Undertaking #20 – Underwater Noise Documents

VFPA Response

The response to this undertaking consists of three appendices:

1. Overview of Updated Underwater Noise Modelling for Terminal Operation (**Appendix A**);
2. JASCO's Mercator Projections Underwater Noise Modelling Update (for Terminal Operation; **Appendix B**); and
3. Underwater Noise Comparison of Ship Classes (**Appendix C**).

Appendices

Appendix A   Overview of Updated Underwater Noise Modelling for Terminal Operation

Appendix B   Mercator Projections Underwater Noise Modelling Update (for Terminal Operation)

Appendix C   Underwater Noise Comparison of Ship Classes

APPENDIX A

OVERVIEW OF UPDATED UNDERWATER NOISE MODELLING FOR TERMINAL OPERATION

OVERVIEW

A forecast was recently provided by Mercator International in its report entitled *Roberts Bank Terminal 2 Container Vessel Call Forecast Study* (the Mercator Study; CEAR Document #1362[1]). There have been developments in the container shipping industry, such as an accelerated trend toward larger ship sizes and the formation of new service alliances among others, which has motivated the VFPA to seek validation of earlier vessel call forecasts presented in the EIS. This report provided an updated forecast of container ship calls at Pacific Northwest ports to better understand how emerging container industry trends would affect container ship traffic at the Port of Vancouver, with and without the RBT2 Project. In light of this information, the VFPA has undertaken additional underwater noise modelling of Project operation.

This memo and accompanying technical report provide the results from updated Project terminal operation underwater noise modelling, for the following:

- For the Project operation phase, a comparison of updated underwater noise predictions based on updated forecasts to previous underwater noise modelling scenarios (**Table 1**); and
- An updated assessment of residual effects to marine mammals from acoustic disturbance during Project operation based on the updated underwater noise modelling prediction.

TERMINAL OPERATION SCENARIOS

EIS Underwater Noise Predictions with 18,000 TEU Container Ship

The RBT2 wharf is designed to accommodate Mega-Max class container ships, and hence, this size class was selected in the EIS for modelling of underwater noise during Project operation to provide for a conservative assessment. Underwater noise modelling of 260 annual 18,000 TEU (twenty-foot equivalent unit) capacity Mega-Max class container vessels calls to the RBT2 terminal with support from three tugs and a line boat. Within VFPA jurisdiction, approach/departure and berthing/unberthing activities during operation were assumed to total 1.75 hours per ship call. For additional information on assumptions and modelling results, refer to EIS Section 9.8.

2018 Update of Underwater Noise Predictions with 9,600 TEU Container Ship

As part of the RBT2 Review Panel process, the VFPA committed to[2] and submitted updated modelling to predict underwater noise from Project operations in 2030 for a more realistic scenario[3] compared to the scenario previously assessed and presented in the RBT2 EIS. This

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[1] CEAR Document #1362 From the Vancouver Fraser Port Authority to the Review Panel re: 2018 Container Vessel Call Forecast Study and Ship Traffic Information Sheet.
[2] IR5-48 (CEAR Document #1167) and IR5-50 (CEAR Document #1172)
[3] CEAR Document #1363 From the Vancouver Fraser Port Authority to the Review Panel

modelling was based on updated information of future container ship forecasts at Roberts Bank completed in 2014[4] that informed the selection of a representative Large Post-Panamax vessel for the purposes of assessing Project-associated vessel transiting in the marine shipping area (Marine Shipping Addendum Table 4-4). This updated modelling predicted substantially smaller underwater noise footprints during Project operation occurring 5% of the year for both Project container ship approach and berthing scenarios[5], compared to those presented in the EIS[6].

2019 Update of Underwater Noise Predictions with 13,000 TEU Container Ship

According to the updated forecast of vessel calls by Mercator, the total number of container ships calling at VFPA terminals will be the same in 2035, whether RBT2 is built or not (i.e., 15 services per week, or 780 services per year). If RBT2 is not built (i.e., expected conditions), it is projected that there will be 364 annual container ship calls at Deltaport Terminal in 2035, with the remaining vessels calling at other VFPA container terminals (i.e., expected conditions). If RBT2 is built, an additional 104 container ships are projected to call at Roberts Bank annually (i.e., 1.75 hours per ship call or 2% of the year). The incremental increase of 260 vessels per year assumed in the EIS underwater noise modelling, therefore has decreased by 156 calls per year. The updated predictions used actual measurements of the average container ship size class expected i.e., (Neo-Panamax, 13,000 TEU), provided by the VFPA ECHO program's Underwater Listening Station (ULS), to estimate the annual incremental contribution of RBT2 terminal operation to cumulative commercial vessel noise within the Strait of Georgia in 2035.

SUMMARY OF CHANGES IN PREDICTIONS OF UNDERWATER NOISE DURING RBT2 OPERATION FROM UPDATED MODELLING BASED ON MERCATOR STUDY

Both updates showed substantially smaller annual incremental increases in underwater noise, based on updated forecasts of container ship calls to Roberts Bank than those presented in the EIS. As assumptions for support tugs did not change for both modelling updates and underwater noise is primarily produced from tug activities, the annual average spatial extent of the incremental contribution of Project operation above expected conditions based on a 13,000 TEU vessel is expected to be similar or smaller to that predicted for a 9,600 TEU vessel (**Figure 1**). However, as there are fewer incremental annual container ship calls to RBT2 for the Mercator study (i.e., 104 calls) scenario compared to the number of annual calls for previous modelling predictions (i.e., 260 calls), the annual average incremental contribution of Project terminal underwater noise at the Roberts Bank receiver station is reduced from 2.8 dB re 1 μPa to 1.8 dB re 1 μPa (**Figure 2**, **Table 2**).

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[4] Seaport Consultants Canada Inc., Update of Projections of Container Ship Characteristics for Roberts Bank Terminal 2, September 2014 (CEAR Document #667).

[5] Underwater noise generated from vessel departure and unberthing were assumed to be similar to the predictions for approach and berthing activities, respectively

[6] For winter scenarios, this reduction is primarily driven by the use in the model of lower tug speeds during approach/departure activities, and average support tug source levels during berthing/unberthing activities. Underwater noise was reduced even further with the use in the model of a summer underwater sound speed profile.
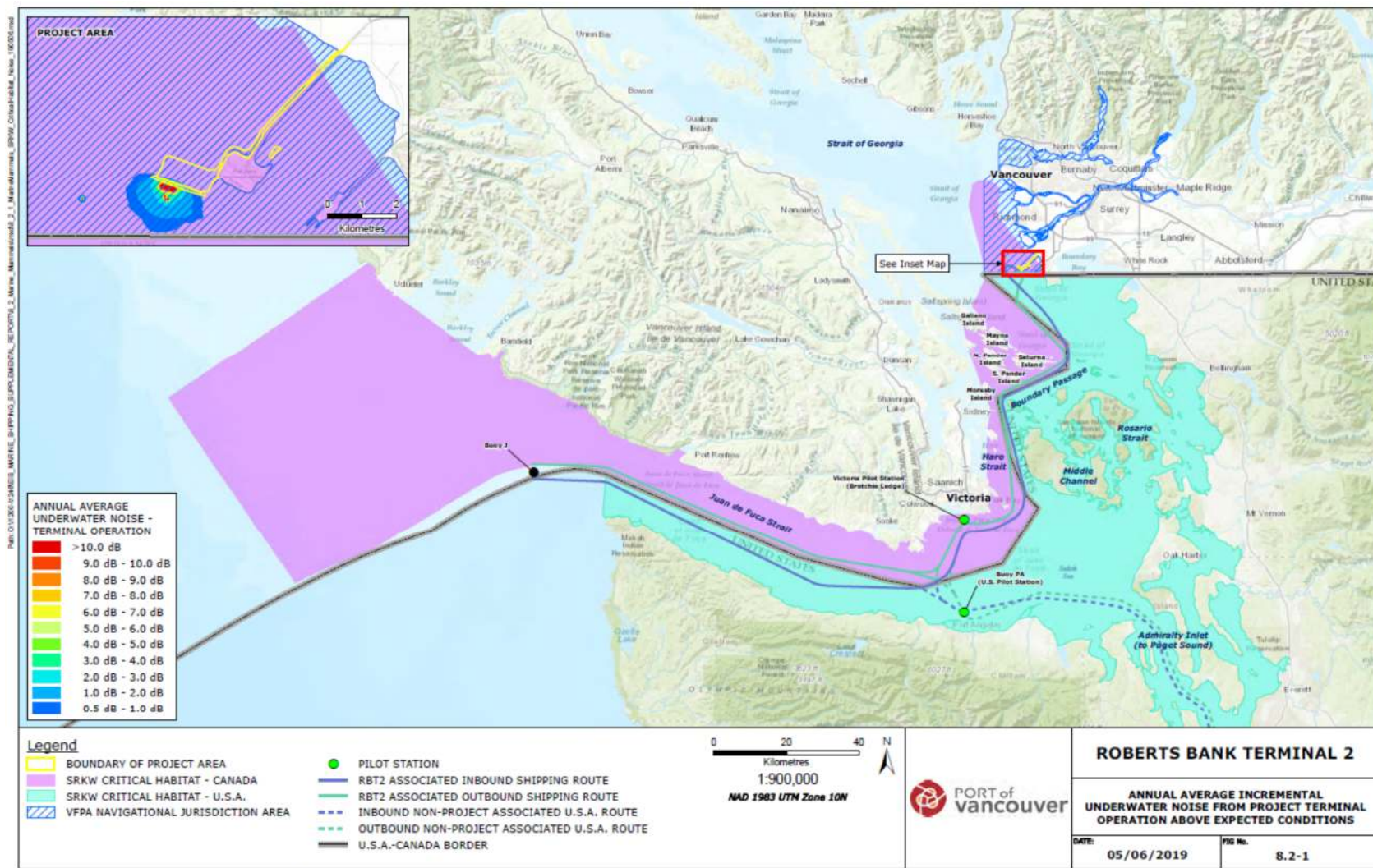
Figure 1. Annual Average Incremental Contribution of Underwater Noise from Project Terminal Operation (104 incremental calls of 13,000 TEU Container Vessels) above Expected Conditions (2035)
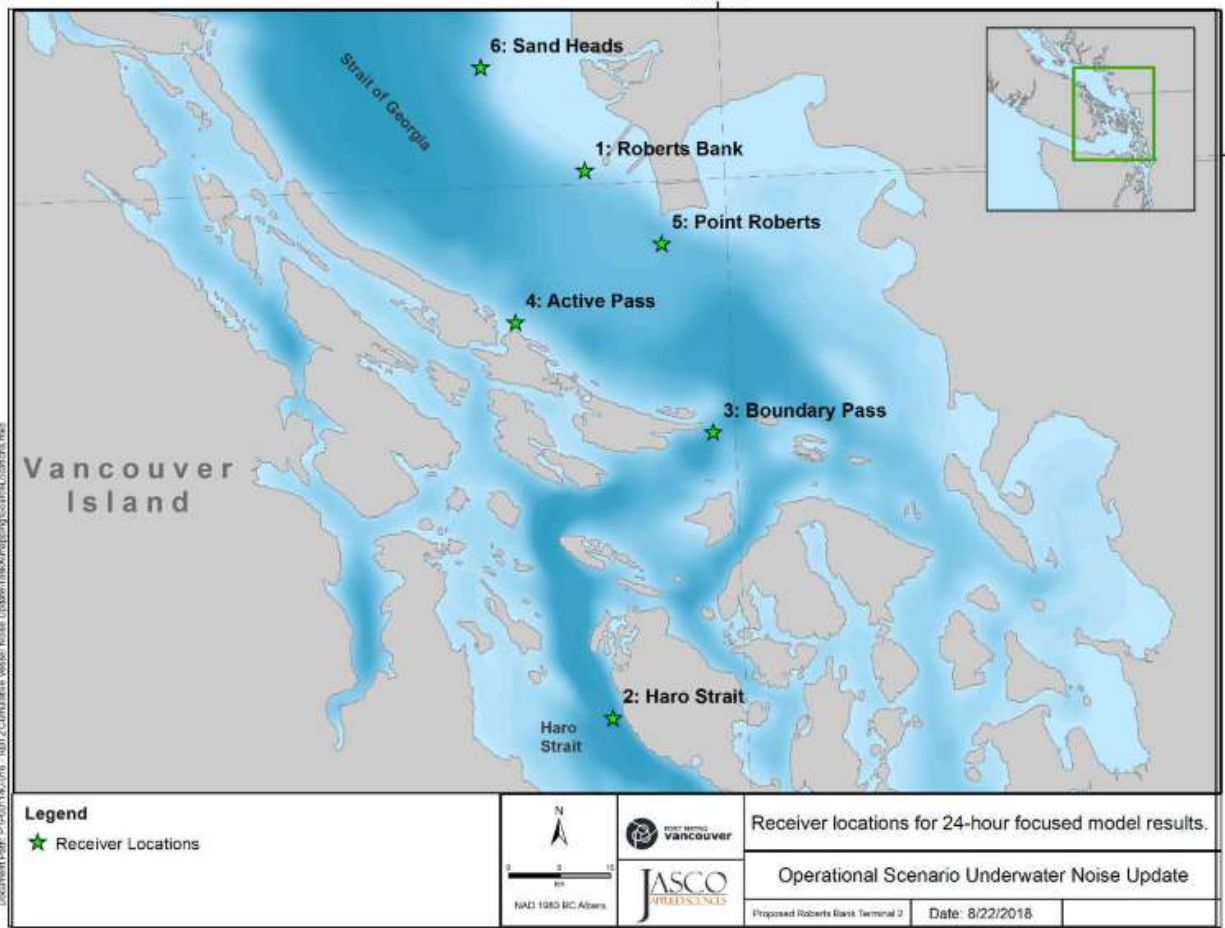
Figure 2. Receiver locations used for assessing incremental increase of underwater sound levels from RBT2 Project operation.

Table 1. Comparison of Underwater Noise modelling Assumptions for Terminal Operation Scenarios.

	Terminal Operation Underwater Noise Scenario		
	EIS Appendix 9.8-A	**2018 Modelling Update**	**2019 Modelling Update**
Container ship size class	Mega-Max	Large Post-Panamax	Neo-Panamax
Container ship TEU	18,000	9,600	13,000
Average container ship length (metres)	400	338	366
Incremental number of annual container ship calls at RBT2 above expected conditions	260[a,d]	260[b,e]	104[c,f]
Percentage of year with incremental RBT2 terminal operation	5	5	2
Container ship speed during approach (knots)	6	6	6
Number of support tugs	4	3	3
Support tug speed upon approach (knots)	12	8	8
Support tug noise during berthing	Loudest 2 minutes[g]	Average[h]	Average[h]

[a] Expected conditions equivalent to existing conditions in 2012.
[b] Expected conditions includes existing conditions 2015 with expected increases in annual calls to Roberts Bank terminals (i.e., Westshore and Deltaport).
[c] Expected conditions includes ship calls to Roberts Banks terminals (i.e., Westshore and Deltaport) in 2035 if RBT2 is not built.
[a,b,c] Expected conditions also included movements of vessels adjacent to Roberts Bank (i.e., BC Ferries, movements of commercial vessel traffic along international shipping lanes.
[d] Future project conditions include expected conditions in 2015 with an additional 260 annual container ships calls in 2030 to the RBT2 terminal.
[e] Future project conditions include expected conditions in 2023 with an additional 260 annual container ships calls in 2030 to the RBT2 terminal.
[f] Future project conditions include expected conditions in 2035 with an additional 104 annual container ship calls in 2035 to the RBT2 terminal plus the movement of 130 expected container ship calls from Deltaport to RBT2.
[g] Loudest 2 minutes of recorded berthing noise assumed for full 30-minute berthing activity.
[h] Average recorded berthing noise assumed for full 30-minute berthing activity.

Table 2. Incremental Increase in Annual Time-Average Underwater Sound Levels from Project Terminal Operation Above Expected Underwater Noise Conditions at the Roberts Bank Receiver Location.

Scenario Description	Annual Time-Average Sound Levels—Leq-1yr (dB re 1 µPa)		
	EIS Appendix 9.8-A	2018 Modelling Update	2019 Modelling Update
Expected conditions	123.3	121.7	**122.3**
Future project conditions	128.1	124.5	**124.1**
Increase above expected conditions	4.8	2.8	**1.8ª**

ª For this update, there was no increase in underwater noise levels at receiver stations 2-6 in Figure 2.

UPDATED CHARACTERISATION OF ACOUSTIC DISTURBANCE TO MARINE MAMMALS FROM OPERATIONAL NOISE

The findings of this work confirm the conservatism that underpinned the predictions of underwater noise, and the assessment of potential effects of underwater noise to marine mammals during RBT2 terminal operation presented in EIS Section 9.8 and Section 14.0. The updated modelling presented here show that the annual incremental contribution of underwater noise from vessels during Project operation (i.e., approach/departure and berthing/unberthing activities) is relatively small compared to those already occurring from expected shipping traffic and other natural sources (i.e., increase of 1.8 dB re 1 µPa over 2.84 km^2).

With a smaller predicted underwater noise footprint from Project operation compared to the EIS and CEAR Document #1363, there is less probability of an interaction with marine mammals, including SRKW. Acoustic monitoring studies conducted to detect SRKW vocalisations at the location of the proposed RBT2 terminal indicate that, while SRKW do occur in this area they more commonly occur in their core feeding area in Haro Strait during 80% of the summer period (see Marine Mammal Habitat Use Studies TDR MM-1 in CEAR Document #388). Previous predictions of acoustic disturbance to SRKW in the EIS (i.e. approximately 3.5 hours per whale per year, EIS Appendix 14-B) are reduced to less than 1.4 hours per whale per year (or 0.016% of the year) above acoustic disturbance predicted to occur to SRKW during expected conditions (i.e. 2035 without RBT2).

Based on this updated underwater noise prediction during Project operation, ratings for criteria and supporting rationale for the criteria rating for this residual effect summarised in EIS Table 14-23 remain unchanged, except for the extent criteria in which the rating has changed from regional to local, due to the reduction in the spatial extent of underwater noise (**Table 3**). This technical report provides additional certainty and confidence in the EIS conclusion of no significant residual effects to marine mammals due to the incremental contribution of Project operation and based on this updated modelling, this conclusion of no significant residual effects to marine mammals remains unchanged.

Table 3. Updated Summary of Criteria Ratings for Acoustic Disturbance to Marine Mammals from Incremental RBT2 Operational Underwater Noise based on 2019 Modelling Update

Criteria	Description	EIS Criteria Rating	Modelling Update Criteria Rating Change (Yes/No) and Supporting Rationale
Magnitude	Expected size or severity of the residual effect	Low-Moderate	SRKW: No In EIS, measurable change within or beyond the range of natural variability including low- and moderate-severity behavioural responses to continuous noise (3.5 hours/whale/year or 0.04% of the year) unlikely to affect SRKW life functions or critical habitat features and is unlikely to affect population viability or recovery. Based on the modelling update, criteria rating does not change (low-moderate) but the incremental residual effect has been reduced to 1.4 hours/whale/year (0.016% of the year)
		Low	North Pacific humpback whales and Steller sea lions: N/A
Extent	Spatial scale over which the residual effect is expected to occur	Regional	SRKW, North Pacific humpback whale, Steller sea lion: **Yes** In EIS, the spatial extent over which the residual effect is expected to occur regionally within the local assessment area. Based on the modelling update, the spatial extent of the residual effect is limited **Locally** to Roberts Bank.
Duration	Length of time over which the residual effect is expected to persist	Short-term	SRKW: N/A
			North Pacific humpback whales and Steller sea lions: N/A
Frequency	How often the residual effect is expected to occur	Frequent	SRKW, North Pacific humpback whale, Steller sea lion: No In the EIS, residual effects to individuals could occur repeatedly during approaching/departure and berthing/unberthing of container ships and use of associated support vessels that occurs during 5% of the year. Based on the modelling update, terminal operation producing underwater noise is reduced from 5% to 2% of the year.
Reversibility	Whether or not the residual effect can be reversed	Reversible	SRKW, North Pacific humpback whale, Steller sea lion: N/A

APPENDIX B

MERCATOR PROJECTIONS UNDERWATER NOISE MODELLING UPDATE (FOR TERMINAL OPERATION)

Mercator Projections Underwater Noise Modelling Update

Roberts Bank Terminal 2 Project

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Disclaimer:

The results presented herein are relevant within the specific context described in this report. They could be misinterpreted if not considered in the light of all the information contained in this report. Accordingly, if information from this report is used in documents released to the public or to regulatory bodies, such documents must clearly cite the original report, which shall be made readily available to the recipients in integral and unedited form.

Contents

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1. Introduction

This technical report presents an updated analysis of the future contribution of Roberts Bank Terminal 2 (RBT2) terminal operations to underwater noise at Roberts Bank, based on vessel forecasts for 2035 from the Mercator Study (Mercator 2018). According to projections by Mercator, the total number of container ships calling at Vancouver Fraser Port Authority (VFPA) terminals will be the same in 2035, whether RBT2 is built or not (i.e. 15 services per week). If RBT2 is built, there are projected to be 468 annual container ship calls at Roberts Bank, split evenly between RBT2 and Deltaport, when the terminal is operating at capacity in 2035 (i.e., under future conditions). If RBT2 is not built, there are projected to be 364 annual container ship calls at Roberts Bank in 2035, at Deltaport alone, with the remaining vessels calls to be directed to other VFPA container terminals (i.e., under expected conditions)[1]. The Mercator projections are summarized in Table 1.

Table 1. Expected annual container ship calls at Roberts Bank container terminals in 2035 under expected and future conditions (Mercator 2018).

	RBT2 Calls	Deltaport Calls	Total Calls
2035 without RBT2 (Expected Conditions)	0	364	364
2035 with RBT2 (Future Conditions)	234	234	468
Net change	*234*	*-130*	*104*

According to the Mercator Study projections, the average size of container ships calling at Roberts Bank will increase from 9,365 twenty-foot equivalent units (TEUs; assumed in the Marine Shipping Addendum) to 13,000 TEUs when the terminal is operating at, or near, capacity, and these vessels will increase in size by 2035 regardless of whether RBT2 is built. The average (approx. 13,000 TEU) future container ship capacity in 2035 corresponds to Neo-Panamax-size vessels, which have recently been measured on the Strait of Georgia Underwater Listening Station (ULS) operated by VFPA's Enhancing Cetacean Habitat and Observation (ECHO) program[2].

This study uses updated measurements of Neo-Panamax vessels[3], provided by the VFPA ECHO program, along with projected vessel numbers for the Marine Shipping Area (MSA) for 2035, to estimate the yearly incremental contributions of RBT2 terminal operations to cumulative vessel noise within the Strait of Georgia. The methods used in this study are based on a previous JASCO study (Warner et al. 2018 - CEAR #1363) that used updated modelling assumptions to provide a more realistic estimate of the noise contribution of anticipated RBT2 Project operations activities in 2030, compared to the original estimate provided in the EIS. The updated assumptions employed in the present study are as follows:

- Average container ships calling at Roberts Bank in 2035 will be Neo-Panamax size (366 m length overall), under expected (i.e., without RBT2) and future (i.e., with RBT2) conditions.

- Source levels for Neo-Panamax container ships (366 m) are based on anonymized measurements from the VFPA's ECHO program.

- Container ship calls at Roberts Bank will increase in 2035 (relative to the existing conditions for 2015), per the Mercator Study forecasts for expected and future conditions.

- Other vessel traffic in the study area will increase, per the MSA projections for the Project Area (i.e., for segment A) (Hemmera Envirochem Inc. 2015).

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[1] As of 2015, there were 268 annual container ship calls at Roberts Bank (i.e., under existing conditions).
[2] https://www.portvancouver.com/2017-echo-program/
[3] All vessel identities were anonymized by ECHO to preserve confidentiality.

Other assumptions related to Project operations, including durations of berthing activities, numbers of tugs, and times of year, are identical to those assumed in the previous modelling update (Warner et al. 2018).

2. Methods

2.1. Source Level Measurements

Average source levels for a Neo-Panamax container ship approaching the terminal at reduced speed were derived from 9 measurements of 366 m long container ships travelling at speeds less than 15 knots. The data were collected on ECHO's ULSs in the Strait of Georgia, Haro Strait, and Boundary Pass in 2017-2018. Note that the underlying confidential vessel source level dataset was not shared with the RBT2 project. Average 1/3-octave-band source levels were computed from the power mean of the individual measurements, after adjusting each measurement to a mean speed of 11.6 knots, using scaling coefficients determined from the Haro Strait slowdown trial (MacGillivray et al. 2018). The average source levels were then adjusted to the 6 knot transit speeds assumed for container ships approaching RBT2 in the VFPA jurisdiction (Figure 1). Comparison with source levels for smaller, Small Post-Panamax-size vessels (mean LOA 300 m) indicates that the Neo-Panamax container ships do not emit higher levels of underwater radiated noise, despite their larger size.
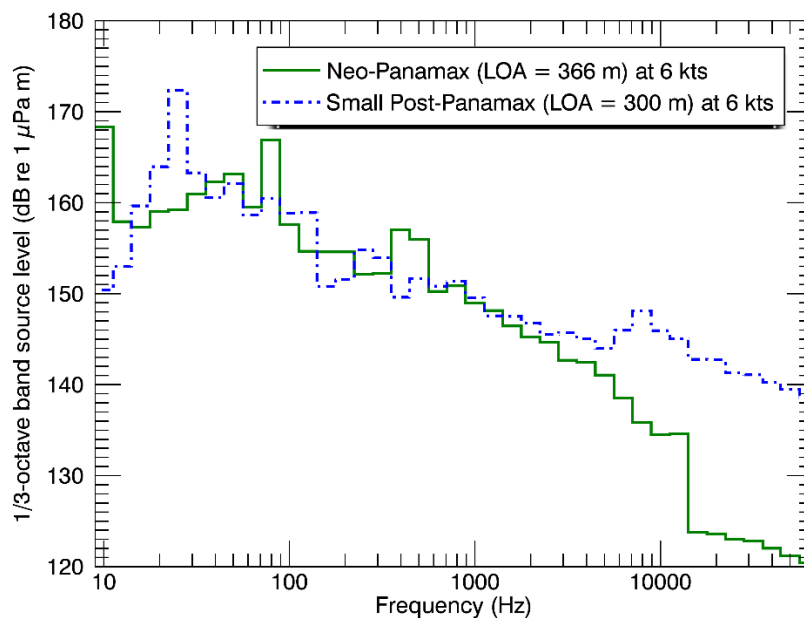

Figure 1. Speed-adjusted source levels in 1/3-octave frequency bands for a Neo-Panamax container ship (366 m LOA, solid green lines) transiting at 6 knots during terminal approach. These are compared with speed-adjusted source levels for Small Post-Panamax-size container ships (~300 m LOA, dot-dashed blue lines), computed from the ECHO ULS dataset, as assumed in the previous modelling update (Warner et al. 2018).

2.2. RBT2 Terminal Operations

Scenarios 3B and 6B[4] involve terminal operations for approaching a Neo-Panamax container ship at RBT2 with three tugs in both summer and winter (Table 2). These scenarios were modelled using JASCO's Marine Operation Noise Model (MONM), which is described in EIS Appendix 9.8-A (Wladichuk et al. 2014). Source levels for the container ship approaching the terminal were based on the adjusted Neo-Panamax

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[4] Corresponding scenario numbers for Small Post-Panamax container ships approaching RBT2 were 3A and 6A in Warner et al. (2018).

measurements from ECHO (**Figure 1**). Source levels for tugs and environmental inputs to MONM were the same as those applied in the previous modelling update (Warner et al. 2018). Source levels for berthing operations were taken to be the same as in Warner et al. (2018) since noise from berthing originates primarily from the berthing tugs, which are unchanged for Neo-Panamax vessels.

Table 2. Scenario parameters for Neo-Panamax container ship approaching and departing terminal.

Scenario	Season	Operation	Source levels
3B	Summer	Neo-Panamax container ship approaching terminal with 3 tugs approaching container ship	Container ship at 6 knots and tugs transiting at 8 knots
6B	Winter	Neo-Panamax container ship approaching terminal with 3 tugs approaching container ship	Container ship at 6 knots and tugs transiting at 8 knots

2.3. Expected and Future Cumulative Vessel Noise Conditions

JASCO's cumulative vessel noise model was used to predict underwater sound levels from non-Project-related vessel traffic under expected conditions (2035 without RBT2) and future conditions (2035 with RBT2) within the focused model area (FMA). Modelled sound levels under existing conditions were taken to be the same as those presented in the previous modelling update (Warner et al. 2018) for baseline Automatic Identification System (AIS) data for 2015. Changes in vessel traffic numbers for 2035, relative to the 2015 baseline, were applied on a per-category basis according to projections from the Marine Shipping Addendum for the Project Area (i.e., segment A; Table 2). These changes were applied in the model by adjusting the total sound power emissions associated with each vessel category according to its projected annual change in traffic volume.

Table 3. Annual changes in 2015 (i.e., existing conditions) vessel traffic volume used to simulate expected and future conditions for 2035. Positive changes correspond to increases and negative changes correspond to decreases in the annual number of vessel transits.

Vessel Category	Expected Conditions (2035 without RBT2)	Future Conditions (2035 with RBT2)
Deltaport Container Ships	35%	-13%
Westshore Bulkers	11%	11%
Non-Roberts-Bank Container Ships	-30%	-40%*
Ferry (Ro-ro Passenger)	5%	5%
Ferry (Ro-ro Cargo)	20%	20%
Fishing	0%	0%
Government	22%	22%
Bulker/Gen. Cargo	20%	20%
Other	22%	22%
Passenger < 100 m	5%	5%
Passenger > 100 m	5%	5%
Recreational	22%	22%
Tanker	225%	225%
Tug	44%	44%
Vehicle Carrier	0%	0%
Naval	0%	0%

* Note that 10% of the reduction in this category is attributable to container ships being re-routed to RBT2 from Deltaport in 2035 (approximately 2 calls per week). Because these vessels are still calling at Roberts Bank, we only assumed a -30% change in non-RBT2 container ship trips under future conditions. This step was taken to avoid over-predicting sound level reductions at Roberts Bank, due to Project-related changes in marine shipping.

2.4. Annual Incremental Contribution of Project Operations

Modelled underwater noise levels for the future and expected conditions were used to calculate the annual incremental contribution of RBT2 terminal operation to underwater noise in the study area. Sound levels from RBT2 operation were computed from berthing and approach scenarios, based on the proportion of time these activities are expected to occur for one year. The incremental underwater noise contribution of the project was assumed to be due to new container ship calls at RBT2 (104 calls), plus the movement of 130 expected container ship calls from Deltaport to RBT2 (Table 4). The annual incremental noise contribution of the RBT2 project was therefore computed from the difference in predicted underwater noise between these two scenarios.

Table 4. Modelled annual duration of container ship berthing and approach operations, at Roberts Bank terminals, under expected conditions and future conditions, as a percentage of the total year. The assumed duration of these activities was 1 hour (combined) for berthing and unberthing, and 0.75 hours (combined) for approach and departure, per call. Note that these percentages refer to the fraction of the year that the operations will increase sound levels in the study area, and not to the percentage by which sound levels will be increased by those operations.

	Expected Conditions (2035 without RBT2)	Future Conditions (2035 with RBT2)
RBT2: Berthing and unberthing	0.00%	2.67%
RBT2: Approach and departure	0.00%	2.00%
Deltaport: Berthing and unberthing	4.16%	2.67%
Deltaport: Approach and departure	3.12%	2.00%

To quantify the annual incremental contributions of Project operations on a time-dependent basis, sound levels versus time and their statistics (cumulative density functions, CDF) were calculated from the cumulative vessel noise models at six receiver locations in the FMA, following the approach described in Warner et al. (2018). Appendix A shows modelled sound levels versus time and the CDF plots used in the incremental Project operations contribution calculation.

Contours of the incremental contribution of Project operations (i.e., as shown in Figures 13 and 14 from Warner et al. (2018)) could not be calculated based on the Mercator Study projections because the non-Project-related vessel movements at Roberts Bank are different under future and expected conditions. Thus, future conditions with RBT2 cannot be represented simply by superimposing noise from Project operations on top of expected conditions, as was assumed in the previous modelling studies. Instead, the annual incremental contribution of the Project has been calculated for the present study based on the difference between the annual time-average sound levels between the future and expected conditions. Annual time-average sound levels (L_{eq1yr}) at receiver locations 1-6 were calculated by averaging the summer and winter sound pressure level (SPL) for each model scenario:

$$L_{eq1yr} = 10 \log \left(\frac{1}{2} \cdot 10^{\text{SPL(summer)}/10} + \frac{1}{2} \cdot 10^{\text{SPL(winter)}/10} \right) \tag{1}$$

The annual contribution was then taken to be the difference between the L_{eq1yr} values for the future and expected conditions scenarios at each of the receiver locations.
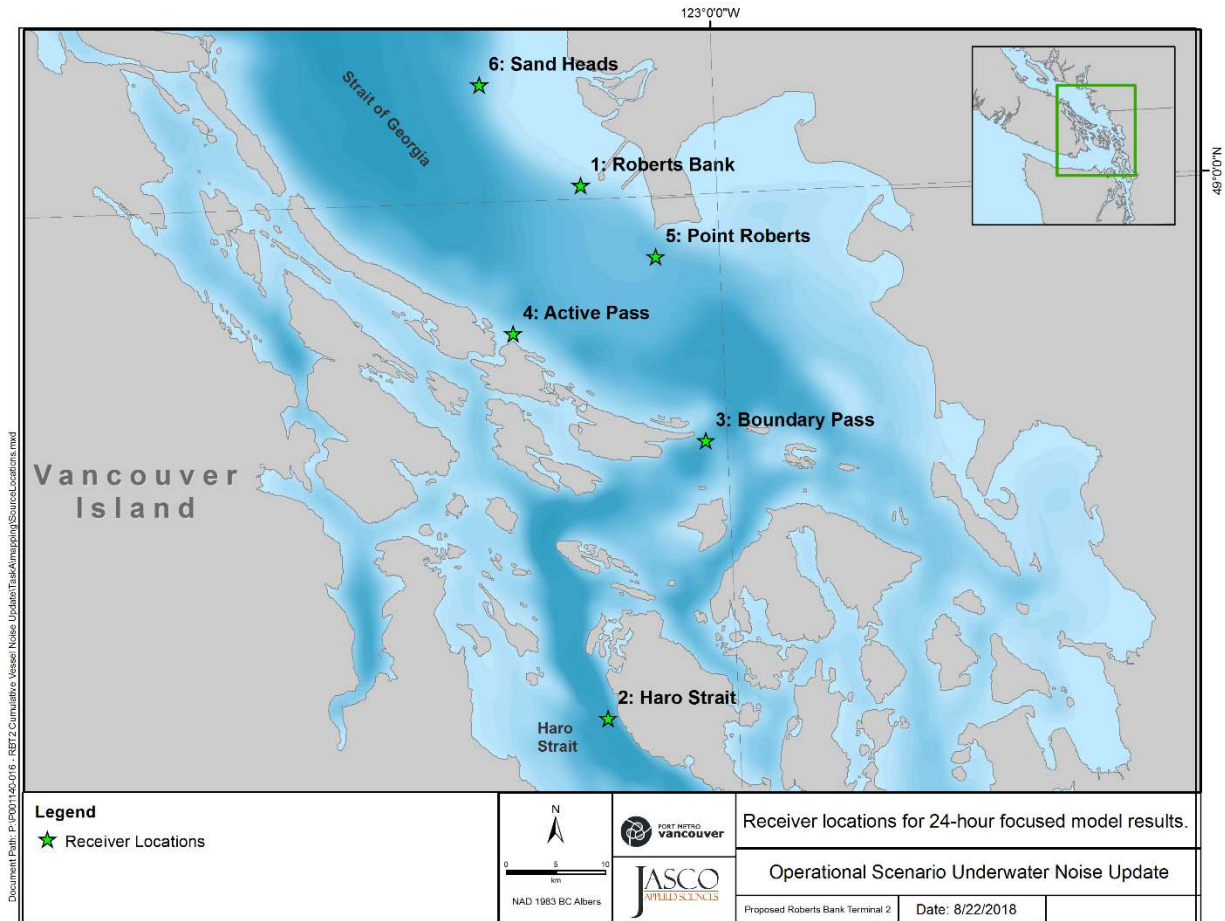
Figure 2. Receiver locations used for assessing underwater sound levels in the FMA under expected and future conditions.

3. Results

3.1. Container Ship Approach and Berthing

Tables 5 and 6 list the NOAA behavioural disturbance radii and SMRU killer-whale-specific low- and moderate-severity behavioural disturbance radii (see SMRU (2014)) for approach and berthing, respectively, of Neo-Panamax container ships at the proposed terminal in summer and winter. The approach radii are compared to Triple-E class (Mega-Max class) container ships in winter (EIS Section 9.8) and Small Post-Panamax container ships in summer and winter (Warner et al. 2018). The $R_{95\%}$ radii represent the radius of a circle centred at the source that encompasses 95% of the area ensonified above the threshold value. Figures 3–8 present the corresponding sound level isopleth maps.

Table 5. Radii of unweighted sound pressure level ($R_{95\%}$) behavioural disturbance contours for approaching container ships during RBT2 operation. Results from the EIS scenarios and previous modelling update (3A and 6A) are shown for comparison with the present study (3B and 6B).

Scenario	Operation	Season	NOAA behavioural (SPL dB re 1 µPa) disturbance radius (m)	Low-severity response (SPL dB re 1 µPa) behavioural disturbance radius (m)			Moderate-severity response (SPL dB re 1 µPa) behavioural disturbance radius (m)		
			120	117	129	146	126	137	153
EIS Section 9.8									
–	Mega-Max (Triple E)-class container ship approaching terminal at 6 knots with 4 tugs approaching container ship at 12 knots	Winter	14,200	20,290	4,050	290	6,370	1,010	110
Previous Modelling Update (Warner et al. 2018, CEAR Document #1363									
3A	Small Post-Panamax container ship approaching terminal at 6 knots with 3 tugs approaching container ship at 8 knots	Summer	843***	3,000*	440**	90**	540**	220**	20[+]
6A	Small Post-Panamax container ship approaching terminal at 6 knots with 3 tugs approaching container ship at 8 knots	Winter	2,540*	3,110*	480**	90**	610**	230**	20[+]
Present Study									
3B	Neo-Panamax container ship approaching terminal at 6 knots with 3 tugs approaching container ship at 8 knots	Summer	710***	2,690*	440**	90**	540**	220**	20[+]
6B	Neo-Panamax container ship approaching terminal at 6 knots with 3 tugs approaching container ship at 8 knots	Winter	2,420***	2,670*	480**	90**	610**	240**	20[+]

* Centroid of all sources used as the reference point for calculating radii.
** Centroid of tugs used as the reference point for calculating radii.
*** Container ship used as the reference point for calculating radii.
[+] Single tug used as the reference point for calculating radii.

Table 6. Radii of unweighted sound pressure level ($R_{95\%}$) behavioural disturbance contours for container ship berthing during RBT2 operation. Results are identical to those provided in the previous modelling update, for Small Post-Panamax vessels, because berthing noise originates primarily from the tugs involved in the berthing operation and the number of tugs involved is unchanged for Neo-Panamax vessels.

Scenario	Operation	Season	NOAA behavioural (SPL dB re 1 µPa) disturbance radius (m)	Low-severity response (SPL dB re 1 µPa) behavioural disturbance radius (m)			Moderate-severity response (SPL dB re 1 µPa) behavioural disturbance radius (m)		
			120	117	129	146	126	137	153
1A	Neo-Panamax container ship berthing with 3 tugs using 30-minute average source level*	Summer	3,850	5,180	1,420	290	1,700	530	50
2A	Neo-Panamax container ship berthing with 3 tugs using loudest 2-minute source level*	Summer	7,220	10,170	2,510	440	4,010	1,160	260
4A	Neo-Panamax container ship berthing with 3 tugs using 30-minute average source level*	Winter	8,460	15,340	1,940	300	3,210	630	50
5A	Neo-Panamax container ship berthing with 3 tugs using loudest 2-minute source level*	Winter	22,000	29,220	5,310	470	8,430	1,410	270

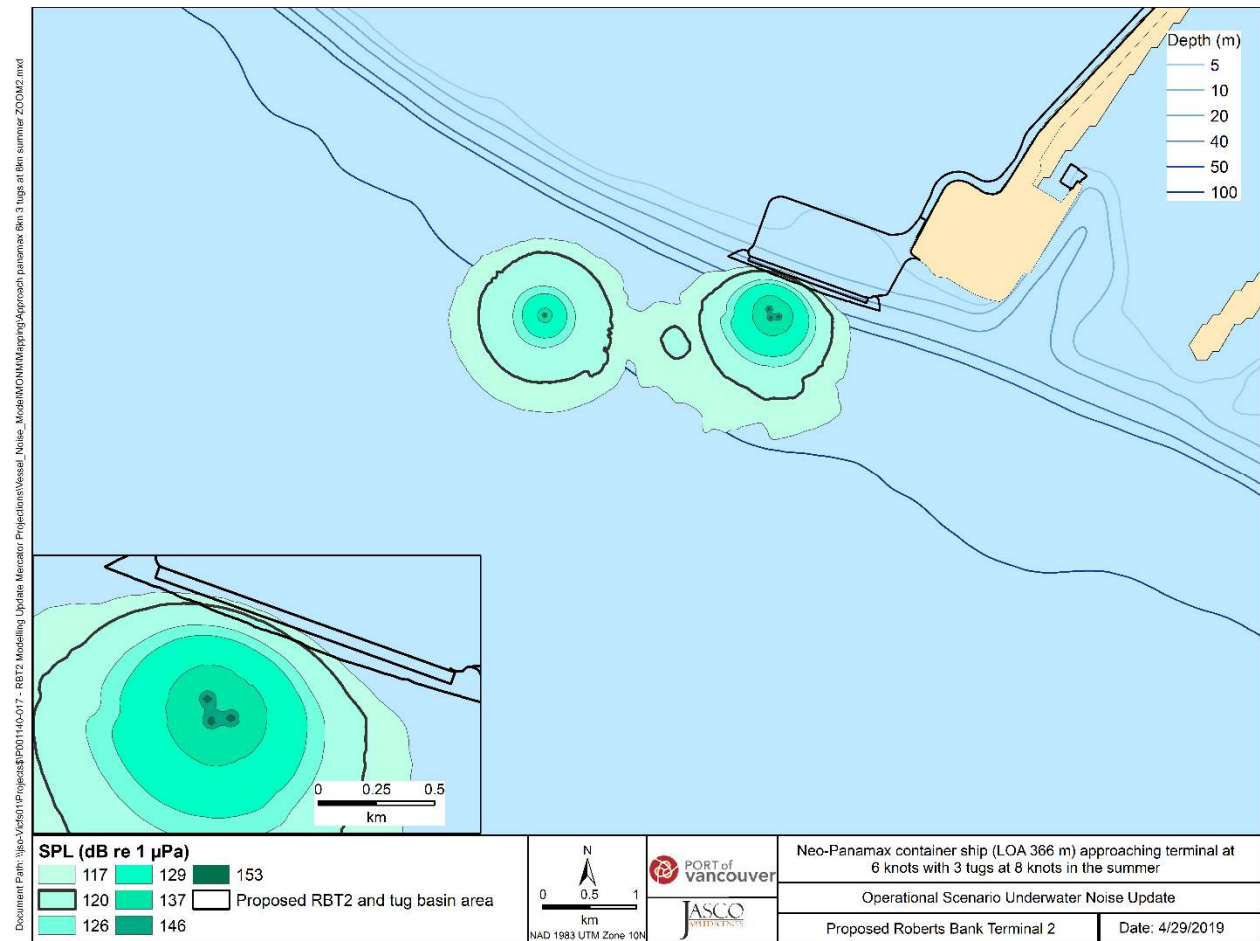* All radii used the middle tug as the reference point for calculating radii.

Figure 3. Scenario 3B: Map of the 120 dB and the SRKW behavioural response contours for a Neo-Panamax container ship approaching terminal at 6 knots with three tugs at 8 knots in summer. Inset shows close-up of contours around the tugs.
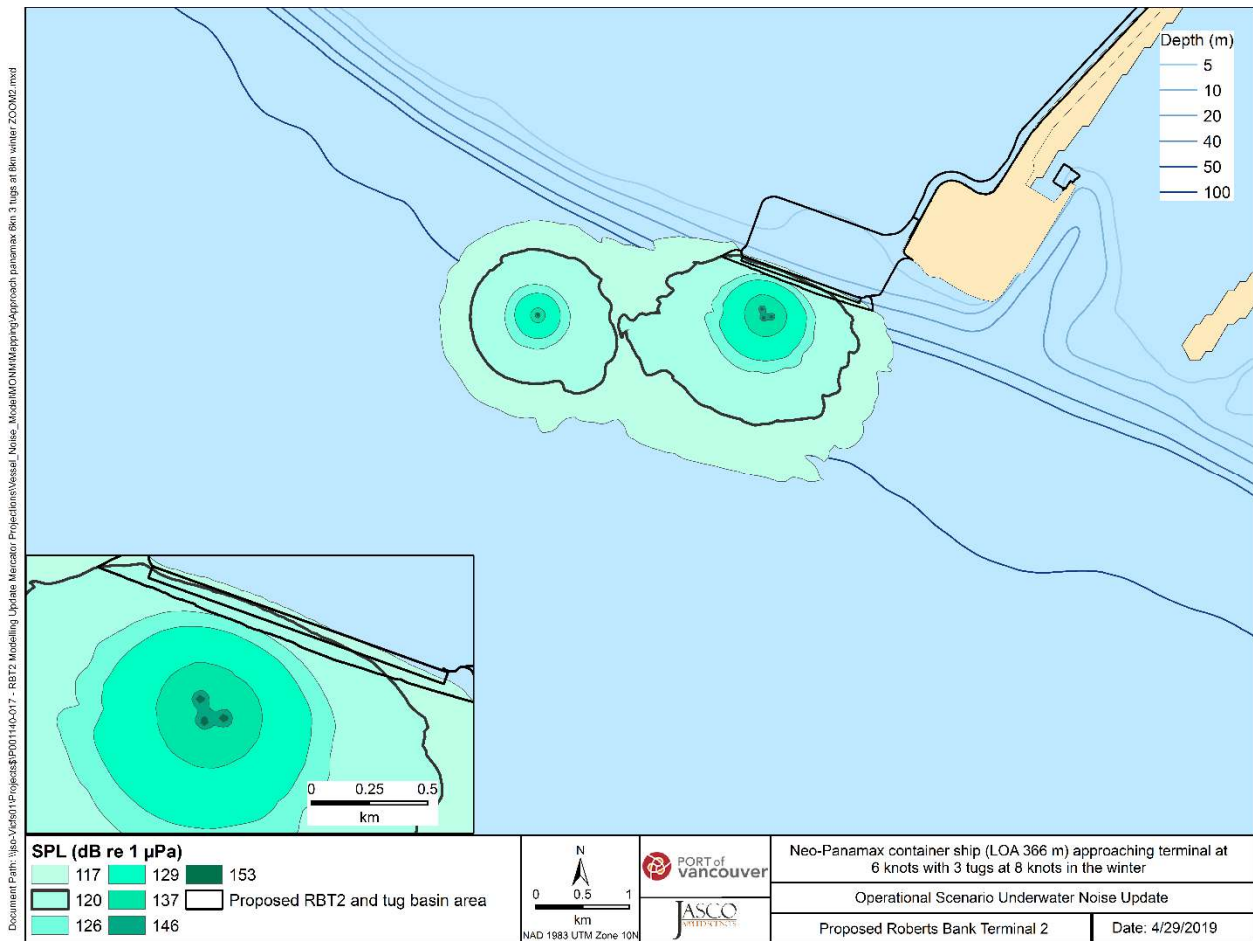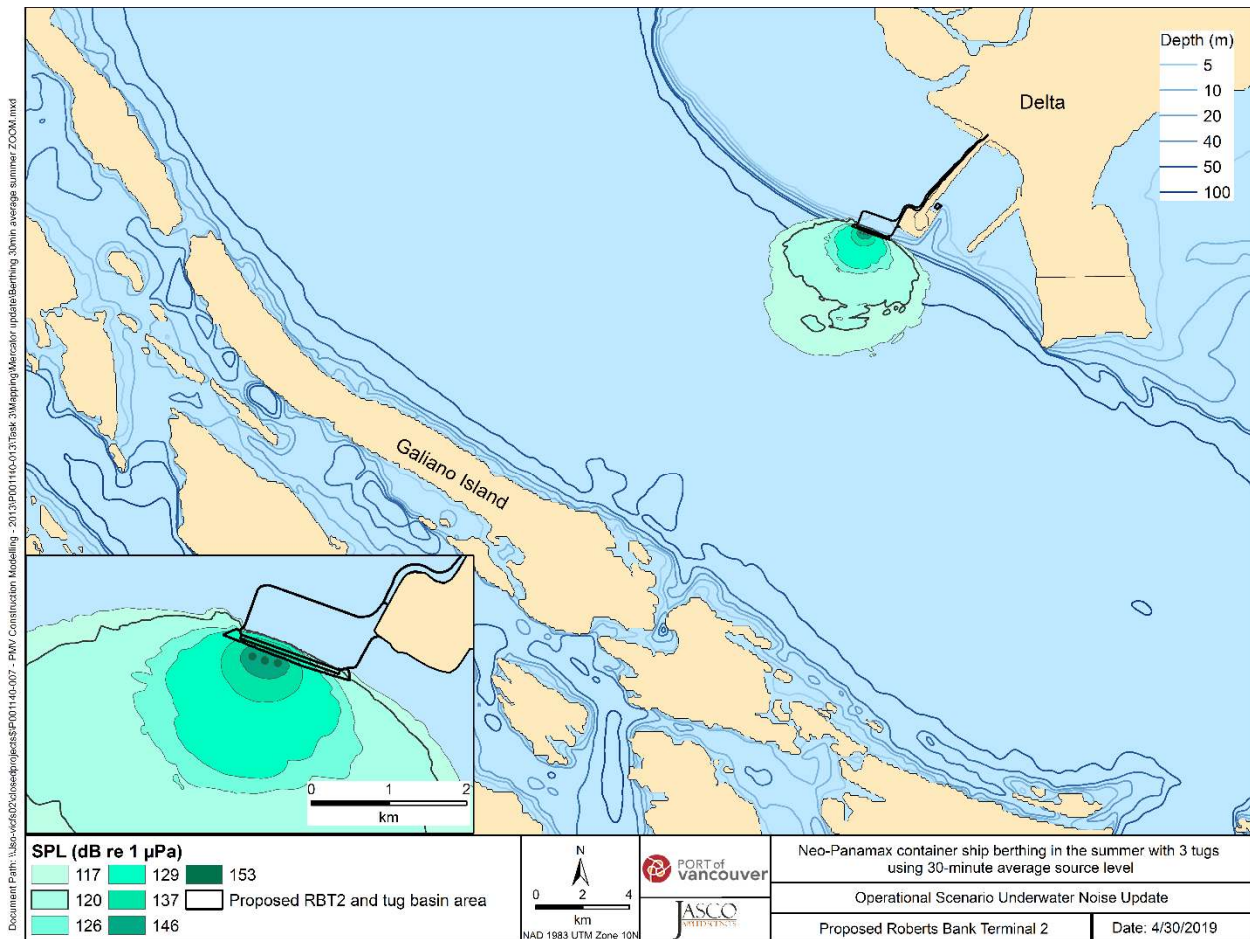
Figure 4. Scenario 6B: Map of the 120 dB and the SRKW low- and moderate severity behavioural disturbance response contours for a Neo-Panamax container ship approaching terminal at 6 knots with three tugs at 8 knots in winter. Inset shows close-up of contours around the tugs.

Figure 5. Scenario 1A: Map of the 120 dB and the SRKW low- and moderate severity behavioural disturbance response contours for a Neo-Panamax container ship berthing with three tugs using the 30-minute average source level in summer. Inset shows close-up of contours around the tugs.
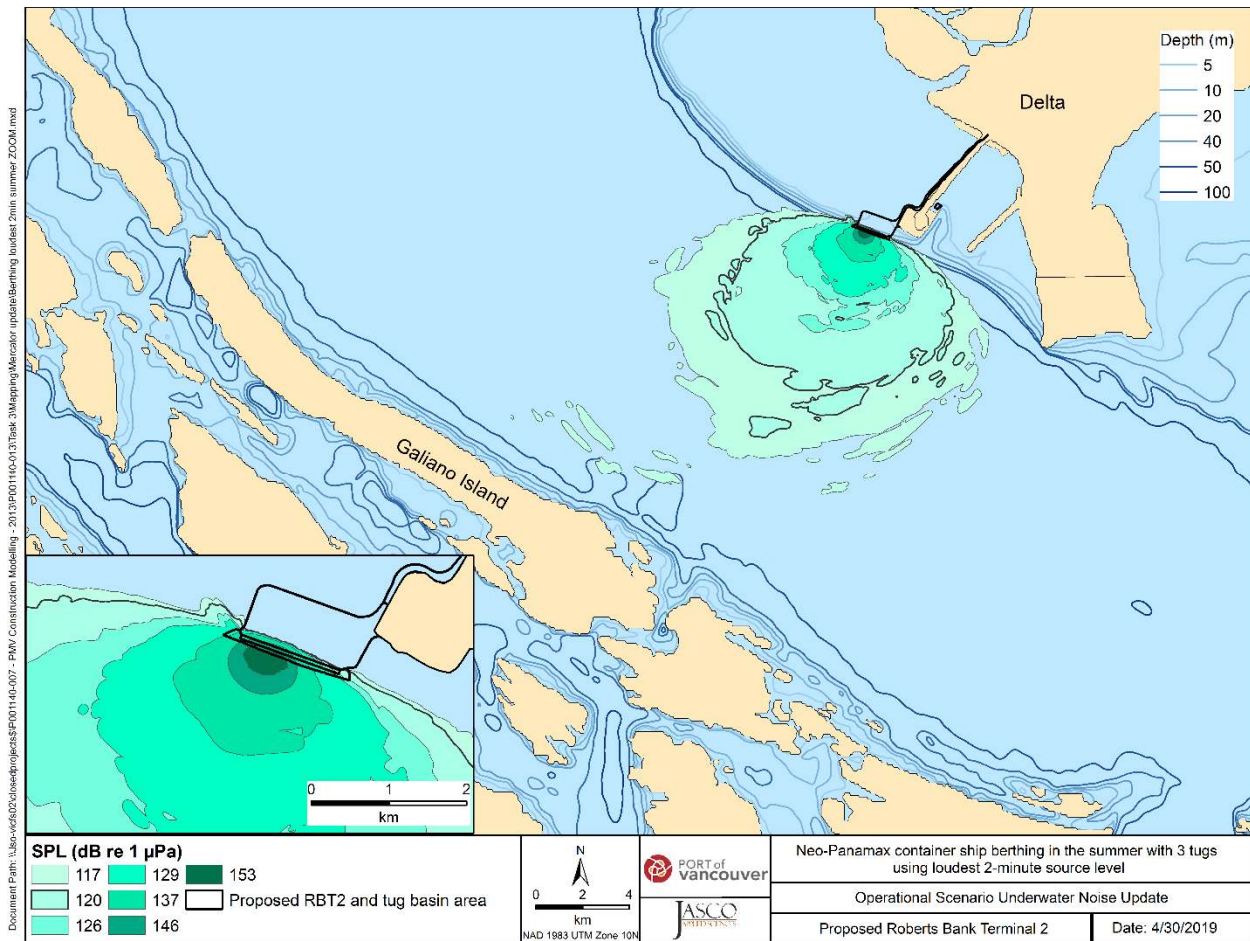
Figure 6. Scenario 2A: Map of the 120 dB and the SRKW low- and moderate severity behavioural disturbance response contours for a Neo-Panamax container ship berthing with three tugs using the loudest 2-minute source level in summer. Inset shows close-up of contours around the tugs.
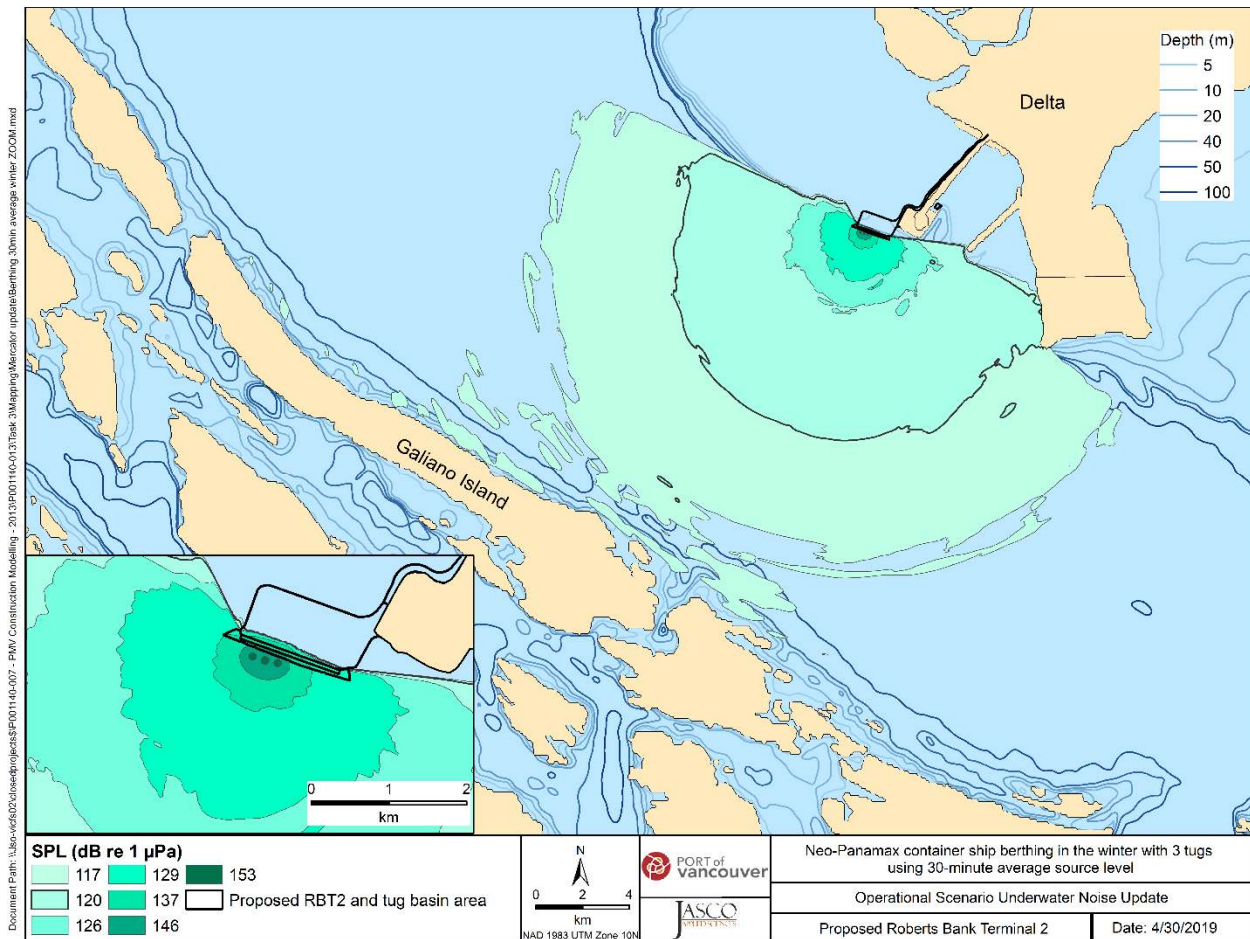
Figure 7. Scenario 4A: Map of the 120 dB and the SRKW low- and moderate severity behavioural disturbance response contours for a Neo-Panamax container ship berthing with three tugs using the 30-minute average source level in winter. Inset shows close-up of contours around the tugs.
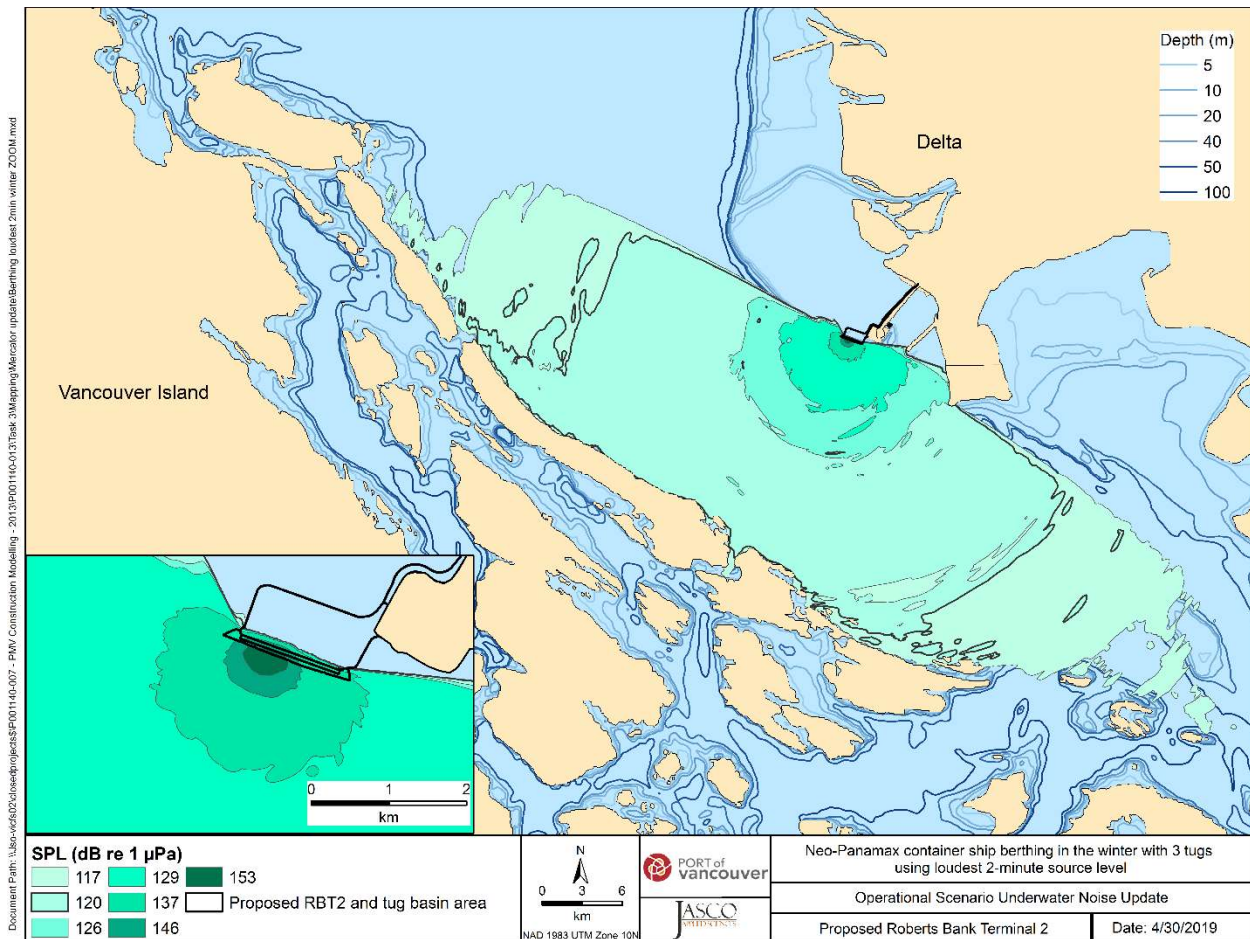
Figure 8. Scenario 5A: Map of the 120 dB and the SRKW low- and moderate severity behavioural disturbance response contours for a Neo-Panamax container ship berthing with three tugs using the loudest 2-minute source level in winter. Inset shows close-up of contours around the tugs.

3.2. Cumulative Vessel Noise Model Results

Table 7 lists the 24-hour time-average sound level (L_{eq24hr}) at receiver locations 1–6 (see Figure 2 for the receiver locations) as computed by the cumulative vessel noise model for the expected and future conditions scenarios.

Table 7. 24-hour time-average sound level (L_{eq24hr}) at receiver locations 1–6 for the existing, expected, and future cumulative vessel noise model scenarios. Shown for comparison are results for existing conditions for the EIS scenarios based on 2010 vessel tracking data from VTOSS and pre-ULS source level data.

Scenario description	L_{eq24hr} (dB re 1 µPa)					
	Receiver 1 Roberts Bank	Receiver 2 Haro Strait	Receiver 3 Boundary Pass	Receiver 4 Active Pass	Receiver 5 Point Roberts	Receiver 6 Sand Heads
EIS Section 9.8						
Existing conditions–summer (2010)	117.14	120.08	125.92	123.49	-	-
Existing conditions–winter (2010)	125.69	118.54	122.61	127.29	-	-
Existing Conditions*						
Existing conditions–summer*	116.98	121.30	127.23	122.37	103.78	120.13
Existing conditions–winter*	124.09	123.83	127.39	126.26	121.94	126.09
Expected and Future Conditions						
Expected conditions–summer	117.75	122.45	127.92	122.64	106.05	121.49
Expected conditions–winter	124.68	124.56	128.00	126.69	122.69	127.14
Future conditions–summer	121.49	122.45	127.92	122.64	106.05	121.49
Future conditions–winter	125.89	124.56	128.00	126.70	122.72	127.14

* Model results from Table 5 of Warner et al. (2018).

3.3. Annual Incremental Contribution of Project Operations

Table 8 shows the annual incremental contribution of future Project operations (104 calls of an average size Neo-Panamax container ship with three associated tugs, plus 130 calls moving from Deltaport to RBT2), computed as the difference between the annual time-average sound levels under future and expected conditions at receiver locations 1–6. These represent the relative differences in the annual time-average sound levels, relative to expected conditions for 2035, due to changes in vessel traffic associated with operations of RBT2. These results show that, under future conditions, the only change in annual time-average sound levels will be at Roberts Bank (Receiver 1), and that there is effectively no difference between average future and expected conditions at the other five receiver locations.

Table 8. Differences between annual time-averaged sound level (Leq-1yr) at receiver locations 1–6 between the future (2035 with RBT2) and expected (2035 without RBT2) model scenarios. Differences less than 0.05 dB are shown as zero.

Scenario description	*Annual Time-Average Sound Levels—$L_{eq\text{-}1yr}$ (dB re 1 µPa)*					
	Receiver 1 Roberts Bank	Receiver 2 Haro Strait	Receiver 3 Boundary Pass	Receiver 4 Active Pass	Receiver 5 Point Roberts	Receiver 6 Sand Heads
Expected conditions	122.3	123.8	127.9	125.3	119.8	125.2
Future conditions	124.1	123.8	127.9	125.3	119.8	125.2
Difference (dB)	1.8	0	0	0	0	0

To interpret the time-varying sound levels predicted by the cumulative vessel noise models, a statistical analysis was applied to the modelled noise levels at each of the six receiver locations. Sampled sound levels were used to generate cumulative distribution function (CDF) curves, that represented the

percentage of time that modelled sound levels were below a specified threshold level at each receiver. For example, **Figure 9** (left) shows CDF curves of summer sound levels at Roberts Bank (Receiver 1) under expected and future conditions. The following example illustrates how to interpret the CDF curves. Under expected conditions, the 50th percentile SPL at Roberts Bank in summer was 105.2 dB re 1 µPa, which means that, 50% of the time, expected sound levels are at or below 105.2 dB re 1 µPa. Figure 9 (right) shows the differences of the modelled CDF curves relative to expected conditions. The following example illustrates how to interpret the difference curves. During summer at Roberts Bank (Receiver 1), the difference between expected and future conditions was 0.4 dB at the 50th percentile level; this means that, under future conditions, 50% of the time the sound level measured would be 0.4 dB higher at Roberts Bank than under expected conditions. Appendix A shows additional CDF curves and sound level versus time plots for all six receiver locations during summer and winter.
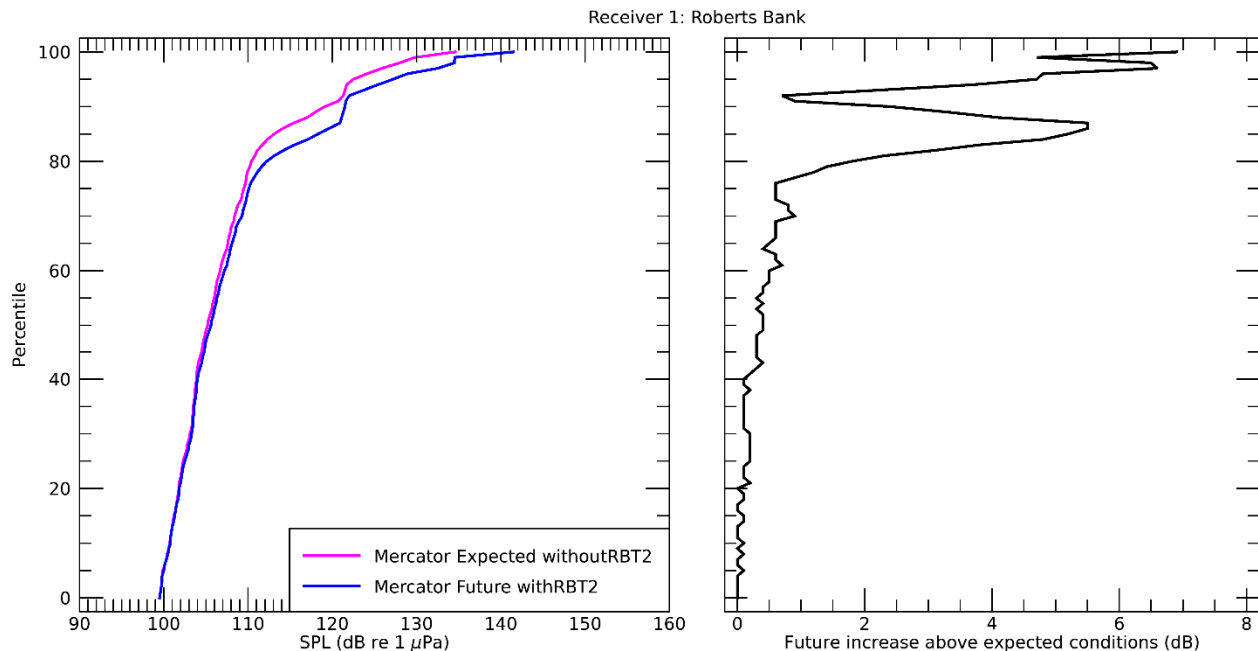

Figure 9. Left panel: Cumulative distribution function (CDF)curves of time-dependent sound pressure level (SPL) for modelled vessel noise at Receiver 1: Roberts Bank in summer. Right panel: Differences between CDF curves shown in the left panel, relative to expected conditions.

Differences between the CDF curves at the six receiver locations are summarized in Table 9, which lists the Project-related incremental change in the SPL percentile statistics, relative to expected conditions. Higher percentiles are affected to a greater degree because the durations of Project-related activities are relatively brief. The results shown in Table 9 also represent a different way of looking at the incremental changes than is shown in Table 8. The percentile differences shown in Table 9 reflect the time-dependent nature of the changes (i.e., in terms of percentage of time when sound levels are exceeded), whereas the results shown in Table 8 reflect time-averaged changes. As with the annual time-averages, there is very little or no difference between future and expected conditions, except at Roberts Bank.

Table 9. Differences in time-dependent sound pressure level (SPL) statistics from future conditions (2035 with RBT2) relative to expected conditions (2035 without RBT2) in summer and winter. This is equal to the difference in the SPL at the specified percentile level that would be measured at the six receiver locations under expected and future conditions (see **Figure 2**). Differences less than 0.05 dB are shown as zero.

Statistic	Difference of future conditions relative to expected conditions (dB)					
	Receiver 1 Roberts Bank	Receiver 2 Haro Strait	Receiver 3 Boundary Pass	Receiver 4 Active Pass	Receiver 5 Point Roberts	Receiver 6 Sand Heads
Summer						
5th percentile SPL	0.1	0	0	0.1	0	0
25th percentile SPL	0.2	0	0	0.1	0	0
50th percentile SPL	0.4	0	0	0.1	0	0
75th percentile SPL	0.6	0	0	0	0	0
95th percentile SPL	4.7	0	0	0	0	0
Winter						
5th percentile SPL	0.1	0	0	0	0.1	0
25th percentile SPL	0.1	0	0	0	0	0
50th percentile SPL	0.1	0	0	0	0	0
75th percentile SPL	0.3	0	0	0.1	0	0
95th percentile SPL	1.5	0	0	0	0.1	0

4. Discussion and Conclusion

The incremental noise around RBT2 from Project operations only occurs during periods when container ships are approaching and berthing, or unberthing and departing, RBT2. It is assumed that, under future conditions, 104 new container ships per year will call at RBT2 and that 130 container ship calls will move from Deltaport to RBT2 (with approximately 1.75 hours of activity per call), so there will be no incremental noise from RBT2 for a substantial portion of the year. Figure 10 shows the modelled difference in percentile SPL statistics at the 6 receiver locations between future and expected vessel traffic conditions in summer and winter (i.e., data from Table 9). Differences are larger in summer than in winter because ambient noise levels are lower in summer. The largest differences would occur at Roberts Bank (Receiver 1) because it is the closest of the six receiver locations to RBT2. Furthermore, this shows that the largest differences would only occur a small proportion of the time (e.g., because the increase above the 95th percentile SPL occurs less than 5% of the time). The differences between future and expected conditions are extremely small (0.1 dB or less) at the other receiver locations, which are more distant from the proposed terminal.
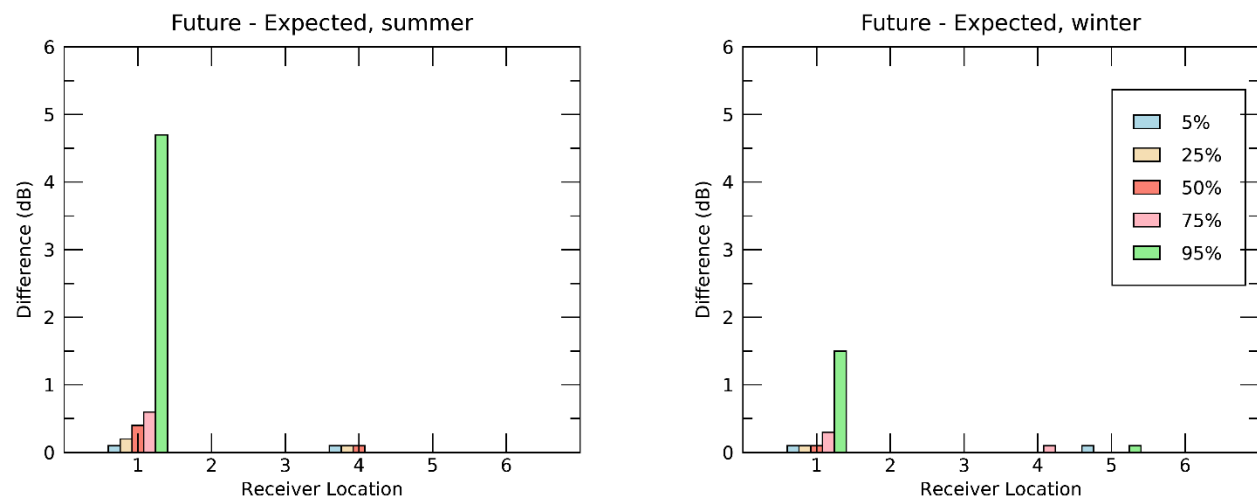
Figure 10. Increase in SPL percentile levels for Project operations above existing and expected vessel traffic conditions in summer and winter. Plotted differences are from Table 9.

Literature Cited

Hemmera Envirochem Inc. 2015. *Roberts Bank Terminal 2 Marine Shipping Supplemental Report: Addendum to the Environmental Impact Statement*. Prepared for Port Metro Vancouver.

MacGillivray, A.O., Z. Li, and H. Yurk. 2018. *Modelling of Cumulative Vessel Noise for Haro Strait Slowdown Trial: Final Report*. Document Number 01577. Version 2.0. Technical report by JASCO Applied Sciences for Vancouver Fraser Port Authority ECHO Program. https://www.flipsnack.com/portvancouver/echo-haro-strait-slowdown-trial-summary/full-view.html

Mercator. 2018. *Roberts Bank Terminal 2 Container Vessel Call Forecast Study* Technical report by Mercator for Vancouver Fraser Port Authority. http://www.robertsbankterminal2.com/wp-content/uploads/RBT2-container-vessel-call-forecast-study-Mercator-November-2018.pdf.

SMRU Canada Ltd. 2014. *Proposed Roberts Bank Terminal 2 Technical Data Report: Marine Mammals—Determination of Behavioral Effect Noise Thresholds for Southern Resident Killer Whales*. Report prepared by SMRU (on behalf of Hemmera) for Port of Vancouver. 269 pp. https://www.ceaa-acee.gc.ca/050/documents/p80054/118046E.pdf.

Warner, G.A., Z. Li, J.L. Wladichuk, and A.O. MacGillivray. 2018. *RBT2 Project Operational Scenario Underwater Noise Update: Roberts Bank Terminal 2 Project*. Document Number 01640, Version 3.0. Technical report by JASCO Applied Sciences for Hemmera.[CEAR #1363]

Wladichuk, J.L., G. Warner, A. McCrodan, and A.O. MacGillivray. 2014. *Appendix 9.8A Construction and Terminal Activity Underwater Noise Modelling Study*. Roberts Bank Terminal 2 Technical Report—Underwater Noise Construction Activities and Terminal Vessel Operations Noise Modelling Study. Technical report prepared by JASCO Applied Sciences for Port Metro Vancouver. 198 pp. http://www.ceaa-acee.gc.ca/050/documents/p80054/101367E.pdf.

Appendix A. Cumulative Vessel Noise Model Results for Expected and Future Conditions

This appendix shows modelled sound levels versus time and cumulative density function (CDF) plots at receiver locations 1–6 for summer (Section) and winter (Section) for future and expected cumulative vessel noise scenarios. Sound level versus time plots show one possible day with additional vessel berthing and unberthing activity at Westshore, Deltaport and RBT2. The CDF plots consider these activities additional occurring at randomly-selected times during the modelled 24-hour period and represent the results from a simulation of 365 days.

A.1. Summer
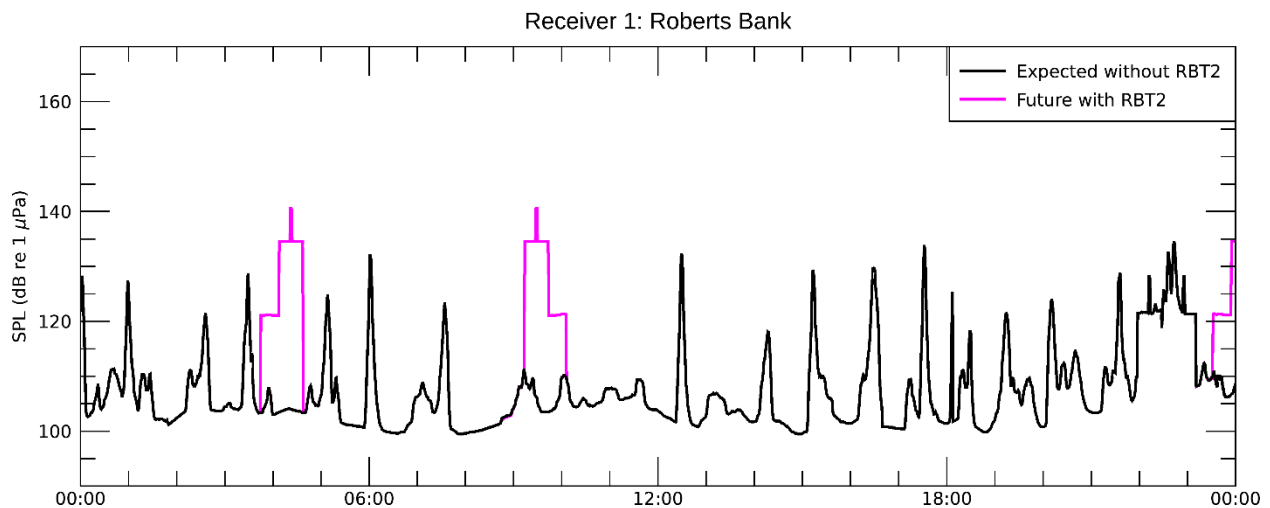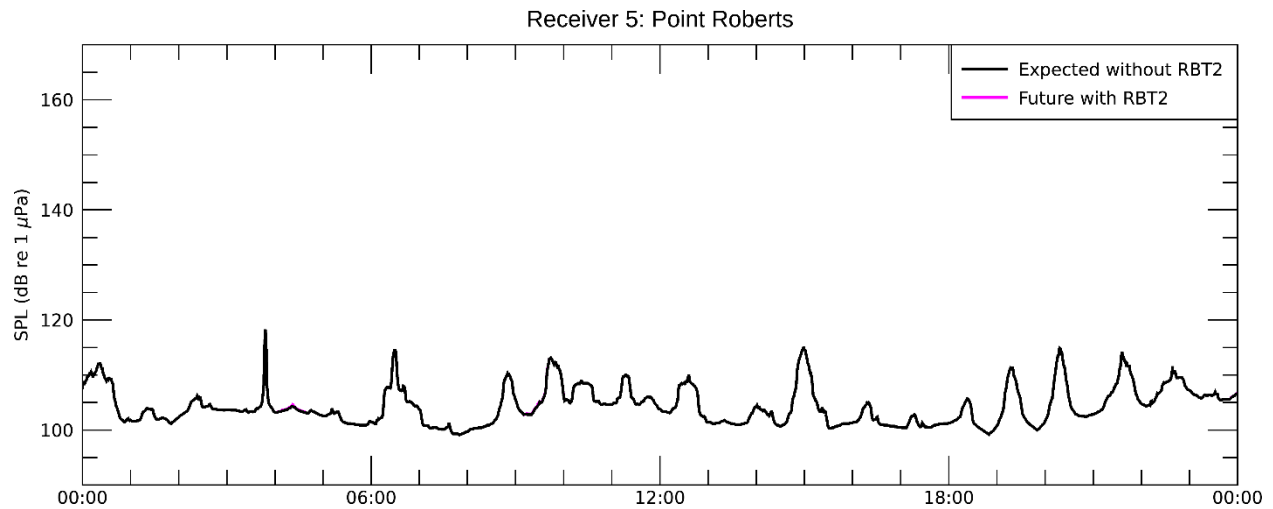

Figure A-1. Example of modelled sound pressure level (SPL) versus time at Receiver 1: Roberts Bank in summer. Where future conditions (pink line) are not visible, they are overlapped by expected conditions (black line).
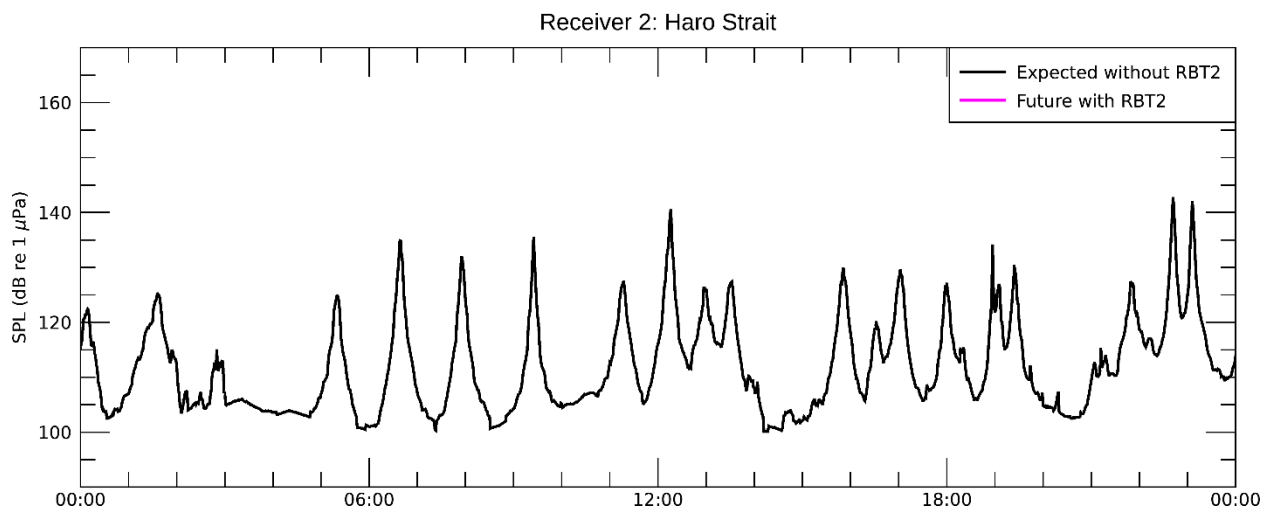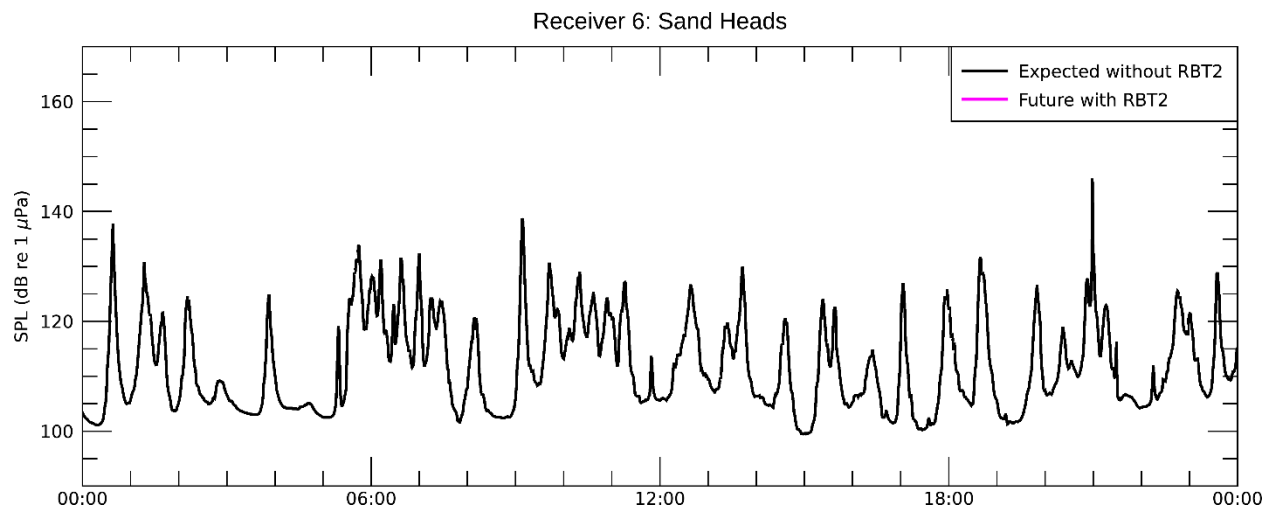

Figure A-2. Example of modelled sound pressure level (SPL) versus time at Receiver 2: Haro Strait in summer. Where future conditions (pink line) are not visible, they are overlapped by expected conditions (black line).

Receiver 3: Boundary Pass
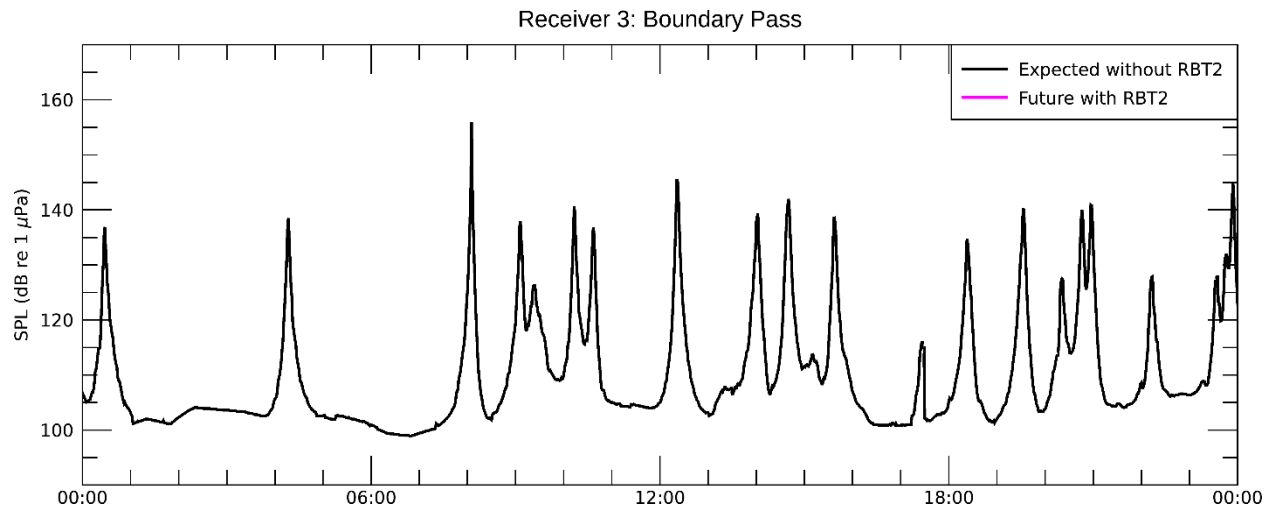
Figure A-3. Example of modelled sound pressure level (SPL) versus time at Receiver 3: Boundary Pass in summer. Where future conditions (pink line) are not visible, they are overlapped by expected conditions (black line).

Receiver 4: Active Pass
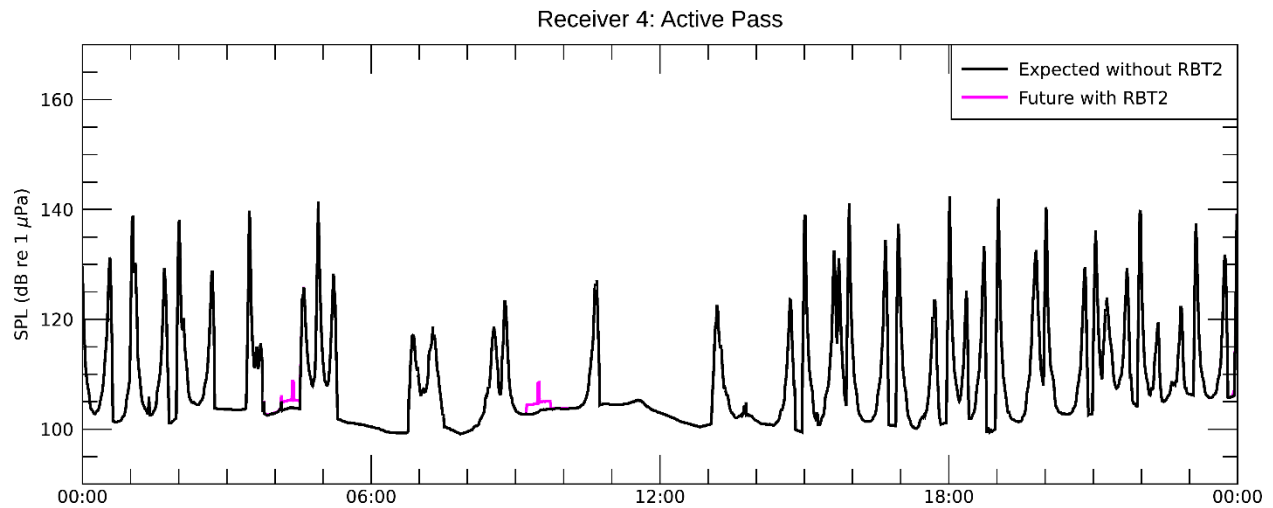
Figure A-4. Example of modelled sound pressure level (SPL) versus time at Receiver 4: Active Pass in summer. Where future conditions (pink line) are not visible, they are overlapped by expected conditions (black line).

Receiver 5: Point Roberts

Figure A-5. Example of modelled sound pressure level (SPL) versus time at Receiver 5: Point Roberts in summer. Where future conditions (pink line) are not visible, they are overlapped by expected conditions (black line).

Receiver 6: Sand Heads

Figure A-6. Example of modelled sound pressure level (SPL) versus time at Receiver 6: Sand Heads in summer. Where future conditions (pink line) are not visible, they are overlapped by expected conditions (black line).
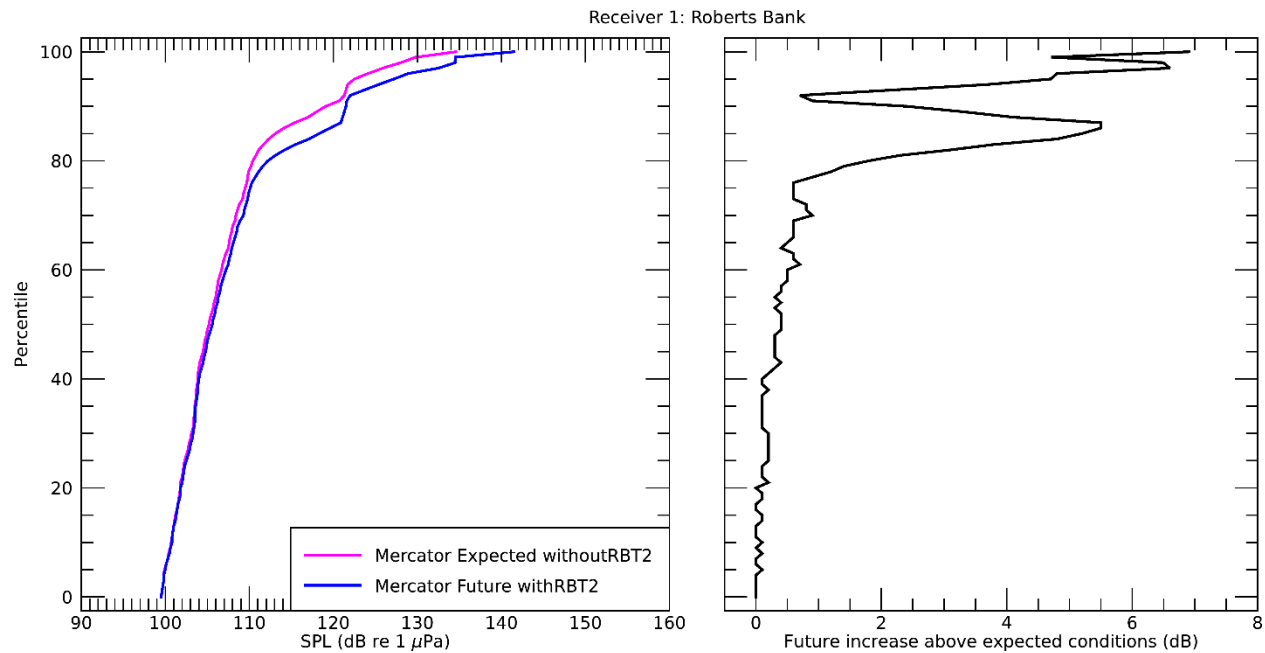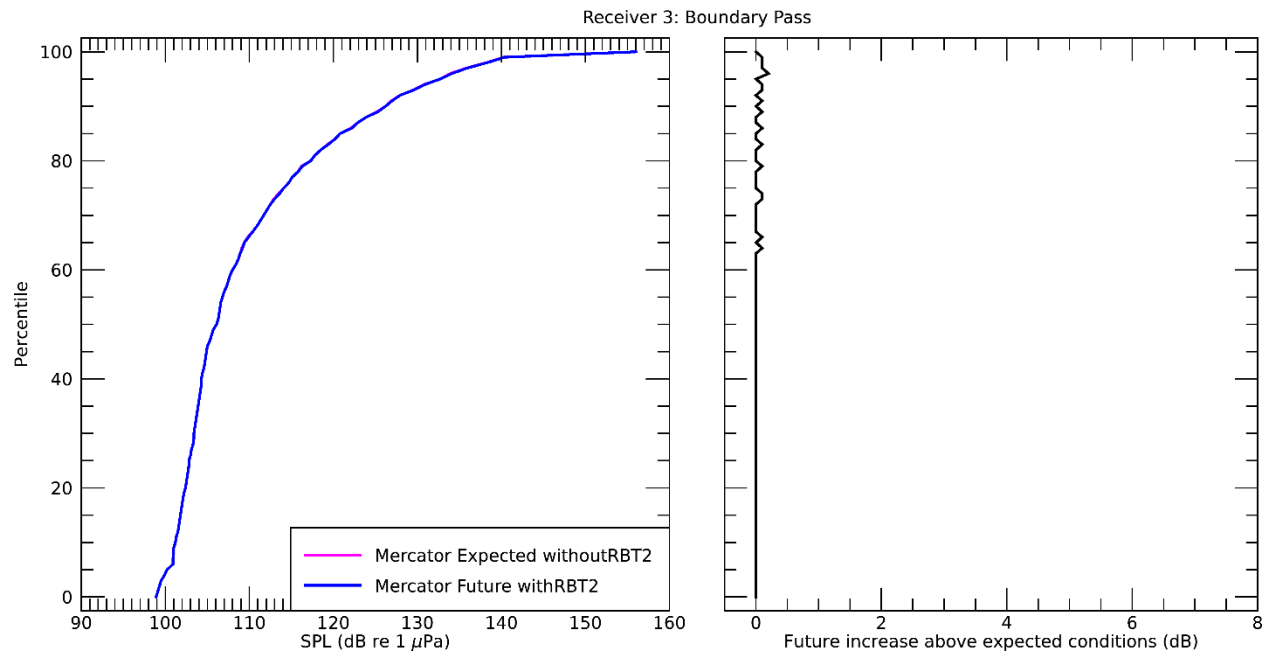
Figure A-7. CDF curves of time-dependent sound pressure level (SPL) for modelled vessel noise at Receiver 1: Roberts Bank in summer. Left panel shows expected and future conditions. Right panel shows the increase in CDF above expected conditions.
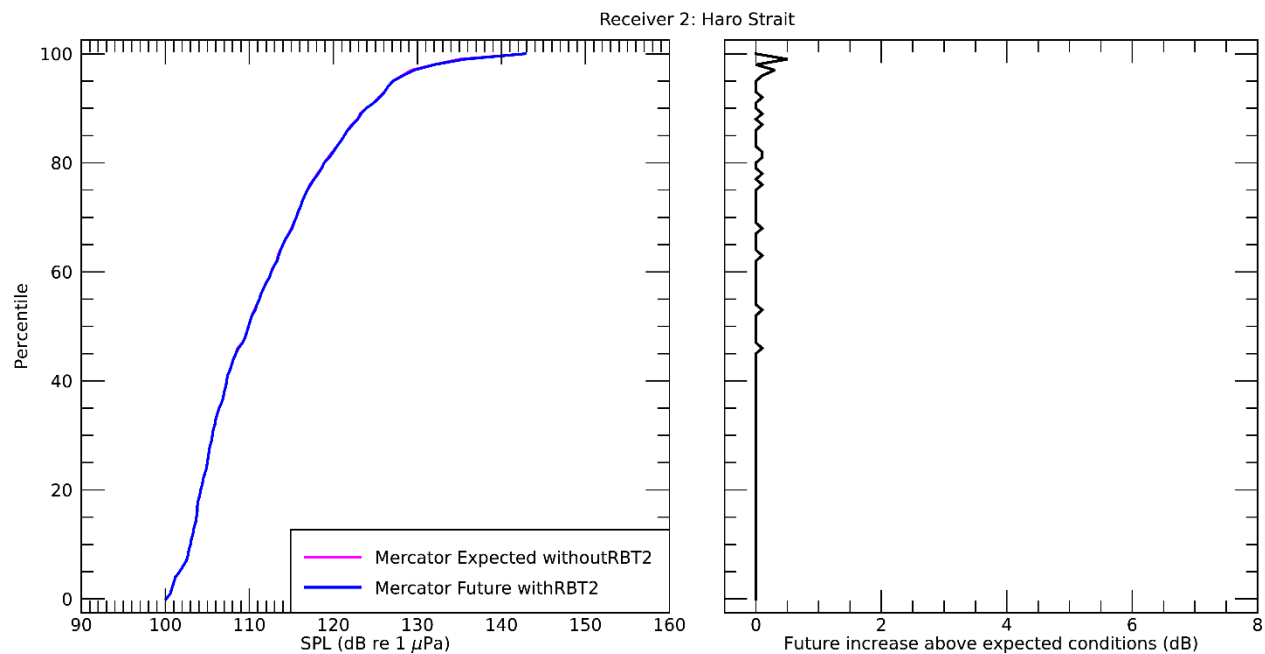
Figure A-8. CDF curves of time-dependent sound pressure level (SPL) for modelled vessel noise at Receiver 2: Haro Strait in summer. Left panel shows expected and future conditions (where expected conditions (pink line) are not visible, they are overlapped by future conditions (blue line)). Right panel shows the increase in CDF above expected conditions.
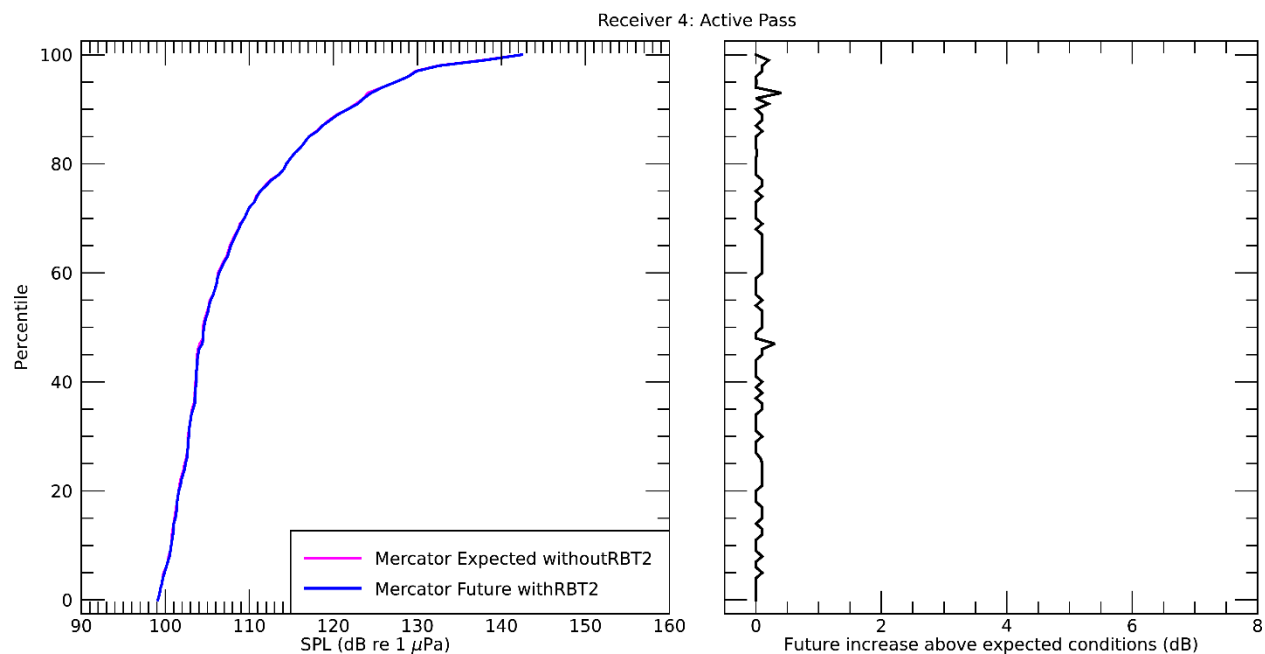
Figure A-9. CDF curves of time-dependent sound pressure level (SPL) for modelled vessel noise at Receiver 3: Boundary Pass in summer. Left panel shows expected and future conditions (where expected conditions (pink line) are not visible, they are overlapped by future conditions (blue line)). Right panel shows the increase in CDF above expected conditions.

Figure A-10. CDF curves of time-dependent sound pressure level (SPL) for modelled vessel noise at Receiver 4: Active Pass in summer. Left panel shows expected and future conditions (where expected conditions (pink line) are not visible, they are overlapped by future conditions (blue line)). Right panel shows the increase in CDF above expected conditions.
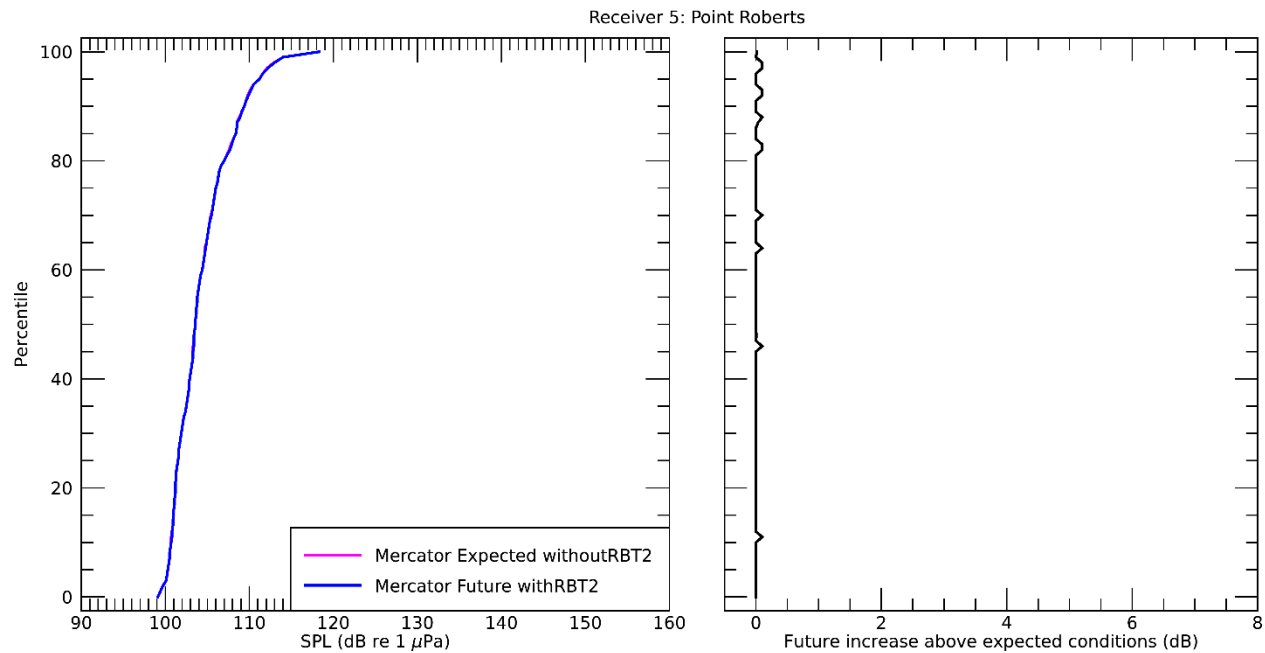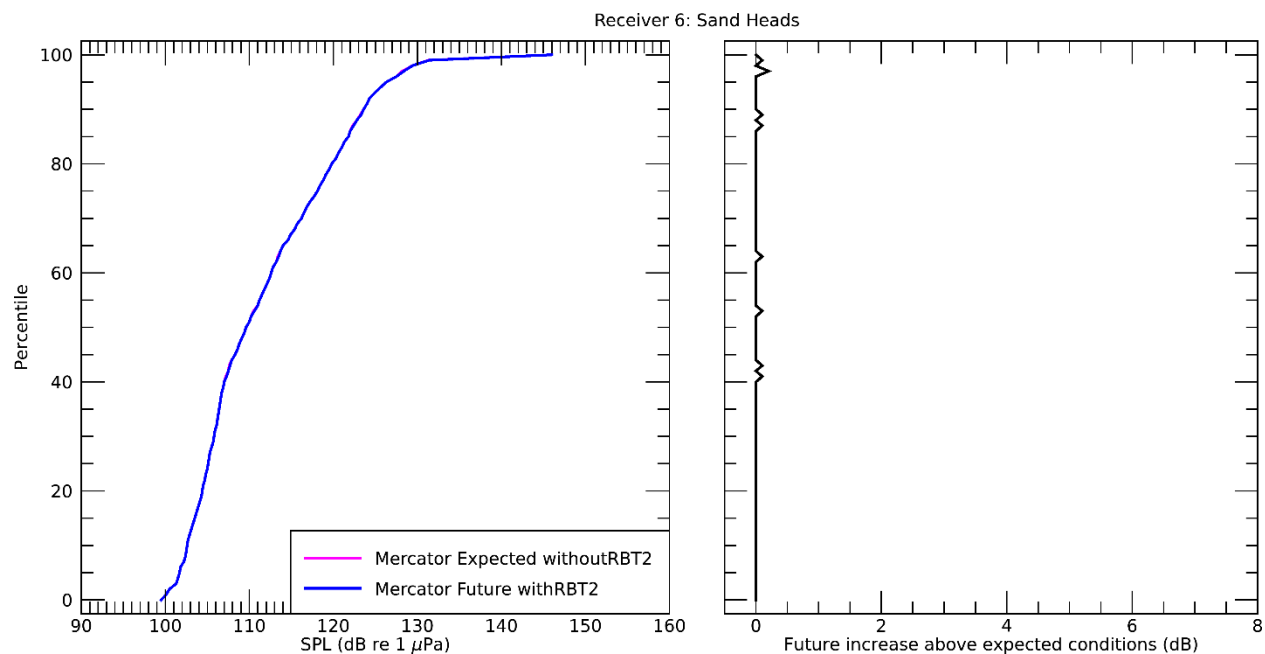
Figure A-11. CDF curves of time-dependent sound pressure level (SPL) for modelled vessel noise at Receiver 5: Point Roberts in summer. Left panel shows expected and future conditions (where expected conditions (pink line) are not visible, they are overlapped by future conditions (blue line)). Right panel shows the increase in CDF above expected conditions.

Figure A-12. CDF curves of time-dependent sound pressure level (SPL) for modelled vessel noise at Receiver 6: Sand Heads in summer. Left panel shows expected and future conditions (where expected conditions (pink line) are not visible, they are overlapped by future conditions (blue line)). Right panel shows the increase in CDF above expected conditions.
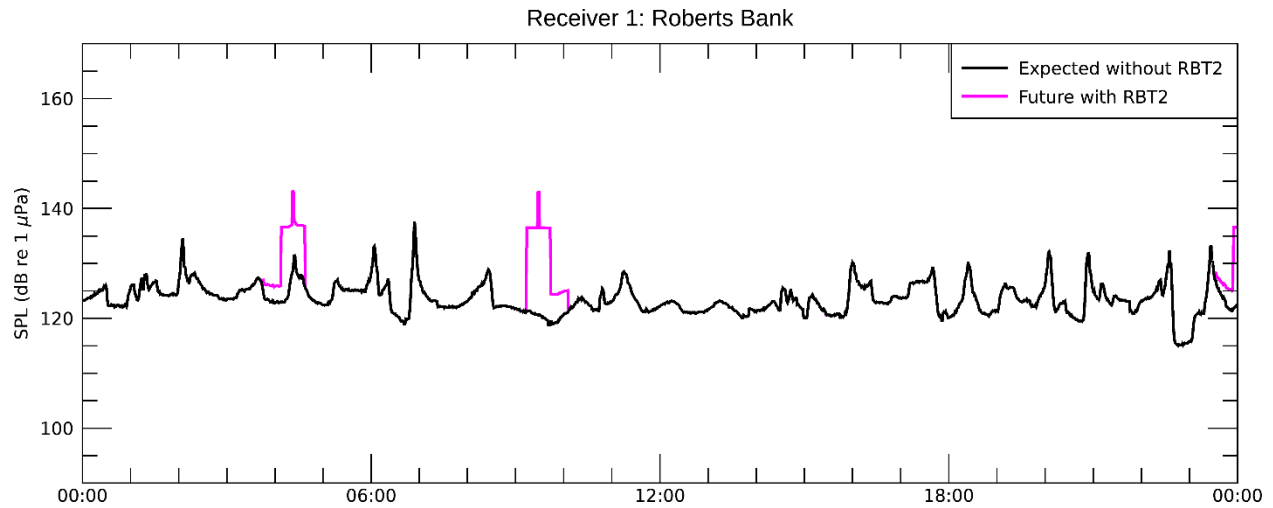
A.2. Winter

Receiver 1: Roberts Bank

Figure A-13. Example of modelled sound pressure level (SPL) versus time at receiver 1: Roberts Bank in winter. Where future conditions (pink line) are not visible, they are overlapped by expected conditions (black line).
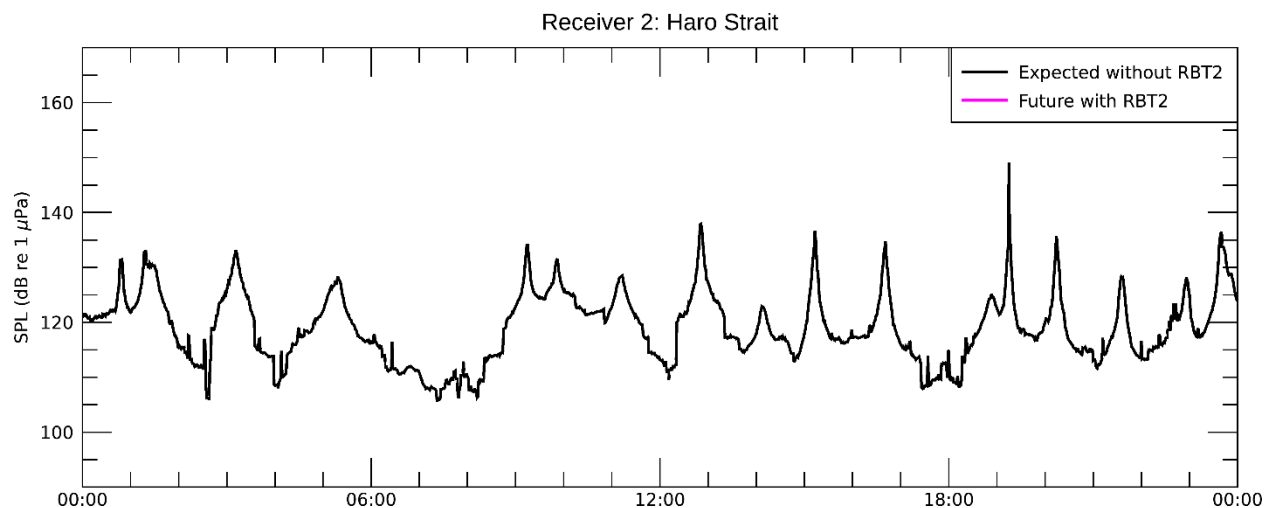
Receiver 2: Haro Strait

Figure A-14. Example of modelled sound pressure level (SPL) versus time at receiver 2: Haro Strait in winter. Where future conditions (pink line) are not visible, they are overlapped by expected conditions (black line).
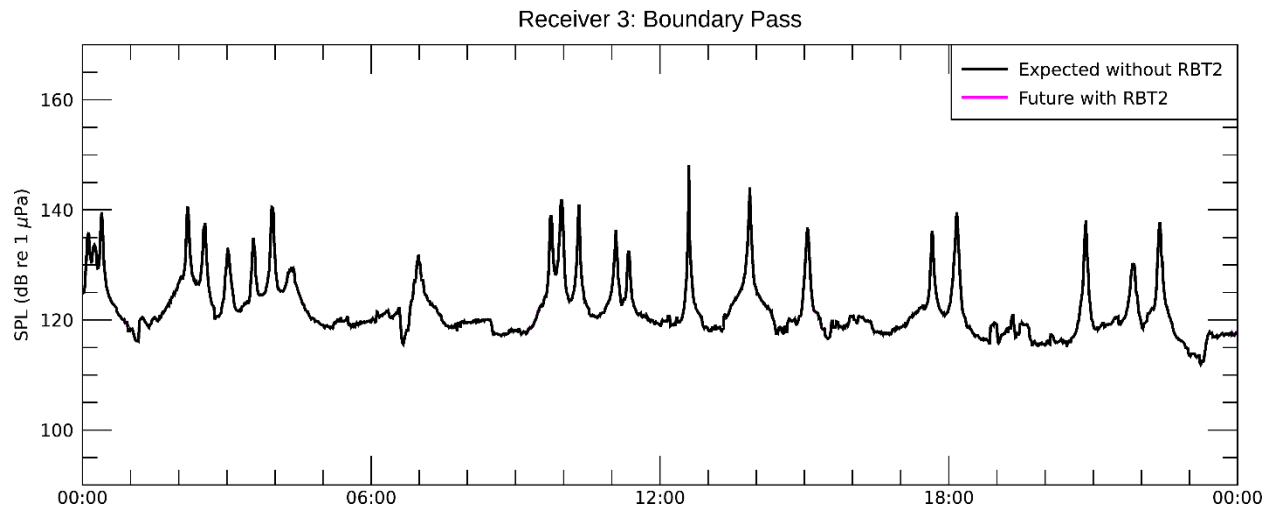
Receiver 3: Boundary Pass

Figure A-15. Example of modelled sound pressure level (SPL) versus time at receiver 3: Boundary Pass in winter. Where future conditions (pink line) are not visible, they are overlapped by expected conditions (black line).
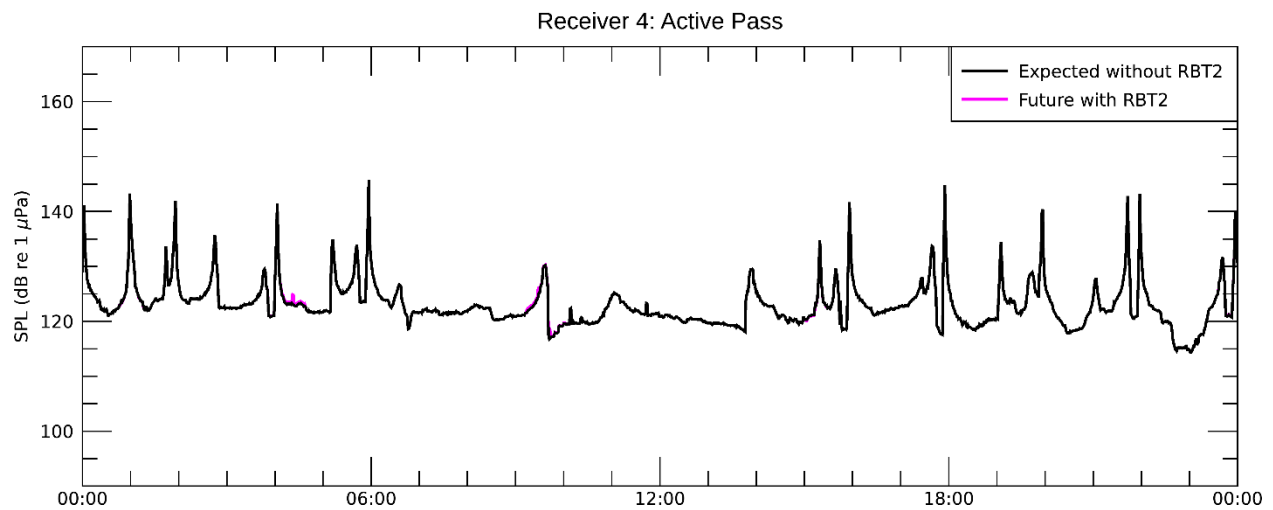
Receiver 4: Active Pass

Figure A-16. Example of modelled sound pressure level (SPL) versus time at receiver 4: Active Pass in winter. Where future conditions (pink line) are not visible, they are overlapped by expected conditions (black line).
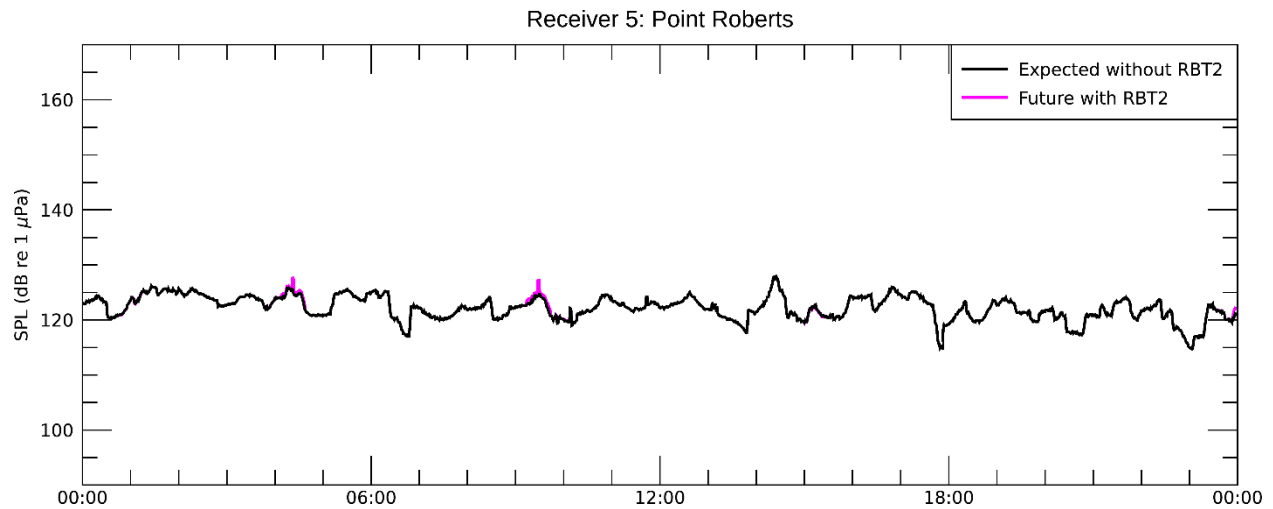
Receiver 5: Point Roberts

Figure A-17. Example of modelled sound pressure level (SPL) versus time at receiver 5: Point Roberts in winter. Where future conditions (pink line) are not visible, they are overlapped by expected conditions (black line).
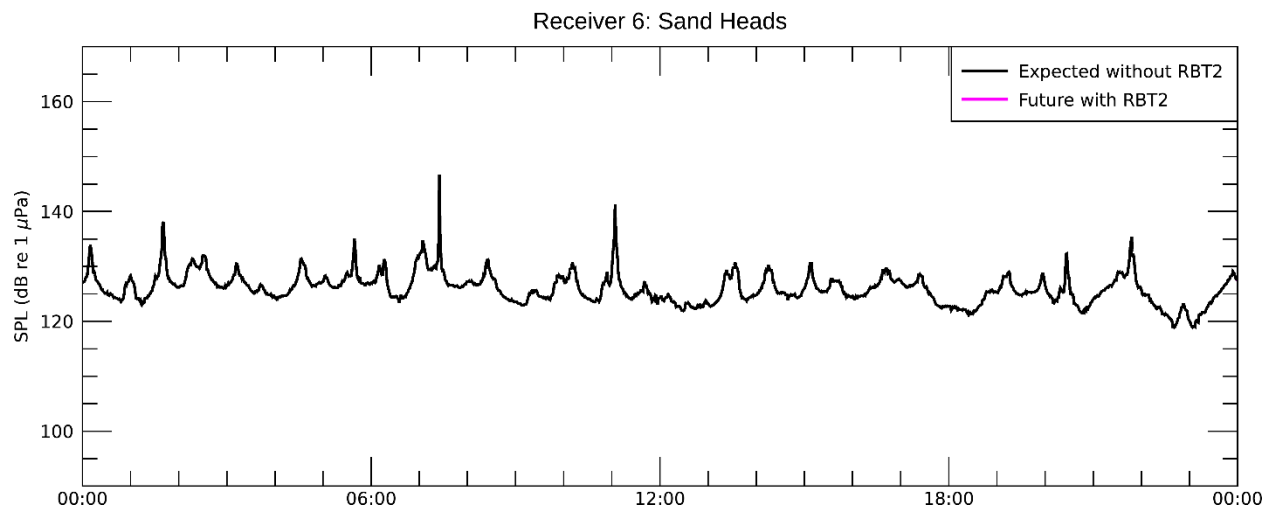
Receiver 6: Sand Heads

Figure A-18. Example of modelled sound pressure level (SPL) versus time at receiver 6: Sand Heads in winter. Where future conditions (pink line) are not visible, they are overlapped by expected conditions (black line).
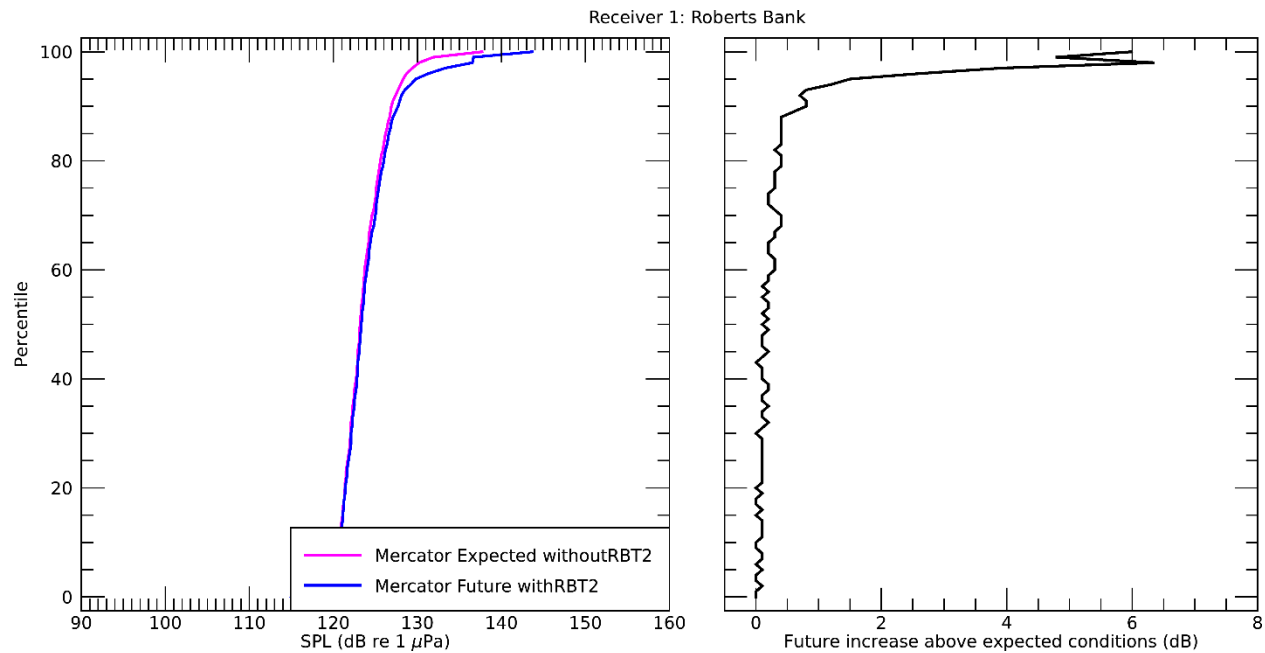
Figure A-19. CDF curves of time-dependent sound pressure level (SPL) for modelled vessel noise at receiver 1: Roberts Bank in winter. Left panel shows expected and future conditions. Right panel shows the increase in CDF above expected conditions.
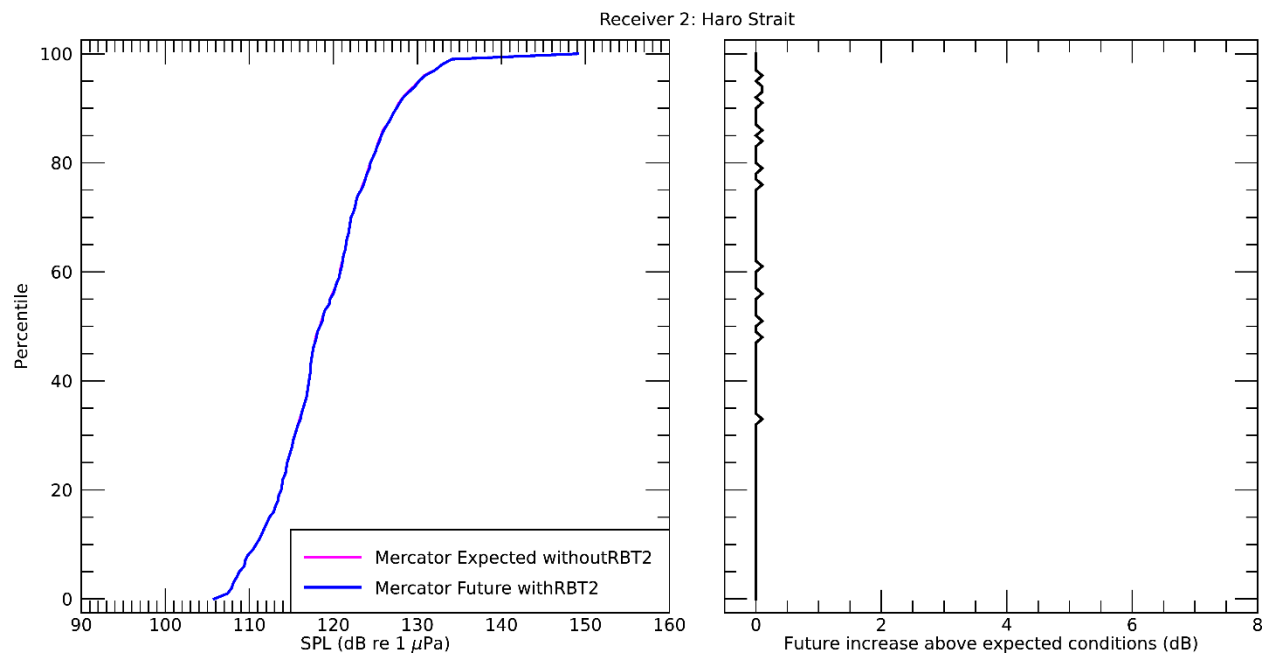

Figure A-20. CDF curves of time-dependent sound pressure level (SPL) for modelled vessel noise at receiver 2: Haro Strait in winter. Left panel shows expected and future conditions (where expected conditions (pink line) are not visible, they are overlapped by future conditions (blue line)). Right panel shows the increase in CDF above expected conditions.
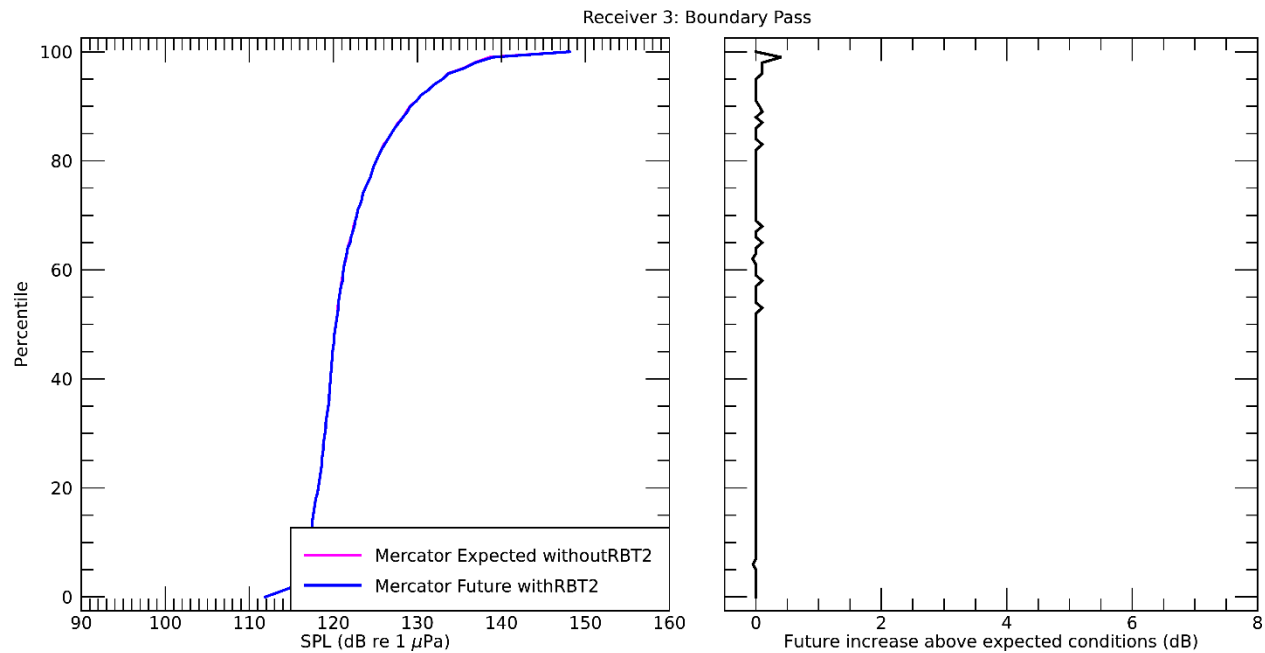
Figure A-21. CDF curves of time-dependent sound pressure level (SPL) for modelled vessel noise at receiver 3: Boundary Pass in winter. Left panel shows expected and future conditions (where expected conditions (pink line) are not visible, they are overlapped by future conditions (blue line)). Right panel shows the increase in CDF above expected conditions.
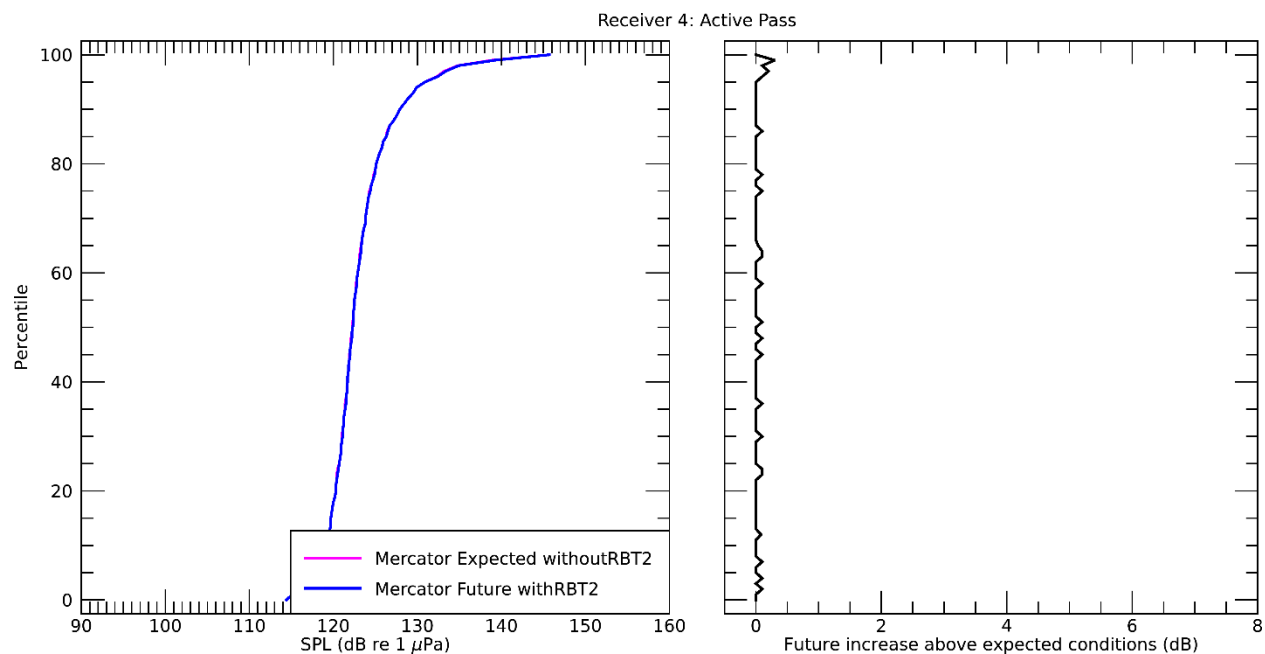

Figure A-22. CDF curves of time-dependent sound pressure level (SPL) for modelled vessel noise at receiver 4: Active Pass in winter. Left panel shows expected and future conditions (where expected conditions (pink line) are not visible, they are overlapped by future conditions (blue line)). Right panel shows the increase in CDF above expected conditions.
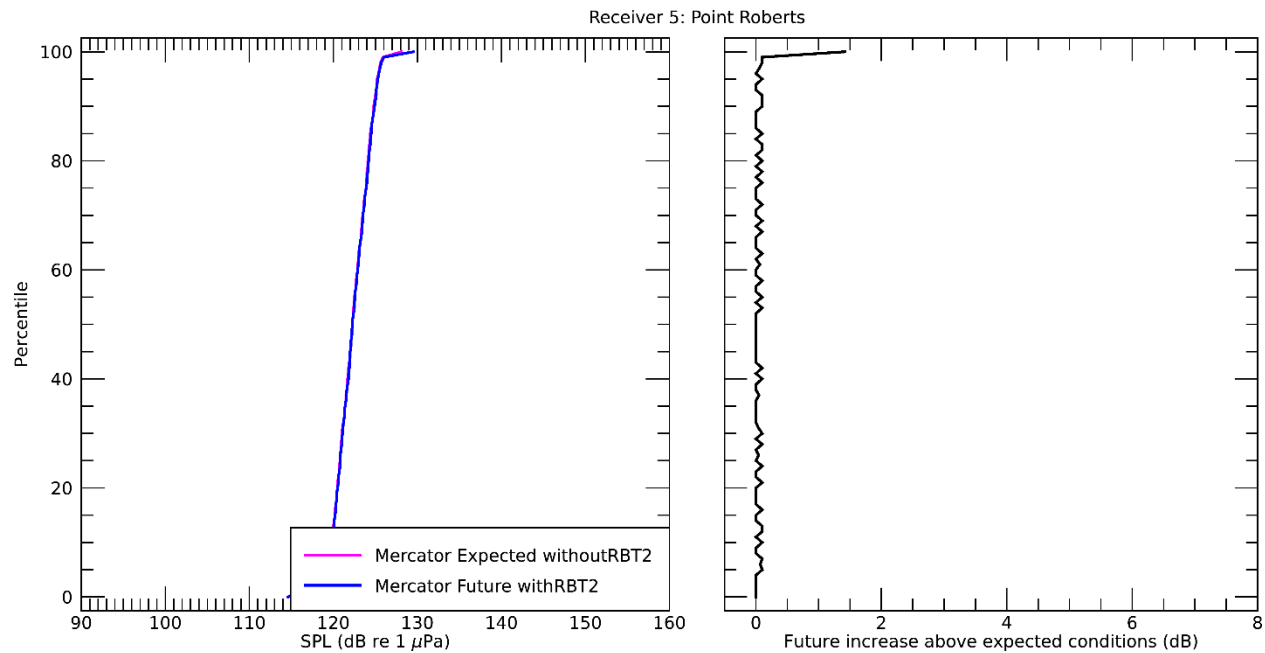
Figure A-23. CDF curves of time-dependent sound pressure level (SPL) for modelled vessel noise at receiver 5: Point Roberts in winter. Left panel shows expected and future conditions (where expected conditions (pink line) are not visible, they are overlapped by future conditions (blue line)). Right panel shows the increase in CDF above expected conditions.

Figure A-24. CDF curves of time-dependent sound pressure level (SPL) for modelled vessel noise at receiver 6: Sand Heads in winter. Left panel shows expected and future conditions (where expected conditions (pink line) are not visible, they are overlapped by future conditions (blue line)). Right panel shows the increase in CDF above expected conditions.
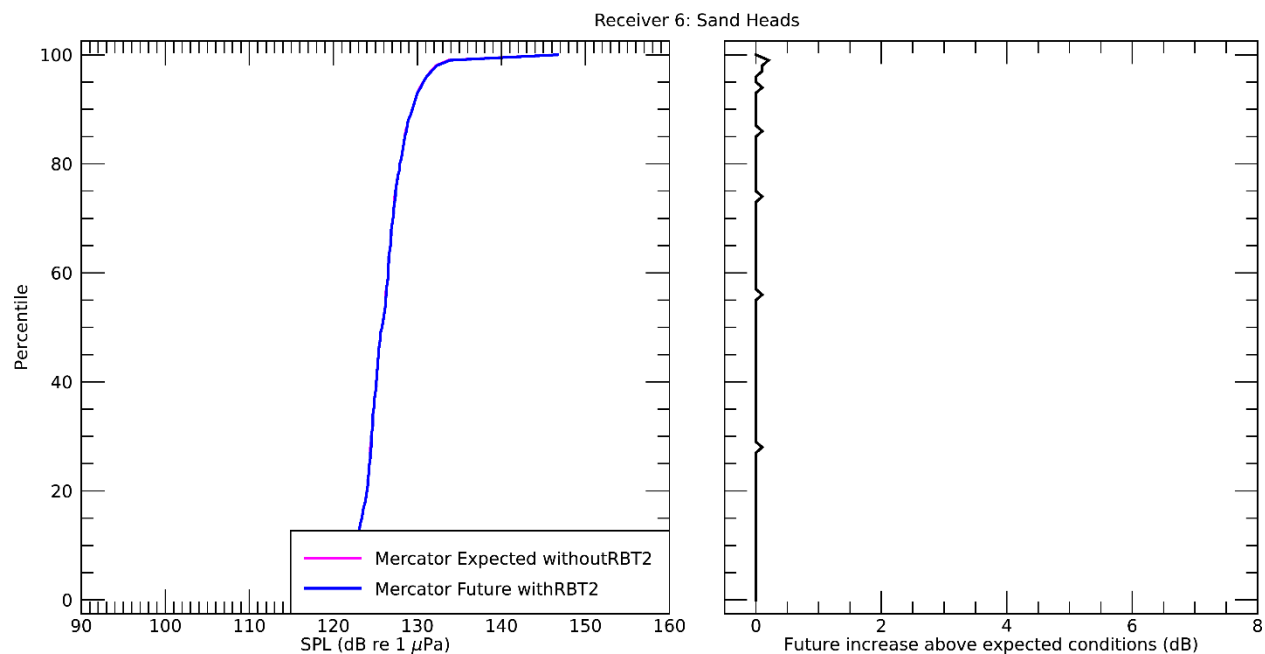
APPENDIX C

UNDERWATER NOISE COMPARISON OF SHIP CLASSES

Table 1 lists modelled distances to marine mammal behavioural response thresholds for Post-Panamax, Neo-Panamax, and Ultra-Large container ships. Modelled distances are provided at four locations in the marine shipping area for summer and winter sound speed profile conditions. Source levels (i.e., underwater noise emissions at the source) for Post-Panamax and Neo-Panamax container ships were provided by the VFPA-led Enhancing Cetacean Habitat and Observation (ECHO) program and originate from data collected on the Strait of Georgia Underwater Listening Station (ULS). Source levels for Ultra-Large container ships were extrapolated from Neo-Panamax source levels using the Ross power-law scaling law for vessel length ($20 \times \log_{10}$(ratio of lengths)).

Table 1. Radii (metres) of Behavioural Response Thresholds for Marine Mammals for Locations 1 to 4. Thresholds are broadband sound pressure level (SPL), 10-63,000 Hz.

Location	Underwater Noise Level (rms SPL – dB re 1μPa)	Container Ship Class					
		Panamax (9,600 TEU)		Neo-Panamax (13,000 TEU)		Ultra-Large (18,000 TEU)	
		$R_{95}\pm$ Winter	R_{95} Summer	R_{95} Winter	R_{95} Summer	R_{95} Winter	R_{95} Summer
1	120[*]	3200	2600	3100	2300	3200	2500
	126[a]	1900	1500	1600	1300	1900	1400
	137[b]	640	620	600	560	640	620
	153[c]	90	90	80	80	90	90
2	120	8000	7600	7900	7400	8100	7700
	126	5100	4700	4800	4500	5200	4700
	137	1300	1200	1100	1100	1200	1100
	153	180	180	140	140	160	150
3	120	7800	6400	7800	6200	8400	6600
	126	3900	3500	3800	3400	4100	3600
	137	1200	1200	1000	980	1100	1100
	153	170	170	130	130	150	140
4	120	9300	8000	9200	7700	10100	8300
	126	4600	4400	4300	4000	4600	4400
	137	1500	1500	1100	1100	1400	1400
	153	160	160	130	130	140	140

[±] $R_{95\%}$ is the radius of a circle centred at the source that encompasses 95% of the area ensonified above the threshold value.
[*]Behavioural response threshold for North Pacific humpback whales and Steller sea lions.
[a] 5% moderate-severity behavioural response threshold for southern resident killer whales.
[b] 50% moderate-severity behavioural response threshold for southern resident killer whales.
[c] 95% moderate-severity behavioural response threshold for southern resident killer whales.

Figure 1. Underwater Noise Modelled Source Locations in Marine Shipping Area (from MSA Appendix 7.6)