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Karen Costello
Executive Director
Nunavut Impact Review Board
Sent to: info@nirb.ca

Sept. 4, 2020

Re: *Comments on the Draft Technical Meeting Agenda for the Baffinland Iron Mine Corp's Phase 2 Proposal*

Dear Ms. Costello,

Thank you for the opportunity to comment on the Draft Technical Meeting Agenda for the Baffinland Iron Mine Corp's Phase 2 Proposal. Overall, we believe the agenda can benefit from more clarity, and question if the time allotted will be adequate for the nature and quantity of technical issues from intervenors.

Our comments have been separated out by each day in the Draft Agenda followed by a General Comments section. Appendix A is the Oceans North response to the Draft 2019 Annual Report, and Appendix B is the document, *Draft Passive Acoustic Monitoring of Underwater Radiated Noise from Ships in Eclipse Sound, Nunavut (2018-2019)* from Joshua M. Jones - Marine Physical Laboratory at the Scripps Institution of Oceanography. This is the report that informed our response to the 2019 Draft Annual Report. We provide it here for reference, and look forward to technical discussions with the proponent, regulators, community representatives, and other intervenors to add to its finalization.

Meeting Attendees from Oceans North will be any of the following:

Amanda Joynt, Policy Advisor, Oceans North

Joshua Jones, Marine Research Scientist, Scripps Institute of Oceanography

Chris Debicki, Vice-President, Policy Development and Counsel

Georgia MacDonald, Researcher, Oceans North

Request for Specific Logistical Arrangements

1. Due to technical nature of our comments, Oceans North proposes a 10 minute presentation from Joshua Jones of the Scripps Institute of Oceanography and Amanda Joynt of Oceans North to clarify the technical issues around marine noise measurement and thresholds, as well as marine mammal responses to noise. These are detailed in our response to the 2019 Draft Annual Report (Appendix A attached), as well as in the Highlights section of Appendix B, but we feel it may be helpful to all parties to hear a background of the topic so our questions and concerns are more easily understood in the context of the data provided .

2. From experiences within the Marine Environmental Working Group as well as other meetings, we feel it is important to ensure proponent presentations provide only information essential to the meeting at hand, and that the agenda be refocused on intervenors' technical questions and concerns.

3. As a format to ensure everyone is able to engage in the process, we suggest a round table approach with a time limit for Round 1 (10-15 minutes per party), then an optional Round 2 for parties who require more time.

4. We suggest that Day 5 be scheduled as a full day, with an option to cut short the day if appropriate.

5. We suggest that providing simultaneous Inuktitut/English translation is essential to this process, and suggest the NIRB explore additional ways (recordings, video) to ensure all of the meeting is accessible to communities. We are concerned that due to the lack of opportunities to speak in a group setting, community members have not been able to hear and understand issues from regulators and intervenors at other meetings, and we want to ensure the issues are clear to everyone.

6. We suggest that someone from NIRB be listening to the translations on the phone to ensure clarity, and ask for a re-translation if the transmission was unclear. This was a major problem at the recent Marine Workshop. Another option is the facilitator could check in with community members and intervenors receiving translation to ensure the translation was understood.

7. We suggest that a commitment list be compiled at the end of each day. To avoid conflicting statuses regarding commitments, consensus between the proponent, NIRB, and the requesting intervenor should be discussed on the status of the commitment prior to entering it into the table.

Comments on Agenda

Day 1

Point 2a(ii) raises concerns around the 'resolved' designation. We recommend clarifying prior to the technical meeting which tables will be used, or which issues are deemed resolved by both parties. For example, we recommend using Document 200811-08MN053, the Amended GoC Disposition Table – IA1E, as well as letters and comments from previous submissions to create a list of issues to be discussed.

Points 2b and 2c require clarification. Are there specific technical issues brought by intervenors or regualtors on these topics? What are the sub-themes within operational flexibility and alternative assessment? What types of topics will be presented?

Day 2

We suggest that Point 2a*, Incorporation of Inuit Qaujimaningit/Use of Inuit knowledge in developing significance determination and monitoring programs and findings* (*20 minutes presentation by Baffinland*) be moved to Day 1, as IQ is applicable to both land and marine issues.

We suggest that 2b(i), *Marine Workshop Update* be moved and included in Day 1, 2a(iii*), Current update on community engagement and responses from communities.*

Day 4

Points 2c and 2d, *cumulative effects and monitoring and management*, may be included in other concerns, such as Day 2 2b, *marine wildlife and related monitoring and mitigation; including anchorage alternative at Hellefiske bank (Greenland).* Separating these issues out may be impractical. We suggest that these issues be incorporated into Day 2, and that any continuation of Day 2 discussions occur on Day 4.

Day 5

We suggest that Point 2 be changed to list of commitments as determined by regulators and intervenors.

General Comments

In 2018, when Northern Affairs Minister Dominic LeBlanc and Crown-Indigenous Affairs Minister Carolyn Bennett overrode the NIRB recommendation and allowed for an increase of up to 6MT for 2018 and 2019, they noted that "*the impacts of the production increase need to be more broadly examined during the Phase 2 reconsideration, and it will be important to integrate the experience, knowledge and data gained over the course of the next two production years into that review process.*"

Discussions of the monitoring reports and annual reports submitted after the November

2019 hearings and into 2020 should be of paramount importance in the Phase 2 Technical Meeting. To this end, the Marine Environmental Working Group is awaiting responses to their June comments on the *Draft 2019 Annual Report*. We suggest that the data provided in these reports is not yet integrated into the original Phase 2 proposal, and should be a part of these Technical Hearings. We expect that these technical hearings will create commitments from the proponent to follow the Ministerial recommendation and integrate the last two years into the submissions for the Phase 2 Hearings.

In addition, we suggest that discussions on how certain technical issues link to the Inuit Certainty Agreement should be discussed in the Technical Meeting. This includes issues surrounding how the Culture, Resources and Land Use Assessment's phased approval will be integrated into the Phase 2 Monitoring and Adaptive Planning frameworks.

Oceans North is deeply concerned about the differences between the legal ICA document and the misleading statements presented to HTOs in the 'Highlight Document,' such as the statement that *"the Culture, Resources, and Land Use Assessment will be conducted before any major construction begins."* This statement implies a completed CRLU Assessment prior to major construction, and contradicts the legal ICA document which states, "*The parties agree that one or more Major Construction Activities may proceed following the achievement of a Milestone Task as identified in the agreed upon Joint CRLU Assessment Work Plan*." Therefore it is implied the CRLU assessment and major construction will occur simultaneously. If the CRLU assessment is conducted in tandem with Major Construction activities, then the assessment cannot effectively influence the construction process or development trajectory should unacceptable negative impacts be identified. With a phased approach, the potential role the CRLU assessment could have in preventing these impacts is undermined. We look forward to clarifying these issues in the Technical Meeting.

Thank you for the opportunity to comment on the Draft Technical Meeting Agenda, we look forward to participating.

Sincerely,

(original signed by Amanda Joynt)

Amanda Joynt
Policy Advisor
Oceans North

Appendix A

Oceans North Comments on Draft 2019 Baffinland Annual Report

Name: Amanda Joynt

Agency / Organization: Oceans North

Date of Comment Submission: June 13, 2020

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

#	Document Name	Section Reference	Comment	Baffinland Response
1	Draft 2019 Passive Acoustic Monitoring Program Report	Section 2.4	When evaluating auditory masking in marine mammals resulting from man-made noise, a common approach is to estimate the loss of area within which effective hearing of acoustic signals can occur. For example, Listening Space Reduction (LSR) has been employed in several published studies evaluating acoustic masking in Arctic marine mammals (e.g. Hannay *et al.,* 2016; Mathews *et al.*, 2016; Pine *et al.*, 2018). "Listening range reduction" (LRR) has been introduced by the proponent for the purpose of this effects assessment. It is estimated by modifying the published LSR equation to give the change in radius (i.e. range from the listener) rather than area. For example, a 50% and 90% reduction of 'listening range' yields a 75% and 99% reduction in listening space, respectively.	

#	Document Name	Section Reference	Comment	Baffinland Response
			A simplified diagrammatic example has been included in these comments (Figs. 1 below). Evaluating masking in this way may understate the effect of ship noise and makes comparison with previous published research more difficult. Section 2.4 suggests that Listening Range Reduction is more 'intuitive.' Please clarify why this measurement was created and why the more common method consistent with previous published literature, Listening Space Reduction, is not being applied. Please provide results in context of LSR or make clear the difference in the results produced by this novel method of masking estimation when compared to previously published studies elsewhere.	
2	Draft 2019 Passive Acoustic Monitoring Program Report	Section 2.4 p.18 Eqn. 1 (Listening range reduction) Section 2.2.1 p.26 (sound spectrum level percentile plots; Fig 18) Section 1.0, pg. 5. Objective of the Report: "Estimate the extent of listening range reduction (LRR) associated with vessel transits along the Northern Shipping Route relative to ambient noise conditions"	Listening Space Reduction is a function of the change in noise added by the ship (NL_2; Sect2.4 Eqn.1) over some reference level of 'background' noise (NL_1; Sect2.4 Eqn.1). Estimates of LSR are sensitive to the difference (NL_2-NL_1). For example, a 10 dB increase in noise is the difference between LRR 50% and LRR 90% (*i.e.* LSR75% and LSR99%; Fig 1 below).	

#	Document Name	Section Reference	Comment	Baffinland Response
			NL_1 is defined (Sect. 2.4 p.18) from "the maximum of the mid-frequency cetacean audiogram (see Table A-9 in Finneran 2015) or the median 1-minute SPL without vessels in each of the 1/3-octave-bands of interest. Please provide the actual dB values used to define NL_1 for each recording site. These values should include the median 1-minute SPL without vessels and the specific values used from the mid-frequency cetacean audiogram for each of the 1/3rd octave bands assessed. Using a single background noise reference level that is lower than actual noise levels about half the time (50th percentile) may result in assuming a larger value for NL_2-NL_1 more often than occurred relative to noise levels at the time of each ship transit. This overestimation of LSR levels may especially occur during the months of Sept and Oct with higher average background noise levels caused by increased wind-driven surface noise in the frequency bands of interest. Again, a single averaged reference noise level does not account for these relatively 'noisy' periods and may make it more difficult to identify LSR caused by ship transits vs. natural noise when ships are not present.	

#	Document Name	Section Reference	Comment	Baffinland Response
			Please provide evaluation of LSR under different noise conditions. For example, Pine *et al.,* (2018) estimate LSR for container ship transits under 'noisy' and 'quiet' ambient noise conditions. Without this, we may often overestimate LSR occurring due to the addition of ship noise and it's difficult to understand what the range of LSR effects may be under normal environmental conditions. An example of two general cargo vessel transits with LSR estimated using median and 90th percentile background noise is provided in Fig 5 below (adapted from Jones, 2020). What steps are taken to avoid long-range ship noise entering 'background' noise periods used to estimate ambient noise for NL_1 in LSR calculations? How far are the ships away during background noise periods? As defined in this report, it is not clear that recording periods 'without ships' do not include <200 Hz noise from ships, propagating over large distances.	
3	Draft 2019 Passive Acoustic Monitoring Program Report	Figure 24, page 30.	What are the characteristics of underwater noise levels recorded by the proponent from all project-related vessels (e.g. bulk carrier, general cargo, tanker, tug)? For reference and as an example, Table 1 below (from Jones 2020) includes	

#	Document Name	Section Reference	Comment	Baffinland Response
			some noise measurements for 4 common types of project-related vessel. The noise levels reported should be accompanied by some context regarding ship characteristics wherever possible.	
4	Draft 2019 Passive Acoustic Monitoring Program Report	Table 11	Model results for ranges to lower broadband received sound pressure levels SPL_{BB} than 120 dB have been requested by DFO (e.g. 110, 115 dB). What are the distances to transiting ships when measured received levels were > 110dB for each of the project vessel types? Modelled versus measured ranges should be included in this report for each different project-related ship type. There should be a table showing these ranges in the report. An example of two transits of project-related general cargo vessels is provided in Figures 2-4 below (figures adapted from Jones, 2020) .	
5	Draft 2019 Passive Acoustic Monitoring Program Report	1.0, pg. 5. Objective of the Report: "Estimate the extent of listening range reduction (LRR) associated with vessel transits along the Northern Shipping Route relative to ambient noise conditions"	The number of transits and how many vessels travelled within the project area is not clear. Periods when vessels were detected does not translate easily into transits and therefore needs context provided by other data such as AIS messages. This helps to understand the relationship between ship type and received level and to better evaluate cumulative impacts of ship noise.	

#	Document Name	Section Reference	Comment	Baffinland Response
			We cannot estimate Phase 1 or proposed Phase 2 impacts without understanding the current and proposed number of transits and types of ships. To estimate impacts, especially if Phase 2 goes forward, the number and type of ship transits should be determined ahead of time as much as possible.	
6	Draft 2019 Passive Acoustic Monitoring Program Report	Sect 3.1.2.1 Figures 20 and 25.	What is the definition of "detected vessels passing the recorder" (Sect 3.1.2.1 p.28 Fig 20, 25)? Is it a period when multiple vessels were present or is it one individual transit of one vessel? To evaluate the relationship between number of vessel transits daily and reported noise levels it would be helpful to have an understanding of the degree to which multiple vessel transits are included in each 'detection'.	
7	Draft 2019 Passive Acoustic Monitoring Program Report	Figure 18 (p.26)	Low-frequency ambient noise median sound spectrum levels below 100 Hz are > 10 dB less than reported for other areas of the Arctic with similar depth (e.g. AMAR-3 and AMAR-BI compared to Roth *et al.*, 2012). What is the explanation for this divergence from expected ambient noise level? This is important to understand as, for example, a systematic underestimate of SPL_{BB} 120 dB occurrence or overestimate of LSR (LRR)	

#	Document Name	Section Reference	Comment	Baffinland Response
			for low frequencies (e.g. ringed seal, bowhead whale) could result from the undermeasurement of noise levels in these frequencies.	

REFERENCES

Hannay, D., Hatch, L., and Harrison, J. (2016). Lost listening area assessment of anthropogenic sounds in the Chukchi Sea. J. Acous. Soc. Am. 140, 3072.

Mathews, M.-N.R., Schlesinger, A., and Hannay, D. (2016). Cumulative and chronic effects in Beaufort and Chukchi Seas: Estimating reduction of listening area and communication space due to seismic and exploratory drilling activities in support of NMFS PEIS. JASCO Doc #01072. Tech. Rep. By JASCO Appl. Sci. AECOM.

Pine, M. K., Hannay, D. E., Insley, S. J., Halliday, W. D., and Juanes, F. (2018). Assessing vessel slowdown for reducing auditory masking for marine mammals and fish of the Western Canadian Arctic. Mar. Poll. Bul. 135,290-302.

Roth, E. H., Hildebrand, J. A., and Wiggins, S. M. (2012). Underwater ambient noise on the Chukchi Sea continental slope from 2006-2009. J. Acous. Soc. Am. 131(1), 104-110.

Wiggins, S. M. and Hildebrand, J. A. (2007). High-frequency Acoustic Recording Package (HARP) for broad-band, long-term marine mammal monitoring. Int'l Symposium on Underwater Technology 2007 and International Workshop on Scientific Use of Submarine Cables and Related Technologies 2007. Institute of Electrical and Electronics Engineers, Tokyo, Japan. 2007.

FIGURES

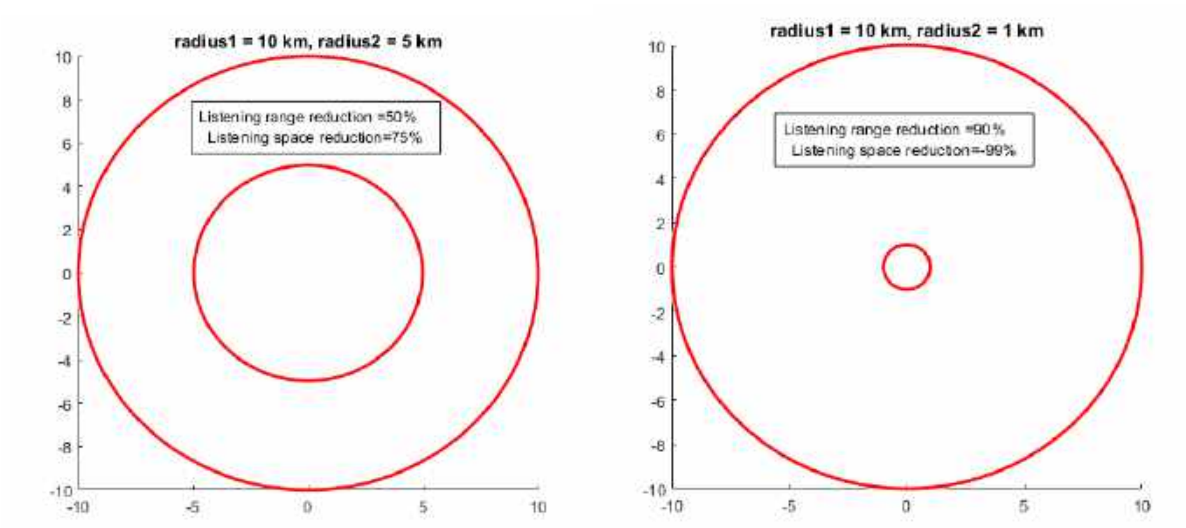

Figure 1. Listening range reduction (LRR) and corresponding listening space reduction (LSR). LRR 50% exemplified by a reduction of listening range from 10 km to 5 km (left) results in 75% LSR (left). LRR 90% exemplified by a reduction of listening range from 10 km to 1 km (right) results in LSR 99%. Relative changes in noise level from background (NL_2-NL_1; Pine *et al.*, 2018) corresponding to LRR 50% and 90% are apx. 5 dB and 15 dB, assuming simple cylindrical propagation loss (N=15; Section 2.4 p.18 Eqn. 1).

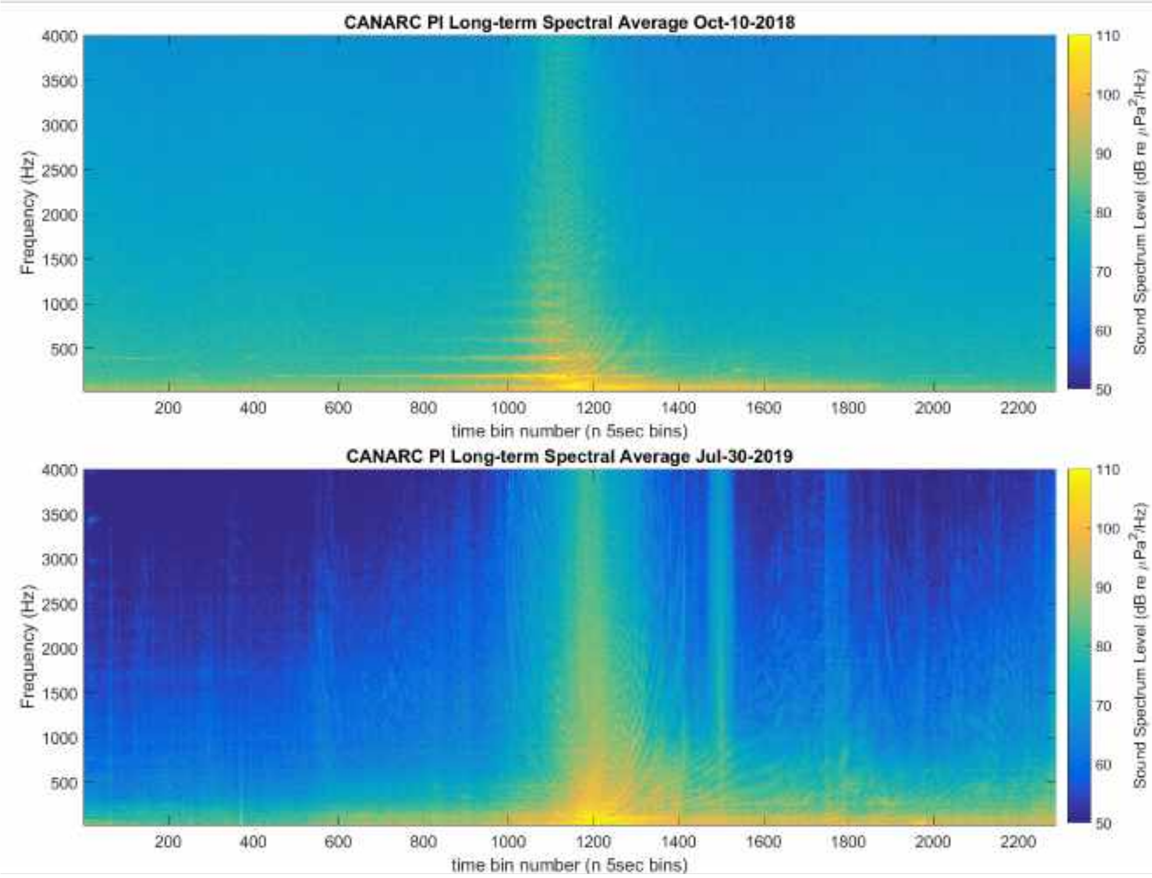

Figure 2. Long-term spectral average (LTSA) of the 6-hour window about the closest point of approach (CPA) of two general cargo vessels transiting past the PI recording site. Recording location eastern Eclipse Sound; recorder/hydrophone depth 670 m; recorder type High-frequency Acoustic Recording Package (HARP; Wiggins and Hildbrand, 2007). Pre Top) 139 m general cargo vessel, Zelada Desgagnes (MMSI 316015133) October 10, 2019. Wind-generated noise below 4 kHz is evident throughout the transit. Bottom) 138 m general cargo vessel Claude Desgagnes (MMSI 316003010) on Jul 30, 2019 during lower background noise conditions. Both transits occur in 0/10 satellite sea ice cover within 15 km of the recording site, although new ice was in early stages of formation in eastern Eclipse Sound during Oct 10, 2018 (Jones personal observation).

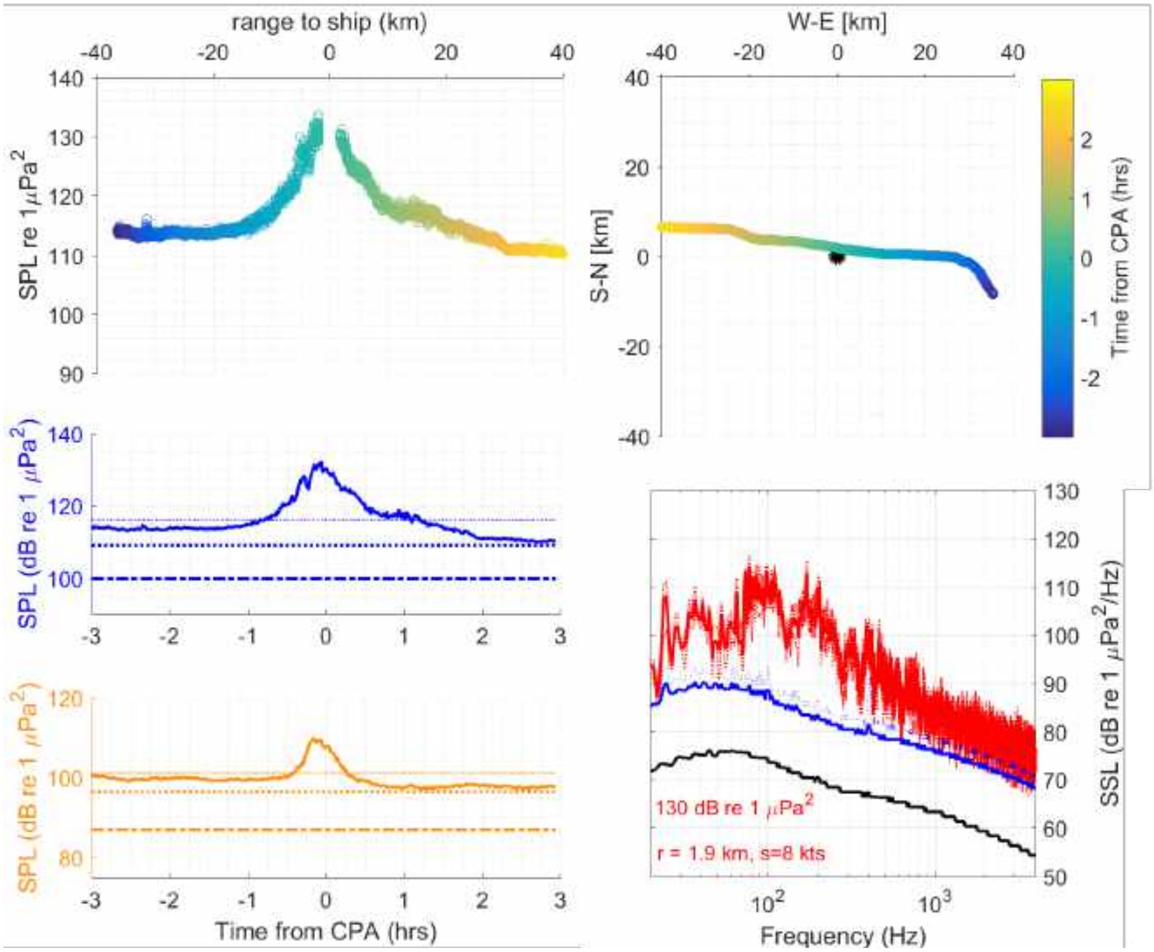

Figure 3. Ship transit analysis for general cargo vessel, Zelada Desgagnes (MMSI 316015133) October 10, 2018 in 'noisy' conditions. Pre-CPA background SSL (bottom right; blue line) 10-15 dB above median background noise (black line) at all frequencies. Broadband sound pressure level (SPL_{BB} 20-4000 Hz) averaged every 5s (top left) and 5-min median (middle left; blue line) increases above pre-CPA SPL_{BB} 113 dB apx. 1 h prior to transit CPA at range 15 km, increasing more rapidly within 30 min of the closest point recorded (CPR; range 1.9 km and max. SPL_{BB} 130 dB re 1 μPa^2. Colors in SPL scatter plot and map showing ship track (top right) represent time from CPA (5s bins). 5-min median received SPL for the 20-4000 Hz band (middle left; blue line) and the 1 kHz 1/3rd octave band (bottom left; orange) during ship transit plotted with 50th (dash-dot line), 90th (dotted line), and 99th (upper dotted line) percentile levels without ships (background levels). Panel d) Sound spectrum level (SSL) of CPR period (red) with median SSL of the 1st 30 min of transit plot (blue) and shipping season median background sound levels during periods without ships (black).

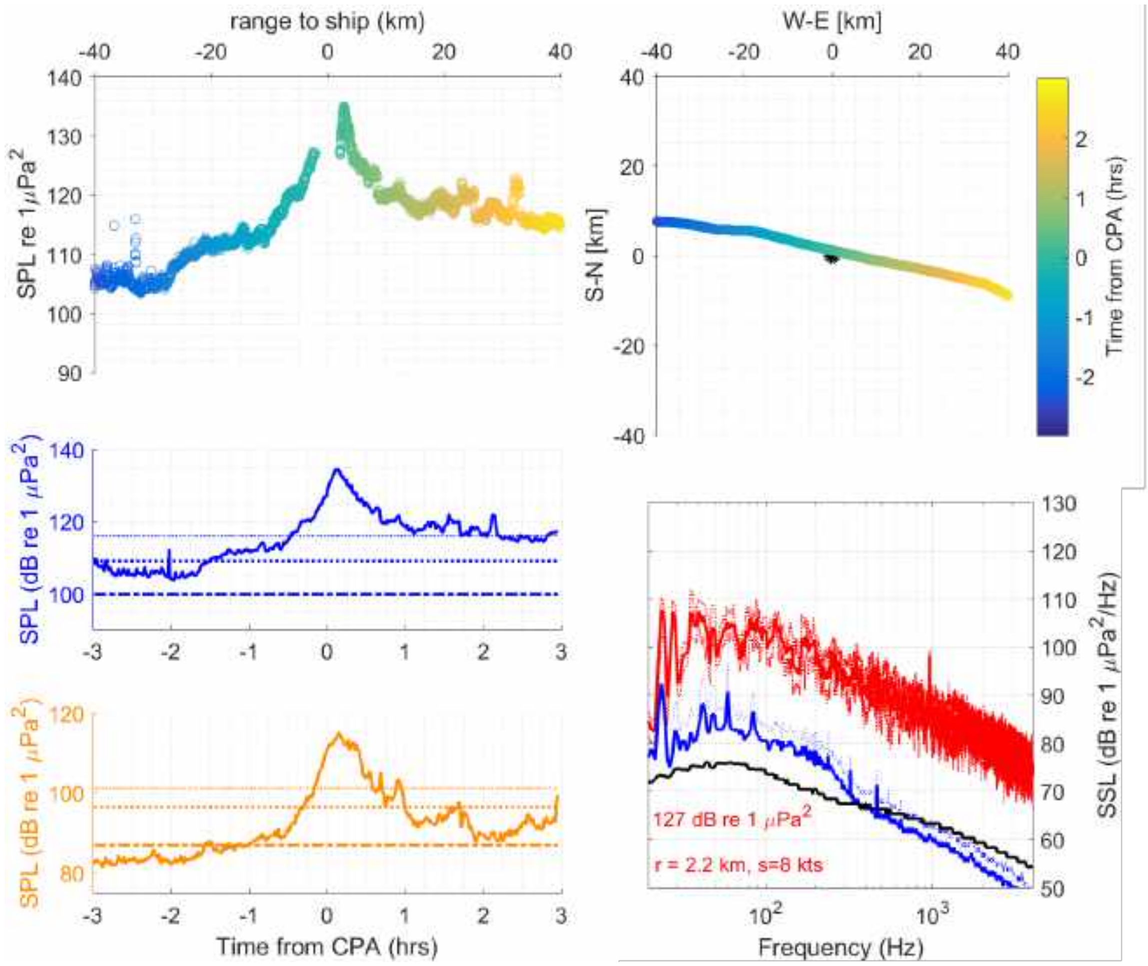

Figure 4. General cargo vessel Claude Desgagnes (MMSI 316003010) July 30th, 2019. Pre-CPA background SSL (bottom right; blue line) 5-10 dB above median background noise (black line) at 20-300 Hz and lower than median above 200 Hz. Broadband sound pressure level (SPL_{BB} 20-4000 Hz) averaged every 5s (top left) and 5-min median (middle left; blue line) increases above pre-CPA SPL_{BB} 105 dB at apx. 2 h prior to transit CPA at range 25 km, increasing more rapidly within 45 min of the closest point recorded (CPR; range 2.2 km and max. SPL_{BB} 127 dB re 1 μPa^2. Colors in SPL scatter plot and map showing ship track (top right) represent time from CPA (5s bins). Middle left) 5-min median received SPL for the 20-4000 Hz band (blue) and the 1 kHz 1/3rd octave band (bottom left; orange) during ship transit plotted with 50th (dash-dot line), 90th (dotted line), and 99th (upper dotted line) percentile levels without ships (background levels). Bottom right) Sound spectrum level (SSL) of CPR period (red) with median SSL of the 1st 30 min of transit plot (blue) and shipping season median background sound levels during periods without ships (black).

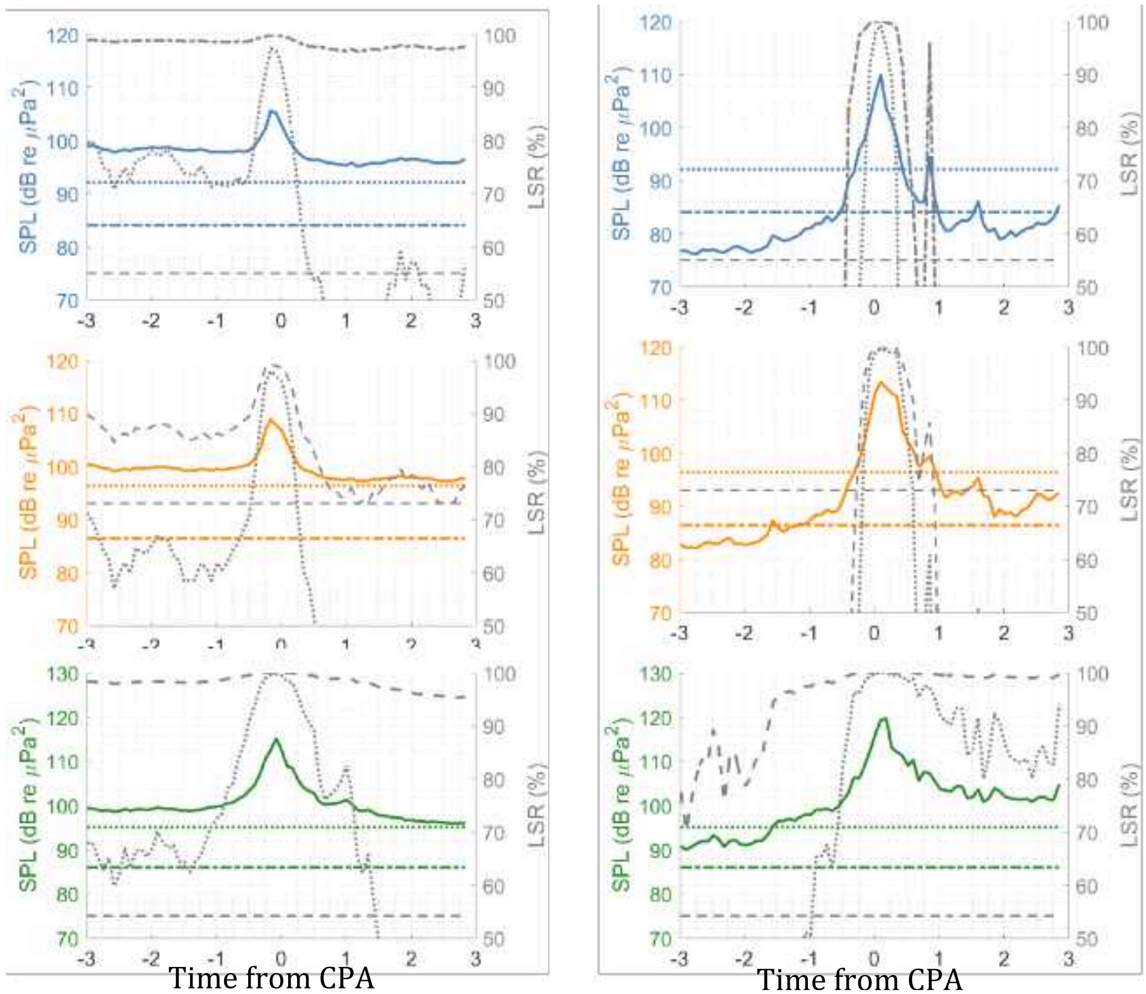

Figure 5. Listening Space Reduction (LSR) estimated by applying Pine *et al.* (2018) methods to example transits of general cargo vessels Zelada Desgagnes (left) and Claude Desgagnes (right) for the 3.5 kHz (top; lt. blue), 1 kHz (middle; orange), and 250 Hz (bottom; green) 1/3rd octave bands for transits. Gray horizontal dashed lines represent composite audiogram threshold values for beluga at 3.5 and 1 kHz (top and middle) and for ringed seal at 250 Hz. Gray dashed and dotted curves are the listening space reduction (LSR) estimates using the maximum of the audibility threshold and the median background noise level (dashed curve) or the 90th percentile background noise level (dotted curve) for the reference noise level (NL_1) for LSR estimation. Pre-CPA background noise in Zelada D. transit was above the 90th percentile background level while pre-CPA background noise in Claude D. transit near or below median background noise.

Table 1. Design characteristics and acoustic measurements of a representative set of ships of seven common types transiting Eclipse Sound. Ranges and 20-4000 Hz broadband received sound pressure levels (in dB re 1 μPa^2) at closest point of approach (CPA) are given for each example ship transit along with observed ranges to the ship when received levels were measured at 110 and 120 dB. Where values for bow and stern aspect 110 and 120 dB RL range differ substantially, both are given (i.e. bow range (km), stern range (km)). Table from Jones, 2020.

Ship information							Acoustic measurements				
Ship type	MMSI number	Ship name	Ship length (m)	Year built	Gross tonnage (10^3)	Deadweight tonnage (10^3)	Ship speed (kts)	Range at CPR (km)	Received level at CPR*	Range to 110 dB (km)	Range to 120 dB (km)
Bulk Carriers	356364000	NORDIC ODIN	225	2015	41071	76180	8.7	0.9	121	4,7	0.9
	356364000	NORDIC ODIN	225	2015	41071	76180	8.6	0.6	123	4,7	0.9
	373437000	NORDIC ORION	225	2011	40142	75603	7.5	2	119	5,7	2
	373437000	NORDIC ORION	225	2011	40142	75603	7.7	2.4	118	5,7	-
	374322000	NORDIC ODYSSEY	225	2010	40142	75603	8.4	1	127	10	3
	538008053	GOLDEN PEARL	225	2013	41718	74300	7.3	1.8	114	4	1.8
	538008053	GOLDEN PEARL	225	2013	41718	74300	8.6	0.3	125	5,7	1
	636015651	NS YAKUTIA	225	2013	40972	74559	8.1	1	115	2,3	-
	636015650	NS ENERGY	225	2012	40972	74518	7	3.1	116	4,6	-
	636092901	KAI OLDENDORFF	229	2019	44029	81243	8	1.9	120	4,7	1.9
	255805765	GISELA OLDENDORFF	229	2013	44218	80839	8.8	1	119	3,7	1
	538004978	AM QUEBEC	230	2013	43987	81792	7	1.1	130	10,20	4,5
General Cargo	316015133	ZELADA DESGAGNES	139	2009	9611	12692	8	1.9	130	-	8
	316011358	ROSAIRE A. DESGAGNES	138	2007	9611	12776	8.2	0.6	127	10,15	3
	246770000	MOLENGRACHT	143	2012	9524	11744	8.9	0.2	135	13,15	4,7
	316003010	CLAUDE A. DESGAGNES	138	2011	9627	12671	8	2.2	126	20	8,10
Oil and Chemical Tankers	316012308	SARAH DESGAGNES	147	2007	11711	17998	9	2	133	10,35	4,16
	316012308	SARAH DESGAGNES	147	2007	11711	17998	8.2	2.6	133	10,20	10,20
	316095000	DARA DESGAGNES	124	1992	6262	10511	8.5	0.3	130	7,20	2,4
	316095000	DARA DESGAGNES	124	1992	6262	10511	7.2	0.6	133	20,25	4,5
	316037373	KITIKMEOT W	150	2010	13097	19983	13	3.1	123	10,25	5
	316037373	KITIKMEOT W	150	2010	13097	19983	13	0.1	135	10,-	3,5
Passenger Ships	311000419	OCEAN ENDEAVOUR	137	1982	12907	1762	11	2	122	8,13	3,4
Pleasure Craft	319030600	ARCADIA	36	8	308						
	304977000	HANSE EXPLORER	48	2006	885	198	11	2.7	119	5,6	3,4
	304977000	HANSE EXPLORER	48	2006	885	198	9.8	2.6	111	4,5	-
Icebreaker	276805000	BOTNICA	97	1998	6370	2850	8.9	0.3	134	(14-28) (17-40)	(4-10) (4-16)
	276805000	BOTNICA	97	1998	6370	2850	8	2.7	133	18,30	7,16
	265182000	ODEN	108	1989	9605	4906	8	3.4	118	10	4
CCGS-SAR	316050000	CCGS AMUNDSEN	98	1979	5910	2865	13	1.9	122	9,10	3
	316050000	CCGS AMUNDSEN	98	1979	5910	2865	10	7	119	15,22	8,12
	316122000	TERRY FOX	88	1983	4233	2113	14	0.7	136	20,25	6

Name: Amanda Joynt

Agency / Organization: Oceans North

Date of Comment Submission: June 8, 2020

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

#	Document Name	Section Reference	Comment	Baffinland Response
1	Draft 2017-2018 Integrated Narwhal Tagging Study	Pg. 125, Paragraph 3. "Results suggest that narwhal orient themselves away from transiting vessels, potentially demonstrating avoidance, within 4-5km of a transiting vessel prior to the CPA, but for the full extent of 10km post CPA."	In Jones (2020), the 10km distance radius around the ship is assessed to have a broadband received sound pressure level (SPL) of 110 dB or less for bulk carriers, the most common project-related ship type (e.g. Jones, 2020; Table 3, Figs 7,8,9). As the full extent of reported avoidance post-CPA is 10km, it is important to include information on these lower levels of noise in impact assessments and monitoring programs. The 10km range limit for evaluating disturbance may not be appropriate. Observed radii to behavioral disturbance in tagged narwhal (1-10 km) suggest that a range of received ship noise levels may provoke a behavioral response. Depending on ship type, ranges to 120 dB broadband SPL may be greater than 10 km, as predicted and observed for project icebreakers and tanker vessels. Also, ranges to ships when behavioral disturbance is observed in tagged animals may correspond to lower received SPL than 120 dB.	

#	Document Name	Section Reference	Comment	Baffinland Response
			Received levels at actual ranges to behavioral disturbance should be evaluated by comparing these ranges with received levels measured in separate/concurrent acoustic studies undertaken by BIMC. Previous visual observation study reports from Bruce Head included response to radii of up to 15 km. Is there a difference in the way the data is being analyzed for tag data that no longer include these longer distances?	
2	Draft 2017-2018 Integrated Narwhal Tagging Study	Document reference number Baffinland Mary River Project Phase 2 Proposal, Appendix N, Attachments related to the Marine Environment. Attachment 2, Technical Memorandum - Analysis of 2018 Narwhal Tagging Data during Fall Shoulder Season. 1663724-162-TM-Rev0-12000, Oct. 15, 2019. Section 3.2 Page 7-9.	There are no results from the icebreaking shoulder season for the narwhal tagging results included in this referenced report. Please clarify why these data not included in the Integrated report.	

#	Document Name	Section Reference	Comment	Baffinland Response
3	Draft 2017-2018 Integrated Narwhal Tagging Study	There are no sections to reference as the comments center on what is not included in the report.	In Jones (2020), there are 19 and 35 ship transit events of the icebreaker Botnica passing the Pond Inlet and Milne Inlet reference locations, respectively, from Sept 28, 2018 to Sept 22, 2019 (Jones, 2020; Table 1). This period includes one late and one early shoulder shipping season during which concurrent acoustic measurements of received noise levels from ships were made by and are reported in Jones 2020. Why are these icebreaking ship events in proximity to tagged narwhal not included or analyzed in the Integrated Report? It would be helpful to see tagged narwhal behavioral response ranges and data analysis for the 2018 fall shoulder season for comparison with acoustic results. Icebreaking is the largest sound source associated with the project and occurs during the quietest time of the shipping year (i.e. July). Icebreaker ship transits are highest both in measured received sound pressure levels relevant to behavioral disturbance and with respect to listening space reduction (LSR). It is important to analyze these data in relation to the radius from the ship at the time of observed behavioural responses as much as possible.	

#	Document Name	Section Reference	Comment	Baffinland Response
4	Draft 2017-2018 Integrated Narwhal Tagging Study	Section 6.0 Pg. 154-155	Please clarify how the Southall (2007; Table 4) severity scale is applied to the post-CPA behaviour, and how it was determined when behavior had returned to pre-response behaviour to then assess the disturbance at the level of moderate. What estimated severity scores are assigned to each of the types of behavioral disturbance significantly related to ship proximity in this study?	

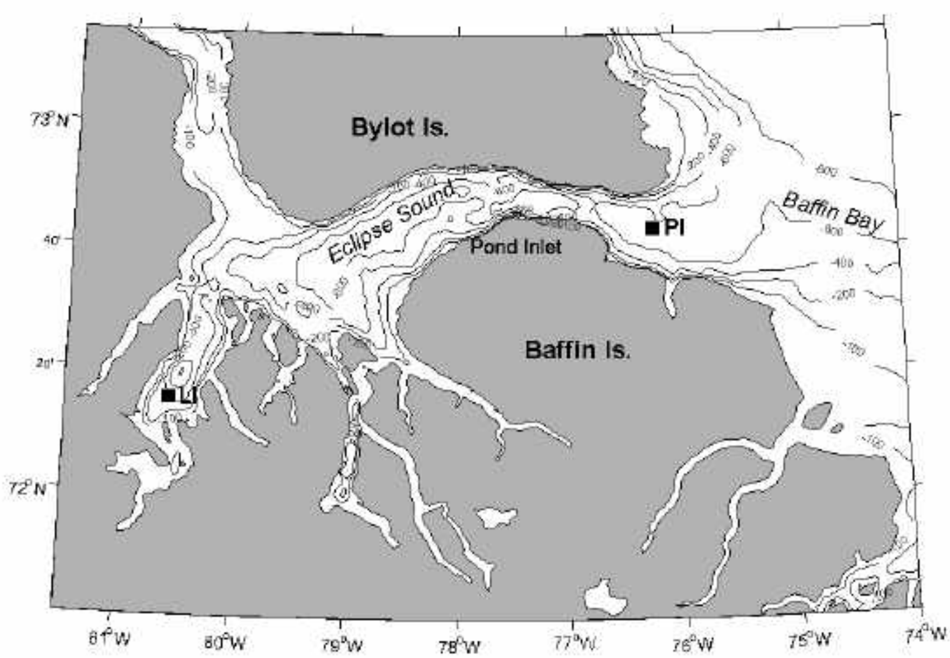

Figure 1. Long-term acoustic recording sites in Eclipse Sound, N. Baffin Island, Nunavut Territory, Canada. High-frequency Acoustic Recording Packages (HARPs) were deployed at Pond Inlet (PI) from May 2016 through September, 2019 and at Milne Inlet (MI) from Sept 2018 through Aug 2019

Bulk carriers

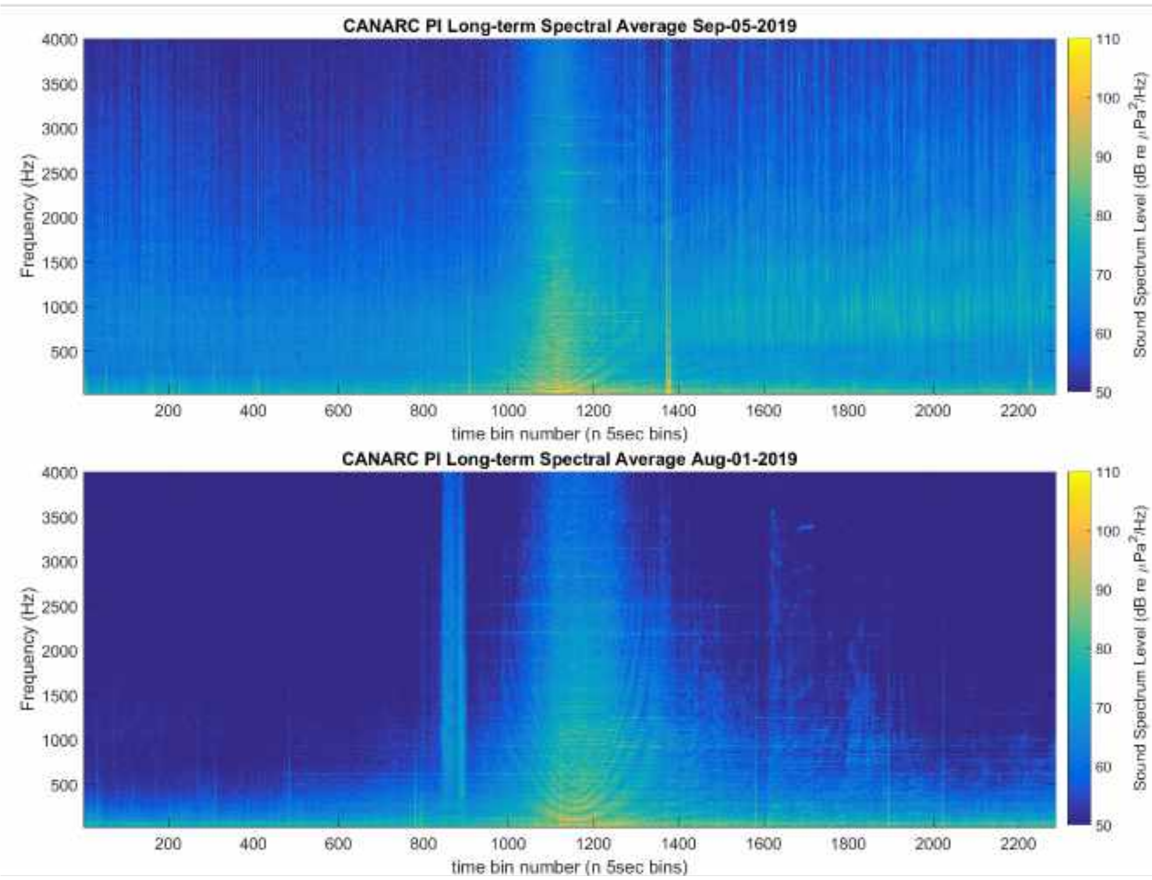

Figure 7. Long-term spectral average (LTSA) of the 6-hour window about the closest point of approach (CPA) of 225 m bulk carrier Nordic Orion (IMO ##) during two transits past the recording location. Wind-generated noise below 4 kHz is evident in the Sep 5, 2019 transit (top panel; CPA range 2 km). A transit of the same vessel Aug 1, 2019 (bottom panel; CPA range 2.4 km) occurs during lower background noise at the start of the ice-free season.

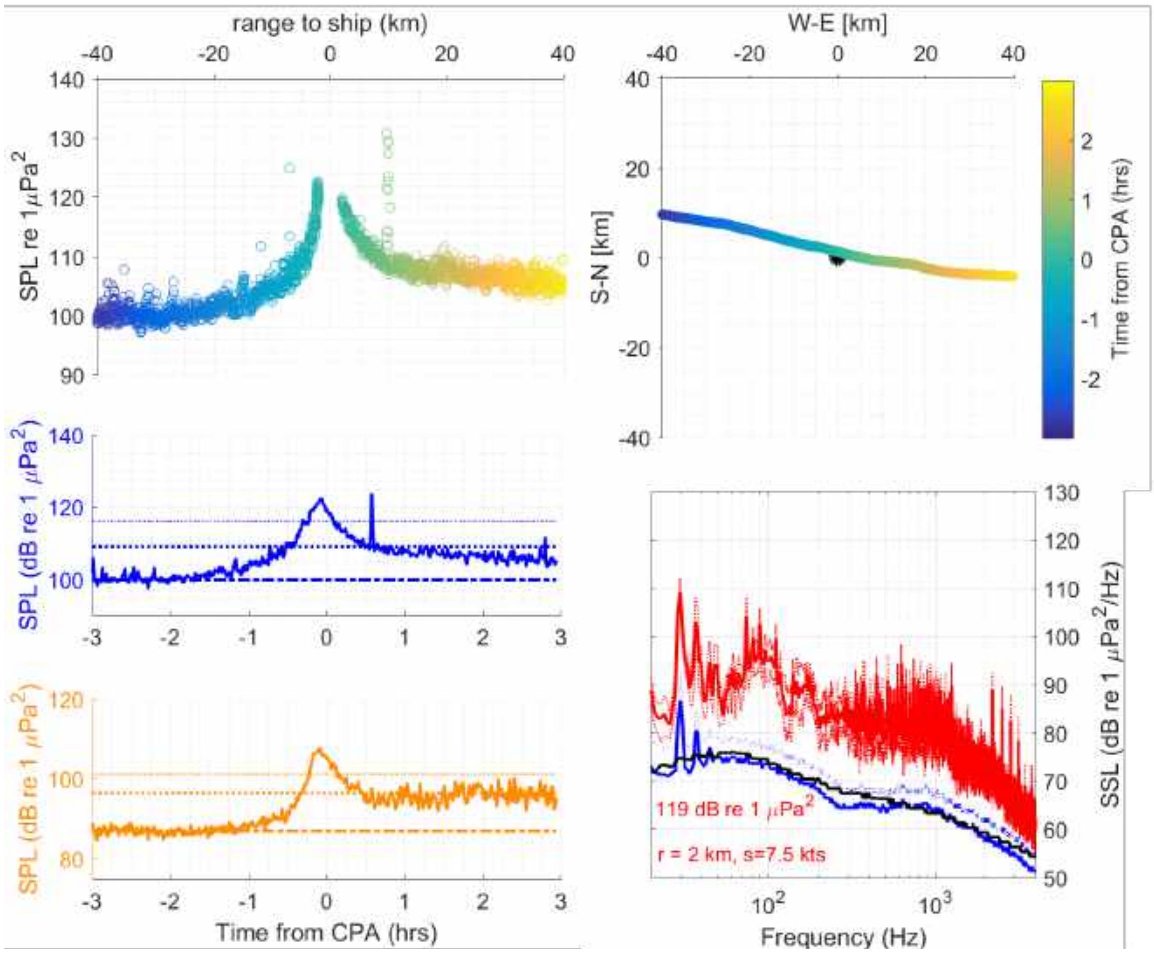

Figure 8. Ship transit analysis for bulk carrier Nordic Orion Sep 05, 2019. Broadband sound pressure level (SPL_{BB} 20-4000 Hz; top left open circles) averaged every 5s increases gradually beginning apx. 2 h prior to the closest point of approach (CPA), increasing more rapidly within 30 min of the closest point recorded (CPR) at a range of 2 km and max. SPL_{BB} 119 dB re 1 μPa^2. Colors in SPL scatter plot and map showing ship track (top right) represent time from CPA (5s bins). Middle left) received SPL for the 20-4000 Hz band (blue) and the 1 kHz 1/3rd octave band (bottom left; orange) during ship transit plotted with 50th (dash-dot line), 90th (dotted line), and 99th (upper dotted line) percentile levels without ships (background levels). Bottom right) Sound spectrum level (SSL) of CPR period (red) with median SSL of the 1st 30 min of transit plot (blue) and shipping season median background sound levels during periods without ships (black).

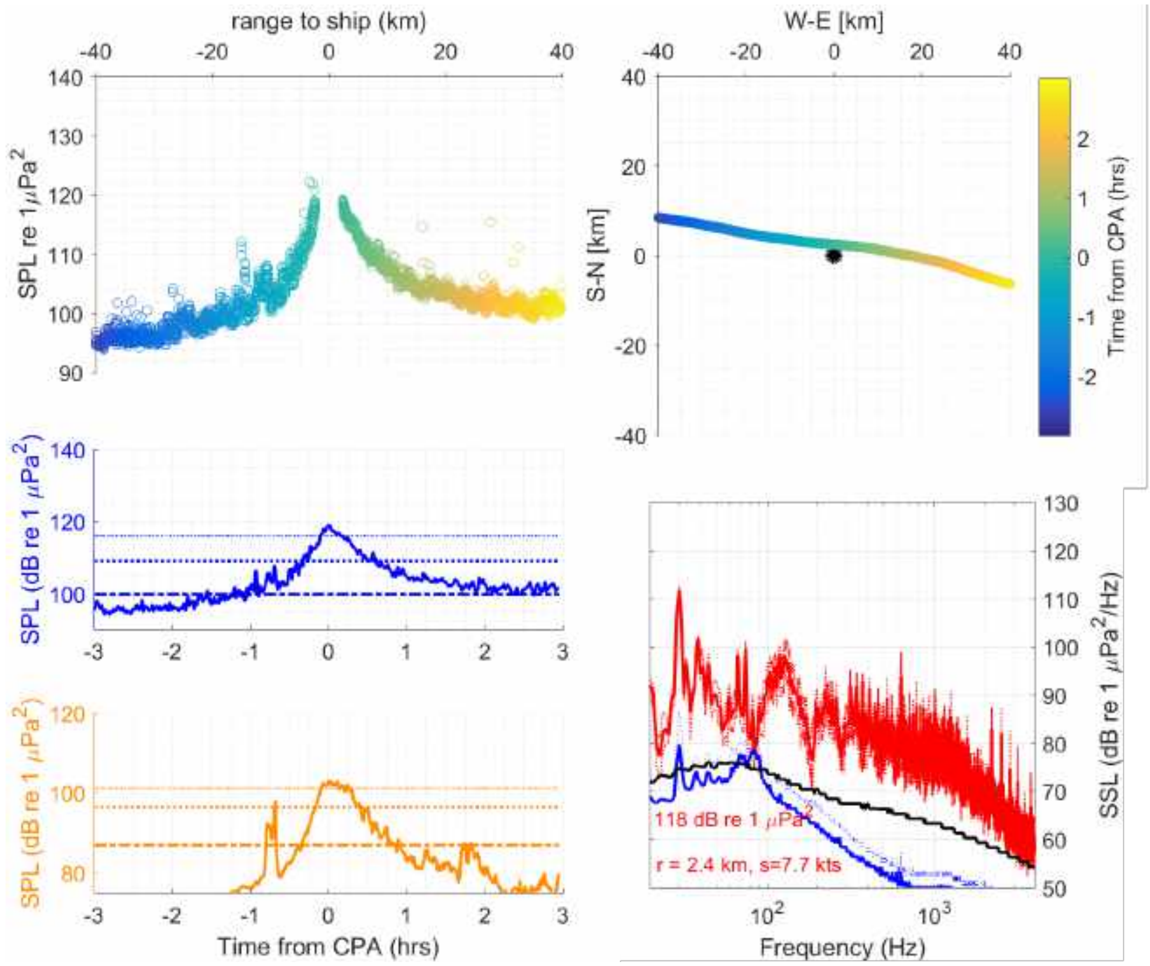

Figure 9. Ship transit analysis for bulk carrier Nordic Orion Aug 01, 2019. Broadband sound pressure level (SPL_{BB} 20-4000 Hz; top left open circles) averaged every 5s increases gradually beginning apx. 2 h prior to the closest point of approach (CPA), increasing more rapidly within 30 min of the closest point recorded (CPR) at a range of 2.4 km and max. SPL_{BB} 118 dB re 1 μPa^2. Colors in SPL scatter plot and map showing ship track (top right) represent time from CPA (5s bins). Middle left) received SPL for the 20-4000 Hz band (blue) and the 1 kHz 1/3rd octave band (bottom left; orange) during ship transit plotted with 50th (dash-dot line), 90th (dotted line), and 99th (upper dotted line) percentile levels without ships (background levels). Bottom right) Sound spectrum level (SSL) of CPR period (red) with median SSL of the 1st 30 min of transit plot (blue) and shipping season median background sound levels during periods without ships (black).

Table 1. Summary of AIS vessel transits, passing within 15 km of the Pond Inlet (PI) and Milne Inlet (MI) acoustic recording locations between Sep 28, 2018 and Sep 21, 2019.

Ship type	Pond Inlet		Milne Inlet	
	Number of transits	Percent of transits	Number of transits	Percent of transits
Bulk Carriers	150	57%	150	63%
General Cargo	25	9%	21	9%
Passenger Ships	20	8%	0	0%
Icebreakers	19	7%	39	16%
Oli and Chemical Tanker	15	6%	10	4%
Pleasure Craft	7	3%	1	0%
Sailing	6	2%	0	0%
Tug	6	2%	9	4%
Military	6	2%	2	1%
Other Cargo	5	2%	6	3%
CCGS-SAR	5	2%	0	0%
Total	264		238	

Table 3. Acoustic characteristics of ship transits

Design characteristics and acoustic measurements of a representative set of ships of seven common types transiting Eclipse Sound. Ranges and 20-4000 Hz broadband received sound pressure levels (in dB re 1 μPa^2) at closest point of approach (CPA) are given for each example ship transit along with observed ranges to the ship when received levels were measured at 110 and 120 dB. Where values for bow and stern aspect 110 and 120 dB RL range differ substantially, both are given (i.e. bow range (km), stern range (km)).

Ship information							Acoustic measurements				
Ship type	MMSI number	Ship name	Ship length (m)	Year built	Gross tonnage (10^3)	Deadweight tonnage (10^3)	Ship speed (kts)	Range at CPR (km)	Received level at CPR*	Range to 110 dB (km)	Range to 120 dB (km)
Bulk Carriers	356364000	NORDIC ODIN	225	2015	41071	76180	8.7	0.9	121	4,7	0.9
	356364000	NORDIC ODIN	225	2015	41071	76180	8.6	0.6	123	4,7	0.9
	373437000	NORDIC ORION	225	2011	40142	75603	7.5	2	119	5,7	2
	373437000	NORDIC ORION	225	2011	40142	75603	7.7	2.4	118	5,7	-
	374322000	NORDIC ODYSSEY	225	2010	40142	75603	8.4	1	127	10	3
	538008053	GOLDEN PEARL	225	2013	41718	74300	7.3	1.8	114	4	1.8
	538008053	GOLDEN PEARL	225	2013	41718	74300	8.6	0.3	125	5,7	1
	636015651	NS YAKUTIA	225	2013	40972	74559	8.1	1	115	2,3	-
	636015650	NS ENERGY	225	2012	40972	74518	7	3.1	116	4,6	-
	636092901	KAI OLDENDORFF	229	2019	44029	81243	8	1.9	120	4,7	1.9
	255805765	GISELA OLDENDORFF	229	2013	44218	80839	8.8	1	119	3,7	1
	538004978	AM QUEBEC	230	2013	43987	81792	7	1.1	130	10,20	4,5
General Cargo	316015133	ZELADA DESGAGNES	139	2009	9611	12692	8	1.9	130	-	8
	316011358	ROSAIRE A. DESGAGNES	138	2007	9611	12776	8.2	0.6	127	10,15	3
	246770000	MOLENGRACHT	143	2012	9524	11744	8.9	0.2	135	13,15	4,7
	316003010	CLAUDE A. DESGAGNES	138	2011	9627	12671	8	2.2	126	20	8,10
Oil and Chemical Tankers	316012308	SARAH DESGAGNES	147	2007	11711	17998	9	2	133	10,35	4,16
	316012308	SARAH DESGAGNES	147	2007	11711	17998	8.2	2.6	133	10,20	10,20
	316095000	DARA DESGAGNES	124	1992	6262	10511	8.5	0.3	130	7,20	2,4
	316095000	DARA DESGAGNES	124	1992	6262	10511	7.2	0.6	133	20,25	4,5
	316037373	KITIKMEOT W	150	2010	13097	19983	13	3.1	123	10,25	5
	316037373	KITIKMEOT W	150	2010	13097	19983	13	0.1	135	10,-	3,5
Passenger Ships	311000419	OCEAN ENDEAVOUR	137	1982	12907	1762	11	2	122	8,13	3,4
Pleasure Craft	319030600	ARCADIA	36	8	308						
	304977000	HANSE EXPLORER	48	2006	885	198	11	2.7	119	5,6	3,4
	304977000	HANSE EXPLORER	48	2006	885	198	9.8	2.6	111	4,5	-
Icebreaker	276805000	BOTNICA	97	1998	6370	2850	8.9	0.3	134	(14-28) (17-40)	(4-10) (4-16)
	276805000	BOTNICA	97	1998	6370	2850	8	2.7	133	18,30	7,16
	265182000	ODEN	108	1989	9605	4906	8	3.4	118	10	4
CCGS-SAR	316050000	CCGS AMUNDSEN	98	1979	5910	2865	13	1.9	122	9,10	3
	316050000	CCGS AMUNDSEN	98	1979	5910	2865	10	7	119	15,22	8,12
	316122000	TERRY FOX	88	1983	4233	2113	14	0.7	136	20,25	6

Name: Amanda Joynt

Agency / Organization: Oceans North

Date of Comment Submission: June 15, 2020

#	Document Name	Section Reference	Comment	Baffinland Response
1	Draft 2019 Bruce Head Shore-based Monitoring Report	1. Increased instance of narwhal travel following ship southbound transit when vessels at range 1-3 km (p.82) 2. More likely to be in tight group spread when vessels 3-4 km away in BSA (p.75) 3. Increased probability of slow swimming when vessel 2-3 km S of behavioral study area (BSA; p.88) 4. Lower probability of observing slow swimming groups when vessels at range 2-3 km N of BSA (p.88) 5. Decreased distance from shore when vessels within 3 km (p.94) 6. Larger probability of observing groups nearer to shore when vessels transiting toward the BSA	Clarify for each of these ranges, what is the range of distance to the animal. The behavioral study area (BSA) is about 1km wide, there is a generalization made that impact across the BSA is the same. Would a reported range of 1-3km between ship and the BSA for a particular behavioral response translate to a range of 1-4 km between the ship and the animal? This information is important to estimate the received sound levels corresponding to the reported radii of impact around the ship.	
2	Draft 2019 Bruce Head Shore-based Monitoring Report	Page 32	In terms of the Southall *et al.* (2007) ranking of the severity of behavioral responses to underwater noise (p.450, Table 4), each of these behavioural changes has a score that fits into the noise impact framework proposed by the proponent. What are the specific behavioral response severity scores assessed by the proponent for the observed responses? For each response, what were the post-exposure times observed for re-establishing post-exposure behavior?	

#	Document Name	Section Reference	Comment	Baffinland Response
3	Draft 2019 Bruce Head Shore-based Monitoring Report	Page 78	In previous reports, the stratified study area would suggest there is a longer range behavioural response. And in this study, the maximum distance for responses is 4km – were there no behavioral responses to ship noise observed past 4km?	

DRAFT DOCUMENT

Passive Acoustic Monitoring of Underwater Radiated Noise from Ships in Eclipse Sound, Nunavut (2018-2019)

Reporting date:
September 4, 2020

Joshua M. Jones
Marine Physical Laboratory
Scripps Institution of Oceanography
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Photo: Oil and chemical tanker transiting in Eclipse Sound near the community of Pond Inlet, Nunavut
October 4, 2018

Analysis period: Sep 28, 2018 – Sep 22, 2019

This project is funded through a private foundation grant to the Marine Physical Laboratory at the Scripps Institution of Oceanography and by Oceans North, with additional support provided by Environment and Climate Change Canada through grant from the World Wildlife Fund. Data collection and fieldwork have been carried out with annual permission from the Mittimatalik Hunters and Trappers Organization, Pond Inlet, Nunavut, Canada.

Table of Contents/ Outline

INTRODUCTION

Commercial shipping is a major contributor to underwater noise in the ocean (Hildebrand, 2009; Wagstaff, 1981; Wenz, 1962), especially within regions where regular shipping routes occur. Increases in ship traffic are occurring rapidly in some areas of the Arctic (e.g. Dawson et al., 2018) and are projected to accelerate with future reductions in sea ice and development of industry and tourism across the region (Smith and Stephenson, 2013; Theocharis et al., 2018).

Within the Canadian Arctic, vessel traffic increased by an estimated 75% from 2005-2015 (Pizzolato et al., 2016). Reductions in sea ice and the use of icebreaking ships have resulted in a lengthening of the season during which Canadian Arctic shipping can occur (Stroeve et al., 2014; Smith and Stephenson, 2013), but other factors, such as industrial development and tourism, may play a larger role in some areas.

The Eclipse Sound region of northern Baffin Island is the main marine waterway for the community of Pond Inlet, Nunavut, and is a location where substantial increases in commercial shipping traffic are occurring. The period 2011-2015 saw a near tripling of average annual vessel traffic past Pond Inlet, compared to 1990-2000 (Dawson *et al.*, 2018), a change attributed primarily to increases in tourism vessels and to bulk carrier and cargo vessel traffic associated with early development phases of the Baffinland Iron Mines Corporation Mary River Mine (MRM).

Starting in 2015, large ore carrier vessels began service along a northern shipping route to and from the MRM in Milne Inlet, bringing substantial additional ship traffic to the region. Iron ore production from the mine is shipped to market via a northern sea route and reported annual production has increased from 0.92 million metric tons (Mt) in 2015 to 5.86 Mt in 2019. Shipping related to the MRM project includes bulk carrier vessels that transport iron ore and also tugs, general cargo, oil and chemical tankers, and icebreaking vessels.

Underwater noise produced by ships is a source of concern for management of marine wildlife, including fish and marine mammals, due to the potential for temporary or permanent hearing loss, behavioral disturbance, and interference with communication (e.g. Nowacek *et al*., 2007; Clark *et al.*, 2009; Hatch *et al*., 2012; Southall *et al*., 2018; Pine *et al*., 2018).

Extensive research and reporting has been undertaken regarding underwater noise from shipping in the Eclipse Sound region as a part of the environmental impacts assessment (EIA) process during development of the MRM, with the aim of increasing understanding of the potential impacts of project-related underwater noise on marine wildlife, particularly marine mammals (*e.g.* Golder Associates Ltd., 2018; Frouin-Muoy et al., 2020; Golder Associates Ltd., 2019). Narwhal and ringed seals have been among the primary species of concern for impacts of noise from ships during this process because they are important species for subsistence hunting by Inuit in waters potentially impacted by increasing ship traffic related to and independent of the MRM project.

This study aims to provide an additional and independent analysis of underwater noise from shipping traffic in Eclipse Sound for comparison with and as a supplement to research undertaken for the EIA process. The report will compile results of passive acoustic monitoring carried out by the Whale Acoustics Laboratory at the Scripps Institution of Oceanography and the Canadian non-governmental organization, Oceans North, during periods in 2018-2019 selected to represent of one annual season of navigable waters for shipping. Underwater acoustic recordings were made continuously during Oct, 2018 and Jul-Sep, 2019 at a location along the most transited shipping route near the entrance to Eclipse Sound from Baffin Bay. Analyses of those recordings will be presented with the specific goals to:

1) Summarize shipping traffic for a one-year period beginning in late-September, 2018 using Automated Information System (AIS) reported locations of ships.
2) Measure the levels of underwater sound that occur during the shipping season at times when ships are not present to describe natural fluctuations in ambient noise (*i.e.* background noise).
3) Measure the levels of underwater sound that occur during the entire shipping season, including periods of noise from transiting ships.
4) Describe the acoustic characteristics of underwater noise from commercial ships in relation to ship type for the most common vessel types.
5) Estimate levels of acoustic masking (*i.e.* Listening Space Reduction) that may occur in marine mammals as a result of measured levels of ship noise at frequencies relevant to narwhal and ringed seal acoustic communication.

METHODS

Acoustic recording and data processing

Underwater acoustic recordings were collected from September 28, 2018 through September 21, 2019 at a location between Baffin and Bylot Islands in eastern Eclipse Sound. This is referred to as the Pond Inlet (PI) recording site (Fig. 1). Recordings were made using High-frequency Acoustic Recording Packages (HARP; Fig. 2; Wiggins and Hildebrand, 2007), which recorded acoustic data at a sampling rate of 200 kHz, continuously during the deployment period. The HARP was deployed to the seafloor at a depth of 670 m and the hydrophone sensor was suspended approximately 10 m above the seafloor. The hydrophone used a spherical omnidirectional transducer (ITC-1042; www.itctransducers.com) with an approximately flat frequency response of -200 decibels (dB) root mean squared (RMS) re 1V/μPa between 1Hz and 100 kHz. Acoustic calibrations were made at the Scripps Institution of Oceanography (SIO) and these calibrations used to convert all acoustic recordings to sound pressure levels.

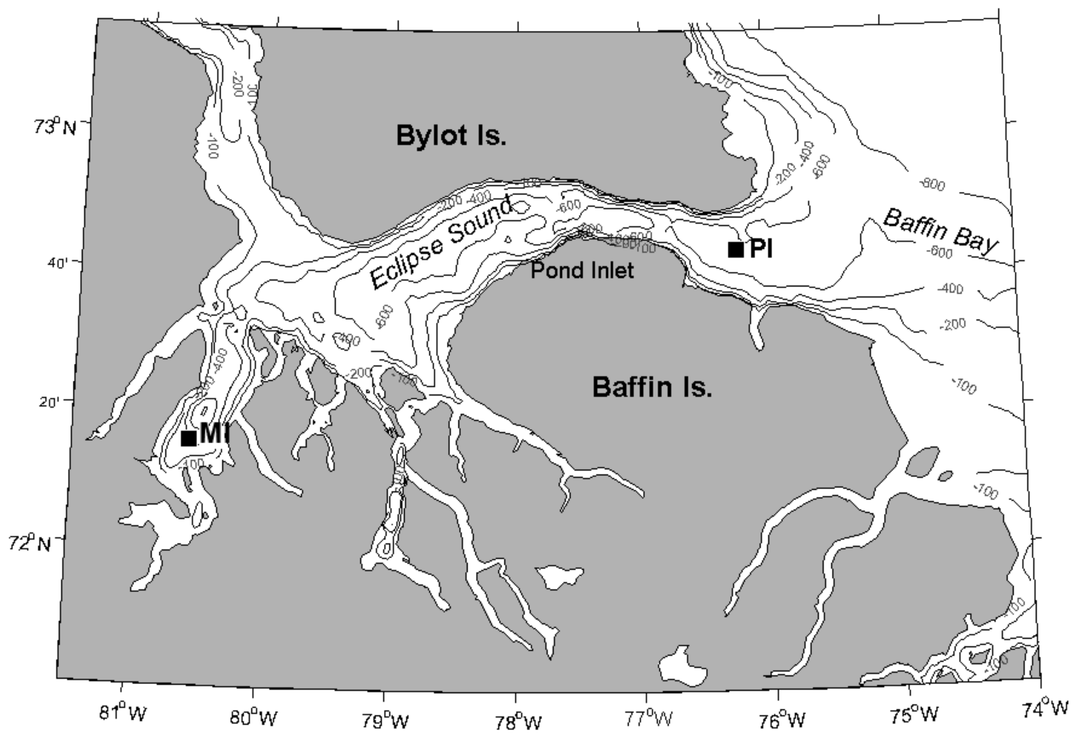
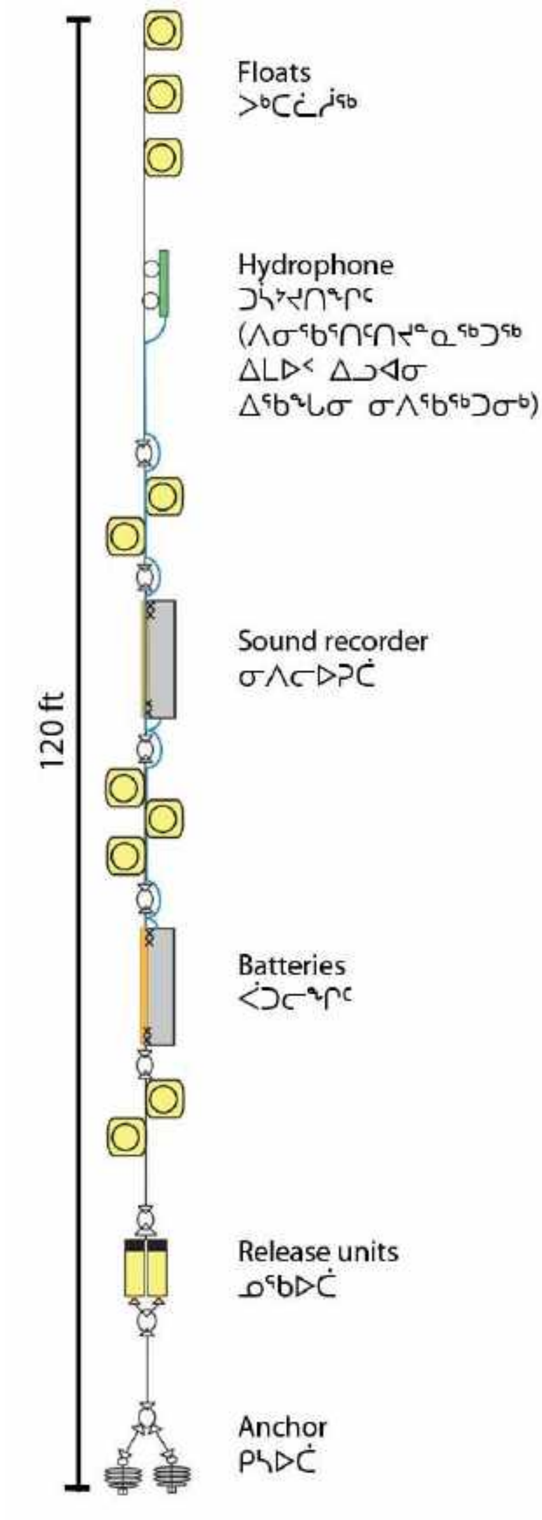


Figure 1. Long-term acoustic recording site in Eclipse Sound, N. Baffin Island, Nunavut Territory, Canada. A High-frequency Acoustic Recording Packages (HARP) was deployed at the Pond Inlet site (PI) from September 28, 2018 through September 21, 2019. A second location in Milne Inlet (MI) is included as a reference location for additional analysis of satellite-received Automated Information System (AIS) ship traffic data.



Note: The HARP is a listening device only and emits no sound into the water, except for a single 10-min period of acoustic communication at the time it is recovered annually.

Figure 2. High-frequency Acoustic Recording Package (HARP) records underwater sound continuously year-round at a sampling rate of 200 kHz.

All recordings were converted to an adapted wav file format (xwav) and decimated by a factor of 20 to yield an effective bandwidth of 10-5000 Hz. Decimated recordings were processed into consecutive non-overlapping 5 s averaged sound spectral density estimates with 1 Hz frequency bin spacing, which were assembled into Long-term Spectral Averages (LTSAs) to facilitate further analysis of acoustic timeseries. To remove system self-noise resulting from HARP disk writes, the first three and last three 5 s spectra in each 75 s recording were not used for averaging. The retained 5 s spectra were further analyzed using custom Matlab-based (www.Mathworks.com) software to provide average and percentile sound spectrum levels, spectrograms, and sound pressure level (SPL) time series for specific frequency bands, including 20-4000 Hz to represent broadband noise radiated by ships and 1/3rd octave frequency bands centered at 250 Hz, 1 kHz, and 3.5 kHz to represent functional hearing of communication signals produced by ringed seals (250 Hz barks) and narwhal (1 kHz burst pulse and 3.5 kHz whistle). All SPL measurements are reported on a logarithmic scale as decibels (dB) with reference pressure 1 μPa^2 and sound spectrum levels (SSL) reported in dB re 1 μPa^2/Hz.

Ship transit information

Satellite Automated Information System AIS (Tetreault, 2005) data were obtained from ExactEarth (www.ExactEarth.com). Distance between AIS ship location and the recording location was calculated to provide radius along the sea surface from the deployment or reference location to the ship reported position. Locations were extracted for all ships within a 100 km radius of the recording sites and AIS data included time, latitude and longitude, speed, heading, maximum draught, Maritime Mobile Service Identity (MMSI) number, vessel name, vessel type and cargo class. Additional ship specification data, including gross and deadweight tonnage (*i.e.* weight carrying capacity), were obtained from Lloyd's Registry of Ships.

Ship transits were defined as periods of continuous presence of a ship (*i.e.* unique MMSI number) within maximum radius of the recording or reference site (100 km site PI, 30 km site MI) during which a ship's closest point of approach (CPA) occurred within 15 km of the recorder for site PI or 10 km for MI. Continuous presence was defined as having no greater than 60 min between AIS position updates within the 100 km radius. A 100 km maximum radius was selected for AIS ship transit data at PI to include vessels of speeds up to 18 knots, the maximum speed in the AIS data included in this study, within a six-hour transit window. A 30 km maximum radius was selected for AIS data at site MI to prioritize transiting ships. This radius excluded ships engaged in port-related operations near the Baffinland Iron Mine shipping terminal at southern terminus of Milne Inlet and ships anchored at a designated cargo ship anchorage apx. 30 km northeast near Ragged Island. The 10 km maximum CPA radius at MI included all ships transiting the inlet. Due to irregularity in satellite transit and vessel transmission, all ship tracks and ship information were interpolated linearly to a uniform temporal resolution of 5 s.

Daily sea ice maps were obtained from the Canadian Ice Service, Environment and Climate Change Canada (https://iceweb1.cis.ec.gc.ca/) to estimate proportion of ice cover near the PI recording site during periods of acoustic data analyzed.

Monthly natural and anthropogenic underwater sound levels

To estimate levels of natural and anthropogenic underwater noise, excluding the presence of ships, sound spectrum levels were obtained for all periods when the difference between successive ship transit CPA events was at least 8 h. For each period meeting this condition, all 5 s LTSA data were extracted from 4 h after the first ship's CPA to 4 h prior to the second ship's CPA. These inter-transit times will be referred to as background noise periods. A monthly random sample of 20,000 5s spectra were selected from the background noise periods during the shipping season to provide a consistent sample size for each month of shipping operations. Combined and monthly spectrum levels of background noise were evaluated from the 1st, 10th, 50th (median), 90th, and 99th percentiles of all 5 s LTSA subsampled from each time period. The 250 Hz, 1 kHz, and 3.5 kHz 1/3rd octave and 20-4000 Hz broadband SPL for all background noise percentiles were calculated from the sum of the squared pressure across the frequency band of the 50th and 90th percentile background spectra. Spectra and frequency band average and percentile SPL measurements were also made for all recorded periods inclusive of ship transits. Measurements including transient ship noise events were made for all recorded periods between September 28 and October 20, 2018 and between July 18 and September 21, 2019. These periods were selected to include all days of shipping traffic during the 2018 sea ice freeze-up, 2019 sea ice break-up, and two months of the 2019 open water season.

Acoustic characteristics of vessel transits

Spectral characteristics of ship transits were analyzed from the LTSA data within a 6-hour (6 h) window centered on each ship CPA. Acoustic ship transits were defined as the 6 h period, consisting of 3 h prior to and 3 h after the ship CPA. This relatively long time-window around each CPA was selected to include long-range propagation of underwater noise from ship transits and sometimes resulted in multiple ship transits occurring within the same 6 h window. Transits were categorized as either overlapping with others or as non-overlapping and containing only one ship within the 6 h window. Sound pressure levels (SPL) for the 20-4000 Hz band (SPL_{BB}) and the 250 Hz, 1 kHz, and 3.5 kHz 1/3rd octave bands were calculated for each 5 s time bin in the ship transit LTSA data from the sum of the squared pressure across the frequency bands. SPL for all frequency bands is reported in units of dB re 1 μPa^2 and will be referred to as SPL in decibels. Band received level percentiles were also computed for 1min, 5min and 1 h time bins across the deployment period to facilitate analyses of received level duration, range to ships at specific received levels, and listening space reduction during transits.

Background noise level for each ship transit was estimated from the minimum of the 5min median band SPL during the period from 3 h prior to the ship CPA to the CPA time. This tended to provide a reasonable estimate of background noise level during the transits and minimized the inclusion of noise from other ships passing prior to or within the pre-CPA portion of the transit window.

Received SSL and band SPL were calculated for the closest point recorded (CPR) of each ship transit, which was the time of acoustic recording when the ship was nearest to the CPA of the ship transit. This distinction was made between CPA and CPR because occasionally the ship CPA occurred during a time period when acoustic data were excluded to remove periodic system self-noise. Received broadband SPL and SSL for each ship transit CPR were derived by averaging the received levels of all 5 s time bins within a data window during which the ship traveled a distance of 1.5 ship lengths with respect to the CPR, similar to the method described in McKenna *et al*. (2012).

Representative transits were selected for each vessel type to evaluate received level at varying ranges to the different ships and the durations of received levels > 110, 115, and 120 dB. If available, non-overlapping transits were chosen to represent a vessel type to minimize additional noise from other ships.

Listening space reduction (LSR)

An analysis of proportional reduction in available listening space (reported as listening space reduction; LSR) was performed for all ship transit windows and for a set of random samples of recording periods used for background noise analysis (i.e. excluding transient ship noise events). Frequency bands were chosen to include ringed seal barks (apx. 250 Hz, Jones *et al.*, 2014) and narwhal burst pulse calls and whistles (1 kHz and 3.5 kHz; Marcoux et al., 2010).

LSR was evaluated for the three frequency bands using methods consistent with previous studies of LSR in Arctic waters (*e.g.* Pine *et al.*, 2018) with the equation,

$$LSR = 100\left(1 - 10^{2\left(\frac{NL_2 - NL_1}{N}\right)}\right) \qquad \text{Eqn. 1}$$

where N is the sound propagation loss coefficient, estimated conservatively as N=15 to represent cylindrical spreading. NL_2 is the masking noise approximated by the 1/3rd octave SPL for each frequency band averaged across a 5-min time bin to smooth the resulting LSR time series. NL_1 is chosen to approximate the perceived ambient noise level during the ship transit. For each frequency band during a transit, NL_1 was set as the maximum of the auditory threshold for the species at the band's center frequency and either the median or 90th percentile Jul-Oct ambient noise SPL for the frequency band. The median and 90th percentile ambient noise levels were chosen to represent 'quiet' and 'noisy' background noise conditions, although the median more closely reflects average noise conditions across the months. Switching between NL_1 referenced to the median and the 90th percentile ambient noise levels results in generally lower estimates of LSR during ship transits with relatively 'noisy' background conditions than when using a single reference noise level such as the median. This method for estimating NL_1 was intended to approximate the change in effective listening space perceived during each transit relative to the ambient noise conditions at the time, similar to the method descried by Pine *et al.* (2018).

An estimated auditory threshold was also included in determining NL_1 for LSR estimation. For ringed seal at 250 Hz, the auditory threshold was estimated as 75 dB (Sills *et al*., 2015). Experimental audiograms are not available for the narwhal hearing system, so available beluga composite audiograms were used as an approximation (Fig. 5 in Finneran *et al.,* 2005). Beluga hearing threshold at 1 kHz and 3.5 kHz were estimated as 93 and 75 dB, respectively, from a composite audiogram of previous beluga hearing studies (Fig. 5 in Finneran *et al.,* 2005). The running threshold for detecting signal in noise was estimated as the maximum of the audiogram value for the species at that frequency and the 1/3 octave band level of the frequency. The 1/3 octave band level of the noise was chosen to approximate the detection threshold for a signal, as it roughly corresponds to the sound pressure spectrum level of the noise plus the critical ratio (CR) of signal to noise consistent with measurements for ringed seals and beluga in previous experiments. CR of ringed seal is apx. 17 dB re 1 μPa^2 at 250 Hz (Sills *et al.*, 2015) and beluga apx. 10 dB re 1 μPa^2 at 1 kHz (Erbe, 2008), so detection threshold of both are conservatively estimated using the 1/3rd octave band levels of the noise.

RESULTS

Ship transit information

During Sept 28, 2018 to September 21, 2019 total of 95 unique ships made 266 transits through the eastern entrance to Eclipse Sound, passing within 15 km of the Pond Inlet (PI) recording location (Fig. 3, Table 1). At the Milne Inlet reference site (MI), a total of 64 unique ships made 240 transits past the recording location (Fig. 4, Table 1). Ships which transited past the PI site, but not the MI site were primarily pleasure craft, passenger vessels, military and Canadian Coast Guard vessels. With few exceptions, ship operations during the 6-h transit windows consisted of vessels under way and making way at relatively constant speeds over ground while making minimal course corrections for navigation. A notable exception occurred occasionally in October and July when an icebreaker (M/V Botnica) approached the recording site then reversed course within 15 km of the site (e.g. Fig. 24.b) while engaged in ice assistance activities. These instances of course reversal near the recording site were counted as a single ship transit. At the PI site, the general orientation of vessel traffic was east-west, entering or exiting Eclipse Sound from Baffin Bay (Fig. 3). In Milne Inlet, the general orientation of vessel traffic was north-south (Fig. 4). Ships were separated into 11 types based on AIS ship-type designation. Among the ship types, cargo vessels, including tankers, represented 74% of all ship transits at PI (n=197) and 79% at MI (n=189). Cargo vessels were separated into four categories to distinguish the three most common cargo sub-types (bulk carrier, general cargo, and tanker) from other less common cargo vessel types (heavy load carrier, deck cargo ship, offshore support vessel). Less common cargo vessel types are grouped in Table 1 as ‘other cargo’ vessels.

Table 1. Summary of AIS vessel transits, passing within 15 km of the Pond Inlet (PI) and Milne Inlet (MI) acoustic recording locations between Sep 28, 2018 and Sep 21, 2019.

Ship type	Pond Inlet		Milne Inlet	
	Number of transits	Percent of transits	Number of transits	Percent of transits
Bulk Carriers	152	57%	152	63%
General Cargo	25	9%	21	9%
Passenger Ships	20	8%	0	0%
Icebreaker-Support Vessel	19	7%	39	16%
Oil and Chemical Tanker	15	6%	10	4%
Pleasure Craft	7	3%	1	0%
Sailing	6	2%	0	0%
Tug	6	2%	9	4%
Military	6	2%	2	1%
Other Cargo	5	2%	6	3%
CCGS-SAR	5	2%	0	0%
Total	266		240	

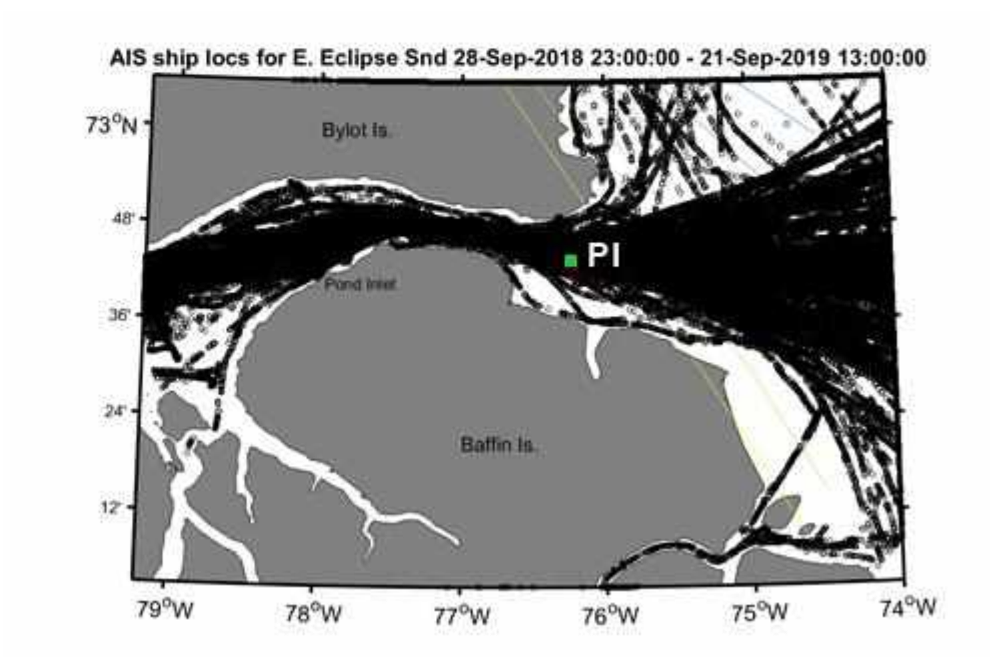


Figure 3. All Automated Information System (AIS) ship locations received by satellite within 100 km of the Pond Inlet recording location (site PI) between Sep 28, 2018 and Sep 21, 2019. Each black circle represents one AIS message received, which included ship identity, position, and operational information (e.g. heading, speed, draught).

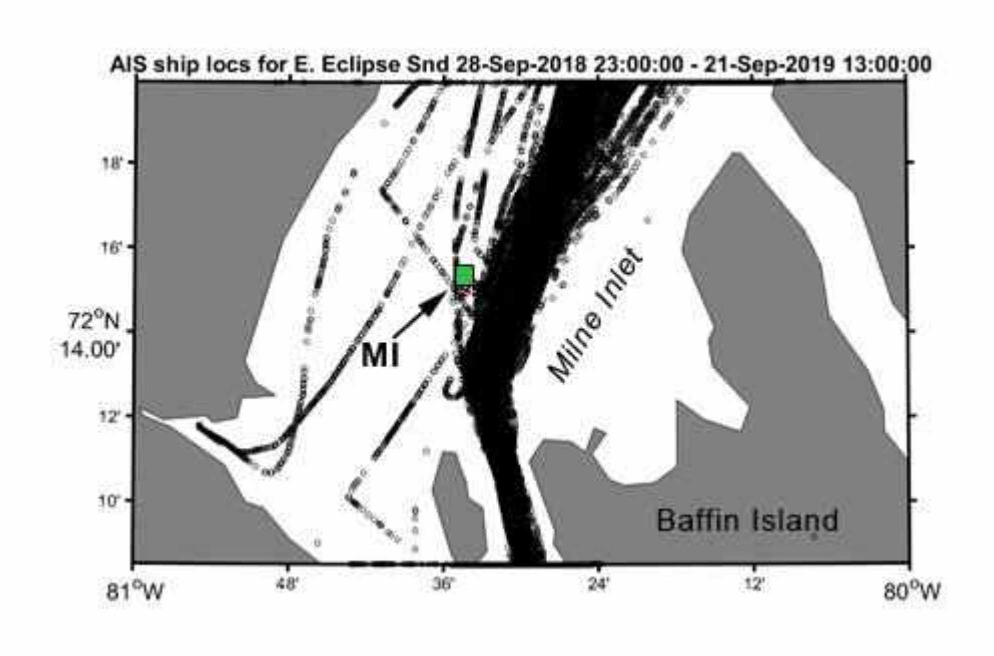


Figure 4. All Automated Information System (AIS) ship locations received by satellite within apx. 20 km of the Milne Inlet recording location (site 'L') between Sep 28, 2018 and Sep 21, 2019. Each black circle represents one AIS message received, which included ship identity, position, and operational information (e.g. heading, speed, draught).

Table 2. Summary of AIS vessel transits, passing within 15 km of the Pond Inlet (PI) recording site and Milne Inlet (MI) reference location between Sep 28, 2018 and Sep 21, 2019.

	Pond Inlet		Milne Inlet	
Ship type	Number of transits	Percent of transits	Number of transits	Percent of transits
Bulk Carriers	152	57%	152	63%
General Cargo	25	9%	21	9%
Passenger Ships	20	8%	0	0%
Icebreaker-Support Vessel	19	7%	39	16%
Oil and Chemical Tanker	15	6%	10	4%
Pleasure Craft	7	3%	1	0%
Sailing	6	2%	0	0%
Tug	6	2%	9	4%
Military	6	2%	2	1%
Other Cargo	5	2%	6	3%
CCGS-SAR	5	2%	0	0%
Total	266		240	

The most common vessel type at both locations was the bulk carrier, with 43 unique vessels comprising 57% of transits at PI and 63% at MI. After bulk carriers, proportions of vessel types differed somewhat between sites. At PI, other vessel types with highest transit occurrence were general cargo (9%, n=25), passenger (8%, n=20), icebreaker (7%, n=19), and tanker (6%, n=15). Pleasure craft, and fishing, sailing, tugs, military, Canadian Coast Guard, and other cargo vessels together made up the remaining 13% of ship transits (n=35) at site PI.

At site MI, the other types with highest occurrence of transits were icebreaker (16%, n=39), general cargo (9%, n=21), tanker (4%, n=10), and tug (~4%, n=9). Other cargo and military vessels made up the remaining 3% (n=8). There was a single transit of a pleasure craft, the 36 m length private yacht Noorderzon, and no transits of passenger ships, sailing vessels, or Search and Rescue ships (SAR; i.e. Canadian Coast Guard Ships) at MI.

Monthly natural and anthropogenic underwater sound levels

A total of 1872 h of acoustic recordings were analyzed for underwater sound levels from 78 days across four periods of the shipping seasons of 2018 and 2019 (Fig. 5 green, blue, and white bars). From these data, 987 h (53% of analysis periods) were extracted for estimation of sound levels with transient ship noise events excluded (*i.e.* background noise; Fig 5. green bars). This was the total time during the shipping periods analyzed when there was greater than 8 h between transiting ships passing site PI. Daily durations of continuous periods of background noise analyzed ranged from apx. 1 to 24 h.

The first analysis period was Oct 1 to Oct 22, the last day of 2018 ship transits past site PI. This period includes the end of the 2018 open water season and the onset of sea ice freeze-up. The second analysis period was from the date of the first vessel transit of the year on July 18, 2019, through July 31. This period includes the beginning of 2019 shipping and onset of continuous sea ice breakup leading to open water. The third and fourth periods included open water shipping during Aug 1-26 and Sep 2-21, 2019. Acoustic data were not recorded between Aug 27 and Sep 2, 2019.

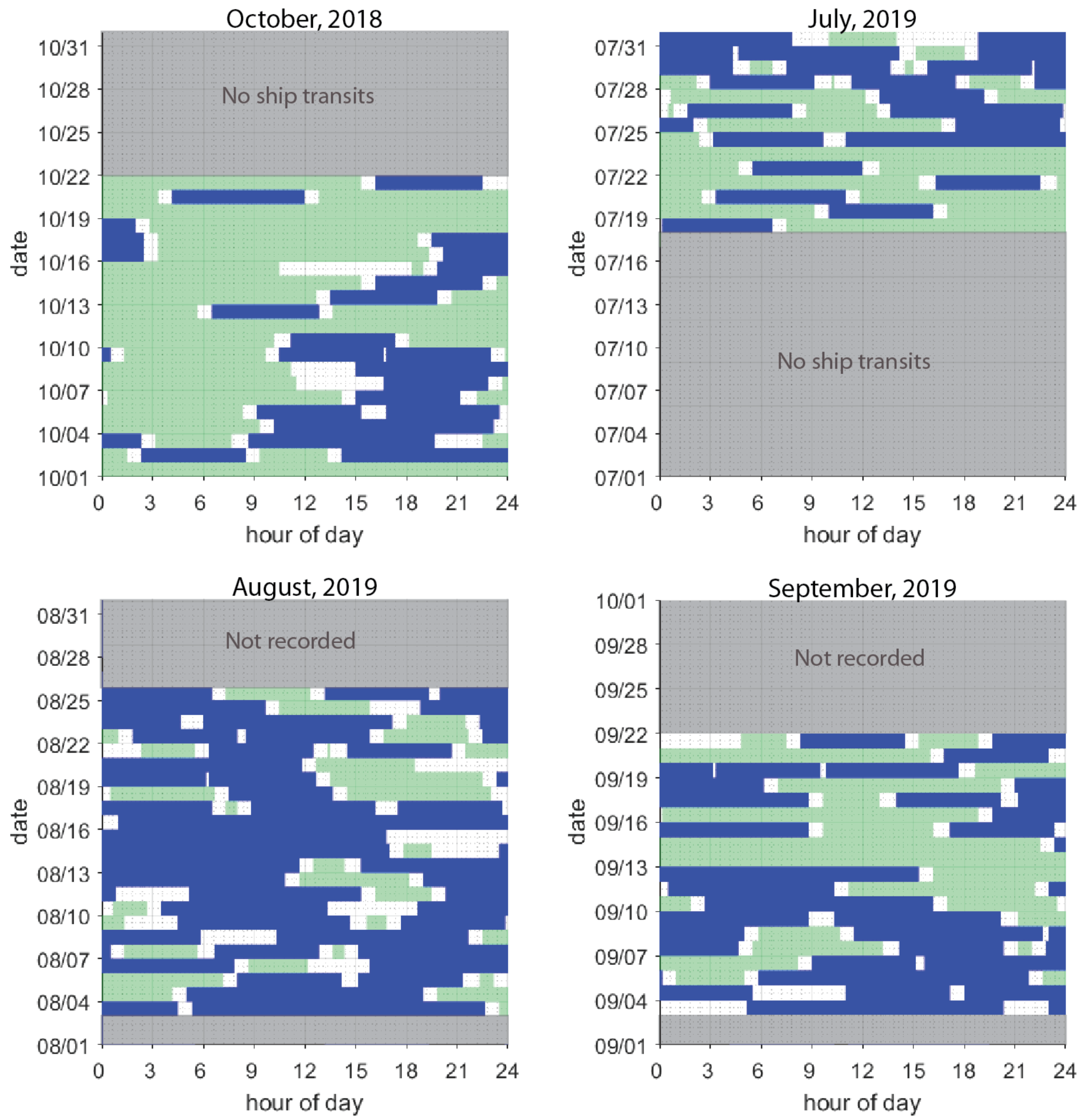


Figure 5. Monthly time periods analyzed for shipping and ambient noise from Oct, 2018 through Sept, 2019. Blue bars include all 6-h ship transit windows. Green bars indicate periods selected for analysis of ambient noise with time between successive ship CPAs of at least 8 h. Gray areas indicate periods either outside of the shipping season (Oct 22-31, 2018 and July 1-17, 2019) or times not recorded. All recording times outside gray areas (blue, green, and white bars) were included in analysis of total monthly sound levels, including ship transits.

In all months, noise from ships transiting past the recording site is apparent in the acoustic recordings as relatively short-duration increases in received sound spectrum level (SSL) with energy concentrated below 2000 Hz and with few exceptions, when hourly median SPL_{BB} exceeds 110 dB (Figs 6-9). Elevated natural underwater sound levels during the background noise periods occurred at varying intensities and durations and was assumed to be primarily wind generated or resulting from sea ice processes. In all months except October, median hourly SPL_{BB} rarely exceeded 110 dB except for during ship transits past the recorder. Monthly median and 90th percentile SPL_{BB} for all background noise periods (Table 2) are lowest in July when they are 97 and 103 dB, and highest in October at 103 and 112 dB, respectively.

Intermittent periods of elevated background sound levels from natural sources, likely wind-generated noise, are most apparent during ice free conditions early to mid-Oct, 2018 (Fig 6) and again in late-Aug and throughout Sept, 2019 (Figs 8 and 9, respectively). These natural noise events can be > 1 d in duration, as in the Oct 6-7 period of elevated received levels across the 20-4000 Hz frequency range (Fig. 6.b.1). Excluding ship transits during this event, maximum SPL_{BB}, represented by the hourly 99th percentile of background noise periods, was 114 dB re 1 μPa^2. After Oct 14, sea ice cover became more prevalent and overall ambient noise decreased as expected with increasing ice cover (e.g. Roth *et al*., 2012; Halliday *et al.*, 2020) while impulsive events, likely associated with sea ice can be seen in the persistence of > 100 dB 99th percentile levels later in October. Transient ship noise events can also be identified in the LTSA and hourly SPL percentiles. All events with hourly median SPL_{BB} >115 dB were associated with ship transits.

Figure 10 presents monthly background noise spectra (left panels for each mo.) from a random sample of 20,000 5 s background noise periods recorded during each month of shipping operations. July and August had the lowest background noise and included a period between July 18 and July 20 during which > 1% sea ice cover remained within a 20 km radius of the recording location. Noise from an icebreaker (M/V Botnica) is apparent at 200 Hz in the July 90th and 99th percentile background SSL (4.a), reaching apx. 77 and 89 dB re 1 μPa^2/Hz respectively. This suggests that apx. 200 Hz noise from the ship is detectable at ranges greater than 40 km from the ship in at least some transits. In August periods of wind noise appear at frequencies above 200 Hz in the 90th and 99th percentiles. Median and lower percentiles reflect relatively quiet periods >200 Hz with lower wind noise apparent at those frequencies. September and October (5.a. and 5.c.) had the highest background noise levels, likely due to increased wind-generated noise raising the median spectrum levels above 200 Hz by 5 to 8 dB re 1 μPa^2/Hz compared to August. October had the highest spectrum levels at all frequencies, with additional broadband noise likely associated with sea ice formation. Icebreaker harmonic noise at 200 Hz is again visible in the 99th percentile background noise samples from October.

Monthly sound spectrum levels for periods including both transient ship noise events and background noise periods (Fig 10. right panels) were similar to background noise spectra in the median and lower percentiles, with the ship-inclusive median SSL higher by a 2-4 dB in the 50-100 Hz range where the largest contributions from ship noise would be expected. Some additional low-frequency noise <40 Hz was apparent in the ship-inclusive ambient median-level spectra, consistent with cavitation noise from large ship propellers (Ross, 1976). The 90th and

99th percentile ship-inclusive levels for July and October clearly exhibit substantial additional noise consistent with ships and the icebreaker operating in the area during both months. In all months, the 99th percentile SSL including ship transit periods was higher at all frequencies by 1 to 15 dB than during background noise periods excluding ship noise, with the greatest relative differences occurring in the 50-250 Hz range.

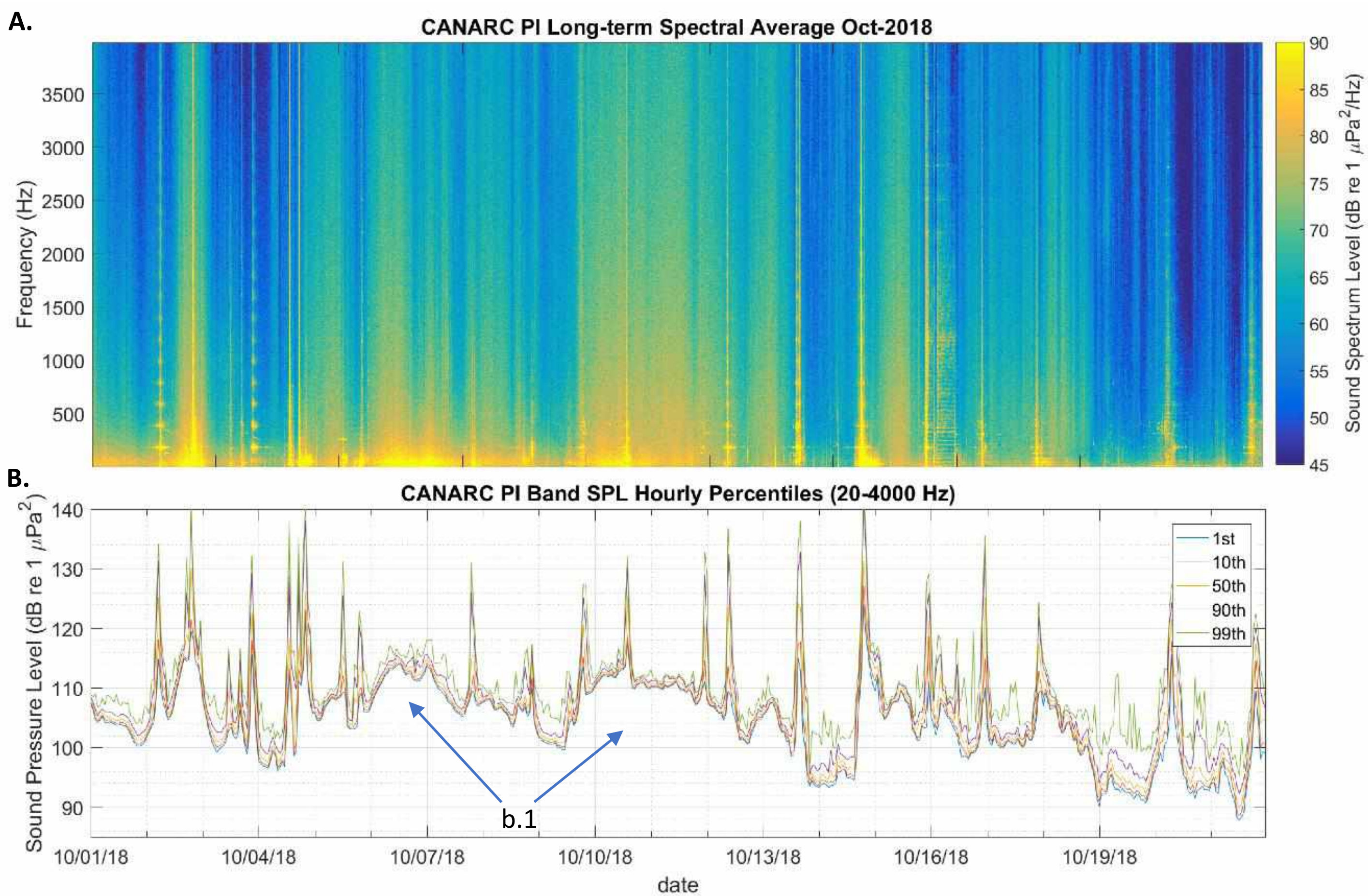


Figure 6. Long-term spectral average (LTSA; a) and hourly percentile 20-4000 Hz broadband sound pressure level (SPL_{BB}; b) percentiles for all recorded periods from Oct 1 to the date of last ship transit Oct 22, 2019. Example periods of elevated sound levels from natural sources, likely wind-generated noise, can be seen Oct 6-7 and Oct 9-12 (b.1).

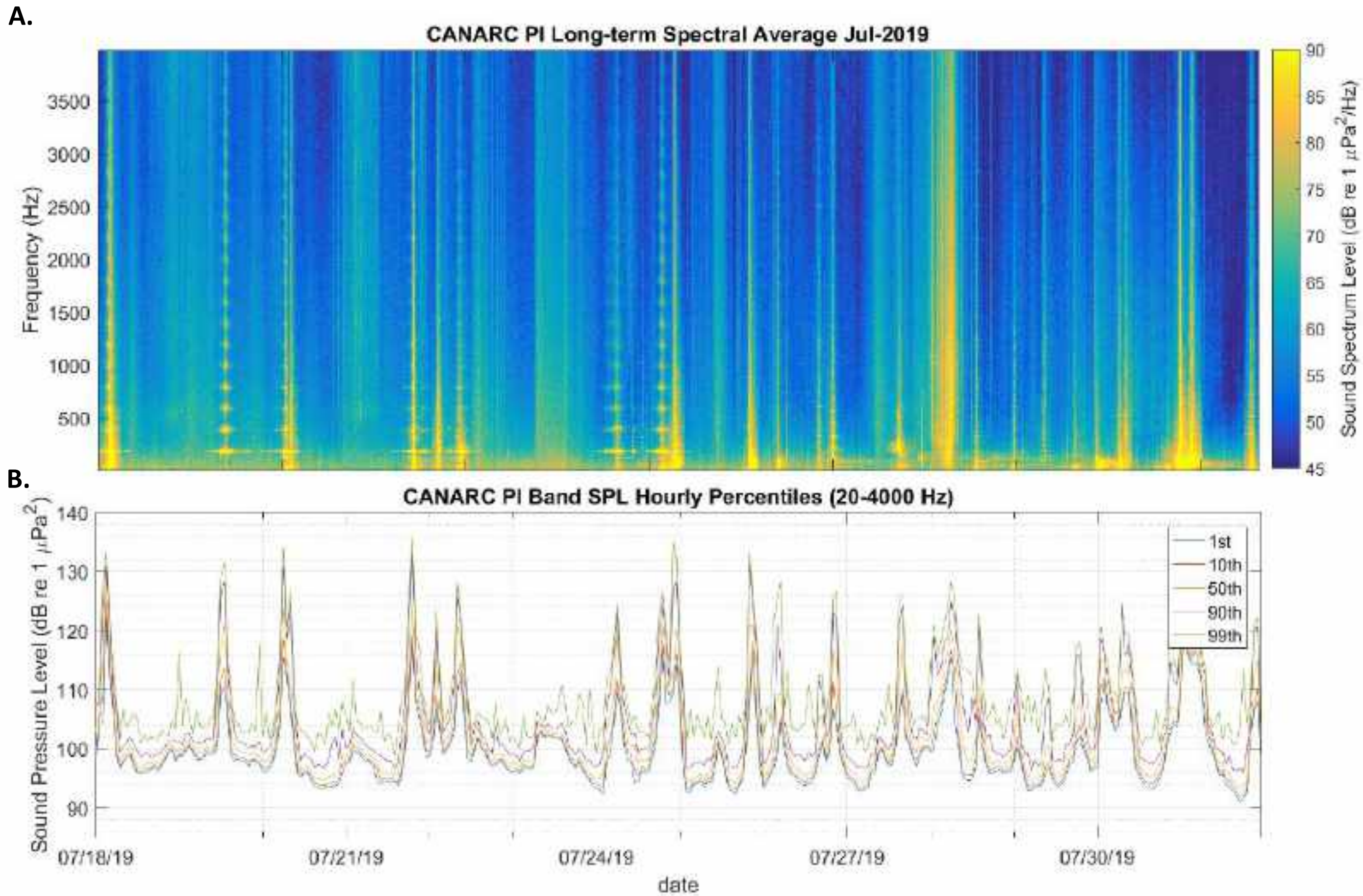


Figure 7. LTSA (top) and hourly percentile SPL_{BB} for all recorded periods at site PI in Jul, 2019 starting on the date of the first ship transit on July 18.

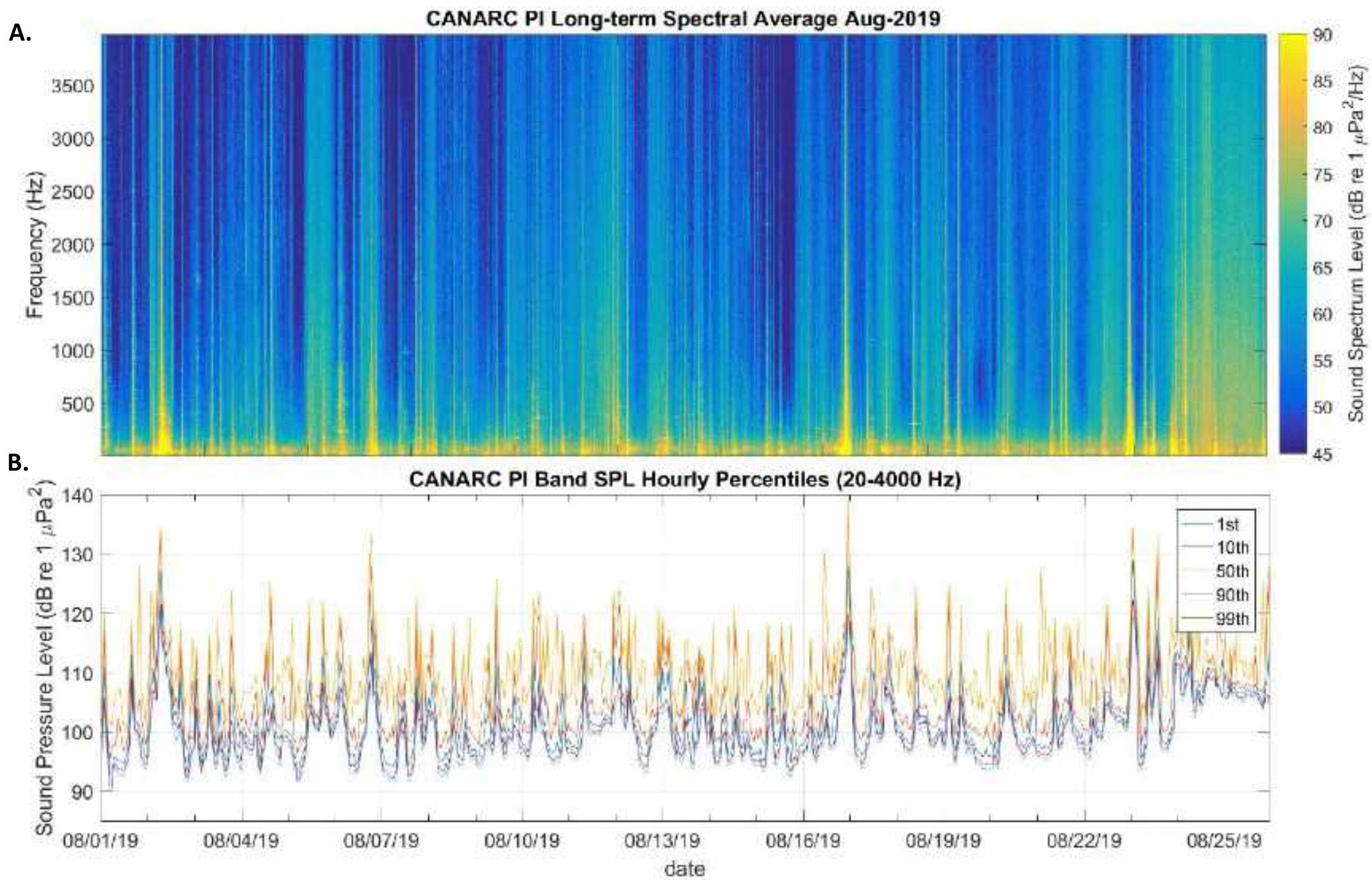


Figure 8. LTSA (top) and hourly percentile SPL_{BB} for all recorded periods at site PI in Aug, 2019.

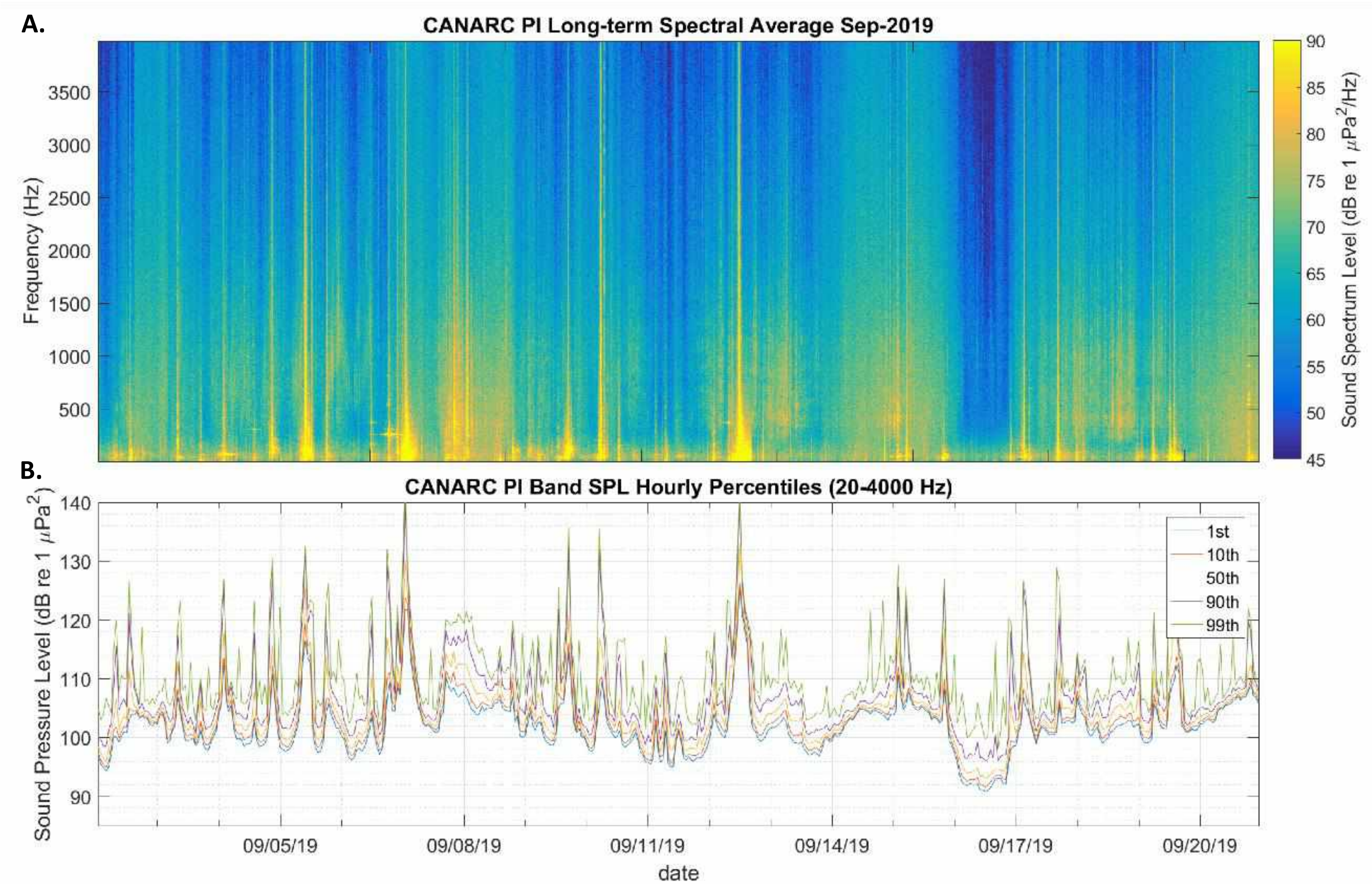


Figure 9. LTSA (top) and hourly percentile SPL_{BB} for all recorded periods at site PI in Sep, 2019.

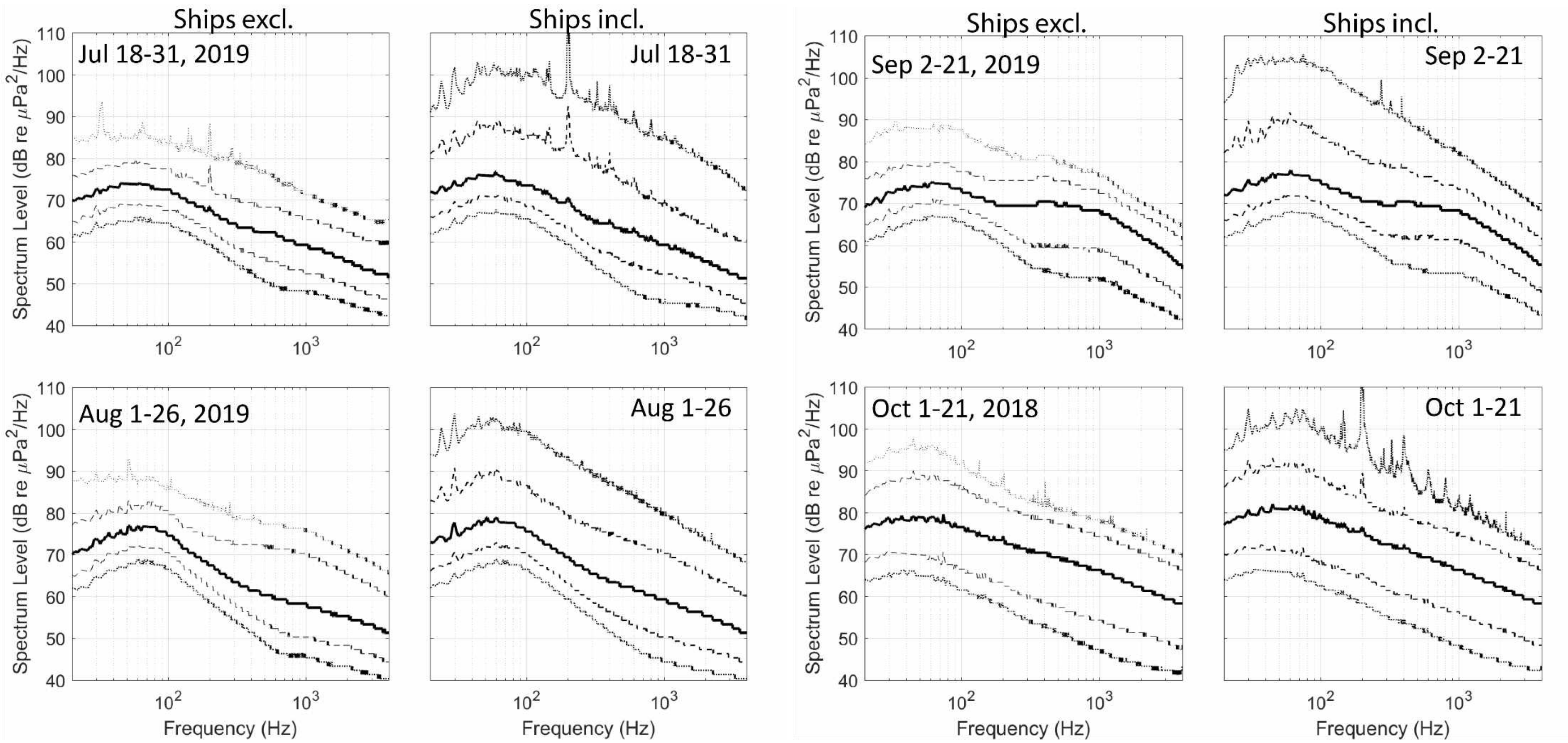


Figure 10. Sound spectrum levels for Jul, Aug, and Sept, 2019 and for Oct, 2018. Levels are represented by the 1st, 10th, 50th (median), 90th, and 99th percentiles of 30,000 random 5 s samples from times excluding transient ship noise events in each period ('Ships excl.') and of all recorded times, including ship transits ('Ships incl.').

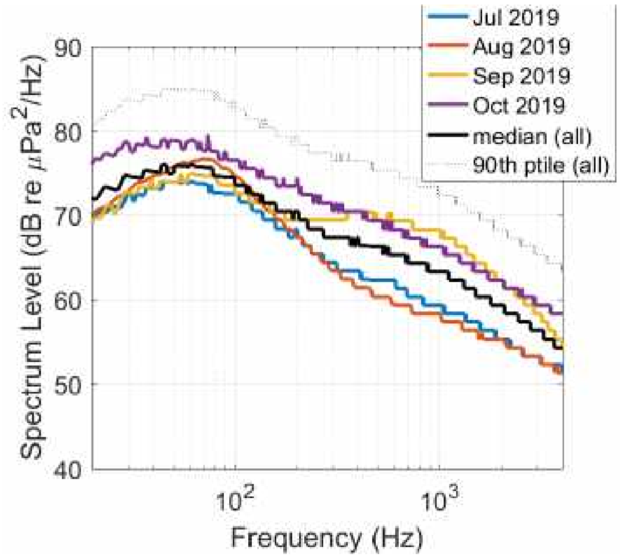


Figure 11. Median monthly sound spectrum levels (SSL) for all months of shipping traffic in Eclipse Sound Oct, 2018 to Sep, 2019. Monthly SSL based on 30,000 5-sec LTSA samples selected randomly from all times in each month with nearest ship CPA time and range ≥ 4 h and ≥ 40 km, respectively.

Table 3. 50th (median) and 90th percentile SPL (in dB re 1 μPa^2) for monthly background noise periods (Bkgnd.) in the 250 Hz, 1 kHz, and 3.5 kHz 1/3rd octave and 20-4000 Hz frequency bands. Number of recording hours included in computation of each percentile value are also provided for all time periods.

	July		August		September		October		All	
Frequency band	Median	90th	Median	90th	Median	90th	Median	90th	Median	90th
20Hz - 4 kHz	97	103	98	106	102	107	103	112	100	109
250 Hz	83	89	83	91	86	93	90	98	86	96
1 kHz	83	89	82	94	91	96	90	98	86	96
3.5 kHz	82	89	81	91	85	92	88	96	84	93
no. hours	96	-	51	-	60	-	162	-	369	-

Acoustic characteristics of ship transits

A total of 220 ship transits were recorded acoustically at site PI during the recording periods analyzed. Design characteristics, operational information, and acoustic measurements at site PI are summarized in Table 4 for a representative set of each ship type.

Six-hour long-term spectral averages of the five most common ship types (i.e. bulk carrier, general cargo, passenger, oil and chemical tanker, icebreaker) show that different ship types exhibit differences in spectral characteristics of underwater noise. These ship types represented 87% of transits past site PI (n=231) and 92% of transits past site MI (n=221). The highest received levels in all frequency bands were associated with icebreakers, oil and chemical tankers, and general cargo vessels. For all ship types, the farthest propagating noise occurs in frequencies at or below 200 Hz, including tonal sounds below 100 Hz that are associated with cavitation of the ship's propeller. Generally, the noise bandwidth extends into higher frequencies as the ship approaches the CPA during a transit and higher-frequency harmonics of the tonal cavitation noise also become apparent. In the LTSA windows, a U-shaped pattern of ship noise about the CPA is apparent during most transits, resulting from interference between the two primary paths for the sound: one directly from the ship's propeller, and one after one reflection off the sea surface. The effect of these two paths for sound propagation from the propeller is a constructive and destructive interference pattern that changes as the ship moves closer to and farther from the receiver, a phenomenon known as the Llyod's Mirror Effect (Ross, 1976). This effect is also evident in the alternating peaks and valleys in received level across frequency band in the sound spectrum levels near the CPR (*e.g.* Fig 17.d).

As in other studies of underwater noise from ships (*e.g.* McKenna *et al*., 2012; Gassmann *et al*., 2018), there is more energy radiating from the stern than from the bow aspect of ships. The result of this aspect dependence of source level is a longer period with elevated noise levels following a ship transit than preceding it. This pattern is most pronounced in the oil/chemical tanker example LTSA (*e.g.* Table 4, Figs. 16-18). Relationship between received 20-4000 Hz sound pressure level (SPL_{BB}) and range to the ships generally was different between vessel types, with longer range propagation of noise evident in the icebreaker and tanker ships than in bulk carriers or general cargo ships (Fig. 12).

Table 4. Design characteristics and acoustic measurements of a representative set of ships of seven common types transiting Eclipse Sound. Ranges and 20-4000 Hz broadband received sound pressure levels (in dB re 1 μPa^2) at closest point at which the ship was recorded (CPR) are given for each example ship transit along with observed ranges to the ship when received levels were measured at 110 and 120 dB. Where values for bow and stern aspect 110 and 120 dB RL range differ substantially, both are given (*i.e.* bow range (km), stern range (km))

Ship information							Acoustic measurements				
Ship type	MMSI number	Ship name	Ship length (m)	Year built	Gross tonnage (10^3)	Deadweight tonnage (10^3)	Ship speed (kts)	Range at CPR (km)	Received level at CPR*	Range to 110 dB (km)	Range to 120 dB (km)
Bulk Carriers	356364000	NORDIC ODIN	225	2015	41071	76180	8.7	0.9	121	4,7	0.9
	356364000	NORDIC ODIN	225	2015	41071	76180	8.6	0.6	123	4,7	0.9
	373437000	NORDIC ORION	225	2011	40142	75603	7.5	2	119	5,7	2
	373437000	NORDIC ORION	225	2011	40142	75603	7.7	2.4	118	5,7	-
	374322000	NORDIC ODYSSEY	225	2010	40142	75603	8.4	1	127	10	3
	538008053	GOLDEN PEARL	225	2013	41718	74300	7.3	1.8	114	4	1.8
	538008053	GOLDEN PEARL	225	2013	41718	74300	8.6	0.3	125	5,7	1
	636015651	NS YAKUTIA	225	2013	40972	74559	8.1	1	115	2,3	-
	636015650	NS ENERGY	225	2012	40972	74518	7	3.1	116	4,6	-
	636092901	KAI OLDENDORFF	229	2019	44029	81243	8	1.9	120	4,7	1.9
	255805765	GISELA OLDENDORFF	229	2013	44218	80839	8.8	1	119	3,7	1
	538004978	AM QUEBEC	230	2013	43987	81792	7	1.1	130	10,20	4,5
General Cargo	316015133	ZELADA DESGAGNES	139	2009	9611	12692	12	1.4	132	20,25	5,8
	316011358	ROSAIRE A. DESGAGNES	138	2007	9611	12776	8.2	0.6	127	10,15	3
	246770000	MOLENGRACHT	143	2012	9524	11744	8.9	0.2	135	13,15	4,7
	316003010	SEDNA DESGAGNES	139	2009	9611	12612	12	0.2	134	10,20	3,5
Oil and Chemical Tankers	316012308	SARAH DESGAGNES	147	2007	11711	17998	9	2	133	10,35	4,16
	316012308	SARAH DESGAGNES	147	2007	11711	17998	8.2	2.6	133	10,20	10,20
	316095000	DARA DESGAGNES	124	1992	6262	10511	8.5	0.3	130	7,20	2,4
	316095000	DARA DESGAGNES	124	1992	6262	10511	7.2	0.6	133	20,25	4,5
	316037373	KITIKMEOT W	150	2010	13097	19983	13	3.1	123	10,25	5
	316037373	KITIKMEOT W	150	2010	13097	19983	13	0.1	135	10,-	3,5
Passenger Ships	311000419	OCEAN ENDEAVOUR	137	1982	12907	1762	11	2	122	8,13	3,4
Pleasure Craft	319030600	ARCADIA	36	8	308						
	304977000	HANSE EXPLORER	48	2006	885	198	11	2.7	119	5,6	3,4
	304977000	HANSE EXPLORER	48	2006	885	198	9.8	2.6	111	4,5	-
Icebreaker	276805000	BOTNICA	97	1998	6370	2850	8.9	0.3	134	(14-28) (17-40)	(4-10) (4-16)
	276805000	BOTNICA	97	1998	6370	2850	8	2.7	133	18,30	7,16
	265182000	ODEN	108	1989	9605	4906	8	3.4	118	10	4
CCGS-SAR	316050000	CCGS AMUNDSEN	98	1979	5910	2865	13	1.9	122	9,10	3
	316050000	CCGS AMUNDSEN	98	1979	5910	2865	10	7	119	15,22	8,12
	316122000	TERRY FOX	88	1983	4233	2113	14	0.7	136	20,25	6

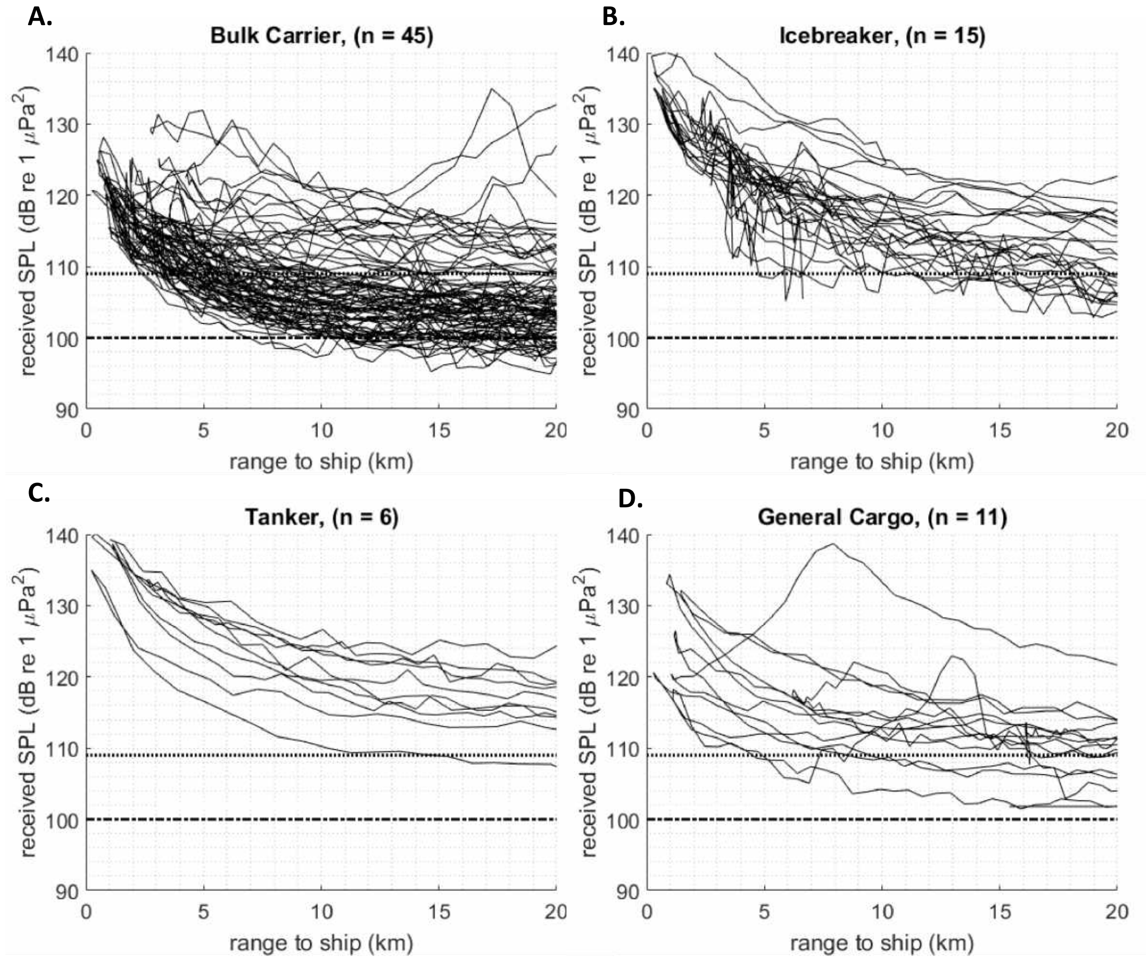


Figure 12. Received SPL_{BB} (1-min median) with range to ship for transit examples in which the closest point of approach (CPA) was within 4 km of the PI recording location. Transits are separated by vessel type. Only transits with no other ship CPA within 1 hr are included for bulk carrier, tanker, and general cargo vessels. Icebreakers were usually transiting with other vessels, so all transit events with CPA <4 km are plotted. Number of transits plotted (n) is included in each panel title. Median (dash-dot line) and 90th percentile (dotted line) SPL_{BB} for all shipping months are also plotted for reference.

Bulk carriers

Two typical open water transit scenarios for a bulk carrier (Nordic Orion) are exemplified in Figures 13-15, one at about the median background noise level during the transit (Sep 5, 2019) and one representing 'quieter' background noise conditions (Aug 1, 2019). Received SSL was highest at frequencies from 30-200 Hz (Figs 14.d, 15.d) throughout the transits, with energy to >4 kHz also present at ranges closer to the CPA. Low-frequency noise below 50 Hz from transiting bulk carriers was apparent from distances >30 km in both background noise conditions (14.d.1, 15.d.1). Estimated background SPL_{BB} during the Aug 1 transit was apx. 5 dB below the median background noise level (Fig 15.c.1) until the ship was at range 25 km from the receiver. SPL_{BB} increased above the relatively quiet transit background noise from 2 h prior to CPA (range 25 km) to > 3 h after CPA (range >40 km), rising more rapidly within 10 km of the vessel. The 250 Hz, 1 kHz, and 3.5 kHz band SPL (Fig 15.e, Fig. 28) followed a similar pattern during the ship transit with relative increases in SPL at CPA of 30, 30, and 18 dB, respectively, above pre-transit levels. During the Sep 5 transit, pre-CPA background noise was close to median levels (Fig. 14.c.1). SPL_{BB} began increasing apx. 1.5 h prior to CPA with relative increases in SPL_{BB} and band SPL of 15-20 dB at CPA. Relative changes in all frequency bands and in the SSL were smaller than during the lower noise scenario Aug 1. Distance to receiver at SPL_{BB} > 110 dB was similar in both transits and the pattern of higher received levels at the stern aspect is visible. SPL_{BB} of 110 dB was reached at range to ship of 4 and 7 km from the bow and stern aspects, respectively (Table 4, Figs. 14.a., 15.a.).

Patterns in received level versus range were examined for a subset of 45 bulk carrier transits during which the nearest time to CPA of another ship transit was > 4 h and with maximum CPA distance to the receiver of 3 km. SPL_{BB} was greater than 110 and 120 dB at ranges from the recorder of apx 3-10 and 1-2 km, respectively (Fig. 12.a). A notable exception was the ship AM Quebec (MMSI 538004978), for which 110 and 120 dB SPL_{BB} occurred 10-20 km and 4-5 from the ship, respectively. Typical speeds of transiting bulk carriers resulted in duration of received SPL_{BB} >110 dB at the recording location for periods of 0.5-1 h and 120 dB for about 0.5 h.

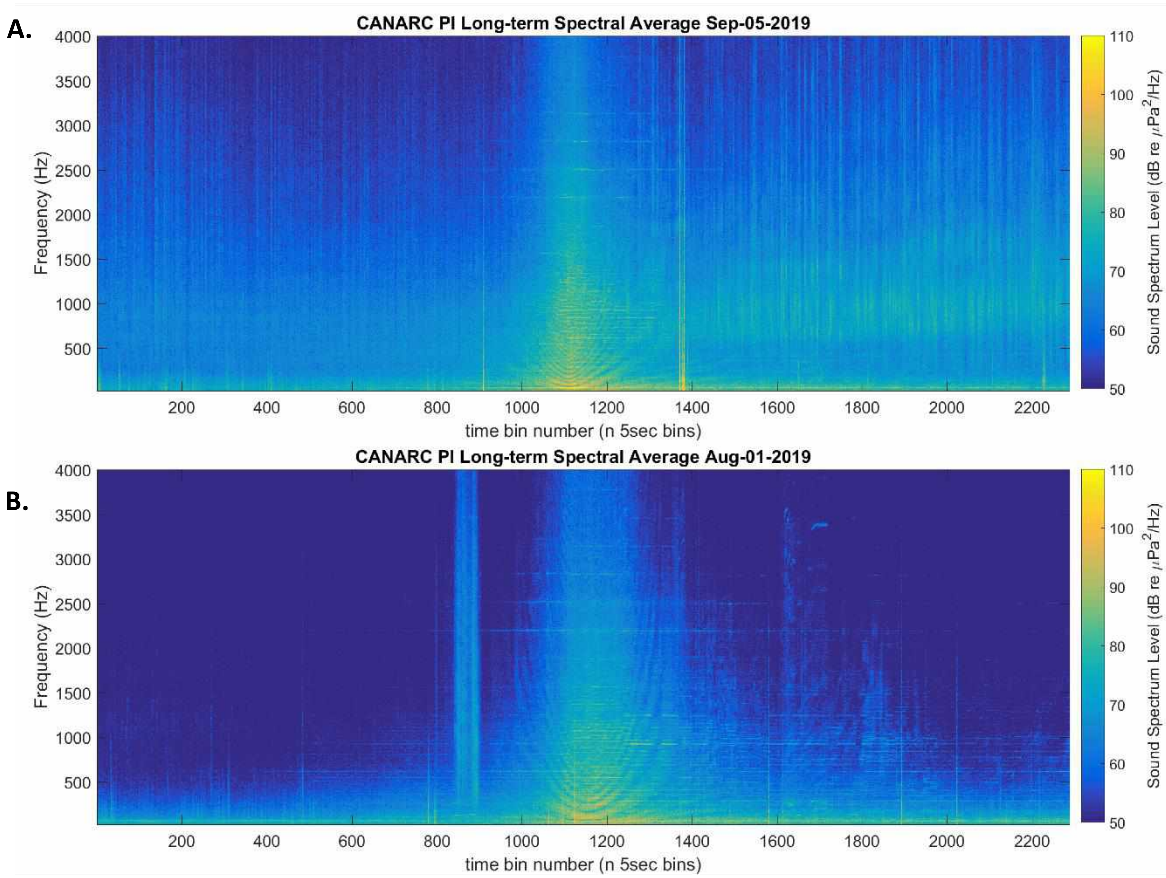


Figure 13. Long-term spectral average (LTSA) of the 6-hour window about the closest point of approach (CPA) of 225 m bulk carrier Nordic Orion (MMSI 373437000) during two transits past the recording location. Wind-generated noise below 4 kHz is evident in the Sep 5, 2019 transit (top panel; CPA range 2 km). A transit of the same vessel Aug 1, 2019 (bottom panel; CPA range 2.4 km) occurs during lower background noise at the start of the ice-free season.

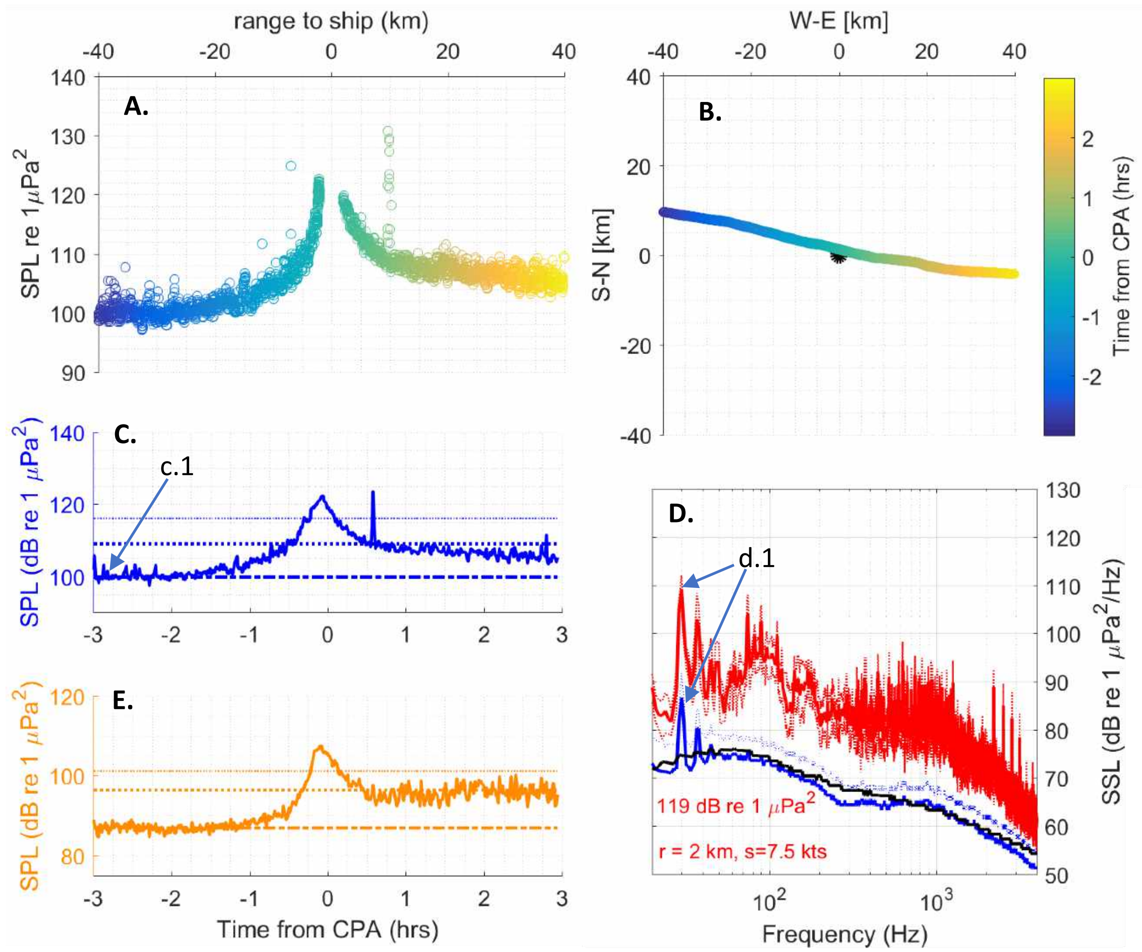


Figure 14. Ship transit analysis for bulk carrier Nordic Orion Sep 05, 2019. Broadband sound pressure level (SPL_{BB} 20-4000 Hz; open circles) averaged every 5s increases beginning at apx. range 20 km prior to closest point of approach (pre-CPA). SPL_{BB} at CPA 119 dB re 1 μPa^2. Colors in SPL scatter plot and map showing ship track (top right) represent time from CPA (5s bins). 1-min median received SPL_{BB} for the 20-4000 Hz band (panel c; blue line) and the 1 kHz 1/3rd octave band (panel e; orange line) during ship transit plotted with 50th (dash-dot line), 90th (dotted line), and 99th (upper dotted line) percentile levels without ships (background levels). Sound spectrum level (SSL; panel d) of CPR period (red) with median SSL of the 1st 30 min of transit plot (blue) and shipping season median background sound levels during periods without ships (black).

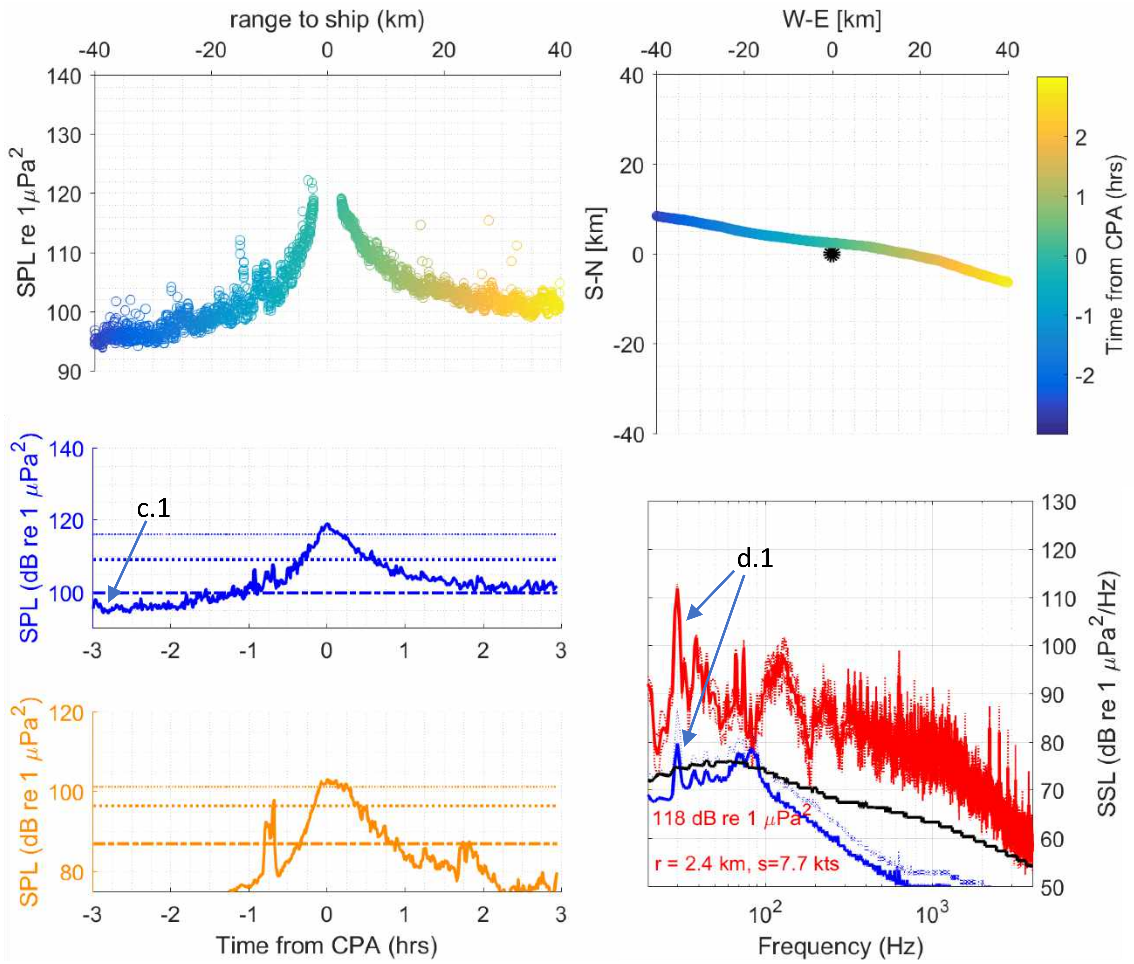


Figure 15. Ship transit analysis for bulk carrier Nordic Orion Aug 01, 2019. SPL_{BB} (panel a, open circles) averaged every 5s increases starting apx 30 km range to ship pre-CPA. SPL_{BB} was 118 dB at CPA range 2.4 km. Colors in SPL scatter plot and map showing ship track (panel b) represent time from CPA (5s bins). 1-min median received SPL_{BB} (panel c; blue line) and 1 kHz 1/3rd octave band SPL (panel e; orange line) during ship transit plotted with 50th (dash-dot line), 90th (dotted line), and 99th (upper dotted line) percentile levels without ships (background levels). Sound spectrum level (SSL; panel d) of CPA period (red line) with median SSL of the 1st 30 min of transit plot (blue line) and shipping season median background sound levels during periods without ships (black line).

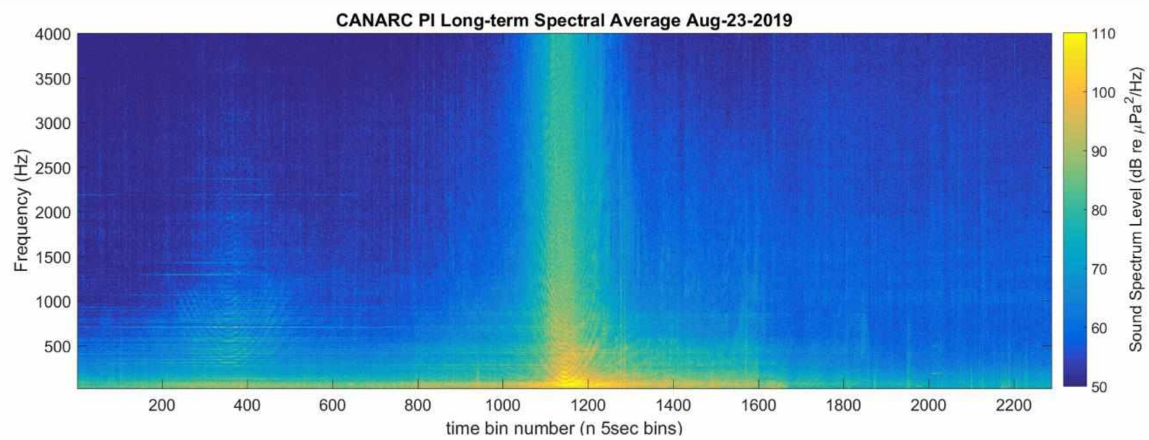
General cargo vessels

Two transit scenarios are exemplified for general cargo vessels in figures 16-18, one with median background noise levels pre-CPA (Zelada Desgagnes, Aug 23, 2019) and one with relatively noisy (90th percentile background noise level) pre-transit conditions (Sedna Desgagnes, Aug 24, 2019). General cargo vessel received SSL was highest at frequencies from 20-200 Hz (Figs 17.d, 18.d) with long-range propagation of 20-30 Hz noise apparent at ranges > 30 km from the receiver. Estimated background SPL_{BB} during the Aug 23 transit was apx 103 dB (Fig. 17.c.1), but determining initial onset of elevated noise at the receiver was complicated by the transit of Canadian Warship (MMSI 316139000) past the recorder 2 h prior to CPA (Fig. 16.a.1, 17.c.2).

Continuous increase in SPL_{BB} is evident from 1.5 h pre-CPA and SPL_{BB} returned to pre-transit levels 1.5 h after CPA at range 35 km from the receiver. Duration of > 110 dB SPL_{BB} was 2.5 h, starting and ending at ranges 20 and 30 km from the bow and stern aspects, respectively. Duration of SPL_{BB} >120 dB was 0.5 h starting at range 4 km from the bow aspect and ending at range 7 km from stern.

On Aug 24, 2019, estimated background noise during the transit of the Sedna Desgagnes (MMSI 316015251) was close to 90th percentile background noise levels (Fig. 18.c.1). SPL_{BB} was elevated above pre-CPA background levels from 0.5 h before to 1.5 h after ship CPA. Duration of > 110 dB SPL_{BB} was 2 h, starting and ending at ranges 10 and 30 km from the bow and stern aspects, respectively. Duration of SPL_{BB} >120 dB was 0.4 h starting at range 3 km from the bow aspect and ending at range 5 km from stern. Relative changes in band SPL and in SSL were smaller and the difference in bow and stern received levels was less visible than in the lower background noise scenario in figure 17.

A.



B.

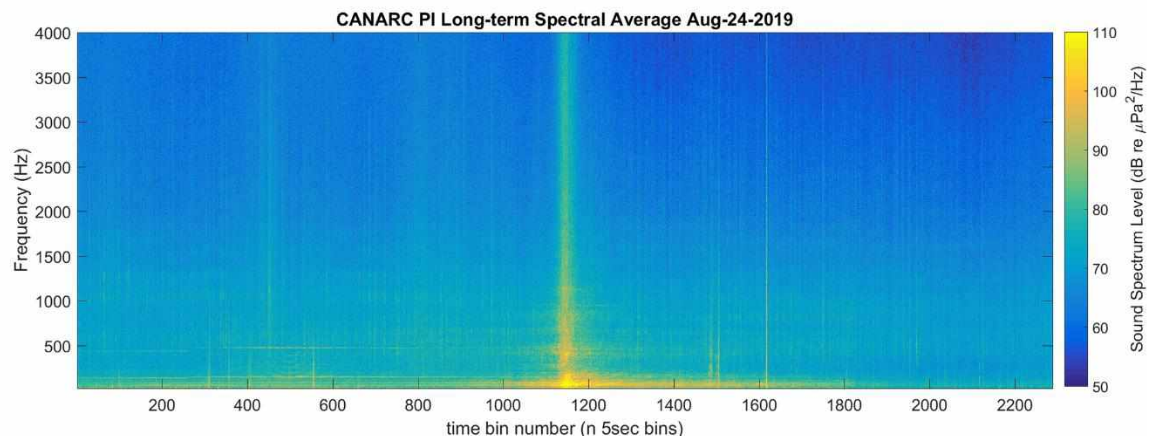


Figure 16. Long-term spectral average (LTSA) of the 6-hour window about the closest point of approach (CPA) of two general cargo vessels transiting past the PI recording site in open water. a) 139 m general cargo vessel, Zelada Desgagnes (MMSI 316015133) Aug 23, 2019, CPA 1.4 km. Canadian Warship 700 (MMSI 316139000) passes at range from recorder 1.5 km (a.1) 2 h prior to CPA. b) 139 m general cargo vessel Sedna Desgagnes (MMSI 316003010) on Aug 24, 2019. Passenger ship, Fram (MMSI 258932000) passes at range 1.6 km from recorder 1.7 h prior to CPA.

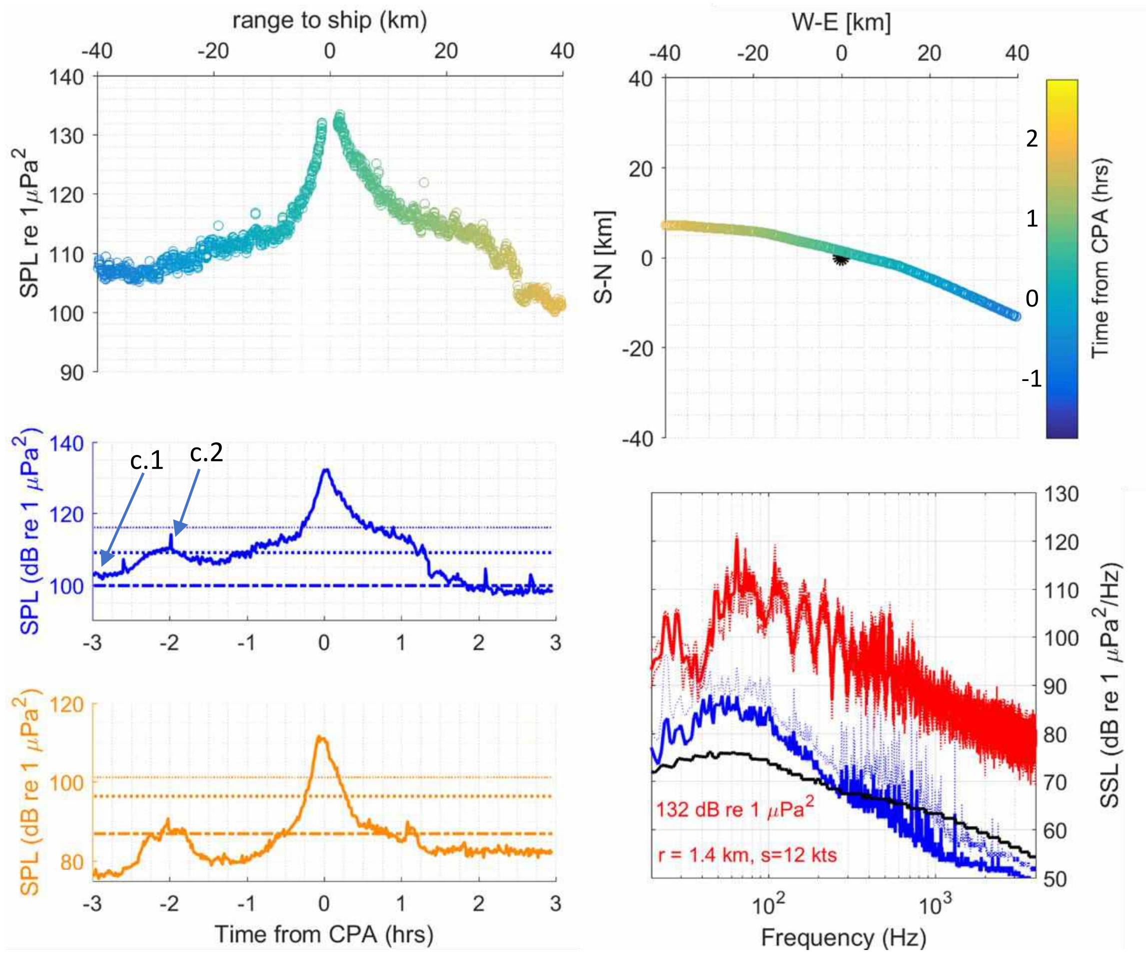


Figure 17. Ship transit analysis for general cargo vessel, Zelada Desgagnes Aug 23, 2019. SPL_{BB} (panel a, open circles) averaged every 5s increases starting apx 30 km range to ship pre-CPA. SPL_{BB} was 132 dB at CPA range 1.4 km. Colors in SPL scatter plot and map showing ship track (panel b) represent time from CPA (5s bins). 1-min median received SPL_{BB} (panel c; blue line) and 1 kHz 1/3rd octave band SPL (panel e; orange line) during ship transit plotted with 50th (dash-dot line), 90th (dotted line), and 99th (upper dotted line) percentile background levels. Sound spectrum level (SSL; panel d) of CPA period (red line) with median SSL of the 1st 30 min of transit plot (blue line) and shipping season median background sound levels during periods without ships (black line).

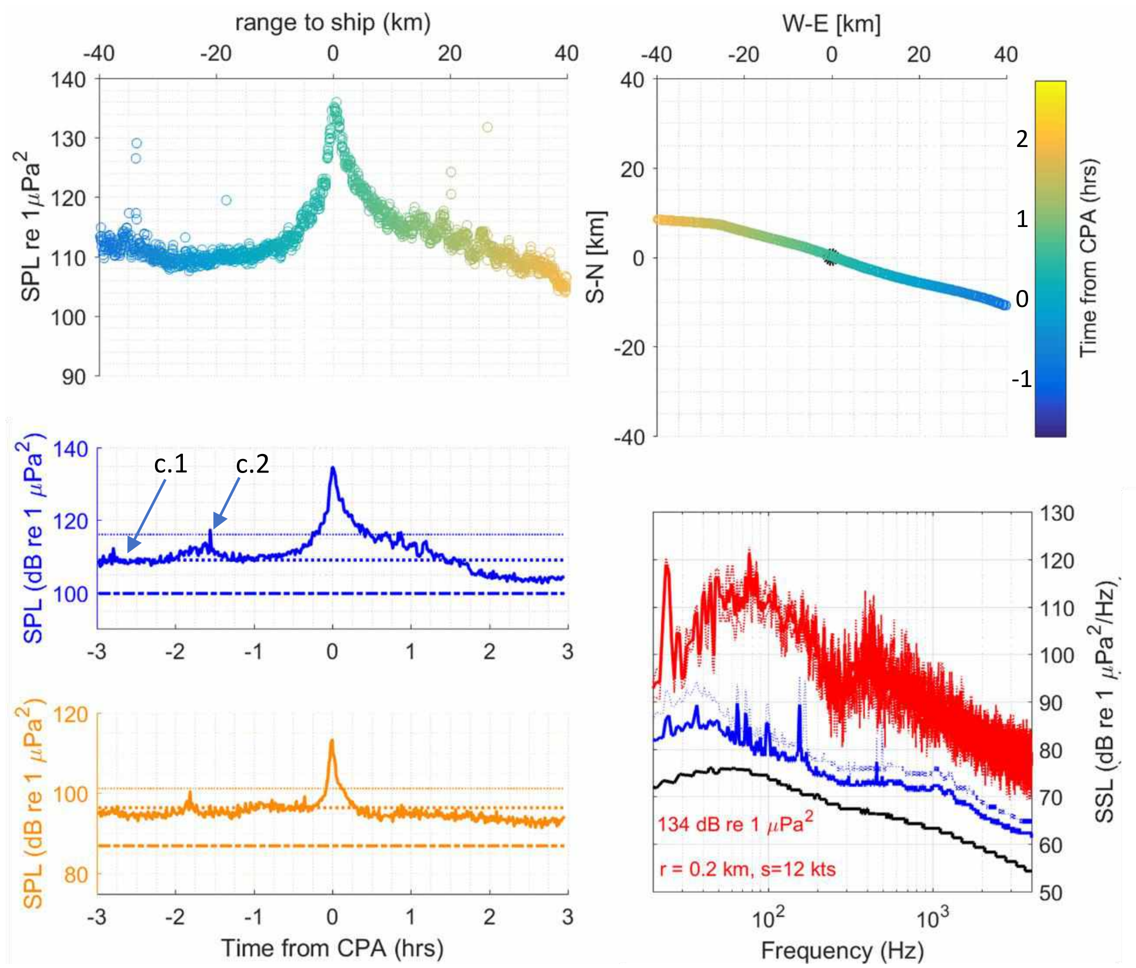


Figure 18. General cargo vessel Sedna Desgagnes (MMSI 316015251) Aug 24, 2019. SPL_{BB} (panel a, open circles) averaged every 5s increases above pre-transit background level (c.1) starting at 10 km range to ship pre-CPA and ending 20 km post-CPA. SPL_{BB} was 134 dB at CPA range 0.2 km. Colors in SPL scatter plot and map showing ship track (panel b) represent time from CPA (5s bins). 1-min median received SPL_{BB} (panel c; blue line) and 1 kHz 1/3rd octave band SPL (panel e; orange line) during ship transit plotted with 50th (dash-dot line), 90th (dotted line), and 99th (upper dotted line) percentile background levels. Sound spectrum level (SSL; panel d) of CPA period (red line) with median SSL of the 1st 30 min of transit plot (blue line) and shipping season median background sound levels during periods without ships (black line).

Patterns in received level versus range were examined for a subset of 11 general cargo ship transits during which the nearest time to CPA of another ship transit was > 1 h and with maximum CPA distance to the receiver of 2 km. SPL_{BB} was more variable between individual ships and transits with this vessel type due to background noise conditions and the presence of other ships within the 6-h ship transit windows. Greater than 110 and 120 dB SPL_{BB} occurred at ranges from the recorder of apx 10-30 and 1-7 km, respectively (Fig. 12.a).

Oil and Chemical Tankers

Two similar transits of the oil and chemical tanker, Sarah Desgagnes (MMSI 316012308), were selected to exemplify the ship type (Figs 19-21). This ship made about half of total tanker transits past site PI during the analysis period. Acoustic characteristics of the vessel had higher SPL and SSL approaching the CPA and longer range and duration of elevated noise levels compared to other cargo vessel types. Received SSL was highest at 30-200 Hz with peak energy at apx. 70-90 Hz. Low-frequency noise propagation at ranges > 30 km is less apparent in transits of this vessel type than in bulk carriers. In both representative transits, background noise levels were within 5 dB of the median background SPL_{BB}. SPL_{BB} increased above estimated pre-CPA background noise from 2 h prior to CPA (range 20-30 km) to > 3 h after CPA (range >40 km). The 250 Hz, 1 kHz, and 3.5 kHz band SPL (Fig. 31) followed a similar pattern during the ship transits with relative increases in SPL at CPA of about 30 dB above pre-transit levels for all bands.

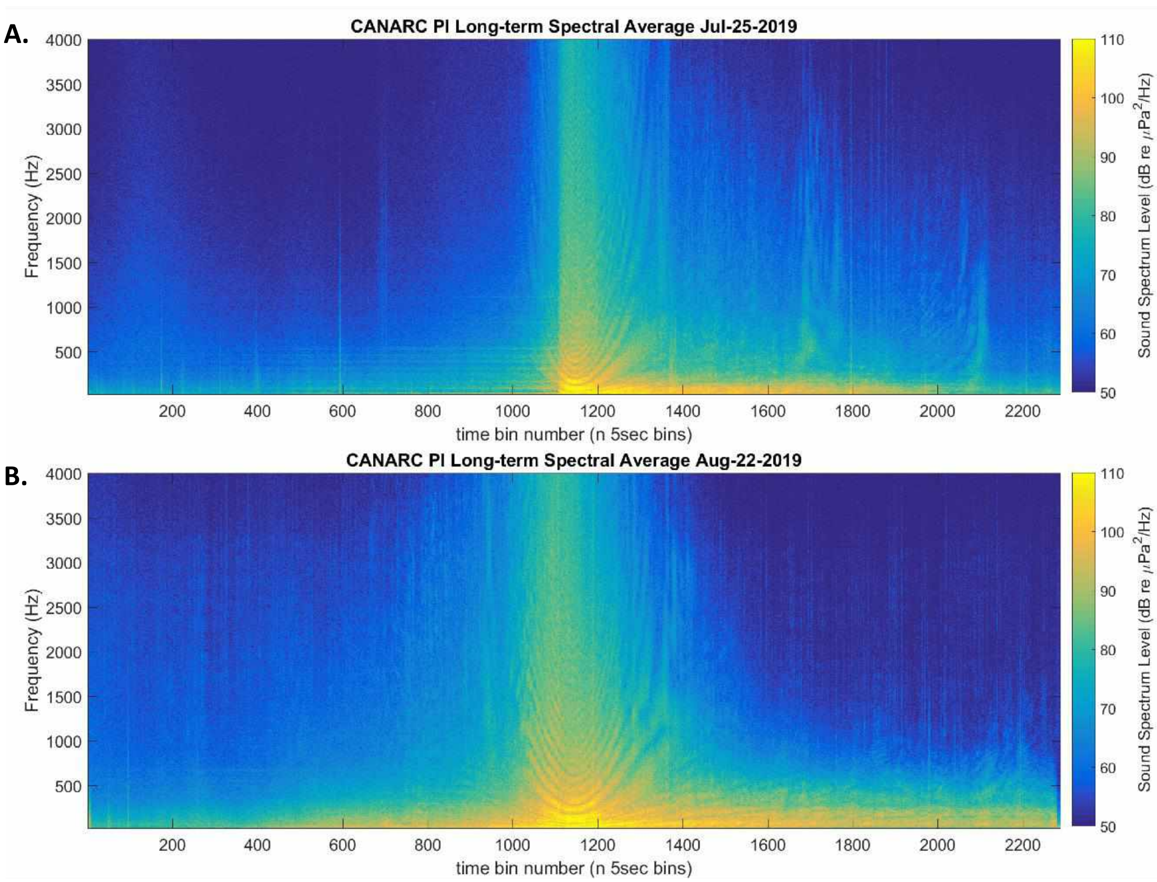


Figure 19. Long-term spectral average (LTSA) of the 6-hour window for 147 m oil and chemical tanker Sarah Desgagnes (MMSI 316012308) transiting past the PI recording site on Jul 25 (top) and Aug 22 (bottom), 2019. Noise from the ship at <200 Hz is evident throughout the transit, with higher levels of low-frequency noise persisting longer at the stern aspect post-CPA than when ship is approaching.

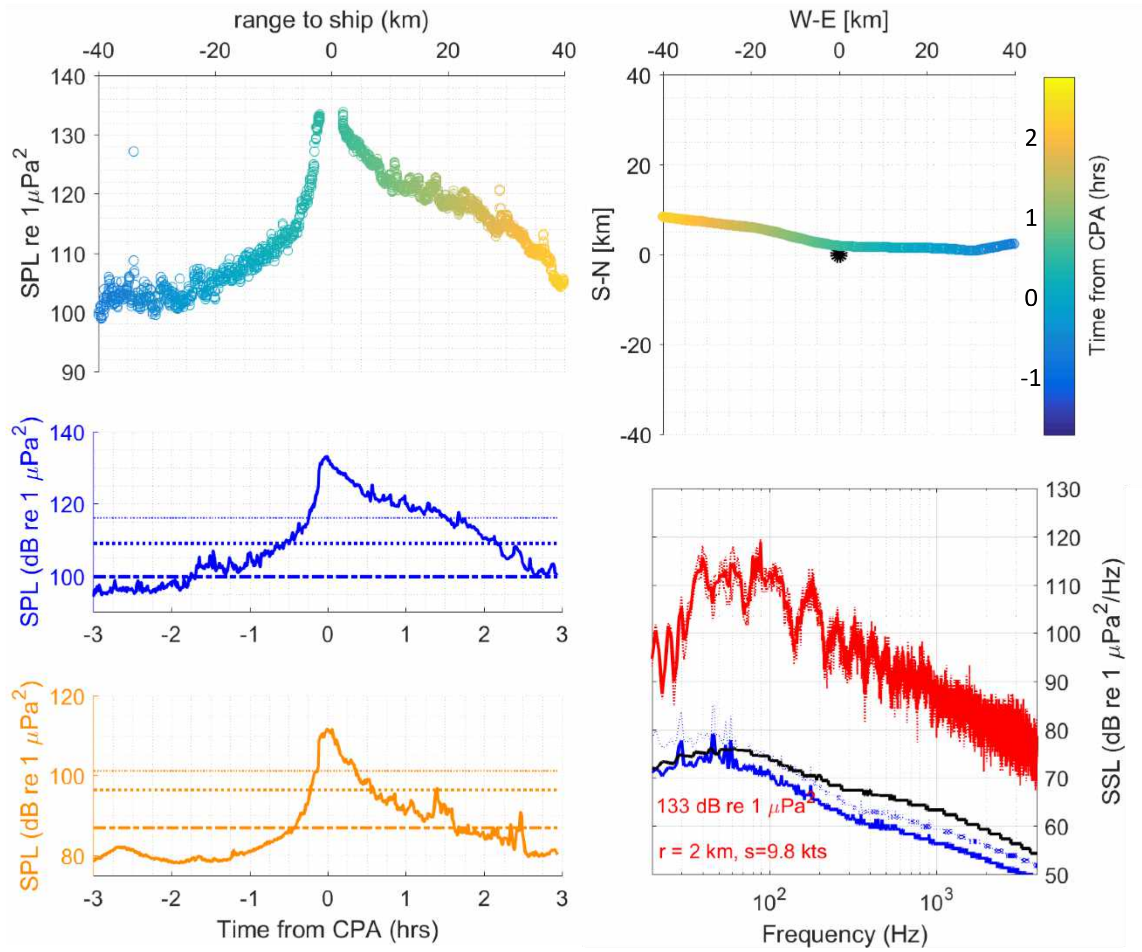


Figure 20. Ship transit analysis for oil and chemical tanker, Sarah Desgagnes July 25, 2019. Pre-CPA background SSL (panel d; blue line) within 5 dB of median background noise (black line) at all frequencies 20-4000 Hz. SPL_{BB} (panel a, open circles; panel c, blue line) increases above median background level from 2 h prior to 2.5h post-CPA, increasing more rapidly within 30 min of the closest point recorded (CPR; range 2 km and max. SPL_{BB} 133 dB). Colors in SPL scatter plot and map showing ship track (panel b) represent time from CPA (5s bins). 5-min median SPL_{BB} (panel c; blue) and 1 kHz 1/3rd octave band (panel e; orange) during ship transit plotted with 50th (dash-dot line), 90th (dotted line), and 99th (upper dotted line) percentile levels without ships (background levels). Sound spectrum level (SSL) of CPR period (panel d; red) with median SSL of the 1st 30 min of transit plot (blue) and shipping season median background sound levels during periods without ships (black).

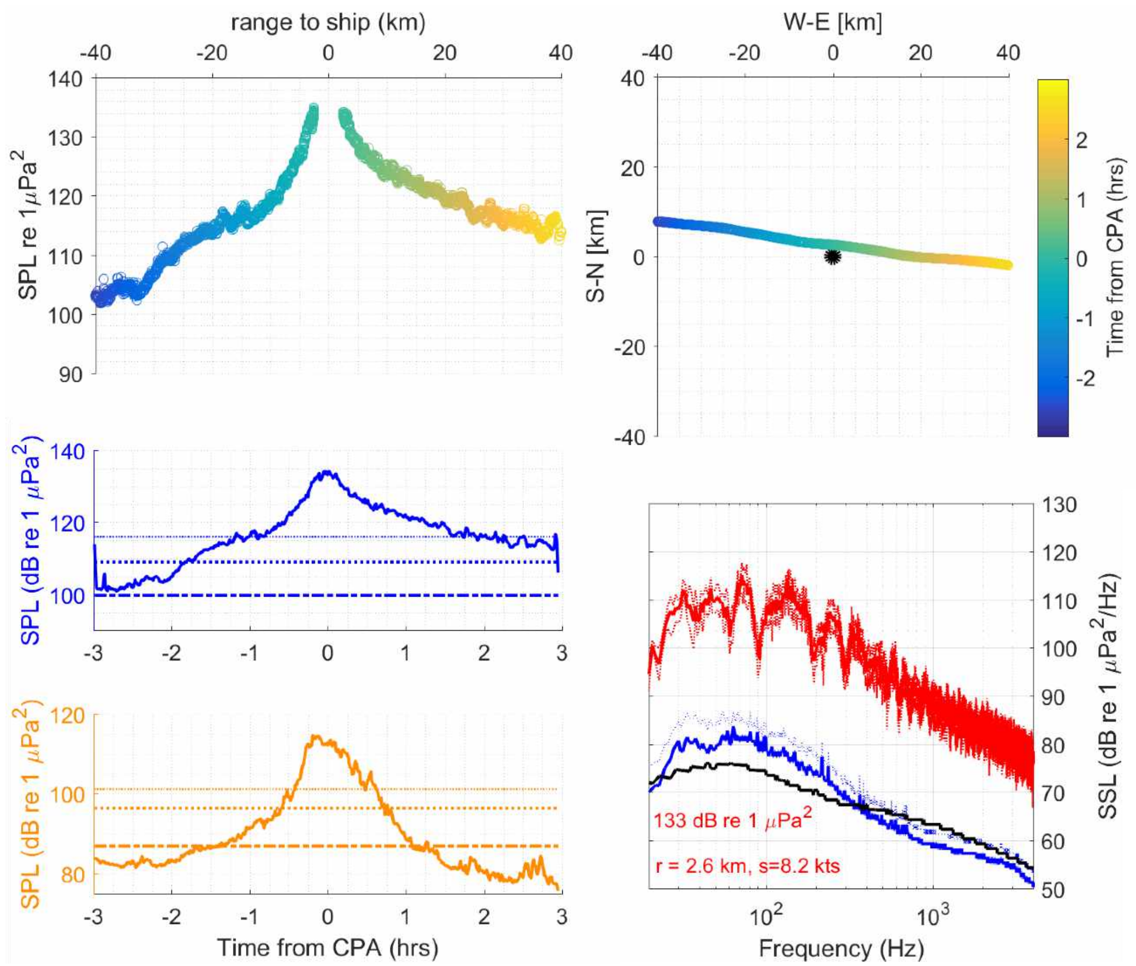


Figure 21. Ship transit analysis for oil and chemical tanker, Sarah Desgagnes August 22, 2019. Pre-CPA background SSL (panel d; blue line) and median background noise (black line). SPL_{BB} (panel a, open circles; panel c, blue line) increases above median background level from 2.75 h prior to beyond 3 h post-CPA (CPR; range 2.6 km and max. SPL_{BB} 133 dB). Colors in SPL scatter plot and map showing ship track (panel b) represent time from CPA (5s bins). 5-min median SPL_{BB} (panel c; blue) and 1 kHz 1/3rd octave band (panel e; orange) during ship transit plotted with 50th (dash-dot line), 90th (dotted line), and 99th (upper dotted line) percentile levels without ships (background levels). Sound spectrum level (SSL) of CPR period (panel d; red) with median SSL of the 1st 30 min of transit plot (blue) and shipping season median background sound levels during periods without ships (black).

Patterns in received level versus range were examined for a subset of 6 tanker ship transits during which the nearest time to CPA of another ship transit was > 4 h and with maximum CPA distance to the receiver of 2 km. Greater than 110 and 120 dB SPL_{BB} occurred at ranges from the recorder of apx 7-35 and 2-20 km, respectively (Fig. 12.a). At speeds of about 9 knots, the duration of SPL_{BB} exceeding 110 dB was 2.5 to >4 h and duration of >120 dB was apx. 1.5-2 h.

Icebreaker-Offshore Support Vessel

One icebreaker-offshore support vessel, Botnica (MMSI 276805000), operated in Eclipse Sound and Milne Inlet to assist commercial shipping operations September 29 to October 22, 2018 and July 17 to August 10, 2019, making a total of 19 and 39 transits past the PI and MI sites, respectively (Table 1). On the majority of transits, Botnica was escorting one or two bulk carriers in convoy. At the end of 2018 and start of 2019 shipping, the icebreaker convoys also included up to two additional ocean tugs. Two representative transits are presented for October (Figs. 22-24) and two for July to exemplify icebreaker operations during freeze-up and break-up periods (Figs. 25-27). Generally, icebreaker transit SSL were distinguished from other vessel transits by the presence of strong tonal noise with harmonic bands of fundamental frequency 200 Hz, extending above 4 kHz as the vessel approached the CPA. During typical ambient noise conditions, the 200 and 400 Hz tonal bands were elevated above background levels at distances exceeding 40 km from the receiver at both the bow and stern aspects. When background noise levels were below the median, tonal bands up to 1 kHz were elevated throughout the 6-h transit window and to ranges > 40 km (*e.g.* Fig. 25-27). These characteristic bands of noise radiated from the ship were present with and without sea ice in the vicinity and both when the ship was traveling alone and escorting other vessels.

A representative multi-vessel icebreaker transit was selected during which the 97m icebreaker Botnica escorted bulk carriers Nordic Oasis and Nordic Odin and tugs Ocean Taiga and Ocean Tundra at a speed of 8 knots into Eclipse Sound in 2/10 ice cover (Figs. 25.a, 26). The broadband background sound pressure level (SPL) was estimated as 95 dB re 1 μPa^2 (20-4000 Hz), which was the mean of the 50th percentile sound spectrum level during the period from 2-3 hours prior to the closest point of approach of the ship (Figure 1.b. blue curve). At the closest point recorded, range to the ship was 2.7 km from the recording site and the broadband SPL was 133 dB re 1 μPa^2 (10-2000 Hz). In the long-term spectral average (Figure 1.c), 200 Hz tonal noise from the ship and harmonics are apparent during the entire six hour window about the ship CPA. This 200 Hz tonal noise and harmonics at 400, 600, and 800 Hz are also apparent in the background spectrum and at much higher spectrum levels in at CPR (Fig. 1.c). During the transit, the SPL_{BB} increased to 110 dB by 1 hr pre-CPA and 120 dB at 30 min before the CPA. Durations of received levels greater than 110 and 120 dB were apx. 2.75 and 1.25 hrs. Range to the 110 and 120 dB received levels were apx. 18 and 8 km, respectively as the vessels approached (Fig. 1.d). After passing, received levels fell below 110 and 120 dB at ranges of apx. 15 and 30 km.

A.

B.

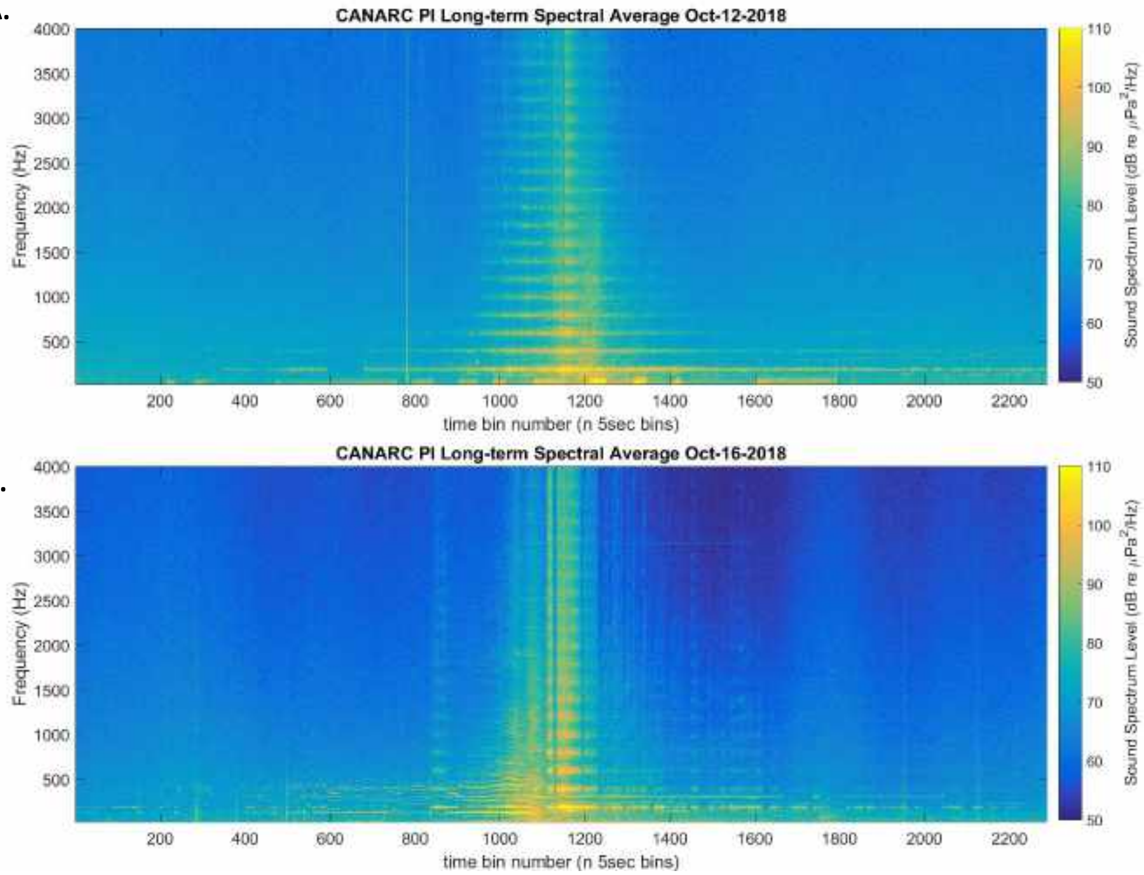


Figure 22. Long-term spectral average (LTSA) of the 6-hour window for Icebreaker, Botnica (MMSI 276805000) escorting one bulk carrier ship and transiting past the PI recording site on Oct 12 (top) and Oct 16 (bottom), 2018. 200 Hz tonal noise from the icebreaker is evident throughout the transit time windows with higher-frequency harmonics extending to above 4 kHz as the ships approach CPA.

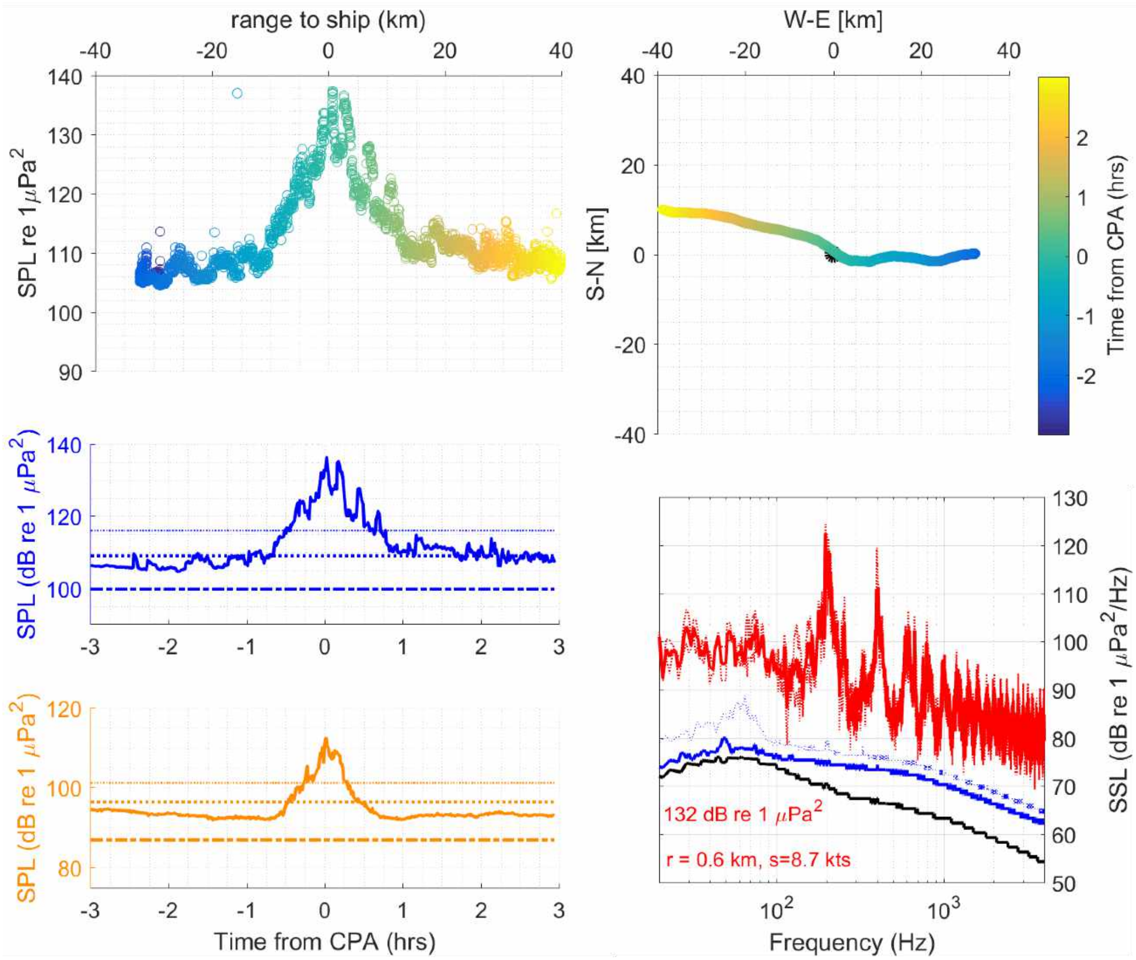


Figure 23. Ship transit analysis for icebreaker Botnica escorting the bulk carrier Nordic Oshima (MMSI 357629000) into Eclipse Sound from Baffin Bay Oct 12, 2018 in 5/10 to 9/10 ice cover. Ships are separated by 2 km distance and reach their respective CPA to the recorder 8 min apart. Pre-CPA background SSL (panel d; blue line) 5-10 dB above median background noise (black line) at 100-2000 Hz. SPL_{BB} (panel a, open circles; panel c, blue line) increases 1 h pre- and post-CPA at range 10 km. Botnica CPR range 0.6 km and max. SPL_{BB} 132 dB re 1 μPa^2 (panel d). Colors in SPL scatter plot and map showing icebreaker track (panel b) represent time from CPA (5s bins). 5-min median SPL_{BB} (panel c; blue) and 1 kHz 1/3rd octave band (panel e; orange) during ship transit plotted with 50th (dash-dot line), 90th (dotted line), and 99th (upper dotted line) percentile levels without ships (background levels). Sound spectrum level (SSL) of CPR period (panel d; red) with median SSL of the 1st 30 min of transit plot (blue) and shipping season median background sound (black).

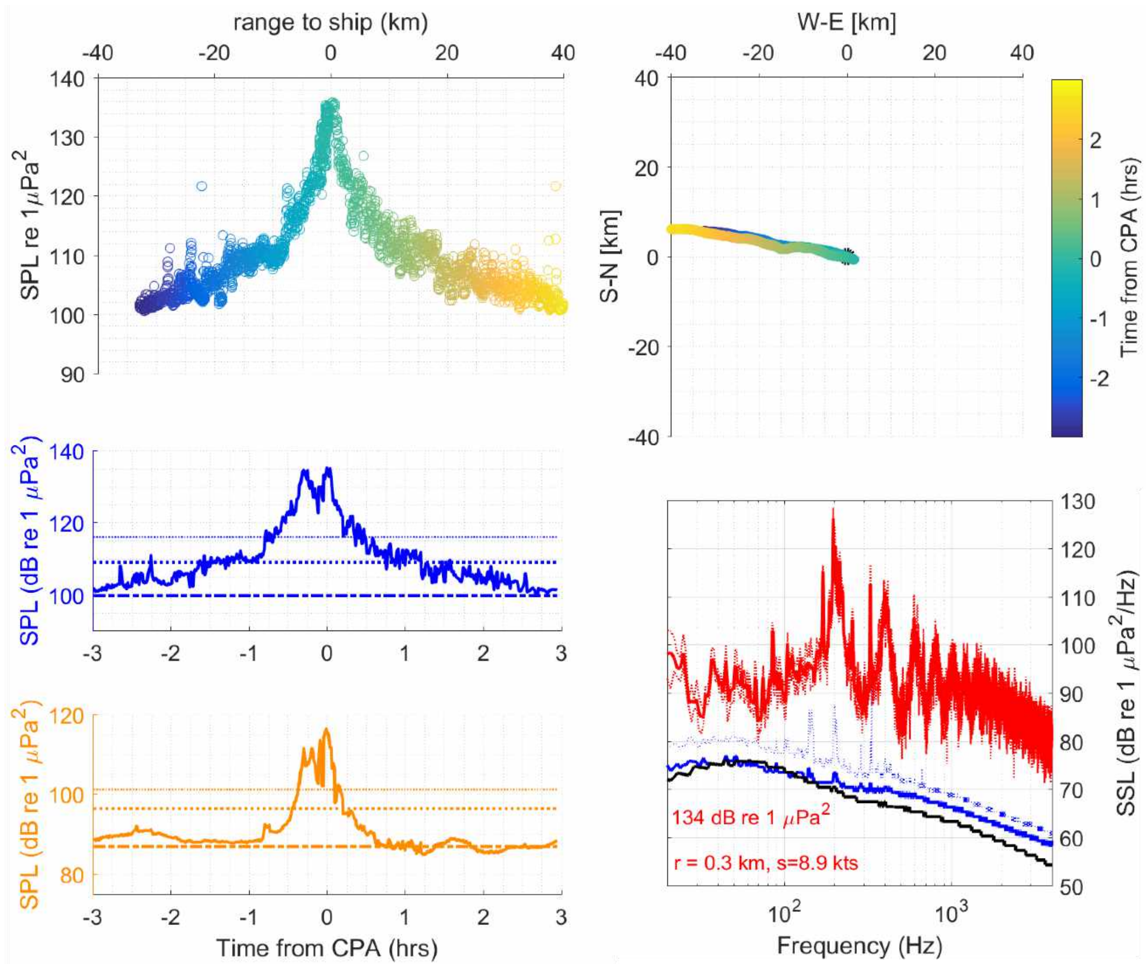


Figure 24. Ship transit analysis for icebreaker Botnica escorting the bulk carrier Nordic Oshima out of Eclipse Sound toward Baffin Bay Oct 16, 2018 in 5/10 to 9/10 ice cover with icebreaker turnaround maneuver near the recording site. Ships are separated by 3 km distance and reach their respective CPA to the recorder 11 min apart. Pre-CPA background SSL (panel d; blue line) <5 dB above median background noise (black line) at 200-2000 Hz. SPL_{BB} (panel a, open circles; panel c, blue line) increases 3 h pre- and post-CPA at range 33 km. Botnica CPR range 0.3 km and max. SPL_{BB} 134 dB re 1 μPa^2 (panel d). Colors in SPL scatter plot and map showing icebreaker track (panel b) represent time from CPA (5s bins). 5-min median SPL_{BB} (panel c; blue) and 1 kHz 1/3rd octave band (panel e; orange) during ship transit plotted with 50th (dash-dot line), 90th (dotted line), and 99th (upper dotted line) percentile levels without ships (background levels). Sound spectrum level (SSL) of CPR period (panel d; red) with median SSL of the 1st 30 min of transit plot (blue) and shipping season median background sound levels (black).

Icebreaker (July ice breakup)

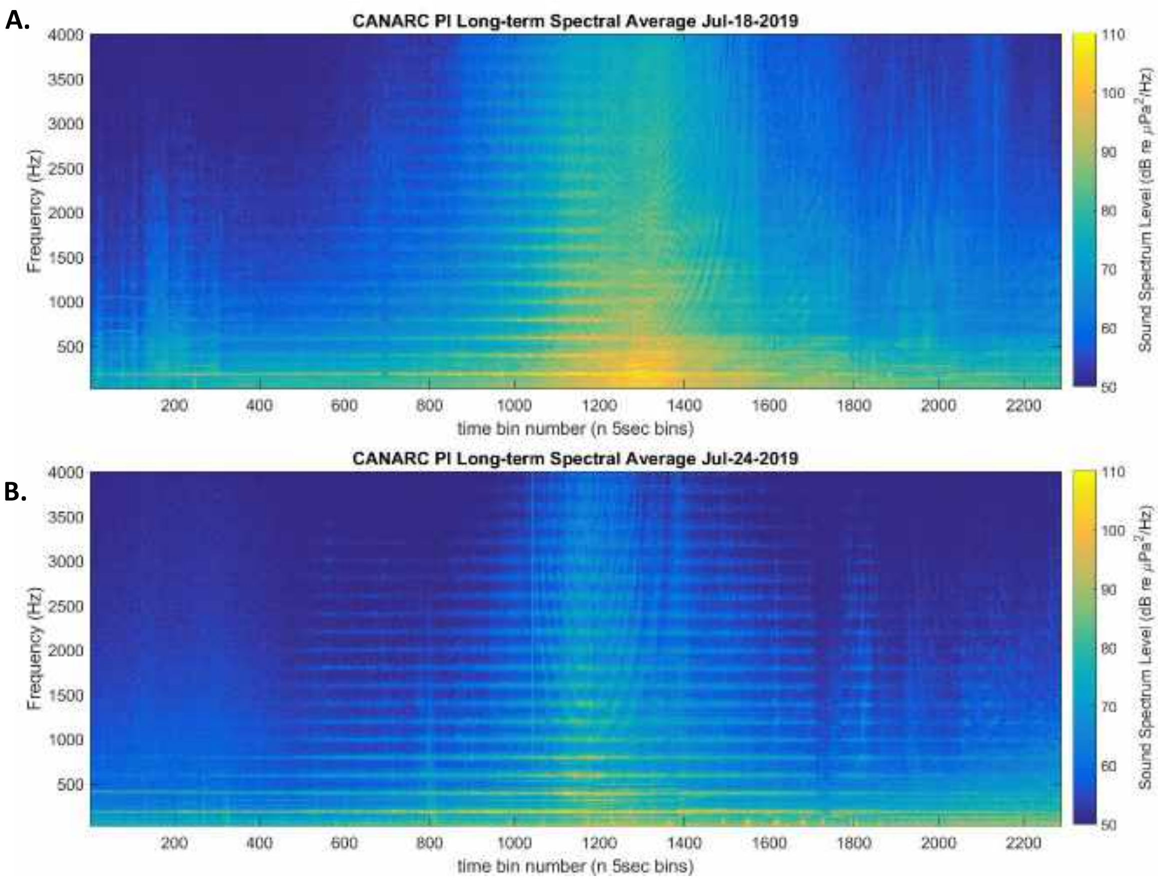


Figure 25. Long-term spectral average (LTSA) of the 6-hour window for icebreaker Botnica (MMSI 276805000) escorting two bulk carriers and two tugs in convoy and transiting past the PI recording site on July 18 (top) and Botnica escorting three bulk carriers on July 24, 2019. Tonal noise up to 1 kHz from the icebreaker is evident throughout the transit time windows with higher-frequency harmonics extending to above 4 kHz as the ships approach CPA. Tonal noise to 3 kHz is evident on July 24 up to 3 h after the CPA.

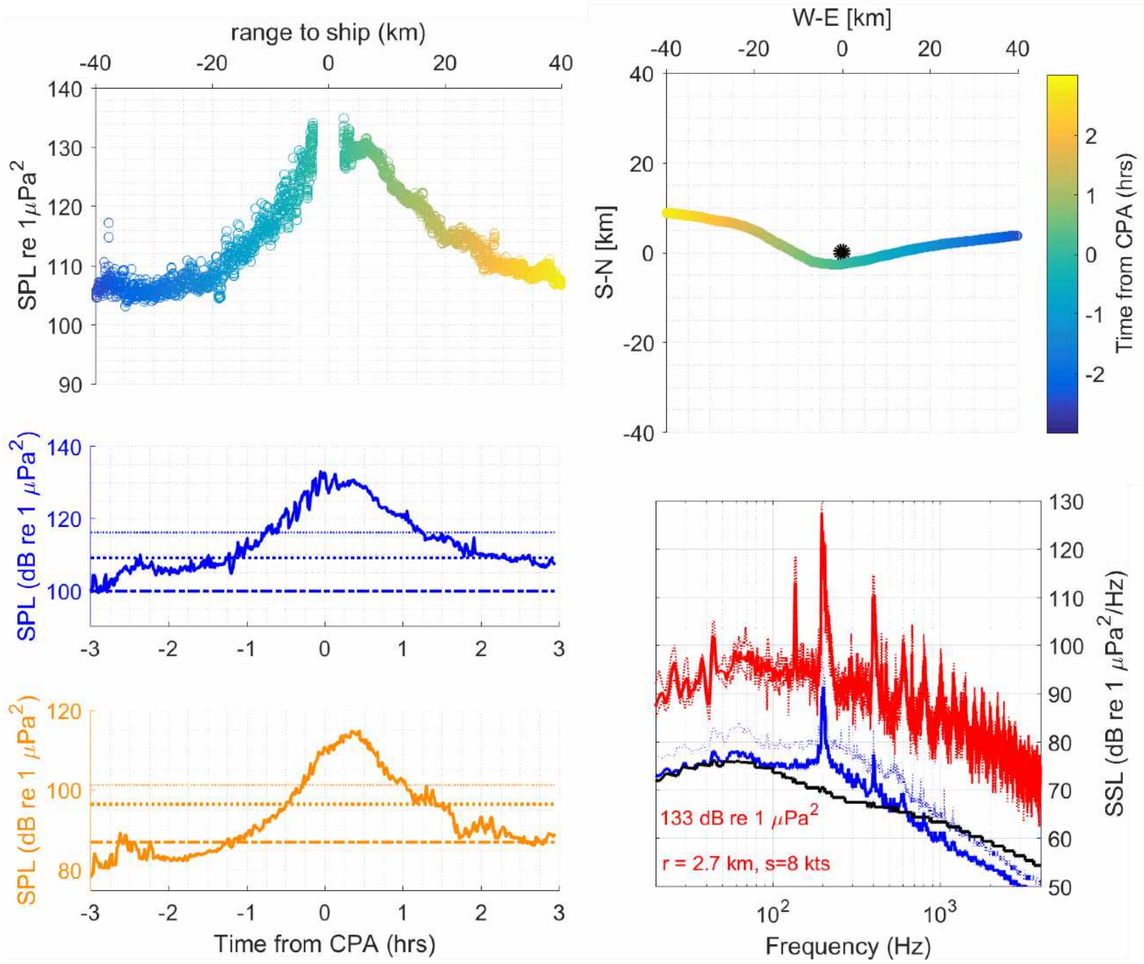


Figure 26. Ship transit analysis for icebreaker Botnica escorting bulk carriers Nordic Odin (MMSI 356364000) and Nordic Oasis (MMSI 374322000) and tugs Ocean Tundra (MMSI 316025785) and Ocean Taiga (MMSI 316007572) into Eclipse Sound from Baffin Bay July 18, 2019 in 2/10 ice cover. Time from icebreaker passing to last ship CPA was 23 min. Ships are separated by 0.3 to 2 km distance and reach their respective CPAs to the recorder 1-10 min apart. Pre-CPA background SSL (panel d; blue line) close to median background noise (black line) at 20-1000 Hz, but elevated by 20 and 10 dB at 200 and 400 Hz, respectively from icebreaker tonal noise. SPL_{BB} (panel a, open circles; panel c, blue line) increases 2 h pre-CPA at range 30 km and remains elevated to post-CPA range >40 km. Botnica CPR range 2.7 km and max. SPL_{BB} 133 dB re 1 μPa^2 (panel d). Colors in SPL scatter plot and map showing icebreaker track (panel b) represent time from CPA (5s bins). 5-min median SPL_{BB} (panel c; blue) and 1 kHz 1/3rd octave band (panel e; orange) during ship transit plotted with 50th (dash-dot line), 90th (dotted line), and 99th (upper dotted line) percentile levels without ships (background levels). Sound spectrum level (SSL) of CPR period (panel d; red) with median SSL of the 1st 30 min of transit plot (blue) and shipping season median background sound levels (black).

Figure 26. (alt caption) Ship transit analysis for icebreaker Botnica entered Eclipse Sound, heading west at a speed of 8 knots in 2/10 ice cover. During the period 2-3 hours before the ship closest point of approach (CPA), the lowest one-minute median broadband received level was 100 dB re 1 μPa[2] (20-4000 Hz; Figure 1.b. blue line). At the closest point recorded the ship was at range 2.7 km and received level 133 dB re 1 μPa[2]. A 200 Hz tonal noise from the ship plus harmonics to above 1 kHz are apparent during the entire six hour LTSA window about the ship CPA (Fig 1.a) and also in the pre-transit background spectra (lower right, blue line), indicating that this noise may propagate substantially farther than 40 km. During the transit, the SPL_{BB} increased to 110 dB by 1.2 hr pre-CPA and to 120 dB at 30 min before the CPA. Durations of received levels greater than 110 and 120 dB were apx. 3 and 0.5 hrs. Range to the 110 and 120 dB received levels were apx. 20 and 8 km, respectively, from the bow aspect and 30km and 12 km, respectively, from the stern aspect (upper left).

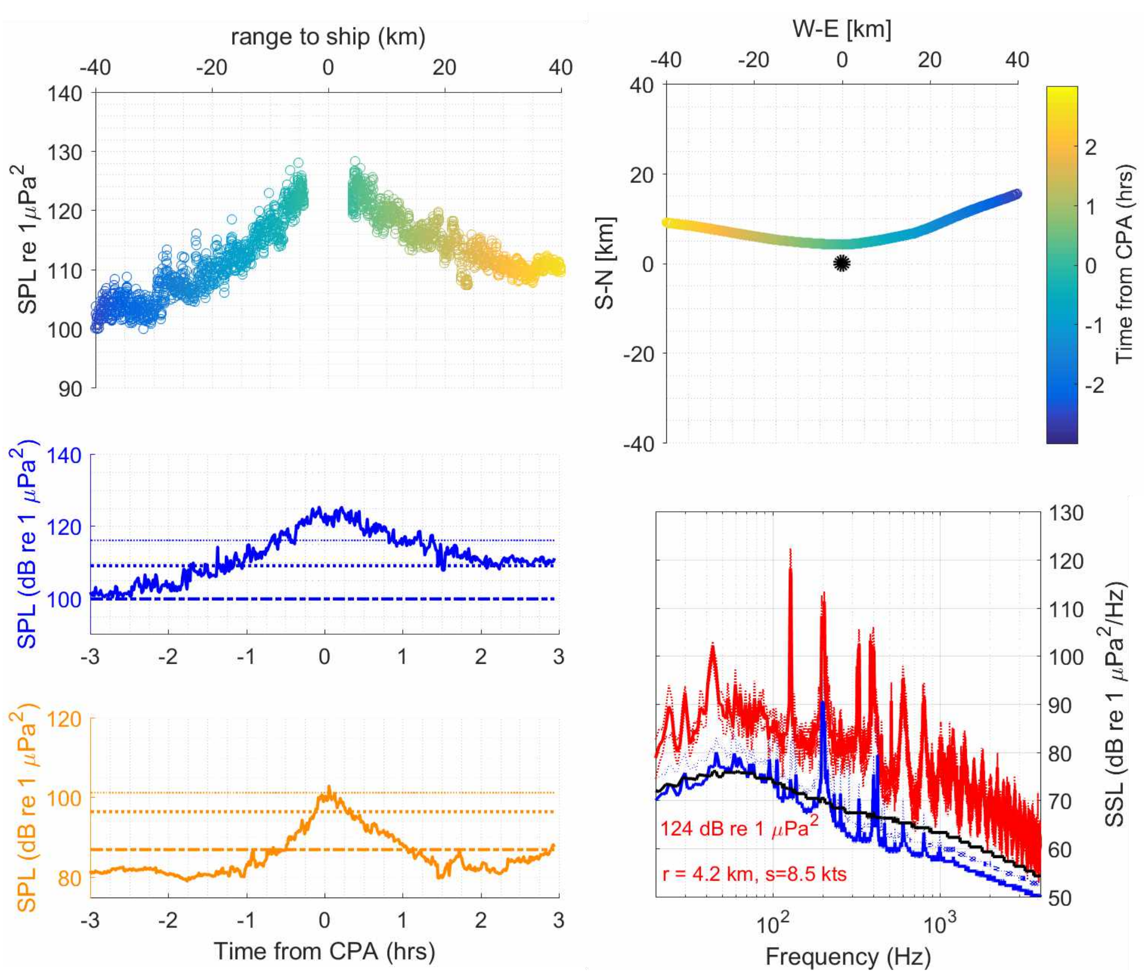


Figure 27. Ship transit analysis for icebreaker Botnica escorting three bulk carriers (Nordic Olympic, MMSI 356986000; Golden Strength, MMSI 538008055; and Golden Ruby, MMSI

477300800) into Eclipse Sound on July 24, 2019 at a speed of 8.5 knots in 0/10 ice cover. Time from icebreaker passing to last ship CPA was 28 min. Ships are separated by 2 to 3 km along their trackline and reach their respective CPAs to the recorder 8-12 min apart. Pre-CPA background SSL (panel d; blue line) apx 5 dB below median background noise (black line) at 100-2000 Hz, but elevated by 30 and 20 dB at 200 and 400 Hz, respectively from icebreaker tonal noise. SPL_{BB} (panel a, open circles; panel c, blue line) increases 2 h pre-CPA at range 30 km and remains elevated to post-CPA range >40 km. Botnica CPR range 4.2 km and max. SPL_{BB} 124 dB re 1 μPa^2 (panel d). Colors in SPL scatter plot and map showing icebreaker track (panel b) represent time from CPA (5s bins). 5-min median SPL_{BB} (panel c; blue) and 1 kHz 1/3rd octave band (panel e; orange) during ship transit plotted with 50th (dash-dot line), 90th (dotted line), and 99th (upper dotted line) percentile levels without ships (background levels). Sound spectrum level (SSL) of CPR period (panel d; red) with median SSL of the 1st 30 min of transit plot (blue) and shipping season median background sound levels (black).

Estimating Listening Space Reduction

Listening Space Reduction (LSR) estimated for all ship types follows the typical patterns of received noise levels during ship transits. The proportion of LSR increases rapidly when received noise from the ship exceeds the reference noise level (NL_1 in Eqn. 1), which was selected for each transit to represent the perceived background noise conditions for ringed seals at 250 Hz and for narwhals at 1 kHz and 3.5 kHz. LSR > 50% occurs at shorter distances from the bow than from the stern aspect of vessels. When background noise prior to a ship transit (*i.e.* pre-CPA minimum 1-min SPL) was above the median background level and the estimated audibility threshold, defining NL_1 as the 90th percentile of ambient noise helped to resolve a more distinct period of elevated LSR around the ship CPA.

Bulk Carriers

Listening space reduction (LSR) estimated for the Aug 1 and Sep 5, 2019 transits of bulk carrier Nordic Orion (Fig. 26) demonstrates typical LSR patterns for this ship type at recording site PI. In both transits, pre-CPA SPL in the 1/3rd octave frequency bands (*i.e.* 250 Hz, 1 kHz, 3.5 kHz) was below the median background level. Noise-adjusted LSR was therefore estimated by defining NL_1 (Eqn. 1) as the median background SPL for the 250 Hz and 3.5 kHz bands and as the threshold of the beluga audiogram for 1 kHz. Received ship noise in the 250 Hz 1/3rd octave band reached levels higher than the median background level during a period from about 1 h prior to CPA to 1 h after. Consequently, noise-adjusted LSR >50% was estimated to occur over a period of similar duration of 1.5 to 2 h. At 1 and 3.5 kHz, LSR >50% occurred over a duration of apx. 45-60 min and 30-40 min, respectively, about the CPA.

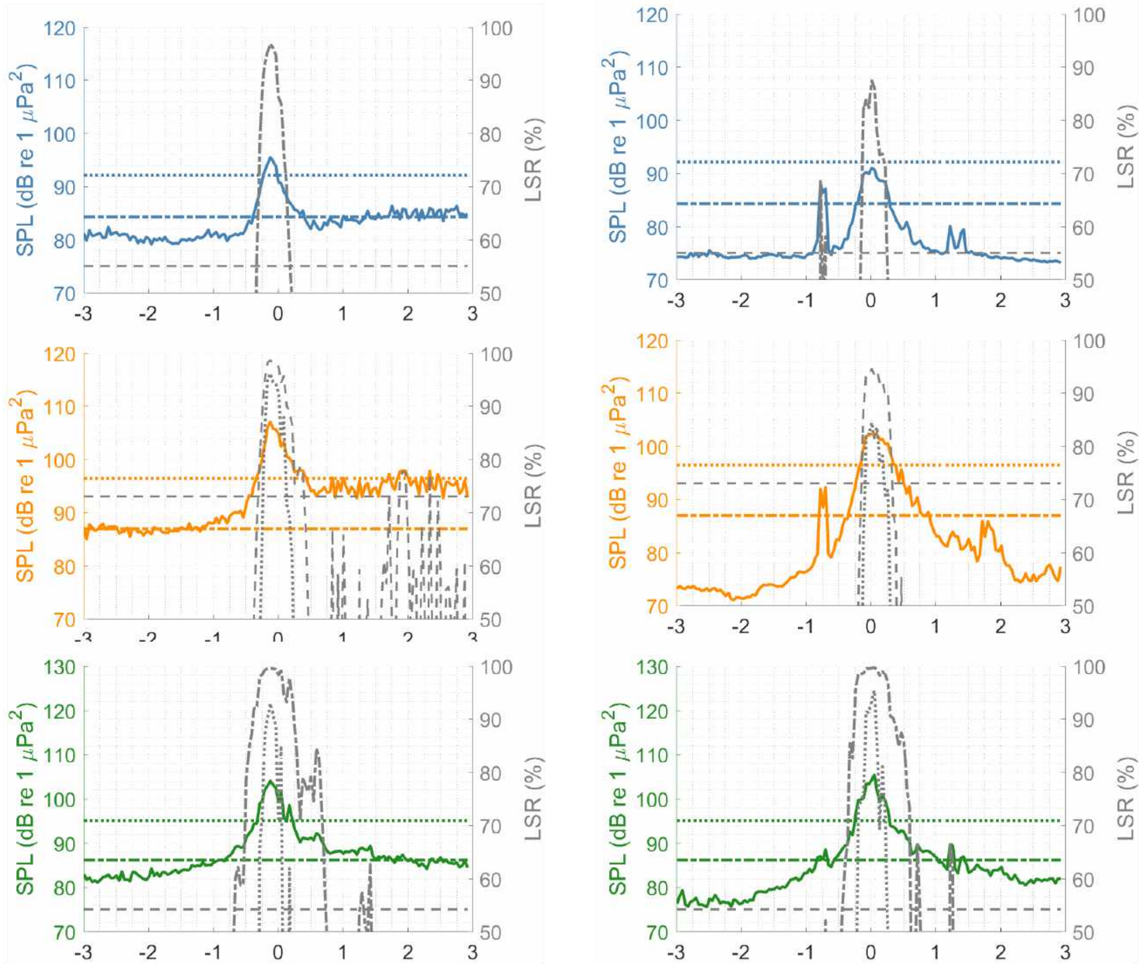


Figure 28. Listening space reduction (LSR) for Bulk Carrier transit examples. LSR estimated for the 3.5 kHz (top; lt. blue), 1 kHz (middle; orange), and 250 Hz (bottom; green) 1/3rd octave bands for transits of the bulk carrier Nordic Orion on Sep 05 (left) and Aug 1, 2019 (right). Gray horizontal dashed lines represent composite audiogram threshold values for beluga at 3.5 and 1 kHz (top and middle) and for ringed seal at 250 Hz. Gray dashed and dotted curves are the listening space reduction (LSR) estimates using either the higher of the audibility threshold and the median background noise level (dashed curve) or the 90th percentile background noise level (dotted curve) for the reference noise level for LSR estimation (NL_1 Eqn. 1). Both 'noisy' and 'quiet' methods for determining LSR are plotted for comparison.

Patterns in estimated LSR versus range were examined for a subset of 60 ore carrier ship transits (Fig. 29) during which the nearest time to CPA of another ship transit was > 4 h to reduce effects of noise from other ships. Greater than 50% LSR occurred at longer ranges from the recorder in the 250 Hz band than in the 1 kHz or 3.5 kHz bands. For narwhal signals, 70% and 90% LSR was estimated to occur at median ranges of 10 and 3 km for 3.5 kHz and at 4 and 3 km for 1 kHz as a result of noise from transiting ore carriers. Ringed seal LSR 70% and 90% was estimated to occur at median ranges of 8 km and 3 km for 250 Hz signals.

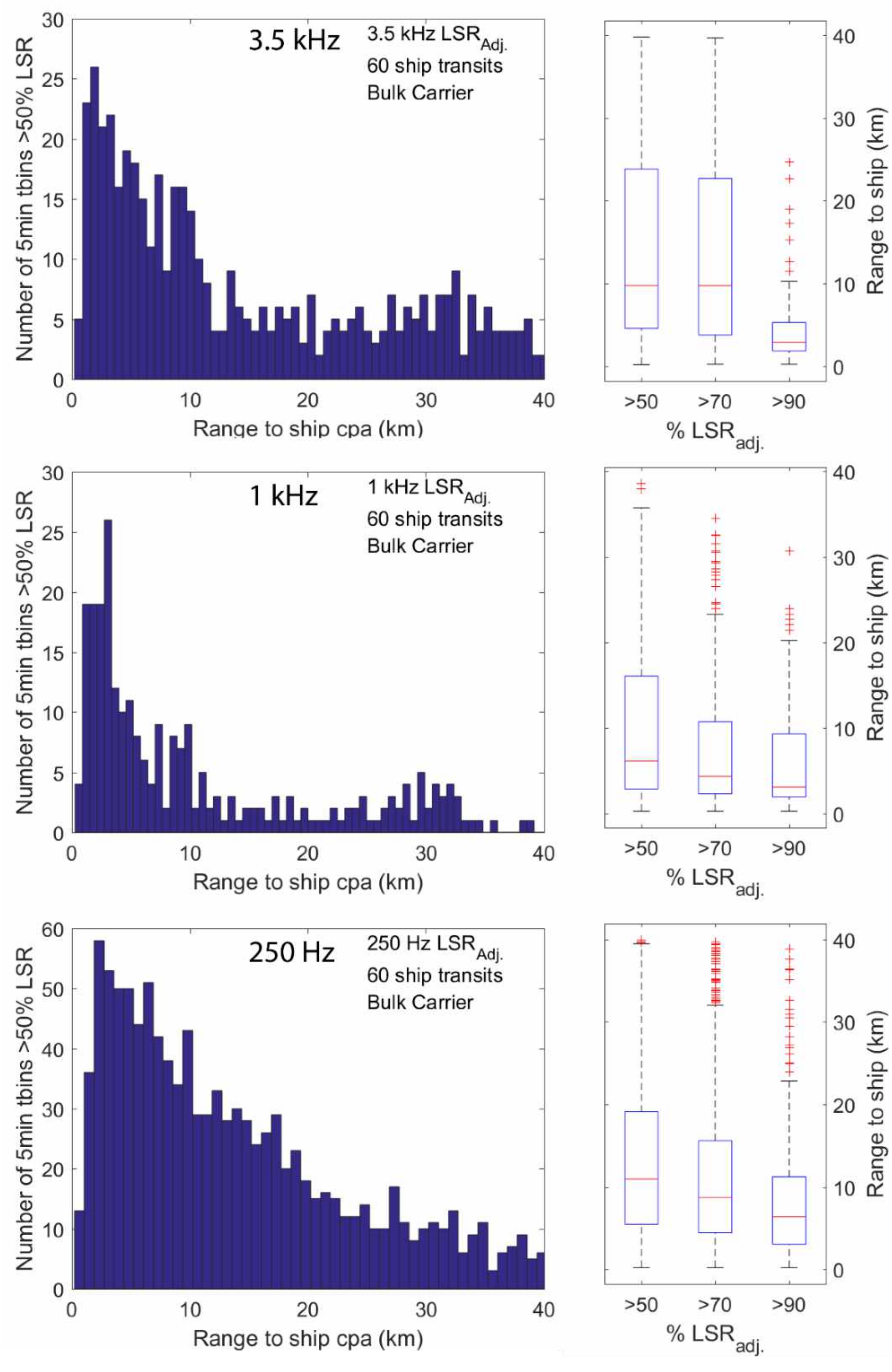


Figure 29. Noise-adjusted listening space reduction (LSR) and range to ship estimated for all 5-min time bins with LSR > 50% in bulk carrier transits with no preceding ships ('clean cpa'; left panel histograms). LSR for each time bin was estimated either from the max of the audiogram value and the median noise level or the 90th percentile, depending on minimum median SPL values in the frequency band pre-CPA. Box plots show the 10th to 90th percentile data values (blue box), median (red line), and outliers removed (red plus sign)

General Cargo

Listening space reduction (LSR) estimated for the Aug 23 and 24, 2019 transits of general cargo vessels Zelada and Sedna Desgagnes (Fig. 30) demonstrates typical LSR patterns for this ship type at recording site PI. Noise-adjusted LSR for the Aug 23 transit (Fig. 30 left panels) was estimated by defining NL_1 (Eqn. 1) as the median background SPL for the 250 Hz and 3.5 kHz bands and as the threshold of the beluga audiogram for 1 kHz. Received ship noise in the 250 Hz 1/3rd octave band reached levels higher than the median background level during a period from about 1 h prior to CPA to 1 h after. Consequently, LSR >50% was estimated to occur for ringed seals over a period of similar duration of 1.5 to 2 h. At 1 and 3.5 kHz, LSR >50% for narwhals occurred over a duration of apx. 45-60 min and 30-40 min, respectively, about the CPA.

Patterns in estimated LSR versus range were examined for a subset of 6 general cargo ship transits (Fig. 30) during which the nearest time to CPA of another ship transit was > 3 h to reduce effects of noise from other ships. Greater than 50% LSR occurred at longer ranges from the recorder in the 250 Hz band than in the 1 kHz or 3.5 kHz bands. For narwhal signals, 70% and 90% LSR was estimated to occur at median ranges of 10 and 3 km for 3.5 kHz and at 4 and 3 km for 1 kHz as a result of noise from transiting ore carriers. Ringed seal LSR 70% and 90% was estimated to occur at median ranges of 8 km and 3 km for 250 Hz signals.

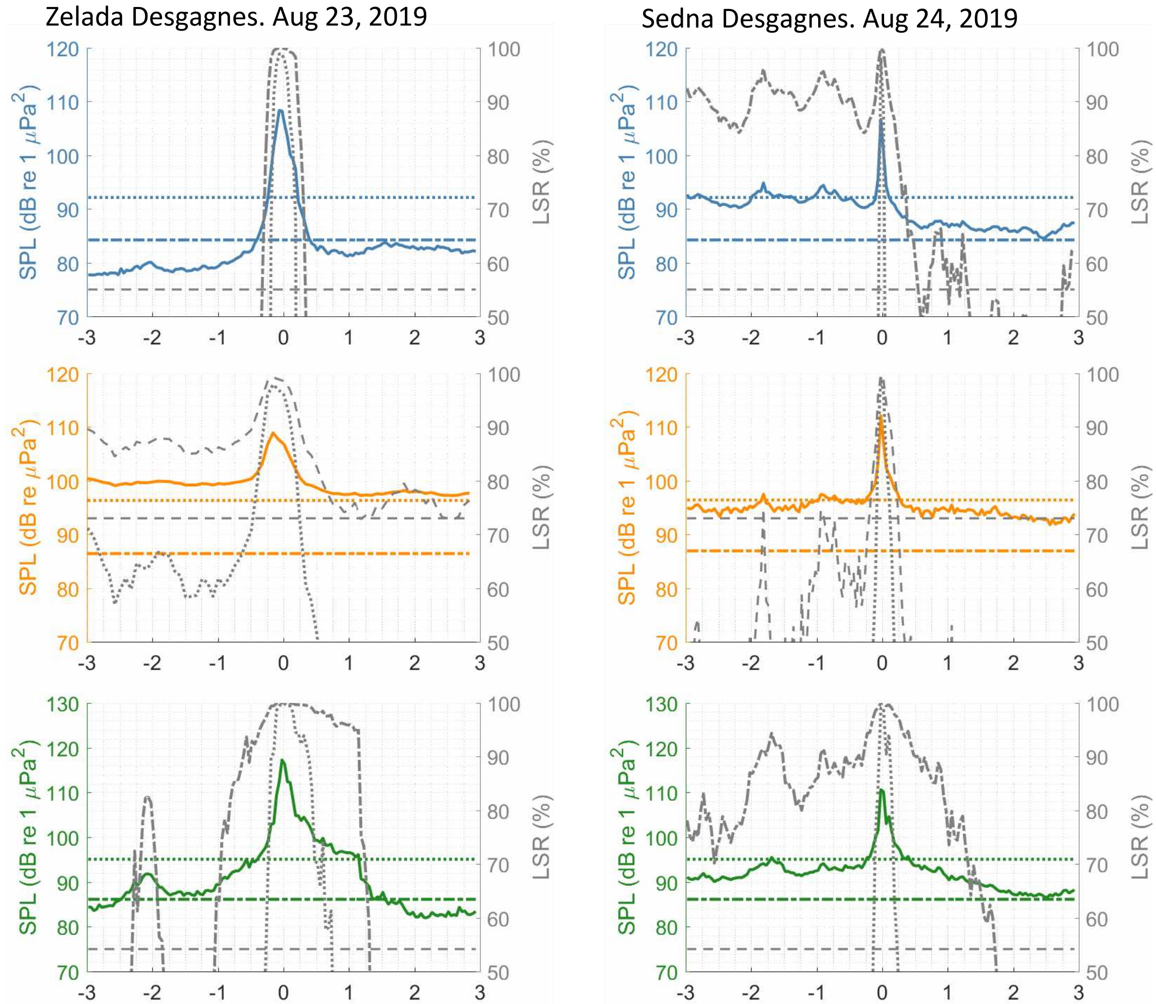


Figure 30. LSR for General Cargo vessel transit examples. LSR estimated for example transits of Zelada Desgagnes (left) and Sedna Desgagnes (right) for the 3.5 kHz (top; lt. blue), 1 kHz (middle; orange), and 250 Hz (bottom; green) 1/3rd octave bands for transits. Gray horizontal dashed lines represent composite audiogram threshold values for beluga at 3.5 and 1 kHz (top and middle) and for ringed seal at 250 Hz. Gray dashed and dotted curves are the listening space reduction (LSR) estimates using the maximum of the audibility threshold and the median background noise level (dashed curve) or the 90th percentile background noise level (dotted curve) for the reference noise level for LSR estimation (NL_1 Eqn. 1). Pre-CPA background noise in Zelada D. transit was above the 90th percentile background level while pre-CPA background noise in Sedna D. transit near or below median background noise.

DRAFT DOCUMENT

Sarah Desgagnes. Jul 25, 2019 Sarah Desgagnes. Aug 22, 2019

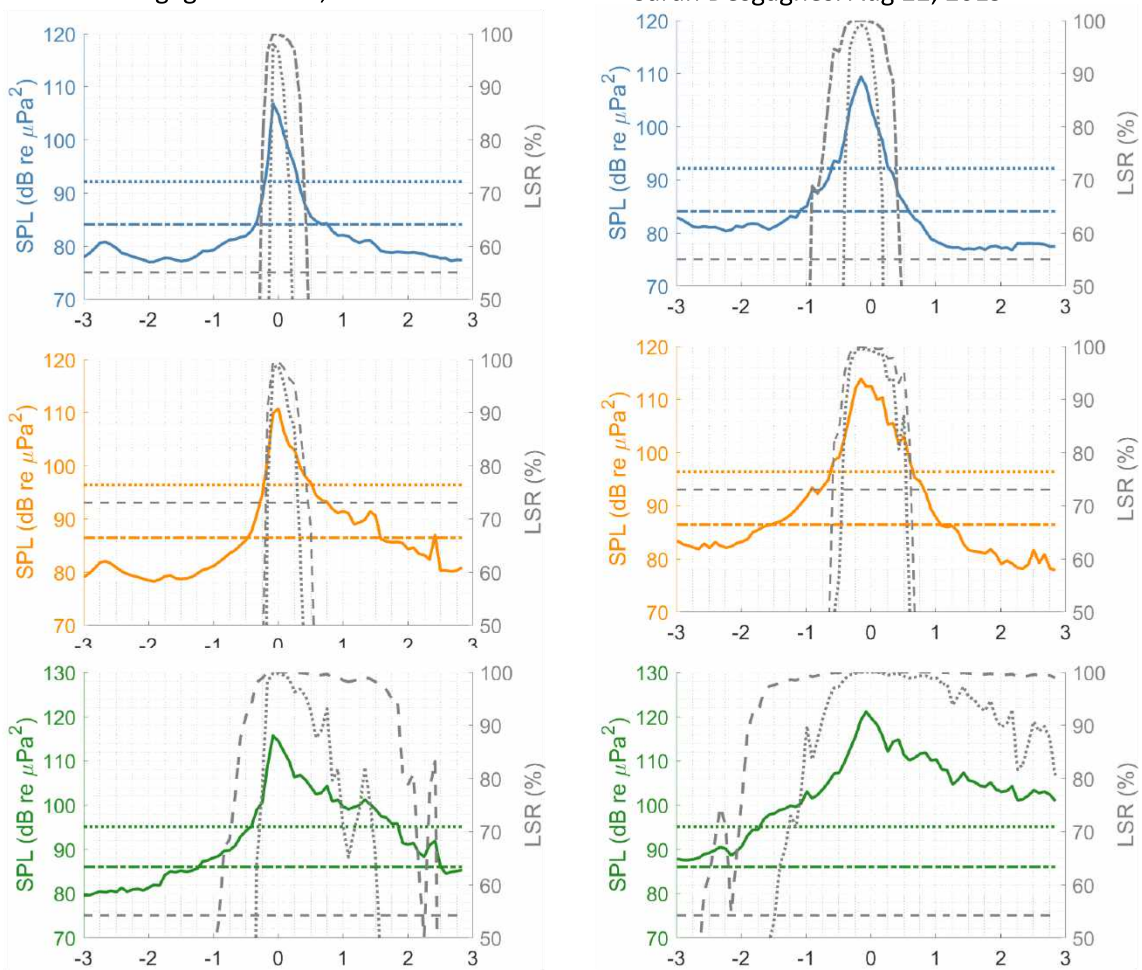


Figure 31. LSR for Oil and Chemical tanker transit examples. LSR estimated for the 3.5 kHz (top; lt. blue), 1 kHz (middle; orange), and 250 Hz (bottom; green) 1/3rd octave bands for transits of the oil and chemical tanker, Sarah Desgagnes on July 25th (left) and August 22nd(right). Gray horizontal dashed lines represent composite audiogram threshold values for beluga at 3.5 and 1 kHz (top and middle) and for ringed seal at 250 Hz. Gray dashed and dotted curves are the listening space reduction (LSR) estimates using the higher of the audibility threshold or the median background noise level (dashed curve) or the 90th percentile background noise level (dotted curve) for the reference noise level for LSR estimation (NL_1 eqn 1).

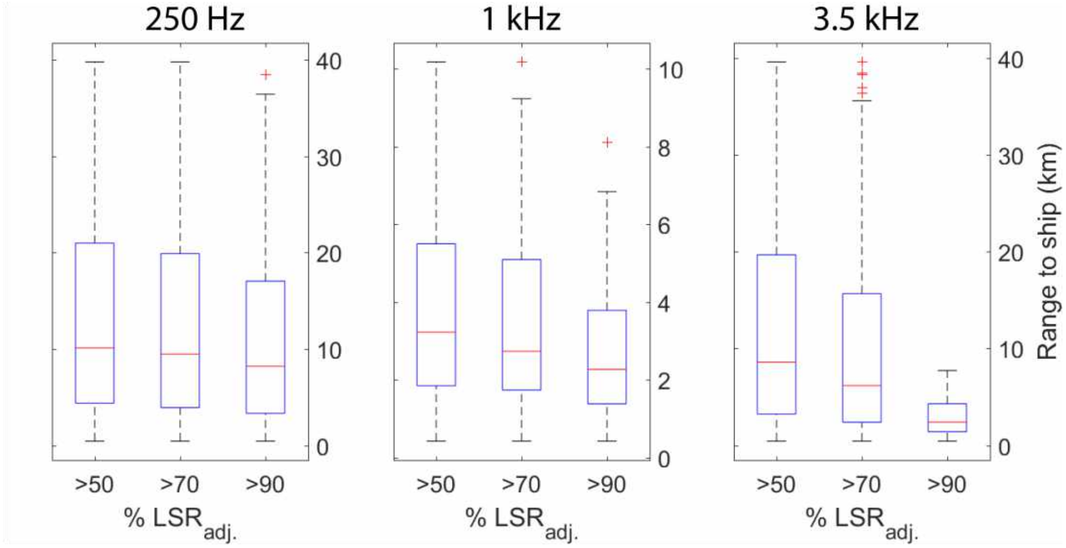


Figure 32. Combined estimates of range from ship to receiver for LSR above 50, 70, and 90% from six transits of general cargo ships at site PI.

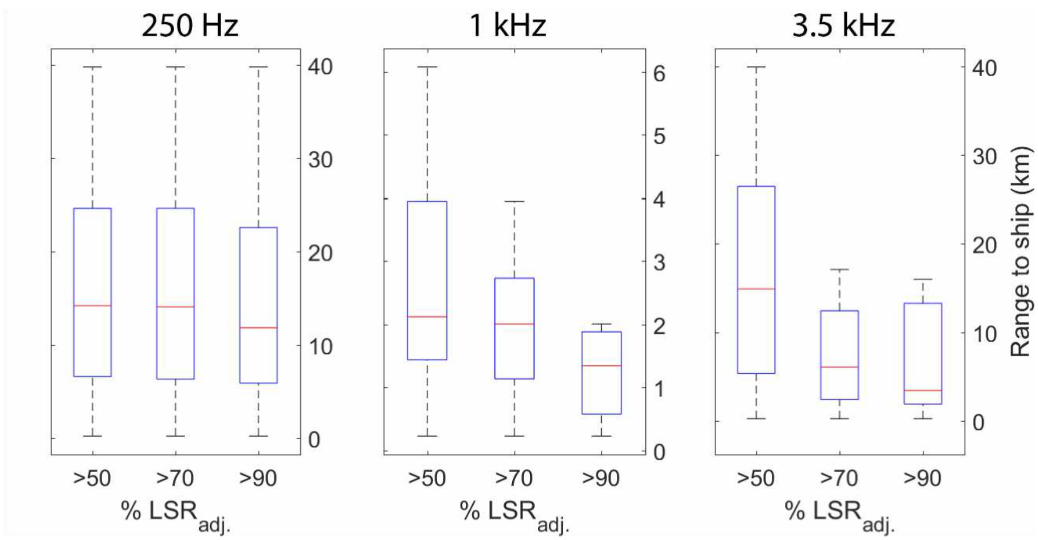


Figure 33. Combined estimates of range from ship to receiver for LSR above 50, 70, and 90% from seven transits of tanker ships at site PI.

Botnica. Oct 12, 2018 Botnica. Oct 16, 2018

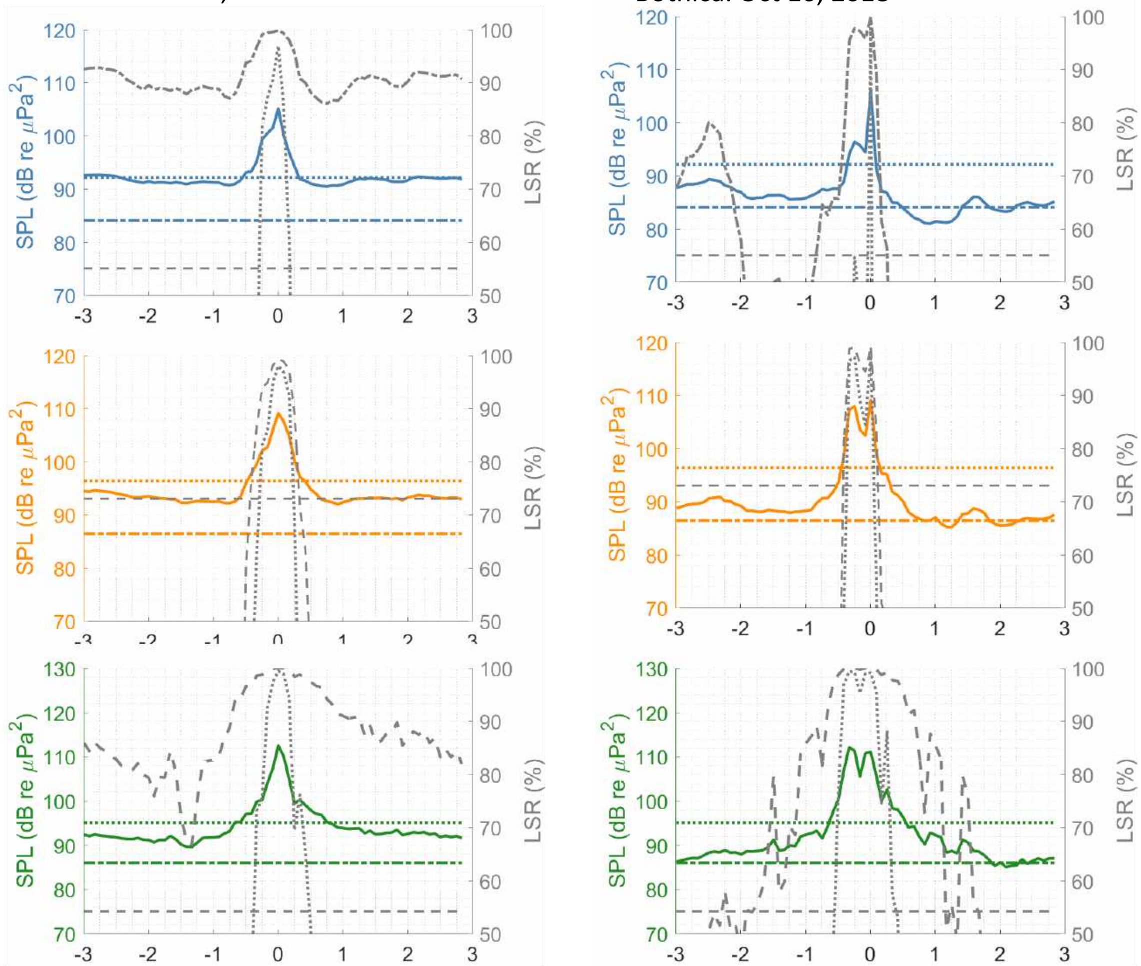


Figure 34. LSR for example transits of the icebreaker, Botnica, during late open water/early freeze-up, 2018 for 3.5 kHz (top; lt. blue), 1 kHz (middle; orange), and 250 Hz (bottom; green) bands on October 12 (left) and Oct 16 (right), 2018.

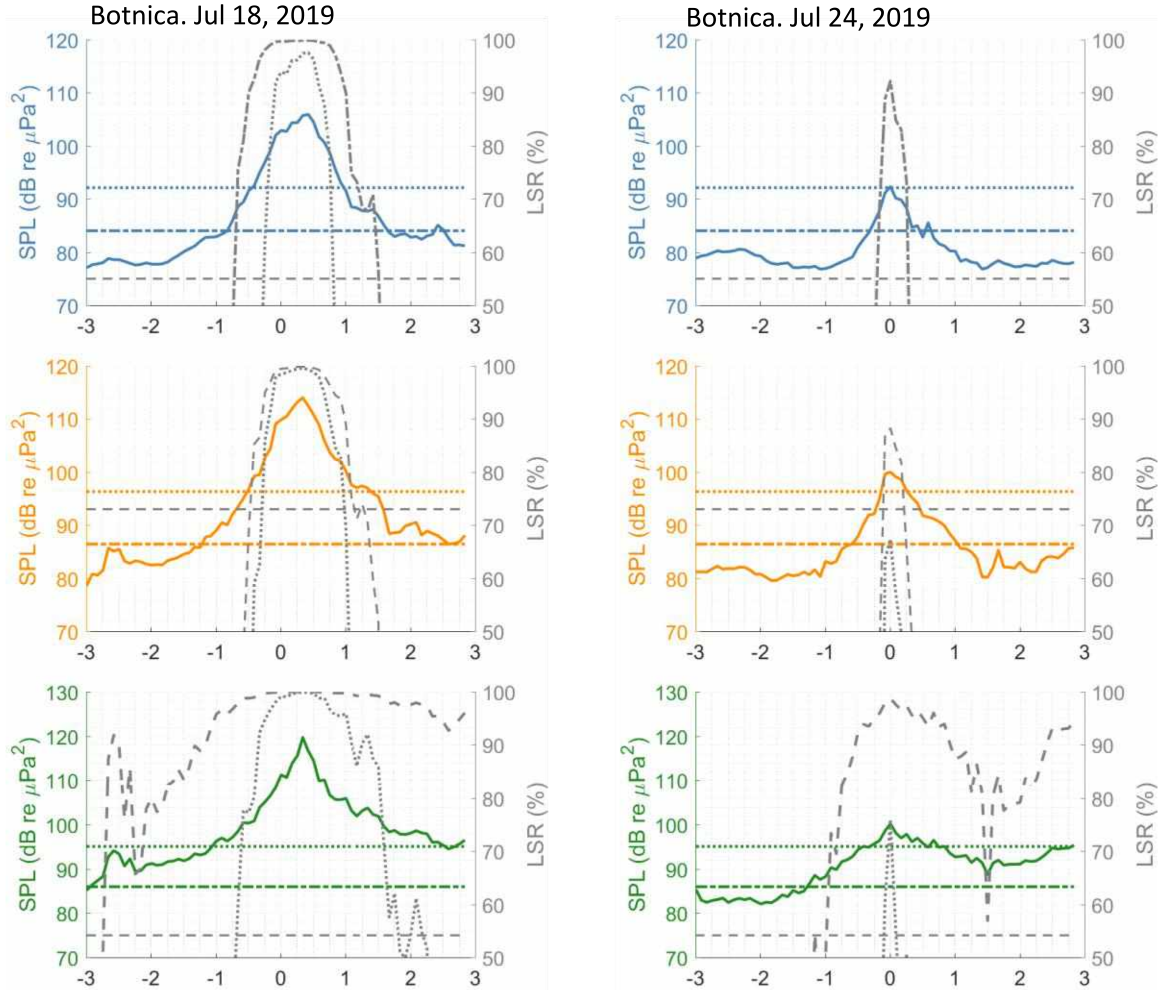


Figure 35. LSR for example transits of the icebreaker Botnica during July, 2019 sea ice breakup for the 3.5 kHz (top; lt. blue), 1 kHz (middle; orange), and 250 Hz (bottom; green) frequency bands for transits of the icebreaker Botnica on July 18 (left) and 24 (right).

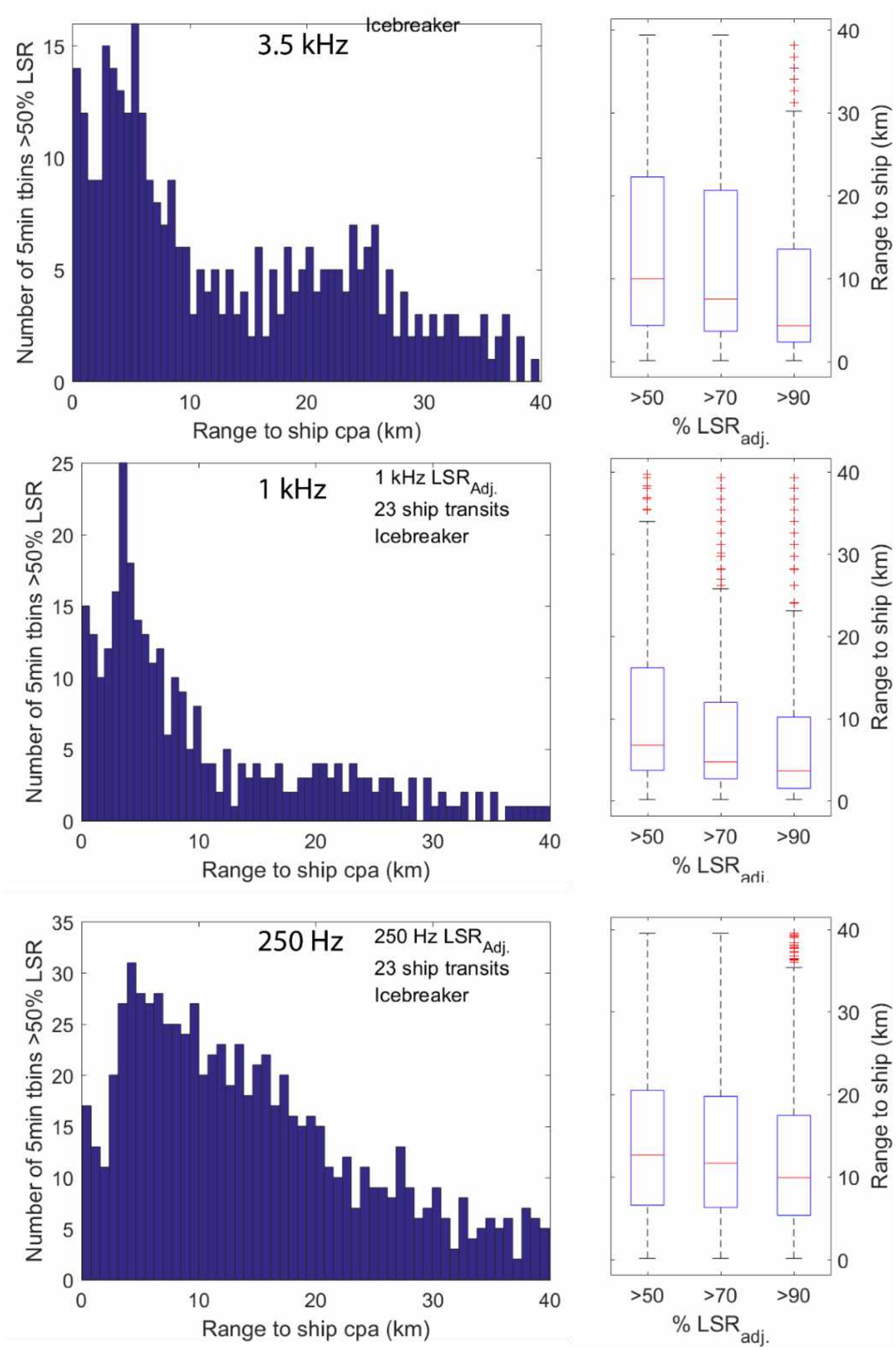


Figure 36. Noise-adjusted listening space reduction (LSR) and minimum range to ship estimated for all 5-min time bins with LSR >50% in transits of the icebreaker Botnica past site PI. (left panel histograms). LSR for each time bin was estimated either from the max of the audiogram value and the median noise level or the 90th percentile, depending on minimum median SPL values in the frequency band pre-CPA. Box plots show the 10th to 90th percentile data values (blue box), median (red line), and outliers removed (red plus sign).

DISCUSSION

Background noise

1. Natural levels of background noise, independent of noise from ships, fluctuate at the acoustic recording site on time scales of minutes to months. Wind noise is likely the primary source of non-man-made noise in the study region during months of shipping traffic.
2. General patterns in background (i.e. noise from natural sources) noise levels show July and August to be the quietest months and Sept and Oct to be noisier due to increases in wind-generated noise with open water. Variability in background noise levels also increases in Sept and Oct.

Acoustic characteristics of ships

1. Noise from ships, especially icebreakers and tankers, raises underwater sound levels from distances greater than 40 km when natural background sound levels are at or below the median level of all the times when ships aren't present.
2. Bulk carriers have relatively lower levels of radiated underwater noise than other types of cargo ships, but long-range propagation of the low-frequency components of the ship noise occurs, likely associated with cavitation of the ship's propeller.
3. Tanker ships are noisier than other cargo ship types from farther away and for longer periods during transits past the recorder.
4. Icebreaker Botnica produces substantial tonal noise from 200 Hz to > 4 kHz during all transits with and without the presence of sea ice or other ships.

Listening Space Reduction

1. Relative changes in received level are smaller during 'noisier' background conditions (e.g. during periods of higher surface winds). This has the effect of reducing the predicted listening space reduction occurring due to noise from transiting ships. The opposite is true for 'quiet days'.
2. Estimated hearing threshold for narwhal obtained from beluga audiogram. At the 1 kHz band, used by narwhal for burst-pulse calls, this limits the amount of predicted LSR due to assumed relatively lower perceived noise levels above those hearing thresholds at the lower end of the estimated narwhal functional hearing bandwidth. Audiogram or hearing estimate specific to narwhal needed for better evaluation of LSR.
3. LSR estimation is sensitive to the reference noise level chosen. If we compare all times to a single quiet time, even the median noise level in the absence of ship noise, then half the time or so we will estimate that listening space is substantially reduced regardless of the presence of ships. If instead, we evaluate listening space reduction as relative to whether ambient conditions are noisy or quiet (e.g. Pine et al., 2018), we can better resolve the effect each transient noise event has on available listening space.
4. Substantial LSR may occur for ringed seals in the frequencies of their barks and growls as a result of ship transits, especially during relatively quiet periods in July and August.

Appendix 1.

Key points and highlights

AIS ship traffic

Shipping traffic through Eclipse Sound and Milne Inlet was comprised predominantly of cargo and commercial ships associated with the Baffinland Iron Mine at the south end of Milne Inlet. Bulk carriers transporting iron ore from the mine constituted 57% and 63% of ship transits at the eastern entrance to Eclipse Sound (site PI) and in central Milne Inlet (site MI), respectively. Over the one-year period analyzed, the total number of ship transits related to the mine, including all cargo vessels, tugs, and the icebreaker, constituted 89% of transits at PI and 99% of transits at MI.

Characteristics of ship noise

Each transit of a ship introduces substantial underwater noise that is a function of the ship type, ship speed, and distance of the listener from the ship.

Noise can be elevated in the 20-200Hz frequency band at ranges of greater than 40 km from some transiting ships.

Disturbance/avoidance

Narwhal behavioral disturbance and avoidance from ships has been documented through 2015-19 Bruce Head and tagging programs. Ranges at which behavioral disturbance has been observed are up to 15 km or greater. Ranges at which avoidance has been observed have been up to 3 km (Golder Associates Ltd., 2018; Golder Associates Ltd., 2019).

Received broadband sound pressure levels in the 20-4000Hz band are less than 110 dB (e.g. 100 dB in open water with a single ore carrier) when transiting ships are at ranges of 15 km, suggesting that thresholds for behavioral disturbance in Eclipse Sound narwhal are less than more general guidelines (e.g. 120 dB; Southall *et al*., 2007) used for preliminary evaluation of environmental impacts of shipping.

Received broadband SPL is usually less than 130 dB when ships are at ranges of 1-3 km, suggesting that threshold for avoidance behavior in Eclipse Sound narwhal is lower than more general guidelines (e.g. 135 dB; Southall *et al*., 2007) used to evaluate risks to narwhal from shipping.

Interference with communication (Listening space reduction)

Ship noise also occurs at frequencies > 500 Hz and overlaps with narwhal communication frequencies when ships are within closer ranges, lasting for 1-2 hours per transit and peaking when the ships are closest.

Ship noise below 500 Hz overlaps with ringed seal communication and is predicted to cause reduction in listening space for this species.

Ship noise during the ice-covered periods results in a larger increase of noise relative to background levels because of the reduced ambient noise under sea ice. This represents a greater predicted reduction of listening space for narwhal resulting from July and potentially October shipping involving icebreaking operations.

Relative reduction of listening space is less during noisier months, especially September, because of increased ambient noise from wind-driven waves.

Ship noise overlaps with bowhead whale tonal calls from much larger ranges, up to 60 km or greater due to bowhead communication in the 50-200Hz band.

Ambient sound and changing noise baseline

A cumulative effect of increased number and density of ships in the Eclipse Sound region may be an increase in background (i.e. ambient) noise levels. As a result, times between ship transits would be noisier, changing the sound levels that would be defined as ‘quite times’. Another effect of this would be to reduce the estimates of listening space reduction in the frequency bands where an increase in ambient noise has occurred due to regional shipping.

Future shipping traffic and underwater noise

Ship traffic from BIM project-related vessels in Eclipse Sound has increased by a factor of six while ore production has increased by apx. 4.6 times over the period from 2015 to 2019 open water seasons (Appendix 2). There’s a linear relationship between ore production and number of ship project-related ship transits with apx. 53 large vessel transits along the shipping route in Eclipse Sound per year per for every 1Mt of additional annual ore production. With current shipping operations, this would suggest more than an additional 200 ship transits needed to double ore production from 6 to 12 Mt. Ship traffic may be reduced by use of larger-capacity ore carriers (e.g. Capesize), but we have not yet measured underwater noise from this type of ship in Eclipse Sound.

Appendix 2. 2015-2019 Eclipse Sound shipping traffic summary from AIS data

Table A.2.1. Numbers of annual ship transits past acoustic recording sites in Pond Inlet (PI) and Milne Inlet (MI) during the annual period from July 1 through November 1, 2015-2019. Ship locations obtained from Automated Information System (AIS) messages received by satellite (www.ExactEarth.com). 'Project-related' transits are those specifically contracted to service the Baffinland Mary River Mine in southern Milne Inlet or to provide vessel support for mine-related shipping activities in the Eclipse Sound region.

	2015		2016		2017		2018		2019		BIMC phase II
Vessel Type	**PI**	**MI**	**PI**	**MI**	**PI**	**MI**	**PI**	**MI**	**PI**	**MI**	estimated
Bulk Carrier	26	26	76	76	112	114	145	142	166	168	332
General Cargo	11	6	9	6	31	30	17	12	26	22	22
Other Cargo	0	0	2	0	0	0	0	0	3	4	8
Oil/chemical Tanker	9	4	8	4	10	6	17	8	14	10	16
Commercial Icebreaker	0	0	0	0	0	0	22	39	22	26	52
Tug	4	4	4	4	7	4	8	8	0	11	22
Other Commercial Vessel	0	0	0	10	1	0	0	0	2	2	4
SAR	2	0	6	4	7	2	6	0	5	0	0
Military	2	1	2	0	7	0	0	0	7	1	1
Fishing	0	0	2	0	8	2	5	2	7	0	0
Passenger Ship	19	1	15	2	19	3	29	0	23	0	0
Sailing	2	0	7	2	9	3	9	0	6	0	0
Pleasure Craft	0	0	2	3	5	2	2	0	7	1	1
Research/Survey Vessel	0	0	2	0	2	0	0	0	0	0	0
Total transits	75	42	135	111	218	166	260	211	288	245	458
Project-related transits	-	40	-	100	-	154	-	209	-	243	
Ore produced (Mt)		1.3		3.2		4.1		5.1		6	12

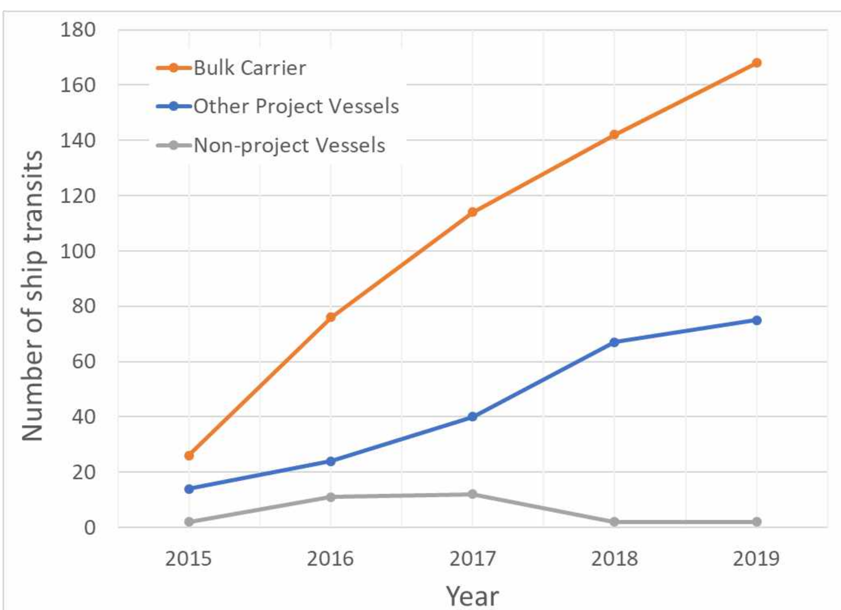


Figure A.2.1. Annual July 1-Nov 1 transits of vessels past the reference location in Milne Inlet (MI) obtained from satellite AIS data. Transits are one-way passages of vessels passing within a radius of 10 km of the recording location.

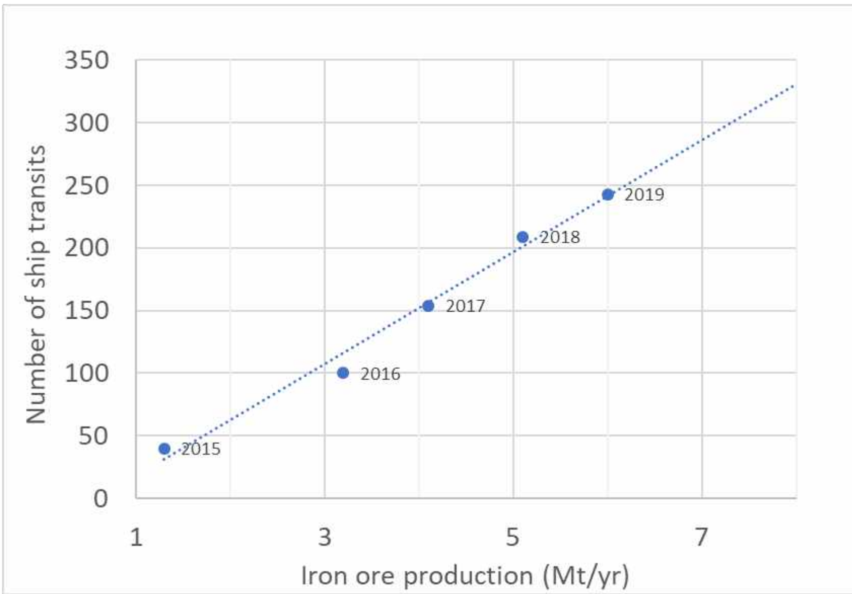


Figure A.2.3. Annual July 1-Nov 1 number of ship transits past reference location MI for each year from 2015 to 2019 plotted with the annual iron ore production reported by the Baffinland Mary River Mine. The line fit to the data has a slope of 44.8 ship transits per million tons (Mt) of ore produced per year.

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