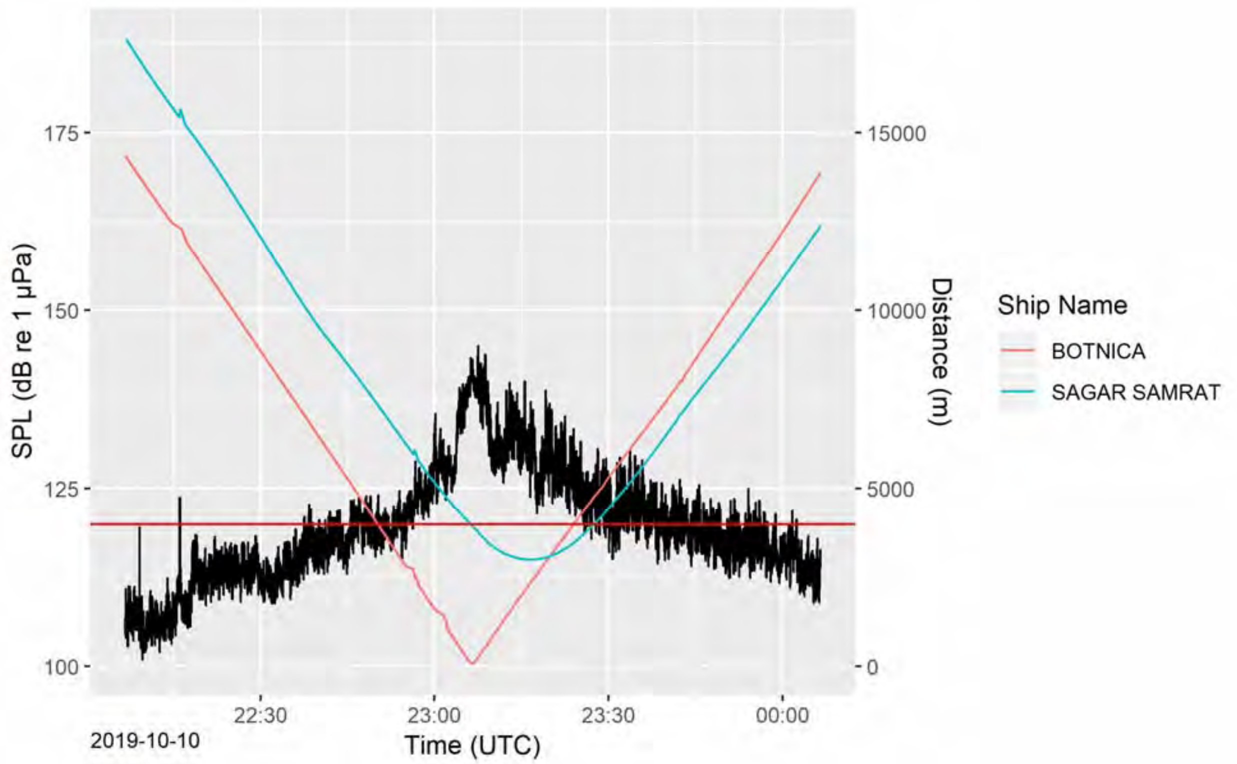


Figure B-3. AMAR-BI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 10 Oct 2019 leaving Milne Port, with 1 vessel in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

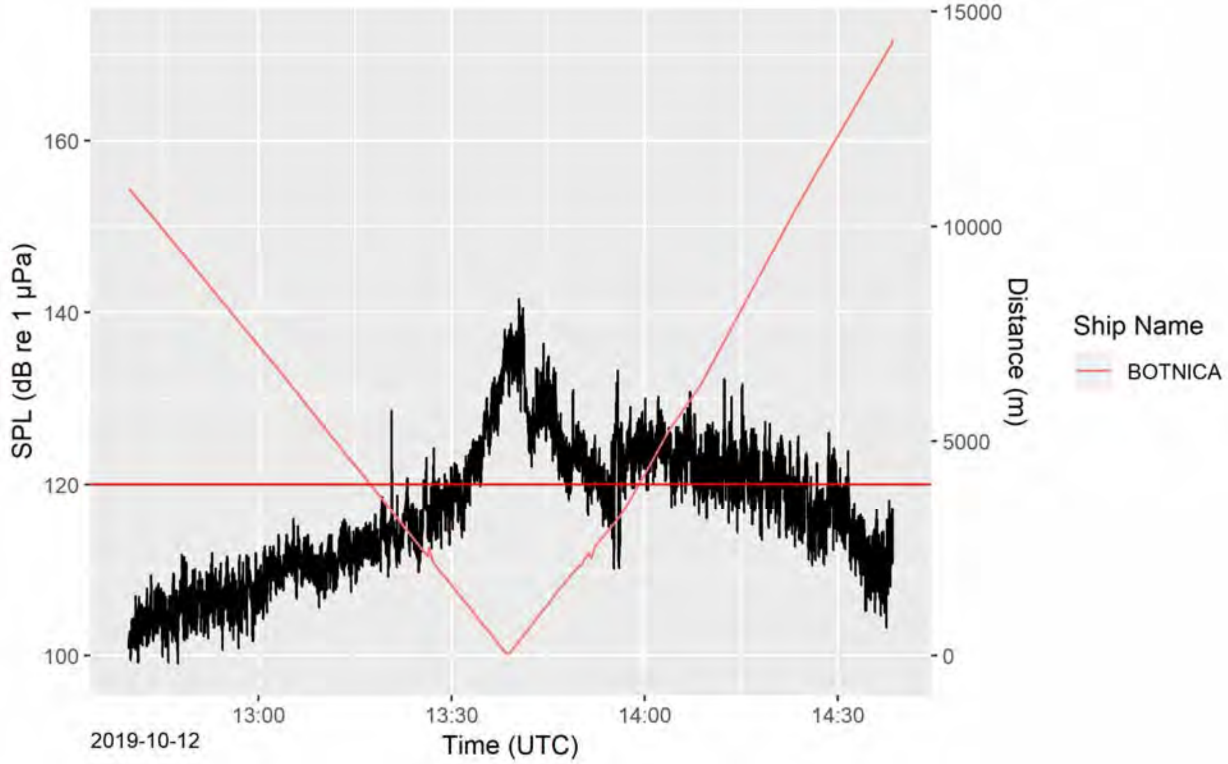


Figure B-4. AMAR-BI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 12 Oct 2019 coming to Milne Port, with no vessels in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

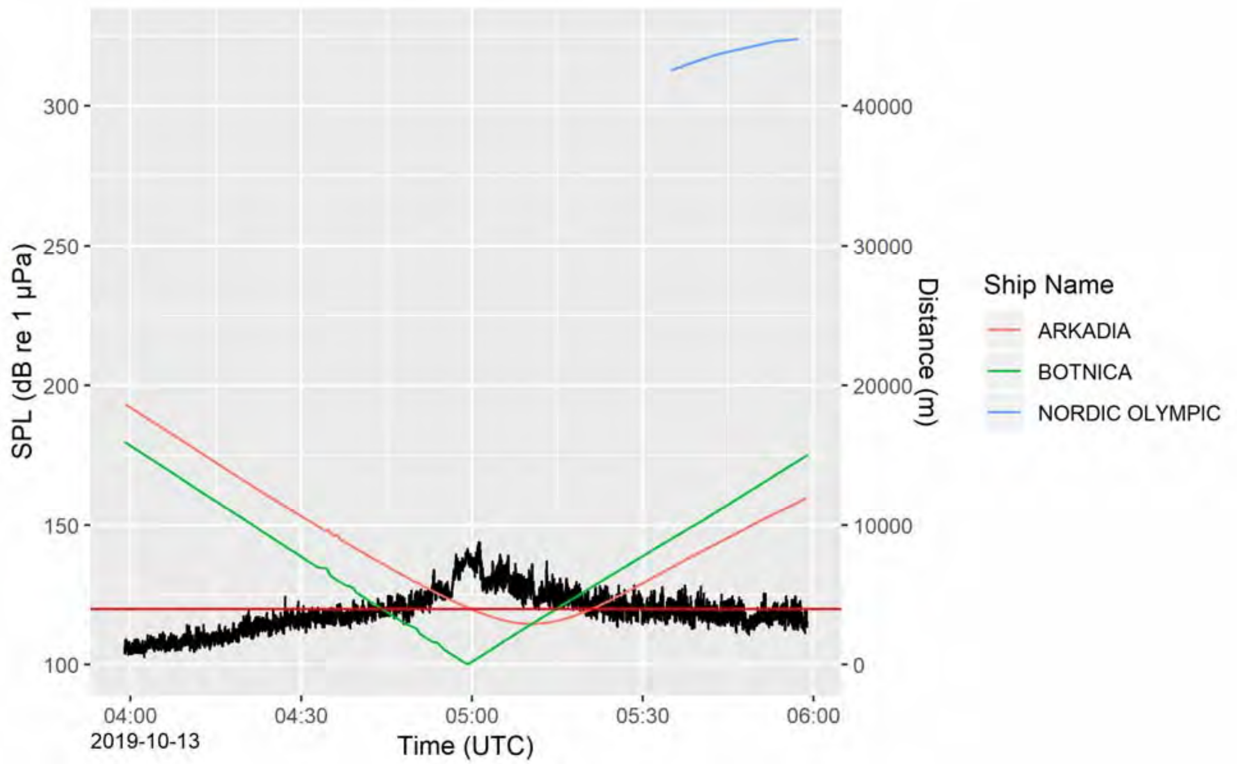


Figure B-5. AMAR-BI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 13 Oct 2019 leaving Milne Port, with 1 vessel in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

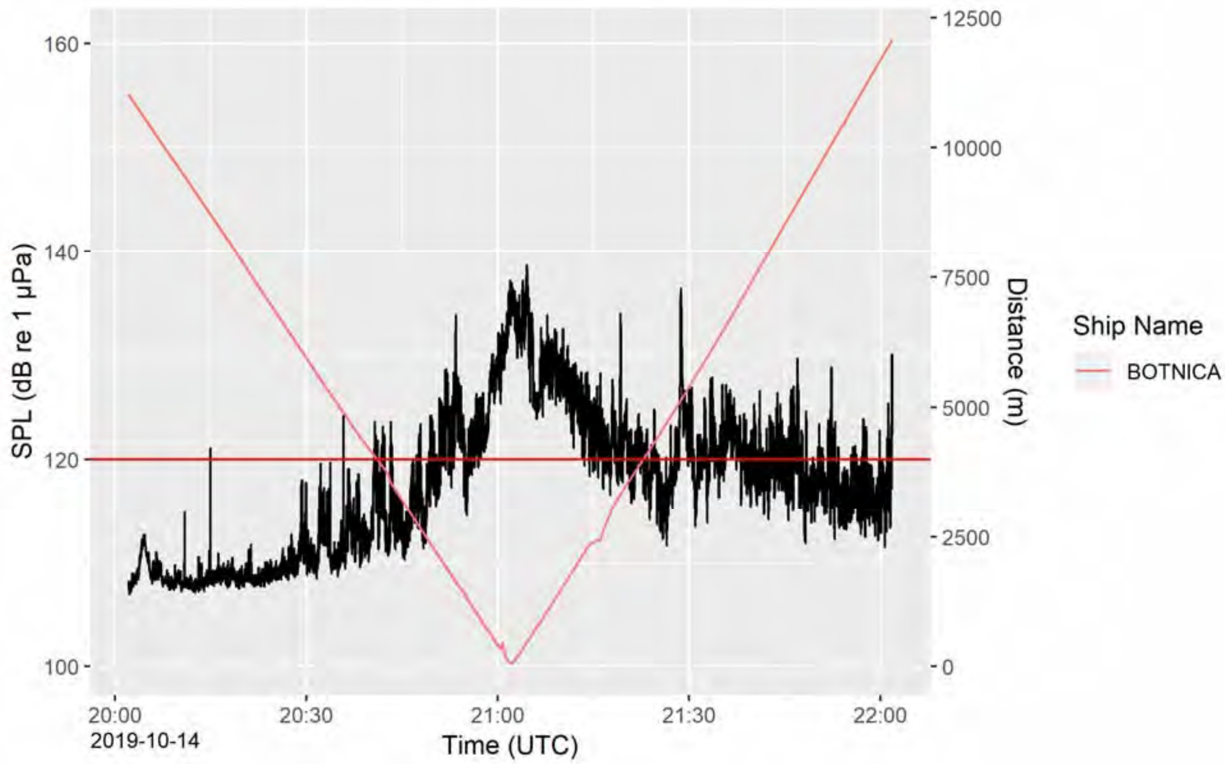


Figure B-6. AMAR-BI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 14 Oct 2019 coming to Milne Port, with no vessels in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

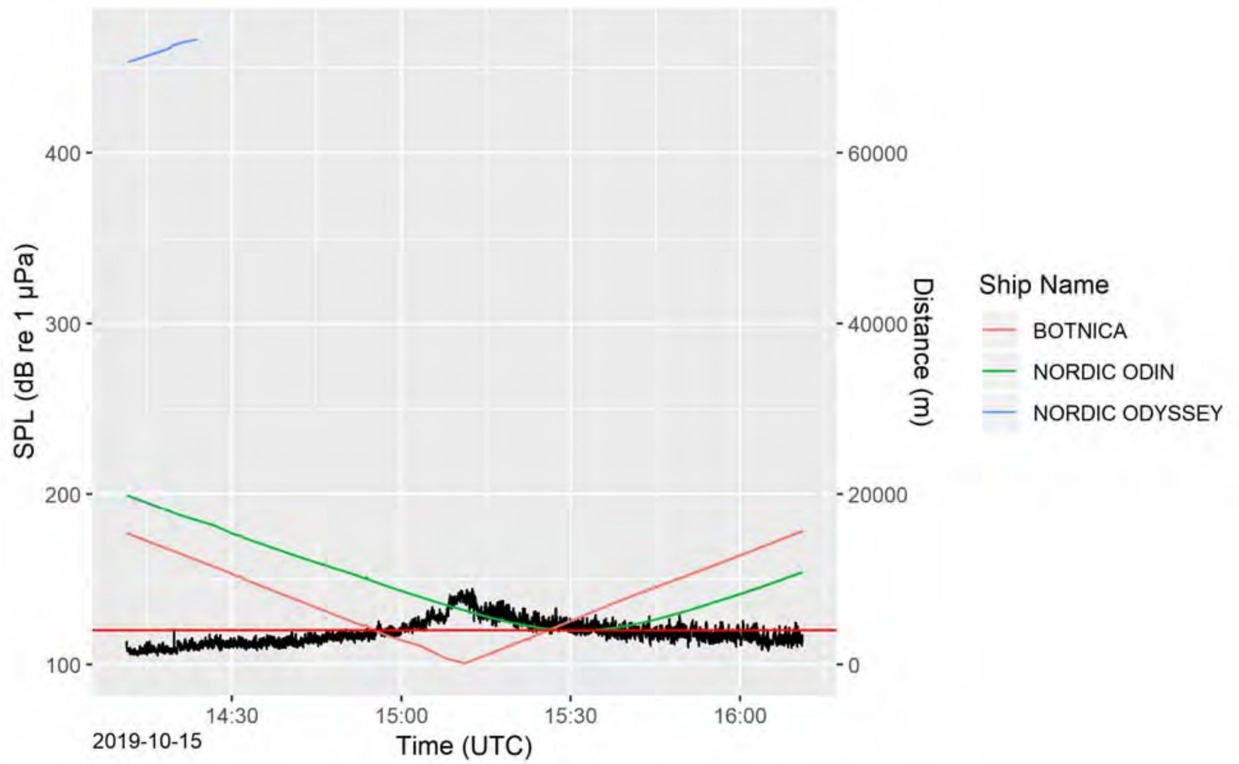


Figure B-7. AMAR-BI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 15 Oct 2019 leaving Milne Port, with 1 vessel in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

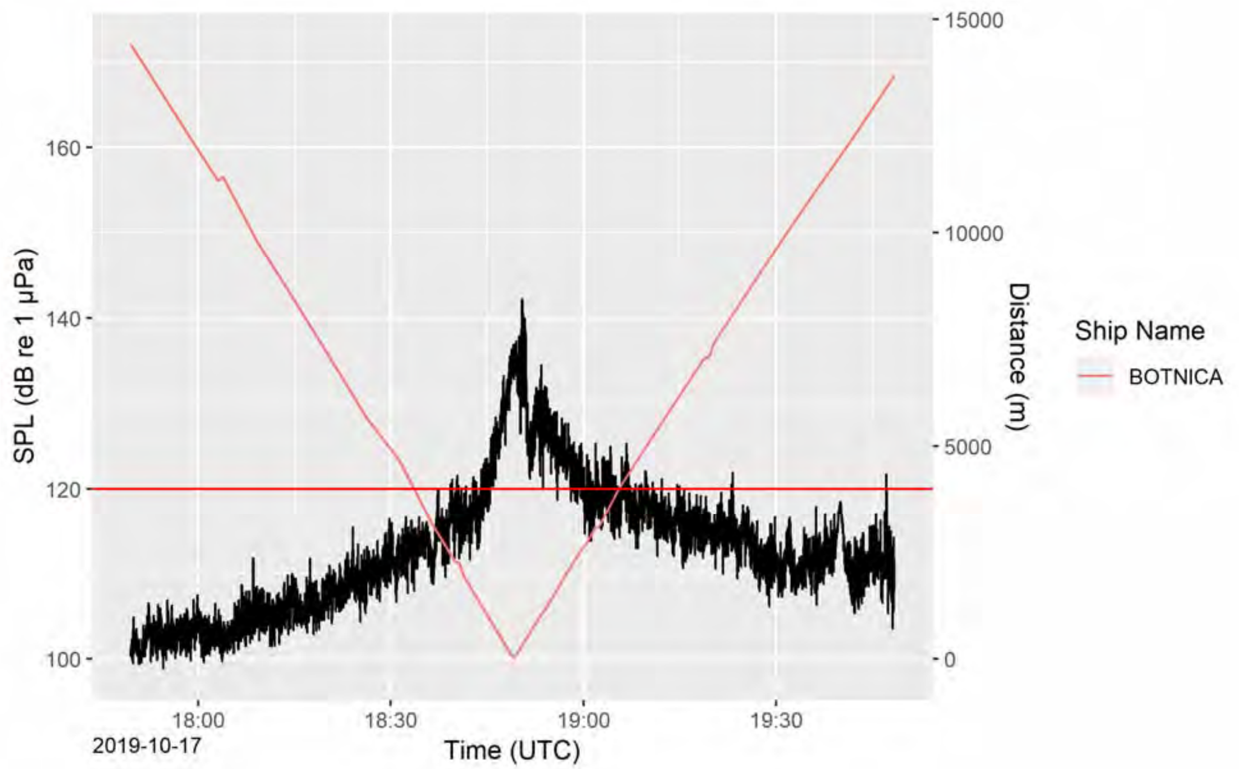


Figure B-8. AMAR-BI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 17 Oct 2019 coming to Milne Port, with no vessels in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

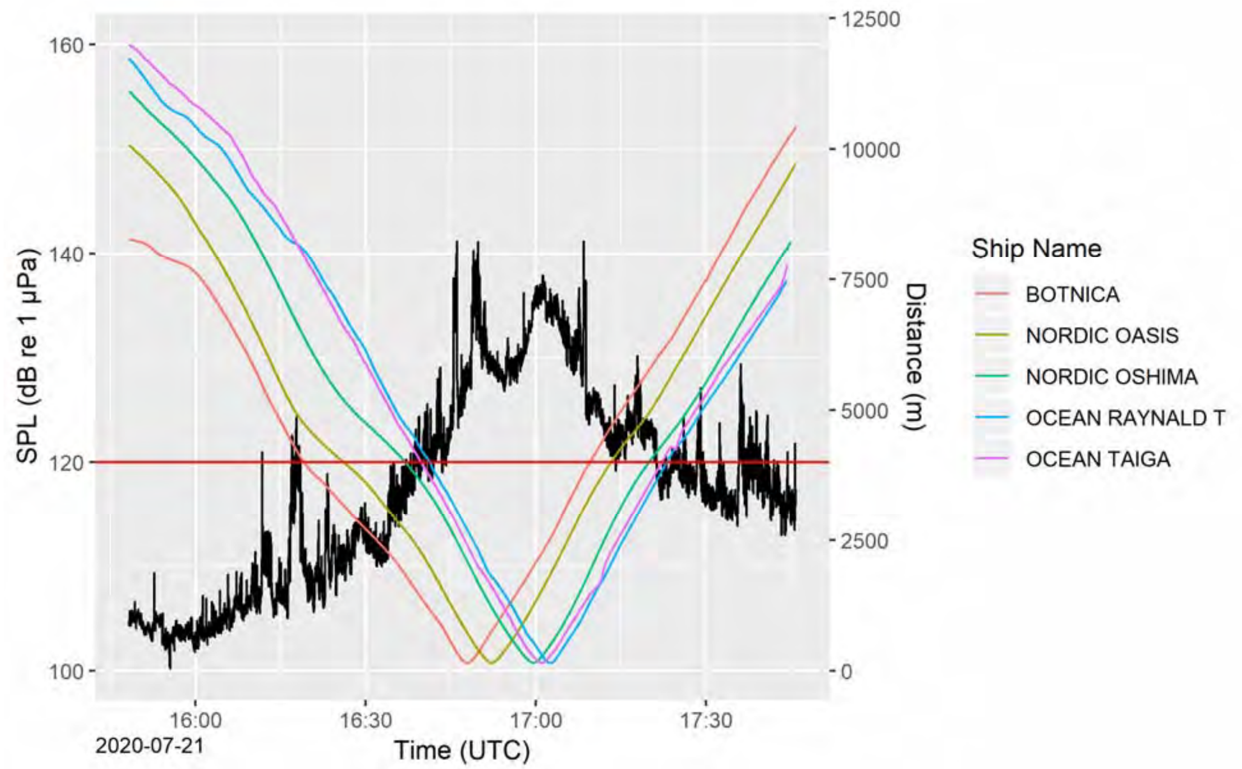


Figure B-9. AMAR-BI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 21 Jul 2020 coming to Milne Port, with 4 vessels in escort and 9/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

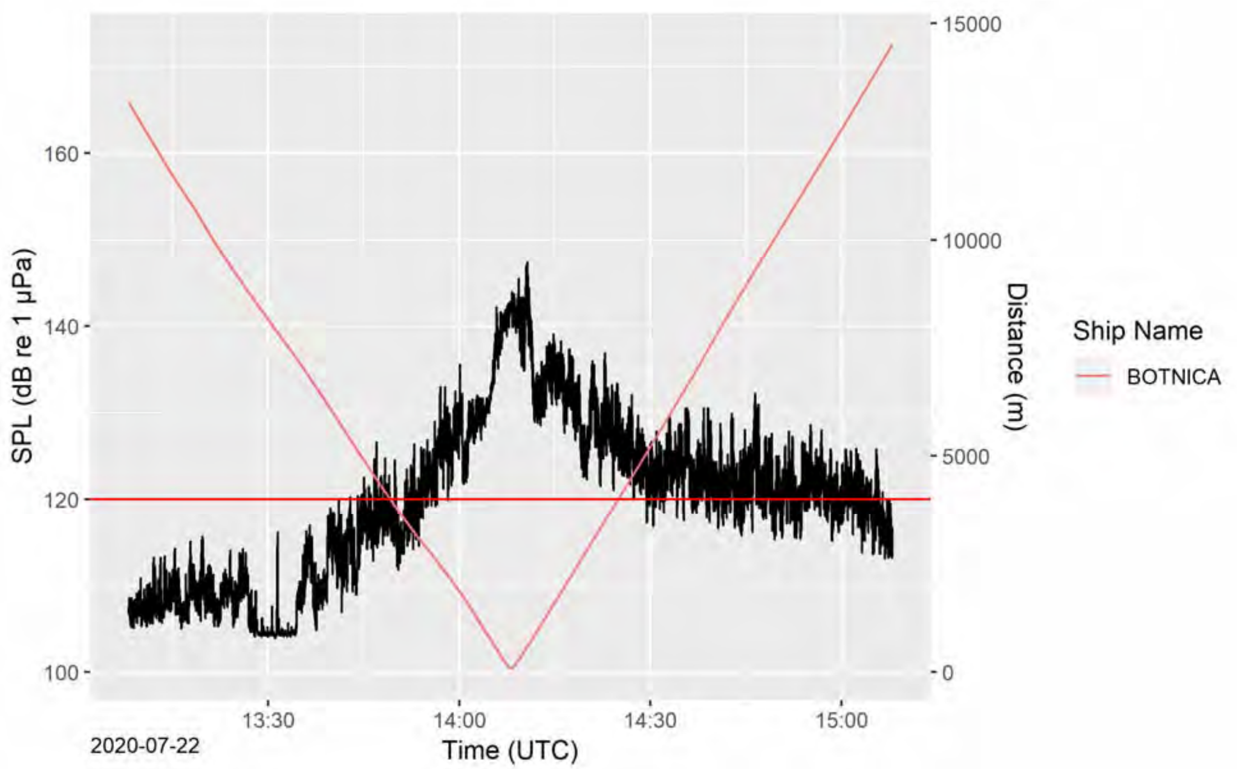


Figure B-10. AMAR-BI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 22 Jul 2020 leaving Milne Port, with no vessels in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

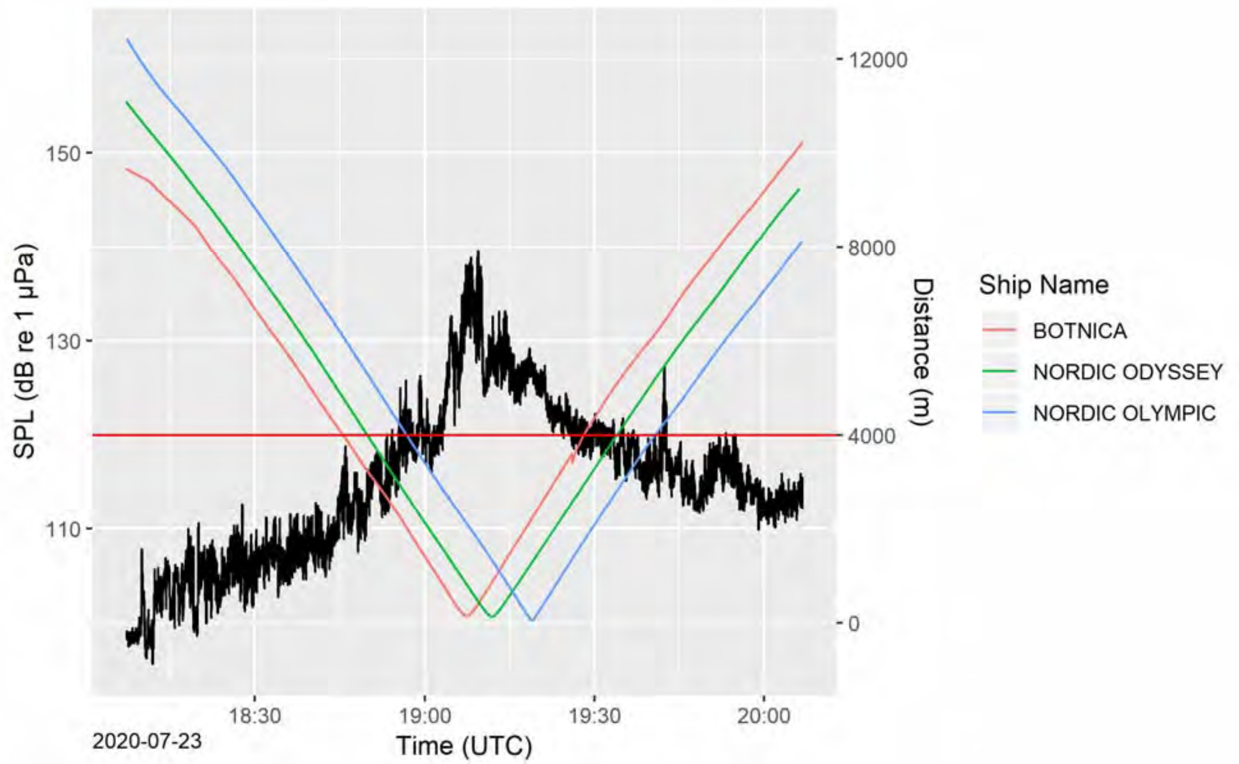


Figure B-11. AMAR-BI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 23 Jul 2020 coming to Milne Port, with 2 vessels in escort and 2/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

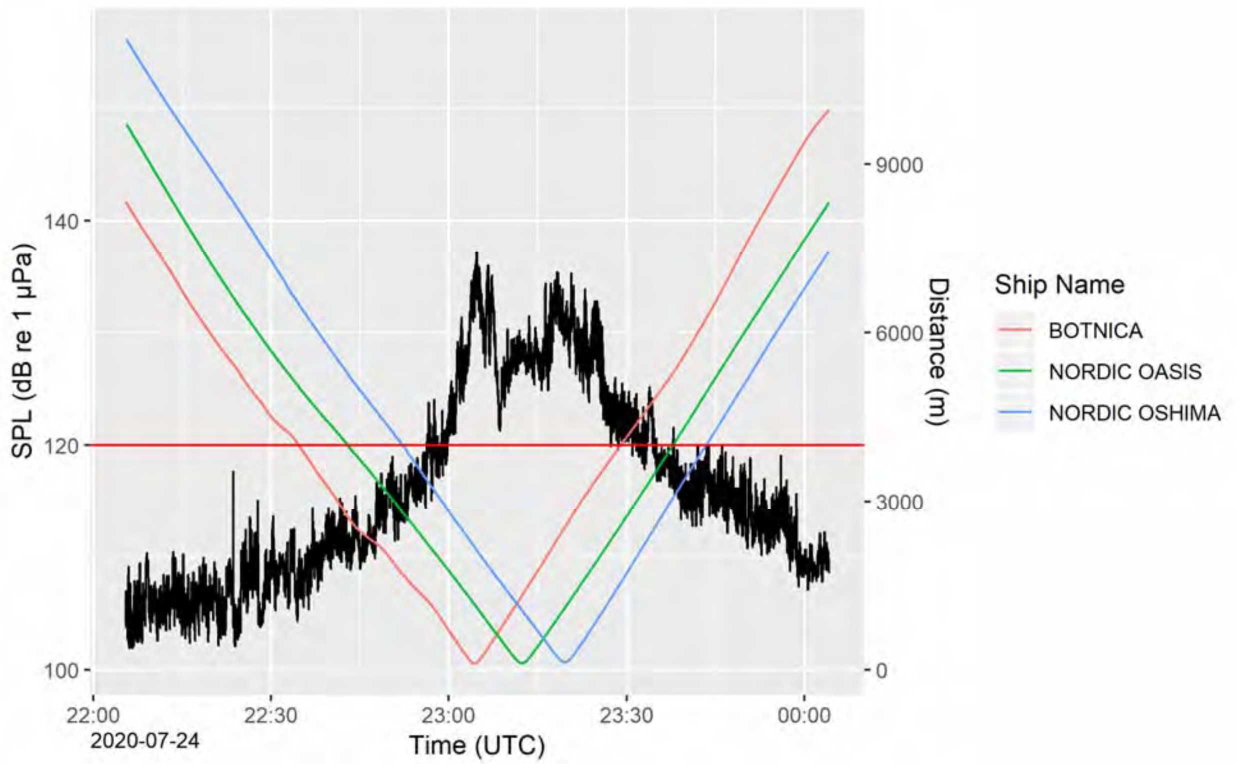


Figure B-12. AMAR-BI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 24 Jul 2020 leaving Milne Port, with 2 vessels in escort and 8/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

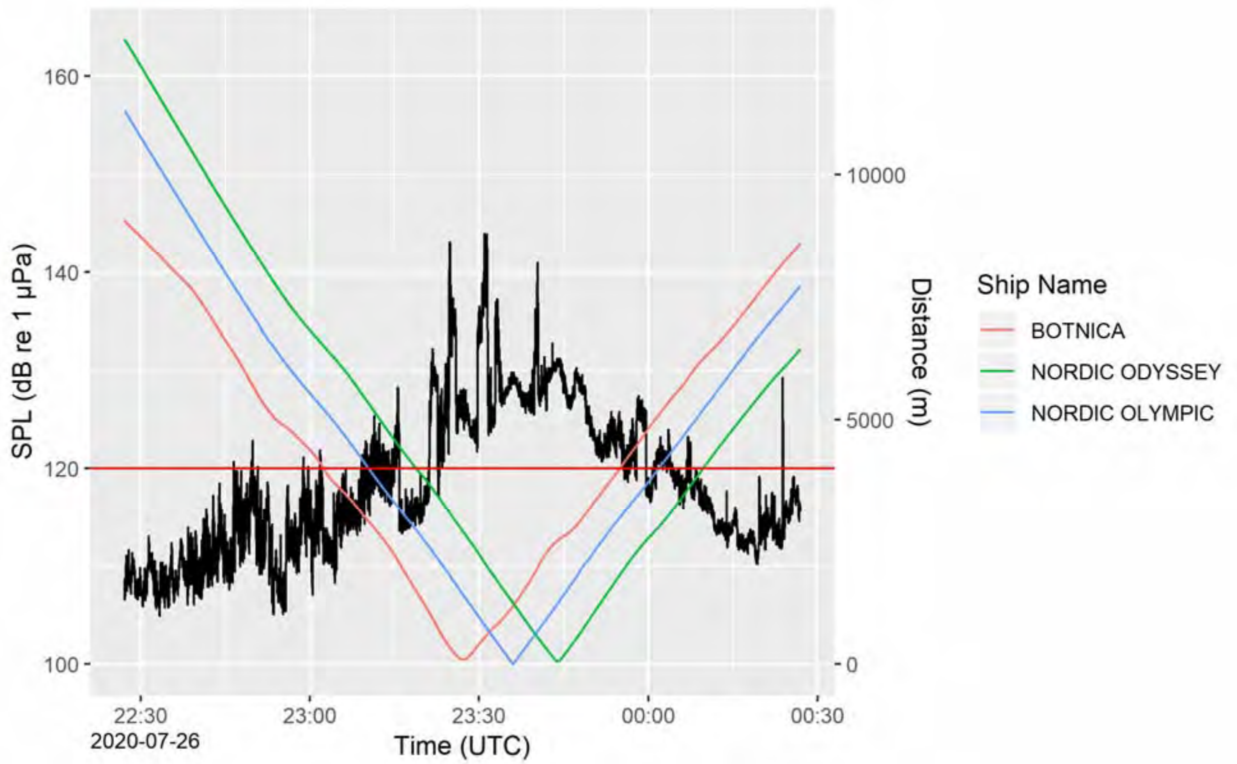


Figure B-13. AMAR-BI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 26 Jul 2020 leaving Milne Port, with 2 vessels in escort and 8/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

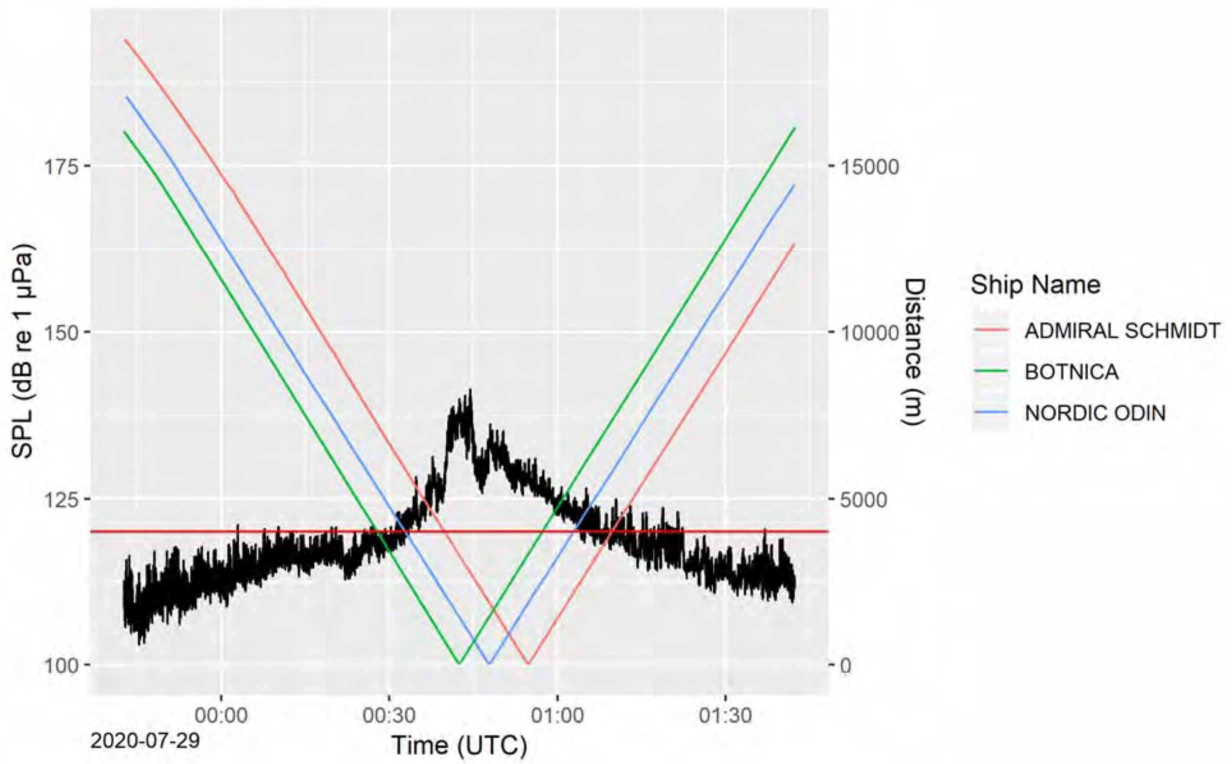


Figure B-14. AMAR-BI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 29 Jul 2020 leaving Milne Port, with 2 vessels in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

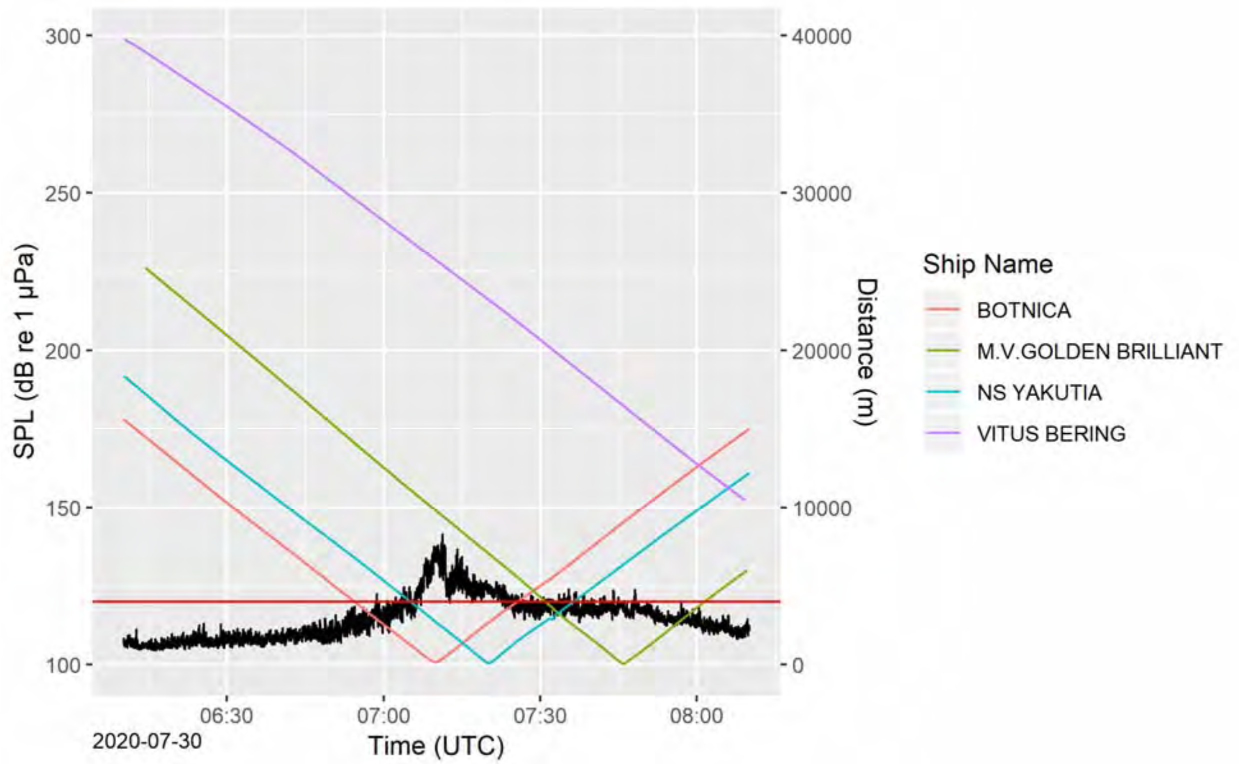


Figure B-15. AMAR-BI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 30 Jul 2020 coming to Milne Port, with 2 vessels in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

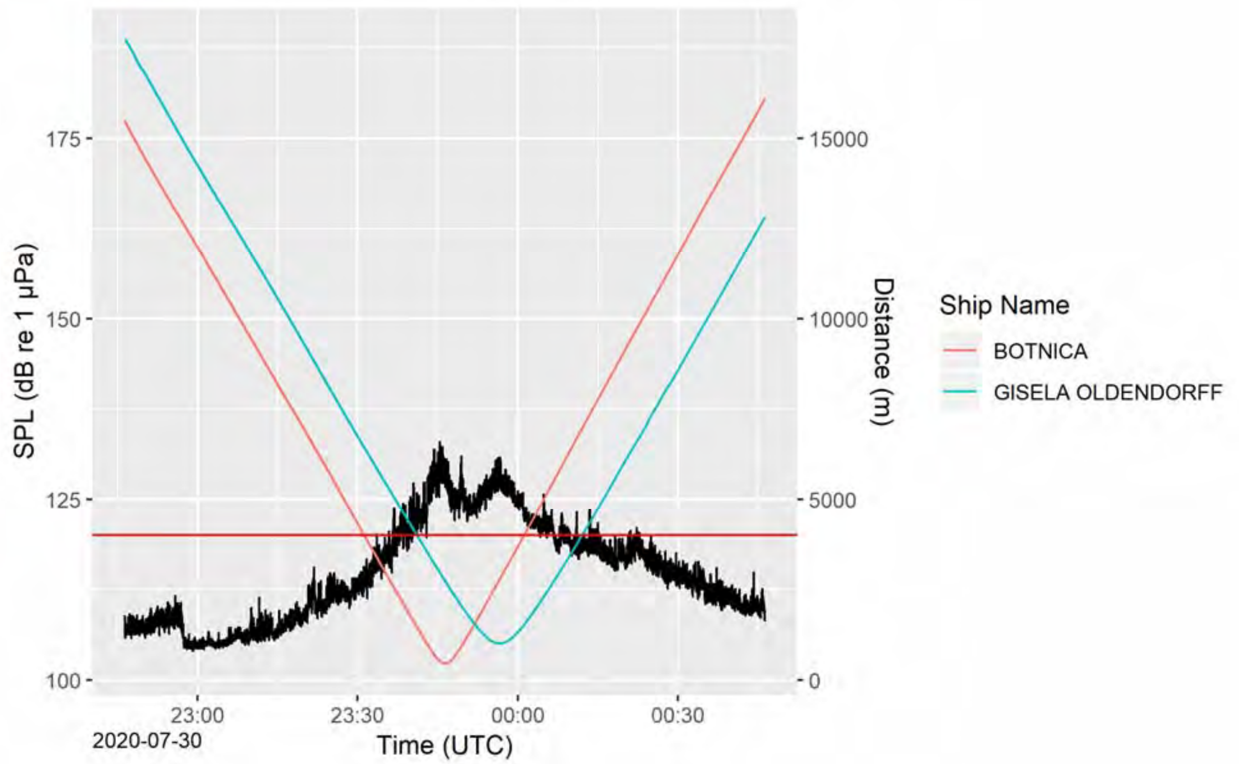


Figure B-16. AMAR-BI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 30 Jul 2020 leaving Milne Port, with 1 vessel in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

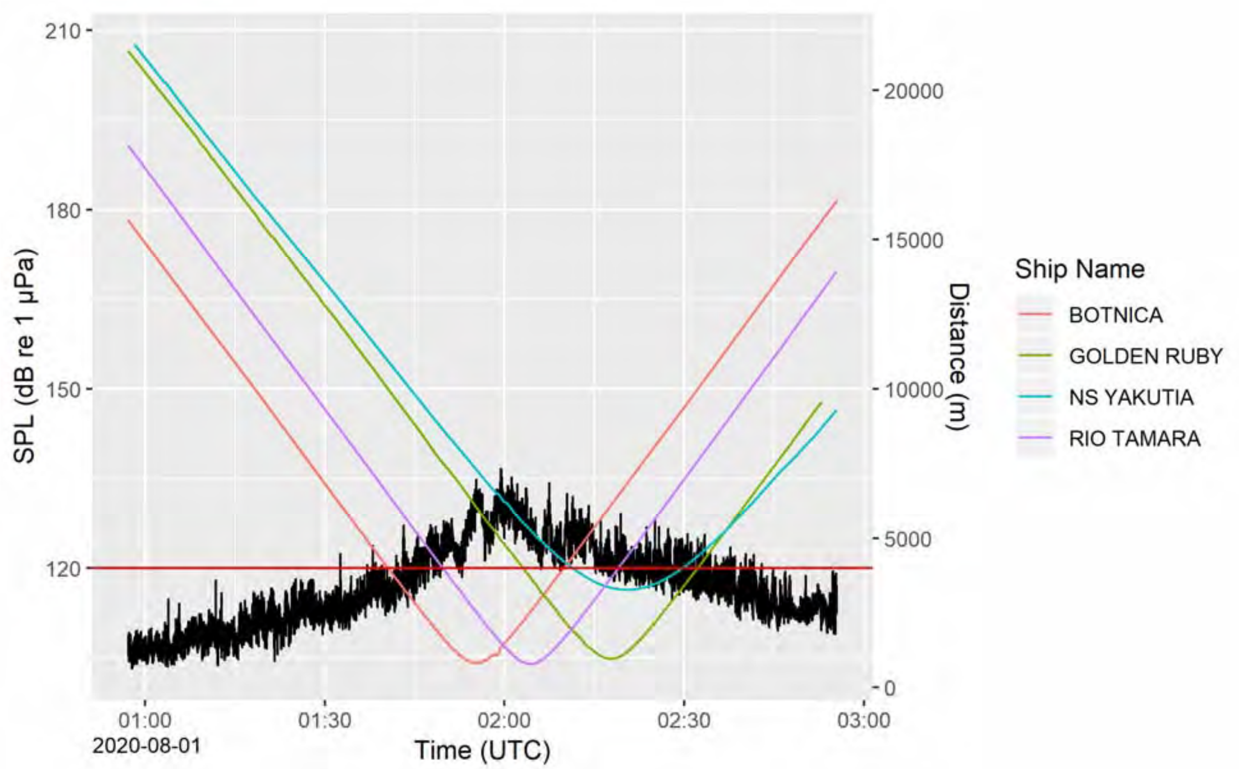


Figure B-17. AMAR-BI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 1 Aug 2020 coming to Milne Port, with 3 vessels in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

B.2. AMAR-RI

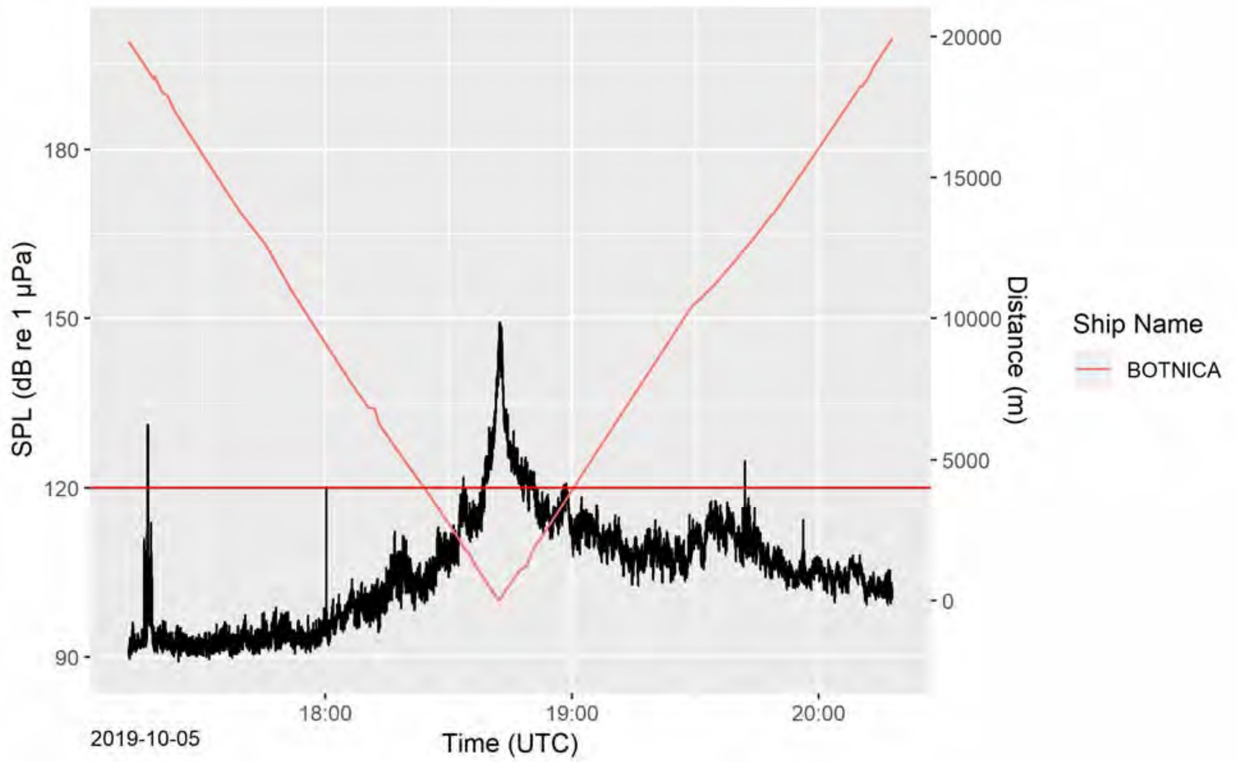


Figure B-18. AMAR-RI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 05 Oct 2019 leaving Milne Port, with no vessels in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

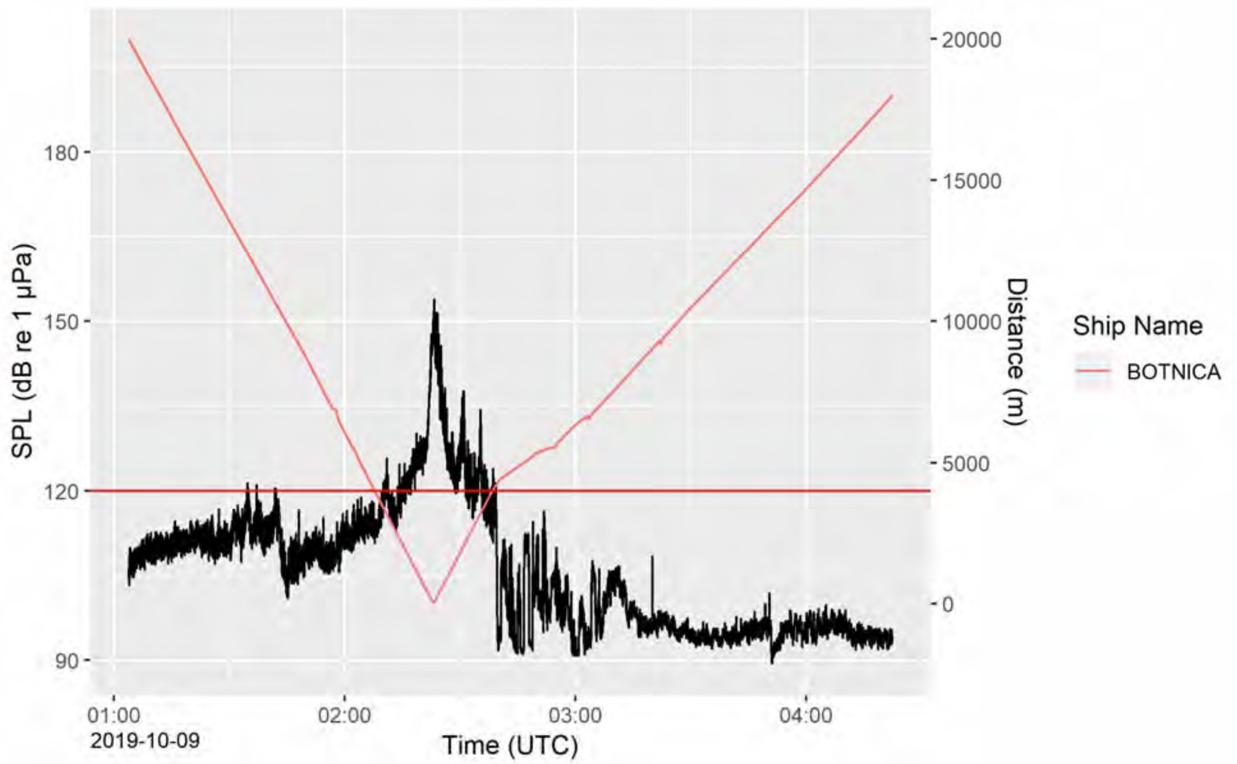


Figure B-19. AMAR-RI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 9 Oct 2019 coming to Milne Port, with no vessels in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

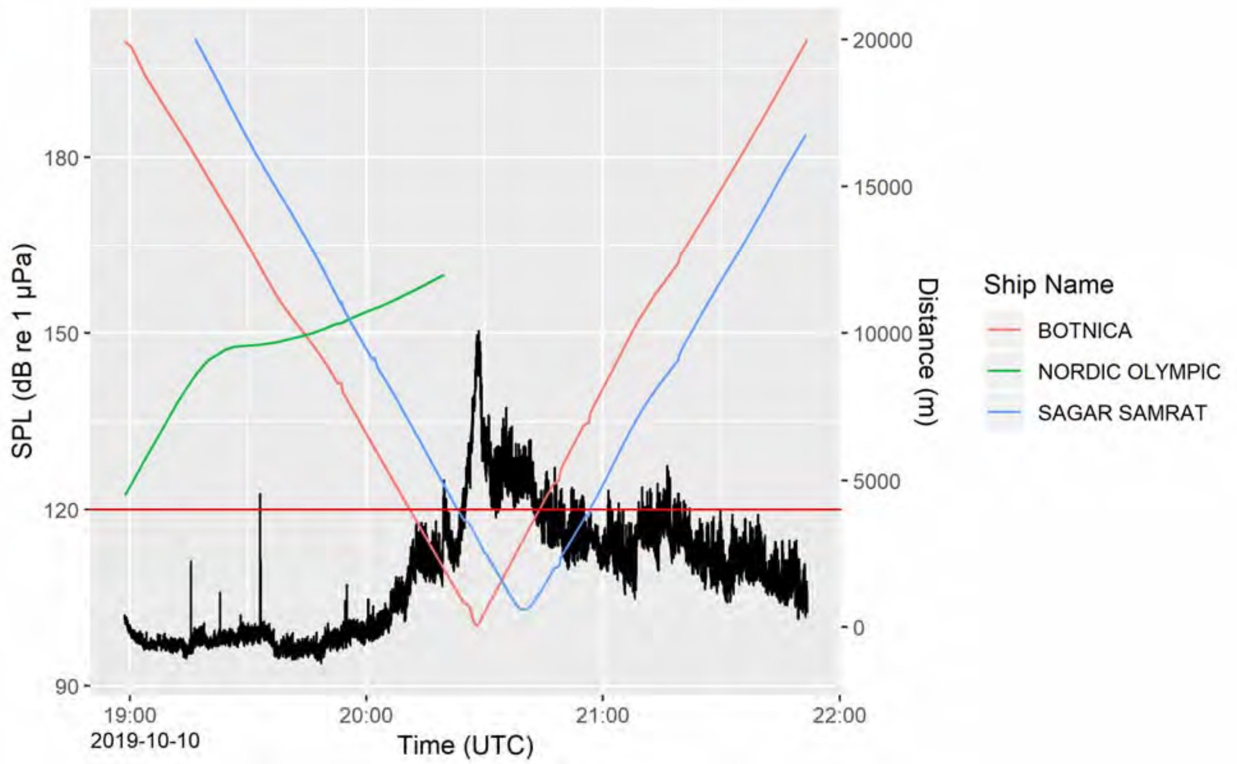


Figure B-20. AMAR-RI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 10 Oct 2019 leaving Milne Port, with 1 vessel in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

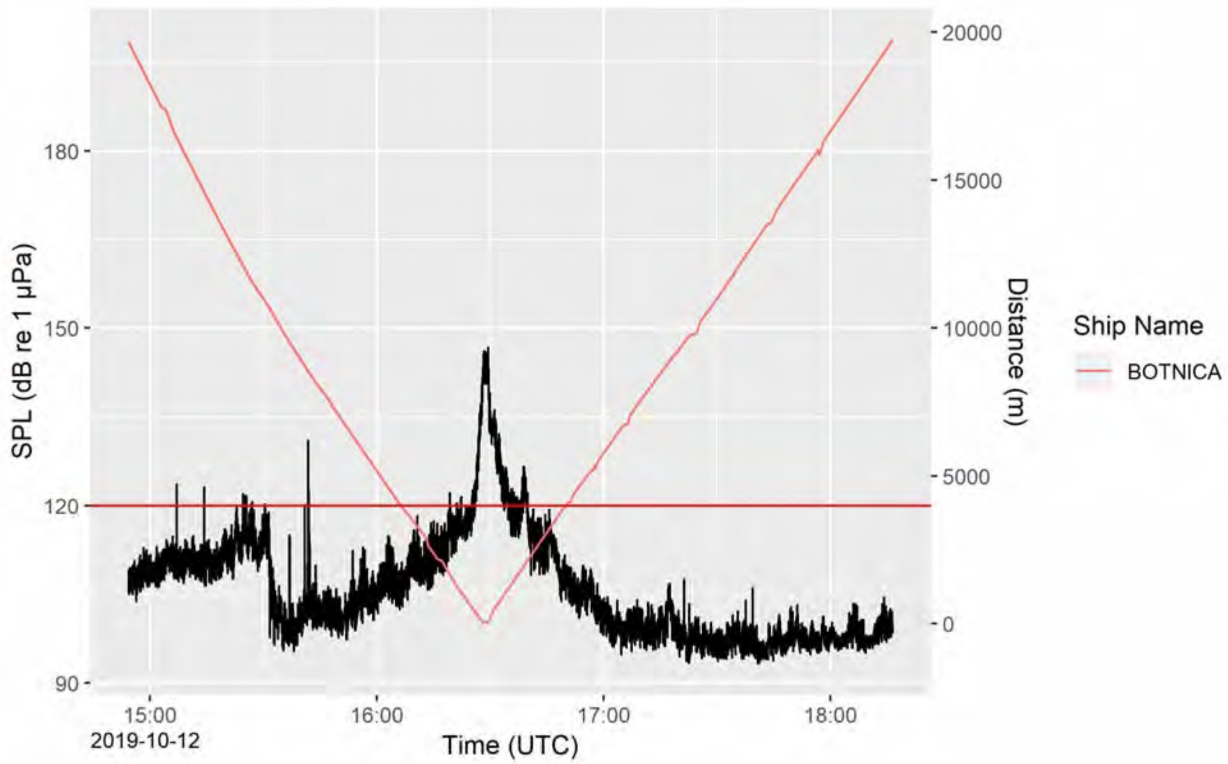


Figure B-21. AMAR-RI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 12 Oct 2019 coming to Milne Port, with no vessels in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

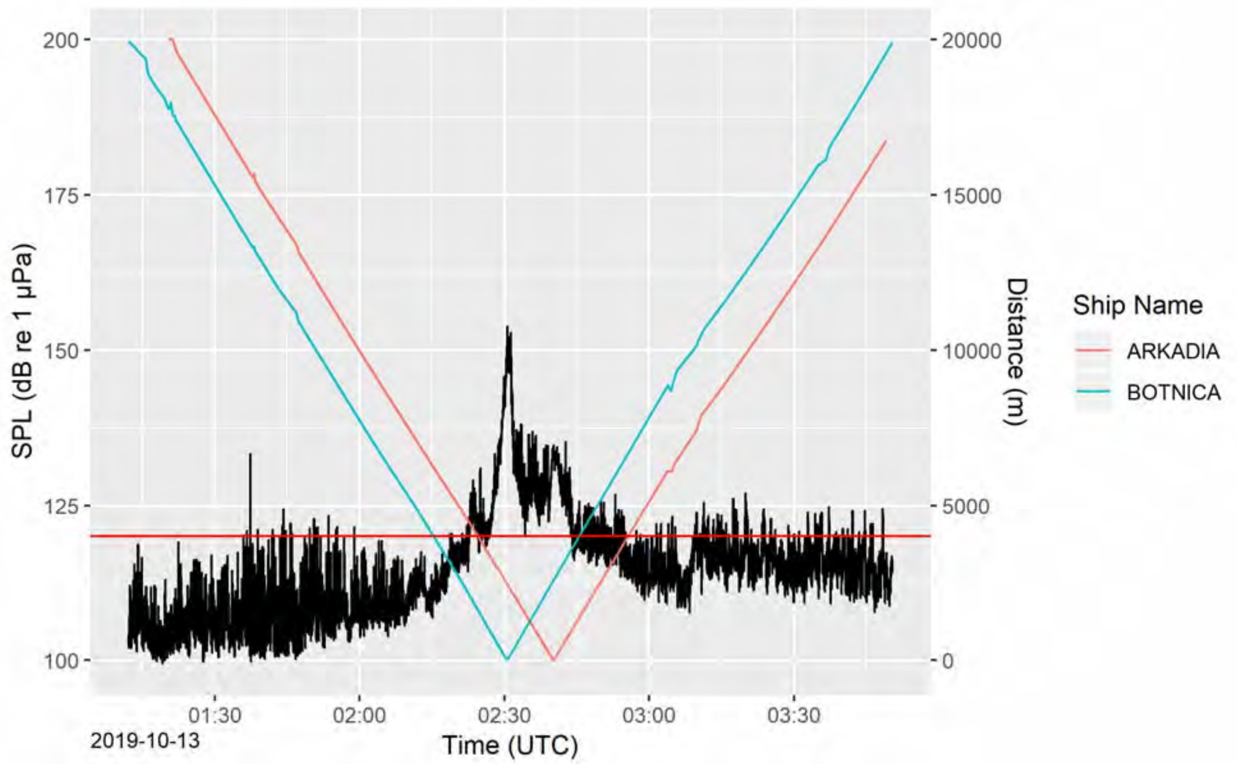


Figure B-22. AMAR-RI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 13 Oct 2019 leaving Milne Port, with 1 vessel in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

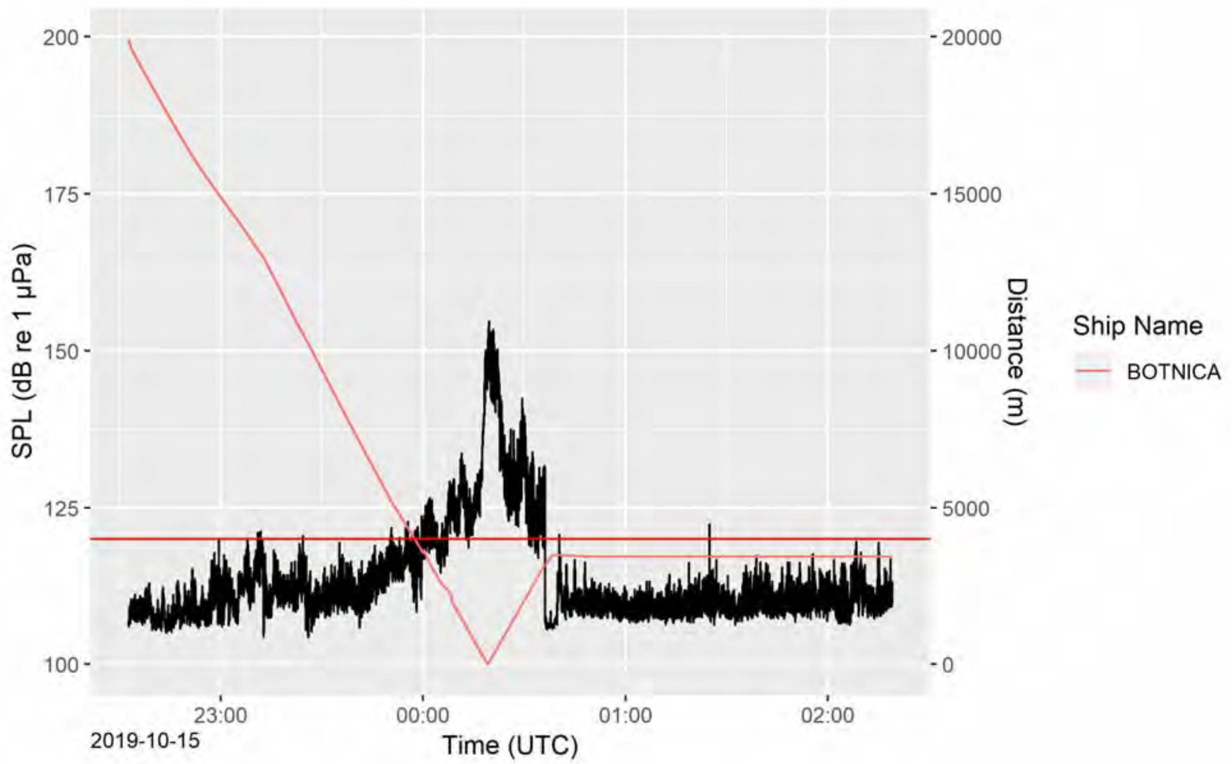


Figure B-23. AMAR-RI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 15 Oct 2019 coming to Milne Port, with no vessels in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

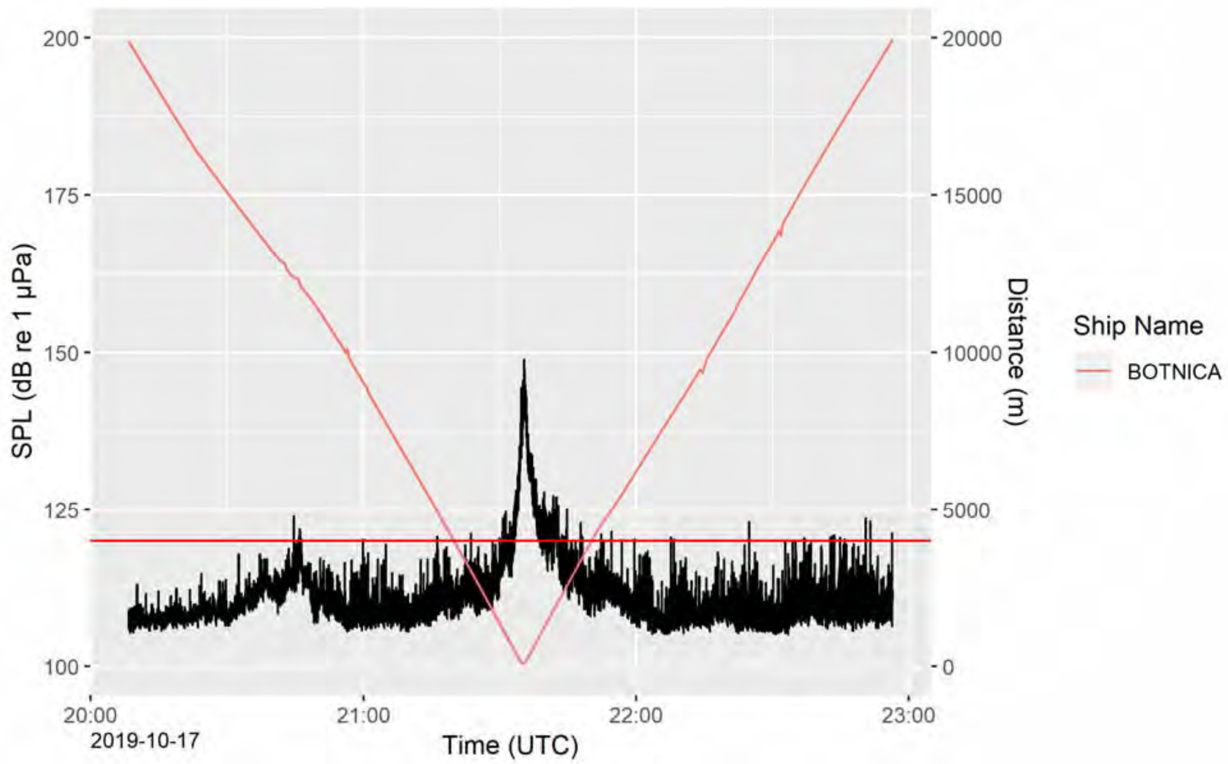


Figure B-24. AMAR-RI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 17 Oct 2019 coming to Milne Port, with no vessels in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance.

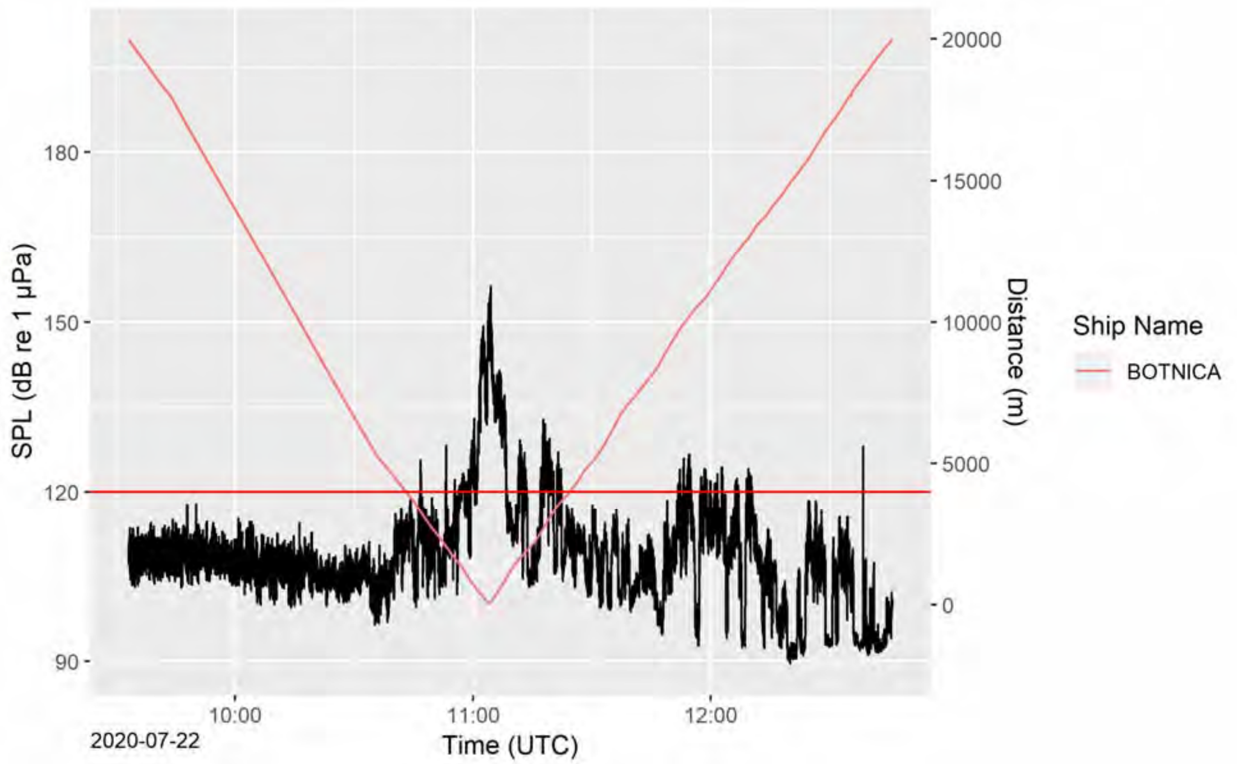


Figure B-25. AMAR-RI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 22 Jul 2020 leaving Milne Port, with no vessels in escort and 9/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance

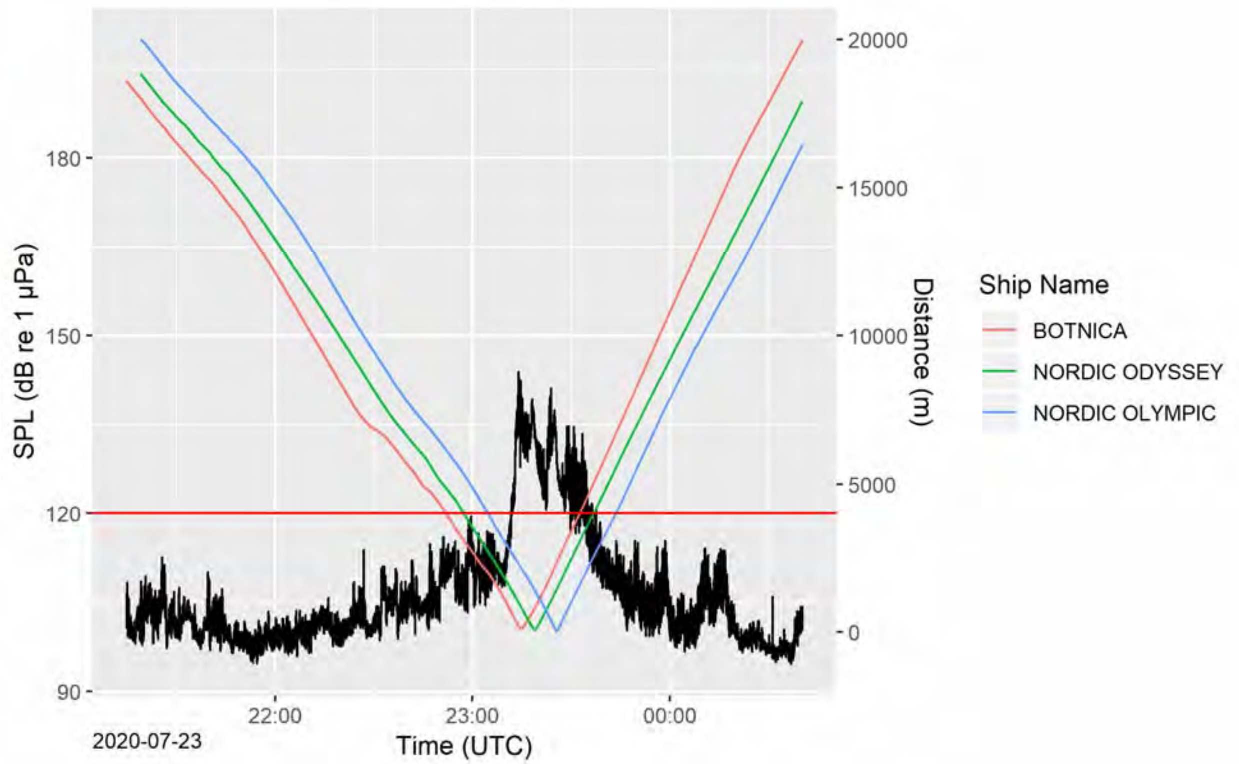


Figure B-26. AMAR-RI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 23 Jul 2020 coming to Milne Port, with 2 vessels in escort and 2/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance

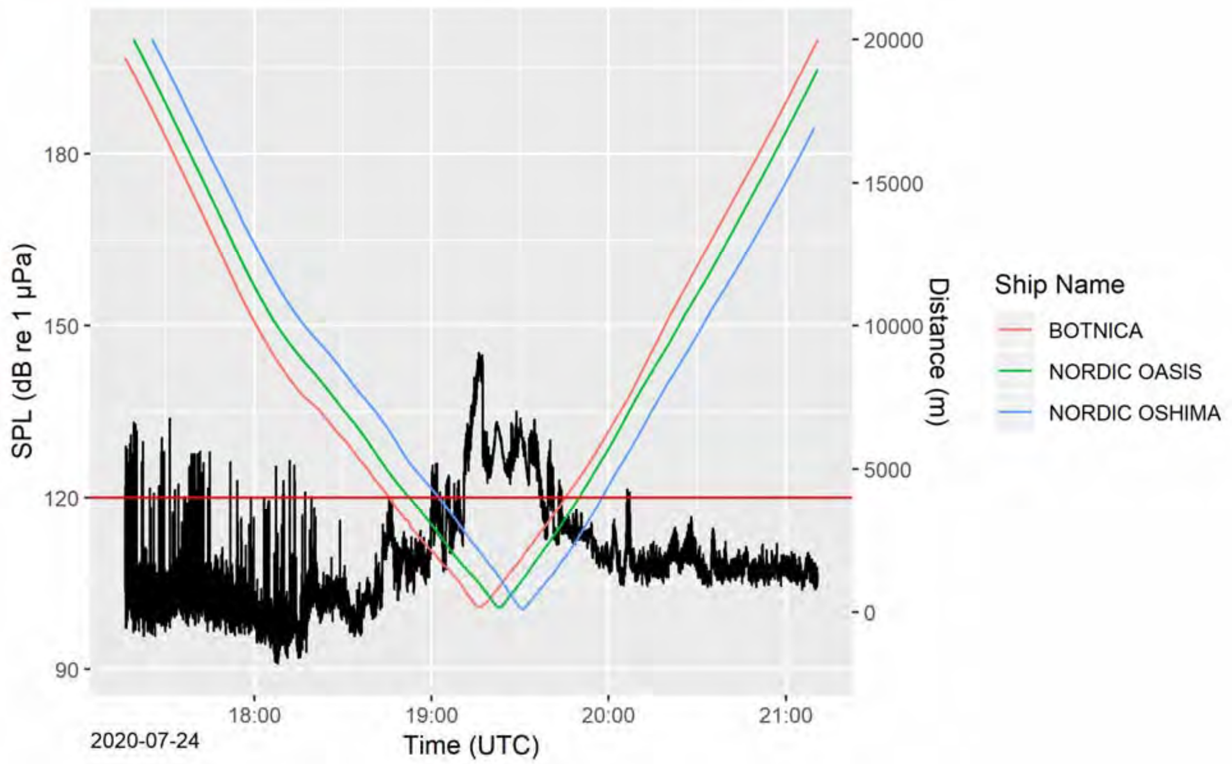


Figure B-27. AMAR-RI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 24 Jul 2020 leaving Milne Port, with 2 vessels in escort and 8/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance

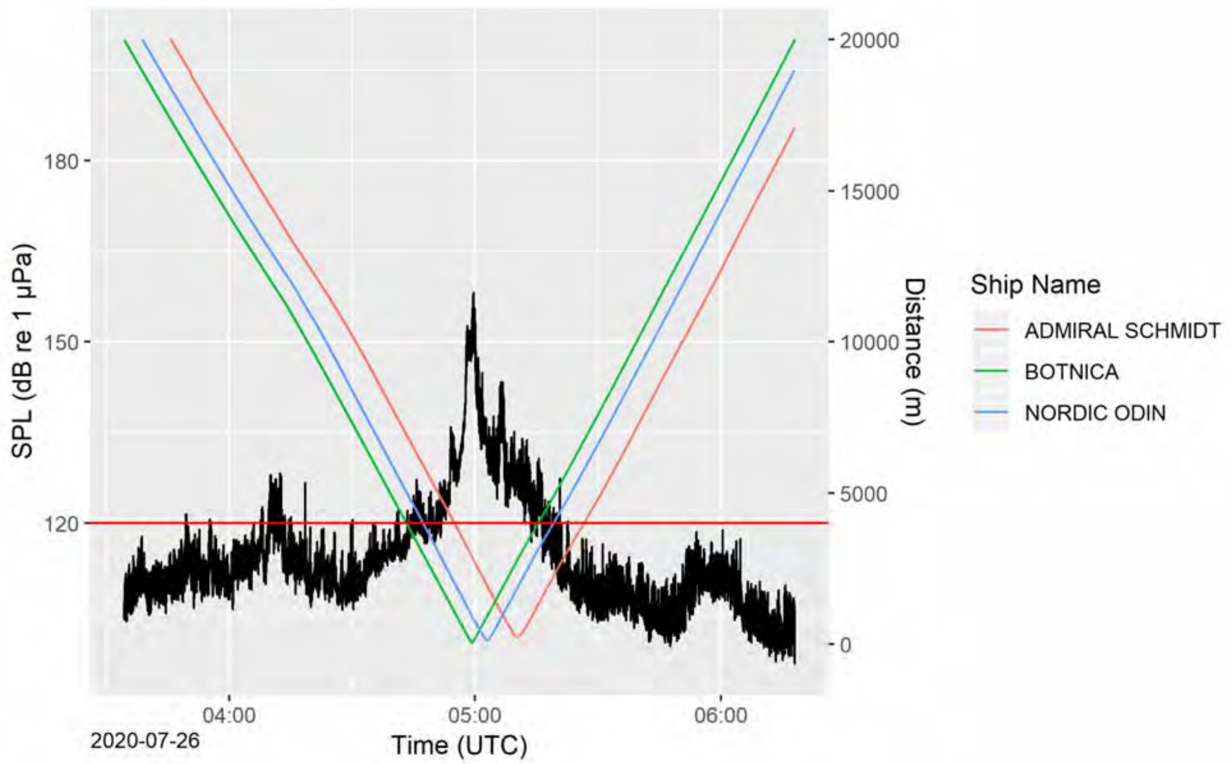


Figure B-28. AMAR-RI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 26 Jul 2020 coming to Milne Port, with 2 vessels in escort and 5/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance

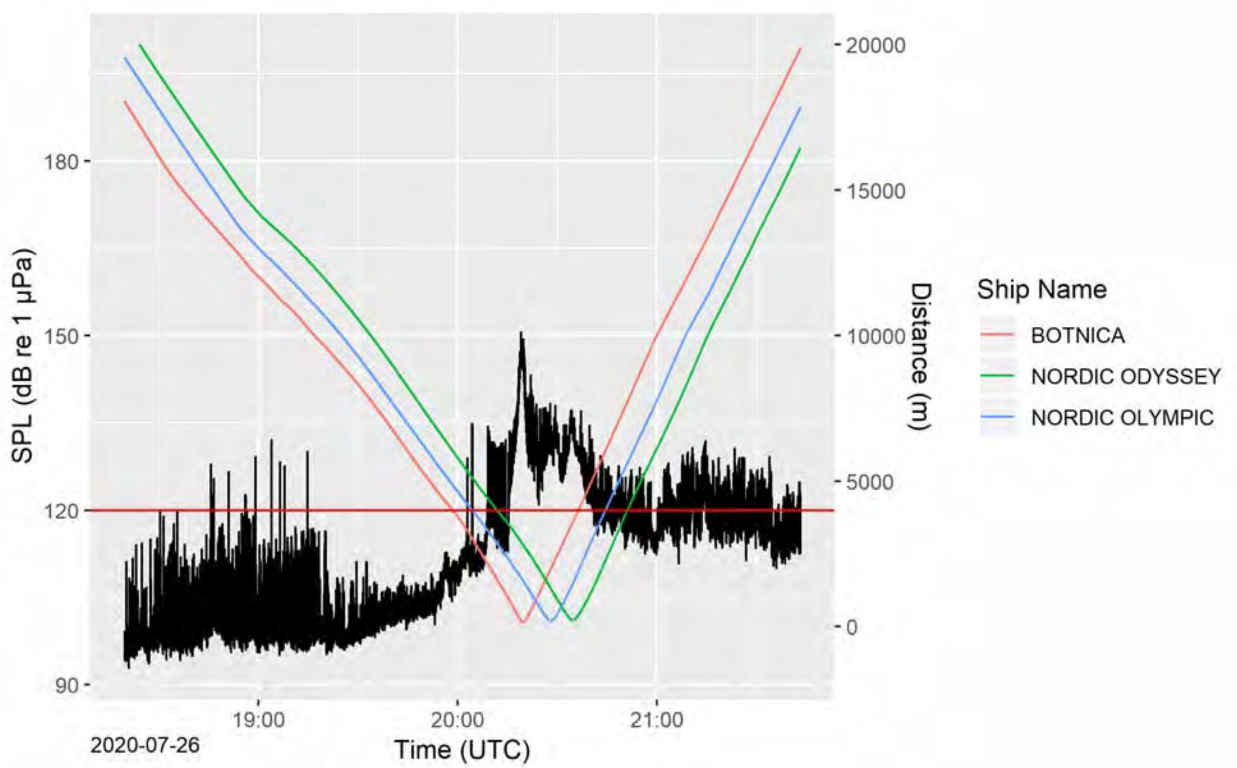


Figure B-29. AMAR-RI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 26 Jul 2020 leaving Milne Port, with 2 vessels in escort and 5/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance

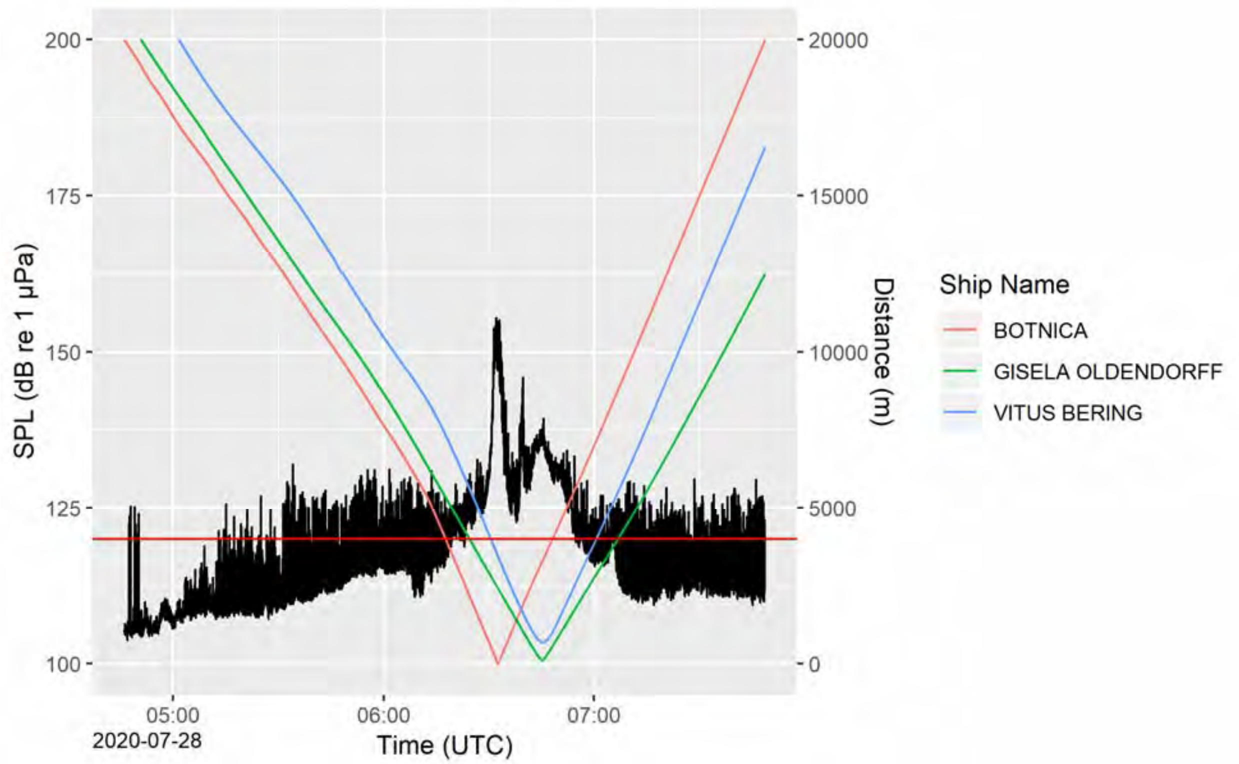


Figure B-30. AMAR-RI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 28 Jul 2020 coming to Milne Port, with 2 vessels in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance

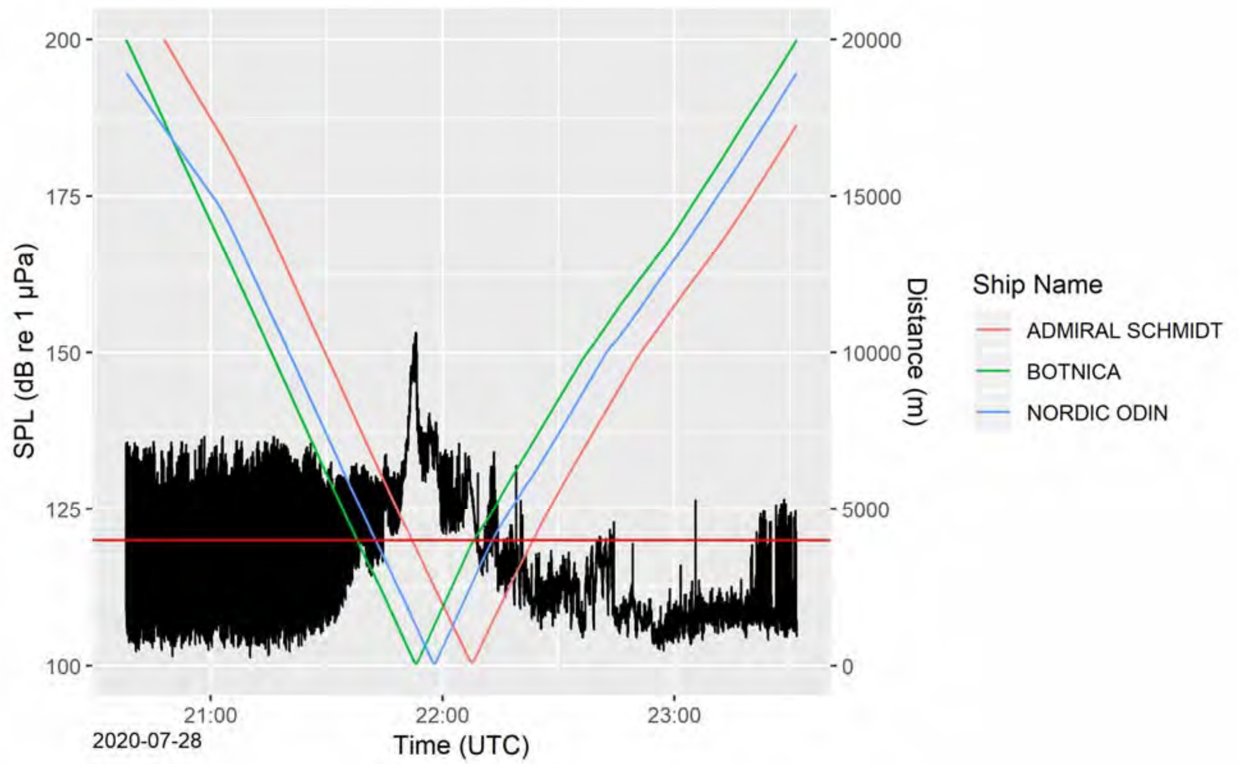


Figure B-31. AMAR-RI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 28 Jul 2020 leaving Milne Port, with 2 vessels in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance

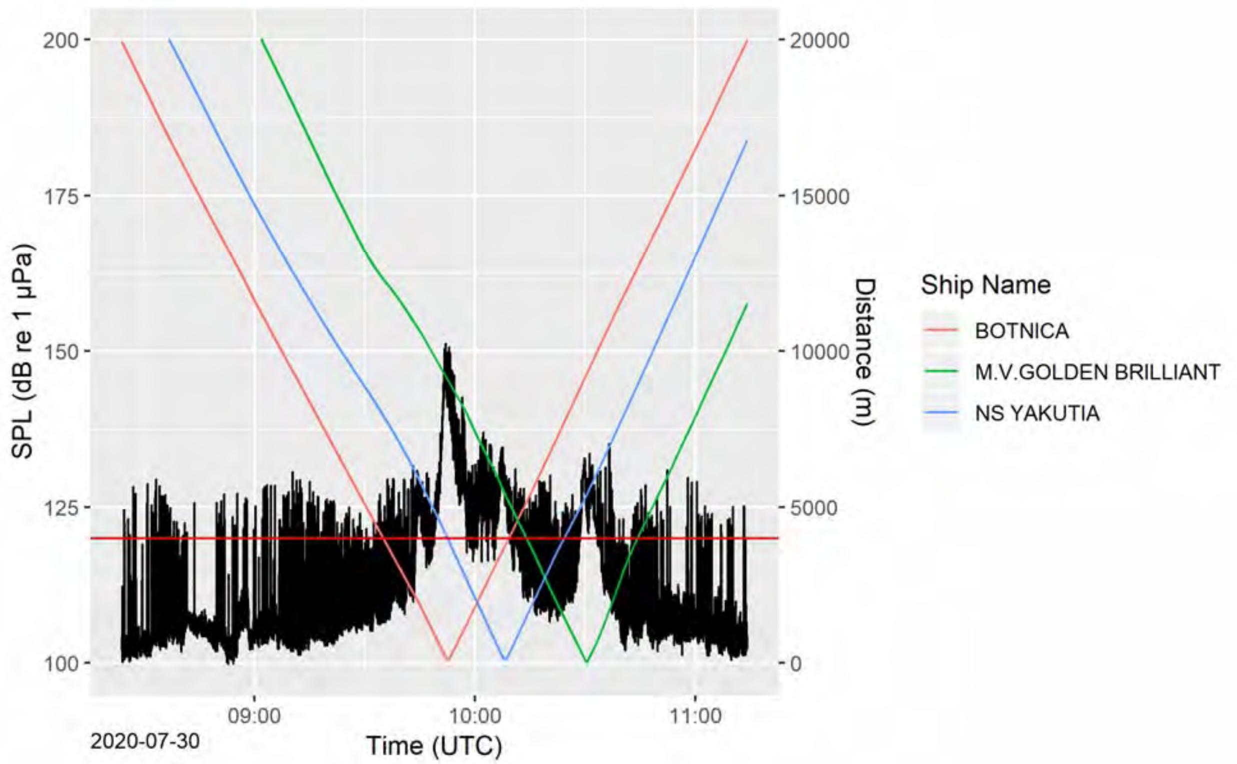


Figure B-32. AMAR-RI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 30 Jul 2020 coming to Milne Port, with 2 vessels in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance

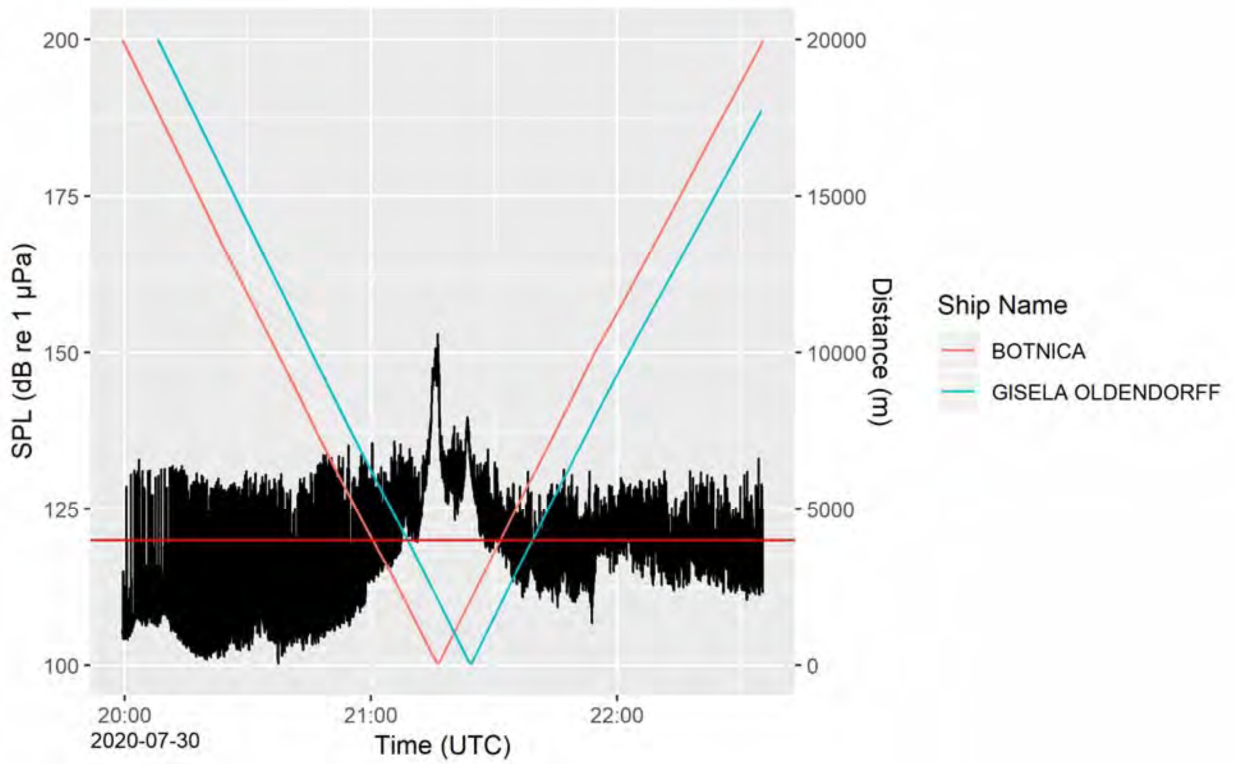


Figure B-33. AMAR-RI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 30 Jul 2020 leaving Milne Port, with 1 vessels in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance

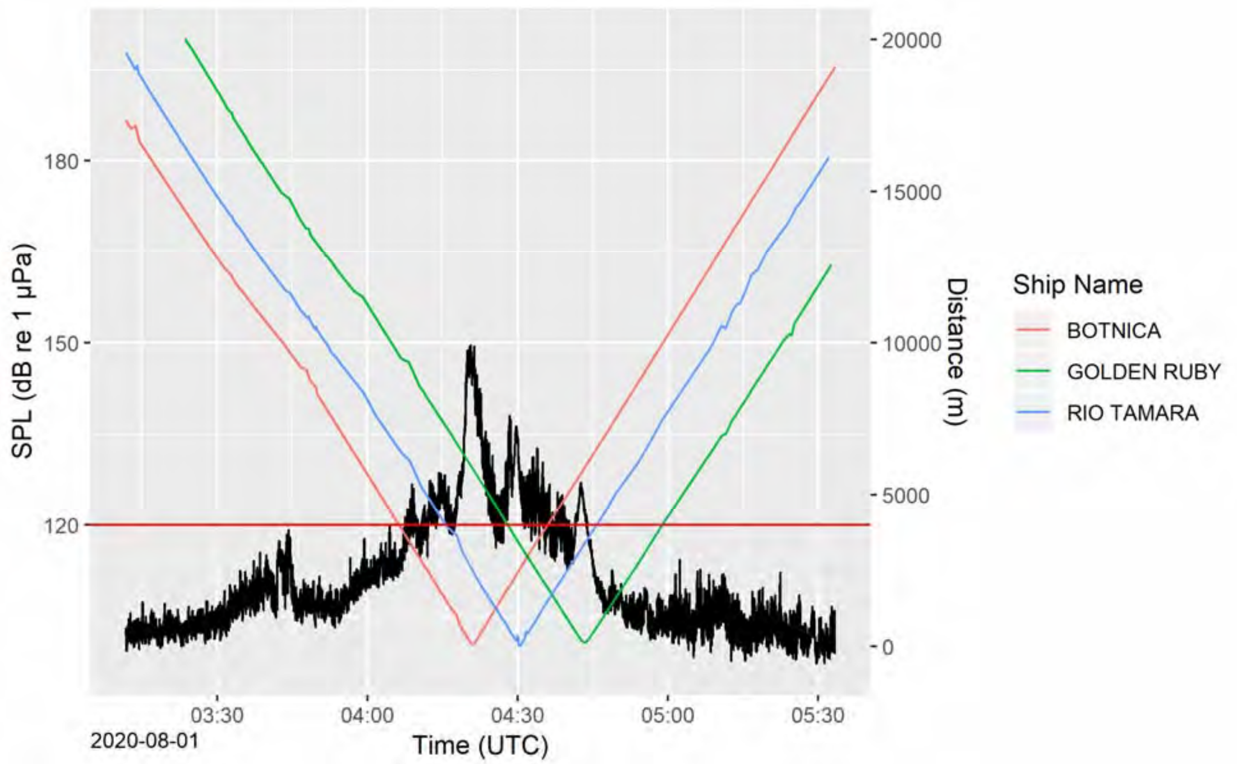


Figure B-34. AMAR-RI: SPL (left axis) as a function of time recorded while MSV *Botnica* transited through Eclipse Sound on 1 Aug 2020 coming to Milne Port, with 2 vessels in escort and 0/10 ice concentration. The distances (right axis) between the vessels and the AMAR is are plotted with color-coded lines. A solid red horizontal line marks the 120 dB re 1 µPa SPL threshold for behavioural disturbance

Appendix C. Spectrogram and Band Level Plots per Transit

This Appendix contains plots showing the spectrogram and band level data generated from 1-minute averaged SPL for each analyzed icebreaker transit. The band levels are labelled 10 – Nyquist, and Decade A through D. The Nyquist frequency is 32 kHz, and the Decades are defined as follows: Decade A 10-100 Hz, Decade B 100-1000 Hz, Decade C 1000- 10,000 Hz, and Decade D 10,000 – 32,000 Hz

C.1. AMAR-BI

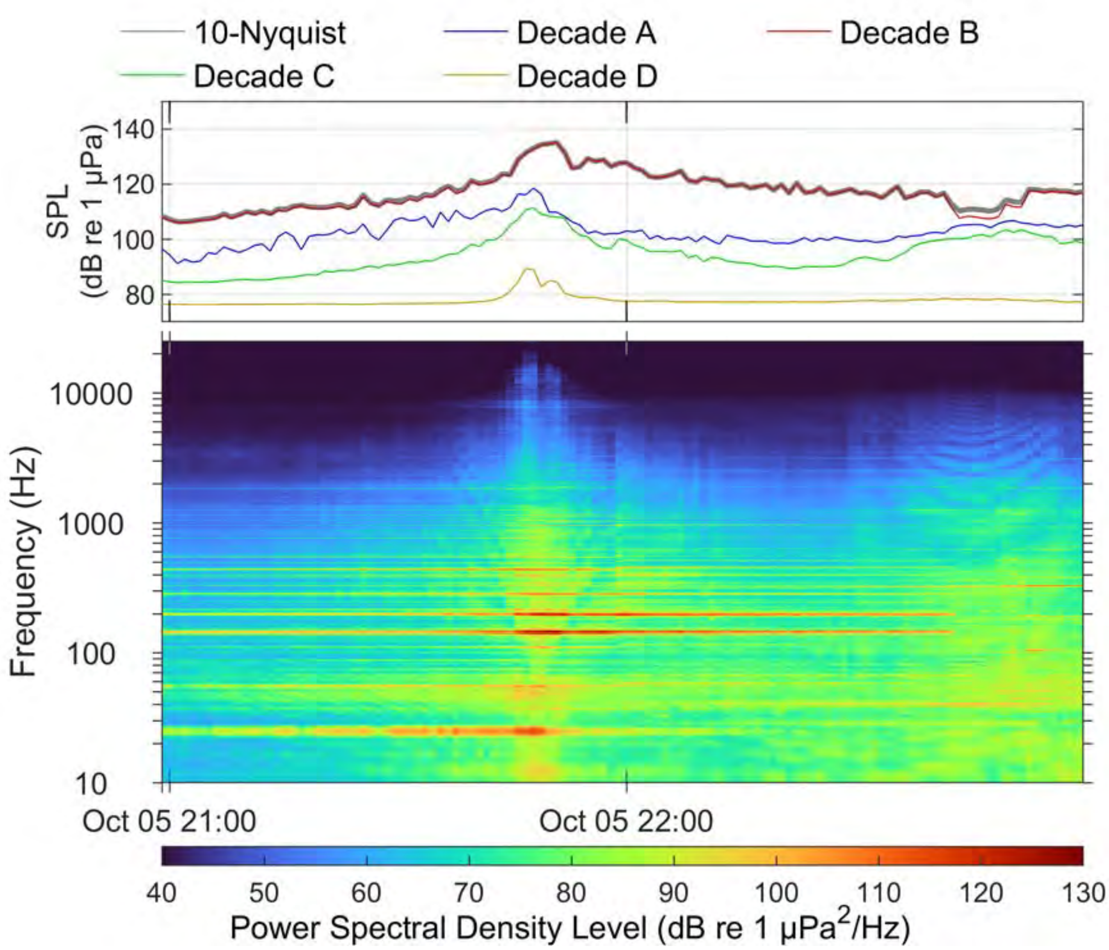


Figure C-1. AMAR-BI 05 Oct 2019: No vessels in escort, 0/10 ice concentration. Spectrogram and band level data.

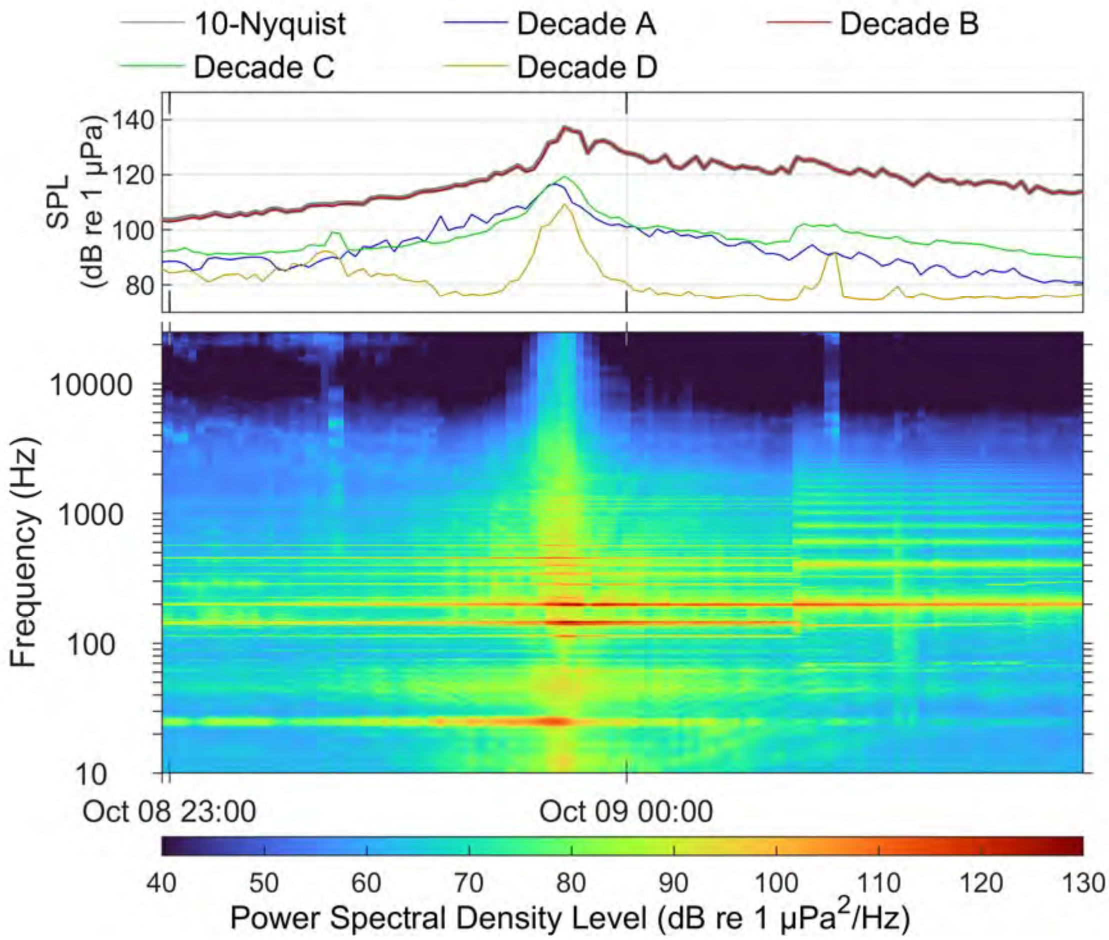


Figure C-2. AMAR-BI 8 Oct 2019: No vessels in escort, 0/10 ice concentration. Spectrogram and band level data.

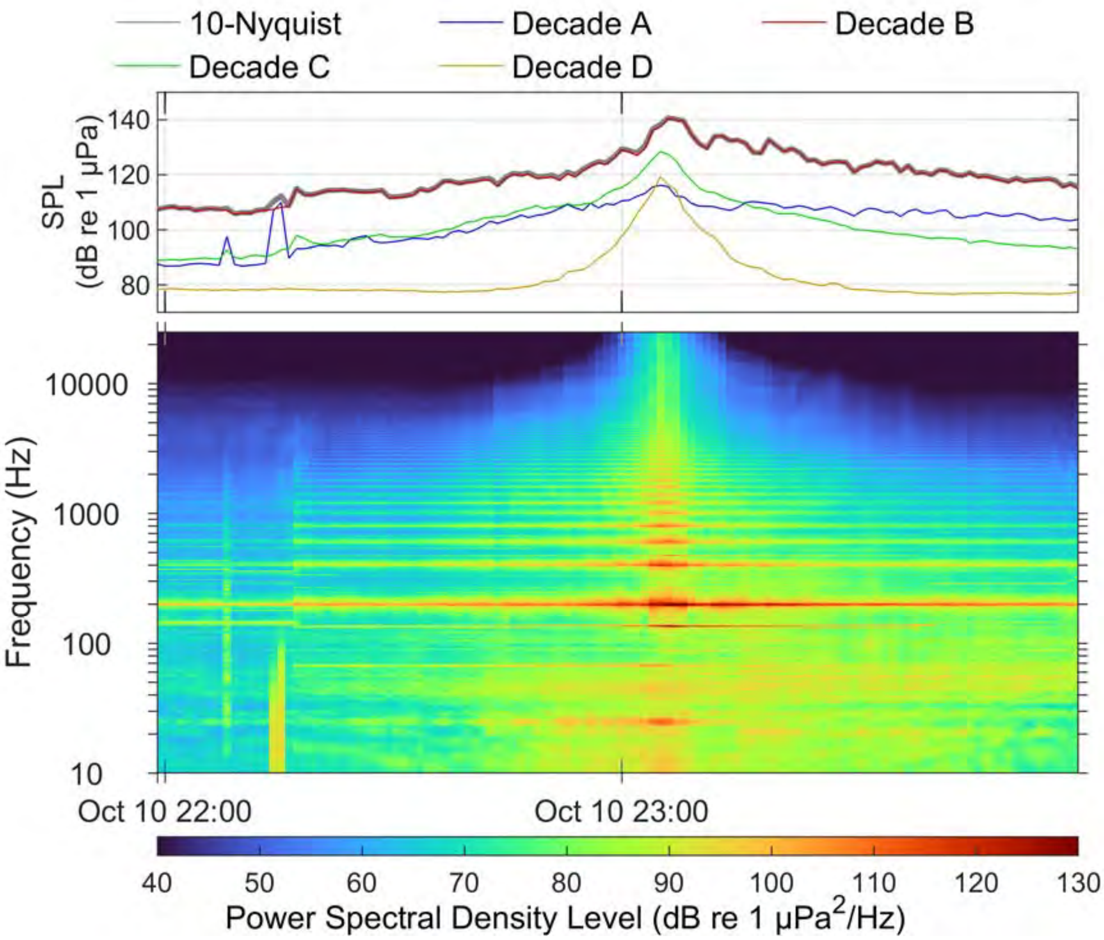


Figure C-3. AMAR-BI 10 Oct 2019: 1 vessel in escort, 0/10 ice concentration. Spectrogram and band level data.

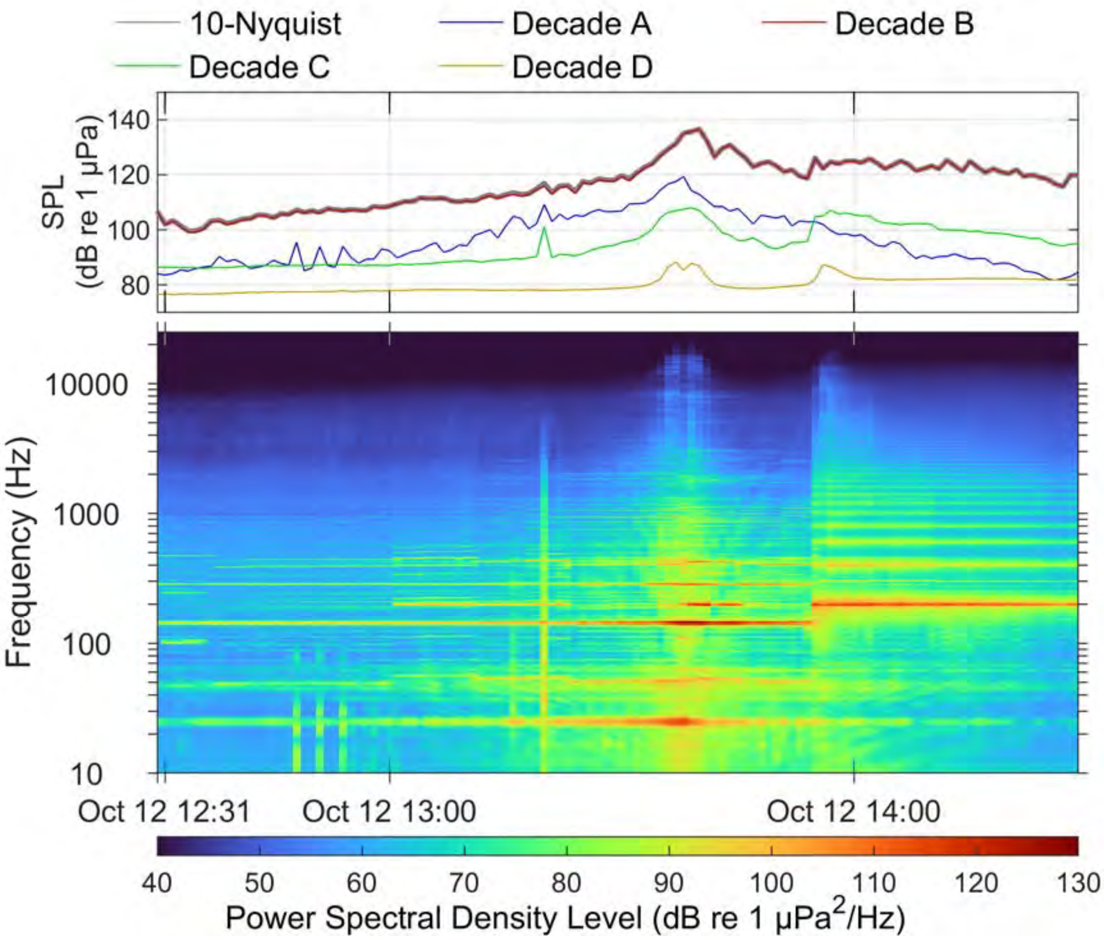


Figure C-4. AMAR-BI 12 Oct 2019: No vessels in escort, 0/10 ice concentration. Spectrogram and band level data.

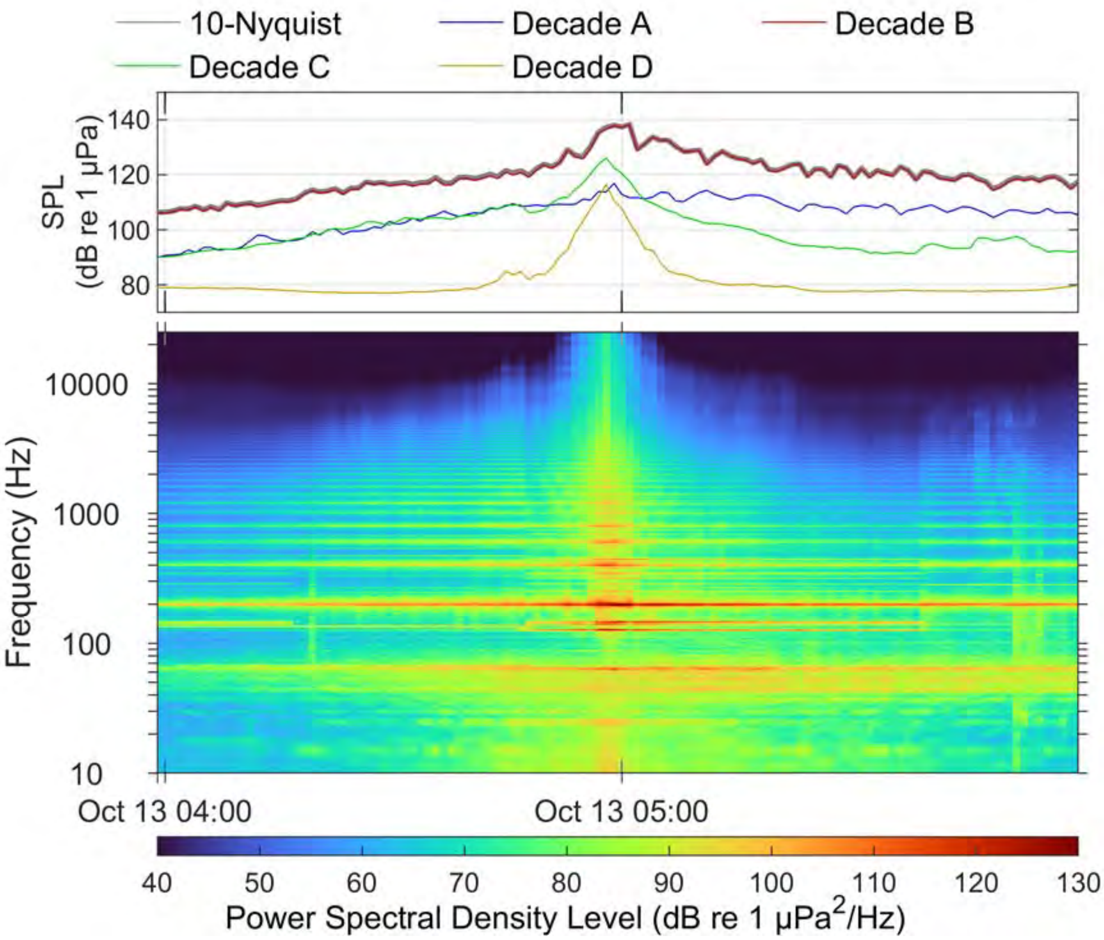


Figure C-5. AMAR-BI 13 Oct 2019: 1 vessel in escort, 0/10 ice concentration. Spectrogram and band level data.

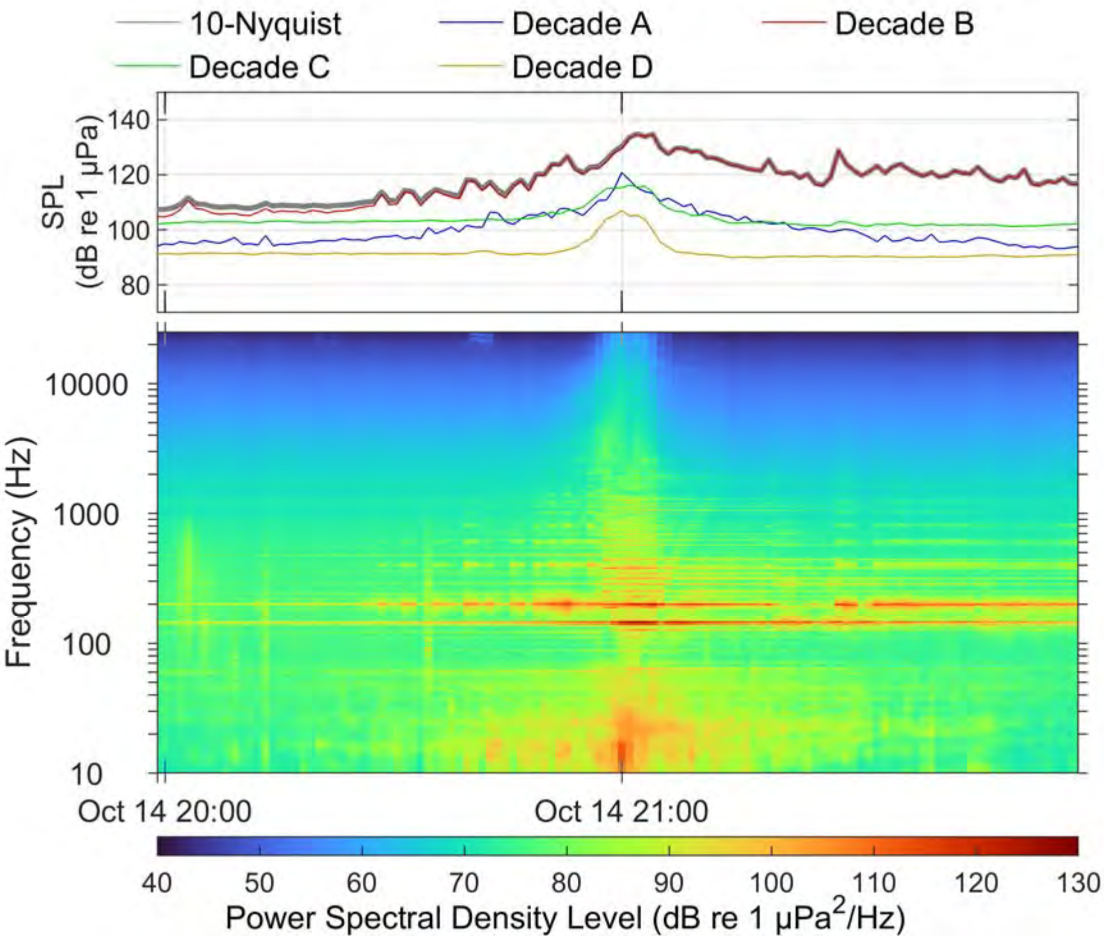


Figure C-6. AMAR-BI 14 Oct 2019: No vessels in escort, 0/10 ice concentration. Spectrogram and band level data.

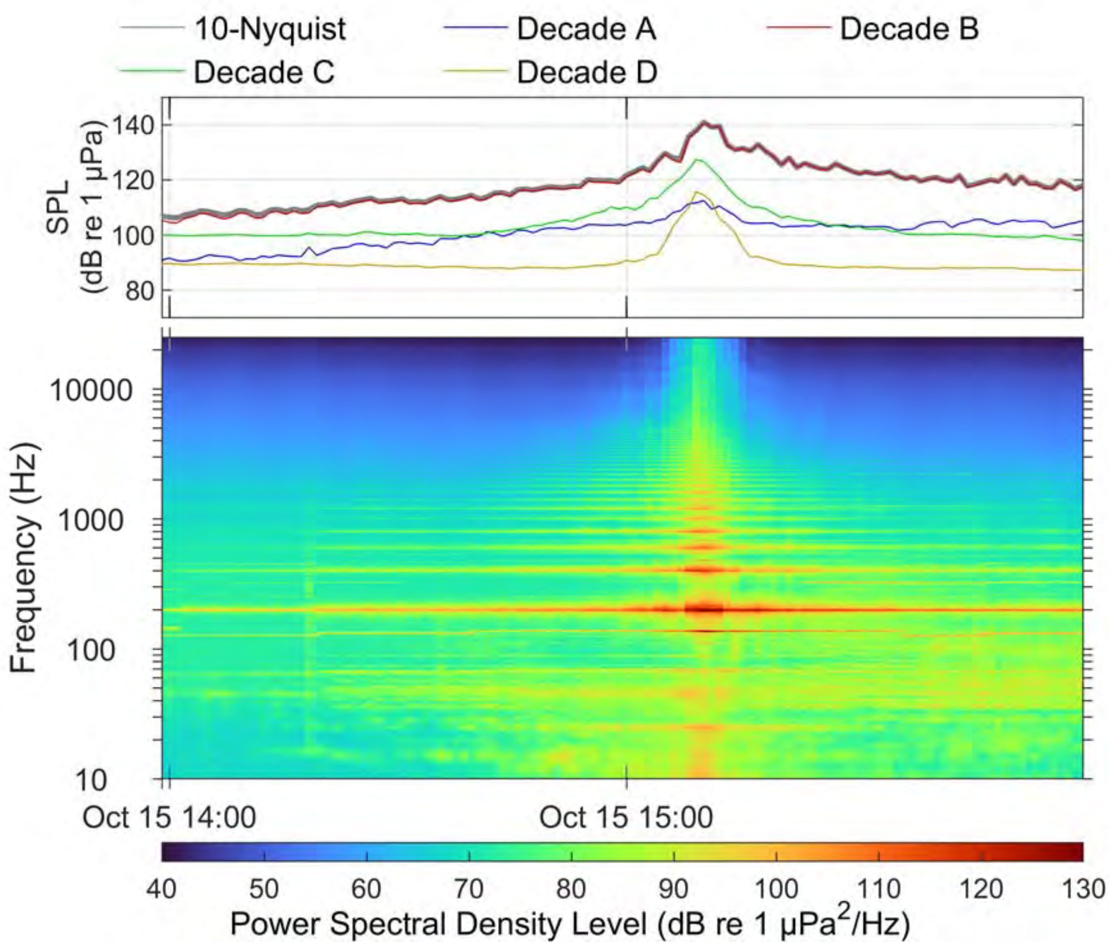


Figure C-7. AMAR-BI 15 Oct 2019: 1 vessel in escort, 0/10 ice concentration. Spectrogram and band level data.

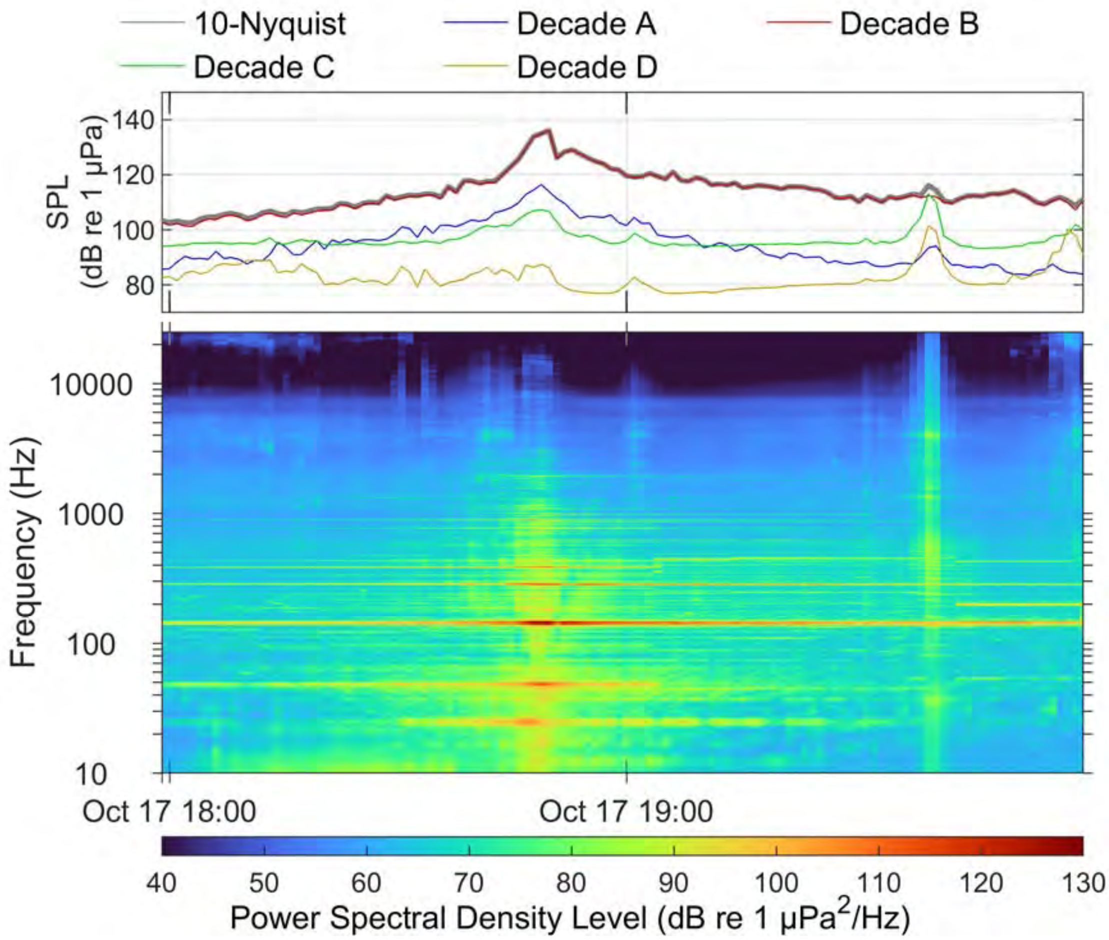


Figure C-8. AMAR-BI 17 Oct 2019: No vessels in escort, 0/10 ice concentration. Spectrogram and band level data.

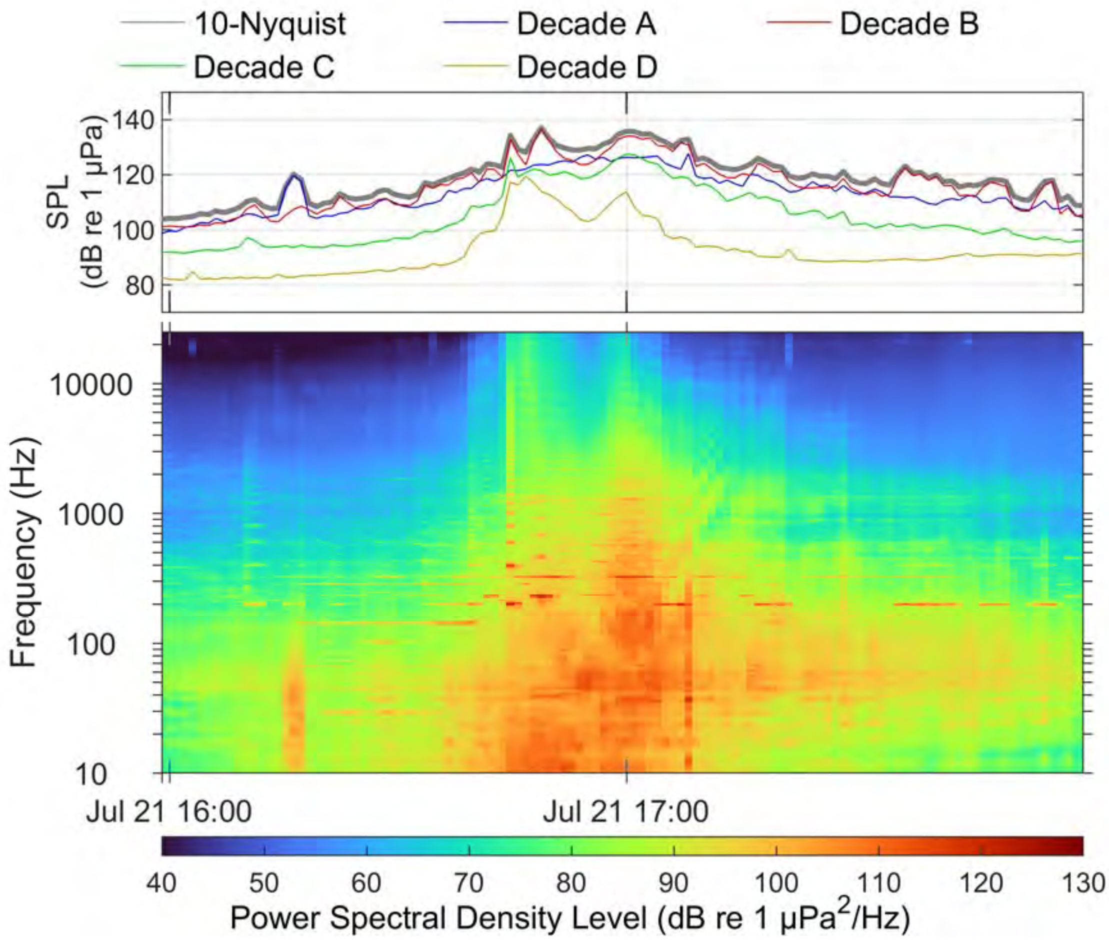


Figure C-9. AMAR-BI 21 Jul 2020: 4 vessels in escort, 9/10 ice concentration. Spectrogram and band level data.

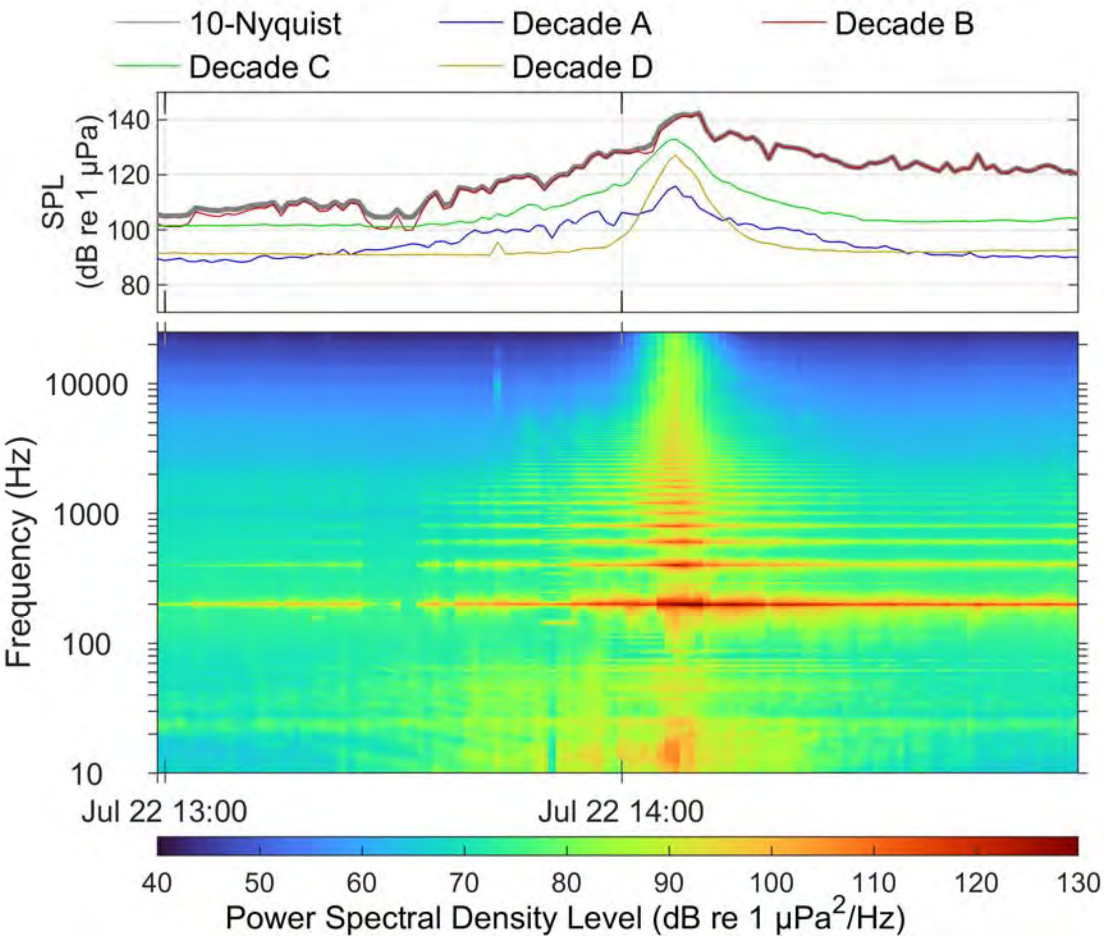


Figure C-10. AMAR-BI 22 Jul 2020: No vessels in escort, 0/10 ice concentration. Spectrogram and band level data.

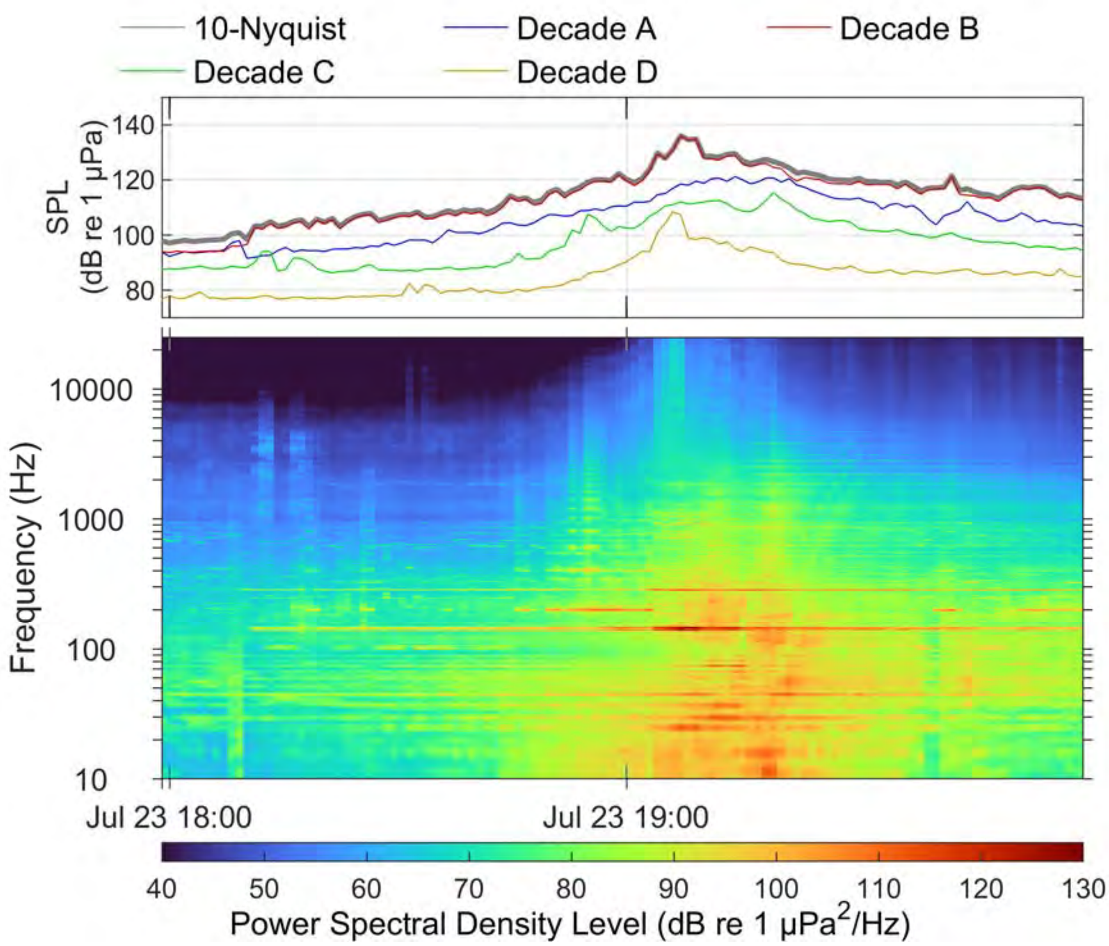
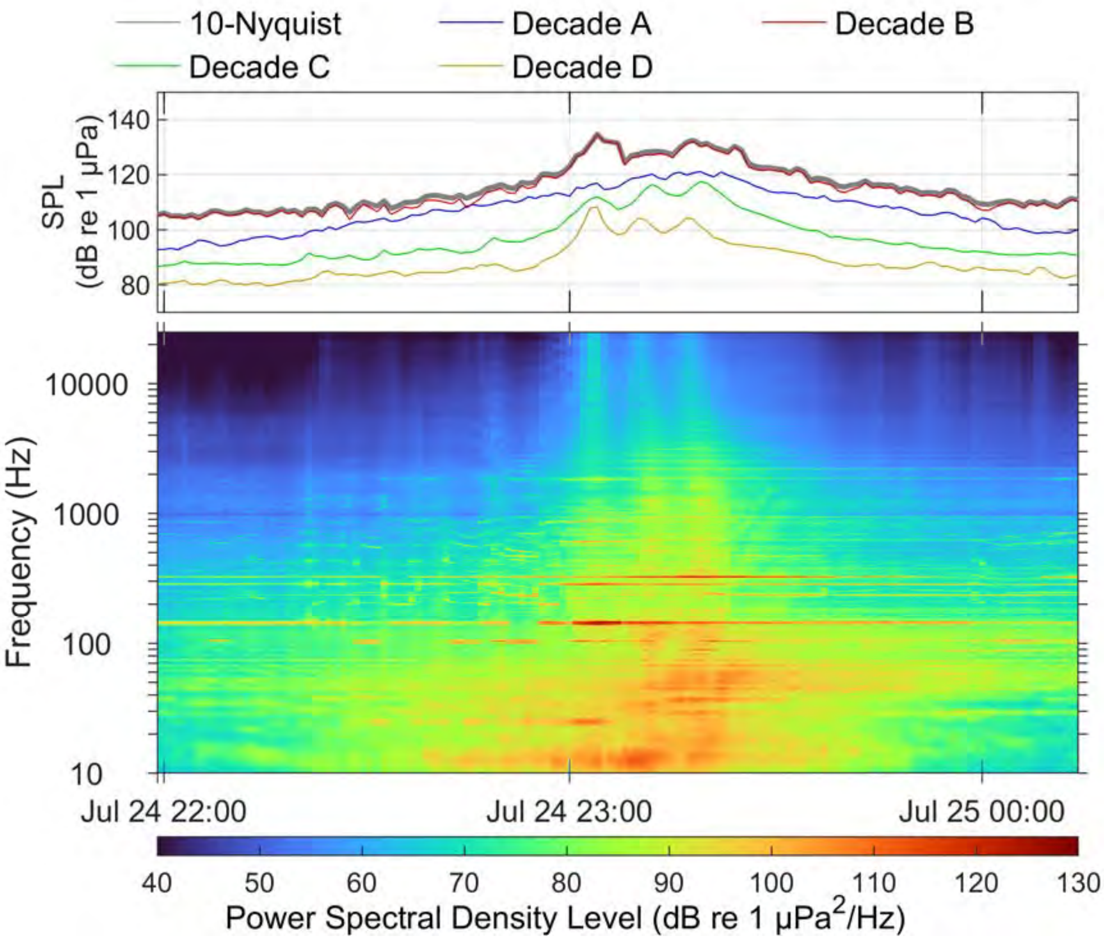


Figure C-11. AMAR-BI 23 Jul 2020: 2 vessels in escort, 2/10 ice concentration. Spectrogram and band level data.



C-12. AMAR-BI 24 Jul 2020: 2 vessels in escort, 8/10 ice concentration. Spectrogram and band level data.

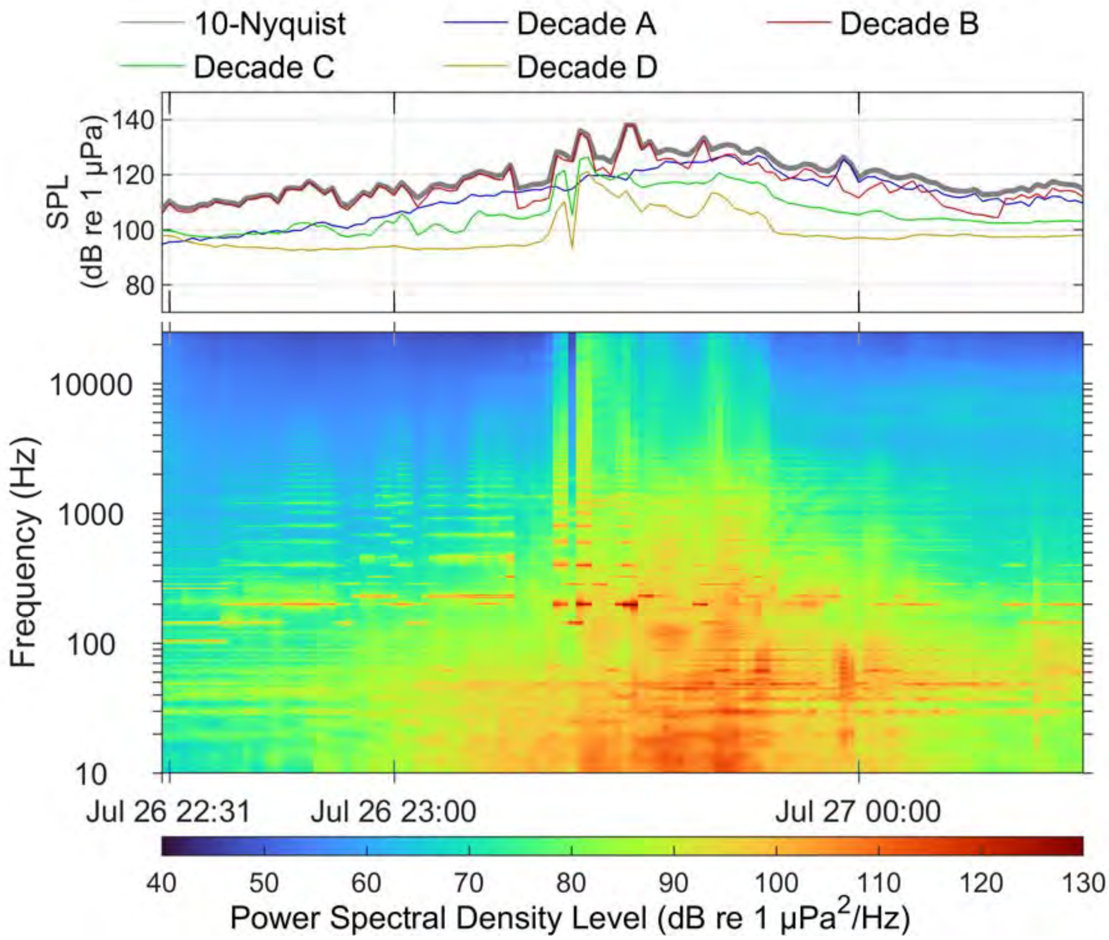


Figure C-13. AMAR-BI 26 Jul 2020: 2 vessels in escort, 8/10 ice concentration. Spectrogram and band level data.

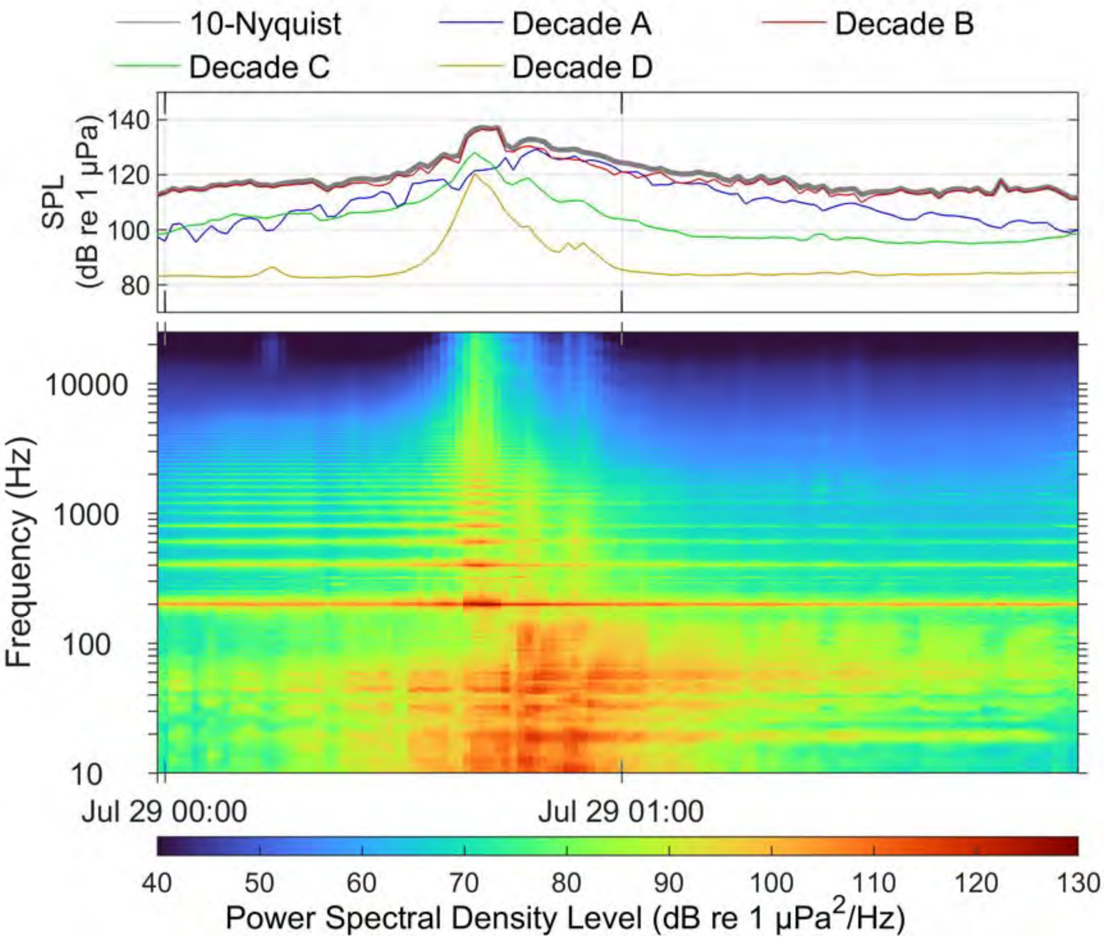


Figure C-14. AMAR-BI 29 Jul 2020: 2 vessels in escort, 0/10 ice concentration. Spectrogram and band level data.

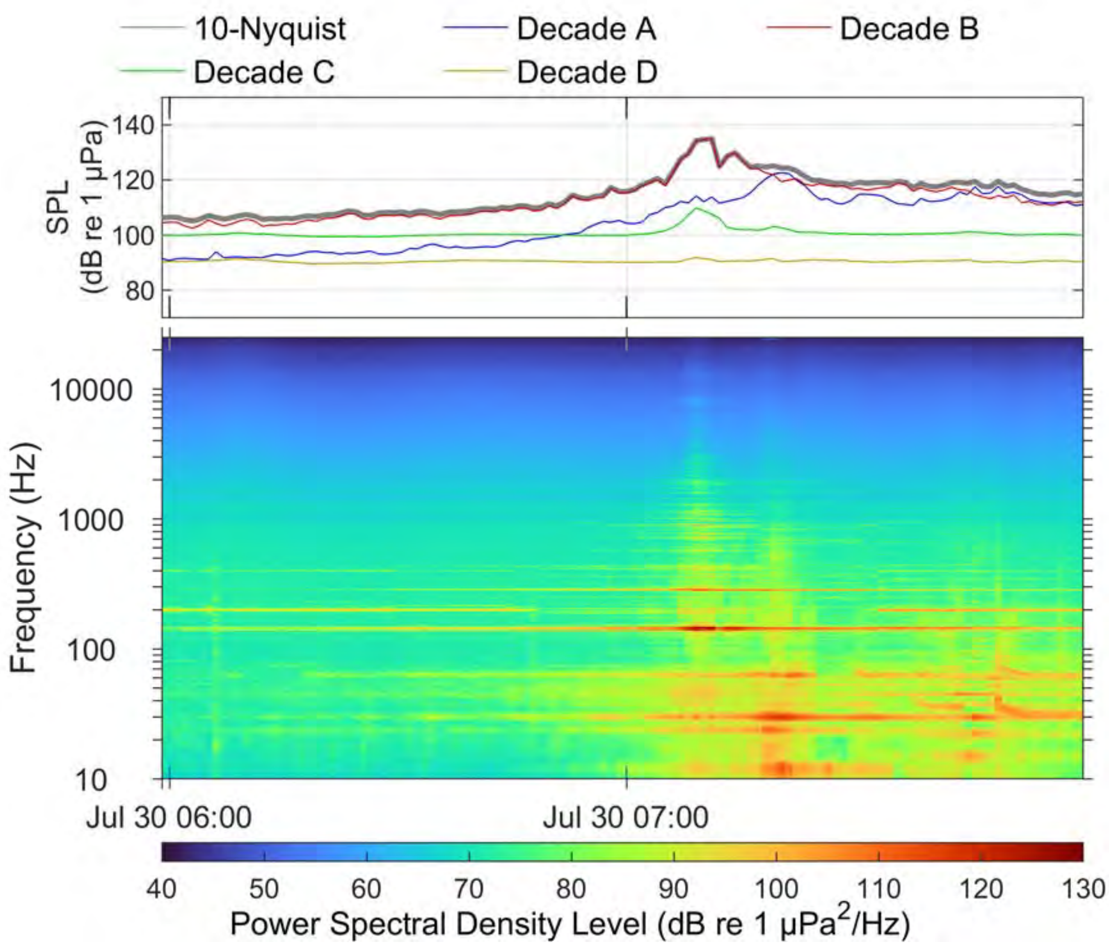


Figure C-15. AMAR-BI 30 Jul 2020: 2 vessels in escort, 0/10 ice concentration. Spectrogram and band level data.

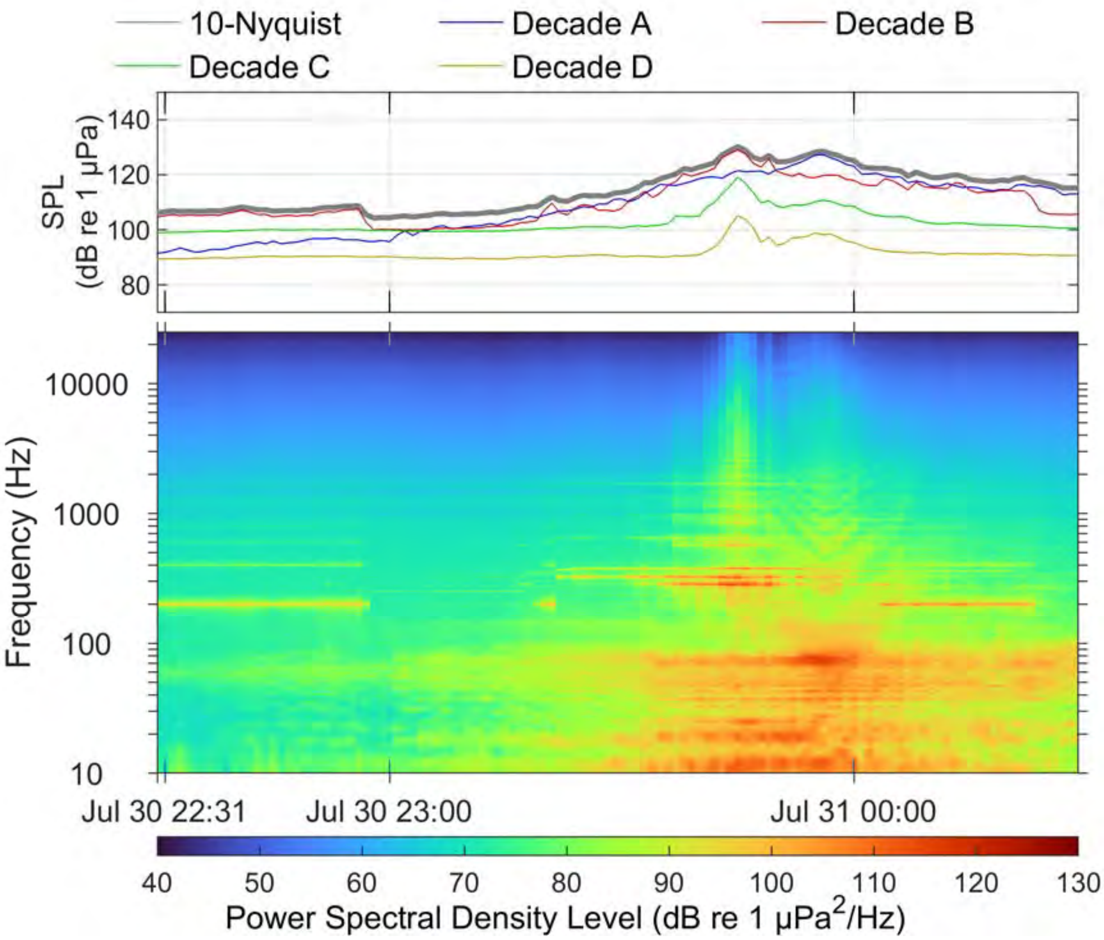


Figure C-16. AMAR-BI 30 Jul 2020: 1 vessel in escort, 0/10 ice concentration. Spectrogram and band level data.

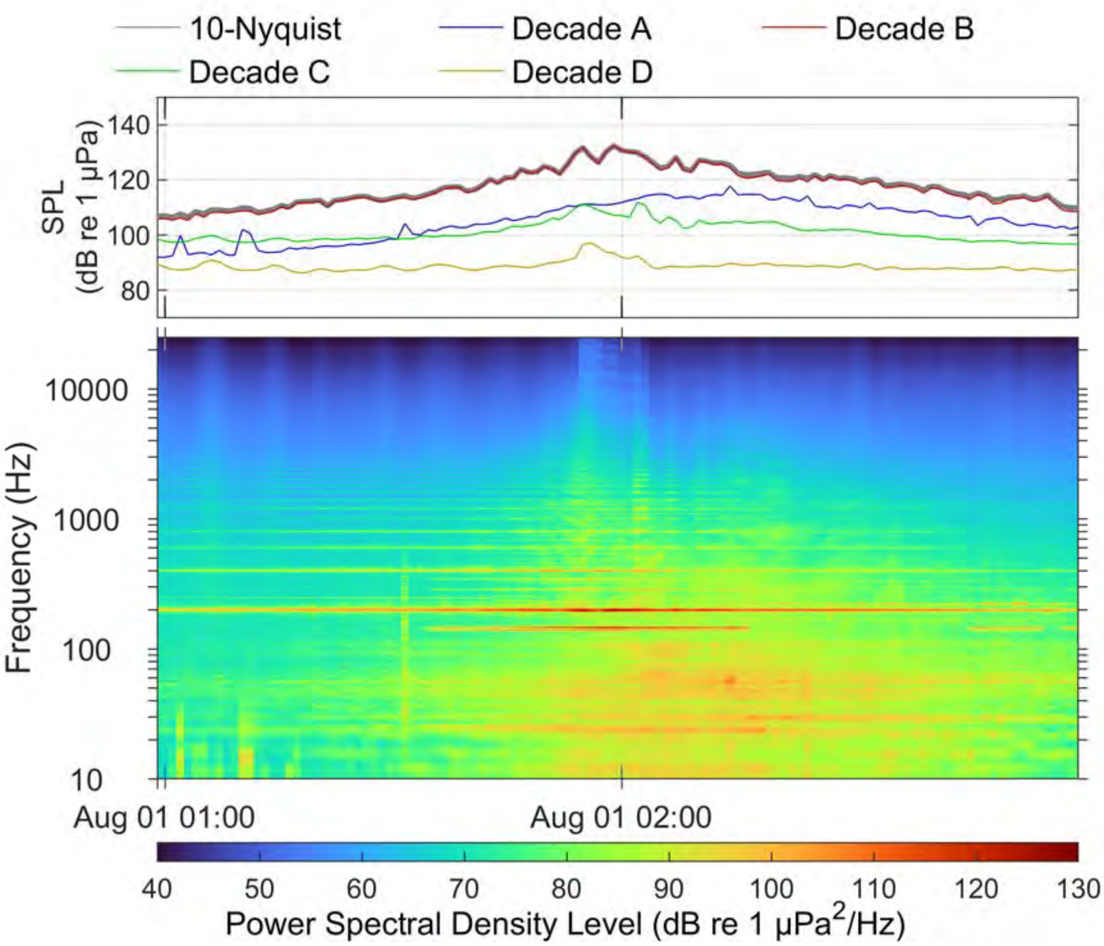


Figure C-17. AMAR-BI 1 Aug 2020: 3 vessels in escort, 0/10 ice concentration. Spectrogram and band level data.

C.2. AMAR-RI

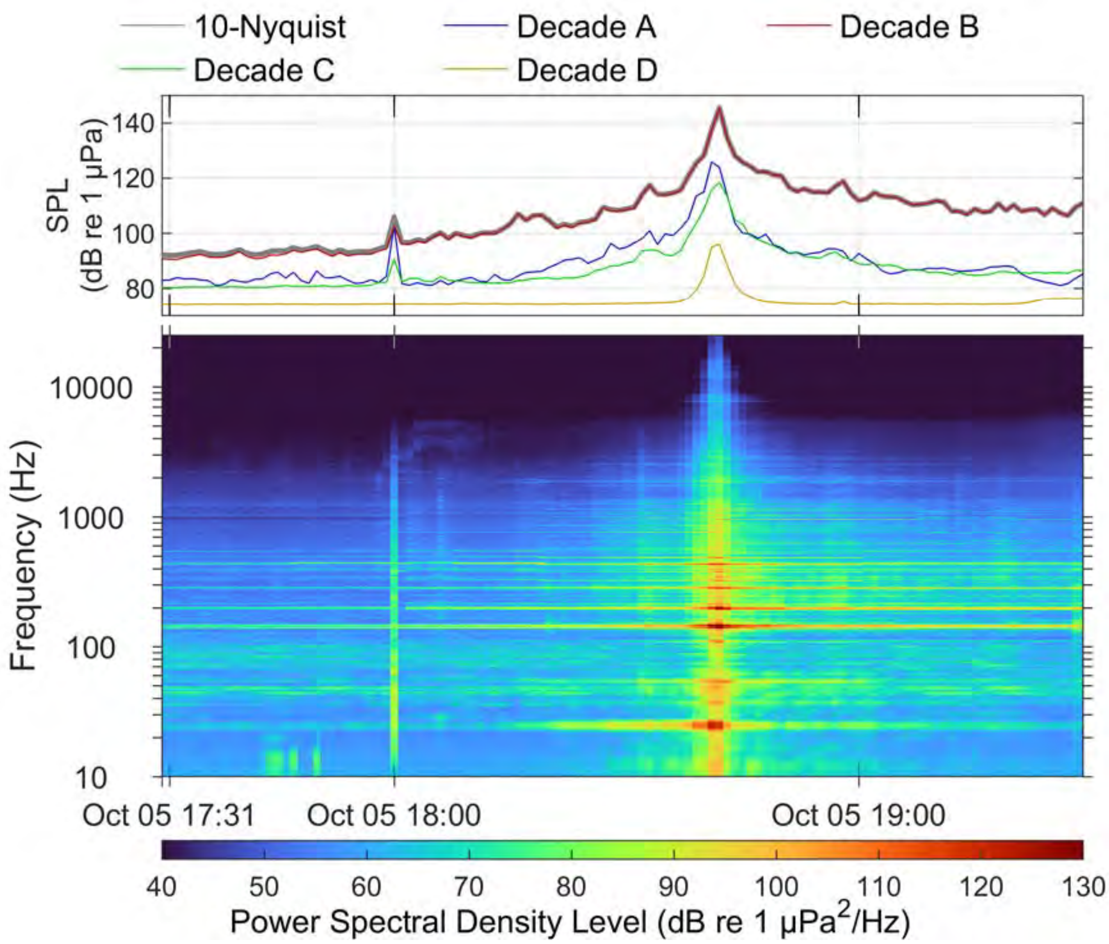


Figure C-18. AMAR-RI 5 Oct 2019: No vessels in escort, 0/10 ice concentration. Spectrogram and band level data.

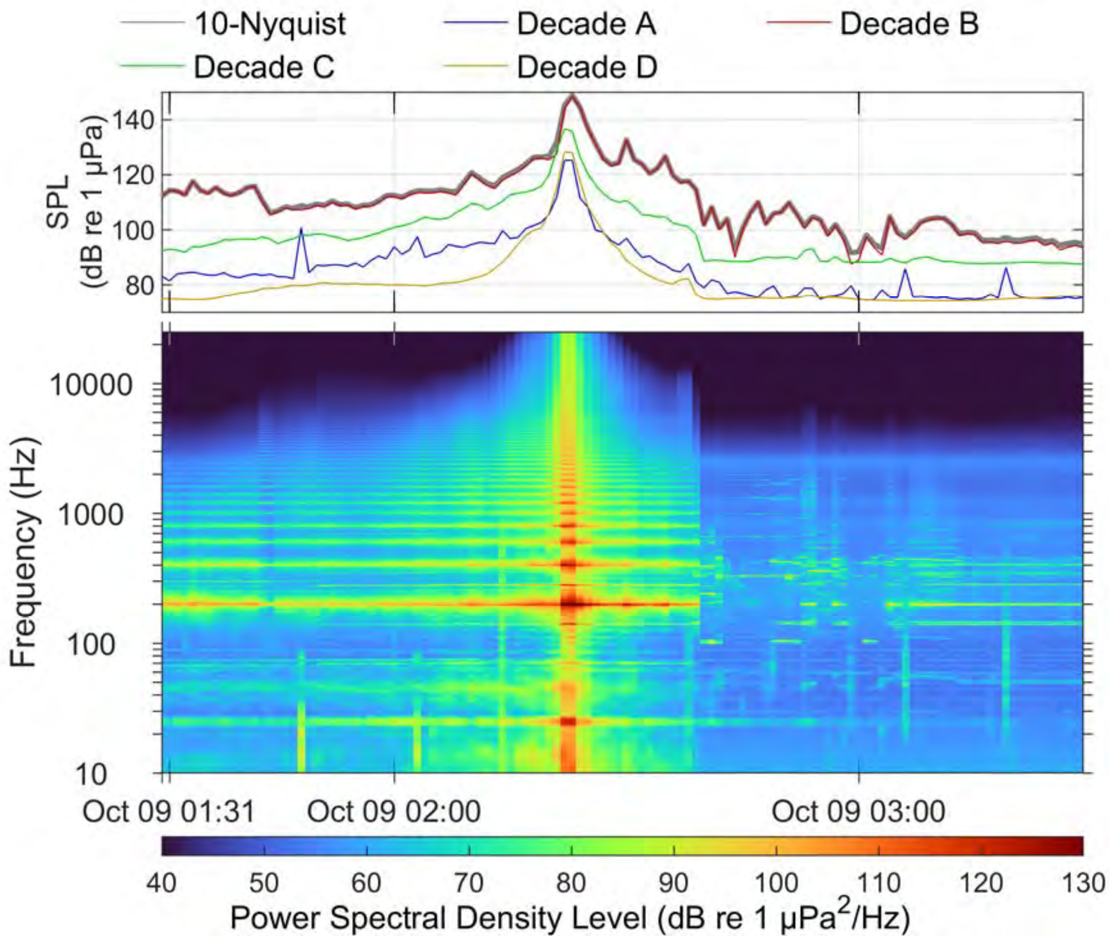


Figure C-19. AMAR-RI 9 Oct 2019: No vessels in escort, 0/10 ice concentration. Spectrogram and band level data.

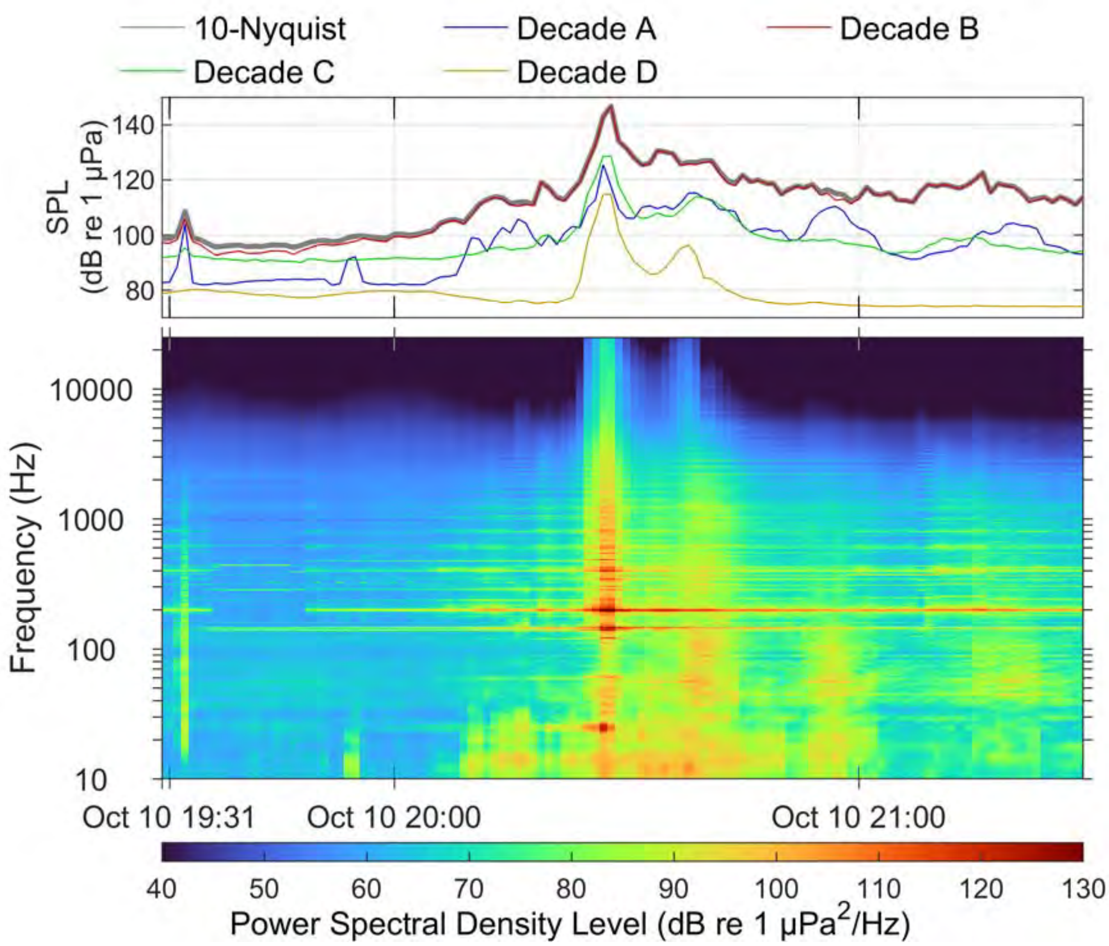


Figure C-20. AMAR-RI 10 Oct 2019: 1 vessel in escort, 0/10 ice concentration. Spectrogram and band level data.

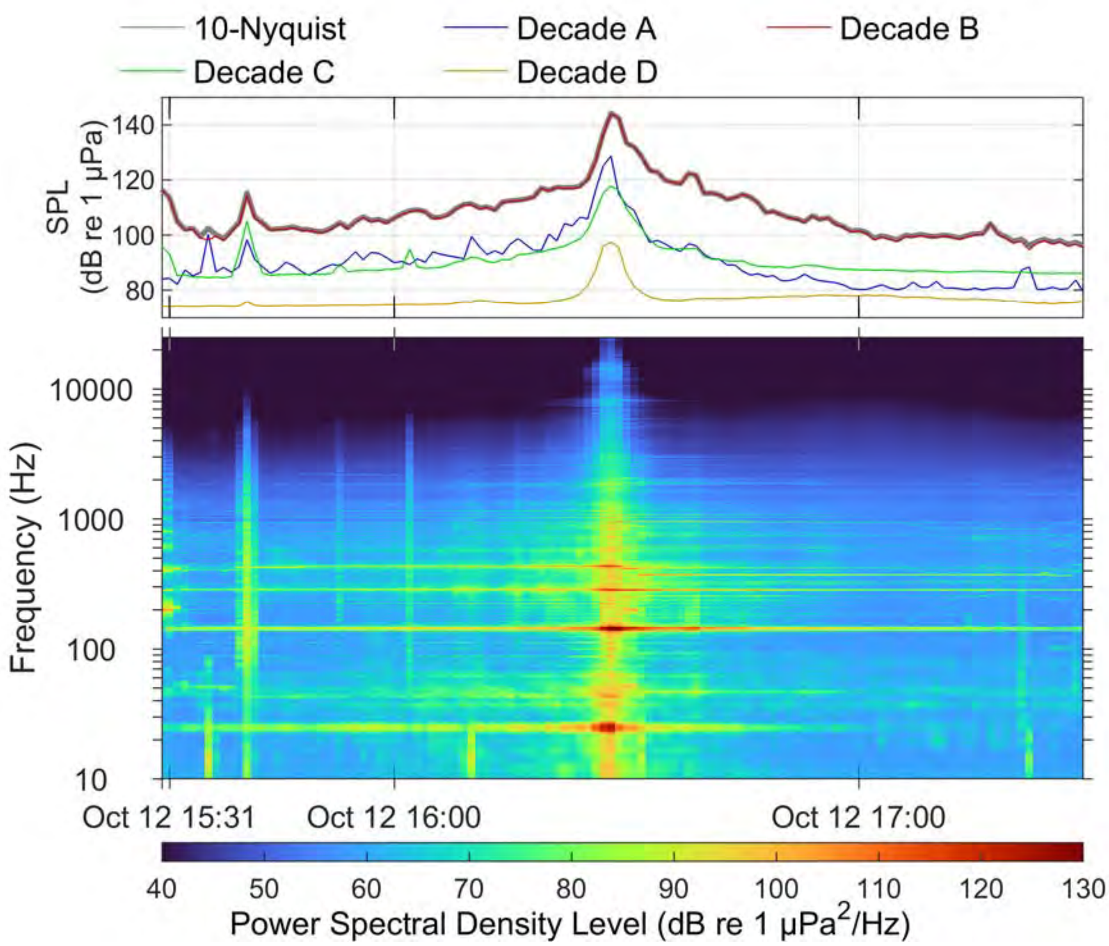


Figure C-21. AMAR-RI 12 Oct 2019: No vessels in escort, 0/10 ice concentration. Spectrogram and band level data.

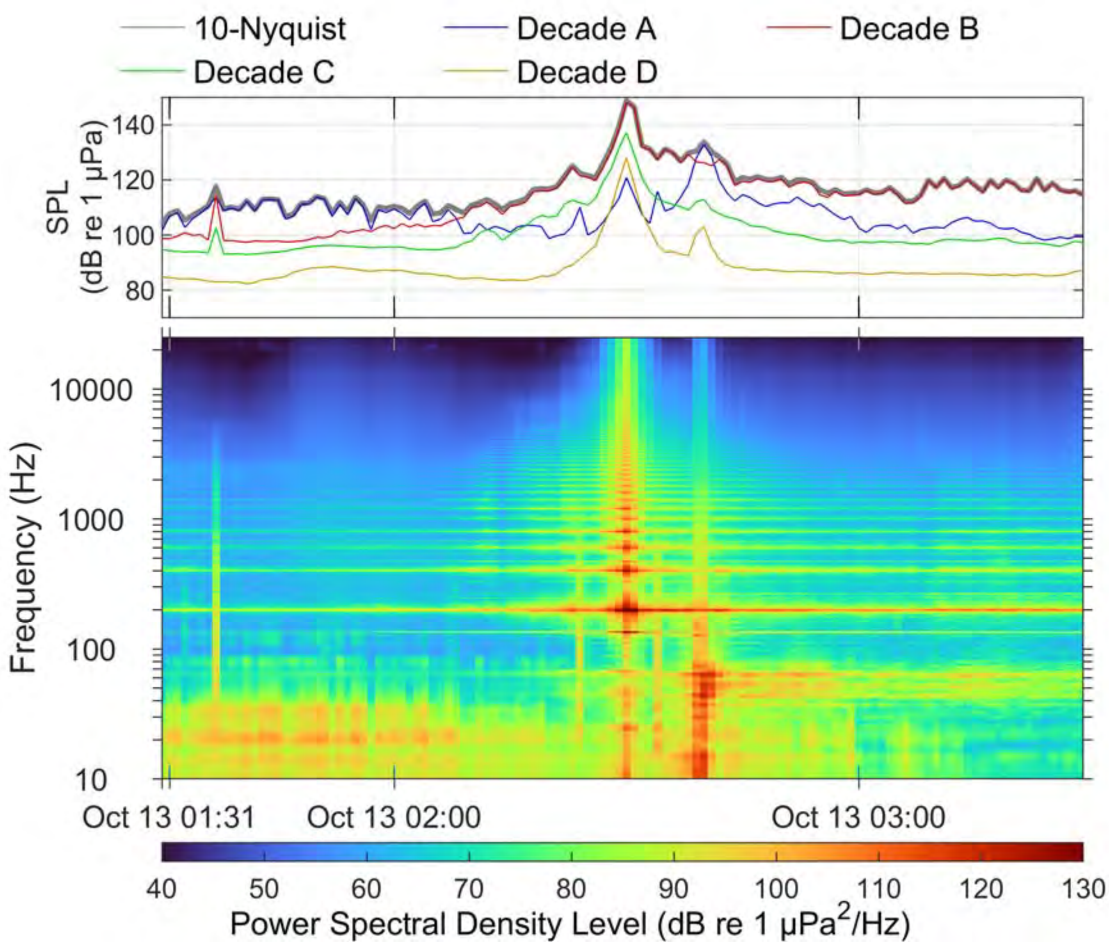


Figure C-22. AMAR-RI 13 Oct 2019: 1 vessel in escort, 0/10 ice concentration. Spectrogram and band level data.

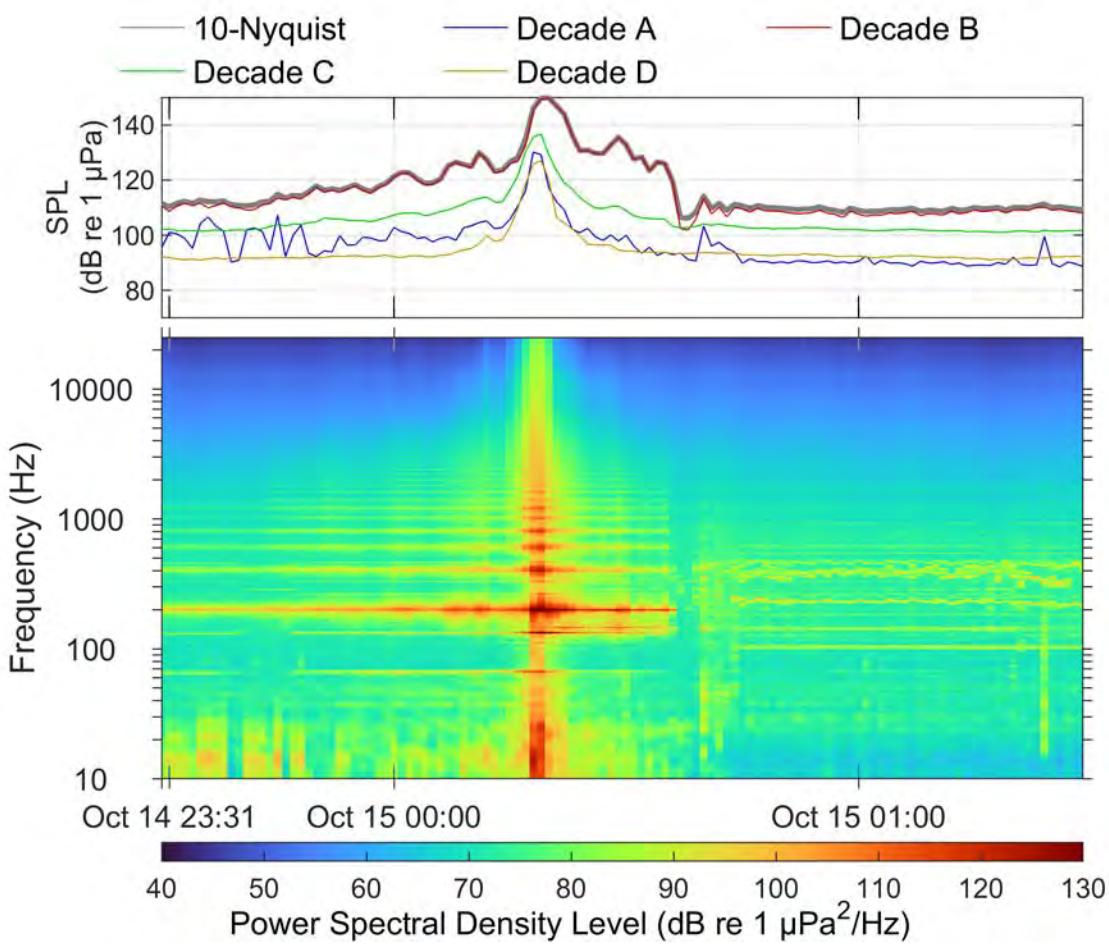


Figure C-23. AMAR-RI 15 Oct 2019: No vessels in escort, 0/10 ice concentration. Spectrogram and band level data.

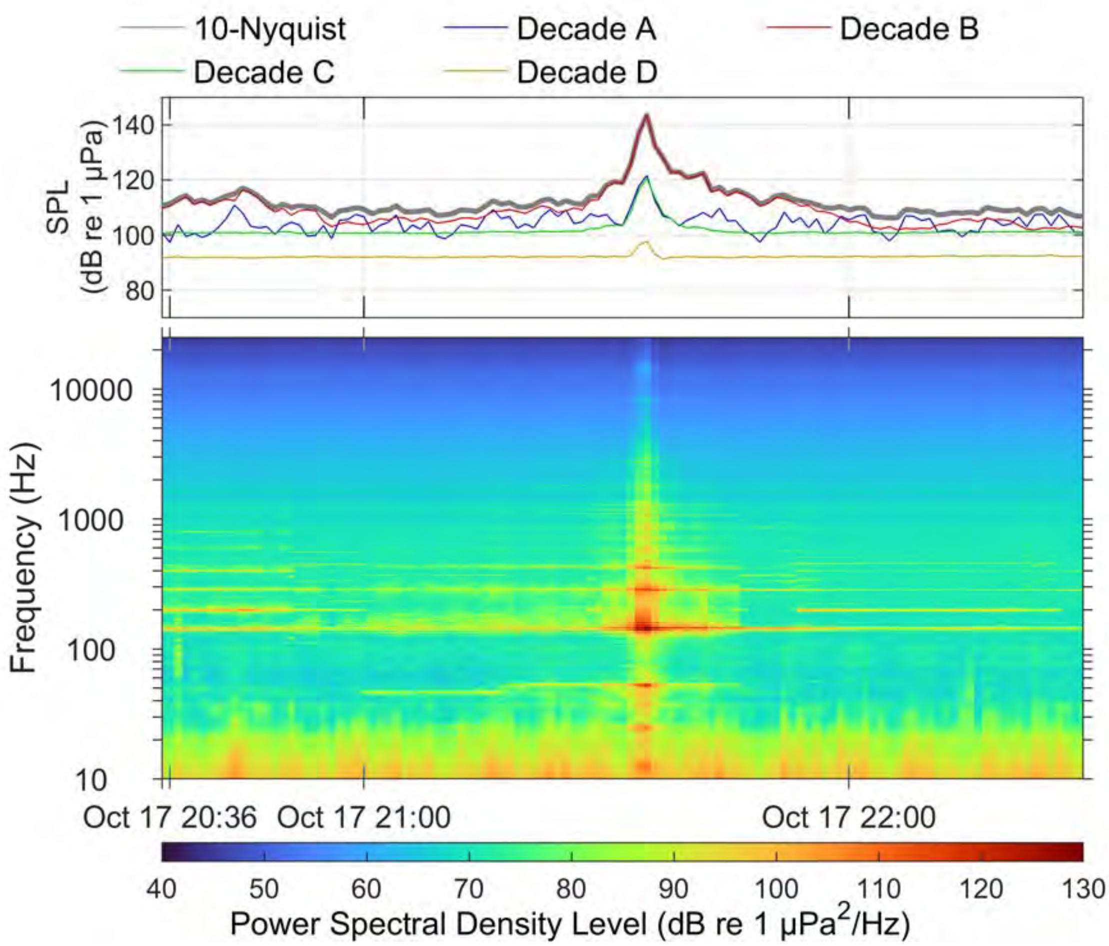


Figure C-24. AMAR-RI 17 Oct 2019: No vessels in escort, 0/10 ice concentration. Spectrogram and band level data.

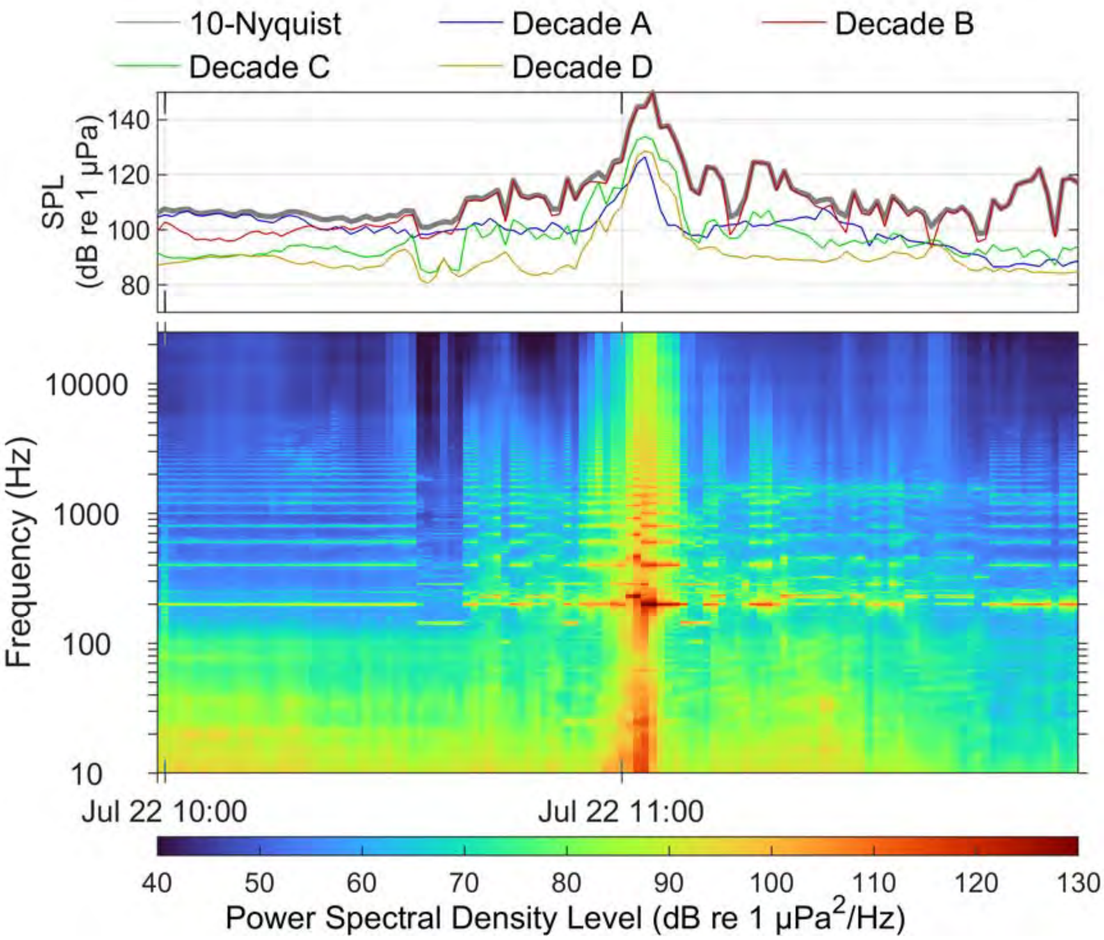


Figure C-25. AMAR-RI 22 Jul 2020: No vessels in escort, 9/10 ice concentration. Spectrogram and band level data.

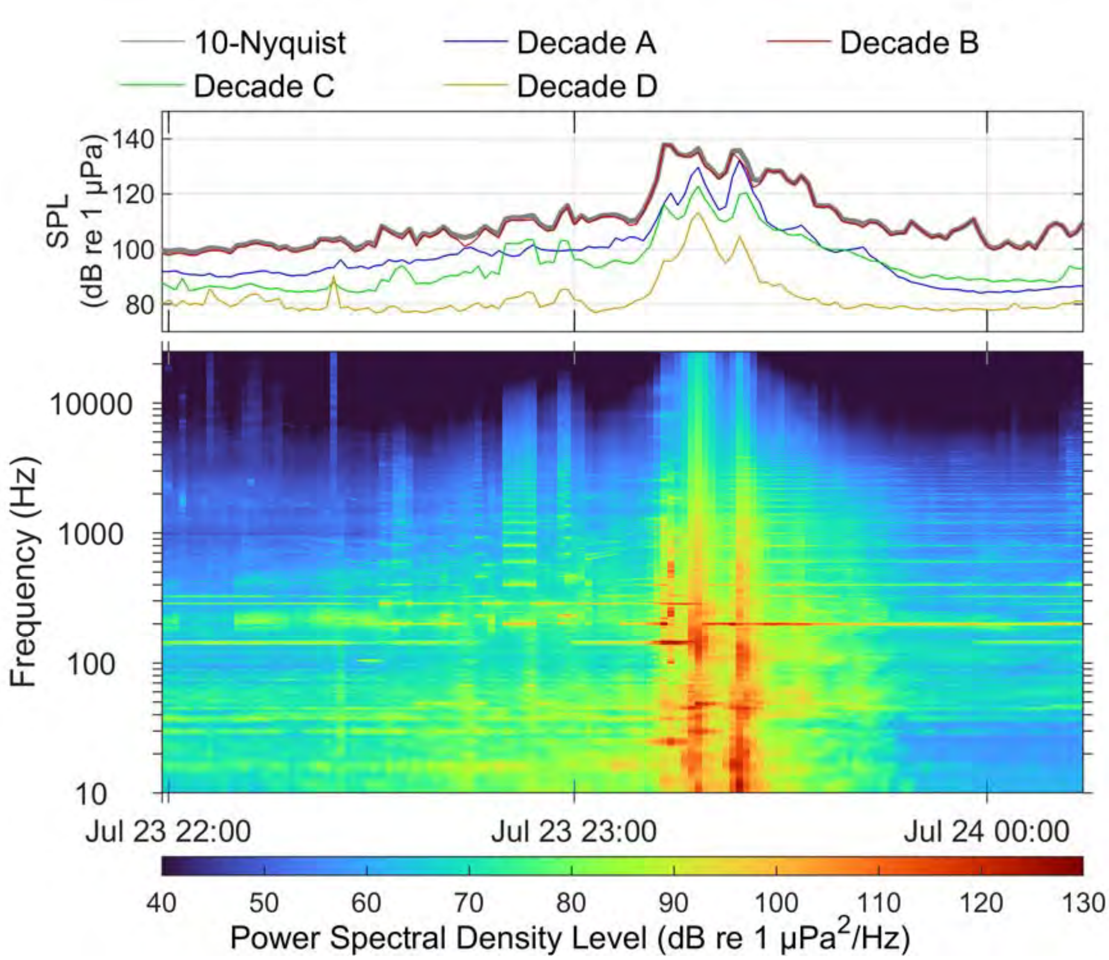


Figure C-26. AMAR-RI 23 Jul 2020: 2 vessels in escort, 2/10 ice concentration. Spectrogram and band level data.

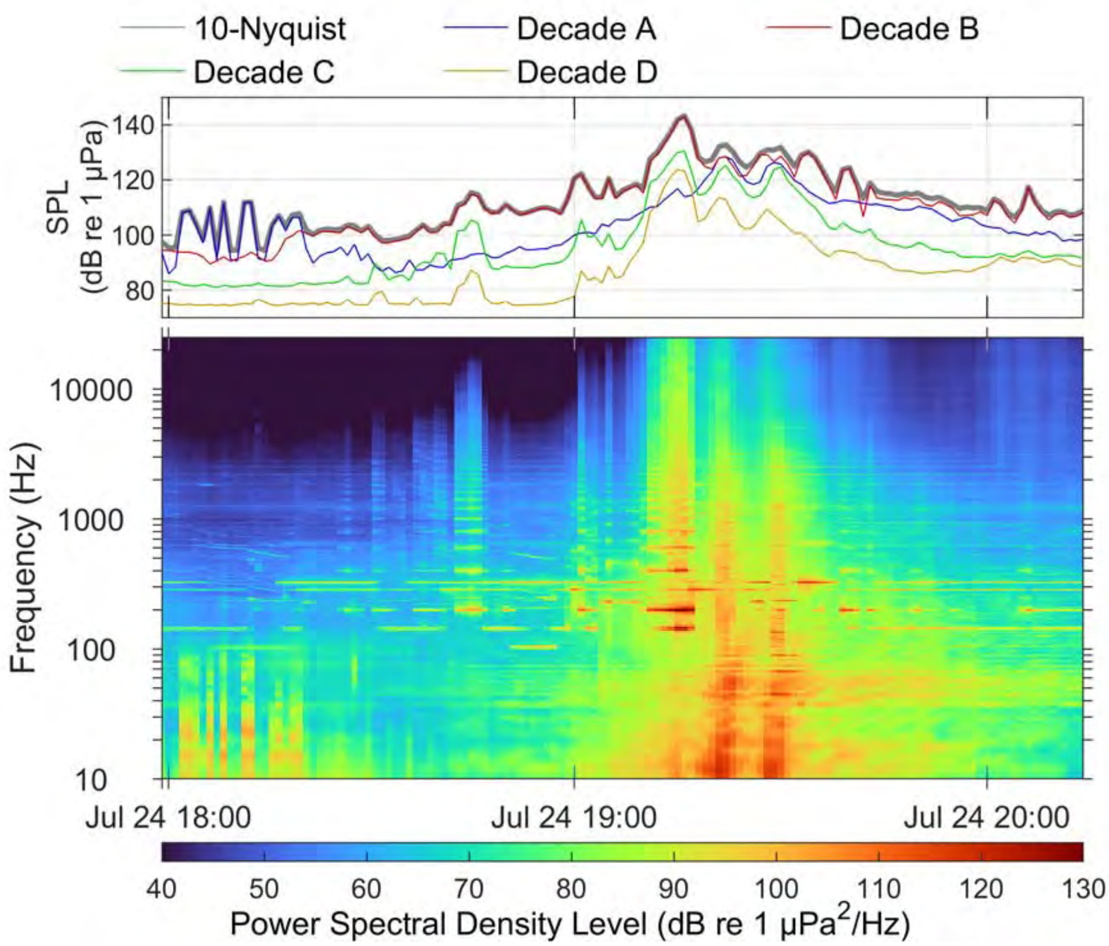


Figure C-27. AMAR-RI 24 Jul 2020: 2 vessels in escort, 810 ice concentration. Spectrogram and band level data.

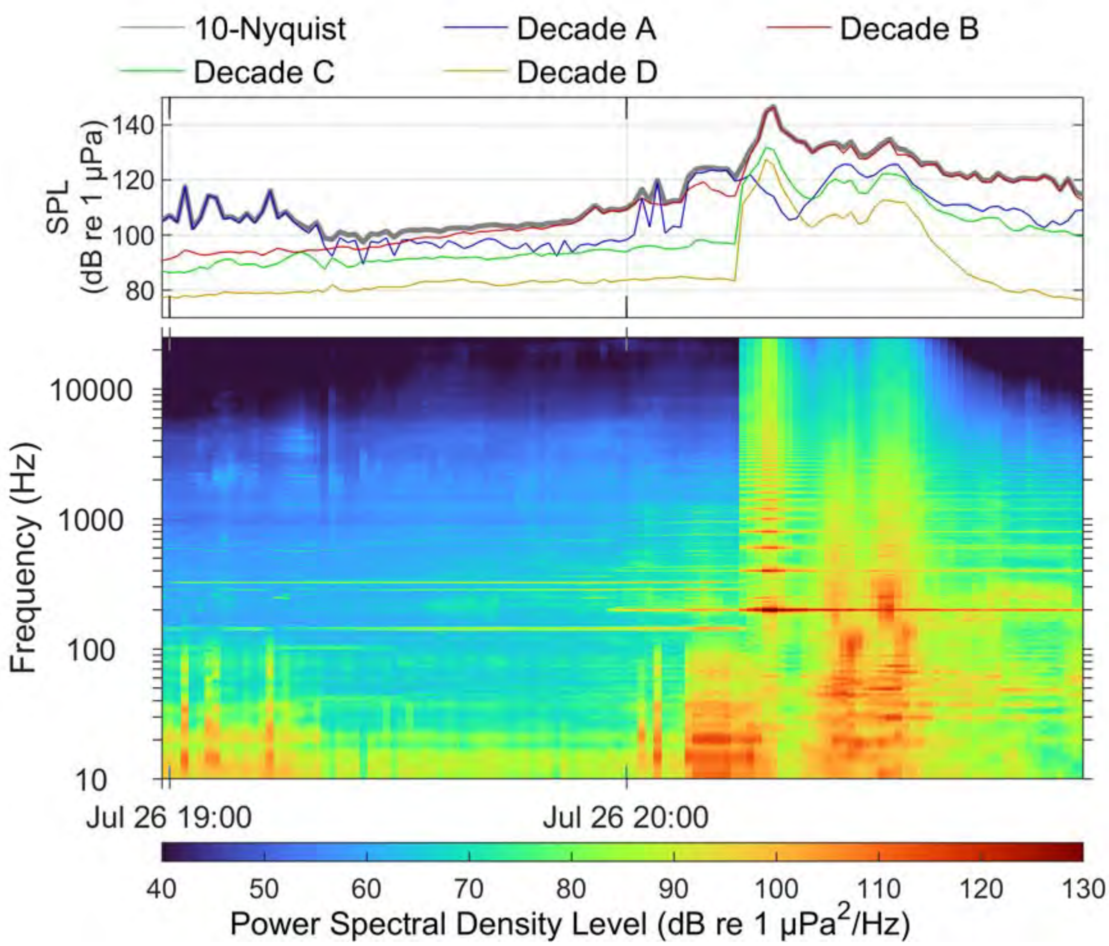


Figure C-28. AMAR-RI 26 Jul 2020: 2 vessels in escort, 5/10 ice concentration. Spectrogram and band level data.

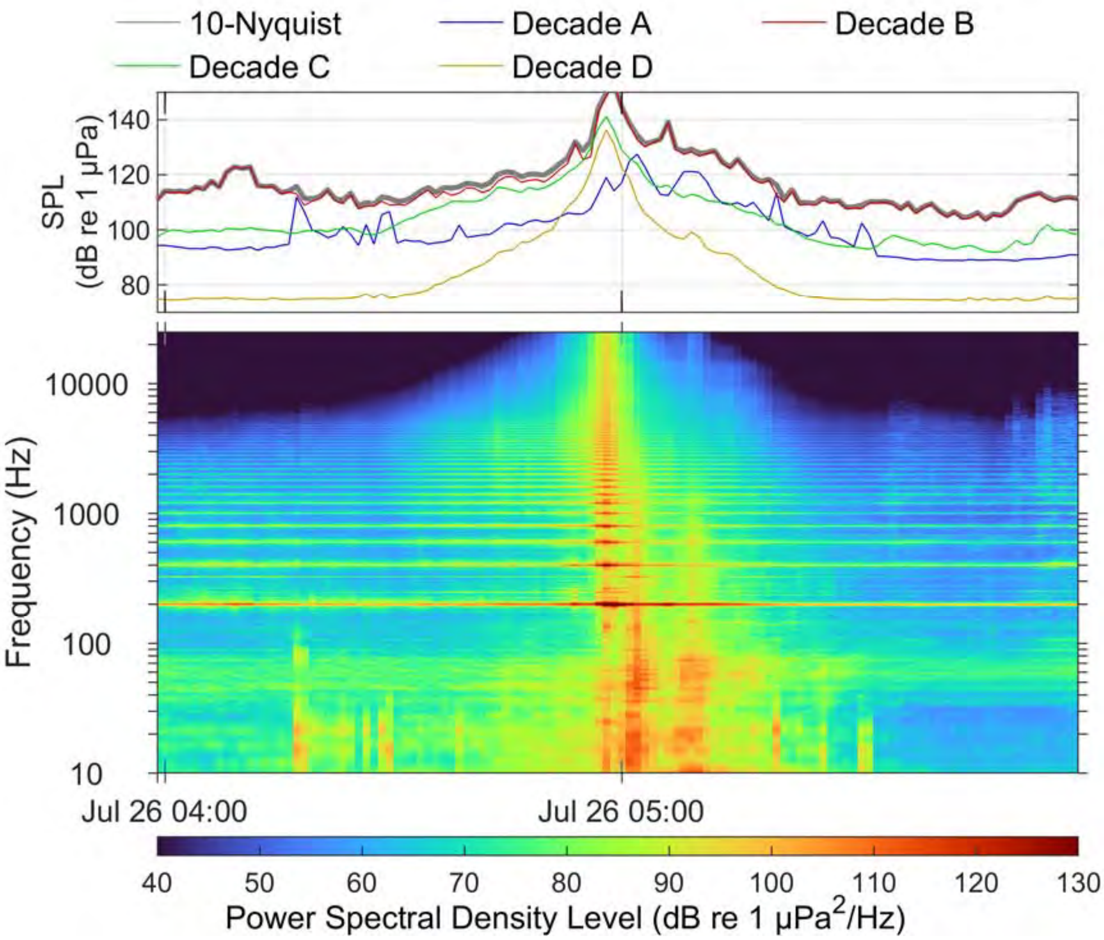


Figure C-29. AMAR-RI 26 Jul 2020: 1 vessel in escort, 5/10 ice concentration. Spectrogram and band level data.

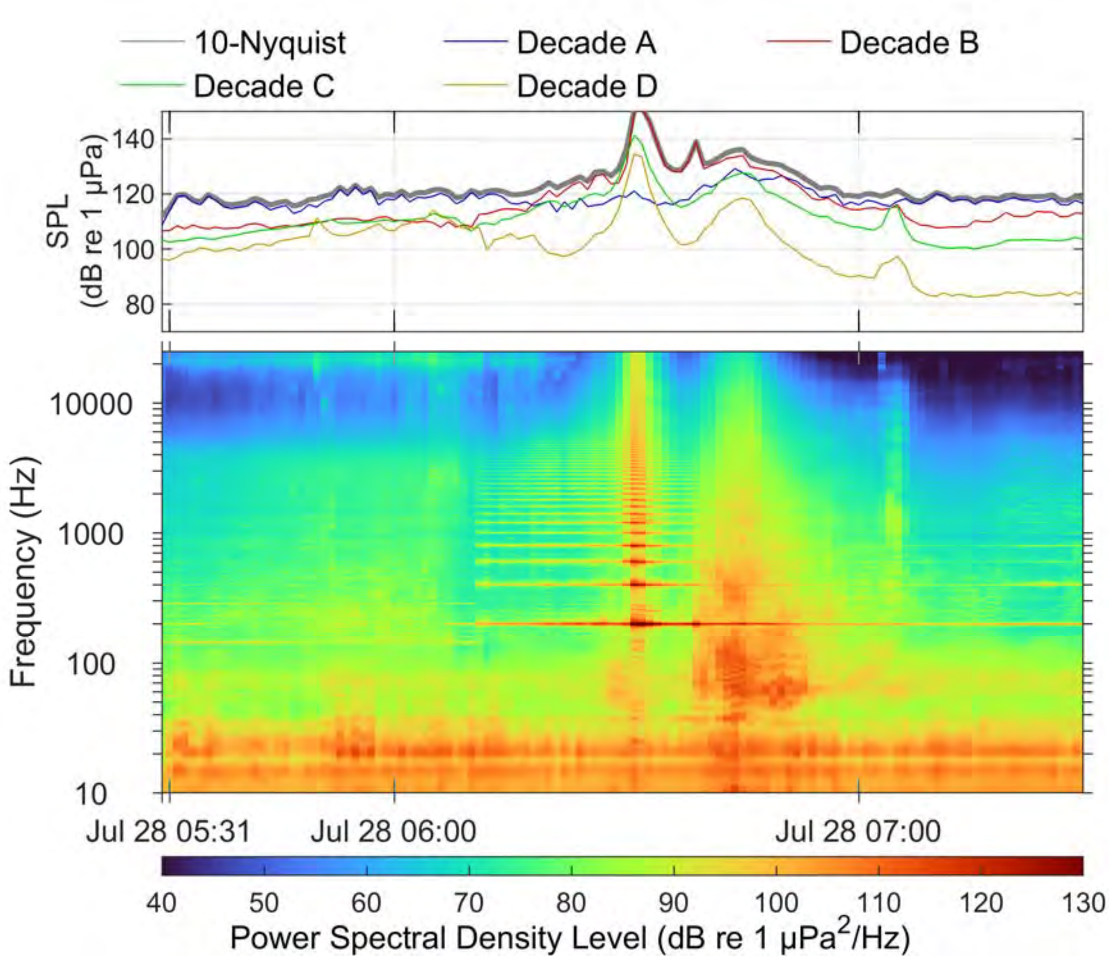


Figure C-30. AMAR-RI 28 Jul 2020: 2 vessels in escort, 0/10 ice concentration. Spectrogram and band level data.

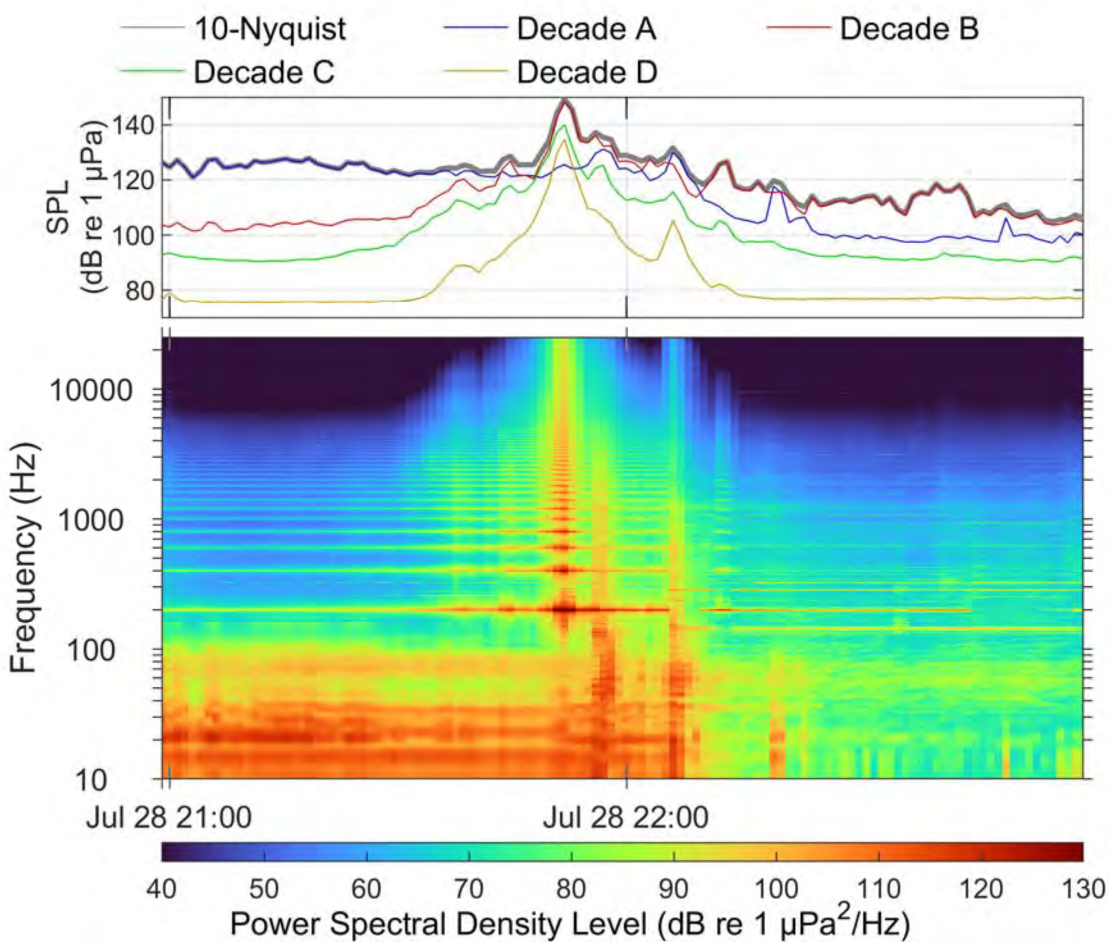


Figure C-31. AMAR-RI 28 Jul 2020: 2 vessels in escort, 0/10 ice concentration. Spectrogram and band level data.

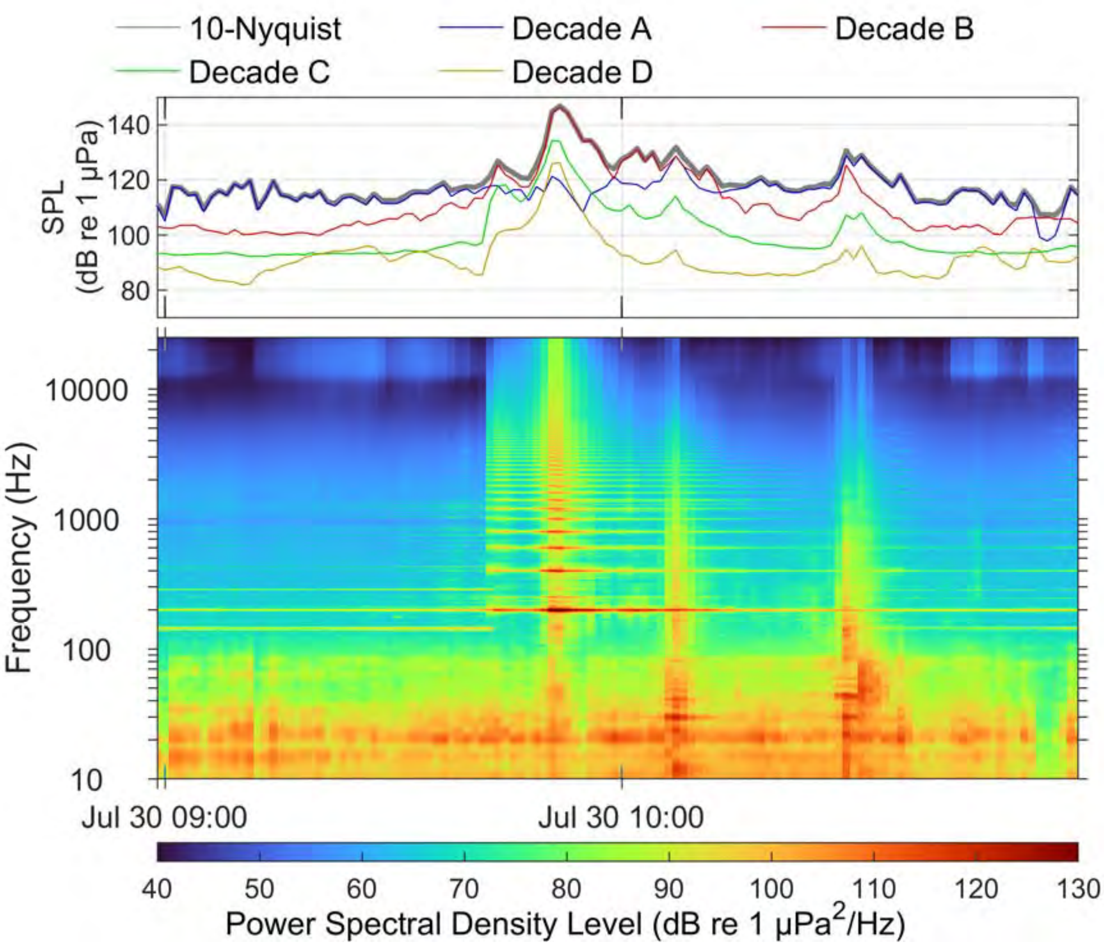


Figure C-32. AMAR-RI 30 Jul 2020: 2 vessels in escort, 0/10 ice concentration. Spectrogram and band level data.

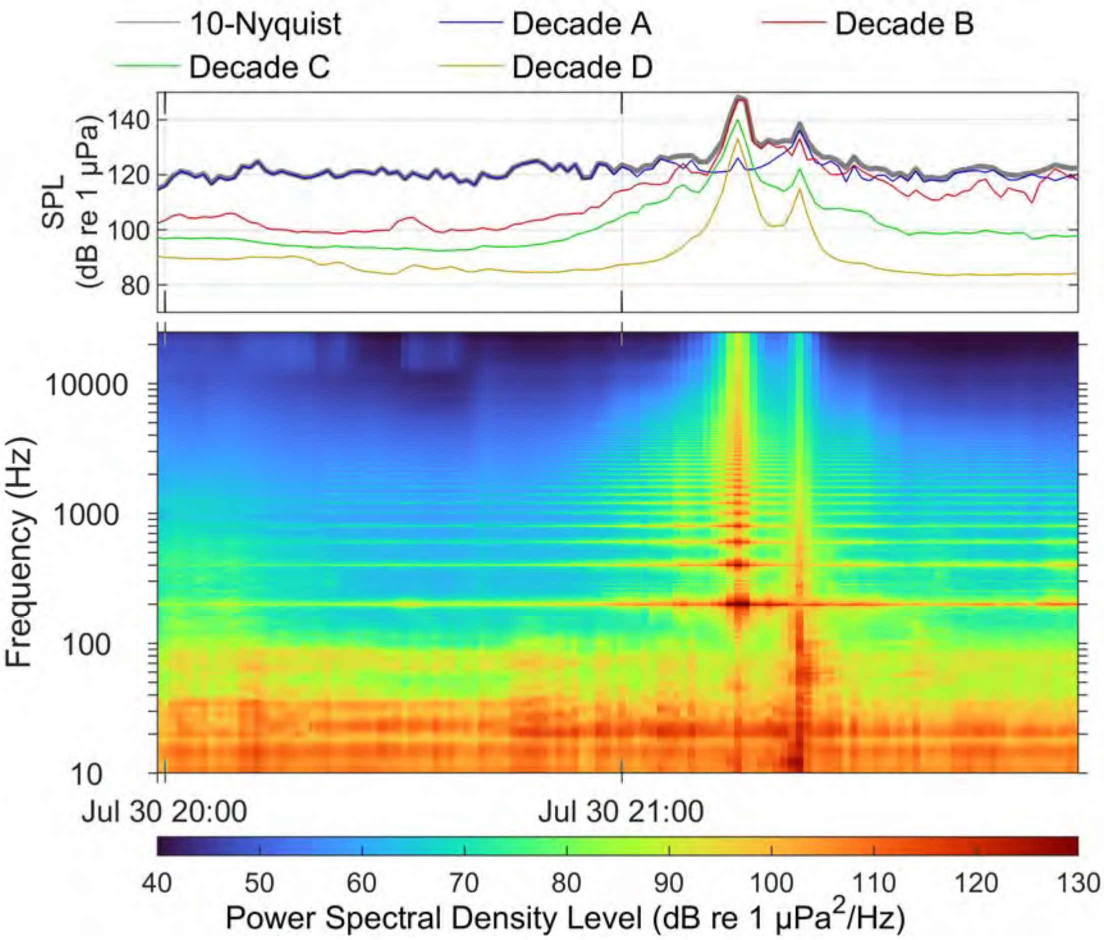


Figure C-33. AMAR-RI 30 Jul 2020: 1 vessel in escort, 0/10 ice concentration. Spectrogram and band level data.

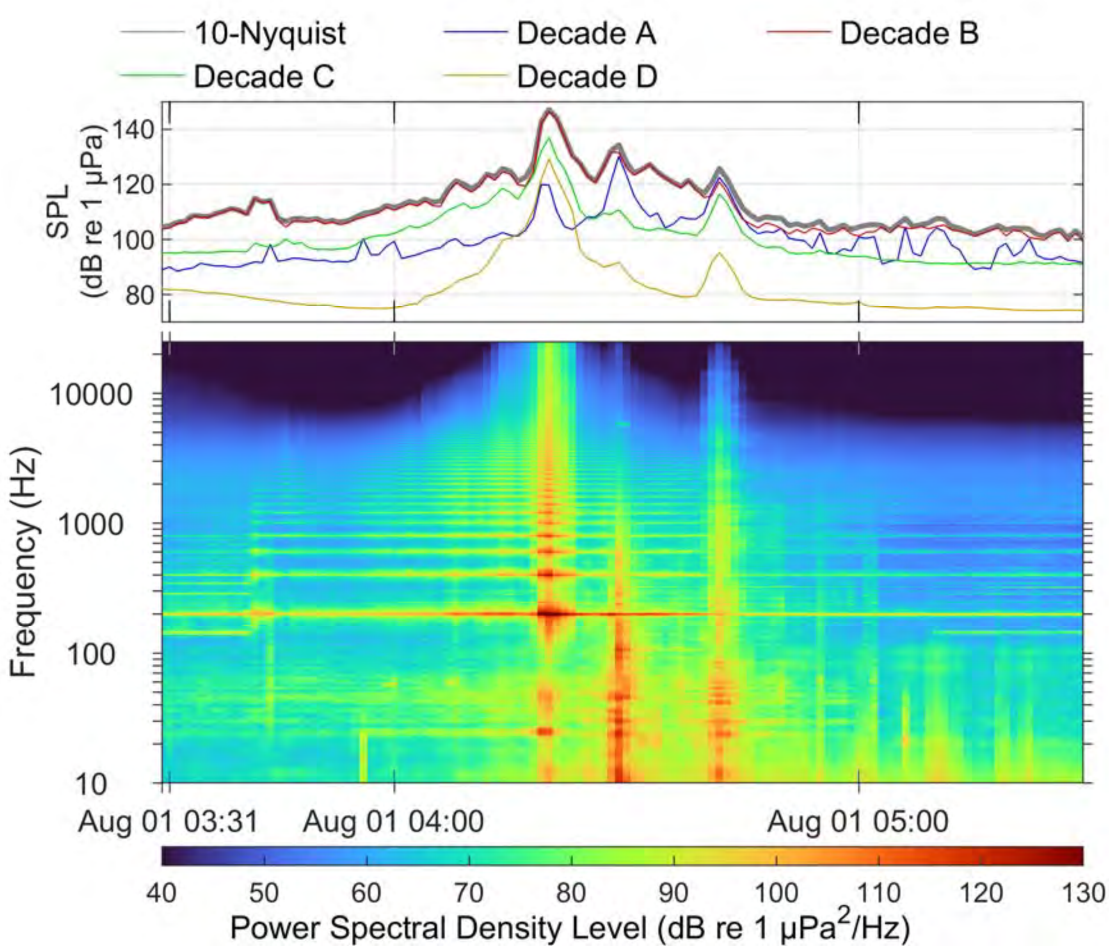


Figure C-34. AMAR-RI 1 Aug 2020: 2 vessels in escort, 0/10 ice concentration. Spectrogram and band level data.

Appendix D. Marine Environment Working Group Comments

D.1. Parks Canada

Name: Chantal Vis, Allison Stoddart, Jordan Hoffman

Agency / Organization: Parks Canada Agency

Date of Comment Submission: July 8th, 2021

#	Document Name	Section Reference	Comment	Baffinland Response
9	Underwater Acoustic Monitoring Baffinland Iron Mines Shoulder Season Shipping 2019-2020	Introduction (Section 1, page 2) “Facilitate assessment of the potential short term, long term, and cumulative effects of vessel noise on marine mammals and marine mammal populations.” “Improve understanding of local environmental processes and potential Project-related cause-and effect relationships.”	Does Baffinland plan to assess the sound pressure levels within biologically significant frequency bands (i.e., where communication and echolocation occur) for narwhal, seals, bowhead whales, and other marine mammal species to further contribute to assessing and preventing impacts from Project shipping activities? Is there potential that sound produced by marine mammals could be masked temporarily from icebreaking or vessel traffic? Are low frequency marine mammals (e.g, bowhead whales) more or less likely to be impacted than mid-frequency marine mammals (e.g., narwhal)?	Yes, Golder and UNB (academic partner) recently prepared a research paper on this topic, titled “Using auditory weighting functions to assess effects of underwater shipping noise on marine mammals in an Arctic inlet”. This paper is currently in review for publication. It is based on Golder’s recent work involving application of auditory weighting functions for different arctic marine mammal hearing groups to in-situ recorded noise levels along the Northern Shipping Route. Broadband sound pressure levels (SPL; 10 Hz-25 kHz) with auditory weighing functions applied were compared between periods of ship presence and absence (determined by AIS data) using noise levels from passive acoustic recorders. Audible distance and exposure duration were analyzed for each weighting function relative to vessel direction, orientation, and year of recording. Results demonstrated that weighting functions had significant effects on the perception of shipping noise in Milne Inlet. Bowhead whale experienced levels similar to unweighted broadband noise levels, but narwhal and ringed seal experienced much lower levels. Narwhal did not perceive noise from shipping unless ships were close (<3km) and ambient levels were sufficiently low. The differences in perceived noise exposure from

#	Document Name	Section Reference	Comment	Baffinland Response
				shipping between groups highlights the importance of accounting for hearing abilities when assessing the impacts of noise on marine mammals. No additional analysis of these data are planned at this time. Yes, there is potential that sound produced by marine mammals could be masked temporarily from icebreaking or vessel noise. This was considered in the icebreaking assessment, and this study has verified that the inputs used in the model for determining vessel noise impacts and the potential for Listening Range Reduction were conservative. Low frequency marine mammals are likely to be more impacted than mid-frequency marine mammals.
10	Underwater Acoustic Monitoring Baffinland Iron Mines Shoulder Season Shipping 2019-2020	Discussion and Conclusions	Does Baffinland plan to follow up on this study with a study to determine if sounds produced by marine mammals in the regional study area including narwhal, bowhead whales, and seals will potentially be masked by icebreaking noise at various ice concentrations?	No additional analysis of these data are planned at this time. Yes, there is potential that sound produced by marine mammals could be masked temporarily by icebreaking noise at various ice concentrations. This was considered in the icebreaking assessment, and this study has verified that the assumptions underlying the predictions of the impact assessment were conservative.

D.2. Qikiqtani Inuit Association

Name: Jeff Higdon, Bruce Stewart

Agency / Organization: Qikiqtani Inuit Association

Date of Comment Submission: 08 July 2021

#	Document Name	Section Reference	Comment	Baffinland Response
1	Austin, M. and T. Dofher. 2021. *Underwater Acoustic Monitoring: Baffinland Iron Mines Shoulder Season Shipping 2019–2020*. Document 02330, Version 1.0. Technical report by JASCO Applied Sciences for Golder Associates, Ltd. (file: P001348-006 2019-20 Shoulder Season Acoustic Monitoring Report.pdf)	General	How do the results inform monitoring and mitigation? For example, how can measured sound levels be used to establish species-specific disturbance thresholds for narwhal?	The results are intended to verify the predictions of the acoustic model that was used to inform the impact assessment. The impact assessment predictions resulted in the implementation of the icebreaker transit restrictions, to mitigate potential noise effects. These monitoring results can be used to provide confirmation that the assumptions and predictions that resulted in the implementation of the transit restrictions during icebreaking, were conservative. This gives confidence in the effectiveness of the mitigation in limiting the amount of time that narwhal are exposed to noise from the icebreaker within a day. Without corresponding behavioural observations of narwhal in the shoulder season, these data cannot be used in isolation to establish species-specific disturbance thresholds for narwhal. Baffinland intends to run a narwhal tagging program in 2022 that will capture behavioural response data during the ice-covered shoulder season that may further support this type of research.
2	Austin, M. and T. Dofher. 2021. *Underwater Acoustic Monitoring: Baffinland Iron Mines Shoulder Season Shipping 2019–2020*. Document 02330, Version 1.0. Technical report by JASCO Applied Sciences for Golder Associates, Ltd. (file: P001348-006 2019-20 Shoulder Season Acoustic Monitoring Report.pdf)	s. 1, pages 2-3	Figure 1 shows that the AMAR sites are not at the same locations as the modeled sites. How does this affect comparisons? Differences in propagation due to local differences in sea ice cover, bathymetry, distance to coast, etc?	The AMARs were located at sites where we had reasonable expectation that icebreaking would occur, based on historical ice charts and the timing when the AMARs would be recording. There was a low likelihood of icebreaking occurring at the Pond Inlet model site or at the Milne Inlet model site during the AMAR recording period, so the AMARs were not located at those sites. It is reasonable to expect the Eclipse Sound model results to be representative of the sound propagation at the AMAR locations. Note that the Model Sites are source locations (i.e. locations of the vessel), and the AMAR sites are receiver locations. The AMARs are located at sites that are within the

#	Document Name	Section Reference	Comment	Baffinland Response
				modelled sound footprints. We recorded sounds on the AMARs at times when the vessels were located at the model sites. Those measurements are directly comparable to the model estimates. The model estimates of the expected sound levels at the AMAR sites exceeded what was measured.
3	Austin, M. and T. Dofher. 2021. *Underwater Acoustic Monitoring: Baffinland Iron Mines Shoulder Season Shipping 2019–2020*. Document 02330, Version 1.0. Technical report by JASCO Applied Sciences for Golder Associates, Ltd. (file: P001348-006 2019-20 Shoulder Season Acoustic Monitoring Report.pdf)	s. 1.1, page 3	"The AMARs recorded underwater noise during all transits between that date [5 Oct 2019] and 17 Oct 2019, when they were pre-programmed to power down for winter." Did it capture the final transits out, or did they occur after the 17th?	There were transits that occurred after 17 Oct 2019, which the AMARs did not record. The AMAR recording schedules were programmed in advance of being deployed. They were programmed to turn off at the pre-determined date. This date was selected to optimize the amount of available recording time the following spring. There was not sufficient capacity to record throughout all of October, and again throughout the following July.
4	Austin, M. and T. Dofher. 2021. *Underwater Acoustic Monitoring: Baffinland Iron Mines Shoulder Season Shipping 2019–2020*. Document 02330, Version 1.0. Technical report by JASCO Applied Sciences for Golder Associates, Ltd. (file: P001348-006 2019-20 Shoulder Season Acoustic Monitoring Report.pdf)	s. 2.2, page 8	"Ice concentrations were obtained from Ship Board Observer logs for 2019 and from daily ice charts from the Canadian Ice Service (2020), validated by logs from vessel master's where available." How do the ice conditions reported in the 2019 SBO logs compare with 2019 CIS data in regards to ice concentration, i.e., are CIS chart data accurately reflecting conditions at operational scales?	Ice concentrations from the SBO logs were used to determine the local ice concentration at the AMAR location, in the vicinity of the vessel, during the analyzed transits. These SBO records cannot be directly linked to the CIS methodology for determining ice concentrations and they do not account for ice thickness or consolidation of floes. As such, these SBO observations are not used for making operational decisions based on ice conditions. These decisions are based on CIS data and assessments of the ice conditions from qualified ice analysts on board.

#	Document Name	Section Reference	Comment	Baffinland Response
5	Austin, M. and T. Dofher. 2021. *Underwater Acoustic Monitoring: Baffinland Iron Mines Shoulder Season Shipping 2019–2020*. Document 02330, Version 1.0. Technical report by JASCO Applied Sciences for Golder Associates, Ltd. (file: P001348-006 2019-20 Shoulder Season Acoustic Monitoring Report.pdf)	s. 2.2, page 8	"Measurements were also rejected if: other vessels were within six times the CPA for the MSV *Botnica*, the MSV *Botnica*'s speed fluctuated by more than three knots within the data window, or the MSV *Botnica* did not follow a relatively straight path." Information on source levels associated with speed fluctuations or route deviations could be important for mitigation. What is the rationale for removing these measurements from the analyses?	Those conditions are the standard requirements for the ShipSound analysis software to yield accurate estimates of a ship source level at a given transit speed and from a fixed aspect. In this context, the data window is relatively short. It is not possible to derive an accurate source level measurement if the speed changed dramatically or the vessel turned sharply within that analysis window. Nevertheless, no measurements were in fact rejected due to speed fluctuations, as speed fluctuations of greater than three knots did not occur within the data windows. Similarly, in this particular case no measurements were removed due to course deviations because the transits were measured while the vessels were instructed to follow a straight-line path over the AMARs. When measurements were rejected it was because of background noise or due to other vessels being nearby.

#	Document Name	Section Reference	Comment	Baffinland Response
6	Austin, M. and T. Dofher. 2021. *Underwater Acoustic Monitoring: Baffinland Iron Mines Shoulder Season Shipping 2019–2020*. Document 02330, Version 1.0. Technical report by JASCO Applied Sciences for Golder Associates, Ltd. (file: P001348-006 2019-20 Shoulder Season Acoustic Monitoring Report.pdf)	s. 3.1, page 11	"These results, and the plots in Appendix B, indicate that the extent and duration of ensonification above the 120 dB threshold increases by a small amount when additional vessels are added to the convoy, but not by amounts that exceed the variability between measurements of the MSV *Botnica* on its own in varying conditions (i.e. in different ice conditions or when travelling at different speeds). These results vary depending on the following factors: the spatial distribution of the vessels in the convoy, the speed of travel, the ice concentration, the sea state, and the vessel draft (also related to the vessel load) during the transits. A detailed noise correlation analysis of these factors was not within the scope of this report." Doing this detailed correlation analysis would provide useful data to improve mitigation. Are there plans for such an analysis? How would consideration of the removed measurements (e.g., due to speed changes or vessel deviations) influence the extent and duration of ensonification?	There are currently no plans to perform a detailed noise correlation analysis due to the relatively small size of the data set for such an analysis. No measurements were actually excluded due to speed fluctuations or course deviations during the source level calculation analysis window.
7	Austin, M. and T. Dofher. 2021. *Underwater Acoustic Monitoring: Baffinland Iron Mines Shoulder Season Shipping 2019–2020*. Document 02330, Version 1.0. Technical report by JASCO Applied Sciences for Golder Associates, Ltd. (file: P001348-006 2019-20 Shoulder Season Acoustic Monitoring Report.pdf)	3.1, pages 19-22	For the Bylot Island recorder data, the forward vs aft difference in distance to 120 dB is ca. 3 to > 5 times (i.e., much further at aft). The differences in aft vs forward distances are much less pronounced for the Ragged Island recorder, which also seems more variable, with several transits even showing a longer range forward (vs aft). What factors (topography, bathymetry, etc) could explain these differences, and how can it inform mitigation?	The bathymetry in Eclipse Sound is not very well defined so it is difficult to determine specifically what factors explain these differences. However, it is recognized that bathymetric effects are likely to be a causing factor. At present, these data do not point to a need for additional mitigation measures. At both AMAR sites, the measured sound propagation distances are less than those predicted through modelling and used to inform the impact assessment.

#	Document Name	Section Reference	Comment	Baffinland Response
8	Austin, M. and T. Dofher. 2021. *Underwater Acoustic Monitoring: Baffinland Iron Mines Shoulder Season Shipping 2019–2020*. Document 02330, Version 1.0. Technical report by JASCO Applied Sciences for Golder Associates, Ltd. (file: P001348-006 2019-20 Shoulder Season Acoustic Monitoring Report.pdf)	s. 3.2, pages 24-25	The draft report says "[t]he modelled estimates exceed all of the measured durations shown in Section 3 (summarized in Table 13)". The modelled distance to the 120 dB disturbance onset for an icebreaker at 9 knots in open water (0/10 ice concentration) was 6.2 km (Table 12). However, the measured distance for the *Botnica* travelling in open water at 5.8-8.4 knots ranged from 2.0 to 20.1 km. This is a pronounced difference in relation to all other available comparisons. The report does indicate that measured exposure periods were lower than modelling estimates "except for the case of the icebreaker transiting through open water with no vessels in escort". It isn't clear from the draft report as to why this might be the case. The Discussion (s. 4, page 26) does note that the icebreaker noise emissions "exhibit many strong tones that are atypical of other vessel classes". Additional information on what this means for mitigation and adaptive management are requested.	Baffinland has agreed to look into possible vessel-specific measures that could mitigate the noise output of the Botnica, and would potentially consider replacing the Botnica with a quieter icebreaking vessel in the future if warranted. At this time, there is insufficient evidence that the noise from Botnica warrants additional mitigation beyond the transit restrictions and restrictions on icebreaking activity frequency that are already implemented.
9	Austin, M. and T. Dofher. 2021. *Underwater Acoustic Monitoring: Baffinland Iron Mines Shoulder Season Shipping 2019–2020*. Document 02330, Version 1.0. Technical report by JASCO Applied Sciences for Golder Associates, Ltd. (file: P001348-006 2019-20 Shoulder Season Acoustic Monitoring Report.pdf)	s. 4, page 26	"The underwater noise emissions of the icebreaker MSV *Botnica* exhibit many strong tones that are atypical of other vessel classes. This is thought to be due to an unusual engine configuration on the MSV *Botnica*, consisting of 12 main diesel engines and 4 stroke diesel secondary power generators. The blade rates in the sound signature are loud with many harmonics. These features make the MSV *Botnica* noise easily distinguishable from that of the other vessels monitored." How can results such as those reported here be used to inform vessel-specific mitigation for the MSV *Botnica*? Are "quieter" icebreaking vessels available?	See response to Comment 8.

#	Document Name	Section Reference	Comment	Baffinland Response
10	Austin, M. and T. Dofher. 2021. *Underwater Acoustic Monitoring: Baffinland Iron Mines Shoulder Season Shipping 2019–2020*. Document 02330, Version 1.0. Technical report by JASCO Applied Sciences for Golder Associates, Ltd. (file: P001348-006 2019-20 Shoulder Season Acoustic Monitoring Report.pdf)	s. 4, page 26	"The duration calculations presented in this report can be used to estimate cumulative noise exposure from multiple transits on marine mammals by multiplying the computed per-transit exposure durations by expected numbers of daily transits with convoys of between 0 and 4 vessels with an icebreaker in Eclipse Sound. This contributes toward the objective from the Project Certificate Terms and Conditions to "Facilitate assessment of the potential short term, long term, and cumulative effects of vessel noise on marine mammals and marine mammal populations."." Is the Proponent planning to use these data to estimate cumulative noise exposure as required by the Project Certificate Terms and Conditions?	Cumulative noise exposure on marine mammals from multiple icebreaker escort transits in the RSA within a daily period have already been presented in Table 10 of Golder's technical memorandum entitled 'Summary of Results for the 2019 Marine Mammal Monitoring Programs' (Golder 2020). Values presented in Table 11 are based on measured acoustic data in open-water conditions and modelled data for open-water and ice covered conditions. Given that only one icebreaker transit is permitted when ice conditions in the RSA are ≥6/10, there is no need to calculate cumulative noise exposure from multiple icebreaker transits under these ice conditions, because only one transit per day is possible. For ice conditions >3/10 but <6/10, only two icebreaker transits are permitted per day. Therefore, all that is required to determine the daily cumulative noise exposure from multiple icebreaker transits in these ice conditions is to double the 'measured' per-transit noise exposure duration (based on measured data, this would be on the order of <2 hours per day – see Table 13 in JASCO's 2020 Report). This has been clearly articulated to the NIRB and to MEWG members during the Phase 2 Technical Meetings and Final Hearing sessions. In summary, measured acoustic data has already been used to estimate the cumulative noise exposure on marine mammals in the RSA from multiple transit exposures and therefore the relevant Term and Condition from Project Certificate No. 05 has been met. No further analysis is currently planned for these data. Golder. 2020. Summary of Results for the 2019 Marine Mammal

#	Document Name	Section Reference	Comment	Baffinland Response
				Monitoring Programs. 25 May 2020. Technical Memorandum 1663724-186-TM-Rev3-38000. 73 p.

D.4. Fisheries and Oceans Canada

Name: Marianne Marcoux

Agency / Organization: Fisheries and Oceans Canada

Date of Comment Submission: July 9, 2021

#	Document Name	Section Reference	Comment	Baffinland Response
20	Underwater Acoustic Monitoring Baffinland Iron Mines Shoulder Season Shipping 2019–2020	p. 10 figure 5	How do you explain why the source noise level of the Botnica were more elevated in the 0/10 ice conditions than in the 9/10 ice conditions? (165 vs 159; according to the equations in the figure)	The Botnica was transiting at 7.8 knots in the 0/10 ice conditions, and at only 5.4 knots in the 9/10 ice conditions. The slower transit speed likely resulted in the lower sound levels, despite this being a transit through ice.

21	Underwater Acoustic Monitoring Baffinland Iron Mines Shoulder Season Shipping 2019–2020	p.23 3.2. Comparison of measurements to modelled estimates	The comparison between the modelled and measured noise areunder different ice conditions as well as different speed. It makes isdifficult to compare between the two.	The specific transit speeds and ice concentrations selected for the modelling were intended to be representative of a range of real-world conditions. When comparing model estimates to measured data we assume that the modelling for 0/10 ice would be representative for 0/10-2/10 ice conditions, modelling for 3/10 ice would be representative for 3/10-6/10 and modelling for 10/10 would be representative for 7/10-10/10 ice conditions. Also, sound levels from vessels transiting at speeds within approximately 1 knot of the modelled transit speed (in similar ice conditions) should be reasonably comparable. It is impractical to expect to be able to collect measurements at exactly the same transit speeds and ice concentrations as modelled when conducting opportunistic measurements of operational activities. Underwater acoustic monitoring during the shoulder seasons will continue in the future, providing a larger collection of measurements in varying conditions and speeds that may more closely match the modelled inputs.
22	Underwater Acoustic Monitoring Baffinland Iron Mines Shoulder Season Shipping 2019–2020	4. Discussion and Conclusion p.26	It might be interesting to reportsounds level higher than 120 dB(i.e. 130 abd 140 dB). This insformation woud help to gain insight into the avoidance threshold of narwhals. The report also point out that the Botnica emitted Intermittent burstsof noise that are louder. These noise	Narwhal at close ranges to the Botnica could have experienced sound at levels exceeding 120 dB. However, without corresponding information about the narwhal behaviour at the time of exposure, it is not clear how this acoustic information alone would give any further insight into the avoidance threshold of narwhals.

			burse might reach the avoidance level for narwhals.	
23	Underwater Acoustic Monitoring Baffinland Iron Mines Shoulder Season Shipping 2019–2020	4. Discussion and Conclusion p.26	It is noted that the Botnica noise signature contain energy is higher frequencies than expected and then what was modelled impact assessment. How does this information change the predictionsabout masking based on the model? Will you conduct an assessment of masking based on this new data?	There is not presently a plan to conduct an additional assessment of masking based on these data. The 2019 passive acoustic monitoring report already contained an assessment of listening range reduction during the shoulder seasons, which included recordings of the Botnica (in open water). There is potential that sound produced by marine mammals could be masked temporarily by icebreaking noise at various ice concentrations. This was considered in the icebreaking assessment, and this study has verified that the assumptions underlying the predictions of the impact assessment were conservative.

D.5. Oceans North

Name: Kristin Westdal

Organization: Oceans North

Date of Comment Submission: July 8, 2021

#	Document Name	Section Reference	Comment	Baffinland Response
15	Underwater Acoustic Monitoring: BIMC Shoulder Season Shipping 2019-2020		Are the 2020 open water season results included in this report? If so, where?	Results from the 2020 open water season results will be presented in a separate report currently scheduled for delivery in Q4 2021.
16	Underwater Acoustic Monitoring: BIMC Shoulder Season Shipping 2019-2020		What are the received levels from project ships at distances associated with observed behavioural disturbances?	This data is not currently available. Baffinland intends to run a narwhal tagging program in 2022 that will capture behavioural response data during ice-covered shoulder season periods that may further support this type of research.

17	Underwater Acoustic Monitoring: BIMC Shoulder Season Shipping 2019-2020	Page 10 Figure 5	Relevant received levels are difficult to evaluate based on the y-axis scale. This makes it difficult to see the relevant received levels. The key received levels are from just below 100-140dB. It is unclear why received levels to 50dB are included. Please provide a version with a focus on received levels where behavioural disturbance and avoidance are known to occur based on BIMC behavioural studies.	Figure 5 is an example plot presented only to demonstrate the curve fitting approach that was used to derive the distances presented in the report. The information requested is already provided in Figures in Appendix B and C.