Appendix IR2020-3-A

Enhancing Cetacean Habitat and Observation (ECHO) Program: Creating quieter oceans for healthier whales

PORT of vancouver | Vancouver Fraser Port Authority | **Enhancing Cetacean Habitat and Observation (ECHO) Program**

Enhancing Cetacean Habitat and Observation (ECHO) Program: Creating quieter oceans for healthier whales

---

About the ECHO Program

The Enhancing Cetacean Habitat and Observation (ECHO) Program is an **internationally recognized, first-of-its-kind program** developed and managed by the Vancouver Fraser Port Authority.

Launched by the port authority in 2014, the program seeks to better understand and reduce the cumulative impacts of commercial shipping on at-risk whales, with particular focus on the endangered southern resident killer whales (SRKW).

As a catalyst for regional collaboration, the port authority-led ECHO Program brings together **over 100 Canadian and US partners and advisors** from across government, the marine transportation industry, Indigenous communities, and environmental groups to develop initiatives that quantifiably reduce the impacts of shipping on at-risk whales.

The ECHO Program currently implements seasonal underwater noise reduction initiatives across the transboundary waters of the Salish Sea, encouraging ships to slow down or stay distanced while transiting through key areas of SRKW habitat along British Columbia's southern coast.

During the ECHO Program's seasonal underwater noise reduction initiatives, underwater sound intensity has been reduced **by nearly 50%** in key SRKW foraging areas, demonstrating the effectiveness of slowdowns and lateral displacements at reducing acoustic disturbance.

In addition to leading seasonal underwater noise reduction efforts, the ECHO Program spearheads world-leading research and public education efforts in fulfilment of the commitments of the *Conservation Agreement*, which the port authority signed with the Government of Canada and industry partners to support the recovery of the SRKW.

Key accomplishments

- Launched by the Vancouver Fraser Port Authority in 2014
- Brings together **over 100 Canadian and US partners and advisors** from across government, the marine transportation industry, Indigenous communities, and environmental groups
- Leads seasonal underwater noise reduction initiatives in key SRKW foraging areas, reducing underwater sound intensity by **nearly 50%**
- Presented **world-leading research** to organizations across the globe, including the International Maritime Organization
- Helped make the Port of Vancouver one of the **first ports in the world** to offer incentives for quieter ships through the EcoAction incentive program
- Inspired the launch of a sister program in Washington state called the **Quiet Sound** program

Leading underwater noise reduction initiatives

Results of the ECHO Program's 2020 underwater noise reduction initiatives in SRKW foraging areas:

Initiative	Participation rate	Average ambient noise reduction
Slowdown in Haro Strait & Boundary Pass	91%	~2.5dB
Lateral displacement in Strait of Juan de Fuca	82%	~5dB per tug displacement
Slowdown at Swiftsure Bank	82%	~2dB

Encouraging the adoption of noise-quieting technologies and quiet vessels

The world-leading science produced by the port authority-led ECHO Program and its partners is helping the port authority encourage quieter vessels to call the Port of Vancouver and beyond.

In 2017, the ECHO Program's research helped the port authority introduce incentives at the Port of Vancouver for ships with quiet certifications and underwater noise quieting technologies through its EcoAction incentive program, making Canada the first country in the world to offer incentives for quieter vessels.

Through the work completed by the ECHO Program, the port authority has also driven awareness of underwater noise reduction strategies by delivering presentations at various international forums, including to the International Maritime Organization, the United Nations-affiliated agency responsible for global shipping policy.

In partnership with Transport Canada and JASCO Applied Sciences, the ECHO Program management team is currently working with ship classification societies across the globe to align the measurement and analysis of underwater noise emissions in order for quiet ships to be more consistently certified and uniformly incentivized by ports.

Educating mariners on threat reduction

The port authority promotes the use of the **Whale Report Alert System** (WRAS), an app developed by Ocean Wise with support from the ECHO Program, which notifies mariners of the presence of whales so that they can slow down or alter course to reduce the risk of physical and acoustic disturbance to whales.

To further reduce the impacts of commercial shipping on at-risk whales, the port authority distributes educational tools and resources like the **Whales in our Waters** tutorial, an online tutorial developed by the ECHO Program and BC Ferries to educate mariners on how to identify local whale species and take appropriate threat reduction measures while navigating in their presence.

Species at Risk Act Conservation Agreement

In 2019, the Vancouver Fraser Port Authority formalized its commitment to support the recovery of the SRKW by entering into a five-year conservation agreement with the Government of Canada and eight other marine transportation industry organizations.

The Vancouver Fraser Port Authority's commitments under the agreement include:

- Providing an ongoing framework for engagement, trust building, collaboration, and information sharing
- Developing and implementing measures to reduce threats to SRKW from large commercial vessels and report on their efficacy
- Working with Transport Canada to develop a strategy to encourage underwater noise reduction incentives in other ports in Canada and internationally
- Maintaining educational outreach efforts to raise awareness of emerging research and threat reduction measures

Looking ahead

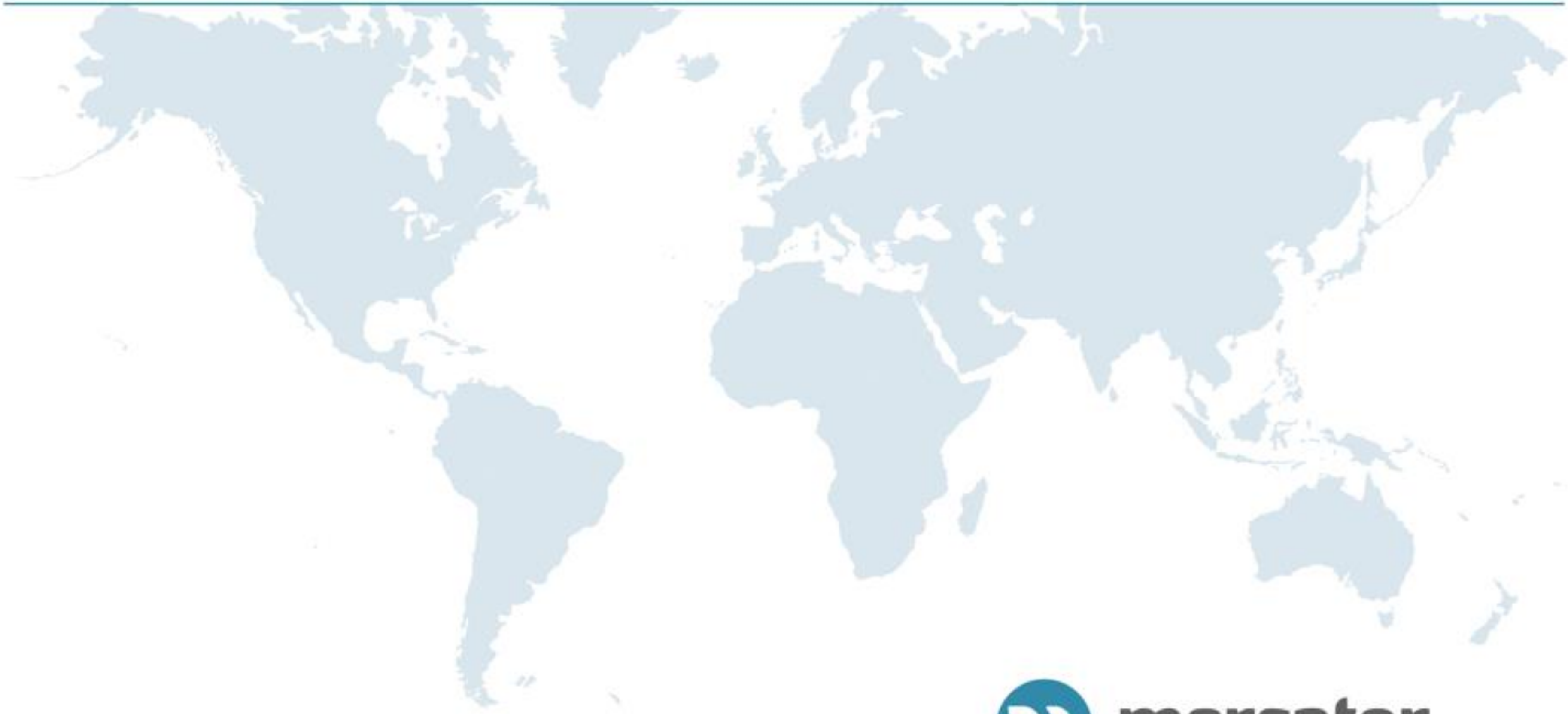
The port authority is proud of the achievements advanced through the ECHO Program and is committed to maintaining the momentum towards creating quieter oceans for healthier whales. With a focus on continuous improvement and adaptive management, the port-authority led ECHO Program management team will continue to collaborate with regional partners and advisors to develop and implement initiatives that reduce short-term threats to at-risk whales as a result of commercial shipping activities. In accordance with the port authority's commitments under the *Conservation Agreement*, the ECHO Program continues to advance research and education efforts to drive change towards the adoption of quieter vessel design and technologies.

Appendix IR2020-3-B

Updated Roberts Bank Terminal 2 container vessel call forecast study, Mercator International 2021

Updated Roberts Bank Terminal 2 Container Vessel Call Forecast Study

For: PORT of vancouver



mercator
Trusted. Independent. Experienced.

August 2021

Contents

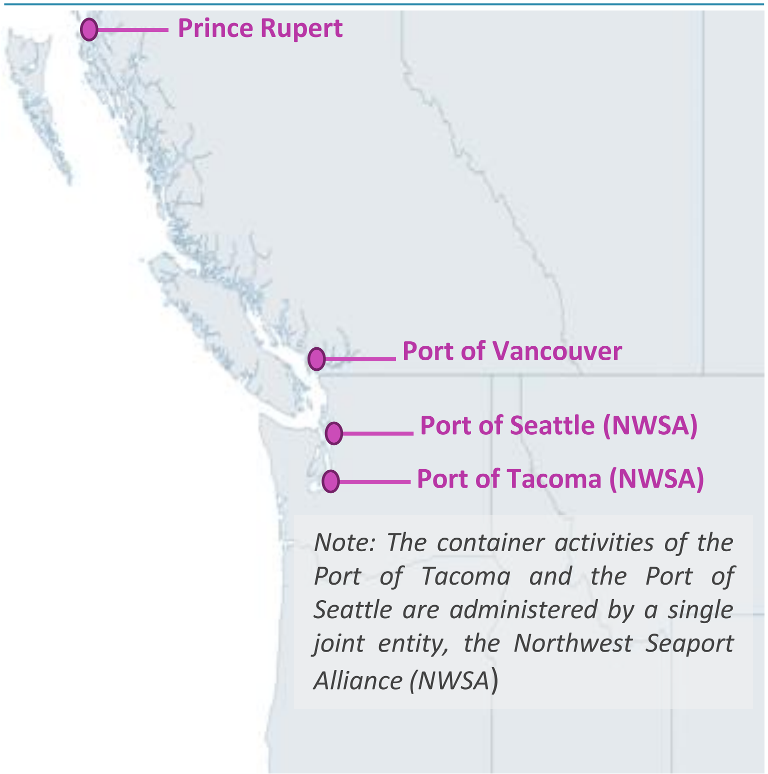
Introduction

Objective of study

Mercator International (Mercator) was engaged through Ecowest Consultants retained by Vancouver Fraser Port Authority (VFPA, Port of Vancouver, Vancouver, or PV) to:

- Review structural dynamics in the liner container shipping industry ("liner industry") over the past two years, along with changes in the configurations and ship assignments for containership services to and from North America, and Vancouver and the Pacific Northwest (PNW) in particular
    - *Note – the rationale for examining vessel deployments for the entire PNW region is that few shipping lines design long-haul, inter-continental vessel services to serve only Vancouver – their services are designed to serve the entire region, even if a particular service does not call at every port in the region*
- Discuss how the developments in liner industry structure and PNW vessel deployments over the past two years affect Mercator's 2018 forecast (the 2018 Mercator Report[1]) of the numbers and sizes of containership services to call in the Port of Vancouver by 2030 and 2035 – for both the "With RBT2" and "Without RBT2" scenarios
- Analyze and summarize historical trends in the numbers and size distributions of several other key liner trades to evaluate the suitability of the analytical framework and parameters that Mercator utilized in its original forecast
- Extend the forecast of the number and size distribution of Vancouver-calling containership services to the years 2040 and 2045 – for both RBT2 scenarios
- Review and incorporate projections of the age distribution of Vancouver-calling containership services in the years 2030, 2035, 2040, and 2045 for both RBT2 scenarios.

Study area— main ports with container terminals in the Pacific Northwest



Note: The container activities of the Port of Tacoma and the Port of Seattle are administered by a single joint entity, the Northwest Seaport Alliance (NWSA))

---

[1] Mercator International (2018), Roberts Bank Terminal 2 Container Vessel Call Forecast Study. Available at Canadian Impact Assessment Registry (Document #1362): https://www.ceaa-acee.gc.ca/050/documents/p80054/126252E.pdf

Executive Summary

Referencing Mercator's Prior (2018) Report

In the second half of 2018, Mercator conducted an in-depth analysis and long-term forecast of containership vessel services to and from the Pacific Northwest (PNW) coastal zone of North America – and especially to and from Vancouver – for all relevant trade lanes.

To produce this vessel services forecast, Mercator utilized a long-term container volume forecast prepared for the Port of Vancouver by Ocean Shipping Consultants (OSC) for this coastal zone, with a focus on the Vancouver port complex.

- OSC's forecast was constructed for the scenario in which Roberts Bank Terminal 2 (RBT2) is built and operational by 2030, and separately for a scenario in which RBT2 is not developed.

Mercator examined and analyzed an array of components, in addition to the OSC volume forecasts, to construct a forecast of the numbers of containership services that could be expected to make regularly-scheduled calls at Vancouver container terminals in 2030, and separately in 2035, along with projections of the average sizes (as measured by the nominal TEU capacity) of containerships utilized in each of the forecasted services.

- These components included reviewing how and why the numbers and size scale of containership services to and from the PNW coastal zone have evolved over the prior twenty-five years, how the portfolio of vessel services to and from the PNW zone has been impacted by changes in the structure/carrier composition of the containership industry, and separately impacted by changes in prevailing vessel sizes and in container terminal infrastructure.

Mercator concluded in the 2018 Report that ***the number of separate containership vessel services likely to be calling in the Vancouver port complex in 2035 will be the same, with or without the completion of RBT2.***

- In both scenarios, Mercator projected that there will be 12 Asia – PNW services, 2 Europe – PNW services, and 1 Australia/New Zealand – PNW service calling at Vancouver terminals each week in 2035. Service to and from Latin America is provided by the Europe Services that pass through Central America and the Panama Canal.
- What changes between our forecast "With RBT2" and "Without RBT2" is the expected average sizes of the containerships in several of those services, and the expected distribution of those services between the Roberts Bank, Burrard Inlet, and Fraser River precincts of the port complex.

Mercator concluded that the completion of RBT2 should NOT lead to an increase in the number of services calling in Vancouver, because the number of services operated in a trade lane is driven more by the number of ports and the geography of the trade lanes being served, the number and concentration of ocean carriers and alliances running those services, and by the continuing economic benefits to ocean containers of operating the fewest possible number of vessel services in a given trade lane, with each service using the largest ships that can be effectively utilized.

Executive Summary

Principal conclusions in Updated Mercator (2021) Report for Most-Realistic Scenario

Mercator projects that **if RBT2 is built**, there would likely be 17 weekly calls at VFPA container terminals in 2045.

12 Asia – Salish Sea services would call at Vancouver:

- 7 of the twelve are predicted to call in the Roberts Bank precinct of the port complex (Deltaport and RBT2)
- The other 5 Asia-Salish Sea services are predicted to call in the Burrard Inlet precinct (Centerm or Vanterm)
- Five of the twelve services would likely utilize ships with 18,000+ TEUs of capacity, and another three would use ships with capacities between 12,800 and 14,500 TEUs.
- Only one of the twelve would likely be operated with ships of under 5,000 TEUs of capacity, and this would be a specialized service catering to the forest products trade.
- We expect that there will be no Asia – Salish Sea eastbound deployments operated that call Seattle/Tacoma, that do **not** also call Vancouver.

4 non-Asia Services: 3 Europe-West Coast services and 1 Australia/New Zealand-West Coast service would call Vancouver, all in Burrard Inlet:

- 1 of the Europe services would likely be of "New Panamax" dimensions (approximately 14,500 TEU scale) and two would be of less than 9,000 TEU scale. The 2018 analysis looked forward to 2035, at which time Europe volume would be accommodated on 2 strings. By 2045, ship sizes would reach the Panama Canal size limit, requiring again a third string.
- The single Australia/New Zealand (ANZ) service would likely be less than 9,000 TEU scale.

1 Asia "Westbound" Service would call Vancouver, inside Burrard Inlet

- There are three services now operating that run eastbound from Asia to California, with a westbound stop in the Salish Sea when returning to Asia. In previous years, these services called only at Seattle or Tacoma terminals (and not at Vancouver), but a new operator offering this service has chosen Vancouver as its PNW westbound port of call. This is evidently a temporary change, but we nonetheless retain it in the long-term counts.

Mercator projects that the 7 vessel services that would likely be calling the Roberts Bank precinct would generate approximately 4.75 million TEUs of VFPA throughput in 2045, accounting for about 66% of Vancouver's total port throughput, with the two terminals collectively operating at about 99% capacity utilization, which reflects an exceedingly high utilization of capacity.

- In this scenario, we also project that the 10 vessel services using the Burrard Inlet precinct would generate roughly 2.45 million TEUs in 2045, accounting for about 34% of total port throughput, resulting in aggregate capacity utilization for this precinct of about 96%, with overall utilization of the port at 98%.
- In all scenarios, ships larger than NPX size (about 14,500 TEU) must call at Roberts Bank due to Lions Gate Bridge/ First Narrows limitations.

Executive Summary

Principal conclusions in Updated Mercator (2021) Report for Most-Realistic Scenario

Mercator projects that **if RBT2 is not built** (or not operational in 2045), there would be **the same number of services (17)** making weekly calls at VFPA container terminals in 2045 as there would be if RBT2 is built:

12 Asia – Salish Sea deployments, utilizing smaller ships than in the With RBT2 scenario, would call at Vancouver:

- 5 of the twelve are predicted to call in the Roberts Bank precinct at the Deltaport Terminal, with 7 calling in the Burrard Inlet precinct.
- The capacity of services would be only slightly scaled back, with 4 (rather than 5) being 18,000 TEU or greater.

4 non-Asia Services: 3 Europe-No American services and 1 in the Australia New Zealand service would call Vancouver, with 1 of them at Roberts Bank:

- The non-Asia services carry primarily Western Canada local cargo that is unlikely to be diverted to other gateways, so wo expect these services to carry the same level of Vancouver traffic utilizing the same sizes of ships as in the With RBT2 scenario, and not be impacted by the capacity limitation of Vancouver terminals.

1 Asia "Westbound" Service would call Vancouver, inside Burrard Inlet

- The westbound calling services would not be impacted by the overall capacity constraint (that redirects inbound – headhaul – traffic), so we expect no change to this subsector of services.

Mercator projects that the 6 vessel services that would be calling the Roberts Bank precinct would generate approximately 2.38 million TEUs of VFPA throughput in 2045, accounting for about 49% of Vancouver's total port throughput, putting the Deltaport terminal at about 99% capacity utilization.

- In this scenario, we also project that the 11 vessel services using the Burrard Inlet terminals would generate roughly 2.48 million TEUs in 2045, accounting for about 51% of total port throughput, resulting in aggregate capacity utilization for this precinct of about 97%, with overall utilization of the port at 98%, assuming terminals achieve a high utilization that is comparable to the base case.

Thus, Mercator projects that ***if RBT2 is not built, the impact will not be a reduction in the number of separate vessel deployments that will likely call Vancouver through 2045***, but rather a reduction in average ship sizes.

The number of ships is unlikely to change because:

- The expected number of carriers and alliances in the Asia – PNW corridor, will be the same with or without RBT2.
- The size/importance of the local Vancouver market and carriers' desires to provide direct links to that market from SE Asia, the Pearl River Delta, the Yangtze Delta, and Busan are what drives the number of services each group offers.
- The relatively low incremental cost for an Asia – Salish Sea deployment to call in both Vancouver and the Puget Sound means that the majority of such deployments will continue to make scheduled calls in both port complexes.
- The consignments for the European and ANZ services (comprised of local cargoes) are unaffected by Vancouver's terminal development.
- The clear and long-established preference for carriers to meet increased capacity requirements is by increasing ship size (rather than by adding new services), and this will lead carriers to adjust ship sizes rather than add to the number of services when RBT2 capacity becomes available.

Contents

Analytical Framework and Overview of Key Industry Trends

Background and geographical/vessel service framework: Container Volume Distribution

Given the geographic location within North America of the PNW region, there are only three distinct offshore regions that are linked directly with the Port of Vancouver and the rest of the PNW by dedicated vessel deployments. Container volumes are distributed across the regions as follows

- Northeast/Southeast Asia, which accounts for nearly 94% of PNW international container traffic
- Europe, which accounts for about 5% of PNW international container traffic
    - PNW traffic to and from Latin America is transported on the vessel deployments that link the PNW region with Europe, and these Latin American containers are relayed in Caribbean Basin/Panamanian ports to and from other vessel services – these volumes are counted already in the 5% portion for Europe. There are no direct vessel services between the PNW and Africa or South America.
- Australia and New Zealand (ANZ) contribute the remaining 1%.

Vessel Service Count Distribution by Region

There are presently twelve weekly-frequency deployments **linking Northeast/Southeast Asia with Vancouver** – nine of these also call in Seattle or Tacoma (NWSA) but not Prince Rupert, while the other three call in Prince Rupert, and then call in Vancouver (2) or NWSA and Vancouver (1).

- Two years ago, there were also nine deployments between Asia and only the Salish Sea (i.e., calling at Vancouver and NWSA ports, but not Prince Rupert), plus one deployment between Asia and Vancouver only (without either Puget Sound or Prince Rupert calls).
- However, there were only two deployments calling in Prince Rupert first and then at Vancouver.
- There were also two deployments calling in Prince Rupert and then running directly to Southern California ports, whereas presently there is just one.
- There are also three weekly-frequency deployments that are designed to transport Northeast/Southeast Asia import containers to California, which stop at a Salish Sea port (Seattle/Tacoma or Vancouver) on the backhaul, westbound voyage leg en-route to Asia.

There are presently three separate, weekly-frequency deployments running **between Europe and Vancouver**, via the Caribbean Basin, the Panama Canal, California, and Seattle. Moreover, **these three services have not fundamentally changed during the past two years** (i.e., since the 2018 Mercator Study) and are still operated by the same ocean carriers that were running these services in 2018.

There is presently one vessel deployment running **between ANZ and Vancouver** which is jointly operated by three carriers. Although this deployment runs to/from ANZ with weekly sailing frequency, the Salish Sea calls (in Vancouver and Seattle) are made only every other week.

- **This deployment also has not fundamentally changed in the past two years** and is still an operational collaboration between three ocean carriers.

Thus, to address VFPA's mandate for this study, **Mercator has forecast how many separate vessel deployments are likely to be operated in each of four separate timeframes** (2030, 2035, 2040, and 2045) for each trade lane, with particular focus on the Asia – PNW trade lane – and to concurrently estimate the size (as reflected in TEU container capacity) and age of ships likely to be used in each forecasted deployment.

Analytical Framework

Key factors for consideration and analysis

In projecting the number of separate vessel deployments likely to be operated within a particular trade lane in the future (whether it is the Asia, Europe, or ANZ trade lane), the 2018 Mercator study and this present study consider several key factors, in particular:

- The current number of services and the average ships sizes of those services, in each relevant trade lane
- The average weekly container volume flow (TEUs of cargo) in the headhaul direction for each trade lane (which is the inbound direction), and the expected growth rate in that volume
    - For this forecast update, Mercator utilized a report by Drewry Shipping Consultants recently produced for VFPA. The 2018 Mercator Report had utilized an earlier forecast study produced in 2016 for VFPA by Ocean Shipping Consultants (OSC).
    - Note that the number of vessel deployments likely to call the Port of Vancouver is not a function of the headhaul volume of containers to be discharged **only** at Vancouver, but rather (for Asian services) containers for discharge at Vancouver plus the other PNW ports or California ports (for European and ANZ services).
- The number of separate ocean carriers and composition of vessel sharing alliances that are currently serving the trade, how these might evolve in the future (considering the structure of the liner shipping industry), and how market share of the trade is concentrated among these carriers/alliances
- For the Asia trade, the geographic distribution of the origin ports that require (for commercial reasons) fast, direct service without a transfer
    - *This factor has an impact on how many separate vessel services the carriers/alliances assess are required to maintain their commercial competitiveness.*
- Harbor/terminal/rail infrastructure constraints for the ports in the region that might limit the sizes of ships that can access those ports
    - *A key constraint for the PNW region is the height above the water-line of the underdeck of the Lions Gate Bridge in Vancouver, which constrains the sizes of containerships that can call at either of the Burrard Inlet terminals.*
- The importance of the trade lane corridor to an ocean carrier, relative to the other trade lanes that the carrier serves, and the composition of the carrier's fleet of ships
    - *For example, the Asia – PNW trade lane is far more important to every global ship line than the Europe – PNW trade lane, but will typically be accorded a lower level of priority (in terms of assignments of the newest and largest ships in the fleet) relative to several other trades such as Asia – North Europe, Asia – California, etc.*

An underlying force that has been driving the number of deployments in a trade lane corridor for more than 40 years and continues to drive aggregate sailing frequency levels in every corridor, is the ongoing pursuit by ship line executives to enhance their competitive cost position by achieving economies of scale **by using the largest ships that can be reliably and effectively utilized in each deployment in the carrier's network**.

This ongoing pursuit of scale economies through the assignment of largest-feasible ships to deployments has led to (and will continue to result in) the consistent presence of vessel sharing agreements in most trade lane corridors and in periodic waves of mergers and acquisitions of ocean carriers.

Analytical Framework

Other significant framework elements

In constructing our forecasts of the numbers and ship sizes of deployments for each trade lane, several background facts or characteristics of the industry that underly the 2018 Mercator Report are still valid and were also utilized in this forecast update. These are noted below:

- Once the current Centerm Expansion Project is completed in 2021, the footprints, berth lengths, and terminal capacities of Vanterm, Centerm, and Deltaport will remain essentially unchanged through the forecast period to 2045.
- There will be enough suitable berths and terminal capacities at NWSA terminals in Seattle and Tacoma after 2020 and through 2045 to handle the numbers and sizes of vessel deployments forecasted to call in the Puget Sound.
    - *In other words, no NWSA port calls for forecasted vessel deployments to/from the PNW region will need to be cancelled (with corollary volumes channeled through Vancouver or other gateways) due to terminal infrastructure constraints in these two Washington State ports.*
- The vessel sharing agreements currently in place in all three corridors will continue to operate through 2025, with relatively few changes in the carrier composition of each agreement, and beyond 2025, some similar arrangement for cooperating and achieving scale economy will remain in place.
- Throughout the forecast period, the liner shipping industry will continue to be dominated by seven to eight very large global carriers, most of which will be supported directly or indirectly by the government of their headquarters country (specifically, China, Japan, Korea, Taiwan, Germany, France and Denmark).
- In the Asia – PNW corridor, most of these seven to eight global carriers will be operating in one of three vessel sharing agreements, possibly with one such global carrier operating independently, and one or two niche carriers continuing to serve this trade.

Near-term Industry Events and Trends that Could Impact PNW Vessel Services

Synopsis

As described in the 2018 Mercator Report, the global container shipping industry continues to experience major changes that are impacting North American ports, and some of these developments affect the vessel services calling the Port of Vancouver. The diagrams below identify selected industry developments in the boxes to the left, along with their known and potential near-term impacts in the boxes to the right.

Major industry events and global trends

Consolidation of ocean carriers impacts

- Specific ports could experience increased levels of concentration of container volumes.
- Ocean carriers could gain leverage over selected gateway ports for discretionary intermodal volumes

Increased use of high-capacity vessels impacts

- Further concentration of volumes could occur on fewer, larger vessel services and in fewer ports.
- Deliveries of 18,000-23,000+ TEU ships into the Asia – North Europe trade are resulting in cascading ships of 12,000-15,000 TEU capacity into Asia – North America trades over the next few years.

Opening of new Panama Canal locks impacts

- Ocean carriers continue to increase vessel service capacities on the Asia - US East Coast route through the Panama Canal and use all-water container routings to a greater extent.

Development of ULCS-capable terminals impacts

- Several North American terminals are being forced to enhance their infrastructures to remain competitive, with large investments required to handle ultra-large container ships (ULCS) of 15,000-18,000 TEU scale.

Issues particularly relevant to Asia - PNW vessel services

Higher capacity vessels in Asia trades impacts

- A higher percentage of Asia – PNW services are likely to be operated with ships of 10,000 – 14,000 TEU capacity over the next five to 10 years.
- Fewer alliances and carriers makes it easier to consolidate deployments and use larger ships.

Changes in North American port calls impacts

- Due to water depth constraints, Portland is no longer included on most Asia – PNW services
- Carriers have changed the sequence of port calls on Asian services within the PNW region in recent years to facilitate routing more intermodal containers via the BC ports, rather than Seattle and Tacoma.

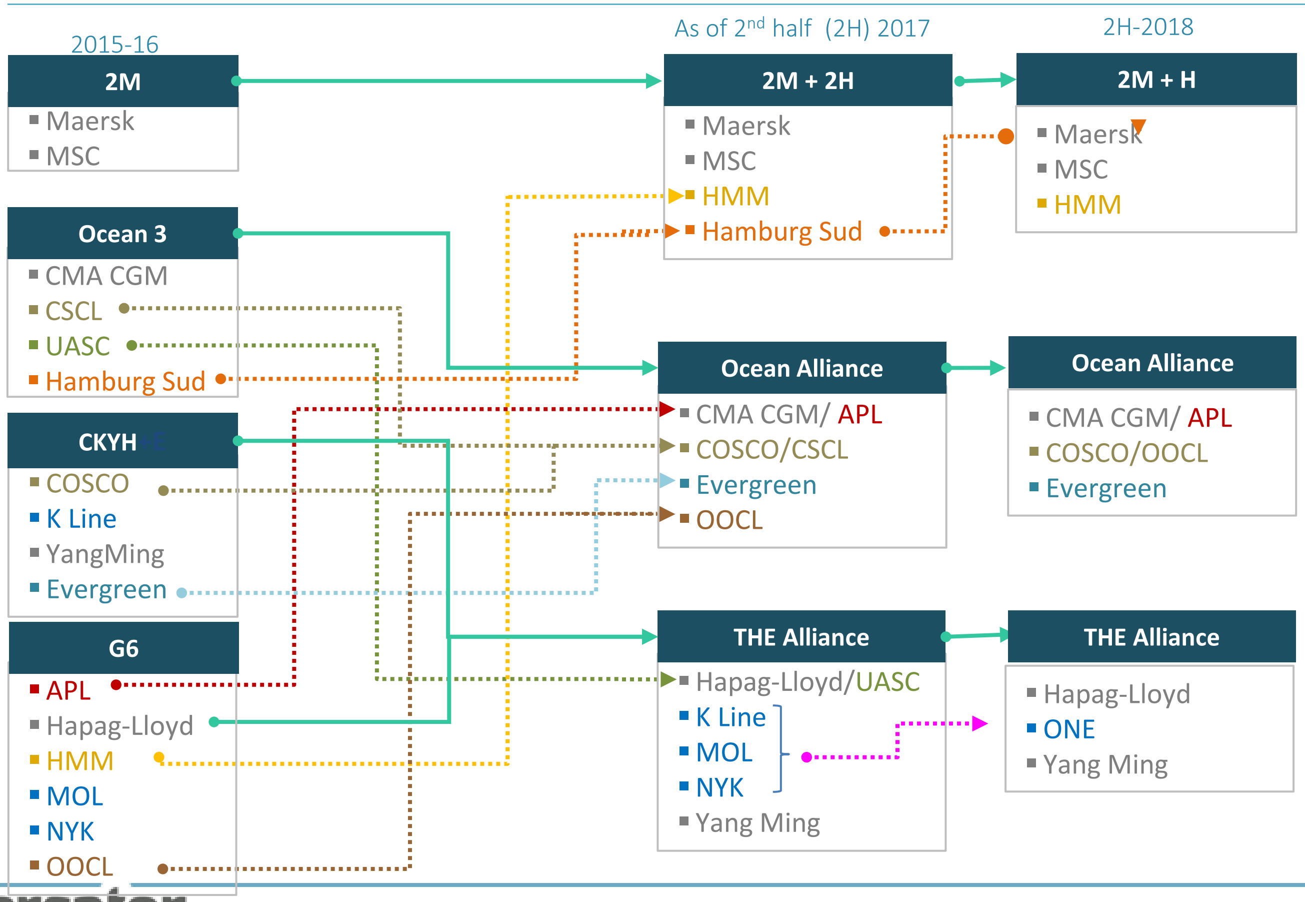
Restructuring of Carrier Alliances and Vessel Sharing Agreements

Consolidation of major ocean carriers: 2015 through 2018

From mid-2015 to the second half of 2017, the container shipping industry consolidated due to merger and acquisition (M&A) activity and because of the bankruptcy of Hanjin, contracting from 16 global carriers to 12, and from four global alliances to three.

In the following year (2018), the global carrier count contracted further to nine, following Cosco's purchase of OOCL, and the consolidation of the Japanese carriers MOL, NYK, and K Line into the Ocean Network Express (ONE) Alliance. During this time, Maersk (the largest carrier in the East-West trades) also acquired Hamburg Sud (the largest line specializing in the North-South trades).

After this period of consolidation and the corollary re-configuration of the carrier alliances, the remaining lines obtained substantial economies of scale and increased market power over the smaller players in competing trades.



2015-16

2M
- Maersk
- MSC

Ocean 3
- CMA CGM
- CSCL
- UASC
- Hamburg Sud

CKYH+E
- COSCO
- K Line
- YangMing
- Evergreen

G6
- APL
- Hapag-Lloyd
- HMM
- MOL
- NYK
- OOCL

As of 2nd half (2H) 2017

2M + 2H
- Maersk
- MSC
- HMM
- Hamburg Sud

Ocean Alliance
- CMA CGM/ APL
- COSCO/CSCL
- Evergreen
- OOCL

THE Alliance
- Hapag-Lloyd/UASC
- K Line
- MOL
- NYK
- Yang Ming

2H-2018

2M + H
- Maersk
- MSC
- HMM

Ocean Alliance
- CMA CGM/ APL
- COSCO/OOCL
- Evergreen

THE Alliance
- Hapag-Lloyd
- ONE
- Yang Ming

M&A activity included:

- Hamburg Sud acquired by Maersk
- APL and the south American regional carrier Mercosul Line acquired by CMA CGM
- OOCL and China Shipping (CSCL) acquired by COSCO
- UASC acquired by/ merged with Hapag-Lloyd
- Formation of ONE by NYK, MOL, and K Line

Restructuring of Carrier Alliances and Vessel Sharing Agreements

Alliance reconfiguration: 2018 through 2020

Since 2018, there have been no further merger/acquisition transactions among the world's major ocean carriers. However, there have been a few noteworthy changes in liner shipping service structures during this period.

- In the latter half of 2019 and early months of 2020, Hyundai (HMM) withdrew from the 2M+H Alliance, and instead joined THE Alliance
- Maersk and MSC responded by inviting Zim (which previously was operating independently of alliances) to share ships with them in the Asia – PNW trade (as well as in other trade lanes). In addition, Maersk and MSC established a vessel sharing agreement with an independent Korean carrier (SM Lines) covering two Asia – California services.

The ten carriers in the three global alliances (which are also the ten largest carriers in the world) now control 85% of the global containership fleet, reflecting an increase in the concentration within the container line industry since 2018.

Changes in carrier alliance structure – 2018 to 2020

2H-2018

2M + H
- Maersk
- MSC
- **HMM**

Ocean Alliance
- CMA CGM/ APL
- COSCO/OOCL
- Evergreen

THE Alliance
- Hapag-Lloyd
- ONE
- Yang Ming

2H-2020

2M + Z
- Maersk
- MSC
- **Zim**

Ocean Alliance
- CMA CGM/ APL
- COSCO/OOCL
- Evergreen

THE Alliance
- Hapag-Lloyd
- ONE
- Yang Ming
- **HMM**

Sizes of containership fleets operated by the top carriers

Top carriers ranking by operated capacity in TEU as of 12-1-2020

		Existing cellular fleet	
Rank	**Carrier**	**Market share**	**Total TEU (000s)**
1	Maersk	17.3%	4,109
2	MSC	16.2%	3,856
3	Cosco/OOCL	12.7%	3,031
4	CMA CGM/APL	12.6%	2,996
5	Hapag-Lloyd	7.2%	1,723
6	ONE	6.6%	1,576
7	Evergreen	5.3%	1,257
8	HMM	3.0%	712
9	Yang Ming	2.6%	623
10	Zim	1.5%	352
	top 10 operators	**85.0%**	**20,235**

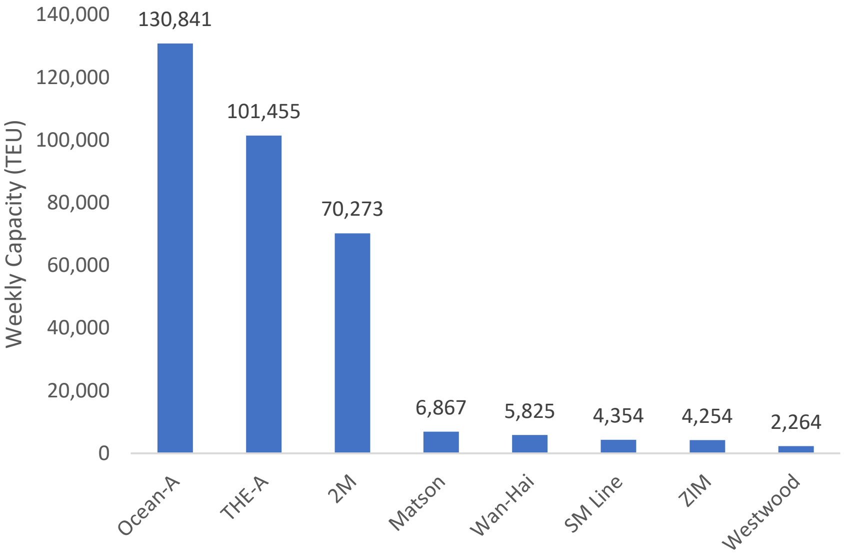
Concentration of capacity shares by alliance and carrier
Asia – West Coast North America theater

Given that the ten largest containership lines control 85% of the global containership fleet, and that they operate in three alliances within the Asia – West Coast North America (WCNA) theater, it is not surprising that these alliances dominate the provision of separate vessel services and capacity in this theater (of which the Asia – PNW trade lane is the secondary segment, after the Asia – California lane). Indeed, as the pie chart below right indicates, the three alliances are now providing over 90% of the TEU-slot capacity for all of the liner services running across the Pacific Ocean from Asia to WCNA ports.

As the bar chart to the lower left indicates, there are five carriers providing capacity to the Asia – WCNA theater, independently of the three alliances, and with relatively small ships. However, each of these carriers are doing so for particular reasons:

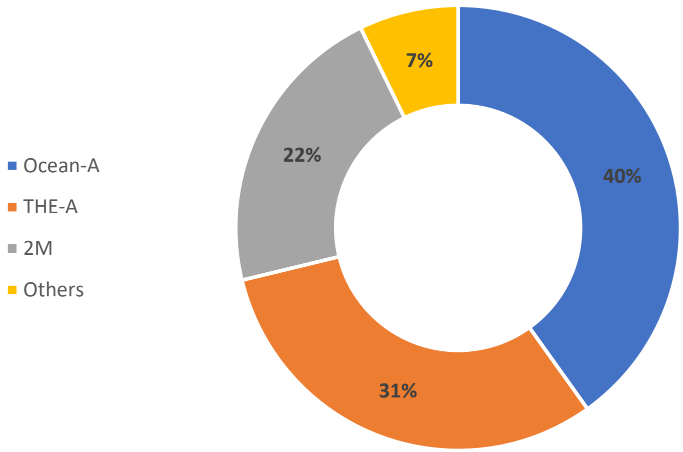
- *Matson is primarily a US-domestic carrier serving Hawaii/Guam – its eastbound service to California is operated essentially as a backhaul voyage.*
- *Westwood is a niche carrier focused on westbound shipments of forest/paper products from the PNW to Asia, using specialized ships, and its Transpacific eastbound service to the Salish Sea is also essentially a backhaul voyage.*
- *SM Line is supported by Korean business conglomerates (chaebols) that want another Korean-flag service to the PNW, in addition to HMM*
- *Wan Hai has reacted to the departure of its former VSA partner (PIL) and strong market conditions, by operating its own service to California.*
- *Zim is capitalizing on a strong market to enter the Asia – California lane as an independent to complement the Asia – PNW service it operates with 2M*

Weekly capacity by alliance: Asia – WCNA trade lane



Source: Developed by Mercator with data from Alphaliner, October 2020

Weekly capacity shares for Asia – WCNA trade lane



Source: Developed by Mercator with data from Alphaliner, October 2020

Vessel Upsizing in the East-West Trade and Cascading of Smaller Vessels to Minor Trades

Economies of scale

In the search for economies of scale, it is a prevailing pattern of ocean carriers (shipping lines) to constantly assign the largest ships they can effectively utilize in each trade lane covered by their respective service networks.

This quest for economies of scale is the ultimate driver of the vessel upsizing and cascading trends.

This pattern has been exhibited by the liner container shipping industry over the last three decades primarily for the following reasons:

- Given that capital and fuel account for the bulk of ship operating costs, a larger ship will have a lower operating cost per TEU than a smaller one, offering an economic incentive to the ship owner favoring the use of larger vessels.
- Ocean carriers (shipping lines) have unilateral control over the sizes of ships they assign to their respective vessel services but have relatively less control over other major components of their operating costs, such as the costs of rail transportation, trucking, and moving containers through marine terminals.

Hence, upsizing ships in deployments and reducing the numbers of separate liner services in a given trade lane by sharing those services has become a prevalent response by carriers to mitigate static or declining rates and earnings or demand for vessel space.

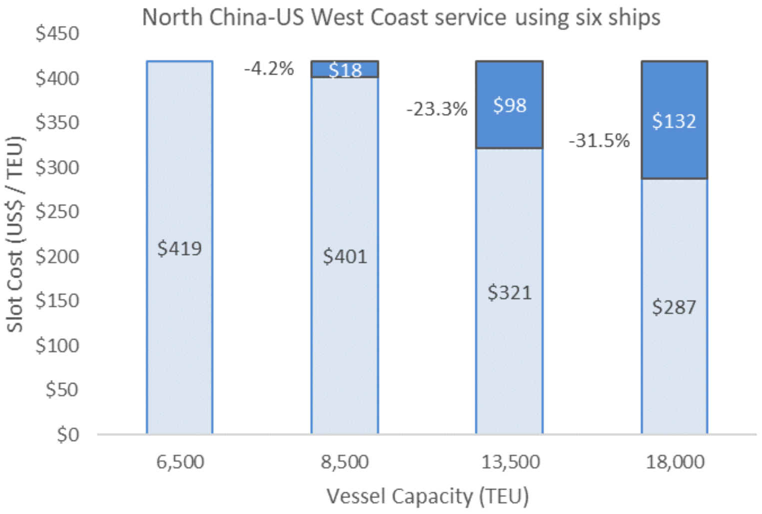
Subsidization of shipyards and M&A of ocean carriers have further stimulated this pattern. M&A activity and participation in carrier alliances also are drivers of the pursuit of economies of scale (and vice versa).

As illustrated in the example to the upper right, the economies of scale that a carrier can obtain for a liner service running between North China and the PNW or California can be significant, with a 31.5% lower slot cost if the service uses 18,000 TEU ships versus multiple strings of 6,500 TEU ships.

The example to the lower right illustrates why an ocean carrier (or alliance) will typically choose to upsize a service that is heavily utilized, instead of adding a similarly-configured service with smaller ships. In this example, the carrier is operating a 9,000-TEU service but needs more capacity. Adding a second string with 5,000 TEU ships costs nearly $50M/year more in operating costs, compared to upsizing the first service to Neopanamax (NPX) Class ships.

Vessel service operating costs per TEU (“slot costs”)

Savings per slot by vessel capacity scale



Example of economics of service upsizing vs. service addition

Asia - PNW Vessel Service Scenarios	Ship Size Class	Effective Capacity	Voyage Costs	Annual Costs	Differentials
	TEU	TEU	($Mil/Voy)	($Mil/Yr)	($Mil/Yr)
One NPX service	13,500	12,150	4.01	208.69	
Two services	9,000 + 5,000	12,085	4.94	257.01	48.32

Updated Assumptions on PNW Terminal Infrastructure Developments and Constraints

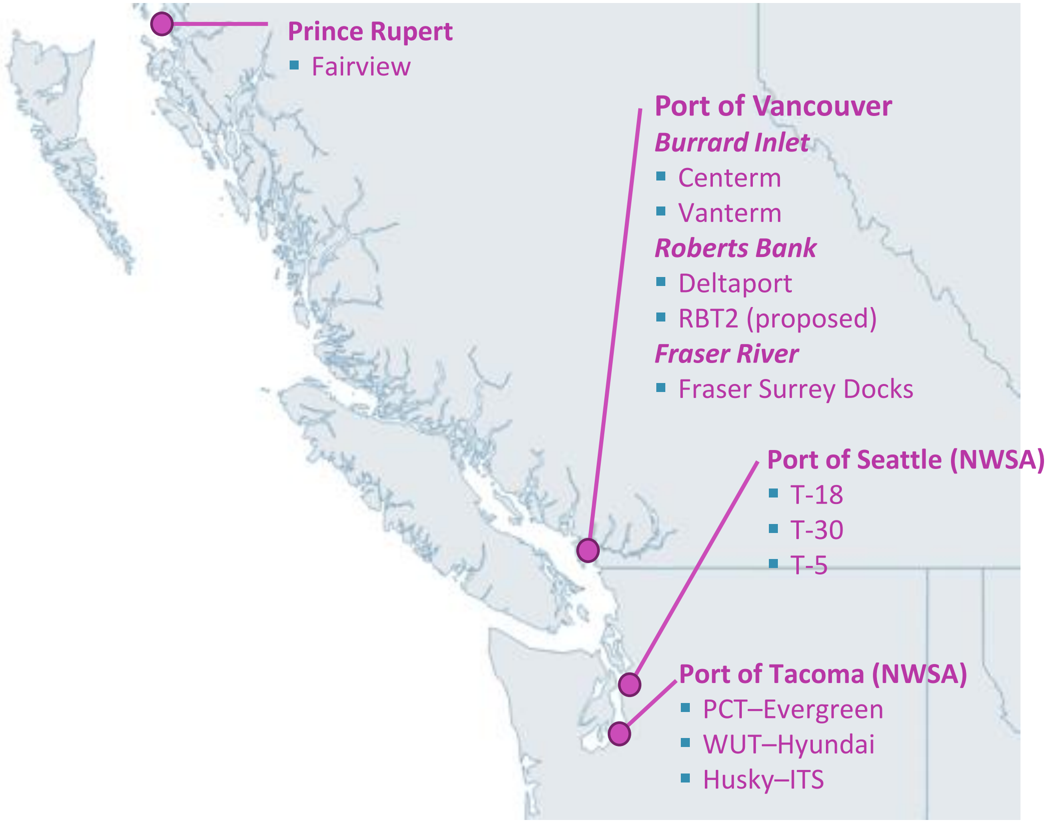
Overview

The next two pages describe terminal infrastructure in the PNW region that is relevant for forecasting container shipping services that can be expected to call in the Port of Vancouver in 2030, 2035, 2040, and 2045.

In particular, key changes and developments in the harbor/terminal infrastructure in this region that have occurred since 2018 are presented. For more information on each terminal, please refer to the 2018 Mercator Report.[3]

This discussion enables us to assess the ability of the other PNW ports to handle Asia container cargo traffic flows to/from rail-served inland destinations that would likely have to be diverted from their current routings through the Port of Vancouver, in a scenario in which RBT2 is not built.

International container terminals in the PNW



Prince Rupert
- Fairview

Port of Vancouver

Burrard Inlet
- Centerm
- Vanterm

Roberts Bank
- Deltaport
- RBT2 (proposed)

Fraser River
- Fraser Surrey Docks

Port of Seattle (NWSA)
- T-18
- T-30
- T-5

Port of Tacoma (NWSA)
- PCT–Evergreen
- WUT–Hyundai
- Husky–ITS

---

[3] Mercator International (2018), Roberts Bank Terminal 2 Container Vessel Call Forecast Study. Available at Canadian Impact Assessment Registry (Document #1362): https://www.ceaa-acee.gc.ca/050/documents/p80054/126252E.pdf

PNW Terminal Infrastructure Developments since 2018

Ports of Seattle and Tacoma

In the past two years, the primary developments in the container terminal infrastructure of the Puget Sound (NWSA) ports worth noting involve the T-5 terminal in Seattle and the Husky Terminal in Tacoma.

The T-5 redevelopment project is now underway, and a long-term concession agreement is being negotiated between the Northwest Seaport Alliance (NWSA, acting on behalf of the Port of Seattle), Carrix/SSA (the largest terminal operator in the port complex), and one or two global carriers.

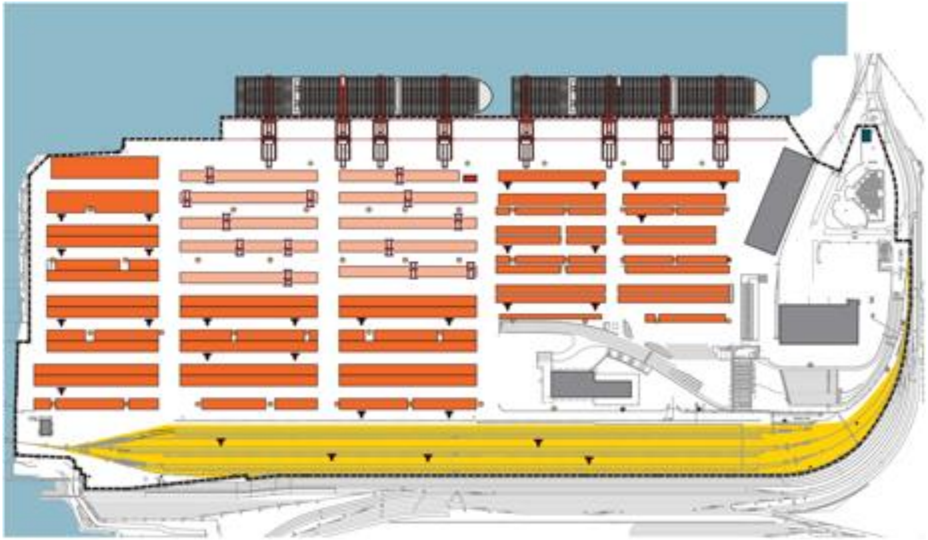
When completed, T-5 will be able to receive, berth, and stevedore one “Mega-Max” (18,000-24,000 TEU) containership and one large post-Panamax (9,000-12,999 TEU) containership concurrently, with on-dock rail-transfer capabilities.

Since the 2018 Mercator Report was produced, the Husky Terminal has installed four additional new ship-to-shore (STS) cranes and is now capable of handling one “Mega-Max” containership at a time.

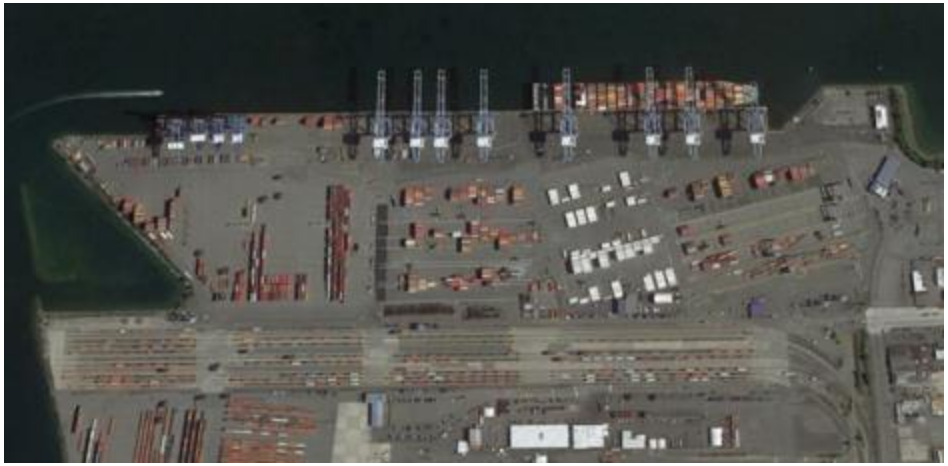
The NWSA and the Port of Tacoma continue to progress a series of projects that over the next ten years will result in the gate complex, container yard, and intermodal transfer facility of this terminal being renovated and expanded – thereby enabling Husky to effectively handle two large ships concurrently.

As a result of the renovation of these two terminals, and considering the level of excess terminal capacity presently in this port complex (as well as the additional capacity that can be developed in some of the other NWSA terminals), Mercator concludes that should RBT2 not be built, there will sufficient capacity in NWSA’s terminals through 2045 to handle the 30% share of diverted Vancouver intermodal volume that we expect will flow through NWSA terminals.

T5 – Improvement project under construction



Husky – Terminal enhancements underway



PNW Terminal Infrastructure Developments since 2018

Port of Prince Rupert

Since 2018, the Prince Rupert Port Authority and DP World Canada (DPW) have progressed the second portion of their Phase II expansion plan for the Fairview Terminal.

This Phase II-B expansion plan is adding container yard acreage, with CN adding support tracks to the south.

Completion of the Phase II-B project is reportedly scheduled for early in 2022, and will increase the throughput capacity of the terminal to 1.8 million TEUs/year.

In May of 2019, the Prince Rupert Port Authority announced that it had completed a long-term master plan for its container terminals. Although the document is not provided on the Authority's website, the announcement indicated that the plan calls for a third phase of expansion for the Fairview Terminal (again in the southerly direction).

The announcement also expressed the Authority's intent to develop a second container terminal in future years, most likely in the area near the Ridley Coal Terminal (which is shown in the aerial photo to the lower right with a yellow star).

Given these current and potential expansion plans, Mercator concludes that should RBT2 not be built, there will be sufficient capacity in Prince Rupert's terminals through 2045 to handle the 30% of intermodal volume diverted from Vancouver that we anticipate would be shifted to Prince Rupert.

Google Earth view of Fairview Terminal (September, 2020)

Google Earth view of Prince Rupert port complex (September 2020)

Contents

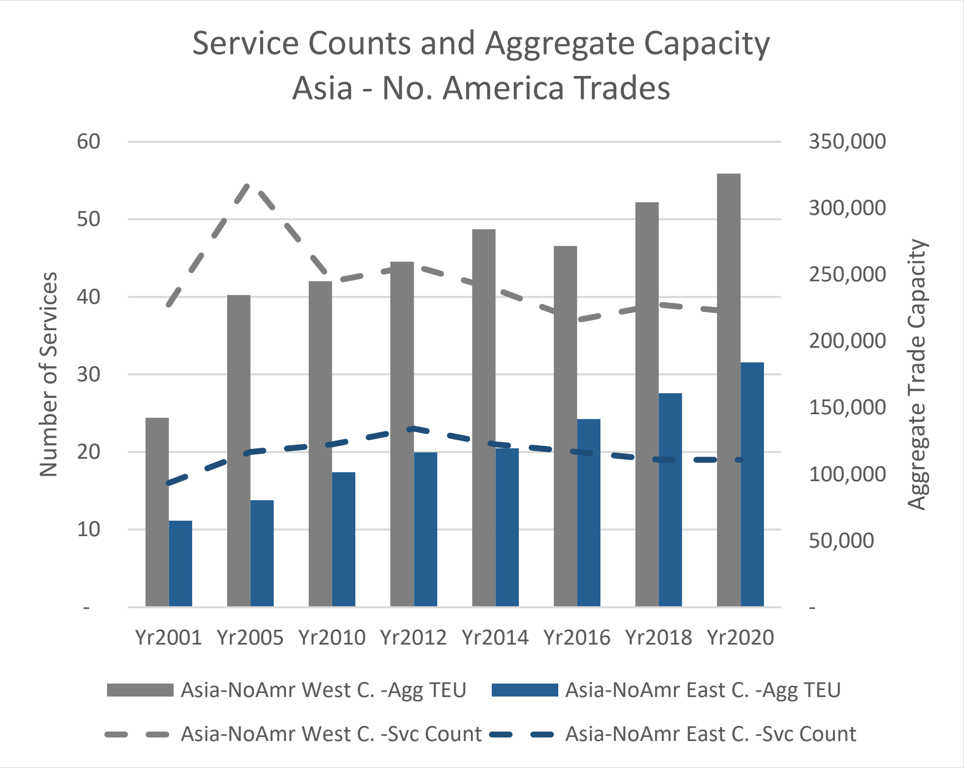
Recent Evolution of Ship Sizes and Sailing Frequencies on Key Trade Lanes

There have been and continue to be two highly-correlated, clear and well-established long-term trends that can be seen in all major inter-continental liner shipping lanes:

- ✓ *Ship sizes (as measured by TEU capacity per service) have been increasing*
- ✓ *The number of services being operated have been either decreasing or holding steady*

These continuing trends are the result of industry consolidation and improving ship technology that delivers improved economics to carriers

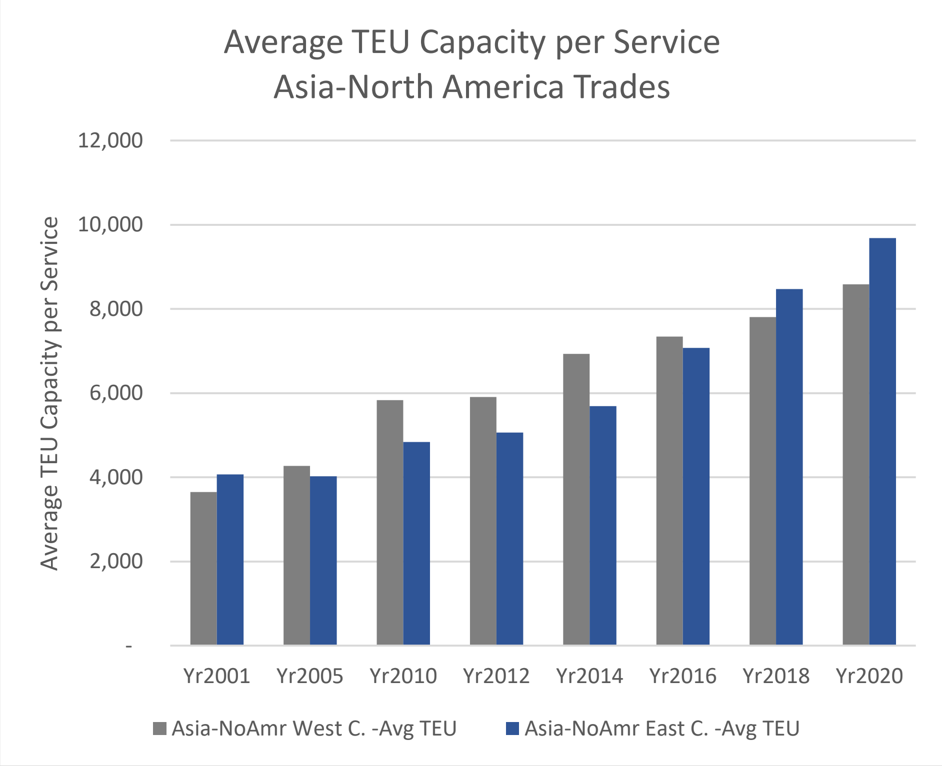
Asia-North America: Aggregate Capacity and Number of Services



Source: Mercator, using Alphaliner, Containerization International

- Since 2005, the West Coast service count has been steady or declining even as volume increased; East Coast service counts increased prior to the new Panama locks (see slide 22).

Asia-North America: Average TEU Capacity Per Service



Source: Mercator, using Alphaliner, Containerization International

- Average capacity per service increased over every interval except for the East Coast between 2001 and 2005, when infrastructure constraints limited ship size increases.

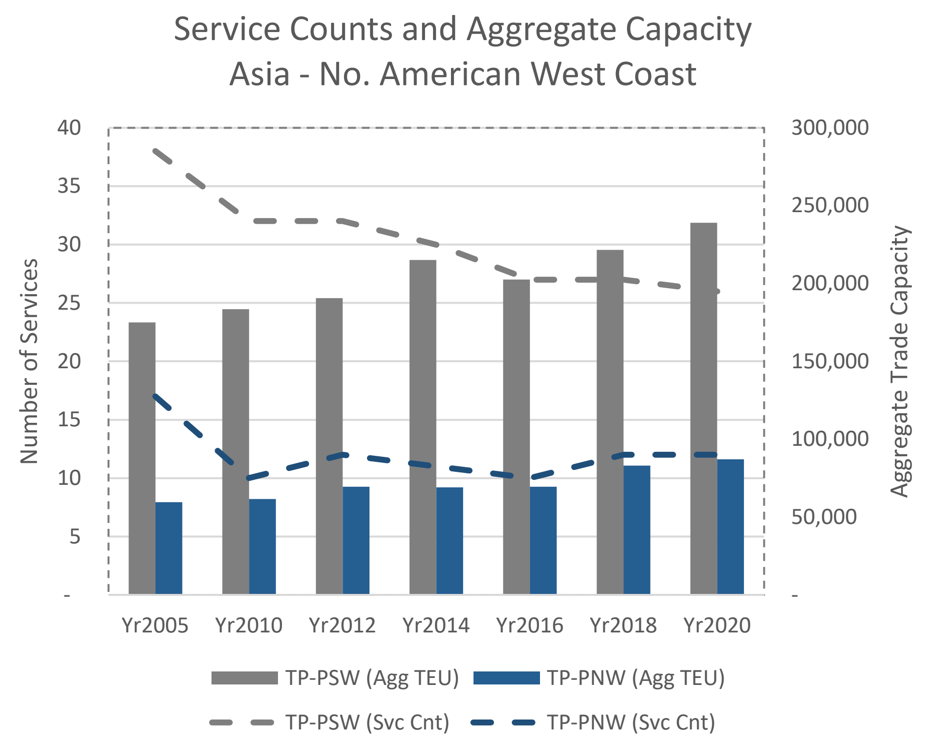
Recent Evolution of Ship Sizes and Sailing Frequencies on Key Trade Lanes

Asia – West Coast of North America theater

If the Asia-North American West Coast services to California are evaluated separately from those to the PNW region (Transpacific southwest or “TP-PSW” vs. Transpacific northwest or “TP-PNW”), a similar result emerges for both lanes:

- ✓ Service counts have been relatively steady or declining in both lanes
- ✓ Ship sizes have been increasing in a fairly consistent way in both lanes

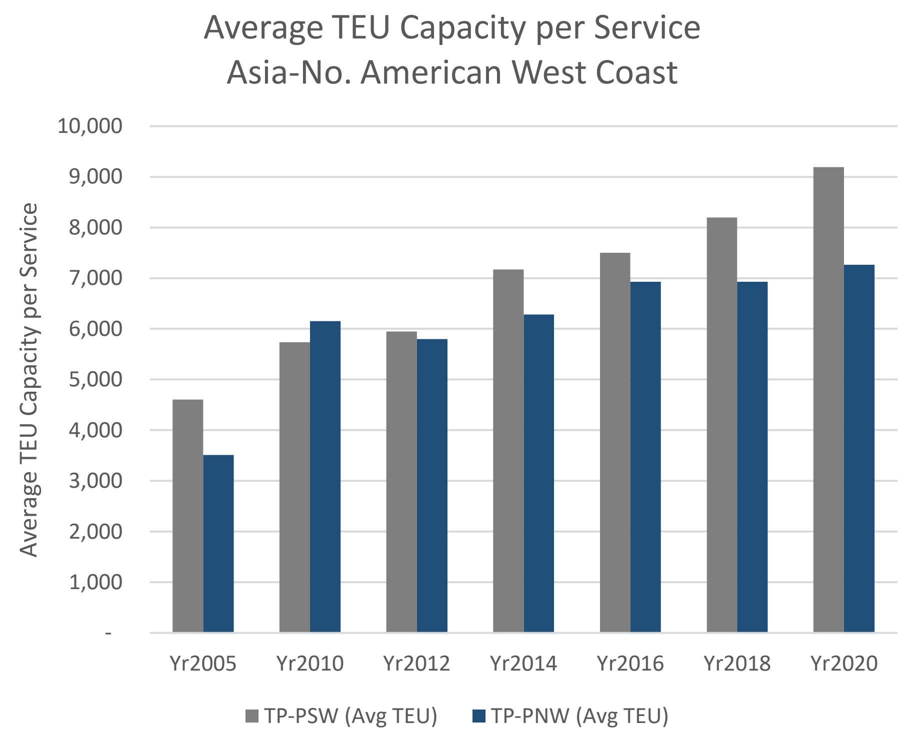
Asia – North America West – Aggregate Capacity and Number of Services



Source: Mercator, using Alphaliner, Containerization International

- The TP-PSW service count has declined by 25% since 2005
- PNW, once with 17 services, has had 10-12 services in last 12 years

Asia-North America West: Average TEU Capacity Per Service



Source: Mercator, using Alphaliner, Containerization International

- With the exception of the PNW between 2010 and 2012, the average capacity per service has increased over every interval.

Recent Evolution of Ship Sizes and Sailing Frequencies on Key Trade Lanes

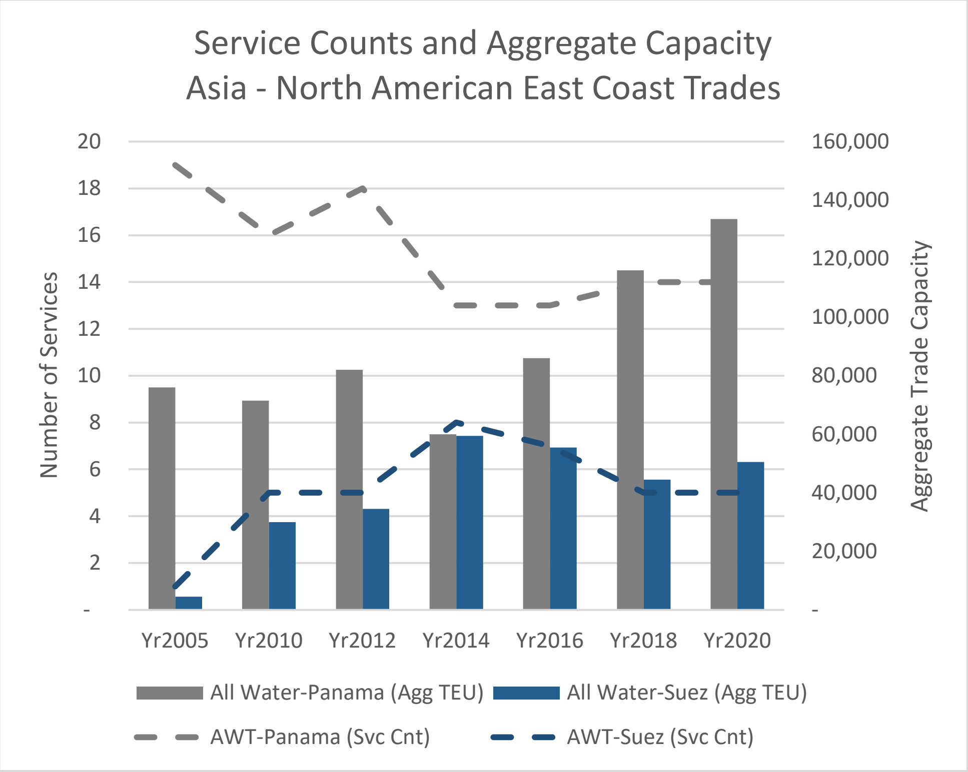
Asia – East Coast of North America theater

Ship sizes, and therefore service counts, on the competing all-water routes have been strongly affected by the 2016 opening of the new Panama Canal locks.

The old Panama Canal locks limited ship size and allowed the Suez route to become more competitive by using larger ships to capture traffic in the middle of the last decade

The new Panama locks opened in 2016, accommodating much larger ships (14,500 TEU versus 5,000 TEU) and initiated a recovery of Panama traffic share

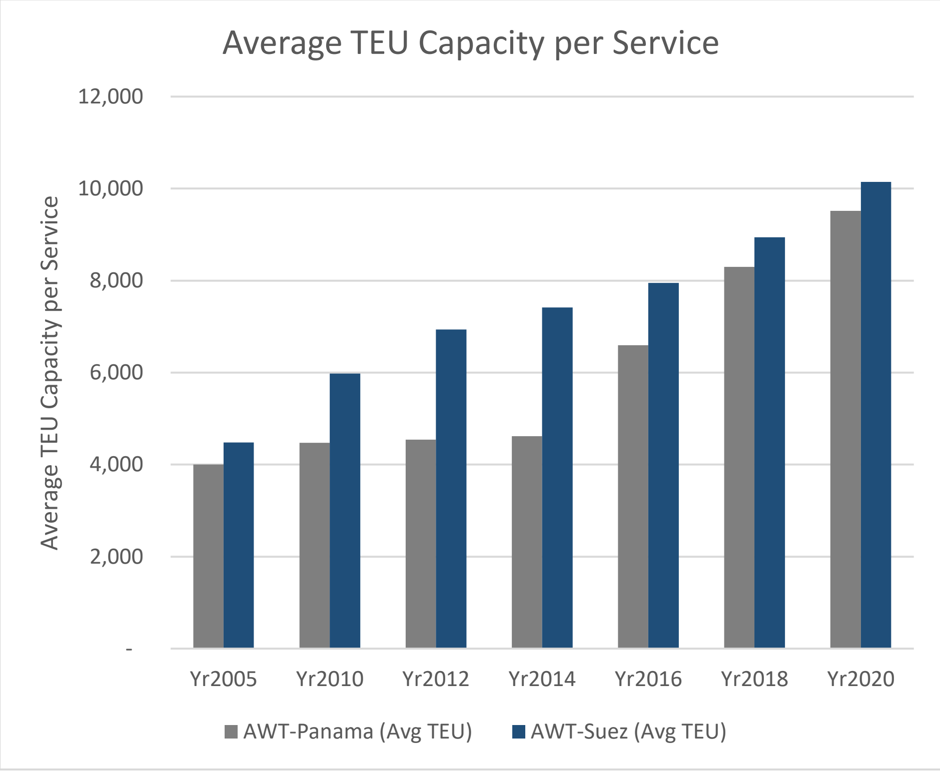
Asia – East Coast: Panama and Suez Routes – Capacity and Number



Source: Mercator, using Alphaliner, Containerization International

- Suez service counts increased when Panama ship size was constrained, then declined when the Panama route regained share in 2016.

Asia – East Coast: Panama and Suez Routes - TEU Per Service



Source: Mercator, using Alphaliner, Containerization International

- Since opening of the new Canal locks in 2016, average service capacity of Panama-route services has again been increasing.

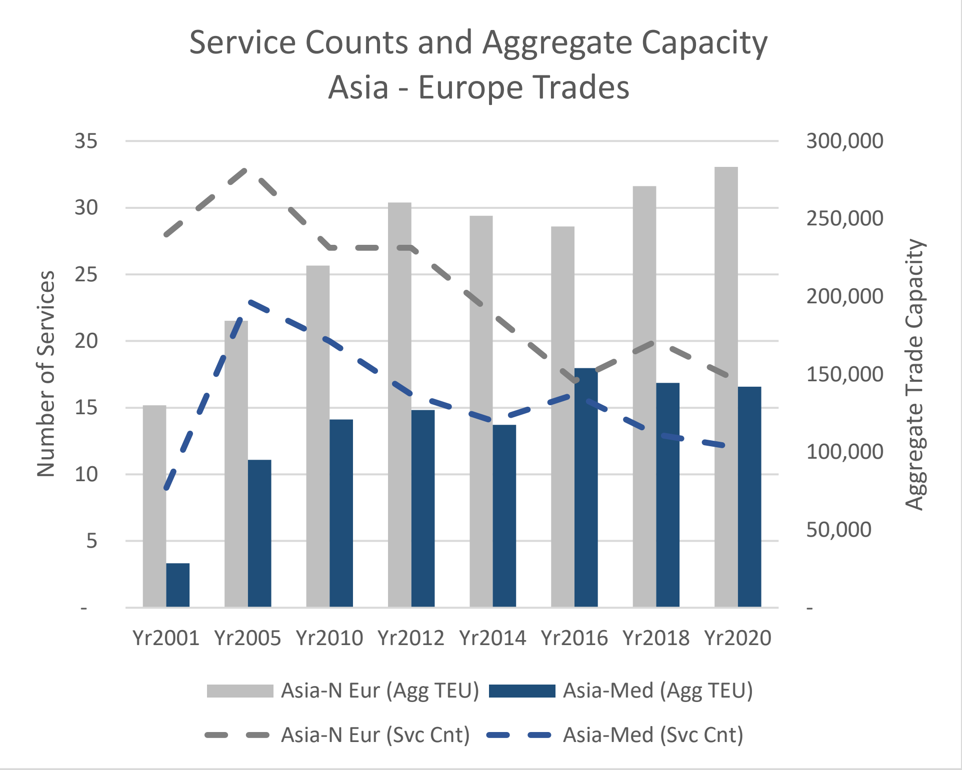
Recent Evolution of Ship Sizes and Sailing Frequencies on Key Trade Lanes

Asia – Europe theater

Carriers' largest ships have generally been deployed on the long-distance Asia-Europe routes for many years, leading to sharp declines in the number of services once average ship sizes rapidly increased following 2005.

This development can be observed for services between Asia and North Europe, as well as for services dedicated to the Asia – Mediterranean (Med) trade.

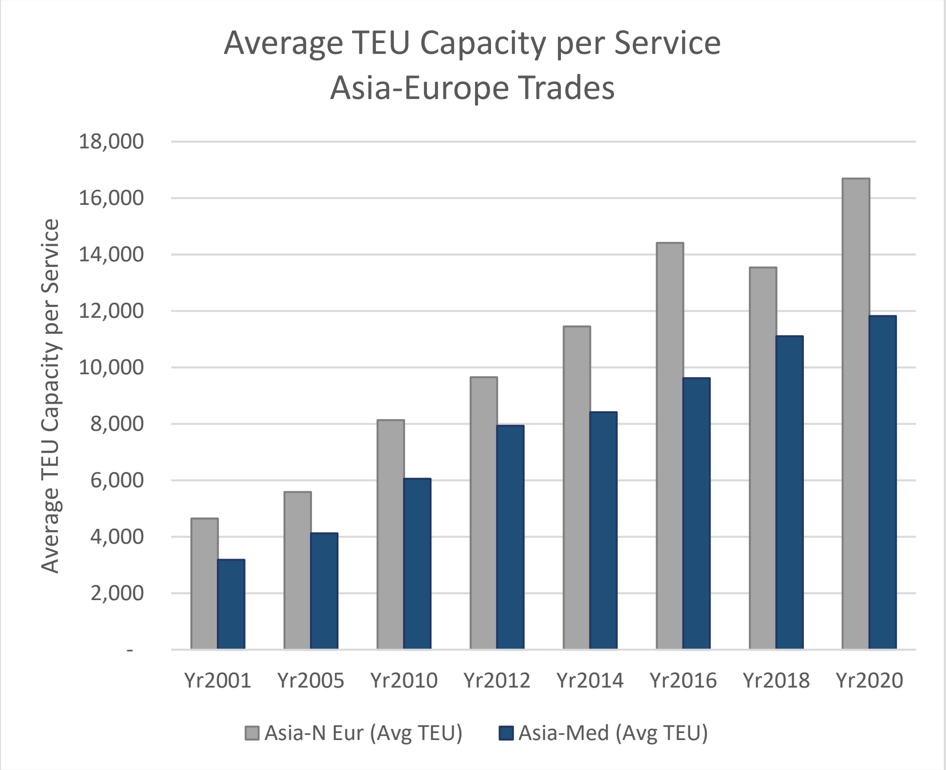
Asia – Europe – Aggregate Capacity and Number of Services



Source: Mercator, using Alphaliner, Containerization International

- Service counts have been sharply down since the introduction of large ships after 2005 for both the North Europe and Med lanes

Asia-Europe: Average TEU Capacity Per Service



Source: Mercator, using Alphaliner, Containerization International

- The large increase in average ship size, especially in the Asia N. Eur and Med trades, has been a defining feature of container shipping

mercator
Trusted. Experienced. Independent.

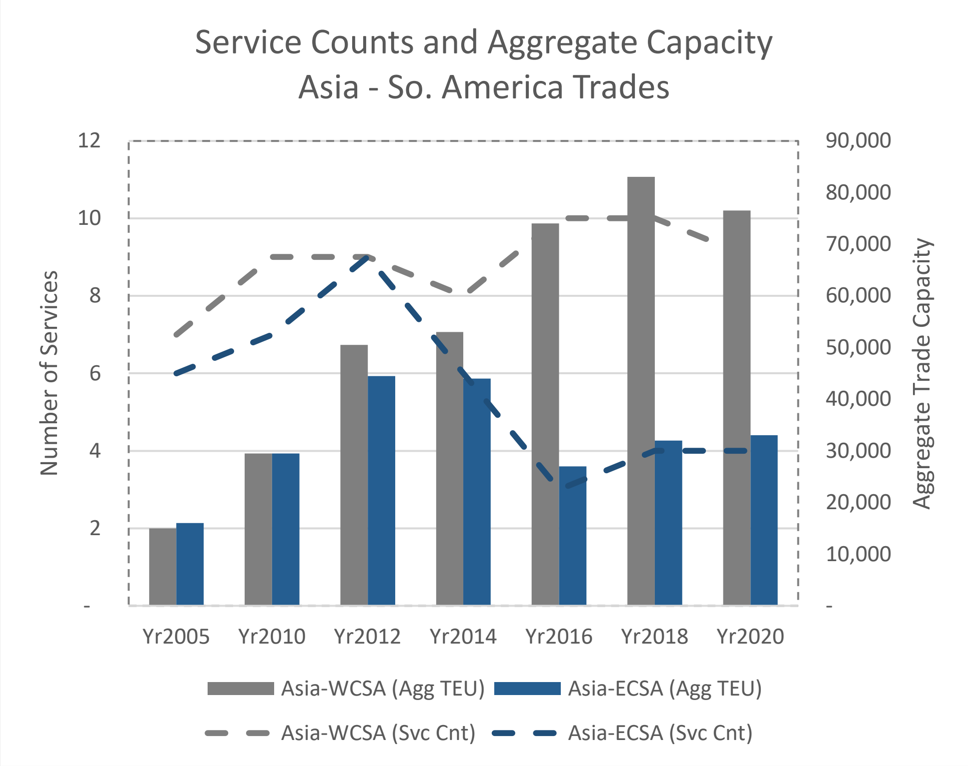
Recent Evolution of Ship Sizes and Sailing Frequencies on Key Trade Lanes

Asia – South America theater

The Asia-East Coast South America (ECSA) lane shows a pattern like the others, with a large drop in the number of services, facilitated by corollary increases in ship sizes.

The Asia-West Coast South America (WCSA) lane is more complicated due to change in the Panama Canal and more complicated service patterns (with more vessel services making intermediate calls in Pacific Mexico and/or Pacific Panama ports), but the drive toward larger vessels per service is clearly evident.

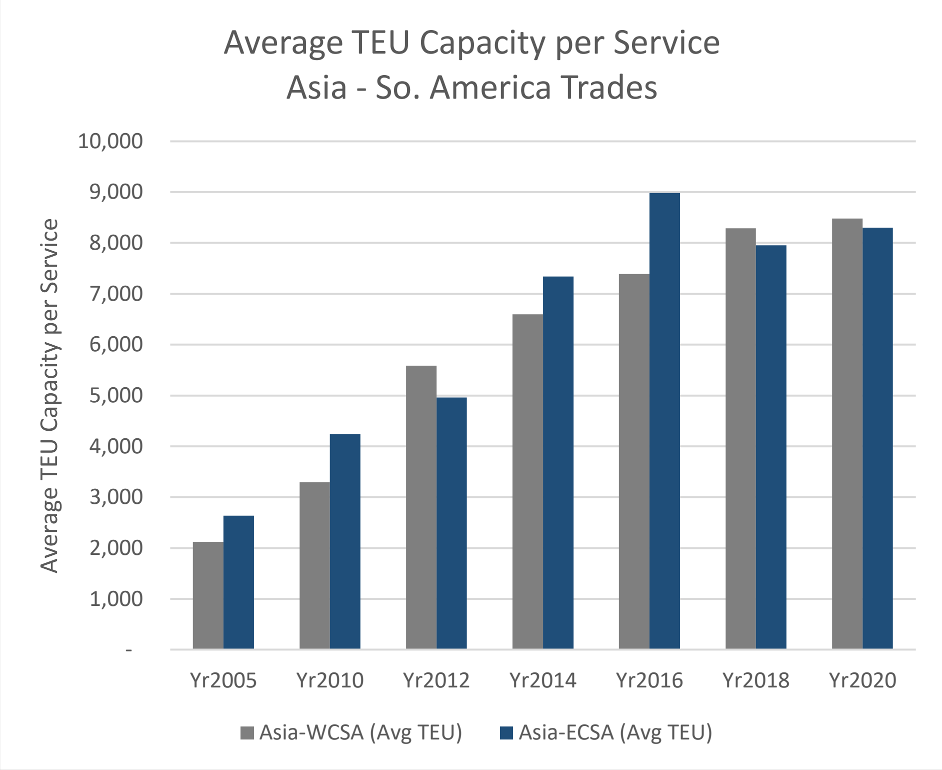
Asia – South America – Aggregate Capacity and Number of Services


Service Counts and Aggregate Capacity
Asia - So. America Trades

Source: Mercator, using Alphaliner, Containerization International

- Asia-WCSA counts increased with the change in service patterns that followed the 2016 opening of the new Panama Canal locks

Asia-South America: Average TEU Capacity Per Service


Average TEU Capacity per Service
Asia - So. America Trades

Source: Mercator, using Alphaliner, Containerization International

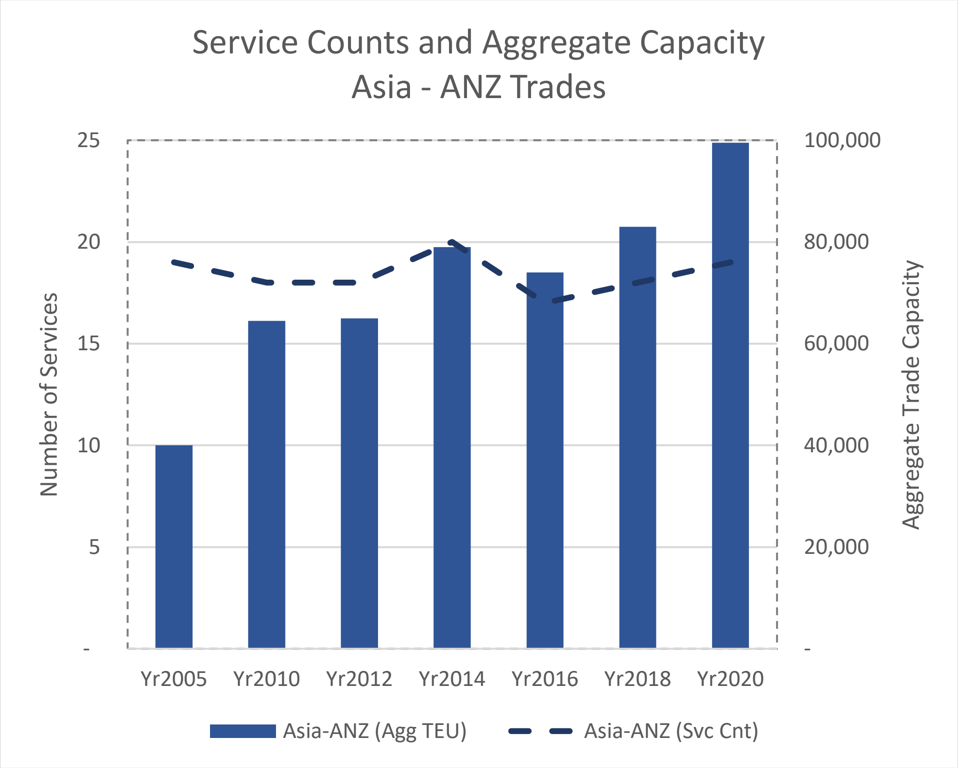
- Average capacity per service increased over nearly every interval.

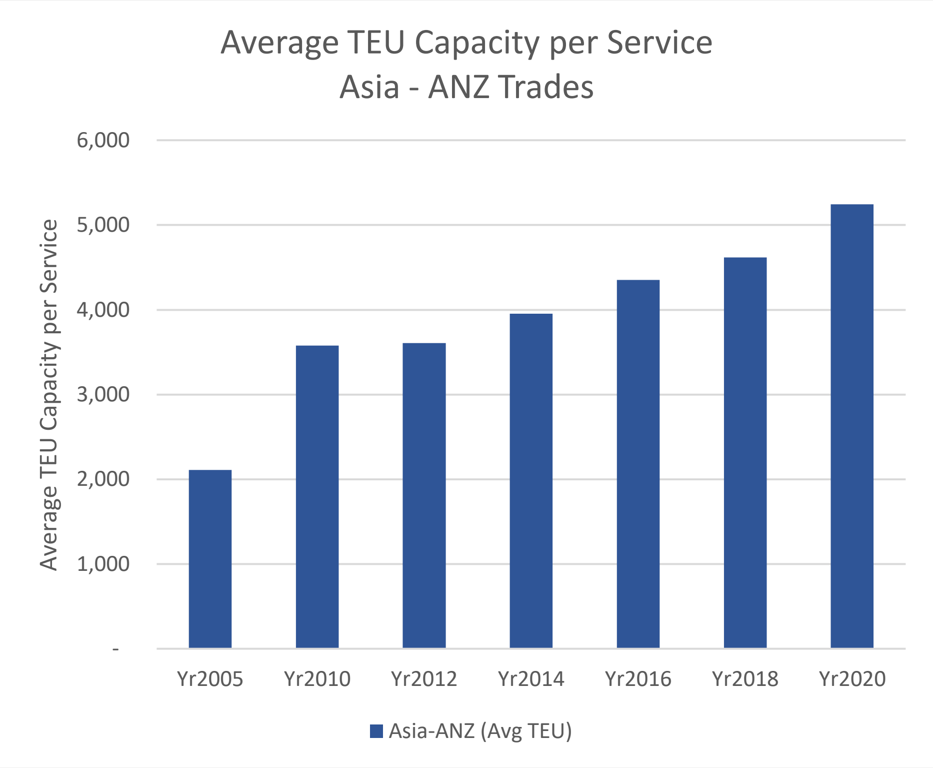
Recent Evolution of Ship Sizes and Sailing Frequencies on Key Trade Lanes

Asia – Australia/New Zealand theater

Due to geography and market considerations, the ANZ trades have generally been less affected by service consolidation, although there have been reductions in sailing frequencies in the lanes between Europe and ANZ, as well as between North America and ANZ.

Moreover, in 2020, market capacity of 100,000 TEUs/wk is being provided between Asia and ANZ by the same number of services (19) as was operated in 2005, when market capacity was only 40,000 TEUs/wk.





Source: Mercator, using Alphaliner, Containerization International

- Number of services has remained within a narrow band, even as total capacity deployed increased by a factor of 2.5x.

Source: Mercator, using Alphaliner, Containerization International

- Average capacity per service increased over every interval.

Contents

Vessel Deployments to/from the PNW Region

Review of Geographic Service Framework

There are fundamentally five separate geographic designs for liner shipping services being operated to and from the Pacific Northwest region:

The most prevalent design are services that shuttle between Asia and the PNW (some of which make scheduled calls only at the Salish Sea ports of Vancouver and Seattle/Tacoma, and some of which also make calls at Prince Rupert, in addition to Salish Sea calls) – this design is noted by the blue solid lines in the diagram.

The second service design's ships run from Asia to California, but return to Asia after making a stop at one of the Salish Sea ports – this design is noted by the black solid lines.

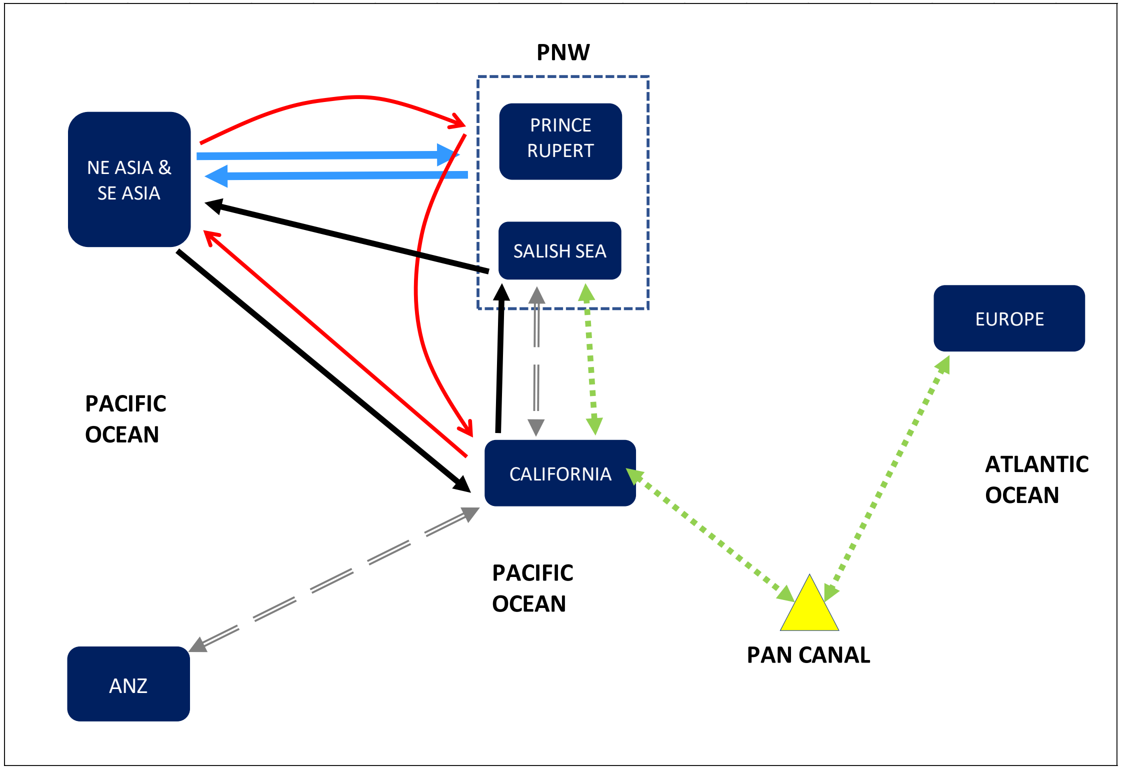
Ships with the third service design run from Asia to Prince Rupert, then to California, and then return to Asia – this design is shown with red lines in the diagram.

These three designs are clearly focused on container trade between Asia and the North American West Coast, and generate the vast majority of VFPA's container throughput.

The fourth service design entails ships running from Europe (either the Mediterranean or North Europe) to and through the Panama Canal to California and the Salish Sea ports, and then reversing course back to Europe via the Canal.

The final service design links Australia and New Zealand with California and the Salish Sea ports.

Types of containership services operated to/from the Pacific Northwest



Vessel Deployments to/from the PNW Region

Review of Asia services calling the Port of Vancouver in 3Q2020

Twelve services, with a weekly nominal capacity of about 87,000 TEUs, operate from Asia to Vancouver. 10 of these also call at NWSA ports, and three also call Prince Rupert. 100% of the capacity of these twelve strings is allocated for Asia – PNW/inland North America traffic.

One service calls Prince Rupert en-route to California **without** calling the Salish Sea (Vancouver or NWSA). About one-third of its 10,000 TEUs per week is allocated for Prince Rupert.

Three services call the PNW after calling in California. These services carry PNW export loads, particularly reefers, and empties back to Asia.

Since 2018, a limited number of service changes have been made by two alliances:

- *The 2M Alliance now includes limited participation by Zim. Consequently, the Zim eastbound service was discontinued, and a second 2M Salish Sea call was added.*
- *The 2M call in Prince Rupert (which had been made by a California service) is being made by a Salish Sea service. Zim added a service that only calls Vancouver westbound (for backhaul cargo) after calling California.*
- *The Transport High Efficiency Alliance (THEA) now includes HMM. The independent HMM PN2 service was discontinued and a fourth THEA service was added.*
- *The HMM westbound service was also discontinued.*

Container vessel services calling at PNW ports: Asia trade lanes

Trade	Alliance	Carrier	Service			Port Calls Within N.Amr. WC - Q3 2020				No. of ships	Min ship (TEU)	Max ship (TEU)	Q3 2020 Svc Cap TEU/wk
						Rupert	Vancouver	NWSA	Calif.				
Asia - P. Rupert – California - Asia													
Asia EB	Ocean	Cosco	PSW2-e/b			FCT			SPB	7	10,000	10,000	10,000
Asia EB	2M	MSC	TP-8	dropped since 2018									
Total Asia - P. Rupert – California			Weekly TEUs										10,000
			Count of Services			1	0						1
Asia – Salish Sea – (CA) - Asia													
Asia EB	Ocean	CMA (APL)	PNW1				GCT Vanterm	T18		6	8,100	10,000	8,600
Asia EB	Ocean	Cosco	PNW2			FCT	DPW Centerm			6	5,700	10,000	8,800
Asia EB	Ocean	Evergreen	PNW3				GCT Vanterm	PCT		6	5,300	7,000	5,800
Asia EB	Ocean	OOCL	PNW4				GCT Deltaport	T30		6	5,700	5,900	5,800
Asia EB	THEA	ONE	PN1				GCT Deltaport	WUT		7	6,300	6,700	6,400
Asia EB	THEA	ONE	PN2				GCT Deltaport	Husky		8	8,600	12,700	10,200
Asia EB	THEA	ONE	PN3				GCT Deltaport	T18		7	6,700	12,700	9,700
Asia EB	HMM	HMM	PN2	dropped since 2018									
Asia EB	THEA	ONE	PN4	New		FCT	GCT Deltaport	WUT		6	6,800	8,700	8,300
Asia EB	2M	MSC - Zim	TP-9				GCT Deltaport	T18		6	8,200	8,800	8,500
Asia EB	2M	MSC	TP-1	New		FCT	DPW Centerm			6	7,100	9,600	8,400
Asia EB		MSC	ZMP	dropped since 2018									
Asia EB	Niche	SM Line	PNS				FSD	T18		6	4,300	4,500	4,400
Asia EB	Specalist	Westwood	PNW				DPW Centerm	T18		7	2,000	2,500	2,300
Asia-Salish Sea-Asia			Weekly TEUs										87,200
			Svc Count			3	12	10					12
Asia – California – Salish Sea (W/B loading) – Asia													
Asia WB	Ocean	Evergreen	PSW8 (TPA)					PCT	SPB	12	6,300	8,800	7,000
Asia WB	THEA	COSCO/PIL/ WHL	TP Loop 1	dropped since 2018									
Asia WB	Ocean	COSCO	PSW2 w/b					T30	SPB	7	10,000	10,000	10,000
Asia WB	N/A	Zim	ZEX	New			GCT Vanterm		SPB		4,250	4,900	4,400
Total California-PNW-Asia			Weekly TEUs										21,400
			Count of Services				1	2					3

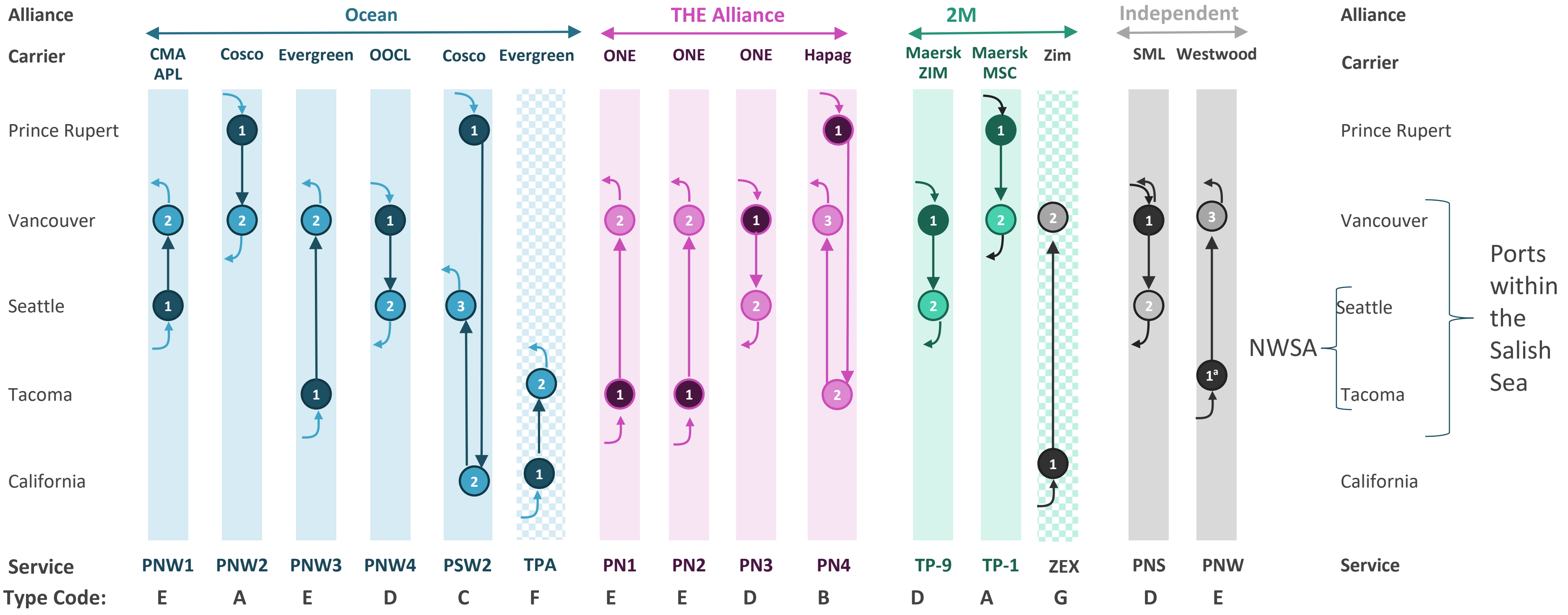
Vessel deployments to/from the PNW Region - 2020

West Coast port rotation sequences for Asian services to or from PNW ports

Between 2018 and 2020, the number of services between Asia and the PNW has declined from 17 to 15, although 1 service now makes a 2nd (w/b) call

2020 Service Table		Eastbound Calls			Westbound Calls		Salish Sea
Code	Description	Rupert	VFPA	NWSA	VFPA	NWSA	Visits
A	Prince Rupert first call + Vancouver second call (two services – PNW2, TP-1)	2	2				2
B	Prince Rupert first call + NWSA second call + Vancouver third call (one service – PN4)	1	1	1			1
C	Prince Rupert first call + LA/Long Beach second call + NWSA third call (one service – PSW2)	1				1	1
D	Vancouver first call + NSWA second call (four services – PNW4, PN3, TP-9, PNS)		4	4			4
E	NWSA first call + Vancouver second call (five services – PNW1, PNW3, PN1, PN2, PNW)		5	5			5
F	California first call + NWSA second call (one service – TPA)					1	1
G	California first call + Vancouver second call (one service – ZEX)				1		1
	Total Service Count = 15	4	12	10	1	2	15

Port rotation sequences of vessel services calling at PNW ports: Asian trades (August 2020)



[a] Also calls at Everett WA; frequency and specific rotation may vary.

mercator
Trusted. Experienced. Independent.

Vessel deployments to/from the PNW Region

Review of West Coast port rotations of Non-Asia – PNW services

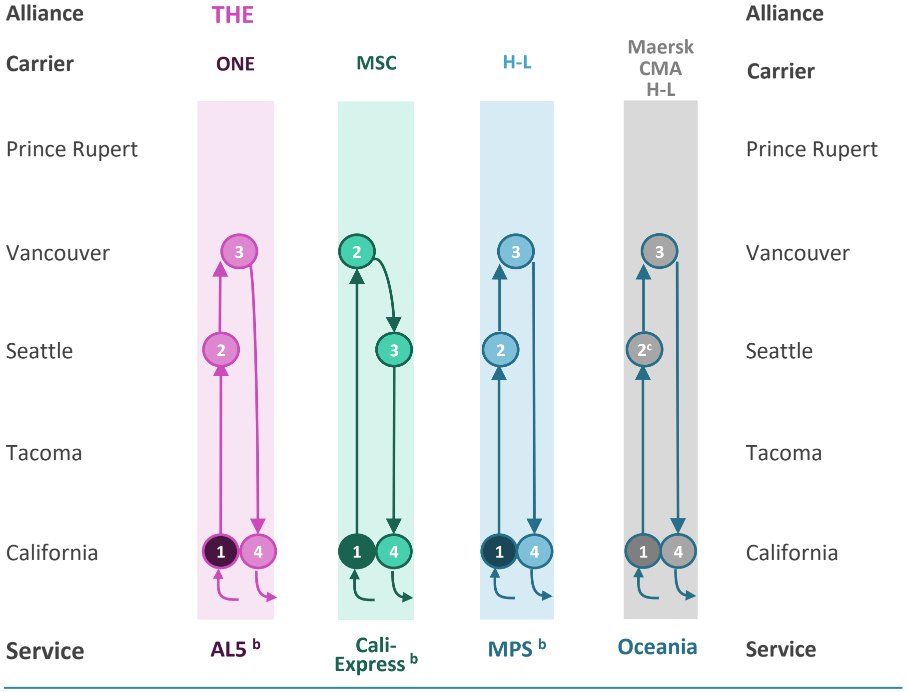
There are presently four vessel services being operated to and from the PNW Region in the two non-Asia trade lanes:

- Three of these cover the European lane, each with weekly sailing frequency, and each calling at Vancouver, as well as at one of the two Puget Sound ports
- The fourth covers the Australia/New Zealand lane with weekly sailing frequency to/from California, but only with bi-weekly frequency to the Salish Sea – in which Vancouver and Seattle are both called.

The chart to the right illustrates the sequences of port calls on the West Coast for each of these four vessel services, while the table below indicates which carriers are operating which service, and the average weekly capacity of each service (in each direction).

None of the key characteristics of these four vessel services – the port rotations, the sizes of ships being used, the carriers operating these ships – have fundamentally changed since 2018.

Vessel services calling at BC ports: Non-Asian trade lanes



b Via Panama Canal

Container vessel services calling at PNW ports: Non-Asian trade lanes

Trade	Alliance	Carrier	Service			Port Calls Within N.Amr. WC - Q3 2020				No. of ships	Min ship (TEU)	Max ship (TEU)	Q3 2020 Svc Cap TEU/wk
						Rupert	Vancouver	NWSA	Calif.				
Other PNW International Services													
Europe (N.Eur)		Hapag/ONE	AL-5				FSD	T18	SPB	11	5,000	5,000	5,000
Europe (Med)		Hapag / Maersk	MPS				FSD	T18	SPB	12	4,250	6,400	4,850
Europe (Med)		MSC	Calif-Exp				Delta	T18	SPB	11	9,400	9,400	8,800
Aust-NZ		Msk/HS/CMA/H-L	WAN				FSD	T18	SPB	9	3,850	4,600	4,250
Total Other PNW International Trades			**Weekly TEUs**										**22,900**
			Count of Calls / Services				**4**	**4**					**4**

Volume Forecast Input to Fleet Forecast

PNW container port volume by port complex – Drewry forecast

During 2020, Drewry was commissioned by the VFPA to prepare a long-term forecast of container cargo volume for the Port of Vancouver (PV), as well as for the other container ports within the PNW region.

Drewry forecasts a greater volume of PNW container cargo traffic beyond 2035, which will require more vessel capacity and, therefore, represents a more demanding outlook (in terms of potential service increases) than the 2016 Ocean Shipping Consultants (OSC) forecast[4] that was utilized in the 2018 Mercator Report.

Mercator has, therefore, based its updated container vessel forecast on the 2020 Drewry container cargo traffic forecast, which is summarized in the table to the right.

PNW container volume as forecast by Drewry in 2020

Drewry Forecast of July 2020		**000s of TEUs per Year**							**CAGR**
Port	Cont Type	2019	2020	2025	2030	2035	2040	2045	'19-'45
		Drewry Model: sheet 5.1 Portshare							
P. Rupert	Import Full	679	589	785	920	1,057	1,201	1,361	2.7%
	Export Full	192	185	238	286	328	363	394	2.8%
	Empty	340	282	382	443	509	585	676	2.7%
	Total	1,211	1,056	1,406	1,649	1,894	2,150	2,431	2.7%
		Drewry Model: sheet 4.5 TEU VFPA Forecast							
Vancouver	Import Full	1,709	1,429	2,007	2,363	2,744	3,164	3,625	2.9%
	Export Full	1,121	1,082	1,447	1,776	2,056	2,297	2,504	3.1%
	Empty	567	416	582	668	775	907	1,094	2.6%
	Total	3,397	2,927	4,036	4,808	5,575	6,368	7,223	2.9%
		Drewry Model: sheet 3.4 TEU Forecasts USA							
NWSA	Import Full	1,369	1,226	1,564	1,822	2,072	2,323	2,603	2.5%
	Export Full	913	878	1,035	1,177	1,303	1,415	1,515	2.0%
	Empty	776	617	762	879	989	1,096	1,207	1.7%
	Domestic	717	670	837	1,003	1,152	1,287	1,410	2.6%
	Total	3,775	3,392	4,198	4,882	5,516	6,121	6,736	2.3%
Total PNW	Import Full	3,757	3,244	4,356	5,105	5,873	6,689	7,589	2.7%
	Export Full	2,226	2,145	2,721	3,240	3,687	4,076	4,414	2.7%
	Empty	1,682	1,315	1,726	1,990	2,273	2,588	2,976	2.2%
	Domestic	717	670	837	1,003	1,152	1,287	1,410	2.6%
	Total	8,383	7,374	9,640	11,339	12,985	14,639	16,389	2.6%
	Total Int'l.	7,666	6,704	8,803	10,335	11,833	13,352	14,979	

[4] Ocean Shipping Consultants (2016): Container Traffic Forecast Study – Port of Vancouver, 2016 (Appendix IR1-03-A). Available at Canadian Impact Assessment Registry (Document #934): https://www.ceaa-acee.gc.ca/050/documents/p80054/122026E.pdf

Volume Forecast Input to Fleet Forecast

PNW container port volume by port and trade-lane

The Drewry (2020) total PNW port forecast figures were allocated to trade lanes and inbound (IB) versus outbound (OB) and empty (Mty) flows based on historical traffic composition. The table contains the annual container traffic volumes which determine the required capacity of services calling the PNW region.

Traffic flows shown here assume that RBT2 is completed and, therefore, exclude any re-routing of traffic due to VFPA capacity constraints.

- *On the next slide, volume for the scenario WITHOUT RBT2 is determined.*

PNW headhaul (inbound) traffic flows by port complex and trade lane

New Drewry Forecast of 2020									
		2019	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**CAGR**
Headhaul By Tradelanes - Driving Vessel Capacity Requirements - Derived from Drewry (2020)									**19-'45**
Rupert		000s of TEUs per Year							
IB Full		679	589	785	920	1,057	1,201	1,361	2.7%
IB Mty	%ofTotMty	-	-	-	-	-	-	-	
Tot IB		679	589	785	920	1,057	1,201	1,361	2.7%
Distribution by Trades									
Asia		679	589	785	920	1,057	1,201	1,361	2.7%
Eur/Amer		-	-	-	-	-	-	-	
Vancouver									
IB Full		1,709	1,429	2,007	2,363	2,744	3,164	3,625	2.9%
IB Mty	%ofTotMty	14	10	14	16	19	22	26	2.6%
Tot IB		1,723	1,439	2,021	2,379	2,763	3,186	3,651	2.9%
Distribution by Trades									
Asia		1,585	1,324	1,859	2,189	2,542	2,931	3,359	2.9%
Eur/Amer/ANZ		138	115	162	190	221	255	292	2.9%
NWSA									
IB Full		1,369	1,226	1,564	1,822	2,072	2,323	2,603	2.5%
IB Mty	%ofTotMty	155	123	152	176	198	219	241	1.7%
Tot IB		1,524	1,350	1,717	1,998	2,269	2,542	2,845	2.4%
Distribution by Trades									
Asia		1,402	1,242	1,579	1,838	2,088	2,339	2,617	2.4%
Eur/Amer/ANZ		122	108	137	160	182	203	228	2.4%
PNW All									
IB Full		3,757	3,244	4,356	5,105	5,873	6,689	7,589	2.7%
IB Mty		169	133	166	192	216	241	268	1.8%
Tot IB		3,926	3,377	4,523	5,297	6,089	6,930	7,857	2.7%
Distribution by Trades									
Asia		3,666	3,154	4,224	4,947	5,686	6,471	7,337	
Eur/Amer/ANZ		260	223	299	350	403	458	520	
TEUs (000s) per week									
Asia		70.5	60.7	81.2	95.1	109.4	124.4	141.1	
Eur/Amer/ANZ		5.0	4.3	5.7	6.7	7.7	8.8	10.0	

mercator
Trusted. Experienced. Independent.

Volume Forecast Input to Fleet Forecast

Diversion analysis for the “Without RBT2” scenario

Without RBT2 constructed, VFPA will become capacity constrained shortly after 2030.

After that point, Mercator assumes that the Western Canada cargo from Europe and Australia would continue to be routed through Vancouver, with some Asia traffic being re-routed to keep VFPA volume within its 4.7 million TEU capacity constraint.

Without RBT2, PV total capacity of 4.7 million would support about 2.4 million TEUs of inbound containers (Inbound flows comprise about 51.2% of total containers). This results in a requirement to “re-route” 1.245 million TEUs of Asia inbound cargo by 2045 (unconstrained demand of 3.651 exceeds IB capacity of 2.406 by 1.245 million TEUs).

We expect that 30% of the re-routed cargo will flow through Prince Rupert (assuming that port has developed significantly more capacity in the interim), 30% via NWSA, and 40% through other gateways (California and East Coast ports).

Prince Rupert and NWSA would each handle about 473,000 TEUs of additional cargo, and the PNW region would “lose” about 500,000 inbound TEUs by 2045.

Consequently, in the WITHOUT RBT2 scenario, the annual ship capacity for inbound Asia containers to the PNW would be about 500,000 TEUs less than in the WITH RBT2 scenario.

Required re-routes if VFPA capacity is limited (the WITHOUT RBT2 scenario

			2025	2030	2035	2040	2045
Port of Vancouver (PV) Total Capacity Limit, TEUs p.a.			4,700	4,700	4,700	4,700	4,700
PV Inbound Limit		51.2% of total	2,406	2,406	2,406	2,406	2,406
Unconstrained PV Inbound F'casts (all trades)			2,021	2,379	2,763	3,186	3,651
PV Inbound that must be re-routed (TEUs)			-	-	356	780	1,245
Unconstrained PV Asia Inbound			1,859	2,189	2,542	2,931	3,359
Less Volume that must be re-routed			-	-	(356)	(780)	(1,245)
PV Asia I/B Remaining After Re-Routes			1,859	2,189	2,185	2,152	2,114
Reallocation of PV Traffic:	P. Rupert	30%	-	-	107	234	373
	NWSA	30%	-	-	107	234	373
	Calif+East Coast (i.e. not via PNW)	40%	-	-	143	312	498
		100%	-	-	356	780	1,245
Revised Asia I/B Volumes to PNW After Re-Routing Traffic Due to PV Capacity Constraint							
	P. Rupert		785	920	1,164	1,435	1,734
	Vancouver		1,859	2,189	2,185	2,152	2,114
	NWSA		1,579	1,838	2,195	2,573	2,991
Total Asia Inbound to PNW (000s TEUs p.a.)			4,224	4,947	5,544	6,159	6,839
Total Asia Inbound to PNW (000s TEUs/wk)			81.2	95.1	106.6	118.4	131.5
Impact of Re-routes on PNW Inbound:							
Change in Asia I/B to PNW (000s TEUs p.a.)			-	-	(143)	(312)	(498)
Change in Asia I/B to PNW (000s TEUs/wk)			-	-	(2.7)	(6.0)	(9.6)
Percent Change in Asia IB to PNW			0%	0%	-3%	-5%	-7%

Projections of PNW Vessel Services for 2025 and 2030 (With or Without RBT2)

Asia eastbound trade lane

Mercator's service projections for 2025 reflect a 17% increase in capacity over 3Q2020 levels, which, combined with the Drewry (2020) forecast, will result in vessel capacity utilization consistent with normal historical levels.

These projections were developed partially on the assumption that the ten global carriers serving the Asia – PNW lane (who are also the ten largest shipping lines in the world) are currently supporting ten Asia – Salish Sea services, through three alliances, and collectively will still need and want to operate that many separate services, even if the assignments of the top-ten lines to the three alliances change during the next five years.

We further project two independent services to be operated outside the framework of the three alliances – one by the niche carrier Westwood Lines (with specialized ships capable of carrying break-bulk forest products), and the other by the Korean carrier SM Lines (or a non-global carrier replacing SM Lines).

Mercator's projections also allow for an additional Asia – Prince Rupert – California service being operated (after the completion of the Fairview Terminal Phase II-B expansion), which enables the forecasted capacity growth for Asia – Salish Sea services to be relatively low.

For 2030, we expect a continuation of the "10+2" structure for the Asia – Salish Sea segment, with ten services operated by the global carriers (in three alliances) and two independent.

The projections for 2025 and 2030 would be applicable regardless of whether RBT2 proceeds.

Projections of Asia – Salish Sea – eastbound vessel deployments, 2025-2030

Trade	Alliance	Carrier	Service	Q3 2020 Svc Cap TEU/wk	2025	2030
Asia - P. Rupert – California - Asia						
Asia EB	Ocean	Cosco	PSW2-e/b	10,000	13,000	13,000
Asia EB	THEA	?	Rpt-Calif		8,000	10,000
Total Asia - P. Rupert – California			**Weekly TEUs**	**10,000**	**21,000**	**23,000**
			Count of Ser	**1**	**2**	**2**
Share of Rupert-CALIF Capacity Used for Rupert				**33%**	**30%**	**33%**
Asia - Rupert (PNW Allocated) Capacity				**3,500**	**6,500**	**7,500**
Asia – Salish Sea – (CA) - Asia				**Asia-Salish Services**		
Asia EB	Ocean	CMA (APL)	PNW1	8,600	8,600	13,000
Asia EB	Ocean	Cosco	PNW2	8,800	9,600	9,600
Asia EB	Ocean	Evergreen	PNW3	5,800	7,000	8,000
Asia EB	Ocean	OOCL	PNW4	5,800	9,400	9,400
Asia EB	THEA	ONE	PN1	6,400	8,000	9,000
Asia EB	THEA	ONE	PN2	10,200	10,200	10,200
Asia EB	THEA	ONE	PN3	9,700	9,700	14,500
Asia EB	THEA	ONE	PN4	8,300	11,000	11,000
Asia EB	2M	MSC - Zim	TP-9	8,500	11,000	11,000
Asia EB	2M	MSC	TP-1	8,400	8,400	11,000
Asia EB	Niche	SM Line	PNS	4,400	4,400	5,000
Asia EB	Specalist	Westwood	PNW	2,300	2,300	4,000
Asia-Salish Sea-Asia			**Weekly TEUs**	**87,200**	**99,600**	**115,700**
			Svc Count	**12**	**12**	**12**
Avg TEUs (Nom. Capac.) per Service				**7,267**	**8,300**	**9,642**

Mercator estimates that the share of vessel capacity that these carriers allocate on their respective services for Prince Rupert discharge will remain limited to about 33%.

Projections of PNW Vessel Services for 2025 and 2030 (With or Without RBT2)

Other trade lanes

Westbound services to Asia

Mercator expects that a few of the global carriers will continue to operate vessel services that are designed primarily to transport Asian import containers to California, but that stop in a Salish Sea port after stopping in California.

These services primarily support carriers' strategies to balance equipment flows, but also enable them to be more competitive for handling PNW export cargos.

We are thus projecting three such services to be operating for the balance of the decade.

Europe services

Two of the three vessel services in the Europe trade are controlled by Hapag Lloyd – a North Europe string operated with ONE, and a separate Med string operated with Maersk. Both services use ships that were sized ten years ago for the old locks of the Panama Canal, but which are now cost-uncompetitive with MSC's Med service.

Thus, Mercator projects that Hapag, ONE, and Maersk will reconfigure and combine these two services by 2025, so that larger ships can be deployed here, in conjunction with one or more of their Europe – West Coast South America services.

ANZ service

Hapag Lloyd, CMA, and Maersk (or ship lines that these companies have acquired) have been collaborating in this low-growth trade for well over ten years, and have generally maintained the only containership service linking ANZ and the West Coast. Mercator expects this stability to continue through the decade, with the service being upsized by 2025.

Projection of PNW – Asia westbound service calls

Trade	Alliance	Carrier	Service	Svc Cap TEU/wk	2025	2030
Asia – California – Salish Sea (W/B loading) – Asia						
Asia WB	Ocean	Evergreen	PSW8 (TPA)	7,000	7,000	10,000
Asia WB	Ocean	COSCO	PSW2 w/b	10,000	13,000	13,000
Asia WB	N/A	Zim	ZEX	4,400	4,400	4,400
Total California-PNW-Asia			**Weekly TEUs**	**21,400**	**24,400**	**27,400**
			Count of Services	**3**	**3**	**3**

Projections of PNW services in non-Asia trade lanes (i.e. Europe and Australia trades)

Trade	Alliance	Carrier	Service	Svc Cap TEU/wk	2025	2030
Other PNW International Services						
Europe (N.Eur)	THEA	Hapag/ONE	AL-5	5,000	consolidated	
Europe (Med)	N/A	Hapag / Mrsk	MPS	4,850	8,500	10,000
Europe (Med)	N/A	MSC	Calif-Exp	8,800	9,400	11,000
Aust-NZ	N/A	Msk/HS/CMA /H-L	WAN	4,250	5,500	5,500
Total Other PNW Intl. Trades			**Weekly TEUs**	**22,900**	**23,400**	**26,500**
			Count of Calls / Services	**4**	**3**	**3**

Terminal Color Code
Vanterm (Burrard)
Centerm (Burrard)
Deltaport (Roberts Bank)
RBT2 (Roberts Bank)
FSD (Fraser River)

Projections of PNW Vessel Deployments Beyond 2030

Overview and framework

The structure of the liner shipping industry, along with the corollary number of vessel sharing alliances (and the carrier memberships in those alliances) becomes increasingly ambiguous beyond 2030.

Nonetheless, in order to formulate a logical view on the number and average vessel size of separate deployments that could be expected to be operated in 2035 through 2045, especially for the critical Asia – Salish Sea – Asia segment, Mercator makes the following assumptions on the future structure of the liner shipping industry:

- There will continue to be, through the forecast period to 2045, one global carrier operating one or more Asia – Salish Sea deployments from each of the following countries – China, Japan, Korea, Taiwan, Germany, Denmark, and France – considering the direct and/or indirect support that the eight global carriers headquartered in those countries will likely continue to receive from their host governments and major exporting/industrial companies.
- Because MSC, CMA CGM, and Evergreen are family-controlled businesses, there is perhaps some possibility that one or more of these companies could potentially merge with another line to obtain scale advantages. However, these three carriers (regardless of whether they remain independent or not, or remain in their current alliances, or merge) will support at least one Asia – Salish Sea deployment apiece through the forecast period.
- Based on the two preceding structural assumptions, and on the developments of the past two years (as well as patterns of the prior two decades), Mercator projects that for the 2030-2045 period, there will be ten global carriers (one of which – COSCO – will be a state-owned company, while most of the others will receive indirect support from their host governments and/or from industrial conglomerates in their home countries). These ten global carriers can be expected to be configured in three separate alliances.
- With support from forest/paper products exporters in the PNW and importers in Japan/Korea/Northeast China, and with the continued use of multi-purpose ships designed for those commodities, Westwood should be able to sustain its niche Asia – PNW service through the forecast period.
- There is likely to be one non-major ocean carrier operating an independent Asia – Salish Sea deployment (outside of the global alliance service structures) at least intermittently through the forecast period, given patterns of the past thirty years, during which new entrants have periodically launched such operations.

Projections of PNW Vessel Services for 2030, and for 2035, 2040 and 2045 – WITH RBT2

Asia eastbound trade lanes

Based on the assumptions outlined on the prior page, as well as on considerations of vessel scale economies and vessel sizing trends, Mercator projects that the Asia – PNW trade will be served during the 2035-2045 period by twelve Asia – Salish Sea eastbound services, together with two Asia – Prince Rupert – California eastbound services.

- Ten of the twelve Asia – Salish services and both Asia – Prince Rupert services are expected to be operated by global carriers, configured in three separate vessel sharing alliances.
- The other two Asia – Salish Sea services are expected to be operated by an independent carrier and by a commodity-specialist carrier.

The projected size evolution (in terms of TEU capacity) of these fourteen services over the 2030-2045 period, for the scenario in which RBT2 is operating, are indicated in the table to the right.

There are a few reasons for the projected stability in the number of services, in addition to the assumptions made regarding industry structure:

- For the three alliances and the carriers in those alliances, by 2035, the capacities required for their ten Asia – Salish Sea services are sufficiently large to make it unlikely they would attempt to consolidate two separate vessel deployments into a single string, which would require ships above 22,000+ TEU capacity. The peak-day impact of such large ships in a shuttle service calling just 2 terminals would put enormous pressure on either of the terminals at the Roberts Bank precinct and on any of the NWSA terminals in Seattle/Tacoma, resulting in low levels of customer service and delayed transit times.
- In addition, the member carriers in these alliances have various commercial requirements for calling specific ports in Northeast and Southeast Asia, that result in pressures to maintain current sailing frequencies in the theater.
- Conversely, the economics of adding a service for any of the three alliances, are detrimental, in terms of network operating costs.

Projections of Asia – PNW – eastbound vessel deployments, 2030-2045

Trade	Alliance	Service	2030	2035	2040	2045
Asia - P. Rupert – California - Asia						
Asia EB	Ocean	PSW2-e/b	13,000	13,000	13,000	14,500
Asia EB	THEA	Rpt-Calif	10,000	13,000	13,000	14,500
Total Asia - P. Rupert – California			23,000	26,000	26,000	29,000
			2	2	2	2
% of Rupert-CALIF Capacity for Rupert			33%	30%	33%	33%
Asia - Rupert (PNW Allocated) Capacity			7,500	8,000	8,500	9,500
Asia – Salish Sea – (CA) - Asia						
Asia EB	Ocean	PNW1	13,000	14,500	14,500	18,000
Asia EB	Ocean	PNW2	9,600	13,000	18,000	22,000
Asia EB	Ocean	PNW3	8,000	12,000	12,000	14,500
Asia EB	Ocean	PNW4	9,400	10,500	10,500	10,500
Asia EB	THEA	PN1	9,000	9,000	14,000	18,000
Asia EB	THEA	PN2	10,200	12,500	12,500	12,500
Asia EB	THEA	PN3	14,500	14,500	18,000	22,000
Asia EB	THEA	PN4	11,000	13,000	13,000	13,000
Asia EB	2M	TP2	11,000	11,000	13,000	13,000
Asia EB	2M	TP1	11,000	14,500	18,000	18,000
Asia EB	Niche	PNS	5,000	5,500	6,000	6,000
Asia EB	Specalist	PNW	4,000	4,000	4,000	4,000
Asia-Salish Sea-Asia			115,700	134,000	153,500	171,500
			12	**12**	**12**	**12**
Avg TEUs (Nom. Capac.) per Service			9,642	11,167	12,792	14,292

Projections of PNW Vessel Services for 2030, and for 2035, 2040 and 2045 – WITHOUT RBT2

Asia eastbound trade lanes

Should RBT2 not be built during the forecast period, Mercator projects that there will be twelve Asia – Salish Sea eastbound vessel services, with the same distribution among the expected vessel sharing alliances among the global carriers, plus the two independent services, following the same pattern as in the With RBT2 scenario.

However, some of the ten Asia – Salish Sea services operated by the global carriers would likely use slightly smaller ships, because of the lack of terminal capacity in the Vancouver port complex, which would lead to the diversion of certain volumes of containers that would otherwise have been routed through Vancouver terminals.

Although a portion of the diversions would be re-routed through Prince Rupert and another portion through Seattle and Tacoma terminals, a significant portion would be re-routed through the Ports of Los Angeles/Long Beach and East Coast ports. That latter portion is expected to lead to less total eastbound on-board TEU capacity being allocated to the Asia – Salish Sea lane by the global carriers.

The lack of sufficient terminal capacity in the Vancouver port complex – in the absence of RBT2 – is also projected by Mercator to result in a third Asia – Prince Rupert – California service being operated (one string for each of the three global carrier alliances), to handle the diversions of intermodal container flows away from Vancouver.

The projected size evolution (in terms of TEU capacity) of Asia-PNW services over the 2035-2045 period, for the scenario in which **RBT2 is NOT operating**, is shown in the table to the right.

Projections of Asia – PNW– eastbound vessel deployments, 2030-2045

Trade	Alliance	Service	2030	2035	2040	2045
Asia						
Asia EB	Alliance A		13,000	13,000	13,000	14,500
Asia EB	Alliance B		10,000	13,000	13,000	14,500
Asia EB	Alliance C			13,000	13,000	14,500
Total Asia - P. Rupert – California			**23,000**	**39,000**	**39,000**	**43,500**
			2	**3**	**3**	**3**
% of Rupert-CALIF Capacity for Rupert			**33%**	**33%**	**33%**	**33%**
Asia - Rupert (PNW Allocated) Capacity			**7,500**	**13,000**	**13,000**	**14,500**
Asia – Salish Sea – (CA) - Asia						
Asia EB	Alliance A	PNW1	13,000	13,000	18,000	18,000
Asia EB	Alliance A	PNW2	9,600	12,000	14,500	18,000
Asia EB	Alliance A	PNW3	8,000	10,500	10,500	13,000
Asia EB	Alliance A	PNW4	9,400	12,000	12,000	12,000
Asia EB	Alliance B	PN1	9,000	9,000	14,000	18,000
Asia EB	Alliance B	PN2	10,200	12,500	12,500	12,500
Asia EB	Alliance B	PN3	14,500	14,500	14,500	18,000
Asia EB	Alliance B	PN4	11,000	11,000	11,000	11,000
Asia EB	Alliance C	TP2	11,000	11,000	14,500	14,500
Asia EB	Alliance C	TP1	11,000	11,000	11,000	13,000
Asia EB	Niche	PNS	5,000	5,000	5,000	5,000
Asia EB	Wood	PNW	4,000	4,000	4,000	4,000
Subtotal - Asia-Salish Sea-Asia			**115,700**	**125,500**	**141,500**	**157,000**
			12	**12**	**12**	**12**
Average TEUs (Nom. Capac.) per Service			**9,642**	**10,458**	**11,792**	**13,083**

Projections of PNW Vessel Services for 2030, and for 2035, 2040 and 2045 – <u>WITH RBT2</u>

Other trade lanes

Westbound services to Asia

Based on our assumptions regarding the liner shipping industry's future structure – i.e., a continuation of the current concentration of the industry, with approximately ten global carriers controlling over 80% of the global containership fleet – and the corollary projection of the global carriers operating in three vessel sharing alliances in the major east-west trade lanes – Mercator projects that there will continue to be three Transpacific services across the forecast period that run eastbound from Asia to California and return in the Salish Sea on the westbound voyage leg.

We further project that each of the three alliances of global carriers will operate such a vessel service – two making calls at Puget Sound terminals, and the third stopping in Vancouver.

One of the reasons for the higher number of stops in Seattle/Tacoma than in Vancouver is there are (and likely will continue to be) terminals in the Puget Sound ports in which selected ocean carriers have ownership stakes. The westbound stops for these carriers can generate higher volumes for their affiliated terminals.

Non-Asia (Europe and ANZ) services

Mercator projects that the Europe – West Coast North America trade lane will continue to be served by no more than two groups of global carriers. By 2045, we expect that one of those groups will operate two services in this trade, in order to have separate strings for North Europe and for the Mediterranean theaters.

We also project the Australia/NZ – West Coast North America lane to continue to be served by one vessel sharing alliance, with one Transpacific sailing per week, and with gradually increasing sizes of ships. The progression of Non-Asia services is shown in the lower table at the right.

Projection of PNW – Asia westbound service calls

Trade	Alliance	Service	2030	2035	2040	2045
Salish Sea (W/B loading) – Asia						
Asia WB	Alliance A	**Puget 1**	10,000	12,000	13,000	13,000
Asia WB	Alliance A	**Puget 2**	13,000	13,000	13,000	14,500
Asia WB	Alliance C	Van 1	4,400	6,500	8,500	10,000
Total California-PNW-Asia			**27,400**	**31,500**	**34,500**	**37,500**
			3	**3**	**3**	**3**

Projections of PNW services in non-Asia trade lanes (i.e. Europe and Australia)

Trade	Alliance	Service	2030	2035	2040	2045
Other PNW International Services						
Europe (N.Eur)	Alliance X	EUR3	restart after 2040			8,500
Europe (Med)	Alliance X	EUR2	10,000	13,000	14,500	8,500
Europe (Med)	Alliance Y	EUR1	11,000	13,000	14,500	14,500
Aust-NZ	Multi-Carrier	ANZ	5,500	6,700	6,700	7,500
Total Other PNW Intl. Trades			**26,500**	**32,700**	**35,700**	**39,000**
			3	**3**	**3**	**4**

Projections of PNW Vessel Services for 2030, and for 2035, 2040 and 2045 – WITHOUT RBT2

Other trade lanes

Westbound services to Asia

In the future, The number and sizes of services that make intermediate westbound stops in the Salish Sea, en-route back to Asia, should not be impacted by the lack of Vancouver port capacity that would result from the non-development of RBT2.

This is because the Asia westbound flows are backhaul volumes and, as long as there is capacity for the headhaul volumes, there will be capacity for the backhaul.

Moreover, the commercial reasons that incent a global carrier to add an intermediate westbound call in Vancouver to a service returning to Asia from California will still be in place, even with capacity pressures in Vancouver.

Non-Asia (Europe and ANZ) services

Separately, the services running between Europe and Vancouver, along with the service operating between ANZ and Vancouver, will still need to be handled at Vancouver. Cancelling BC port calls and routing containers originating or terminating in British Columbia through NWSA terminals would then entail extra costs and delays of cross-border trucking and is not likely.

Thus, Mercator expects that the vessel services for these non-Asia trade lanes will continue to have access to Vancouver's berth and terminal capacities in the Without RBT2 scenario. We assume, in other words, that all Vancouver capacity shortfalls in this Without RBT2 scenario are accommodated by diverting Asia inbound containers, not by diverting non-Asia cargoes.

Projection of PNW – Asia westbound service calls

Trade	Alliance	Service	2030	2035	2040	2045
Salish Sea (W/B loading) – Asia						
Asia WB	Alliance A	Puget 1	10000	12000	13000	13000
Asia WB	Alliance A	Puget 2	13000	13000	13000	14500
Asia WB	Alliance C	Van 1	4400	6500	8500	10000
Total California-PNW-Asia			**27,400**	**31,500**	**34,500**	**37,500**
			3	**3**	**3**	**3**

Projections of PNW services in non-Asia trade lanes (i.e. Europe and Australia trades)

Trade	Alliance	Service	2030	2035	2040	2045
Other PNW International Services						
Europe (N.Eur	Alliance X	EUR3	restart after 2040			8,500
Europe (Med)	Alliance X	EUR2	10,000	13,000	14,500	8,500
Europe (Med)	Alliance Y	EUR1	11,000	13,000	14,500	14,500
Aust-NZ	Multi-Carri	ANZ	5,500	6,700	6,700	7,500
Total Other PNW Intern'l. Trades			**26,500**	**32,700**	**35,700**	**39,000**
			3	**3**	**3**	**4**

Projections of PNW Vessel Services for 2030 and 2035 – WITH RBT2

Comparison of Mercator's 2018 and 2020 forecasts

As indicated in the table to the right, for the scenario in which RBT2 is operating after 2030, Mercator projects the number of services making scheduled calls within the Vancouver port complex in 2035 – at 16 – is one more than the projection included in the 2018 Mercator Report. The increase in Vancouver calls is accompanied by a decrease in NWSA calls, because one of the three westbound Asia services is calling at Vancouver rather than at a NWSA terminal. The number of Salish Sea visits is unchanged.

As in the 2018 Mercator Report, we are still projecting that all twelve of the expected Asia – Salish Sea services will make eastbound calls at Vancouver. Said another way, there are no Transpacific eastbound vessel services operated presently that call at either of the NWSA ports without also calling at Vancouver. We expect that pattern to continue, because of both the size of the local BC market and also because of the intermodal rail services that ocean carriers can exploit from/to Vancouver.

Similar to the 2018 Report, we are still projecting that the two European services will call in Vancouver and that the ANZ service will call on a bi-weekly basis.

The differences between this 2021 Report and the 2018 Mercator Report are as follows:

a) Small changes in distribution of ship sizes in Asia-Salish E/B, reflecting our views on evolution of container fleet composition:
   - ** Services expected to use 15,000 and 17,000 TEU "ULCS" ships now forecast to use "workhorse" NPX class (to 14,999 TEU)*
   - ** Services sized just below "NPX" upgraded to NPX*

b) A westbound Salish service with NPX ships has been replaced by a service with smaller ships

Salish Sea container ship visits and VFPA Calls (changes in the forecast are shaded)

Service Count Recaps - With RBT2

2018 Mercator Analysis			**Salish Sea Visits/wk**	**2021 Mercator Analysis**		
Less Than:	2030	2035	Service Types:	Less Than:	2030	2035
9000	5	4	**All Salish Services**	9000	5	4
12700	10	6	Asia -Salish E/B	12700	10	6
14999	2	6	Calif-Salish-Asia W/B	14999	3	8
17999	1	2	Other trades	17999	-	-
24000	-	-		24000	-	-
Salish Visits	18	18		Salish Visits	18	18
Vancouver Calls	15	15		Vancouver Calls	16	16
Less Than:	2030	2035	**Asia -Salish E/B**	Less Than:	2030	2035
9000	4	3	**Services**	9000	3	2
12700	6	5		12700	7	5
14999	1	2		14999	2	5
17999	1	2		17999	-	-
24000	-	-		24000	-	-
Salish Visits	12	12		Salish Visits	12	12
Vancouver Calls	12	12		Vancouver Calls	12	12
Less Than:	2030	2035	**Calif-Salish-Asia W/B**	Less Than:	2030	2035
9000			**Services**	9000	1	1
12700	2	1	Note: in 2018, none of th	12700	1	1
14999	1	2	three Calif-Salish-Asia	14999	1	1
17999	-	-	services were calling VFPA	17999	-	-
24000	-	-	In 2020, one calls VFPA bu	24000	-	-
Salish Visits	3	3	not NWSA	Salish Visits	3	3
Vancouver Calls	-	-		Vancouver Calls	1	1
Less Than:	2030	2035	**Services in**	Less Than:	2030	2035
9000	1	1	**Other trades**	9000	1	1
12700	2	-		12700	2	-
14999	-	2		14999	-	2
17999	-	-		17999	-	-
24000	-	-		24000	-	-
Salish Visits	3	3		Salish Visits	3	3
Vancouver Calls	3	3		Vancouver Calls	3	3

Projections of PNW Vessel Services for 2030 and 2035 – WITHOUT RBT2

Comparison of Mercator’s 2018 and 2020 forecasts

Mercator’s current forecast of scheduled service calls for the Vancouver port complex for 2035 for the Without RBT2 scenario has not fundamentally changed from the 2018 Mercator projections, as this table conveys.

The differences between this 2021 Report and the 2018 Mercator Report are as follows:

a) Small changes in distribution of ship sizes in Asia-Salish E/B (one more large Post-Panamax, one fewer sub-9,000 TEU vessel)

b) A westbound Salish service with NPX ships has been replaced by a westbound service with smaller ships.

Salish Sea container ship visits and VFPA Calls (changes in the forecast are shaded)

Service Count Recaps - Without RBT2

2018 Mercator Report			**Salish Sea Visits/wk**	2021 Mercator Analysis		
Less Than:	2030	2035	Service Types:	Less Than:	2030	2035
9000	5	4	**All Salish Services**	9000	5	4
12700	10	8	Asia -Salish E/B	12700	10	9
14999	3	6	Calif-Salish-Asia W/B	14999	3	5
17999	-	-	Other trades	17999	-	-
24000	-	-		24000	-	-
Salish Visits	18	18		Salish Visits	18	18
Vancouver Calls	15	15		Vancouver Calls	16	16
Less Than:	2030	2035	**Asia -Salish E/B**	Less Than:	2030	2035
9000	4	3	**Services**	9000	3	2
12700	6	7		12700	7	8
14999	2	2		14999	2	2
17999	-			17999	-	-
24000				24000	-	-
Salish Visits	12	12		Salish Visits	12	12
Vancouver Calls	12	12		Vancouver Calls	12	12
Less Than:	2030	2035	**Calif-Salish-Asia W/B**	Less Than:	2030	2035
9000			**Services**	9000	1	1
12700	2	1	Note: in 2018, none of the	12700	1	1
14999	1	2	three Calif-Salish-Asia	14999	1	1
17999	-	-	svcs. was calling Vancouver	17999	-	-
24000	-	-	In 2020, one calls Vancouve	24000	-	-
Salish Visits	3	3	but not NWSA	Salish Visits	3	3
Vancouver Calls	-	-		Vancouver Calls	1	1
Less Than:	2030	2035	**Services in**	Less Than:	2030	2035
9000	1	1	**Other trades**	9000	1	1
12700	2	-		12700	2	-
14999	-	2		14999	-	2
17999	-	-		17999	-	-
24000	-	-		24000	-	-
Salish Visits	3	3		Salish Visits	3	3
VFPA Calls	3	3		VFPA Calls	3	3

Assignment of Forecasted Vessel Services to VFPA Precincts

Overview

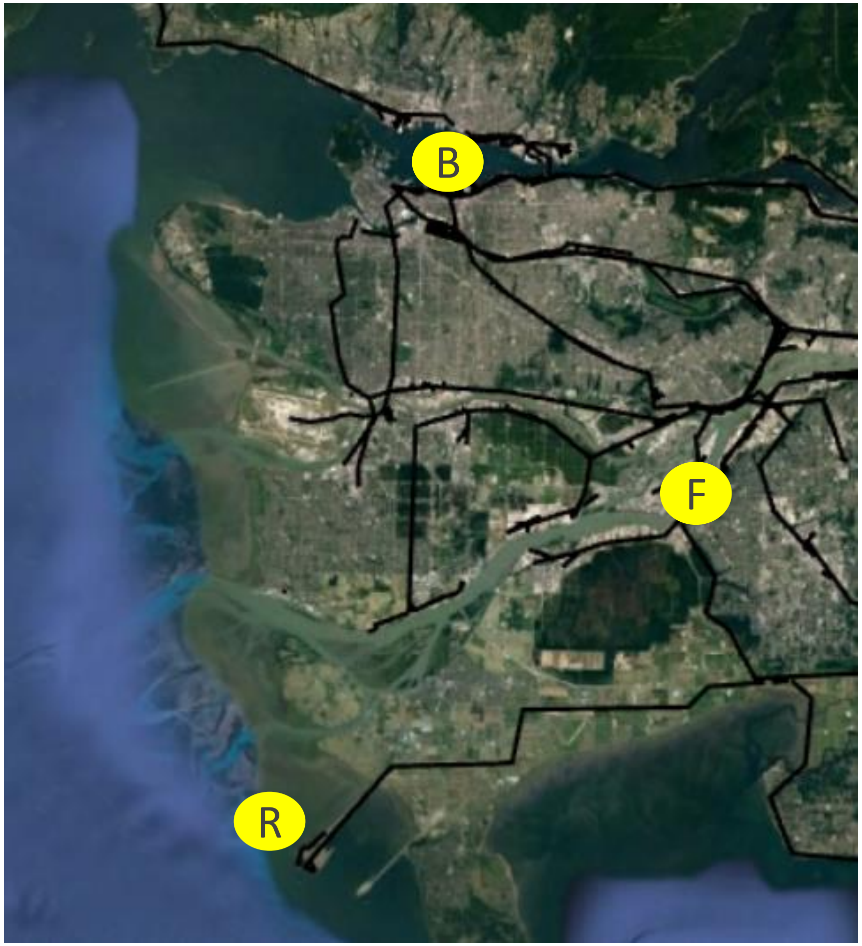
The next few pages provide Mercator's projected distributions of the forecasted vessel services calling the Vancouver port complex among its three different precincts – Roberts Bank (R), Burrard Inlet (B), and Fraser River (F).

By 2035, if not by 2030, only one liner service is expected to be using ships that can safely access the Fraser Surrey Docks (FSD) terminal in Fraser River precinct. This vessel service would be operated by Westwood Line (or a niche carrier similar to Westwood, with specialized ships and a similar focus on the forest products/paper products westbound trade to Asia).

The allocation of other services between the Roberts Bank and Burrard Inlet precincts will be determined by carrier preferences, the need to balance cargo traffic and terminal throughput capacity, and physical limitations on ship size. The clearance below the Lions Gate Bridge (pictured below), coupled with the water depth in that channel, impedes conventionally-designed containerships with capacities above about 14,500 TEUs from transiting to and from either Vanterm or Centerm.

Lions Gate (First Narrows) Bridge

Precincts within the VFPA port complex



Port of Vancouver – Terminals In Each Precinct

Burrard Inlet	***Roberts Bank***	***Fraser River***
▪ Centerm	▪ Deltaport	▪ Fraser Surrey Docks
▪ Vanterm	▪ Proposed RBT2	

Projections of PNW Vessel Services for 2035 – With and Without RBT2

Distribution of services within the Vancouver port complex

Precinct distribution

With RBT2, the Roberts Bank precinct will handle eight large-ship services projected to call Vancouver in 2035, with four for Deltaport and an equal number for RBT2.

This will result in the Roberts Bank precinct handling about 3.6 million TEUs (66% of the 5.45 million TEUs of cargo throughput projected by Drewry for the Port of Vancouver for 2035), with the Burrard Inlet terminals remaining well-utilized with about 1.8 million TEUs. Utilization for Roberts Bank would be about 90%, with Burrard Inlet utilization about 72%.

Conversely, without RBT2, Deltaport would be expected to handle more calls/week (six vs four) and about 30% more volume than without RBT2, with the Burrard Inlet precinct required to handle about 2.45 million TEUs (51% of Vancouver's projected 4.81 million TEUs of cargo throughput). All terminals would be at their capacity limits, with higher costs and lower service levels, with utilization of about 96% at Burrard Inlet terminals and about 98% at Deltaport.

Projected split of vessel services and throughputs by harbor precinct, 2035 – with and without RBT2

With RBT2			2035
Alliance	**Trade Lane**	**Svc ID**	**Vsl Scale**
Alliance A	Asia Eastbound	PNW1	14,500
Alliance A	Asia Eastbound	PNW2	13,000
Alliance A	Asia Eastbound	PNW4	10,500
Alliance B	Asia Eastbound	PN1	9,000
Alliance B	Asia Eastbound	PN3	14,500
Alliance B	Asia Eastbound	PN4	13,000
Alliance C	Asia Eastbound	TP2	11,000
Alliance C	Asia Eastbound	TP1	14,500
Annual TEUs (000s) - Roberts Bank			**3,600**
Alliance A	Asia Eastbound	PNW3	12,000
Alliance B	Asia Eastbound	PN2	12,500
Niche	Asia Eastbound	PNS	5,500
Wood	Asia Eastbound	PNW	4,000
Alliance C	Asia Westbound	ZEX	6,500
Multi-Carrier	Australia-NZ	ANZ	6,700
Alliance X	Europe	EUR2	13,000
Alliance Y	Europe	EUR1	13,000
Annual TEUs (000s) - Burrard Inlet			**1,800**

Without RBT2			2035
Alliance	**Trade Lane**	**Svc ID**	**Vsl Scale**
Alliance A	Asia Eastbound	PNW4	12,000
Alliance B	Asia Eastbound	PN1	9,000
Alliance B	Asia Eastbound	PN2	12,500
Alliance B	Asia Eastbound	PN3	14,500
Alliance B	Asia Eastbound	PN4	11,000
Alliance C	Asia Eastbound	TP2	11,000
Annual TEUs (000s) - Roberts Bank			**2,400**
Alliance A	Asia Eastbound	PNW1	13,000
Alliance A	Asia Eastbound	PNW2	12,000
Alliance A	Asia Eastbound	PNW3	10,500
Alliance C	Asia Eastbound	TP1	11,000
Niche	Asia Eastbound	PNS	5,000
Wood	Asia Eastbound	PNW	4,000
Alliance C	Asia Westbound	ZEX	6,500
Multi-Carrier	Australia-NZ	ANZ	6,700
Alliance X	Europe	EUR2	13,000
Alliance Y	Europe	EUR1	13,000
Annual TEUs (000s) - Burrard Inlet			**2,500**

Projections of PNW Vessel Services for 2045 – With and Without RBT2

Distribution of services within the Vancouver port complex

Precinct distribution

With RBT2, the Roberts Bank precinct is expected to handle seven large-ship services calling Vancouver in 2045.

The reason for the reduction from eight in the 2035 projection is the increase in the number of Asia – Salish Sea services expected to be operated in 2045 with 18,000+ TEU ships, with their attendant increase in TEUs per call.

Notwithstanding the reduction to seven services, throughput for this precinct is forecasted to increase by nearly 1.2 million TEUs to about 4.8 million TEUs, still about 66% of the Port’s cargo throughput as in 2035.

Conversely, without RBT2, Deltaport would be expected to handle the same number of calls (six) as in 2035, operating at close to 100% utilization with potential cost and service level implications.

Projected split of vessel services and throughputs by harbor precinct, 2045 – with and without RBT2

With RBT2			**2045**	**Without RBT2**			**2045**
Alliance	**Trade Lane**	**Svc ID**	**Vsl Scale**	**Alliance**	**Trade Lane**	**Svc ID**	**Vsl Scale**
Alliance A	Asia Eastbound	PNW1	18,000	Alliance A	Asia Eastbound	PNW1	18,000
Alliance A	Asia Eastbound	PNW2	22,000	Alliance A	Asia Eastbound	PNW2	18,000
Alliance A	Asia Eastbound	PNW4	10,500	Alliance B	Asia Eastbound	PN1	18,000
Alliance B	Asia Eastbound	PN1	18,000	Alliance B	Asia Eastbound	PN2	12,500
Alliance B	Asia Eastbound	PN3	22,000	Alliance B	Asia Eastbound	PN3	18,000
Alliance C	Asia Eastbound	TP2	13,000	Alliance Y	Europe	EUR1	14,500
Alliance C	Asia Eastbound	TP1	18,000				
Annual TEUs (000s) - Roberts Bank			**4,800**	**Annual TEUs (000s) - Roberts Bank**			**2,400**
Alliance A	Asia Eastbound	PNW3	14,500	Alliance A	Asia Eastbound	PNW3	13,000
Alliance B	Asia Eastbound	PN2	12,500	Alliance A	Asia Eastbound	PNW4	12,000
Alliance B	Asia Eastbound	PN4	13,000	Alliance B	Asia Eastbound	PN4	11,000
Niche	Asia Eastbound	PNS	6,000	Alliance C	Asia Eastbound	TP2	14,500
Wood	Asia Eastbound	PNW	4,000	Alliance C	Asia Eastbound	TP1	13,000
Alliance C	Asia Westbound	ZEX	10,000	Niche	Asia Eastbound	PNS	5,000
Multi-Carrier	Australia-NZ	ANZ	7,500	Wood	Asia Eastbound	PNW	4,000
Alliance X	Europe	EUR3	8,500	Alliance C	Asia Westbound	ZEX	10,000
Alliance X	Europe	EUR2	8,500	Multi-Carrier	Australia-NZ	ANZ	7,500
Alliance Y	Europe	EUR1	14,500	Alliance X	Europe	EUR3	8,500
				Alliance X	Europe	EUR2	8,500
Annual TEUs (000s) - Burrard Inlet			**2,400**	**Annual TEUs (000s) - Burrard Inlet**			**2,500**

Projections of VFPA Calls – WITH and WITHOUT RBT2

Port calls By Ships Size and VFPA Terminal – through 2030

VFPA Call Summary Matrix – Calls by Terminal and By Ship Size through 2030

The distribution of the size-classes of the sixteen vessel services projected to make scheduled calls at the Vancouver port complex is outlined in the tables to the right. RBT2 is not expected to be open during this period so the "with" and "without" scenarios are assumed to be the same.

In particular, we are expecting that in 2030 (see bottom table):

- five of the services will be operated with ships that have capacities of less than 9,000 TEU
- Nine of the services will be operated with ships that have capacities ranging between 9,000 and 12,999 TEUs
- Two of the services will be operated with ships having capacities ranging between 13,000 and 14,999 TEUs
- Eight of the sixteen services are expected to call the Burrard Inlet precinct (Vanterm and Centerm), six to the Roberts Bank precinct (Deltaport), and two to the Fraser River precinct (FSD).

VFPA Container Ship Calls - With and Without RBT2

With or Without RBT2

VFPA Calls By Size Class By Year (ship TEU capacity - kTEU)

2020

	<9	<12.9	<14.9	<17.9	<24	Total
Vant.	4	-	-	-	-	4
Cent.	3	-	-	-	-	3
Delta	4	2	-	-	-	6
RBT2	-	-	-	-	-	-
FSD	4	-	-	-	-	4
Total	15	2	0	0	0	17

2025

	<9	<12.9	<14.9	<17.9	<24	Total
Vant.	3	1	-	-	-	4
Cent.	3	1	-	-	-	4
Delta	1	5	-	-	-	6
RBT2	-	-	-	-	-	-
FSD	2	-	-	-	-	2
Total	9	7	0	0	0	16

2030

	<9	<12.9	<14.9	<17.9	<24	Total
Vant.	2	1	1	-	-	4
Cent.	1	3	-	-	-	4
Delta	-	5	1	-	-	6
RBT2	-	-	-	-	-	-
FSD	2	-	-	-	-	2
Total	5	9	2	0	0	16

Projections of VFPA Calls – WITH and WITHOUT RBT2 cont.

Port calls By Ships Size and VFPA Terminal – 2035 through 2045

By and after 2035, the distribution of the size-classes of the sixteen vessel services projected to make scheduled calls at the Vancouver port complex will be affected by the development (or lack of development) of RBT2.

In particular, by 2035, three more services (for a total of seven) will have been up-sized to capacities ranging between 13,000 and 14,999 TEUs than would be up-sized if RBT2 is not developed – and so three fewer services in the 9,000 – 12,999 TEUs range would remain.

Moreover, by 2045, Vancouver is projected to receive one more service that has been up-graded to "Mega-Max" capacity of 18,000+ TEU if RBT2 is built, than it would see if RBT2 is not developed. All ships over 15,000 TEUs must call Roberts Bank terminals.

The projected distributions in 2035 to 2045 of the vessel services calling the port complex are of course impacted by the availability or absence of RBT2, with:

- Two more services in the Burrard Inlet precinct (Vanterm and Centerm) in 2035 without RBT2 (versus with), and accordingly two less in the Roberts Bank precinct
- One more service in the Burrard Inlet in 2045 without RBT2 (versus with), and similarly one less at Roberts Bank

VFPA Call Summary Matrix – Calls by Terminal and By Ship Size – 2035 through 2045

	With RBT2								**Without RBT2**					
VFPA Calls By Size Class By Year (cont.)														
	2035								**2035**					
	<9	<12.9	<14.9	<17.9	<24	Total			<9	<12.9	<14.9	<17.9	<24	Total
Vant.	2	1	1	-	-	4		Vant.	2	1	1	-	-	4
Cent.	2	1	1	-	-	4		Cent.	2	2	2	-	-	6
Delta	-	2	3	-	-	5		Delta	-	5	1	-	-	6
RBT2	-	1	2	-	-	3		RBT2	-	-	-	-	-	-
FSD	-	-	-	-	-	-		FSD	-	-	-	-	-	-
Total	4	5	7	0	0	16		Total	4	8	4	0	0	16
	2040								**2040**					
	<9	<12.9	<14.9	<17.9	<24	Total			<9	<12.9	<14.9	<17.9	<24	Total
Vant.	2	1	1	-	-	4		Vant.	2	1	1	-	-	4
Cent.	2	1	1	-	-	4		Cent.	2	3	1	-	-	6
Delta	-	-	2	-	2	4		Delta	-	1	4	-	1	6
RBT2	-	-	2	-	2	4		RBT2	-	-	-	-	-	-
FSD	-	-	-	-	-	-		FSD	-	-	-	-	-	-
Total	4	2	6	0	4	16		Total	4	5	6	0	1	16
	2045								**2045**	0	0	0	0	
	<9	<12.9	<14.9	<17.9	<24	Total			<9	<12.9	<14.9	<17.9	<24	Total
Vant.	1	1	2	-	-	4		Vant.	1	1	2	-	-	4
Cent.	4	1	1	-	-	6		Cent.	4	2	1	-	-	7
Delta	-	-	-	-	3	3		Delta	-	1	1	-	4	6
RBT2	-	1	1	-	2	4		RBT2	-	-	-	-	-	-
FSD	-	-	-	-	-	-		FSD	-	-	-	-	-	-
Total	5	3	4	0	5	17		Total	5	4	4	0	4	17

VFPA Callers - Size Make-up Over Time

	<9000	9000-12900	13000-14999	15000-17999	18000-24000	Total			<9000	9000-12900	13000-14999	15000-17999	18000-24000	Total
2020	15	2	0	0	0	17		2020	15	2	0	0	0	17
2025	9	7	0	0	0	16		2025	9	7	0	0	0	16
2030	5	9	2	0	0	16		2030	5	9	2	0	0	16
2035	4	5	7	0	0	16		2035	4	8	4	0	0	16
2040	4	2	6	0	4	16		2040	4	5	6	0	1	16
2045	5	3	4	0	5	17		2045	5	4	4	0	4	17

Contents

Overview of World Container Vessels

This table lists the vessels in the global fleet by size and year built.

Number of ships by TEU size bracket and year built

Active Fleet + Orderbook As of Oct 2020

Count of Teu Col **Row Label**	**1990**	**1995**	**2000**	**2005**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**Total**	**TEU/Ship Average**
<1000	1	39	22	56	24	27	19	18	12	23	24	19	15	13	6	3			933	666
1000-1999	5	14	34	48	51	36	59	50	43	44	36	39	34	59	64	50	21		1393	1,422
2000-2999	1	8	15	43	17	12	7	8	7	20	19	23	43	20	51	41	13		762	2,546
3000-3999		1	5	7	15	4	5	22	16	11	3	6	10	7	2	10			263	3,469
4000-4999	3	1	11	38	63	21	37	31	16	5	1	2			1				534	4,441
5000-5999		2	14	29	13	10	8	9	13	6					1	1			266	5,422
6000-6999			9	4	24	10	5	14	5	3		1							219	6,556
7000-7999				7	2	5													54	7,299
8000-8999				24	29	28	26	33	7	20	2								281	8,503
9000-9999			4	4	3	5	5	13	26	37	17	7							186	9,409
10000-10999				4	2	5	8	4	25	17	13	6	8						104	10,296
11000-11999					4	6					3	10	9	3	4	13	4		76	11,537
12000-12999						2						4	1	1	9	4			21	12,362
13000-13999					16	23	37	22	24	5			9	4			6		150	13,403
14000-14999					9	11	4		1	14	16	20	13	12	3	7	7		119	14,334
15000-15999												4	4	7	5	15	3		38	15,088
16000-16999							1	2	2	3	1								9	16,441
17000-17999								6	2	6									22	17,619
18000-18999								4	11	10									25	18,468
19000-19999										10	12	4	4	2					32	19,448
20000-20999												10	19	7					36	20,401
21000-21999												5	3	4					12	21,325
23000-23999														10	17	12	8	5	52	23,532
Grand Total	**10**	**65**	**114**	**264**	**272**	**205**	**221**	**236**	**210**	**234**	**147**	**160**	**172**	**149**	**163**	**156**	**62**	**5**	**5587**	**4,576**

The world fleet as of October 2020, including ships on order for delivery in 2021-2023, includes about 5,600 ships with an average stated (nominal) capacity of 4,576 TEUs.

As can be seen from the chart, there has been a steady progression over the last 30 years with respect to the sizes of ships being added to the fleet.

Container Ship Fleet Age

The table below presents the number and average age of ships in the Asia - PNW trade lane alongside the average age and number of ships (of the same size groups) for the world fleet. Figures are for late 2020, showing the size ranges then relevant to the Asia-PNW trade.

Age of Asia – PNW calling fleet compared with the world fleet – 2020 (ships of 2,000 – 12,999 TEUs)

Asia-PNW Fleet				**World Fleet**				Compare:
Size Range	Ship Count	Average Age	Max Age	Size Range	Ship Count	Average Age	Max Age	Diff in Avg Age (PNW-WrldFlt) (younger) / older
2000-2999	7	13.9	18	2000-2999	722	12.7	41	1.1
3000-3999				3000-3999	254	12.1	31	
4000-4999	11	10.9	15	4000-4999	535	12.5	31	(1.6)
5000-5999	12	17.8	21	5000-5999	265	13.9	25	3.9
6000-6999	10	13.5	19	6000-6999	219	13.4	22	0.1
7000-7999	10	13.5	16	7000-7999	54	13.7	24	(0.2)
8000-8999	25	11.0	18	8000-8999	281	10.8	24	0.2
9000-9999	7	11.6	21	9000-9999	186	9.2	23	2.3
10000-10999	16	6.1	8	10000-10999	104	6.6	15	(0.5)
11000-11999	1	2.0	2	11000-11999	59	6.6	13	(4.6)
12000-12999	1	-	-	12000-12999	17	1.9	9	(1.9)
Total - Asia PNW	100	11.6	21	Wrld Fleet (2k-12.9k)	2696	11.9		(0.4)

- For the size groups most commonly deployed in the Asia - PNW trade (4,000-11,000 TEUs), the average ages are nearly the same, with no clear pattern with respect to any differences.
- Ships in the PNW trade lane make up a small subset (about 5.5%) of the overall world fleet in the most relevant 4k-10.9k size range.
- Because carriers generally order a high percentage of new capacity at the upper end of ship sizes, larger ship sizes tend to be younger than smaller ships.
- However, going forward, there is no reason to expect PNW-calling ships to be significantly younger or older than the balance of the world fleet in each respective size range.

Based on the similarity of fleet characteristics, it is reasonable to assume that in the future, the age mix of PNW-calling ships of a given size will closely reflect the age mix of the world fleet of similarly-sized ships.

Container Ship Life Expectancy and Retirement

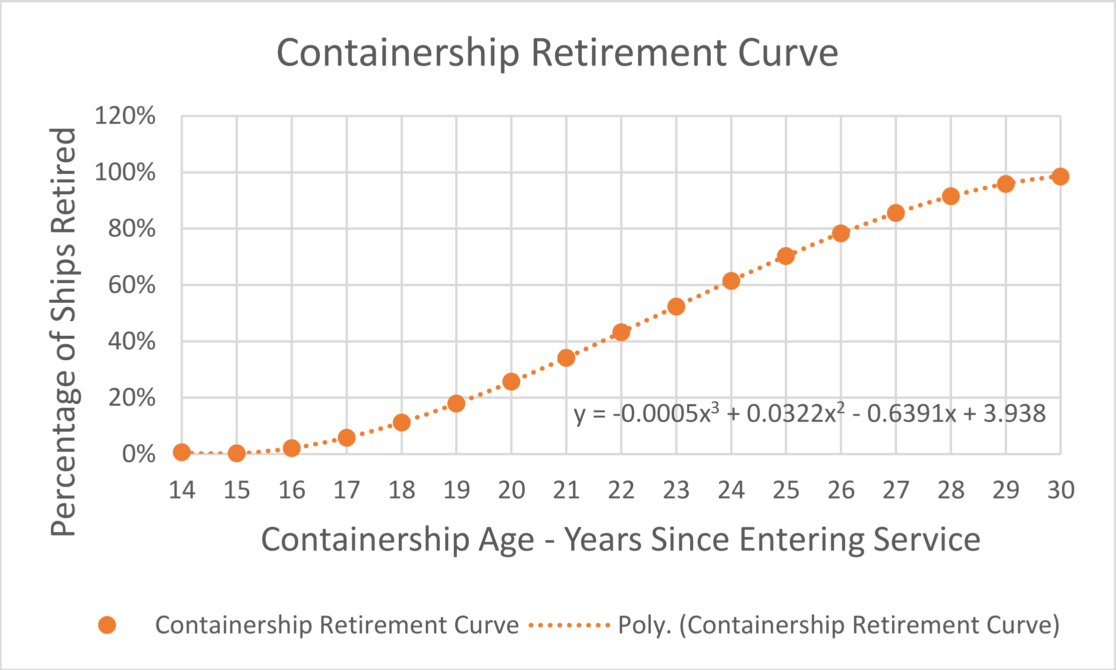
By examining world containership fleet lists across time, the progressive reduction in the number of ships from a given construction year cohort was identified in order to reveal the approximate pace at which aging containerships are withdrawn from service.

The result of the analysis is plotted at the right. This "retirement curve" was used to construct a model of year-by-year world fleet containership retirements and to estimate the new ships that would be added to the fleet to maintain fleet utilization.

Year by year, retiring ships are withdrawn from the fleet, and new ships are added. After deducting retirements of ships based on the Retirement Curve, we estimated new additions such that fleet capacity is grown to keep up with worldwide trade growth (assumed to be about 2% per year).

We expect that over time, the upper-end of ship sizes will continue to increase, but with a practical limit assumed to be at about the 26,000 TEU capacity level. New ships are assumed to be added to the fleet across the range of sizes to maintain a balance that can meet the requirements across worldwide trade lanes.

Expected life of container ships



Age and Capacity Forecast for World Fleet – Continued Emphasis on Mega-Max Vessel Fleet Expansion

The average age of the world fleet will decline slightly overall between 2020 and 2040, but among the principal size categories calling at Vancouver (ships between 9,000 and 18,000 TEUs), the average age of the world fleet is expected to increase by five or more years.

The current Vancouver-calling ships are concentrated in the 4,000-11,000 TEU range, with an average age of 11.6 years (see slide 50). As the fleet ages and Vancouver-calling ship sizes increase to be predominately in the 9,000-15,000 TEU range, the average age of Vancouver-calling ships calling in 2040 and beyond is likely to remain close to the current average of 11-12 years old.

This prediction is based on an expectation that carriers will continue expanding capacity at the top end of the size range (building more Mega-Max ships above 18,000 TEUs). However, if carriers elect to limit the growth of this size segment to something like 10% of the world fleet, the number of ships built in the 9,000-18,000 TEU range will need to be increased, thereby decreasing the age of ships in these sizes. This case is described on the next page.

Forecast containership counts and average age by size range

Ship TEU Size		Number of Ships					Average Age, yrs				
From:	To:	2020	2025	2030	2035	2040	2020	2025	2030	2035	2040
0	3999	3,213	2,785	2,509	2,297	2,271	13.0	13.2	12.7	11.6	11.2
4000	5999	799	742	688	639	712	13.0	14.9	13.1	9.8	8.7
6000	8999	554	484	468	437	490	12.1	15.8	13.7	9.9	8.3
9000	12999	366	410	435	410	366	7.7	10.5	12.3	13.0	12.3
13000	14999	249	322	376	378	379	6.2	9.0	11.3	12.3	11.0
15000	17999	51	80	107	157	160	5.3	7.3	9.1	8.9	10.7
18000	21999	105	129	169	212	230	3.5	7.1	9.7	10.7	10.7
22000	24999	27	71	111	161	211	0.4	3.4	6.1	8.3	9.7
25000	27999	-	-	6	36	66	-	-	-	2.5	5.0
Total		5,364	5,023	4,869	4,727	4,885	11.9	12.8	12.3	11.1	10.4
Average		4,469	5,241	5,973	6,736	7,058					

Forecast fleet capacity by containership size range

Ship TEU Size		Fleet Capacity (Millions of TEUs)					Share of World Fleet Slot Capacity					% Chg of TEU Capacity				
From:	To:	2020	2025	2030	2035	2040	2020	2025	2030	2035	2040	2025	2030	2035	2040	CAGR
0	3999	5.2	4.8	4.6	4.4	4.4	22%	18%	16%	14%	13%	-8%	-5%	-3%	-1%	-1%
4000	5999	3.8	3.6	3.4	3.1	3.5	16%	14%	12%	10%	10%	-5%	-7%	-7%	11%	0%
6000	8999	4.2	3.7	3.6	3.3	3.7	18%	14%	12%	10%	11%	-13%	-3%	-7%	12%	-1%
9000	12999	3.7	4.2	4.4	4.2	3.7	16%	16%	15%	13%	11%	12%	6%	-6%	-11%	0%
13000	14999	3.4	4.5	5.3	5.3	5.3	14%	17%	18%	17%	15%	30%	18%	1%	0%	2%
15000	17999	0.8	1.3	1.7	2.6	2.6	3%	5%	6%	8%	8%	59%	34%	47%	2%	6%
18000	21999	2.1	2.5	3.3	4.2	4.5	9%	10%	11%	13%	13%	23%	31%	25%	8%	4%
22000	24999	0.6	1.7	2.6	3.8	5.0	3%	6%	9%	12%	14%	163%	56%	45%	31%	11%
25000	27999	-	-	0.2	0.9	1.7	0%	0%	1%	3%	5%			500%	83%	
Total		24.0	26.3	29.1	31.8	34.5										
CAGR:			1.9%	2.0%	1.8%	1.6%										

Age and Capacity Forecast for World Fleet – Reduced Reliance on MMX+ Ships

If the number of new ships above 22,000 TEU is reduced sharply from the base forecast of the prior slide, the number of new ships to be built in the smaller sizes, including especially NPX class ships, will necessarily increase.

This increased emphasis on building ships in the 9,000-18,000 TEU sizes would reduce the average age of these ships as compared to the alternative "Mega-Max" strategy.

Nonetheless, the average age of ships calling Vancouver, which would generally be in the 9,000-18,000 TEU range, would still increase compared the current (2020) fleet because the large number of such ships already in the fleet would themselves be getting older.

In this scenario, the average age of Vancouver calling ships in 2040, and beyond, would likely be about 8-10 years.

Forecast containership counts and average age by size range

Ship TEU Size		Number of Ships					Average Age, yrs				
From:	To:	2020	2025	2030	2035	2040	2020	2025	2030	2035	2040
0	3999	3,213	2,785	2,509	2,297	2,271	13.0	13.2	12.7	11.6	11.2
4000	5999	799	742	738	689	762	13.0	14.9	12.3	9.6	8.9
6000	8999	554	499	483	452	504	12.1	15.4	13.5	10.0	8.5
9000	12999	366	410	435	460	491	7.7	10.5	12.3	11.8	10.2
13000	14999	249	322	376	443	469	6.2	9.0	11.3	10.8	10.0
15000	17999	51	80	117	182	235	5.3	7.3	8.5	8.2	8.6
18000	21999	105	123	163	196	204	3.5	7.4	9.8	11.1	11.1
22000	24999	27	59	89	109	119	0.4	3.9	6.6	9.8	12.2
25000	27999	-	-	-	-	-	-	-	-	-	-
Total		5,364	5,020	4,910	4,828	5,055	11.9	12.8	12.3	10.9	10.3
Average		4,469	5,187	5,868	6,536	6,765					

Forecast fleet capacity by containership size range

Ship TEU Size		Fleet Capacity (Millions of TEUs)					Share of World Fleet Slot Capacity					% Chg of TEU Capacity				
From:	To:	2020	2025	2030	2035	2040	2020	2025	2030	2035	2040	2025	2030	2035	2040	CAGR
0	3999	5.2	4.8	4.6	4.4	4.4	22%	19%	16%	14%	13%	-8%	-5%	-3%	-1%	-1%
4000	5999	3.8	3.6	3.6	3.4	3.7	16%	14%	13%	11%	11%	-5%	-1%	-7%	11%	0%
6000	8999	4.2	3.8	3.7	3.4	3.8	18%	15%	13%	11%	11%	-10%	-3%	-6%	12%	0%
9000	12999	3.7	4.2	4.4	4.7	5.0	16%	16%	15%	15%	15%	12%	6%	6%	7%	1%
13000	14999	3.4	4.5	5.3	6.2	6.6	14%	17%	18%	20%	19%	30%	18%	18%	6%	3%
15000	17999	0.8	1.3	1.9	3.0	3.8	3%	5%	7%	9%	11%	59%	46%	56%	29%	8%
18000	21999	2.1	2.4	3.2	3.9	4.0	9%	9%	11%	12%	12%	17%	33%	20%	4%	3%
22000	24999	0.6	1.4	2.1	2.6	2.8	3%	5%	7%	8%	8%	119%	51%	22%	9%	8%
25000	27999	-	-	-	-	-	0%	0%	0%	0%	0%					
Total		24.0	26.0	28.8	31.6	34.2										
CAGR:			1.7%	2.0%	1.8%	1.6%										

Alternative scenario analysis overview

Prior sections of this report outline ocean carrier characteristics and industry trends and the key assumptions applicable for projecting the number of container vessel (and vessel sizes) calling at the Port of Vancouver and RBT2 for the most-realistic scenario. The most-realistic scenario would be the continuation of the current ocean carrier alliance framework plus a continued focus on cost reduction strategies through the sharing of vessel assets and upsizing of vessels to meet cargo demand.

In consideration of the uncertainty inherent with long-term forecasting, this section provides the results of the analysis of alternative vessel call forecast scenarios to estimate the potential range in the number of container vessels calling at the Port of Vancouver in the future. Six alternative scenarios were analyzed including:

1. *Alliance restructuring from the current three ocean carrier alliances to four alliances*
2. *Introduction by two alliances of smaller ‘premium’ services*
3. *Vessels with maximum capacities of 18,000 TEUs deployed to the Pacific Northwest (PNW) region*
4. *Vessels with maximum capacities of 14,500 TEUs deployed to the PNW region*
5. *Increased average size of container vessels deployed to the PNW region*
6. *Change in the cargo demand growth rate in the PNW region*

It is assumed that since the Asia-Pacific Northwest (PNW) trade lane accounts for the vast majority of the Port of Vancouver’s container throughput, scenarios were assumed to apply to this trade lane only and the Europe and Australia/New Zealand (ANZ) trade lane projections remain unchanged (relative to the most-realistic scenario).

For each scenario, the applicable key assumption of the most-realistic scenario is stated followed by the “chains of events” or changes that could create different operational environments for the industry and lead to alternative deployment strategies by ocean carriers. For the Port of Vancouver, a comparison of the extent to which vessel calls would differ from the most-realistic scenario projection is provided for the 2045 forecast year. It is important to note that the factors related to these scenarios that could influence the number of container vessel calls to the PNW region and Port of Vancouver could occur at any time in the future and are not related to RBT2.

Alternative Scenario - Four Alliances

Most realistic scenario - key assumption related to alliance structure

The most likely scenario would be the continuation of the current ocean carrier alliance framework, in which there are three ocean carrier alliances (Ocean, THE Alliance, 2M) that include all 10 of the 10 largest container carriers.

Alternative four alliance scenario

This alternative alliance structure scenario could be driven by a regulatory edict to increase competition or the desire of one or more carriers to have greater independence. It is assumed that one carrier from the Ocean Alliance and one carrier from the THE Alliance withdraw from those alliances and form a New Alliance that operates its own services in the Asia-PNW trade lane. It is assumed that the new alliance would operate a total of three services, with capacity roughly on par with other three existing alliances. The two existing alliances from which these carriers withdrew would each lose one service, for a net change of one additional service (as shown in the table at right; (e/b = eastbound, w/b = westbound). This scenario could potentially occur at any time over the forecast period (or beyond).

Asia-PNW trade container vessel service projections in 2045 – with/without RBT2

Alliance Name	Most-realistic Scenario	Four Alliances Scenario
2M	3 (2 e/b + 1 w/b)	3 (2 e/b + 1 w/b)
Ocean Alliance	6 (4 e/b + 2 w/b)	5 (3 e/b + 2 w/b)
THE Alliance	4 (4 e/b)	3 (3 e/b)
New Alliance	not applicable	3 (3 e/b)
Independent	2 (2 e/b)	2 (2 e/b)
Total	**15 (12 e/b + 3 w/b)**	**16 (13 e/b + 3 w/b)**

Compared to the most-realistic scenario, the introduction of a fourth alliance would add an incremental Asia-PNW-calling service, regardless of whether RBT2 is operational. The additional service would reduce the average vessel capacity of the services in the Asia-PNW trade lane, thereby making it easier to upsize those services when Port of Vancouver cargo volume grows beyond the level that can be accommodated without RBT2. Consequently, the four-alliance scenario reduces the likelihood (as compared to the most realistic scenario) that additional services would be required to carry the additional cargo associated with the opening of RBT2. The additional service could call at any of the Port of Vancouver existing container terminals or RBT2, if operational.

Port of Vancouver alternative scenario summary

With the introduction of a fourth carrier alliance, the number of services calling at the Port of Vancouver could potentially increase from 17 (most-realistic scenario) to 18 (four alliance scenario) in 2045, with or without RBT2.

Port of Vancouver container vessel service projections in 2045 – with/without RBT2

Trade Lane	Most-realistic scenario	Four-alliance scenario
Asia	12 e/b + 1 w/b	13 e/b + 1 w/b
Europe	3	3
ANZ	1	1
Total	**17**	**18**

Alternative Scenario – Smaller Premium Services

Most realistic scenario - key assumption related to service numbers

The most likely network design strategy of ocean carriers serving the PNW market is to continue to seek scale economy by operating the fewest services possible while maintaining adequate coverage of the main export markets in Asia. With the achievement of lower costs through scale economy as their guiding strategy, carriers will periodically upsize vessels in order to add capacity to satisfy growth in market demand without adding a new service.

Alternative smaller premium services scenario

In this alternative smaller premium services scenario, it is assumed that each of the three existing ocean carrier alliances decides to operate a "premium" service to offer shorter transit times to the PNW region from selected ports in Asia. With the strategic change by each alliance to add a focused premium market service, there would be a net incremental increase of three services. This scenario could potentially occur at any time over the forecast period (or beyond).

Asia-PNW trade container vessel service projections in 2045 – with/without RBT2

Alliance Name	Most-realistic Scenario	Premium Services Scenario
2M	3 (2 e/b + 1 w/b)	4 (3 e/b + 1 w/b)
Ocean Alliance	6 (4 e/b + 2 w/b)	7 (5 e/b + 2 w/b)
THE Alliance	4 (4 e/b)	5 (5 e/b)
Independent	2 (2 e/b)	2 (2 e/b)
Total	**15 (12 e/b + 3 w/b)**	**18 (15 e/b + 3 w/b)**

Compared to the most-realistic scenario, the introduction of a smaller premium service for each of the three existing alliances would add three Asia-PNW services, regardless of whether RBT2 is operational. The addition of three new premium services calling the PNW from Asia would reduce the average capacity of the services in this trade lane, thereby allowing for greater vessel upsizing on those services when Port of Vancouver cargo volume exceeds current vessel capacity. Consequently, this alternative services scenario reduces the likelihood that additional services would be required to carry the additional cargo that would be associated with the operation of RBT2. The additional services could call at any of the Port of Vancouver existing container terminals or RBT2, if operational.

Port of Vancouver alternative scenario summary

With the introduction of smaller premium services, the number of services calling at the Port of Vancouver could potentially increase from 17 (most-realistic scenario) to 20 (premium services scenario) in 2045, with or without RBT2.

Port of Vancouver container vessel service projections in 2045 – with/without RBT2

Trade Lane	Most-realistic scenario	Premium Services Scenario
Asia	13 (12 e/b + 1 w/b)	16 (15 e/b + 1 w/b)
Europe	3	3
ANZ	1	1
Total	**17**	**20**

Alternative Scenario –18,000 TEU Maximum Vessel Capacity – With RBT2

Most-realistic scenario - key assumption related to vessel capacity

As the PNW trade volume grows, it is expected that ocean carriers will deploy larger vessels in the Asia-PNW trade lane with capacities that are now being operated in the Asia-Europe trade lanes (i.e., 22,000 TEUs). For the most-realistic scenario assuming RBT2 is operational (see page 37), eastbound capacity can be met in 2035 to 2045 with 2 Asia-Prince Rupert-California services and 12 Asia-Salish Sea-Asia services. By 2045, two of the services calling the Salish Sea are expected to deploy 22,000 TEU capacity vessels, with one calling at RBT2 and the other at Deltaport.

Alternative 18,000 TEU maximum vessel capacity scenario

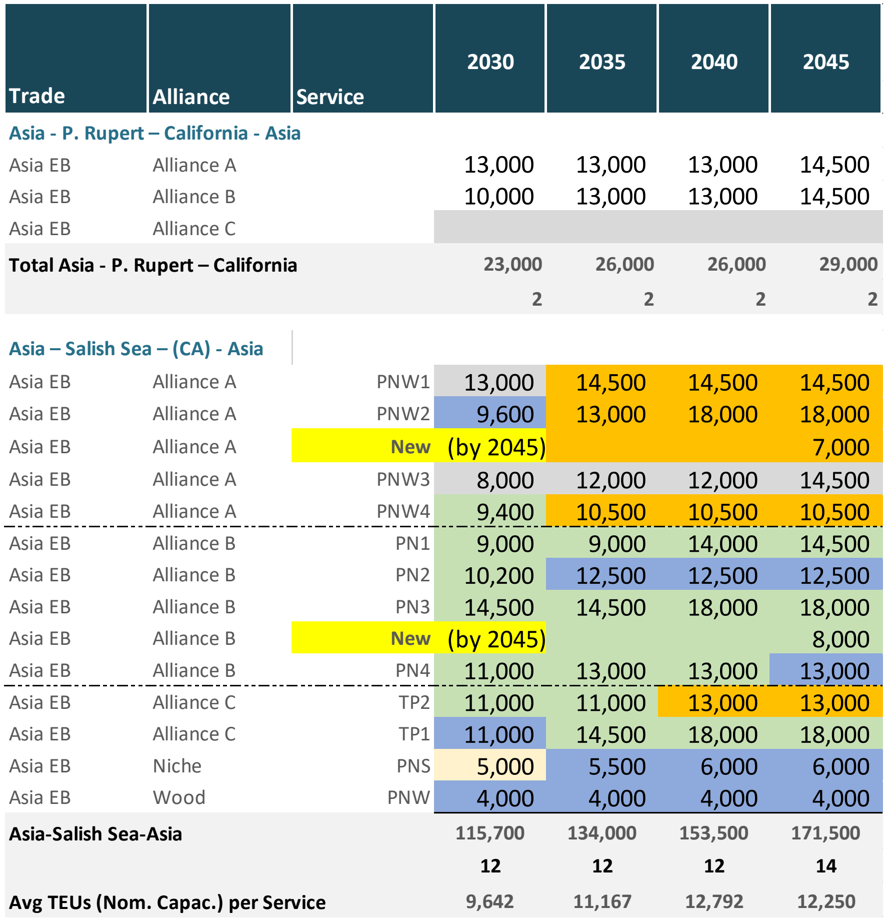
In the future with RBT2 (without RBT2 case on next page), should carriers determine that ship sizes above 18,000 TEUs are not attractive in this trade lane due to, for example, commercial and service level or transit time issues, they may elect to accommodate increased cargo volumes by adding services rather than deploying any ships with capacity greater than 18,0000 TEUs.

Because the largest ships in the Asia-PNW trade would not exceed the 18,000 TEU capacity level until about 2040, an increase in vessels from this change in service design and deployment strategy would not occur until 2045. The adjacent table shows that carriers could meet the projected cargo demand in 2045 without deploying ships larger than 18,000 TEUs capacity. With RBT2, the number of services in the eastbound Asia-Salish Sea trade lane is expected to increase from 12 to 14 services, as highlighted in the table.

With the replacement of a 22,000 TEU vessel at both RBT2 and Deltaport with two smaller vessels, the number of weekly Asia-Salish Sea-Asia services at these terminals would increase by one relative to the most-realistic scenario. A summary of the vessel calls to the Port of Vancouver with RBT2 and without RBT2 in 2045 for this scenario is provided on the next page.

With the deployment of two more but smaller vessels for two of the services, the average nominal capacity per service would decrease from 14,292 TEUs to 12,250 TEUs in 2045 with RBT2.

Projections of Asia-PNW-eastbound vessel deployments – with RBT2



Trade	Alliance	Service	2030	2035	2040	2045
Asia - P. Rupert – California - Asia						
Asia EB	Alliance A		13,000	13,000	13,000	14,500
Asia EB	Alliance B		10,000	13,000	13,000	14,500
Asia EB	Alliance C					
Total Asia - P. Rupert – California			23,000	26,000	26,000	29,000
			2	2	2	2
Asia – Salish Sea – (CA) - Asia						
Asia EB	Alliance A	PNW1	13,000	14,500	14,500	14,500
Asia EB	Alliance A	PNW2	9,600	13,000	18,000	18,000
Asia EB	Alliance A	**New**	(by 2045)			7,000
Asia EB	Alliance A	PNW3	8,000	12,000	12,000	14,500
Asia EB	Alliance A	PNW4	9,400	10,500	10,500	10,500
Asia EB	Alliance B	PN1	9,000	9,000	14,000	14,500
Asia EB	Alliance B	PN2	10,200	12,500	12,500	12,500
Asia EB	Alliance B	PN3	14,500	14,500	18,000	18,000
Asia EB	Alliance B	**New**	(by 2045)			8,000
Asia EB	Alliance B	PN4	11,000	13,000	13,000	13,000
Asia EB	Alliance C	TP2	11,000	11,000	13,000	13,000
Asia EB	Alliance C	TP1	11,000	14,500	18,000	18,000
Asia EB	Niche	PNS	5,000	5,500	6,000	6,000
Asia EB	Wood	PNW	4,000	4,000	4,000	4,000
Asia-Salish Sea-Asia			115,700	134,000	153,500	171,500
			12	**12**	**12**	**14**
Avg TEUs (Nom. Capac.) per Service			9,642	11,167	12,792	12,250

Note: Updated from most-realistic scenario with RBT2 presented on page 37.

Terminal Color Code
Vanterm (Burrard)
Centerm (Burrard)
Deltaport (Roberts Bank)
RBT2 (Roberts Bank)
FSD (Fraser River)

Alternative Scenario –18,000 TEU Maximum Vessel Capacity – Without RBT2

Most-realistic scenario - key assumption related to vessel capacity

As the PNW trade volume grows, it is expected that ocean carriers will deploy larger vessels in the Asia-PNW trade lane with capacities that are now being operated in the Asia-Europe trade lanes (i.e., 22,000 TEUs). For the most-realistic scenario assuming RBT2 is not operational (see page 38), eastbound capacity can be met in 2035 to 2045 with 3 Asia-Prince Rupert-California services and 12 Asia-Salish Sea-Asia services.

Alternative 18,000 TEU maximum vessel capacity scenario

Without RBT2, eastbound Asia-Salish Sea cargo volumes could be accommodated on 12 services without the need for ships larger than 18,000 TEUs. Therefore, the projected number of vessel calls with this alternative scenario are the same as with the most–realistic scenario.

Port of Vancouver alternative scenario summary

If carriers choose to add services rather than increase ship sizes above 18,000 TEUs, then the impact of RBT2 being built is two additional weekly ship calls at the Port of Vancouver in 2045, with RBT2 and Deltaport each having one more call. If RBT2 is not built, no changes relative to the most-realistic scenario are expected.

Port of Vancouver container vessel service projections in 2045 – with/without RBT2

Trade Lane	Most-realistic scenario	18,000 TEU Max Vessel Capacity Scenario	
	With or without RBT2	With RBT2	Without RBT2
Asia	13	15	13
Europe	3	3	3
ANZ	1	1	1
Total	**17**	**19**	**17**

Projections of Asia-PNW-eastbound vessel deployments – without RBT2

Trade	Alliance	2030	2035	2040	2045
Asia - P. Rupert – California - Asia					
Asia EB	Alliance A	13,000	13,000	13,000	14,500
Asia EB	Alliance B	10,000	13,000	13,000	14,500
Asia EB	Alliance C		13,000	13,000	14,500
Total Asia - P. Rupert – California		23,000	39,000	39,000	43,500
		2	3	3	3
Asia – Salish Sea – (CA) - Asia					
Asia EB	Alliance A	13,000	13,000	18,000	18,000
Asia EB	Alliance A	9,600	12,000	14,500	18,000
Asia EB	Alliance A	8,000	10,500	10,500	13,000
Asia EB	Alliance A	9,400	12,000	12,000	12,000
Asia EB	Alliance B	9,000	9,000	14,000	18,000
Asia EB	Alliance B	10,200	12,500	12,500	12,500
Asia EB	Alliance B	14,500	14,500	14,500	18,000
Asia EB	Alliance B	11,000	11,000	11,000	11,000
Asia EB	Alliance C	11,000	11,000	14,500	14,500
Asia EB	Alliance C	11,000	11,000	11,000	13,000
Asia EB	Niche	5,000	5,000	5,000	5,000
Asia EB	"Wood"	4,000	4,000	4,000	4,000
Subtotal - Asia-Salish Sea-Asia		115,700	125,500	141,500	157,000
		12	**12**	**12**	**12**
Average TEUs (Nom. Capac.) per Ser		9,642	10,458	11,792	13,083

Note: No changes for most-realistic scenario without RBT2 presented on page 38.

Alternative Scenario –14,500 TEU Maximum Vessel Capacity – With RBT2

Most-realistic scenario - key assumption related to vessel capacity

As the PNW trade volume grows, it is expected that ocean carriers will deploy larger vessels in the Asia-PNW trade lane with capacities that are now being operated in the Asia-Europe trade lanes (i.e., 22,000 TEUs). For the most-realistic scenario assuming RBT2 is operational (see page 37), eastbound capacity can be met in 2035 to 2045 with 2 Asia-Prince Rupert-California services and 12 Asia-Salish Sea-Asia services. The largest ships in the Asia-PNW trade would reach the 14,500 TEU capacity level in about 2035 and 18,000 TEU capacity by about 2040. By 2045, two of the services calling the Salish Sea are expected to deploy 22,000 TEU capacity vessels, with one calling at RBT2 and the other at Deltaport.

Alternative 14,500 TEU maximum vessel capacity scenario

A more limiting, alternative scenario assumes that ocean carriers determine that ship sizes above 14,500 TEUs are not attractive in the Asia-PNW trade lane due to, for example, commercial and service level or transit time issues. Carriers may, therefore, elect to add additional services rather than deploy any ships with capacities greater than 14,500 TEUs – the approximate size limit for the New Panama Canal.

Beyond 2035, deploying container vessels at capacities less than 14,500 TEUs would increase the number of vessel calls at the Port of Vancouver. The adjacent table shows how carriers could meet projected cargo demand in 2040 and 2045 in the future with RBT2 (without RBT2 case on next page), without deploying ships larger than 14,500 TEUs capacity. Assuming that RBT2 is operational, the number of services in the eastbound Asia-Salish Sea trade lane is expected to increase from 12 to 15 services due to the replacement of three vessel services of 18,000 TEU capacity and two vessel services of 22,000 TEU capacity with eight smaller vessels.

Compared to the most-realistic scenario, this alternative scenario could potentially increase the number of weekly services from 17 to 20 by 2045, with projected RBT2 calls increasing from four to five, and at Deltaport from three to five. A summary of weekly vessel calls to the Port of Vancouver in 2045 with RBT2 and without RBT2 for this scenario is provided on the next page.

With the deployment of smaller vessels by all three alliances, the average nominal capacity per service would decrease from 14,292 TEUs (slide 37) to 11,430 TEUs in 2045.

Projections of Asia-PNW-eastbound vessel deployments – with RBT2

Trade	Alliance	Service	2030	2035	2040	2045
Asia - P. Rupert – California - Asia						
Asia EB	Alliance A		13,000	13,000	13,000	14,500
Asia EB	Alliance B		10,000	13,000	13,000	14,500
Asia EB	Alliance C				12,500	12,500
Total Asia - P. Rupert – California			23,000	26,000	38,500	41,500
			2	2	3	3
Asia – Salish Sea – (CA) - Asia						
Asia EB	Alliance A	PNW1	13,000	14,500	14,500	14,500
Asia EB	Alliance A	PNW2	9,600	13,000	13,000	14,500
Asia EB	Alliance A	New	(by 2040)		6,000	11,000
Asia EB	Alliance A	PNW3	8,000	12,000	12,000	14,500
Asia EB	Alliance A	PNW4	9,400	10,500	10,500	10,500
Asia EB	Alliance B	PN1	9,000	9,000	14,500	14,500
Asia EB	Alliance B	PN2	10,200	12,500	12,500	12,500
Asia EB	Alliance B	PN3	14,500	14,500	14,500	14,500
Asia EB	Alliance B	New	(by 2040)		5,500	10,000
Asia EB	Alliance B	PN4	11,000	13,000	13,000	13,000
Asia EB	Alliance C	TP2	11,000	11,000	13,000	13,000
Asia EB	Alliance C	TP1	11,000	14,500	14,500	14,500
Asia EB	Alliance C	New	(by 2045)			4,500
Asia EB	Niche	PNS	5,000	5,500	6,000	6,000
Asia EB	Wood	PNW	4,000	4,000	4,000	4,000
Asia-Salish Sea-Asia			115,700	134,000	153,500	171,500
			12	12	14	15
Avg TEUs (Nom. Capac.) per Service			9,642	11,167	10,964	11,433

Note: Updated from most-realistic scenario with RBT2 presented on page 37.

mercator
Trusted. Experienced. Independent.

Alternative Scenario –14,500 TEU Maximum Vessel Capacity – Without RBT2

Most-realistic scenario - key assumption related to vessel capacity

As the PNW trade volume grows, it is expected that ocean carriers will deploy larger vessels in the Asia-PNW trade lane with capacities that are now being operated in the Asia-Europe trade lanes (i.e., 22,000 TEUs). For the most-realistic scenario assuming RBT2 is not operational (see page 38), eastbound capacity can be met in 2035 to 2045 with 3 Asia- Prince Rupert-California services and 12 Asia-Salish Sea-Asia services.

Alternative 14,500 TEU maximum vessel capacity scenario

Without RBT2 and without vessels larger than 14,500 TEUs, eastbound Asia-Salish Sea cargo volumes could be accommodated on 14 services, as shown in the adjacent table. One additional service would be needed by 2040 and another by 2045, even without RBT2. It is expected that Vanterm and Deltaport would each have an additional weekly call.

Port of Vancouver alternative scenario summary

If carriers choose to add services rather than increase ship sizes above 14,500 TEUs, without RBT2, there would be two additional weekly ship calls at the Port of Vancouver in 2045 compared to the most-realistic scenario. With RBT2, there could be three additional weekly calls. Comparing with and without RBT2 cases, the impact of RBT2 being built assuming vessels no larger than 14,500 TEUs are deployed, is one additional weekly ship call in 2045 to the Port of Vancouver.

Port of Vancouver container vessel service projections in 2045 – with/without RBT2

Trade Lane	Most-realistic scenario	14,500 TEU Max Vessel Capacity Scenario	
	With or without RBT2	With RBT2	Without RBT2
Asia	13	16	15
Europe	3	3	3
ANZ	1	1	1
Total	**17**	**20**	**19**

Projections of Asia-PNW-eastbound vessel deployments – without RBT2

Trade	Alliance	2030	2035	2040	2045
Asia - P. Rupert – California - Asia					
Asia EB	Alliance A	13,000	13,000	13,000	14,500
Asia EB	Alliance B	10,000	13,000	13,000	14,500
Asia EB	Alliance C		13,000	13,000	14,500
Total Asia - P. Rupert – California		**23,000**	**39,000**	**39,000**	**43,500**
		2	**3**	**3**	**3**
Asia – Salish Sea – (CA) - Asia					
Asia	Alliance A	13,000	13,000	13,000	13,000
Asia	Alliance A	9,600	12,000	14,500	14,500
Asia	Alliance A	New by 2040		5,000	8,500
Asia	Alliance A	8,000	10,500	10,500	13,000
Asia	Alliance A	9,400	12,000	12,000	12,000
Asia	Alliance B	9,000	9,000	14,000	14,500
Asia	Alliance B	10,200	12,500	12,500	12,500
Asia	Alliance B	New by 2045			7,000
Asia	Alliance B	14,500	14,500	14,500	14,500
Asia	Alliance B	11,000	11,000	11,000	11,000
Asia	Alliance C	11,000	11,000	14,500	14,500
Asia	Alliance C	11,000	11,000	11,000	13,000
Asia	Niche	5,000	5,000	5,000	5,000
Asia	Wood	4,000	4,000	4,000	4,000
Subtotal - Asia-Salish Sea-Asia		**115,700**	**125,500**	**141,500**	**157,000**
		12	**12**	**13**	**14**
Average TEUs (Nom. Capac.) per Ser		**9,642**	**10,458**	**10,885**	**11,214**

Note: Updated from most-realistic scenario without RBT2 presented on page 38.

Alternative Scenario – Increased Vessel Capacity – With RBT2

Most-realistic scenario - key assumption related to vessel capacity

It is expected that ocean carriers will deploy larger vessels in the Asia-PNW trade lane as trade volume grows. The largest ships in this trade would reach the 14,500 TEU capacity level in about 2035, 18,000 TEU capacity by about 2040 and 22,000 TEU capacity by about 2045. Assuming RBT2 is operational, eastbound capacity can be met in 2035 to 2045 with 2 Asia-Prince Rupert-California services and 12 Asia-Salish Sea-Asia services (see page 37). By 2045, two of the services calling the Salish Sea are expected to deploy 22,000 TEU capacity vessels, with one calling at RBT2 and the other at Deltaport.

Alternative increased vessel capacity scenario

In the future with RBT2 (without RBT2 case on next page), carriers could focus less on providing responsive service to importers/exporters and more on achieving the lowest vessel slot costs (i.e., operating cost per TEU). This could be achieved by increasing ship sizes and reducing the number of services required to carry the forecasted cargo volumes in the Asia-PNW trade lane. With RBT2 and more focus on vessel economy, the number of weekly services in the eastbound Asia-Salish Sea-Asia lane could potentially be 11 in 2045, as shown in the adjacent table, assuming the deployment of six ships with 18,000 TEU capacity or more (vs. five in most-realistic scenario) and just two ships under 14,500 TEU capacity (vs six in most-realistic scenario). It is also possible that the reduction to 11 services could be achieved by 2040, but this would require earlier deployment of ships over 20,000 TEUs.

Compared to the most-realistic scenario, this alternative scenario could potentially reduce the number of weekly services from 17 to 16 by 2045 at the Port of Vancouver, with projected RBT2 calls decreasing from four to three. A summary of weekly vessel calls to the Port of Vancouver in 2045 with RBT2 and without RBT2 for this scenario is provided on the next page.

With the deployment of larger vessels by all three alliances, the average nominal capacity per service would increase from 14,292 TEUs (page 37) to 15,591 TEUs in 2045.

Projections of Asia-PNW-eastbound vessel deployments – with RBT2

Trade	Alliance	Service	2030	2035	2040	2045
Asia - P. Rupert – California - Asia						
Asia EB	Alliance A		13,000	13,000	13,000	14,500
Asia EB	Alliance B		10,000	13,000	13,000	14,500
Asia EB	Alliance C					
Total Asia - P. Rupert – California			23,000	26,000	26,000	29,000
			2	2	2	2
Asia – Salish Sea – (CA) - Asia						
Asia EB	Alliance A	PNW1	13,000	14,500	14,500	18,000
Asia EB	Alliance A	PNW2	9,600	13,000	18,000	22,000
Asia EB	Alliance A	PNW3	8,000	12,000	12,000	14,500
Asia EB	Alliance A	PNW4	9,400	10,500	10,500	
Asia EB	Alliance B	PN1	9,000	9,000	14,000	18,000
Asia EB	Alliance B	PN2	10,200	12,500	12,500	14,500
Asia EB	Alliance B	PN3	14,500	14,500	18,000	22,000
Asia EB	Alliance B	PN4	11,000	13,000	13,000	14,500
Asia EB	Alliance C	TP2	11,000	11,000	13,000	18,000
Asia EB	Alliance C	TP1	11,000	14,500	18,000	20,000
Asia EB	Niche	PNS	5,000	5,500	6,000	6,000
Asia EB	Wood	PNW	4,000	4,000	4,000	4,000
Asia-Salish Sea-Asia			115,700	134,000	153,500	171,500
			12	**12**	**12**	**11**
Avg TEUs (Nom. Capac.) per Service			9,642	11,167	12,792	15,591

Note: Updated from most-realistic scenario with RBT2 presented on page 37.

Alternative Scenario – Increased Vessel Capacity – Without RBT2

Most-realistic scenario - key assumption related to vessel capacity

It is expected that ocean carriers will deploy larger vessels in the Asia-PNW trade lane as trade volume grows. For the most-realistic scenario assuming RBT2 is not operational, eastbound capacity can be met in 2035 to 2045 with 3 Asia- Prince Rupert-California services and 12 Asia-Salish Sea-Asia services (see page 38).

Alternative increased vessel capacity scenario

Without RBT2, the deployment of larger ships (to achieve the lowest vessel slot costs) is projected to reduce the number of services in the Asia-Salish Sea trade lane in 2045 by one to 11 weekly calls. This assumes the deployment of three ships with 18,000 TEU capacity and one with 22,000 TEU capacity (vs. four with 18,000 TEU capacity in most-realistic scenario) and just three ships under 14,500 TEU capacity (vs seven in most-realistic scenario). The deployment of 22,000 TEU vessels could occur by 2045 under this alternative scenario. With larger ships being deployed, the challenge with this scenario is that fewer vessels could feasibly transit under the Lions Gate Bridge. Deltaport could potentially have very high utilization and at least one of the Burrard Inlet container terminals could be under utilized.

Projections of Asia-PNW-eastbound vessel deployments – without RBT2

Trade	Alliance	2030	2035	2040	2045
Asia - P. Rupert – California - Asia					
Asia EB	Alliance A	13,000	13,000	13,000	14,500
Asia EB	Alliance B	10,000	13,000	13,000	14,500
Asia EB	Alliance C		13,000	13,000	14,500
Total Asia - P. Rupert – California		23,000	39,000	39,000	43,500
		2	3	3	3
Asia – Salish Sea – (CA) - Asia					
Asia EB	Alliance A	13,000	13,000	18,000	22,000
Asia EB	Alliance A	9,600	12,000	14,500	18,000
Asia EB	Alliance A	8,000	10,500	10,500	14,000
Asia EB	Alliance A	9,400	12,000	12,000	
Asia EB	Alliance B	9,000	9,000	14,000	18,000
Asia EB	Alliance B	10,200	12,500	12,500	14,500
Asia EB	Alliance B	14,500	14,500	14,500	18,000
Asia EB	Alliance B	11,000	11,000	11,000	14,500
Asia EB	Alliance C	11,000	11,000	14,500	14,500
Asia EB	Alliance C	11,000	11,000	11,000	14,500
Asia EB	Niche	5,000	5,000	5,000	5,000
Asia EB	"Wood"	4,000	4,000	4,000	4,000
Subtotal - Asia-Salish Sea-Asia		115,700	125,500	141,500	157,000
		12	**12**	**12**	**11**
Average TEUs (Nom. Capac.) per Ser		9,642	10,458	11,792	14,273

Note: Updated from most-realistic scenario without RBT2 presented on page 38.

Port of Vancouver alternative scenario summary

If carriers choose to incrementally deploy larger ships, with or without RBT2, projected cargo demand could be accommodated with one less weekly ship call at the Port of Vancouver in 2045, compared to the most-realistic scenario.

Port of Vancouver container vessel service projections in 2045 – with/without RBT2

Trade Lane	Most-realistic scenario	Increased Vessel Capacity Scenario	
	With or without RBT2	With RBT2	Without RBT2
Asia	13	12	12
Europe	3	3	3
ANZ	1	1	1
Total	**17**	**16**	**16**

Comparing with and without RBT2 cases, there is no impact of RBT2 being built. In fact, RBT2 would be a key enabler of this strategy because it increases the availability of terminals that are suited for larger capacity vessels. Under this scenario, more cargo could be handled with RBT2 with potentially fewer ship calls, compared to if RBT2 was not operational.

Alternative Scenario – Cargo Demand Growth Rate Change

Most-realistic scenario - key assumption related to cargo demand growth rate

The most-realistic container vessel call forecast scenario for the PNW region was based on the 2020 Drewry VFPA Long Term Container Forecast: 2020-2060, Final Report[1] (summary on pages 31 - 32). This container cargo forecast was used to determine the pace at which the vessel fleet capacity could change in both the with and without RBT2 cases. More optimistic or lower cargo growth rates were not evaluated as part of the most-realistic scenario, because only the timing of containerized cargo being diverted from the Port of Vancouver will change (once available terminal capacity is exceeded), not the number of vessel calls.

Alternative cargo demand growth rate scenario – changes in longer-term demand

An increase in the rate of growth of cargo moving through the PNW region would accelerate the date at which ocean carriers deploy larger ships and advance the date at which Port of Vancouver container terminals reach their maximum capacity. In the event that cargo growth happens faster than forecast, the point in time at which cargo (that would otherwise be handled through the Port of Vancouver) is diverted to other gateways would also shift, with such diversions happening sooner than they would under a lower-growth scenario. Conversely, a decrease in the rate of cargo demand growth would delay the introduction of larger ships and the diversion of cargo to other ports (compared to that assumed under the most-realistic scenario).

Although sudden increases or decreases in containerized cargo volume may lead to a varied short-term responses, it is expected that over the long-term, carriers will continue to satisfy cargo demand by adjusting ship sizes rather than by adding or eliminating services.

Alternative cargo demand growth rate scenario – changes in shorter-term demand

If changes in cargo demand happen rapidly or unexpectedly, and carriers are unable to accommodate the market changes by acquiring or redeploying ships of the appropriate / optimum capacity, then carriers will adjust capacity by adding or deleting services in such a way to make use of the available ships.

This type of response to changing market demands was observed in 2020/2021, when carriers added services to respond to the pandemic-induced surge in cargo demand, and the reduced operational efficiency and congestion of Southern California ports. To meet the shortfall in capacity, which came on too quickly to allow carriers to acquire and deploy larger ships, carriers deployed additional ships that were available, generally of a smaller size. The introduction of smaller vessels allow ocean carriers to meet demand and to shift some traffic away from the most-congested ports. It is expected that most of these new services will be short-lived, and that carriers will, over the next year or two, adjust their fleet composition and re-deploy vessels to revert to the optimum number and size mix to serve each trade in the most cost-efficient manner.

Port of Vancouver alternative scenario summary

With gradual increases or decreases in forecast cargo demand, the timing of cargo being diverted from the Port of Vancouver is expected to change, not the number of vessel calls. The deployment of larger or smaller vessels could also change in response to changes in forecast cargo demand. Ocean carrier responses to rapid or short-lived cargo demand changes, including the addition of new services, are expected to be temporary due to the higher cost associated with additional services. It is anticipated that there will be a return to the operation of the fewest possible number of vessel services using the largest ships that can be effectively utilized.

---

1. 2020 Drewry Report available at: https://www.portvancouver.com/wp-content/uploads/2021/03/Drewry-container-forecast-report-final.pdf

Summary of Alternative Scenario Analysis – Port of Vancouver Vessel Calls

Port of Vancouver alternative scenario summary

In addition to analyzing the most-realistic vessel scenario, alternative scenarios have been analyzed to project the potential range in weekly vessel calls at the Port of Vancouver. Six alternative scenarios were analyzed including:

1. *Alliance restructuring from the current three ocean carrier alliances to four alliances*
2. *Introduction by two alliances of smaller 'premium' services*
3. *Vessels with maximum capacities of 18,000 TEUs deployed to the Pacific Northwest (PNW) region*
4. *Vessels with maximum capacities of 14,500 TEUs deployed to the PNW region*
5. *Increased average size of container vessels deployed to the PNW region*
6. *Change in the cargo demand growth rate in the PNW region*

Since the Asia-PNW trade lane accounts for the vast majority of the Port of Vancouver's container throughput, scenarios were applied to this trade lane only and the Europe and Australia/New Zealand (ANZ) trade lane projections remain unchanged (relative to the most-realistic scenario).

The table below provides a comparison of the extent to which calls to the Port of Vancouver in 2045 would differ from the projections for the most-realistic scenario considering both with and without RBT2 cases. Although the table summarizes weekly vessel call projection in 2045, the factors related to these scenarios that influence the number of container vessel calls to the Port of Vancouver could occur at any time in the future and are not related to RBT2.

Conclusion: In comparison to the most-realistic scenario of 17 weekly container vessel calls on average to the Port of Vancouver in 2045 (with or without RBT2), container vessel calls could range from 16 to 20 calls per week on average, depending on the alternative scenario. Since 16 calls per week are projected (with or without RBT2) in 2035 and 2040, vessel calls to the Port of Vancouver could range from 15 to 19 calls per week on average prior to 2045.

Port of Vancouver container vessel service projections in 2045 – with/without RBT2

Scenario	With RBT2	Without RBT2
Most-realistic	**17**	**17**
Four-alliance	18	18
Smaller premium services	20	20
18,000 TEU max vessel capacity	19	17
14,500 TEU max vessel capacity	20	19
Increased vessel capacity	16	16
Changes in cargo demand	17	17

Contents

Section 2 (Key Industry Trends)

- Mergers and acquisitions within the containership industry have resulted in a relatively stable number of vessel services being operated in each of the three trade lanes to/from the PNW coastal zone (Asia, Europe, and Australia/New Zealand (ANZ)), with almost all of those services controlled by ten global ocean carriers (that also dominate the entire global container shipping sector).
- In each major trade lane, ocean carriers continue to minimize the number of separate vessel services that they operate and maximize the sizes of the ships that they assign to those services. Demand for new capacity has been met by increasing ship sizes, not adding new services.
- Given current terminal infrastructure and potential expansion plans in the ports of Prince Rupert, Seattle, and Tacoma, should RBT2 not be built, there should be sufficient capacity in these other PNW ports through 2045 to handle at least 60% of the intermodal volume diverted from Vancouver due to the lack of terminal capacity in the Vancouver port complex (as a result of the absence of RBT2). Traffic diverted to other PNW ports will continue to be carried on the same services that call Vancouver, limiting changes in the size of ships that call Vancouver.

Section 3 (Evolution of Ship Sizes and Sailing Frequencies in Key Trade Lanes)

- There have been and continue to be two highly-correlated, clear and well-established long-term trends that can be seen in all major inter-continental liner shipping lanes (such as Asia-North America West Coast, Asia – North Europe and Asia – US East Coast):
    - ✓ *Ship sizes (as measured by TEU capacity per service) have been increasing*
    - ✓ *The number of services being operated have been either decreasing or holding steady*
- These continuing trends are the result of industry consolidation and improving ship technology that delivers improved economics to carriers.

Section 4 (Forecast of Vancouver-calling Vessel Services to 2045)

- There are projected to be 8-10 global carriers, configured in 3-4 alliances, operating the vast majority of vessel services to/from the PNW region through the forecast period to 2045.
- With RBT2, 12 Asia inbound services are projected to call Vancouver, five of which will use “Mega-max” ships of 18,000+ TEU capacity --- without RBT2, the projection is also for 12 Asia services but only four of these will be operated with Mega-max ships.
- With or without RBT2, 3 Europe services are projected to call Vancouver in 2045, along with 1 ANZ service, and 1 Asia – California service that stops in Vancouver for loading westbound containers. The average sizes of ships expected to be used in these five separate services are expected to be the same for the with and without RBT2 scenarios.

Section 4 (Forecast of Vancouver-calling Vessel Services to 2045) - continued

- With RBT2, the Roberts Bank precinct is projected to handle 7 Asia weekly inbound services (including the five services using Mega-max ships that call the Vancouver port complex) and process 4.8 million TEUs/year (66%) of VFPA's total throughput
    - *The Burrard Inlet precinct is projected in this scenario to handle the other five (of twelve) Asia weekly inbound services and the 5 services of the other trade lanes*
- Without RBT2, the Roberts Bank precinct is projected to handle 5 Asia weekly inbound services (including all four services using Mega-max ships), plus 1 Europe service that uses Neo-Panamax ships, and process 2.4 million TEUs (49%) of VFPA's total annual throughput
    - *In this scenario, the Burrard Inlet precinct is projected to handle the other 7 Asia weekly inbound services, plus the Asia westbound, the ANZ, and 2 Europe services*
- The conclusion as to the effect of the RBT2 development on Vancouver containership calls – **that building RBT2 will not change the number of calls made at the Port of Vancouver** – is reached, whether we consider the OSC cargo volume forecast or the somewhat higher forecast of Drewry. This is because ocean carriers will adapt to changes in container volumes by adjusting the sizes of ships deployed, rather than by adjusting the number of services operated.

Section 5 (Age Composition of Vancouver-calling Vessel Fleet)

- The average age of the containerships presently assigned to Asia – PNW vessel services (11.6 years) is relatively close to the average age of the global fleet of containerships within the same size range (11.9 years)
- It is reasonable to assume that across the forecast period, the average age of the ships operated in Asia – PNW vessel services (of whatever size) will continue to be comparable to the average age of the global fleet of that same size.
- Our fleet composition model indicates that the average age of ships calling Vancouver is likely to continue to be about 11-12 years, even as the size of ships increase.

Section 6 (Analysis of Alternative Scenarios)

- In comparison to the most-realistic scenario of 17 weekly container vessel calls on average to the Port of Vancouver in 2045 (with or without RBT2), container vessel calls could range from 16 to 20 calls per week on average, depending on the alternative scenario.
- Prior to 2045, vessel calls to the Port of Vancouver could range from 15 to 19 calls per week on average, depending on the alternative scenario.

Contents

Appendix – Glossary of Terms

The following definitions are provided to clarify the use of certain terms.

Airdraft	Airdraft is the vertical distance from the surface of the water to the highest point on a vessel. Airdraft is important when assessing the adequacy of clearance beneath a bridge or other obstruction. An airdraft limitation of 55.9m applies at higher high water (HHWLT) to NPX vessels (beam of 49m or more) passing under the Lions Gate Bridge (First Narrows).
ANZ (Australia-New Zealand)	Refers to the tradelane between North America and Australia, New Zealand and neighboring islands
Backhaul	For a vessel service or trade, the backhaul direction is the direction with a lower volume of cargo flow. In the backhaul direction, a substantial number of containers are carried empty (with no cargo). The direction with higher volume of cargo flow (more laden containers) is the headhaul direction.
Beam	Beam is the width of a ship; a ship dimension measured from side-to-side. The beam of a containership is often referred to by the number of containers that may be stowed across the ship. Conventional "old Panama" containerships carried containers 13 rows across, while the newest and largest super-post Panamax ships carry 22 or 23 rows across.
Berth	A berth is a location in a port lying alongside a wharf and used for mooring a ship during cargo loading or unloading operations.
Compound Average Growth Rate (CAGR)	CAGR is the constant rate at which a measure would need to grow each in order for that measure (X) to increase from a base value (X_0 in year 0) to another value (Xn in year n). Mathematically, CAGR is the value R for which $X_n/X_0 = (1+R)^n$ is true.
Container	A container is a standard, reusable steel box used for shipping. Containers used for international shipping are 8-feet wide, 8.50-feet or 9.50-feet tall, and 20-feet, 40-feet or 45-feet in length.

Container repositioning	Container repositioning (also called empty repositioning) refers to the movement by carriers of empty containers from an area with surplus empties (more empties than what is required to meet export demand) to a location where the empty equipment can be loaded.
Direct **Direct Service**	Refers to container transportation that is carried out by a single ship service, without a transfer from one ship to another ship. The alternative to direct service is called transshipment service.
East-West trades **North-South trades**	Major container trades are loosely categorized as being East-West or North-South based on the direction of the main axis. East-West trades connect Asia to Europe, North America and South America, and Europe to North America. North-South trades are between Asia and Australia, North America and South America, Europe and Africa.
Empty container	An empty container is one that carries no cargo and generates no revenue for the ocean carrier. However, terminal operators do charge ocean carriers for handling these containers.
Forty-foot equivalent unit (FEU)	One 40-foot standard dimension container or two 20-foot containers comprise one FEU. One FEU is equivalent to two TEUs.
Gantry crane	A gantry crane is a large ship-to-shore (STS) crane mounted on fixed rails found at container terminals used for loading and unloading containers to and from container ships.
Headhaul	With respect to a vessel service or tradelane, the headhaul is the direction with the highest volume of laden containers, and normally the highest revenue, for the ocean carrier. Opposite of backhaul.
Laden container	Laden containers are loaded with cargo and generating income for the ocean carrier. Opposite of empty containers.
Mega-Max (MMX)	A Mega-Max vessel is a containership that can carry more than 18,000 TEUs. It will have a beam of 59-62m with 23 or 24 containers stowed across the deck, with a length of about 400m.

Neo-Panamax (NPX) **New Panamax**	A neo-Panamax (NPX) containership has a beam of 49-51m (carrying 19 or 20 containers across on deck) and so is at the upper limit of what is allowed to transit the new locks at the Panama Canal (which were opened in 2016), and can typically carry up to about 15,000 TEUs. In comparison, an “Old Panamax” vessel has a carrying capacity up to approximately 5,000 TEUs with a beam of 32m to permit navigation through the original, smaller Panama Canal locks.
Northwest Seaport Alliance (NWSA)	The Northwest Seaport Alliance (NWSA) is the entity formed by agreement between the Port of Seattle and the Port of Tacoma to manage and control all container-related activities of the two constituent Ports.
Ocean Carrier	The ocean carrier is the entiry provided container transportation service via ships. May be used interchangeable with “shipping line”.
Panamax ship	Panamax (sometimes referred to as “old Panamx”) vessels are the largest class of ships capable of passing through the Panama Canal’s old locks, with max length of 294m and max beam of 32.2.
Port	A port is comprised of some number of separately operated terminals. A modern seaport terminal typically serves a particular cargo type, such as container cargo, dry bulk cargo, liquid bulk cargo, roll-on-roll-off cargo (vehicles and trucks), or passengers.
Post-Panamax ship	A post -Panamax ship is a ship too large to transit through the old locks at the Panama Canal, and will have abeam more than 32.2m.
Post-neo-Panamax ship	A post-neo-Panamax vessel is too large to transit through the new locks at the Panama Canal, with a beam more than 51m, stowing containers 21 or more across on deck.
Roberts Bank	Location of the existing Delta Port Terminal in Tsawwassen, BC
Roberts Bank Terminal 2 (RBT2)	The new container terminal proposed for construction at Roberts Bank.
Salish Sea	The body of water bounded by Vancouver Island, the Olympic Peninsula and the North American mainland, including the Strait of Juan de Fuca, the Strait of Georgia Puget Sound, and adjoining waterways.

Service **String** **Deployment**	A containership service (sometimes referred to as a "deployment", "vessel string" or simply a "string") is a set of generally similar ships that are operated together on a regular route with a regular set of port calls. Services are nearly always designed to provide a call at each port every week on same day of the week.
Ship-to-shore gantry crane (STS)	These are cranes positioned on the quay and used to load and unload containers from vessels.
Slot Cost	Slot Cost refers to the ocean carrier's operational cost per TEU and is defined for a given vessel string. Slot cost includes the costs for vessel hire, crew, maintenance, fuel, port calls (tugs, pilots, dues), but excludes the costs for handling cargo.
Super-post-Panamax (SPPX) crane	The term super-post-Panamax (SPPX) is generally applied to cranes that can serve ships of 19 or more containers across.
Terminal (seaport terminal)	A terminal is a facility within a port that handles cargo or passengers. A modern seaport terminal typically serves a particular cargo type, such as container cargo, dry bulk cargo, liquid bulk cargo, roll-on-roll-off cargo (vehicles and trucks), or passengers. Medium sized ports often have two to four container terminals, as well as a number of terminals handling other cargo types.
TEU Capacity	Containerships are classified according to their "nominal" capacity, which reflects the maximum number of TEUs that they can stow on a purely volumetric basis. The "nominal" volumetric capacity is always higher than the "effectvive" capacity which considers, draft, stability, lashing strength and other physical and operational constraints that may vary according to where the ship is deployed.
Tradelane **Trade Theater**	Tradelane refers to a shipping corridor that connects two major markets, generally served by a discrete set of vessel services. Examples include Asia-PNW, Asia-Californa, Asia-N. Europe, Asia-Med, Europe-US East Coast, US east Coast – East Coast South America, etc. A trade theater is a higher level and more general geographic assemblage of tradelanes, and may be referred to by the ocean being crossed or the principal land-masses that are involved, such as "Asia-Europe", "Asia-North America", "Transpacific", or "Transatlantic".

Transshipment	Transshipment refers to shipment of cargo from origin to an intermediate destination (transfer point) from which it is then transported to another (final) location via a different ship.
Twenty-foot equivalent unit (TEU)	A TEU is a standard unit of measure for container cargo. A standard 20-foot container measuring 8-feet wide, by 8-feet 6-inches tall, and 20-feet long is one TEU. A standard 40’ container is two TEUs.
Ultra-large container ship (ULCS)	An Ultra-Large containership (ULCS) is a containership that can carry between 15,000 and 18,000 TEUs. It will have a beam of 53-56m with 21 or 22 containers stowed across the deck, with a length of 350-400 m.
Vancouver Fraser Port Authority (VFPA)	The port authority for the Port of Vancouver. Also referred to as the Port of Vancouver (PV).
Vessel cascading	Vessel cascading is the process whereby an ocean carrier replaces smaller vessels in a tradelane with larger ships and then deploys the smaller (displaced) ships into another trade where they, in turn, replace other vessels.
Vessel utilization	Vessel utilization is the percentage of a vessel's container slots that are filled with loaded, revenue-generating containers. Carriers seek to achieve high levels of utilization to maintain profitability; above 90% utilization is desirable.
Water draft	The draft (water draft) of a ship is the distance below the water surface of the lowest point of the ship. The required depth of a channel is equal to the draft plus a suitable allowance for safe navigation.
Wharf	The wharf is the structure forming the boundary between water and sea at the edge of a container terminal. The wharf provides a means to secure ships during cargo operations and supports the ship-to- shore cranes.

mercator

United States

Headquarters
4040 Lake Washington Blvd.
Suite 310
Kirkland WA 98033
Phone: 425.803.9876
mercatorintl.com

Appendix IR2020-3-C

Technical data report – Underwater Noise Modelling of RBT2 Project Operation

Underwater Noise Modelling of RBT2 Project Operation

Submitted to:

Pamela Dinn
Ecofish Research Ltd.
Contract: PO 1384-07

Authors:

Alexander MacGillivray
Connor Grooms
Zizheng Li
Marie-Noël Matthews

23 September 2021

P001571-001
Document 02360
Version 3.1

JASCO Applied Sciences (Canada) Ltd
Suite 2305, 4464 Markham St.
Victoria, BC V8Z 7X8 Canada
Tel: +1-250-483-3300
Fax: +1-250-483-3301
www.jasco.com

Suggested citation:

MacGillivray, A., C. Grooms, Z. Li., and M. Matthews, 2021. *Underwater Noise Modelling of RBT2 Project Operation*. Document 02360, Version 3.1. Technical report by JASCO Applied Sciences for Ecofish Research Ltd..

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

Figures

Tables

Glossary

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

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

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

background noise
Total of all sources of interference in a system used for the production, detection, measurement, or recording of a signal, independent of the presence of the signal (ANSI S1.1-1994 R2004). Ambient noise detected, measured, or recorded with a signal is part of the background noise.

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

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

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

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

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

ensonified
Exposed to sound.

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

geoacoustic
Relating to the acoustic properties of the seabed.

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

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

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

point source
A source that radiates sound as if from a single point (ANSI S1.1-1994 R2004).

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

propagation loss (PL)
The decibel reduction in sound level between two stated points that results from sound spreading away from an acoustic source subject to the influence of the surrounding environment.

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

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

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

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

sound intensity
Sound energy flowing through a unit area perpendicular to the direction of propagation per unit time.

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

For sound in water, the reference sound pressure is one micropascal ($p0$ = 1 µPa) and the unit for SPL is dB re 1 µPa2:

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

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

sound speed profile (SSP)
The speed of sound in the water column as a function of depth below the water surface.

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

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

Executive Summary

This study provides an updated assessment of underwater noise from RBT2 Project operations, in response to the information request to the port authority from the Minister of Environment and Climate Change (the Minister). The Minister requested that the port authority provide updated estimates of underwater sound exposures for Southern Resident Killer Whales (SRKW) from Project operations, based on an analysis of vessel source level measurements and the composition of vessel classes projected to call at the RBT2 terminal during operation. The minister also requested that the port authority re-assess the total masking of SRKW echolocation from continuous exposure to noise from container vessels calling at the RBT2 terminal during Project operations, by assessing noise signal masking for more than one frequency (including frequencies where container vessel noise is more prominent).

To support the port authority in responding to the Minister's request, JASCO Applied Sciences carried out an updated analysis of the contribution of RBT2 Project operations to underwater noise at Roberts Bank, based on new projections of container vessel calls at RBT2 for 2035, 2040, and 2045 by Mercator International. According to the new projections, under the most-realistic vessel scenario, the total number of container vessels calling at Port of Vancouver terminals will be the same with or without the RBT2 terminal. We also evaluated a less likely high-case vessel scenario with one extra Mega Max vessel call at RBT2 per week (i.e., 52 additional calls annually). Project operations will increase sound levels locally, near the proposed terminal at Roberts Bank, as container vessels are redistributed from other terminals to call on RBT2. Furthermore, the average size of container vessels calling at the Port of Vancouver will increase, due to the increased container throughput capacity provided by RBT2.

Sound propagation in the study area was modelled using JASCO’s Marine Operation Noise Model (MONM), following the methodology originally used in the Environmental Impact Statement (EIS) and during the public hearing. Previous modelling estimates for Neo Panamax vessels were updated using new information on container vessel noise source levels trends from publicly available reports prepared for the VFPA-led ECHO Program, to provide estimates for all vessel size classes projected to call at the terminal, including Large Post Panamax, Neo Panamax, and Mega Max vessels. Noise levels from project operations were modelled using multiple scenarios, representing different sizes of container vessels, stages of Project operations, vessel speeds, and seasonal sound propagation conditions. Project operations were modelled with a finer activity resolution than used for the EIS and presented at the public hearing (e.g., including container vessels turning on and off the shipping lanes, transiting with tugs, berthing with tugs, and while at berth). Tugs were modelled at different speeds to examine the potential benefits of slowdown mitigation while transiting. The container vessels at berth were modelled on and off shore power to examine the potential benefits of this mitigation. Specific noise criteria were used for SRKW for computing radii for low- and moderate-severity behavioural response thresholds. Noise from Project operations may also mask SRKW vocalizations and limit the range at which individuals can receive echolocation clicks from potential prey. Echolocation masking was evaluated using sound power spectral density (PSD) thresholds in two separate frequency bands of 20 kHz and 50 kHz. The modelling was updated to estimate distances to SRKW echolocation masking with PSD thresholds of 37.9 dB re 1 μPa^2/Hz (20 kHz) and 35.7 dB re 1 μPa^2/Hz (50 kHz).

The model study predicts that Project operations will increase underwater noise levels near the proposed terminal at Roberts Bank, as container vessels redistribute from other terminals to call on RBT2. Furthermore, echolocation masking was predicted to be greater at 20 kHz than at 50 kHz, as noise levels from tugs and container vessels decrease with increasing frequency. As in previous modelling studies, berthing and unberthing operations were predicted to have the largest acoustic footprints due to the presence of tugs. Footprints were generally greater for larger vessels than for smaller vessels, and for faster vessels than for slower vessels, due to the influence of vessel size and speed on noise emissions. Masking thresholds, in particular, were predicted to be greater for larger container vessels than for small container vessels due to the influence of draft on radiated noise at high frequencies. Furthermore, modelled footprints were predicted to be larger in winter than in summer, due to seasonal differences in sound propagation conditions. Reducing speeds of support tugs from 8 knots to 5 knots during transiting was predicted to reduce the extent of their noise footprints by 30-70%, depending on the actual effectiveness of slowdowns at reducing their underwater radiated noise (i.e., reflecting the range of available data).

The incremental increase in average sound levels ($L_{eq\text{-}1yr}$) of Project operations at Roberts Bank was calculated by adding modelled sound levels to estimated background conditions (i.e., from existing vessel traffic and ambient noise), according to the expected number of calls per week for 2035, 2040, and 2045 for the most-realistic and high-case scenarios. The incremental contributions of project operations were highest for 2040 and predicted to be smaller with increasing distance from the berth face. Under the most-realistic scenario for 2040, Project operations were predicted to increase average sound levels ($L_{eq\text{-}1yr}$) by 4.7 dB above existing conditions near the terminal (at 300 m distance) and by 0.4 dB above existing conditions near the turnoff to the shipping lanes (beyond 3.5 km distance). Under the less-likely high-case scenario for 2040, with 1 additional Mega Max call per week, Project operations were predicted to increase average sound levels ($L_{eq\text{-}1yr}$) by 5.2 dB above existing conditions near the terminal (at 300 m distance) and by 0.5 dB above existing conditions near the turnoff to the shipping lanes (beyond 3.5 km distance). The use of shore power by 30% of vessels was predicted to have a marginal effect on the incremental contribution of project operations above existing conditions, with average sound levels only reduced by 0.1 dB at distances where SRKW most frequently travel past Roberts Bank (approximately 1.5 km from the berth face).

The incremental contributions of project operations near the terminal were slightly higher than previous comparable estimates presented during the public hearing (which were 2.8 dB above existing conditions based on 5 weekly vessel calls). However, this increase reflects the inclusion of noise from vessels while at berth in the analysis, which was not considered in previous estimates. It is important to note that the incremental contribution of noise from at-berth vessels is expected to be limited to a small area near the berth face. The incremental contribution of Project operations above existing conditions at greater distances (0.75-3 km from the berth face), is less than previous comparable estimates, due to the lower projected numbers of weekly container vessel calls at RBT2 under the most-realistic scenario.

1. Introduction

On August 24, 2020, the Vancouver Fraser Port Authority (the port authority) received a letter from the Minister of Environment and Climate Change (the Minister) seeking additional information in support of his decision under the *Canadian Environmental Assessment Act, 2012* in relation to the Roberts Bank Terminal 2 (RBT2) Project. The Minister requested that the port authority provide updated estimates of sound exposure levels for Southern Resident Killer Whales (SRKW) from Project operations, based on an analysis of vessel source level measurements and the composition of vessel classes projected to call at the RBT2 terminal during operation. The minister also requested that the port authority re-assess the total masking of SRKW echolocation from continuous exposure to noise from container vessels calling at the RBT2 terminal during Project operations, by assessing noise signal masking for more than one frequency (including frequencies where container vessel noise is more prominent).

To support the port authority in responding to the Minister's request, this technical data report presents an updated analysis of the contribution of RBT2 Project operations to underwater noise at Roberts Bank, based on new forecasts of container vessel calls for 2035, 2040, and 2045 (Mercator International 2021). According to the new projections, under the most-realistic vessel scenario, the total number of container vessels calling at Port of Vancouver terminals will be the same whether RBT2 is built or not. We also evaluated a less likely high-case scenario which includes one extra Mega Max vessel call at RBT2 per week, for 2035, 2040, and 2045 (i.e., 52 additional calls annually). Project operations will increase sound levels locally, near the proposed terminal at Roberts Bank, as container vessels are redistributed from other terminals to call on RBT2. Furthermore, the average size of container vessels calling at the Port of Vancouver will increase, due to the increased container throughput capacity provided by RBT2. The updated projections of weekly container vessel calls at RBT2, for 2035, 2040, and 2045, broken down by size class, are summarized in Table 1.

Table 1. Projected weekly calls at RBT2 for different sizes of container vessels under the most-realistic vessel scenario and high-case vessel scenario (one extra Mega Max vessel per week) in 2035, 2040, and 2045 (Mercator International 2021)..

Year	Most-realistic Vessel Scenario				High-case Vessel Scenario			
	Small Post-Panamax	Large Post-Panamax	Neo Panamax	Mega Max	Small Post-Panamax	Large Post-Panamax	Neo Panamax	Mega Max
2035	0	1	2	0	0	1	2	1
2040	0	0	2	2	0	0	2	3
2045	0	1	1	2	0	1	1	3

This study uses recent data on container vessel noise emissions, available by request from the Port-of-Vancouver-led Enhancing Cetacean Habitat and Observation (ECHO) Program, to estimate the yearly incremental contributions of RBT2 terminal operations to underwater noise levels near the proposed terminal at Roberts Bank. The methods used in this study are based on previous JASCO noise modelling studies (Warner et al. 2018, MacGillivray et al. 2019) that used updated modelling assumptions to provide more realistic estimates of the noise contribution of anticipated RBT2 Project operations based on the most recent projections of container vessel calls and classes predicted to call on the RBT2 terminal. Previous modelling of project operations focused on Neo Panamax vessels, whereas the current study provides estimates of sound pressure levels (SPLs) for the four different size classes of container vessels projected to call at the terminal. Modelled sound levels are also provided for support tugs transiting at normal speed (8 knots) and reduced speed (5 knots). Weekly call projections are used to provide an updated estimate of the incremental increase in average sound level ($L_{\text{eq-1yr}}$; also referred to in related documents as “annual incremental noise” but this represents an average over one year and not a yearly increase) of project operations, above the existing noise conditions at Roberts Bank, for 2035, 2040, and

2045 to respond to the Minister's information request. Sound level predictions from this study have also been used as input to the Acoustic Effects model that estimates the acoustic effects of Project operations and the effectiveness of mitigation measures to reduce acoustic effects to SRKW (Buren et al. 2021).

2. Methods

2.1. Model Scenarios

Underwater noise from RBT2 Project operations is expected to originate principally from container vessels and support tugs, during those periods when container vessels arrive at and depart from the terminal. The highest noise levels are expected to be generated during berthing and unberthing, when support tugs are pushing on a container vessel to maneuver it in and out of the berth. Container vessels and support tugs will also generate underwater noise when they are transiting in the vicinity of the terminal, though the noise levels from these activities are expected to be lower than from berthing and unberthing. Container vessels transit at 18 knots, on average, in the shipping lanes near RBT2 and begin to slow down as they reach the terminal. They would travel at approximately 10.5 knots as they reach port authority jurisdiction and slow further to approximately 6 knots when they approach the terminal and are accompanied by the support tugs. The noise emissions from the vessels decline as the ships slow down as they approach the terminal. The container vessels at berth were modelled with and without shore power connection, to examine the potential benefits of this mitigation. The with shore-power scenario assumed 30% shore power uptake.

Noise levels from project operations were modelled using multiple scenarios, representing different sizes of container vessels, stages of Project operations, vessel speeds, and seasonal sound propagation conditions (Table 2). Representative source locations were used for modelling underwater sound propagation for each of the different model scenarios (Figure 1). Project operations were modelled at a finer level of granularity than in previous studies, with new scenarios reflecting a range of transiting speeds for tugs and container vessels. Two scenarios (13 and 14) were added to evaluate the effectiveness of slowing down transiting tugs (from 8 to 5 knots) in reducing underwater noise. Since the amount of reduction in underwater noise emissions remains uncertain when tugs are transiting at lower speeds, two different tug slowdown scenarios were evaluated, representing a range of possible mitigation effectiveness. Note that tug slowdowns were not considered when computing incremental noise contributions of Project operations (Section 2.2).

Table 2. Description of updated underwater noise modelling scenarios for RBT2 project operations. Scenarios 1 and 4 are unchanged from previous modelling carried out in support of Undertaking #20 (MacGillivray et al. 2019). SPPX = Small Post-Panamax, LPPX = Large Post-Panamax, NPX = Neo Panamax, MMX = Mega Max.

Scenario	Variant	Description	Sources	Season
1*	A	Container vessel berthing with 3 tugs in summer	3 tugs berthing container vessel	Summer
4*	A	Container vessel berthing with 3 tugs in winter	3 tugs berthing container vessel	Winter
7	A	Container vessel turning off shipping lane at 10.5 knots in summer	SPPX container vessel	Summer
	B		LPPX container vessel	
	C		NPX container vessel	
	D		MMX container vessel	
8	A	Container vessel turning off shipping lane at 10.5 knots in winter	SPPX container vessel	Winter

Scenario	Variant	Description	Sources	Season
	B		LPPX container vessel	
	C		NPX container vessel	
	D		MMX container vessel	
9	A	Container vessel approaching terminal travelling with 3 tugs at 6 knots in summer	3 tugs SPPX container vessel	Summer
	B		3 tugs LPPX container vessel	
	C		3 tugs NPX container vessel	
	D		3 tugs MMX container vessel	
10	A	Container vessel approaching terminal travelling with 3 tugs at 6 knots in winter	3 tugs SPPX container vessel	Winter
	B		3 tugs LPPX container vessel	
	C		3 tugs NPX container vessel	
	D		3 tugs MMX container vessel	
11	–	3 Tugs transiting at 8 knots in summer	3 tugs	Summer
12	–	3 Tugs transiting at 8 knots in winter	3 tugs	Winter
13	A	3 Tugs transiting at 5 knots (high mitigation) in summer	3 tugs	Summer
	B	3 Tugs transiting at 5 knots (low mitigation) in summer		
14	A	3 Tugs transiting at 5 knots (high mitigation) in winter	3 tugs	Winter
	B	3 Tugs transiting at 5 knots (low mitigation) in winter		
15	A	Container vessel approaching terminal at 6 knots in summer	SPPX container vessel	Summer
	B		LPPX container vessel	
	C		NPX container vessel	
	D		MMX container vessel	
16	A	Container vessel approaching terminal at 6 knots in winter	SPPX container vessel	Winter
	B		LPPX container vessel	
	C		NPX container vessel	
	D		MMX container vessel	
17	A	One container vessel at Berth 2 with own power	MMX container vessel	Summer
	B	One container vessel at Berth 2 with shore power	MMX container vessel	
18	A	One container vessel at Berth 2 with own power	MMX container vessel	Winter
	B	One container vessel at Berth 2 with shore power	MMX container vessel	
19	A	One container vessel at Berth 2 with own power, one container vessel at Berth 3 with own power	MMX container vessel	Summer
	B	One container vessel at Berth 2 with own power, one container vessel at Berth 3 with shore power	MMX container vessel	

Scenario	Variant	Description	Sources	Season
20	A	One container vessel at Berth 2 with own power, one container vessel at Berth 3 with own power	MMX container vessel	Winter
	B	One container vessel at Berth 2 with own power, one container vessel at Berth 3 with shore power	MMX container vessel	
21	A	One NPX at Berth 1 with own power, one MMX at Berth 2 with own power, and one MMX at Berth 3 with own power	NPX container vessel and MMX container vessel	Summer
	B	One NPX at Berth 1 with own power, one MMX at Berth 2 with own power, and one MMX at Berth 3 with shore power	NPX container vessel and MMX container vessel	
22	A	One NPX at Berth 1 with own power, one MMX at Berth 2 with own power, and one MMX at Berth 3 with own power	NPX container vessel and MMX container vessel	Winter
	B	One NPX at Berth 1 with own power, one MMX at Berth 2 with own power, and one MMX at Berth 3 with shore power	NPX container vessel and MMX container vessel	

* Scenarios 1 and 4 (container vessel berthing) were previously modelled for undertaking #20. Details of these scenarios and modelled radii remain unchanged from (MacGillivray et al. 2019).

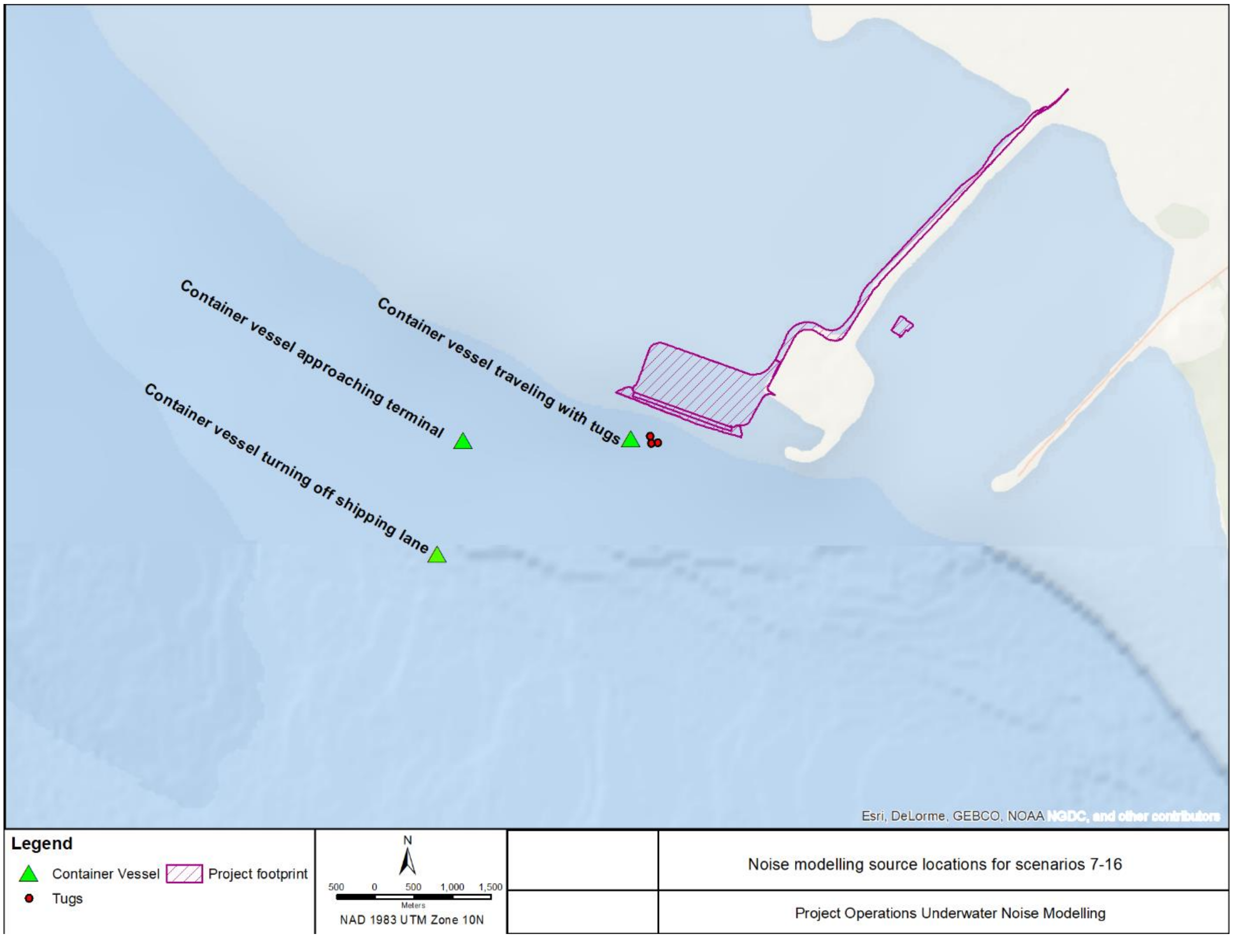


Figure 1. Acoustic source locations for modelling RBT2 Project operations (scenarios 7-16).

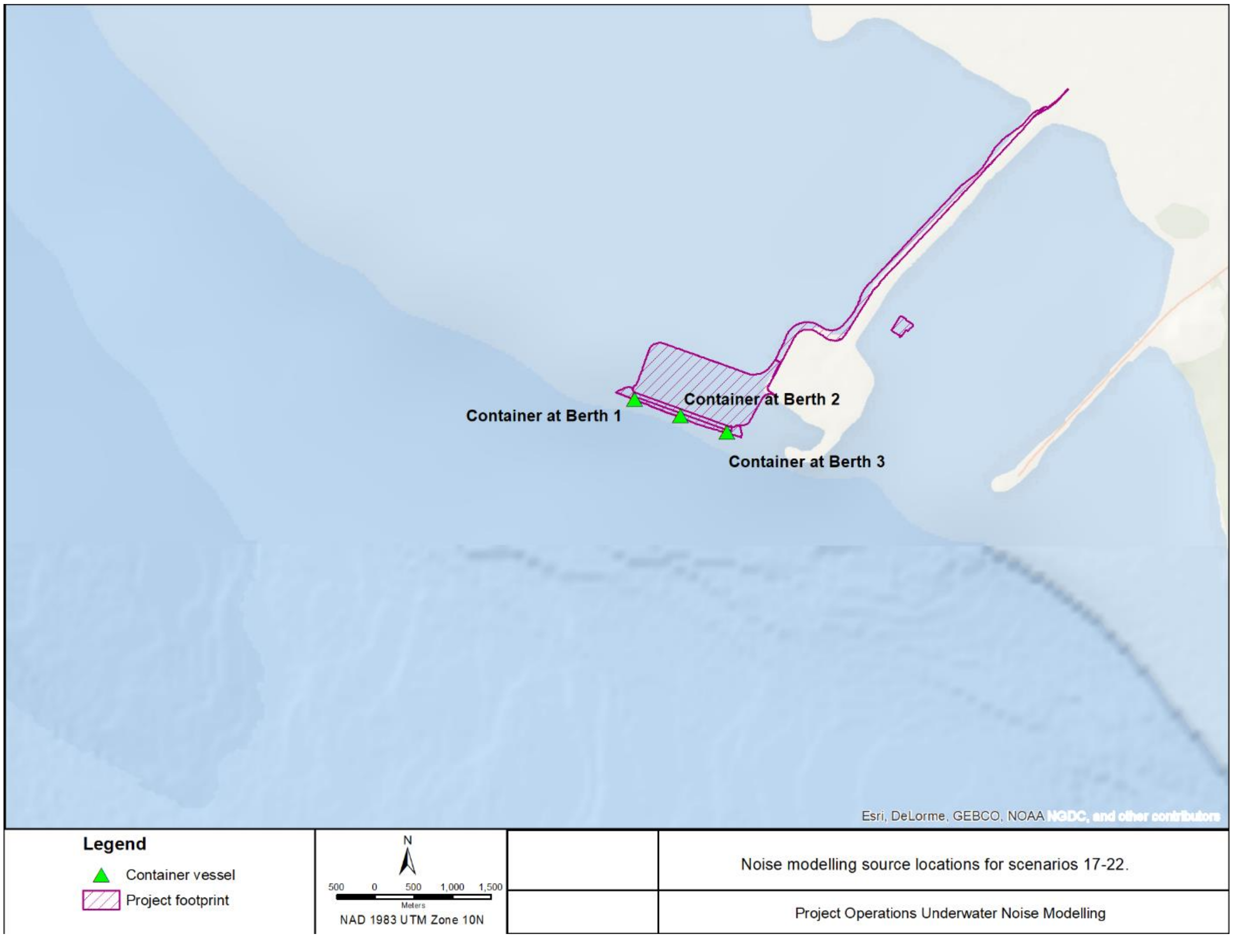


Figure 2. Acoustic source locations for modelling RBT2 Project operations (scenarios 17-22).

2.2. Incremental Contribution of Project Operations

The contribution of Project operations to underwater noise at Roberts Bank was calculated by summing their yearly equivalent continuous sound levels ($L_{\text{eq-1yr}}$) over 1 year, according to the expected number of calls per week for different classes of container vessels projected to call RBT2 (Table 1). Timings for the various stages of the Project operations were based on expected durations for container vessels to transit to and from the shipping lanes and to berth and unberth at the terminal with support tugs (Table 3). The time at berth includes all components from finishing berthing to commencing unberthing. Container vessels with call sizes significantly less than 6000 TEU (LPPX) will require less operations time and consequently will spend less time at berth. For these scenarios, the container vessels at berth were modelled both on and off shore power to examine the potential benefits of this mitigation. In this study, we assumed 30% vessels would connect to shore power, which is based on the proportion of vessels (34%) currently calling at the Port of Vancouver that have shore power capability (VFPA 2021). The total durations of Project operations, as a fraction of the year, were different than assumed in previous studies due to the revised call projections and to the consideration of additional stages of operations in the noise modelling. The updated Mercator vessel traffic projections (Mercator International 2021), indicate that under the most-realistic scenario, on average three to four vessels would call at RBT2 per week (Table 1). We also evaluated a high-case scenario that includes one extra Mega Max vessel call at RBT2 per week for 2035, 2040, and 2045 (on average four to five vessels per week). Following the methodology applied in the Environmental Impact Statement (EIS) (Wladichuk et al. 2014), the $L_{\text{eq-1yr}}$ footprint for Project operations was calculated from the sum of the modelled SPLs from each activity, weighted by each activity's expected duration within a one year period. Yearly cumulative noise levels in the study area with RBT2 were calculated by adding the expected $L_{\text{eq-1yr}}$ of the Project operations to estimated background conditions.

Table 3. Minutes per call assumed in calculation of yearly equivalent continuous sound levels ($L_{\text{eq-1yr}}$) for different stages of Project operations. Timings of different phases of container vessel activities (including arrival, departure, and at-berth) were chosen to be consistent with assumptions employed in the Acoustic Effects model (Buren et al. 2021). The full duration of the operational activity (excluding time while at berth) is assumed to be 154 minutes.

Scenarios	Description	Minutes per Call
Arrival at RBT2		
7, 8	Container vessel turning off shipping lane at 10.5 knots	12.6*
11, 12	3 Tugs transiting at 8 knots	25.2*
15, 16	Container vessel approaching terminal at 6 knots	12.6*
9, 10	Container vessel approaching terminal travelling with 3 tugs at 6 knots	24
1, 4	Container vessel berthing with 3 tugs	30
Departure from RBT2		
1, 4	Container vessel unberthing with 3 tugs	30
9, 10	Container vessel departing terminal travelling with 3 tugs at 6 knots	24
15, 16	Container vessel departing terminal at 6 knots	10.5**
11, 12	3 Tugs transiting at 8 knots	21**
7, 8	Container vessel turning onto shipping lane at 10.5 knots	10.5**
At Berth		
17–22	LPPX at Berth 1, 2, or 3	2331.6
	NPX at Berth 1, 2, or 3	2822.4
	MMX at Berth 1, 2, or 3	3605.4

*, ** Container vessel and tug movements are concurrent during initial arrival (25.2 minutes) and final departure (21 minutes) phases, although this does not impact the calculation of the incremental increase in average sound level ($L_{\text{eq-1yr}}$).

Background conditions were estimated based on a previous modelling study of cumulative noise from existing vessel traffic (ca. 2015) and wind-driven ambient noise at Roberts Bank (MacGillivray et al. 2019) in the Focused Model Area (FMA; Figure 3). Cumulative sound levels (10 Hz to 63,000 Hz SPL at 10 m receiver depth) from existing vessel traffic were modelled using 2015 AIS data, for two representative days (one in summer and one in winter). Wind-driven ambient noise was included in the model, based on historical wind speed data from the FMA. Modelled estimates of future background noise levels are not available for expected conditions in 2035-2045. Comparisons based on existing noise levels presented in this study do not reflect expected increases in future background (i.e., non-project related) noise due to changes in non-RBT2 vessel traffic, including both recreational and commercial vessel traffic. If noise levels from non-Project related traffic increase over time then the absolute changes resulting from RBT2 traffic, relative to future baseline (here assumed to be 121.7 dB re μPa broadband), will be smaller than presented here. This is only because the RBT2 traffic would then constitute a smaller fraction of the total future noise increase.

The incremental contribution of Project operations at Roberts Bank (Δ) was calculated from the increase in $L_{\text{eq-1yr}}$ from the background, after adding the contribution of Project operations:

$$\Delta = L_{eq\text{-}1yr}^{(\text{background})} - 10 \times \log_{10}\left(\log_{10}^{-1} L_{eq\text{-}1yr}^{(\text{background})}/10 + \log_{10}^{-1} L_{eq\text{-}1yr}^{(\text{RBT2})}/10\right)$$

where $L_{eq\text{-}1yr}^{(\text{background})}$ is the one year average background noise level, $L_{eq\text{-}1yr}^{(\text{RBT2})}$ is the yearly average noise level from Project operations, and $\log_{10}^{-1}$ is the antilog function. Following previous studies, the incremental yearly contribution of Project operations was calculated at 6 locations within the Focused Model Area (Figure 3). In this study, however, the incremental contribution was only reported at location 1 (Roberts Bank) since it was found that underwater noise contribution from the Project was negligible (< 0.1 dB) at the other 5 receiver locations (Figure 3). A more detailed analysis of noise level increases near Roberts Bank was performed by defining four new test receiver locations near Station 1 of the original study, with these now referred to as Stations 1A to 1D. These stations are positioned at distances of 300 m, 750 m, 1500m and 3000 m perpendicularly off the RBT2 berth face (Figure 4), with these distances selected based on the Acoustic Effects model (Buren et al. 2021). The 1.5 km distance (Station 1C) is the distance corresponding with the highest SRKW transit density. The incremental increases of underwater sound levels from RBT2 Project operation at these new stations are provided in Figure 4.

The incremental project noise contributions used to generate the noise increase contour maps (Appendices A.2 and A.3) over large areas of Georgia Strait are referenced to a baseline SPL of 122.9 dB re μPa, which is the average of the predicted baseline levels at test receivers 1A, 4, 5, and 6. The incremental noise level increases at receivers 1A-1D and the area exceedance values presented in Table 11 are based on a slightly lower baseline of 121.7 dB SPL, obtained from the value only at Station 1A which is closest to RBT2.

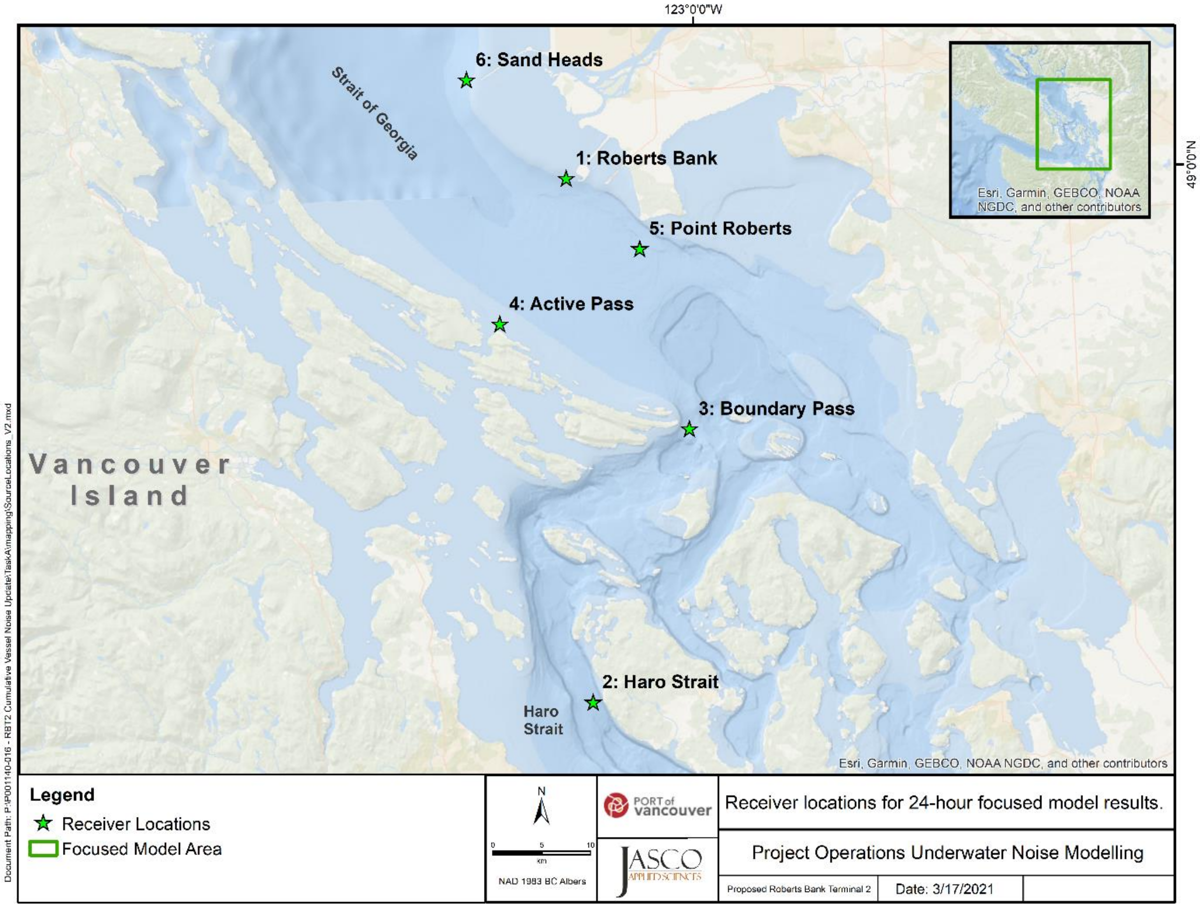


Figure 3. Focused Model Area (FMA; green box) and test receiver locations used for assessing incremental increase of underwater sound levels from RBT2 Project operation. Increases in one year averaged noise levels were negligible at all receivers except Roberts Bank (location 1).

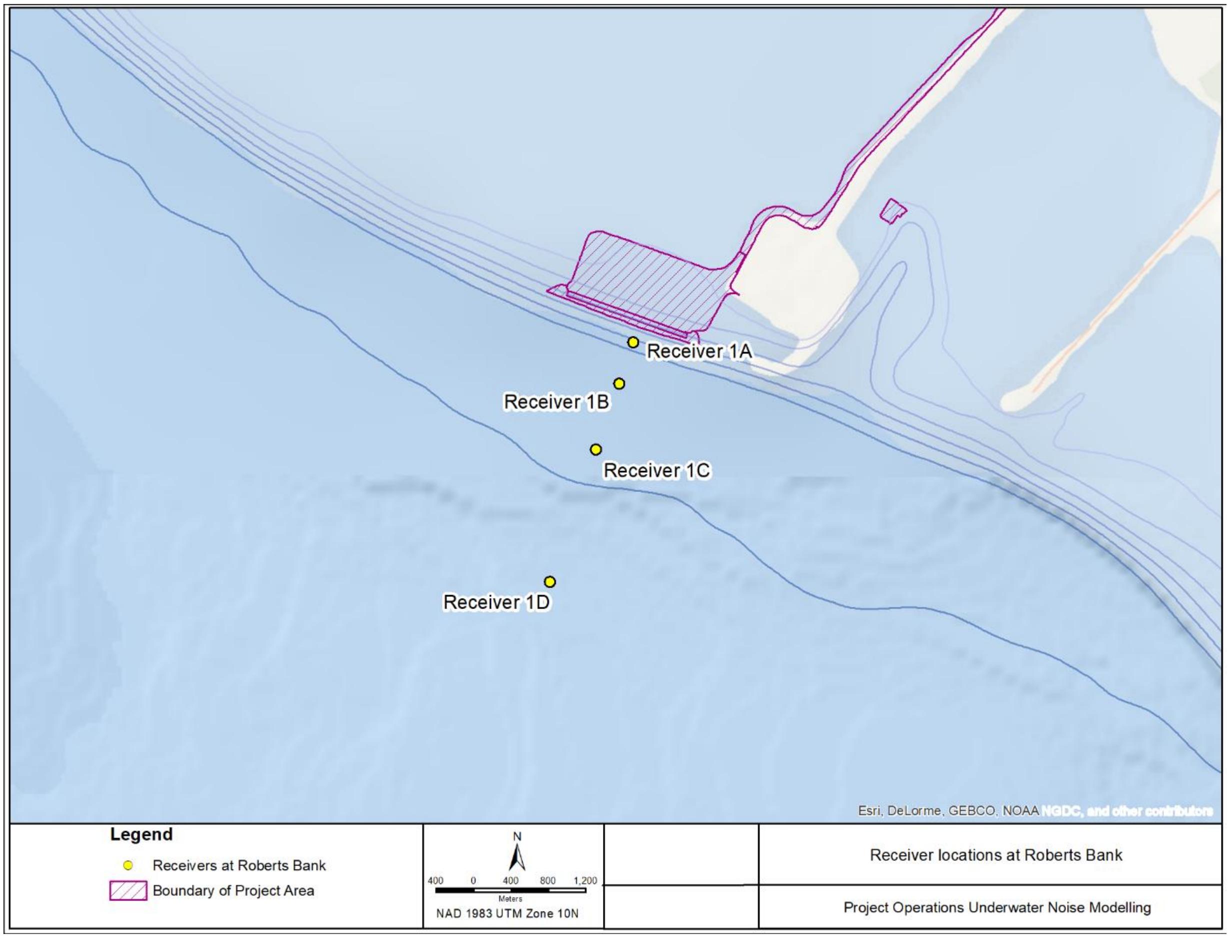


Figure 4. Four test receiver locations defined near Roberts Bank Station (location 1 from Figure 3).

Table 4. Coordinates for the four selected receivers at Roberts Bank.

Receiver	Perpendicular distance from berth face (m)	Latitude (deg)	Longitude (deg)	Easting (m)	Northing (m)	UTM zone
1A	285	49.01283	-123.18611	486391	5428899	10
1B	750	49.00888	-123.18818	486239	5428460	
1C	1500	49.00250	-123.19151	485993	5427751	
1D	3000	48.98975	-123.19819	485501	5426335	

2.3. Acoustic Sources

Source levels were estimated for four different classes of container vessels travelling at reduced speeds while approaching and departing from the RBT2 terminal (Table 5, Figure 5), and while at berth alongside the terminal under own and shore power (Figure 6). Reference source levels for container vessels transiting at reduced speed (11.6 knots) were based on statistical representation of measurements for Neo Panamax vessels collected on the underwater listening stations in Strait of Georgia, Haro Strait, and Boundary Pass in 2017-2018 previously available from the ECHO Program (MacGillivray et al. 2019). Note that only summary statistics of source levels were provided by the ECHO Program for this analysis, to maintain operator confidentiality. Nominal source levels were estimated for the four container vessel classes in Table 5, by adjusting the reference measurements from MacGillivray et al. (2019) according to frequency-dependent length, draft and speed trends reported by the ECHO Program's recently published vessel noise correlations study (MacGillivray et al. 2020). Data from the ECHO Program represent the best available information on noise emissions from container vessels likely to call at the proposed terminal in the future.

Reference source levels for container vessels at berth under own power were obtained from measured underwater sound during the loading of containers on the *CMA CGM La Scala* at Deltaport, Roberts Bank (Warner et al. 2013). The far-field source levels for the *CMA CGM La Scala* (length overall (LOA): 334 m) were divided into 33 discrete point source levels, simulating one monopole every 10 m from stern to bow. This approach of distributing the noise emissions over the length of the vessel was taken because ships may have a variety of pumps and power generators distributed throughout the vessel. Furthermore, noise and vibration from container loading and unloading is expected to originate from different compartments along the length of the vessel. The four container vessel classes in Table 5 were modelled using the same monopole source levels (Figure 6), but the total number of monopoles was adjusted for the class's average LOA (assuming one monopole every 10 m). As a result, modelled noise emissions were higher for larger vessels while at berth.

Little information is available about underwater source levels for container vessels at berth under shore power. A broadband difference of 5.8 dB in source levels for a container vessel off and on shore power was derived from underwater measurements at the Centerm terminal (Tollit 2020); the measurements show this reduction in source levels occurring below 10 kHz. The monopole source levels for container vessels under shore power were modelled by applying a reduction of 5.8 dB at frequencies below 10 kHz to the monopole source levels for vessels under own power (described above).

Table 5. Details of container vessel classes used for modelling noise levels from Project operations. Average length overall (LOA) and nominal draft values were used for estimating vessel source levels based on trends identified by the ECHO Program vessel noise correlations study (MacGillivray et al. 2020).

Vessel size class	Capacity (TEU)	Average LOA (m)	Nominal Draft (m)
Small Post-Panamax (SPPX)*	< 9,000	307	11.4
Large Post-Panamax (LPPX)	9,000-12,700	347	12.5
Neo Panamax (NPX)	13,000-14,999	366	13.5
Mega Max (MMX)	18,000-23,000	400	14.0

* Small post-panamax vessels are not expected to call at RBT2, according to Mercator vessel traffic projections, but are included in the current study for comparative purposes.

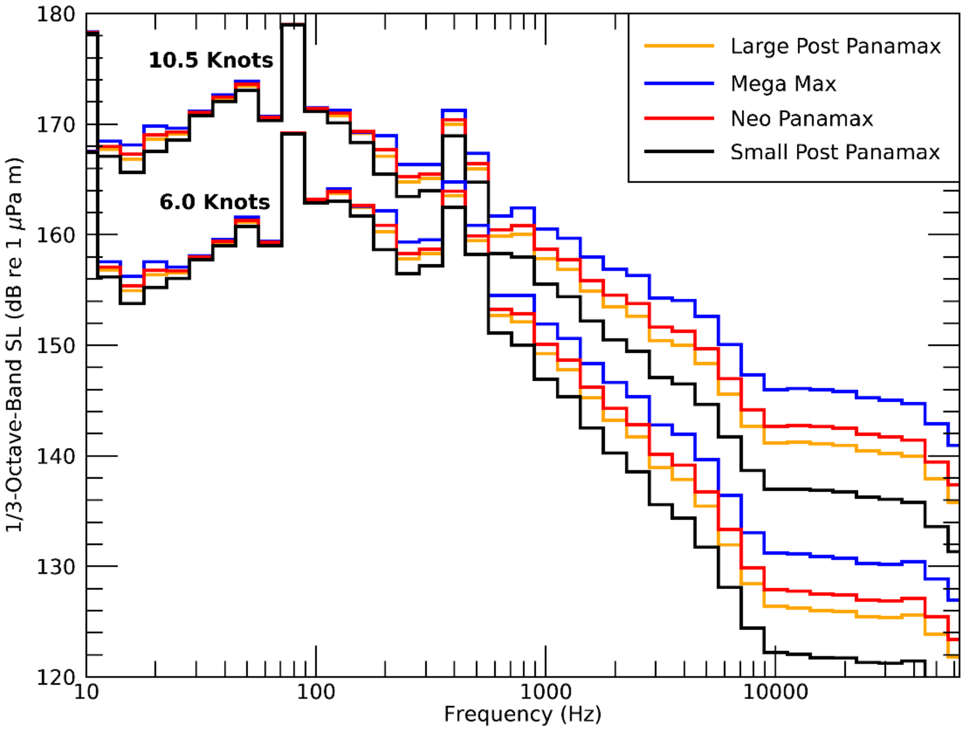


Figure 5. Speed-adjusted source levels in 1/3-octave frequency bands for container vessels transiting at 10.5 and 6 knots during approach and departure from the terminal. Source level data for container vessels were available by request from the ECHO Program and adjusted for vessel size according to trends identified in the recent ECHO vessel noise correlations study (MacGillivray et al. 2020).

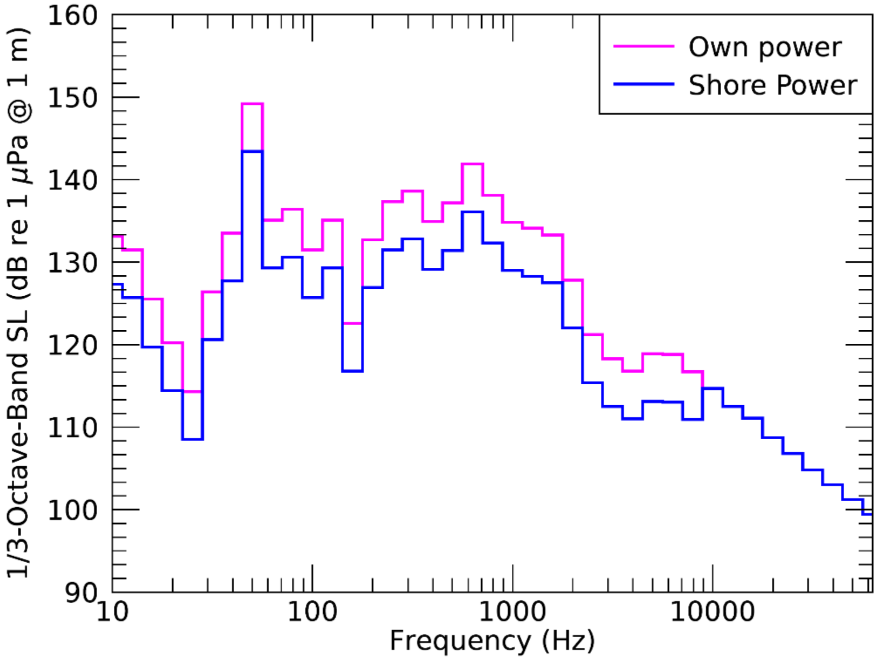


Figure 6. Power-adjusted monopole source levels in 1/3-octave frequency bands for container vessels while at berth alongside the terminal, using own power and shore power. Monopole source level were based on source level data for a container vessel loading (Warner et al. 2013) and expected reduction while on shore power (Tollit 2020).

Source levels for support tugs were based on controlled measurements of the berthing tug *Seaspan Resolution*, collected at Roberts Bank in 2013 (Warner et al. 2013), and are the same as used in previous RBT2 modelling studies. These tug source levels were adjusted for transit speeds of 8, 6, and 5 knots to represent different stages of Project operations (Figure 7). In previous studies, tug source levels were adjusted for speed according to a $60\times\log_{10} V$ (i.e., sixth power) dependence, which was consistent with measurements of *Seaspan Resolution* and the trend reported by Ross (1987). However, analysis of other tug source levels collected by the ECHO Program from various different types of tugs during the 2017 slowdown trial (MacGillivray and Li 2018) suggested that the class as a whole has a weaker speed dependence than predicted by the Ross model ($18\times\log_{10} V$). For a speed reduction from 8 knots to 5 knots, the Ross law predicts a 12.2 dB change in source level, whereas the trend of the ECHO Program data predicts a 3.7 dB change in source level. Since it was unknown whether *Seaspan Resolution* is representative of support tugs that will be used at RBT2 in the future, source levels for the 5 knot transiting scenarios were calculated using both reported trends, reflecting a range of potential effectiveness for slowdown mitigation (i.e., high (i.e., optimistic) and low (i.e., conservative) mitigation effectiveness scenarios).

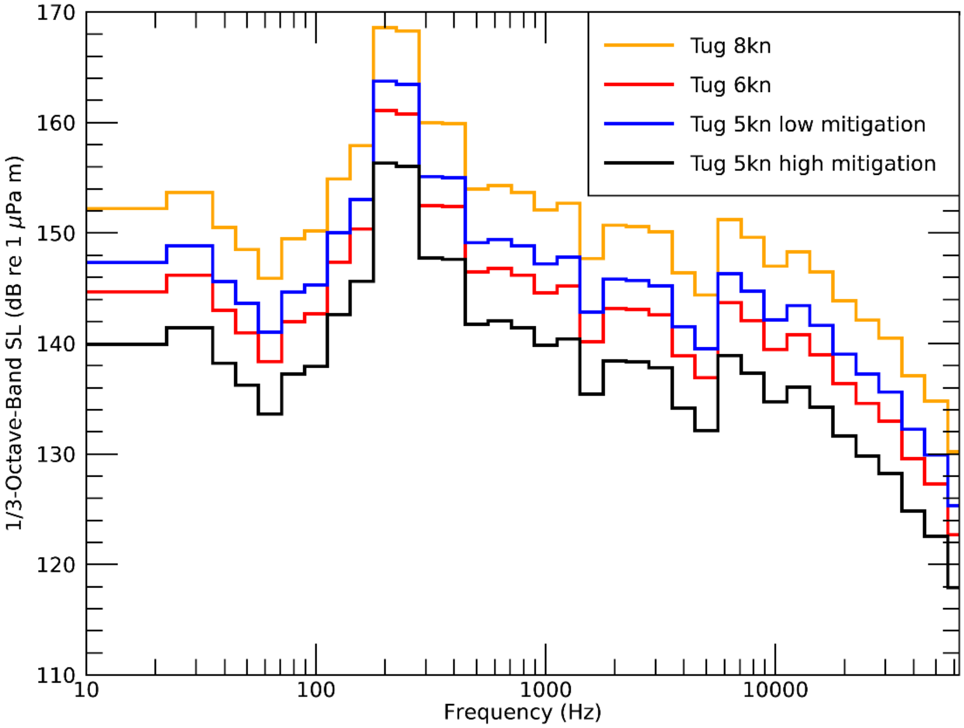


Figure 7. Speed-adjusted source levels in 1/3-octave frequency bands for support tugs at 8, 6, and 5 knots during approach and departure from the terminal. High and low mitigation values at 5 knots reflect optimistic (12.2 dB) and conservative (3.7 dB) estimates of speed-related source level reductions, based on trends from RBT2 and ECHO Program studies respectively.

For scenarios 1 and 4, simulation of noise from container vessel berthing with 3 tugs in summer and winter, followed the same methodology used in previous studies (Warner et al. 2018), where source levels for berthing were derived from 30-minute average measurements obtained at Roberts Bank (Warner et al. 2013). Berthing noise originates primarily from tugs pushing on the container vessels, and therefore was assumed to depend on the number of tugs involved in the berthing operation rather than the size of the container vessel. Project operations were modelled assuming container vessels require three berthing tugs, regardless of size, which is likely a conservative assumption.

For scenarios 17–22, simulation of container vessels (Mega Max and Neo Panamax) at berth (under own or shore power) used a series of noise sources (i.e., monopoles) distributed over the lengths of ships, as described previously, to model the different classes of container vessels at three berthing locations along the terminal wall. While at berth, underwater noise originates from the machinery onboard the vessels, as opposed to originating from the main propulsion system. Noise sources were therefore distributed every 10 m along the vessels. Project operations were modelled assuming one, two, and three vessels at berth, with a maximum of one vessel under shore power.

2.4. Acoustic Impact Criteria

Several acoustic impact criteria were used to determine where noise from Project operations would have potential to result in behavioural effects to SRKW. The selection of criteria is further described in Buren et al. (2021) and considered the following sources:

1. Generic cetacean disturbance criteria applied by the National Marine Fisheries Service (NMFS) (MMPA 2007, NOAA 2019).
2. Species-specific behavioural response thresholds for SRKW (SMRU Canada Ltd. 2014), which are based on probabilities of low and moderate responses.

Specific criteria were used for behavioural response thresholds for SRKW that were developed for the EIS. SMRU Canada Ltd. obtained input from outside experts and reanalyzed three existing data sets to quantify unweighted broadband SPL at which behavioural responses had been observed (Table 6). For this study, radii were computed for SMRU's low- and moderate-severity response thresholds of 120 dB re 1 µPa, which corresponds to the 10% probability of low-severity behavioural response and 1% probability of moderate behavioural response and the behavioural disturbance threshold used by NMFS, 129 dB re 1 µPa and 137 dB re 1 µPa which correspond to the 50% probability of low- and moderate-severity behavioural responses, respectively. Project operations were not expected to generate sound levels that that could result in injury to marine mammals, therefore auditory injury criteria were not evaluated for this study.

Table 6. Behavioural response criteria (unweighted broadband SPL, dB re 1 µPa) for SRKWs (SMRU Canada Ltd. 2014). Note that 120 dB re 1 µPa SPL (NMFS level B) corresponds to the 10% probability threshold for low-severity behavioural response.

Severity of response	Probability of response		
	5%	50%	95%
Low	117	129	146
Moderate	126	137	153

Noise from Project operations may also mask SRKW vocalizations and limit the range at which individuals can receive echolocation clicks from potential prey. Echolocation masking was evaluated using sound power spectral density (PSD) thresholds in two separate frequency bands (Table 7). These two PSD thresholds were based on an estimate of noise levels that would mask a SRKW click return at 250 m range (Au et al. 2004, SMRU Canada Ltd. 2014). Radii for these thresholds were calculated from modelled PSD levels in the 20 kHz and 50 kHz frequency bands.

Table 7. Estimated noise spectrum (PSD) level that would mask a SRKW click return at 250 m at 20 kHz and 50 kHz (Au et al. 2004, SMRU Canada Ltd. 2014).

Frequency (kHz)	Masking level (dB re 1 µPa^2/Hz)
20	37.9
50	35.7

2.5. Sound Propagation Modelling

Sound propagation in the study area was modelled using JASCO's Marine Operation Noise Model (MONM), which is described in EIS Appendix 9.8-A (Wladichuk et al. 2014). MONM models sound propagation via a wide-angle parabolic equation solution to the acoustic wave equation (Collins 1993) based on a version of the U.S. Naval Research Laboratory's Range-dependent Acoustic Model (RAM), which has been modified to account for an elastic seabed (Zhang and Tindle 1995). The parabolic equation method has been extensively benchmarked and is widely employed by researchers and practitioners in the underwater acoustics community (Collins et al. 1996).

The environmental inputs to MONM—i.e., bathymetry, geoacoustic properties, and sound speed profiles—were the same as those used in previous RBT2 modelling studies (Wladichuk et al. 2014, Warner et al. 2018). Past studies have established that sound propagation near Roberts Bank is sensitive to seasonal changes in oceanographic conditions. During summer, the sound speed profile exhibits a negative gradient in the thermocline whereas during winter the sound speed profile exhibits a positive gradient in the thermocline (Figure 8). The positive gradient tends to reduce propagation loss, whereas the negative gradient tends to increase propagation loss. As a result, sound level radii are predicted to be higher in winter than in summer, particularly for receivers near the sea-surface. This means that underwater sound will travel farther in winter than in summer, and the spatial extent of the area affected by Project noise would be greater in winter than in summer.

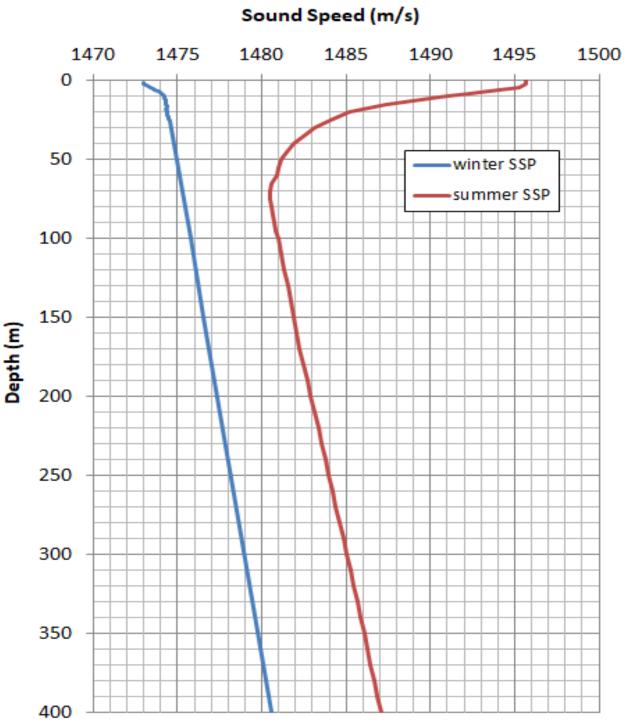


Figure 8. Sound speed profiles from measurements near Roberts Bank used for modelling sound propagation in the current study.

3. Results

3.1. Modelled Noise Levels of Project Operations

Table 8 summarizes modelled radii of behavioural disturbance and echolocation masking thresholds for all scenarios representing Project operations in summer and winter. For scenarios 1-16, these are 95th-percentile ($R_{95\%}$) radii, which represent the radius of a circle centred at the source that encompasses 95% of the area ensonified above the threshold level. For scenarios 17-22, the 95th-percentile radii were calculated in the two directions parallel and perpendicular to the berth face (Appendix B), which is a more suitable method for calculating radii for distributed noise sources (see Li et al. (2021)). Averages of the parallel and perpendicular radii are presented in Table 8. Figure 9 shows an isopleth map of SPL contours for a Mega Max container vessel travelling with 3 tugs at 6 knots in winter at RTB2 (scenario 10D). Maps of SPL for other scenarios are presented in Appendix A.1.

As in previous modelling studies, berthing operations (also representing unberthing) are predicted to have the largest acoustic footprints (scenarios 1A and 4A). Furthermore, modelled footprints are predicted to be larger in winter than in summer, due to seasonal differences in sound propagation conditions (see Section 2.5). Footprints are generally greater for larger vessels than for smaller vessels, and for faster vessels than for slower vessels, due to the influence of vessel size and speed on noise emissions. Masking thresholds, in particular, are predicted to be greater for larger container vessels than for small container vessels due to the influence of draft on radiated noise at high frequencies (i.e., as predicted by recent data from the ECHO Program (MacGillivray et al. 2020), see Figure 5). Reducing speeds of support tugs from 8 knots to 5 knots during transiting is predicted to reduce the extent of their noise footprints by 30-70%, depending on the actual effectiveness of slowdowns at reducing underwater radiated noise (i.e., reflecting the range of available data).

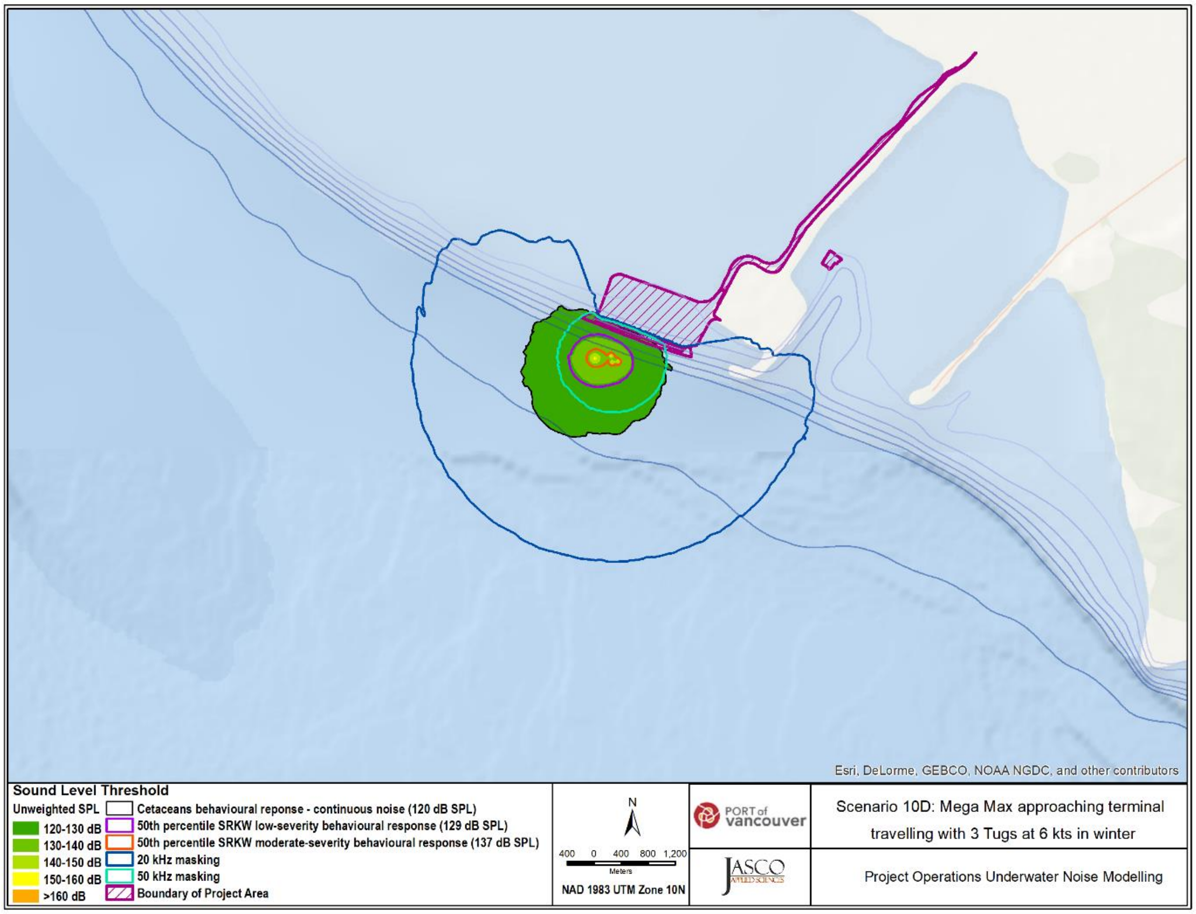


Figure 9. Modelled SPL isopleths for scenario 10D: Mega Max travelling with 3 tugs at 6 knots in winter.

Table 8. Modelled distances in metres to SRKW behavioural response (120, 129 and 137 dB re 1 µPa SPL, corresponding to 10% and 50% probability of low-severity, and 50% probability of moderate-severity), and SRKW echolocation click masking (20 kHz and 50 kHz) thresholds for RBT2 Project operations. Distances are 95th percentile radii ($R_{95\%}$). For scenarios 1–16, radii have been given relative to the centroid of activity. For scenarios involving distributed sources (17–22), radii have been given as the averaged 95th percentile distances to the berth face in perpendicular and parallel directions. SPPX = Small Post-Panamax, LPPX = Large Post-Panamax, NPX = Neo Panamax, MMX = Mega Max.

Scenario	Description	Season	120 dB SPL	129 dB SPL	137 dB SPL	20 kHz Masking	50 kHz Masking
1*	Container vessel (all sizes) berthing with 3 tugs (30-minute average SPL)	Summer	3,850	1,420	530	5,103	834
4*	Container vessel (all sizes) berthing with 3 tugs (30-minute average SPL)	Winter	8,460	1,940	630	8,709	1,214
7A	SPPX Container vessel turning off shipping lane at 10.5 knots	Summer	1,868	892	348	1,846	616
7B	LPPX Container vessel turning off shipping lane at 10.5 knots	Summer	1,906	930	362	2,373	841
7C	NPX Container vessel turning off shipping lane at 10.5 knots	Summer	1,922	962	371	2,422	1,028

Scenario	Description	Season	120 dB SPL	129 dB SPL	137 dB SPL	20 kHz Masking	50 kHz Masking
7D	MMX Container vessel turning off shipping lane at 10.5 knots	Summer	1,965	1,054	387	2,665	1,251
8A	SPPX Container vessel turning off shipping lane at 10.5 knots	Winter	2,208	923	351	1,476	597
8B	LPPX Container vessel turning off shipping lane at 10.5 knots	Winter	2,297	1,053	375	2,190	776
8C	NPX Container vessel turning off shipping lane at 10.5 knots	Winter	2,325	1,065	384	2,493	848
8D	MMX Container vessel turning off shipping lane at 10.5 knots	Winter	2,403	1,070	399	3,208	1,018
9A	SPPX Container vessel approaching terminal travelling with 3 tugs at 6 knots	Summer	919	459	283	1,704	637
9B	LPPX Container vessel approaching terminal travelling with 3 tugs at 6 knots	Summer	942	476	294	1,707	642
9C	NPX Container vessel approaching terminal travelling with 3 tugs at 6 knots	Summer	950	480	299	1,709	647
9D	MMX Container vessel approaching terminal travelling with 3 tugs at 6 knots	Summer	973	504	301	1,733	687
10A	SPPX Container vessel approaching terminal travelling with 3 tugs at 6 knots	Winter	1,061	478	283	2,867	766
10B	LPPX Container vessel approaching terminal travelling with 3 tugs at 6 knots	Winter	1,099	504	294	2,873	767
10C	NPX Container vessel approaching terminal travelling with 3 tugs at 6 knots	Winter	1,139	516	300	2,876	768
10D	MMX Container vessel approaching terminal travelling with 3 tugs at 6 knots	Winter	1,206	526	301	2,886	771
11	3 Tugs transiting at 8 knots	Summer	840	423	213	2,638	859
12	3 Tugs transiting at 8 knots	Winter	1,155	467	222	4,047	1,129
13A	3 Tugs transiting at 5 knots (high mitigation)	Summer	322	123	83	1,310	420
13B	3 Tugs transiting at 5 knots (low mitigation)	Summer	563	281	115	1,940	680
14A	3 Tugs transiting at 5 knots (high mitigation)	Winter	353	123	83	2,113	486
14B	3 Tugs transiting at 5 knots (low mitigation)	Winter	657	306	119	3,166	860
15A	SPPX Container vessel approaching terminal at 6 knots	Summer	815	309	96	276	168
15B	LPPX Container vessel approaching terminal at 6 knots	Summer	884	330	102	592	245
15C	NPX Container vessel approaching terminal at 6 knots	Summer	928	342	110	806	275
15D	MMX Container vessel approaching terminal at 6 knots	Summer	964	354	112	1,143	437
16A	SPPX Container vessel approaching terminal at 6 knots	Winter	863	315	98	357	169

Scenario	Description	Season	120 dB SPL	129 dB SPL	137 dB SPL	20 kHz Masking	50 kHz Masking
16B	LPPX Container vessel approaching terminal at 6 knots	Winter	932	344	105	535	276
16C	NPX Container vessel approaching terminal at 6 knots	Winter	952	351	110	653	328
16D	MMX Container vessel approaching terminal at 6 knots	Winter	989	362	112	886	434
17A	MMX Container vessel at Berth 2 on own power	Summer	345	145	115	480	190
17B	MMX Container vessel at Berth 2 on shore power	Summer	190	120	120	480	190
18A	MMX Container vessel at Berth 2 on own power	Winter	405	150	115	565	200
18B	MMX Container vessel at Berth 2 on shore power	Winter	200	125	120	565	200
19A	MMX Container vessel at Berth 2 on own power and MMX Container vessel at Berth 3 on own power	Summer	600	345	320	730	385
19B	MMX Container vessel at Berth 2 on own power and MMX Container vessel at Berth 3 on shore power	Summer	475	315	325	730	385
20A	MMX Container vessel at Berth 2 on own power and MMX Container vessel at Berth 3 on own power	Winter	695	350	320	910	395
20B	MMX Container vessel at Berth 2 on own power and MMX Container vessel at Berth 3 on shore power	Winter	525	320	325	910	395
21A	NPX Container at Berth 1 on own power, MMX Container at Berth 2 on own power, and MMX Container at Berth 3 on own power	Summer	635	350	325	800	390
21B	NPX Container at Berth 1 on own power, MMX Container at Berth 2 on own power, and MMX Container at Berth 3 on shore power	Summer	590	345	325	800	390
22A	NPX Container at Berth 1 on own power, MMX Container at Berth 2 on own power, and MMX Container at Berth 3 on own power	Winter	775	360	325	1030	405
22B	NPX Container at Berth 1 on own power, MMX Container at Berth 2 on own power, and one MMX Container at Berth 3 on shore power	Winter	700	350	325	1030	405

* During berthing (scenarios 1A and 4A), threshold distances are the same for all sizes of container vessels since noise from this operation originates primarily from the three support tugs. See Warner et al. (2018).

3.2. Incremental Contribution of Project Operations

Figure 10 shows the incremental contribution of Project operations in 2045 above existing background noise conditions (ca. 2015) at Roberts Bank. This figure represents the cumulative noise of container vessels arriving, departing, and while at berth, with sound sources modelled at locations shown in Figures 1 and 2. The cumulative noise contours are centered at the static locations of the sources used in the scenarios representing various stages of Project operations (see Table 3). Smaller contours of increased sound levels to the west of the terminal correspond to the selected source locations of container vessels during their approach to and departure from the terminal (i.e., Scenarios 7, 8, 15, and 16). This is the Project-related change in the 1-year time-averaged sound levels that would be measured by a hydrophone recording cumulative noise from all noise sources in the vicinity of the proposed terminal. Because the change is based on a 1-year time-average, it includes periods both with and without Project operation activities. Background noise for existing vessel traffic and ambient noise conditions ($L_{eq\text{-}1yr}^{(\text{background})}$) was calculated in Warner et al. (2018). This estimate was based on mean modelled summer and winter sound levels at locations 1, 4, 5, and 6 (see Figure 3), for a receiver depth of 10 m. Appendices A.2 and A.3 present incremental contribution maps for all three years included in the vessel traffic projections (Mercator International 2021) (i.e., 2035, 2040 and 2045) for the most-realistic scenario and less likely high-case scenario, respectively, considering 30% shore power uptake. Appendices A.4 and A.5 present similar incremental contribution maps, but considering no shore power uptake (i.e., all vessels using own power while at berth).

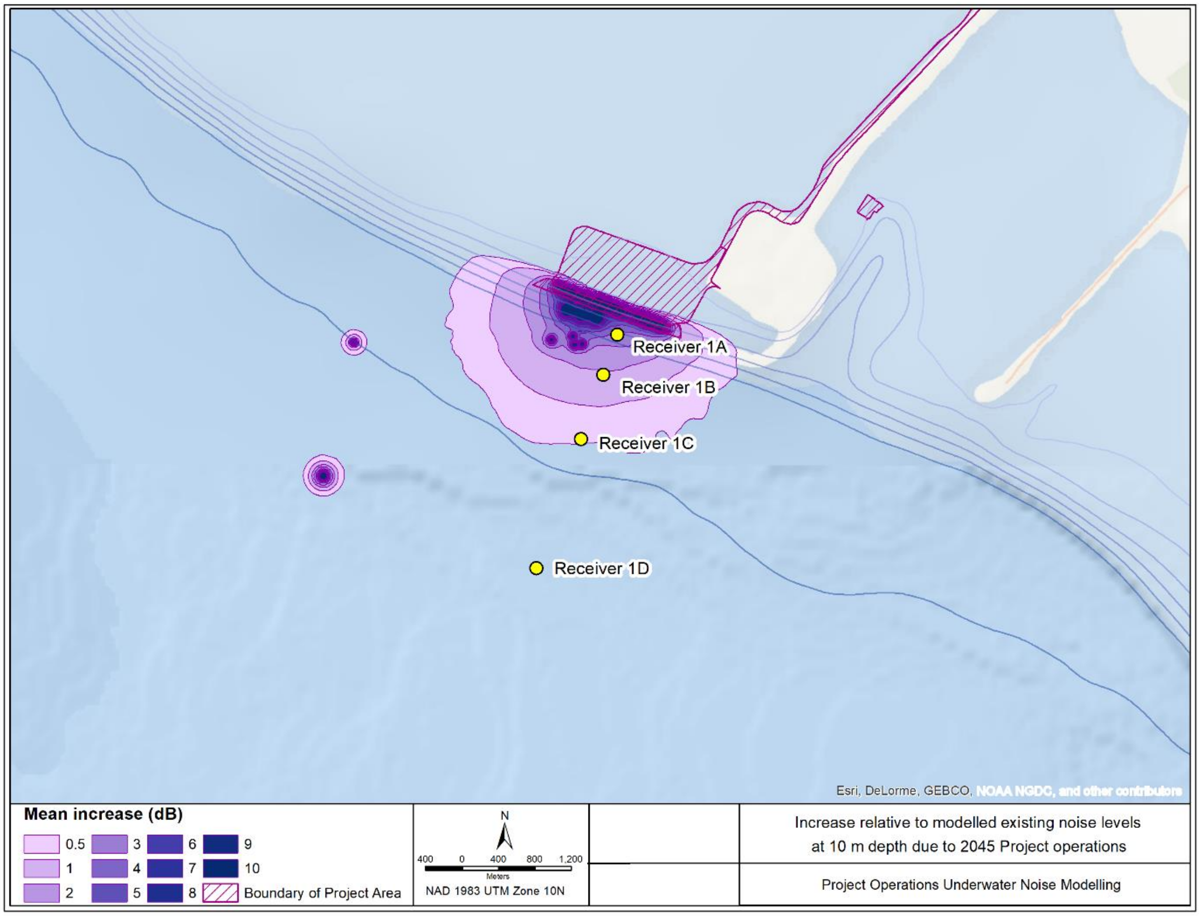


Figure 10. Modelled increase of one year time-averaged sound levels ($L_{\text{eq-1yr}}$), due to 2045 RBT2 project operations, above existing (2015 background) conditions; most-realistic scenario with 30% shore power uptake. Contours show the decibel increase for 10 m receiver depth. Smaller contours of increased sound levels to the west of the terminal correspond to the selected source locations of container vessels during their approach to and departure from the terminal (i.e., Scenarios 7, 8, 15, and 16).

Table 9 presents the predicted areas of incremental increases to underwater noise levels above existing conditions (i.e., corresponding to the areas of the contours shown in the maps), with 30% shore power uptake. Noise levels were predicted to increase by less than 0.5 dB beyond approximately 3.56 km (most-realistic scenario) and 3.92 km (high-case scenario) distances from the berth face of the RBT2 terminal. Compared to the results for scenarios with no shore power uptake (Table 10), the use of shore power did not appreciably change the incremental noise footprint. The average sound levels (Leq-1yr) at receivers 1A–1D with no shore power are less than 0.5 dB higher than those with 30% shore power uptake. To facilitate comparison with previous modelling studies, the incremental increase was calculated at Roberts Bank at receiver location 1A (see Figure 3). Earlier underwater noise modelling conducted in 2018 predicted an increase of 2.8 dB (i.e., 91% increase) above existing conditions based on 5 weekly vessel calls projected at the terminal. Modelled increases from the current study for most-realistic scenario are predicted to be 3.5 dB in 2035, 4.7 dB in 2040, and 4.6 dB in 2045, for receiver 1A, above background conditions (i.e., 2015) (Table 11). These estimates are slightly higher than previous comparable estimates presented during the public hearing, due to the close proximity of receiver 1A to the berth face (300 m distance) and inclusion of noise emissions of vessels while at berth. The high-case scenario gave higher noise level increases, since one extra Mega Max vessel per week was added for each year. For modelled scenarios with no shore power (using own power), the incremental increases in average sound level ($L_{\text{eq-1yr}}$) are higher at receiver 1A (300 m) compared to modelled scenarios with 30% shore power uptake (Table 12). The increases are smaller (0.1 dB or less) at greater distances from the berth face, as is evident from results for receiver locations 1B–1D.

Table 9. Areas of incremental increase in average sound level ($L_{eq\text{-}1yr}$) above existing background conditions (ca. 2015) due to Project operations in 2035, 2040, and 2045, with 30% shore power uptake. Areas in the table correspond to contours shown in Figure 10 and Appendices A.2 and A.3. Areas are given in hectares, where 1 ha = 0.01 km^2.

$L_{eq\text{-}1yr}$ Increase Relative to Existing (2015) Noise Levels (dB)	Most-realistic Scenario			High-case Scenario		
	2035 Area (ha)	2040 Area (ha)	2045 Area (ha)	2035 Area (ha)	2040 Area (ha)	2045 Area (ha)
0.5	344.4	492.4	479.9	409.7	616.6	600.0
1	191.1	257.3	253.9	223.3	289.5	285.3
2	89.9	128.3	125.9	107.9	145.3	143.1
3	60.3	82.0	80.8	72.1	93.3	91.6
4	45.8	60.0	58.9	53.1	67.9	67.1
5	37.0	47.3	46.8	42.3	52.6	52.0
6	31.6	38.9	38.5	35.7	42.8	42.3
7	27.0	33.4	33.2	30.8	36.5	35.9
8	21.7	29.2	28.7	26.8	31.8	31.6
9	16.5	25.5	25.2	21.7	27.9	27.7
10	11.3	20.4	19.6	16.8	23.4	23.2

Table 10. Areas of incremental increase in average sound level ($L_{eq\text{-}1yr}$) above existing background conditions (ca. 2015) due to Project operations in 2035, 2040, and 2045, with no shore power uptake (using own power). Areas in the table correspond to contours shown in Appendices A.4 and A.5. Areas are given in hectares, where 1 ha = 0.01 km^2.

$L_{eq\text{-}1yr}$ Increase Relative to Existing (2015) Noise Levels (dB)	Most-realistic Scenario			High-case Scenario		
	2035 Area (ha)	2040 Area (ha)	2045 Area (ha)	2035 Area (ha)	2040 Area (ha)	2045 Area (ha)
0.5	378.1	581.9	564.1	462.2	772.4	744.1
1	207.6	285.3	279.4	245.5	325.6	319.8
2	99.9	143.1	140.6	121.2	163.8	160.6
3	66.2	91.6	89.2	80.1	103.9	102.1
4	49.3	66.5	65.3	58.9	75.7	74.8
5	39.6	52.0	50.5	46.3	58.1	57.3
6	33.6	42.1	41.6	38.5	46.8	46.1
7	28.8	36.1	35.5	33.0	39.4	39.1
8	24.6	31.4	31.0	29.0	34.2	34.0
9	19.2	27.5	27.3	24.5	30.2	29.6
10	14.4	23.4	22.9	19.6	26.4	26.1

Table 11. Modelled increase in one year time averaged sound levels ($L_{eq\text{-}1yr}$), above existing (2015 background) conditions, due to RBT2 Project operations at locations at Roberts Bank: Receiver 1A (0.3 km), Receiver 1B (0.75 km), Receiver 1C (1.5 km), and Receiver 1D (3 km) based on container vessel traffic projections using the most-realistic vessel scenario and high-case vessel scenario (one additional Mega Max weekly). The distance is from the receiver to berth face. Model results are for 30% shore power uptake (i.e., 30% of vessels using shore power while at berth).

Scenario	**Description**	**Time-averaged sound levels ($L_{eq\text{-}1yr}$) at specified receiver location**												
		2015	*2035*				*2040*				*2045*			
		1A to 1D	1A	1B	1C	1D	1A	1B	1C	1D	1A	1B	1C	1D
Most-realistic	Estimated sound level with RBT2	121.7	125.2	123.5	122.2	122.0	126.4	124.1	122.4	122.1	126.3	124.1	122.4	122.1
	Increase above background condition in 2015	0.0	3.5	1.8	0.5	0.3	4.7	2.4	0.7	0.4	4.6	2.4	0.7	0.4
	Projected weekly calls at RBT2	0	3				4				4			
	Projected annual calls at RBT2	0	156				208				208			
High-case	Estimated sound level with RBT2	121.7	125.9	123.7	122.3	122.0	126.9	124.2	122.5	122.2	126.8	124.2	122.5	122.2
	Increase above background condition in 2015	0.0	4.2	2.0	0.6	0.3	5.2	2.5	0.8	0.5	5.1	2.5	0.8	0.5
	Projected weekly calls at RBT2	0	4				5				5			
	Projected annual calls at RBT2	0	208				260				260			

Table 12. Modelled increase in one year time averaged sound levels ($L_{\text{eq-1yr}}$), above existing (2015 background) conditions, due to RBT2 Project operations at locations at Roberts Bank: Receiver 1A (0.3 km), Receiver 1B (0.75 km), Receiver 1C (1.5 km), and Receiver 1D (3 km) based on container vessel traffic projections using the most-realistic vessel scenario and high-case vessel scenario (one additional Mega Max weekly). The distance is from the receiver to berth face. Modelled results are for no shore power uptake (i.e., all vessels using own power while at berth).

Scenario	**Description**	**Time-averaged sound levels ($L_{\text{eq-1yr}}$) at specified receiver location**												
		2015	*2035*				*2040*				*2045*			
		1A to 1D	1A	1B	1C	1D	1A	1B	1C	1D	1A	1B	1C	1D
Most-realistic	Estimated sound level with RBT2	121.7	125.6	123.6	122.3	122.0	126.9	124.2	122.5	122.2	126.8	124.2	122.5	122.2
	Increase above background condition in 2015	0.0	3.9	1.9	0.6	0.3	5.2	2.5	0.8	0.5	5.1	2.5	0.8	0.5
	Projected weekly calls at RBT2	0	3				4				4			
	Projected annual calls at RBT2	0	156				208				208			
High-case	Estimated sound level with RBT2	121.7	126.3	123.8	122.4	122.1	127.4	124.4	122.6	122.3	127.3	124.4	122.6	122.2
	Increase above background condition in 2015	0.0	4.6	2.1	0.7	0.4	5.7	2.7	0.9	0.6	5.6	2.7	0.9	0.5
	Projected weekly calls at RBT2	0	4				5				5			
	Projected annual calls at RBT2	0	208				260				260			

4. Summary and Conclusions

This study provides an updated assessment of underwater noise from RBT2 Project operations in response to the information request to the port authority from the Minister of Environment and Climate Change Canada. Modelling predictions from this study are based on new projections of container vessel calls at RBT2 for 2035, 2040, and 2045 by Mercator International (2021). Previous modelling estimates for Neo Panamax vessels (MacGillivray et al. 2019) have been updated using new information on source level trends for different size classes of container vessels available by request from the VFPA-led ECHO Program (MacGillivray et al. 2020). This study provides new estimates for all vessel size classes projected to call at the terminal, including Large Post Panamax, Neo Panamax, and Mega Max container vessels. Project operations have been modelled with a finer degree of granularity (e.g., including container vessels turning on and off the shipping lanes, transiting with tugs, berthing with tugs, and while at berth). Tugs have been modelled at different speeds to examine the potential benefits of slowdown mitigation while transiting and use of shore-power has been modelled for 30% of at-berth vessels. The modelling has also been updated to estimate distances to SRKW echolocation masking at frequencies of 20 kHz and 50 kHz.

The model results from this study predict that Project operations will increase underwater noise levels near the proposed terminal at Roberts Bank, as container vessels are redistributed from other terminals to call on RBT2. Background noise levels are already high at Roberts Bank due to existing vessel traffic and marine terminals. Modelled existing average noise levels ($L_{eq\text{-}1yr}$) at Roberts Bank are 121.7 dB re 1 µPa (MacGillivray et al. 2019), a finding supported by hydrophone measurements collected during the EIS (Hemmera Envirochem Inc. et al. 2014). The largest noise contributions from terminal operations are predicted to be from berthing and unberthing operations, when support tugs are pushing on container vessels to maneuver them into and out of their berths. Echolocation masking is predicted to be greater at 20 kHz than at 50 kHz, as noise emissions from tugs and container vessels decrease with increasing frequency. Noise levels from Project operations are predicted to be higher in winter than in summer due to seasonal changes in the sound speed profile that affects how sounds propagate through the ocean. Reducing speeds of support tugs from 8 knots to 5 knots during transiting was predicted to reduce the extent of their noise footprints by 30-70%, depending on the actual effectiveness of slowdowns at reducing their underwater radiated noise (i.e., reflecting the range of available data).

Under the most-realistic scenario for 2040, Project operations are predicted to increase average sound levels ($L_{eq\text{-}1yr}$) by 4.7 dB above existing conditions near the terminal (at 300 m distance) and by 0.4 dB above existing conditions near the turnoff to the shipping lanes (beyond 3.5 km distance). Under the less-likely high-case scenario for 2040, with 1 additional Mega Max call per week, Project operations are predicted to increase average sound levels ($L_{eq\text{-}1yr}$) by 5.2 dB above existing conditions near the terminal and by 0.5 dB above existing conditions near the turnoff to the shipping lanes. The use of shore power by 30% of vessels is predicted to have a marginal effect on the incremental contribution of project operations, with average sound levels only reduced by 0.1 dB at distances where SRKW most frequently travel past Roberts Bank (approximately 1.5 km from the berth face).

Under the most-realistic scenario, the incremental contributions of Project operations to average sound levels at receiver 1A (300 m from the berth face) are greater than the previous estimate of 2.8 dB above existing conditions which was presented during the panel review (MacGillivray et al. 2019), but this is because noise from at-berth vessels was not considered in previous estimates. It is important to note, however, that the noise contribution from at-berth vessels is restricted to a relatively small area near the berth face. At greater distances from the berth face, the incremental contribution of Project operations (receivers 1B-1C at 0.75-3 km), is less than 2.8 dB, due to the lower projected numbers of weekly container vessel calls at RBT2 under the most-realistic scenario.

Noise modelling predictions from this study are used in IR2020-3 Appendix D to estimate acoustic effects of Project operations on SRKW and measure the predicted effectiveness of proposed mitigation measures to reduce acoustic effects to SRKW (Buren et al. 2021).

Literature Cited

[FHWG] Fisheries Hydroacoustic Working Group. 2008. *Agreement in Principle for Interim Criteria for Injury to Fish from Pile Driving Activities*. 12 Jun 2008 edition. http://www.dot.ca.gov/hq/env/bio/files/fhwgcriteria_agree.pdf.

[ISO] International Organization for Standardization. 2017. *ISO 18405:2017. Underwater acoustics – Terminology*. Geneva. https://www.iso.org/standard/62406.html.

Marine Mammal Protection Act of 1972 as Amended. 2007. United States Pub. L. No. 92-522, 16 U.S.C. 1361 (Oct. 21, 1972). http://www.nmfs.noaa.gov/pr/laws/mmpa/text.htm.

[NOAA] National Oceanic and Atmospheric Administration (US). 2019. *ESA Section 7 Consultation Tools for Marine Mammals on the West Coast* (webpage). https://www.fisheries.noaa.gov/west-coast/endangered-species-conservation/esa-section-7-consultation-tools-marine-mammals-west. (Accessed December 2020).

ANSI S1.1-1994. R2004. *American National Standard: Acoustical Terminology*. American National Standards Institute and Acoustical Society of America, NY, USA. https://webstore.ansi.org/Standards/ASA/ANSIS11994R2004.

ANSI/ASA S1.13-2005. R2010. *American National Standard: Measurement of Sound Pressure Levels in Air*. American National Standards Institute and Acoustical Society of America, NY, USA. https://webstore.ansi.org/Standards/ASA/ANSIASAS1132005R2010.

Au, W.W., J.K.B. Ford, J.K. Horne, and K.A. Allman. 2004. Echolocation signals of free-ranging killer whales (Orcinus orca) and modeling of foraging for chinook salmon (Oncorhynchus tshawytscha). *Journal of the Acoustical Society of America* 115: 901–909.

Buren, A.D., D.J. Tollit, M. Gilbert, A. Johnson, J. Wood, K. Akaoka, H. Regehr, A. MacGillivray, Z. Li, et al. 2021. *Roberts Bank Terminal 2 Project Technical Data Report - Assessing effectiveness of mitigation to reduce potential acoustic effects on Southern Resident Killer Whales from project operation.* Consultants report prepared for Vancouver Fraser Port Authority by Ecofish Research Ltd., SMRU Consulting North America, and JASCO Applied Sciences Ltd. September 16, 2021.

Collins, M.D. 1993. A split-step Padé solution for the parabolic equation method. *Journal of the Acoustical Society of America* 93: 1736-1742.

Collins, M.D., R.J. Cederberg, D.B. King, and S. Chin-Bing. 1996. Comparison of algorithms for solving parabolic wave equations. *Journal of the Acoustical Society of America* 100(1): 178-182. https://doi.org/10.1121/1.415921.

Hemmera Envirochem Inc., SMRU Canada Ltd., and JASCO Applied Sciences (Canada) Ltd. 2014. *Roberts Bank Terminal 2 Technical Report: Underwater Noise. Ambient Underwater Noise Measurements*. 52 pp. http://www.robertsbankterminal2.com/wp-content/uploads/RBT2-Ambient-Underwater-Noise-Measurements-TDR.pdf.

Li, Z., Z. Alavizadeh, X. Mouy, C. N. E., and A.O. MacGillivray. 2021. *Underwater Noise Modelling of RBT2 Construction to Inform Mitigation*. Document 01996, Version 5.5. Technical report by JASCO Applied Sciences for Hemmera. .

MacGillivray, A.O. and Z. Li. 2018. Appendix A. Vessel Noise Measurements from the ECHO Slowdown Trial. *In* Trouce, K. (ed.). *Voluntary Vessel Slowdown Trial Summary Findings*. Vancouver Fraser Port Authority ECHO Program. https://www.flipsnack.com/portvancouver/echo-haro-strait-slowdown-trial-summary/full-view.html.

MacGillivray, A.O., Z. Li, J.L. Wladichuk, and G.A. Warner. 2019. *Mercator Projections Underwater Noise Modelling Update: Roberts Bank Terminal 2 Project*. Document Number 01759, Version 1.0. Technical report by JASCO Applied Sciences for Hemmera.

MacGillivray, A.O., J. Ainsworth, H. Frouin-Mouy, J.N. Dolman, and M.A. Bahtiarian. 2020. *ECHO Vessel Noise Correlations Study: Final Report*. Document Number 02025, Version 2.0. Technical report by JASCO Applied Sciences, ERM, and Acentech for Vancouver Fraser Port Authority ECHO Program.

Mercator International. 2021. *Appendix IR2020-3-B: Updated RBT2 Container Vessel Call Forecast Study*. Report to the Vancouver Fraser Port Authority.

Ross, D. 1987. *Mechanics of Underwater Noise*. Pergamon Press, NY, USA.

SMRU Canada Ltd. 2014. *Roberts Bank Terminal 2 Technical Data Report: Determination of Behavioral Effect Noise Thresholds for Southern Resident Killer Whales*. Report by SMRU Canada Ltd. (on behalf of Hemmera) for Port Metro Vancouver, Vancouver, BC. 44 pp. http://www.robertsbankterminal2.com/.

Tollit, K.A.J.W.J.T.K.P.D. 2020. *Burrard Inlet Underwater Noise Characterization: 2019 Final Report*. Technical report by SMRU Consulting North America for VFPA ECHO Program.

VFPA. 2021. *Vancouver Fraser Port Authority. Shore power. Available at https://www.portvancouver.com/environmental-protection-at-the-port-of-vancouver/climate-action-at-the-port-of-vancouver/shore-power/.* (webpage). (Accessed March).

Warner, G.A., C. O'Neill, A. McCrodan, H. Frouin-Mouy, J. Izett, and A.O. MacGillivray. 2013. *Underwater Acoustic Measurements in Haro Strait and Strait of Georgia: Transmission Loss, Vessel Source Levels, and Ambient Measurements*. Document Number 00659, Version 2.0. Technical report by JASCO Applied Sciences for Hemmera.

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.

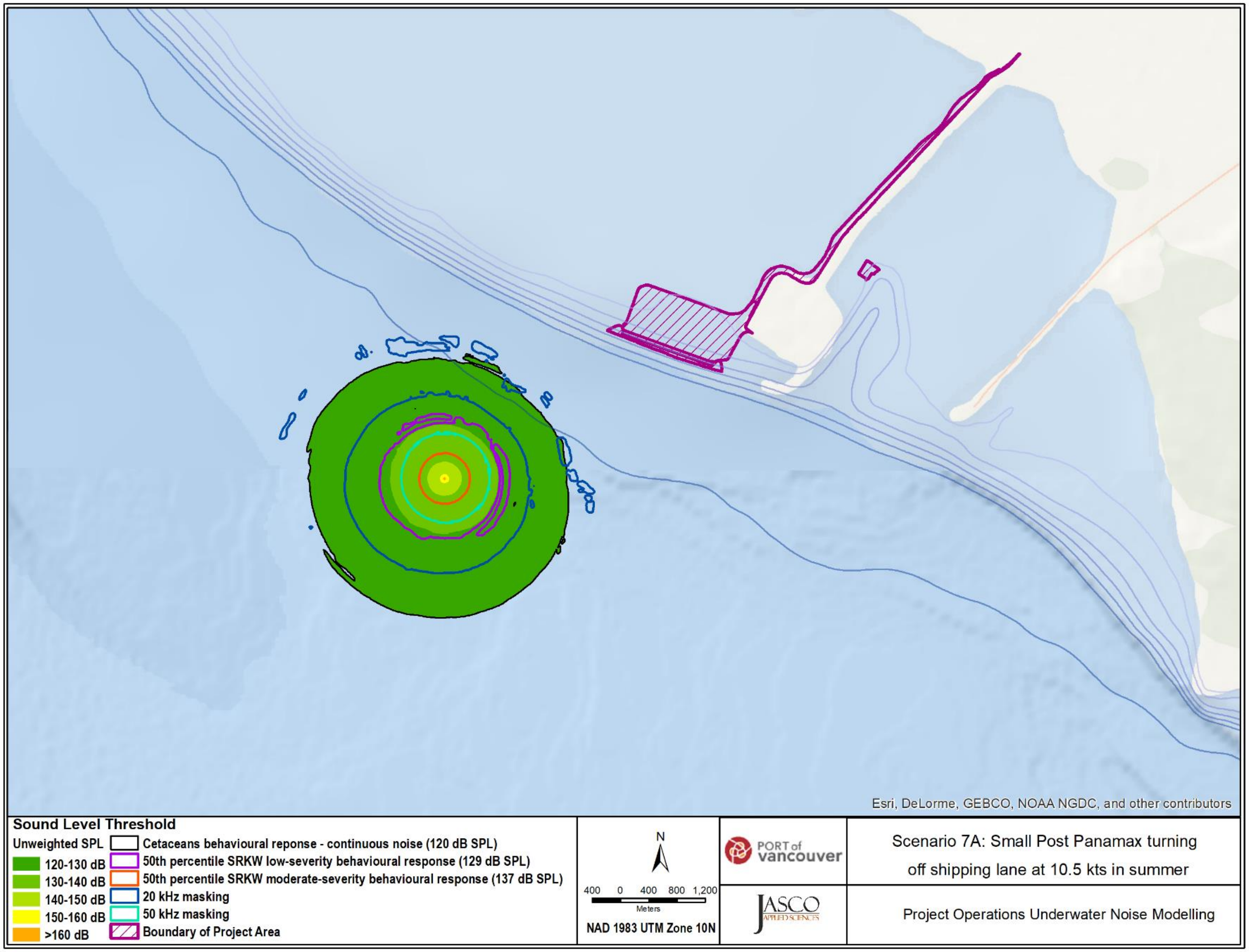
Wladichuk, J.L., G.A. Warner, A. McCrodan, and A.O. MacGillivray. 2014. *Appendix 9.8-A Construction and Terminal Activity Underwater Noise Modelling Study*. Roberts Bank Terminal 2 Technical Report—Underwater Noise Construction Activities and Terminal Vessel Operations Noise Modelling Study. Technical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

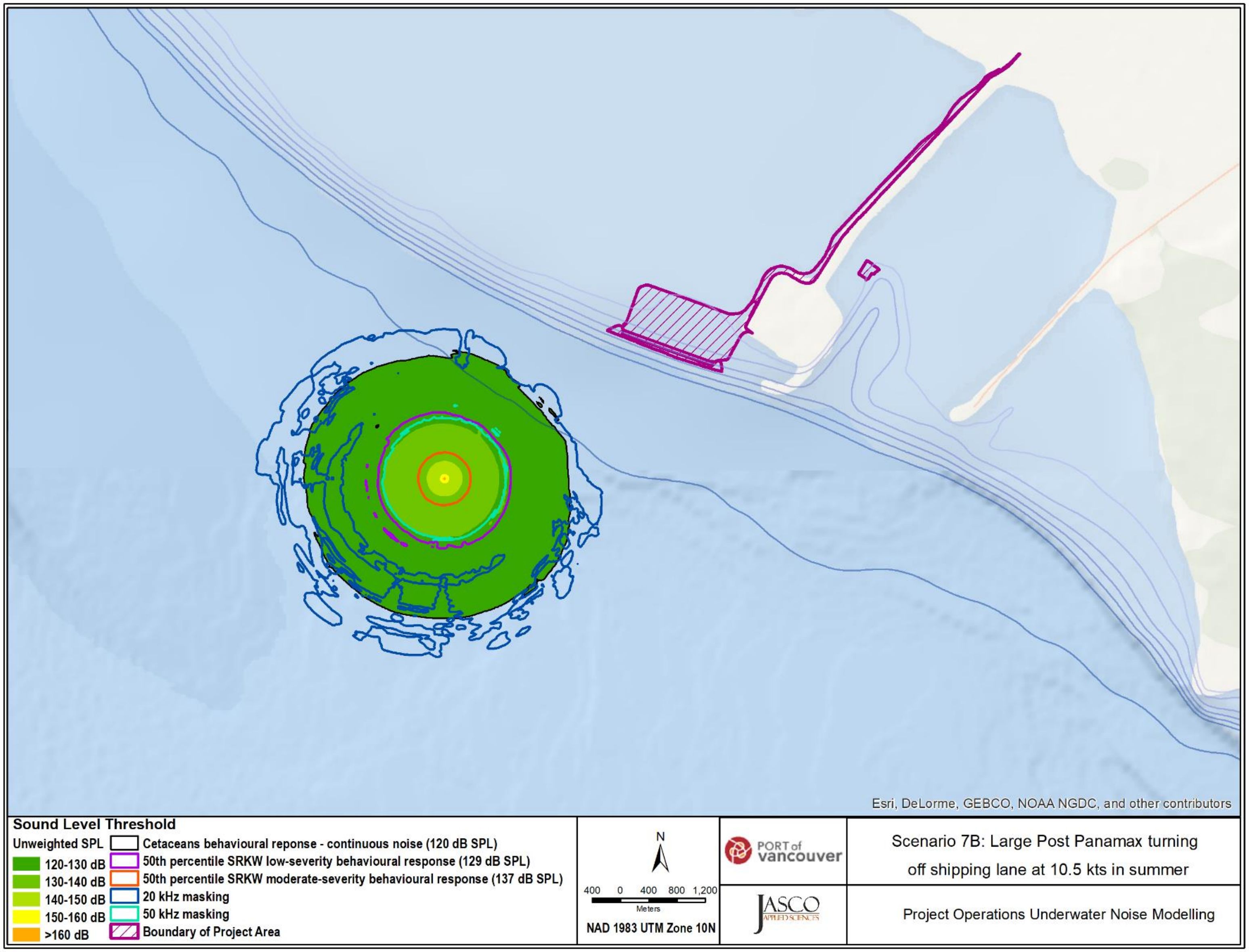
Zhang, Z.Y. and C.T. Tindle. 1995. Improved equivalent fluid approximations for a low shear speed ocean bottom. *Journal of the Acoustical Society of America* 98(6): 3391-3396. https://doi.org/10.1121/1.413789.

Appendix A. Sound Level Maps

A.1. Sound Pressure Levels

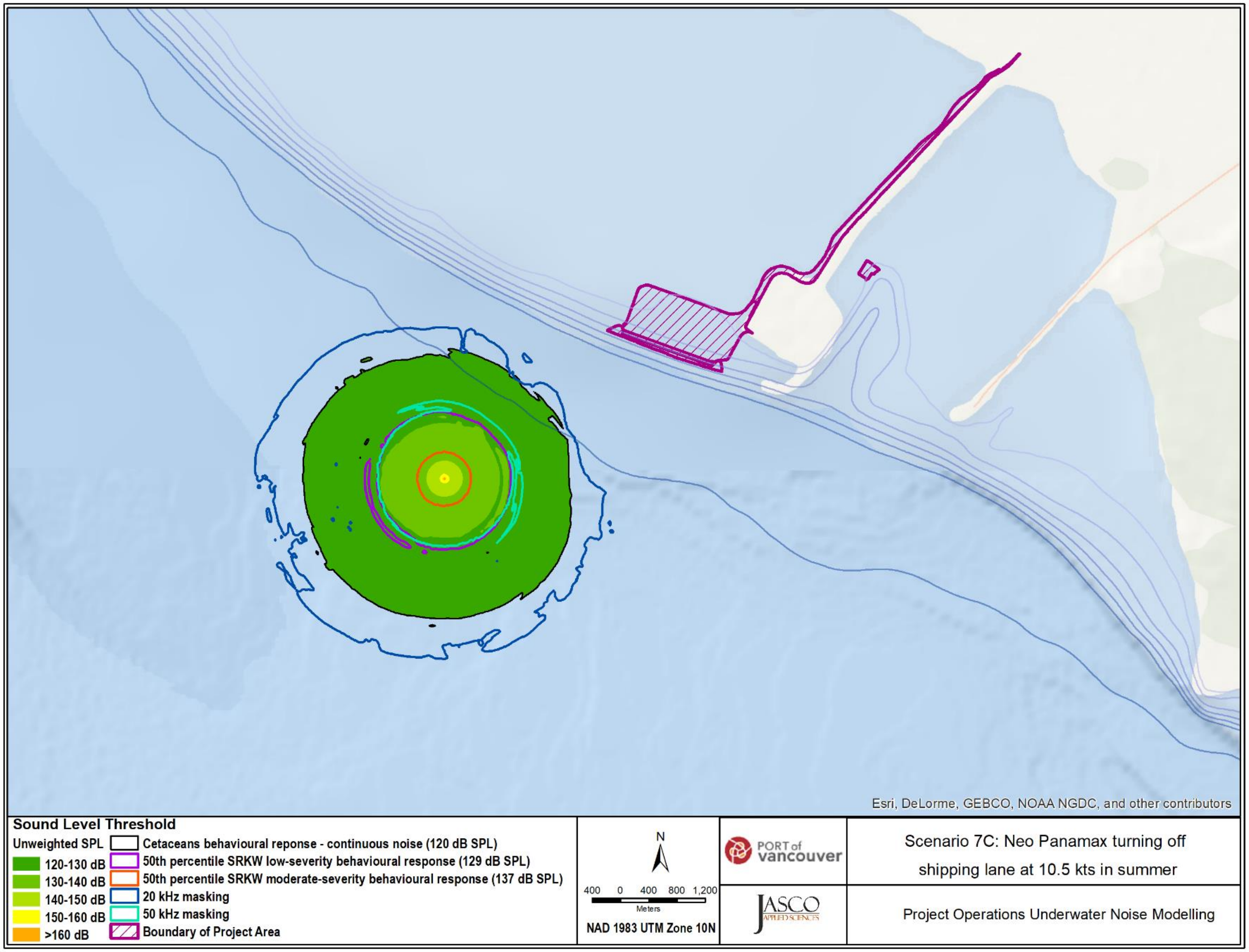
This appendix provides maps of modelled SPLs from Project operations for each of the different scenarios in Table 2. The map for each scenario shows contours of unweighted SPL, including cetacean disturbance and SRKW behavioural response thresholds (see Section 2.4 for a description of the various thresholds).


Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Sound Level Threshold
Unweighted SPL
🟩 120-130 dB
🟩 130-140 dB
🟩 140-150 dB
🟨 150-160 dB
🟧 >160 dB
☐ Cetaceans behavioural reponse - continuous noise (120 dB SPL)
☐ 50th percentile SRKW low-severity behavioural response (129 dB SPL)
☐ 50th percentile SRKW moderate-severity behavioural response (137 dB SPL)
☐ 20 kHz masking
☐ 50 kHz masking
▨ Boundary of Project Area
N
400 0 400 800 1,200
Meters
NAD 1983 UTM Zone 10N
PORT of vancouver
JASCO APPLIED SCIENCES
Scenario 7A: Small Post Panamax turning off shipping lane at 10.5 kts in summer
Project Operations Underwater Noise Modelling



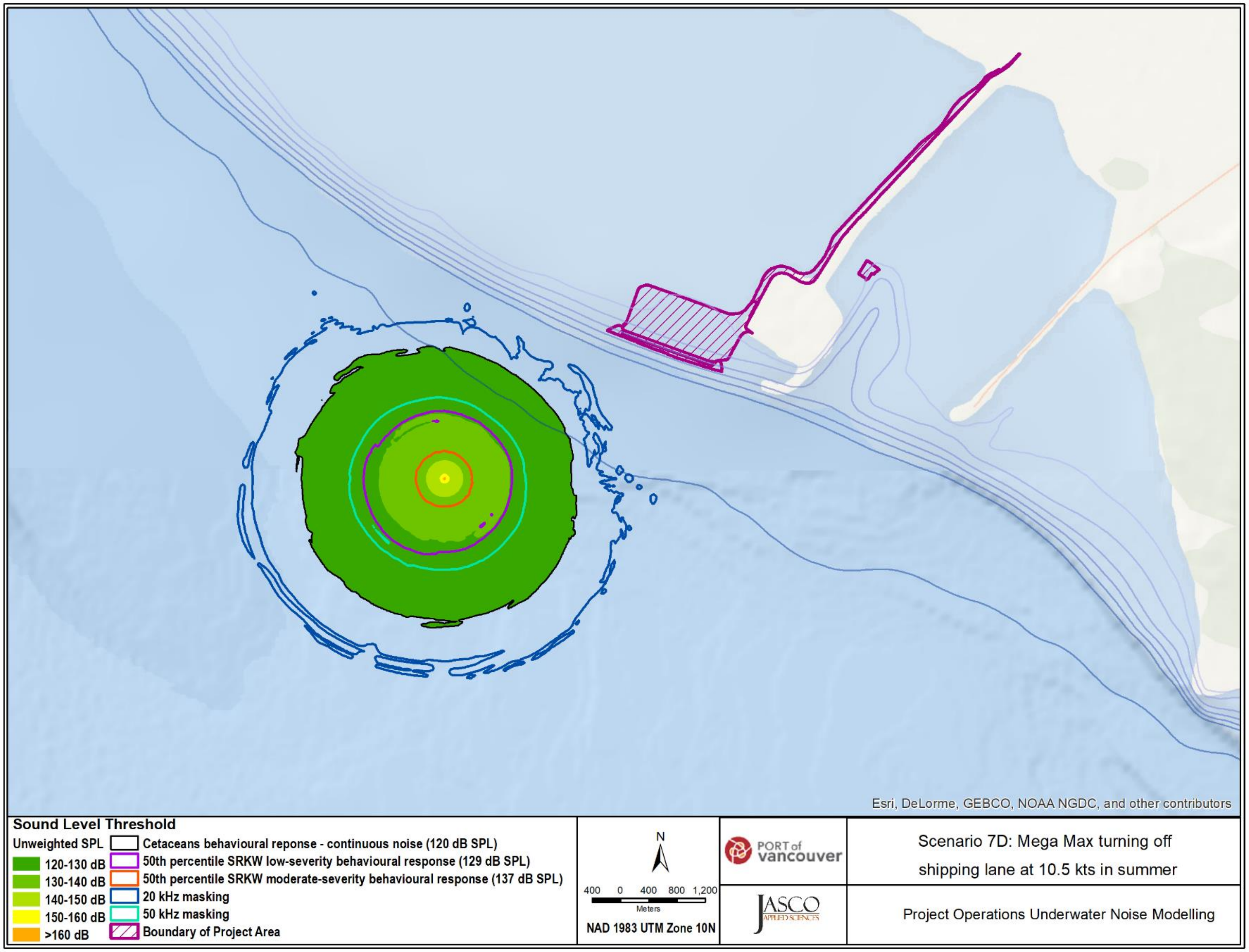
Scenario 7B: Large Post Panamax turning off shipping lane at 10.5 kts in summer

Project Operations Underwater Noise Modelling



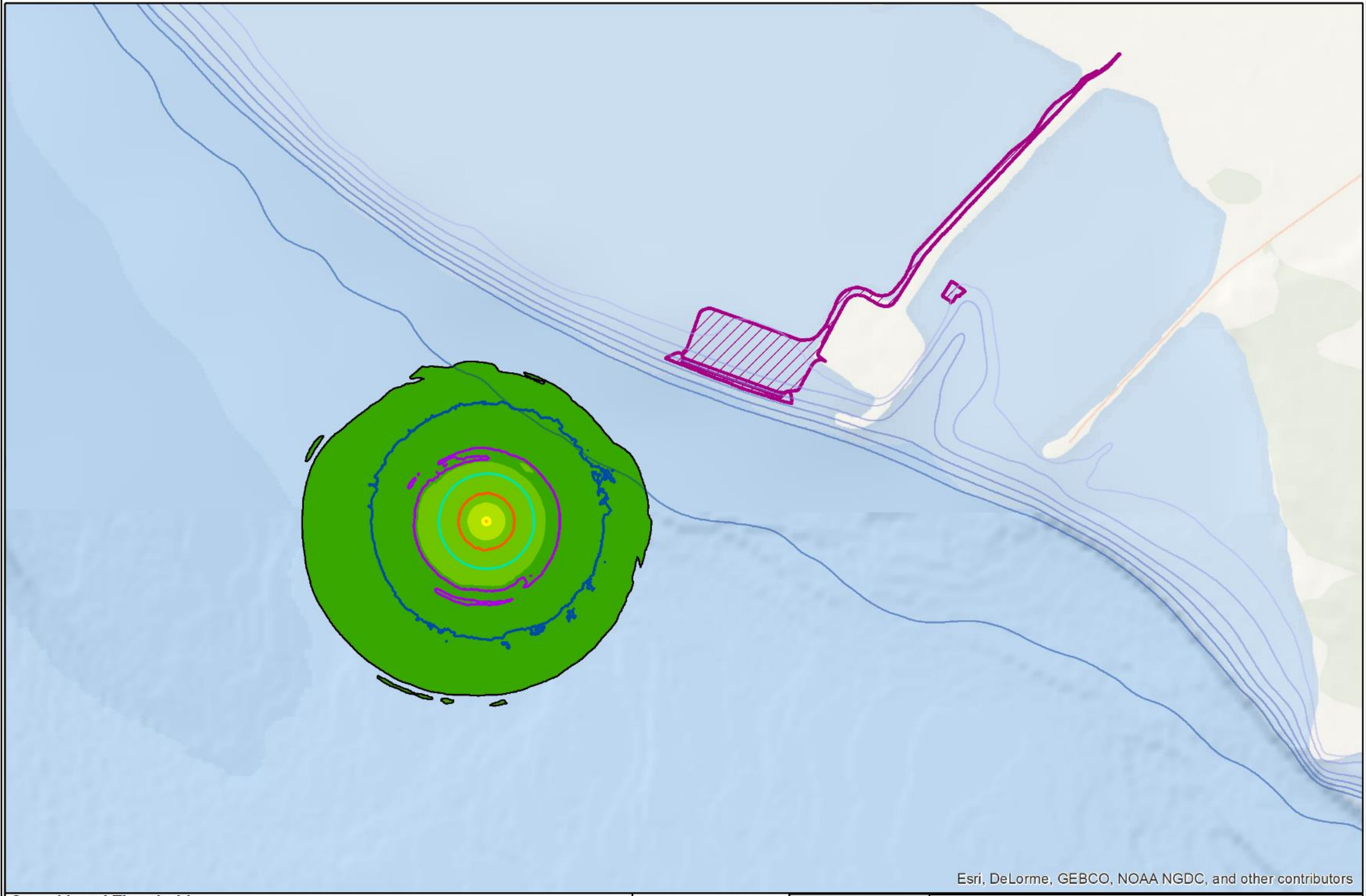
Scenario 7C: Neo Panamax turning off shipping lane at 10.5 kts in summer

Project Operations Underwater Noise Modelling



Scenario 7D: Mega Max turning off shipping lane at 10.5 kts in summer

Project Operations Underwater Noise Modelling



Sound Level Threshold

Unweighted SPL
🟩 120-130 dB
🟩 130-140 dB
🟩 140-150 dB
🟨 150-160 dB
🟧 >160 dB

☐ Cetaceans behavioural reponse - continuous noise (120 dB SPL)
☐ 50th percentile SRKW low-severity behavioural response (129 dB SPL)
☐ 50th percentile SRKW moderate-severity behavioural response (137 dB SPL)
☐ 20 kHz masking
☐ 50 kHz masking
▨ Boundary of Project Area

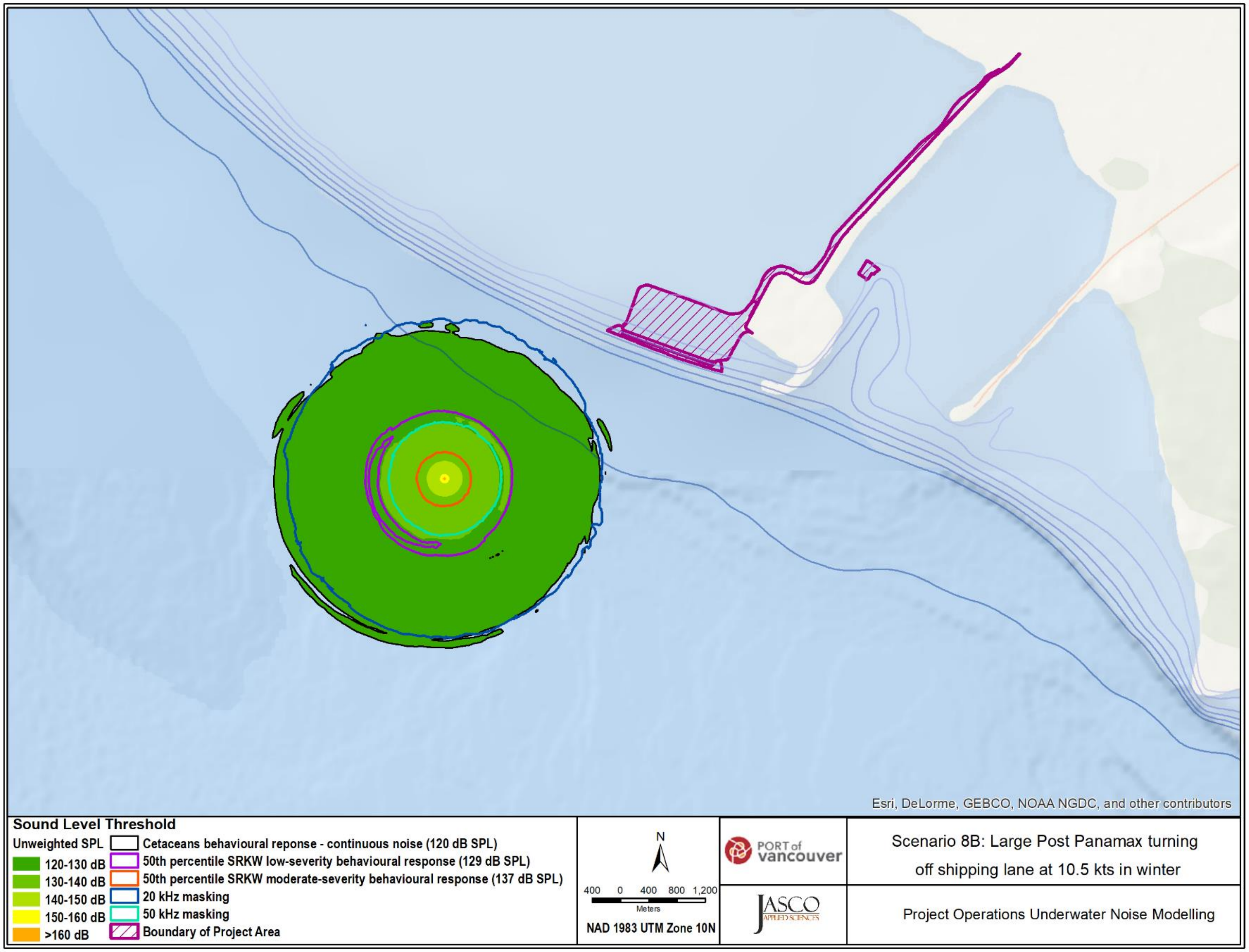
N
400 0 400 800 1,200
Meters
NAD 1983 UTM Zone 10N

PORT of vancouver

Scenario 8A: Small Post Panamax turning off shipping lane at 10.5 kts in winter

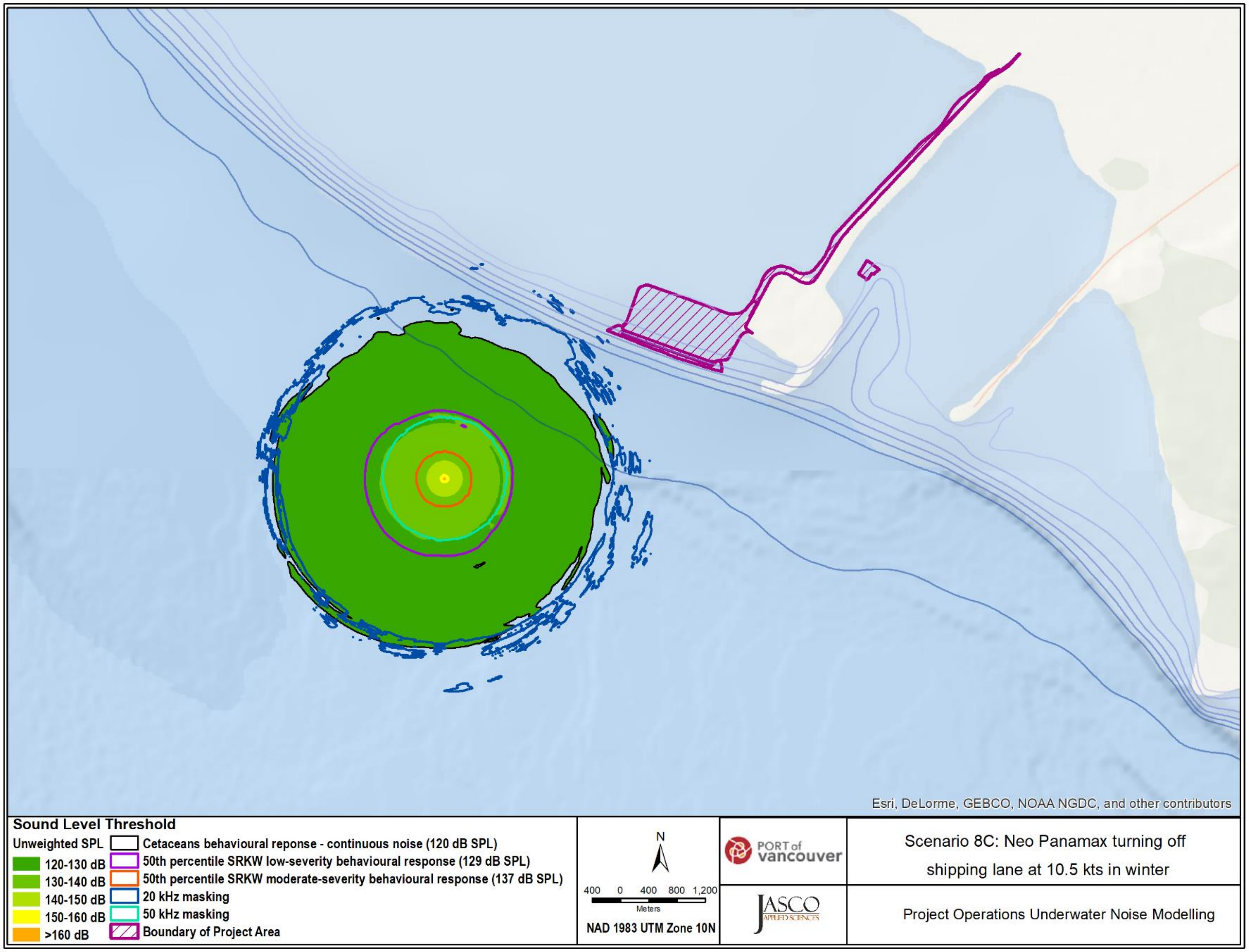
JASCO APPLIED SCIENCES

Project Operations Underwater Noise Modelling



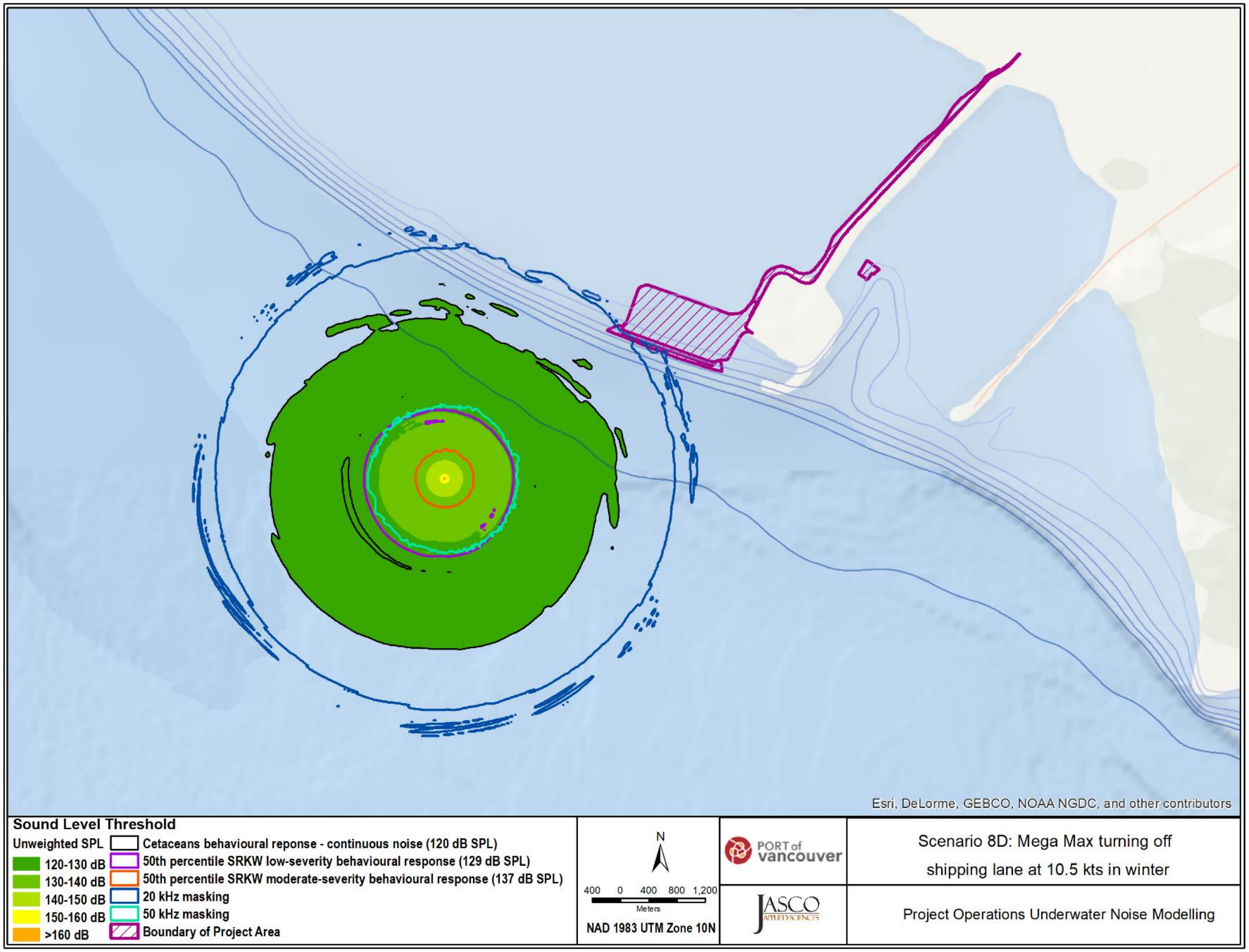
Scenario 8B: Large Post Panamax turning off shipping lane at 10.5 kts in winter

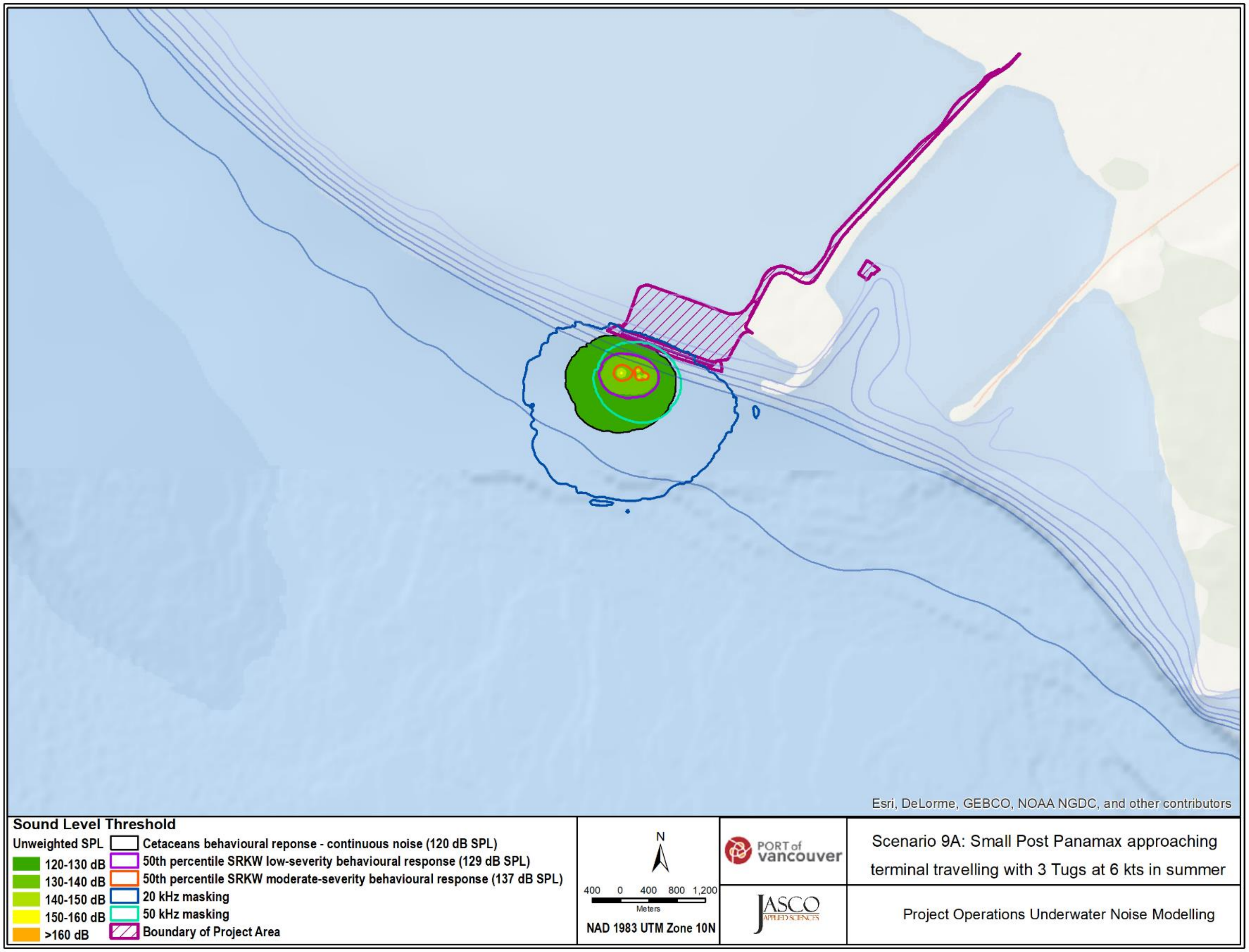
Project Operations Underwater Noise Modelling



Scenario 8C: Neo Panamax turning off shipping lane at 10.5 kts in winter

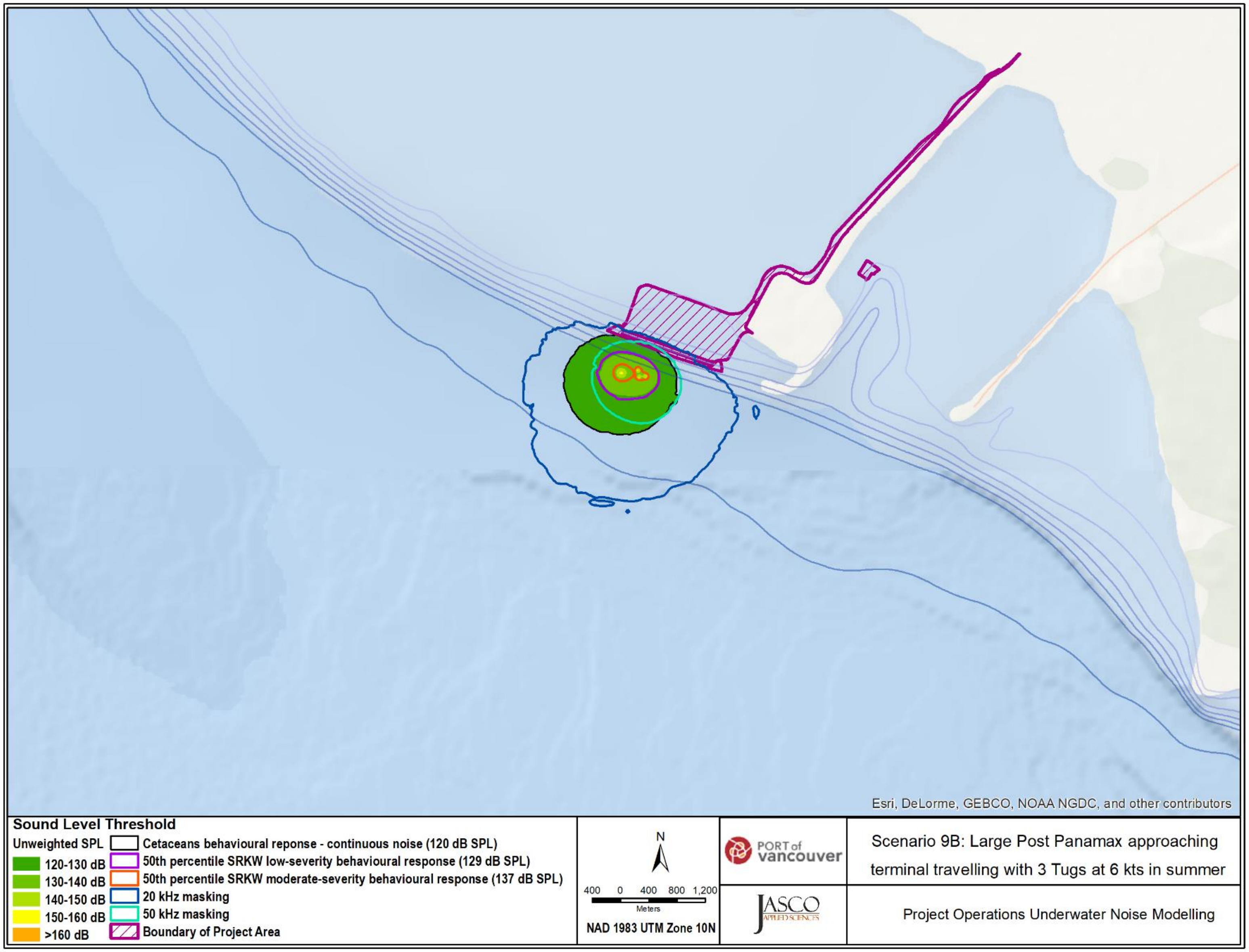
Project Operations Underwater Noise Modelling


Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Sound Level Threshold
Unweighted SPL
🟩 120-130 dB
🟩 130-140 dB
🟩 140-150 dB
🟨 150-160 dB
🟧 >160 dB
☐ Cetaceans behavioural reponse - continuous noise (120 dB SPL)
☐ 50th percentile SRKW low-severity behavioural response (129 dB SPL)
☐ 50th percentile SRKW moderate-severity behavioural response (137 dB SPL)
☐ 20 kHz masking
☐ 50 kHz masking
▨ Boundary of Project Area
N
400 0 400 800 1,200
Meters
NAD 1983 UTM Zone 10N
PORT of vancouver
JASCO APPLIED SCIENCES
Scenario 8D: Mega Max turning off shipping lane at 10.5 kts in winter
Project Operations Underwater Noise Modelling



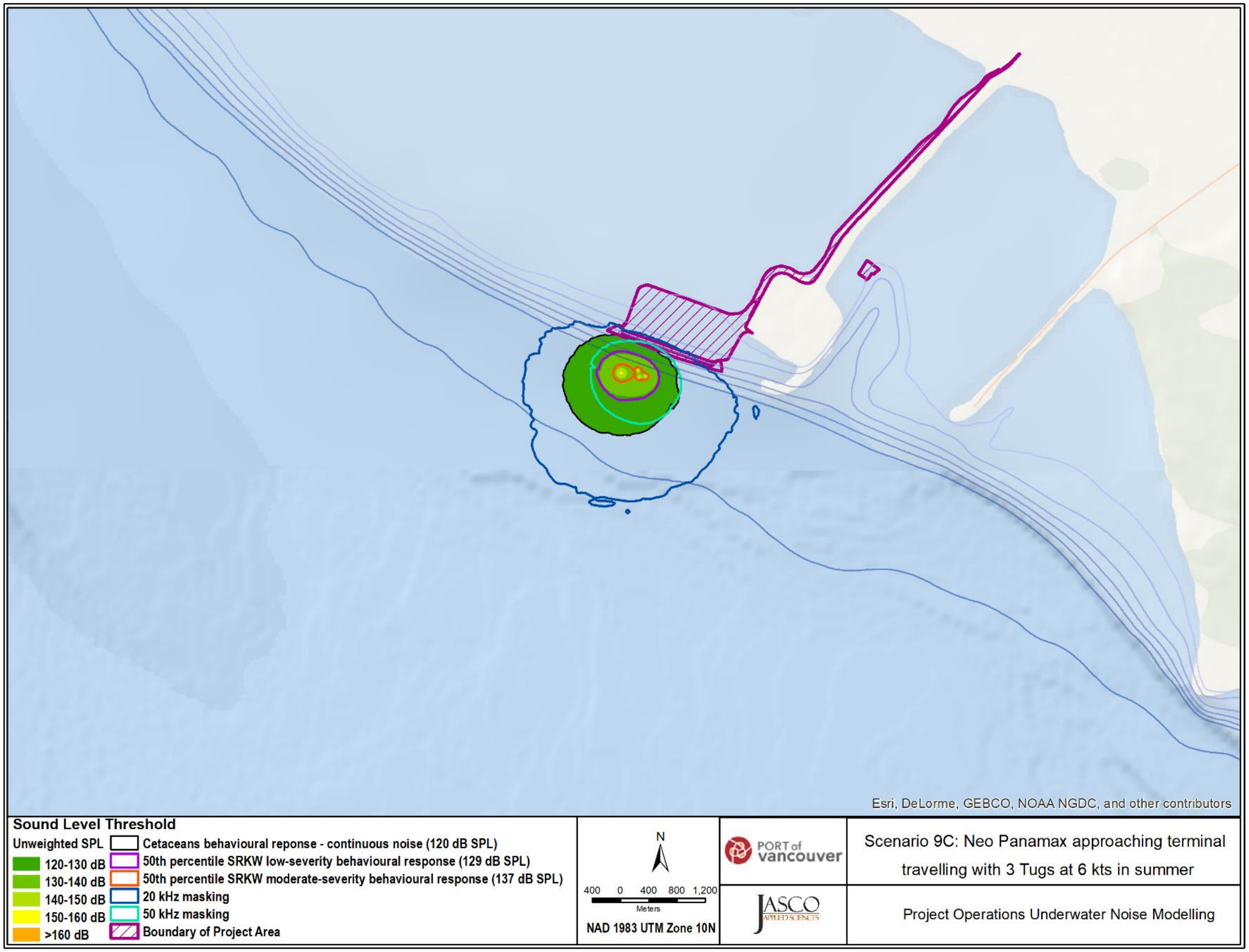
Scenario 9A: Small Post Panamax approaching terminal travelling with 3 Tugs at 6 kts in summer

Project Operations Underwater Noise Modelling



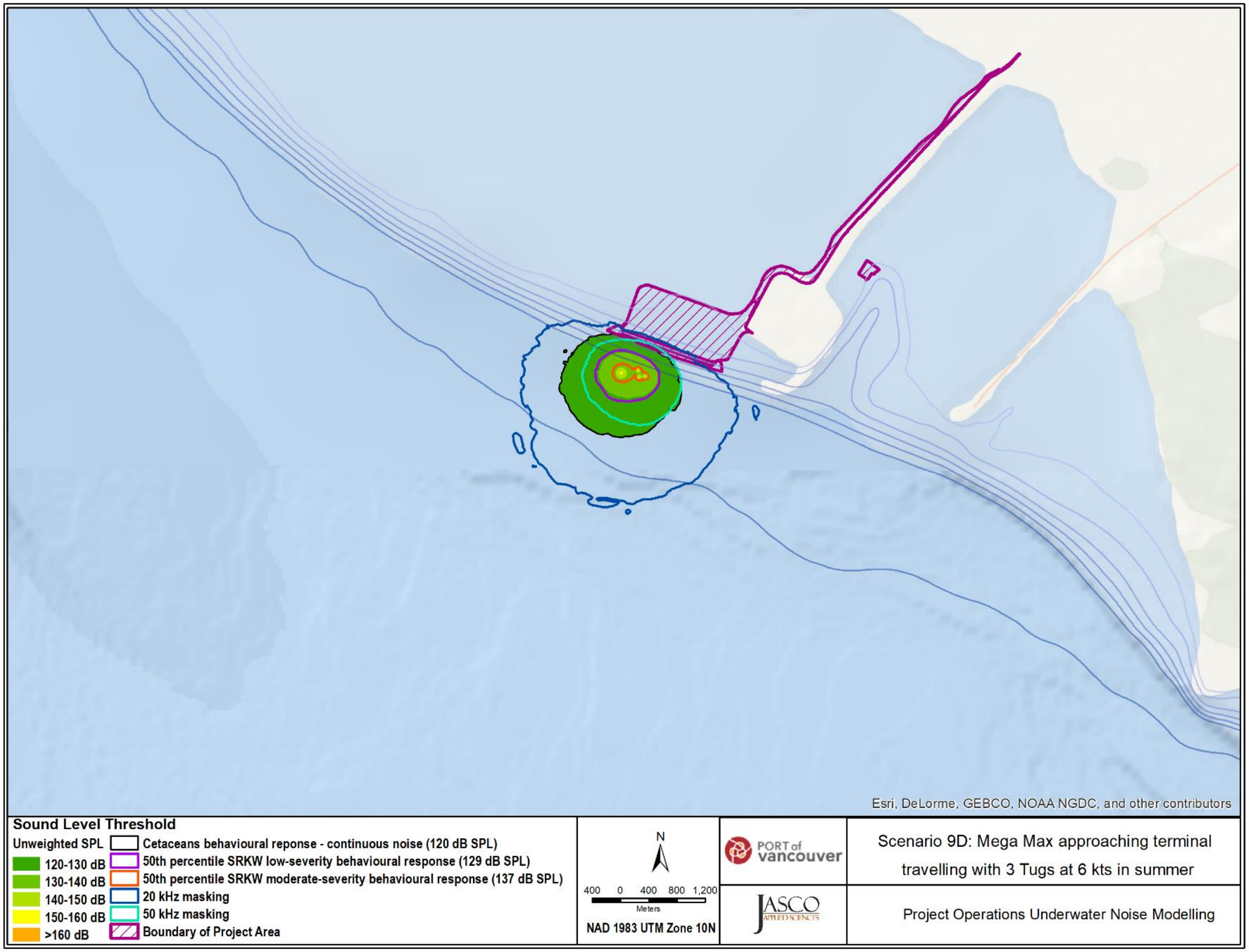
Scenario 9B: Large Post Panamax approaching terminal travelling with 3 Tugs at 6 kts in summer

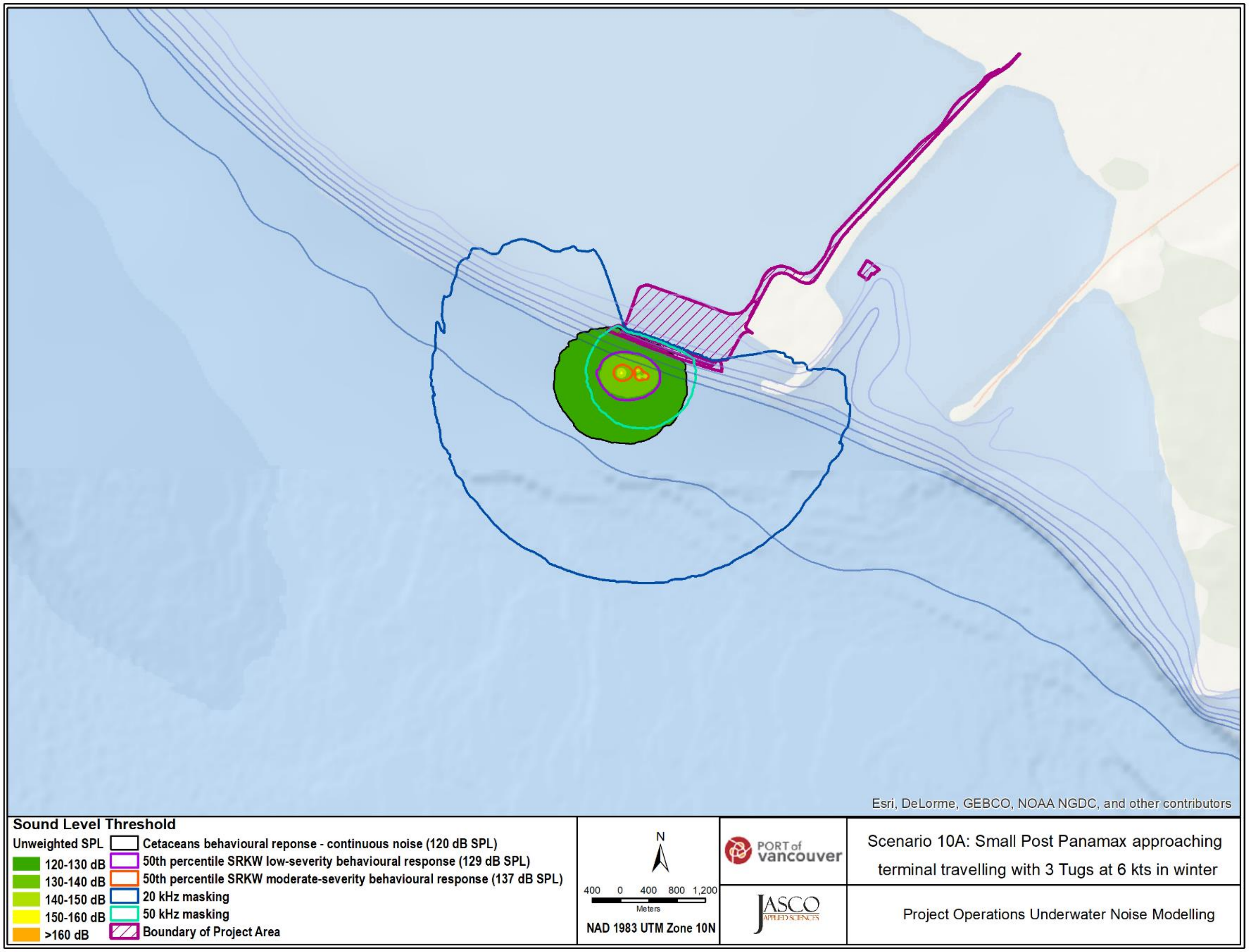
Project Operations Underwater Noise Modelling

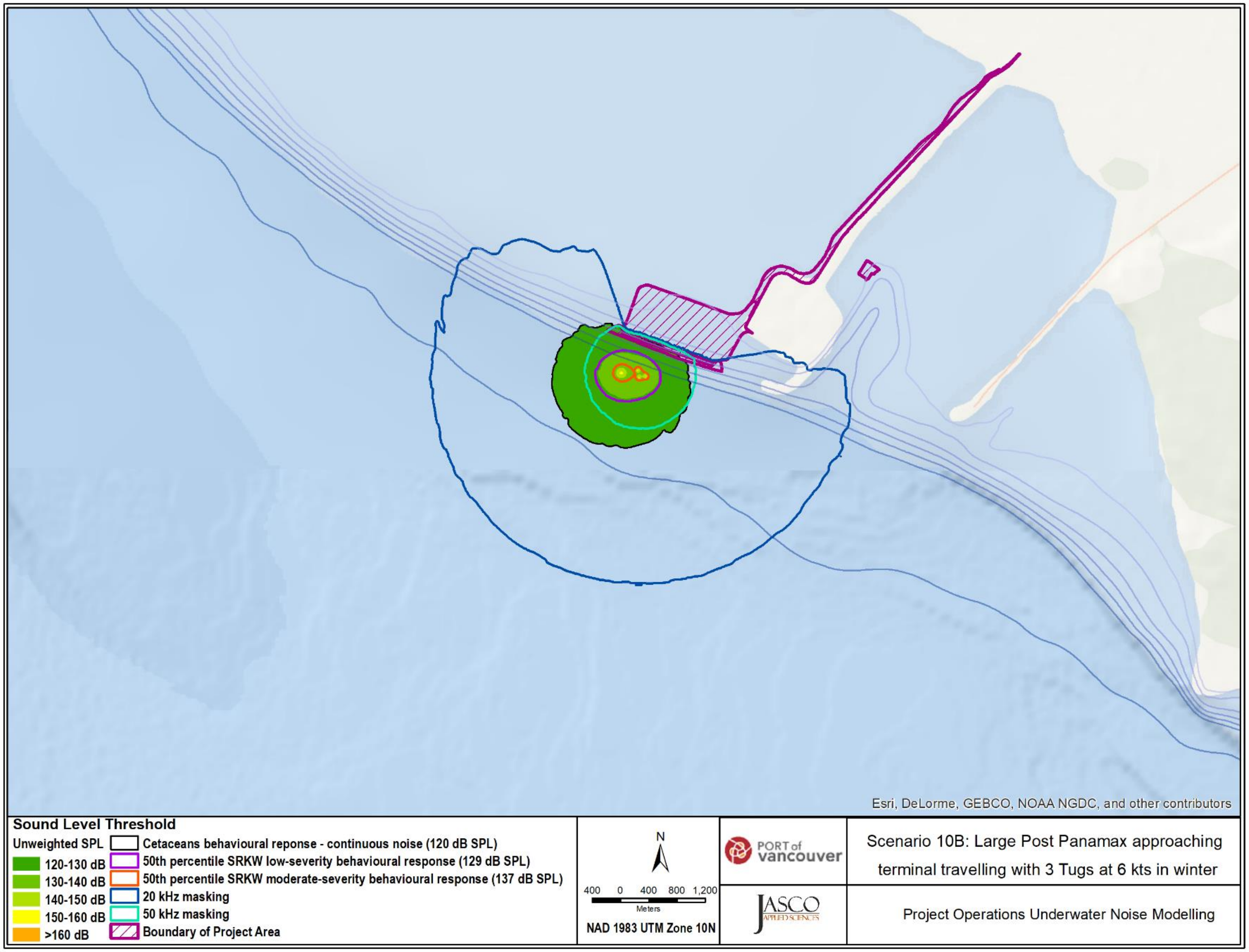


Scenario 9C: Neo Panamax approaching terminal travelling with 3 Tugs at 6 kts in summer

Project Operations Underwater Noise Modelling

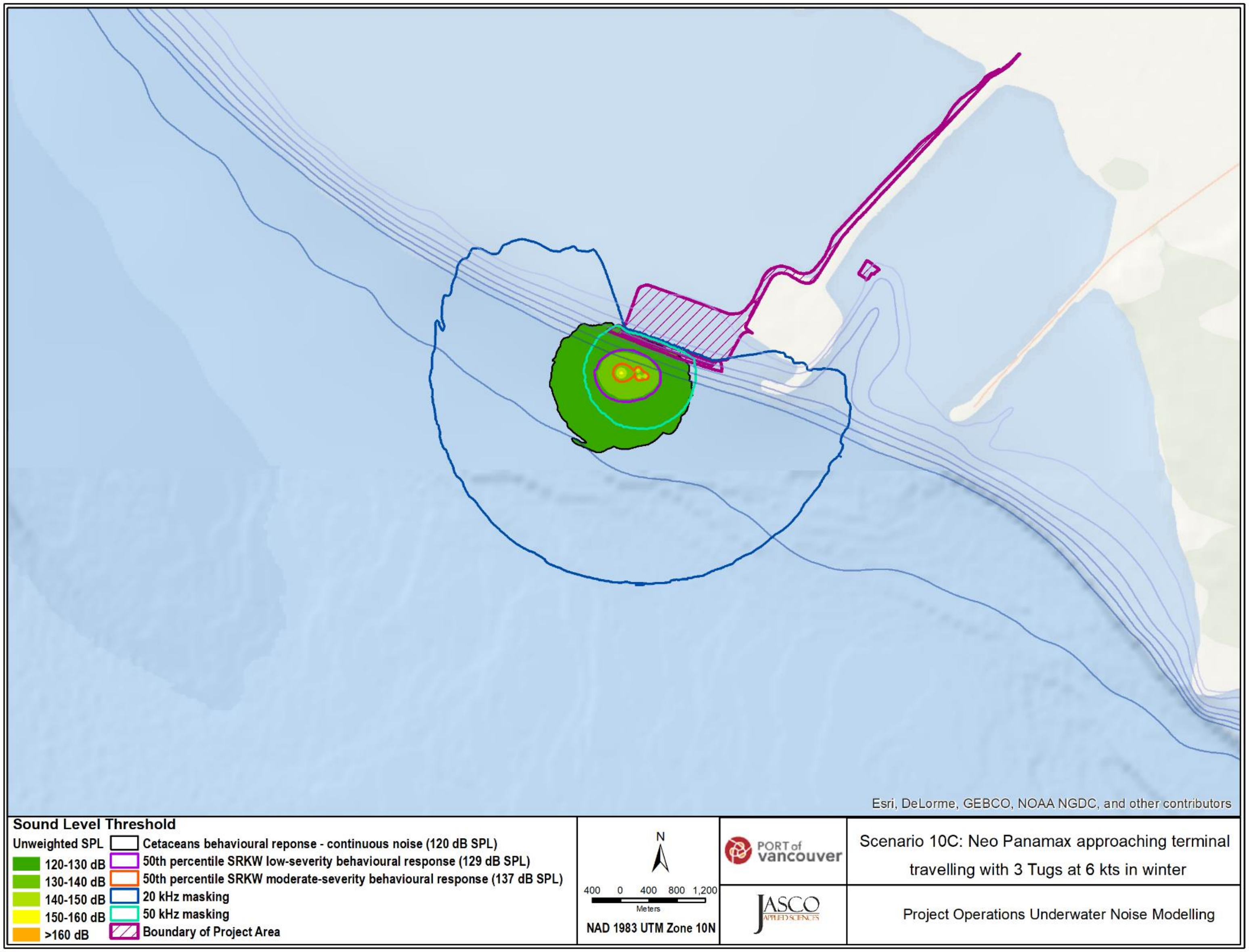

Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Sound Level Threshold
Unweighted SPL
🟩 120-130 dB
🟩 130-140 dB
🟩 140-150 dB
🟨 150-160 dB
🟧 >160 dB
☐ Cetaceans behavioural reponse - continuous noise (120 dB SPL)
☐ 50th percentile SRKW low-severity behavioural response (129 dB SPL)
☐ 50th percentile SRKW moderate-severity behavioural response (137 dB SPL)
☐ 20 kHz masking
☐ 50 kHz masking
▨ Boundary of Project Area
N
400 0 400 800 1,200
Meters
NAD 1983 UTM Zone 10N
PORT of vancouver
JASCO APPLIED SCIENCES
Scenario 9D: Mega Max approaching terminal travelling with 3 Tugs at 6 kts in summer
Project Operations Underwater Noise Modelling

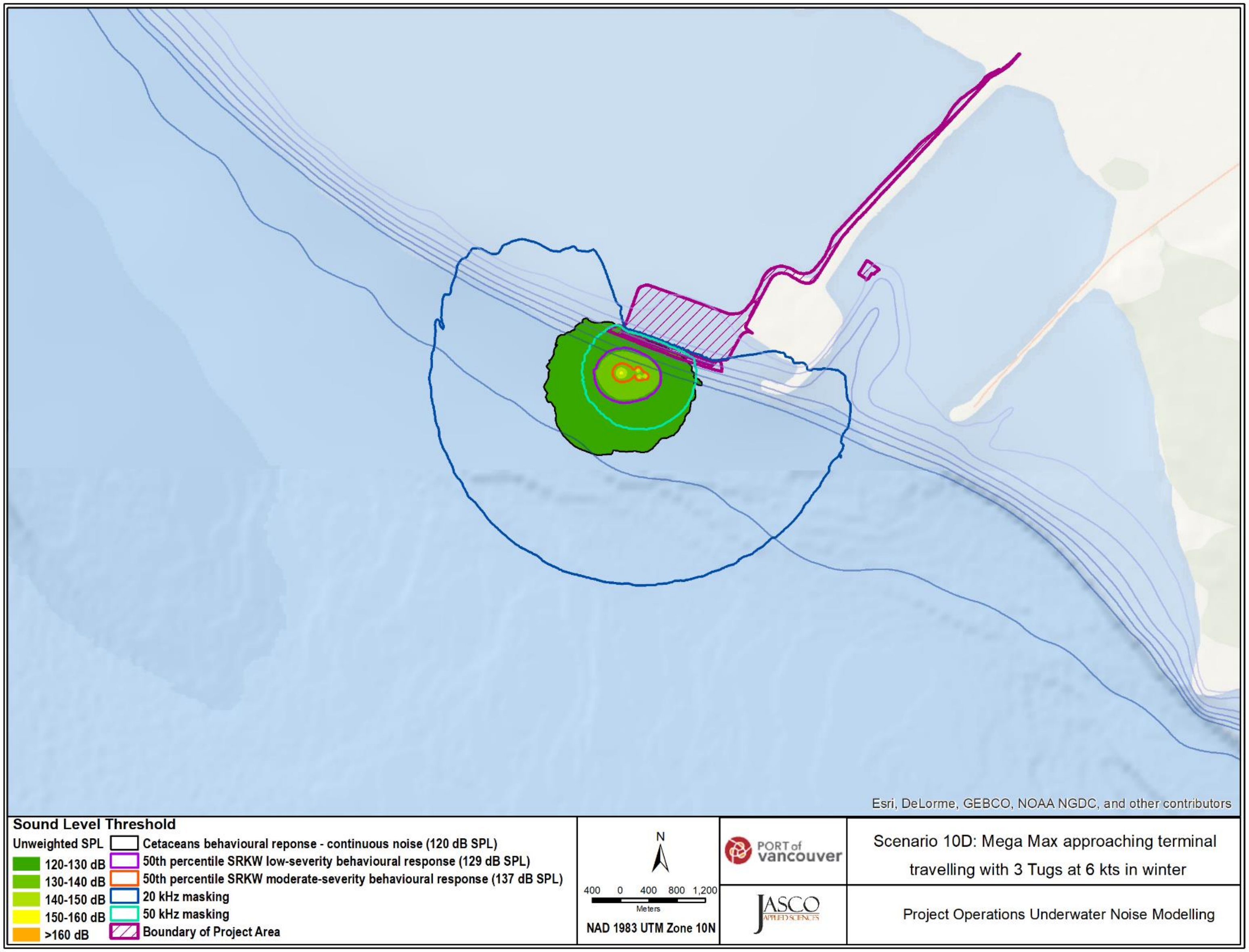

Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Sound Level Threshold
Unweighted SPL
120-130 dB
130-140 dB
140-150 dB
150-160 dB
>160 dB
Cetaceans behavioural reponse - continuous noise (120 dB SPL)
50th percentile SRKW low-severity behavioural response (129 dB SPL)
50th percentile SRKW moderate-severity behavioural response (137 dB SPL)
20 kHz masking
50 kHz masking
Boundary of Project Area
N
400 0 400 800 1,200
Meters
NAD 1983 UTM Zone 10N
PORT of vancouver
JASCO APPLIED SCIENCES
Scenario 10A: Small Post Panamax approaching terminal travelling with 3 Tugs at 6 kts in winter
Project Operations Underwater Noise Modelling



Scenario 10B: Large Post Panamax approaching terminal travelling with 3 Tugs at 6 kts in winter

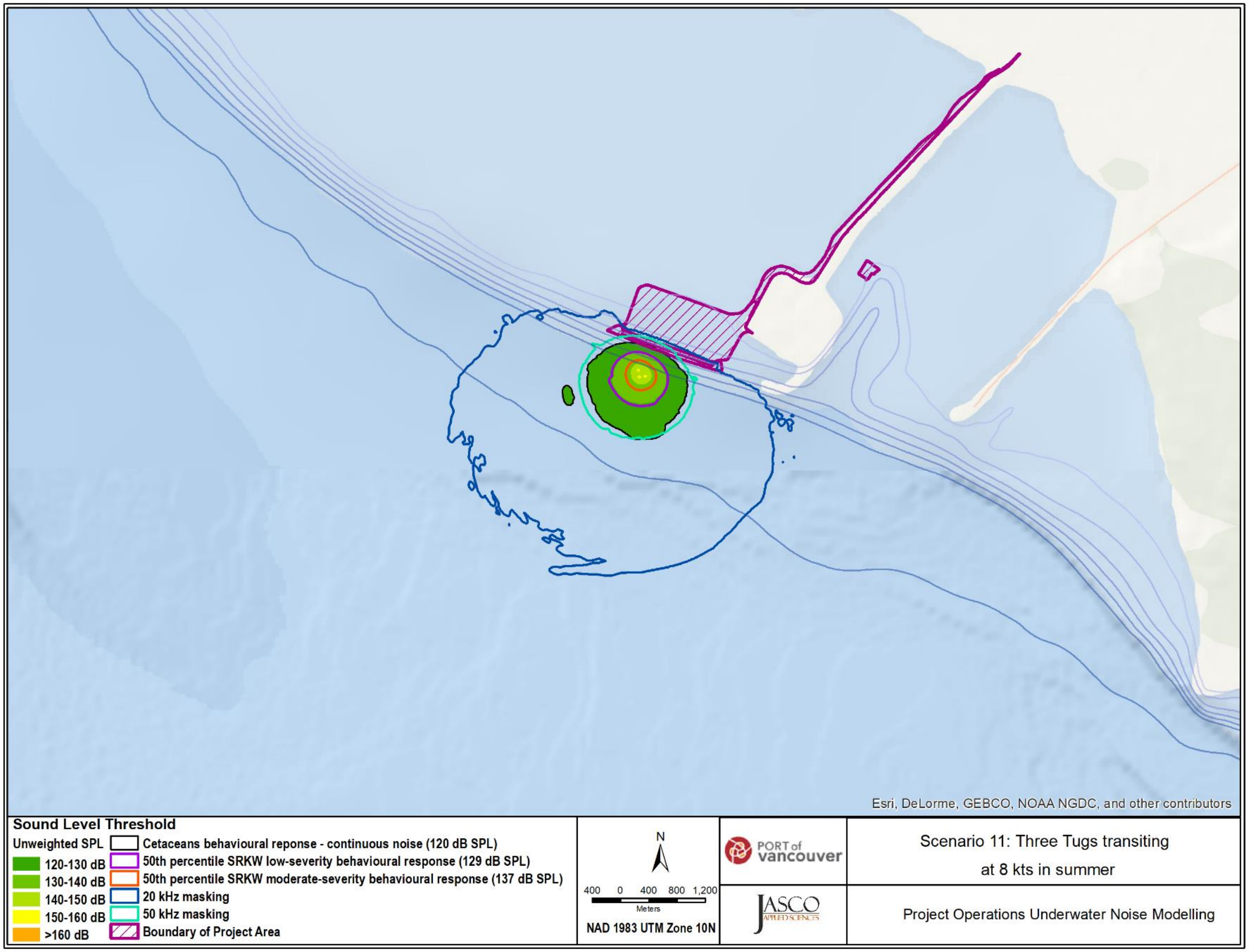
Project Operations Underwater Noise Modelling

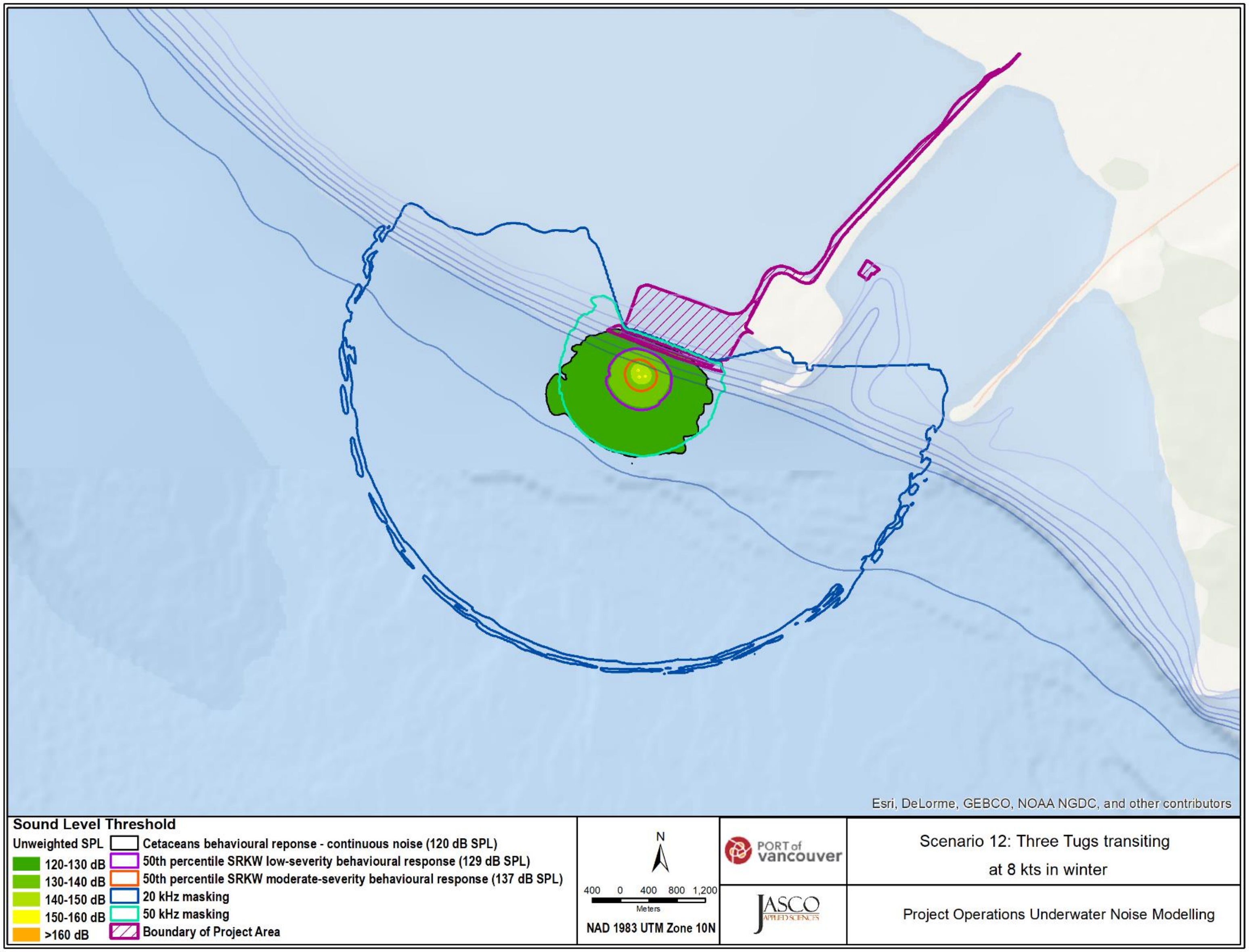

Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Sound Level Threshold
Unweighted SPL
120-130 dB
130-140 dB
140-150 dB
150-160 dB
>160 dB
Cetaceans behavioural reponse - continuous noise (120 dB SPL)
50th percentile SRKW low-severity behavioural response (129 dB SPL)
50th percentile SRKW moderate-severity behavioural response (137 dB SPL)
20 kHz masking
50 kHz masking
Boundary of Project Area
N
400 0 400 800 1,200
Meters
NAD 1983 UTM Zone 10N
PORT of vancouver
JASCO APPLIED SCIENCES
Scenario 10C: Neo Panamax approaching terminal travelling with 3 Tugs at 6 kts in winter
Project Operations Underwater Noise Modelling

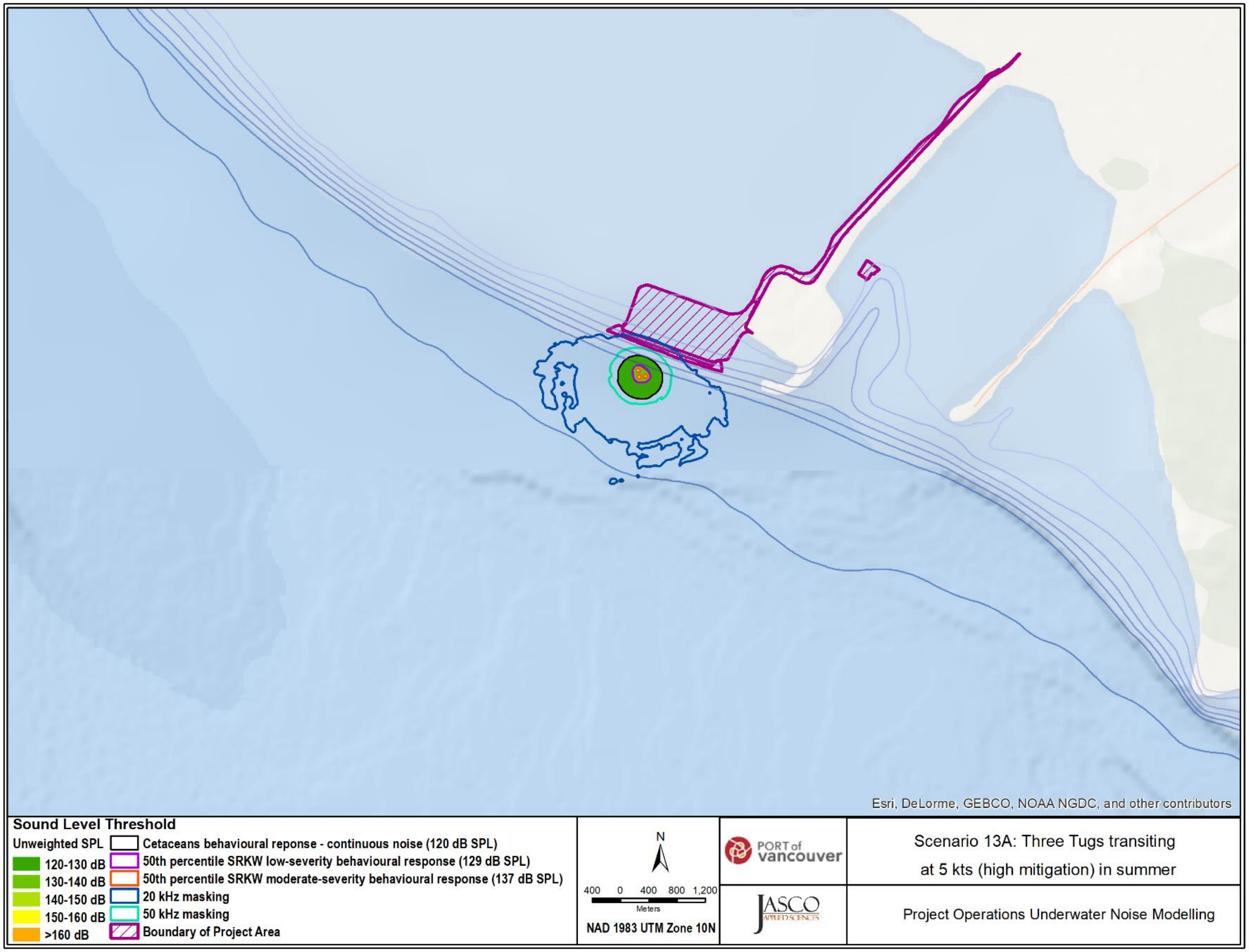


Scenario 10D: Mega Max approaching terminal travelling with 3 Tugs at 6 kts in winter

Project Operations Underwater Noise Modelling

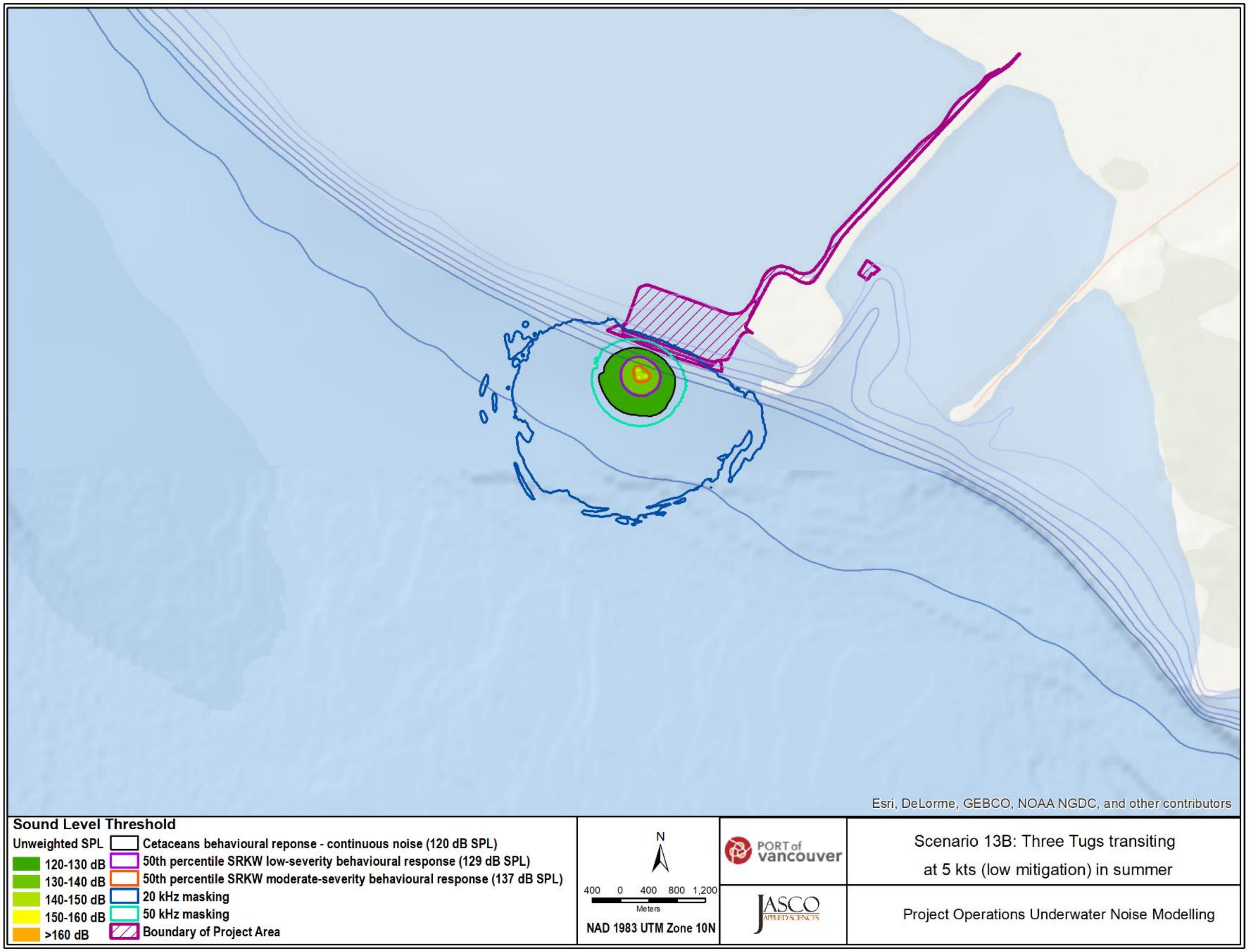

Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Sound Level Threshold
Unweighted SPL
🟩 120-130 dB
🟩 130-140 dB
🟩 140-150 dB
🟨 150-160 dB
🟧 >160 dB
☐ Cetaceans behavioural reponse - continuous noise (120 dB SPL)
☐ 50th percentile SRKW low-severity behavioural response (129 dB SPL)
☐ 50th percentile SRKW moderate-severity behavioural response (137 dB SPL)
☐ 20 kHz masking
☐ 50 kHz masking
▨ Boundary of Project Area
N
400 0 400 800 1,200
Meters
NAD 1983 UTM Zone 10N
PORT of vancouver
JASCO APPLIED SCIENCES
Scenario 11: Three Tugs transiting
at 8 kts in summer
Project Operations Underwater Noise Modelling

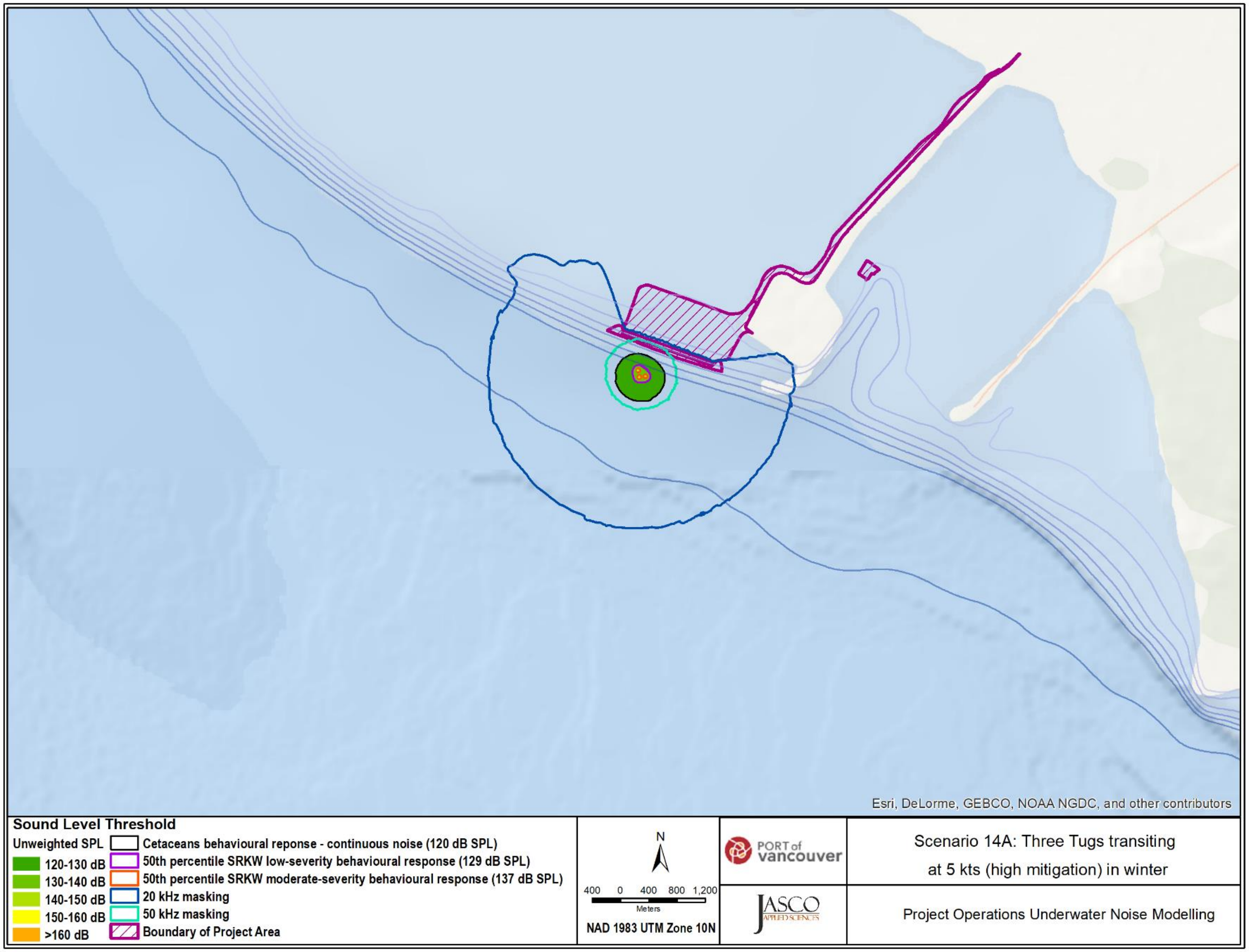

Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Sound Level Threshold
Unweighted SPL
120-130 dB
130-140 dB
140-150 dB
150-160 dB
>160 dB
Cetaceans behavioural reponse - continuous noise (120 dB SPL)
50th percentile SRKW low-severity behavioural response (129 dB SPL)
50th percentile SRKW moderate-severity behavioural response (137 dB SPL)
20 kHz masking
50 kHz masking
Boundary of Project Area
N
400 0 400 800 1,200
Meters
NAD 1983 UTM Zone 10N
PORT of vancouver
JASCO APPLIED SCIENCES
Scenario 12: Three Tugs transiting at 8 kts in winter
Project Operations Underwater Noise Modelling

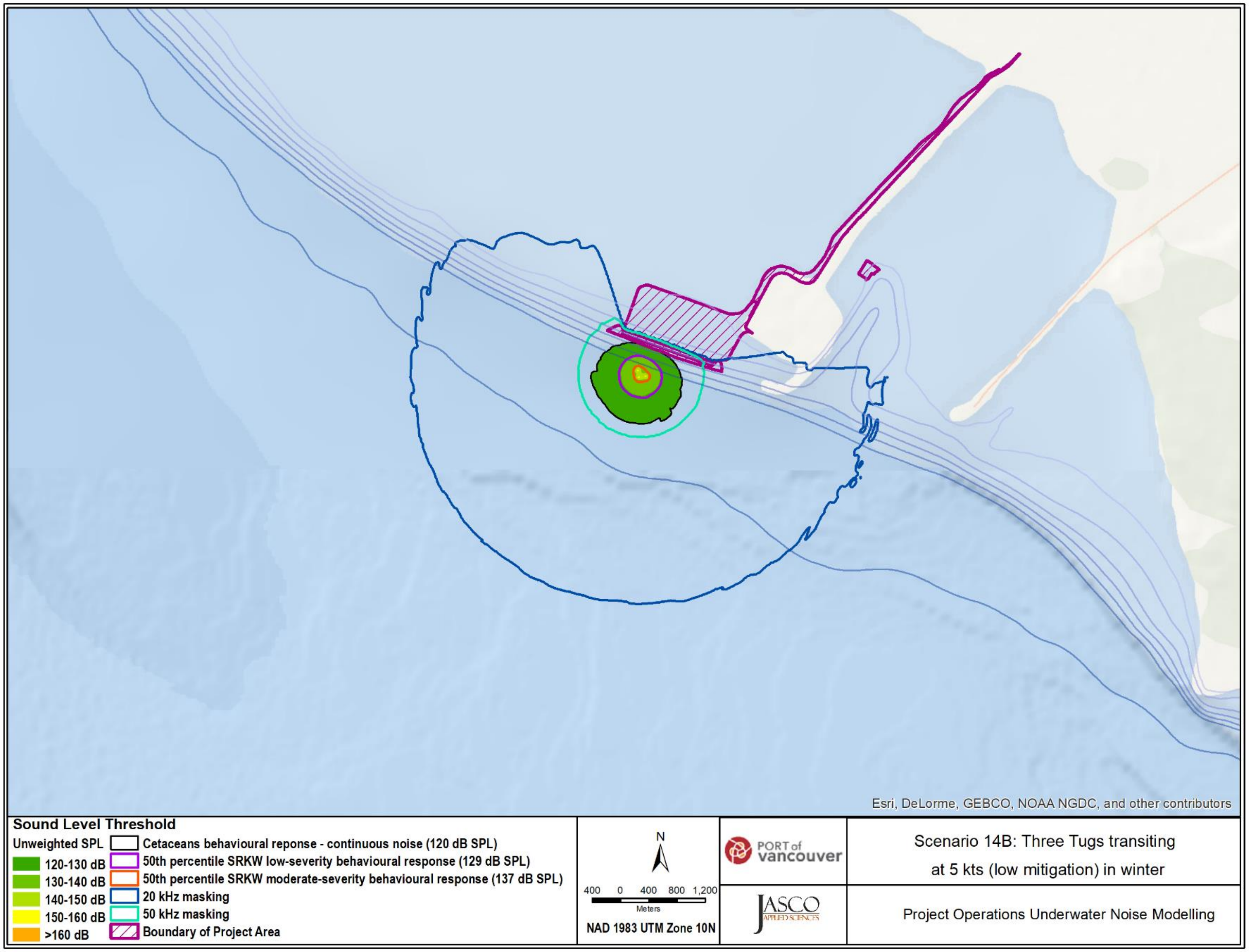


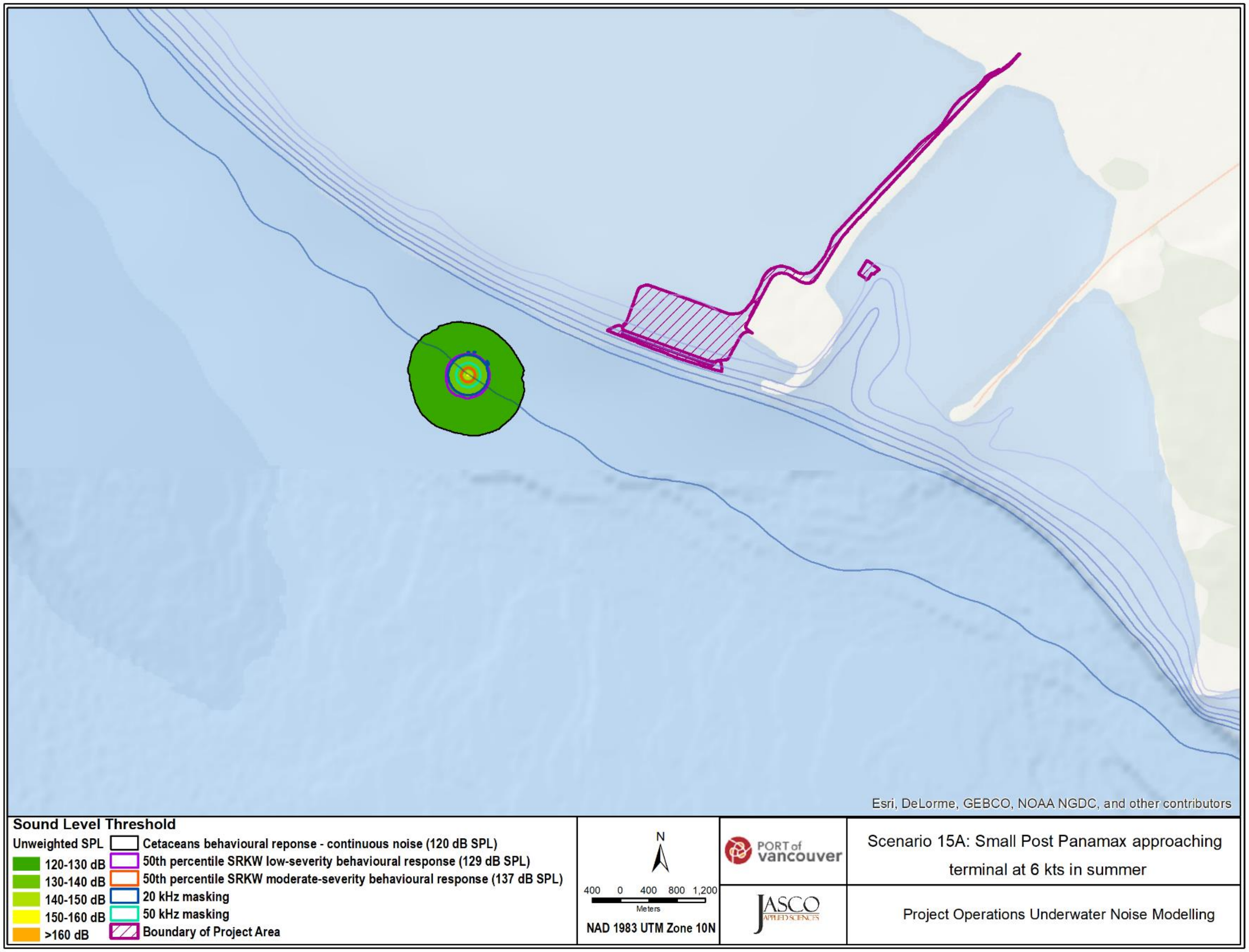
Scenario 13A: Three Tugs transiting at 5 kts (high mitigation) in summer

Project Operations Underwater Noise Modelling


Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Sound Level Threshold
Unweighted SPL
120-130 dB
130-140 dB
140-150 dB
150-160 dB
>160 dB
Cetaceans behavioural reponse - continuous noise (120 dB SPL)
50th percentile SRKW low-severity behavioural response (129 dB SPL)
50th percentile SRKW moderate-severity behavioural response (137 dB SPL)
20 kHz masking
50 kHz masking
Boundary of Project Area
N
400 0 400 800 1,200
Meters
NAD 1983 UTM Zone 10N
PORT of vancouver
JASCO APPLIED SCIENCES
Scenario 13B: Three Tugs transiting at 5 kts (low mitigation) in summer
Project Operations Underwater Noise Modelling

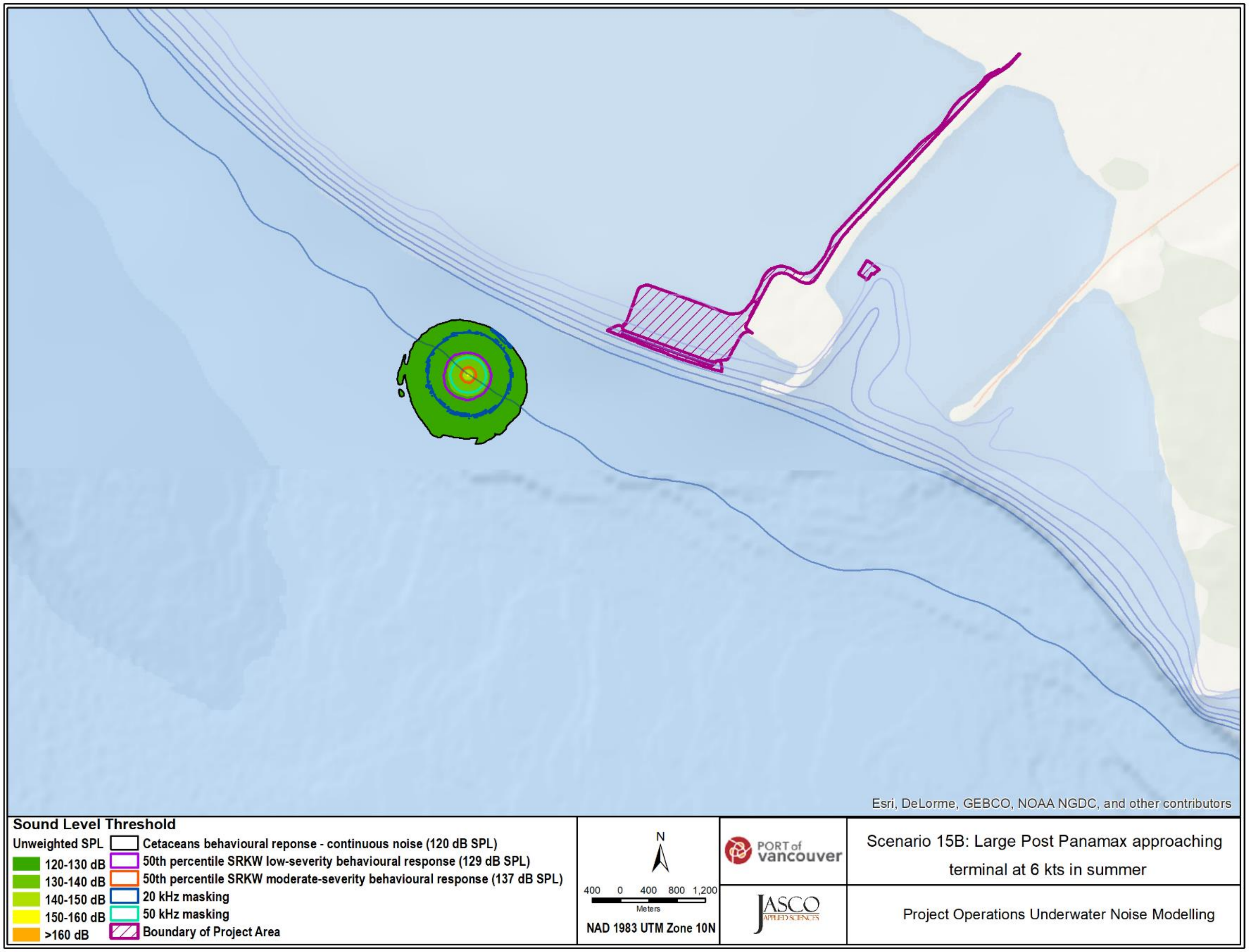

Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Sound Level Threshold
Unweighted SPL
120-130 dB
130-140 dB
140-150 dB
150-160 dB
>160 dB
Cetaceans behavioural reponse - continuous noise (120 dB SPL)
50th percentile SRKW low-severity behavioural response (129 dB SPL)
50th percentile SRKW moderate-severity behavioural response (137 dB SPL)
20 kHz masking
50 kHz masking
Boundary of Project Area
N
400 0 400 800 1,200
Meters
NAD 1983 UTM Zone 10N
PORT of vancouver
JASCO APPLIED SCIENCES
Scenario 14A: Three Tugs transiting at 5 kts (high mitigation) in winter
Project Operations Underwater Noise Modelling


Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Sound Level Threshold
Unweighted SPL
🟩 120-130 dB
🟩 130-140 dB
🟩 140-150 dB
🟨 150-160 dB
🟧 >160 dB
☐ Cetaceans behavioural reponse - continuous noise (120 dB SPL)
☐ 50th percentile SRKW low-severity behavioural response (129 dB SPL)
☐ 50th percentile SRKW moderate-severity behavioural response (137 dB SPL)
☐ 20 kHz masking
☐ 50 kHz masking
▨ Boundary of Project Area
N
400 0 400 800 1,200
Meters
NAD 1983 UTM Zone 10N
PORT of vancouver
JASCO APPLIED SCIENCES
Scenario 14B: Three Tugs transiting
at 5 kts (low mitigation) in winter
Project Operations Underwater Noise Modelling



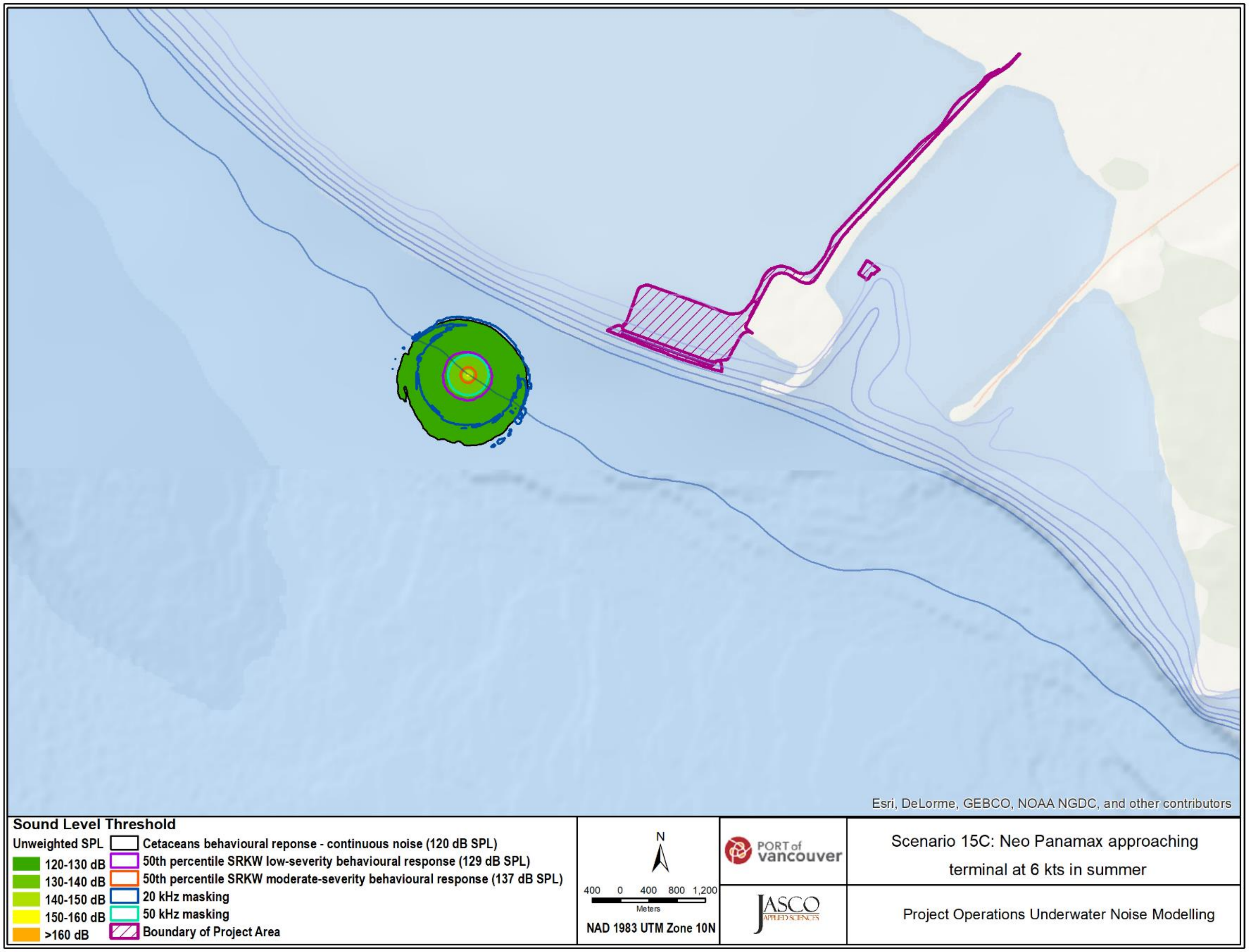
Scenario 15A: Small Post Panamax approaching terminal at 6 kts in summer

Project Operations Underwater Noise Modelling



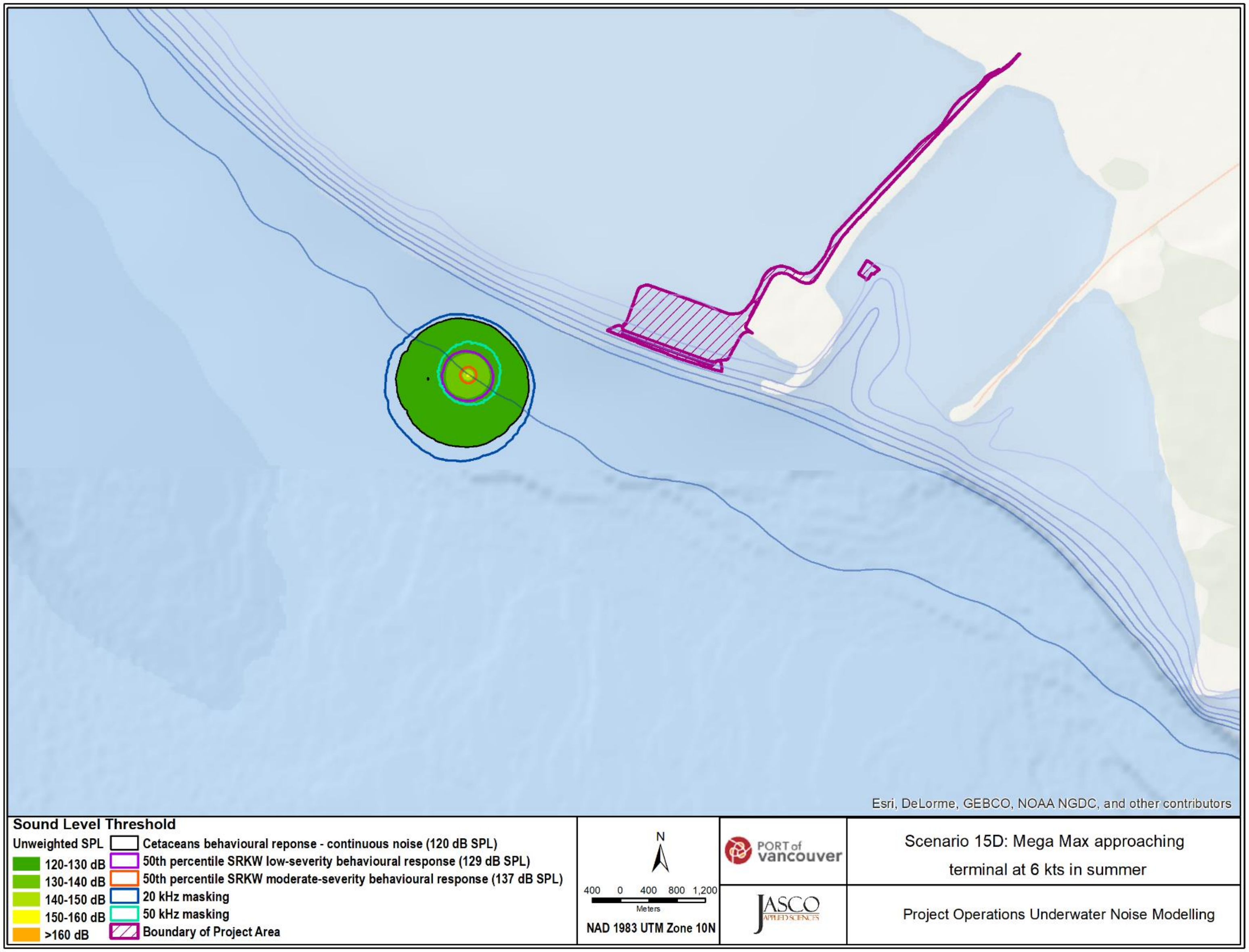
Scenario 15B: Large Post Panamax approaching terminal at 6 kts in summer

Project Operations Underwater Noise Modelling



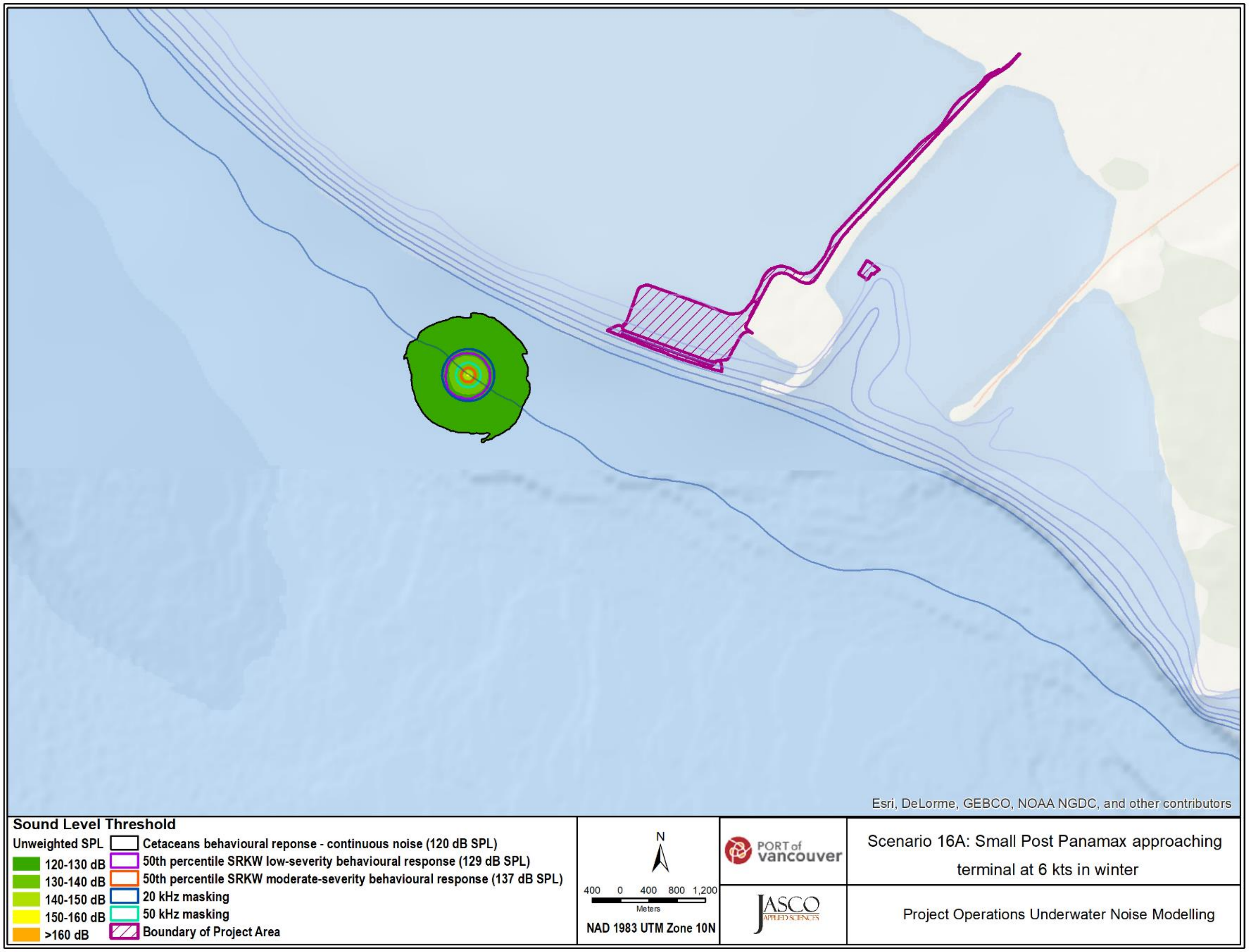
Scenario 15C: Neo Panamax approaching terminal at 6 kts in summer

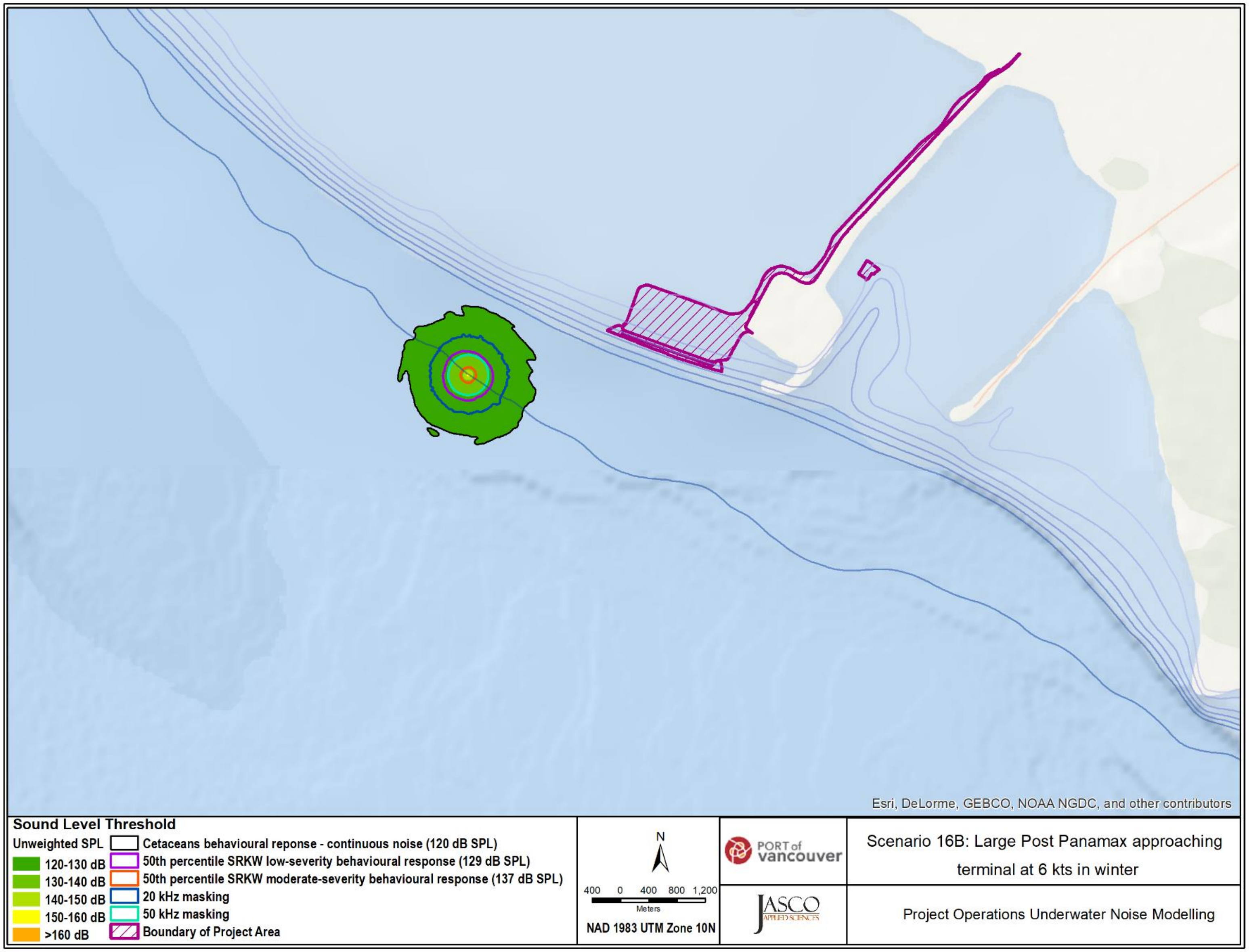
Project Operations Underwater Noise Modelling

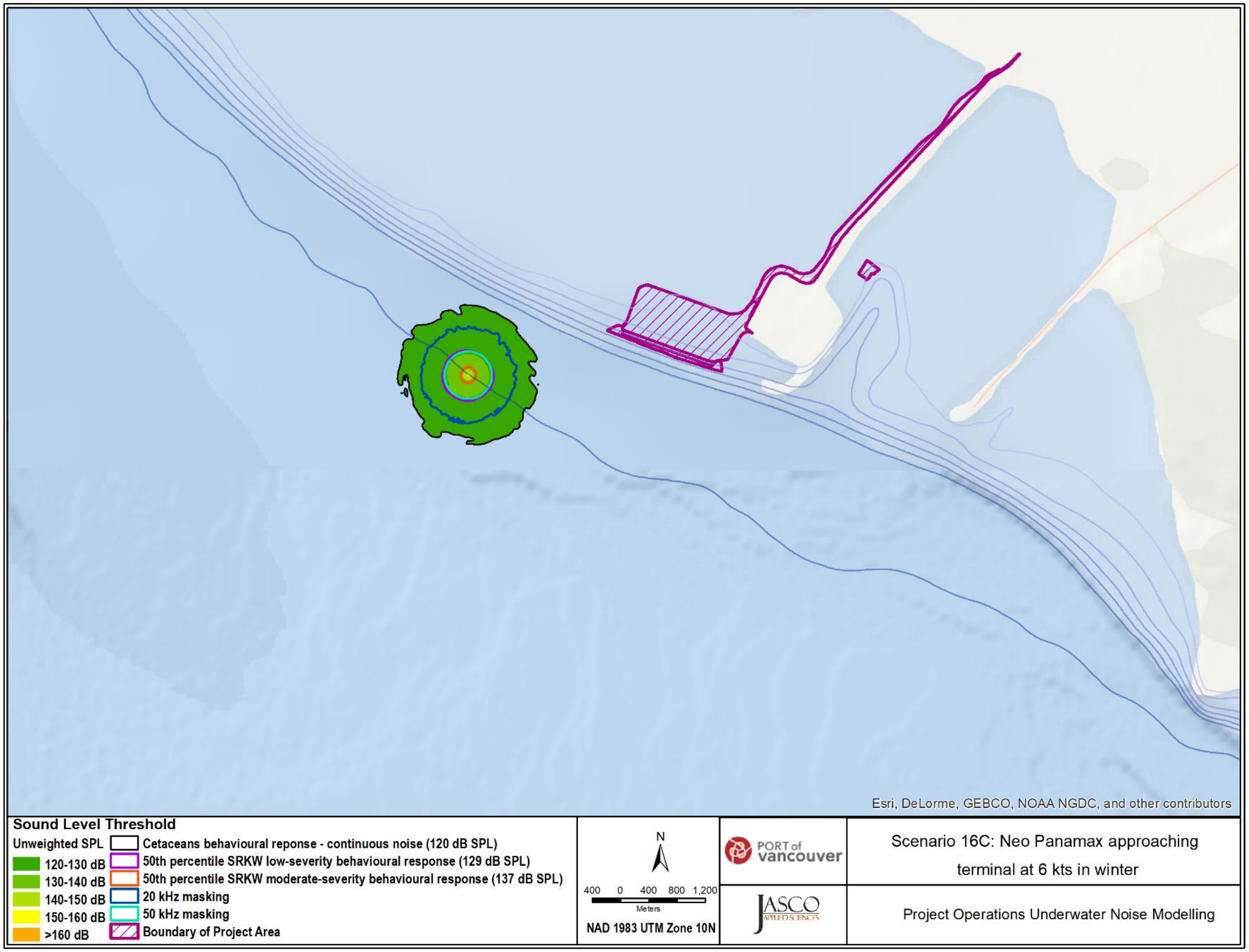


Scenario 15D: Mega Max approaching terminal at 6 kts in summer

Project Operations Underwater Noise Modelling

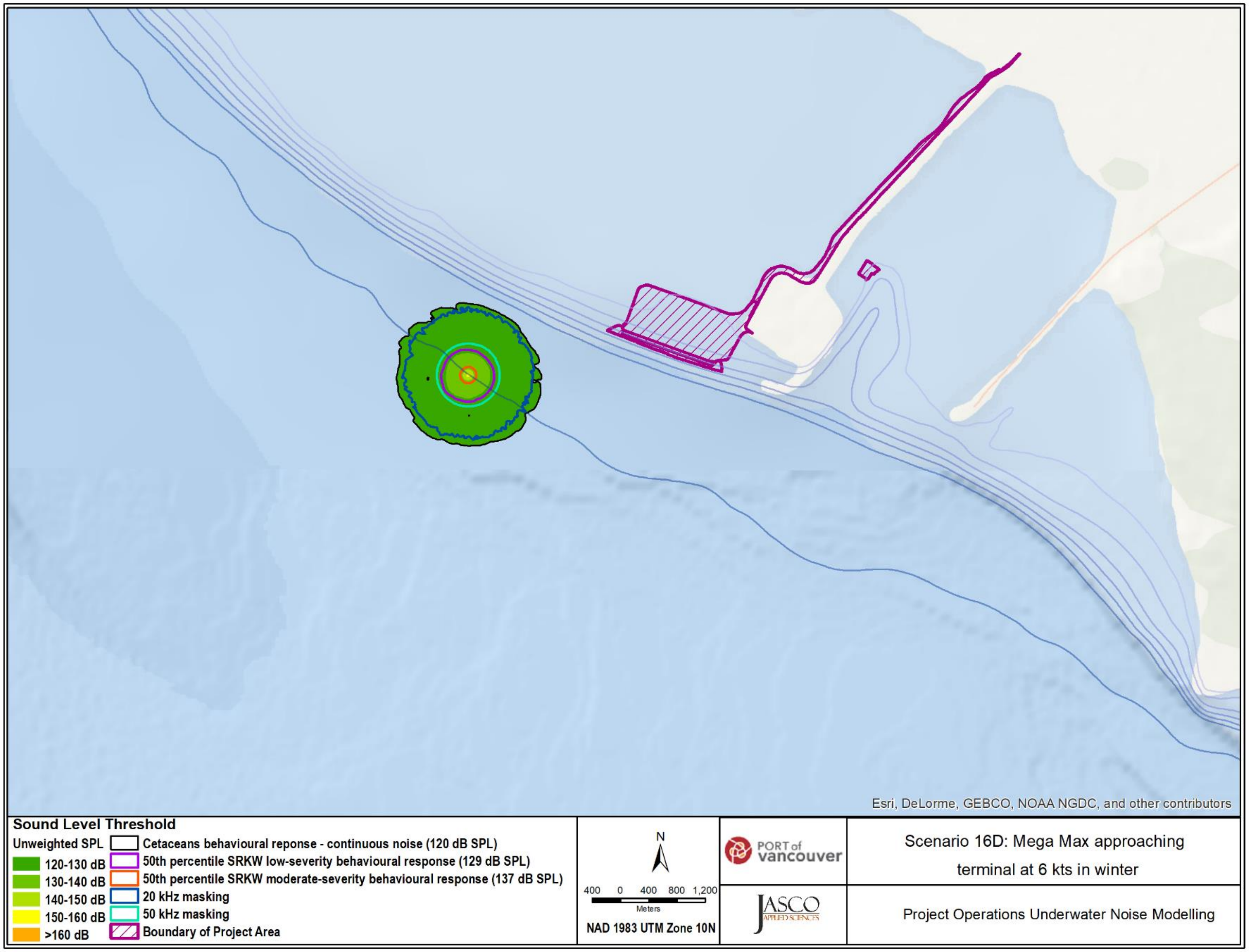

Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Sound Level Threshold
Unweighted SPL
🟩 120-130 dB
🟩 130-140 dB
🟩 140-150 dB
🟨 150-160 dB
🟧 >160 dB
☐ Cetaceans behavioural reponse - continuous noise (120 dB SPL)
☐ 50th percentile SRKW low-severity behavioural response (129 dB SPL)
☐ 50th percentile SRKW moderate-severity behavioural response (137 dB SPL)
☐ 20 kHz masking
☐ 50 kHz masking
▨ Boundary of Project Area
N
400 0 400 800 1,200
Meters
NAD 1983 UTM Zone 10N
PORT of vancouver
JASCO APPLIED SCIENCES
Scenario 16A: Small Post Panamax approaching terminal at 6 kts in winter
Project Operations Underwater Noise Modelling

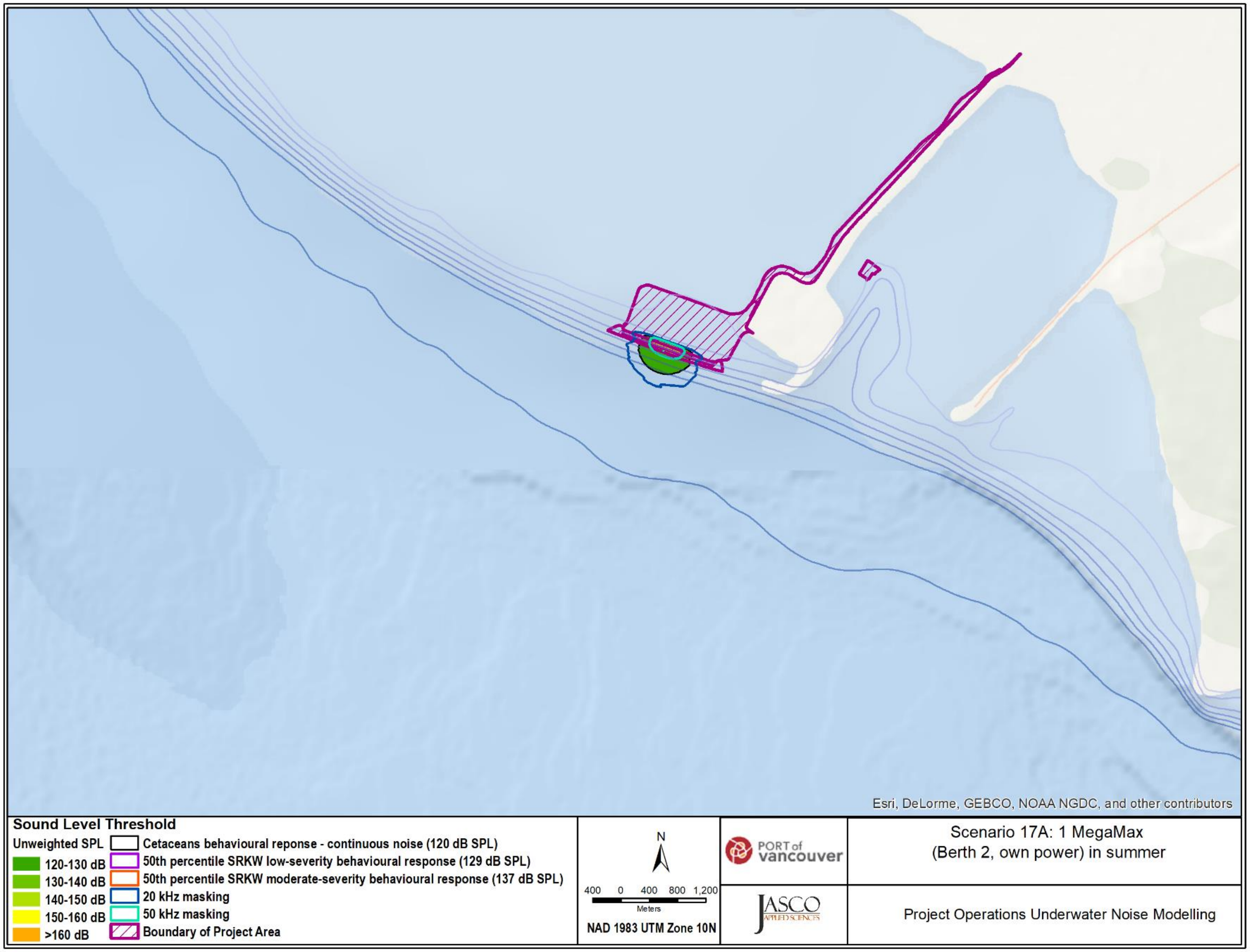

Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Sound Level Threshold
Unweighted SPL
🟩 120-130 dB
🟩 130-140 dB
🟩 140-150 dB
🟨 150-160 dB
🟧 >160 dB
☐ Cetaceans behavioural reponse - continuous noise (120 dB SPL)
☐ 50th percentile SRKW low-severity behavioural response (129 dB SPL)
☐ 50th percentile SRKW moderate-severity behavioural response (137 dB SPL)
☐ 20 kHz masking
☐ 50 kHz masking
▨ Boundary of Project Area
N
400 0 400 800 1,200
Meters
NAD 1983 UTM Zone 10N
PORT of vancouver
JASCO APPLIED SCIENCES
Scenario 16B: Large Post Panamax approaching terminal at 6 kts in winter
Project Operations Underwater Noise Modelling



Scenario 16C: Neo Panamax approaching terminal at 6 kts in winter

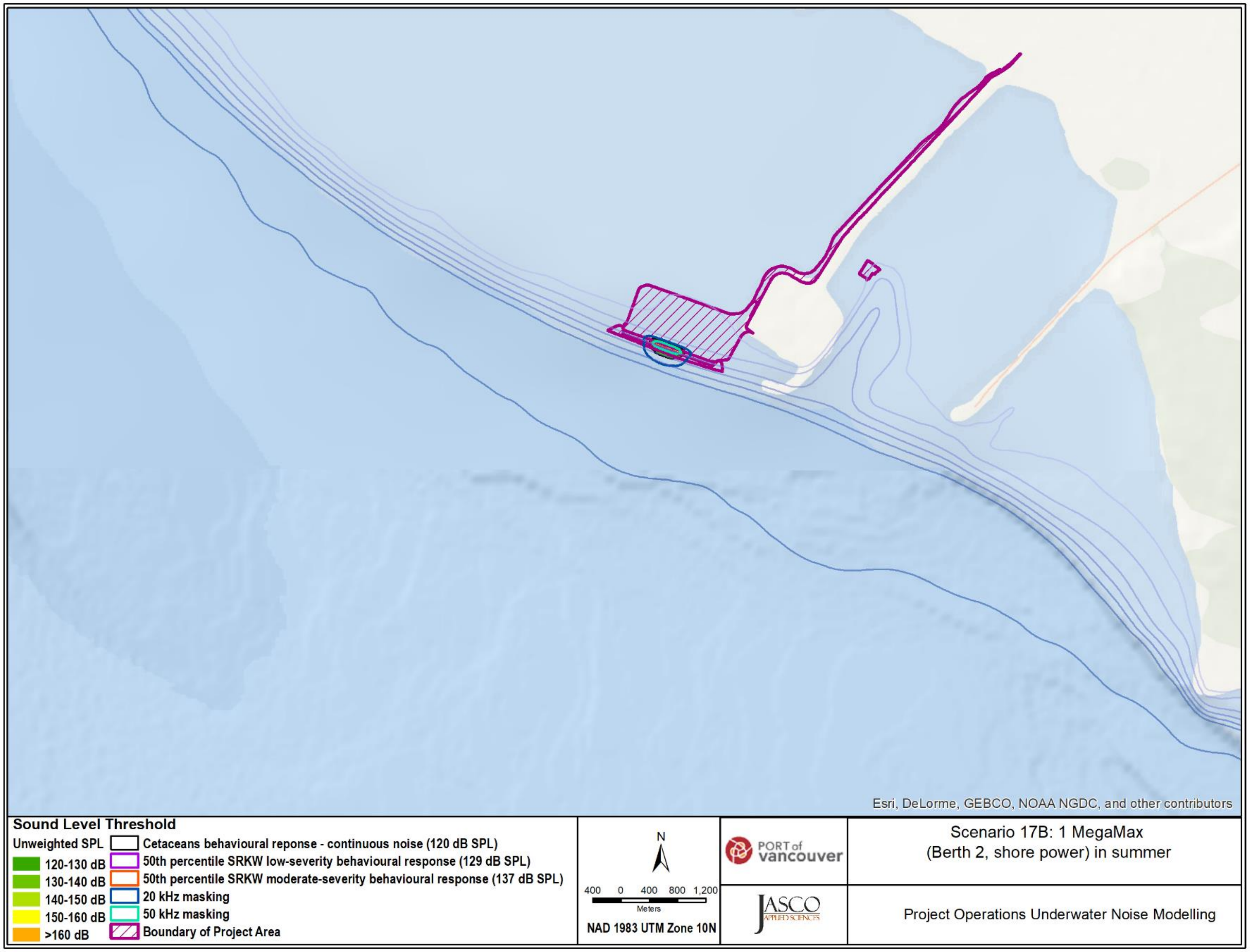
Project Operations Underwater Noise Modelling


Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Sound Level Threshold
Unweighted SPL
120-130 dB
130-140 dB
140-150 dB
150-160 dB
>160 dB
Cetaceans behavioural reponse - continuous noise (120 dB SPL)
50th percentile SRKW low-severity behavioural response (129 dB SPL)
50th percentile SRKW moderate-severity behavioural response (137 dB SPL)
20 kHz masking
50 kHz masking
Boundary of Project Area
N
400 0 400 800 1,200
Meters
NAD 1983 UTM Zone 10N
PORT of vancouver
JASCO APPLIED SCIENCES
Scenario 16D: Mega Max approaching terminal at 6 kts in winter
Project Operations Underwater Noise Modelling



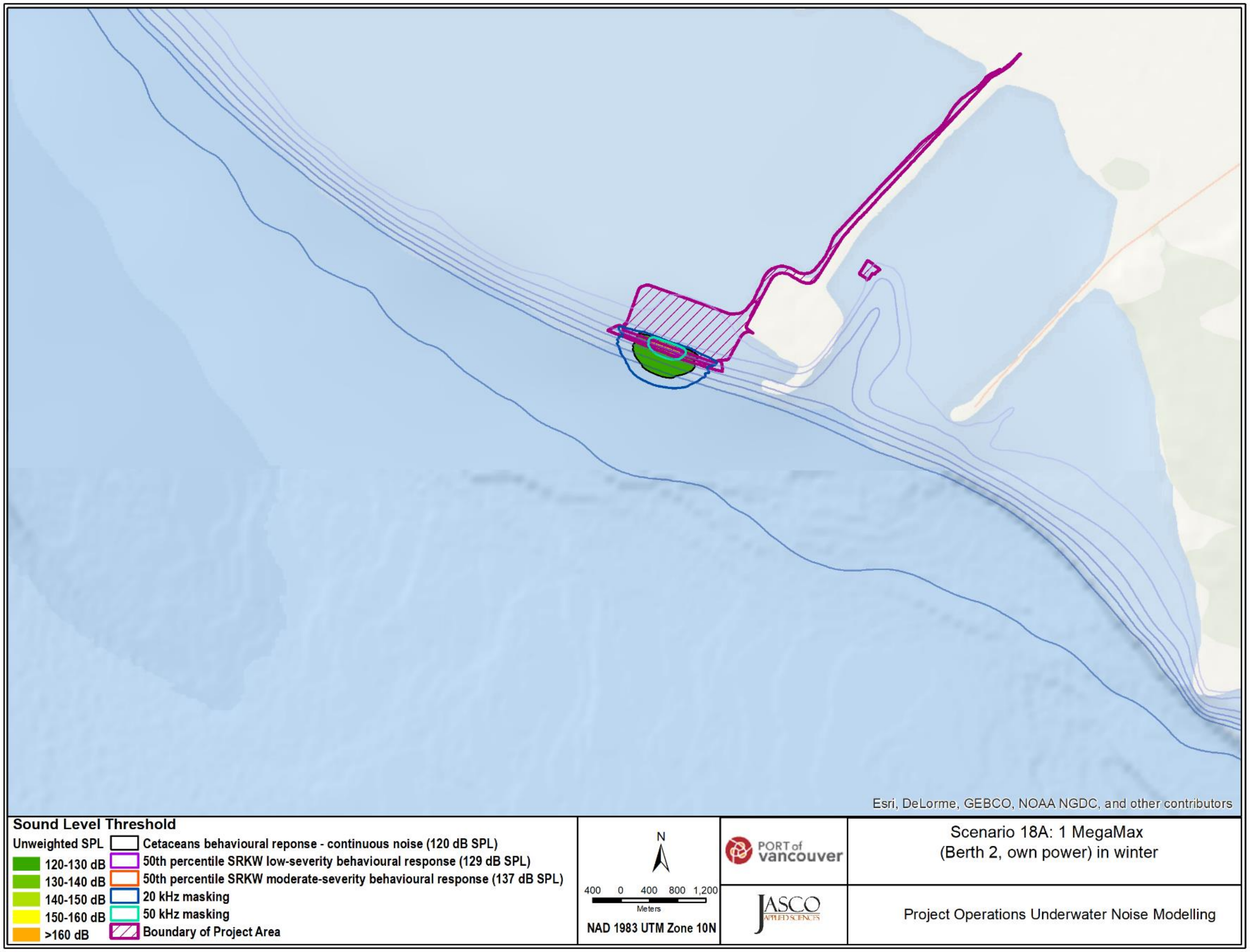
Scenario 17A: 1 MegaMax
(Berth 2, own power) in summer

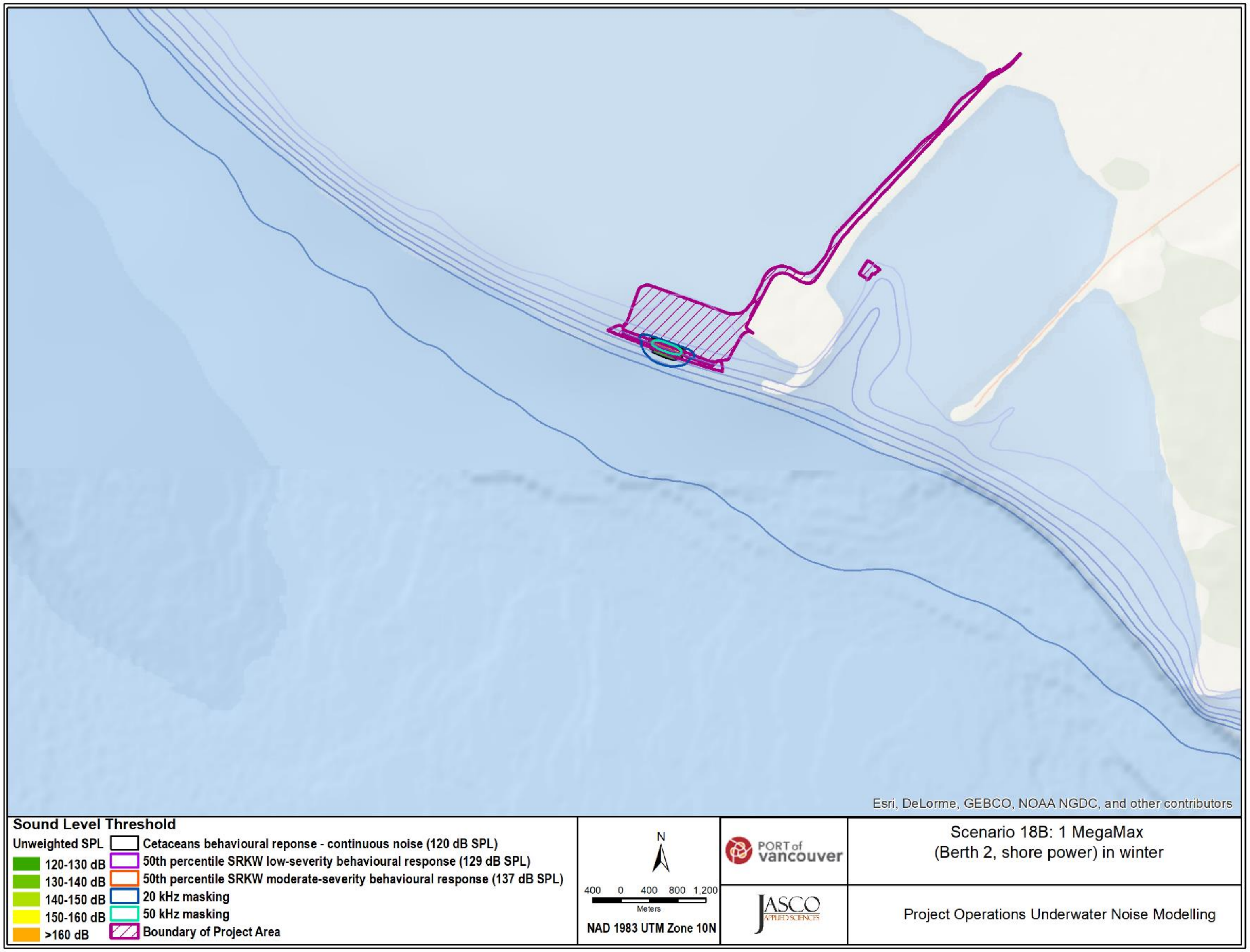
Project Operations Underwater Noise Modelling

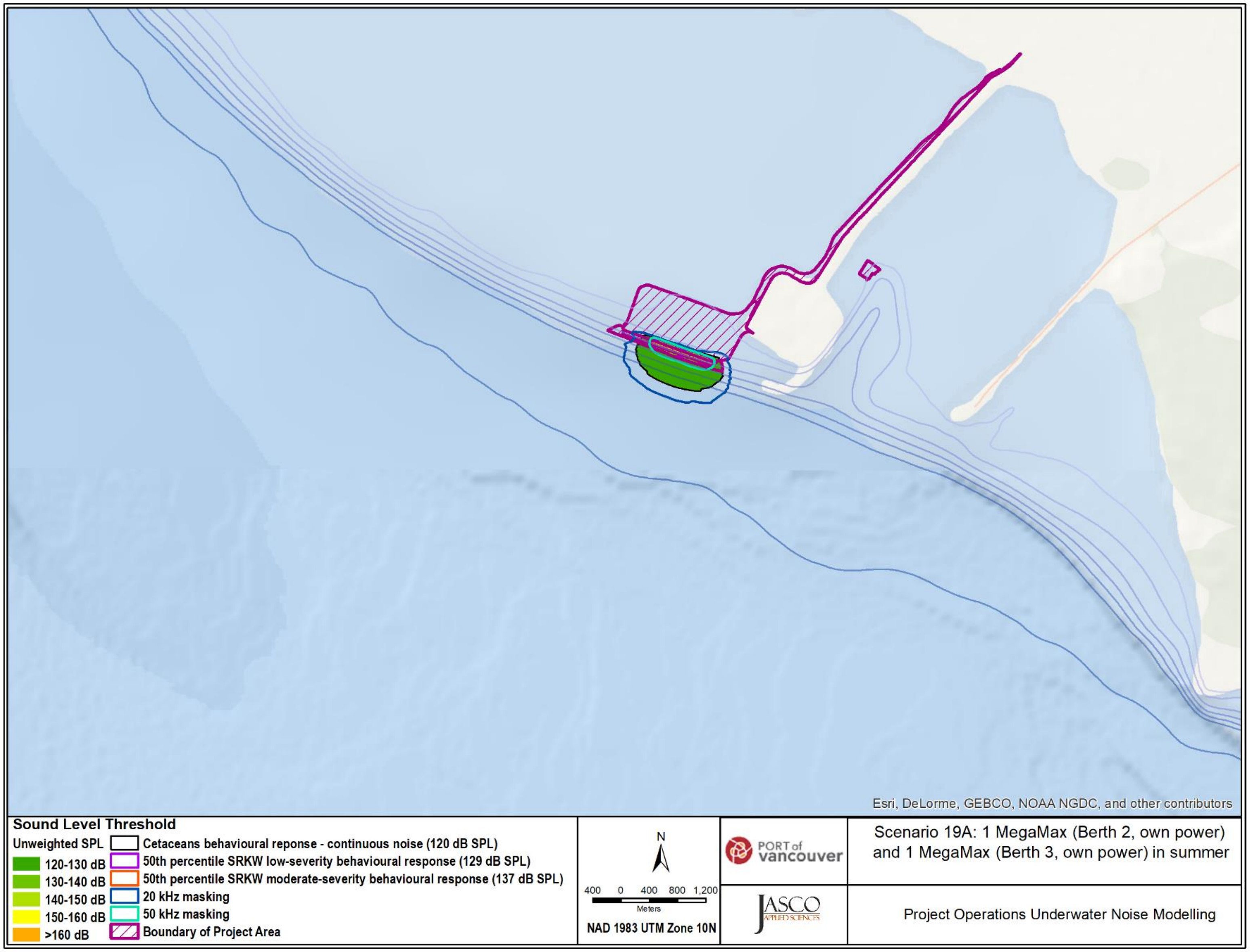


Scenario 17B: 1 MegaMax
(Berth 2, shore power) in summer

Project Operations Underwater Noise Modelling

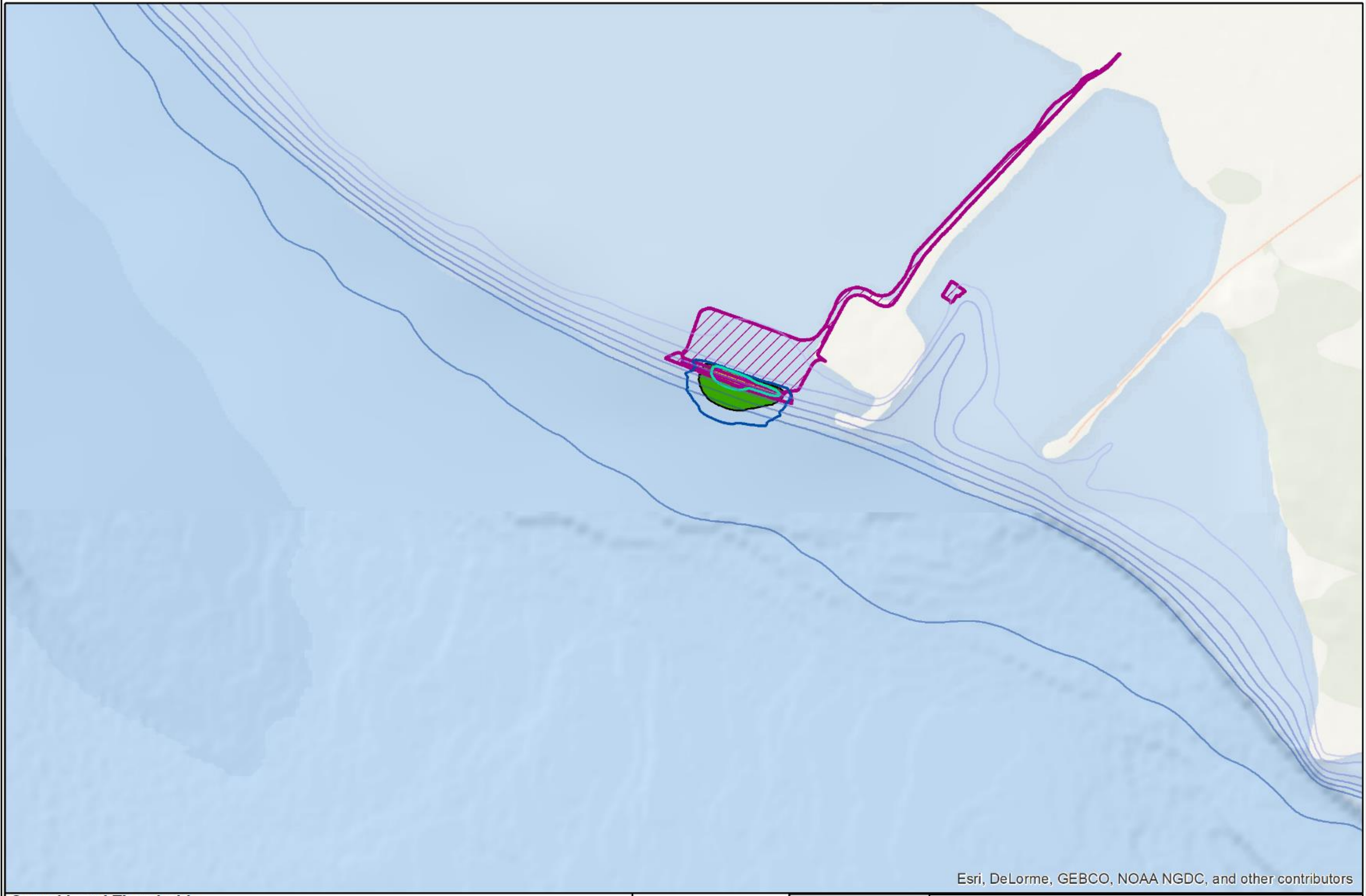

Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Sound Level Threshold
Unweighted SPL
🟩 120-130 dB
🟩 130-140 dB
🟩 140-150 dB
🟨 150-160 dB
🟧 >160 dB
☐ Cetaceans behavioural reponse - continuous noise (120 dB SPL)
☐ 50th percentile SRKW low-severity behavioural response (129 dB SPL)
☐ 50th percentile SRKW moderate-severity behavioural response (137 dB SPL)
☐ 20 kHz masking
☐ 50 kHz masking
▨ Boundary of Project Area
N
400 0 400 800 1,200
Meters
NAD 1983 UTM Zone 10N
PORT of vancouver
JASCO APPLIED SCIENCES
Scenario 18A: 1 MegaMax
(Berth 2, own power) in winter
Project Operations Underwater Noise Modelling


Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Sound Level Threshold
Unweighted SPL
120-130 dB
130-140 dB
140-150 dB
150-160 dB
>160 dB
Cetaceans behavioural reponse - continuous noise (120 dB SPL)
50th percentile SRKW low-severity behavioural response (129 dB SPL)
50th percentile SRKW moderate-severity behavioural response (137 dB SPL)
20 kHz masking
50 kHz masking
Boundary of Project Area
N
400 0 400 800 1,200
Meters
NAD 1983 UTM Zone 10N
PORT of vancouver
JASCO APPLIED SCIENCES
Scenario 18B: 1 MegaMax
(Berth 2, shore power) in winter
Project Operations Underwater Noise Modelling



Scenario 19A: 1 MegaMax (Berth 2, own power) and 1 MegaMax (Berth 3, own power) in summer

Project Operations Underwater Noise Modelling



Sound Level Threshold

Unweighted SPL	
🟩 120-130 dB	☐ Cetaceans behavioural reponse - continuous noise (120 dB SPL)
🟩 130-140 dB	☐ 50th percentile SRKW low-severity behavioural response (129 dB SPL)
🟩 140-150 dB	☐ 50th percentile SRKW moderate-severity behavioural response (137 dB SPL)
🟨 150-160 dB	☐ 20 kHz masking
🟧 >160 dB	☐ 50 kHz masking
	▨ Boundary of Project Area

N

400 0 400 800 1,200
Meters

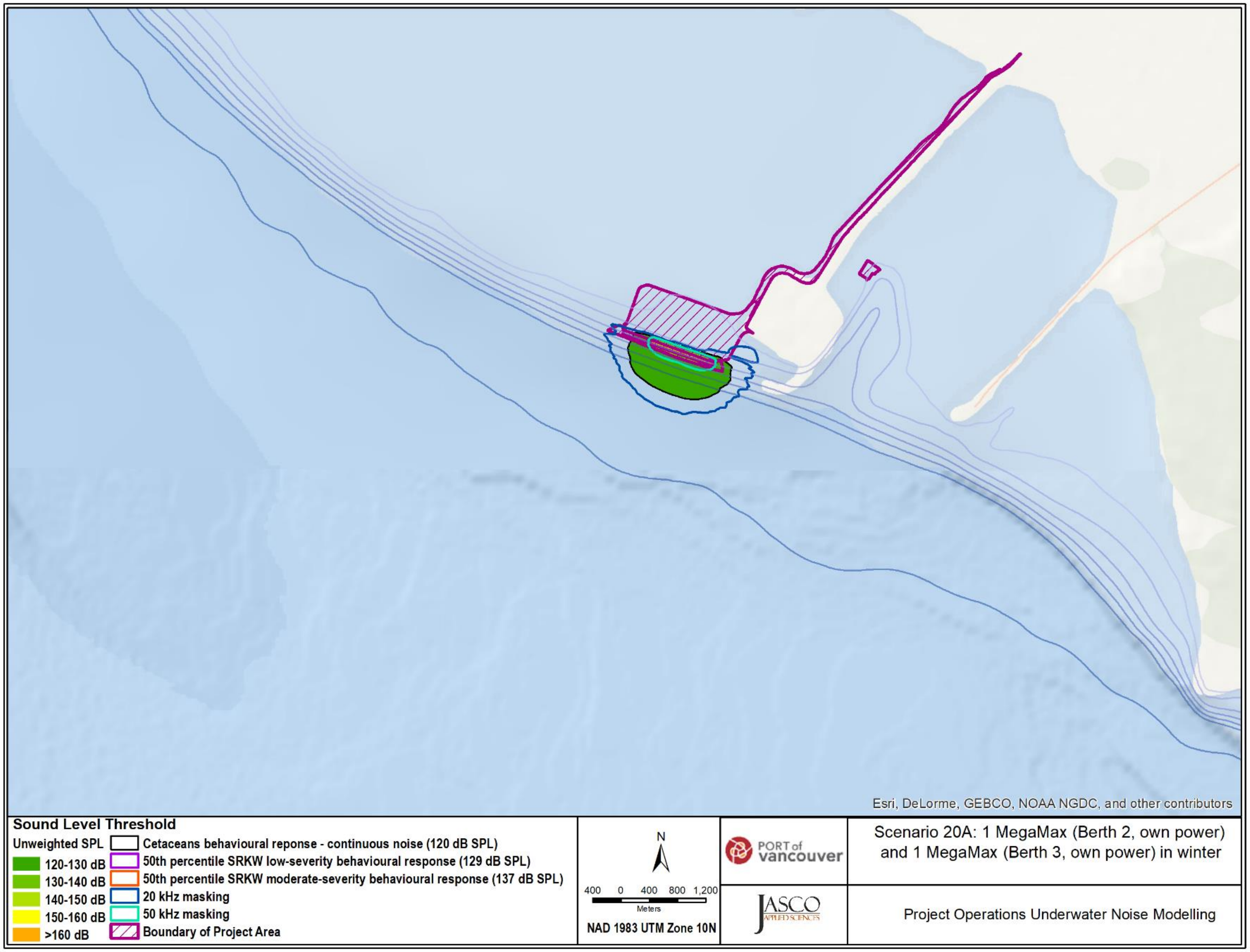
NAD 1983 UTM Zone 10N

PORT of vancouver

Scenario 19B: 1 MegaMax (Berth 2, own power) and 1 MegaMax (Berth 3, shore power) in summer

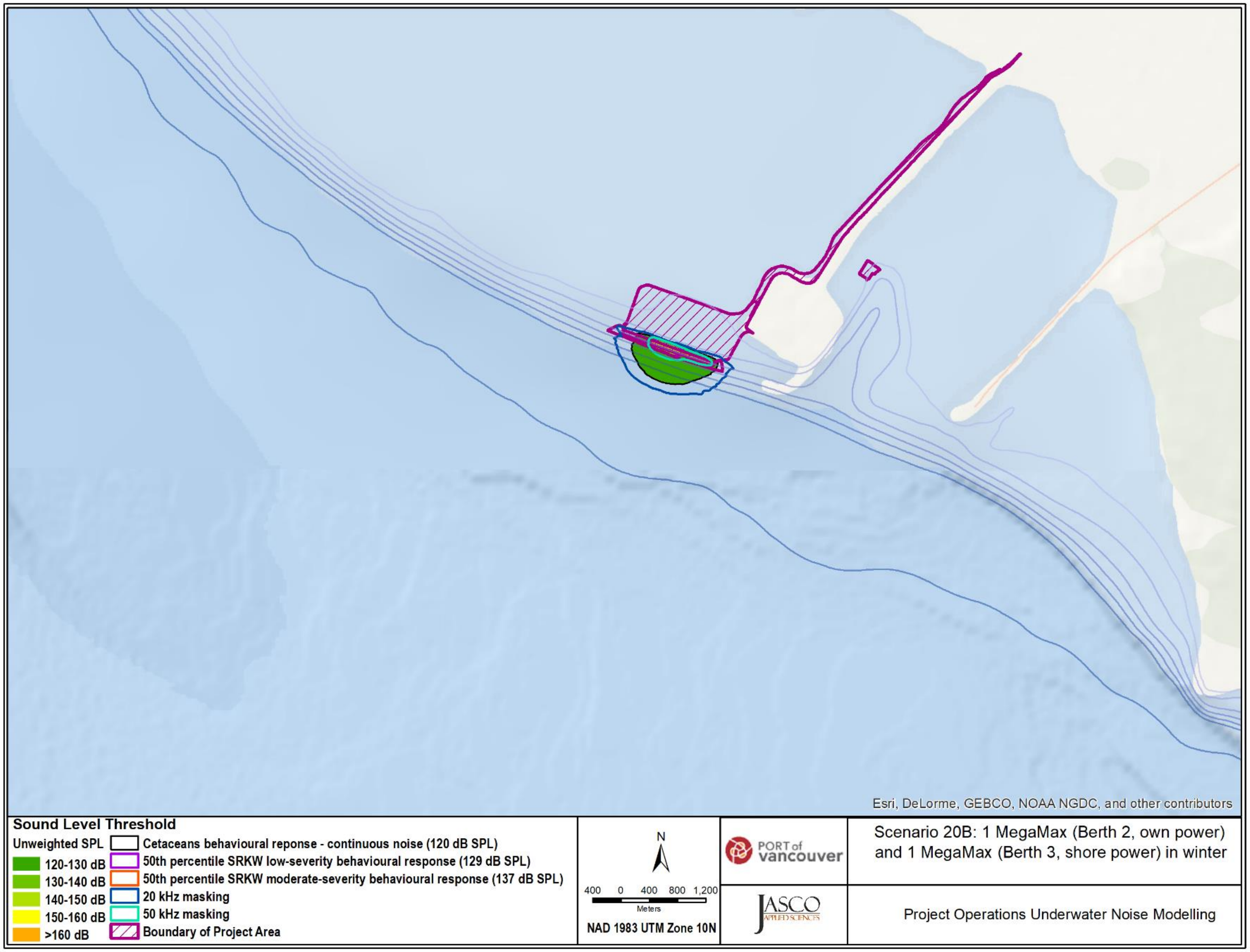
JASCO APPLIED SCIENCES

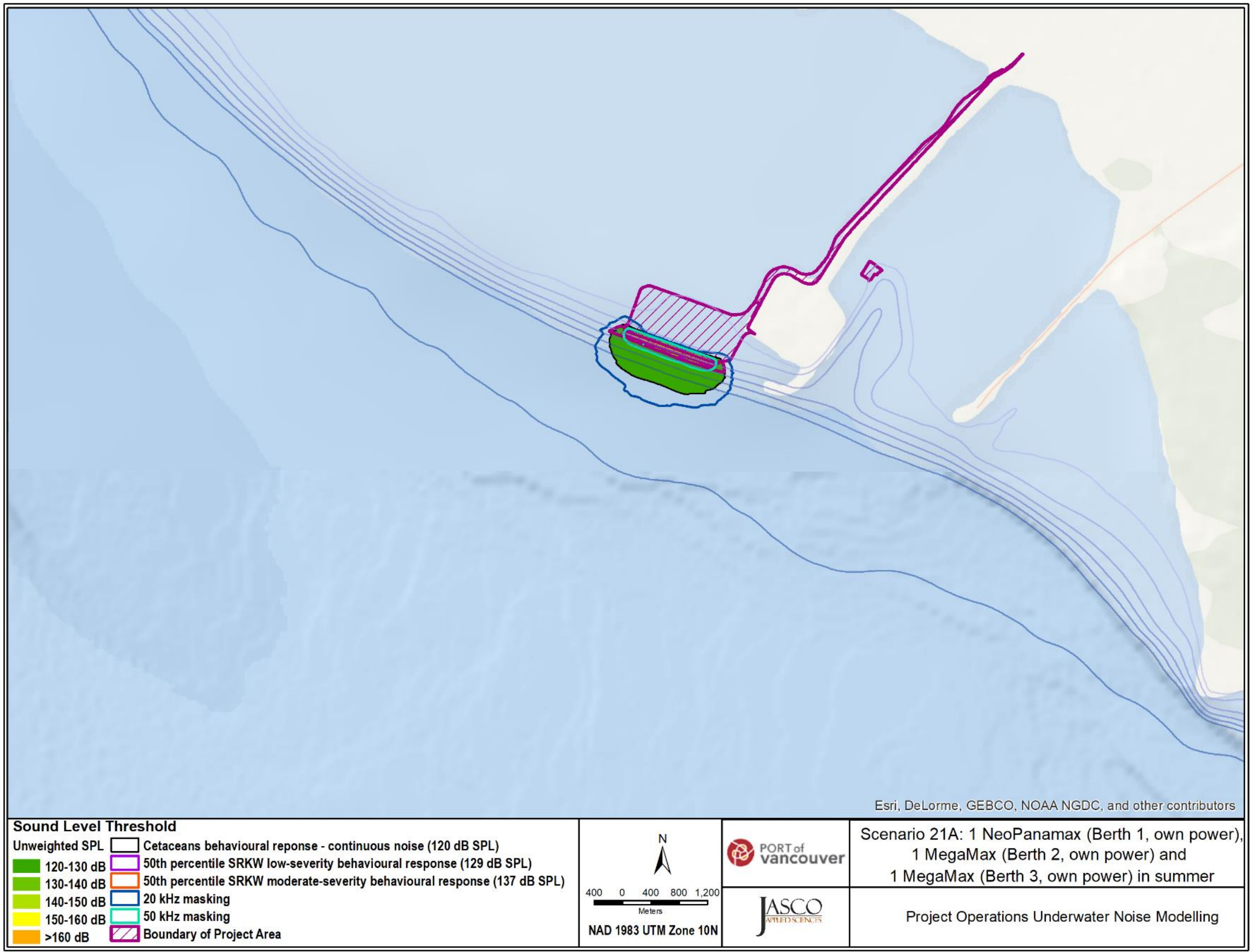
Project Operations Underwater Noise Modelling



Scenario 20A: 1 MegaMax (Berth 2, own power) and 1 MegaMax (Berth 3, own power) in winter

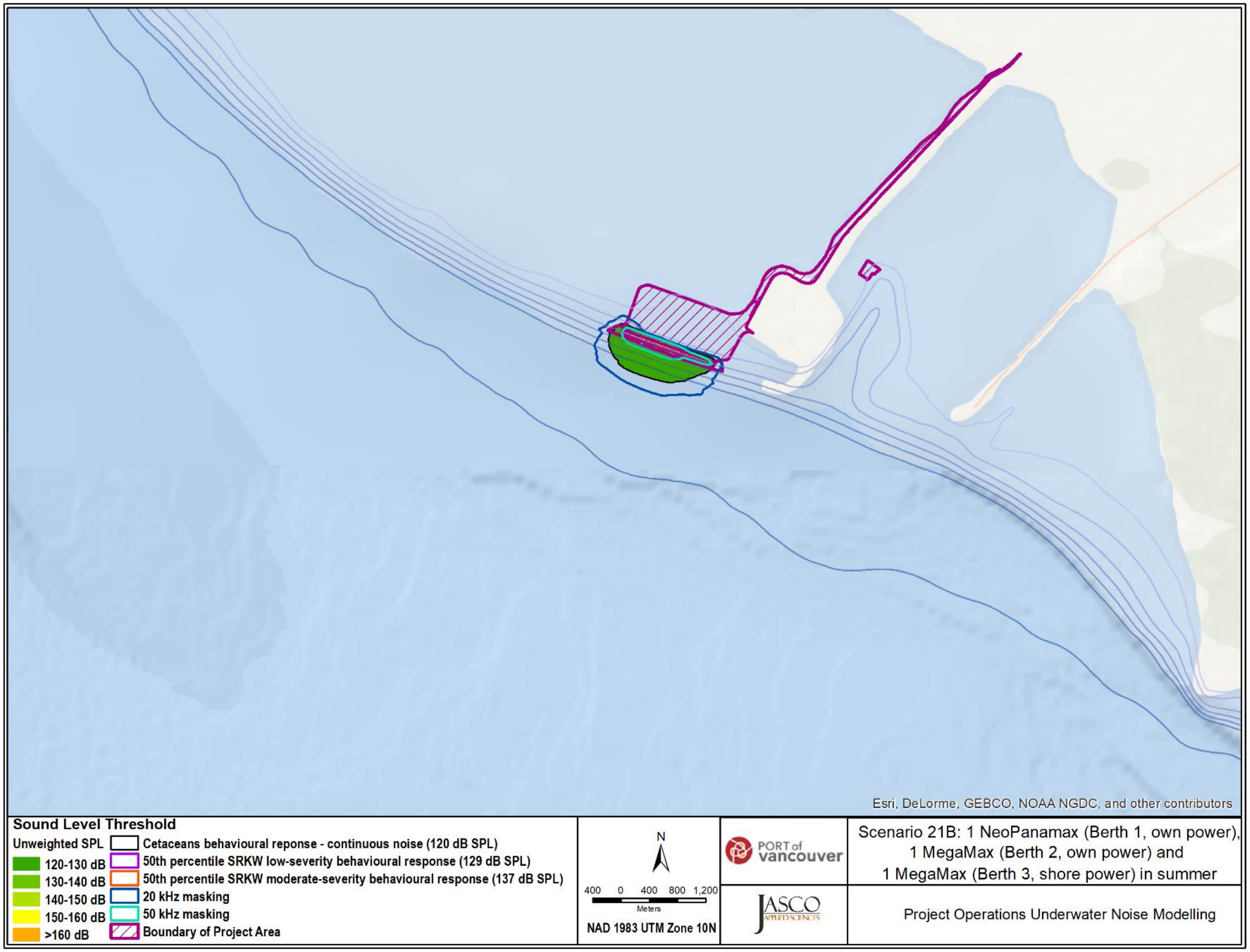
Project Operations Underwater Noise Modelling

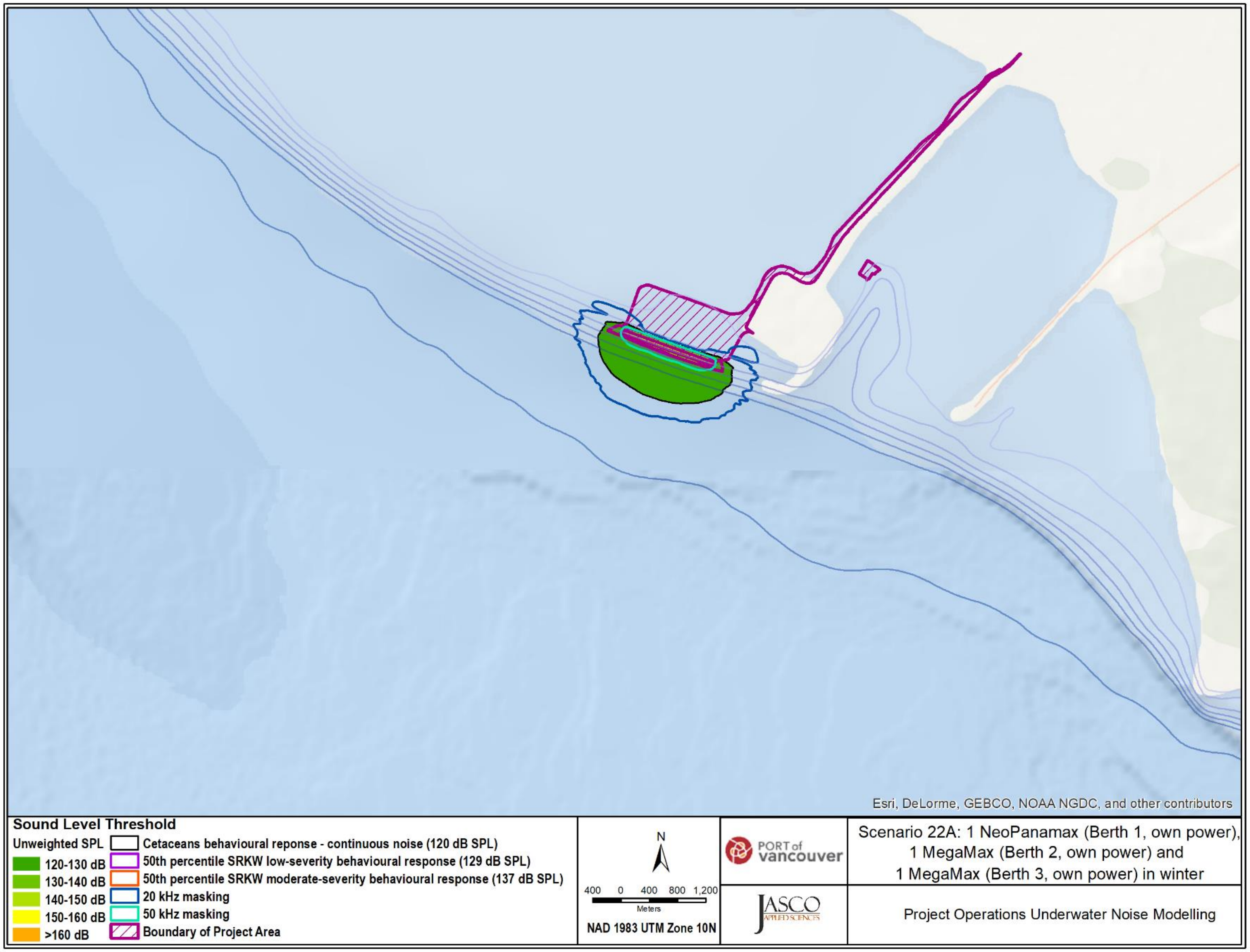

Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Sound Level Threshold
Unweighted SPL
🟩 120-130 dB
🟩 130-140 dB
🟩 140-150 dB
🟨 150-160 dB
🟧 >160 dB
☐ Cetaceans behavioural reponse - continuous noise (120 dB SPL)
☐ 50th percentile SRKW low-severity behavioural response (129 dB SPL)
☐ 50th percentile SRKW moderate-severity behavioural response (137 dB SPL)
☐ 20 kHz masking
☐ 50 kHz masking
▨ Boundary of Project Area
N
400 0 400 800 1,200
Meters
NAD 1983 UTM Zone 10N
PORT of vancouver
JASCO APPLIED SCIENCES
Scenario 20B: 1 MegaMax (Berth 2, own power) and 1 MegaMax (Berth 3, shore power) in winter
Project Operations Underwater Noise Modelling

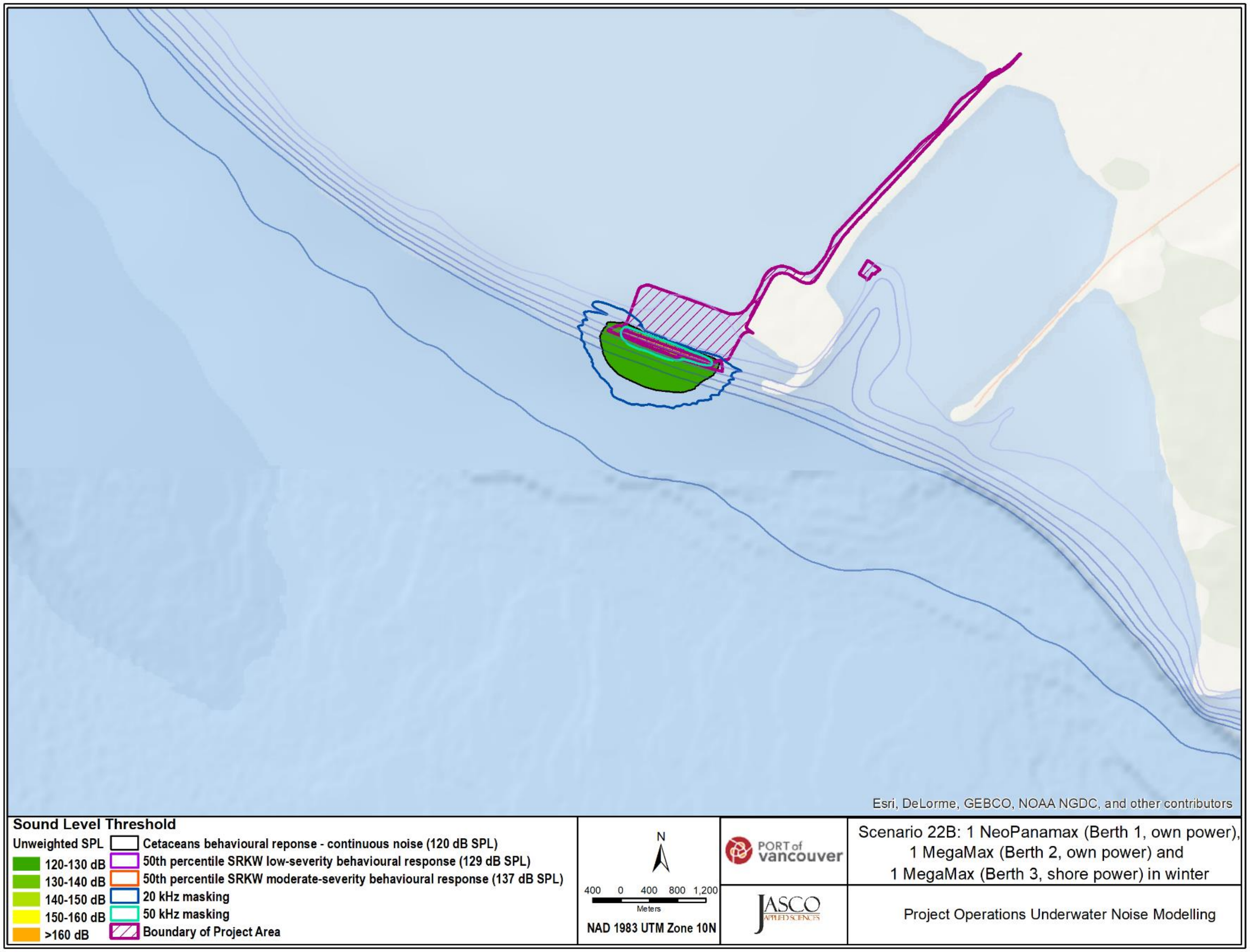


Scenario 21A: 1 NeoPanamax (Berth 1, own power), 1 MegaMax (Berth 2, own power) and 1 MegaMax (Berth 3, own power) in summer

Project Operations Underwater Noise Modelling

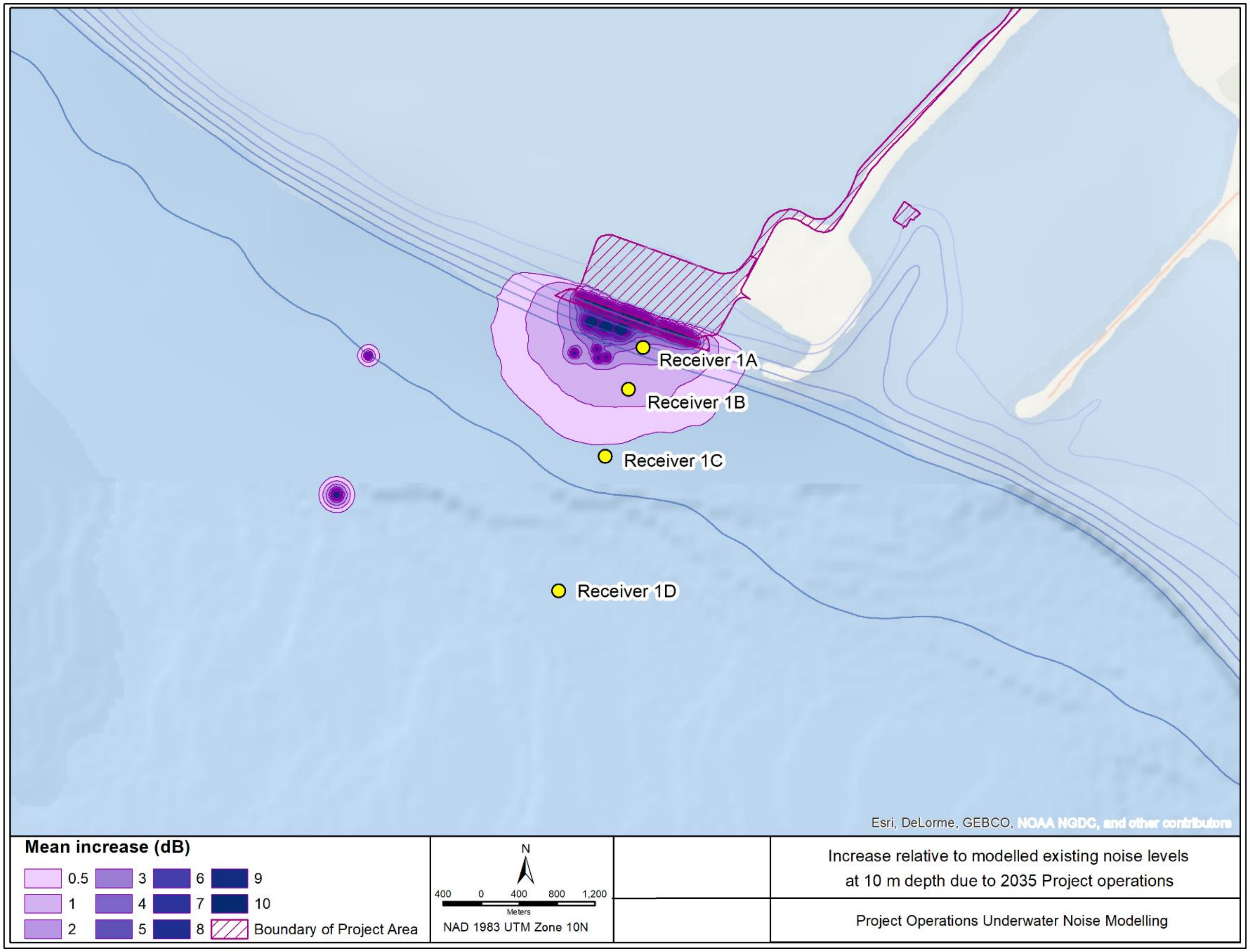

Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Sound Level Threshold
Unweighted SPL
🟩 120-130 dB
🟩 130-140 dB
🟩 140-150 dB
🟨 150-160 dB
🟧 >160 dB
☐ Cetaceans behavioural reponse - continuous noise (120 dB SPL)
☐ 50th percentile SRKW low-severity behavioural response (129 dB SPL)
☐ 50th percentile SRKW moderate-severity behavioural response (137 dB SPL)
☐ 20 kHz masking
☐ 50 kHz masking
▨ Boundary of Project Area
N
400 0 400 800 1,200
Meters
NAD 1983 UTM Zone 10N
PORT of vancouver
JASCO APPLIED SCIENCES
Scenario 21B: 1 NeoPanamax (Berth 1, own power), 1 MegaMax (Berth 2, own power) and 1 MegaMax (Berth 3, shore power) in summer
Project Operations Underwater Noise Modelling


Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Sound Level Threshold
Unweighted SPL
🟩 120-130 dB
🟩 130-140 dB
🟩 140-150 dB
🟨 150-160 dB
🟧 >160 dB
☐ Cetaceans behavioural reponse - continuous noise (120 dB SPL)
☐ 50th percentile SRKW low-severity behavioural response (129 dB SPL)
☐ 50th percentile SRKW moderate-severity behavioural response (137 dB SPL)
☐ 20 kHz masking
☐ 50 kHz masking
▨ Boundary of Project Area
N
400 0 400 800 1,200
Meters
NAD 1983 UTM Zone 10N
PORT of vancouver
JASCO APPLIED SCIENCES
Scenario 22A: 1 NeoPanamax (Berth 1, own power),
1 MegaMax (Berth 2, own power) and
1 MegaMax (Berth 3, own power) in winter
Project Operations Underwater Noise Modelling


Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Sound Level Threshold
Unweighted SPL
120-130 dB
130-140 dB
140-150 dB
150-160 dB
>160 dB
Cetaceans behavioural reponse - continuous noise (120 dB SPL)
50th percentile SRKW low-severity behavioural response (129 dB SPL)
50th percentile SRKW moderate-severity behavioural response (137 dB SPL)
20 kHz masking
50 kHz masking
Boundary of Project Area
N
400 0 400 800 1,200
Meters
NAD 1983 UTM Zone 10N
PORT of vancouver
JASCO APPLIED SCIENCES
Scenario 22B: 1 NeoPanamax (Berth 1, own power), 1 MegaMax (Berth 2, own power) and 1 MegaMax (Berth 3, shore power) in winter
Project Operations Underwater Noise Modelling

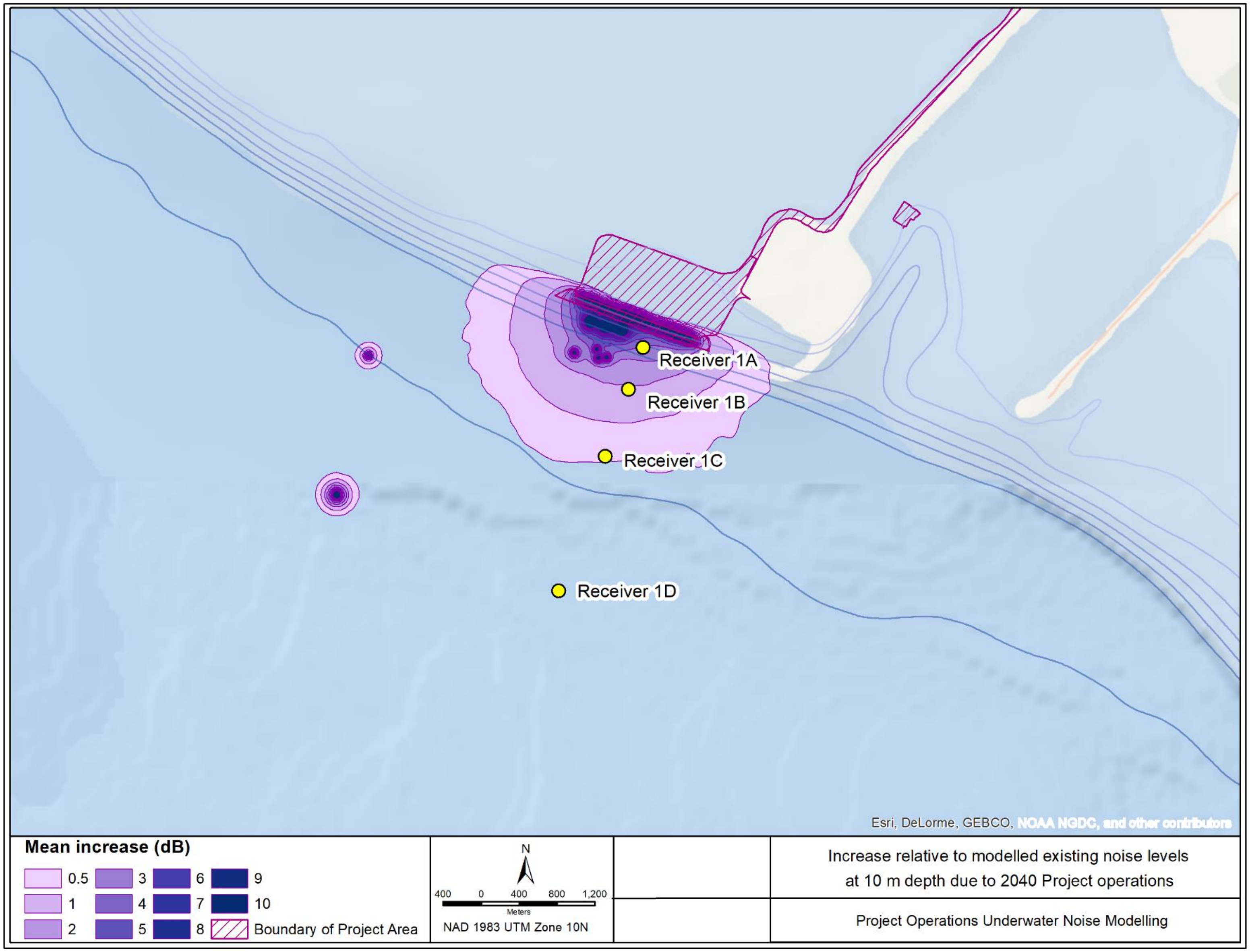
A.2. Incremental Contribution – Most-realistic Scenario with 30% shore power uptake

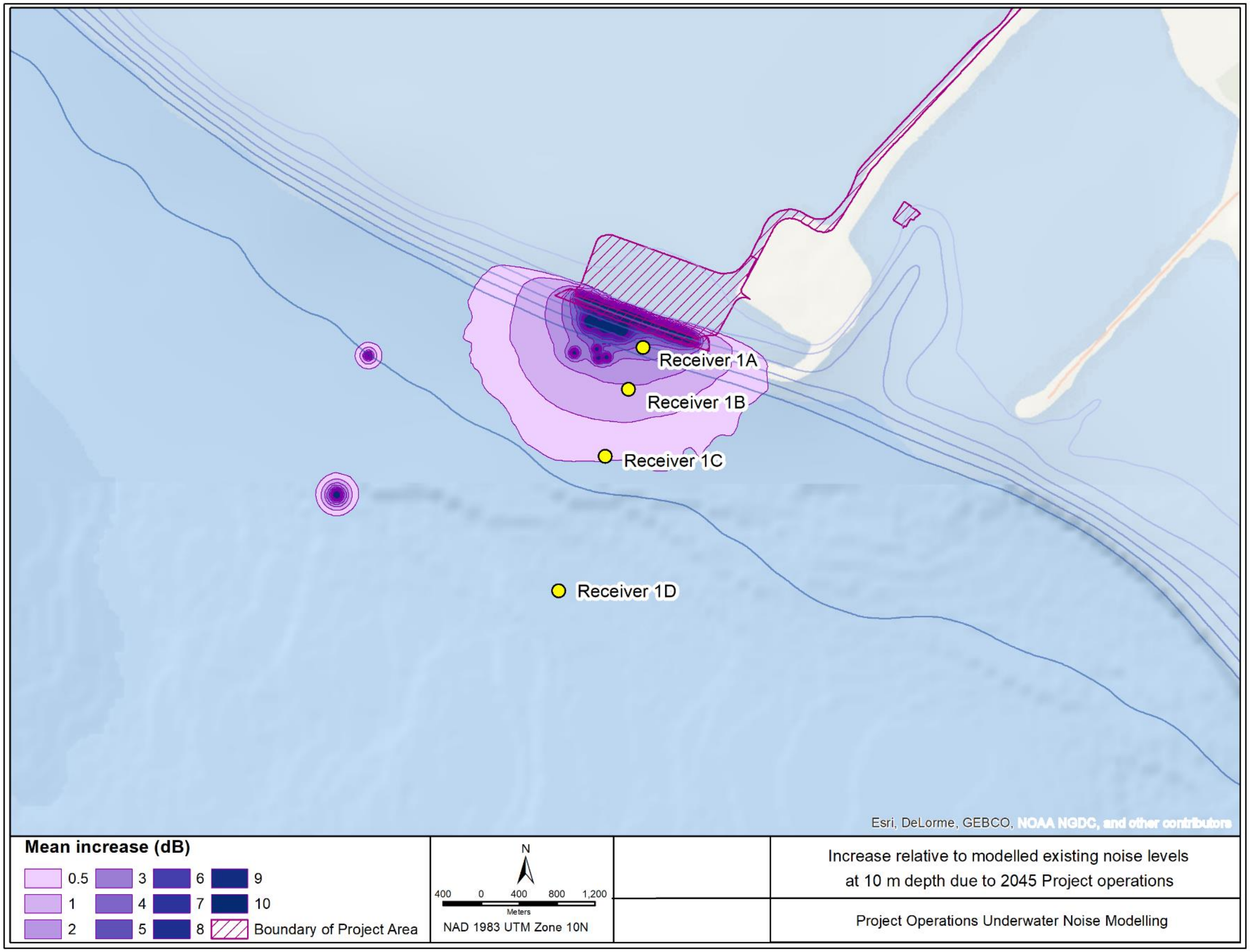
This appendix provides contour maps of modelled increases in one year time averaged sound levels ($L_{eq\text{-}1yr}$), due to RBT2 Project operations, above existing (2015 background) conditions in 2035, 2040, and 2045, for most-realistic scenario, with 30% shore power uptake. Contours show the decibel increase in average noise levels, from 0.5 to 10 dB, at 10 m receiver depth.



Increase relative to modelled existing noise levels at 10 m depth due to 2035 Project operations

Project Operations Underwater Noise Modelling


Receiver 1A
Receiver 1B
Receiver 1C
Receiver 1D
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Mean increase (dB)
0.5
1
2
3
4
5
6
7
8
9
10
Boundary of Project Area
N
400 0 400 800 1,200
Meters
NAD 1983 UTM Zone 10N
Increase relative to modelled existing noise levels at 10 m depth due to 2040 Project operations
Project Operations Underwater Noise Modelling

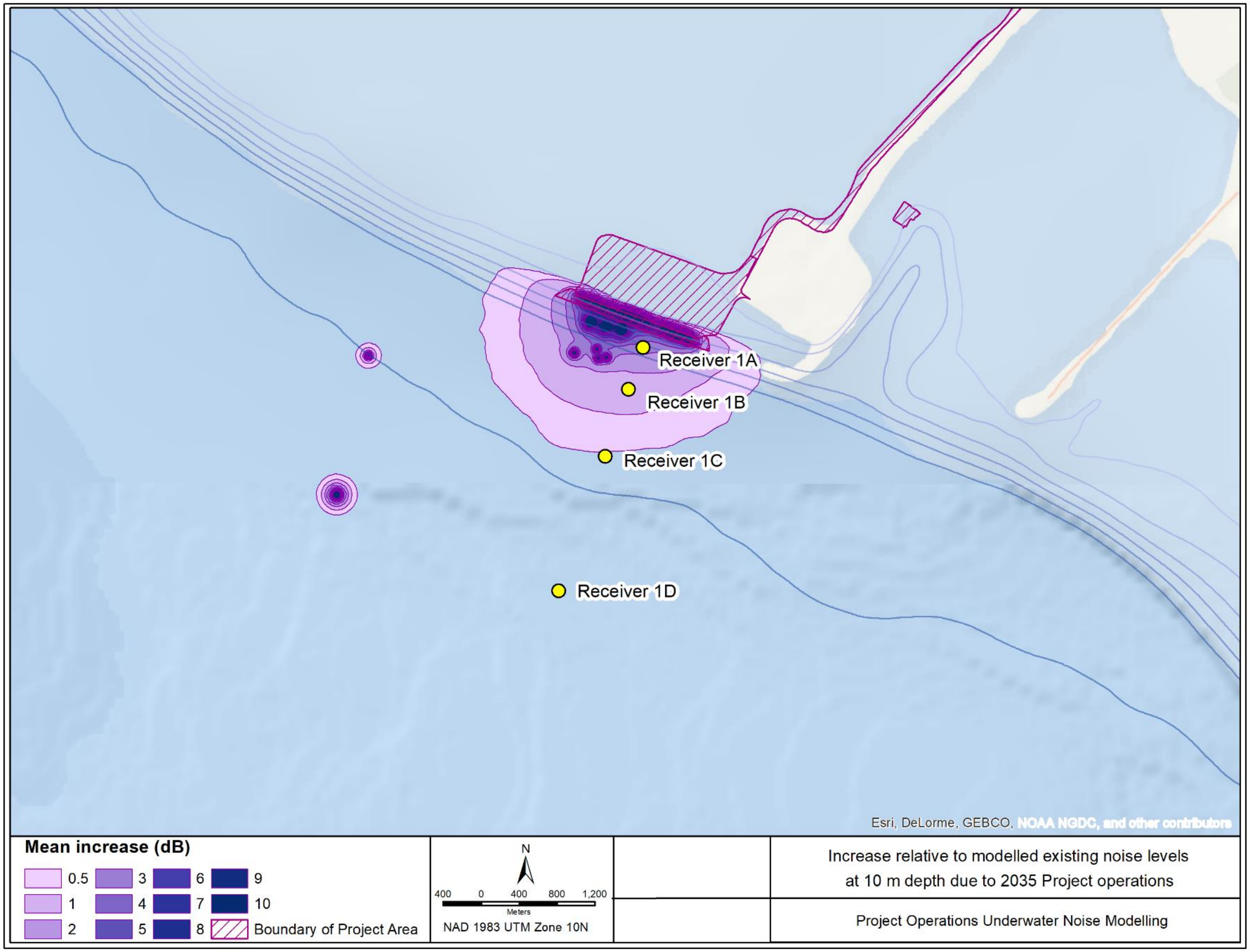


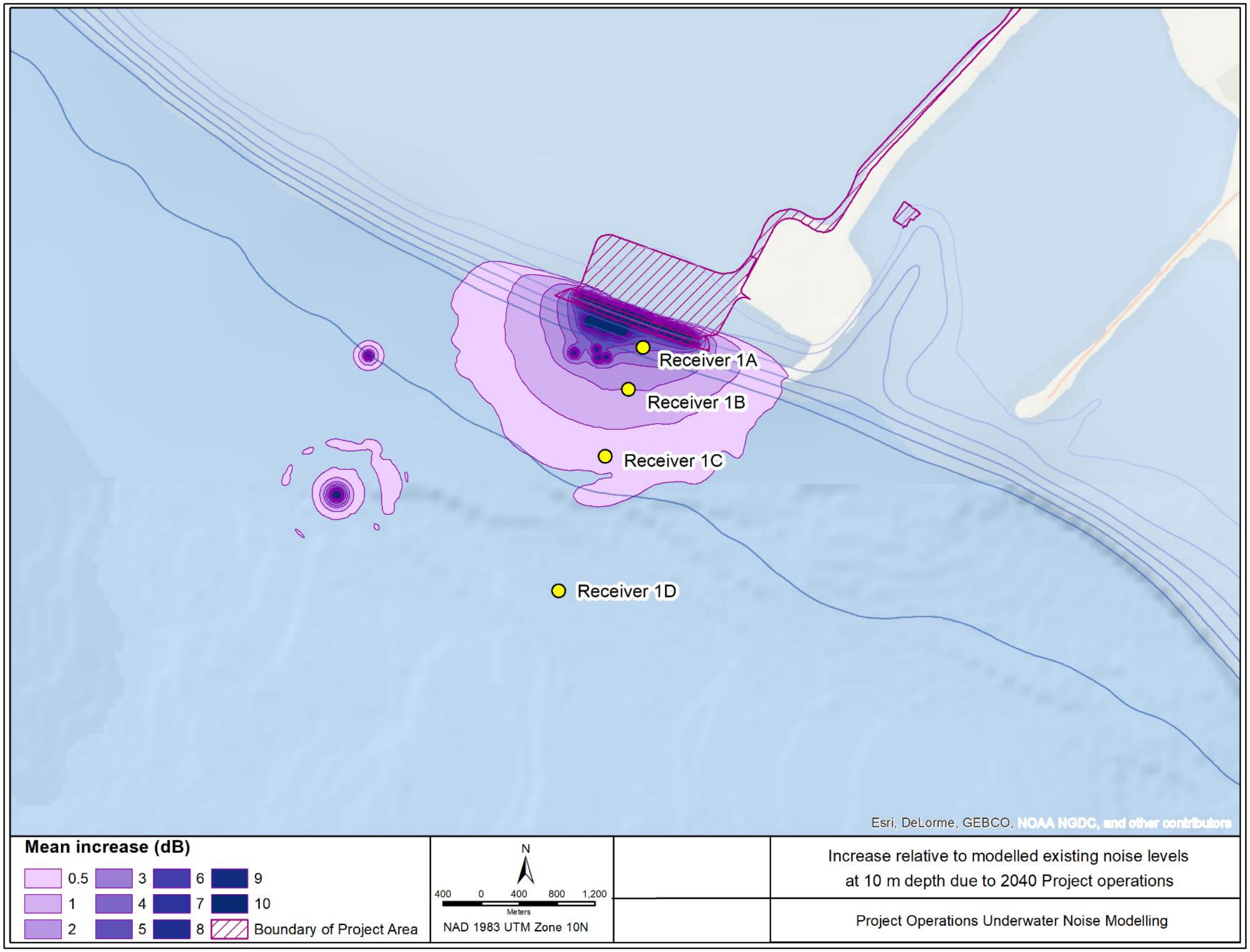
Increase relative to modelled existing noise levels at 10 m depth due to 2045 Project operations

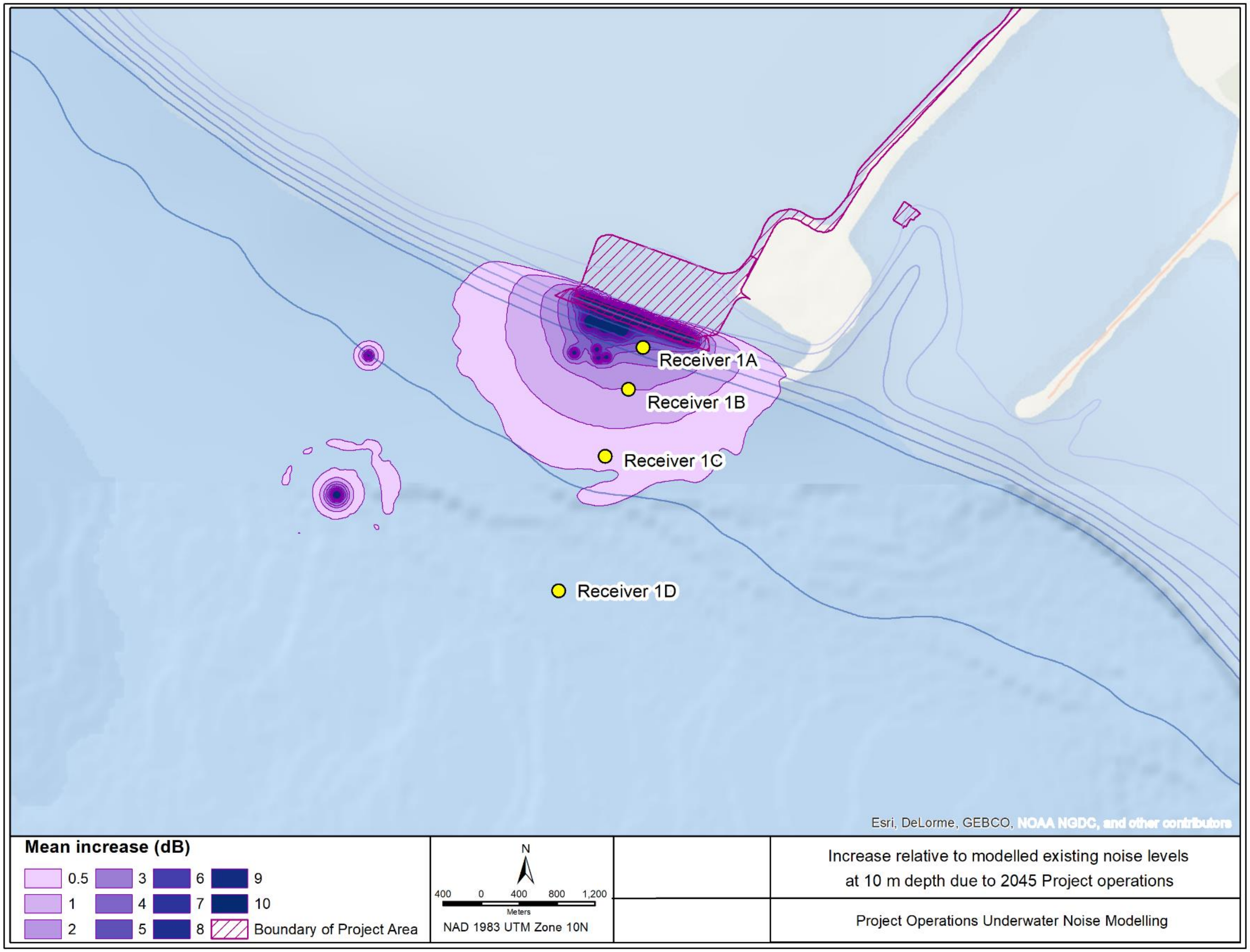
Project Operations Underwater Noise Modelling

A.3. Incremental Contribution – High-case Vessel Scenario, with 30% shore power uptake

This appendix provides contour maps of modelled increases in one year time averaged sound levels ($L_{eq\text{-}1yr}$), due to RBT2 Project operations, above existing (2015 background) conditions in 2035, 2040, and 2045, for high-case container vessel scenario, with 30% shore power uptake. Contours show the decibel increase in average noise levels, from 0.5 to 10 dB, at 10 m receiver depth.


Receiver 1A
Receiver 1B
Receiver 1C
Receiver 1D
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Mean increase (dB)
0.5
1
2
3
4
5
6
7
8
9
10
Boundary of Project Area
N
400 0 400 800 1,200
Meters
NAD 1983 UTM Zone 10N
Increase relative to modelled existing noise levels at 10 m depth due to 2035 Project operations
Project Operations Underwater Noise Modelling


Receiver 1A
Receiver 1B
Receiver 1C
Receiver 1D
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Mean increase (dB)
0.5
1
2
3
4
5
6
7
8
9
10
Boundary of Project Area
N
400 0 400 800 1,200
Meters
NAD 1983 UTM Zone 10N
Increase relative to modelled existing noise levels at 10 m depth due to 2040 Project operations
Project Operations Underwater Noise Modelling

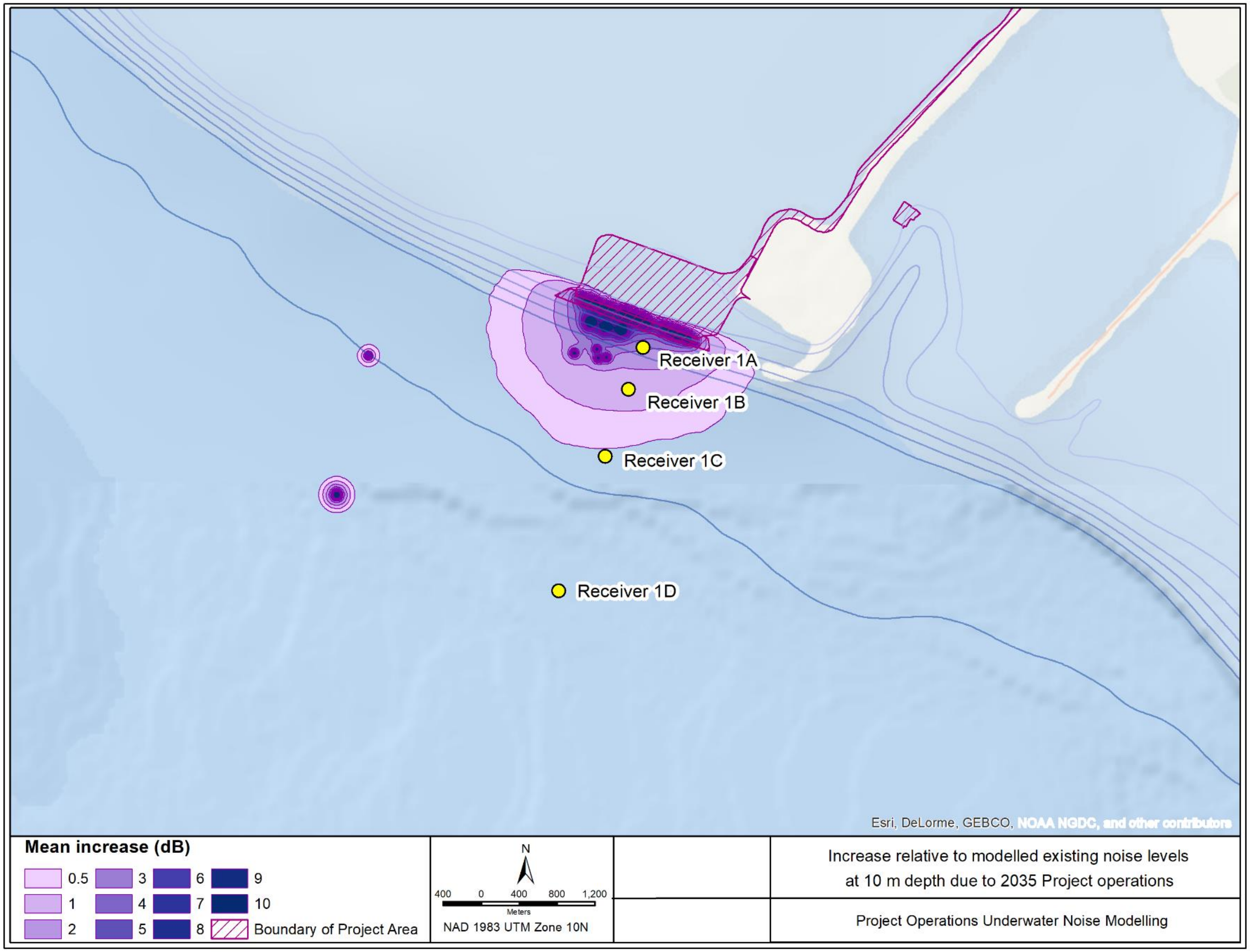


Increase relative to modelled existing noise levels at 10 m depth due to 2045 Project operations

Project Operations Underwater Noise Modelling

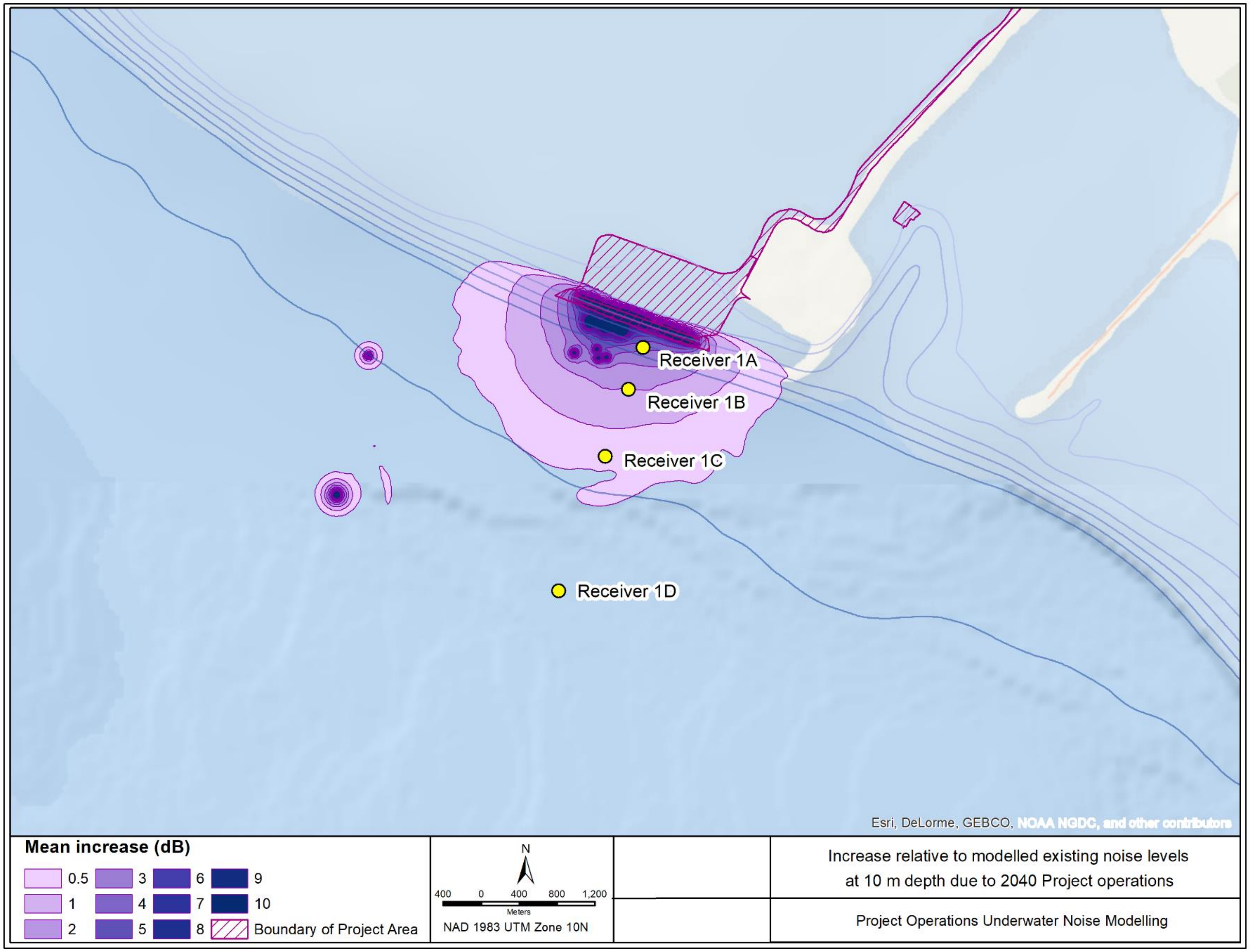
A.4. Incremental Contribution – Most-realistic Scenario, with no shore power uptake

This appendix provides contour maps of modelled increases in one year time averaged sound levels ($L_{eq\text{-}1yr}$), due to RBT2 Project operations, above existing (2015 background) conditions in 2035, 2040, and 2045, for most-realistic scenario, with no shore power uptake (using own power). Contours show the decibel increase in average noise levels, from 0.5 to 10 dB, at 10 m receiver depth.



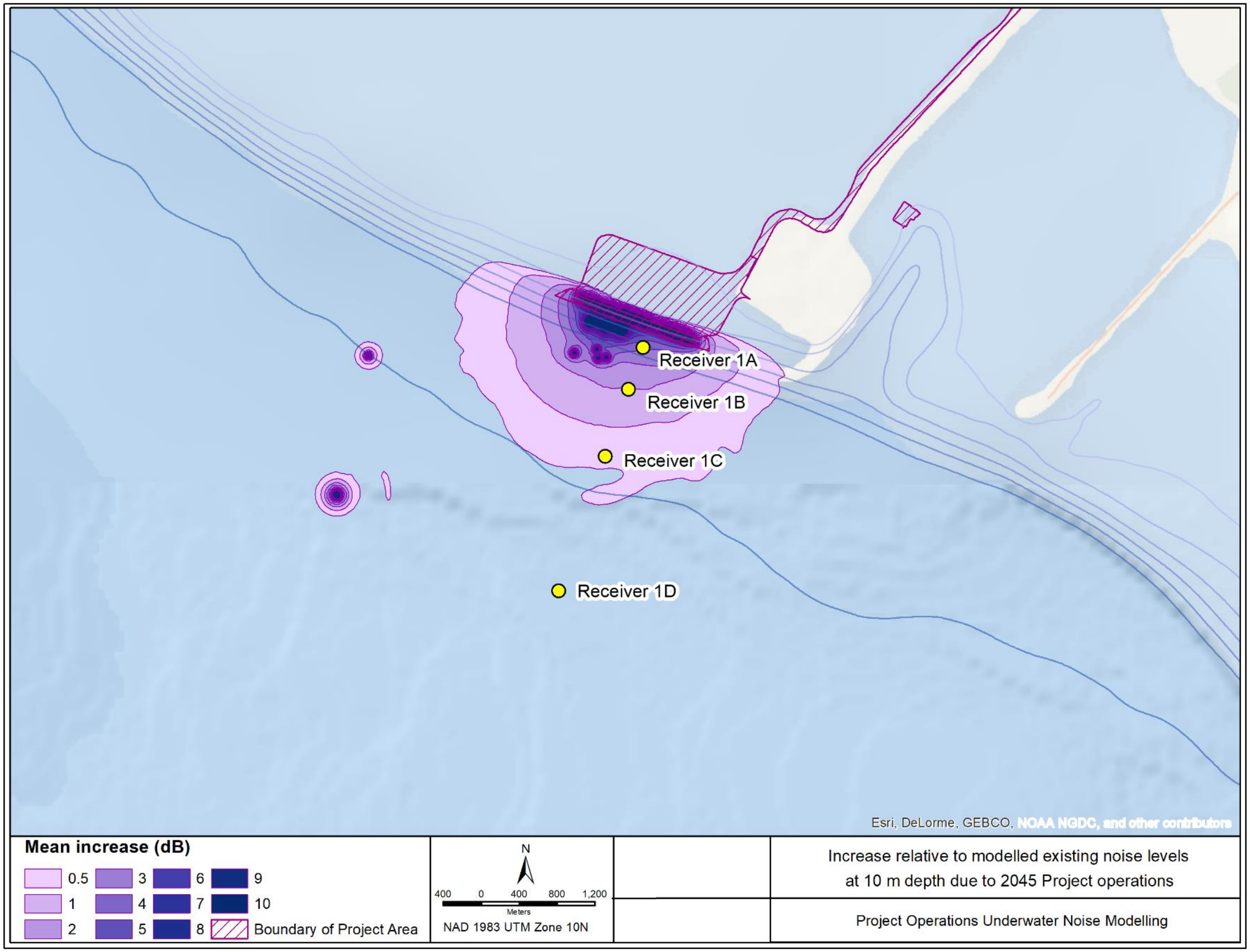
Increase relative to modelled existing noise levels at 10 m depth due to 2035 Project operations

Project Operations Underwater Noise Modelling



Increase relative to modelled existing noise levels at 10 m depth due to 2040 Project operations

Project Operations Underwater Noise Modelling

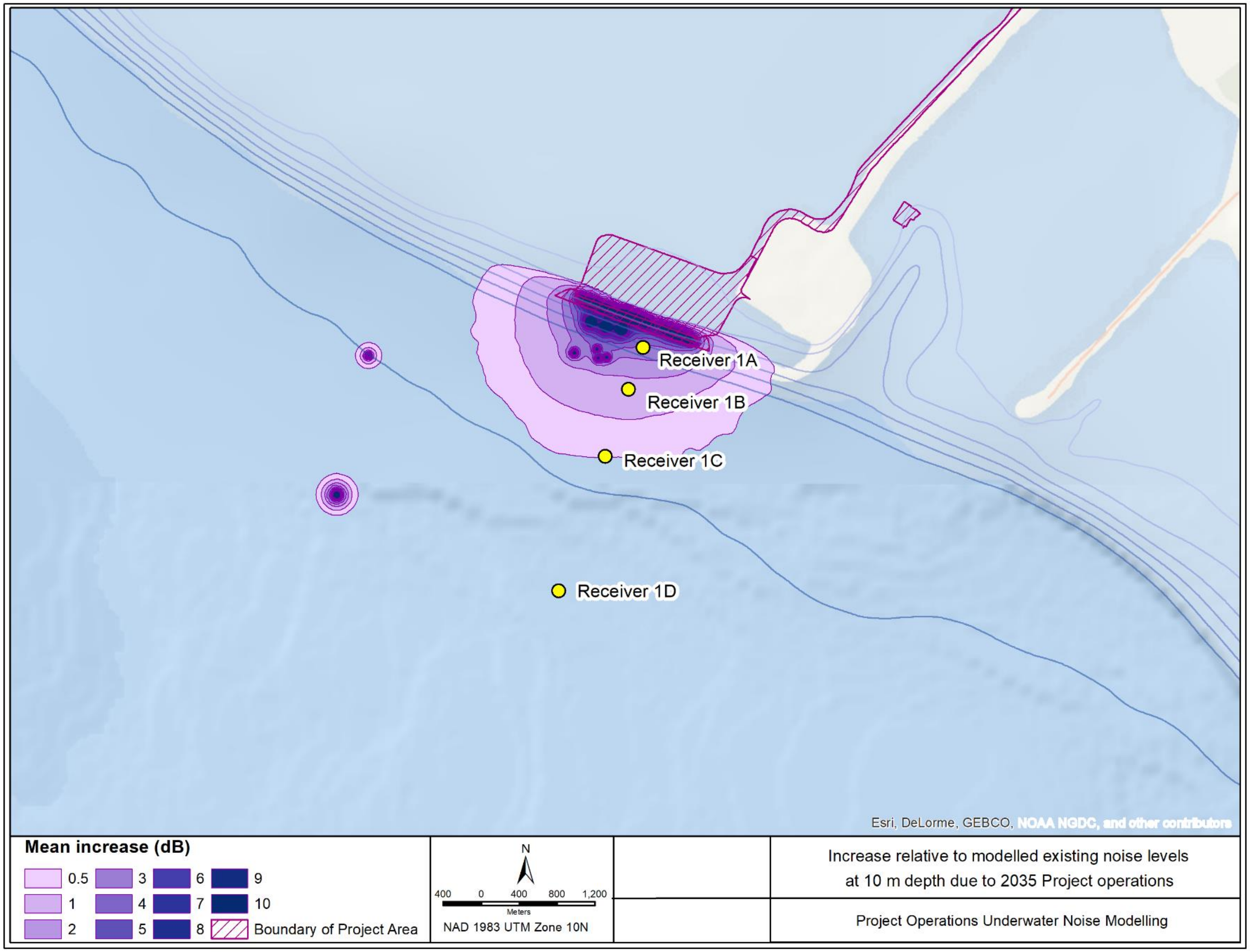


Increase relative to modelled existing noise levels at 10 m depth due to 2045 Project operations

Project Operations Underwater Noise Modelling

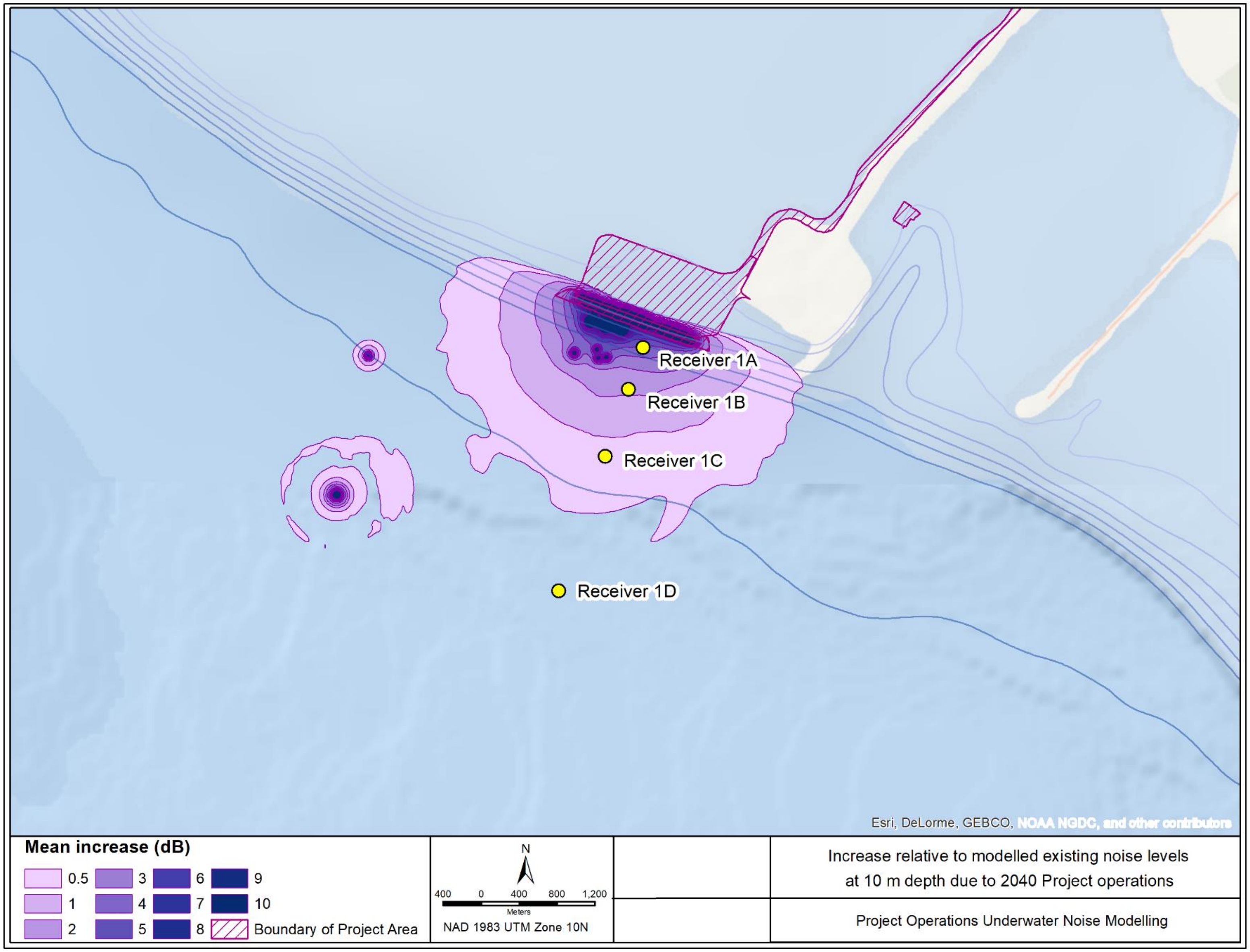
A.5. Incremental Contribution – High-case Vessel Scenario, with no shore power uptake

This appendix provides contour maps of modelled increases in one year time averaged sound levels ($L_{eq\text{-}1yr}$), due to RBT2 Project operations, above existing (2015 background) conditions in 2035, 2040, and 2045, for high-case container vessel scenario, with no shore power uptake (using own power). Contours show the decibel increase in average noise levels, from 0.5 to 10 dB, at 10 m receiver depth.



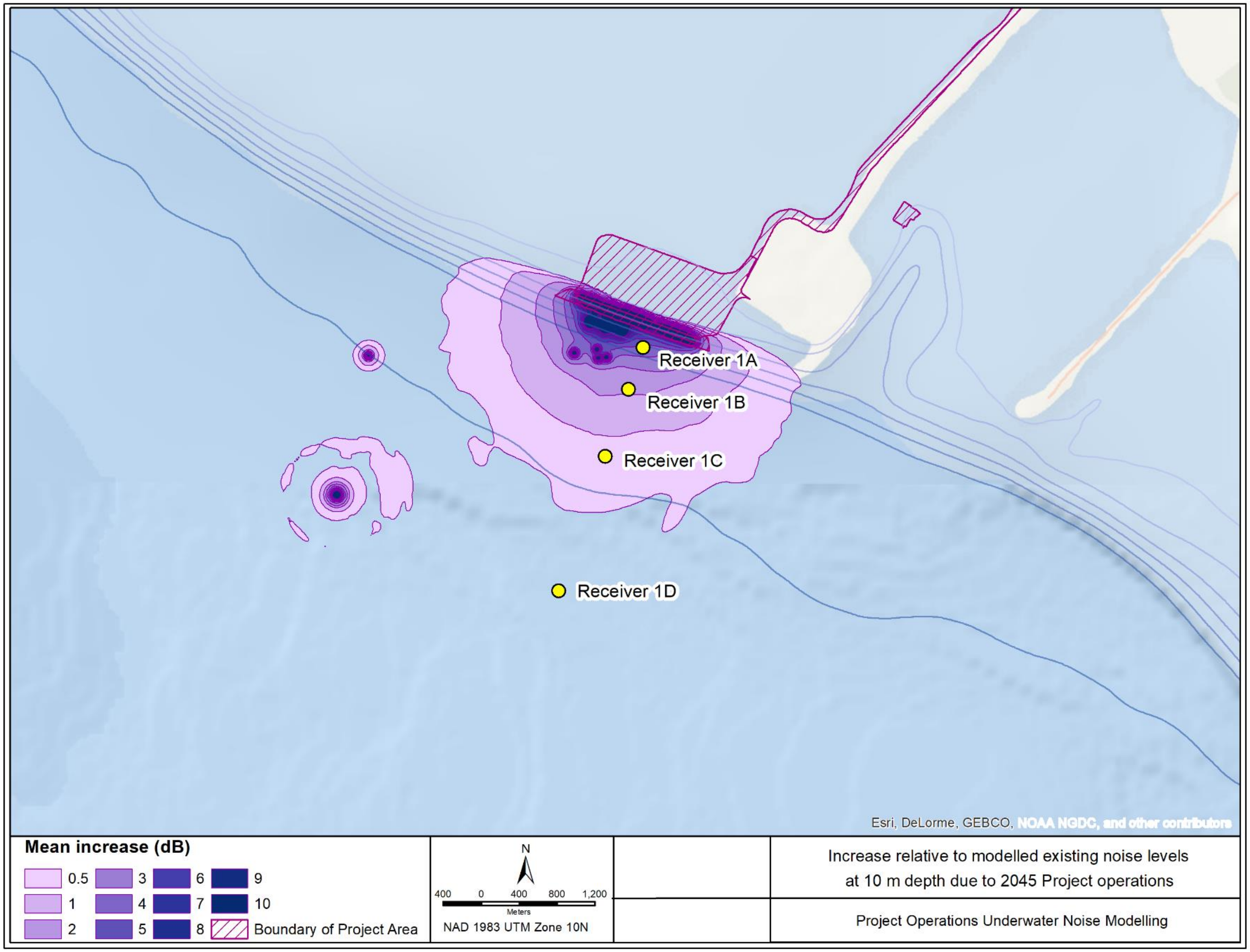
Increase relative to modelled existing noise levels at 10 m depth due to 2035 Project operations

Project Operations Underwater Noise Modelling



Increase relative to modelled existing noise levels at 10 m depth due to 2040 Project operations

Project Operations Underwater Noise Modelling



Increase relative to modelled existing noise levels at 10 m depth due to 2045 Project operations

Project Operations Underwater Noise Modelling

Appendix B. Threshold radii for at-berth scenarios

The following table presents perpendicular and parallel 95th percentile radii for scenarios 17-22, representing noise from container vessels at berth. Average distances are presented in Table 8.

Table B-1. Modelled distances in metres to SRKW behavioural response (120, 129 and 137 dB re 1 µPa SPL, corresponding to 10% and 50% probability of low-severity, and 50% probability of moderate-severity), and SRKW echolocation click masking (20 kHz and 50 kHz) thresholds for RBT2 Project operations. Separate distances (95th percentile radii) are given in the perpendicular and parallel directions relative to the center of the berth face. SPPX = Small Post-Panamax, LPPX = Large Post-Panamax, NPX = Neo Panamax, MMX = Mega Max.

Scenario	Description	Season	120 dB SPL	129 dB SPL	137 dB SPL	20 kHz Masking	50 kHz Masking
Perpendicular distance							
17A	MMX Container vessel at Berth 2 on own power	Summer	350	80	40	500	140
17B	MMX Container vessel at Berth 2 on shore power	Summer	140	40	30	500	140
18A	MMX Container vessel at Berth 2 on own power	Winter	390	90	40	510	150
18B	MMX Container vessel at Berth 2 on shore power	Winter	150	50	30	510	150
19A	MMX Container vessel at Berth 2 on own power and MMX Container vessel at Berth 3 on own power	Summer	460	90	40	610	150
19B	MMX Container vessel at Berth 2 on own power and MMX Container vessel at Berth 3 on shore power	Summer	370	80	40	610	150
20A	MMX Container vessel at Berth 2 on own power and MMX Container vessel at Berth 3 on own power	Winter	560	100	40	730	160
20B	MMX Container vessel at Berth 2 on own power and MMX Container vessel at Berth 3 on shore power	Winter	440	90	40	730	160
21A	NPX Container at Berth 1 on own power, MMX Container at Berth 2 on own power, and MMX Container at Berth 3 on own power	Summer	510	90	40	710	150

Scenario	Description	Season	120 dB SPL	129 dB SPL	137 dB SPL	20 kHz Masking	50 kHz Masking
21B	NPX Container at Berth 1 on own power, MMX Container at Berth 2 on own power, and MMX Container at Berth 3 on shore power	Summer	460	90	40	710	150
22A	NPX Container at Berth 1 on own power, MMX Container at Berth 2 on own power, and MMX Container at Berth 3 on own power	Winter	670	110	40	890	160
22B	NPX Container at Berth 1 on own power, MMX Container at Berth 2 on own power, and one MMX Container at Berth 3 on shore power	Winter	580	100	40	890	160
Parallel distance							
17A	MMX Container vessel at Berth 2 on own power	Summer	340	210	190	460	240
17B	MMX Container vessel at Berth 2 on shore power	Summer	240	200	210	460	240
18A	MMX Container vessel at Berth 2 on own power	Winter	420	210	190	620	250
18B	MMX Container vessel at Berth 2 on shore power	Winter	250	200	210	620	250
19A	MMX Container vessel at Berth 2 on own power and MMX Container vessel at Berth 3 on own power	Summer	740	600	600	850	620
19B	MMX Container vessel at Berth 2 on own power and MMX Container vessel at Berth 3 on shore power	Summer	580	550	610	850	620
20A	MMX Container vessel at Berth 2 on own power and MMX Container vessel at Berth 3 on own power	Winter	830	600	600	1090	630
20B	MMX Container vessel at Berth 2 on own power and MMX Container vessel at Berth 3 on shore power	Winter	610	550	610	1090	630
21A	NPX Container at Berth 1 on own power, MMX Container at Berth 2 on own power, and MMX Container at Berth 3 on own power	Summer	760	610	610	890	630

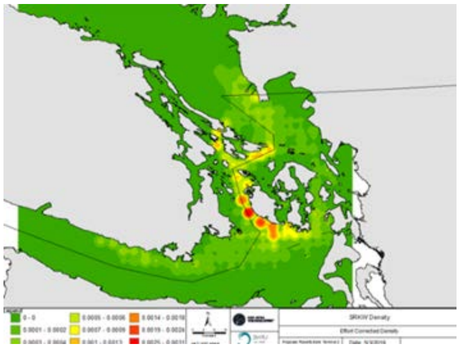
Scenario	Description	Season	120 dB SPL	129 dB SPL	137 dB SPL	20 kHz Masking	50 kHz Masking
21B	NPX Container at Berth 1 on own power, MMX Container at Berth 2 on own power, and MMX Container at Berth 3 on shore power	Summer	720	600	610	890	630
22A	NPX Container at Berth 1 on own power, MMX Container at Berth 2 on own power, and MMX Container at Berth 3 on own power	Winter	880	610	610	1170	650
22B	NPX Container at Berth 1 on own power, MMX Container at Berth 2 on own power, and one MMX Container at Berth 3 on shore power	Winter	820	600	610	1170	650

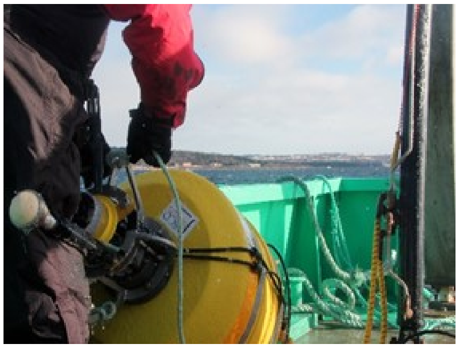
Appendix IR2020-3-D

Technical data report – Assessing effectiveness of mitigation at the terminal to reduce potential acoustic effects on Southern Resident Killer Whales from project operation

Roberts Bank Terminal 2
Project Technical Data Report

Assessing Effectiveness of Mitigation at the Terminal to Reduce Potential Acoustic Effects on Southern Resident Killer Whales from Project Operation





Prepared for:

Vancouver Fraser Port Authority
100 The Pointe, 999 Canada Place
Vancouver, BC, V6C3T4

September 16, 2021

Prepared by:

Ecofish Research Ltd.
SMRU Consulting North America
JASCO Applied Sciences Ltd.

Photographs and illustrations copyright © 2021

Coverpage photograph 1 Adapted EIS Figure 14-4

Coverpage photographs 2 and 4 credit to JASCO Applied Sciences Ltd.

Published by Ecofish Research Ltd., 600 Comox Rd., Courtenay, B.C., V9N 3P6

For inquiries contact: Technical Lead documentcontrol@ecofishresearch.com 250-334-3042

Citation:

Buren, A.D., D.J. Tollit, M. Gilbert, A. Johnson, J. Wood, K. Akaoka, H. Regehr, A. MacGillivray, Z. Li, and D. Lacroix. 2021. Roberts Bank Terminal 2 Project Technical Data Report - Assessing effectiveness of mitigation at the terminal to reduce potential acoustic effects on Southern Resident Killer Whales from project operation. Consultant's report prepared for Vancouver Fraser Port Authority by Ecofish Research Ltd., SMRU Consulting North America, and JASCO Applied Sciences Ltd. September 16, 2021.

Certification: *Certified - stamped version on file*

Senior Reviewer:

Deborah Lacroix, M.Sc., R.P.Bio. No. 2089
Senior Ecologist/Project Director
Ecofish Research Ltd.

Technical Leads:

Alejandro Buren, Ph.D.
Senior Scientist
Ecofish Research Ltd.

Dominic Tollit, Ph.D.
Principal Scientist
SMRU Consulting North America

Disclaimer:

This report was prepared by Ecofish Research Ltd. for the account of Vancouver Fraser Port Authority. The material in it reflects the best judgement of Ecofish Research Ltd. in light of the information available to it at the time of preparation. Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, is the responsibility of such third parties. Ecofish Research Ltd. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions, based on this report. This numbered report is a controlled document. Any reproductions of this report are uncontrolled and may not be the most recent revision.

EXECUTIVE SUMMARY

The Roberts Bank Terminal 2 (RBT2) Project is a proposed marine container terminal project at Roberts Bank in Delta, British Columbia (BC) within the Fraser River estuary, led by the Vancouver Fraser Port Authority (the port authority). The Project would increase the annual container capacity at the Port of Vancouver by up to 2.4 million TEUs (twenty-foot equivalent units). During operation of the terminal, container vessels will arrive and depart the terminal regularly, and while at berth, containers would be unloaded and offloaded. The Project location and adjacent waters overlap with the critical habitat of the federally endangered and provincially red-listed Southern Resident Killer Whale (SRKW, *Orcinus orca*).

The Minister of Environment and Climate Change (the Minister) requested information on mitigation measures for SRKW underwater noise (acoustic) effects and their effectiveness during Project operation. This study addressed this information request by examining the effectiveness of mitigation measures identified to reduce potential acoustic effects on SRKW from Project operation beyond what was considered by the review panel. Mitigation effectiveness was evaluated by developing and implementing an acoustic effects model that was used to simulate the interaction of SRKW presence with the acoustic footprints of vessels calling at the RBT2 terminal, and then quantifying and comparing potential acoustic effects on SRKW with and without mitigation measures implemented. The approach and mitigation measures identified and evaluated were guided by consultation with Indigenous groups, engagement with government agencies and review panel recommendations. Most of the underwater noise associated with Project operation is anticipated to be from vessel activities. We therefore focused analyses on operational acoustic effects from these activities. The mitigation measures identified and considered by the port authority since the public hearing, in response to the Minister's information request, and that are evaluated in this study, are:

- Delay the unberthing and departure of container vessels when SRKW are present;
- Reduce speed of support tugs transiting from and to the tug basin to assist the container vessel during arrival and departures;
- Provide shore power connections for container vessels when berthed at the terminal; and
- Evaluate the potential effectiveness of quiet tug technologies to reduce underwater noise associated with tug activities (e.g., electric tugs) and implement once feasible.

The first three of these mitigation measures were evaluated through an acoustic effects model that simulated potential interactions, and their consequences to SRKW, of vessels calling at the RBT2 terminal and SRKW transiting through the area, with and without mitigation implemented. The fourth mitigation measure (implementation of quiet tug technologies) was evaluated through a literature review.

To estimate potential acoustic effects on SRKW due to vessel activities during Project operation, we used updated projections of the number and class of container vessels expected to call at the RBT2 terminal in 2035, 2040, and 2045, simulated SRKW transits through the study area, and determined probabilities of spatiotemporal overlap between acoustic footprints of vessels calling at RBT2 and SRKW transits. Estimates of numbers and classes of vessels were generated for two scenarios: the most-realistic vessel scenario (on average three to four vessels calling the terminal per week or ~156 to 208 per year) and the less likely high-case vessel scenario (on average four to five vessels per week or ~208 to 260 per year) (Mercator International 2021; Appendix IR2020-3-B). The study conservatively assumed for the high-case scenario that the additional container vessels would be Mega-Max. To simulate individual SRKW transits through the study area, we synthesized monthly SRKW presence within 20 km of the proposed terminal and SRKW seasonal use of the area based on SRKW habitat use information from sightings networks compiled for the Environmental Impact Statement (EIS) that were updated to include recent data for the study area.

We next considered the predicted acoustic effect zones (zones of acoustic effects reflecting SRKW thresholds for behavioural response and echolocation click masking thresholds at two frequencies) of container vessels and support tugs during Project operation, including vessels in motion (arriving, berthing, unberthing, and departing from the terminal) and vessels at berth. We assessed potential behavioural response and echolocation click masking effects on SRKW and conservatively assumed that noise above the behavioural response and echolocation click masking thresholds will lead to cessation of feeding. We therefore quantified acoustic effects on SRKW in terms of potential lost foraging time and potential lost prey captures per SRKW. Based on a coarse estimate derived from a National Oceanic and Atmospheric Administration SRKW tagging study, the number of lost prey captures is similar to hours of potential lost foraging time. The behavioural dose-response probabilities (i.e., probability of an animal responding when exposed to noise within the acoustic effect zones) were based on studies presented in the EIS, and we also assessed the effect to SRKW if the probability of behavioural response is higher than assumed in the EIS. Mitigation effectiveness in reducing underwater noise (which reduces the vessel's acoustic footprint) was then evaluated by comparing results of the acoustic effects model (potential lost foraging time and potential lost prey captures of SRKW) with and without mitigation measures implemented. The acoustic effects model was implemented within a Monte Carlo framework, which allowed the assessment of uncertainties in predicted acoustic effects on SRKW.

No Mitigation

During Project operation, with no mitigation, the predicted annual potential lost foraging time per SRKW was 2.2 hours (0 hours – 10.5 hours) for the most-realistic vessel scenario, with small interannual variations. Under the less likely high-case vessel scenario, the predicted annual potential lost foraging time per SRKW was 3.2 hours (0 hours – 11.7 hours). These estimates are averaged across the three years modelled and combine lost foraging time caused by behavioural response and echolocation click masking. The predicted potential lost foraging time per SRKW was largely due to behavioural responses (~90%), whereas the potential lost foraging time due to echolocation click masking was minimal (~10%) for the most-realistic vessel scenario. The estimated potential lost foraging time without mitigation was essentially the same for 2040 and 2045, indicating that the results were insensitive to changes in container vessel class between those years.

Berthing and unberthing during operation was responsible for the largest amount of potential lost foraging time (each amounting to under 1 hour of potential lost foraging time per SRKW per year), followed by vessel arrival and departure (when the vessel container and vessel-assist tugs are travelling separately), whereas the potential lost foraging time predicted to be induced by the container vessel travelling with the vessel-assist tugs was much less. Vessels at berth had the smallest contribution to potential lost foraging time; ~6.8 minutes (0.1 – 31.6 minutes) per SRKW per year, even under the less likely high-case vessel scenario.

Delayed Container Vessel Unberthing and Departure

Berthing and unberthing have the largest operational acoustic footprints, primarily due to the vessel-assist tugs pushing and pulling the container vessel in place. We simulated the effectiveness of delayed unberthing at reducing predicted lost foraging time per SRKW (including deployment of vessel-assist tugs) when employing different detection methods. These methods would inform the terminal operator when to delay the unberthing and departure of a scheduled container vessel until SRKW have left the area. We evaluated three detection methods: early detection sources (visual and non-visual), marine mammal observers (MMOs), and the inclusion of a passive acoustic monitoring (PAM) system. We assumed that early detection sources and MMOs, which rely primarily on visual observations, can only be used in daytime to detect SRKW and delay unberthing and departure. Given that the acoustic effect zone associated with unberthing is smaller, the weather is typically calmer in summer, and that the probability of detecting a SRKW by early detection sources increases with increased human activity, we assumed a 75% probability of detection in summer and 25% probability of detection in winter. The probability of MMOs detecting SRKW was a function of distance from the terminal and weather conditions (~3-4 km detection range). For the PAM detection method, we assumed a 75% detection rate for a radial distance of 6 km from the RBT2 terminal.

For the most-realistic vessel scenario, the acoustic effects predicted by the model suggest that delaying daytime unberthing will reduce total potential lost foraging time from Project operation by ~15% from an estimated ~2.2 hours (95% confidence interval: 0 – 10.5 hours) to ~1.9 hours (0 – 10.1 hours) per SRKW per year if both early detection sources and MMOs are used to detect SRKW. Under the less likely high-case vessel scenario, delaying unberthing will reduce potential lost foraging time from Project operation by ~13% from an estimated ~3.2 hours (0 – 11.7 hours) to ~2.8 hours (0 – 11.2 hours) per SRKW per year when implemented with early detection and MMOs. The inclusion of a PAM system as an additional detection method to monitor SRKW during the day and at night was estimated to further reduce potential lost foraging time by an additional 17 minutes (~0.3 hour (0 – 1.1 hours)) per SRKW per year for the most-realistic case. The port authority has determined that it is not feasible to implement a PAM system for project operations in light of the substantial cost and limited reductions in overall potential acoustic effects to SRKW.

Reduce Transit Speed of Vessel-assist Tugs

Speed reductions can potentially reduce noise from transiting tugs. Vessel-assist tugs travelling at 5 knots instead of 8 knots while transiting to and from the arriving or departing container vessel could have an estimated broadband noise reduction of ~3.7 dB to 12.2 dB based on measurements made during the Enhancing Cetacean Habitat and Observation (ECHO) Program slowdown trial or acoustic studies conducted at Roberts Bank, respectively. We used the acoustic effects model (most-realistic vessel scenario) with the reduced footprints from vessel-assist tugs travelling at reduced speed of 5 knots instead of 8 knots, assuming a low mitigation effectiveness scenario (3.7 dB noise reduction) and a high mitigation effectiveness scenario (12.2 dB noise reduction), to evaluate the effect of implementing this mitigation on potential lost foraging time for SRKW. The acoustic effects model predictions suggest that reducing the speed of vessel-assist tugs would not reduce potential lost foraging time (reduction of 0.4 minutes (95% confidence interval: -0.7 – 1.6 minutes) per SRKW per year) for either the low or high noise reduction scenarios. This suggests that in some situations, vessel-assist tug slowdowns could increase potential lost foraging time. This is because even though slower tugs have a smaller acoustic footprint, the time required for slower tugs to transit back and forth from the tug basin to the container vessel is longer, thus there is a higher probability the travelling tug overlaps a transiting SRKW which would outweigh the benefit of the small acoustic footprint reduction.

Shore Power at RBT2 Terminal

Container vessels at berth can contribute underwater noise within a localized area near the terminal. The port authority is proposing to provide shore power connections at the proposed RBT2 terminal, which can reduce underwater noise of vessels at berth. One study predicts that the use of shore power reduces the localized noise contribution of vessels while at berth by about 5.8 dB (dB re 1 μPa @ 1 m). We evaluated the potential effectiveness of shore power in reducing underwater noise by comparing results of the acoustic effects model (most-realistic scenario) with and without the shore power mitigation implemented. We assumed that ~30% of vessels would use shore power while at berth (given that approximately 34% of container vessels currently calling at the Port of Vancouver have shore power capability). Modelling results indicate that this mitigation is anticipated to reduce the behavioural disturbance zone of berthed vessels from ~600 m to <550 m on average in summer and from ~750 to 600 m in winter but that it will not affect the size of the predicted zone of echolocation click masking. Although implementation of the shore power mitigation measure is predicted to reduce the acoustic footprints of vessels at berth, shore power was predicted to have minimal effect on potential lost foraging time. Results from the acoustic effects model predicted that the effectiveness of this measure on potential lost foraging time is likely to be small (a reduction of less than one minute of potential lost foraging time per SRKW per year) because little overlap is anticipated between the behavioural response acoustic footprints of vessels at berth and transiting SRKW.

Quiet Tug Technology

We conducted a literature review of the potential noise reduction from tugs with quieting technologies (e.g., electric or hybrid-electric engines) to reduce underwater noise associated with berthing and unberthing activities and transiting back and forth to meet container vessels. When considering the effectiveness of quiet tug technology, cavitation is often the dominant noise source for tugs, and therefore the effectiveness of noise reduction from hybrid or electric engines can be overshadowed by propeller noise. However, implementation of technologies that reduce underwater noise associated with tug activities is anticipated to reduce acoustic effects on SRKW from Project operation. Published information on noise reduction benefits is currently limited but findings from the literature review suggest that potential noise reductions (~5 dB to 25 dB) could be equal to or greater than that of slower tugs in transit. In addition, there are other tug design measures that could further reduce underwater noise, such as propeller noise reduction through propeller design. At this time, there is insufficient information to quantify the effectiveness and estimate the potential reduction in acoustic effects to SRKW. It is likely that tugs with quiet vessel notations (a quiet vessel notation from a ship classification society) will be available in the future and are likely to reduce underwater noise generated from Project operation. The port authority has proposed to monitor ongoing advancements in quiet tug technology and to implement feasible measures in the future to further reduce underwater noise associated with Project operation.

Uncertainty in SRKW's Response to Underwater Noise

We evaluated the sensitivity of estimates of potential lost foraging time to uncertainties in the severity of behavioural responses to underwater noise from vessels in motion using conservative probabilities that SRKW will cease feeding when exposed to noise within each acoustic effect zone. We examined vessels in motion (arrival, berthing, unberthing, and departure) as these activities were associated with most of the lost foraging time (95%). Instead of using the median (50th percentile) dose-response probability of response coefficient, we used the 97.5th percentile (or upper confidence interval) to generate an upper bound estimate of behavioural response effects to SRKW. With the application of the conservative behavioural response coefficient values, estimates increased on average by ~26% in each year compared to using the median probability of response coefficients. The use of the conservative behavioural response coefficient values resulted in mean potential lost foraging time of 2.6 hours per SRKW per year (95% confidence interval: 0 – 12.1 hours) for vessels in motion with no mitigation and 2.2 hours per SRKW per year (0 – 11.6 hours) with delayed unberthing with the use of early detection and MMOs. Our approach in evaluating sensitivity of the estimates addresses uncertainties in the definition of the behavioural response dose-response curve, and our results imply that if we assumed that SRKW exhibit a higher probability of disturbance when exposed to underwater noise, then the estimate of potential lost foraging time due to Project operation would be less than 3 hours per SRKW per year for vessels in motion under the most-likely vessel scenario.

Conclusion

This study assessed the effectiveness of potential mitigation measures in reducing potential acoustic effects to SRKW from Project operation. Key study results indicate that:

- Prior to mitigation, the effects of underwater noise from vessel activities during arrival, berthing, unberthing, departure, and vessels at berth are anticipated to be ~2.2 hours (0 – 10.5 hours) of potential lost foraging time per SRKW per year for the most-realistic vessel scenario and 3.2 hours (0 – 11.7 hours) for the less likely high-case vessel scenario.

- Delayed unberthing reduced potential lost foraging time from Project operation by 15% (from ~2.2 hours (95% confidence interval: 0 – 10.5 hours) to ~1.9 hours (0 – 10.1 hours)) per SRKW per year when assuming both early detection sources and MMOs are used for the most-realistic vessel scenario. For the high-case vessel scenario, delayed unberthing reduced potential lost foraging time by ~13% (from ~3.2 hours (0 – 11.7 hours) to ~2.8 hours (0 – 11.2 hours)) when assuming both early detection sources and MMOs are used.

- Vessel-assist tugs transiting slower to and from a container vessel and the tug basin would not reduce potential lost foraging time.

- Shore power could reduce the distance to the SRKW behavioural disturbance thresholds by ~50-150 m depending on the season but not the predicted zone of echolocation click masking. The effectiveness of implementing this measure is predicted to be small (a reduction of less than one minute of potential lost foraging time per SRKW per year) because little overlap is anticipated between the behavioural response acoustic footprints of vessels at berth and transiting SRKW.

- Developments in quiet tug technology could further reduce underwater noise in the future but there was insufficient information to quantify the potential reduction in acoustic effects to SRKW at this time.

- The port authority's proposed measures of delayed unberthing and providing shore power connections is anticipated to reduce the overall potential lost foraging time from both vessels at berth and vessels in motion by ~16%, from 2.2 hours (0 – 10.5 hours) to 1.8 hours (0 – 10.0 hours) per SRKW per year under the most-likely vessel scenario (if early detection sources and MMOs industry standard protocols are used). For the high-case vessel scenario, the implementation of these mitigation measures would reduce potential lost foraging time by ~13% from 3.2 hours (0 – 11.7 hours) to 2.7 hours (0 – 11.2 hours).

The updated estimates of acoustic effects of Project operation on SRKW are based on finer scale representation of potential interactions between operational noise from vessels and SRKW in the study area compared to the EIS and are based on the updated vessel projections including a less likely high-case scenario (i.e., 260 container vessels calling RBT2 per year). Therefore, the confidence in the findings is increased relative to information previously presented at the public hearing. With the mitigation measures at the terminal proposed by the port authority since the public hearing, the potential acoustic effects to SRKW predicted from vessel activities during Project operation will be further reduced.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF MAPS

LIST OF APPENDICES

1. INTRODUCTION

The Roberts Bank Terminal 2 (RBT2) Project (hereafter, the Project) is a proposed marine container terminal project at Roberts Bank in Delta, British Columbia (BC) within the Fraser River estuary, led by the Vancouver Fraser Port Authority (port authority) (Map 1). The Project would increase the annual container capacity at the Port of Vancouver by up to 2.4 million TEUs (twenty-foot equivalent units). Terminal operation is anticipated to commence soon after construction is complete with the regular arrival and departure of container vessels to RBT2. Operational capacity will progressively increase to the terminal's intended capacity (projected to be reached by 2040), with throughput capacity ramping up and reaching terminal operating capacity by 2040.

The Project location and adjacent waters are used by several marine mammal species and overlap with the critical habitat of the federally endangered and provincially red-listed Southern Resident Killer Whale (SRKW, *Orcinus orca*) (Map 2). The recovery strategy for SRKW (DFO 2018) describes the critical habitat and associated functions, features, and attributes necessary for the survival and recovery of the species, which are legally protected. When present, SRKW are believed to use the critical habitat near the proposed Project primarily for the critical habitat function of feeding and foraging. The features of this function consist of availability of prey species (e.g., Chinook Salmon), acoustic environment, water quality, and physical space (DFO 2018). The recovery strategy describes the attributes associated with these features as:

- Prey availability: sufficient quantity, quality, and diversity of salmon to provide for profitable foraging;
- Acoustic environment: anthropogenic noise level that does not interfere with life functions; acoustic environment allows effective acoustic social signaling and echolocation of prey and does not result in loss of habitat availability or function;
- Water quality: sufficient to support SRKW prey species (e.g., Chinook Salmon, Chum Salmon, and other fish species); and
- Physical space: providing unimpeded physical space surrounding individual whales (DFO 2018).

The Project is subject to an environmental assessment by a review panel pursuant to the *Canadian Environmental Assessment Act, 2012*. Fisheries and Oceans Canada (DFO), during the environmental assessment process, acknowledged that a key potential effect on SRKW would be Project-related increases in underwater noise that could affect SRKW by causing behavioural effects (including potential displacement from, or avoidance of, a portion of their critical habitat) and acoustic masking of echolocation clicks used for feeding or communication calls (DFO 2017). In 2019, DFO made recommendations associated with the evaluation of Project-related changes in the acoustic environment for SRKW. One recommendation stated, "*To estimate the effects of acoustic disturbance to SRKW critical habitat associated with construction and operation of the project, areas of high SRKW use and model* *noise maps should be used to estimate the area that will be, at least temporarily, degraded by acoustic disturbance during construction and operation of the project.*" (Recommendation 26, DFO 2019). DFO also recommended the continued evaluation of mitigation measures for Project operation and supporting modelling to assess their efficacy (Recommendation 23, DFO 2019).

In a letter received on August 24, 2020, the Minister of Environment and Climate Change (the Minister) requested information regarding mitigation measures for Project operation (MECC 2020). As part of this request, the port authority was asked to provide a mitigation plan addressing potential acoustic effects to SRKW from underwater noise due to operational activities. Guided by consultation with Indigenous groups, engagement with government agencies, and recommendations made by the review panel (The Review Panel for the Roberts Bank Terminal 2 Project 2020), the port authority identified mitigation measures at the terminal anticipated to further reduce impacts to SRKW from underwater noise during Project operation that were additional to those identified in the review panel's report. These mitigation measures were directed at vessel activities, the arrival, berthing, unberthing, departure, and vessels at berth. Based on clarification provided by the Impact Assessment Agency of Canada (IAAC), the effectiveness and feasibility of mitigation measures identified since the public hearing were to be assessed. The mitigation measures assessed in this study are:

- Delayed Unberthing: Delay the unberthing and departure of container vessels when SRKW are present;
- Reduced Tug Transit Speed: Reduce speed of support tugs transiting from and to the tug basin to assist the container vessel during arrival and departure;
- Shore Power Connections: Provide shore power connections for container vessels when berthed at the terminal; and
- Quiet Tug Technology: Evaluate the potential effectiveness of quiet tug technologies to reduce underwater noise associated with tug activities (e.g., electric tugs) and implement once feasible.

This study was conducted to assess the predicted effectiveness of these four potential mitigation measures to avoid or reduce acoustic effects on SRKW from Project operation. The effectiveness of three of the four mitigation measures (delayed unberthing, reduced tug transit speed, and shore power connections) was quantitatively evaluated by developing an acoustic effects model that incorporated key factors in the interaction between underwater noise from operational vessel activities and the seasonal presence of SRKW. The fourth mitigation measure, quiet tug technology, was assessed qualitatively based on results of a literature review.

Projections of numbers of container vessels calling at RBT2 annually were a key assumption in the assessment of acoustic effects on SRKW and in the evaluation of mitigation measures. This study used the most recent forecasted container vessel projections made by Mercator International (2021; Appendix IR2020-3-B). These projections were based on trends in the shipping lines, services, and container demand that indicate that the number of container vessels calling at the

Port of Vancouver would be the same with or without the RBT2 project (Mercator International 2018, 2021). The most recent forecast, provided since the public hearing, projects that a total of 156 container vessels (on average three vessels per week) would call at RBT2 annually in 2035 (during the initial phase of operation), and that this would increase to 208 by 2040 and 2045 (on average four vessels per week), with larger container vessel classes calling at RBT2 over this time period (Mercator International 2021). These projections were used for modelling in this study as the "most-realistic" vessel scenario. To provide additional conservatism, a less likely "high-case" container vessel traffic scenario was also modelled. The high-case vessel scenario for Project operation assumed the proposed RBT2 Project could accommodate one additional Mega-Max container vessel per week for 2035, 2040, and 2045 (52 additional container vessels per year or on average four to five vessels per week; ~208 to 260 per year) beyond that considered by the most-realistic scenario.

1.1. Objectives

The purpose of this study is to evaluate the effectiveness of potential mitigation measures at the terminal identified since the public hearing (i.e., measures that were not considered by the review panel) for avoiding or reducing acoustic effects to SRKW from Project operation in support of the response to the Minister's information request (MECC 2020). Specifically, the objectives of the study are to:

- Quantify predicted acoustic effects from vessel activities during Project operation on SRKW, with updated sizes of acoustic effect zones (zones of effect defined in relation to SRKW disturbance thresholds) from vessel activities based on container vessel call numbers and container vessel class composition for three projection years (i.e., 2035, 2040, and 2045) under the most-realistic and high-case vessel scenarios (as per Mercator International 2021), as well as on expected spatial and temporal variations in SRKW use;
- Where possible (i.e., for all mitigation measures except quiet tug technology), quantify the effectiveness of proposed mitigation measures on SRKW during Project operation; and
- Quantify uncertainties in predicted acoustic effects on SRKW through revised methodology that allows evaluation of differences in acoustic effects by incorporating uncertainties in acoustic effect assumptions. This allows the estimation of an upper bound of expected acoustic effects on SRKW.

In addition, to inform an evaluation of feasibility of the proposed delayed unberthing mitigation measure, the frequency of anticipated operational delays that would result from this mitigation measure was calculated.

The subsequent sections present the methods applied to evaluate potential acoustic effects of key underwater noise generating activities during Project operation on SRKW and the effectiveness of mitigation measures considered, the results of this evaluation, and a brief discussion of the key findings that will support the development of effective mitigation measures to reduce acoustic effects to SRKW from Project operation, if the Project is approved.

2. METHODS

We developed and used an analytical modelling approach to quantify the potential acoustic effects on SRKW from Project operation and to assess the effectiveness of three of the four mitigation measures (delayed unberthing, reduced tug transit speed, and shore power connections) identified since the RBT2 public hearing, while accounting for uncertainties in the estimates. The approach also considered the federal review panel recommendations, DFO's comments provided in support of the public hearing, and clarifications provided by IAAC on the Minister's information request (MECC 2020). Mitigation related to quiet tug technologies, which are in early stages of design and development, were assessed through a literature review. This section describes the approaches taken and data used to quantify acoustic effects and evaluate the effectiveness of these mitigation measures to avoid or reduce acoustic effects to SRKW from Project operation.

The simulation modelling approach involved predicting the probability of an interaction (overlap in space and time) between SRKW and the underwater acoustic footprints of vessels calling at RBT2, estimating the consequences of such interactions for SRKW (acoustic effects on SRKW), and quantifying the extent to which the proposed mitigation measures can reduce acoustic effects on SRKW. In developing the modelling approach, we therefore considered the following:

- The fine-scale spatiotemporal use of the study area by SRKW;
- The means by which, and extent to which, noise can affect SRKW (e.g., behavioural disturbance, echolocation click masking, and communication masking); and
- Acoustic footprints of key vessel noise generating activities during operation in relation to SRKW acoustic thresholds (acoustic effect zones).

The approach used in this study provides an estimate of potential effects per SRKW for three future years of Project operation (2035, 2040, and 2045), reflecting projections of container vessel numbers and sizes (i.e., size class composition) anticipated to call at the terminal (Mercator International 2021). The acoustic effects model was developed to consider and reflect the areas of high SRKW use that would be degraded acoustically during Project operation (Recommendation #26, DFO 2019) and to allow comparison among different future container vessel scenarios. We also partitioned effects by vessel activity to assess the effectiveness of different mitigation measures. For example, predicted effects were considered for vessel operational stages including vessels in motion (arrival, berthing, unberthing, departure) and vessels at berth, and scenarios without mitigation implemented were directly compared to scenarios with mitigation implemented. For this study, the area of interest was defined as the area within a 20 km radius of the proposed RBT2 terminal (hereafter referred to as the study area) (Map 1).

The acoustic effects model first simulated SRKW transits through the study area and vessels arriving at and departing from RBT2, along with their acoustic footprints (which differ by vessel class, vessel speed, and season (summer and winter)), thereby simulating probabilities of overlap between SRKW transits through the area and vessel operation. The number of SRKW transits per month (described in Section 2.1.1), and the distance from the proposed RBT2 terminal at which they are expected to occur (described in Section 2.1.3), were estimated using SRKW habitat use information from sightings networks compiled for the EIS that were updated to include recent data for the study area. Expected number and class of container vessels calling at the proposed RBT2 terminal were obtained from Mercator International (2021) (described in Section 2.4.1), and acoustic footprints for key vessel noise generating activities during arrival, berthing, unberthing, and departure, and from vessels at berth were obtained from MacGillivray *et al.* (2019, 2021) (described in Section 2.4.2). Based on these data, the probabilities of spatial overlap between SRKW transits and the acoustic footprints of vessels calling at RBT2 (i.e., they co-occur on the same day and at the same time, as well as overlap in space) were simulated by the model 10,000 times, incorporating variability into key input parameters to derive values of model outputs and uncertainty levels.

The next step in the modelling process was to predict the consequences (acoustic effects) to SRKW of any simulated overlap between SRKW presence and vessel acoustic footprints. This required generating "acoustic effect zones" for each vessel activity which could be intersected by a SRKW transit. Acoustic effect zones for vessel noise were defined by combining globally recognized received level acoustic disturbance thresholds with behavioural response and click masking thresholds developed specifically for continuous noise effects on SRKW (described in Section 2.2). The noise exposure time was translated into a measure of cost to SRKW (potential lost foraging time and lost prey captures) in relation to the severity of noise exposure within each acoustic effect zone. Thus, in cases where there was overlap between simulated SRKW transits and vessel acoustic effect zones, we calculated the length of time that SRKW were exposed to underwater noise from vessel operation, and then converted this to SRKW potential lost foraging time (Section 2.3). We used the dose response approach developed for the EIS (SMRU 2014a), which assumes a higher probability of response when noise levels are higher. We also estimated lost prey captures (i.e., salmon) per SRKW that may be missed due to lost foraging time, using recent SRKW tagging data that estimates prey capture rates per hour of foraging (Section 2.3.1).

The effectiveness of mitigation measures in reducing the cost to SRKW were then evaluated by comparing the results of model scenarios (i.e., potential lost foraging time and lost prey captures) with and without mitigation measures implemented (Section 2.5).

Finally, we evaluated uncertainties in severity of behavioural responses (Section 2.6) by applying more conservative behavioural dose-response coefficients (i.e., by considering the case where SRKW exhibit a higher probability of disturbance than the mean). The following sections describe each of these steps in more detail.

2.1. SRKW Transits

To meet the described objectives (Section 1.1), the study considered recent and higher spatiotemporal resolution data on SRKW presence in the study area, incorporating more current sightings network data than were used for the EIS (the EIS used data to 2011). As described in more detail in the sub-sections below, the SRKW habitat use information considered for the study includes three key components: the anticipated number of monthly transits by SRKW through the study area, the pod size for each transit, and the closest point of approach to the Project.

2.1.1. Anticipated Monthly SRKW Transits

We compiled SRKW sightings between 2002 and 2017 from the B.C. Cetacean Sightings Network (BCCSN, for Canada) and Orca Master (OM, for the United States of America) sightings databases to update density data following the approach from Hemmera and SMRU (2014). The mean number of days SRKW were sighted per month within the study area (Map 3) were accumulated across the 16-year dataset (n=3572; Table 1). We applied two correction coefficients to address seasonal and time of day differences in observer effort, given that data from sightings networks are largely collected during summer and during daylight hours. Using sightings effort information from Hemmera and SMRU (2014), information from ongoing area use studies, and expert opinion, a seasonal correction factor of 1.2 was applied for May to October, and a winter correction of 4.0 was applied between November and April (reflecting both poor winter weather and lower recreational boat activity). Secondly, we estimated a time-of-day correction factor based on passive acoustic monitoring (PAM) undertaken by the port authority near the proposed Project in 2012 and 2013 (SMRU 2014b). These PAM data were reviewed to provide a correction coefficient of 1.3 to represent the number of additional days that night-time transits likely occurred.

Following these corrections, it was estimated that SRKW transit the area on ~70 days in summer (May to October) and ~19 days in winter (November to April), for a total of ~89 transits per year (Table 1). Peak transit months were identified as June to August, which both had a mean estimate of ~14 to 17 transits per month, followed by April and September which both had a mean of ~11 estimated transits per month (Table 1, Figure 1). The June to August period captured over 50% of SRKW visits to the area. Between year variability was highest in months with high number of transits (i.e., June to August). This long-term dataset had an estimated total of 89 annual transits that was conservatively used for this study, recognizing that effort-correcting of opportunistic sightings data is an evolving science (Harvey *et al.* 2018, Olson *et al.* 2018, Watson *et al.* 2019). The number of monthly transits used in the modelling approach were randomly drawn from normal distributions based on these data as described in Section 2.4.3.

Information recently published by DFO (2021) shows a high likelihood of SRKW presence at Roberts Bank in September, which focused on whale watching data from May to October 2009-2018. Similarly, when considering trends from recent years (2009-2017), the comprehensive sightings dataset used for this study identifies June 1 to September 30 as the peak use period for SRKW at Roberts Bank (Figure 2).

Table 1. **Monthly SRKW sightings in the study area (20 km of the proposed RBT2 terminal) and sightings corrected for estimated seasonal effort and night-time transit. SRKW sightings were compiled from the B.C. Cetacean Sightings Network (BCCSN, for Canada) and Orca Master (OM, for the United States of America) for the period between 2002 and 2017.**

Month	Mean whale days (sightings)	Std. Dev. whale days	Mean whale days (sightings) with effort correction	Mean total whale days with effort and night-time
January	0.5	0.6	2.0	2.6
February	0.2	0.4	0.8	1.0
March	0.4	0.5	1.5	2.0
April	2.1	1.8	8.3	10.8
May	5.3	2.5	6.3	8.2
June	10.3	4.6	12.1	15.9
July	11.2	5.2	13.2	17.2
August	9.3	5.3	11.0	14.4
September	6.9	3.1	8.2	10.7
October	2.3	1.7	2.6	3.5
November	0.3	0.4	1.0	1.3
December	0.3	0.5	1.3	1.6
Summer	45.3	-	53.3	69.8
Winter	3.7	-	14.8	19.3
Total	49	-	68.1	89.2

Figure 1. **Average monthly SRKW sightings from 2002 to 2017 corrected for seasonal effort and night-time transits, within the study area (20 km of the proposed RBT2 terminal), showing SRKW peak use from June to August. Original, uncorrected data were compiled from the B.C. Cetacean Sightings Network (BCCSN, for Canada) and Orca Master (OM, for the United States of America).**

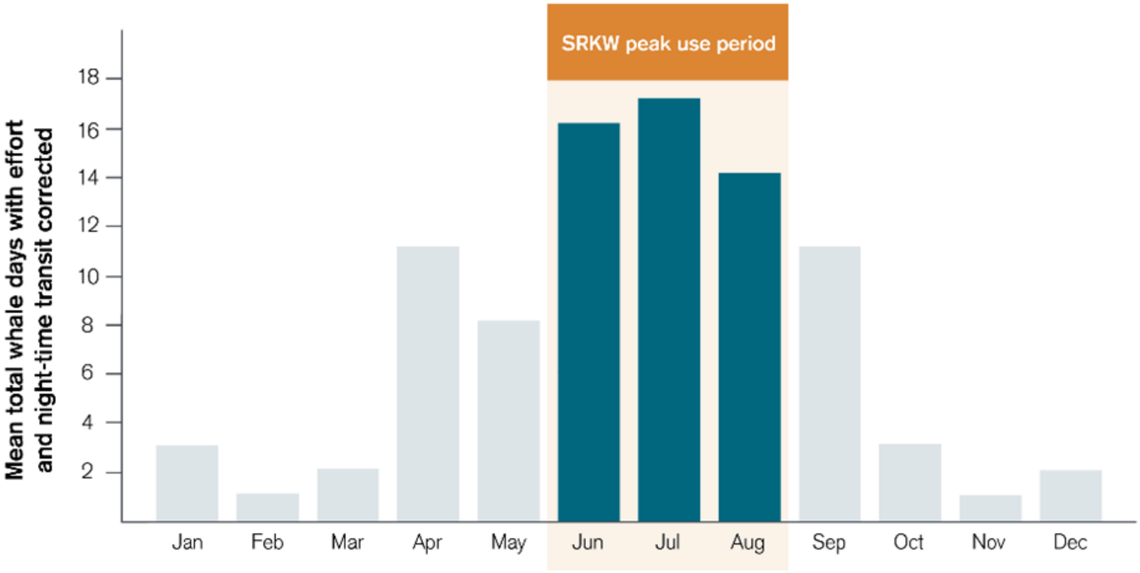
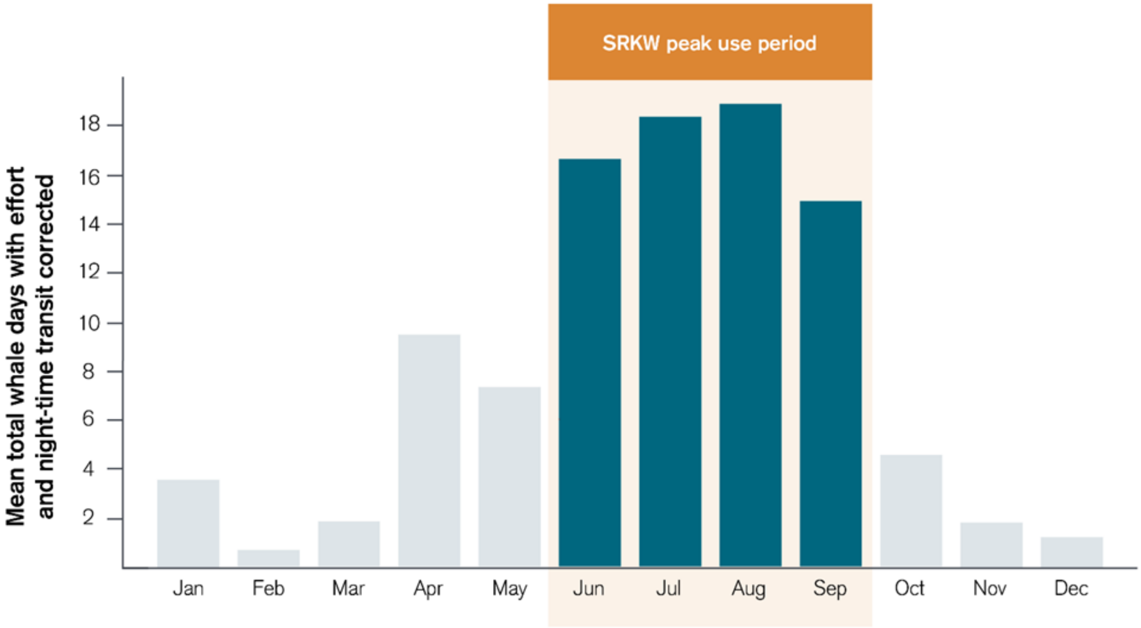


Figure 2. **Average monthly SRKW sightings from 2009 to 2017 corrected for seasonal effort and night-time transit, within the study area (20 km of the proposed RBT2 terminal), showing SRKW peak use from June to September. Original, uncorrected data were compiled from the B.C. Cetacean Sightings Network (BCCSN, for Canada) and Orca Master (OM, for the United States of America).**



2.1.2. Anticipated SRKW Pod Size Per Transits

The compiled SRKW sightings for 2002 to 2017 were reviewed to determine how different pods or pod assemblages used the study area. The SRKW population includes three separate pods (named J, K, and L), which sometimes transit together and form pod assemblages. Table 2 provides a breakdown for each pod or assemblage, noting that for some sightings there was no pod or assemblage identification provided and these have been categorized as 'SRKW'. To estimate the number of individuals within each pod assemblage, we followed the methods described in Hemmera and SMRU (2014), modified to account for pod population changes that have occurred since submission of the EIS (CWR 2020). In summary, pod assemblage estimates were based on numbers recorded during sightings, recognizing that matrilines do not always travel together (notably L-pod), and that one member of L-pod typically travels with J-pod. For the JK and JKL pod assemblages, which had clear bimodal peaks in size, the midpoint between the two peaks of each distribution was retained as the group size. For all other pod assemblages, the mode of group size for each pod assemblage was retained.

As expected, based on historical information, J-pod dominated the sightings year-round in the study area (36.40% and 59.30% of sightings during the summer and winter, respectively, with a pod or assemblage size of 23 individuals; Table 2).

Table 2. Seasonal occurrence and size of various pods or assemblages based on sightings. Unknown pod or assemblage sightings were identified only as "SRKW". SRKW sightings were compiled from the B.C. Cetacean Sightings Network (BCCSN, for Canada) and Orca Master (OM, for the United States of America) for the period between 2002 and 2017.

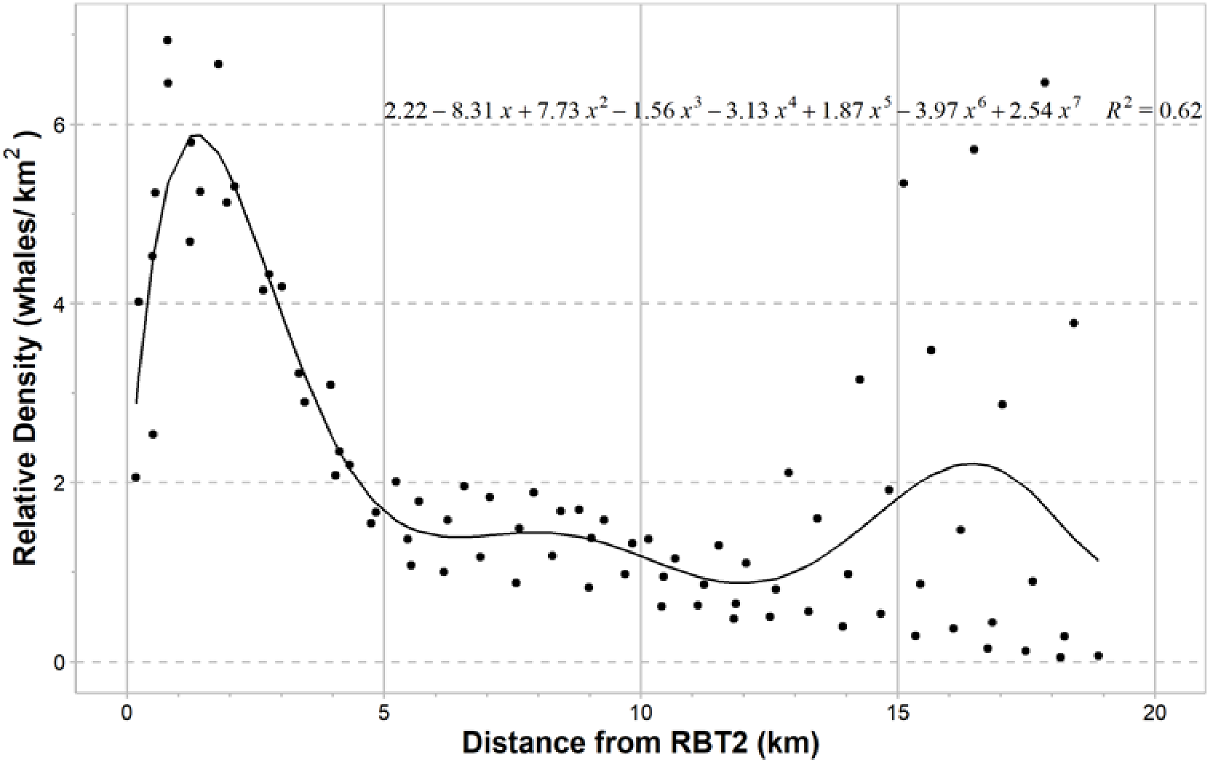
Pod assemblage	Summer (May-Oct) breakdown	Winter (Nov-Apr) breakdown	# of individuals (2019) per pod or pod assemblage[1]
J	36.40%	59.30%	23
JK	16.60%	16.90%	32
JKL	26.20%	6.80%	61
JL	9.20%	3.40%	35
K	2.50%	0.00%	19
KL	0.00%	0.00%	26
L	1.20%	1.70%	17
SRKW	7.90%	11.90%	23

[1] Number of individuals based on 2019 population estimates from the Center for Whale Research (https://www.whaleresearch.com/orca-population)

2.1.3. Anticipated Closest Point of Approach for SRKW Transits

The closest point of approach (CPA) of SRKW transits to the Project was estimated as the perpendicular distance between the SRKW transits and the berth face of the proposed RBT2 terminal. The effort-corrected 2002-2017 sightings database (described in Section 2.1.1) was first used to develop a relative SRKW summer density estimate for the study area. Then, an approximately 2 kilometre (km)-wide polygon strip from the RBT2 terminal berth face was projected onto the relative density map (Map 3). All 1 km grid squares within the polygon strip were accumulated based on distance from the RBT2 terminal and plotted to develop a polynomial relationship between distance from the terminal and SRKW density to estimate the CPA of SRKW transits (Figure 3). The relationship has an R-Squared value of 0.62 and shows that most SRKW transits occur between 0 to 4 km from the terminal berth face, with a peak at approximately 1.5 km. After a decline mid-channel, coinciding with the international shipping lanes, a second smaller peak occurs at approximately 16 to 17 km from the RBT2 terminal. This is thought to be associated with movement of SRKW in and out of Active Pass (Map 3). We assumed all SRKW transits occur parallel to the terminal berth face (i.e., SRKW move up and down the coastline, which is supported by sightings in Map 3).

Figure 3. **Relationship between SRKW relative density and distance from the berth face of the RBT2 terminal. SRKW sightings were compiled from the B.C. Cetacean Sightings Network (BCCSN, for Canada) and Orca Master (OM, for the United States of America) for the period between 2002 and 2017.**



2.2. Acoustic Effects on SRKW

Marine mammals use sound to obtain information on their environment and locate prey. Underwater noise from anthropogenic sources can have a broad range of effects on marine mammals including: acoustic injury (loss of hearing sensitivity), behavioural changes such as displacement from important habitat, induced stress responses, and acoustic masking (i.e., interference with an individual's ability to detect, recognize, and (or) discriminate sounds used for foraging (i.e., echolocation click masking), conspecific communications (i.e., communication masking), navigation, and predator/hazard avoidance) (Richardson *et al.* 1995, Nowacek *et al.* 2007, Southall *et al.* 2007, Weilgart 2007, Wright *et al.* 2007, André *et al.* 2009, Rolland *et al.* 2012, Ketten 2014, Erbe *et al.* 2015, NMFS 2015, Gomez *et al.* 2016). The types and ranges of acoustic effects are highly dependent on the characteristics of the sound source, the environment in which the sound occurs, context, and the species receiving the sounds (Richardson *et al.* 1995, Southall *et al.* 2019).

RBT2 operation is not expected to cause any acoustic injury to SRKW. JASCO Applied Sciences previously investigated whether exposure to continuous noise from large commercial vessels transiting past a stationary Killer Whale could cause acoustic injury and concluded that sound levels were insufficient to reach the acoustic injury threshold, regardless of distance from the vessel (Li and MacGillivray 2014). Thus, this study focuses on potential behavioural changes and acoustic masking from continuous noise exposure from vessels during Project operation on SRKW.

The Minister requested that the port authority assess total masking of SRKW's echolocation and provide more information on avoidance and other mitigation measures to address acoustic effects such as behavioural disturbance, and echolocation and communication masking (MECC 2020). The Minister also requested that the findings from Gomez *et al.* (2016) be considered in updated behavioural response assessments (MECC 2020). For the EIS, the assessment of potential acoustic effects on SRKW considered potential behavioural disturbance and additional echolocation click masking at 50 kHz (i.e., if there was no behavioural disturbance predicted from Project-related underwater noise) (SMRU 2014c). DFO considered this assessment approach as appropriate and using the best available science (DFO 2019). Triggering a behavioural response was assumed to temporarily inhibit a Killer Whales' ability to forage (e.g., changing from foraging to traveling, Lusseau *et al.* 2009), and that this response to broadband noise includes the equivalent of complete masking (either of echolocation clicks or communication calls and whistles). In the following sections, we present some of the elements incorporated into the acoustic effects model developed to address the Minister's request, i.e., the noise exposure criteria used to assess behavioural response and echolocation click masking and discuss potential communication masking in relation to mitigation effectiveness.

2.2.1. Behavioural Response

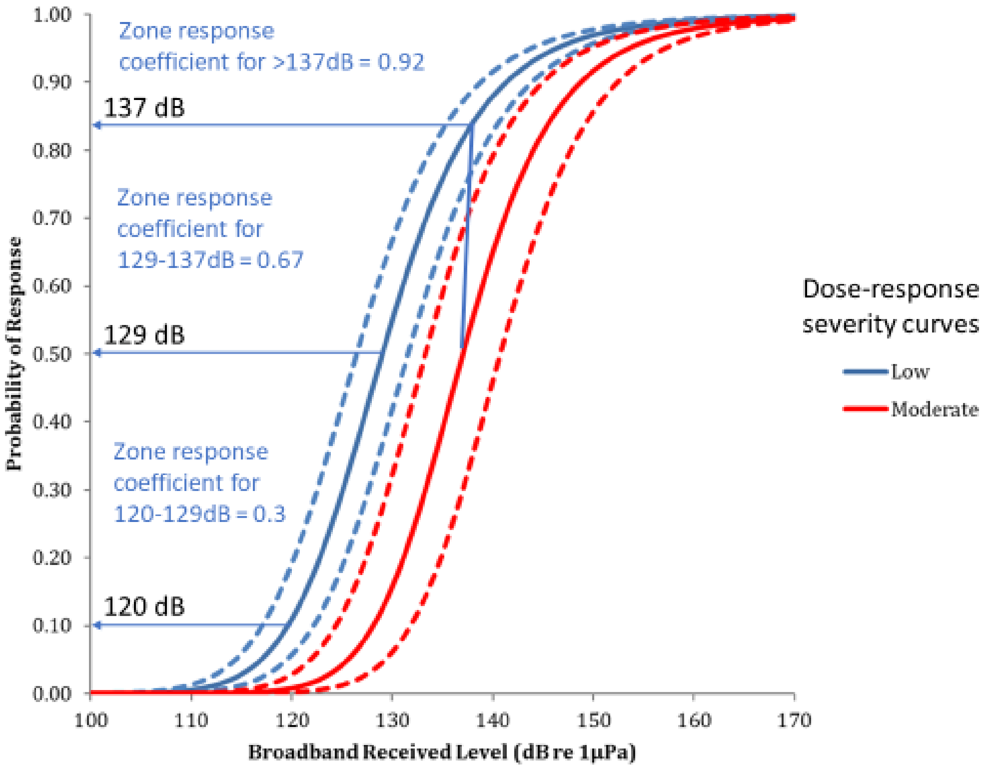
Noise exposure can elicit changes in marine mammal behaviour. Potential behavioural reactions are varied and have differing potential biological significance. We quantified the effects of behavioural responses assuming that these would lead to cessation of feeding, and therefore we chose to quantify the effects in terms of potential lost foraging time and potential lost prey captures (see Section 2.3 and Section 2.3.1, respectively).

For this study, we used SRKW-specific behavioural response thresholds to define relevant acoustic effects zones where SRKW could respond to the operational noise by potentially ceasing to forage. We used the National Oceanic and Atmospheric Administration (NOAA) behavioural disturbance threshold of 120 dB re 1 μPa (broadband, unweighted, root-mean-square (rms)) for continuous noise (NOAA 2019), which was also assessed in the EIS (SMRU 2014a). This threshold has consistently been used in noise impact studies for marine mammals both globally (e.g., Xodus Group Ltd. 2015, US Government 2020) and in Canada (often following DFO reference and guidance).

The EIS and this study also considered the concerns highlighted by Gomez *et al.* (2016) regarding behavioural response thresholds. The authors cautioned on the use of single thresholds to represent a wide range of marine mammal species and recommended the optimal use of species- and stressor-specific disturbance thresholds (that incorporate both surface behaviour and vocal behaviour), and that other contextual factors such as previous exposure experience, proximity, and demographic group should ideally be considered. The approach used for the EIS addressed the most important contextual factors identified by Gomez *et al.* (2016) in defining newly developed SRKW specific dual dose-response (i.e., for low and moderate severity responses) behavioural response thresholds (SMRU 2014a), which were described as 'superior' by DFO (2017). The EIS approach appropriately defined noise exposure thresholds by using behavioural response data for an appropriate noise source (vessel noise) and for the species in question (i.e., resident Killer Whale) (Buren and Tollit 2021, i.e., Appendix IR2020-3-H). Further, the EIS approach considered previous exposure experience of Killer Whales to the noise source and used both surface and acoustic observations with a range of proximities and demographic groupings. Notably, the 120 dB re 1 µPa behavioural disturbance threshold was well supported by the EIS dual dose-response approach for resident Killer Whales, as it represented the 10% probability of low behavioural responses and 1% probability of moderate behavioural responses (SMRU 2014a; Figure 4).

To further evaluate how pertinent a 120 dB re 1 µPa (unweighted, rms) behavioural response threshold for continuous noise (i.e., stressor-specific) is to SRKW (i.e., as a species-specific behavioural disturbance threshold), we reviewed the meta-data from various studies presented by Gomez *et al.* (2016) for continuous noise effects on mid-frequency cetaceans, which include Killer Whales. The authors reported that low and moderate severity behavioural responses peaked at thresholds between ~125-135 dB re 1 µPa (broadband, unweighted). Higher severity startle responses were documented at lower thresholds, but on review were found to be avoidance responses in acoustically naïve belugas in the Arctic (Southall *et al.* 2007), which highlights the contextual importance of using appropriate response data. Williams *et al.* (2014) modelled behavioural responses of Killer Whales to vessel transits during 35 "natural experiments" as a dose–response function of estimated received noise levels and observed subtle responses (50% probability) around broadband received levels of 130 dB re 1 µPa (unweighted, rms). The Killer Whale specific dual dose-response thresholds developed for the EIS (SMRU 2014a) had 50% probability of moderate and low behavioural response at broadband received levels of 137 and 129 dB re 1 µPa (unweighted, rms), respectively. More generally, a review of noise effects found sounds at received levels of 120 dB re 1 µPa typically disrupt the behaviour of 50% of exposed cetaceans (Richardson *et al.* 1995). This evaluation supports the use in this study of a 120 dB as a precautionary cut-off threshold to predict behavioural responses in resident Killer Whales to continuous noise sources, noting that beyond this acoustic effect zone this study now also assesses echolocation click masking using conservative thresholds at two Killer Whale relevant frequencies, the inclusion of which is considered a novel advancement, compared to traditional noise effect assessments. Mean response probabilities for the behavioural response acoustic effect zones used in this study were derived using the low severity curve (Figure 4) using 120, 129, and 137 dB as thresholds (see Section 2.2.4 for details). Note that mean probability of response coefficients are referred to as the "Mid-point" (i.e., 50th percentile or median) coefficients (which contrast with "Upper Confidence Interval" coefficients used for assessing uncertainty that are based on the more conservative dashed blue 95% confidence interval line to the left of the Figure 3 plot; see Section 2.6). This is discussed further in Section 2.2.4.

Figure 4. Dose-response behavioural response probabilities used to derive potential lost foraging time zone coefficients associated with 120, 129, and 137 dB acoustic effect zones. Dashed lines are 95% confidence intervals. The arrows indicate how the coefficients for the Mid-point coefficients were derived using probabilities based on the low severity curve. A similar approach was implemented to derive coefficients for the Upper Confidence Interval, using the dashed blue line to the left of the plot, as subsequently used in an uncertainty analysis.



2.2.2. Communication Masking

Acoustic masking (i.e., interference) occurs when the ability to detect or recognize a sound of interest is degraded by the presence of another sound. Masking can affect a whale's ability to effectively communicate (i.e., communication masking), navigate and orient spatially, and detect prey, predators, and conspecifics (Clark *et al.* 2009).

Based on clarification received from IAAC in relation to the Minister's information request, our updated approaches do not include a specific communication masking assessment across 0.5-15 kHz. Communication masking is complex, and no standardized methods have been developed to assess effects and potential consequences. However, communication masking is inherently incorporated into this assessment through the use of a broadband 120 dB acoustic effect threshold (frequency range 0.01-64 kHz) used to define acoustic effect zones. It is expected that, within the 120 dB noise footprint of effect assessed here (which can range over several kilometers depending on the sound source), the most significant effects of communication masking on Killer Whales have also been captured (especially for the more frequent short-range communication within pods), noting both the transient nature of container vessel transits that will occur during RBT2 operation and the range of masking release mechanisms available to SRKW. This is supported by associations of vessel slowdown mitigation-based reductions in broadband noise levels with concurrent decreased levels within the sound frequency range used by SRKW for communicating (i.e., the 0.5-15 kHz communication band). For example, MacGillivray and Li (2018) documented that for a container vessel slowing down by 7.7 knots on average during the Enhancing Cetacean Habitat and Observation (ECHO) Program slowdown, reductions in mean source level were 11.2 dB for broadband (0.01-64 kHz) and 9.3 dB for the communication band assessed (0.5-15 kHz). Thus, mitigation plans to reduce total broadband noise will also reduce communication masking effects.

Acoustic communication in resident Killer Whales is an important behaviour used to socialize, maintain contact (including group membership and reproduction), and co-ordinate foraging or prey sharing (Ford 1991). In most instances, the whistles and pulsed calls used by Killer Whales (Ford 1991) are likely for communication within individual pods or matrilines. These whistles and pulsed calls represent high importance short-term communication that facilitate within-group social functions, such as mother-calf cohesion, complex foraging co-ordination, and prey sharing, and are believed to occur when individuals are in close proximity. Miller (2006) stated that "group members rarely separate by more than a few kilometers". In contrast, long-range signals are considered more important for inter-group functions such as spatial competition (Miller and Bain 2000), mate attraction (Yurk *et al.* 2002), or to maintain contact when widely dispersed.

Call detection ranges of SRKW and the potential impact of competing noise sources are affected by a number of factors, among which sea state conditions are particularly important. Miller (2006) documented variation in the detection ranges of different calls (termed active space), averaging 10-16 km for long-range calls and 5-9 km for short-range calls at sea state zero (i.e., in calm seas with very low ambient noise levels). Active space of calls was shown to decrease dramatically (75-83%) in sea state six (at high ambient noise levels from large waves and high winds), which clearly demonstrates how natural sounds can substantially reduce the active space of Killer Whale communication (i.e., mask the calls). Shipping noise has been clearly shown to overlap with communication frequencies (0.5-15 kHz, Heise *et al.* 2017; up to 20 kHz, Veirs *et al.* 2016) and in select frequency bands (1-2 kHz), it is noisy enough, when compared to perfect weather conditions, to reduce the active space of Killer Whales by a level comparable to sea state six ambient noise levels

(Williams *et al*. 2014). However, unlike wind and rain, masking by container vessels is expected to be shorter-lived and, at current daily traffic rates in the study area, provide regular periods of lower anthropogenic noise levels that would allow for longer-range (e.g., inter-pod) communication to occur.

We considered the biological significance of long range communication masking by passing container vessels to be relatively small, especially if one considers that Killer Whales have a range of available mechanisms to reduce the effects of masking (termed masking release), such as increasing call amplitude and/or duration, co-modulation masking release (improvement of the signal detection threshold), within-valley listening (detecting the presence of a target signal within quieter gaps), multiple looks (taking advantage of repeated signals) (Erbe 2015), and potentially, temporarily delaying communication attempts. Of particular relevance for both short- and long-range communication, SRKW have been shown to be able to compensate for increased anthropogenic noise levels up to and beyond noise levels of 120 dB sound pressure level (SPL) by increasing their call amplitude when background levels increase (Holt *et al*. 2008, SRMU 2014a). Notably, Holt *et al*. (2008) reported a linear relationship between noise and call amplitude, with SRKW increasing call amplitude by 1 dB for every 1 dB increase in vessel noise, though compensatory behaviour may have limits (Blackwell *et al*. 2015). The published estimates of active space reduction in Killer Whales discussed earlier (e.g., Miller *et al*. 2014, Williams *et al*. 2014) include no masking release mechanisms and typically evaluate effects using very low ambient noise levels (i.e., resulting in worst case active space reductions). In estimating masking, additional key assumptions are required, for example the amount of the call that must be heard to infer its meaning, the critical bandwidths of hearing, and accurate auditory thresholds for Killer Whales at low sound frequencies. In summary, communication masking is highly contextual and complex to assess. The mitigation of broadband 120 dB effect zones in this study are likely, given the direct frequency overlap, to result in concurrent benefits in communication masking.

2.2.3. Echolocation Click Masking

This study assessed echolocation click masking associated with Project operation. Echolocation click masking can affect a whale's ability to effectively detect prey (Clark *et al*. 2009). As previously mentioned, masking of sounds most important for foraging is expected to primarily occur within distances where behavioural responses are anticipated. Such masking is incorporated to a certain extent in the dose-response curve presented in Figure 4, as the alteration of a whale's behaviour integrates the effects of acoustic masking due to noise exposure.

There are no published received sound level thresholds to explicitly assess the effects of echolocation click masking. Thus, we extended the approach used to assess the effects of behavioural responses. Echolocation click masking beyond the 120 dB acoustic effect zone may occur and potentially impact foraging under certain conditions. The EIS considered masking at 50 kHz (SMRU 2014c), which is the center frequency of killer whale clicks (Au *et al*. 2004). Based on clarification provided by IAAC, this study also assessed masking at 20 kHz, which is the second most important frequency for Killer Whales echolocation after 50 kHz.

Power spectral density (PSD) thresholds for both 20 and 50 kHz were estimated to detect the echo of a click returning from a salmon 250 m away, using data and approaches described in Au *et al.* (2004) and SMRU (2014a). The 250 m value was based on SRKW inter-click intervals recorded at Lime Kiln hydrophone (SMRU 2014a) and was considered highly conservative, given that Au *et al.* (2004) used only a 100 m range. The PSD level of noise at 20 kHz and 50 kHz was calculated from the modelled 1/3-octave band SPL, as follows:

$$\mathrm{L_{PSD}} = \mathrm{L_{SPL}} - 10 \times \log_{10}(0.231 \times \mathrm{f})$$

where f is the 1/3-octave band center frequency (Hz), 0.231×f is the bandwidth (Hz), $\mathrm{L_{SPL}}$ is the 1/3-octave band sound pressure level (dB re 1 µPa), and $\mathrm{L_{PSD}}$ is the power spectral density level (dB re 1 μPa^2/Hz). Thresholds for click detection were 37.90 dB and 35.67 dB re 1 μPa^2/Hz, for 20 and 50 kHz, respectively. We used these thresholds to define the additional echolocation click masking effect beyond behavioural response.

2.2.4. Acoustic Effects Zones and Severity of SRKW Response

Based on the relevant thresholds described in the previous three sections, we defined acoustic effect zones (which are based on the distance from the noise sources) to reflect decreasing probability (severity) of SRKW behavioural response and echolocation click masking to continuous noise from the various vessel activities during Project operation. Acoustic effect zones were defined in relation to SRKW response thresholds based on the modelled acoustic footprints for vessel activities (Section 2.4). The acoustic effect zone closest to the sound source (which has the smallest acoustic footprint) has the highest broadband unweighted received level of noise and the highest associated probability of behavioural response, while the other zones have progressively larger footprint sizes and lower probabilities of behavioural response and masking with increasing distance from the noise source. For the first three zones, we used the modelled distance to the broadband unweighted received level thresholds of 137 dB, 129 dB, and 120 dB re 1 µPa (rms), for each acoustic scenario described in Section 2.4.2, based on rationale described in Section 2.2.1. An additional acoustic effect zone, which was used to assess additional echolocation click masking for received levels beyond the 120 dB threshold, was also defined based on echolocation click masking PSD thresholds developed for 20 kHz and 50 kHz (see Section 2.2.3).

To partially address uncertainty in the contextual severity of the effect within each acoustic zone, we adopted more conservative (higher) probability of response coefficients than for the EIS, by basing them on the low behavioural dose-response curve (blue curve in Figure 4) rather than basing the coefficients on the moderate dose-response curve (red curve in Figure 4). These response coefficients are used to convert exposure time from an acoustic effect zone into an acoustic effect, here termed "potential lost foraging time", which can then be summed across all exposure zones. Similar to the approach used in the EIS, we conservatively assumed that SRKW are foraging 100% of the time, despite evidence that SRKW spend 40-67% of their time foraging (Ford *et al.* 2017). This assumption adds further confidence that the estimates of potential lost foraging time are conservative.

We adopted arithmetic means of the response probabilities within each acoustic effect zone to convert noise exposure time to potential lost foraging time (see Section 2.3). This assumption is conservative given the log nature of noise propagation. The following Mid-point probability of response coefficients were implemented (Figure 4):

- 0.92 (92nd percentile response) for the acoustic effect zone that encompasses 137 dB and higher (mid-point between an 84th percentile and 100th percentile probability of response). In other words, more than 9 out of 10 individuals within this zone are predicted to respond and thus accrue potential lost foraging time when transiting through that zone;
- 0.67 (67th percentile response) for the acoustic effect zone encompassing 129 to 137 dB, representing the mid-point between a 50th percentile and 84th percentile probability of response;
- 0.30 (30th percentile response) for the acoustic effect zone encompassing 120 to 129 dB, representing the mid-point between the 10th percentile and 50th percentile probability of response; and
- 0.05 (5th percentile response) for the acoustic effect zone encompassing the echolocation masking threshold to 120 dB, representing the mid-point between no response and 10th percentile probability of response. In other words, 5 out of 100 individuals within this zone are predicted to respond and thus accrue potential lost foraging time when transiting through that zone.

The probability of response applied to the residual click masking zones represents a progression in probability at SPL levels below the 120 dB isopleth. Thresholds for masking at 50 kHz were not exceeded in most cases beyond 120 dB but they were exceeded for masking at the 20 kHz frequency. The estimated click masking zone for 20 kHz extends to where no masking occurs for detecting echolocation clicks at 250 m. We therefore considered the use of a 20 kHz acoustic effect zone conservative and note that spatial release (i.e., accounting for sounds coming from the sides and back of the animal, which are not generally heard as well and therefore less important for masking) was not included. We also did not include compensatory behaviour (i.e., the ability of animals to vocalize louder to compensate for increasing background noise) (Holt *et al.* 2008) in the estimation.

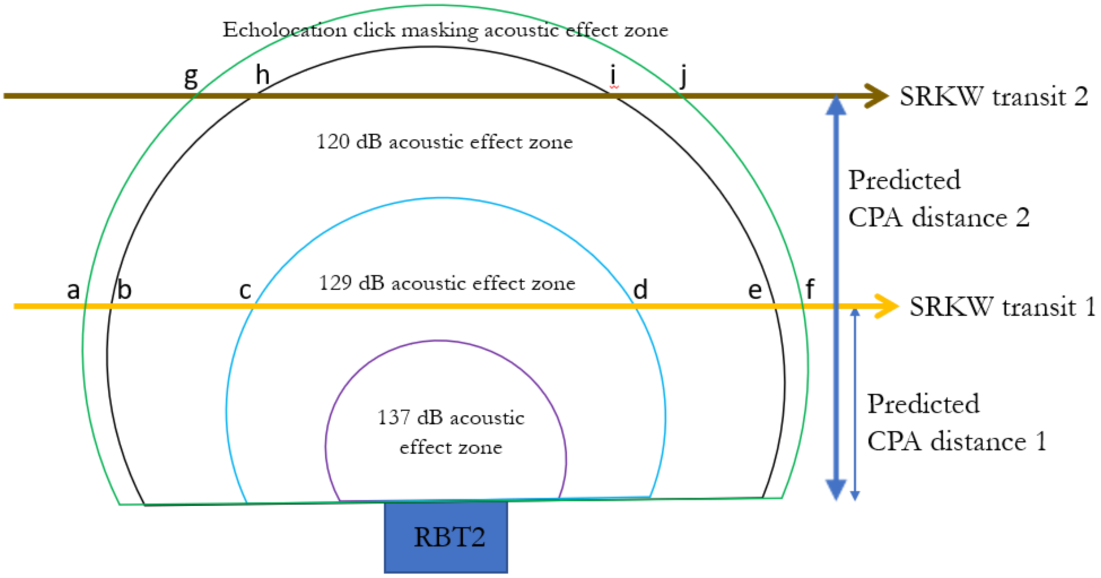
2.3. Quantification of Potential Lost Foraging Time

The estimation of potential lost foraging time was a two-step process. We first estimated the time SRKW travel through acoustic effect zones and we subsequently transformed this exposure time to potential lost foraging time by applying the probability of response coefficients described in Section 2.2.4 (i.e., more individuals respond to underwater noise and accrue potential lost foraging time in behavioural response zones closest to the source than those farther away in the echolocation click masking zone).

The time spent in each zone during each predicted transit was calculated based on the distance through the zone (in 100 m band increments) divided by the average speed of Killer Whale engaged in typical "travel/forage" activity (i.e., 1.6 m/s, Williams and Noren 2009). A graphical depiction of an example is provided in Figure 5. In this example, SRKW transit 1 occurs at the predicted CPA (distance 1) when berthing activities are being undertaken. In this case, the transit does not pass through the 137 dB zone but passes through both the 120 dB and 129 dB acoustic zones. Time in each zone is calculated and accumulated for each transit (i.e., in the example, transit 1 and 2). The radii used in each case are based on the applicable acoustic footprint (i.e., radii) modelled for each of the operational activities (MacGillivray *et al.* 2019, 2021) described in Section 2.4.2. The CPA of each of the estimated SRKW transits per year is generated as described in Section 2.1.3.

Figure 5. Diagram and table with equations showing how predicted time exposure to underwater noise is calculated based on closest point of approach (CPA) during two transits of SRKW in the area affected by underwater noise generated by berthing and unberthing. Acoustic effect zones are represented by the semi-circles originating from the sound source.

SRKW transit number	Exposure time in each acoustic effect zone			
	137 dB	129 dB	120 dB	Echolocation click masking (20 Hz)
1	0	(distance c to d)/speed	$\frac{((\text{distance b to c})+(\text{distance d to e}))}{\text{speed}}$	$\frac{((\text{distance a to b})+(\text{distance e to f}))}{\text{speed}}$
2	0	0	(distance h to i)/speed	$\frac{((\text{distance g to h})+(\text{distance i to j}))}{\text{speed}}$



2.3.1. Number of Lost Prey Captures Conversion

The number of lost prey captures were coarsely estimated from potential lost foraging time based on estimated prey (salmon) capture events per hour obtained from a study using bio-logging tags (D-tag) attached to individual SRKW by suction cups (Tennessen *et al*. 2019). Data on daytime foraging events were available for 22 SRKW tags (similar numbers of males and females were tagged), collected in September across multiple years. In total, 84.37 hours of D-tag data were collected, during which a maximum of 131 prey captures were detected either visually, via prey crunching sounds, or via dive kinematics (i.e., stereotyped movements that indicate a prey capture).

Prey capture rates, reported in the Tennessen *et al.* (2019) study, were used to generate a prey capture rate for a 24-hour period for this study using two correction factors, one to correct for false positives in prey capture data and one to account for reduced foraging at night. Based on the results of Tennessen *et al*. (2019), a false positive rate of 20% for kinematic-based prey detections was applied, resulting in a revised total of 109 prey capture events, which equates to an average daytime prey capture event rate of one prey item every 46.5 minutes. However, a correction is also needed for differences in capture rates between day and night because unpublished data from D-tag monitoring of resident Killer Whales has indicated that call rates in daylight are 1.83 times more frequent than at night (DFO unpublished data in Thornton *et al*. 2019) and calls are believed to be frequently used to coordinate foraging (which suggests that foraging occurs more commonly in the day than at night). Thus, a nighttime prey capture event every 85.1 minutes (i.e., 46.5 minutes times 1.83) was assumed for this study. Applying these adjustments factors therefore generated a prey capture rate of approximately one prey capture event per hour over a 24-hour period.

Noren (2011) used bio-energetic modelling to coarsely estimate that SRKW need a minimum of 10 to 12 Chinook Salmon per day but note that prey resources can be patchy and ephemeral. While Chinook Salmon is a key prey, other species are also consumed (e.g., steelhead, Chum Salmon, Sockeye Salmon, and Coho Salmon; Ford 2014; Hanson 2015; Ford *et al*. 2016). Furthermore, fish are known to be shared with younger animals and size of available Chinook Salmon are thought to be smaller in recent years. Overall, given the tagging data also comes from a summer month and region of known foraging success, the estimated value (24 per day) used in this study is considered reasonable, but is likely somewhat conservative.

2.4. Operational Acoustic Effects

Most of the underwater noise that will be generated during the operation of RBT2 will be from container vessel arrival, berthing, unberthing, and departure. However, some underwater noise from on-board machinery will also be generated while vessels are at berth unloading and loading containers. Thus, for modelling underwater noise effects on SRKW, underwater noise-generating vessel activities were categorized as those generated by vessels in motion (arriving, berthing, unberthing, and departing) and by vessels at berth.

To estimate acoustic effects on SRKW due to operational noise-generating activities (vessel arrival, berthing, unberthing, departure, and vessels at berth), we considered the expected number of container vessel calls to the RBT2 terminal in 2035, 2040, and 2045 (Mercator International 2021; Appendix IR2020-3-B) and the predicted acoustic effect zones of container vessels and support tugs during Project operation using different acoustic scenarios (MacGillivray *et al.* 2019, 2021). For each key noise generating vessel activity during Project operation, we developed representative vessel activity scenarios and modelled their acoustic footprints to assign the predicted acoustic effect zones. We used these acoustic effect zones as inputs in the acoustic effects model simulating the overlap of transiting SRKW and Project operation vessel noise to estimate acoustic effects on SRKW. We evaluated the effectiveness of mitigation measures for reducing underwater noise and/or interactions and, where feasible, used the acoustic effects model to quantify the effectiveness for reducing potential lost foraging time on the whales.

2.4.1. Project Operation and Container Vessel Projections

It is anticipated, under the most-realistic scenario, that the RBT2 terminal will receive on average three (2035) to four (2040 and 2045) weekly container vessel calls that vary in size class depending on the projection year (i.e., 156 to 208 vessels annually) (Mercator International 2021; Table 3). The less likely high-case scenario was also modelled by including one additional weekly container vessel call to the terminal in each of the projection years (i.e., four to five weekly container vessel calls, 208 to 260 vessels annually). This additional vessel was conservatively assumed to be a Mega-Max. Vessel arrival and departures are expected to be regularly spaced throughout the year and to have no specific pattern in time of day (i.e., night vs. day).

Table 3. Projected weekly calls at RBT2 for different classes of container vessels in 2035, 2040, and 2045 for the most-realistic and high-case scenarios (Mercator International 2021).

Year	Most-realistic vessel scenario				High-case vessel scenario			
	Large Post-Panamax	Neo Panamax	Mega-Max	Total	Large Post-Panamax	Neo Panamax	Mega-Max	Total
2035	1	2	0	3	1	2	1	4
2040	0	2	2	4	0	2	3	5
2045	1	1	2	4	1	1	3	5

Large Post Panamax (capacity 9,000-12,999 TEUs)
Neo Panamax (capacity 13,000-14,900 TEUs)
Mega-Max (capacity 18,000-24,000 TEUs)

The estimated distances that vessels travel when calling at RBT2 and duration that they are engaged in each vessel activity when in motion (arrival, berthing, unberthing, and departure) used for modelling underwater noise effects on SRKW are shown in Table 4 and presented in Map 4. For container vessel arrivals, it was assumed that three vessel-assist tugs[1] travel (at a speed of 8 knots) from the tug basin to meet the container vessel that has exited out from the inbound shipping lane (first stage of container vessel approach, travelling at an average estimated average speed of 10.5 knots). The container vessel and vessel-assist tugs then transit together towards the terminal (second stage of vessel approach, travelling at a speed of 6 knots). The vessel-assist tugs then berth the vessel by maneuvering it into place (berthing) and return to the tug basin. For container vessel departures, the three vessel-assist tugs transit from the tug basin to the container vessel at the terminal, unberth the vessel from the terminal (unberthing), accompany it to a point where the container vessel can maneuver independently (first stage), and return to the tug basin while the container vessel continues to the outbound shipping lane (second stage). The total duration of these operational activities was assumed to be 154.2 minutes. This is based on vessel speeds estimated between different locations and distance travelled by the container vessel along the anticipated route (i.e., ~20 km from point A to B on Map 4) and vessel-assist tugs between points indicated in Table 4, and the estimated berthing time for tugs at Roberts Bank (HPC 2021). The assumptions made for this approach provide more granularity than previous operational effects analyses. Further, additional vessel scenarios were considered in the approach presented here, and a longer duration (~1.5 times longer) was assumed for the process of arrival through departure than scenarios presented in the EIS, which therefore provides a more conservative assessment.[2]

To assess effects of underwater noise for vessels at berth, container vessels were assumed to have their engine running to power on-board machinery and equipment required during container loading and unloading. Time at berth was assumed to vary, based on vessel class and cargo load (i.e., time required to handle the containers), from ~39 hours to 60 hours (Table 5; Goertz, pers. comm. 2021). Berth occupation was assumed to vary from 0 to 3 container vessels based on vessel numbers and class, available berths at the terminal (three), and time at berth.

---

[1] Analyses assumed the use of three vessel-assist tugs for all vessel classes. Currently, container vessels calling at Deltaport terminal at Roberts Bank up to 14,999 TEU (i.e., Neo Panamax) require two berthing tugs under most circumstances. Only the Mega-Max container vessels are anticipated to require three vessels-assist tugs (i.e., tugs that assist with berthing and unberthing). A line tug may also assist berthing and unberthing all container vessels. Underwater noise contributions from these vessels are considered through the conservative assumption that all container vessels will require three berthing tugs.

[2] We included additional stages of operation for the updated underwater noise modelling study. We conservatively included the time in the shipping lane when container vessels start slowing down to arrive and turn towards RBT2. We also included the entire time vessel-assist tugs and container vessels are travelling together and separately during departure, including time outside the port's jurisdiction. In comparison, the studies for the EIS considered the duration of arrival and departure activities within the jurisdiction of the port authority.

Table 4. **Container vessel (vessel) and support tug location, vessel speed (knots), and distances (km) travelled when calling at RBT2 used to determine duration of each activity stage of vessels in motion (arrival, berthing, unberthing, and departure) in the acoustic effects model. Locations correspond to the points depicted on Map 4 and distances are from actual measurements made between points on the anticipated vessel track using ArcGIS.**

Activity	Stage	Location		Speed (knots)		Distance (km)		Duration (mins)
Arrival	First	Tug: 4 to 1	Vessel: A to 1	Tug: 8	Vessel: 10.5	Tug: 6.2	Vessel: 4.3	25.2
	Second	1 to 2 (together)		6		5.6		24
Berthing		RBT2 terminal (2)		n/a		n/a		30[1]
Unberthing		RBT2 terminal (2)		n/a		n/a		30[1]
Departure	First	2 to 3 (together)		6		3.5		24
	Second	Tug: 3 to 4	Vessel: 3 to B	Tug: 8	Vessel: 10.5	Tug: 2.3	Vessel: 6.8	21

[1] Hamburg Port Consulting (HPC) 2021. VFPA Tug Slowdown Study. Prepared for the Vancouver Fraser Port Authority.

Table 5. Estimated time at berth for container vessels based on size class.

Size of vessel	Hours at berth
Large Post Panamax	38.86
Neo-Panamax	47.04
Mega-Max	60.09

2.4.2. Acoustic Models

Predicted acoustic effect zones were initially developed for the EIS and were subsequently updated in MacGillivray *et al.* (2019) based on more realistic scenarios, Neo-Panamax container vessel source levels, and updated vessel projections. Additional acoustic modelling was conducted for this study (MacGillivray *et al.* 2021, i.e., Appendix IR2020-3-C) to reflect the latest vessel projections for 2035, 2040, and 2045 and anticipated variation in the classes of container vessels projected to call at the RBT2 terminal (Mercator International 2021). The new scenarios modelled reflect the additional granularity of operational vessel activities described in the previous section for vessel movements near the terminal and include new scenarios for vessels at berth. Mitigation scenarios were also modelled as part of this study to evaluate their effectiveness.

2.4.2.1. Vessels in Motion

Acoustic scenarios were developed to represent the different stages of arrival and departure described in Table 4 for different vessel classes anticipated to call at the RBT2 terminal (Large Post Panamax (LPPX), Neo-Panamax (NPX), and Mega-Max (MMX)) in summer and winter. Table 6 presents the range (i.e., distance) to acoustic thresholds modelled (including applicable R95% radii threshold values) for the new scenarios and berthing and unberthing acoustic models previously described in MacGillivray *et al.* (2019) which were updated to include echolocation click masking thresholds. For example, 120 dB radii for scenarios with no mitigation vary between 0.84 km (for vessel-assist tugs travelling at 8 knots to meet the container vessel in summer) to 8.5 km (for a container vessel being berthed by three vessel-assist tugs in winter) (Table 6). Scenarios included vessel-assist tugs travelling at reduced speed to evaluate this as a possible mitigation measure, noting that reduced speed equates to smaller acoustic footprints but longer transit duration.

For this study, we assumed that the scenarios for berthing can be applied to unberthing, and that the scenarios for arrival to the RBT2 terminal can be applied for container vessels departing the terminal. In all cases, radii of echolocation click masking effect zones were greater for the 20 kHz band than the 50 kHz band, and thus, the 20 kHz radii was used throughout to estimate the range to echolocation click masking beyond the behavioural disturbance threshold. Examples of the acoustic footprints of different Project operation scenarios modelled are presented in Figure 6, Figure 7, Figure 8, and Figure 9.

Table 6. **R95% radii (m) for selected behavioural response (137, 129, and 120 dB, SPL) and echolocation click masking (20 and 50 kHz, PSD) effect threshold values for continuous noise source for the different acoustic models (scenarios) developed to represent the predicted project operational noise effects of vessels in motion on SRKW in summer and winter.**

Description of the acoustical models representing project operation and stages		Sources[1]	Season	Speed (knots)	Scenario ID	Radii (R95%, m)				
						137 dB (m)	129 dB (m)	120 dB (m)	20 kHz (m)	50 kHz (m)
Arrival/ departure	Container vessels transiting alone out of shipping lane	LPPX	Summer	10.5	7b	362	930	1,906	2,373	841
		NPX	Summer		7c	371	962	1,922	2,422	1,028
		MMX	Summer		7d	387	1,054	1,965	2,665	1,251
		LPPX	Winter	10.5	8b	375	1,053	2,297	2,190	776
		NPX	Winter		8c	384	1,065	2,325	2,493	848
		MMX	Winter		8d	399	1,070	2,403	3,208	1,018
	Vessel-assist tugs transiting alone at normal speed	3 tugs	Summer	8	11	213	423	840	2,638	859
			Winter		12	222	467	1,155	4,047	1,129
	Vessel-assist tugs transiting alone at reduced speed (high mitigation effectiveness scenario)	3 tugs	Summer	5	13a	83	123	322	1,310	420
			Winter		14a	83	123	353	2,113	486
	Vessel-assist tugs transiting alone at reduced speed (low mitigation effectiveness scenario)	3 tugs	Winter	5	14b	119	306	657	3,166	860
			Summer		13b	115	281	563	1,940	680
	Container vessel and vessel-assist tugs transiting together	LPPX and 3 tugs	Summer	6	9b	294	476	942	1,707	642
		NPX and 3 tugs	Summer		9c	299	480	950	1,709	647
		MMX and 3 tugs	Summer		9d	301	504	973	1,733	687
		LPPX and 3 tugs	Winter	6	10b	294	504	1,099	2,873	767
		NPX and 3 tugs	Winter		10c	300	516	1,139	2,876	768
		MMX and 3 tugs	Winter		10d	301	526	1,206	2,886	771
Berthing / unberthing	Three vessel-assist tugs berthing container vessel (based on 30-minute average SPL)	Container vessel and 3 tugs	Summer	n/a	1a	530	1,420	3,850	4,715	838
			Winter		4a	630	1,940	8,460	8,092	1,204

[1] LPPX = Large Post Panamax (9,000 – 12,999 TEUs); NPX = Neo Panamax (13,000 – 14,999 TEUs); MMX = Mega-Max (18,000 – 24,000 TEUs)

Figure 6. The acoustic model representing a Mega Max container vessel turning off the shipping lane modelled at 10.5 kn in summer (scenario 7D) for the different acoustic effect thresholds modelled (from MacGillivray *et al.* 2021, Appendix IR2020-3-C).

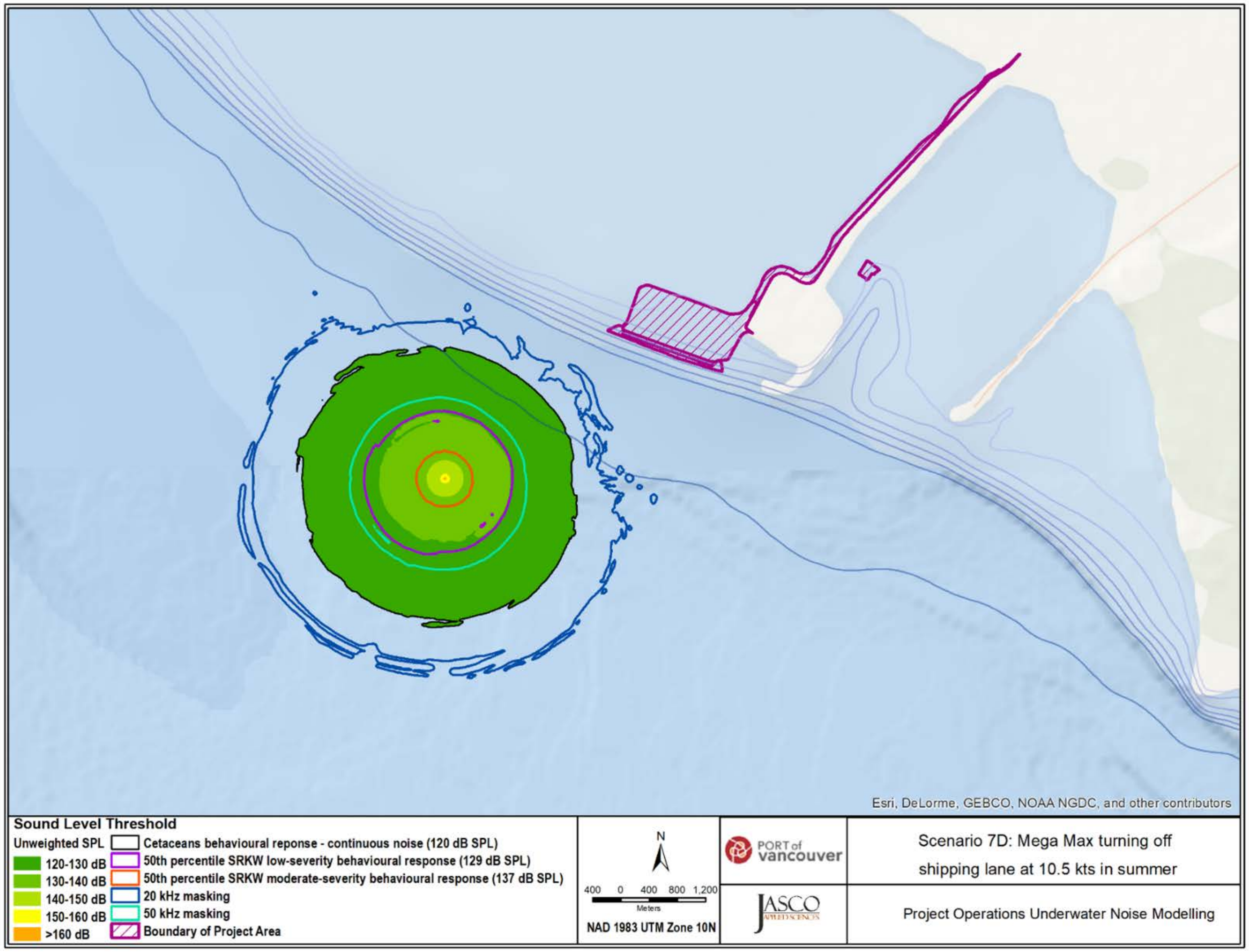


Figure 7. **The acoustic model representing three vessel-assist tugs travelling at 8 kn to meet the arriving container vessel in summer (scenario 11) for the different acoustic thresholds modelled (from MacGillivray *et al.* 2021, Appendix IR2020-3-C).**

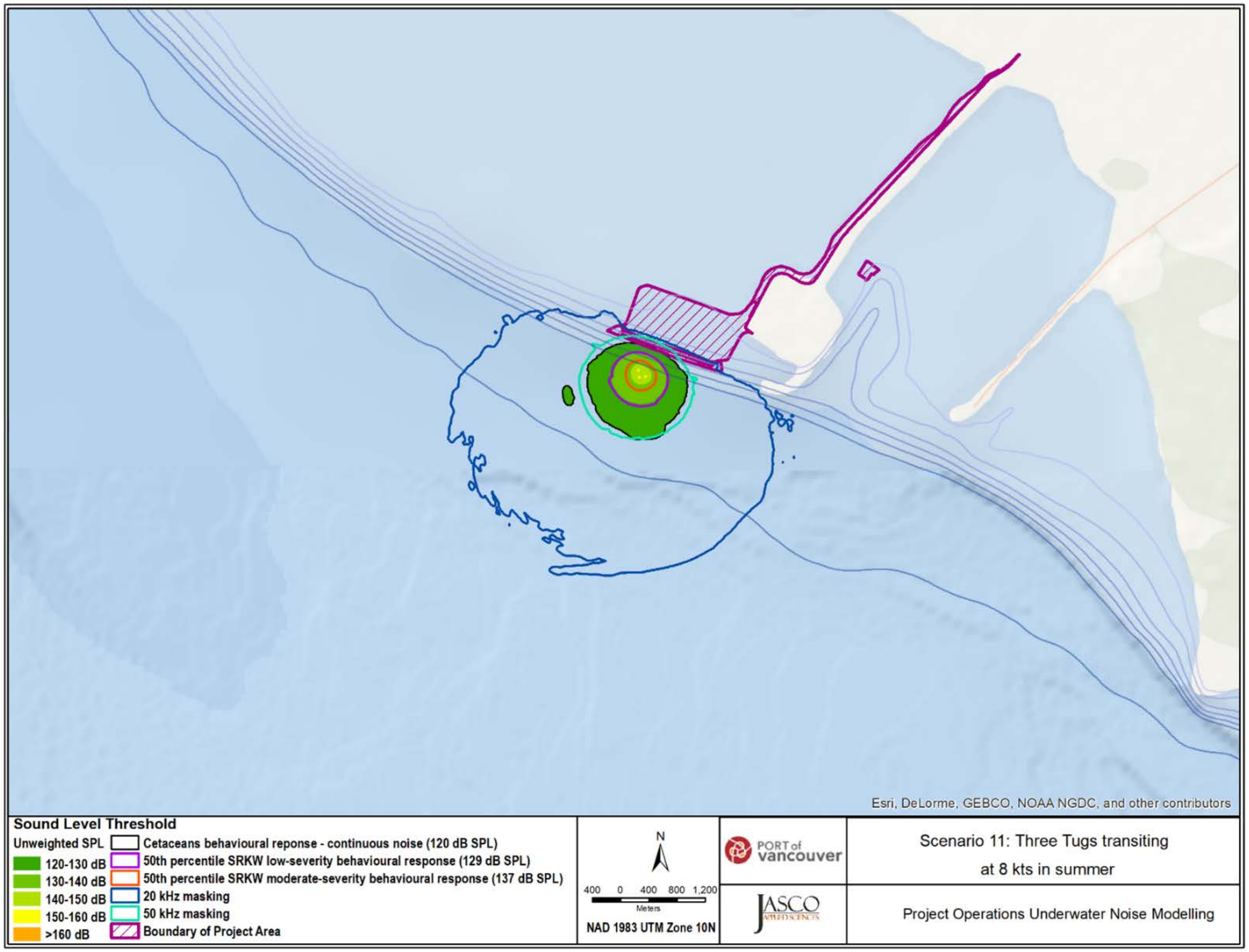


Figure 8. The acoustic model representing a Mega Max travelling with three vessel-assist tugs at 6 kn towards the RBT2 terminal in summer (scenario 9D) for the different acoustic thresholds modelled (from MacGillivray *et al.* 2021, Appendix IR2020-3-C).

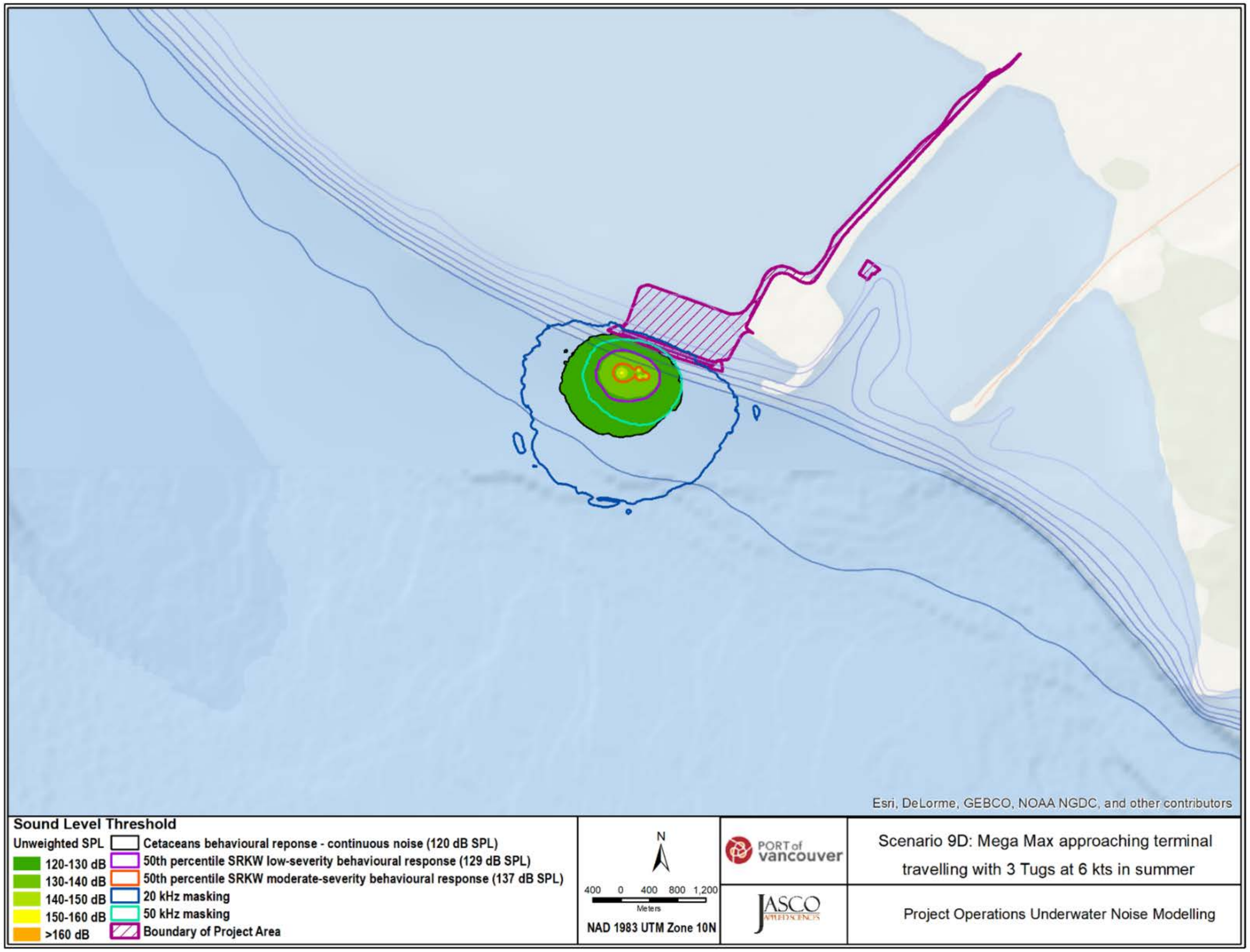
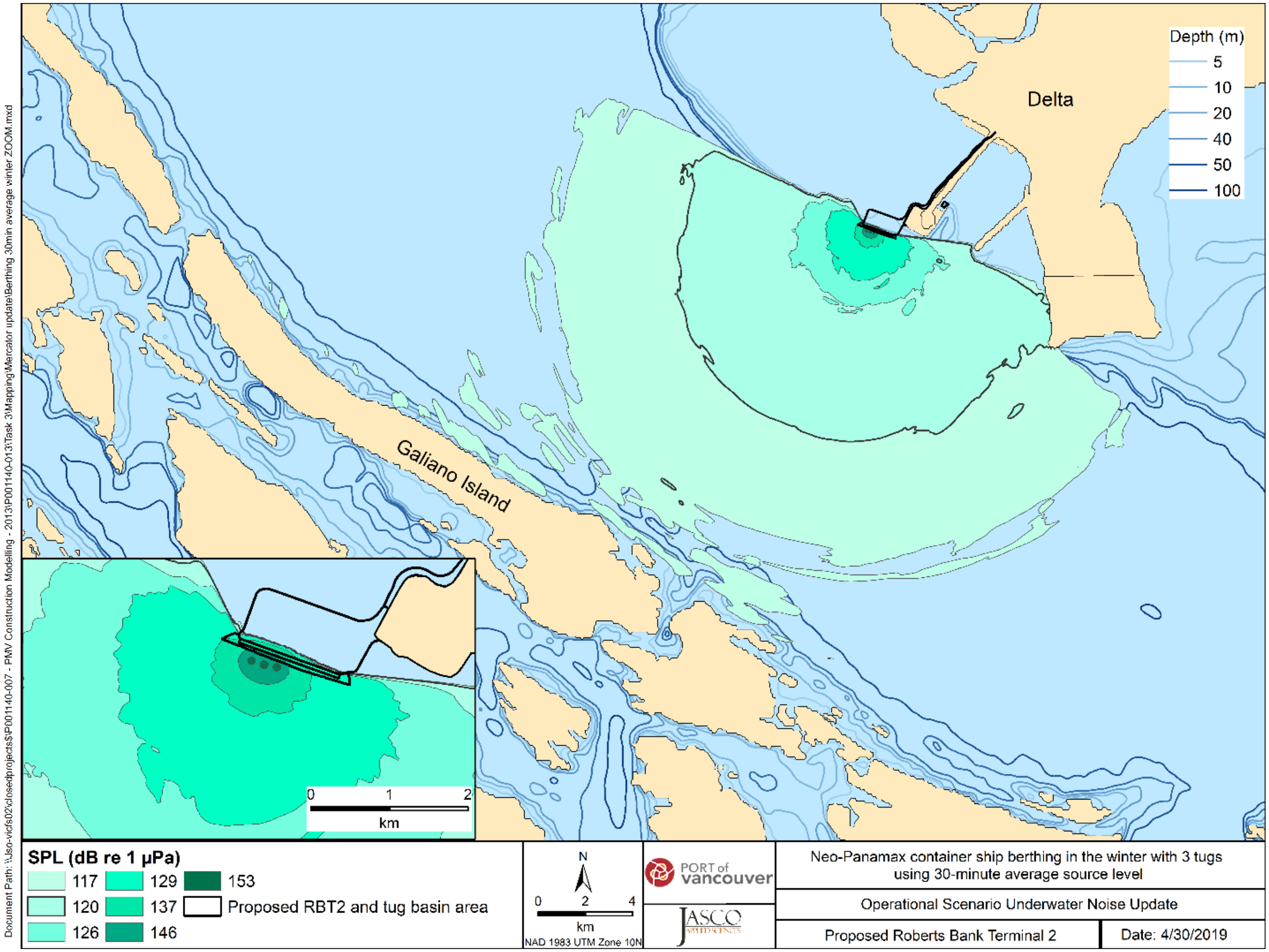


Figure 9. The acoustic model representing a Neo-Panamax berthing with support from three vessel-assist tugs in winter (scenario 4A) for the different acoustic thresholds modelled (from MacGillivray *et al.* 2019).



2.4.2.2. Vessels at Berth

Acoustic models were developed to reflect the presence of one, two, or three vessels at berth simultaneously, given that there are several possible combinations of vessel numbers and classes that could be at berth simultaneously (MacGillivray *et al.* 2021). For models with one or two vessels at berth simultaneously, it was conservatively assumed that all would be the largest vessel class (Mega-Max). When three vessels were modelled at berth simultaneously, two Mega-Max and one smaller Neo-Panamax were assumed present. This was a reasonable assumption because the available space at the terminal precludes presence of three Mega-Max simultaneously.

Table 7 presents the range (i.e., distance) to acoustic thresholds modelled (including applicable R95% radii threshold values) for the modelled scenarios in winter and summer. Because the noise footprints of vessels at berth are ellipsoidal, both the perpendicular and parallel distances (R95% radii) relative to the berth face are included for the behavioural disturbance thresholds and click masking thresholds. For example, parallel radii for a Mega-Max on vessel power in scenario 17A range between 340 m (for the 120 dB threshold) and 460 m (for the 20 kHz threshold). Scenarios included vessels that connected to shore power to evaluate the potential reduction in underwater noise footprints with shore power as a mitigation measure. Using the same example (scenario 17A), use of shore power for the Mega-Max decreased the 120 dB parallel radii from 340 m to 240 m but the distance of the 20 kHz masking radii remained the same.

In all cases, radii of echolocation click masking effect zones were greater for the 20 kHz band than the 50 kHz band, and thus, the 20 kHz radii was used throughout to estimate the range to echolocation click masking beyond the behavioural response threshold.

Examples of the acoustic footprints of different Project operation scenarios modelled are presented in Figure 10, Figure 11, Figure 12, and Figure 13.

Table 7. **R95% radii (m) from the center of the berth face (parallel and perpendicular directions) for selected behavioural response (137, 129, and 120 dB, SPL) and echolocation click masking (20 and 50 kHz, PSD) effect threshold values for continuous noise source for the different acoustic models (scenarios) developed to represent the predicted project operational noise effects of vessels at berth on SRKW in summer and winter without (i.e., vessels on own power) and with shore power connection.**

Description[1]	Season	Scenario ID	Parallel Radii (R95%, m)					Perpendicular Radii (R95%, m)				
			137 dB	129 dB	120 dB	20 kHz	50 kHz	137 dB	129 dB	120 dB	20 kHz	50 kHz
1 MMX on vessel's power	Summer	17A	190	210	340	460	240	40	80	350	500	140
1 MMX on shore power	Summer	17B	210	200	240	460	240	30	40	140	500	140
1 MMX on vessel's power	Winter	18A	190	210	420	620	250	40	90	390	510	150
1 MMX on shore power	Winter	18B	210	200	250	620	250	30	50	150	510	150
2 MMX on vessel's power	Summer	19A	600	600	740	850	620	40	90	460	610	150
1 MMX on shore power and 1 MMX on vessel's power	Summer	19B	610	550	580	850	620	40	80	370	610	150
2 MMX on vessel's power	Winter	20A	600	600	830	1,090	630	40	100	560	730	160
1 MMX on shore power and 1 MMX on vessel's power	Winter	20B	610	550	610	1,090	630	40	90	440	730	160
2 MMX and 1 NPX on vessel's power	Summer	21A	610	610	760	890	630	40	90	510	710	150
1 MMX on shore power and 1 MMX and 1 NPX on vessel's power	Summer	21B	610	600	720	890	630	40	90	460	710	150
2 MMX and 1 NPX on vessel's power	Winter	22A	610	610	880	1,170	650	40	110	670	890	160
1 MMX on shore power and 1 MMX and 1 NPX on vessel's power	Winter	22B	610	600	820	1,170	650	40	100	580	890	160

[1] LPPX = Large Post Panamax (9,000 – 12,999 TEUs); NPX = Neo Panamax (13,000 – 14,999 TEUs); MMX = Mega-Max (18,000 – 24,000 TEUs)

Figure 10. The acoustic model representing a Mega-Max container vessel at berth (Berth 2) on vessel power in summer (scenario 17A) for the different acoustic effect thresholds modelled (from MacGillivray *et al.* 2021, Appendix IR2020-3-C).

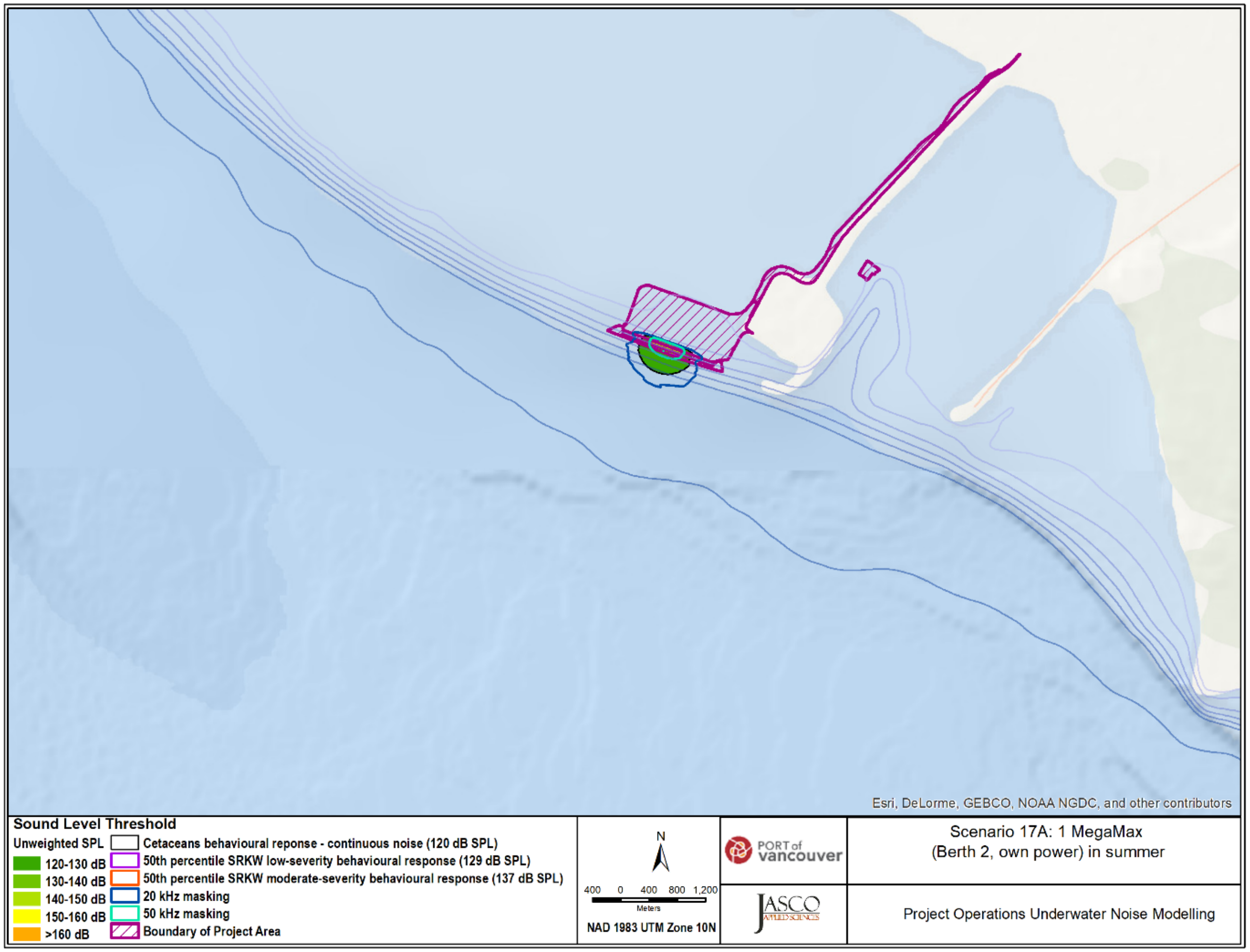


Figure 11. The acoustic model representing a Mega-Max container vessel at berth (Berth 2) on shore power in summer (scenario 17B) for the different acoustic effect thresholds modelled (from MacGillivray *et al.* 2021, Appendix IR2020-3-C).

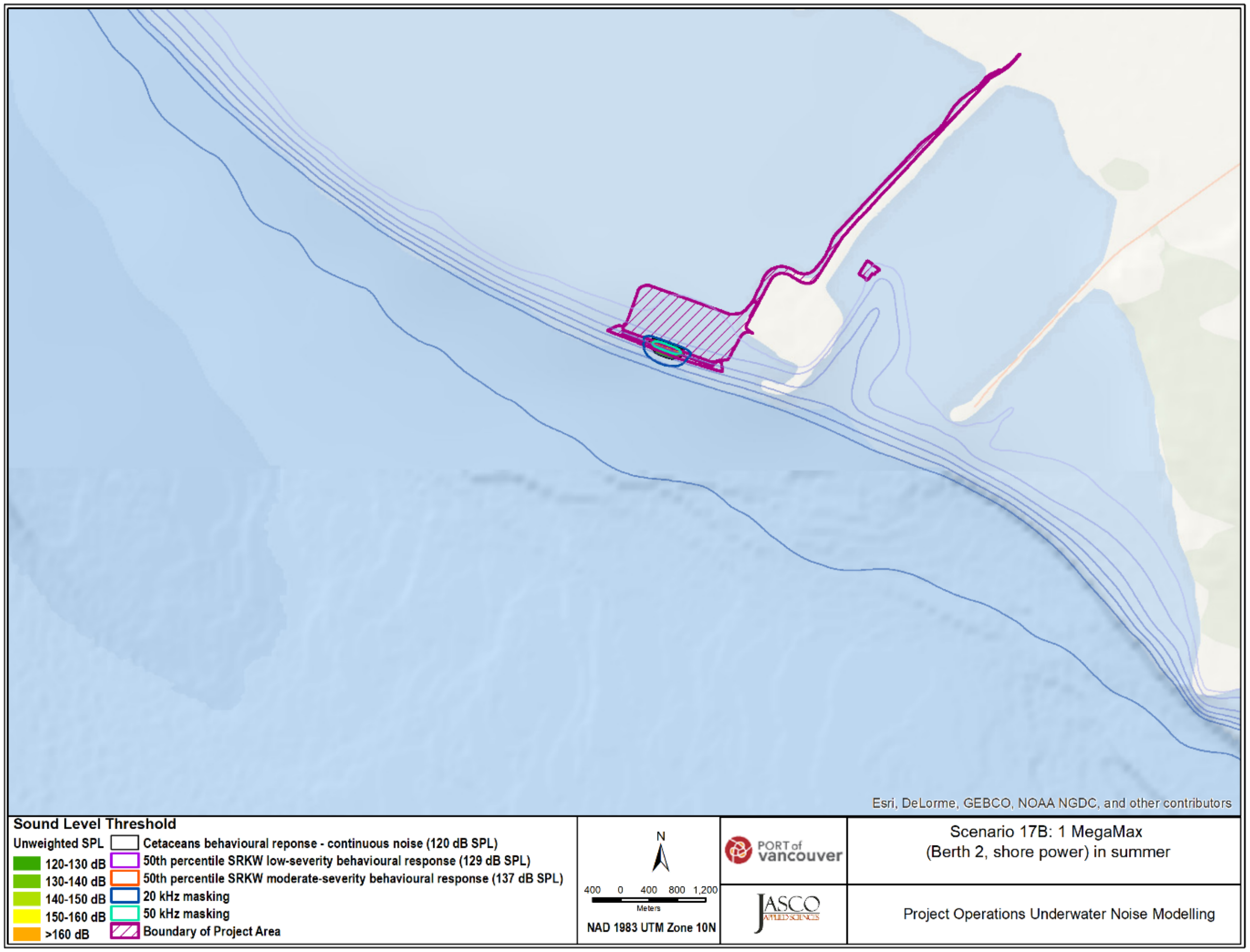


Figure 12. The acoustic model representing one Neo Panamax (Berth 1) and two Mega-Max (Berth 2 and Berth 3) container vessels at berth on vessel power in winter (scenario 22A) for the different acoustic effect thresholds modelled (from MacGillivray *et al.* 2021, Appendix IR2020-3-C).

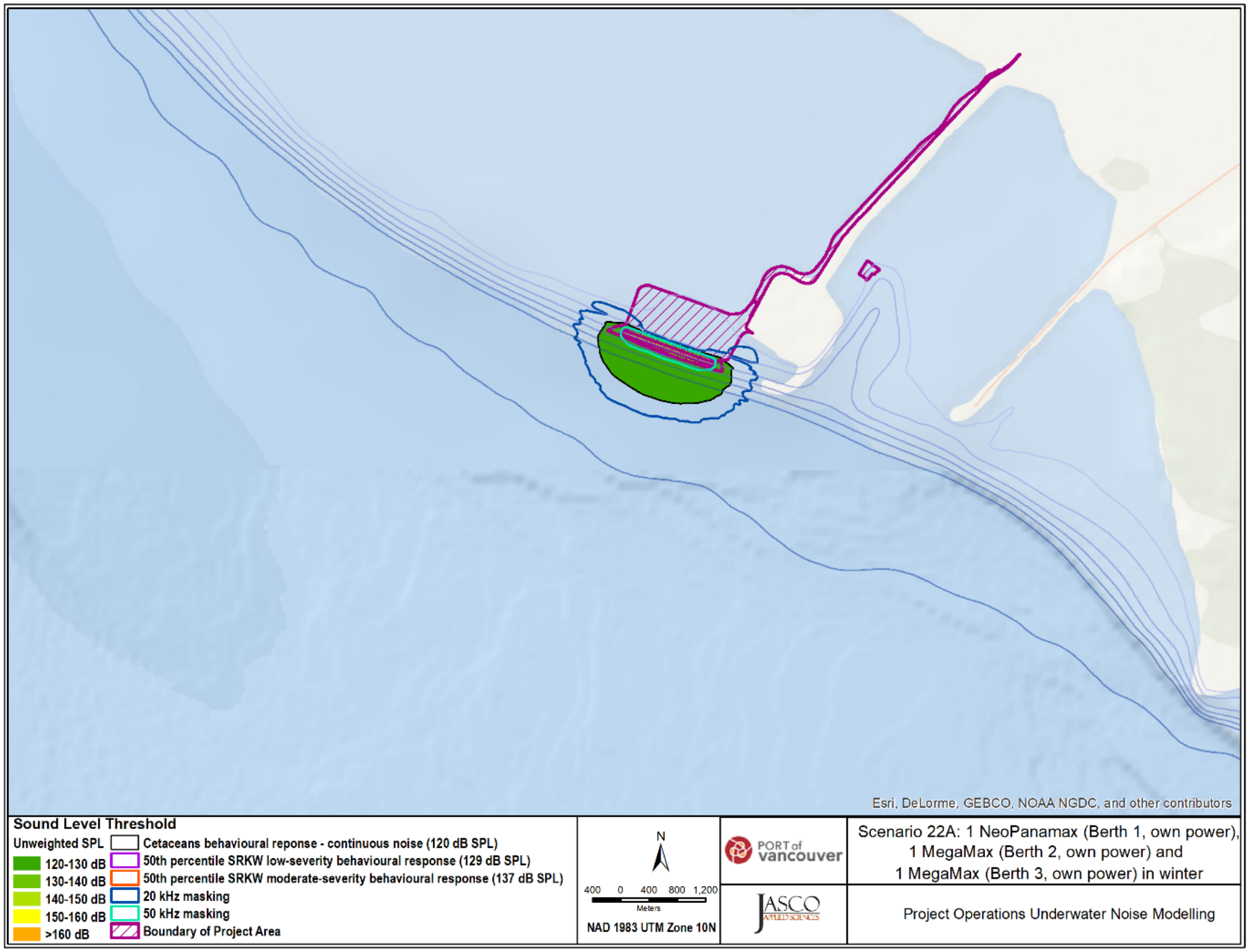
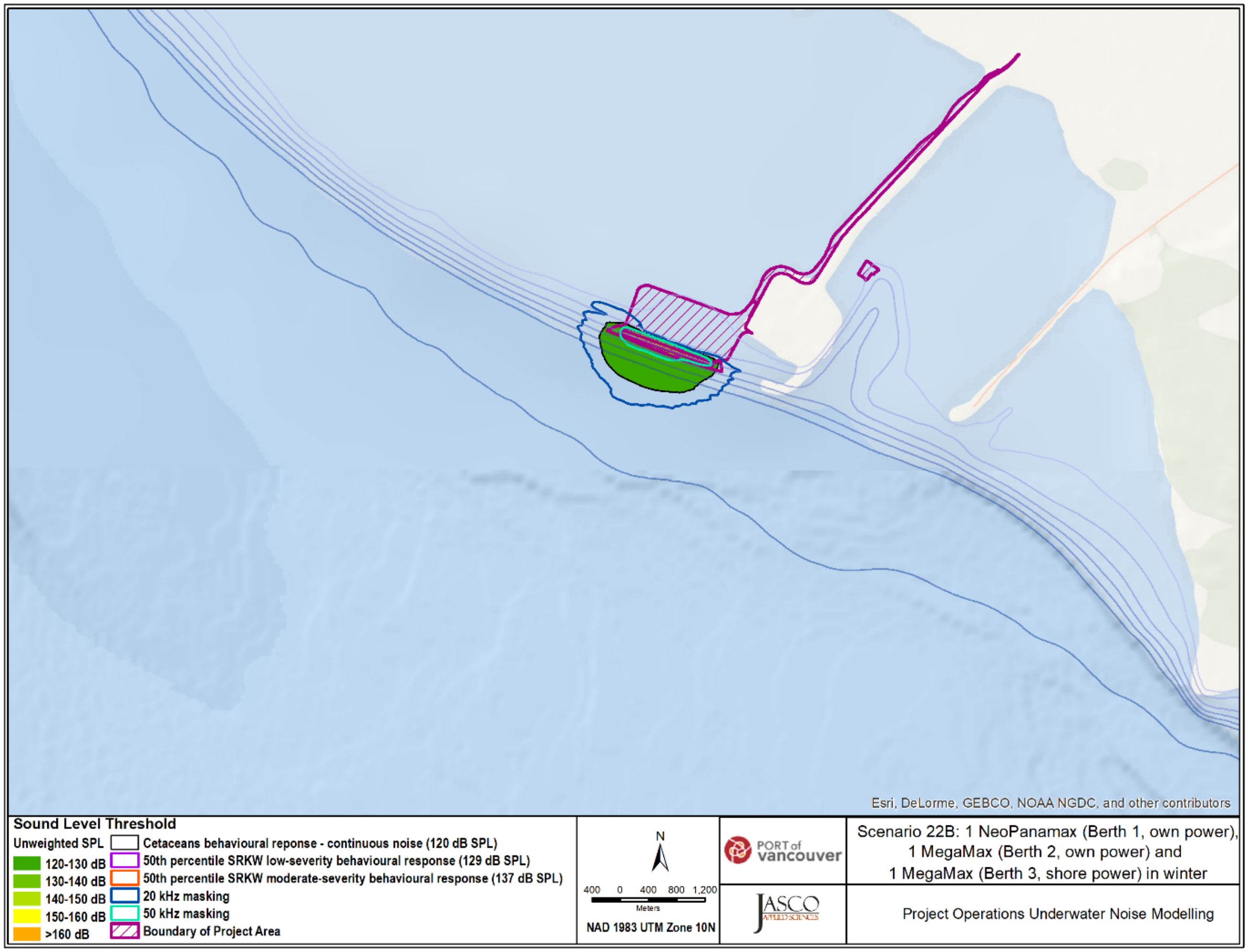


Figure 13. The acoustic model representing one Neo Panamax (Berth 1) and two Mega-Max (Berth 2 and Berth 3) container vessels, with one Mega-Max and the Neo Panamax on vessel power and the other Mega-Max on shore power, in winter (scenario 22B) for the different acoustic effect thresholds modelled (from MacGillivray *et al.* 2021, Appendix IR2020-3-C).



2.4.3. Acoustic Effects Model Implementation

The SRKW acoustic effects model integrates multiple sources of information, each of which carries its own uncertainties. Variability in input data translates into variability in the output metric (i.e., potential lost foraging time). Therefore, to provide a complete description of the distribution of potential lost foraging time, we implemented the calculation within a Monte Carlo simulation framework, and provided all results as means or as medians, with 95% confidence intervals based on 10,000 model iterations. Modelling methods differed for vessels in motion and vessels at berth (reflecting differences in acoustic footprint shapes due to noise propagation constraints along the berth face), thus information on model implementation is given separately for these two types of activities in the sections below.

2.4.3.1. Vessels in Motion

Here, we describe the pseudo-code implemented to calculate potential lost foraging time. For a given year, we:

1) Defined Project operation as either arrival or departure. Arrivals and departures will not occur on the same day (or night). Therefore, there will be two chances per container vessel call to overlap with a SRKW transit, first when the container vessel arrives and berths at the terminal and a second chance when the container vessel unberths and departs the terminal. Hence, we defined the number of annual vessel operations as twice the number of annual vessel calls (calculated as number of projected weekly calls presented in Table 3 times the number of weeks in a year (52)) and distributed them randomly throughout the year - equally between day and night, staggering arrivals and departures.

2) Assigned, for each arrival, whether the container vessel was approaching the terminal or berthing. We randomly drew from a binomial distribution, where the probability of drawing "Vessel Approach" is proportional to the duration of the activity (Table 4), where the activity is defined as either vessel approach or berthing:

   i. $p_{(\mathrm{VesselApproach|arrival})}$ = 49.2 minutes /(49.2 minutes + 30 minutes), and

   ii. $p_{(\mathrm{Berthing|arrival})}$ = 30 minutes /(49.2 minutes + 30 minutes).

   If vessel approach was selected, we then assigned if it corresponds to the first stage of vessel approach (i.e., container vessels and vessel-assist tugs are travelling to the point where they meet), or the second stage of vessel approach (i.e., container vessel is escorted by vessel-assist tugs to the terminal). We randomly drew from a binomial distribution, where the probability of drawing "First Stage" is proportional to the duration of the activity, where the activity is defined as either first stage or second stage of vessel approach during arrival:

   i. $p_{(\mathrm{FirstStage|VesselApproach})}$ = 25.2 minutes /(25.2 minutes + 24 minutes), and

   ii. $p_{(\mathrm{SecondStage|VesselApproach})}$ = 24 minutes /(25.2 minutes + 24 minutes)

3) Assigned, for each departure, whether the container vessel is departing or unberthing. We randomly drew from a binomial distribution, where the probability of drawing "Vessel Departure" is proportional to the duration of the activity, where the activity is defined as either vessel departure or unberthing:

   i. $p_{(VesselDeparture|departure)}$ = 45 minutes /(45 minutes + 30 minutes), and

   ii. $p_{(Unberthing|departure)}$ = 30 minutes /(45 minutes + 30 minutes).

   If vessel departure was selected, we then assigned if it corresponds to the first stage of vessel departure (i.e., container vessel is escorted by vessel-assist tugs from the berth face), or the second stage of vessel departure (i.e., container vessel travels to the outbound shipping lane and vessel-assist tugs travel back to the tug basin). We randomly drew from a binomial distribution, where the probability of drawing "First Stage" is proportional to the duration of the activity, where the activity is defined as either first stage or second stage:

   i. $p_{(FirstStage|VesselDeparture)}$ = 21 minutes /(21 minutes + 24 minutes), and

   ii. $p_{(SecondStage|VesselDeparture)}$ = 24 minutes /(21 minutes + 24 minutes)

4) Assigned corresponding acoustic Scenario ID presented in Table 6. Note that the combination of season, stage of operation, and source dictated the acoustic scenario to use.

5) Obtained, for each year and month, the number of expected SRKW transits as the 50th quantile of a normal distribution with monthly means and standard deviations presented in Table 1.

6) Applied effort and time of day correction factors to the resulting number of monthly expected transits. Distributed resulting monthly SRKW transits randomly over the month.

7) Randomly chose, for each transit, a CPA, proportional to the relative density of whales in Figure 3.

8) Randomly chose, for each transit, a SRKW pod/assemblage, proportional to the seasonal occurrence presented in Table 2.

9) Determined, for each transit, whether the SRKW transit occurred during the same day (or night) when there was a vessel operation. If,

   a) No → Potential lost foraging time for the transit = 0.

   b) Yes → Next step.

10) Determined, for each transit, whether the SRKW transit and vessel operation overlapped in time. We carried out a simulation where we considered that these could occur at any time during the day or night. We thus drew a start time for each from uniform distributions between 0 and 10 for day and 0 and 14 for night. Given these start times, and the length of time for the vessel operation (described in points 2 and 3 above) and the SRKW transit (defined as the length of time that it takes a SRKW swimming in a straight line at a constant speed of 1.6 m/s

to transverse the distance corresponding to the R95% of the appropriate acoustic scenario), determine if the vessel operation and the SRKW transit occurred at the same time. Repeated 50,000 times recording each time whether there was overlap and defined the probability of overlap $_{(poverlap)}$ as the ratio between the simulations where there was temporal overlap to the number of simulations. We finally drew randomly from a binomial distribution, where the probability of drawing "Overlap" is $_{poverlap}$. If,

a) No → Potential lost foraging time for the transit = 0.

b) Yes → Next step (#11).

11) Determined, for each selected transit, whether the SRKW transits and vessel operation overlapped in space (i.e., if the CPA assigned in step 5 overlapped with the acoustic effect zone of the corresponding acoustic scenario). The placement of the acoustic models in space was as follows:

    a) Vessel Approach, First Stage:

        i. Container vessel: outer edge of the 120 dB acoustic effect zone tangential to the inbound shipping lane.

        ii. Vessel-assist tugs: inner edge of the 120 dB acoustic effect zone tangential to the RBT2 terminal berth face.

    b) Vessel Approach, Second Stage: acoustic effect zone is centered halfway (perpendicular distance) between the RBT2 terminal berth face and the location where the container vessel exits the inbound shipping lane (point 1 in Map 4).

    c) Berthing and Unberthing: acoustic effect zones are represented by a semicircle centered on the RBT2 terminal berth face.

    d) Vessel Departure, First Stage: acoustic effect zone is placed in the same location as Vessel Approach, Second Stage.

    e) Vessel Departure, Second Stage:

        i. Container vessel: inner edge of the 120 dB acoustic effect zone tangential to the inbound shipping lane.

        ii. Vessel-assist tugs: inner edge of the 120 dB acoustic effect zone tangential to the RBT2 terminal berth face.

        Was there spatial overlap between vessel operation and SRKW transit?

        No → Potential lost foraging time for the transit = 0.

        Yes → Next step (#12).

12) Calculated, for each selected transit, the distance of each SRKW transit within each of the acoustic effect zones.

13) Converted, for each selected transit, the distance travelled within the relevant acoustic effect zones to potential lost foraging time and potential lost prey captures.
14) Repeated steps 1 to 13, 10,000 times.
15) Calculated the mean and 95% confidence intervals of potential lost foraging time and potential lost prey captures over the 10,000 Monte Carlo iterations.

2.4.3.2. Vessels at Berth

A new analysis was undertaken to understand the acoustic effects of vessels at berth. This consists of the time vessels are stationary at the terminal unloading and loading containers. The analysis included an assessment of the benefits of these vessels switching from vessel engine power to shore power. Given that the shapes of the acoustic footprints for vessels at berth (see Figure 10 through Figure 13) are ellipsoidal, we modified the modelling approach presented in the preceding section to incorporate the effects of each axis (i.e., parallel and perpendicular) of the acoustic footprints separately. The two axes of the acoustic footprints have different effects:

- The perpendicular axis (i.e., perpendicular to the terminal) affects the probability (yes/no) of spatial overlap between the acoustic footprint of a vessel (or multiple vessels) at berth and a SRKW transit given the SRKW transit's CPA (i.e., the distance from the berth face at which the interaction with the SRKW transit occurs).
- Given that there is spatial overlap between the acoustic footprint and a SRKW transit, the parallel axis affects the duration that a SRKW is exposed to noise of vessel(s) at berth.

Here, we describe the pseudo-code implemented to calculate potential lost foraging time. For a given year, we:

1) Randomly assigned day and time of vessel arrival at berth (by vessel class, see Table 3), assuming that vessels can arrive and depart at any time during the 24-hour period.
2) Calculated time of departure of each vessel, given its time of arrival (assigned in Step 1), and the expected length of stay of each vessel class at berth (Table 5).
3) Tracked number of vessels at berth during the elapsed year, imposing a limit of three simultaneous vessels at berth (see Section 2.4.2.2).
4) Assigned corresponding acoustic Scenario ID presented in Table 7, based on the number of vessels at berth.
5) Obtained, for each year and month, the number of expected SRKW transits as the 50th quantile of a normal distribution with monthly means and standard deviations presented in Table 1.
6) Applied effort and time of day correction factors to the resulting number of monthly expected transits. Distributed resulting monthly SRKW transits randomly over the month.

7) Randomly chose, for each transit, a CPA, proportional to the relative density of whales in Figure 3.
8) Randomly chose, for each transit, a SRKW pod/assemblage, proportional to the seasonal occurrence presented in Table 2.
9) Randomly assigned the day in which each SRKW transit occurred.
10) Randomly assigned a start time for each SRKW transit through the study area.
11) Calculated end time for the SRKW transit by conservatively assuming that the whales would have to swim through the largest potential acoustic footprint for vessels at berth (i.e., two Mega-Max and one Neo-Panamax on vessel power in winter; Scenario 22A, Table 7, Figure 12: Note that at 20 kHz, the radius of the acoustic footprint is 1170 m, i.e., the whales need to swim twice the radius to transit the entire footprint, which would be 2340 m).
12) Determined, for each transit, whether there was temporal overlap between SRKW transit and vessels at berth. If,
    a) No → Potential lost foraging time for the transit = 0.
    b) Yes → Next step.
13) For each selected SRKW transit, assessed if the transit overlapped spatially with the acoustic footprint of the vessel(s) at berth (i.e., $CPA \leq R95\%_{perpendicular}$):
    a) No → Potential lost foraging time for the transit = 0.
    b) Yes → Next step.
14) Calculated the distance of each selected SRKW transit within each of the acoustic effect zones, using $R95\%_{parallel}$.
15) Converted the distance travelled within the relevant acoustic effect zones to potential lost foraging time and potential lost prey captures.
16) Repeated steps 1 to 15, 10,000 times.
17) Calculated the median and 95% confidence intervals of potential lost foraging time and potential lost prey captures over the 10,000 Monte Carlo iterations.

2.5. Mitigation Evaluation

Mitigation effectiveness was evaluated for the four additional mitigation measures identified since the public hearing (see Section 1). For those mitigation measures evaluated by modelling (first three mitigation measures in the sections below), mitigation effectiveness was evaluated by comparing modelling results (impacts of vessel activities on SRKW potential lost foraging time and lost prey captures) with mitigation implemented and without mitigation ("no mitigation" scenario). A literature review was used to evaluate quiet tug technology. Methods, including modelling assumptions, are further described for each mitigation measure in the following sections.

2.5.1. Delayed Unberthing

Berthing and unberthing noise is generated primarily by the vessel-assist tugs pushing and pulling the container vessel into place. These activities generate the largest operational acoustic footprints among vessel activities (Table 6). To reduce potential acoustic disturbance effects from unberthing, we evaluated the potential benefits to SRKW of delayed unberthing (and subsequent departure of a container vessel), if a SRKW is detected near the proposed RBT2 terminal, until the SRKW has left the area. Detection of SRKW is a critical component of this mitigation measure; thus assumptions for the effectiveness of detection by different methods were made and scenarios adopting differing detection methods and combinations of methods were modelled. It was also important to estimate the frequency of operational delays that would result from delaying unberthing when SRKW are present to ensure that this mitigation measure would be feasible from an operational perspective.

To quantify the effectiveness of the delayed unberthing mitigation measure in reducing potential lost foraging time and prey captures, we implemented the delayed unberthing mitigation acoustic effects model scenario (described above) and compared it to the no mitigation scenario. This was conducted for both the most-realistic and high-case vessel scenarios (see Section 2.4).

We evaluated a SRKW detection system using methods covering different spatial scopes and evaluated the effectiveness. The detection methods evaluated included: 1) early detection (detections of SRKW within, or imminently expected to enter, the Strait of Georgia as reported by a variety of sources and methods); and 2) marine mammal observers (MMOs) (located at the RBT2 terminal). These detection methods rely primarily on visual observations and therefore would not likely be effective at night. These methods are summarized in the sections below and further details on MMO protocols are also described in Buren *et al.* (2021), Appendix IR2020-2.3-E.

For modelling of the delayed unberthing mitigation, it was assumed that:

- Detection efforts begin prior to the start of unberthing. If a SRKW is detected by any of the detection methods, unberthing is delayed, and therefore potential lost foraging time = 0;
- Early detection and MMOs can detect SRKW in daytime only (i.e., detection probability was applied only to daytime SRKW transits);
- MMO industry standard protocols are followed for the MMO detection method, and these are effective within ~3-4 km of the terminal; and
- No whale transits occur once unberthing has started. This is a reasonable assumption because the unberthing process is short in duration and SRKW transits in the vicinity of the terminal berth are rare (Table 4), thus there is a low chance of temporal overlap.

2.5.1.1. Early Detection

Early detection sources include visual and non-visual detections reported by various sources[3] (e.g., government, social media, whale watching enterprises). These sources could be reviewed (e.g., by an MMO) and inform the terminal operator whether a container vessel scheduled to unberth and depart could overlap with a transiting SRKW at Roberts Bank. Detection of SRKW from these sources is more dependable in summer than winter, and it was assumed that the detection rate during summer would be 75% (when many people are on or near the water) and 25% in winter (given that data from sightings networks are largely collected during summer; see Section 2.1).

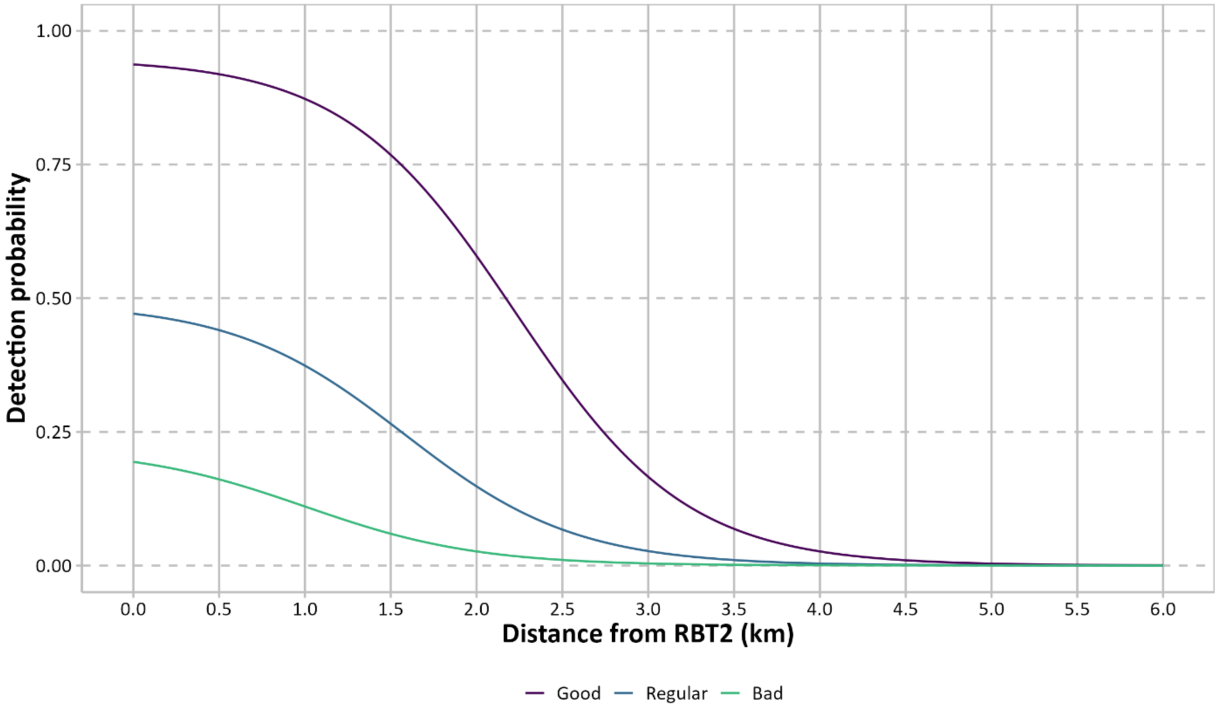
2.5.1.2. MMO Industry

Effectiveness of SRKW detection by MMOs stationed at the terminal during vessel unberthing depends on observation methods, distance of the SRKW from the terminal, and weather conditions. Detection probabilities used for incorporating MMO detection into this study were based on detection curves developed to represent typical MMO effort based on industry practices for construction monitoring (Buren *et al.* 2021, Appendix IR2020-2.3-E) which predict detection probabilities by distance and weather conditions (Figure 14). The probabilities predicted by these curves assume that MMO industry standard protocols are followed and that these are effective within ~3-4 km of the terminal (as described in Buren *et al.* 2021, Appendix IR2020-2.3-E). For the acoustic effects model, MMO detection probabilities were applied to SRKW transits that were not detected by initially early detection. Weather conditions were categorized and incorporated into modelling based on weather data for the Vancouver area from May 2013 to March 2020 from the Canada Weather Stats website (ECCC 2020, https://www.weatherstats.ca/), as described in Buren *et al.* (2021), Appendix IR2020-2.3-E.

---

[3] Early detection sources could include shared sightings by the Canadian Coast Guard (i.e., Marine Mammal Desk), community groups (e.g., Saturna Islanders), near real-time whale notifications to commercial vessel operators via the BC Cetacean Sightings Network's Whale Report Alert System application, or detections by hydrophones such as from DFO's Whale Tracking Network, Transport Canada's Underwater Listening Station in Boundary Pass, Oceans Network Canada, Department of National Defence, or Saturna Island Marine Research and Education Society (SIMRES).

Figure 14. Probability of detecting SRKW following industry protocols for MMOs, as a function of perpendicular distance from RBT2 in three weather conditions.



2.5.1.3. Additional Acoustic Detection Method

We also evaluated the effectiveness of a passive acoustic monitoring (PAM) system to enable the port authority to determine if this additional detection method would be feasible for project operation. PAM is a monitoring method commonly used during seismic surveys or to increase detection probability of marine mammals during periods of low visibility and darkness (Compton *et al.* 2008, DFO 2015, Verfuss *et al.* 2018, Smith *et al.* 2020). Its effectiveness, however, depends on vocalizations and detectability of these over ambient noise conditions. For this detection method, we assumed a 75% detection rate at a radial distance of 6 km from the RBT2 terminal both during the day and at night (see Buren *et al.* 2021, Appendix IR2020-2.3-E, for further details and rationale for the selected detection rate). To evaluate the additional effectiveness of implementing a PAM system, the three detection methods were applied in a hierarchical fashion selecting the method with the furthest detection ability first. For each SRKW transit, we first applied early detection (spatial scope: Strait of Georgia), followed by the PAM system (~ 6 km detection range) and then MMOs (~3-4 km detection range).

2.5.1.4. Frequency of Unberthing Delays

Estimation of the frequency of operational delays due to SRKW presence in the applicable acoustic effect zones informs the evaluation of feasibility of the proposed mitigation measure from an operational perspective. We assumed for this estimate that efforts to detect SRKW in the area would begin two hours prior to unberthing, and that the area encompassed would have a radius of at least five km from the berth face. Thus, we set the duration of the unberthing operation (this affects the probabilities described in steps 2, 3, and 9 in the pseudo-code presented in Section 2.4.3.1) to 2.5 h. To calculate the length of time that it would take a transiting SRKW to travel across the area of interest (i.e., to estimate the probability of overlap between a SRKW transit and unberthing described in step 9 of the pseudo-code presented in Section 2.4.3.1), we considered the SRKW transit to be 10 km in length (i.e., twice the radial distance of interest (5 km)) in summer, and 16.92 km in length in winter (i.e., twice the R95% radius of the corresponding acoustic scenario). We reran the Monte Carlo simulation described in Section 2.4.3.1 with the appropriate durations of SRKW transits and vessel unberthing, and then calculated the mean and 95% confidence intervals of the number of operational delays over the 10,000 Monte Carlo iterations.

2.5.2. Reduced Tug Transit Speed

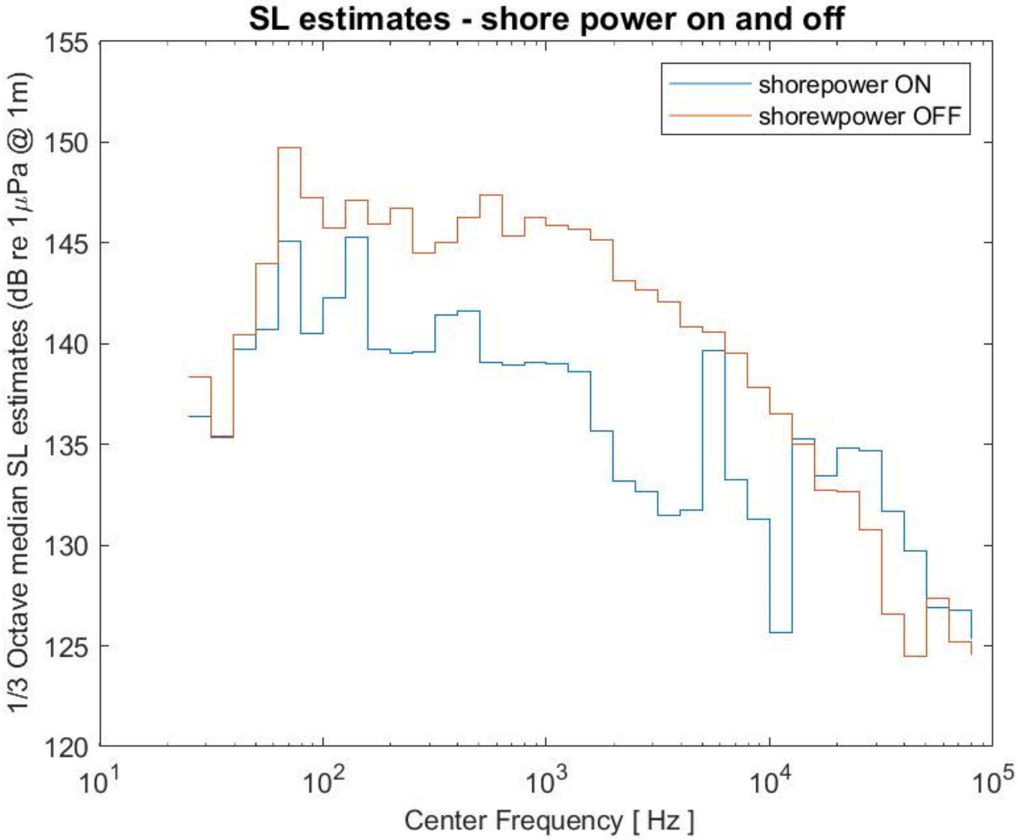
Vessel speed influences underwater noise, with slower transiting speeds resulting in less noise. Vessel slowdowns have been demonstrated as an effective mitigation measure for reducing underwater noise (MacGillivray *et al.* 2020). Speed reductions can also reduce noise from transiting tugs. Tugs travelling at 5 knots instead of 8 knots while transiting to and from the container vessel could have an estimated noise reduction of ~3.7 dB (based on tug source levels recorded by the ECHO Program during the 2017 slowdown trial; MacGillivray and Li 2018) to 12.2 dB (based on source levels for support tugs measurements made of the berthing tug Seaspan Resolution collected at Roberts Bank (Warner *et al.* 2013) and the trend report by Ross (1987) (MacGillivray *et al.* 2021)). For this study, we developed acoustic models for mitigation scenarios reflecting the underwater noise footprints of vessel-assist tugs under two different noise reduction effectiveness assumptions (MacGillivray *et al.* 2021; Table 6). Based on these two assumptions, two noise reduction effectiveness scenarios were modelled that considered vessel-assist tugs travelling at a reduced speed of 5 knots representing: 1) an average 3.7 dB noise reduction (i.e., low mitigation effectiveness scenario); and 2) an optimistic scenario of 12.2 dB reduction (i.e., high mitigation effectiveness scenario). We estimated the effectiveness of these two mitigation effectiveness scenarios by comparing acoustic effects model outputs of these two scenarios to the no mitigation scenario. We conservatively estimated the acoustic effects considering only iterations of the simulation when there was a spatiotemporal overlap between SRKW transits and vessel-assist tug transits (i.e., did not consider all the times when there would be no overlap). The two mitigation effectiveness scenarios were assumed to be implemented from July 1st to October 31st, reflecting the period associated with the ECHO Program voluntary Haro Strait and Boundary Pass slowdown initiative in 2020 (VFPA 2021a).

2.5.3. Shore Power Connections

Vessels at berth have on-board machinery and equipment in operation that can contribute underwater noise within a localised area near the terminal (although noise produced by vessels at berth is lower relative to that generated by vessels in motion). The port authority is proposing to provide shore power for vessels equipped for plugging into land-based electric power. To assess the potential underwater noise reductions from shore power and potential effects on SRKW, we compared the range of the acoustic effects and then quantified the difference in potential lost foraging time of SRKW from transits predicted within the acoustic effect zones with and without shore power. We conservatively estimated the acoustic effects considering only iterations of the simulation when there was a spatiotemporal overlap between SRKW transits and vessels at berth (i.e., did not consider all the times when there would be no overlap).

To conduct this analysis, we first combined data from two recent source level studies. In the first study, the monopole source level of a container vessel at berth relying on onboard engines was measured at the Deltaport terminal (Warner *et al.* 2013) and a broadband value of 167 dB re 1 µPa @ 1 m was recorded. In the second study, container vessel source levels were measured at the Centerm terminal off and on shore power, with a resulting broadband difference of 5.8 dB (Angadi *et al.* 2020) (Figure 15). As shown in Figure 15, results of this study indicated that switching to shore power results in noise reductions between 100-10,000 Hz, but not at higher frequencies (such as 20 kHz and 50 kHz identified as SRKW echolocation click masking thresholds). JASCO Applied Sciences developed new acoustic models of vessels at berth, off and on shore power, following the methodology described in MacGillivray *et al.* (2021, Appendix IR2020-3-C). The models were used to estimate the reduction in the range (radii) for the behavioural response and echolocation click masking thresholds presented in Table 7.

Figure 15. **Median source levels in 1/3 octave for a container vessel at berth at Centerm terminal OFF and ON shore power (figure reproduced from Angadi *et al.* 2020).**



Because not all vessels may have shore power capabilities, assessment of shore power mitigation effectiveness through modelling required that assumptions were made regarding the use of shore power by vessels. It is difficult to predict the percentage of container vessels that will switch to shore power in the future. However, given incentives provided by the port authority for vessels (terminals are becoming equipped with shore power connections and there is a trend towards increasing requirements to reduce air emissions), there have been recent increases in the number of vessels equipped with shore power capabilities. For this study, the mitigation scenarios modelled assumed that 30% of container vessels would connect to shore power. This was based on the proportion of vessels (34%) currently calling at the Port of Vancouver that have shore power capability (VFPA 2021b). To assess the effectiveness of this mitigation measure using the acoustic effects model, we randomly assigned if the ship was provided with shore power (binomial random draw with probability of success 0.3) for each overlap between a SRKW transit and vessels at berth. Based on the models described in Table 7, only one of the vessels at berth was provided with shore power, independent from the number of vessels at berth when the overlap occurred.

2.5.4. Quiet Tug Technology

The port authority has proposed to evaluate the potential effectiveness of technologies to reduce underwater noise associated with tug activities (e.g., hybrid or electric tugs) and to implement these once feasible for the project. We conducted a literature review to evaluate the potential noise reductions from quieter tugs to reduce underwater noise associated with berthing and unberthing activities. We used Google Scholar to perform a search for articles using the search terms: tug, vessel, ship, electric, hybrid, and noise. Thirty-four studies were retained and relevant information on noise reduction potential from quiet vessels was extracted and compiled (Appendix A).

2.6. Assessing Uncertainty in SRKW Response

Uncertainty in the severity of the effect was explored by re-running the acoustic effects models for vessels in motion assuming that the SRKW exhibit a higher probability of disturbance than the mean (i.e., the probability of response occurs at a lower noise level). We examined vessels in motion (arrival, berthing, unberthing, and departure) as these activities were associated with most of the lost foraging time attributable to the project. We considered the acoustic effects modelled for vessels in motion with no mitigation and with mitigation, specifically delayed unberthing. For these more conservative scenarios, the probability of response coefficients was derived from the upper confidence interval (dashed line to the left of the solid blue line representing the median response curve in Figure 4) of the low behavioural response dose-response curve (as opposed to the values used for the Mid-point scenario). This approach resulted in the following response coefficients:

- 0.93 (93rd percentile response), representing the mid-point between the 86th percentile and 100th percentile probability of response for the acoustic zone than encompasses 137 dB and higher;
- 0.73 (73rd percentile response), representing the mid-point between the 60th percentile and 86th percentile probability of response, for the acoustic zone encompassing 129 to 136 dB;
- 0.39 (39th percentile response), representing the mid-point between the 17th percentile and 60th percentile probability of response, for the acoustic zone encompassing 120 to 129 dB; and
- 0.085 (8.5th percentile response), representing the mid-point between no response and the 17th percentile probability of response, for the echolocation click masking zone.

This more conservative approach was termed “Upper Confidence Interval” and is considered by this study an upper bound estimate of potential acoustic effects to SRKW.

3. RESULTS

This section presents the results of the analyses conducted to quantify potential acoustic effects of Project-related underwater noise on SRKW during operation and assess the predicted effectiveness of the mitigation measures identified since the review panel completed their report. In the sections below, we first quantify acoustic effects to SRKW based on Project operation container vessel projections and defined vessel activities with no mitigation for both the most-realistic and high-case scenarios (Section 3.1). We then compare unmitigated expected acoustic effects (potential lost foraging time and lost prey captures due to effects of noise on behavioural response and echolocation click masking) to expected acoustic effects when delayed unberthing, reduced tug speed, and shore power mitigation measures are implemented based on predictions from the acoustic effects model (Section 3.2). We also describe the findings from the literature review for quiet tugs. For evaluation of the delayed unberthing mitigation measure, results are presented for both the most-realistic case and the high-case vessel scenarios, and estimates of frequency of operational delays resulting from delayed unberthing are presented to inform the port authority's evaluation of the feasibility of this mitigation measure. Following this, we present the assessment of uncertainty in the severity of the behavioural response effects (Section 3.2.5).

3.1. Acoustic Effects on SRKW Based on Project Operation and Container Vessel Projections

3.1.1. Vessels in Motion

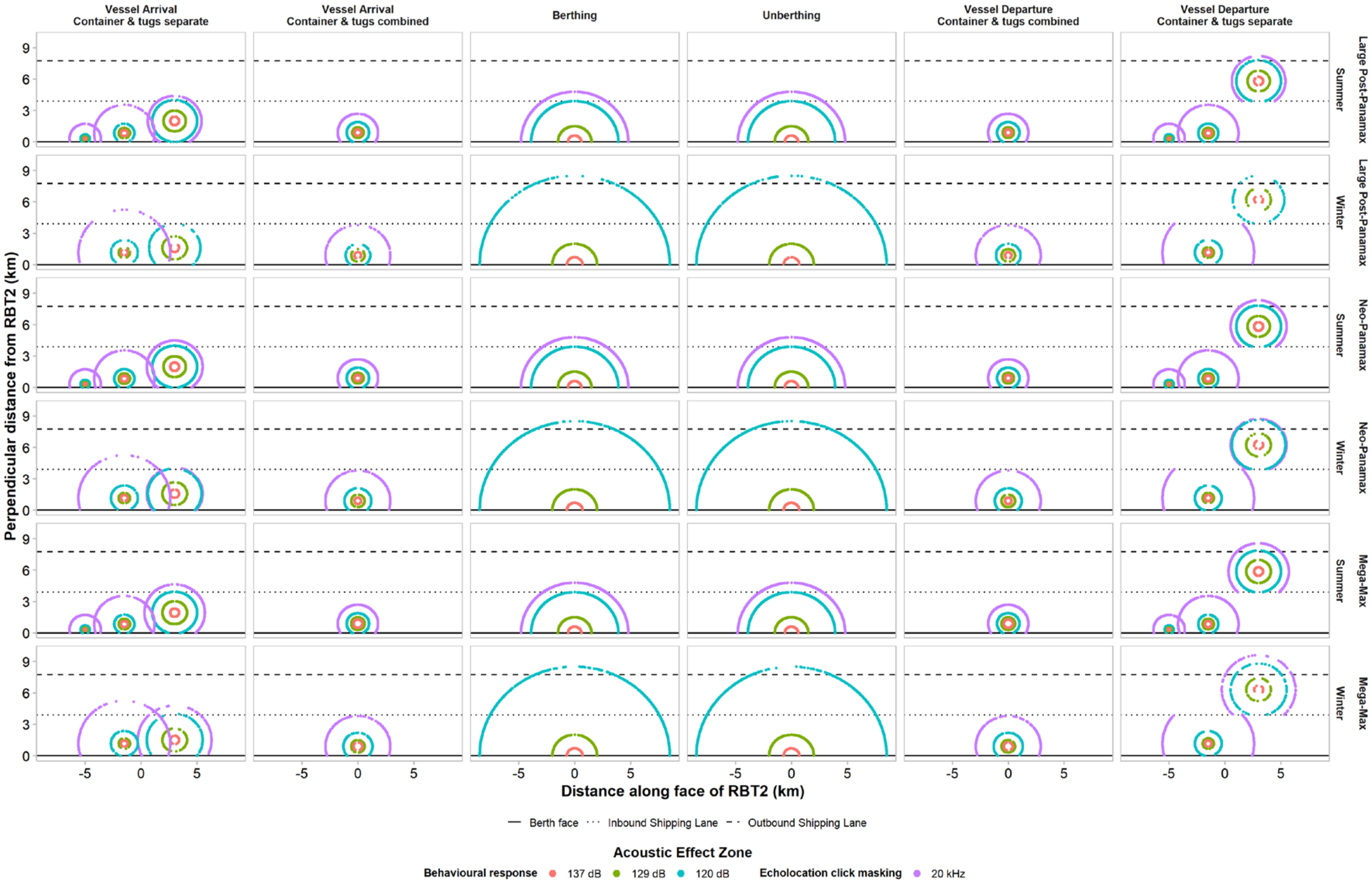
During Project operation, container vessels will arrive, berth, unberth, and depart RBT2 with the support of vessel-assist tugs. Noise generated from these activities has the potential to acoustically affect SRKW. Figure 16 illustrates the spatiotemporal overlaps predicted by the acoustic effects model for vessels in motion under the most-realistic vessel scenario. Specifically, the figure presents the predicted overlap between SRKW transits and Project operation, reflecting the acoustic effect zones (behavioural response and echolocation click masking) of the different stages of operation (i.e., arrival, berthing, unberthing, and departure), which generate underwater noise. Figure 16 also presents results by vessel class (Large Post-Panamax, Neo-Panamax, and Mega-Max) and season (summer and winter). For example, the interaction between SRKW transits and vessel operation for the Mega-Max vessel class are shown in the last two rows of Figure 16 for the six stages of operation (from arrival to departure), with container vessel and vessel-assist tugs during arrival and departure travelling separately (i.e., during initial arrival) or together (i.e., when travelling together to the berth face). Note that echolocation click masking zones (20 kHz; purple circles in Figure 16) were encompassed within the behavioural response acoustic effect zones (i.e., 137 dB, 129 dB, and 120 dB; red, green, and blue circles, respectively, in Figure 16) for berthing and unberthing in winter and for Large Post-Panamax container vessels travelling alone in winter and are therefore not visible in Figure 16.

The largest acoustic effect zones are associated with berthing and unberthing in winter (Figure 16). The acoustic effect zones of the different container vessel classes, both when container vessels and vessel-assist tugs are travelling separately or together, were similar, particularly for the behavioural response acoustic effect zones (i.e., 137 dB, 129 dB, and 120 dB). There were some differences in the echolocation click masking (20 kHz) acoustic effect zones among container vessel classes (when acoustic footprints of vessel and vessel-assist tugs are separate): the zones were largest for Mega-Max vessels and smallest for Large Post-Panamax vessels. The acoustic effect zones of berthing and unberthing were larger than those of container vessels transiting alone. The smallest behavioural response acoustic effect zones were those of vessel-assist tugs transiting alone, whereas the smallest echolocation click masking acoustic effect zones were those of container vessel escorted by vessel-assist tugs, independent of season.

Figure 16 also shows the predicted effectiveness of the mitigation measure to reduce speeds of vessel-assist tugs transiting back and forth from the tug basin to assist the container vessel during arrival and departure. The acoustic effect zones of the two scenarios, one with vessel-assist tugs travelling at normal speed (8 kn) and the other with tugs travelling at reduced speeds (5 kn, high mitigation effectiveness scenario), are shown during arrival and departure for the summer season for all vessel classes, in the left-most and right-most panels of the figure. The comparison is only made for the summer season, given that this mitigation was assumed to be implemented between July 1st and October 31st. The acoustic effect zones of the vessel-assist tugs with reduced speeds are smaller than those of the tugs with normal speed.

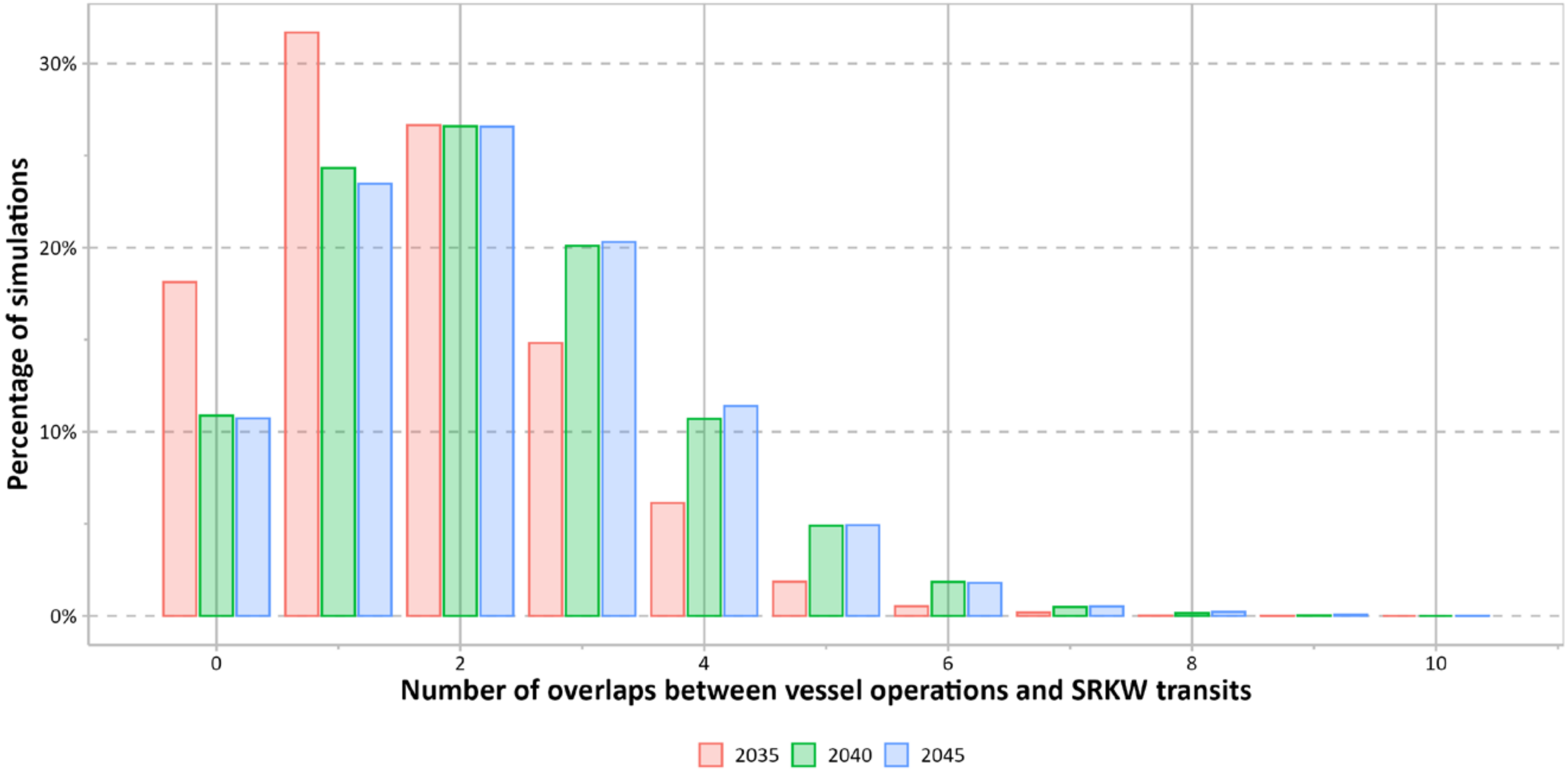
It should be noted that whether or not the proposed mitigation of delaying container vessels from unberthing and departure during daytime hours when SRKW are present is applied would not affect the outcome of the results presented in Figure 16 because changes in timing, which affects the number of spatial interactions, would only affect the number of data points that the zones (circles) are composed of, not the sizes of the zones.

Figure 16. Acoustic effect zones for SRKW behavioural response and echolocation click masking (20 and 50 kHz) from Project operation by vessel class and season. Note that the acoustic effect zones are obtained as output of the acoustic effects model Monte Carlo simulation, i.e., these represent instances where there was overlap between SRKW transit and Project operation. The acoustic effect zones of both container vessels and support tugs are shown in the left-most and right-most columns (vessel arrival and departure, container and tugs separate). The vessel-assist tugs can be distinguished from container vessels in these panels by their much smaller 120 dB effect zones. The smallest zones in these left-most and right-most columns in summer represent slowed tugs from July to October, representing the reduced tug speed mitigation (high mitigation effectiveness scenario). Details of model scenarios, including vessel speeds, are shown in Table 6.



Killer whales are exposed to underwater noise only when there is spatiotemporal overlap between the SRKW transit and the acoustic footprint of a noise generating Project operational activity. The relative frequency of realized SRKW transits that were predicted to overlap with each individual stage of vessel operation was low. For example, for the most-realistic vessel scenario, there was only one overlap between a SRKW transit and vessel berthing in ~32% of the 10,000 simulations in 2035, and in ~24% of the simulations in 2040 and 2045 (Figure 17). Two overlaps occurred in ~26% of simulations across all three years. When one includes the percent of simulations shown in Figure 17 where no overlap occurred, then in 60-76% of all 10,000 simulations, two or less overlaps occurred per year (Figure 17). The lower predicted frequency of overlap in the year 2035 is due to the lower number of projected vessels calling at RBT2. For any one stage of Project operation, the maximum number of overlaps ranged between two to five per season (i.e., summer or winter). This was expected given the short temporal duration of each operational stage and that even during the period when SRKW are most commonly sighted in the area (i.e., summer season), SRKW are predicted to transit through the study area approximately once every three days. There was a small increase in the relative frequency of overlaps predicted to occur between 2035 and 2040; however, there was little difference in predictions between 2040 and 2045. The relative frequency of overlaps was predicted to be higher in summer than in winter due to higher SRKW use of the area during the summer. The relative frequency of overlap between SRKW transits and berthing and unberthing was similar. The relative frequency of overlap between SRKW transits and vessel arrival or departure was consistently lower than the overlap with berthing or unberthing; even when considering both stages of arrival or departure (i.e., summing across first and second stage of vessel arrival or departure). The frequency of overlap between SRKW transits and vessel arrival or vessel departure (when overlaps between SRKW and vessel operations did occur) was ~25% lower in summer and ~55% lower in winter than the relative frequency of overlap with berthing or unberthing.

Figure 17. Frequency of spatiotemporal overlaps between vessel operations (arrival, berthing, unberthing and departure) and SRKW transits, and numbers of overlaps predicted, for 2035, 2040, and 2045, without mitigation, by the acoustic effects model for the most-realistic vessel scenario.



Under the most-realistic vessel scenario, the predicted mean annual potential lost foraging time per SRKW (i.e., combining lost foraging time caused by behavioural response and echolocation click masking) for vessels in motion, prior to implementing mitigation (i.e., no mitigation scenario), was 1.5 hours (95% confidence interval: 0 – 9.0 hours) in 2035, 2.3 hours (0 – 10.5 hours) in 2040, and 2.4 hours (0 – 10.4 hours) in 2045 (Table 8). This equates to approximately two potential lost prey captures per SRKW per year (Figure 18). The contribution of behavioural response to the overall estimate of potential lost foraging per SRKW ranged from 1.4 hours (0 – 8.6 hours) in 2035 to 2.2 hours (0 – 10.1 hours) in 2040 and 2045, i.e., approximately 90%. In contrast, the contribution of potential lost foraging time due to echolocation click masking beyond the 120 dB behavioural response acoustic effect zone was 0.1 hours (0 – 0.6 hours) in 2035 and 0.1 hours (0 – 0.7 hours) in 2040 and 2045, i.e., approximately 10% (Table 8, Figure 18).

The operational activities that were predicted to result in the largest amount of potential lost foraging time were berthing and unberthing (each amounting to under 1 hour of potential lost foraging time per SRKW per year), followed by vessel arrival and departure (in both cases considering the stage when the vessel container and vessel-assist tugs are travelling separately), whereas the potential lost foraging time predicted to be caused by the container vessel travelling with vessel-assist tugs was much less (Figure 18). The estimated amount of potential lost foraging time from Project operation also differed by season. The predicted mean potential lost foraging time, averaged across the three years modelled, was higher in summer (1.22 hours (0 – 5.3 hours)) than in winter (0.85 hours (0 – 4.6 hours)).

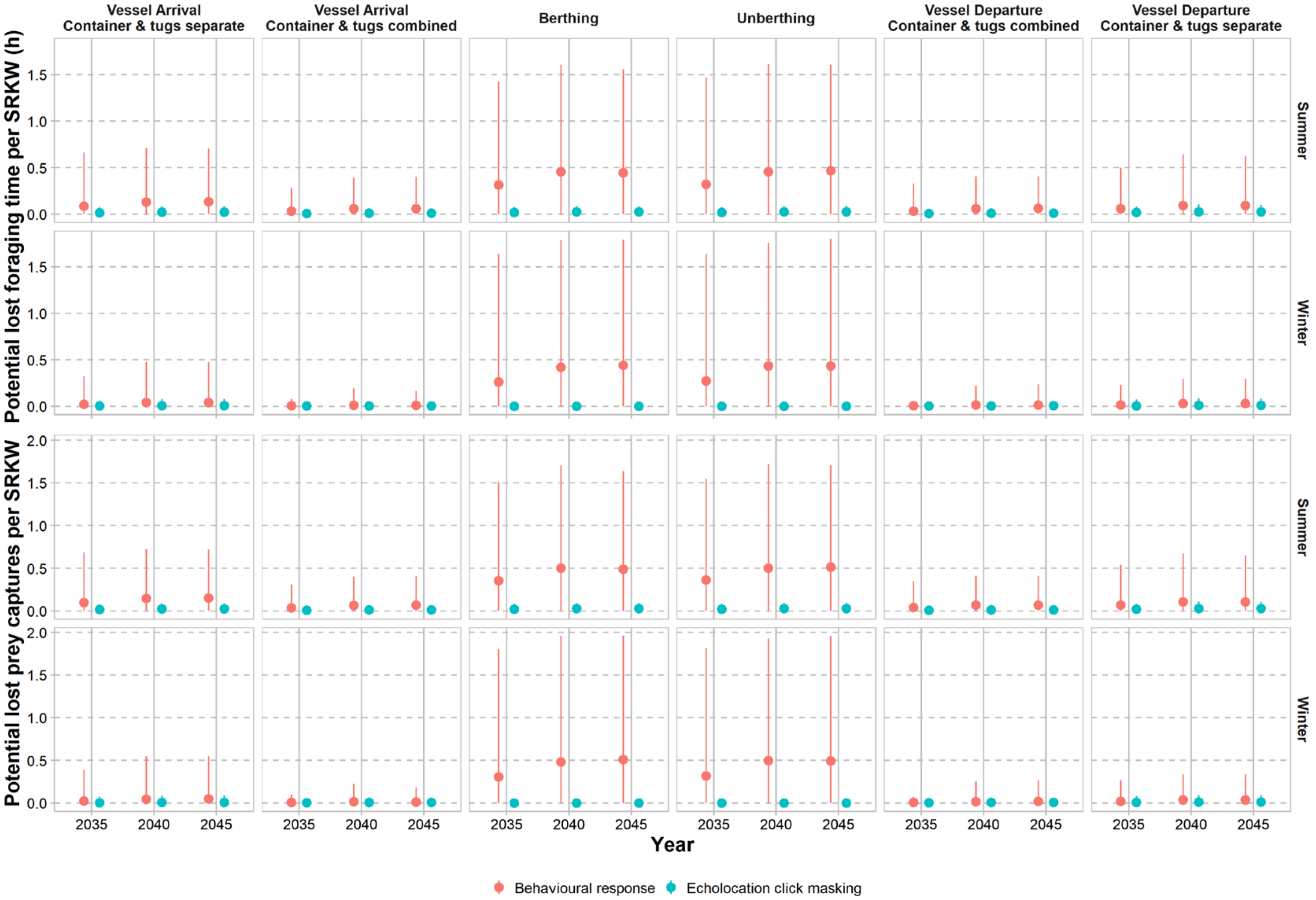
Under the high-case vessel scenario, the predicted mean potential lost foraging time per SRKW, prior to implementing mitigation, was 2.4 hours (0 – 10.4 hours) in 2035, 3.3 hours (0 – 11.4 hours) in 2040, and 3.3 hours (0 – 11.4 hours) in 2045 (Table 8). This equates to approximately three potential lost prey captures per SRKW per year. The contribution of behavioural response to the overall estimate of potential lost foraging per SRKW ranged from 2.3 hours (0 – 10.0 hours) in 2035 to 3.1 hours (0 – 11.1 hours) in 2045, i.e., approximately 90%, whereas the contribution of potential lost foraging time due to echolocation click masking beyond the 120 dB acoustic effect zone ranged from 0.1 hours (0 – 0.7 hours) in 2035 to 0.2 hours (0 – 0.8 hours) in 2040 and 2045, i.e., approximately 10%.

All the patterns described above were identical for potential prey losses per SKRW, irrespective of the projection year assessed (i.e., 2035, 2040, 2045). Further, the patterns of variation in the estimated potential prey losses per SRKW mirrored the patterns of variation in potential lost foraging time per SRKW (Figure 18). Henceforth, we present results in terms of potential lost foraging time per SRKW only.

Table 8. **Estimated potential lost foraging time (mean hours (95% confidence interval) per SRKW per year from vessels in motion based on the most-realistic vessel scenario and the less likely high-case vessel scenario in 2035, 2040, and 2045, accounting for additional echolocation click masking beyond the behavioural disturbance threshold of 120 dB based on the largest modelled masking acoustic footprint (i.e., at 20 kHz). Potential lost foraging time estimates are rounded to one decimal place.**

Scenario	Thresholds	Estimated potential lost foraging time (hours) per SRKW per year		
		2035	2040	2045
Most-realistic	Behavioural disturbance	1.4 (0-8.6)	2.2 (0-10.1)	2.2 (0-10.1)
	Echolocation click masking at 20 kHz	0.1 (0-0.6)	0.1 (0-0.7)	0.1 (0-0.7)
	Total for thresholds combined	1.5 (0-9.0)	2.3 (0-10.5)	2.4 (0-10.4)
	Projected weekly calls at RBT2	3	4	4
	Projected annual calls at RBT2	156	208	208
High-case	Behavioural disturbance	2.3 (0-10.0)	3.1 (0-11.0)	3.1 (0-11.1)
	Echolocation click masking at 20 kHz	0.1 (0-0.7)	0.2 (0-0.8)	0.2 (0-0.8)
	Total for thresholds combined	2.4 (0-10.4)	3.3 (0-11.4)	3.3 (0-11.4)
	Projected weekly calls at RBT2	4	5	5
	Projected annual calls at RBT2	208	260	260

Figure 18. Potential lost foraging time per SRKW and potential lost prey captures per SRKW per year, by season and vessel operation stages (mean and 95% confidence intervals), predicted by the acoustic effects model for 2035, 2040, and 2045, without mitigation, for the most-realistic vessel scenario. Colours represent different acoustic effect zones.



3.1.2. Vessels at Berth

During Project operation, container vessels will remain at berth while containers are unloaded and loaded. Noise generated from vessels at berth has the potential to affect SRKW by reducing their foraging time. Under the most-realistic vessel scenario, the average annual predicted median potential lost foraging time per SRKW across the three years modelled (i.e., combining lost time caused by behavioural response and echolocation click masking), prior to implementing mitigation (i.e., no mitigation), was ~6.8 minutes (95% confidence interval: 0.1 – 31.6 minutes) for vessels at berth. As observed for vessels in motion, the contribution of behavioural response to the overall estimate of potential lost foraging time per SRKW was greater (87% of total) than for echolocation click masking. The total predicted median potential lost foraging time was predicted to be slightly lower in winter (1.5 minutes (0 – 9.3 minutes)) than in summer (5.3 minutes (0.1 – 22.3 minutes)). These estimates are considerably smaller than for the vessels in motion (hence presented in minutes instead of hours). They reflect that overlaps between SRKW transits and behavioural disturbance acoustic effect zones are short-term and that most overlaps are with the echolocation click masking zone acoustic effect zone (therefore only 5% of exposure time is accrued as potential lost foraging time).

Under the less likely high-case vessel scenario for vessels at berth, the total predicted median potential lost foraging time per SRKW (i.e., combining lost time caused by behavioural response and echolocation click masking), prior to implementing mitigation (i.e., no mitigation), was 8.9 minutes (0.2 – 38 minutes). As observed for vessels in motion and for the most-realistic scenario for vessels at berth, the contribution of behavioural response to the overall estimate of potential lost foraging per SRKW was greatest (88% of total) than for echolocation click masking. The total predicted median potential lost foraging time was predicted to be slightly lower in winter (1.8 minutes (0 – 10.5 minutes)) than in summer (7.2 minutes (0.1 – 27.5 minutes)).

3.1.3. All Project Operation

For the most-realistic vessel scenario, Project operation (vessels in motion and vessels at berth combined) was predicted to result in a total potential lost foraging time of 2.2 hours (0 – 10.5 hours) per SRKW per year on average across the three years modelled, without mitigation (Table 9). The estimate considered potential acoustic effects from behavioural response (120 dB behavioural disturbance threshold) and echolocation click masking (i.e., at the 20 kHz). Behavioural response to underwater noise is predicted to contribute a total of 2.0 hours (95% confidence interval: 0 – 10.1 hours) of lost foraging time per SRKW per year, without mitigation. Accounting for total echolocation click masking increased the estimated lost foraging time by 0.1 to 0.2 hours (6 to 12 minutes) per SRKW per year, depending on the year modelled, when compared to estimates based on behavioural disturbance thresholds alone.

Under the less likely high-case scenario, the estimated total potential lost foraging time was approximately one hour higher (3.2 hours per year (0 – 11.7 hours)) than under the most-realistic scenario, which is attributable to one more Mega-Max vessel calling RBT2 weekly, without mitigation (Table 9). Total echolocation click masking contributed 0.2 hours (12 minutes) per SRKW per year, whereas behavioural response contributed the most at 3.0 hours (0 – 11.3 hours)) to the total estimate on average across the three years modelled.

Table 9. Estimated potential lost foraging time (mean hours (95% confidence interval)) per SRKW per year from all Project operation based on the most-realistic vessel scenario and the less likely high-case vessel scenario in 2035, 2040, and 2045, accounting for additional echolocation click masking beyond the behavioural disturbance threshold of 120 dB based on the largest modelled masking acoustic footprint (i.e., at 20 kHz). Potential lost foraging time estimates are rounded to one decimal place.

Scenario	Thresholds	Estimated potential lost foraging time per SRKW per year (hours)			
		2035	2040	2045	Average
Most-realistic	Behavioural disturbance	1.5 (0-9.0)	2.3 (0-10.6)	2.3 (0-10.6)	2.0 (0-10.1)
	Echolocation click masking at 20 kHz	0.1 (0-0.7)	0.2 (0-0.8)	0.2 (0-0.8)	0.1 (0-0.7)
	Total for thresholds combined	1.6 (0-9.5)	2.5 (0-11.1)	2.5 (0-11.0)	2.2 (0-10.5)
	Projected weekly calls at RBT2	3	4	4	
	Projected annual calls at RBT2	156	208	208	
High-case	Behavioural disturbance	2.4 (0-10.5)	3.3 (0-11.6)	3.2 (0-11.7)	3.0 (0-11.3)
	Echolocation click masking at 20 kHz	0.2 (0-0.8)	0.2 (0-0.9)	0.2 (0-0.9)	0.2 (0-0.8)
	Total for thresholds combined	2.5 (0-10.9)	3.5 (0-12.1)	3.4 (0-12.1)	3.2 (0-11.7)
	Projected weekly calls at RBT2	4	5	5	
	Projected annual calls at RBT2	208	260	260	

3.2. Mitigation Evaluation

3.2.1. Delayed Unberthing

Delaying unberthing of container vessels from the Project terminal when SRKW are present would reduce potential lost foraging time, particularly in summer (Figure 19, Figure 20). We assessed the effectiveness of implementing the unberthing delays for three different SRKW detection methods: 1) use of early detection in the daytime (SRKW detected within, or imminently expected to enter, the Strait of Georgia as reported by a variety of sources and methods and monitored in daytime); 2) use of early detection (daytime only) and MMOs located at the RBT2 terminal for daytime departures, and 3) use of early detection (daytime only), MMOs (daytime only), with the option of adding a PAM system. Results are presented for these three detection mitigation methods for both the most-realistic and high-case vessel scenarios.

3.2.1.1. Most-Realistic Vessel Scenario

Use of combined SRKW detection methods increased the effectiveness of the delayed unberthing mitigation measure. Implementing unberthing delays based on early detection and MMOs reduced potential lost foraging time from vessels in motion by ~20 minutes (or 16%) per SRKW per year on average for the three years modelled from an estimated ~2.1 hours (95% confidence interval: 0 – 10.0 hours) to ~1.7 hours (0 – 9.5 hours) per SRKW per year. This assumes SRKW detection rates of 25% in winter and 75% in summer for the early detection method, and the application of industry standard protocols for MMOs. Use of a PAM system, which would allow for delayed unberthing both day and night, would provide an additional reduction of approximately 17 minutes (Table 10, Figure 19), assuming a 75% detection rate for a radial distance of 6 km from the RBT2 terminal.

The reductions in potential lost foraging time were greater in summer than winter (Figure 19). For example, in summer, potential lost foraging time due to unberthing was reduced by approximately 14 minutes, from 0.4 hours (0 – 1.6 hours) to 0.2 hours (0 – 1.2 hours) per SRKW per year, when mitigation was implemented with early detection and MMOs. In winter, potential lost foraging time due to vessel unberthing was reduced from 0.4 hours (0 – 1.7 hours) to 0.3 hours (0 – 1.7 hours) per SRKW per year when mitigation was implemented with the early detection and MMOs.

3.2.1.2. High-Case Vessel Scenario

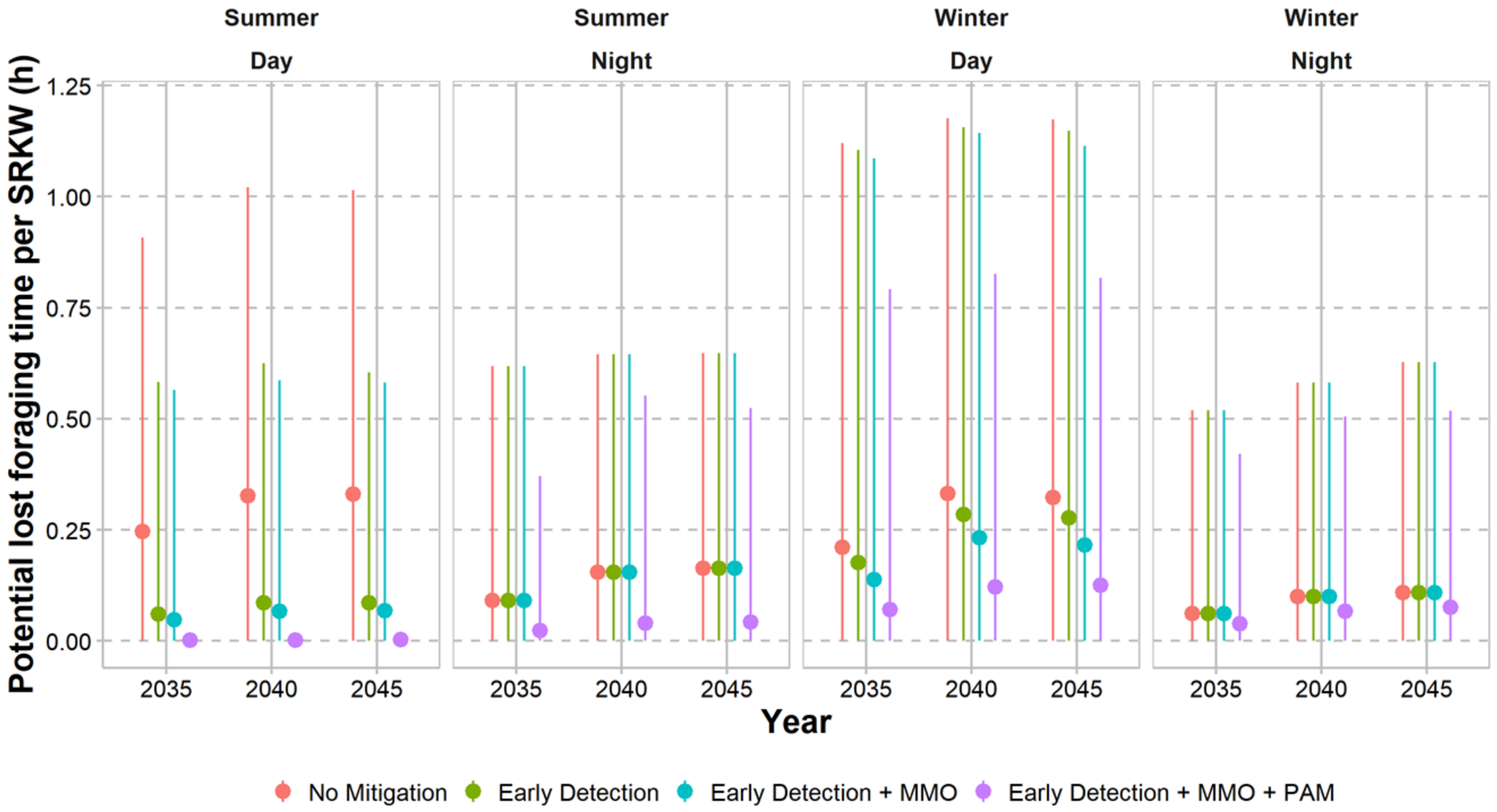
Results and patterns for the less likely high-case vessel scenario were similar to those described for the most-realistic vessel scenario, but potential lost foraging time estimates were slightly higher and mitigation effectiveness under each detection method was slightly lower (Table 10). We therefore highlight only key differences. For the less likely high-case vessel scenario, implementing unberthing delays based on early detection and MMOs led to a 13% (~25 minutes) reduction of potential lost foraging time per SRKW per year on average for the three years modelled: from 3.0 hours (95% confidence interval: 0 – 11.1 hours) without mitigation to 2.6 hours (0 – 10.5 hours) with mitigation. The inclusion of a PAM system would provide an additional reduction in potential lost foraging time of approximately 24 minutes per SRKW per year.

Table 10. Potential lost foraging time per SRKW per year and mitigation effectiveness of delayed unberthing mitigation measure for the most-realistic and high-case vessel scenarios for vessels in motion. Potential lost foraging time estimates are rounded to one decimal place.

Vessel Scenario	Mitigation	Potential Lost Foraging Time (h)			
		Mean	Lower Bound (95% CI)	Upper Bound (95% CI)	Percent Reduction (%)[1]
Most-Realistic	No Mitigation	2.1	0.0	10.0	-
	Early Detection	1.8	0.0	9.6	13
	Early Detection + MMO	1.7	0.0	9.5	16
	Early Detection + MMO + PAM	1.5	0.0	8.4	29
High-Case	No Mitigation	3.0	0.0	11.1	-
	Early Detection	2.7	0.0	10.6	11
	Early Detection + MMO	2.6	0.0	10.5	13
	Early Detection + MMO + PAM	2.2	0.0	9.4	26

[1] Percent reduction calculated on mean value.

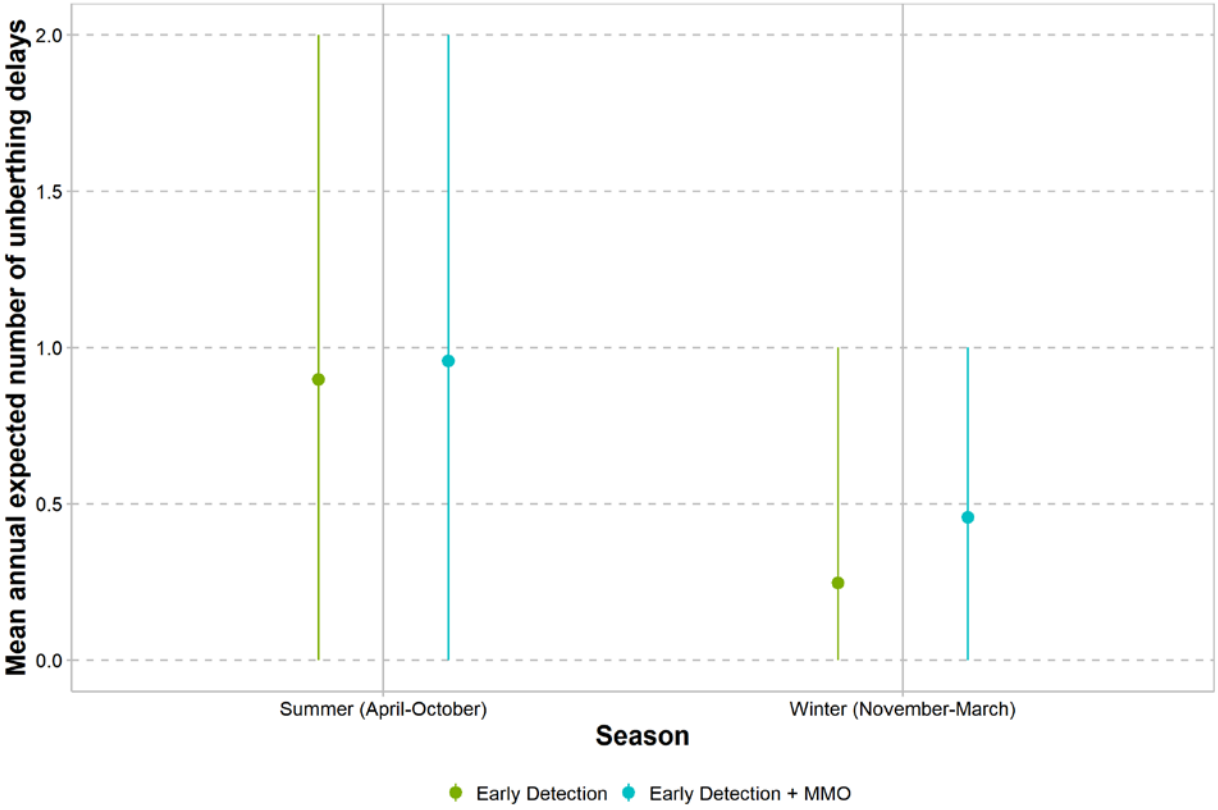
Figure 19. Potential lost foraging time per SRKW per year by season during the vessel unberthing stage (mean and 95% confidence intervals) predicted for 2035, 2040, and 2045 by the acoustic effects model, with and without implementation of the unberthing delay mitigation, under the most-realistic vessel scenario.



3.2.1.3. Frequency of Unberthing Delays

For the most-realistic vessel scenario, the mean number of predicted unberthing delays due to SRKW presence was less than 1 delay (95% confidence interval: 0-2 delays) in summer and less than 0.5 (0-1 delays) in winter (Figure 20) when early detection and MMOs were used in combination to detect SRKW. As expected from the assumptions for early detection, early detection would trigger most of the delays in the summer, whereas each detection method would contribute somewhat similar amounts to the mean number of unberthing delays in winter.

Figure 20. Frequency of unberthing delays (mean and 95% confidence intervals) in summer and winter that would be required due to SRKW presence for the most-realistic vessel scenario.



3.2.2. Reduced Tug Transit Speed

Reducing the speed of vessel-assist tugs during transits, in July-October, did not lead to notable reductions in potential lost foraging time relative to the no mitigation scenario. The estimated potential lost foraging time due to vessel-assist tugs travelling at 8 knots was already small. We estimated an annual mean potential lost foraging time of 3.2 minutes (95% confidence interval: 0.2 – 15.0 minutes) per SRKW.

Under the most-realistic vessel scenario, the median reduction in potential lost foraging time (calculated conditional on there being spatiotemporal overlap between SRKW transits and transiting vessel-assist tugs, across the low and high noise reduction scenarios) when this mitigation was implemented was 0.4 minutes per SRKW per year (-0.7 – 1.6 minutes). Notably, confidence intervals of potential lost foraging time per SRKW per year were not different between normal and reduced tug speeds. Further, in some situations the tug slowdown increases potential lost foraging time. This is because even though slower tugs have a smaller acoustic footprint, the time required for slower tugs to transit back and forth from the tug basin to the container vessel is longer, thus there is a higher probability the travelling tug overlaps a transiting SRKW. Given lack of benefit effect of reducing tug speed on potential lost foraging time predicted by the most-realistic vessel scenario, the high-case scenario was not modelled for this mitigation measure.

3.2.3. Shore Power Connections

Shore power is anticipated to reduce the behavioural disturbance zone of berthed vessels from ~600 m to <550 m on average in summer and from ~750 to 600 m in winter. However, shore power does not affect the size of the predicted zone of echolocation click masking. When taking into account reductions in acoustic footprints from vessels at berth, shore power was predicted to have minimal reduction on potential lost foraging time. Under the most-realistic vessel scenario, shore power mitigation would reduce potential lost foraging time by 0.9 minutes per SRKW per year from an estimated ~6.8 minutes (95% confidence interval: 0.1 – 31.6 minutes) without mitigation to ~5.9 minutes (0.1 – 30.1 minutes) with mitigation (Table 11). Under the less likely high-case vessel scenario, shore power would reduce potential lost foraging time by 0.9 minutes from an estimated ~8.9 minutes (0.2 – 38 minutes) to ~8 minutes (0.2 – 36.4 minutes) per SRKW per year.

Table 11. Potential lost foraging time per SRKW per year and percent reduction in potential lost foraging time for the shore power connections mitigation measure for the most-realistic and high-case vessel scenarios. Potential lost foraging time estimates are rounded to two decimal places.

Vessel Scenario	Mitigation	Potential Lost Foraging Time (h)			
		Median	Lower Bound (95% CI)	Upper Bound (95% CI)	Percent Reduction (%)[1]
Most-Realistic	No Mitigation	0.11	0.00	0.53	-
	Shore Power	0.10	0.00	0.50	13
High-Case	No Mitigation	0.15	0.00	0.63	-
	Shore Power	0.13	0.00	0.61	10

[1] Percent reduction calculated on mean value.

3.2.4. Summary of the Effectiveness of Proposed Mitigation

The results provided in previous sections indicate that potential lost foraging time is predicted to be accrued from both vessels in motion and vessels at berth and that some mitigation measures assessed can reduce potential lost foraging time predicted for SRKW. The summary section focuses on the measures and means that are effective and feasible to implement. Of the mitigation measures evaluated, reduced tug speed was not effective at reducing potential lost foraging time. Also, the port authority determined that, due to the high cost and small benefit to SRKW, a PAM system as an additional detection option to delay unberthing was not feasible for project operations. Below we describe the total predicted potential lost foraging time and lost prey captures, averaged across 2035, 2040, and 2045 (representing on average three to four vessels calling the terminal per week) for vessels in motion and vessels at berth combined, and the effectiveness of the mitigation measures evaluated by the acoustic effects model for the most-realistic scenario and high-case vessel scenarios.

3.2.4.1. Most-Realistic Vessel Scenario

Under the most-realistic vessel scenario, implementation of both delayed unberthing and shore power connections would reduce potential lost foraging time by 16% (using early detection method sources and MMOs to implement delayed unberthing) per SRKW per year (Table 12, Figure 21). Total potential lost foraging time per SRKW per year would be reduced from 2.2 hours (95% confidence interval: 0 – 10.5 hours) to 1.8 hours (0 – 10.0 hours) with shore power and delayed unberthing based on early detection with MMO industry standard protocols.

Total potential lost prey captures estimated are also anticipated to be reduced from an estimated ~2.4 prey (0 – 7.4 prey) per SRKW per year on average across the three years modelled to 2.0 prey (0 – 7.1 prey) with the implementation of early detection and MMOs (Table 12).

Vessels in motion (i.e., arrival, berthing, unberthing, and departure) are expected to contribute almost all the potential lost foraging time predicted, whereas vessels at berth only contributed ~0.1 hour of potential lost foraging time (Table 12). Shore power mitigation measure is expected to reduce potential lost foraging time by less than one minute (Table 11). Given the much greater contribution of vessels in motion to overall potential lost foraging time and prey captures, the overall mitigation effectiveness of delayed unberthing and shore power connection combined is very similar to that of delayed unberthing alone (Section 3.2.1).

Table 12. Summary of potential lost foraging time and lost prey captures per SRKW per year and mitigation effectiveness of delayed unberthing and shore power connections for the most-realistic vessel scenario for all Project operation. Potential lost foraging time estimates are rounded to one decimal place.

Mitigation	Potential Lost Foraging Time (h)				Potential Lost Prey Captures			
	Estimate[1]	Lower Bound (95% CI)	Upper Bound (95% CI)	Percent Reduction (%)[2]	Estimate[1]	Lower Bound (95% CI)	Upper Bound (95% CI)	Percent Reduction (%)[2]
No Mitigation	2.2	0.0	10.5	-	2.4	0.0	7.4	-
Shore Power	2.2	0.0	10.5	1	2.4	0.0	7.4	0
Delayed Unberthing (Early Detection + MMO)	1.9	0.0	10.1	15	2.0	0.0	7.1	18
Shore Power + Delayed Unberthing (Early Detection + MMO)	1.8	0.0	10.0	16	2.0	0.0	7.1	18

[1] Estimate for vessels at berth is a median across simulations; estimate for vessels in motion is a mean across simulations.

[2] Percent reduction calculated on estimate value.

3.2.4.1. High-Case Vessel Scenario

Results and patterns for the less likely high-case vessel scenario were similar to those described for the most-realistic vessel scenario, but potential lost foraging time estimates were slightly higher and mitigation effectiveness was slightly lower (Table 13). For the high-case vessel scenario, the effectiveness of implementing unberthing delays in addition to providing shore power connections reduced the potential lost foraging time estimate by 13% per SRKW per year on average for the three years modelled: from an estimated 3.2 hours (95% confidence interval: 0 – 11.7) hours) without mitigation to ~2.7 hours (0 – 11.2 hours) with delayed unberthing based on early detection and MMO industry standard protocols. Lost prey captures were reduced by similar quantities because one hour of lost foraging time equates to approximately one lost prey capture.

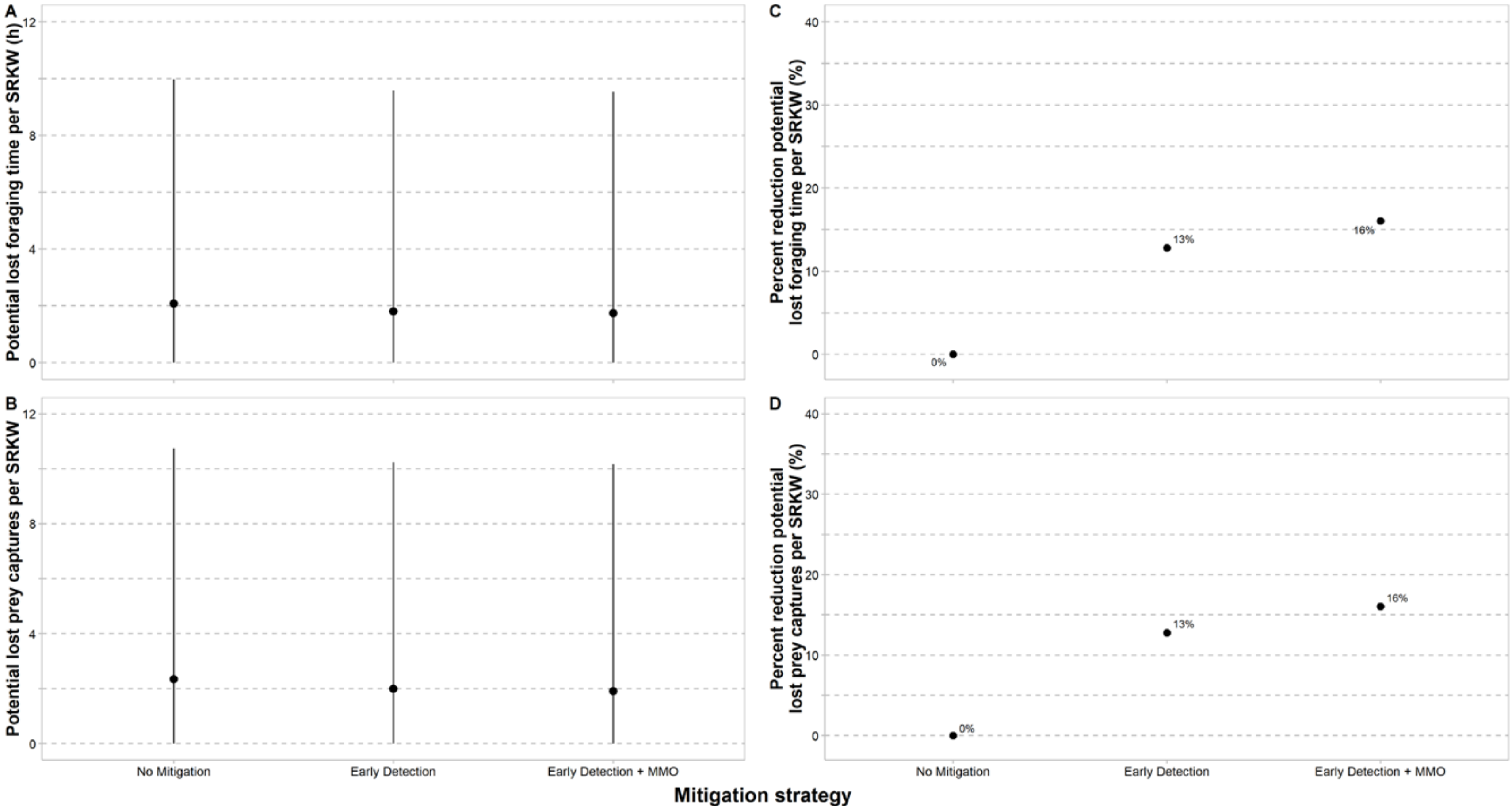
Table 13. Summary of potential lost foraging time (hours), percent reduction in potential lost foraging time, and lost prey captures, and percent reduction in lost prey captures per SRKW per year and mitigation effectiveness of delayed unberthing and shore power connections for the high-case vessel scenario for all Project operation. Potential lost foraging time estimates are rounded to one decimal place.

Mitigation	Potential Lost Foraging Time (h)				Potential Lost Prey Captures			
	Estimate[1]	Lower Bound (95% CI)	Upper Bound (95% CI)	Percent Reduction (%)[2]	Estimate[1]	Lower Bound (95% CI)	Upper Bound (95% CI)	Percent Reduction (%)[2]
No Mitigation	3.2	0.0	11.7	-	3.5	0.0	8.5	-
Shore Power	3.1	0.0	11.7	0	3.4	0.0	8.4	0
Delayed Unberthing (Early Detection + MMO)	2.8	0.0	11.2	13	2.9	0.0	8.1	15
Shore Power + Delayed Unberthing (Early Detection + MMO)	2.7	0.0	11.2	13	2.9	0.0	8.1	15

[1] Estimate for vessels at berth is a median across simulations; estimate for vessels in motion is a mean across simulations.

[2] Percent reduction calculated on estimate value.

Figure 21. Potential lost foraging time per SRKW (A), potential lost prey captures per SRKW (B), percent reductions in potential lost foraging time per SRKW (C), and percent reductions in potential lost prey captures per SRKW (D), with and without unberthing delay mitigation methods applied for the most-realistic vessel scenario.



3.2.5. Quiet Tug Technology

Implementation of technologies that reduce underwater noise associated with tug activities is anticipated to provide some reduction in acoustic effects on SRKW from Project operation. Results of the literature review indicated that there is some quantitative evidence for reduced underwater noise associated with transiting to hybrid and electric vessels; however, this evidence is limited by small sample sizes. Previous research indicated that electric ferries were 12 dB quieter for monopole source levels and radiated noise levels, and 10–25 dB quieter at frequencies below 500 Hz than diesel ferries (Parsons *et al.* 2020), while hybrid vessels (mainly cruise ships) were 5-17 dB quieter than diesel powered vessels (but 2-9 dB louder at slower speeds of 10 knots; Kipple 2002, Spence *et al.* 2007, Litwin *et al.* 2019). However, although hybrid tugs are at a higher technology readiness level than full-sized ship-handling electric tugs, both designs are still under development. We therefore could not further assess the effectiveness of this measure at reducing acoustic effects to SRKW from Project operation. When considering the effectiveness of quiet tug technology, it is important to consider the sources of greatest noise contribution. Cavitation, while pushing and pulling during berthing and unberthing, is often the dominant noise source for tugs and therefore the effectiveness of noise reduction from hybrid or electric engines can be overshadowed by propeller noise beyond the cavitation inception speed (Matthews *et al.* 2018, Kendrick and Terweij 2019). As a result, there may be limited opportunities for quieter design criteria to reduce tug noise during berthing and unberthing. However, there are other tug design measures that could reduce underwater noise, such as propeller noise reduction through propeller design (e.g., podded and/or azimuthing propulsors), wake flow modification, and increasing the cavitation inception speed (Kendrick and Terweij 2019). The use of alternative fuel types such as liquefied natural gas (LNG) can also potentially reduce underwater noise from tugs (Tronstad *et al.* 2017, Vakili *et al.* 2020a, 2020b).

It is likely that tugs with quiet vessel notations (a quiet vessel notation from a ship classification society) will be available for future project operation. For example, HaiSea Marine recently announced a partnership to design, build, and operate new battery-powered and low emissions tugs that will be used for the LNG Canada Project in Kitimat.

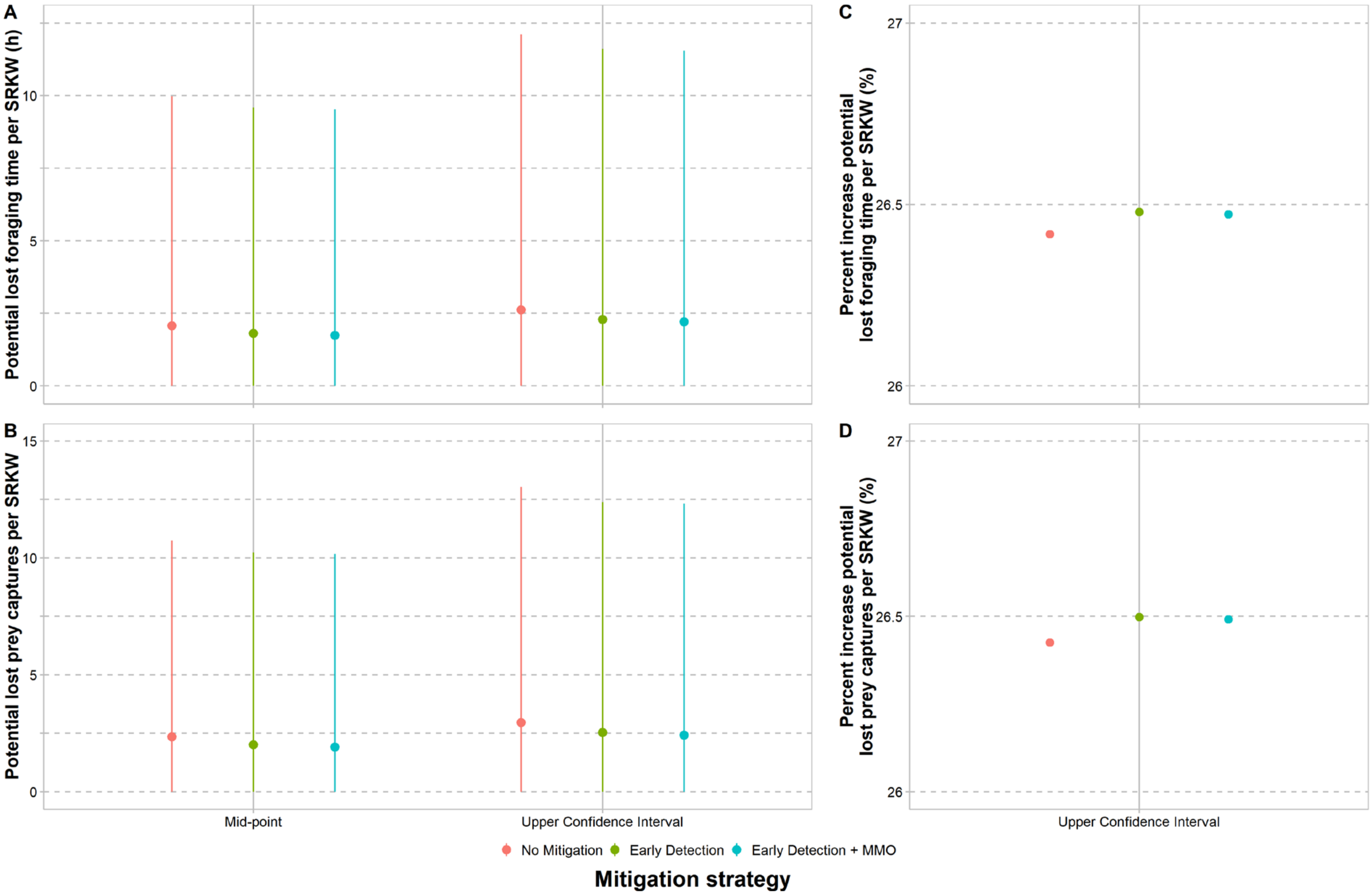
Noise reductions from future developments in quieter tug technology could provide benefits for SRKW by reducing the potential for behavioural disturbance and masking from Project operation.

3.3. Assessing Uncertainty in SRKW Response

Assessment of uncertainty in the severity of the behavioural response and echolocation click masking elicited by container vessel and vessel-assist tug noise during arrival, berthing, unberthing, and departure was calculated to allow evaluation of the sensitivity of estimates of potential lost foraging time to model assumptions. To obtain an upper bound estimate of acoustic effects on SRKW, we recalculated potential lost foraging time for vessels in motion assuming that SRKW exhibit a higher probability of disturbance than the mean (i.e., "Upper Confidence Interval" scenario presented in Section 2.6). We then compared this more conservative Upper Confidence Interval scenario to the Mid-point scenario.

Increases in mean potential lost foraging time for the Upper Confidence Interval scenario relative to the Mid-point scenario were ~26% (~33 minutes per SRKW per year and an additional loss of less than 1 prey capture per SRKW per year) for vessels in motion with the mitigation measure of delayed unberthing under the most-realistic scenario (Figure 22). A large proportion of the added potential lost foraging time was accrued within the 120 dB acoustic effect zone (i.e., between the 120-129 dB thresholds) and the echolocation click masking acoustic effect zone, where the probability of vessel operation noise eliciting behavioural responses (severity) is lower than in the other zones, but the uncertainty increases as noise level decreases. Estimated total potential lost foraging time per SRKW was on average 2.6 hours per SRKW per year (95% confidence interval: 0 – 12.1 hours) with no mitigation. With mitigation, the potential lost foraging time was 2.2 hours (0 – 11.6 hours) per SRKW per year for delayed unberthing using early detection and MMOs, averaged over the three forecasted years (2035, 2040, 2045) for vessels in motion.

Figure 22. Potential lost foraging time per SRKW compared between the Upper Confidence Interval scenario and the Mid-point scenario, with and without delayed unberthing mitigation measures under the most-realistic vessel scenario as predicted for 2035, 2040, and 2045 by the acoustic effects model: (A), potential lost prey captures per SRKW (B), percent increases in potential lost foraging time per SRKW (C), and potential lost prey captures per SRKW (D), percent increases in potential lost prey captured per SRKW. Colours represent implementation of delayed unberthing mitigation measures.



4. DISCUSSION

This study examined the effectiveness of four additional potential mitigation measures for reducing potential acoustic effects to SRKW from RBT2 Project operation at the terminal: delayed unberthing of vessels, reduced vessel-assist tug transit speed, shore power connections, and quiet tug technology. These four mitigation measures were identified since the RBT2 public hearing and therefore were not considered by the review panel in their report.

The potential acoustic effects that were considered specifically included behavioural response and echolocation click masking. Based on clarification provided by IAAC, a quantitative assessment of communication masking was not conducted. However, biologically meaningful communication masking is inherently incorporated in the assessment through the use of a broadband 120 dB acoustic effect threshold.

To address the Minister's information request (MECC 2020), we considered feedback received during consultation with Indigenous groups and engagement with government agencies, as well as the review panel recommendations and feedback received from DFO. We quantified potential effects (including metrics of uncertainty) within a probabilistic simulation framework using an acoustic effects model. We then evaluated the effectiveness of three of the four potential mitigation measures — delayed unberthing, reduced vessel-assist tug transit speed, and shore power connections — by comparing modelling results with and without mitigation. A literature review was conducted to evaluate the potential of quiet tug technology.

4.1. Acoustic Effects Model Development

The acoustic effects model was based on several conservative measures. These included the assumption that Killer Whales forage 100% of the time, the application of behavioural dose-response coefficients derived from the low behavioural response curve, and the adoption of behavioural response coefficients as arithmetic means for each acoustic effect zone, even though sound levels decrease exponentially with distance from the source (thus the coefficients used in modelling are higher (more precautionary) than those used in the EIS). To evaluate the effectiveness of delayed unberthing, the model considered two vessel projection scenarios. The most-realistic vessel scenario (on average three to four vessels calling the terminal per week or ~156 to 208 per year) and a less likely high-case vessel scenario (on average four to five vessels per week or 208 to 260 per year). The additional weekly container vessel call per week was conservatively assumed to be a Mega-Max. Effectiveness of the unberthing mitigation was also explored under three SRKW detection methods.

This study recognized the challenges of developing a local area model that relies on effort-corrected opportunistic SRKW sightings data and that incorporates various noise effects on SRKW. Therefore, Monte Carlo techniques were adopted to provide confidence intervals. In addition, estimates of potential lost foraging time and prey capture (metrics of behavioural response and echolocation click masking effects) incorporated additional uncertainty and precaution. The model was specifically designed to be easily adaptable to examine input parameters (or mitigation measures) and determine resulting mitigation effectiveness.

4.2. No Mitigation

Overall, the total estimated potential lost foraging time for SRKW was low without mitigation, regardless of the vessel scenario employed or year modelled, and the contribution of behavioural response to the estimate of potential lost foraging time per SRKW (90%) was much greater than the contribution of echolocation click masking beyond the 120 dB behavioural response acoustic effect zone (10%). Without mitigation, potential lost foraging time due to vessels in motion (i.e., arrival, berthing, unberthing and departure) considering both behavioural response and echolocation click masking was predicted to be approximately 2.1 hours per SRKW per year (95% confidence interval: 0 – 10.0 hours) for the most-realistic vessel scenario and 3.0 hours per SRKW per year (0 – 11.1 hours) for the less likely high-case vessel scenario. Vessels at berth contributed an additional loss of only about 0.1 hour per SRKW per year (0 – 0.3 hour), even under the less likely high-case vessel scenario. The average total estimated potential lost foraging time for Project operation (vessels in motion and vessels at berth combined) was 2.2 hours (0 – 10.5 hours) per SRKW per year for the most-realistic scenario. The average predicted potential lost foraging time was approximately 1 hour per SRKW per year higher (3.2 hours per year (0 – 11.7 hours)) for the less likely high-case vessel scenario than for the most-realistic vessel scenario. The estimated potential lost foraging time without mitigation was essentially the same for 2040 and 2045, indicating that the results were insensitive to changes in container vessel class between those years. Based on a coarse estimate derived from a SRKW tagging study, the number of lost prey captures is similar to hours of potential lost foraging time.

The low estimated potential lost foraging time per SRKW is largely a reflection of the low probability of a SRKW transit overlapping in both time and space with Project operation and the probabilities of SRKW responding to the noise generated from these activities. Notably, the results of this study are very similar to those predicted in the EIS (SMRU 2014c), which reported a potential lost foraging time of 3.52 hours per SRKW per year using a different method. Our estimates of potential lost foraging time are based on more conservative (i.e., precautionary) effects assumptions and provide a finer scale representation of potential interactions between operational noise from vessel operation and SRKW in the study area compared to the EIS. Our estimates also consider updated vessel projections for three future years (2035, 2040, and 2045) and potential underwater noise effects from vessels at berth which were not previously quantified in the EIS. Therefore, confidence in the main findings is increased.

4.3. Effectiveness of Mitigation Measures

4.3.1. Delayed Unberthing

Under the most-realistic vessel scenario, delayed unberthing applying early detection and MMOs as detection methods reduced SRKW potential lost foraging time from all Project operation by 15%, from approximately 2.2 hours (95% Confidence interval: 0 – 10.5 hours) per SRKW per year without mitigation to 1.9 hours (0 – 10.1 hours) per SRKW per year. This study assumed a SRKW detection rates of 25% in winter and 75% in summer for the early detection method, and the application of industry standard protocols for MMOs. Under the high-case vessel scenario, the effectiveness of delayed unberthing was similar to the most-realistic vessel scenario. The inclusion of a PAM system as an additional detection method to monitor SRKW during the day and at night was estimated to further reduce potential lost foraging time by an additional 17 minutes (~0.3 hour (0 – 1.1 hours) per SRKW per year for the most-realistic case. The port authority determined that it would not be feasible to implement a PAM system for project operations due to the high cost and limited reductions in overall potential acoustic effects to SRKW.

4.3.2. Reduced Tug Transit Speed

Under the most-realistic vessel scenario, the proposed measure to reduce vessel-assist tug travelling speed from 8 knots to 5 knots did not reduce predicted potential lost foraging time. The nil predicted effectiveness of this mitigation is partly due to the marginally smaller acoustic footprint. A vessel-assist tug travelling at 5 knots has only a marginally smaller acoustic footprint than that of a vessel-assist tug travelling at 8 knots. Overall, a vessel-assist tug slowdown (travelling at 5 knots, under the most-realistic vessel case) was predicted to reduce potential lost foraging time by 0.4 minutes per SRKW per year (under the conservative approach of considering only iterations of the simulation when there was a spatiotemporal overlap between SRKW transits and vessel-assist tug transits). The 95% confidence interval for this estimate overlaps with 0 (-0.7 minutes to 1.6 minutes), suggesting that in some situations, vessel-assist tug slowdowns could increase potential lost foraging time. This is because even though slower tugs have a smaller acoustic footprint, the time required for slower tugs to transit back and forth from the tug basin to the container vessel is longer, thus there is a higher probability the travelling tug overlaps a transiting SRKW, which would outweigh the benefit of the small acoustic footprint reduction.

4.3.3. Shore Power Connections

Since the public hearing, the port authority has also proposed to provide shore power connections at the terminal for vessels equipped to plug into land-based electric power. Approximately 34% of container vessels currently calling at the Port of Vancouver have shore power capability, and forecasts predict shore power demand will increase in the future (VFPA 2021b). The port authority provides incentives to vessels that use shore power through the EcoAction program (VFPA 2021b), which may help accelerate the adoption of shore power technology by vessels calling at RBT2.

With respect to underwater noise, switching to shore power has the benefit of reducing the relatively small behavioural response acoustic effect zones of container vessels at berth by ~50-150 m depending on the season but not the predicted zone of echolocation click masking. Shore power can therefore reduce the likelihood of exposure to noise that could cause behavioural responses in SRKW. However, modelling indicated that the effect of this mitigation measure on potential lost foraging time is likely to be small (a reduction of less than one minute of potential lost foraging time per SRKW per year) because little overlap is anticipated between the behavioural response acoustic footprints of vessels at berth and transiting SRKW. Nevertheless, the use of shore power is anticipated to reduce underwater noise near the terminal as well as air emissions.

4.3.4. Quiet Tug Technology

Literature review results provided support for the noise reduction potential (~5 dB to 25 dB) of quiet tugs (e.g., hybrid or electric tugs); however, there was insufficient quantitative information to evaluate the potential reduction in acoustic effects on SRKW from Project operation that would be gained by quiet tug technology. It is likely that tugs with quiet vessel notations (a quiet vessel notation from a ship classification society) will be available in the future and could reduce underwater noise generated from Project operation. The port authority has proposed to monitor ongoing advancements in quiet tug technology and to implement the measures in the future once feasible for the Project to further reduce underwater noise associated with Project operation.

4.4. Accounting for Behavioural Uncertainty

In addition to assessing mitigation effectiveness, we evaluated the sensitivity of estimates of potential lost foraging time from vessels in motion to uncertainties in the severity of behavioural responses to underwater noise of SRKW. We examined vessels in motion (arrival, berthing, unberthing, and departure) as these activities were associated with most of the lost foraging time (90%). Specifically, we used more conservative probabilities that SRKWs will cease feeding when exposed to noise within each acoustic effect zone. Instead of using the median dose-response probability of behavioural response coefficient (Mid-point scenario), we used the upper confidence interval (97.5th percentile) to generate an upper bound estimate of behavioural response effects to SRKW (Upper Confidence Interval scenario). With the application of the more conservative behavioural response coefficient values, estimates of potential lost foraging time increased on average by 26% compared to the Mid-point scenario. The use of the conservative behavioural response coefficient values resulted in mean potential lost foraging time of 2.6 hours per SRKW per year (95% confidence interval: 0 – 12.1 hours) under no mitigation. When considering potential mitigation, particularly the most effective measure of delaying unberthing, when accounting for behavioural uncertainty the estimated potential lost foraging time is reduced to 2.2 hours per SRKW per year (0 – 11.6 hours) based the early detection and MMOs combined detection methods. Our approach in evaluating the sensitivity of the coefficient estimates aims to address a degree of uncertainty in the definition of the behavioural response dose-response curve (Figure 4). Our results imply that if we assumed that SRKW exhibit a higher probability of disturbance when exposed to underwater noise, then the annual estimate of potential lost foraging time, even under the high-case vessel scenario would be less than 4 hours per SRKW per year for container vessel arrival, berthing, unberthing, and departure, supported by vessel-assist tugs.

4.5. Conclusion

This study increases confidence that the acoustic effects to SRKW during Project operation, without mitigation, are anticipated to be 2.2 hours (95% confidence interval: 0 – 10.5 hours) of potential lost foraging time per SRKW per year under the most-realistic vessel scenario. Potential lost foraging time from Project operation was approximately one hour higher under the less likely high-case vessel scenario.

Implementation of the delayed unberthing mitigation (delaying unberthing of container vessels when SRKW are present in the area) is predicted to reduce potential lost foraging time per SRKW per year by ~15% to ~1.9 hours (0 – 10.1 hours) per SRKW per year under the most-realistic vessel scenario. Providing shore power connections at the proposed terminal would reduce potential acoustic effects to SRKW within a small area near the terminal. Implementing both delayed unberthing and shore power connections mitigation measures is anticipated to reduce overall potential lost foraging time (i.e., from both vessels at berth and vessels in motion) by 16% to 1.8 hours (0 – 10.0 hours) per SRKW per year under the most-likely vessel scenario. Also, ongoing advancements in quiet tug technology are anticipated in the future, which will further reduce underwater noise. In conclusion, the additional mitigation measures proposed by the port authority, beyond what was considered by the review panel, will further reduce the potential acoustic effects to SRKW predicted from vessel activities during Project operation. With the mitigation measures at the terminal proposed by the port authority since the public hearing, the potential acoustic effects to SRKW predicted from vessel activities during Project operation will be further reduced.

REFERENCES

André, M., M. Morell, A. Mas, M. Solé, M. van der Schaar, L. Houégnigan, S. Zaugg, J.V. Castell, C. Álvarez Baquerizo, and L. Rodríguez Roch. 2009. Best practices in management, assessment and control of underwater noise pollution. Report by the Laboratory of Applied Bioacoustics (LAB) and the Technical University of Catalonia (UPC). 105 p.

Angadi, K., J. Wood, J. Turner, K. Palmer, and D. Tollit. 2020. Burrard Inlet underwater noise characterization: 2019 final report. Prepared by SMRU Consulting North America for the ECHO Program. Available online at: https://www.portvancouver.com/wp-content/uploads/2020/10/Burrard-Inlet-2019-Year-1-Final-Report-with-framing-document.pdf. Accessed on March 10, 2021.

Au, W., J. Ford, J. Horne, and K. Newman. 2004. Echolocation signals of free-ranging Killer Whales (*Orcinus orca*) and modeling of foraging for Chinook Salmon (*Oncorhyncus tshawytscha*). The Journal of the Acoustical Society of America 115:901-909. DOI: 10.1121/1.1642628.

Blackwell S.B., C.S. Nations, T.L. McDonald, A.M. Thode, D. Mathias, K.W. Kim, C.R. Greene Jr., and A.M. Macrander. 2015. Effects of airgun sounds on bowhead whale calling rates: evidence for two behavioral thresholds. PLoS ONE 10(6):e0125720. https://doi.org/10.1371/journal.pone.0125720.

Buren, A. and D. Tollit. 2021. Appendix IR2020-3-H: Gomez *et al.* 's (2016) findings relevant to 2020 Minister's information request regarding avoidance and other mitigation measures for Southern Resident Killer Whales from RBT2 operation and marine shipping associated with the project). Memorandum to the Vancouver Fraser Port Authority.

Buren, A.D., D.J. Tollit, M. Gilbert, A. Johnson, J. Wood, A. MacGillivray, Z. Li, and D. Lacroix. 2021. Roberts Bank Terminal 2 Project Technical Data Report - Assessing effectiveness of mitigation to reduce potential acoustic effects on Southern Resident Killer Whales from project construction. Consultant's report prepared for Vancouver Fraser Port Authority by Ecofish Research Ltd., SMRU Consulting North America, and JASCO Applied Sciences Ltd. August 4, 2021.

Clark, C.W., W.T. Ellison, B.L. Southall, L. Hatch, S.M. Van Parijs, A. Frankel, and D. Ponirakis. 2009. Acoustic masking in marine ecosystems: intuitions, analysis, and implication. Marine Ecology Progress Series 395:201-222.

Canadian Environmental Assessment Act, 2012 (S.C. 2012, c. 19, s. 52). Available online at: https://laws-lois.justice.gc.ca/eng/acts/C-15.21/page-1.html. Accessed on March 2, 2021.

Compton, R., L. Goodwin, R. Handy, and V. Abbott. 2008. A critical examination of worldwide guidelines for minimizing the disturbances to marine mammals during seismic surveys. Marine Policy 32(3): 255-262.

CWR (Center for Whale Research). 2020. Population. Available online at: https://www.whaleresearch.com/orca-population. Accessed on March 2, 2020.

DFO (Fisheries and Oceans Canada). 2015. Review of mitigation and monitoring measures for seismic survey activities in and near the habitat of cetacean species at risk. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 33 (2015/005).

DFO (Fisheries and Oceans Canada). 2017. DFO Canadian Science Advisory Secretariat. Technical review of Roberts Bank Terminal 2 Environmental Impact Statement and Marine Shipping Supplement Report: Effects on Marine Mammals. At p. 10. Available online at https://iaac-aeic.gc.ca/050/evaluations/document/117102. Accessed on June 6, 2020.

DFO (Fisheries and Oceans Canada). 2018. Recovery Strategy for the Northern and Southern Resident Killer Whales (*Orcinus orca*) in Canada (Proposed). Species at Risk Act Recovery Strategy Series, Fisheries and Oceans Canada, Ottawa, 84 p. Available online at https://www.sararegistry.gc.ca/virtual_sara/files/plans/Rs-ResidentKillerWhale-v00-2018Aug-Eng.pdf. Accessed on February 16, 2020.

DFO (Fisheries and Oceans Canada). 2019. Fisheries and Oceans Canada's Response to the Roberts Bank Terminal 2 Project Review Panel's March 5, 2019 letter. 74 p. + Appendices. Available online at: https://www.ceaa-acee.gc.ca/050/documents/p80054/129340E.pdf. Accessed on August 6, 2020.

DFO (Fisheries and Oceans Canada). 2021. Identification of areas for mitigation of vessel-related threats to survival and recovery for Southern Resident Killer Whales. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2021/025.

ECCC (Environment and Climate Change Canada). 2020. Canada Weather Stats. Available online at: https://www.weatherstats.ca/. Accessed on July 2, 2020.

Erbe, C. 2015. The Maskogram: a tool to illustrate zones of masking. Aquatic Mammals 41(4):434 443.

Erbe, C., C. Rechmuth, K. Cunningham, K. Lucke, and R. Dooling. 2015. Communication masking in marine mammals: A review and research strategy. Marine Pollution Bulletin 103(102):15 38.

Ford, J.K.B. 1991. Vocal traditions among resident killer whales (*Orcinus orca*) in coastal waters of British Columbia. Canadian Journal of Zoology 69:1454–1483.

Ford, J.K.B. 2014. Marine Mammals of British Columbia Volume 6 of Mammals of British Columbia. Volume 6 of Royal BC Museum Handbook Series. Royal British Columbia Museum handbook. 460 p.

Ford, M., J. Hempelmann, M.B. Hanson, K.L. Ayres, R.W. Baird, C.K. Emmons, J.I. Lundin, G.S. Schorr, S.K. Wasser, and L. K. Park. 2016. Estimation of a killer whale (*Orcinus orca*) population's diet using sequencing analysis of DNA from feces. PLoS ONE. 11(1):e0144956.

Ford, J.K.B., J.F. Pilkington, A. Reira, M. Otsuki, B. Gisborne, R.M. Abernethy, E.H. Stredulinsky, J.R. Towers, and G.M. Ellis. 2017. Habitats of special importance to resident killer whales (*Orcinus orca*) off the west coast of Canada. Fisheries and Oceans Canada Canadian Science Advisory Secretariat Research Document2017/035. viii + 57 p.

Gomez, C., J.W. Lawson, A.J. Wright, A.D. Buren, D. Tollit, and V. Lesage. 2016. A systematic review on the behavioural responses of wild marine mammals to noise: the disparity between science and policy. Canadian Journal of Zoology 94(12):801-819. Available online at: https://doi.org/10.1139/cjz-2016-0098. Accessed on February 26, 2021.

Hanson, B. 2015. Distribution and diet of Southern Resident Killer Whales. Presentation from NOAA Fisheries. July 28, 2015. Available online at: https://repository.library.noaa.gov/view/noaa/17031/noaa_17031_DS1.pdf?. Accessed on February 14, 2020.

Harvey, G., T.A. Nelson, P.C. Paquet, C.J. Ferster, and C.H. Fox. 2018. Comparing citizen science reports and systematic surveys of marine mammal distributions and densities. Biological Conservation 226:92-100. doi:10.1016/j.biocon.2018.07.024.

Heise, K.A., L.G. Barrett-Lennard, N.R. Chapman, D.T. Dakin, C. Erbe, and D.E. Hannay. 2017. Proposed metrics for the management of underwater noise for Southern Resident Killer Whales Coastal Ocean Report Series (2). Vancouver: Ocean Wise, 31.

Hemmera Envirochem (Hemmera) and Sea Mammal Research Unit Canada Ltd. (SMRU). 2014. Roberts Bank Terminal 2 technical data report, marine mammals Southern Resident Killer Whale (SRKW) relative density and distribution: Network sighting synthesis. Prepared for Port Metro Vancouver. December 2014, 23 p. + Appendices. Available online at https://iaac-aeic.gc.ca/050/documents/p80054/107590E.pdf. Accessed on January 14, 2020.

Holt, M., V. Veirs, and S. Veirs. 2008. Noise effects on the call amplitude of Southern Resident Killer Whales (*Orcinus Orca*). Bioacoustics 17(1-3):164-166. Available online at: https://www.researchgate.net/publication/254215112_Noise_effects_on_the_call_amplitude_of_southern_resident_killer_whales_orcinus_orca. Accessed on Feb 16, 2021.

HPC (Hamburg Port Consulting) 2021. VFPA Tug Slowdown Study. Prepared for the Vancouver Fraser Port Authority.

Kendrick, A. and R. Terweij. 2019. Ship underwater radiated noise patterns. VARD Marine Inc. Report 368-000–001. Available online at: https://tcdocs.ingeniumcanada.org/sites/default/files/2019-05/Ship%20Underwater%20Radiated%20Noise.pdf. Accessed on February 9, 2021.

Ketten, D. 2014. Sonars and strandings: are beaked whales the aquatic acoustic canary? Acoustics Today 10:46–56.

Kipple, B. 2002. Southeast Alaska cruise ship underwater acoustic noise. Naval Surface Warfare Center: NSWCCD-71-TR-2002/574.

Li, Z. and A. MacGillivray. 2014. Supplemental Underwater Noise Modelling for Trans Mountain Expansion Project. JASCO Document 00542, Version 5.0. Technical report prepared by JASCO Applied Sciences for Stantec.

Litwin, W., W. Lesniewski, D. Piatek, and K. Niklas. 2019. Experimental research on the energy efficiency of a parallel hybrid drive for an inland ship. Energies 12:1675.

Lusseau, D., D.E. Bain, R. Williams, and J.C. Smith. 2009. Vessel traffic disrupts the foraging behavior of southern resident Killer Whales *Orcinus orca*. Endangered Species Research 6:211-221.

MacGillivray, A.O. and Z. Li. 2018. Appendix A. Vessel Noise Measurements from the ECHO Slowdown Trial. In Trounce, K. (ed.). Voluntary Vessel Slowdown Trial Summary Findings. Vancouver Fraser Port Authority ECHO Program. Available online at: https://www.flipsnack.com/portvancouver/echo-haro-strait-slowdown-trial-summary/full-view.html. Accessed on April 6, 2021.

MacGillivray, A.O., Z. Li, J.L. Wladichuk, and G.A. Warner. 2019. Mercator Projections Underwater Noise Modelling Update: Roberts Bank Terminal 2 Project. Document Number 01759, Version 1.0. Technical report by JASCO Applied Sciences for Hemmera. Available online at: https://ceaa-acee.gc.ca/050/documents/p80054/129951E.pdf. Accessed on March 26, 2021.

MacGillivray, A.O., L. Ainsworth, J. Zhao, H. Frouin-Mouy, J. Dolman, and M. Bahtiarian. 2020. ECHO Vessel Noise Correlations Study: Final Report. Document 02025, Version 2.1. Technical report by JASCO Applied Sciences, ERM, and Acentech for Vancouver Fraser Port Authority ECHO Program. Available online at: https://www.portvancouver.com/wp-content/uploads/2020/05/2020-05-26-ECHO-Program-Vessel-Noise-Correlations-Study.pdf. Accessed on March 12, 2021.

MacGillivray, A., C. Grooms, and Z. Li. 2021. Appendix IR2020-3-C: RBT2 Project Operation Underwater Noise Modelling: Document 02360, Version 1.0. Technical report by JASCO Applied Sciences for Ecofish Research Ltd.

Matthews, M.-N.R., Z. Alavizadeh, D.E. Hannay, L. Horwich, and H. Frouin-Mouy. 2018. Assessment of vessel noise within the Southern Resident Killer Whale critical habitat: Final report. Document number 01618, Version 2.1. Technical report by JASCO Applied Sciences for the Innovation Centre, Transport Canada/Government of Canada. Available online at https://iaac-aeic.gc.ca/050/documents/p80054/129319E.pdf. Accessed on February 9, 2021.

MECC (Minister of Environment and Climate Change). 2020. Letter to Robin Silvester Vancouver Fraser Port Authority. CIAR Document #2067. Available online at: https://www.ceaa-acee.gc.ca/050/documents/p80054/135827E.pdf. Accessed on September 24, 2020.

Mercator International. 2018. Roberts Bank Terminal 2 Container Vessel Call Forecast Study. CIAR Document #1362. Available online at: https://www.ceaa-acee.gc.ca/050/documents/p80054/126252E.pdf. Accessed on April 9, 2021.

Mercator International. 2021. Appendix IR2020-3-B: Updated RBT2 Container Vessel Call Forecast Study. Report to the Vancouver Fraser Port Authority.

Miller, P.J.O. 2006. Diversity in sound pressure levels and estimated active space of resident killer whale vocalizations. Journal of Comparative Physiology A 192:449–459.

Miller, P.J.O. and D.E. Bain. 2000. Within-pod variation in the sound production of a pod of killer whales (*Orcinus orca*). Animal Behaviour 60:617–628.

Miller, P.J.O., Antunes, R.N., Wensveen, P.J., Samarra, F.I., Alves, A.C. and Tyack, P.L. 2014. Dose-response relationships for the onset of avoidance of sonar by free-ranging killer whales. Journal of the Acoustical Society of America 135(2):975-993.

NMFS (National Marine Fisheries Service). 2015. Draft guidance for assessing the effects of anthropogenic sound on marine mammals—acoustic thresholds for onset of permanent and temporary threshold shifts. Federal Register 80(147):45642-45643.

NOAA (National Oceanic and Atmospheric Administration). 2019. ESA Section 7 consultation tools for marine mammals on the West Coast. Available online at: https://www.fisheries.noaa.gov/west-coast/endangered-species-conservation/esa-section-7-consultation-tools-marine-mammals-west. Accessed on December 17, 2020.

Noren, D.P. 2011. Estimated field metabolic rates and prey requirements of resident Killer Whales. Marine Mammal Science 27(1):60–77. Available online at: https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1295andcontext=usdeptcommercepub. Accessed on July 7, 2020.

Nowacek, D., L. Thorne, D. Johnston, and P. Tyack. 2007. Responses of cetaceans to anthropogenic noise. Mammal Review 37(2):81–115.

Olson, J.K., J. Wood, R.W. Osborne, L. Barrett-Lennard, and S. Larson. 2018. Sightings of southern resident killer whales in the Salish Sea 1976–2014: the importance of a long-term opportunistic dataset. Endangered Species Research 37:105–118. doi: 10.3354/esr00918.

Parsons, M.J.G., A.J. Duncan, S.K. Parsons, and C. Erbe. 2020. Reducing vessel noise: An example of a solar-electric passenger ferry. The Journal of the Acoustical Society of America 147:3575 3583.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. 1995. Marine mammals and noise. Academic Press, San Diego, California.

Rolland, R., S. Parks, K. Hunt, M. Castellote, P. Corkeron, D. Nowacek, S. Kraus, S. Wasser, and S. Kraus. 2012. Evidence that ship noise increases stress in right whales. Proceedings of the Royal Society B: Biological Sciences 279:2363–2368.

Ross, D. 1987. Mechanics of Underwater Noise. Pergamon Press, NY, USA.

Smith, H. R., D. P. Zitterbart, M. Flau, T. F. Norris, E. L. Ferguson, C. Jones, O. Boebel, and V. D. Moulton, 2020. A field comparison of marine mammal detections via visual, acoustic, and infrared (IR) imaging methods offshore Atlantic Canada. Mar. Pollut. Bull., 154, 111026. Available online at: https://doi.org/10.1016/j.marpolbul.2020.111026. Accessed on February 26, 2021.

SMRU (Sea Mammal Research Unit Canada Ltd.). 2014a. Determination of behavioral effect noise thresholds for Southern Resident Killer Whales. Technical report prepared for the proposed Roberts Bank Terminal 2 project for Port Metro Vancouver. Available online at https://iaac-aeic.gc.ca/050/documents/p80054/118046E.pdf. Accessed May 4, 2020.

SMRU (Sea Mammal Research Unit Canada Ltd.). 2014b Proposed Roberts Bank Terminal 2 technical data report - marine mammals Southern Resident Killer Whale acoustic detection study December 2014, 34 p. + Appendices. Available at: https://iaac-aeic.gc.ca/050/documents/p80054/107590E.pdf. Accessed January 2020.

SMRU (Sea Mammal Research Unit Canada Ltd.). 2014c. Southern Resident Killer Whale noise exposure and acoustic masking technical report. Technical report prepared for the proposed Roberts Bank Terminal 2 project for Port Metro Vancouver. Appendix 14-B of the Environmental Impacts Statement. Available online at https://iaac-aeic.gc.ca/050/documents/p80054/101359E.pdf. Accessed on May 4, 2020.

Southall, B., A. Bowles, W. Ellison, J. Finneran, R. Gentry, C. Greene, D. Kastak, D. Ketten, J. Miller, P. Nachtigall, J. Richardson, J. Thomas, and P. Tyack. 2007. Marine mammal noise exposure criteria: initial scientific recommendations. Aquatic Mammals 33(4):411–522.

Southall, B., J. Finneran, C. Reichmuth, P. Nachtigall, D. Ketten, A. Bowles, W. Ellison, D. Nowacek, and P. Tyack. 2019. Marine mammal noise exposure criteria: updated scientific recommendations for residual hearing effects. Aquatic Mammals 45(2):125-232. Available online at: https://sea-inc.net/wp-content/uploads/2019/10/Southall-et-al_2019_MM-Noise-critieria-update-with-errata_Aq-Mammals.pdf. Accessed on March 14, 2020.

Spence, J., R. Fischer, M. Bahtiarian, L. Boroditsky, N. Jones, and R. Dempsey. 2007. Review of existing and future potential treatments for reducing underwater sound from oil and gas industry activities. Noise Control Engineering, Inc. Report 07-001. Available online at: https://gisserver.intertek.com/JIP/DMS/ProjectReports/Cat1/JIP-Proj1.3_UnderwaterSoundFromOil_2007.pdf. Accessed on July 16, 2020.

Tennessen, J.B., M.M. Holt, M.B. Hanson, C.K. Emmons, D.A. Giles, and J.T. Hogan. 2019. Kinematic signatures of prey capture from archival tags reveal sex differences in Killer Whale foraging activity. Journal of Experimental Biology 222. Available online at: https://jeb.biologists.org/content/jexbio/222/3/jeb191874.full.pdf. Accessed on July 7, 2020.

The Review Panel for the Roberts Bank Terminal 2 Project. 2020. Federal Review Panel Report for the Roberts Bank Terminal 2 Project. March 27, 2020. 627 p. Available online at: https://www.ceaa-acee.gc.ca/050/documents/p80054/134506E.pdf. Accessed on February 26, 2021.

Thornton S., K. Gavrilchuk, J. Towers, and M. DeRoos. 2019. Identifying diel variation in Northern Resident Killer Whale vocal activity, call type and temporal frequency of echolocation using digital acoustic recordings from DTAGs. World Marine Mammal Conference Proceedings. December 9-12, 2019. Barcelona, Spain.

Tronstad, T., H.H. Åstrand, G.P. Haugom, and L. Langfeldt. 2017. Study on the use of fuel cells in shipping. European Maritime Safety Agency.

United States Government. 2020. Federal Register. The Daily Journal of the United States Government. Taking of Marine Mammals. Available online at: https://www.federalregister.gov/taking-of-marine-mammals. Accessed September 2020.

Vakili, S.V., A.I. Olcer, and F. Ballini. 2020a. The trade-off analysis for the mitigation of underwater noise pollution from commercial vessels: Case study – Trans Mountain project, Port of Vancouver, Canada. Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment 234(2):599–617.

Vakili, S.V., A.I. Olcer, and F. Ballini. 2020b. The development of a policy framework to mitigate underwater noise pollution from commercial vessels. Marine Policy 118:104004.

Veirs, S., V. Veirs, and J.D. Wood. 2016. Ship noise extends to frequencies used for echolocation by endangered killer whales. PeerJ 4:e1657. doi: 10.7717/peerj.1657.

Verfuss, U.K., D. Gillespie, J. Gordon, T.A. Marques, B. Miller, R. Plunkett, J.A. Theriault, D.J. Tollit, D.P. Zitterbart, P. Hubert, and L. Thomas. 2018. Comparing methods suitable for monitoring marine mammals in low visibility conditions during seismic surveys. Mar. Pollut. Bull. 126: 1 18.

VFPA (Vancouver Fraser Port Authority). 2021a. ECHO Program 2020 Annual report April 2021. Available online at: https://www.portvancouver.com/wp-content/uploads/2021/04/2021-04-05-ECHO-2020-Annual-report_Final-1.pdf. Accessed September 2021.

VFPA (Vancouver Fraser Port Authority). 2021b. Shore power. Available online at: https://www.portvancouver.com/environmental-protection-at-the-port-of-vancouver/climate-action-at-the-port-of-vancouver/shore-power/. Accessed on March 19, 2021.

Warner, A., C. O'Neill, A. McCrodan, H. Frouin-Mouy, J. Izett, and A. MacGillivray. 2013. Underwater acoustic measurements in Haro Strait and Strait of Georgia: transmission loss, vessel source levels, and ambient measurements. JASCO Document 00659, Version 2.0 DRAFT. Technical report by JASCO Applied Sciences for Hemmera.

Watson, J., R. Joy, D. Tollit, S.J. Thornton, and M. Auger-Méthé. 2019. Estimating animal utilization distributions from multiple data types: a joint spatio-temporal point process framework. arXiv preprint arXiv:1911.00151.

Weilgart, L.S. 2007. The impacts of anthropogenic ocean noise on cetaceans and implications for management. Canadian Journal of Zoology 85(11):1091–1116.

Williams R. and D.P. Noren. 2009. Swimming speed, respiration rate, and estimated cost of transport in adult Killer Whales. Marine Mammal Science 25:327–350. doi:10.1111/j.1748-7692.2008.00255.x. Available online at: https://www.oceansinitiative.org/wp-content/uploads/2010/11/williamsnoren2009_costoftransport.pdf. Accessed on July 7, 2020.

Williams, R., C. Erbe, E. Ashe, A. Beerman, and J. Smith. 2014. Severity of Killer Whale behavioural responses to ship noise: A dose-response study. Marine Pollution Bulletin 29(1-2):254-260. Available online at: https://www.sciencedirect.com/science/article/pii/S0025326X13007376. Accessed on September 10, 2020.

Wright A.J., N.A. Soto, A.L. Baldwin, M. Bateson, C.M. Beale, C. Clark, T. Deak, E.F. Edwards, A. Fernandez, A. Godinho, L. Hatch, A. Kakuschke, D. Lusseau, D. Martineau, M. Romero, L.S. Weilgart, B. Wintle, G. Notarbartolo-diSciara, and V. Martin. 2007. Do marine mammals experience stress related to anthropogenic noise? International Journal of Comparative Psychology 20(2):274 316.

Xodus Group Ltd. 2015. Marine noise inputs technical note on underwater noise. Prepared for Statoil ASA. Assignment Number: A100142-S20 Document Number: A-100142-S20-TECH-001. Available online at: http://marine.gov.scot/sites/default/files/underwater_noise_technical_assessment_a-100142-s20-tech-001-a01_0.pdf. Accessed on September 24, 2020.

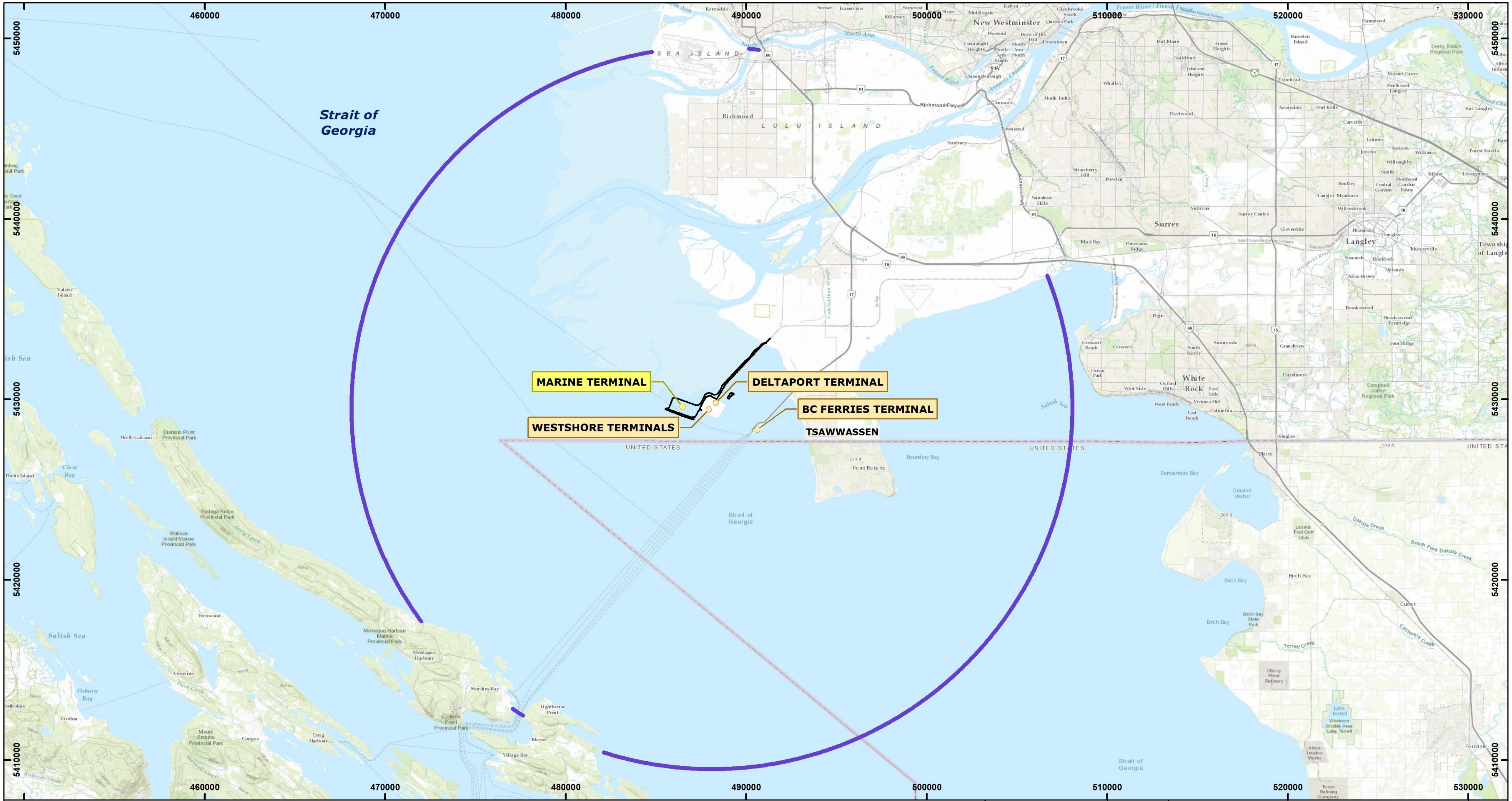
Yurk H., L. Barrett-Lennard, J.K.B. Ford and C.O. Matkin. 2002. Cultural transmission within maternal lineages: vocal clans in resident killer whales in southern Alaska. Animal Behaviour 63:1103–1119.

Personal Communications

Goertz, D. 2021. Terminal Planning Specialist, Hamburg Port Consulting, Hamburg, Germany. Personal Communication. Email communication with Deborah Lacroix, July 2021.

PROJECT MAPS

Path: M:\Projects-Active\1384\MXD\Wildlife\1384_RBT2_StudyArea_3663_20201130.mxd



Legend

▭ BOUNDARY OF PROJECT AREA

— 20 KM STUDY AREA

PROJECT COMPONENT

EXISTING LANDMARK

0 2.5 5

Kilometres

1:200,000

NAD 1983 UTM Zone 10N

N

Note:
The Boundary of the Project Area reflects the updated Project footprint presented in the June 2018 RBT2 Project Construction Update (see CEAR Document #1210).

ECOFISH RESEARCH

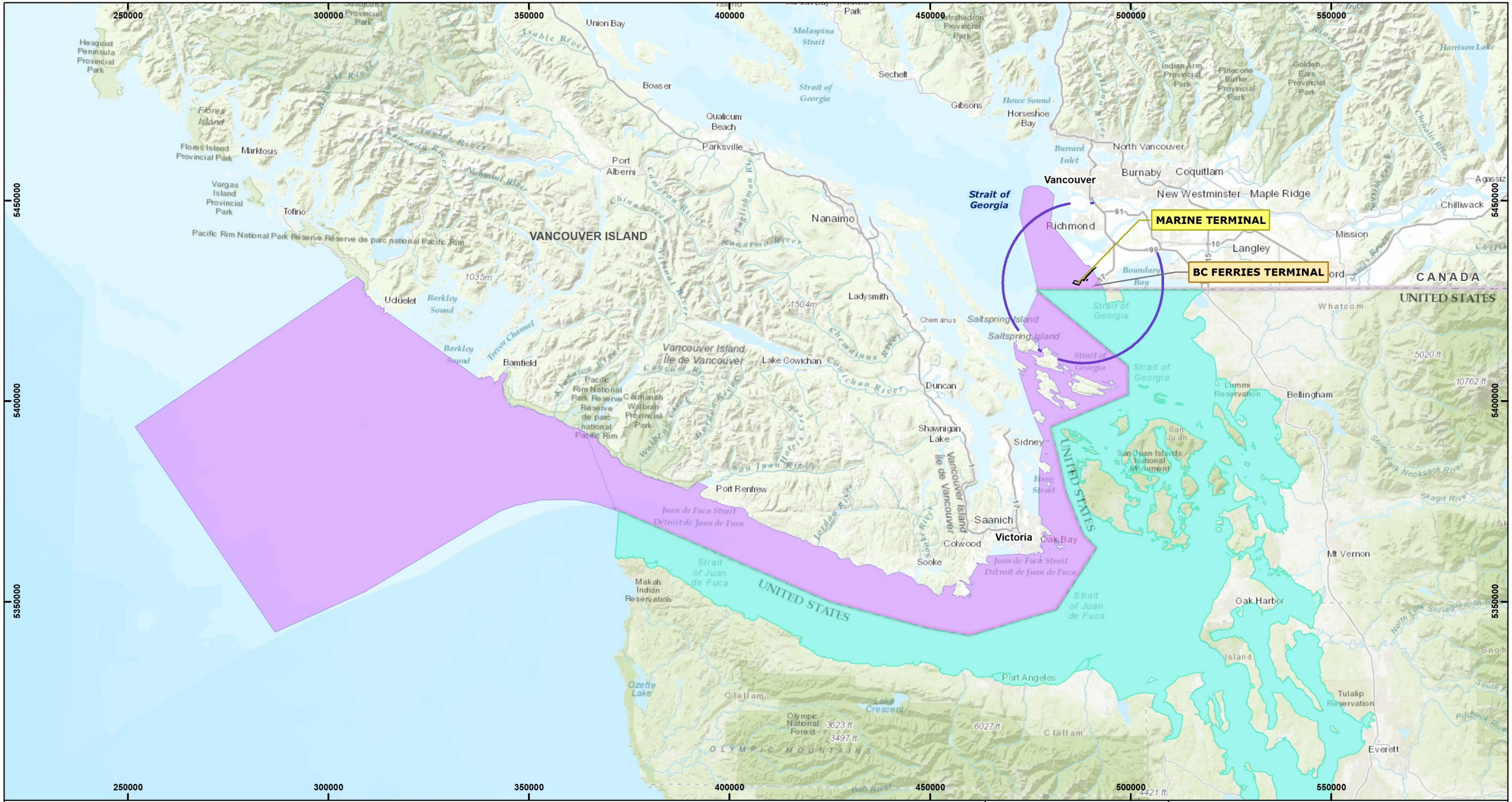
ROBERTS BANK TERMINAL 2

MARINE MAMMAL ASSESSMENT AREA

DATE:	FIG No.
11/30/2020	Map 1

Basemap Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Path: M:\Projects-Active\1384\MXD\Wildlife\1384_RBT2_SRKW_CriticalHabitat_4115_20210216.mxd



Legend

☐ BOUNDARY OF PROJECT AREA
🟪 SRKW CRITICAL HABITAT - CANADA
🟦 SRKW CRITICAL HABITAT - U.S.A.
— 20 KM STUDY AREA

PROJECT COMPONENT

EXISTING LANDMARK

0 10 20
Kilometres
1:900,000
NAD 1983 UTM Zone 10N

N

Note:
The Boundary of the Project Area reflects the updated Project footprint presented in the June 2018 RBT2 Project Construction Update (see CEAR Document #1210).

ECOFISH RESEARCH

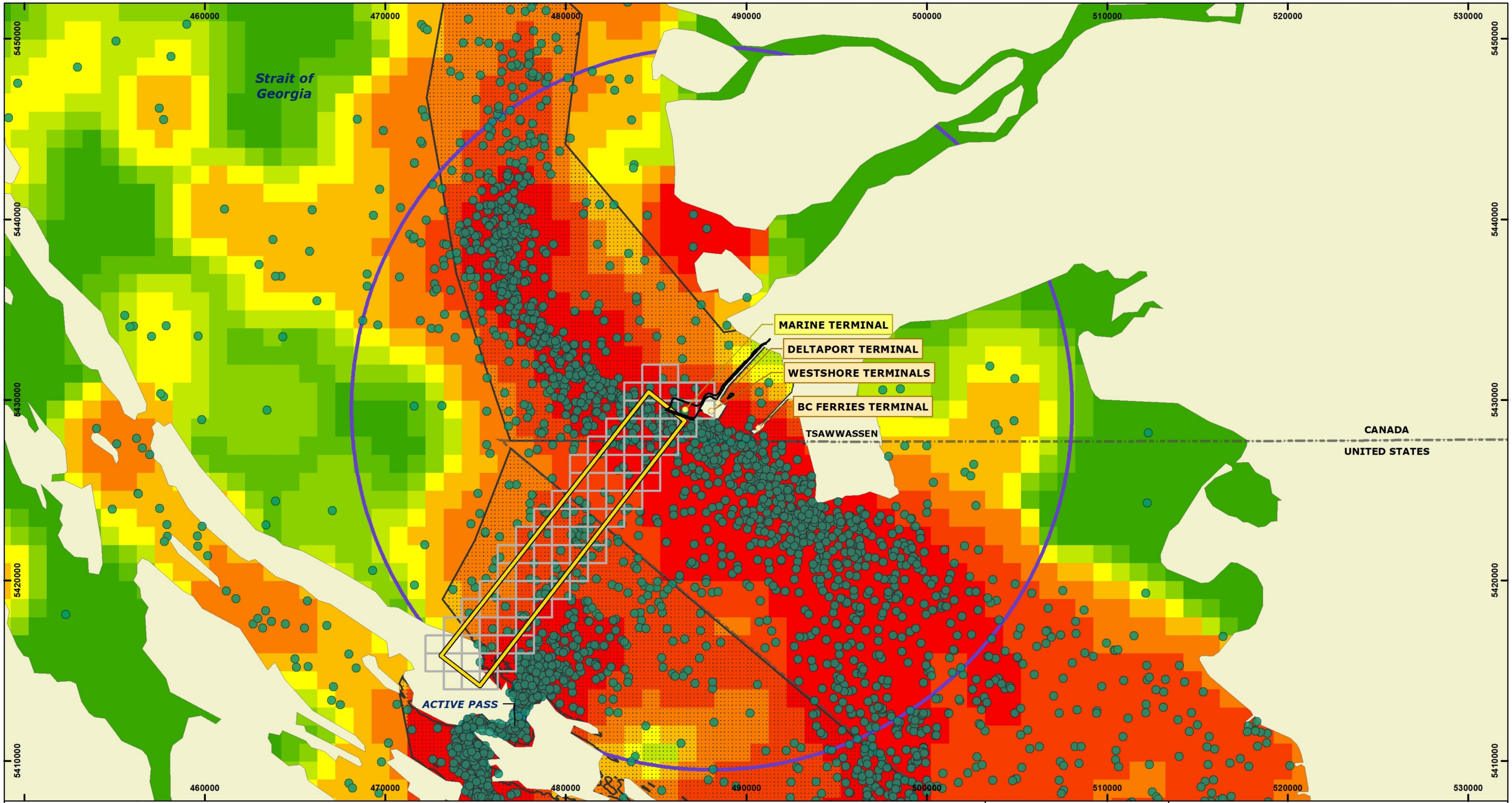
ROBERTS BANK TERMINAL 2

SOUTHERN RESIDENT KILLER WHALE CRITICAL HABITAT IN CANADA AND U.S.A. (ADAPTED FROM GOC 2018A)

DATE:	FIG No.
02/16/2021	Map 2

Basemap Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Path: M:\Projects-Active\1384\MXD\Wildlife\1384_RBT2_SRKW_Observations_4198_20210401.mxd



Legend

● SRKW OBSERVATIONS (2002-2017)
▭ BOUNDARY OF PROJECT AREA
▭ 20 KM STUDY AREA
▭ POLYGON STRIP LOCATION
▭ RELATIVE SRKW DENSITY GRIDS
▨ SRKW CRITICAL HABITAT
⋯ INTERNATIONAL BOUNDARY

RELATIVE DENSITY

- 0
- 0 - 0.005
- 0.005 - 0.0167
- 0.0167 - 0.0356
- 0.0356- 0.071
- 0.071 - 0.166
- 0.166 - 0.602
- 0.602- 2.034
- 2.034 - 82.408

PROJECT COMPONENT

EXISTING LANDMARK

Note:
The Boundary of the Project Area reflects the updated Project footprint presented in the June 2018 RBT2 Project Construction Update (see CEAR Document #1210).
Sightings data from the Orca Master database, The Whale Museum, and B.C. Cetacean Sightings Network (2002 to 2017). Vancouver Aquarium Marine Science Center and Fisheries and Oceans Canada. Sightings represented by dots are not corrected for effort. Used with permission.

0 2.5 5
Kilometres
1:200,000
NAD 1983 UTM Zone 10N

N

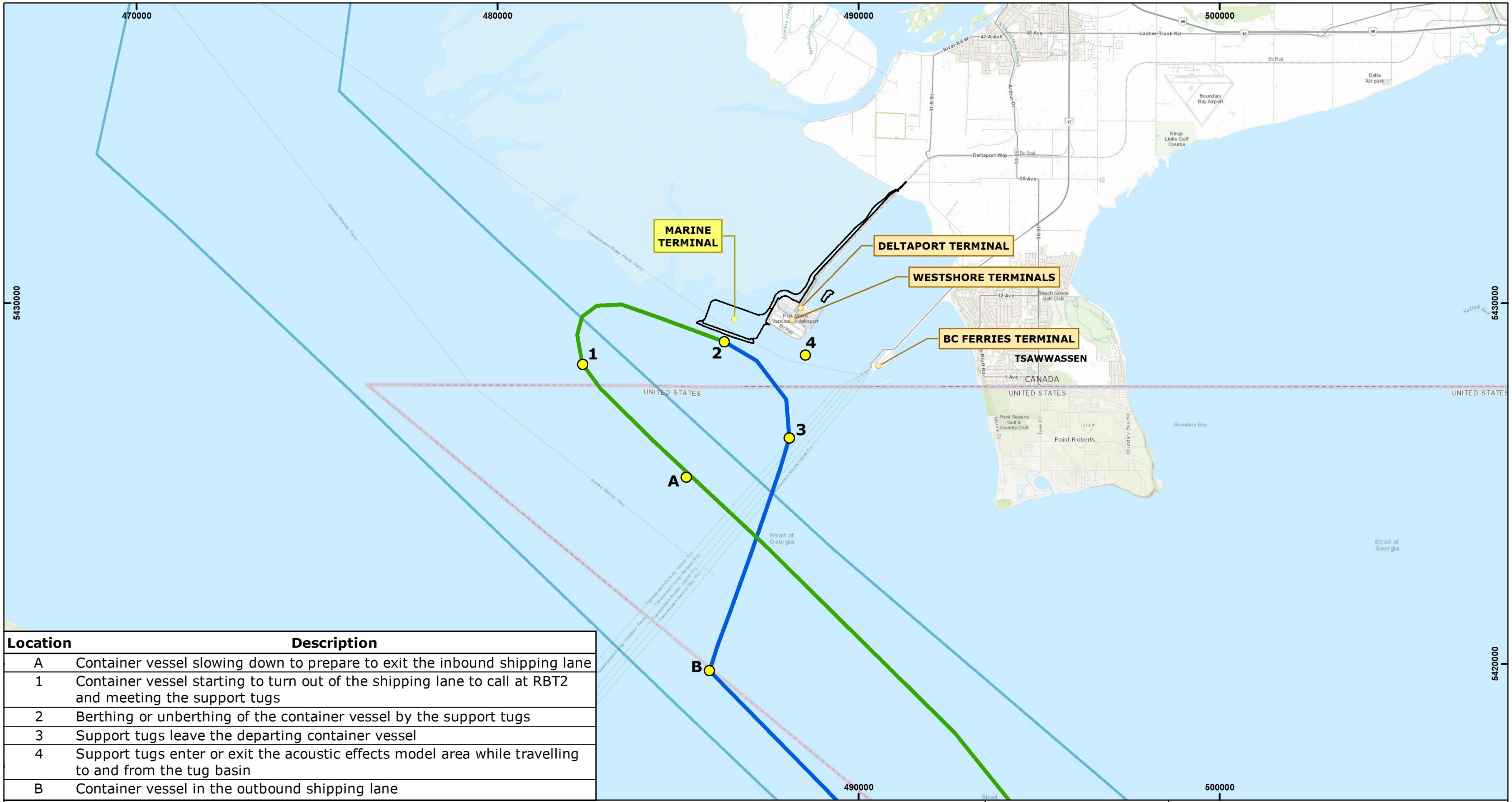
ECOFISH RESEARCH

ROBERTS BANK TERMINAL 2

SOUTHERN RESIDENT KILLER WHALE SIGHTINGS BETWEEN 2002 AND 2017 FROM A COMPILATION OF OPPORTUNISTIC SIGHTINGS DATA AND EFFORT CORRECTED RELATIVE DENSITIES

DATE:	FIG No.
07/28/2021	Map 3

Path: M:\Projects-Active\1384\MXD\Infrastructure\1384_RBT2_PredictedRoutes_4198_20210401.mxd



Location	Description
A	Container vessel slowing down to prepare to exit the inbound shipping lane
1	Container vessel starting to turn out of the shipping lane to call at RBT2 and meeting the support tugs
2	Berthing or unberthing of the container vessel by the support tugs
3	Support tugs leave the departing container vessel
4	Support tugs enter or exit the acoustic effects model area while travelling to and from the tug basin
B	Container vessel in the outbound shipping lane

Legend

●	LOCATIONS USED TO DEFINE CONTAINER VESSEL ACTIVITIES, INCLUDING SUPPORT TUGS, DURING PROJECT OPERATION
☐	BOUNDARY OF PROJECT AREA
☐	EXTENT OF SHIPPING LANES
—	ARRIVAL SHIPPING ROUTE
—	DEPARTURE SHIPPING ROUTE

PROJECT COMPONENT

EXISTING LANDMARK

0 2 4
Kilometres
1:100,000
NAD 1983 UTM Zone 10N

N

Note:
The Boundary of the Project Area reflects the updated Project footprint presented in the June 2018 RBT2 Project Construction Update (see CEAR Document #1210).

PORT of vancouver

ROBERTS BANK TERMINAL 2

ROUTE AND LOCATIONS OF CONTAINER VESSEL AND SUPPORT TUGS DURING RBT2 OPERATION (I.E., ARRIVAL, BERTHING, UNBERTHING, DEPARTURE) ASSUMED FOR THE MODELLING STUDY

Map 1

DATE: 04/08/2021

FIG No. Map 4

Basemap Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

APPENDICES

Appendix A. Quiet Vessels Literature Review

Achieve Quieter Oceans (AQUO) Consortium. 2014. On-site measurements - experimental data for accurate identification and quantification of cavitation noise and other sources. Collaborative Project number 314227 D3.3. 110 pp.

Achieve Quieter Oceans (AQUO) Consortium. 2015a. Assessment of the solutions to reduce underwater radiated noise. Collaborative Project number 314227. D 5.3. 96pp.

Achieve Quieter Oceans (AQUO) Consortium. 2015b. Guidelines for regulation on UW noise from commercial shipping. Collaborative Project number 314227. Revision 4.3. 49 pp.

Achieve Quieter Oceans (AQUO) Consortium. 2015c. Comprehensive listing of possible improvement solutions and mitigation measures. Collaborative Project number 314227. D 5.1. 105 pp.

Achieve Quieter Oceans (AQUO) Consortium. 2015d. Impact of solutions on fuel efficiency. Collaborative Project number 314227 D5.5. 79 pp.

Achieve Quieter Oceans (AQUO) Consortium. 2015e. Ship underwater radiated noise patterns. Collaborative Project number 314227. R2.9. 133 pp.

Achieve Quieter Oceans (AQUO) Consortium. 2015. Synthesis of recommendations: underwater noise footprint of shipping: the practical guide. Collaborative Project number 314227. D 5.8. 42 pp.

Al-Falahi, M.D.A., K.S. Nimma, S.D.G. Jayasinghe, H. Enshaei and J.M. Guerrero. 2018. Power management optimization of hybrid power systems in electric ferries. Energy Conversion and Management 172:50–66.

De Bernardinis, A. and J. Moussodji. 2019. Electrification solution with supercapacitor storage of a bow thruster for river tugboat. Journal of Energy and Power Engineering 13:43–58.

De Breucker, S., E. Peeters and J. Driesen. 2009. Possible applications of plug-in hybrid electric ships. IEEE Electric Ship Technologies Symposium 310–317.

Dong, Z. 2020. Modeling and optimization of green ships using diesel/natural gas/fuel cell hybrid or pure electric propulsions. Proceedings of the International Offshore and Polar Engineering Conference 3804–3811.

Geertsma, R.D., R.R. Negenborn, K. Visser and J.J. Hopman. 2017. Design and control of hybrid power and propulsion systems for smart ships: A review of developments. Applied Energy 194:30–54.

Geertsma, R.D., K. Visser and R.R. Negenborn. 2018. Adaptive pitch control for ships with diesel mechanical and hybrid propulsion. Applied Energy 228:2490–2509.

Kendrick, A. and R. Terweij. 2019. Ship underwater radiated noise patterns. VARD Marine Inc 368-000–001.

Kipple, B. 2002. Southeast Alaska cruise ship underwater acoustic Noise. Naval Surface Warfare Center. NSWCCD-71-TR-2002/574.

Kipple, B. and C. Gabriele. 2007. Underwater noise from skiffs to ships. Proceeding of the Fourth Glacier Bay Science Symposium 172–175.

Kowalski, J., W. Leśniewski and W. Litwin. 2013. Multi-source-supplied parallel hybrid propulsion of the inland passenger ship STA.H. Research work on energy efficiency of a hybrid propulsion system operating in the electric motor drive mode. Polish Maritime Research 3:20–27.

Litwin, W., W. Leśniewski and J. Kowalski. 2017. Energy efficient and environmentally friendly hybrid conversion of inland passenger vessel. Polish Maritime Research 4:77–84.

Litwin, W., W. Lesniewski, D. Piatek and K. Niklas. 2019. Experimental research on the energy efficiency of a parallel hybrid drive for an inland ship. Energies 12:1675.

Matthews, M.-N.R., Z. Alavizadeh, D.E. Hannay, L. Horwich and H. Frouin-Mouy. 2018. Assessment of vessel noise within the Southern Resident Killer Whale critical habitat: final report. Document number 01618, Version 2.1. Technical report by JASCO Applied Sciences for the Innovation Centre, Transport Canada/Government of Canada.

McHorney, D.H., G.M. Pelella, L.C. Hilliard and M.R. Palmieri. 2018. Methods to minimize commercial vessel-generated marine acoustic pollution. Worcester Polytechnic Institute.

Minami, S., T. Toki, N. Yoshikawa, T. Hanada, M. Ashida, S.-I. Kitada and K. Tsukuda. 2010. A newly developed plug-in hybrid electric boat (PHEB). Journal of Asian Electric Vehicles 8:1385–1392.

Morandin, M., S. Bolognani, P. Campostrini, A. Ferrari and M. Guarnieri. 2015. Electric waterborne public transportation in Venice: A case study. 2015 IEEE Transportation Electrification Conference and Expo 1–8.

Nguyen, H.P., A.T. Hoang, S. Nizetic, X.P. Nguyen, A.T. Le, C.N. Luong, V.D. Chu, and V.V. Pham. 2020. The electric propulsion system as a green solution for management strategy of CO2 emission in ocean shipping: A comprehensive review. International Transactions on Electrical Energy Systems e12580.

Parsons, M.J.G., A.J. Duncan, S.K. Parsons and C. Erbe. 2020. Reducing vessel noise: An example of a solar-electric passenger ferry. The Journal of the Acoustical Society of America 147:3575–3583.

Pestana, H. 2014. Future trends of electrical propulsion and implications to ship design. Maritime Technology and Engineering 811–820.

Renilson, M., R. Leaper and O. Boisseau. 2013. Hydro-acoustic noise from merchant ships – impacts and practical mitigation techniques. Third International Symposium on Marine Propulsors 201–208.

Roa, M.J. 2015. Application of classification rules to hybrid marine electrical propulsion plants. Record of Conference Papers - Annual Petroleum and Chemical Industry Conference 1–7.

Spence, J., R. Fischer, M. Bahtiarian, L. Boroditsky, N. Jones and R. Dempsey. 2007. Review of existing and future potential treatments for reducing underwater sound from oil and gas industry activities. Noise Control Engineering, Incorporated NCE Report 07-001.

Tronstad, T., Å.H. Høgmoen, G.P. Haugom and L. Langfeldt. 2017. Study on the use of fuel cells in shipping. European Maritime Safety Agency (EMSA).

Vakili, S. V., A.I. Ölcer and F. Ballini. 2020. The development of a policy framework to mitigate underwater noise pollution from commercial vessels. Marine Policy 118:104004.

Vakili, S. 2018. Under-water noise pollution sources, mitigation measures in commercial vessels: the trade-off analysis in the case of study for trans mountain project, Port of Vancouver, Canada. World Maritime University Dissertations.

Vakili, S., A.I. Ölcer and F. Ballini. 2020. The trade-off analysis for the mitigation of underwater noise pollution from commercial vessels: Case study – Trans Mountain project, Port of Vancouver, Canada. Proceedings of the Institution of Mechanical Engineers Part M: Journal of Engineering for the Maritime Environment 234:599–617.

Yuan, Y., J. Wang, X. Yan, B. Shen and T. Long. 2020. A review of multi-energy hybrid power system for ships. Renewable and Sustainable Energy Reviews 132:110081.

Appendix IR2020-3-E

Technical data report – Underwater Noise Modelling of RBT2 Marine Shipping: Container Vessel Transit Exposure Model

Underwater Noise Modelling of RBT2 Marine Shipping

Container Vessel Transit Exposure Model

Submitted to:

Pamela Dinn
Ecofish Research Ltd.
Contract: PO 1384-07

Authors:

Alexander MacGillivray
Connor Grooms
Jorge Quijano
Dominic Tollit (SMRU Consulting)

23 September 2021

P001571-001
Document 02382
Version 5.1

JASCO Applied Sciences (Canada) Ltd
Suite 2305, 4464 Markham St.
Victoria, BC V8Z 7X8 Canada
Tel: +1-250-483-3300
Fax: +1-250-483-3301
www.jasco.com

Suggested citation:

MacGillivray, A., C. Grooms, J. Quijano, and D. Tollit. 2021, *Underwater Noise Modelling of RBT2 Marine Shipping: Container Vessel Transit Exposure Model*. Document 02382, Version 5.1. Technical report by JASCO Applied Sciences.

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

Figures

Tables

Glossary

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

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

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

background noise
Total of all sources of interference in a system used for the production, detection, measurement, or recording of a signal, independent of the presence of the signal (ANSI S1.1-1994 R2004). Ambient noise detected, measured, or recorded with a signal is part of the background noise.

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

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

cavitation
Cavitation is the rupture of a liquid caused by a rapid reduction in local pressure. Small vapor bubbles form at the rupture and generate intense noise when they collapse. Cavitation commonly occurs in water flowing around a rapidly rotating propeller.

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

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

CTD (conductivity-temperature-depth)
Measurement data of the ocean’s conductivity, temperature, and depth; used to compute sound speed and salinity.

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

ensonified
Exposed to sound.

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

geoacoustic
Relating to the acoustic properties of the seabed.

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

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

median
The 50th percentile of a statistical distribution.

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

parabolic equation method
A computationally efficient solution to the acoustic wave equation that is used to model transmission loss. The parabolic equation approximation omits effects of back-scattered sound, simplifying the computation of transmission loss. The effect of back-scattered sound is negligible for most ocean-acoustic propagation problems.

point source
A source that radiates sound as if from a single point (ANSI S1.1-1994 R2004).

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

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

propagation loss (PL)
The decibel reduction in sound level between two stated points that results from sound spreading away from an acoustic source subject to the influence of the surrounding environment.

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

rms
root-mean-square.

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

sound exposure

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

sound exposure level (SEL)

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

sound field

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

sound intensity

Sound energy flowing through a unit area perpendicular to the direction of propagation per unit time.

sound pressure level (SPL)

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

For sound in water, the reference sound pressure is one micropascal ($p0$ = 1 µPa) and the unit for SPL is dB re 1 µPa2:

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

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

sound speed profile (SSP)

The speed of sound in the water column as a function of depth below the water surface.

source level (SL)

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

spectrum

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

Executive Summary

This study provides an assessment of differences in underwater noise exposures from changes in container vessel traffic incidental to Roberts Bank Terminal 2 Project (RBT2), in response to the information request to the port authority from the Minister of Environment and Climate Change (the Minister). The Minister requested that the port authority provide updated estimates of sound exposure levels for Southern Resident Killer Whales (SRKW) from marine shipping incidental to the project, based on an analysis of vessel source level measurements and the composition of vessel classes projected to call at the RBT2 terminal in future. The Minister also requested that the port authority re-assess the total masking of SRKW echolocation from continuous exposure to noise from marine shipping incidental to the project, by assessing noise signal masking for more than one frequency (including frequencies where container vessel noise is more prominent).

To support the port authority in responding to the Minister's request, JASCO Applied Sciences developed a Transit Exposure Model (TEM) to assess differences in underwater noise exposure from changes in container vessel traffic incidental to RBT2. The TEM is a spreadsheet tool that was used to analyze yearly differences in underwater noise in the marine shipping area, based on new projections of container vessel calls at Port of Vancouver for 2035, 2040, and 2045 by Mercator International (2021). The TEM was also used to investigate the effectiveness of different mitigation measures involving slowdowns of container vessels along the marine shipping routes to the Port of Vancouver. According to the most-realistic container vessel traffic projections, the total number of container vessels calling at Port of Vancouver terminals is predicted to be the same whether RBT2 is built or not, but the average size of container vessels calling at the Port of Vancouver will increase due to the increased container throughput capacity provided by the proposed RBT2 project. Therefore, the TEM calculations provided in this study are based on all container vessels calling at the Port of Vancouver (i.e., not just container vessels incidental to the project).

The TEM used updated data on container vessel noise emissions, available by request through the port-authority-led Enhancing Cetacean Habitat and Observation (ECHO) Program, to estimate underwater noise exposures from different size classes of container vessels transiting in the international shipping lanes. Note that only summary statistics of source levels were provided by the ECHO Program for this analysis, to maintain operator confidentiality. Data from the ECHO Program indicate that source levels for different classes of container vessels have the greatest differences at frequencies above 1 kHz, with larger container vessels having higher noise emissions than smaller vessels in this frequency range. Consequently, vessel size has a greater influence on SRKW echolocation click masking thresholds (above 1 kHz) than on behavioural response thresholds (which are dominated by noise below 1 kHz).

The TEM estimated noise exposure for three sub-areas (Georgia Strait, Haro Strait, and Juan de Fuca Strait), within the marine shipping area which overlaps the critical habitat of SRKW, using sound propagation loss curves calculated using JASCO's Marine Operation Noise Model (MONM). Sound levels for different size classes of container vessels were calculated by combining source level estimates with frequency-dependent propagation loss computed by MONM at the three source locations. These sound pressure level (SPL) curves (adjusted for transit speed) were used by the TEM for calculating underwater noise exposures in each of the three sub-areas.

The TEM assessed noise exposure in terms of two acoustic metrics, which were selected to provide information on long-term changes in underwater sound levels and potential acoustic behavioural disturbance effects on SRKW:

- Yearly time-averaged underwater sound level ($L_{eq\text{-}1yr}$; unweighted), which reflects the long-term, time-averaged noise level received at a given location from passing container vessels over a one-year period and is directly related to the total sound exposure level (SEL) over the same period;
- Annual exceedance hours above behavioural disturbance and masking thresholds, which reflects the total time a static receiver could be exposed to noise above the threshold, from container vessels transiting in the marine shipping area, over one year.

These metrics were assessed for broadband SPL (unweighted) and for SRKW echolocation click masking frequencies at 20 kHz and 50 kHz. The broadband SPL threshold was 120 dB re 1 µPa, which corresponds to the 10% probability of low-severity behavioural response and 1% probability of moderate behavioural response for SRKW. Echolocation click masking thresholds were developed specifically for the RBT2 assessment, based on an analysis of background noise levels that would mask detection of an SRKW echolocation click return at 250 m range. The 20 kHz and 50 kHz frequencies were selected for analysis, as these reflect the most important frequencies for SRKW echolocation clicks. Updated weekly container vessel call projections were used to estimate annual differences in these metrics, with and without RBT2, for the receivers in each of the three sub-areas within the marine shipping area. Differences are indicative of changes in acoustic quality of SRKW habitat that would be expected if RBT2 is built. The TEM focused only on noise originating from container vessels over time, to eliminate the confounding effects of noise from other vessel traffic and non-shipping noise sources (e.g., such as wind-driven ambient or biological sources).

Under the most-realistic container vessel traffic scenarios, broadband sound levels were nearly identical with and without RBT2 for all three projection years: yearly L_{eq} was less than 0.1 dB lower with RBT2 and annual exceedance hours were less than 1.2% higher with RBT2. However, echolocation click masking was predicted to be higher with RBT2, with yearly L_{eq} up to 1.3 dB greater and yearly exceedance times up to 4.7% greater. The RBT2-related differences were greatest in 2040, which was the year with the largest projected difference in the number of Mega Max calls. Nonetheless, the predicted deltas for both scenarios were small in magnitude, given that the overall number of container vessel transits is expected to be the same with and without RBT2. Thus, under the most-realistic scenario, existing broadband noise levels in the marine shipping area would be approximately the same with and without the Project.

Under three, less-likely high-case container vessel traffic scenarios, noise levels with RBT2 were expected to be higher than noise levels without RBT2. Noise exposures were evaluated for scenarios involving an additional 52, 104, and 156 Mega-Max container vessels per year (i.e., corresponding to 1, 2, or 3 extra Mega-Max calls per week to the Port of Vancouver, on top of the most-realistic projections). Note, however, that because the proposed RBT2 Project is anticipated to accommodate on average five container vessels per week, additional Mega-Max vessels under the 104-vessel and 156-vessel high-case scenarios would need to call at other Port of Vancouver terminals and would therefore not be incidental to the project. TEM results for the high-case container vessel scenarios showed that additional Mega-Max vessels would increase both exceedance hours and yearly average sound levels in the marine shipping area, beyond the expected conditions for the most-realistic scenarios. However, when accounting for existing noise levels from all other vessel traffic and from other noise sources present in the marine shipping area (estimated to be 119.9 dB 1 µPa based on published data from 2015-2017), the effect of adding 52–156 extra Mega-Max vessels per year would be to increase existing broadband yearly time-average sound levels by only 0.1–0.4 dB within the marine shipping area.

In the event that vessel calls with the Project are higher than expected, contingency mitigation measures may be used to offset underwater noise from additional vessels. Slowdowns, in particular, have been demonstrated as an effective measure for reducing underwater noise from marine vessels and are currently employed by the Port-led ECHO program to reduce underwater radiated noise in critical habitat areas for SRKW. For each scenario (most-realistic and three high-case) five different contingency mitigation measures were analyzed, involving speed reductions for container vessels within different areas along the marine shipping route for 6-months out of the year (May-October):

1. 95% of RBT2-bound vessels slow down from 18 to 14.5 knots for six months in Haro Strait, Boundary Pass, and at Swiftsure Bank (“14.5 kn only RBT2 vessels”)
2. 80% of RBT2-bound vessels and 80% of all other container vessels slow down from 18 to 14.5 knots for six months in Haro Strait, Boundary Pass, and at Swiftsure Bank (“14.5 kn all container vessels (all 80%)”)
3. 95% of RBT2-bound vessels and 80% of all other container vessels slow down from 18 to 14.5 knots for six months in Haro Strait, Boundary Pass, and at Swiftsure Bank (“14.5 kn all container vessels”)

4. 95% of RBT2-bound vessels and 80% of all other container vessels slow down from 18 to 11 knots for six months in Haro Strait, Boundary Pass, and at Swiftsure Bank ("11 kn all container vessels")
5. 95% of RBT2-bound vessels and 80% of all other container vessels slow down from 18 to 11 knots for six months in Haro Strait, Boundary Pass, and at Swiftsure Bank; and in additional areas of the Strait of Juan de Fuca and Strait of Georgia ("11 kn expanded slowdown all container vessels").

The slowdown contingency mitigation measures were found to be more effective as speeds were reduced, the number of participating vessels was increased, and the area of the slowdowns was expanded. This study found that under the most-realistic vessel traffic scenario with RBT2, all five mitigation measures would reduce broadband noise levels below expected conditions without RBT2. Under the less-likely high-case container vessel traffic scenarios, the following contingency measures could be used to mitigate average broadband noise below expected conditions (i.e., without RBT2):

- 52 additional Mega-Max vessels annually could be mitigated by further reducing transit speed for six months from 14.5 knots to 11 knots;
- 104 additional Mega-Max vessels annually could be mitigated by further reducing the transit speed for six months to 11 knots combined with expanding the slowdown area to include Juan de Fuca Strait and the Strait of Georgia;
- 156 additional Mega-Max vessels annually could be mitigated by further reducing the transit speed for six months to 11 knots combined with expanding the slowdown area to include Juan de Fuca Strait and the Strait of Georgia.

In general, analysis of the contingency mitigation options showed that, compared to broadband noise, the more expansive measures would be needed to reduce sound levels from marine shipping in the 20 kHz and 50 kHz echolocation bands. Under the higher high-case scenario (+156 Mega-Max calls per year), contingency mitigation options beyond those considered in this study would be needed to reduce sound levels in these two echolocation bands. Such mitigation options are achievable given the small difference compared to existing conditions and could be achieved, for example, by expanding slowdown durations beyond the 6 months considered in this study. It should also be noted that these findings are based on estimates of Mega-Max source levels extrapolated from present-day ECHO Program data. It is expected that updated source level measurements will be collected for new classes of container vessels calling at the Port of Vancouver as part of the port authority's marine shipping follow-up program (FUP) element.

It is anticipated that the TEM methodology described in this technical report could be relied upon as part of the marine shipping FUP element, proposed by the port authority since the public hearing. The TEM could be used to assess whether unforeseen increases in project-related container vessel calls, size classes, or noise emissions have increased underwater noise exposures beyond predicted levels.

1. Introduction

On August 24, 2020, the Vancouver Fraser Port Authority (the port authority) received a letter from the Minister of Environment and Climate Change (the Minister) seeking additional information in support of his decision under the *Canadian Environmental Assessment Act, 2012* in relation to the Roberts Bank Terminal 2 (RBT2) Project. The Minister requested that the port authority provide updated estimates of sound exposure levels for Southern Resident Killer Whales (SRKW) from marine shipping incidental to the project, based on an analysis of vessel source level measurements and the composition of vessel classes projected to call at RBT2 (MECC 2020). The Minister also requested that the port authority re-assess the total masking of SRKW echolocation from continuous exposure to noise from marine shipping incidental to the project, by assessing noise signal masking for more than one frequency (including frequencies where container vessel noise is more prominent). Marine shipping in the Salish Sea transits directly through SRKW critical habitat, as designated by Fisheries and Oceans Canada (DFO) in their 2018 recovery strategy (DFO 2018a).

To support the port authority in responding to the Minister's information requests, this technical report presents results of a Transit Exposure Model (TEM) that has been developed to assess differences in underwater noise exposure from changes in container vessel traffic incidental to RBT2. The TEM is a spreadsheet tool that has been used to analyze yearly differences in underwater noise in the marine shipping area, based on updated forecasts of container vessel calls at the Port of Vancouver for 2035, 2040, and 2045. The TEM has also been used to investigate the effectiveness of different contingency mitigation measures involving slowdowns of container vessels along the marine shipping routes to the Port of Vancouver.

Expected container vessel calls at Port of Vancouver terminals, under the most-realistic traffic scenario, were based on the updated projections by Mercator International (ca. 2021) which includes projections of the number and size of container vessels anticipated to call the Port of Vancouver in the future with and without RBT2 (Mercator International 2021). According to the updated projections, the total number of container vessels calling at the Port of Vancouver is predicted to be the same whether RBT2 is built or not. However, the average size of container vessels calling at the Port of Vancouver will increase, due to the increased container throughput capacity provided by RBT2. The updated projections of weekly container vessel calls at the Port of Vancouver under the most-realistic scenario, for 2035, 2040, and 2045, broken down by size class, are summarized in Table 1.

Table 1. Projected weekly container vessel calls under the most-realistic scenario with and without RBT2 at all VFPA terminals (top rows) and at RBT2 only (bottom rows) for 2035, 2040, and 2045 (Mercator International 2021). Actual calls from 2020 are shown for comparison. SPPX = Small Post-Panamax, LPPX = Large Post-Panamax, NPX = Neo Panamax, MMX = Mega Max.

Terminals	Vessel Class	2020	2035		2040		2045	
		no RBT2	with RBT2	no RBT2	with RBT2	no RBT2	with RBT2	no RBT2
All VFPA container terminals	SPPX	15	4	4	4	4	5	5
	LPPX	2	5	8	2	5	3	4
	NPX	0	7	4	6	6	4	4
	MMX	0	0	0	4	1	5	4
	All (total)	*17*	*16*	*16*	*16*	*16*	*17*	*17*
RBT2 only	SPPX	–	0	0	0	0	0	0
	LPPX	–	1	0	0	0	1	0
	NPX	–	2	0	2	0	1	0
	MMX	–	0	0	2	0	2	0
	All (total)	–	*3*	*0*	*4*	*0*	*4*	*0*

To further support the Minister’s information request and provide additional conservatism, this technical report assesses the potential effects on SRKW from marine shipping under three less-likely, high-case container vessel traffic scenarios. Under the most-realistic scenario, the average number of container vessels projected to call at RBT2 each week would range from three to four over the forecast period of 2035 to 2045 (Mercator International 2021). Four to five container vessels could call at RBT2 each week in the less likely high-case scenario. In the EIS it was assumed that, on average, five container vessels would call at RBT2 weekly based on 2010 container vessel data (including container shipping schedules) and projected container shipping services and vessel size characteristics. The high-case scenarios indicate that container vessel calls at all Port of Vancouver terminals could range from 16 to 20 calls per week on average (i.e., approximately 52 fewer to 156 additional vessel calls per year) depending on the alternative scenario, noting that only one of those additional weekly services would call to the RBT2 project. These three less-likely, high-case scenarios were analyzed using the TEM by adding extra Mega Max calls to the most-realistic vessel traffic scenario with RBT2 (Table 2).

Table 2. Weekly container vessels calls at Port of Vancouver terminals under different vessel traffic scenarios for 2035, 2040, and 2045. See Table 1 for per-class calls under the under most-realistic scenarios. Per-class calls under the high-case scenarios (+52, +104, and +156) were obtained by adding extra MMX calls to the most-realistic vessel traffic scenario with RBT2 (Table 1).

Vessel Traffic Scenario	Additional Weekly MMX Calls		Total Weekly Container Vessel Calls (All Classes)		
	RBT2	Other Terminals	2035	2040	2045
Most-realistic without RBT2	0	0	16	16	17
Most-realistic with RBT2	0	0	16	16	17
+52 vessels annually with RBT2	1	0	17	17	18
+104 vessels annually with RBT2	1	1	18	18	19
+156 vessels annually with RBT2	1	2	19	19	20

The TEM uses updated data on container vessel noise emissions, available by request through the port-authority-led Enhancing Cetacean Habitat and Observation (ECHO) Program, to estimate underwater noise exposures from different size classes of container vessels transiting in the shipping lanes in the Georgia Strait, Haro Strait, and Juan de Fuca Strait. The TEM assesses noise exposure in terms of two acoustic metrics, which have been selected to provide information on long-term changes in underwater sound levels and potential acoustic behavioural effects on SRKW:

- Yearly time-averaged sound level ($L_{eq\text{-}1yr}$, also referred to as equivalent continuous time-averaged sound level), which reflects the long-term, time-averaged noise level received at a given location from passing container vessels over a one-year period and is directly related to the total sound exposure level (SEL) over the same period;
- Annual exceedance hours above behavioural disturbance and masking thresholds, which reflects the total time a static receiver could be exposed to noise above the threshold, from container vessels transiting in the marine shipping area, over one year.

These metrics are assessed for broadband sound pressure level (SPL, unweighted) and for SRKW echolocation click masking in 1/3-octave bands at 20 kHz and 50 kHz. Weekly container vessel call projections are used to estimate annual differences in these metrics, with and without RBT2, for receivers in the marine shipping area.

The TEM has also been used to illustrate the effectiveness of five potential contingency mitigation measures, involving slowdowns of container vessels within different areas along the marine traffic routes (Table 3). Under these contingency mitigation measures, vessels are assumed to reduce their transit speeds in order to lower their underwater noise emissions inside specified slowdown areas along the marine traffic route. The mitigation measures have been evaluated in terms of how much they reduce annual average exceedance hours and sound levels from container vessels, over the entirety of the marine shipping route.

Table 3. Contingency mitigation measures involving vessel slowdowns investigated using the Transit Exposure Model. The current ECHO slowdowns (ca. 2021) include sections of Haro Strait, Boundary Pass, and Swiftsure Bank and comprise approximately one third of the marine shipping route to RBT2. The expanded slowdown area includes all three sub-areas included in the TEM, comprised of the current ECHO Program slowdown areas plus Juan de Fuca Strait (to Buoy J) and Strait of Georgia (to the Proposed terminal). The 80% participation rate reflects voluntary composite container vessel participation rates modelled for the ECHO Program 2020 slowdown (VFPA, 2021) and the 95% participation rate reflects required slowdown participation of RBT2 vessels. All mitigations options are assumed to occur over a 6-month period, during months with summer sound propagation conditions (e.g., May-Oct). See Section 2.7 for additional details.

Mitigation Measure	Slowdown Area	Speed Limit (kn)	Slowdown Participation Rate	
			RBT2 vessels	Other vessels
No mitigation	–	–	0%	0%
14.5 kn only RBT2 vessels	Current ECHO (1/3 route)	14.5	95%	0%
14.5 kn all container vessels (all 80%)	Current ECHO (1/3 route)	14.5	80%	80%
14.5 kn all container vessels	Current ECHO (1/3 route)	14.5	95%	80%
11 kn all container vessels	Current ECHO (1/3 route)	11	95%	80%
11 kn expanded slowdown all container vessels	All areas (full route)	11	95%	80%

The TEM has been developed to specifically assess changes in container vessel traffic, including future calls of Mega Max vessels that do not currently call at the Port of Vancouver. Other types of commercial vessel traffic will not be affected by RBT2. As such, the TEM does not include (or provide updated projections of) cumulative regional noise from non-container vessel traffic, which were assessed previously in the Environmental Impact Statement (EIS) (MacGillivray et al. 2014). It is anticipated that the TEM methodology described in this technical report could be relied upon as part of the marine shipping follow-up program (FUP) element, proposed by the port authority since the public hearing. The TEM could be used to assess whether unforeseen increases in project-related container vessel calls, size classes, or noise emissions have increased underwater noise exposures to SRKW beyond predicted levels.

2. Methods

2.1. Overview of Transit Exposure Model

The purpose of the TEM is to assess how expected changes in container vessel traffic may affect the acoustic quality of SRKW critical habitat within the marine shipping area. The TEM evaluates potential noise exposures by accumulating the total sound exposure from one year of container vessel transits at three representative locations along the shipping lanes to and from Port of Vancouver terminals (Figure 1). These locations have been selected to represent different sub-areas within the marine shipping area with distinct sound propagation conditions. To assess the changes with RBT2, the model employs a delta approach, where differences in annual total noise exposures are calculated with and without RBT2 for each projection year. The TEM focuses only on noise originating from container vessels over time, to eliminate the confounding effects of noise from other vessel traffic and non-shipping noise sources (e.g., such as wind-driven ambient or biological sources).

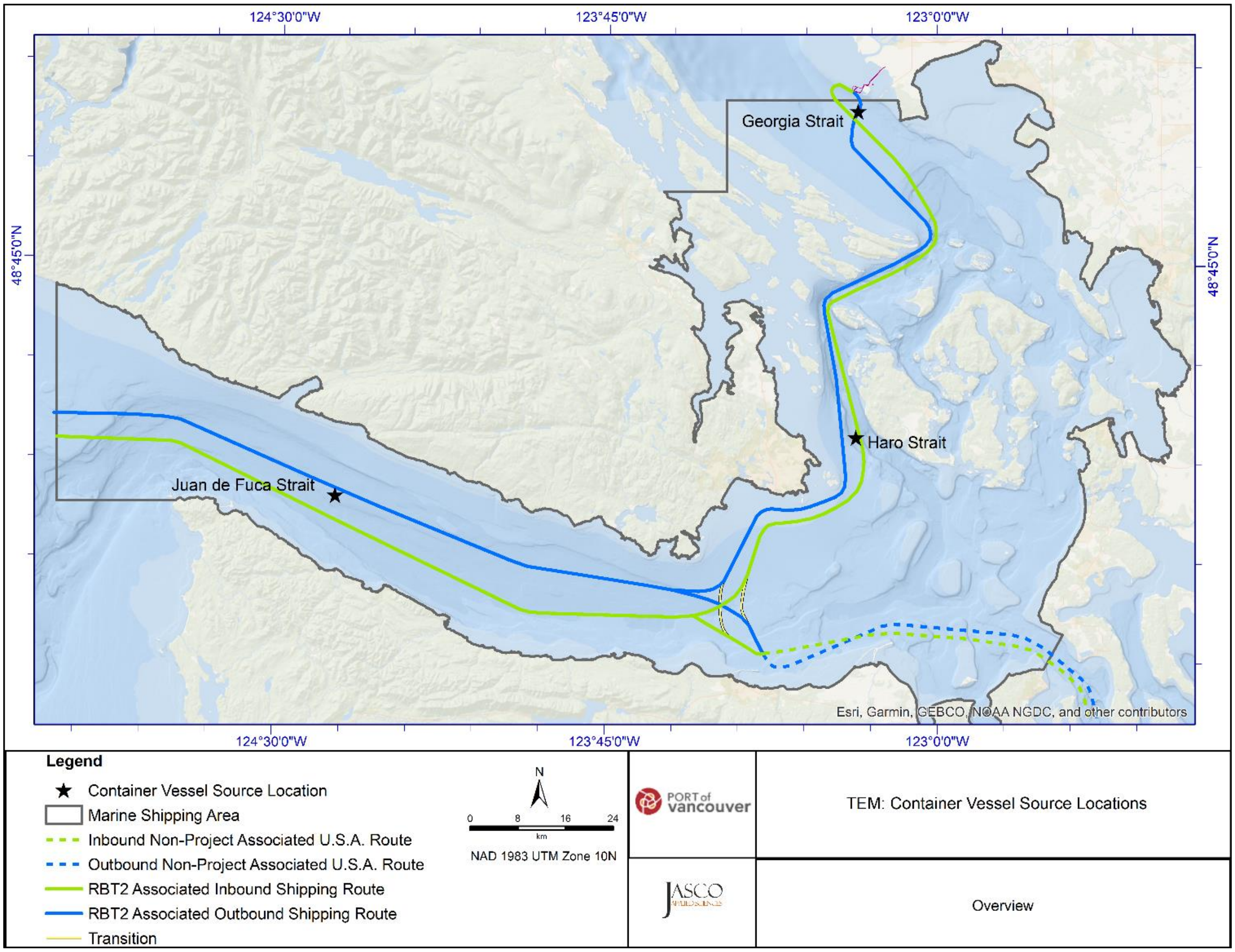


Figure 1. Source locations for sound propagation modelling employed in the Traffic Exposure Model (TEM), representing the three main sub-areas along the container vessel transit route to/from the Port of Vancouver.

In each sub-area, the TEM accumulates yearly noise exposures from transiting container vessels (both inbound and outbound) for three fixed receiver loci at 0.4 km, 2 km, and 4 km from the vessel transit route

(Figure 2). The 0.4 km locus corresponds to the statutory closest approach distance to SRKW (DFO 2018b), whereas the 2 km and 4 km loci represent exposures at intermediate (×5) and long (×10) ranges from the transit route. The TEM calculates noise exposures for 52 weeks (i.e., 1 year) of container vessel transits in terms of two types of metrics:

- Total exceedance time (hours) above a specified sound pressure level (SPL) threshold, representing onset of behavioural disturbance or masking (see Section 2.2);
- Total time-integrated sound exposure in a specified frequency band, converted to sound exposure level (SEL) and yearly time-averaged sound level ($L_{\text{eq-1yr}}$).

The TEM accumulates noise exposures from single container vessels up to a maximum distance of 20 km from closest point of approach (CPA) to the receiver loci. Sound levels at each receiver locus are averaged over the upper 100 m of the water column, reflecting the range of depths where SRKW are most likely to be present. The total sound exposure and exceedance minutes from each transiting container vessel are averaged over the three receiver loci. This spatial-depth sampling reflects the uncertainty of animal locations with respect to the shipping lanes. The TEM accumulates noise exposures year-round, regardless of animal presence, and therefore assesses acoustic habitat quality (i.e., potential for effects) rather than actual effects on SRKW.

Container vessel transit speeds in the TEM are based on average speeds from historical (2015) AIS data for each of the three sub-areas (Table 4), unless slowdown mitigations are explicitly applied (see Table 3 and Section 2.7). The TEM uses representative source levels for four different size classes of container vessels, projected to call at the Port of Vancouver, which have been estimated based on recent source level measurements (anonymized) available by request from the ECHO Program (Section 2.3). To capture the effect of speed changes on noise exposures, the TEM adjusts vessel source levels according to vessel speed in each of the three sub-areas. The TEM considers seasonal changes in sound propagation conditions by modelling separately summer and winter sound speed profiles at each location (Section 2.4). When calculating sound exposures, summer and winter vessel calls are split equally between summer and winter periods (assumed to be 26 weeks each), to represent the range of sound propagation conditions present in the study area.

In the final step, exceedances are compared with and without RTB2 to obtain delta differences representing changes in noise exposures with and without the project. These deltas are indicative of changes in acoustic quality of SRKW habitat that would be expected if RBT2 is built.

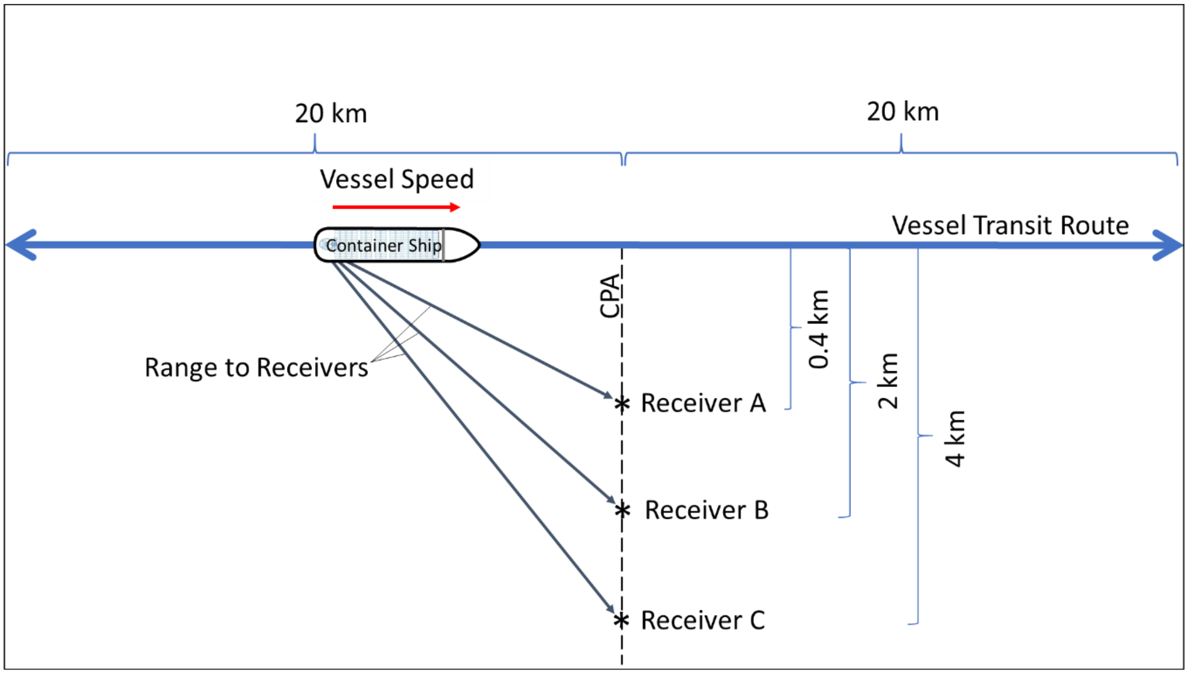


Figure 2. Plan-view diagram of noise exposure calculation for a single container vessel transiting through one of the three sub-areas. CPA = closest point of approach. Noise exposures from each container vessel transit are accumulated for distances less than 20 km from the CPA to the receiver loci.

Table 4. Average historical speeds of container vessels used for representing transit speeds in the TEM. Transit speeds are assumed the same for all size classes of container vessels. Speeds were obtained from historical AIS data from 2015. The TEM assumes vessel speed is through water for calculating noise emissions but does not attempt to correct for daily variations in ocean currents. Neglecting currents is a good representation of the average case, since currents are tidally driven (i.e., mean speed through water and mean speed over ground are equal in the long term).

Location	Average Container Vessel Speed Through Water (knots)
Georgia Strait	18.0
Haro Strait	18.0
Juan de Fuca Strait	16.5

2.2. Acoustic Metrics

The TEM uses three acoustic criteria to calculate distances where noise from marine shipping has the potential to cause behavioural disturbance or echolocation click masking for SRKW (Table 5). The selection of criteria is further described in Buren et al. (2021) and has considered the following sources:

1. Generic cetacean disturbance criteria applied by the National Marine Fisheries Service (NMFS) (MMPA 2007, NOAA 2019).
2. Species-specific behavioural response thresholds for SRKW (SMRU Canada Ltd. 2014), which are based on probabilities of low and moderate responses.

Table 5. Behavioural response and echolocation click masking criteria for SRKWs (SMRU Canada Ltd. 2014). Note that the 120 dB re 1 µPa SPL (NMFS level B) corresponds to the 10% probability threshold for low-severity behavioural response and 1% probability of moderate behavioural response. SPL = sound pressure level; PSD = power spectral density. Echolocation click masking thresholds are for a SRKW click return at 250 m range.

Criteria	Frequency (kHz)	Threshold (dB)	Metric	Reference Level
SRKW behavioural response	0.01-100 (broadband)	120	SPL	1 µPa
SRKW echolocation click masking	20 (1/3-octave band)	37.9	PSD level	1 µPa²/Hz
	50 (1/3-octave band)	35.7		

Behavioural thresholds for SRKW were developed for the EIS by SMRU Canada Ltd. (2014), who obtained input from a Technical Advisory Group comprising experts on SRKW and underwater noise (Compass 2013) and subsequently reanalyzed three existing obseravtional and acoustic data sets to quantify unweighted broadband SPL at which behavioural responses had been observed. The TEM computes exceedance thresholds for SMRU's low- and moderate-severity response thresholds of 120 dB re 1 µPa, which corresponds to the 10% probability of low-severity behavioural response and 1% probability of moderate behavioural response. This threshold also represents the current National Oceanic and Atmospheric Administration (NOAA) behavioural disturbance threshold for continuous noise (NOAA 2019). Marine shipping is not expected to generate sound levels that could result in injury to marine mammals, therefore auditory injury criteria have not been evaluated for this study.

Noise from marine shipping may also mask SRKW vocalizations and limit the range at which individuals can receive echolocation clicks from potential prey. The TEM evaluates echolocation click masking using sound power spectral density (PSD) thresholds in two separate frequency bands. These two PSD thresholds are conservatively based on an estimate of background noise levels that would mask a SRKW click return at 250 m range (Au et al. 2004, SMRU Canada Ltd. 2014). Radii for these thresholds are calculated from modelled PSD levels in the 20 kHz and 50 kHz frequency bands (Buren et al. 2021). The 20 kHz and 50 kHz frequency bands capture the two most important frequencies for SRKW echolocation clicks.

2.3. Container Vessel Source Levels

The TEM calculates underwater noise exposures for the four different size classes of container vessels projected to call at the Port of Vancouver in 2035, 2040 and 2045 (Mercator International 2021, Table 6). Source levels for each of these size classes were derived from recent measurements of container vessels collected on the Underwater Listening Stations in Georgia Strait and Boundary Pass, which were made available by request from the ECHO Program (Figure 3). Note that only summary statistics of source levels were provided by the ECHO Program for this analysis, to maintain operator confidentiality. Mean source levels for Small Post-Panamax, Large Post Panamax, and Neo Panamax vessels were estimated by averaging measurements of container vessels, according to the length overall (LOA) ranges from Table 6, for transit speeds through water between 17 and 21 knots (i.e., representing typical speeds along the transit routes). No measurements of Mega Max vessels were available at the time of this study so source levels for this class were extrapolated from measurements of the other vessel classes based on length, draft and speed trends reported by the ECHO Program's recently published vessel noise correlations study (MacGillivray et al. 2020).

To determine a representative source level for the Mega Max class, source levels for the other three classes were each scaled to a LOA of 400 m and draft of 14 m and the results were averaged in terms of sound power (a conservative approach). The resulting average is used to represent Mega Max source levels in the TEM. Data from the ECHO Program represent the best available information on noise emissions from container vessels likely to call at Port of Vancouver in the future. Thousands of vessel source level measurements were collected and analyzed for the ECHO studies, thus their findings supersede the older Ross (1987) power law trends that were previously used to extrapolate source levels of the largest container vessels in the EIS and public hearings.

Table 6. Container vessel size class categories. Container capacity (TEU=twenty-foot equivalent unit), length overall (LOA), and nominal draft as defined in Appendix B of VFPA response to Panel Information Session: January 30, 2019 Undertaking #2 (VFPA 2019).

Vessel Size Class	Capacity (TEU)	LOA Range (m)	Nominal Draft (m)
Small Post Panamax (SPPX)	4000-9000	275-335	11.4
Large Post Panamax (LPPX)	9000-12700	334-365	12.5
Neo-Panamax (NPX)	13000-14999	366	13.5
Mega Max (MMX)	18000-23000	400	14.0

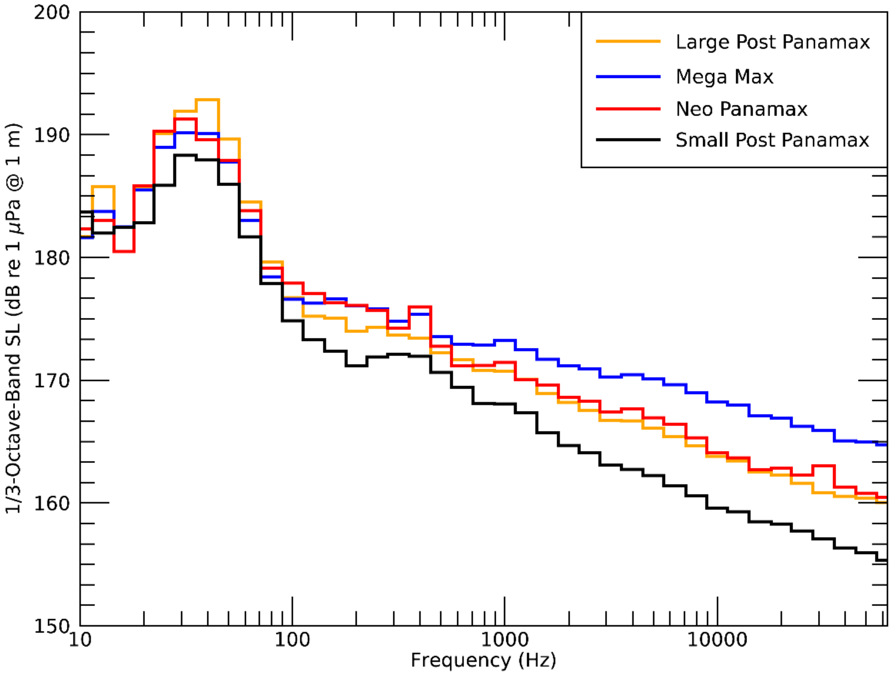


Figure 3. Container vessel source level estimates by size class, in decidecade frequency bands, scaled to a reference speed of 19 knots. Source level data extend to a maximum frequency of 63.1 kHz.

Data indicate that source levels for different classes of container vessels have the greatest differences at frequencies above 1 kHz (1000 Hz), with larger vessels having higher noise emissions than smaller vessels in this frequency range. Consequently, vessel size has a greater influence on echolocation click masking thresholds (above 1 kHz) than on behavioural response thresholds (which are dominated by noise below 1 kHz). Thus, based on correlations identified by the ECHO Program (MacGillivray et al. 2020), we expect Mega Max container vessels to have similar noise emissions to existing container vessels below 1 kHz but higher noise emissions above 1 kHz.

The TEM accounts for the effect of speed changes on noise exposures by adjusting source levels and transit speeds of container vessels in each sub-area. The TEM accounts for the influence of speed changes on vessel source levels by applying frequency-dependent source level scaling factors derived from the ECHO Program's 2017 slowdown trial (MacGillivray et al. 2019).

It is currently unknown whether container vessels built in future will incorporate design modifications that will reduce their underwater noise emissions. The International Maritime Organization (IMO) does not currently regulate underwater noise emissions, though they have published guidelines for reducing noise pollution from commercial shipping (IMO 2014). For the purposes of forecasting, the TEM calculations assume that present-day measurements of container vessel noise emissions are representative of the future fleet when RBT2 is operating. It is expected that any unforeseen changes in container vessel noise emissions will be addressed via monitoring associated with the marine shipping FUP element.

2.4. Propagation Loss

The TEM analyzes noise exposure for each sub-area using sound propagation loss curves calculated using JASCO’s Marine Operation Noise Model (MONM). The MONM model is described in EIS Appendix 9.8-A (Wladichuk et al. 2014). MONM models sound propagation via a wide-angle parabolic equation solution to the acoustic wave equation (Collins 1993) based on a version of the U.S. Naval Research Laboratory’s Range-dependent Acoustic Model (RAM), which has been modified to account for an elastic seabed (Zhang and Tindle 1995). The parabolic equation method has been extensively benchmarked and is widely employed by researchers and practitioners in the underwater acoustics community (Collins et al. 1996).

The environmental inputs to MONM—i.e. bathymetry, geoacoustic properties, and sound speed profiles—are based on those used in a regional vessel noise modelling study undertaken for the ECHO Program's 2017 slowdown trial (MacGillivray et al. 2018, Joy et al. 2019). Past studies have established that sound propagation in the Salish Sea is sensitive to seasonal changes in oceanographic conditions. During summer, the sound speed profile exhibits a negative gradient in the thermocline whereas during winter the sound speed profile exhibits a positive gradient in the thermocline. The positive gradient tends to reduce propagation loss, whereas the negative gradient tends to increase propagation loss. As a result, sound level radii are predicted to be higher in winter than in summer, particularly for receivers near the sea-surface.

Sound levels for different size classes of container vessels were calculated by combining source level estimates (see Section 2.3) with frequency-dependent propagation loss computed by MONM at the three source locations (Table 7). Figures 4 to 6 show examples of noise level footprints for a container vessel (Neo Panamax) at each of the three source locations included in the TEM (in winter). Note that these sound levels were computed for a 19-knot reference speed, corresponding to the reference source levels in Figure 3, and do not reflect the actual transit speed of container vessels at each location. The TEM adjusts the reference sound levels according to the actual transit speed in each sub-area when computing noise exposures.

Average curves of propagation loss (PL) versus distance were generated from the MONM predictions by selecting two representative transects at each site and averaging the PL over the top 100 m of the water column to a maximum range of 20 km from the source. These transects (dashed lines in the figures) were selected such that they were oriented approximately along the shipping lanes and represented long-distance sound propagation uninterrupted by land. The resulting PL data along the transects were used to calculate SPL versus range curves for both summer and winter environmental conditions for each size class of container vessel (Figure 7). These SPL curves (adjusted for transit speed) are used by the TEM for calculating underwater noise exposures in each of the three sub-areas.

Table 7. Source locations and seasons used in sound propagation calculations.

Site	Location	Latitude (N)	Longitude (W)	Season
1	Georgia Strait	48° 59.094'	123° 10.817'	Summer
				Winter
2	Haro Strait	48° 29.566'	123° 11.051'	Summer
				Winter
3	Strait of Juan de Fuca	48° 23.901'	124° 21.892'	Summer
				Winter

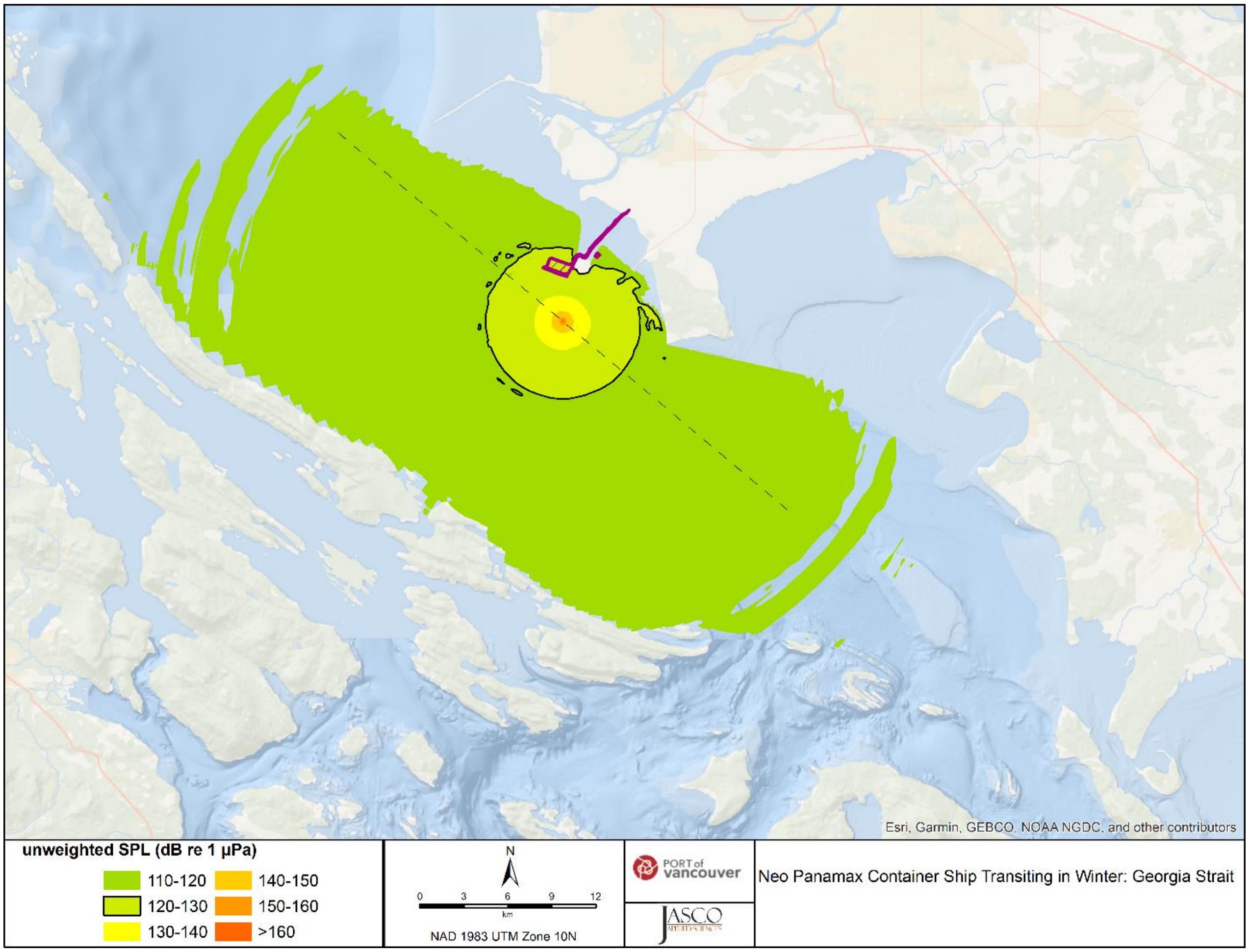


Figure 4. Modelled noise footprints for a Neo Panamax container vessel transiting at 19 knots in Georgia Strait in winter. The dashed line indicates the selected transect used to calculate propagation loss for the Georgia Strait sub-area. Sound levels are shown for a 19-knot reference speed (corresponding to the reference source levels in Figure 3) and do not reflect the actual transit speed of container vessels at this location (Roberts Bank bound vessels would not transit at this speed in this area). Sound levels are adjusted, when computing noise exposures, according to the actual transit speeds in each sub-area.

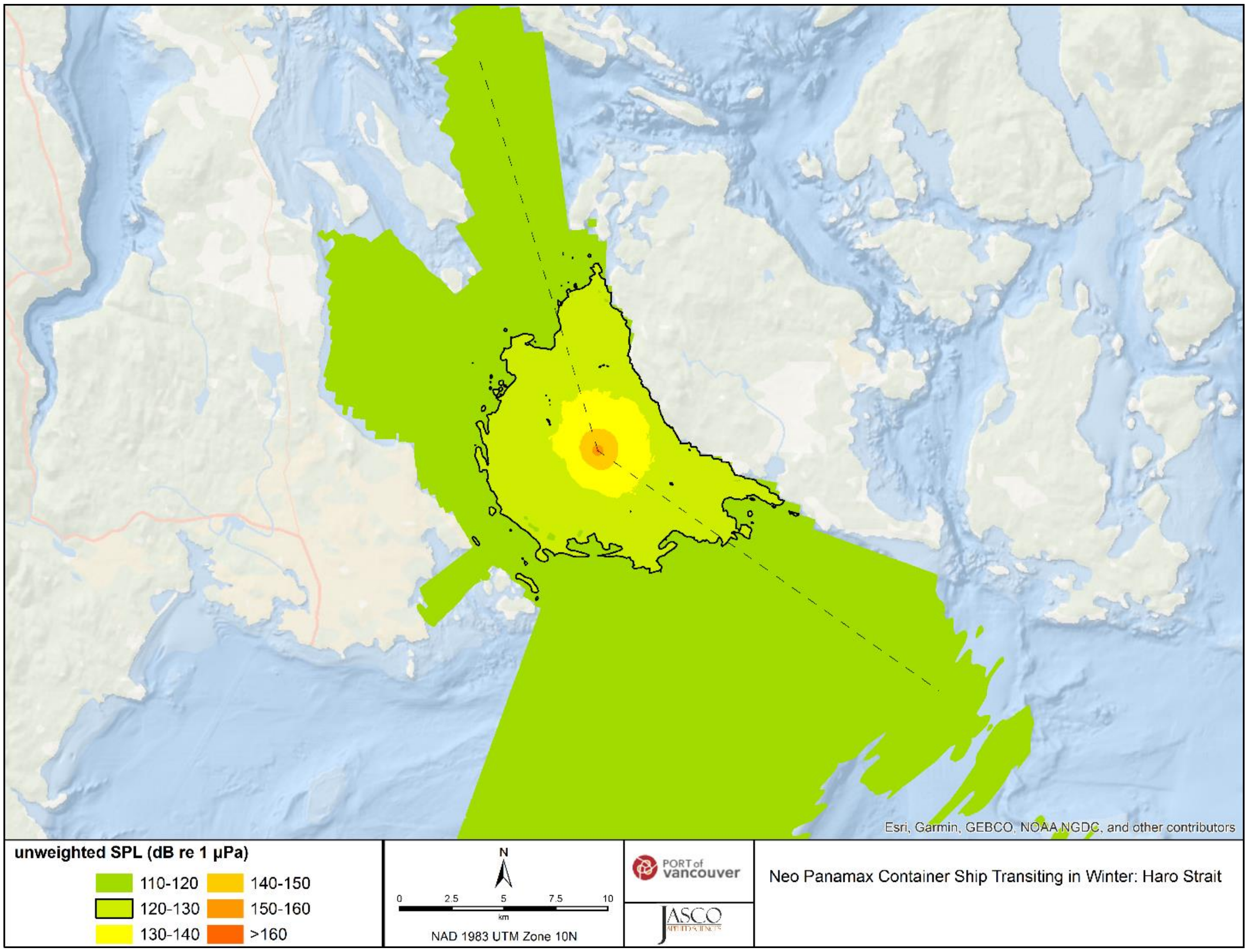


Figure 5. Modelled noise footprints for a Neo Panamax container vessel transiting at 19 knots in Haro Strait in winter. The dashed line indicates the selected transect used to calculate propagation loss for the Haro Strait sub-area. Sound levels are shown for a 19-knot reference speed (corresponding to the reference source levels in Figure 3) and do not reflect the actual transit speed of container vessels at this location (Roberts Bank bound vessels would not transit at this speed in this area). Sound levels are adjusted, when computing noise exposures, according to the actual transit speeds in each sub-area.

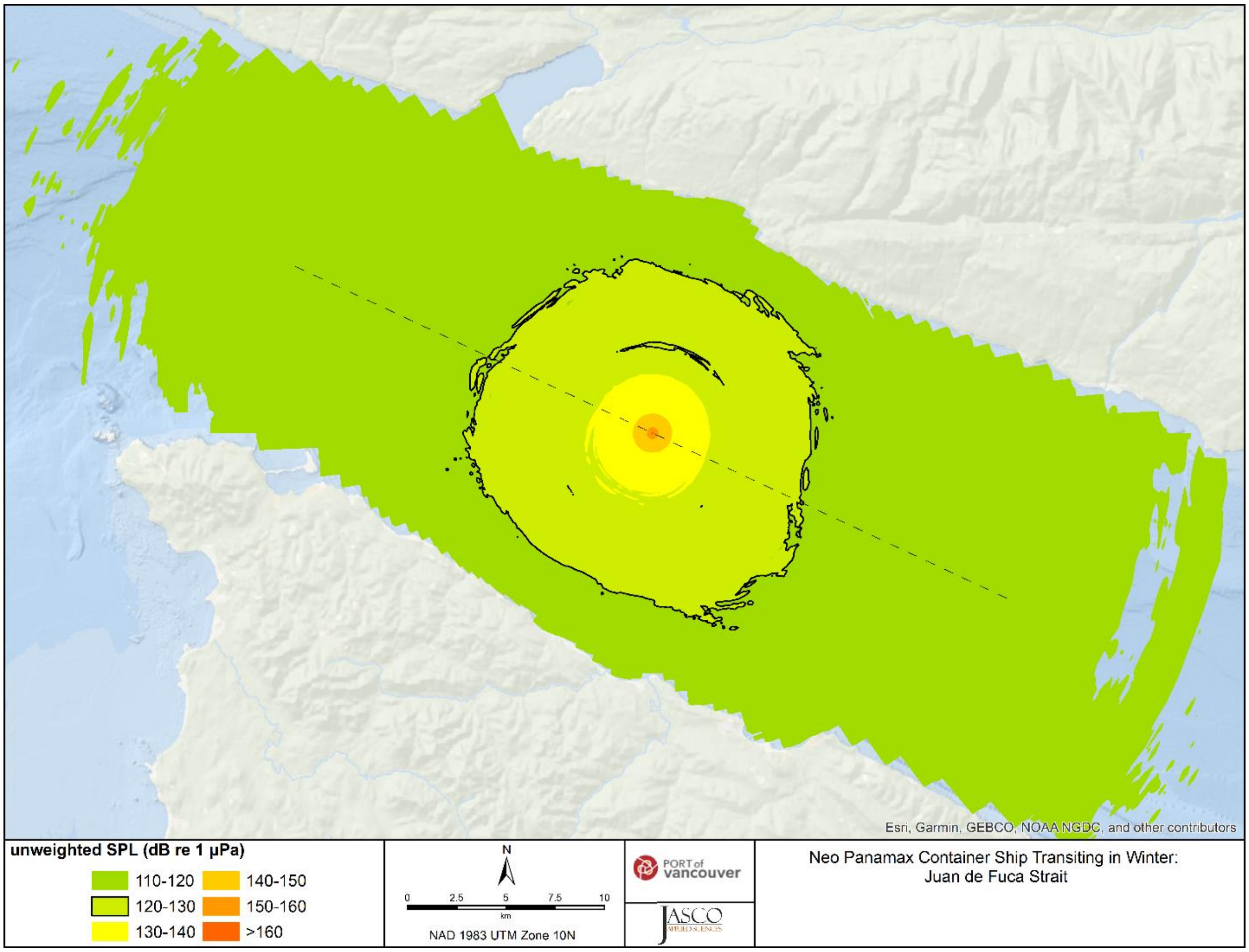


Figure 6. Modelled noise footprints for a Neo Panamax container vessel transiting at 19 knots in Juan de Fuca Strait in winter. The dashed line indicates the selected transect used to calculate propagation loss for the Juan de Fuca Strait sub-area. Sound levels are shown for a 19-knot reference speed (corresponding to the reference source levels in Figure 3) and do not reflect the actual transit speed of container vessels at this location (Roberts Bank bound vessels would not transit at this speed in this area). Sound levels are adjusted, when computing noise exposures, according to the actual transit speeds in each sub-area.

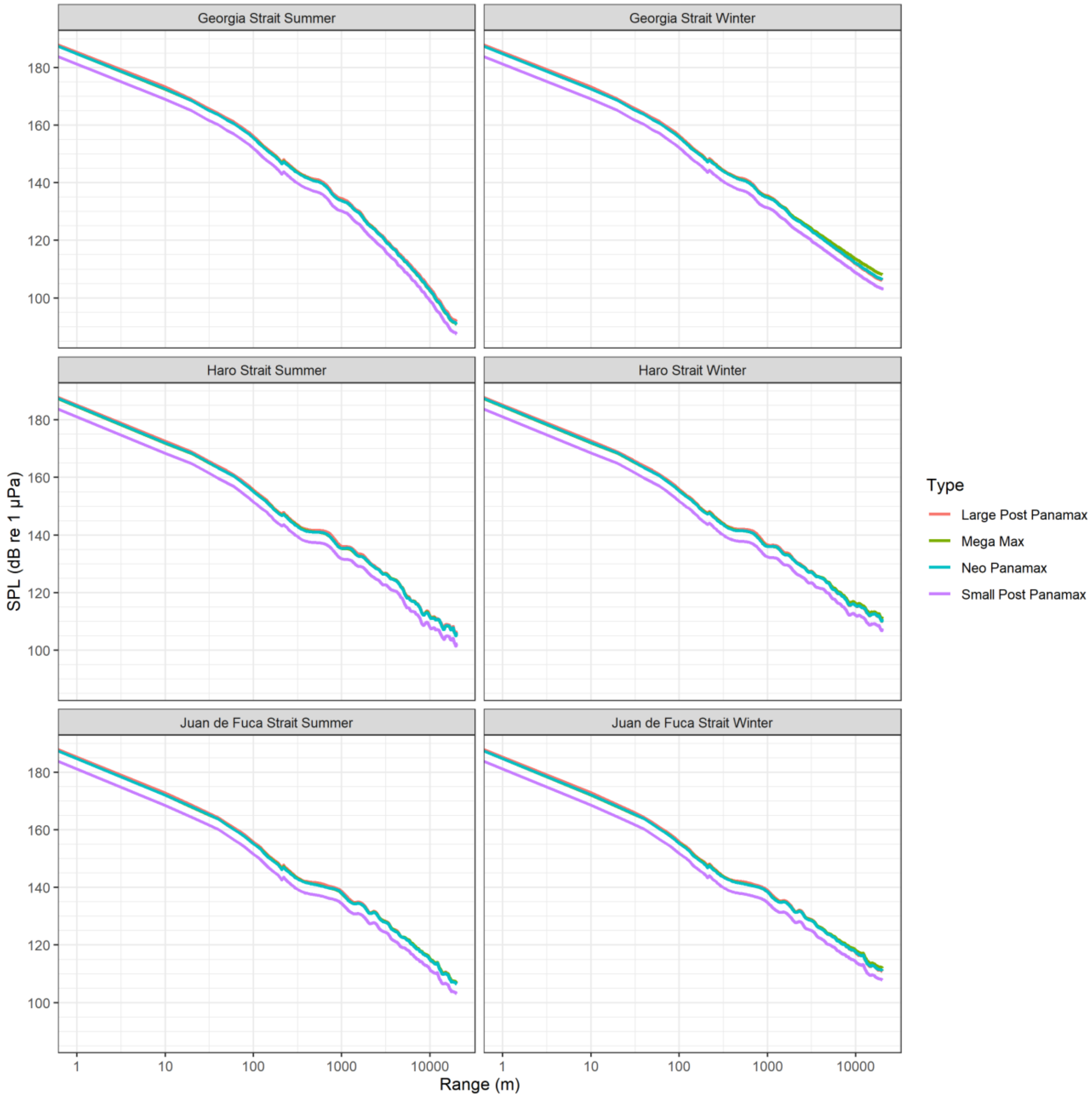


Figure 7. Broadband SPL versus range curves for each container vessel size class (referenced to 19 knots) for the three different sub-areas in summer (left) and winter (right): Georgia Strait, Haro Strait, and Juan de Fuca Strait. Additional SPL versus range curves were calculated for the 20 kHz and 50 kHz bands used in the echolocation click masking analysis (not shown). Sound levels are shown for a 19-knot reference speed (corresponding to the reference source levels in Figure 3) and do not reflect the actual transit speed of container vessels at this location. Sound levels are adjusted, when computing noise exposures, according to the actual transit speeds in each sub-area.

2.5. Exceedance Calculations

The TEM calculates yearly noise exposures for different scenarios by aggregating L_{eq} and exceedance hour data from each of the three sub-areas. For each sub-area, total sound exposure and exceedance minutes are calculated for a single container vessel transiting past each of the three receiver loci (see Figure 2), based on the assumed transit speed, adjusted source level, and SPL versus range curves.

Sound exposure level (L_e) for a single transit is calculated from the time integral of the squared pressure versus time:

$$L_e = 10\log_{10}\int_{-d_{max}/v}^{d_{max}/v} p^2\left(r(t) = \sqrt{d_{cpa}^2 + v^2t^2}\right) dt\,/(1\mu\text{Pa}^2\text{s})$$

where $p^2(r)$ is the squared sound pressure at range *r*, $r(t)$ is the time-dependent range to the receiver locus, *v* is the vessel speed, *t* is time, d_{max} is the maximum vessel distance from the CPA (20 km), and d_{cpa} is the distance to the receiver locus at the CPA. The exceedance time (*T*) for a single transit is calculated from the vessel speed and the distance to the specified sound level threshold (r_{L_p}) as follows:

$$T = \frac{1}{v}\sqrt{r_{L_p}^2 - d_{cpa}^2}$$

where *T* = 0 when $r_{L_p} < d_{cpa}$. The exposures and exceedance times are then averaged over the three loci to obtain mean per-transit sound exposures and exceedance minutes for each season and vessel class (Figures 8 and 9). Yearly total sound exposure and exceedance hours are then calculated by summing the single-transit values according to the projected weekly calls (as given in Table 1) over a duration of 52 weeks (with 26 weeks using summer SPL curves and 26 weeks using winter SPL curves). Note that the number of transits per week is taken to be double the number of container vessel calls per week, since each call corresponds to one inbound trip and one outbound trip. The yearly total L_{eq} is calculated from the yearly SEL according to the total number of seconds in a year:

$$\text{L}_{\text{eq-1yr}} = L_{\text{e-1yr}} - 10\log_{10}(31556952\text{ s})$$

In the final step, the TEM calculates delta differences for each projection year based on the accumulated noise exposure results for scenarios with and without RBT2.

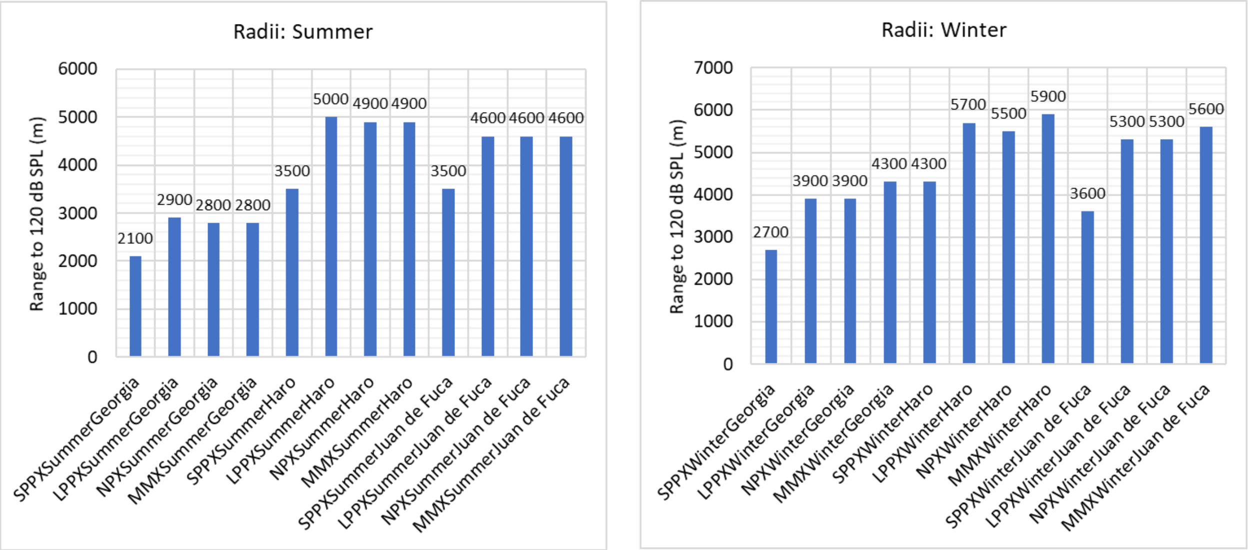


Figure 8. Range to 120 dB re 1 µPa SPL threshold per vessel transit, by container vessel size class, and sub-area in summer (left panel) and winter (right panel), for normal transit speeds (see Table 4). SPPX = Small Post-Panamax, LPPX = Large Post-Panamax, NPX = Neo Panamax, MMX = Mega Max.

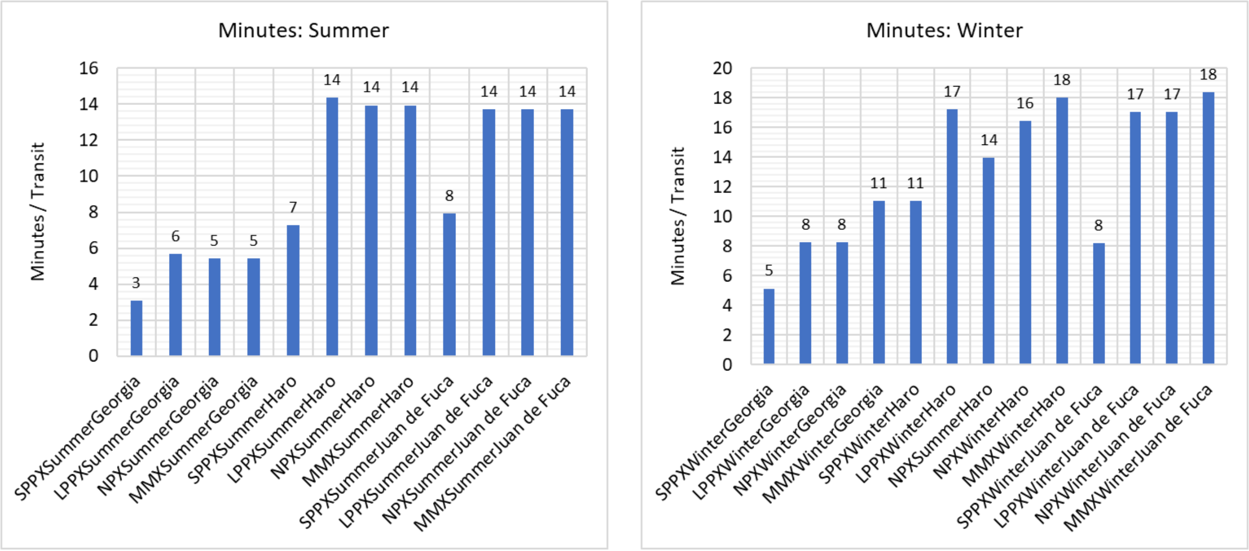


Figure 9. Minutes of exceedance above the 120 dB re 1 µPa SPL threshold per vessel transit, by container vessel size class, and sub-area in summer (left panel) and winter (right panel), for normal transit speeds (see Table 4). Bars show average value for the three receiver loci at each site. SPPX = Small Post-Panamax, LPPX = Large Post-Panamax, NPX = Neo Panamax, MMX = Mega Max.

2.6. Existing Underwater Noise Conditions

The TEM alone cannot assess changes in overall (i.e., cumulative) underwater noise conditions, because it only accounts for noise originating from container vessel traffic. Underwater noise in the marine shipping area, however, comes from myriad different types of marine vessels (e.g., bulkers, tankers, tugs, ferries, recreational craft, ecotourism, etc.), as well as from natural sources such as wind, waves, and marine organisms. Separate assessments of existing underwater noise levels within the marine shipping area must be used to place the TEM predictions into the wider regional context. Furthermore, noise level estimates must be provided in terms of the same SPL metric used by the TEM (i.e., $L_{eq\text{-}1yr}$), to ensure a like-with-like comparison.

Three independent data sources were identified that provided compatible assessments of existing underwater noise levels within the marine shipping area:

- Modelled summer and winter underwater noise levels for the marine shipping area were provided for 2015 by the Regional Commercial Vessel Traffic Underwater Noise Modelling Study, prepared for the RBT2 EIS (MacGillivray et al. 2014; Table 2-5). This study considered the noise contributions of 13 different categories of vessels to underwater noise within the marine shipping area, based on historical regional vessel traffic data. The average of summer and winter noise levels from this study was 120.7 dB re 1 µPa (L_{eq}, broadband, 10-63,000 Hz), along the marine shipping route.
- Measured monthly average underwater noise levels for 2016-2017, from the Lime Kiln hydrophone near the shipping lanes in Haro Strait, were reported by the ECHO Salish Sea Ambient Noise Evaluation study (Warner et al. 2019; Table 20). The average of monthly noise levels at this hydrophone station was 119.2 dB re 1 µPa (L_{eq}, broadband, 10-100,000 Hz)[1].

---

[1] Measurements at Lime Kiln included some data from the 2017 slowdown trial in Haro Strait (~25% of data from this source). However, the inclusion of a limited amount of data from the slowdown trial was only expected to have a marginal impact on the long-term average sound level (reduction of 0.1 dB or less) at this site. It was preferred to include this data source, rather than exclude it, due to the limited availability of existing noise level data in the study area.

- Measured monthly average underwater noise levels for 2016-2017, from the ECHO Program Underwater Listening Station near the shipping lanes in Strait of Georgia, were also reported by the ECHO Program Salish Sea Ambient Noise Evaluation study (Warner et al. 2019; Table 20). The average of monthly noise levels at this hydrophone station was 119.8 dB re 1 μPa (L_{eq}, broadband, 10-32,000 Hz).

Based on the average of these three independent data sources, the existing yearly time-averaged underwater sound levels ($L_{eq\text{-}1yr}$) along the marine shipping route was estimated to be 119.9 dB re 1 μPa (Figure 10). Note that estimates of future expected noise conditions for 2035-2045 were unavailable, and such forecasts (which would require detailed forecasts of future regional vessel traffic) were outside the scope of the current study. Thus, this study only compares predictions of the TEM to existing noise level conditions from the past studies cited above.

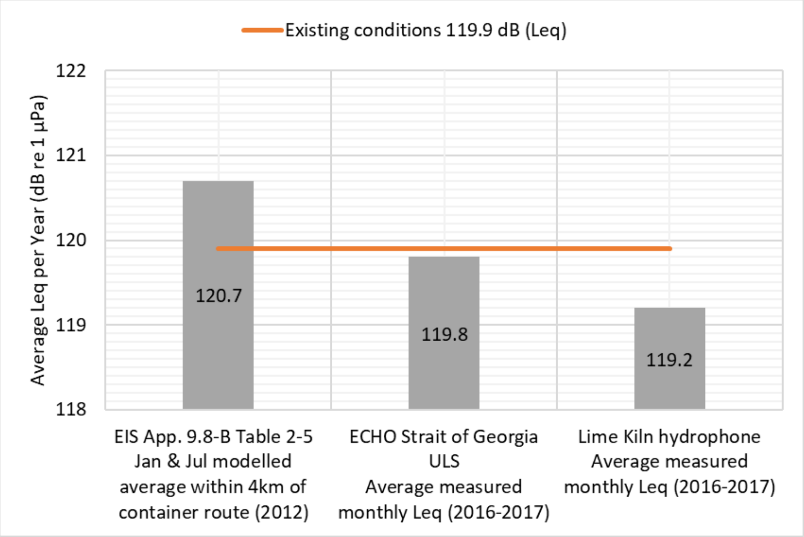


Figure 10. Yearly time-averaged underwater sound levels ($L_{eq\text{-}1yr}$, unweighted, broadband) in the marine shipping area, as reported by prior EIS and ECHO Program studies (MacGillivray et al. 2014, Warner et al. 2019). Based on these three data sources, the average $L_{eq\text{-}1yr}$ under existing conditions was estimated to be 119.9 dB re 1 μPa.

2.7. Contingency Mitigation Measures

Should container vessel calls at RBT2 be higher than predicted by the most-realistic forecast, contingency mitigation measures may be adopted to offset additional underwater noise from these vessels. Slowdowns have been demonstrated as an effective measure for reducing underwater noise from marine vessels (Joy et al. 2019, MacGillivray et al. 2019, Burnham et al. 2021) and have been used successfully by the Port-led ECHO program since 2017. The ECHO Program currently implements voluntary slowdowns during months when SRKW are most frequently present in the Salish Sea to reduce underwater radiated noise in critical habitat areas.

Five contingency mitigation measures, as well as the "no mitigation" scenario, were evaluated using the TEM:

1. 95% of RBT2-bound vessels slow down from 18 to 14.5 knots for six months in Haro Strait, Boundary Pass, and at Swiftsure Bank (“14.5 kn only RBT2 vessels”);
2. 80% of RBT2-bound vessels and 80% of all other container vessels slow down from 18 to 14.5 knots for six months in Haro Strait, Boundary Pass, and at Swiftsure Bank (“14.5 kn all container vessels (all 80%)”);

3. 95% of RBT2-bound vessels and 80% of all other container vessels slow down from 18 to 14.5 knots for six months in Haro Strait, Boundary Pass, and at Swiftsure Bank ("14.5 kn all container vessels");
4. 95% of RBT2-bound vessels and 80% of all other container vessels slow down from 18 to 11 knots for six months in Haro Strait, Boundary Pass, and at Swiftsure Bank ("11 kn all container vessels");
5. 95% of RBT2-bound vessels and 80% of all other container vessels slow down from 18 to 11 knots for six months in Haro Strait, Boundary Pass, and at Swiftsure Bank; and in additional areas of the Strait of Juan de Fuca and Strait of Georgia ("11 kn expanded slowdown all container vessels").

All five mitigation measures assumed six months of vessel slowdowns (i.e., half the year) for summer sound propagation conditions (e.g., representing May-October)[2]. For implementation in the TEM, speeds for participating vessels for Measures 1-4 were reduced only in the Haro Strait sub-area, representing approximately one third of the vessel traffic route (present-day ECHO Program slowdowns zones at Haro Strait, Boundary Pass, and Swiftsure Bank cover roughly 1/3 of the vessel transit route to buoy J). For Measure 5, speeds of participating vessels were reduced in all three sub-areas, representing the entirety of the vessel transit route from RBT2 to buoy J. The two different participation rates (80% and 95%) were intended to represent voluntary participation and required RBT2 vessel participation in slowdown measures, respectively. The 80% voluntary participation rate for non-RBT2 vessels was based on the composite container vessel participation rate used by the ECHO Program for modelling potential lost foraging time for SRKW during 2020 (VFPA, 2021). The 95% participation rate for RBT2 vessels was based on the assumption that there may be times when navigational safety considerations prevent container vessels from slowing to the prescribed mitigation speeds.

---

[2] This is longer than the current 4-5 month voluntary slowdown actions that are currently implemented by the ECHO program (ca. 2021) within Haro Strait and Boundary Pass (July-October) and at Swiftsure Bank (June-October).

3. Results

3.1. Most-Realistic Scenario

The TEM was used to analyze underwater noise exposures for the 2035, 2040, and 2045 Mercator container vessel call projections at the Port of Vancouver, using historical average speeds in each sub-area (see Table 4). Annual L_{eq} and exceedance hours, and their deltas with and without RBT2, were calculated for broadband SPL (Figures 11 and 12), the 20 kHz echolocation click masking band (Figures 13 and 14), and the 50 kHz echolocation click masking band (Figures 15 and 16). Appendix A provides tabulated TEM results.

The broadband results show that there is very little difference in SPLs from container vessel traffic with and without RBT2. The yearly L_{eq} is slightly lower with RBT2 (≤ 0.1 dB) and exceedance hours are slightly higher with RBT2 (≤ 1.2%) than without. The $L_{eq\text{-}1yr}$ is predicted to be slightly lower with RBT2 during 2035, due to three Neo Panamax calls replacing three Large Post Panamax calls with the project (Large Post-Panamax vessels have slightly higher broadband noise emissions than Neo Panamax vessels, see Figure 3). Likewise, the exceedance hours are predicted to be slightly higher with RBT2 during 2040, due to three more Mega Max calls replacing Large Post-Panamax calls with the project. The deltas for exceedance hours and L_{eq} have opposite signs because these two metrics are not perfectly correlated and differences between the project and no project scenarios are marginal. While there are some site-specific differences due to local sound propagation conditions, overall, the deltas are very small in magnitude, which suggests that broadband sound levels from container vessels (and thus potential behavioural responses) will be nearly identical in the marine shipping area with and without RBT2.

The echolocation click masking results (i.e., for the 20 kHz and 50 kHz bands) show that masking levels from container vessel traffic will be higher with RBT2 than without RBT2. The yearly L_{eq} is up to 1.3 dB greater with RBT2 and exceedance hours are up to 4.7% greater in the two echolocation bands (Table 8). The RBT2 scenarios have more noise in the echolocation bands because larger size classes of container vessels have higher noise emissions above 1 kHz. Deeper drafts and longer vessels lengths have been associated with higher noise emissions at echolocation click masking frequencies by the recent ECHO vessel noise correlations study (MacGillivray et al. 2020). The estimated deltas are highest in 2040, as this is the year with the largest projected difference in the number of Mega Max calls (3 more with RBT2 than without). The deltas are nonetheless small in magnitude, because the overall number of container vessel transits is expected to be the same with and without RBT2.

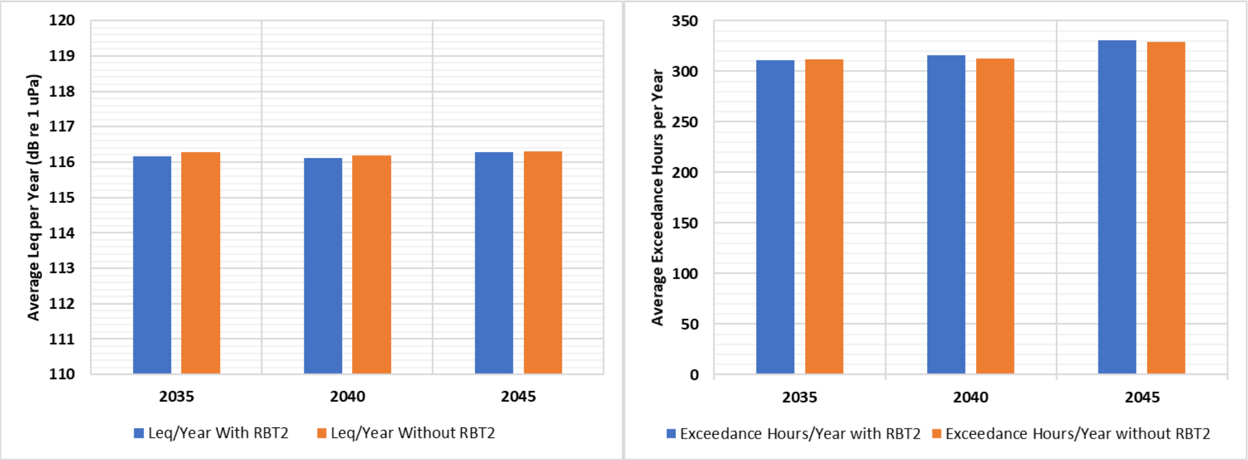


Figure 11. Broadband averages: Average L_{eq} per year (left) and average exceedance hours per year above the 120 dB re 1 µPa threshold (right) with and without RBT2 for the most-realistic scenario. Values are averaged over Georgia Strait, Haro Strait, and Juan de Fuca Strait sub-areas.

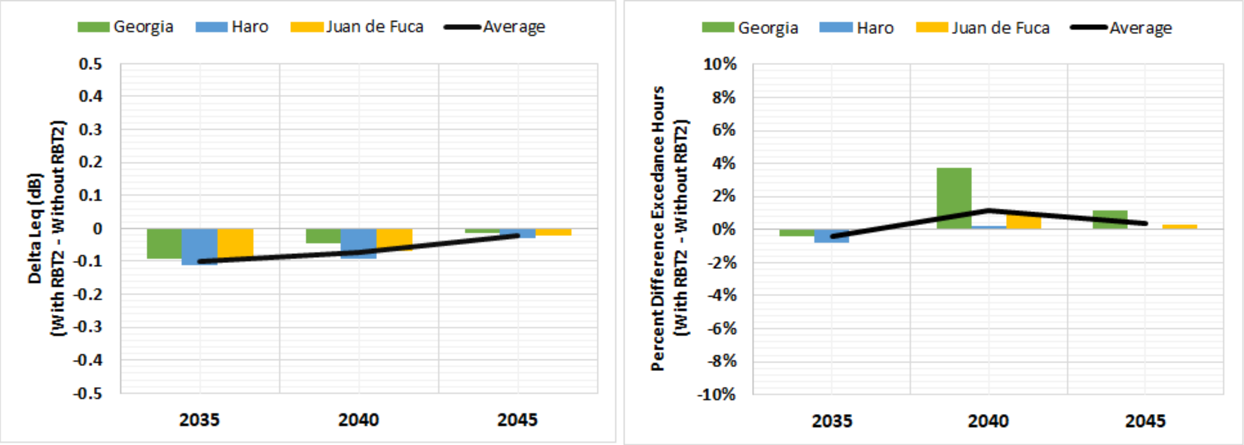


Figure 12. Broadband differences: Delta-differences in yearly L_{eq} (left) and annual exceedance hours above the 120 dB re 1 µPa behavioural response threshold (right) with and without RBT2 for the most-realistic scenario. Bars show per-site differences and black lines shows average value versus year. Values greater than zero indicate the metric is higher with RBT2 and values less than zero indicate the metrics is lower with RBT2.

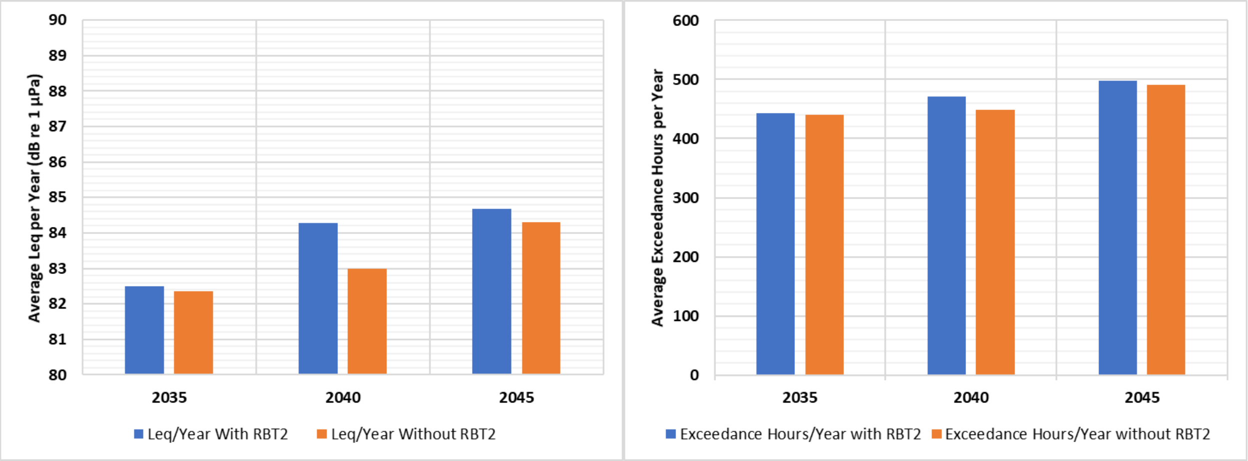


Figure 13. 20 kHz echolocation click masking band averages: Average L_{eq} per year (left) and average exceedance hours per year above the 20 kHz echolocation click masking threshold (right) with or without RBT2 for the most-realistic scenario. Values are averaged over Georgia Strait, Haro Strait, and Juan de Fuca Strait sub-areas.

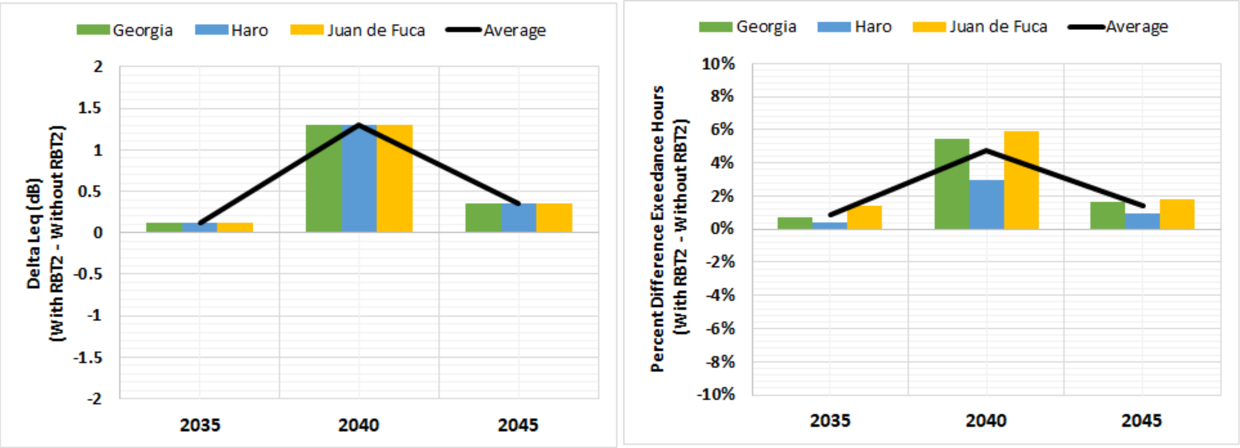


Figure 14. 20 kHz echolocation click masking band differences: Delta-differences in yearly L_{eq} (left) and annual exceedance hours above the 20 kHz echolocation click masking threshold (right) with and without RBT2 for the most-realistic scenario. Bars show per-site differences and black lines shows average value versus year. Values greater than zero indicate the metric is higher with RBT2 and values less than zero indicate the metrics is lower with RBT2.

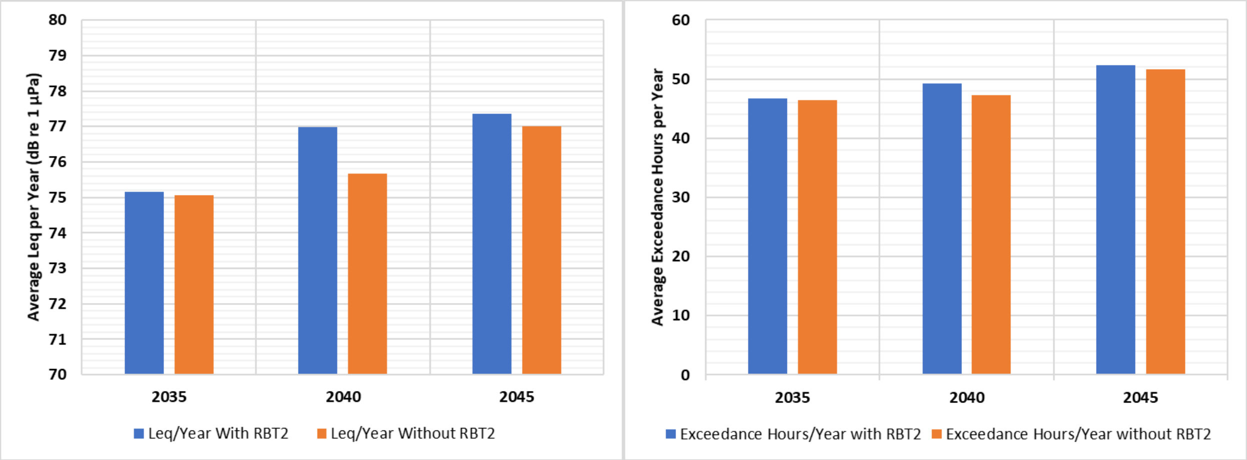


Figure 15. 50 kHz echolocation click masking band averages: Average L_{eq} per year (left) and average exceedance hours per year above 50 kHz echolocation click masking threshold (right) with or without RBT2 for the most-realistic scenario. Values are averaged over Georgia Strait, Haro Strait, and Juan de Fuca Strait sub-areas.

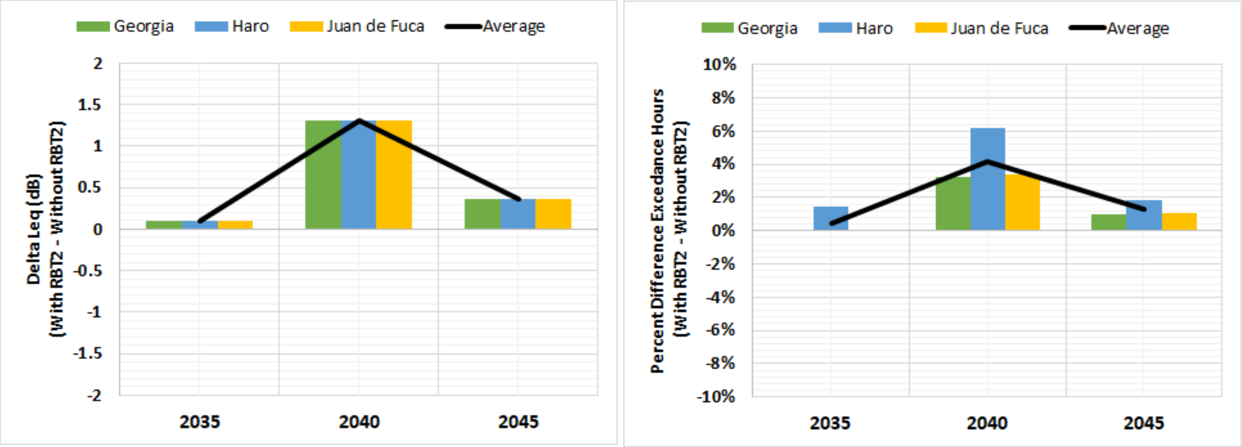


Figure 16. 50 kHz echolocation click masking band differences: Delta-differences in yearly L_{eq} (left) and annual exceedance hours above the 50 kHz echolocation click masking threshold (right) with and without RBT2 for the most-realistic scenario. Bars show per-site differences and black lines shows average value versus year. Values greater than zero indicate the metric is higher with RBT2 and values less than zero indicate the metrics is lower with RBT2.

Table 8. Average differences in yearly time-averaged underwater sound levels ($L_{eq\text{-}1yr}$, unweighted, 1/3-octave band) and annual exceedance hours above SRKW echolocation click masking threshold (20 kHz frequency) from container vessels in the marine shipping area with and without RBT2 based on the most-realistic scenario. Values greater than zero indicate the metric is higher with RBT2.

Year	Difference in $L_{eq\text{-}1yr}$ in 20 kHz band (dB)	Difference in Annual Exceedance Hours (% increase)
2035	0.1	4 (+0.9%)
2040	1.3	21 (+4.7%)
2045	0.4	7 (+1.5%)

3.2. High-Case Scenarios

The TEM was used to analyze underwater noise exposures for the three less-likely high-case scenarios, incorporating 1-3 additional weekly Mega-Max calls at Port of Vancouver terminals during 2035-2045. Exceedance hours and sound level predictions for the high-case scenarios were averaged over all three sub-areas, for comparison with TEM results for the most-realistic scenario. Results were calculated for broadband SPL (Figure 17), the 20 kHz echolocation masking band (Figure 18), and the 50 kHz echolocation masking band (Figure 19). For each scenario, the separate contributions (in terms of exceedance hours and $L_{eq\text{-}1yr}$) are presented for three different categories of vessels:

1. Container vessels calling at RBT2, under the most-realistic scenario (per Table 1);
2. Container vessels calling at terminals other than RBT2, under the most-realistic scenario (per Table 1);
3. Additional Mega-Max container vessels, calling at any terminal, under the less-likely high-case scenario (per Table 2);

Note that the proposed RBT2 terminal is anticipated to accommodate up to on average five container vessel calls per week. Therefore, additional Mega-Max vessels for the +104 and +152 vessel high-case scenarios are assumed to call at other Port of Vancouver terminals and are therefore not incidental to the project. Results reported in this section focus on the 2040 scenarios, since this year had the greatest difference with and without the Project. Results for all years are provided in Appendix B. The TEM results show how the total noise contribution of other container terminals (gray bars) would be smaller with RBT2 than without, due to the smaller number of vessels calling at these terminals if RBT2 is built, per the most-realistic container vessel traffic projections from Mercator International (2021). TEM results for the high-case scenarios show that additional Mega-Max vessels would increase both exceedance hours and yearly average sound levels in the marine shipping area, beyond the estimates for the most-realistic scenarios. The incremental contributions of additional Mega-Max vessels are generally greatest in the 20 kHz echolocation masking band (Table 9). These increases can be offset by implementing slowdown mitigations, as discussed in Section 3.4.

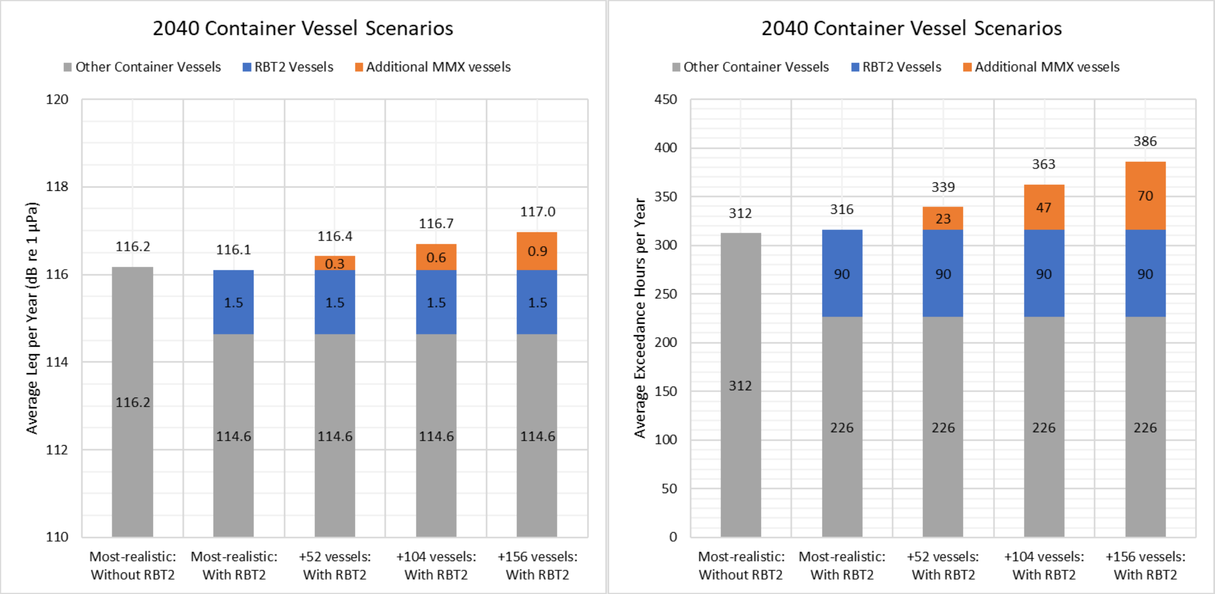


Figure 17. Broadband: Average L_{eq} per year (left) and average exceedance hours per year above the 120 dB re 1 µPa behavioural response threshold (right) under the most-realistic and high-case scenarios for 2040. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. Values are averaged over Georgia Strait, Haro Strait, and Juan de Fuca Strait sub-areas. Exceedance numbers shown in the figure have been rounded to the nearest whole hour.

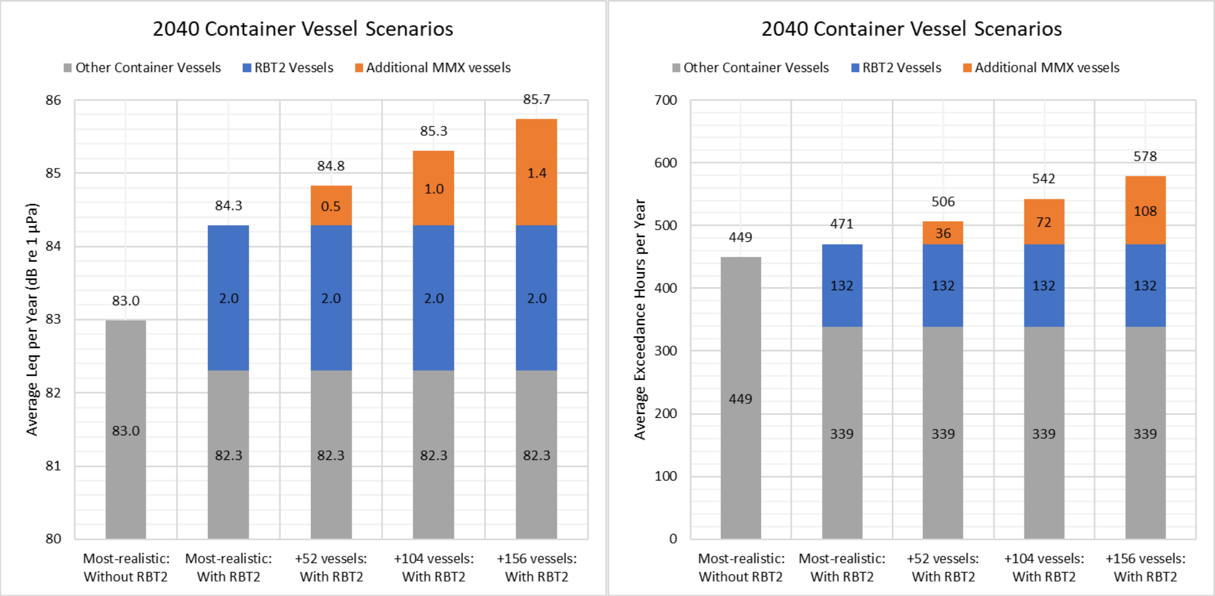


Figure 18. 20 kHz echolocation click masking band: Average L_{eq} per year (left) and average exceedance hours per year above 20 kHz echolocation click masking threshold (right) under the most-realistic and high-case scenarios for 2040. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. Values are averaged over Georgia Strait, Haro Strait, and Juan de Fuca Strait sub-areas. Exceedance numbers shown in the figure have been rounded to the nearest whole hour.

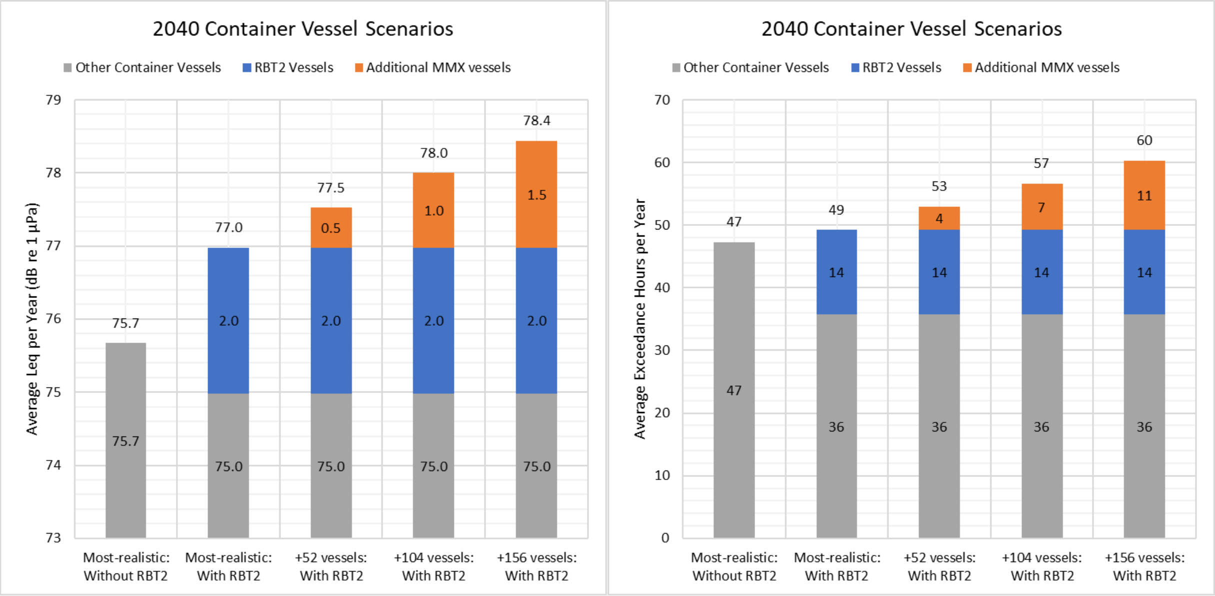


Figure 19. 50 kHz echolocation click masking band: Average L_{eq} per year (left) and average exceedance hours per year above 50 kHz echolocation click masking threshold (right) under the most-realistic and high-case scenarios for 2040. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. Values are averaged over Georgia Strait, Haro Strait, and Juan de Fuca Strait sub-areas. Exceedance numbers shown in the figure have been rounded to the nearest whole hour.

Table 9. Average differences in yearly time-averaged underwater sound levels ($L_{eq\text{-}1yr}$,unweighted, 1/3-octave band) and annual exceedance hours above SRKW echolocation click masking threshold (20 kHz frequency) from container vessels in the marine shipping area, compared to the most-realistic scenarios without RBT2 in 2040. Values greater than zero indicate the metric is higher with RBT2.

Scenario (2040)	Difference in $L_{eq\text{-}1yr}$ in 20 kHz band (dB)	Difference in annual exceedance hours (% increase)
Most-realistic: With RBT2	1.3	21 (+4.7%)
High-case: +52 MMX vessels per year	1.8	57 (+12.7%)
High-case: +104 MMX vessels per year	2.3	93 (+20.7%)
High-case: +156 MMX vessels per year	2.8	129 (+28.7%)

Exceedance hours are a purely additive quantity in the TEM; therefore, each extra Mega-Max vessel adds the same amount of hours to the total exceedances under the high-case scenarios. For example, Figure 17 shows that each additional Mega-Max vessel adds 23.3 hours per year to the average exceedance hours above 120 dB re 1 µPa SPL (assuming no slowdowns). Sound levels, on the other hand, are measured on a logarithmic scale, where each 1 decibel increase represents a 12.2% increase in total sound energy. Therefore, each Mega-Max vessel cannot be said to increase broadband sound levels by a fixed amount (e.g., by 0.3 dB) because the incremental contribution depends, critically, on the baseline sound level that its noise is being added to (gray bars in Figures 17 to 19 include only noise originating from non-RBT2 container vessels, thus excluding noise from other regional vessel traffic). The decibel contribution of additional Mega-Max vessels, considering the total contribution of other noise sources in the marine shipping area, is addressed in Section 3.3.

3.3. Increases Above Existing Conditions

Under the most-realistic vessel traffic scenarios, broadband underwater noise from containerships in the marine shipping area is expected to be approximately the same with and without RBT2 (see Section 3.1). Therefore, existing noise conditions are only expected to increase under the less-likely high-case scenarios. Under the three high-case scenarios examined in this study, noise from additional Mega-Max vessels would add to existing underwater noise along the marine shipping route. The existing yearly average noise level in the marine shipping area, from all marine vessel traffic and natural ambient sources, is estimated to be 119.9 dB re 1 µPa (L_{eq}, unweighted, broadband), based on published data from 2015-2017 (see Section 2.6). According to the TEM predictions, the effect of adding 52–156 extra Mega-Max vessels per year would be to increase existing broadband yearly time-average sound levels by 0.1–0.4 dB within the marine shipping area (Figure 20).

While it is outside the scope of the present study to forecast changes in underwater noise conditions for 2035-2045, it should be noted that the decibel increase under the high-case scenarios would change if existing noise levels also change. For example, if existing conditions increase by 1 dB in future (to 120.9 dB re 1 µPa), then adding 156 additional Mega-Max vessels per year would further increase noise levels by 0.3 dB (i.e., to 121.2 dB total) rather than by 0.4 dB. This is a consequence of the logarithmic decibel scale that is customarily used for measuring underwater sound because it better represents how animals perceive sound than a linear scale (see Section 3.2).

Figure 20. Increase in yearly average sound levels (dB; orange bars) from adding extra Mega-Max vessels to existing conditions ($L_{eq\text{-}1yr}$, unweighted, broadband; gray bars), when accounting for noise from all vessel traffic in the marine shipping area, under the high-case vessel scenarios. Additional container vessels are assumed to be Mega-Max (MMX) class. Annotations above the bars indicate total values.

3.4. Contingency Mitigation Measures

The TEM was used to analyze five contingency mitigation measures (see Section 2.7) for the 2035, 2040, and 2045 call projections at the Port of Vancouver under the most-realistic and three less-likely high-case vessel traffic scenarios. Exceedance hours and sound level predictions for five mitigation options were averaged over all three sub-areas, for both summer and winter periods, to reflect changes in overall noise conditions within the marine shipping area over a single year (i.e., not just within the areas targeted by the mitigation). Results reported in this section focus on the 2040 scenarios, since this year had the greatest difference with and without the project. Likewise, for the echolocation bands, only 20 kHz results are presented in this section since findings were similar for the 50 kHz echolocation band. Results for all years are provided in Appendix C. The effectiveness of the mitigation measures was evaluated in terms of annual exceedance hours (Figures 21 and 22) and $L_{eq\text{-}1yr}$ (Figures 23 and 24), by comparing against expected noise metrics for the most-realistic vessel traffic scenario without RBT2.

The results of this analysis show that the slowdown contingency mitigation measures are more effective as speeds are reduced, the number of participating vessels is increased, and the area of the slowdowns is expanded. Note, however, that the results also show that there is only a small difference in noise levels between 80% and 95% participation of RBT2 vessels (i.e., comparing Measures 2 and 3). Under the most-realistic container vessel traffic scenario with RBT2, all contingency measures are predicted to mitigate average broadband noise below the expected conditions without RBT2. Under the less-likely high-case container vessel traffic scenarios, the following measures would mitigate average broadband noise below expected conditions:

- 52 additional Mega-Max vessels annually could be mitigated by further reducing transit speed for six months from 14.5 knots to 11 knots;
- 104 additional Mega-Max vessels annually could be mitigated by further reducing the transit speed for six months to 11 knots combined with expanding the slowdown area to include Juan de Fuca Strait and the Strait of Georgia;

- 156 additional Mega-Max vessels annually could be mitigated by further reducing the transit speed for six months to 11 knots combined with expanding the slowdown area to include Juan de Fuca Strait and the Strait of Georgia.

When compared to the broadband results, analysis of the echolocation bands shows that the most expansive slowdown mitigation measures would be needed reduce sound levels below expected conditions at 20 kHz and 50 kHz. This is because larger vessels will call at the Port under the most-realistic scenario with RBT2, and these types of vessels are predicted to have greater high-frequency noise emissions than the smaller vessels that will call without RBT2 (see Section 3.1). However, the results also indicate that offsetting noise in the echolocation bands remains achievable, given the small differences compared to existing conditions for the mitigation options considered in this study. Furthermore, these results are based on estimates of Mega-Max source levels extrapolated from present-day ECHO Program data. It is expected that actual measurements of Mega-Max source levels would be collected in future, as part of the port authority's marine shipping follow up program element, and that appropriate mitigation measures would be devised based on these data.

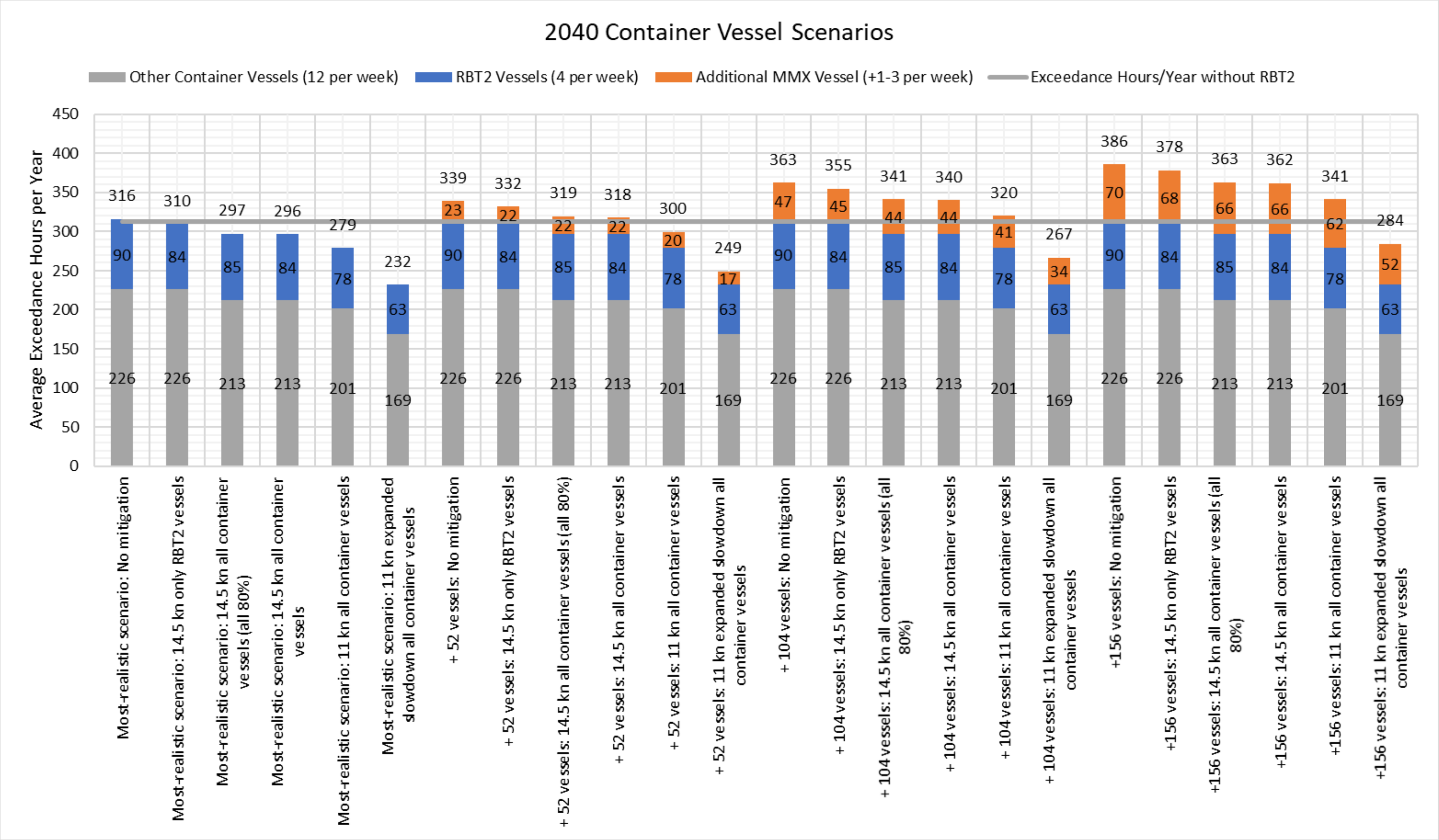


Figure 21. Broadband exceedance hours: The effectiveness of potential contingency mitigation measures for an additional 52-156 Mega-Max (MMX) container vessels annually in the marine shipping area, in terms of average exceedance hours per year for 2040. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. The line indicates the average exceedance hours per year under the most-realistic scenario without RBT2. Exceedance numbers shown in the figure have been rounded to the nearest whole hour.

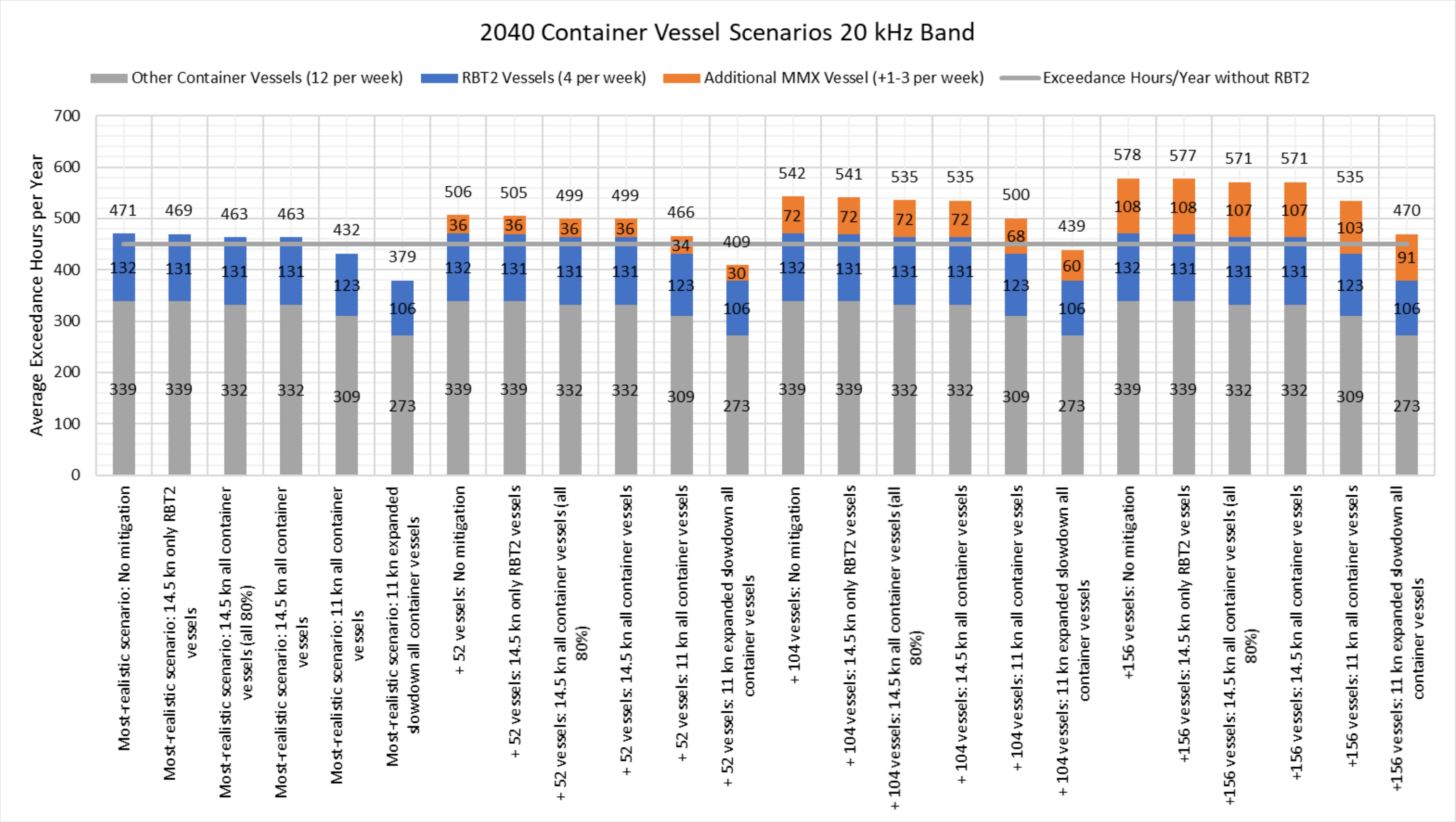


Figure 22. 20 kHz echolocation band exceedance hours: The effectiveness of potential contingency mitigation measures for an additional 52-156 Mega-Max (MMX) container vessels annually in the marine shipping area, in terms of average exceedance hours per year for 2040. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. The line indicates the average exceedance hours per year under the most-realistic scenario without RBT2. Exceedance numbers shown in the figure have been rounded to the nearest whole hour.

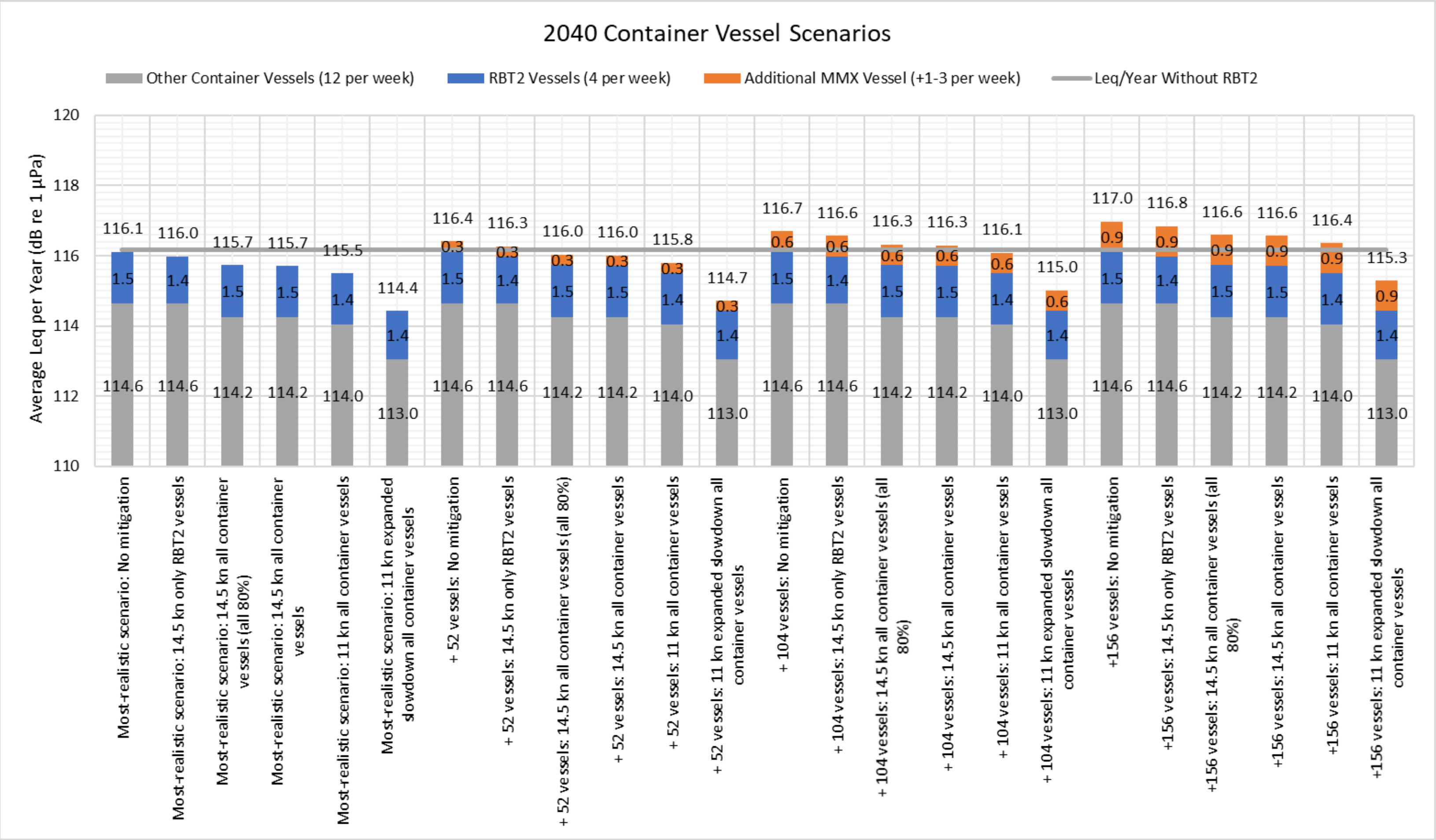


Figure 23. Broadband L_{eq}: The effectiveness of potential contingency mitigation measures for an additional 52-156 Mega-Max (MMX) container vessels annually in the marine shipping area, in terms of average L_{eq} per year for 2040. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. The line indicates the average L_{eq} per year under the most-realistic scenario without RBT2.

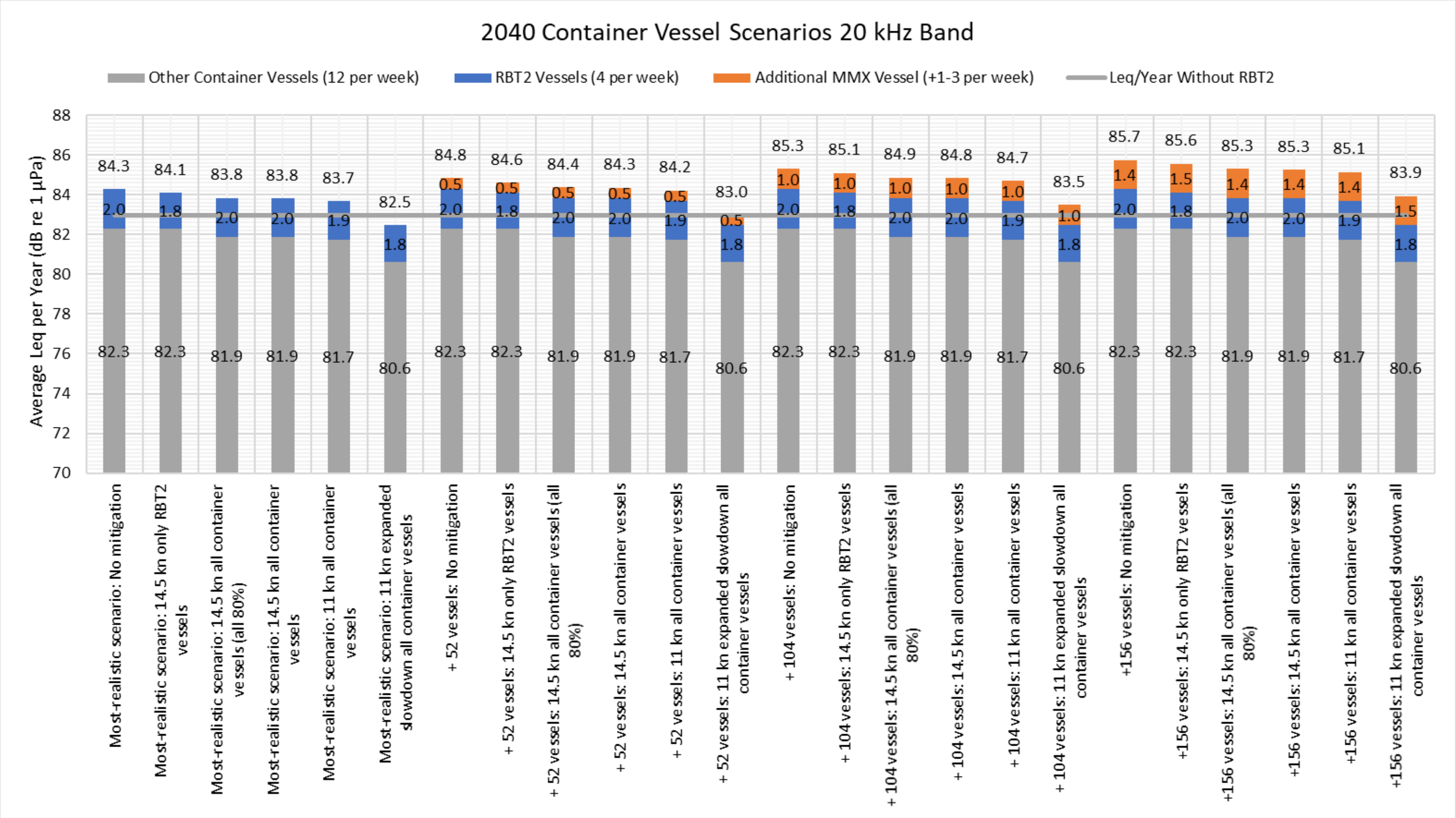


Figure 24. 20 kHz echolocation band L_{eq}: The effectiveness of potential contingency mitigation measures for an additional 52-156 Mega-Max (MMX) container vessels annually in the marine shipping area, in terms of average L_{eq} per year for 2040. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. The line indicates the average L_{eq} per year under the most-realistic scenario without RBT2.

4. Discussion and Conclusion

This study applied a Transit Exposure Model (TEM) to estimate differences in potential underwater noise exposures to SRKW due to marine shipping incidental to RBT2, in response to the information request to the port authority from the Minister of Environment and Climate Change. Modelling predictions from this study were based on updated projections of container vessel calls at RBT2 for 2035, 2040, and 2045 by Mercator International (2021). Noise exposure estimates from this study accounted for sound emissions from four size classes of container vessels projected to transit the marine shipping area: Small Post Panamax, Large Post Panamax, Neo Panamax, and Mega Max. Noise exposure estimates were based on average results for three different sub-areas within the marine shipping area (Georgia Strait, Haro Strait, and Juan de Fuca Strait), considering seasonal and spatial differences in sound propagation conditions. These sub-areas also coincide with the federally designated critical habitat for SRKW. Noise exposures were assessed in terms of broadband sound levels (for evaluating SRKW behavioural response) and in terms of 20 kHz and 50 kHz 1/3-octave band PSD levels (for evaluating SRKW echolocation click masking). For each of these sound level metrics, noise exposures were computed in terms of yearly exceedance hours (above a behavioural response or echolocation click masking threshold) and in terms of yearly time-average sound level ($L_{eq\text{-}1yr}$; unweighted).

Differences in noise exposures were evaluated with and without RBT2 and were found to be small in magnitude under the most-realistic vessel traffic scenario. Increases in container vessel size over time were predicted to result in small increases in broadband yearly time-average sound levels and exceedance times, for both the project and no project scenarios. Nonetheless, under the most-realistic scenario, broadband sound levels (and thus potential for SRKW behavioural responses) were predicted to be nearly identical with and without RBT2. Echolocation click masking was predicted to be slightly higher with RBT2 because recent source level data available by request from the ECHO Program indicate that larger vessels have greater noise emissions above 1 kHz. Exceedance hours above the echolocation click masking threshold were higher in the 20 kHz band than in the 50 kHz band, as vessel noise is more prominent at lower frequencies. For both the behavioural response and echolocation click masking metrics, the deltas were greatest in 2040, as this was the year with the largest projected difference in the number of Mega Max calls. The predicted deltas were nonetheless small in magnitude, given that the overall number of container vessel transits is expected to be the same with and without RBT2. Results for the most-realistic scenarios indicate that existing broadband noise levels in the marine shipping area would be approximately the same with and without the Project.

Under the three less-likely, high-case scenarios, noise levels were expected to be higher with RBT2 than without, before taking contingency mitigation measures into account. Noise exposures were evaluated for scenarios involving an additional 52, 104, and 156 Mega-Max container vessels per year (i.e., corresponding to 1, 2, or 3 extra Mega-Max calls per week, on top of the most-realistic projections). TEM results for these less-likely high-case scenarios showed that the additional Mega-Max vessels would increase both the exceedance hours and the yearly average sound levels in the marine shipping area, beyond the expected conditions for the most-realistic scenarios. However, when accounting for existing noise levels from all other (non-container) vessel traffic and from other noise sources present in the marine shipping area (estimated to be 119.9 dB 1 µPa based on published data from 2015-2017), the effect of adding 52–156 extra Mega-Max vessels per year would increase the existing broadband yearly time-average sound levels by only 0.1–0.4 dB within the marine shipping area, under the high-case scenarios.

In the event that vessel calls with the Project are higher than predicted, contingency mitigation measures may be used to offset underwater noise from the additional vessels. Slowdowns, in particular, have been demonstrated as an effective mitigation measure for reducing underwater noise from marine vessels and are currently employed by the Port-led ECHO Program to reduce underwater radiated noise in critical habitat areas for SRKW. In the current study, five different slowdowns mitigation measures were analyzed, involving speed reductions for container vessels within different areas along the marine shipping route for a total of six months (e.g., May-October). Slowdown mitigation measures are more effective as speeds are reduced, the number of participating vessels is increased, and the area of the slowdowns is expanded. This study found that under the most-realistic vessel traffic scenario with RBT2, all five mitigation measures were predicted to reduce broadband noise levels below expected conditions without RBT2.

Under the less-likely high-case container vessel traffic scenarios, the following contingency measures could be used to mitigate average broadband noise below expected conditions (i.e., without RBT2):

- 52 additional Mega-Max vessels annually could be mitigated by further reducing transit speed for six months from 14.5 knots to 11 knots;
- 104 additional Mega-Max vessels annually could be mitigated by further reducing the transit speed for six months to 11 knots combined with expanding the slowdown area to include Juan de Fuca Strait and the Strait of Georgia;
- 156 additional Mega-Max vessels annually could be mitigated by further reducing the transit speed for six months to 11 knots combined with expanding the slowdown area to include Juan de Fuca Strait and the Strait of Georgia.

Analysis for the echolocation bands indicated that, in general, more expansive measures were needed to reduce sound levels from marine shipping, when compared to broadband noise. The analysis also suggests that offsetting noise in these two bands would require contingency mitigation options beyond those considered in this study under the higher high-case scenario (+156 Mega-Max calls per year). Such contingency mitigation options are nonetheless achievable given the small differences compared to existing conditions and could be realized, for example, by expanding slowdown durations beyond the 6 months considered in this study. It should also be noted that these findings are based on estimates of Mega-Max source levels extrapolated from present-day ECHO Program data. It is expected that updated source level measurements will be collected for new classes of container vessels calling at the Port of Vancouver as part of the port authority’s marine shipping follow-up program (FUP) element.

The TEM developed for this study could be relied upon as part of the marine shipping FUP element, to assess how future changes in container vessel calls, size classes, or noise emissions would affect underwater noise exposures from container vessel traffic. Note that the purpose of the TEM is to evaluate acoustic habitat quality, regardless of animal presence, and does not reflect actual effects of noise exposures on SRKW.

Literature Cited

[DFO] Fisheries and Oceans Canada. 2018a. *Recovery Strategy for the Northern and Southern Resident Killer Whales (Orcinus orca) in Canada (Proposed)*. Species at Risk Act Recovery Strategy Series, Fisheries and Oceans Canada, Ottawa. 84 pp. https://www.sararegistry.gc.ca/virtual_sara/files/plans/Rs-ResidentKillerWhale-v00-2018Aug-Eng.pdf.

[DFO] Fisheries and Oceans Canada. 2018b. *R.S.C., c. F-14 Fisheries Act - Regulations Amending the Marine Mammal Regulations*. *P.C. 2018-842 June 21, 2018*. Canada Gazette, Part II, Volume 152, Number 14. https://canadagazette.gc.ca/rp-pr/p2/2018/2018-07-11/html/sor-dors126-eng.html.

[IMO] International Maritime Organization. 2014. *MEPC.1/Circ.833. Guidelines for the Reduction of Underwater Noise from Commercial Shipping to Address Adverse Impacts on Marine Life*. London. 8 pp. http://www.imo.org/en/MediaCentre/HotTopics/Documents/833%20Guidance%20on%20reducing%20underwater%20noise%20from%20commercial%20shipping,.pdf#search=MEPC%2E1%2FCirc%2E833%202014.

[ISO] International Organization for Standardization. 2017. *ISO 18405:2017. Underwater acoustics – Terminology*. Geneva. https://www.iso.org/standard/62406.html.

[MECC] Ministry of Environment and Climate Change. 2020. *Letter to Robin Silvester Vancouver Fraser Port Authority*. CIAR Document #2067. https://www.ceaa-acee.gc.ca/050/documents/p80054/135827E.pdf.

[NOAA] National Oceanic and Atmospheric Administration (US). 2019. *ESA Section 7 Consultation Tools for Marine Mammals on the West Coast* (webpage). https://www.fisheries.noaa.gov/west-coast/endangered-species-conservation/esa-section-7-consultation-tools-marine-mammals-west. (Accessed December 2020).

[VFPA] Vancouver Fraser Port Authority. 2019. *Appendix B: Container Vessel Characteristics and Naming*. Panel Information Session: January 30, 2019. Undertaking Request #2. https://www.ceaa-acee.gc.ca/050/documents/p80054/126863E.pdf.

[VFPA] Vancouver Fraser Port Authority. 2021. *2020 voluntary vessel slowdown in Haro Strait and Boundary Pass*. Vancouver, BC. 202 pp. https://www.portvancouver.com/wp-content/uploads/2021/06/2021-06-11-Summary-Report-2020-Haro-Boundary-slowdown.pdf.

ANSI S1.1-1994. R2004. *American National Standard: Acoustical Terminology*. American National Standards Institute and Acoustical Society of America, NY, USA. https://webstore.ansi.org/Standards/ASA/ANSIS11994R2004.

ANSI/ASA S1.13-2005. R2010. *American National Standard: Measurement of Sound Pressure Levels in Air*. American National Standards Institute and Acoustical Society of America, NY, USA. https://webstore.ansi.org/Standards/ASA/ANSIASAS1132005R2010.

Au, W.W., J.K.B. Ford, J.K. Horne, and K.A. Allman. 2004. Echolocation signals of free-ranging killer whales (Orcinus orca) and modeling of foraging for chinook salmon (Oncorhynchus tshawytscha). *Journal of the Acoustical Society of America* 115: 901–909.

Buren, A.D., D.J. Tollit, M. Gilbert, A. Johnson, J. Wood, K. Akaoka, H. Regehr, A. MacGillivray, Z. Li, et al. 2021. *Roberts Bank Terminal 2 Project Technical Data Report - Assessing effectiveness of mitigation to reduce potential acoustic effects on Southern Resident Killer Whales from project* *operation.* Consultants report prepared for Vancouver Fraser Port Authority by Ecofish Research Ltd., SMRU Consulting North America, and JASCO Applied Sciences Ltd. September 16, 2021.

Burnham, R.E., S. Vagle, C. O'Neill, and K. Trounce. 2021. The Efficacy of Management Measures to Reduce Vessel Noise in Critical Habitat of Southern Resident Killer Whales in the Salish Sea. *Frontiers in Marine Science* 8(1034). https://www.frontiersin.org/article/10.3389/fmars.2021.664691.

Collins, M.D. 1993. A split-step Padé solution for the parabolic equation method. *Journal of the Acoustical Society of America* 93(4): 1736-1742. https://doi.org/10.1121/1.406739.

Collins, M.D., R.J. Cederberg, D.B. King, and S. Chin-Bing. 1996. Comparison of algorithms for solving parabolic wave equations. *Journal of the Acoustical Society of America* 100(1): 178-182. https://doi.org/10.1121/1.415921.

Compass Resource Management Ltd. 2013. *Roberts Bank Terminal 2 Technical Advisory Group (TAG) Process Report: Southern Resident Killer Whales – Final report*. Report by Compass for Port Metro Vancouver. http://www.robertsbankterminal2.com/wp-content/uploads/RBT2-TAG-Summary-Report-SRKW-November-2013.pdf.

Joy, R., D.J. Tollit, J.D. Wood, A.O. MacGillivray, Z. Li, K. Trounce, and O. Robinson. 2019. Potential Benefits of Vessel Slowdowns on Endangered Southern Resident Killer Whales. *Frontiers in Marine Science* 6: 344. https://doi.org/10.3389/fmars.2019.00344.

MacGillivray, A.O., Z. Li, G.A. Warner, and C. O'Neill. 2014. *Appendix 9.8-B Regional Commercial Vessel Traffic Underwater Noise Exposure 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. 80 pp. http://www.ceaa-acee.gc.ca/050/documents/p80054/101367E.pdf.

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. *In* Vancouver Fraser Port Authority (ed.). *ECHO Program: Voluntary Vessel Slowdown Trial Summary Findings (Appendix A)*. 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.

MacGillivray, A.O., Z. Li, D.E. Hannay, K.B. Trounce, and O. Robinson. 2019. Slowing deep-sea commercial vessels reduces underwater radiated noise. *Journal of the Acoustical Society of America* 146: 340-351. https://doi.org/10.1121/1.5116140.

MacGillivray, A.O., J. Ainsworth, H. Frouin-Mouy, J.N. Dolman, and M.A. Bahtiarian. 2020. *ECHO Vessel Noise Correlations Study: Final Report*. Document Number 02025, Version 2.0. Technical report by JASCO Applied Sciences, ERM, and Acentech for Vancouver Fraser Port Authority ECHO Program.

Marine Mammal Protection Act of 1972 as Amended. 2007. United States Pub. L. No. 92-522, 16 U.S.C. 1361 (Oct. 21, 1972). http://www.nmfs.noaa.gov/pr/laws/mmpa/text.htm.

Mercator International. 2021. *Appendix IR2020-3-B: Updated RBT2 Container Vessel Call Forecast Study*. Report to the Vancouver Fraser Port Authority.

Ross, D. 1987. *Mechanics of Underwater Noise*. Pergamon Press, NY, USA.

SMRU Canada Ltd. 2014. *Roberts Bank Terminal 2 Technical Data Report: Determination of Behavioral Effect Noise Thresholds for Southern Resident Killer Whales*. Report by SMRU Canada Ltd. (on behalf of Hemmera) for Port Metro Vancouver, Vancouver, BC. 44 pp. http://www.robertsbankterminal2.com/.

Warner, G.A., J.D. Wood, S. Frey, L. McWhinnie, A.O. MacGillivray, Z. Li, and D.J. Tollit. 2019. *Salish Sea Ambient Noise Evaluation 2016–2017: Enhancing Cetacean Habitat and Observation Program*. Document Number 01756, Version 2.0. Technical report by JASCO Applied Sciences, SMRU Consulting, Coastal and Ocean Resource Analysis Laboratory for Vancouver Fraser Port Authority.

Wladichuk, J.L., G.A. Warner, A. McCrodan, and A.O. MacGillivray. 2014. *Appendix 9.8-A 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 by JASCO Applied Sciences for Port Metro Vancouver. 198 pp. http://www.ceaa-acee.gc.ca/050/documents/p80054/101367E.pdf.

Zhang, Z.Y. and C.T. Tindle. 1995. Improved equivalent fluid approximations for a low shear speed ocean bottom. *Journal of the Acoustical Society of America* 98(6): 3391-3396. https://doi.org/10.1121/1.413789.

Appendix A. Tabulated TEM Results

A.1. Most-Realistic Scenario

Table A-1. Broadband: annual exceedance hours above the 120 dB re 1 µPa behavioural response threshold, SEL, and L_{eq} for container vessels transiting through the marine shipping area (2035-2045) with and without RBT2 from Mercator International (2021) projections.

Year	Exceedance Hours/Year				SEL/Year (dB re:1 µPa^{2}s)			Leq/Year (dB re:1 µPa)		
	With RBT2	Without RBT2	Difference*	% Difference	With RBT2	Without RBT2	Difference*	With RBT2	Without RBT2	Difference*
Georgia Strait										
2035	172	173	-1	-0.4%	190.2	190.3	-0.1	115.2	115.3	-0.1
2040	181	174	7	3.7%	190.1	190.2	0.0	115.2	115.2	0.0
2045	191	188	2	1.2%	190.3	190.3	0.0	115.3	115.4	0.0
Haro Strait										
2035	385	388	-3	-0.8%	191.9	192.1	-0.1	117.0	117.1	-0.1
2040	387	386	1	0.2%	191.9	192.0	-0.1	116.9	117.0	-0.1
2045	405	405	0	0.1%	192.0	192.1	0.0	117.1	117.1	0.0
Juan de Fuca Strait										
2035	376	376	0	0.0%	191.2	191.3	-0.1	116.2	116.3	-0.1
2040	380	377	3	0.9%	191.1	191.2	-0.1	116.1	116.2	-0.1
2045	396	394	1	0.3%	191.3	191.3	0.0	116.3	116.3	0.0
Average										
2035	311	312	-1	-0.4%	191.2	191.3	-0.1	116.2	116.3	-0.1
2040	316	312	4	1.2%	191.1	191.2	-0.1	116.1	116.2	-0.1
2045	330	329	1	0.4%	191.3	191.3	0.0	116.3	116.3	0.0

* With RTB2 values minus without RTB2 values.

Table A-2. 20 kHz echolocation click masking band: annual exceedance hours above the echolocation click masking threshold, SEL, and L_{eq} for container vessels transiting through the marine shipping area (2035-2045) with and without RBT2, from Mercator International (2021) projections.

Year	Exceedance Hours/Year				SEL/Year (dB re:1 µPa²s)			Leq/Year (dB re:1 µPa)		
	With RBT2	Without RBT2	Difference*	% Difference	With RBT2	Without RBT2	Difference*	With RBT2	Without RBT2	Difference*
Georgia Strait										
2035	365	363	3	0.7%	158.3	158.1	0.1	83.3	83.1	0.1
2040	391	371	20	5.5%	160.1	158.8	1.3	85.1	83.8	1.3
2045	415	408	7	1.7%	160.4	160.1	0.4	85.5	85.1	0.4
Haro Strait										
2035	475	473	2	0.4%	158.0	157.9	0.1	83.0	82.9	0.1
2040	493	479	14	3.0%	159.8	158.5	1.3	84.8	83.5	1.3
2045	522	517	5	0.9%	160.2	159.8	0.4	85.2	84.8	0.4
Juan de Fuca Strait										
2035	490	483	7	1.4%	155.8	155.7	0.1	80.8	80.7	0.1
2040	527	497	30	5.9%	157.6	156.3	1.3	82.6	81.3	1.3
2045	555	546	10	1.8%	158.0	157.6	0.4	83.0	82.6	0.4
Average										
2035	443	440	4	0.9%	157.5	157.4	0.1	82.5	82.4	0.1
2040	471	449	21	4.7%	159.3	158.0	1.3	84.3	83.0	1.3
2045	497	490	7	1.5%	159.7	159.3	0.4	84.7	84.3	0.4

* With RTB2 values minus without RTB2 values.

Table A-3. 50 kHz echolocation click masking band: annual exceedance hours above the echolocation click masking threshold, SEL, and L_{eq} for container vessels transiting through the marine shipping area (2035-2045) with and without RBT2, from Mercator International (2021) projections.

Year	Exceedance Hours/Year				SEL/Year (dB re:1 µPa²s)			Leq/Year (dB re:1 µPa)		
	With RBT2	Without RBT2	Difference*	% Difference	With RBT2	Without RBT2	Difference*	With RBT2	Without RBT2	Difference*
Georgia Strait										
2035	47	47	0	0.0%	151.1	151.0	0.1	76.1	76.0	0.1
2040	49	48	2	3.2%	152.9	151.6	1.3	77.9	76.6	1.3
2045	52	52	1	1.0%	153.3	153.0	0.4	78.3	78.0	0.4
Haro Strait										
2035	44	43	1	1.4%	150.7	150.6	0.1	75.7	75.6	0.1
2040	47	45	3	6.2%	152.5	151.2	1.3	77.5	76.2	1.3
2045	50	49	1	1.9%	152.9	152.5	0.4	77.9	77.5	0.4
Juan de Fuca Strait										
2035	49	49	0	0.0%	148.1	148.0	0.1	73.1	73.0	0.1
2040	51	50	2	3.4%	149.9	148.6	1.3	74.9	73.6	1.3
2045	54	54	1	1.0%	150.3	150.0	0.4	75.3	75.0	0.4
Average										
2035	47	46	0	0.4%	150.2	150.1	0.1	75.2	75.1	0.1
2040	49	47	2	4.2%	152.0	150.7	1.3	77.0	75.7	1.3
2045	52	52	1	1.3%	152.4	152.0	0.4	77.4	77.0	0.4

* With RTB2 values minus without RTB2 values.

A.2. High-Case Scenario: +52 Mega-Max Container Vessels

Table A-4. Broadband: annual exceedance hours above the 120 dB re 1 µPa behavioural response threshold, SEL, and L_{eq} for container vessels transiting through the marine shipping area (2035-2045) with and without RBT2 from Mercator International (2021) projections.

Year	**Exceedance Hours/Year**				**SEL/Year (dB re:1 µPa²s)**			**Leq/Year (dB re:1 µPa)**		
	With RBT2	**Without RBT2**	**Difference***	**% Difference**	**With RBT2**	**Without RBT2**	**Difference***	**With RBT2**	**Without RBT2**	**Difference***
Georgia Strait										
2035	186	173	14	7.8%	190.5	190.3	0.2	115.5	115.3	0.2
2040	195	174	21	11.9%	190.5	190.2	0.3	115.5	115.2	0.3
2045	205	188	16	8.7%	190.6	190.3	0.3	115.6	115.4	0.3
Haro Strait										
2035	412	388	24	6.3%	192.2	192.1	0.2	117.3	117.1	0.2
2040	415	386	29	7.4%	192.2	192.0	0.2	117.2	117.0	0.2
2045	433	405	28	6.9%	192.3	192.1	0.3	117.3	117.1	0.3
Juan de Fuca Strait										
2035	404	376	28	7.4%	191.5	191.3	0.2	116.5	116.3	0.2
2040	408	377	31	8.3%	191.4	191.2	0.2	116.4	116.2	0.2
2045	423	394	29	7.3%	191.6	191.3	0.3	116.6	116.3	0.3
Average										
2035	334	312	22	7.0%	191.5	191.3	0.2	116.5	116.3	0.2
2040	339	312	27	8.6%	191.4	191.2	0.2	116.4	116.2	0.2
2045	354	329	24	7.4%	191.6	191.3	0.3	116.6	116.3	0.3

* With RTB2 values minus without RTB2 values.

Table A-5. 20 kHz echolocation click masking band: annual exceedance hours above the echolocation click masking threshold, SEL, and L_{eq} for container vessels transiting through the marine shipping area (2035-2045) with and without RBT2, from Mercator International (2021) projections.

Year	Exceedance Hours/Year				SEL/Year (dB re:1 µPa^{2}s)			Leq/Year (dB re:1 µPa)		
	With RBT2	Without RBT2	Difference*	% Difference	With RBT2	Without RBT2	Difference*	With RBT2	Without RBT2	Difference*
Georgia Strait										
2035	396	363	33	9.2%	159.0	158.1	0.9	84.1	83.1	0.9
2040	422	371	51	13.7%	160.6	158.8	1.8	85.6	83.8	1.8
2045	445	408	37	9.2%	160.9	160.1	0.9	85.9	85.1	0.9
Haro Strait										
2035	510	473	38	7.9%	158.8	157.9	0.9	83.8	82.9	0.9
2040	529	479	50	10.4%	160.3	158.5	1.8	85.3	83.5	1.8
2045	557	517	40	7.8%	160.7	159.8	0.9	85.7	84.8	0.9
Juan de Fuca Strait										
2035	531	483	48	10.0%	156.6	155.7	0.9	81.6	80.7	0.9
2040	569	497	71	14.3%	158.1	156.3	1.8	83.1	81.3	1.8
2045	597	546	51	9.4%	158.5	157.6	0.9	83.5	82.6	0.9
Average										
2035	479	440	40	9.0%	158.3	157.4	0.9	83.3	82.4	0.9
2040	506	449	57	12.7%	159.8	158.0	1.8	84.8	83.0	1.8
2045	533	490	43	8.8%	160.2	159.3	0.9	85.2	84.3	0.9

* With RTB2 values minus without RTB2 values.

Table A-6. 50 kHz echolocation click masking band: annual exceedance hours above the echolocation click masking threshold, SEL, and L_{eq} for container vessels transiting through the marine shipping area (2035-2045) with and without RBT2, from Mercator International (2021) projections.

Year	Exceedance Hours/Year				SEL/Year (dB re:1 µPa^{2}s)			Leq/Year (dB re:1 µPa)		
	With RBT2	Without RBT2	Difference*	% Difference	With RBT2	Without RBT2	Difference*	With RBT2	Without RBT2	Difference*
Georgia Strait										
2035	51	47	4	7.6%	151.9	151.0	0.9	76.9	76.0	0.9
2040	53	48	5	10.7%	153.5	151.6	1.8	78.5	76.6	1.8
2045	56	52	4	7.9%	153.8	153.0	0.9	78.8	78.0	0.9
Haro Strait										
2035	48	43	4	9.9%	151.5	150.6	0.9	76.5	75.6	0.9
2040	51	45	6	14.4%	153.0	151.2	1.8	78.0	76.2	1.8
2045	54	49	5	9.3%	153.4	152.5	0.9	78.4	77.5	0.9
Juan de Fuca Strait										
2035	53	49	4	7.7%	148.9	148.0	0.9	73.9	73.0	0.9
2040	55	50	5	11.0%	150.5	148.6	1.8	75.5	73.6	1.8
2045	58	54	4	8.1%	150.8	150.0	0.9	75.8	75.0	0.9
Average										
2035	50	46	4	8.4%	151.0	150.1	0.9	76.0	75.1	0.9
2040	53	47	6	12.0%	152.5	150.7	1.8	77.5	75.7	1.8
2045	56	52	4	8.4%	152.9	152.0	0.9	77.9	77.0	0.9

* With RTB2 values minus without RTB2 values.

A.3. High-Case Scenario: +104 Mega-Max Container Vessels

Table A-7. Broadband: annual exceedance hours above the 120 dB re 1 µPa behavioural response threshold, SEL, and L_{eq} for container vessels transiting through the marine shipping area (2035-2045) with and without RBT2 from Mercator International (2021) projections.

Year	Exceedance Hours/Year				SEL/Year (dB re:1 µPa²s)			Leq/Year (dB re:1 µPa)		
	With RBT2	Without RBT2	Difference*	% Difference	With RBT2	Without RBT2	Difference*	With RBT2	Without RBT2	Difference*
Georgia Strait										
2035	200	173	28	16.1%	190.8	190.3	0.5	115.8	115.3	0.5
2040	209	174	35	20.1%	190.7	190.2	0.6	115.8	115.2	0.6
2045	219	188	31	16.3%	190.9	190.3	0.6	115.9	115.4	0.6
Haro Strait										
2035	440	388	52	13.5%	192.5	192.1	0.5	117.5	117.1	0.5
2040	442	386	56	14.6%	192.5	192.0	0.5	117.5	117.0	0.5
2045	461	405	56	13.8%	192.6	192.1	0.5	117.6	117.1	0.5
Juan de Fuca Strait										
2035	431	376	56	14.8%	191.8	191.3	0.5	116.8	116.3	0.5
2040	436	377	59	15.7%	191.7	191.2	0.5	116.7	116.2	0.5
2045	451	394	57	14.4%	191.9	191.3	0.5	116.9	116.3	0.5
Average										
2035	357	312	45	14.5%	191.7	191.3	0.5	116.8	116.3	0.5
2040	363	312	50	16.1%	191.7	191.2	0.5	116.7	116.2	0.5
2045	377	329	48	14.5%	191.8	191.3	0.5	116.9	116.3	0.5

* With RTB2 values minus without RTB2 values.

Table A-8. 20 kHz echolocation click masking band: annual exceedance hours above the echolocation click masking threshold, SEL, and L_{eq} for container vessels transiting through the marine shipping area (2035-2045) with and without RBT2, from Mercator International (2021) projections.

Year	Exceedance Hours/Year				SEL/Year (dB re:1 µPa^{2}s)			Leq/Year (dB re:1 µPa)		
	With RBT2	Without RBT2	Difference*	% Difference	With RBT2	Without RBT2	Difference*	With RBT2	Without RBT2	Difference*
Georgia Strait										
2035	426	363	64	17.6%	159.7	158.1	1.6	84.7	83.1	1.6
2040	453	371	82	22.0%	161.1	158.8	2.3	86.1	83.8	2.3
2045	476	408	68	16.7%	161.4	160.1	1.3	86.4	85.1	1.3
Haro Strait										
2035	546	473	73	15.4%	159.4	157.9	1.6	84.5	82.9	1.6
2040	564	479	85	17.8%	160.8	158.5	2.3	85.8	83.5	2.3
2045	593	517	76	14.6%	161.1	159.8	1.3	86.1	84.8	1.3
Juan de Fuca Strait										
2035	573	483	90	18.6%	157.3	155.7	1.6	82.3	80.7	1.6
2040	610	497	113	22.7%	158.6	156.3	2.3	83.6	81.3	2.3
2045	639	546	93	17.1%	158.9	157.6	1.3	83.9	82.6	1.3
Average										
2035	515	440	76	17.2%	158.9	157.4	1.6	83.9	82.4	1.6
2040	542	449	93	20.7%	160.3	158.0	2.3	85.3	83.0	2.3
2045	569	490	79	16.1%	160.6	159.3	1.3	85.6	84.3	1.3

* With RTB2 values minus without RTB2 values.

Table A-9. 50 kHz echolocation click masking band: annual exceedance hours above the echolocation click masking threshold, SEL, and L_{eq} for container vessels transiting through the marine shipping area (2035-2045) with and without RBT2, from Mercator International (2021) projections.

Year	Exceedance Hours/Year				SEL/Year (dB re:1 µPa^{2}s)			Leq/Year (dB re:1 µPa)		
	With RBT2	Without RBT2	Difference*	% Difference	With RBT2	Without RBT2	Difference*	With RBT2	Without RBT2	Difference*
Georgia Strait										
2035	54	47	7	15.2%	152.6	151.0	1.6	77.6	76.0	1.6
2040	56	48	9	18.3%	153.9	151.6	2.3	79.0	76.6	2.3
2045	59	52	8	14.8%	154.3	153.0	1.3	79.3	78.0	1.3
Haro Strait										
2035	51	43	8	18.4%	152.2	150.6	1.6	77.2	75.6	1.6
2040	55	45	10	22.7%	153.5	151.2	2.3	78.5	76.2	2.3
2045	58	49	8	16.8%	153.8	152.5	1.3	78.8	77.5	1.3
Juan de Fuca Strait										
2035	57	49	8	15.5%	149.6	148.0	1.6	74.6	73.0	1.6
2040	59	50	9	18.7%	151.0	148.6	2.3	76.0	73.6	2.3
2045	62	54	8	15.1%	151.3	150.0	1.3	76.3	75.0	1.3
Average										
2035	54	46	8	16.3%	151.6	150.1	1.6	76.6	75.1	1.6
2040	57	47	9	19.8%	153.0	150.7	2.3	78.0	75.7	2.3
2045	60	52	8	15.6%	153.3	152.0	1.3	78.3	77.0	1.3

* With RTB2 values minus without RTB2 values.

A.4. High-Case Scenario: +156 Mega-Max Container Vessels

Table A-10. Broadband: annual exceedance hours above the 120 dB re 1 µPa behavioural response threshold, SEL, and L_{eq} for container vessels transiting through the marine shipping area (2035-2045) with and without RBT2 from Mercator International (2021) projections.

Year	Exceedance Hours/Year				SEL/Year (dB re:1 µPa^{2}s)			Leq/Year (dB re:1 µPa)		
	With RBT2	**Without RBT2**	**Difference***	**% Difference**	**With RBT2**	**Without RBT2**	**Difference***	**With RBT2**	**Without RBT2**	**Difference***
Georgia Strait										
2035	215	173	42	24.4%	191.0	190.3	0.8	116.1	115.3	0.8
2040	224	174	49	28.3%	191.0	190.2	0.8	116.0	115.2	0.8
2045	233	188	45	23.9%	191.2	190.3	0.8	116.2	115.4	0.8
Haro Strait										
2035	468	388	80	20.6%	192.8	192.1	0.7	117.8	117.1	0.7
2040	470	386	84	21.8%	192.7	192.0	0.8	117.7	117.0	0.8
2045	488	405	83	20.6%	192.9	192.1	0.8	117.9	117.1	0.8
Juan de Fuca Strait										
2035	459	376	83	22.2%	192.0	191.3	0.8	117.0	116.3	0.8
2040	464	377	87	23.1%	192.0	191.2	0.8	117.0	116.2	0.8
2045	479	394	85	21.4%	192.1	191.3	0.8	117.1	116.3	0.8
Average										
2035	381	312	68	21.9%	192.0	191.3	0.8	117.0	116.3	0.8
2040	386	312	73	23.5%	192.0	191.2	0.8	117.0	116.2	0.8
2045	400	329	71	21.6%	192.1	191.3	0.8	117.1	116.3	0.8

* With RTB2 values minus without RTB2 values.

Table A-11. 20 kHz echolocation click masking band: annual exceedance hours above the echolocation click masking threshold, SEL, and L_{eq} for container vessels transiting through the marine shipping area (2035-2045) with and without RBT2, from Mercator International (2021) projections.

Year	Exceedance Hours/Year				SEL/Year (dB re:1 µPa²s)			Leq/Year (dB re:1 µPa)		
	With RBT2	Without RBT2	Difference*	% Difference	With RBT2	Without RBT2	Difference*	With RBT2	Without RBT2	Difference*
Georgia Strait										
2035	457	363	94	26.0%	160.3	158.1	2.2	85.3	83.1	2.2
2040	483	371	112	30.2%	161.5	158.8	2.8	86.5	83.8	2.8
2045	507	408	99	24.1%	161.8	160.1	1.7	86.8	85.1	1.7
Haro Strait										
2035	581	473	109	23.0%	160.0	157.9	2.2	85.0	82.9	2.2
2040	600	479	121	25.2%	161.2	158.5	2.8	86.2	83.5	2.8
2045	628	517	111	21.5%	161.5	159.8	1.7	86.5	84.8	1.7
Juan de Fuca Strait										
2035	615	483	132	27.3%	157.8	155.7	2.2	82.8	80.7	2.2
2040	652	497	154	31.1%	159.0	156.3	2.8	84.1	81.3	2.8
2045	680	546	135	24.7%	159.3	157.6	1.7	84.3	82.6	1.7
Average										
2035	551	440	112	25.4%	159.5	157.4	2.2	84.5	82.4	2.2
2040	578	449	129	28.7%	160.7	158.0	2.8	85.7	83.0	2.8
2045	605	490	115	23.4%	161.0	159.3	1.7	86.0	84.3	1.7

* With RTB2 values minus without RTB2 values.

Table A-12. 50 kHz echolocation click masking band: annual exceedance hours above the echolocation click masking threshold, SEL, and L_{eq} for container vessels transiting through the marine shipping area (2035-2045) with and without RBT2, from Mercator International (2021) projections.

Year	Exceedance Hours/Year				SEL/Year (dB re:1 µPa²s)			Leq/Year (dB re:1 µPa)		
	With RBT2	Without RBT2	Difference*	% Difference	With RBT2	Without RBT2	Difference*	With RBT2	Without RBT2	Difference*
Georgia Strait										
2035	58	47	11	22.8%	153.2	151.0	2.2	78.2	76.0	2.2
2040	60	48	12	25.8%	154.4	151.6	2.8	79.4	76.6	2.8
2045	63	52	11	21.8%	154.7	153.0	1.7	79.7	78.0	1.7
Haro Strait										
2035	55	43	12	26.9%	152.7	150.6	2.2	77.7	75.6	2.2
2040	58	45	14	30.9%	154.0	151.2	2.8	79.0	76.2	2.8
2045	61	49	12	24.3%	154.2	152.5	1.7	79.2	77.5	1.7
Juan de Fuca Strait										
2035	60	49	11	23.2%	150.2	148.0	2.2	75.2	73.0	2.2
2040	63	50	13	26.3%	151.4	148.6	2.8	76.4	73.6	2.8
2045	66	54	12	22.2%	151.7	150.0	1.7	76.7	75.0	1.7
Average										
2035	58	46	11	24.2%	152.2	150.1	2.2	77.2	75.1	2.2
2040	60	47	13	27.6%	153.4	150.7	2.8	78.4	75.7	2.8
2045	63	52	12	22.7%	153.7	152.0	1.7	78.7	77.0	1.7

* With RTB2 values minus without RTB2 values.

Appendix B. Exceedance and Yearly L_{eq} Charts for Most-Realistic and High-Case Scenarios

B.1. 2035

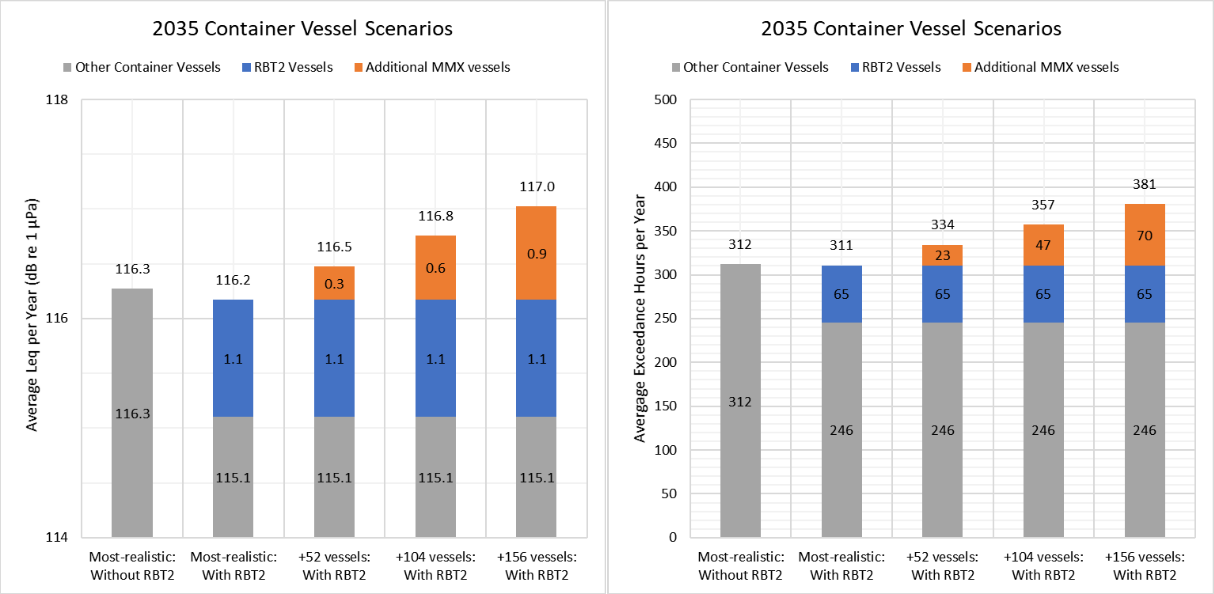


Figure B-1. Broadband: Average L_{eq} per year (left) and average exceedance hours per year above the 120 dB re 1 µPa behavioural response threshold (right) under the most-realistic and high-case scenarios for 2035. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. Values are averaged over Georgia Strait, Haro Strait, and Juan de Fuca Strait sub-areas. Exceedance numbers shown in the figure have been rounded to the nearest whole hour.

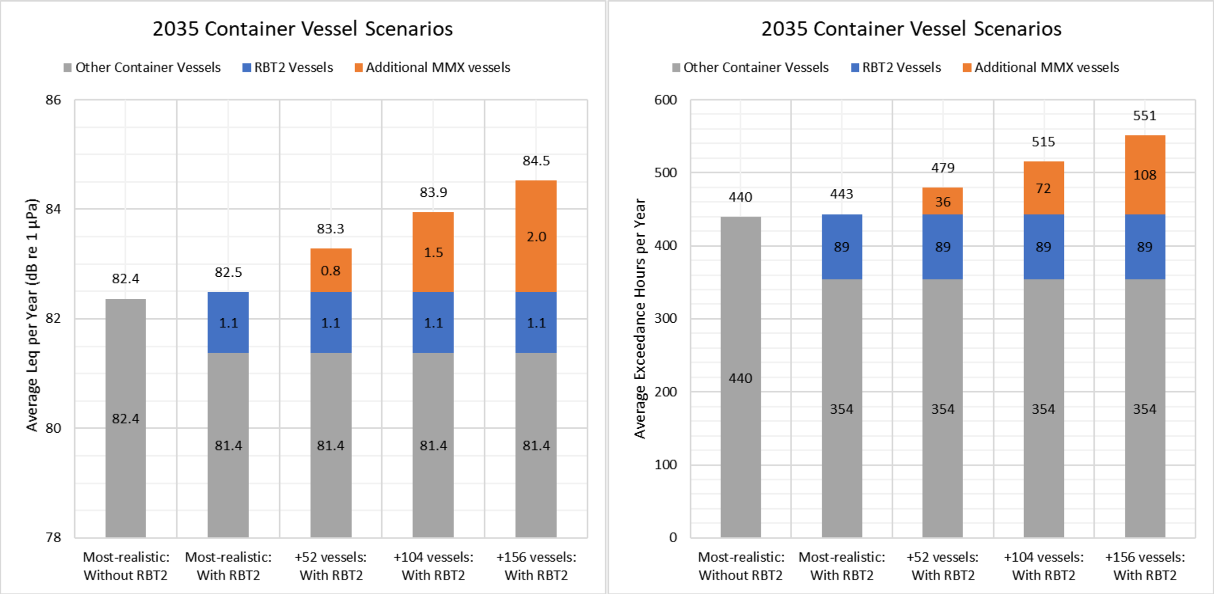


Figure B-2. 20 kHz echolocation click masking band: Average L_{eq} per year (left) and average exceedance hours per year above 20 kHz echolocation click masking threshold (right) under the most-realistic and high-case scenarios for 2035. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. Values are averaged over Georgia Strait, Haro Strait, and Juan de Fuca Strait sub-areas. Exceedance numbers shown in the figure have been rounded to the nearest whole hour.

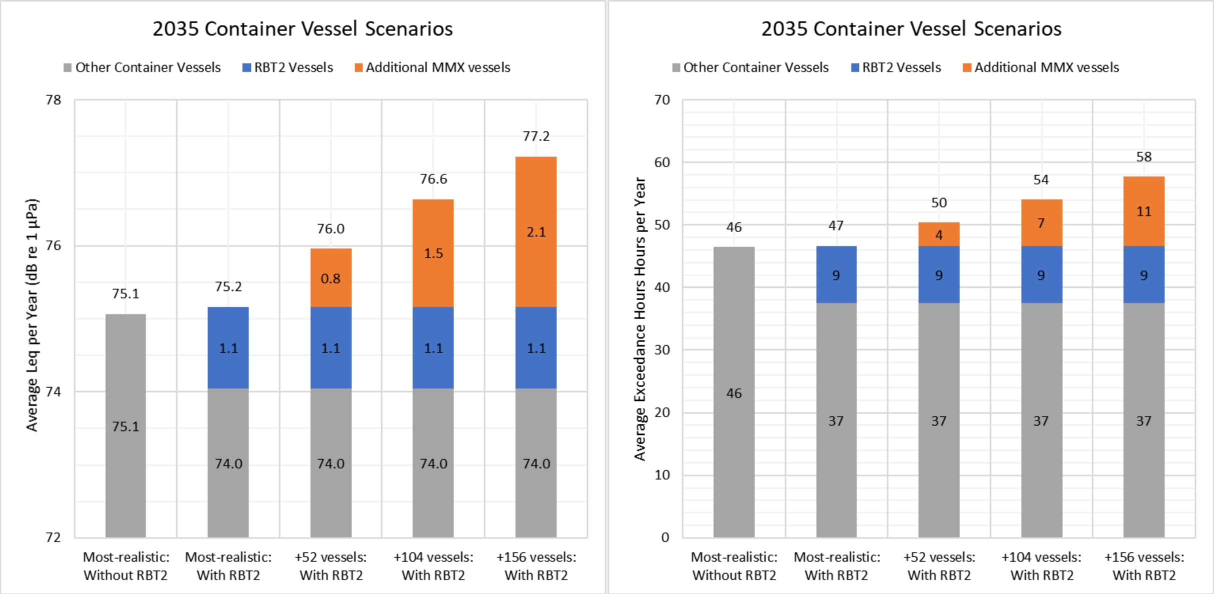


Figure B-3. 50 kHz echolocation click masking band: Average L_{eq} per year (left) and average exceedance hours per year above 50 kHz echolocation click masking threshold (right) under the most-realistic and high-case scenarios for 2035. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. Values are averaged over Georgia Strait, Haro Strait, and Juan de Fuca Strait sub-areas. Exceedance numbers shown in the figure have been rounded to the nearest whole hour.

B.2. 2040

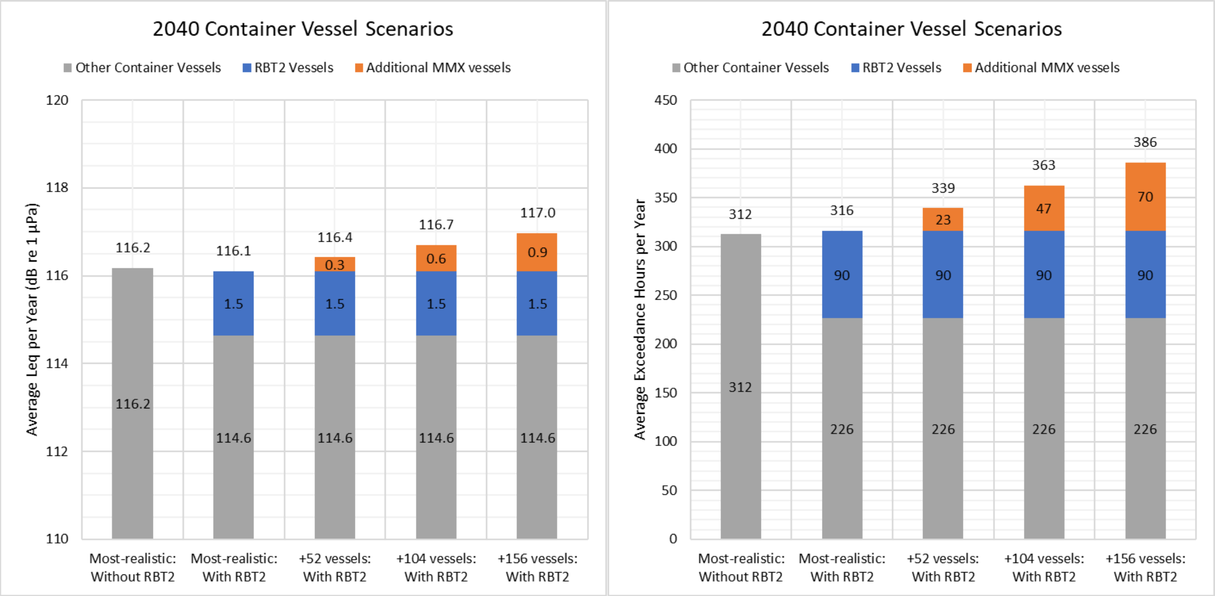


Figure B-4. Broadband: Average L_{eq} per year (left) and average exceedance hours per year above the 120 dB re 1 µPa behavioural response threshold (right) under the most-realistic and high-case scenarios for 2040. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. Values are averaged over Georgia Strait, Haro Strait, and Juan de Fuca Strait sub-areas. Exceedance numbers shown in the figure have been rounded to the nearest whole hour.

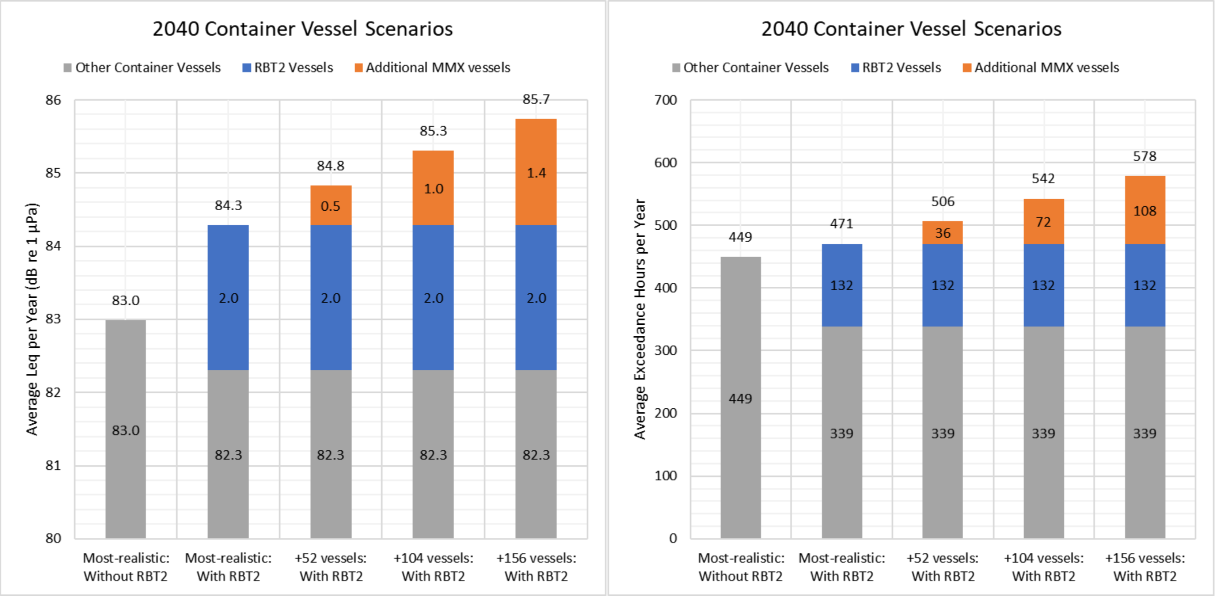


Figure B-5. 20 kHz echolocation click masking band: Average L_{eq} per year (left) and average exceedance hours per year above 20 kHz echolocation click masking threshold (right) under the most-realistic and high-case scenarios for 2040. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. Values are averaged over Georgia Strait, Haro Strait, and Juan de Fuca Strait sub-areas. Exceedance numbers shown in the figure have been rounded to the nearest whole hour.

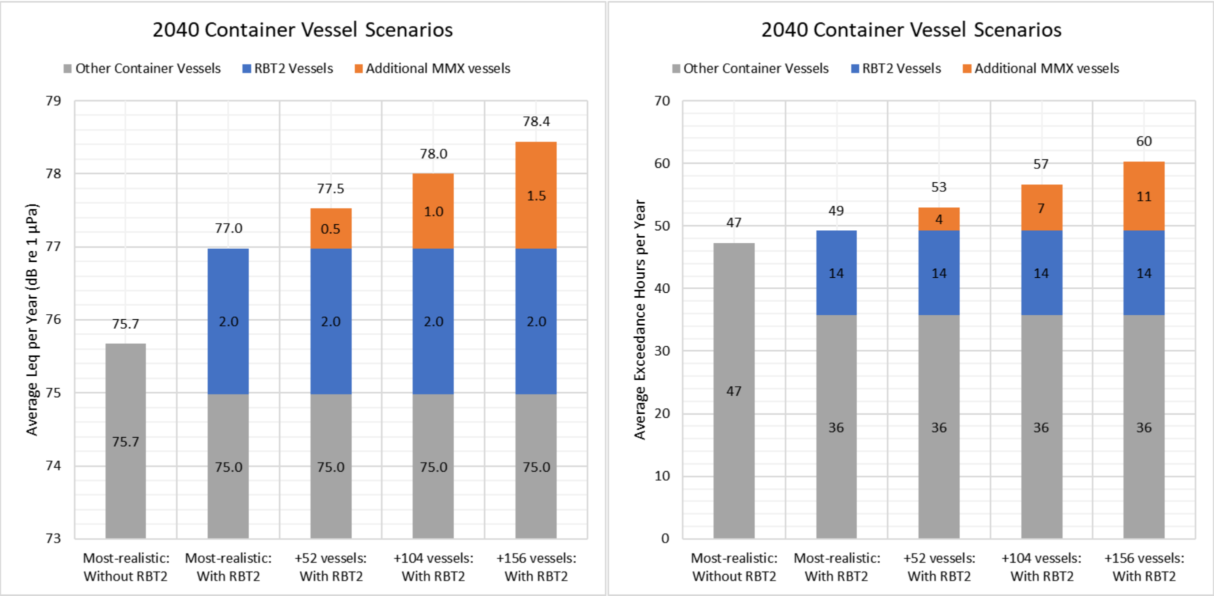


Figure B-6. 50 kHz echolocation click masking band: Average L$_{eq}$ per year (left) and average exceedance hours per year above 50 kHz echolocation click masking threshold (right) under the most-realistic and high-case scenarios for 2040. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. Values are averaged over Georgia Strait, Haro Strait, and Juan de Fuca Strait sub-areas. Exceedance numbers shown in the figure have been rounded to the nearest whole hour.

B.3. 2045

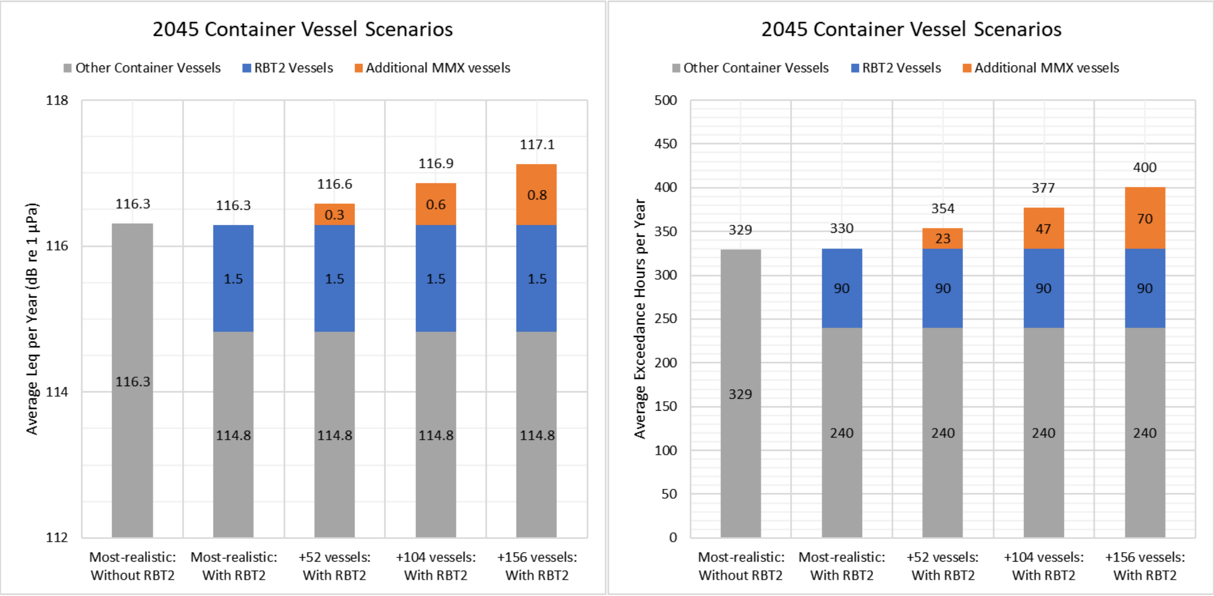


Figure B-7. Broadband: Average L$_{eq}$ per year (left) and average exceedance hours per year above the 120 dB re 1 µPa behavioural response threshold (right) under the most-realistic and high-case scenarios for 2045. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. Values are averaged over Georgia Strait, Haro Strait, and Juan de Fuca Strait sub-areas. Exceedance numbers shown in the figure have been rounded to the nearest whole hour.

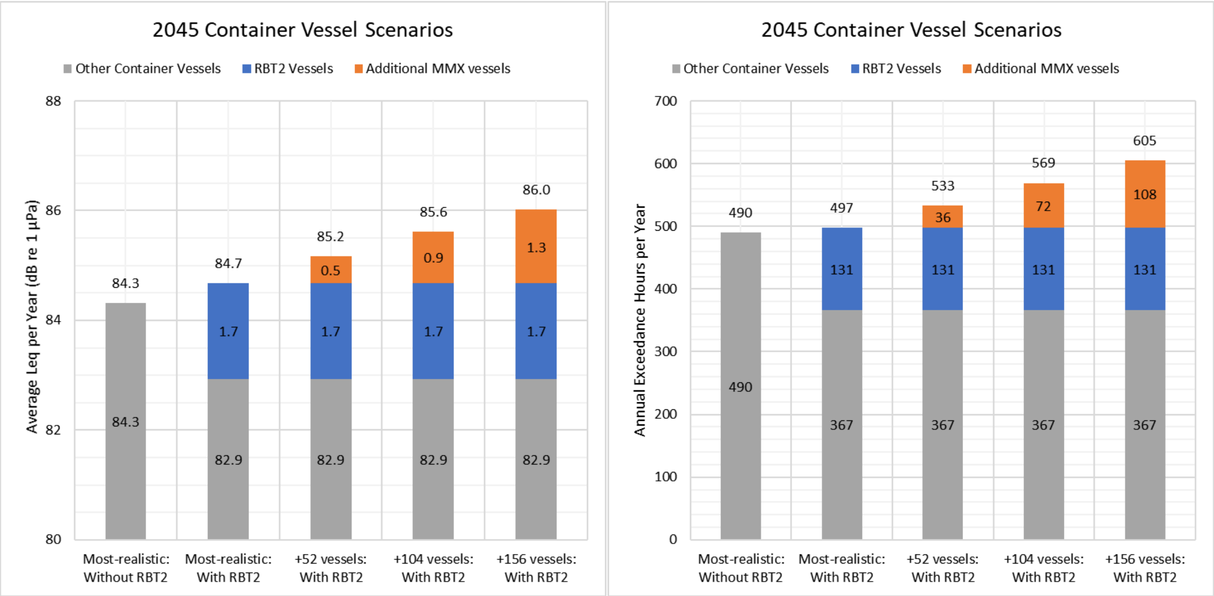


Figure B-8. 20 kHz echolocation click masking band: Average L_{eq} per year (left) and average exceedance hours per year above 20 kHz echolocation click masking threshold (right) under the most-realistic and high-case scenarios for 2045. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. Values are averaged over Georgia Strait, Haro Strait, and Juan de Fuca Strait sub-areas. Exceedance numbers shown in the figure have been rounded to the nearest whole hour.

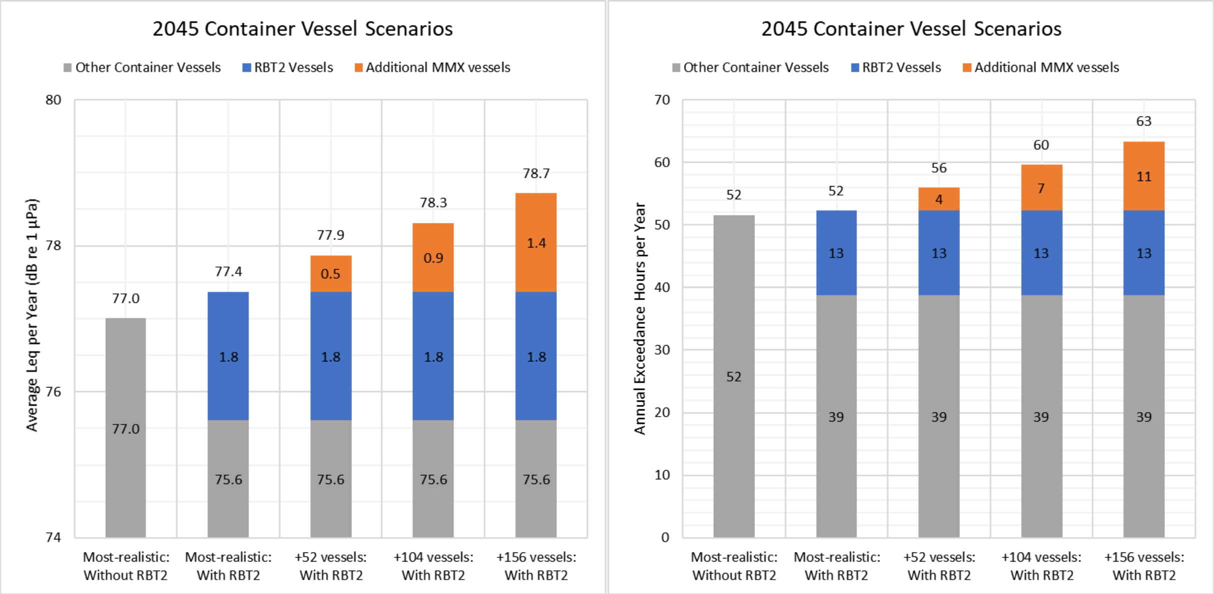


Figure B-9. 50 kHz echolocation click masking band: Average L_{eq} per year (left) and average exceedance hours per year above 50 kHz echolocation click masking threshold (right) under the most-realistic and high-case scenarios for 2045. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. Values are averaged over Georgia Strait, Haro Strait, and Juan de Fuca Strait sub-areas. Exceedance numbers shown in the figure have been rounded to the nearest whole hour.

Appendix C. Exceedance and Yearly L_{eq} Charts for Contingency Mitigation Measures

C.1. 2035

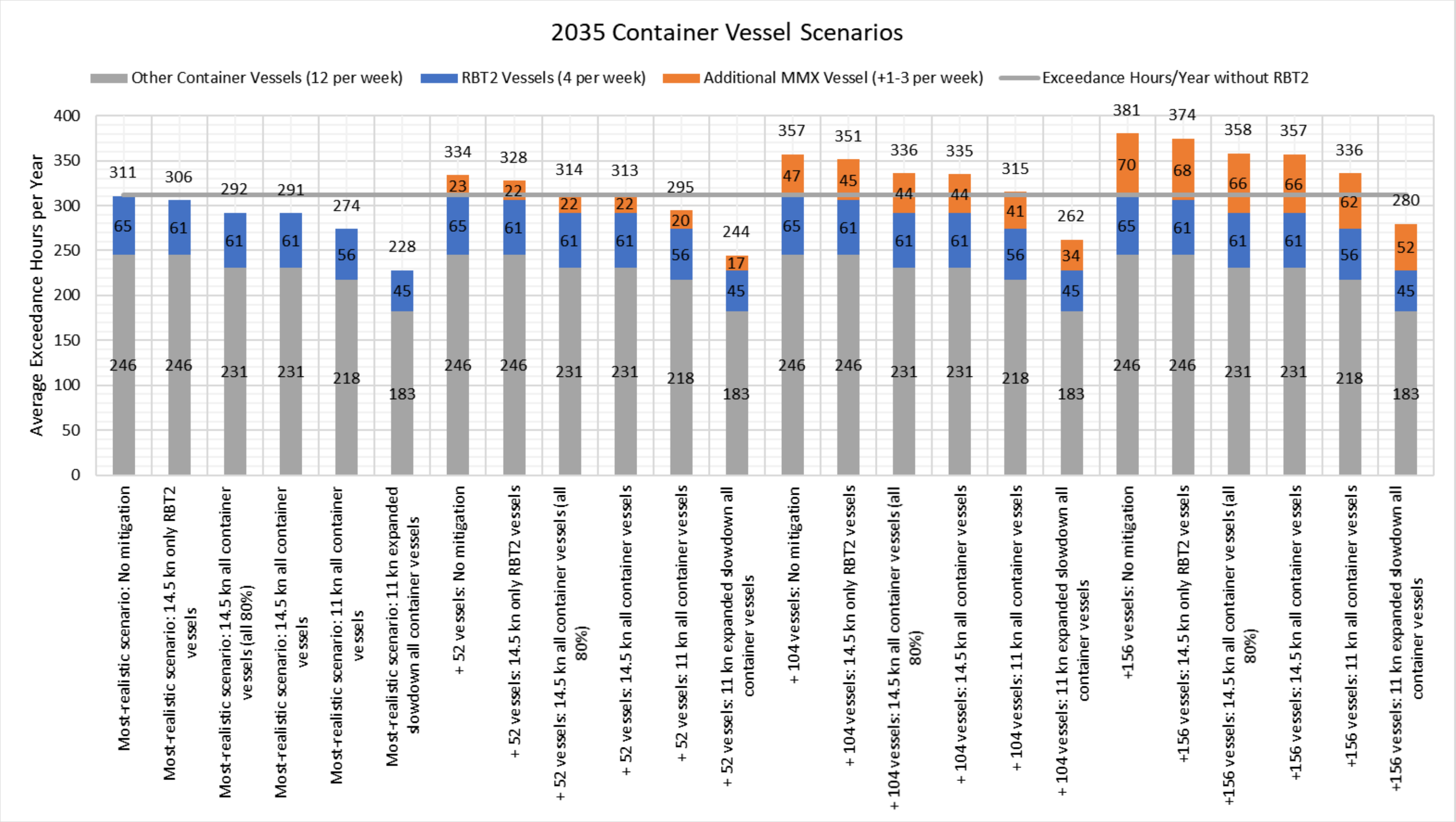


Figure C-1. Broadband exceedance hours: The effectiveness of potential contingency mitigation measures for an additional 52-156 Mega-Max (MMX) container vessels annually in the marine shipping area, in terms of average exceedance hours per year for 2035. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. The line indicates the average exceedance hours per year under the most-realistic scenario without RBT2. Exceedance numbers shown in the figure have been rounded to the nearest whole hour.

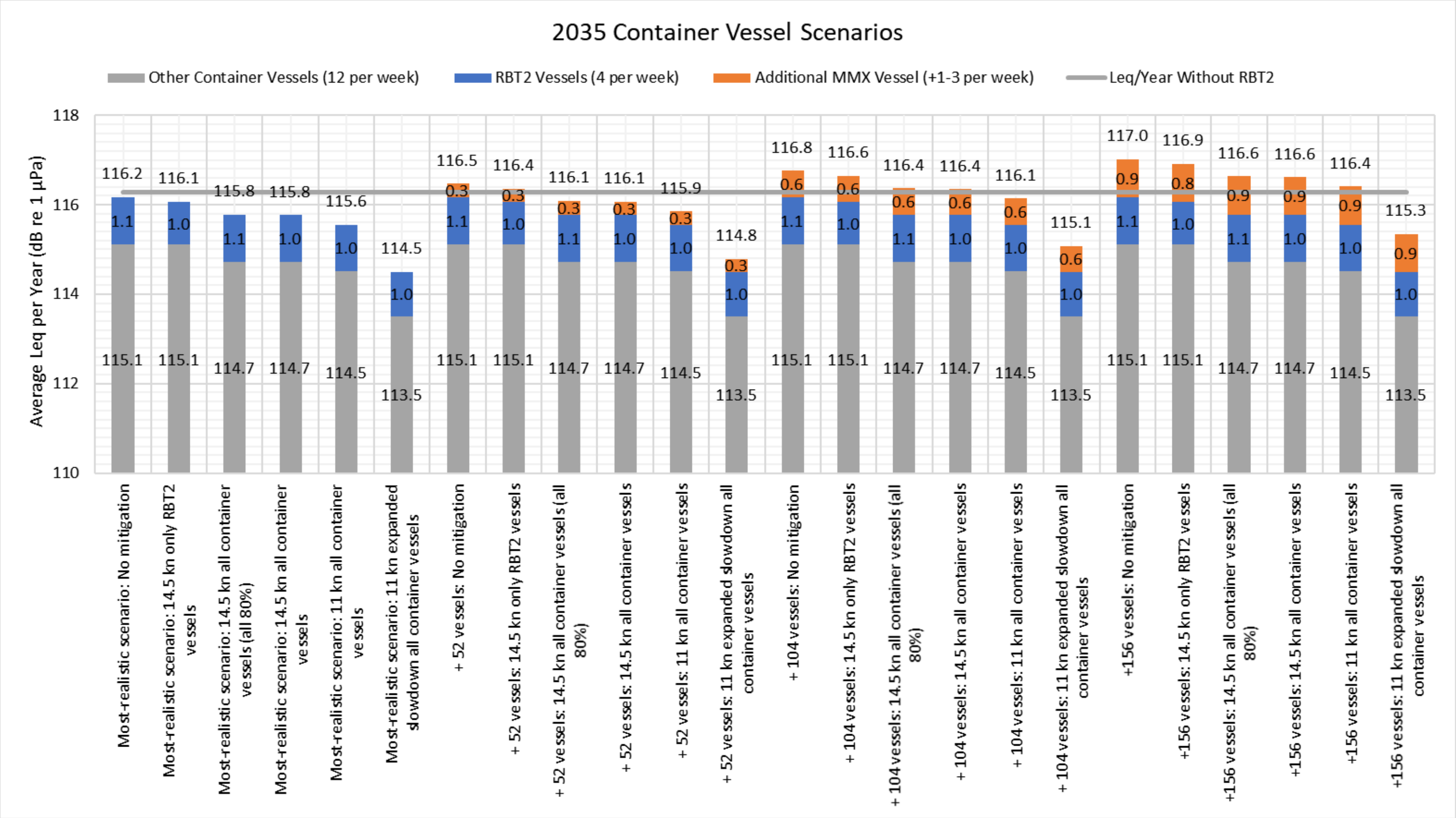


Figure C-2. Broadband L_{eq}: The effectiveness of potential contingency mitigation measures for additional Mega-Max (MMX) container vessels annually in the marine shipping area, in terms of average L_{eq} per year for 2035. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. The line indicates the average L_{eq} per year under the most-realistic scenario without RBT2.

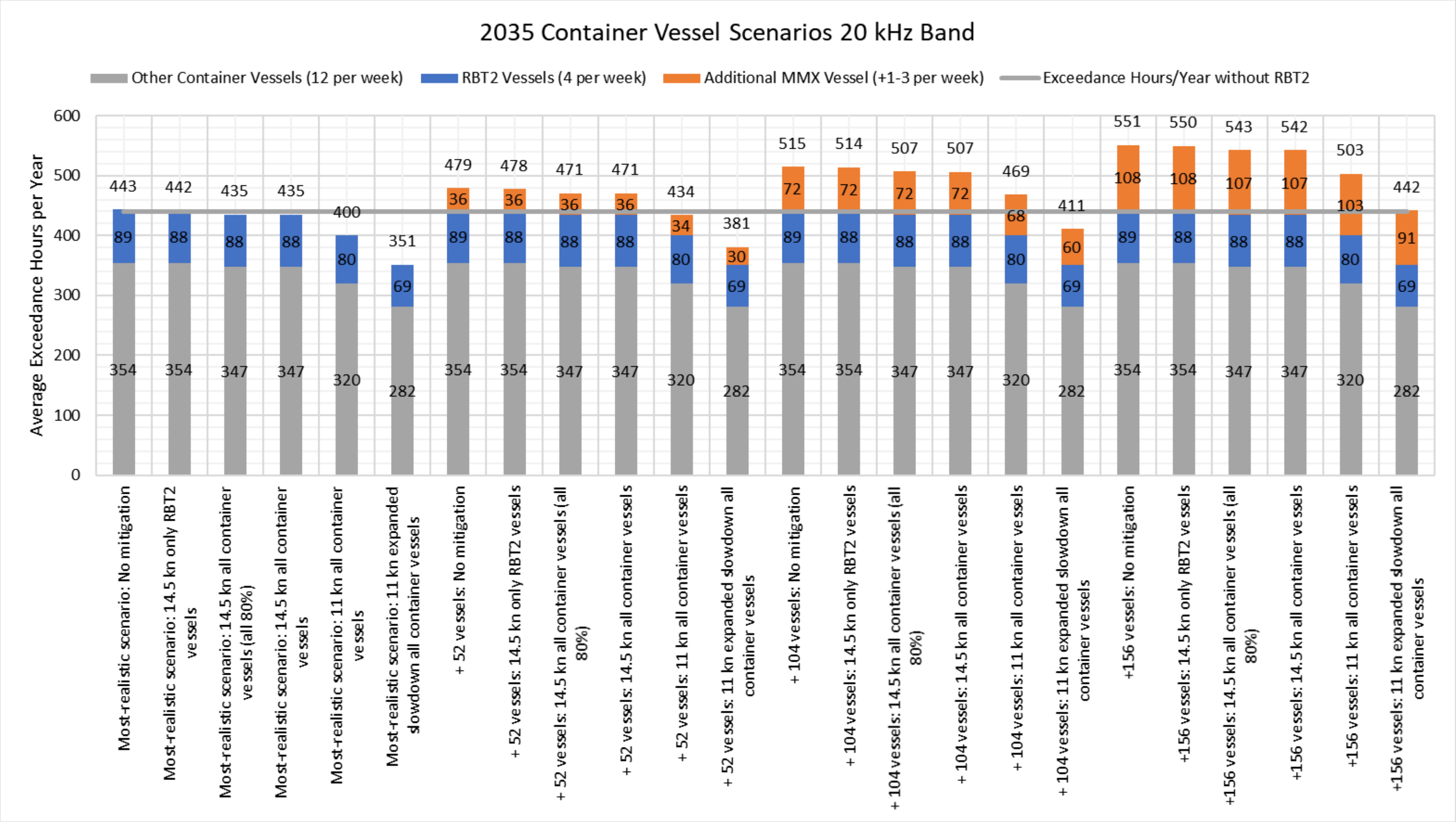


Figure C-3. 20 kHz echolocation band exceedance hours: The effectiveness of potential contingency mitigation measures for additional Mega-Max (MMX) container vessels annually in the marine shipping area, in terms of average exceedance hours per year for 2035. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. The line indicates the average exceedance hours per year under the most-realistic scenario without RBT2. Exceedance numbers shown in the figure have been rounded to the nearest whole hour.

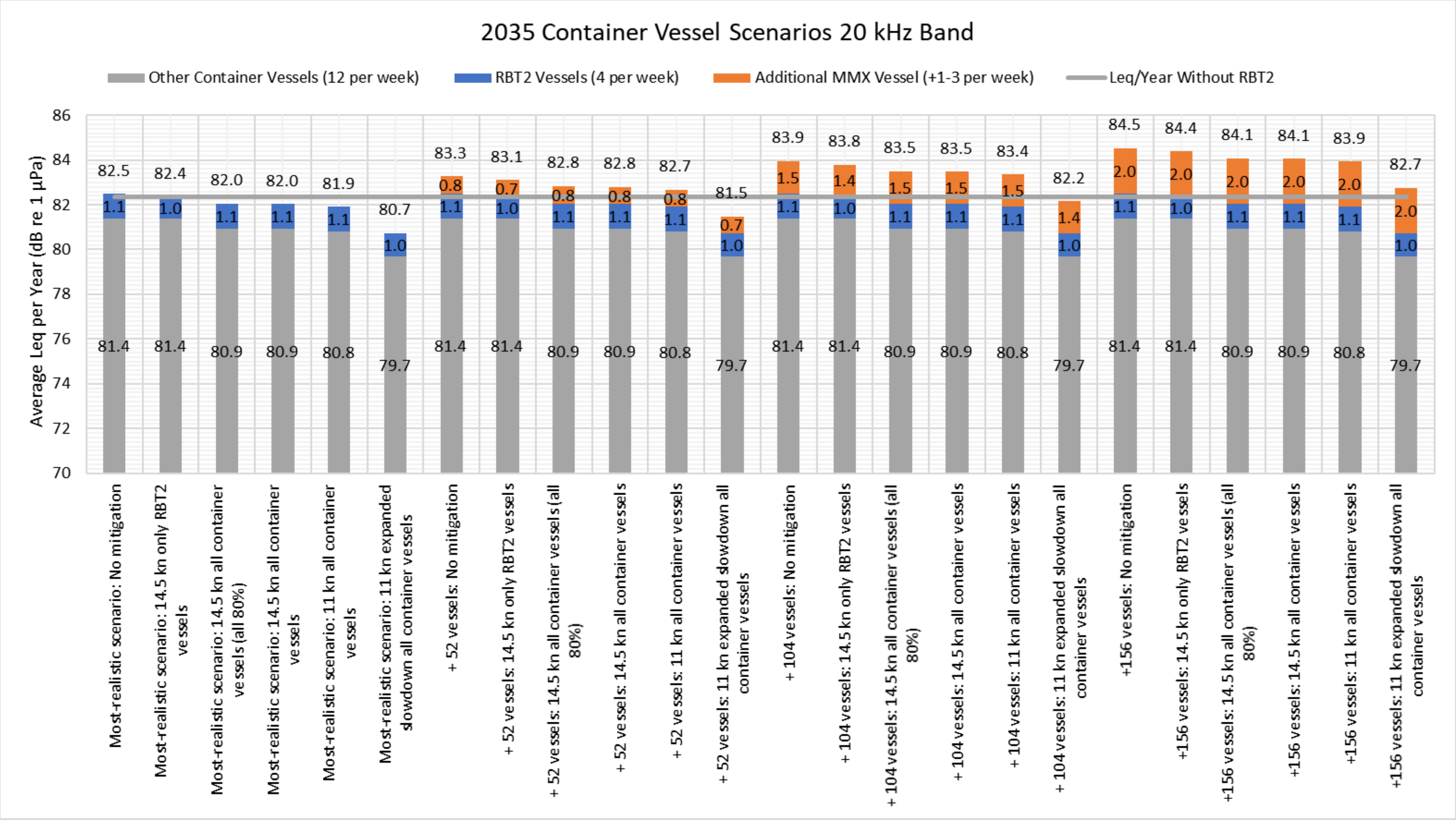


Figure C-4. 20 kHz echolocation band L_{eq}: The effectiveness of potential contingency mitigation measures for additional Mega-Max (MMX) container vessels annually in the marine shipping area, in terms of average L_{eq} per year for 2035. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. The line indicates the average L_{eq} per year under the most-realistic scenario without RBT2.

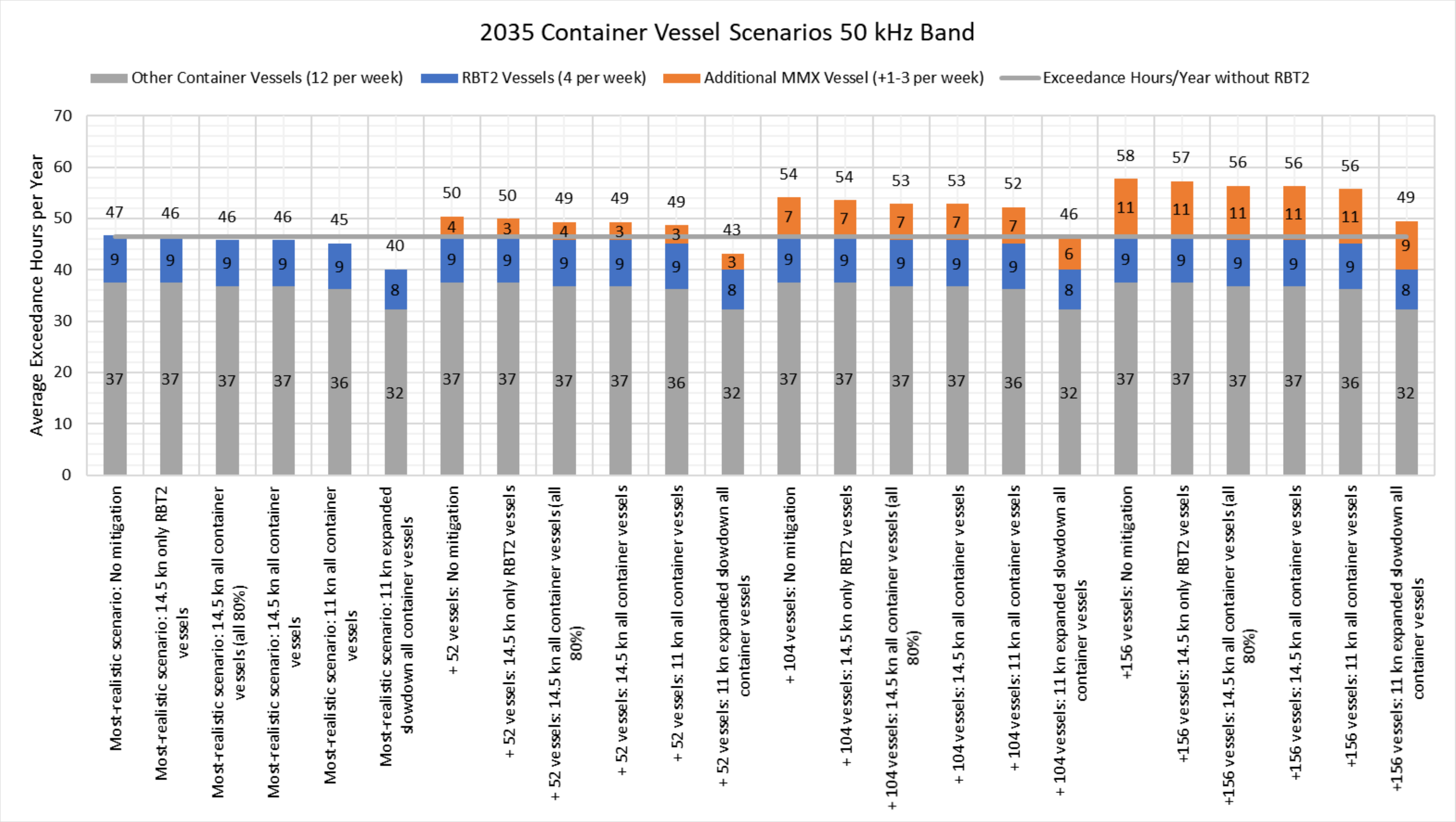


Figure C-5. 50 kHz echolocation band exceedance hours: The effectiveness of potential contingency mitigation measures for additional Mega-Max (MMX) container vessels annually in the marine shipping area, in terms of average exceedance hours per year for 2035. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. The line indicates the average exceedance hours per year under the most-realistic scenario without RBT2. Exceedance numbers shown in the figure have been rounded to the nearest whole hour.

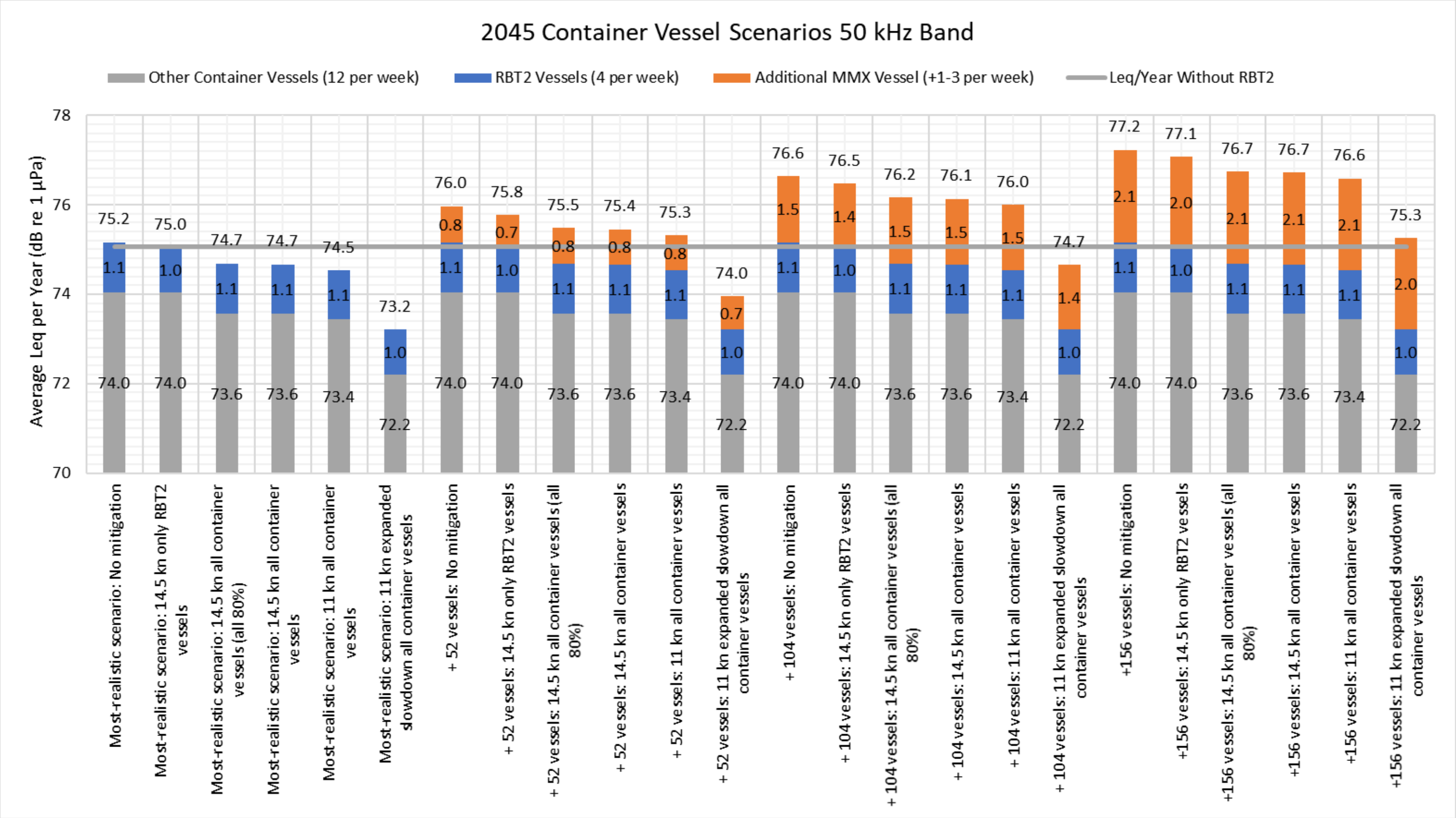


Figure C-6. 50 kHz echolocation band L_{eq}: The effectiveness of potential contingency mitigation measures for additional Mega-Max (MMX) container vessels annually in the marine shipping area, in terms of average L_{eq} per year for 2035. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. The line indicates the average L_{eq} per year under the most-realistic scenario without RBT2.

C.2. 2040

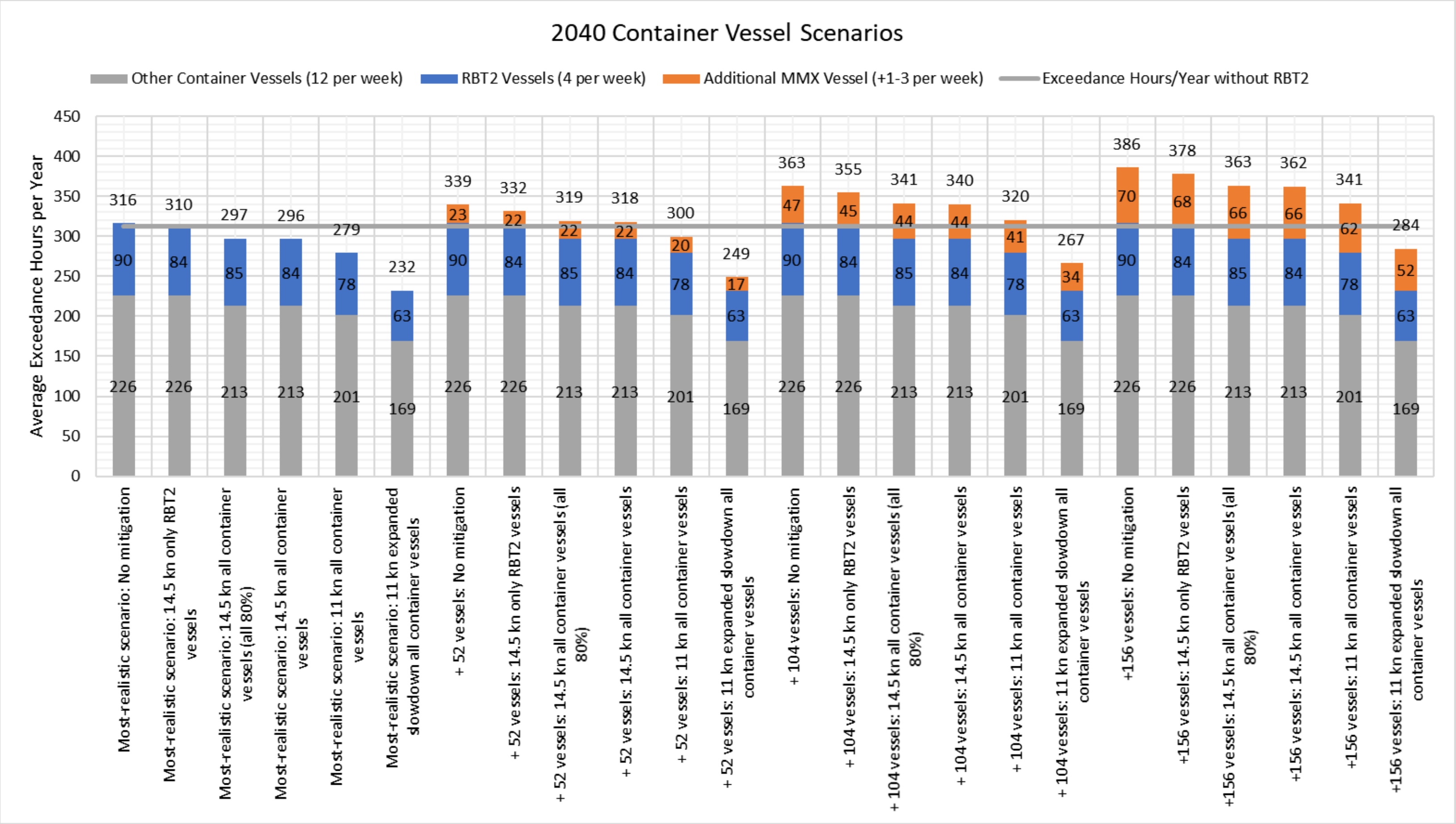


Figure C-7. Broadband exceedance hours: The effectiveness of potential contingency mitigation measures for an additional 52-156 Mega-Max (MMX) container vessels annually in the marine shipping area, in terms of average exceedance hours per year for 2040. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. The line indicates the average exceedance hours per year under the most-realistic scenario without RBT2. Exceedance numbers shown in the figure have been rounded to the nearest whole hour.

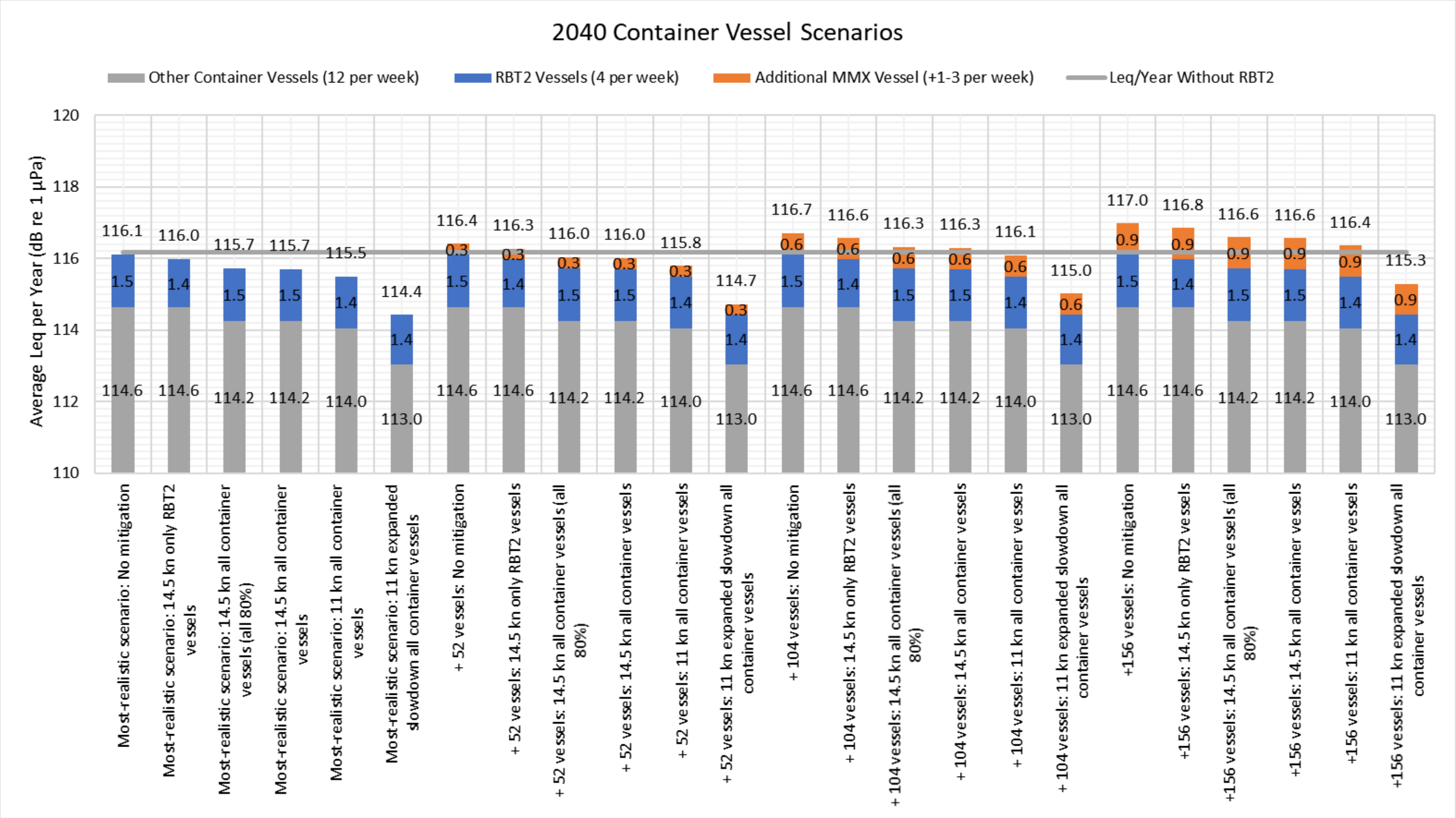


Figure C-8. Broadband L_{eq}: The effectiveness of potential contingency mitigation measures an additional 52-156 Mega-Max (MMX) container vessels annually in the marine shipping area, in terms of average L_{eq} per year for 2040. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. The line indicates the average L_{eq} per year under the most-realistic scenario without RBT2.

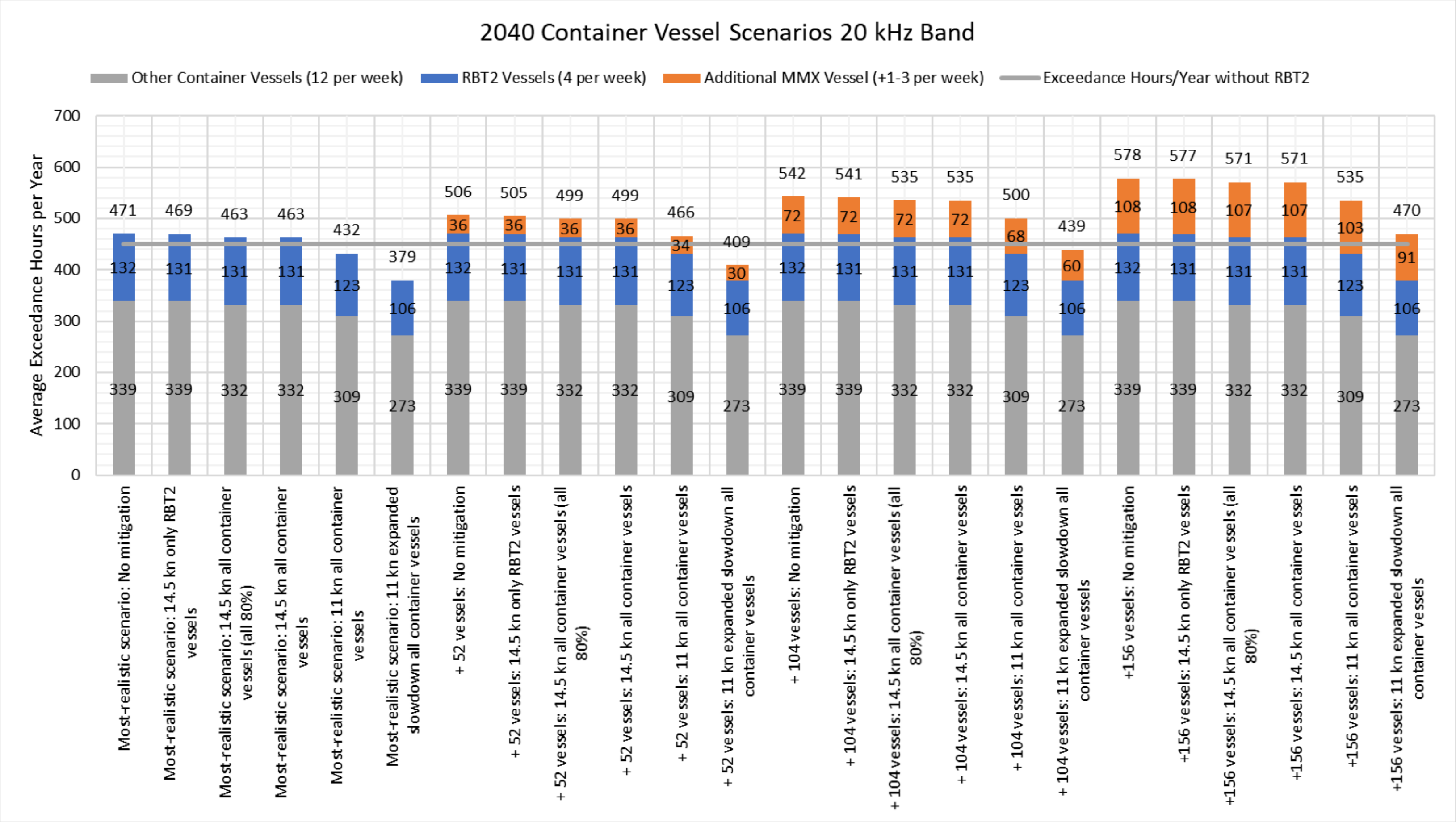


Figure C-9. 20 kHz echolocation band exceedance hours: The effectiveness of potential contingency mitigation measures for an additional 52-156 Mega-Max (MMX) container vessels annually in the marine shipping area, in terms of average exceedance hours per year for 2040. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. The line indicates the average exceedance hours per year under the most-realistic scenario without RBT2. Exceedance numbers shown in the figure have been rounded to the nearest whole hour.

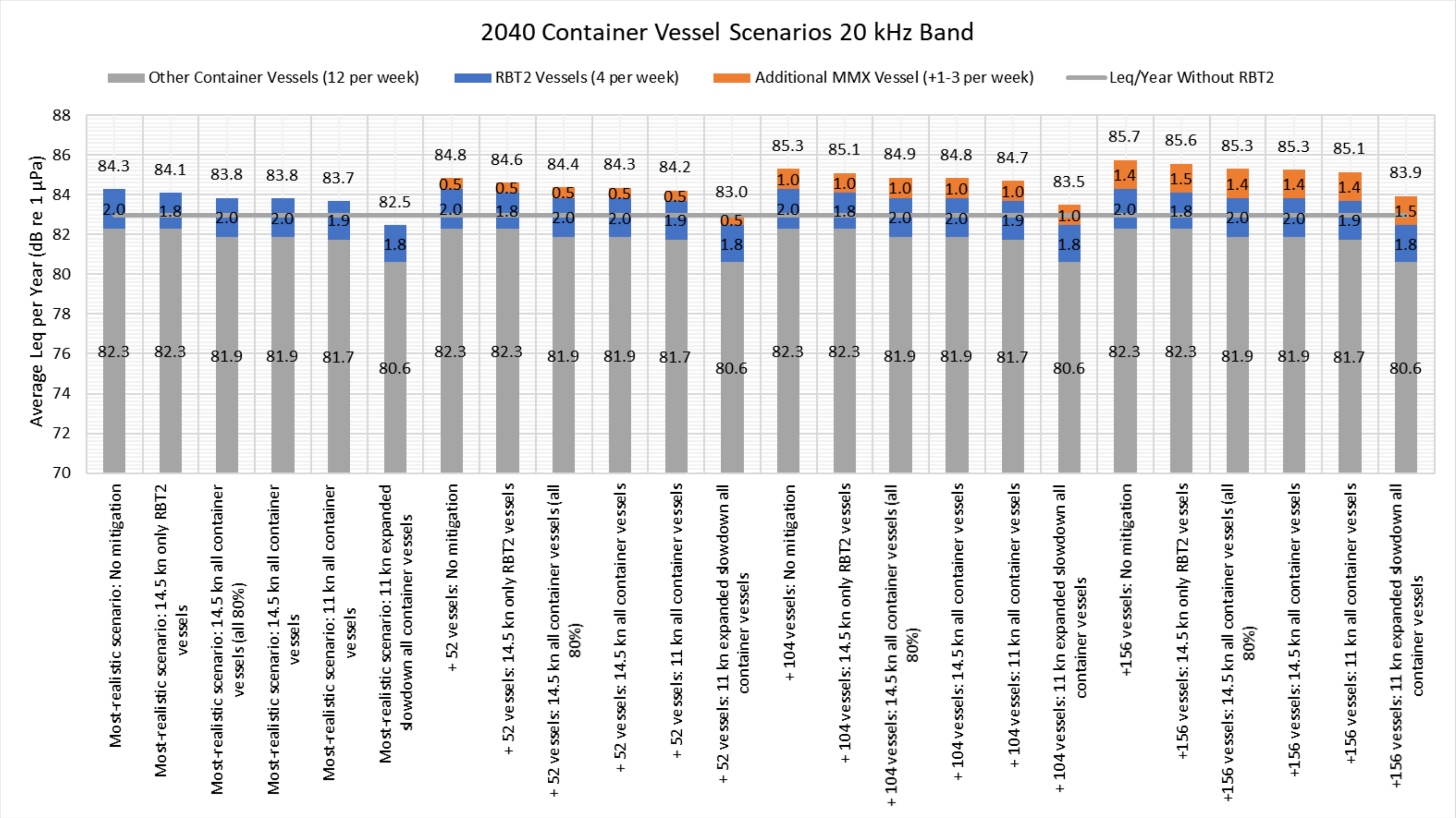


Figure C-10. 20 kHz echolocation band L_{eq}: The effectiveness of potential contingency mitigation measures for an additional 52-156 Mega-Max (MMX) container vessels annually in the marine shipping area, in terms of average L_{eq} per year for 2040. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. The line indicates the average L_{eq} per year under the most-realistic scenario without RBT2.

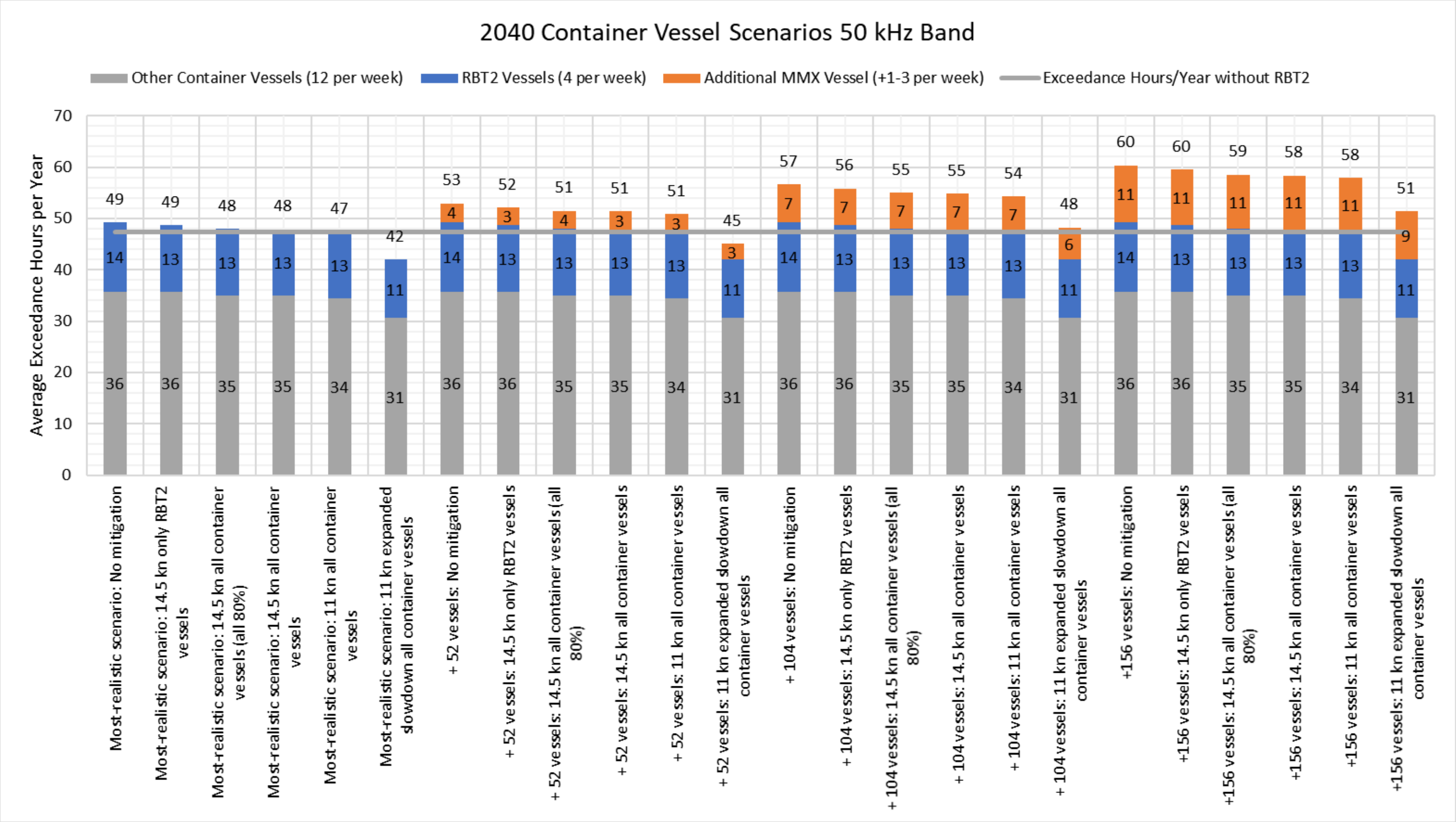


Figure C-11. 50 kHz echolocation band exceedance hours: The effectiveness of potential contingency mitigation measures for an additional 52-156 Mega-Max (MMX) container vessels annually in the marine shipping area, in terms of average exceedance hours per year for 2040. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. The line indicates the average exceedance hours per year under the most-realistic scenario without RBT2. Exceedance numbers shown in the figure have been rounded to the nearest whole hour.

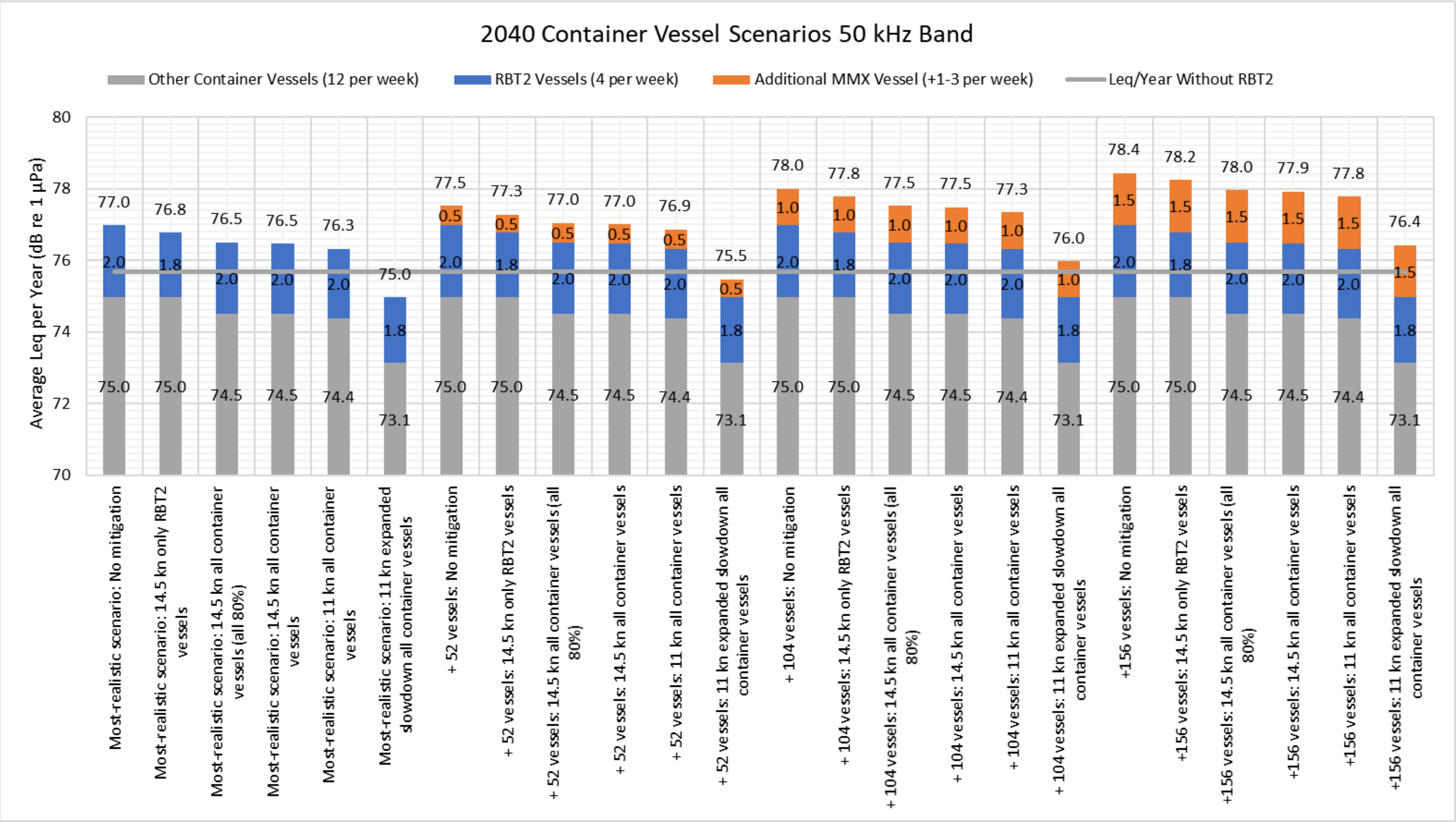


Figure C-12. 50 kHz echolocation band L_{eq}: The effectiveness of potential contingency mitigation measures for an additional 52-156 Mega-Max (MMX) container vessels annually in the marine shipping area, in terms of average L_{eq} per year for 2040. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. The line indicates the average L_{eq} per year under the most-realistic scenario without RBT2.

C.3. 2045

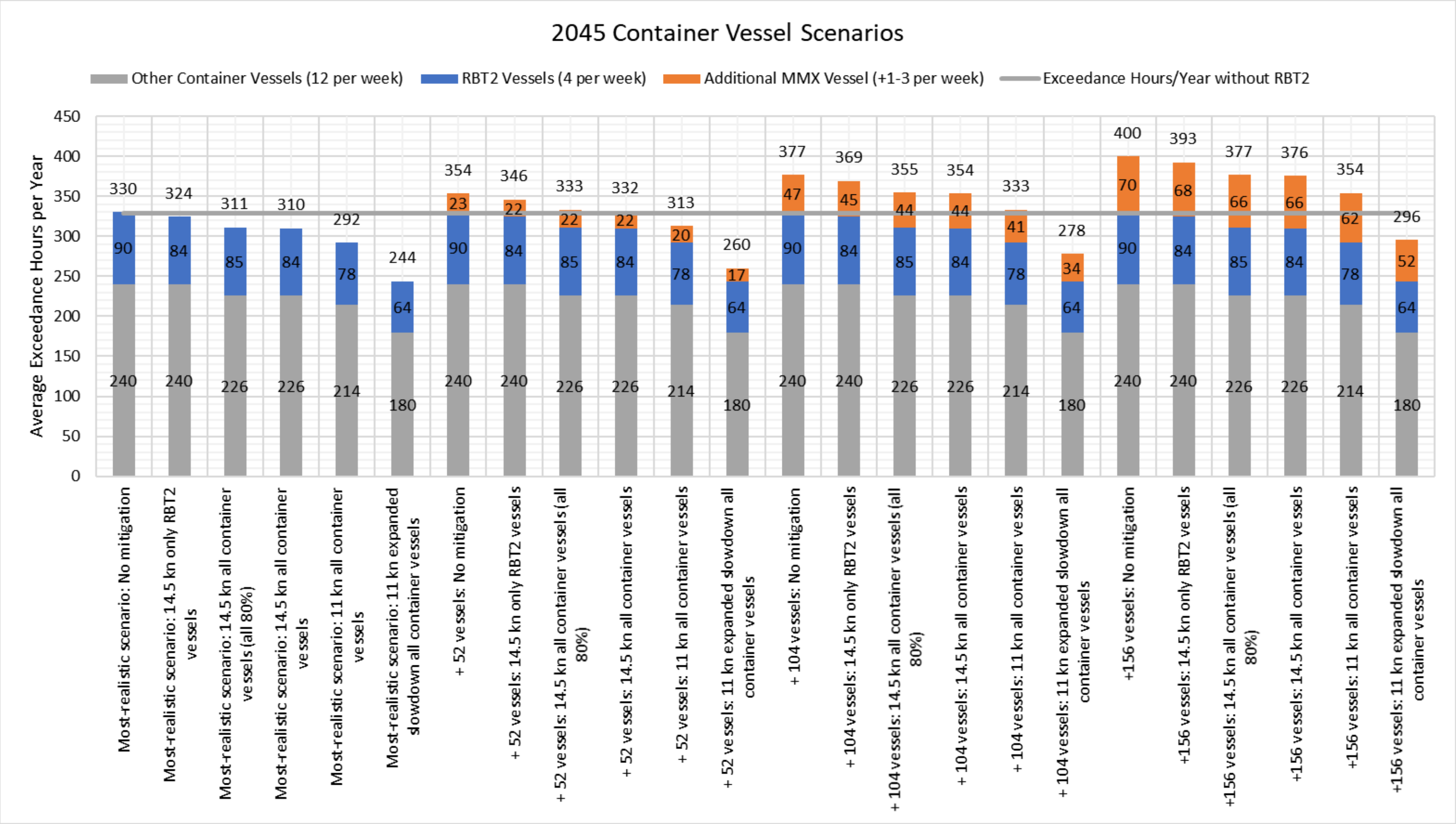


Figure C-13. Broadband exceedance hours: The effectiveness of potential contingency mitigation measures for an additional 52-156 Mega-Max (MMX) container vessels annually in the marine shipping area, in terms of average exceedance hours per year for 2045. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. The line indicates the average exceedance hours per year under the most-realistic scenario without RBT2. Exceedance numbers shown in the figure have been rounded to the nearest whole hour.

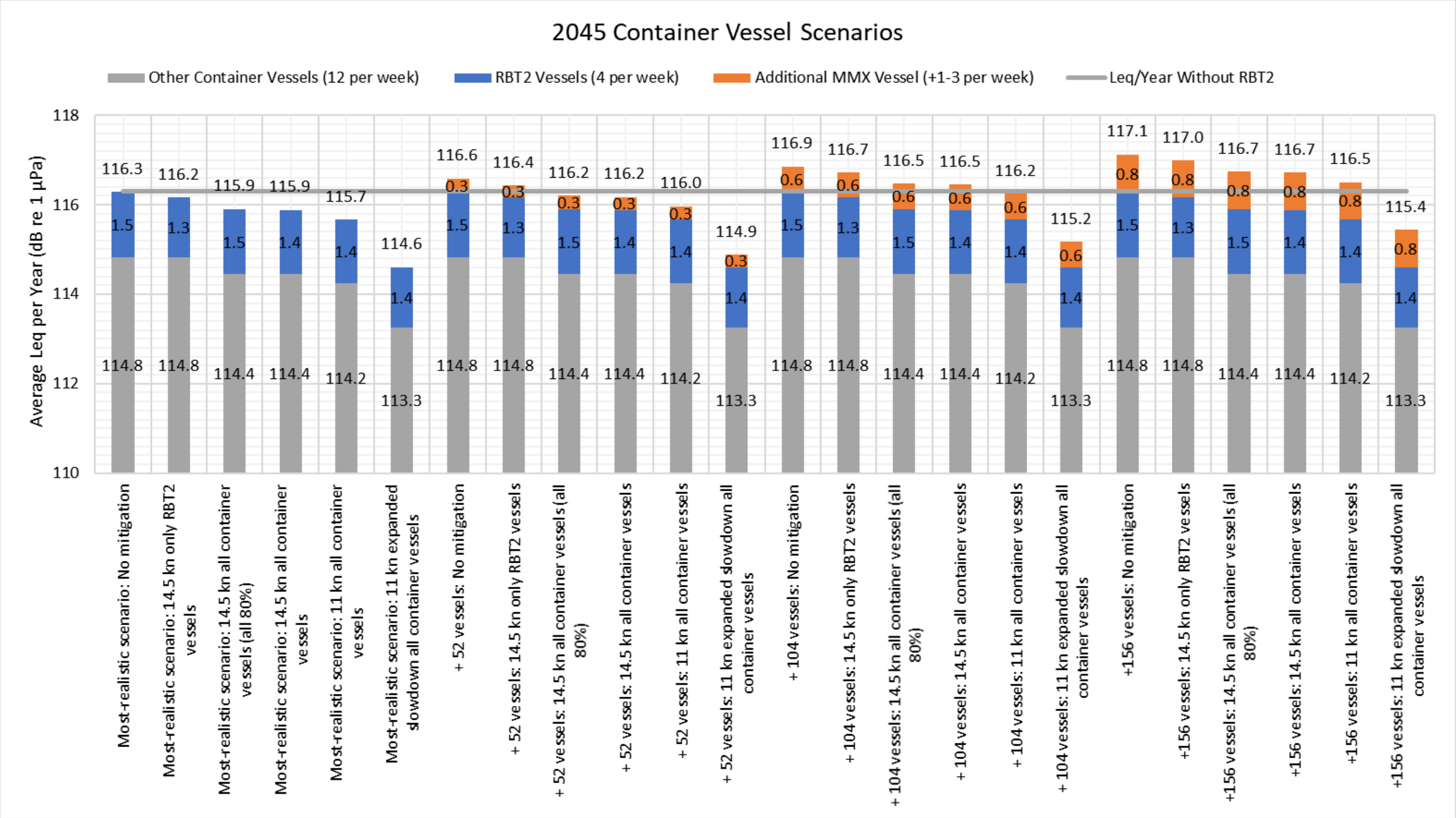


Figure C-14. Broadband L_{eq}: The effectiveness of potential contingency mitigation measures for an additional 52-156 Mega-Max (MMX) container vessels annually in the marine shipping area, in terms of average L_{eq} per year for 2045. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. The line indicates the average L_{eq} per year under the most-realistic scenario without RBT2.

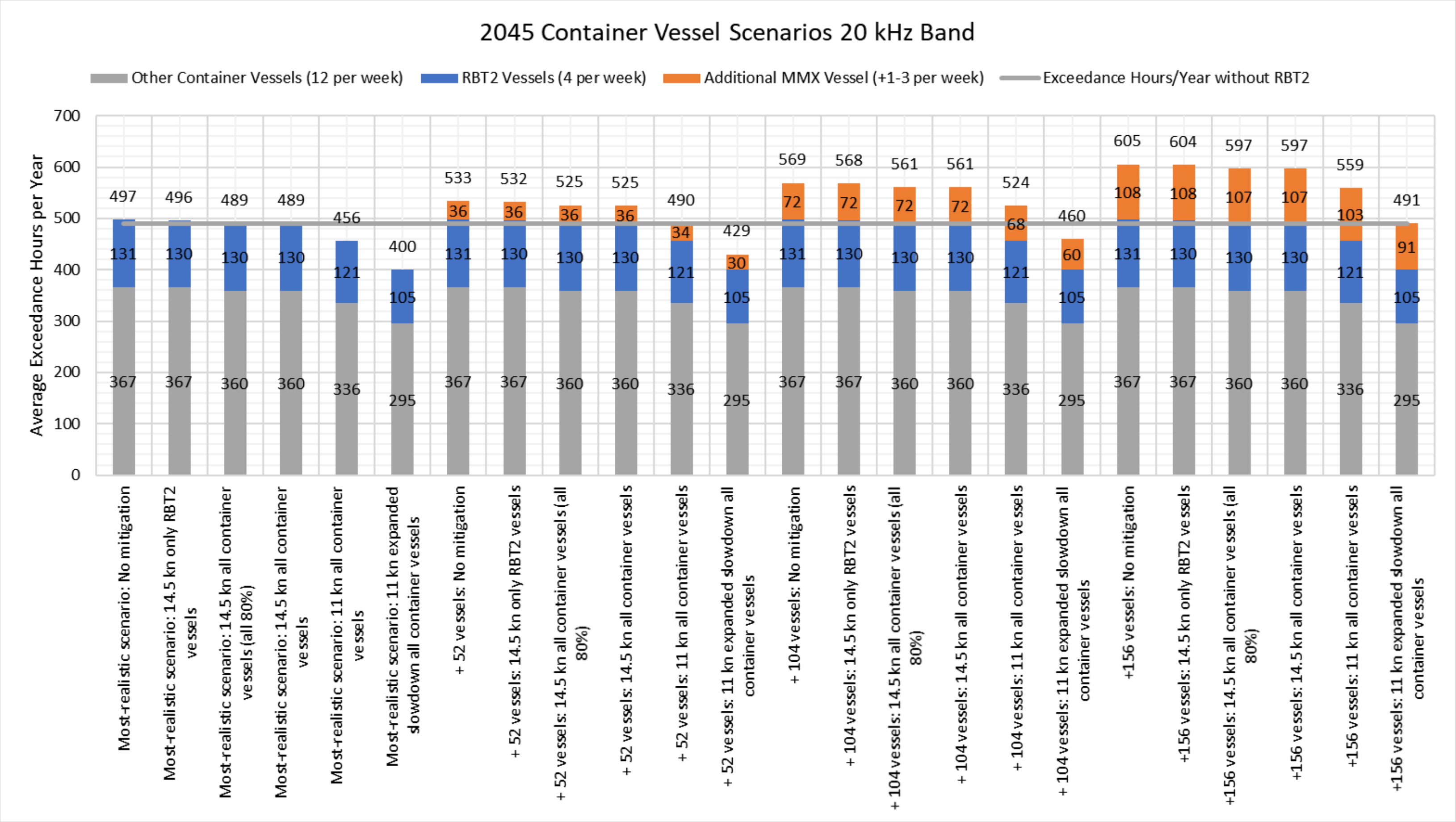


Figure C-15. 20 kHz echolocation band exceedance hours: The effectiveness of potential contingency mitigation measures for an additional 52-156 Mega-Max (MMX) container vessels annually in the marine shipping area, in terms of average exceedance hours per year for 2045. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. The line indicates the average exceedance hours per year under the most-realistic scenario without RBT2. Exceedance numbers shown in the figure have been rounded to the nearest whole hour.

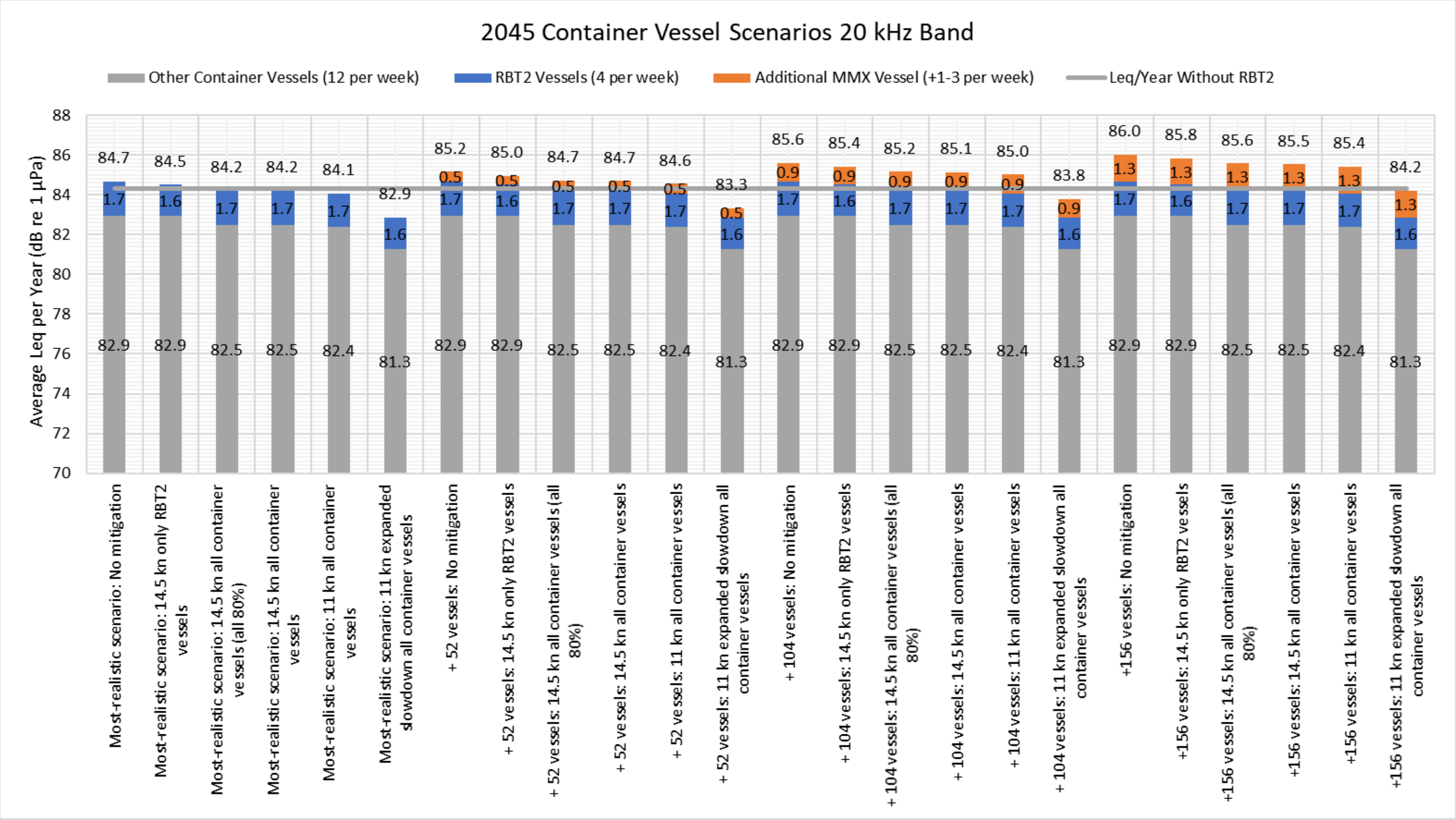


Figure C-16. 20 kHz echolocation band L_{eq}: The effectiveness of potential contingency mitigation measures for an additional 52-156 Mega-Max (MMX) container vessels annually in the marine shipping area, in terms of average L_{eq} per year for 2045. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. The line indicates the average L_{eq} per year under the most-realistic scenario without RBT2.

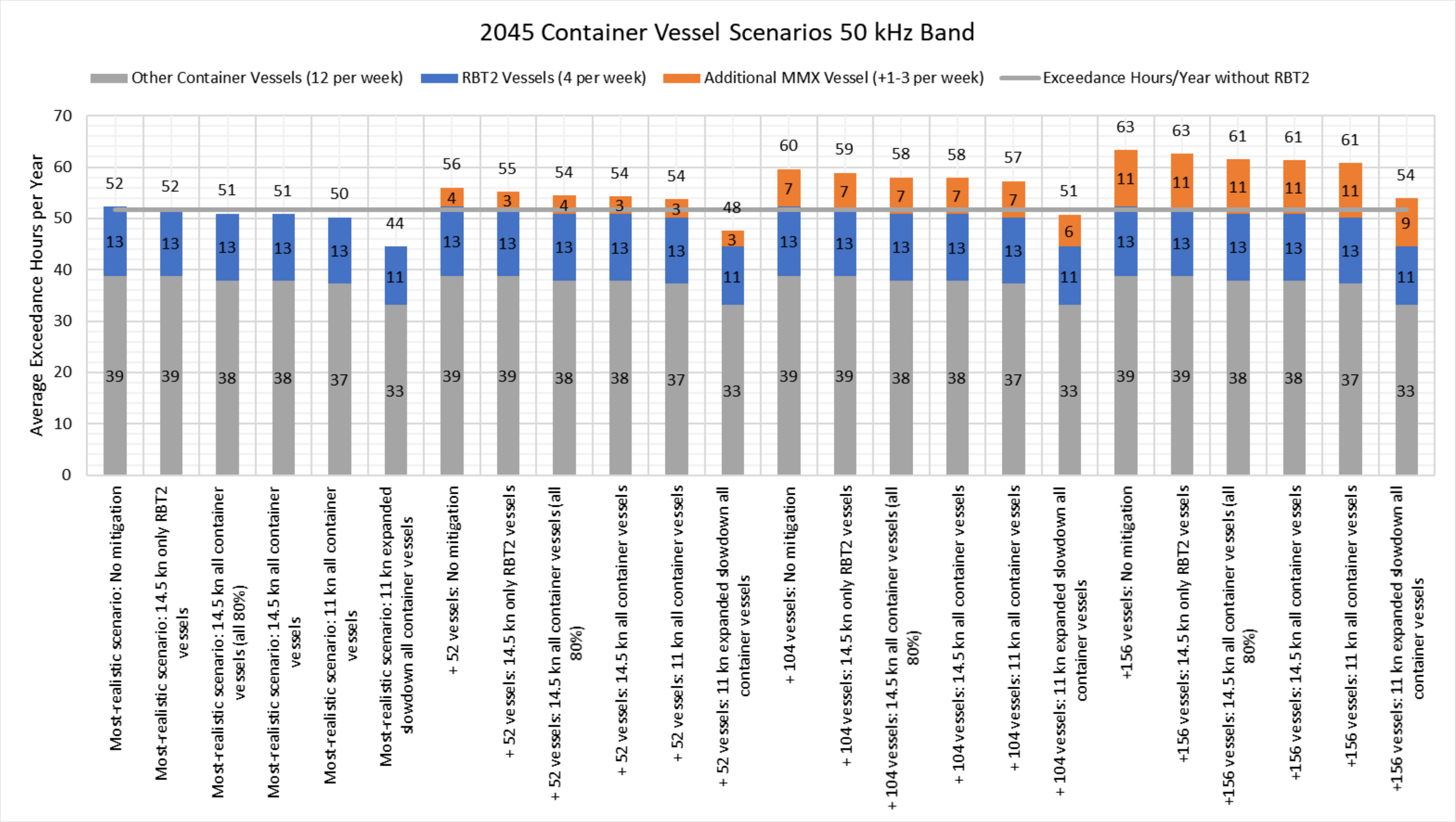


Figure C-17. 50 kHz echolocation band exceedance hours: The effectiveness of potential contingency mitigation measures for an additional 52-156 Mega-Max (MMX) container vessels annually in the marine shipping area, in terms of average exceedance hours per year for 2045. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. The line indicates the average exceedance hours per year under the most-realistic scenario without RBT2. Exceedance numbers shown in the figure have been rounded to the nearest whole hour.

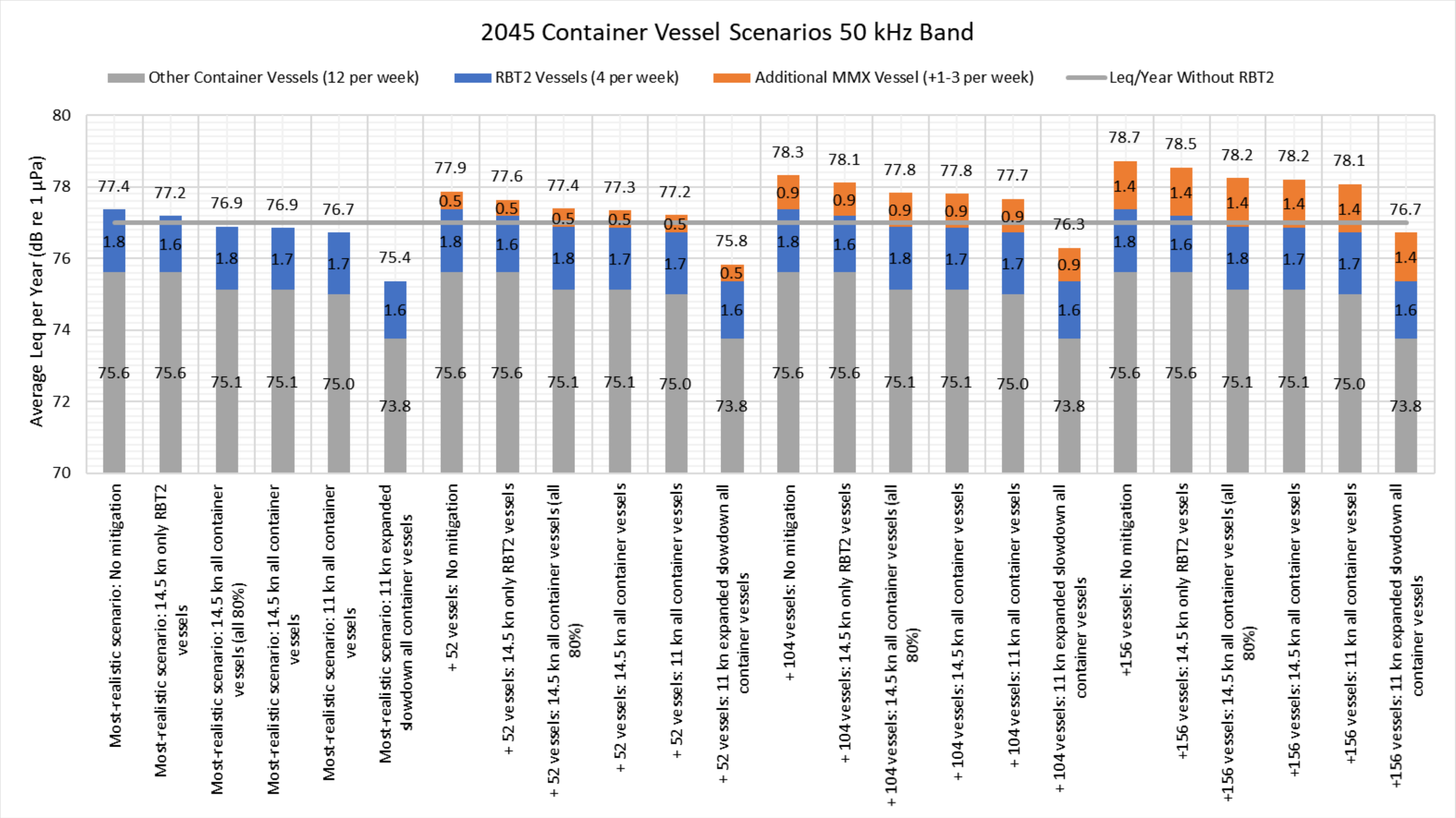


Figure C-18. 50 kHz echolocation band L_{eq}: The effectiveness of potential contingency mitigation measures for an additional 52-156 Mega-Max (MMX) container vessels annually in the marine shipping area, in terms of average L_{eq} per year for 2045. Colors and annotations within the bars indicate the contributions of different categories of vessels (see main text for details). Annotations above the bars indicate total values. The line indicates the average L_{eq} per year under the most-realistic scenario without RBT2.

Appendix IR2020-3-F

Technical data report – Effectiveness of RBT2 container vessel slowdowns to mitigate SRKW acoustic exposures from project operation

Effectiveness of RBT2 container vessel slowdowns to mitigate SRKW acoustic exposures from Project operation

Prepared for Ecofish Research Ltd.

[September 2021]

815D Spring St. Unit 1
Friday Harbor, WA 98250
USA

SMRU Consulting North America

55 Water Street, Suite 604
Vancouver, BC V6B 1A1
Canada

Effectiveness of RBT2 container vessel slowdowns to mitigate SRKW acoustic exposures from Project operation

September 2021

Prepared by SMRU Consulting

Canada Office
55 Water Street, Suite 604
Vancouver, BC
V6B 1A1

Authors:

Dominic Tollit, PhD

Ruth Joy, PhD

Alex Harris, MSc

Jason Wood, PhD

Suggested citation: Tollit, D., Joy, R., Harris, A., and Wood, J. (2021). Effectiveness of RBT2 container vessel slowdowns to mitigate SRKW acoustic exposures from Project operation. Prepared by SMRU Consulting (Canada) on behalf of Ecofish Research Ltd., September, 2021.

Table of Contents

List of Figures

List of Tables

1. Executive summary

The operation of the proposed Roberts Bank Terminal 2 Project (RBT2 Project or Project), specifically, the arrival, berthing, unberthing, and departure of container vessels assisted by tugs and while container vessels are at berth, is predicted to increase underwater noise and in turn cause potential acoustic effects to Southern Resident Killer Whales (SRKW) utilizing Roberts Bank. Since the public hearing, the Minister of Environment and Climate Change (the Minister) requested additional information regarding Project operation mitigation measures and their anticipated effectiveness. In response, the Vancouver Fraser Port Authority (the port authority) has identified and evaluated additional mitigation measures. To support the port authority's response to the Minister's information request, SMRU Consulting conducted a noise footprint modelling study to assess the potential to mitigate acoustic effects on SRKW by reducing the number of acoustic exposures from vessel noise from RBT2 Project operation at Roberts Bank with container vessel speed reductions of Project-associated container vessels in Haro Strait and Boundary Pass (i.e., in the marine shipping area).

This study estimated total SRKW acoustic exposures by modelling acoustic footprints (broadband 120 dB re 1 µPa, root mean square, unweighted) from container vessel activities and the overlap with SRKW summer habitat use (May-October, 2002-2017). This study compared model-predicted numbers of increased SRKW acoustic exposures due to RBT2 Project operation with reduced numbers of exposures predicted from mitigation of slowing down RBT2-bound container vessels transiting high SRKW use areas in the marine shipping area (i.e., Haro Strait and Boundary Pass). This SRKW acoustic footprint exposure model assumes the selected broadband threshold is representative of continuous noise effects on SRKW and the underlying opportunistic data derived SRKW habitat use map is representative, noting that this is an evolving science (e.g., Harvey et al. 2018, Watson et al. 2019). The total exposures estimated by this study for Project operations do not consider the other mitigation measures proposed by the port authority to avoid or reduce noise exposure to SRKW during Project operation (e.g., delayed unberthing).

This study first modelled effects of 4.5 weekly container vessel calls to RBT2 (or 234 calls per year, Mercator International 2018) and results were extrapolated to predict effects of the most-realistic container vessel forecast (4 weekly container vessel calls to RBT2 or 208 calls per year) and the less likely high-case scenario (5 weekly container vessel calls or 260 calls per year) (Mercator International 2021). Each container vessel call represents two vessel transits through the marine shipping area, inbound and outbound. The study initially focussed on a six-month summer period, but also considered the entire year.

The study results estimated that there would be a median total of 47 SRKW acoustic exposures (95% confidence interval, CI: 0-141) from RBT2 Project operation during the summer (i.e., over a 6 months period of 4.5 weekly container vessel calls (117 container vessel calls or 234 container vessel transits)). Information provided by Buren et al. (2021) on seasonal Roberts Bank SKRW transits resulted in an extrapolated year-round estimate of 60 SRKW acoustic exposures (95% CI: 0-180) from

RBT2 Project operation. This low number of predicted exposures is due to the relatively low density of SRKW around the proposed terminal within the 120 dB acoustic footprint associated with Project operation. The wide variance in confidence intervals of model predicted Project operation SRKW acoustic exposures are largely a consequence of how SRKW are distributed across the study area's habitat each month. In contrast, SRKW density is higher in areas of Haro Strait and Boundary Pass and the model predicted 1,715 SRKW acoustic exposures in the scenario of container vessels transiting at their normal 18 knot speeds.

Vessel slowdowns in Haro Strait have been demonstrated to reduce vessel noise source levels and ambient noise levels during transits, reducing predicted disturbance to SRKW (Joy et al. 2019, Burnham et al. 2021, VFPA 2021). This modelling study predicted that slowing down Project-associated container vessels transits through Haro Strait and Boundary Pass, a region with relatively high density of SRKW (Cominelli et al. 2018, Olson et al. 2018, DFO 2021), would substantially reduce the number of SRKW acoustic exposures. The results for 4.5 weekly container vessel calls (234 container vessel calls per year) indicate the median number of SRKW acoustic exposures from Project operation per year could be mitigated by approximately 24 container vessel transits (95% CI: 0-71) slowing from 18 to 14.5 knots.

Extrapolation to the Mercator International (2021) most-realistic container vessel call scenario (4 weekly container vessel calls, or 8 weekly transits or 208 calls per year), mitigation of the median SRKW acoustic exposures at Roberts Bank from Project operation over the entire year could be achieved by slowing approximately 21 container vessel transits (95% CI: 0-63) from 18 to 14.5 knots or alternately 12 container vessel transits (95% CI: 0-35) from 18 to 11 knots. Under the high-case scenario (5 weekly container vessel calls, or 10 weekly transits or 206 calls per year), it would require slowing approximately 26 container vessel transits (95% CI: 0-78) from 18 to 14.5 knots or alternately 15 container vessel transits (95% CI: 0-61) from 18 to 11 knots.

These median estimates of RBT2 container vessels equate to a 10.1% (for 14.5 knots) and 5.6% (for 11 knots) of the six-month total of predicted number of transits that occur over the summer six-month period. This percent of total summer transits is scalable, because if container vessel calls are higher or lower than predictions, then both Project operation and mitigation action for SRKW acoustic exposures would scale proportionally. Currently, the maximum duration of ECHO Program slowdowns is five months and over this shorter period, to realize the same median number of container vessel transits to counterbalance year-round Project operation SRKW acoustic exposures requires 12.1% (95% CI: 0-36.2%) of container vessel transits at 14.5 knots and 6.7% (95% CI: 0-20.2%) of container vessel transits at 11 knots to slow down over the five months.

Therefore, a median 10.1% (six-month slowdown) or 12.1% (five-month slowdown) of container vessel transits are predicted to need to slow down from 18 knots to 14.5 knots during the summer through the ECHO Program 29.6 nm slowdown area of Haro Strait and Boundary Pass in the marine shipping area to counterbalance the year round SRKW acoustic exposures (to noise above the 120 dB re 1 µPa broadband threshold) estimated due to RBT2 Project operation. If we assume that 15% more RBT2-bound container vessel transits will slow down due to the contractual requirement to do so (in addition to the voluntary participation in the ECHO program slowdown, assumed to be 80% (based on

2020 ECHO-modelled participation rates) then this 14.5 knot slow down measure is predicted to mitigate the SRKW acoustic exposure effects of project operations by approximately 1.5 times (six-month slowdown) or 1.2 times (five-month slowdown) respectively. High variance around median Project operation SRKW acoustic exposures result in a residual level of uncertainty in these complete mitigation predictions when consideration of 80% ECHO program participation is included. Results for RBT2 container vessel with slow down speeds of 11 knots increased certainty in mitigating Project operation SRKW acoustic exposures when considering upper confidence intervals. Likewise, speed reductions between 14.5 and 11 knots would add certainty in mitigating Project operation SRKW acoustic exposures above that predicted for 14.5 knot reductions.

2. Introduction and Objectives

The Southern Resident Killer Whale (SRKW) population in British Columbia is listed as endangered under the *Species at Risk Act* (SARA) because of their small population size, low reproductive rate, and the existence of a variety of anthropogenic threats (DFO 2011). These threats include increased underwater noise due to transiting commercial and recreational vessels, as well as strike risk and physical disturbance from vessel presence and proximity (DFO 2017).

Operation of the proposed new container vessel terminal at Roberts Bank (Roberts Bank Terminal 2 Project or Project) is expected to increase underwater noise within the surrounding environment of Roberts Bank, due to the arrival/berthing and unberthing/departure of container vessels assisted by tugs and while container vessels are at berth. Without mitigation, it is predicted that operational noise generating activities would result in acoustic effects to SRKW utilizing Roberts Bank (VFPA 2015). In his letter of August 24, 2020, the Minister of Environment and Climate Change (the Minister) requested additional information regarding Project operation mitigation measures and their anticipated effectiveness.

Multiple studies have highlighted Haro Strait and Boundary Pass as valuable summer habitat to SRKW (e.g., Cominelli et al. 2018, Olson et al. 2018, DFO 2021), with detailed analysis identifying dominant SRKW behaviour confirming Haro Strait as an important foraging area (DFO 2021). Vessel slowdowns in Haro Strait have been demonstrated to reduce vessel source levels and ambient noise levels during transits, leading to reductions in predicted disturbance to SRKW (Joy et al. 2019; Burnham et al. 2021). For example, in 2020 the Enhancing Cetacean Habitat and Observation (ECHO) Program[1] vessel slowdown in Haro Strait and Boundary Pass reduced underwater noise by 2.5-2.8 dB (a 44-48% reduction in sound intensity) with an estimated reduction in lost foraging time of 17-20% (VFPA 2021). The current modelling study aimed to assess the potential effectiveness of speed reductions of Project-associated container vessels in Haro Strait and Boundary Pass in mitigating the number of SRKW acoustic exposures from vessel noise from RBT2 Project operation. Slowdown trial study

---

[1] https://www.portvancouver.com/environmental-protection-at-the-port-of-vancouver/maintaining-healthy-ecosystems-throughout-our-jurisdiction/echo-program/projects/voluntary-vessel-slowdown-trial/

boundaries were as defined in 2020 by the ECHO Program (see JASCO Applied Sciences and SMRU Consulting 2020). For this study, Project operation is defined as container vessels transiting from the inbound international shipping lane to berth/unberth at the Project terminal and then returning to the outbound shipping lane. Project operation was assumed to include the movement and berthing/unberthing support of three tugs. This mitigation assessment differs from previous assessments as it evaluates mitigation action outside the Roberts Bank area. This study used the equivalent of 234 annual container vessel calls (4.5 per week, Mercator international 2018) to estimate SRKW acoustic exposures. Model results were extrapolated to provide mitigation efficacy information based on the most-realistic scenario of 208 annual container vessel calls, as well as a less likely high-case scenario of 260 container vessel calling RBT2 annually (Mercator International 2021). These are equivalent to 4 and 5 container vessel calls per week respectively.

This study aimed to quantify the effectiveness of measures in the marine shipping area for mitigating vessel noise from Project operation using an SRKW acoustic effects ‘vessel footprint’ exposure or overlap approach, focusing on the six months when SRKW are predominantly present (May-October) in the inshore waters of critical habitat. Standardized SRKW acoustic effect vessel footprints (120 dB re 1µPa isopleth, broadband, rms, with no animal hearing-based frequency weighting applied) of container vessels were combined using a computer simulation model with the number of container vessel transits per month, number of days of SRKW presence per month, and SRKW relative habitat density[2] (2002-2017) to derive a metric termed “SRKW acoustic exposures”. The resulting numbers of SRKW acoustic exposures were then subsequently used to evaluate the effectiveness of various container vessel slowdown scenarios to mitigate annual SRKW acoustic exposures from Project operation. Finally, this study examined mitigation efficacy in the light of assumptions on current ECHO Program slowdown participation rates and temporal duration.

2. Methods

2.1. Model runs required to assess mitigation scenarios

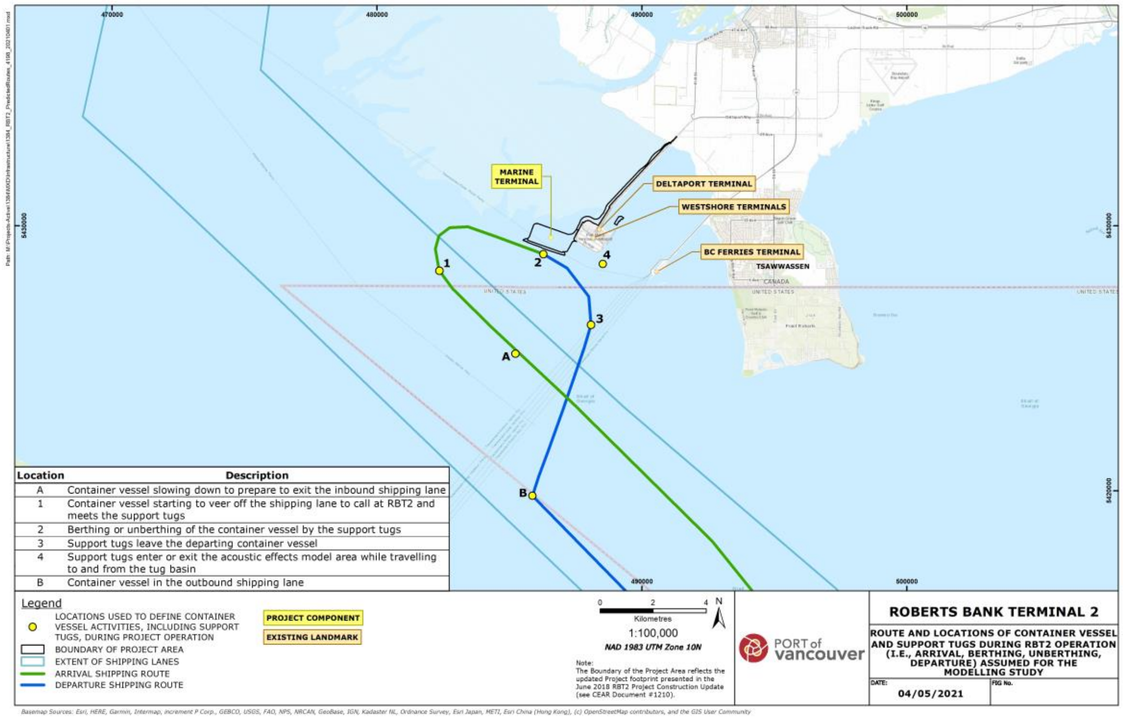
A total of eight SRKW acoustic exposure model runs were required to assess the different slowdown mitigation measures (Table 1). The study period focused on the six months when SRKW are predominantly present (May-October) in the inshore waters of critical habitat, for which updated effort-corrected SRKW relative habitat density data were available. Future container vessel forecast forecasts used were based on those presented during the public hearing (Mercator International 2018), noting model results were then extrapolated using container vessel forecasts based on Mercator International (2021).

---

[2] Relative habitat density here refers to a composite map, 81 km (N-S) by 139 km (E-W) of inshore Salish Sea waters shown in Figure 2, based on SRKW opportunistic sightings data that describes how the three SRKW pods use the habitat within the study area, i.e., a relative number of animals per km^2. Low values reflect low use.

Summary details of the model runs and scenarios are as follows:

a) **RBT2 Project operation scenario:**
Acoustic exposure for future RBT2 Project operation required combining two model runs: **1)** the transit off the inbound shipping lane to the berthing terminal with tug support; and **2)** unberthing and departure back to the outbound shipping lane (depicted in Figure 1). Together, model runs #1 and #2 represent the RBT2 Project operation scenario (a ~20.1 km round-trip journey in total, ~9.8 km inbound and ~10.3 km outbound) used to estimate the total number of SRKW acoustic exposures during RBT2 Project operation (Table 1). Details of container vessel and tug movements are described in Buren et al. (2021). In summary, for model run #1, the acoustic exposure footprint was assumed to start as the container vessel exits the inbound shipping lane (Location A in Figure 1), slowing down from an estimated 15 knots to 6 knots (i.e., transiting at an average of 10.5 knots) to make the wide right-hand turn towards the proposed RBT2 terminal, where after travelling ~4.3 km, the container vessel is joined by three support tugs that have travelled at 8 knots from the proposed expanded tug basin. The container vessel and tugs then transit together towards the terminal travelling at a speed of 6 knots, and then the tugs berth the container vessel by maneuvering it into place (mid-point of terminal berth face) before returning to the tug basin. For container vessel departures (model run #2), the three tugs transit from the tug basin to the container vessel at the terminal, unberth the container vessel from the terminal berth face and then accompany it to a point where the container vessel is able to maneuver independently (~3.5 km distance) before the tugs return to the tug basin while the container vessel continues to the outbound shipping lane (Location B in Figure 1). The overall acoustic footprint of this combined movement of vessels as well as berthing and unberthing procedures is considered in this study as Project operation. Container vessels at berth have not been explicitly modelled here, but the predicted noise footprints (< 500 m in summer, MacGillivray et al. 2021) would be captured by any Project operation activity that would occur on that day. Across the six-month study period (May-October), based on the projections presented at the public hearing (Mercator International 2018), the study evenly distributed a total of 117 container vessel calls evenly across summer months, reflecting an annual total of 234 calls (see Table 1 and section 2.3 for further details). This is a conservative estimate as the most-realistic vessel forecast scenario suggests an annual total of 208 calls by 2040 (Mercator International 2021, also Appendix IR2020-3-B).



Location	Description
A	Container vessel slowing down to prepare to exit the inbound shipping lane
1	Container vessel starting to veer off the shipping lane to call at RBT2 and meets the support tugs
2	Berthing or unberthing of the container vessel by the support tugs
3	Support tugs leave the departing container vessel
4	Support tugs enter or exit the acoustic effects model area while travelling to and from the tug basin
B	Container vessel in the outbound shipping lane

Figure 1. Schematic of predicted route of a container vessel arriving and departing RBT2. Locations in yellow were used to define the vessel activities considered part of RBT2 Project operation in this study. Locations A and B reflect the start and end point used to develop acoustic footprints for RBT2 Project operation. Numbers 1 and 3 depict the start and end of tug support.

Table 1. SRKW acoustic exposure model runs required for each scenario, including the number of container vessel calls per six-month study period (May - October).

Scenario	**Model run #**	**Model run description**	**Container vessels per six months**
RBT2 Project operation	1	Turn off inbound shipping lane - berthing at RBT2 (3 tugs in support)	117
	2	Unberthing from RBT2 - return to outbound shipping lane (3 tugs in support)	117
Container vessel slowdown	3	Haro-Boundary (18 knots) – inbound	117
	4	Haro-Boundary (18 knots) – outbound	117
	5	Haro-Boundary Slowdown (14.5 knots) – inbound	117
	6	Haro-Boundary Slowdown (14.5 knots) – outbound	117
	7	Haro-Boundary Slowdown (11 knots) – inbound	117
	8	Haro-Boundary Slowdown (11 knots) – outbound	117

b) **Container vessel slowdown mitigation scenarios:**
Six model runs (#3-8) were developed to allow an assessment of the effectiveness of a container vessel slowdown, either to 14.5 knots or 11 knots, in reducing SRKW acoustic exposures estimated from Project Operation (i.e., RBT2 Project scenario; Table 1). The 29.6 nautical mile (nm) slowdown area under this assessment corresponds to the ECHO Program slowdown initiatives held in Haro Strait and Boundary Pass[1]. A total of 117 RBT2-bound container vessel calls were distributed evenly across the six-month study period transiting these two areas in the marine shipping area. Two model runs (#3 and #4) were developed for normal container vessel speeds (18 knots, MacGillivray et al. 2016; Joy et al. 2019), for transits in the inbound and outbound shipping lanes, two scenarios (#5 and #6) were developed for reduced inbound and outbound speeds of 14.5 knots (the 2020 speed over water requested by the ECHO Program for container ships participating in the current slowdown measures[1]), and two model runs (#7 and #8) similarly developed for reduced speeds of 11 knots (considered to represent the minimum safe speed for navigation and the target speed of the 2017 ECHO Program slowdown trial[3]). Over the six months, the predicted Haro-Boundary slowdown SRKW acoustic exposure reduction was calculated using the difference (delta) between SRKW acoustic exposures at 18 knot speeds and those at either 14.5 or 11 knots. Inbound and outbound transits were considered separately and therefore for the slowdown to 14.5 knots, this reduction value was calculated using results of model runs described in Table 1 as (#5-#3)+(#6-#4), while for the slowdown to 11 knots, this reduction value was calculated as (#7-#3)+(#8-#4). Thus, resulting negative numbers represent how many fewer acoustic exposures would be experienced by SRKW due to the smaller acoustic footprints associated with slower transit speeds in Haro Strait and Boundary Pass compared to those experienced at 18 knots (see MacGillivray et al. 2018).

2.2. Model inputs

2.2.1 SRKW habitat use (relative density and monthly occurrence)

Relative density (Figure 2) and monthly occurrence (Table 2) of SRKW in the 81 km (N-S) by 139 km (E-W) inshore waters study area were determined using a 16-year (2002-2017) synthesis of opportunistic SRKW sightings databases. Sighting data were obtained through two voluntary sightings networks – the Canadian-based B.C. Cetacean Sightings Network (BCCSN) and the American-based Orca Master (OM) collated by the Whale Museum. Our methodology was originally developed in partnership with the Vancouver Aquarium (Ocean Wise) and technical advisors, with details found in Hemmera and SMRU (2014). The general approach used was subsequently published in Olson et al. (2018), recognizing that effort-correcting of opportunistic sightings data is an evolving science (e.g., Harvey et al. 2018, Watson et al. 2019). The extent of the study area was selected to incorporate all areas of interest to assess the effectiveness of mitigation measures (Figure 2).

---

[3] https://www.portvancouver.com/environmental-protection-at-the-port-of-vancouver/maintaining-healthy-ecosystems-throughout-our-jurisdiction/echo-program/projects/voluntary-vessel-slowdown-trial/

Methods to determine relative density were as follows:

a) Sightings collected within an hour of each other and located within two nautical miles (nm) of each other were considered a duplicate following BCCSN protocols. Sightings only reported to the nearest grid centroid by OM were 'jittered' (i.e., shifted) based on the spatial density of sightings within that grid square that did have latitude/longitude location data. This approach was required to reduce the bias of those OM sightings originally apportioned to the centre of a 5 km grid square. Complete removal of these data was not considered reasonable as it would understate relative SRKW use within that grid compared to other grids. There were a total of 75,789 BCCSN and OM killer whale sightings in the study area from 2002-2017. After removal of possible transient killer whales, duplicate sightings, etc., there were a total of 35,851 SRKW sightings.

b) Each sighting was systematically assigned a number of whales based on an average group size for each pod or pod group combination.

c) The number of whales per sighting was then corrected for effort through the application of the BCCSN developed observer effort model to the BCCSN dataset (Rechsteiner et al. 2013). A similar observer effort model was created for the OM dataset and all OM sightings were also corrected for observer effort, noting that assumptions on defining effort were required. This created an estimate of the Number of Whales per Unit Effort (NWUE). The Rechsteiner et al. (2013) model quantified effort for each sighting by reconstructing the distribution of effort for seven observer groups and combining these effort layers to generate a total value of observer effort for each grid cell. Observer groups included large vessel crews, ecotourism operators, residents of population centres, lighthouse keepers, park users, coastal workers and frequent observers. Once sightings were corrected, both the BCCSN and OM sightings databases were merged. After merging, the duplicates were once again removed based on the standardized criteria described previously. When in Canadian waters, duplicates were removed from the OM database, and when in American waters duplicates were removed from the BCCSN sightings database.

d) Effort-corrected kernel density estimates were generated across the six-month study period (May through October, Figure 2). Kernel density estimates were used to identify geographic areas associated with a higher relative density distribution of SRKW. Kernel density estimation is a non-parametric method for calculating the probability that an animal occurs within a defined area or the probability distribution of animal locations (Quakenbush et al. 2010). The kernel density was calculated in ArcGIS, V. 10.1 (ESRI) from the NWUE value for each sighting using a 4 km search radius and output into 200 m grid cells throughout the entire study area.

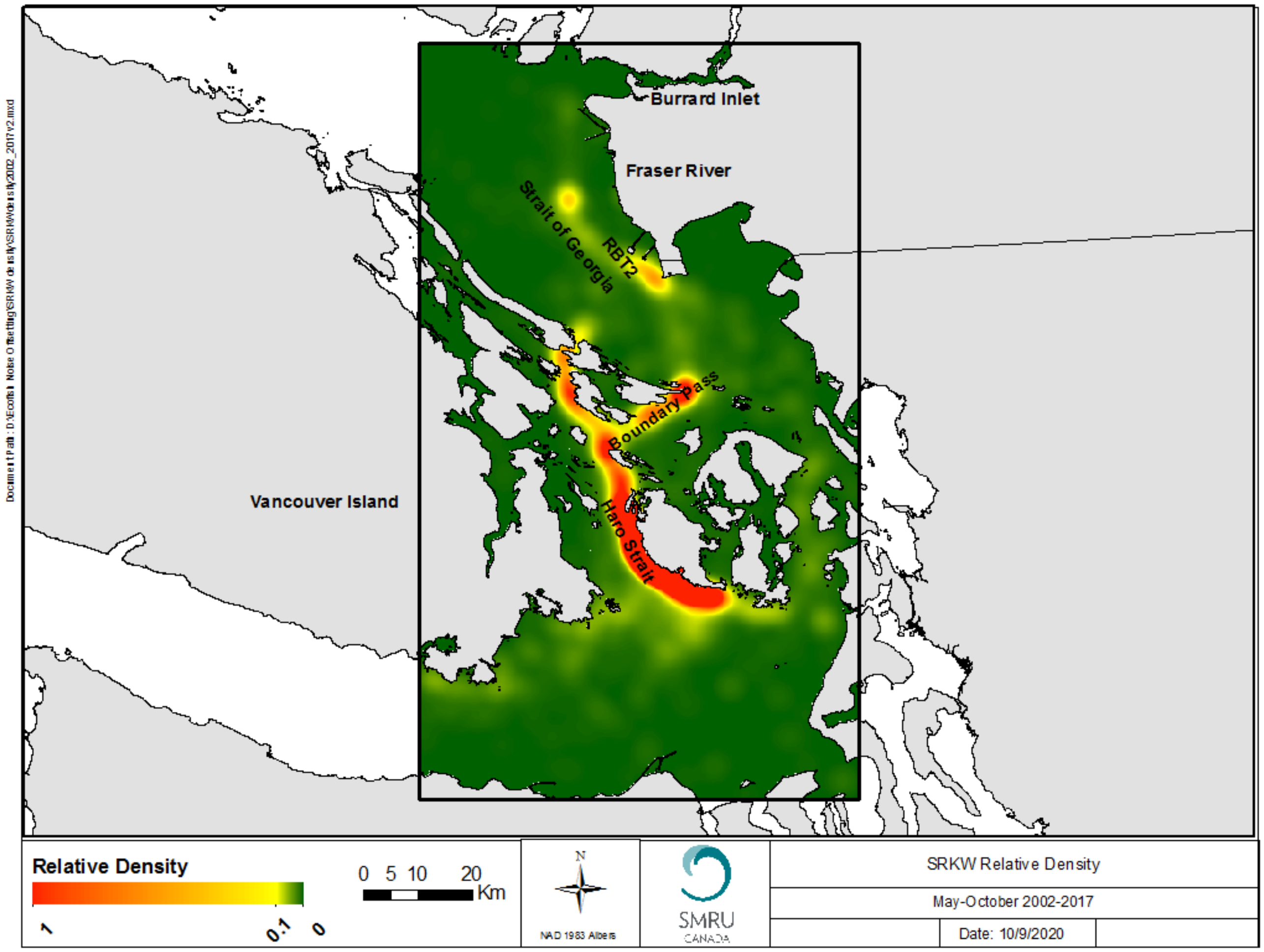


Figure 2. SRKW relative density (effort-corrected) for the study area and six-month study period (May-Oct) and all the years included in analyses (2002-2017). Raw sightings data were kindly provided by the BCCSN and the Whale Museum (which compiles the US-focused Orca Master sightings database).

Monthly sightings rates of each pod were assessed using the same 2002-2017 filtered SRKW database within the study area to generate a measure of SRKW 'whale sighting days'. These are unique days during which there was at least one sighting of SRKW within the study area. These were then averaged by pod assemblage and month across the 16 years of sightings data. Results for all SRKW are provided in Table 2. SRKW presence was highest in July and lowest in October within the study area (Roberts Bank) during the six-month study period. On average, during the six-month study period, SRKW occurred in the study area on 142 days (range = 67-166, Standard Deviation = 25.6) or 77% of summer days, noting that since 2012, average occurrence was 15% lower (<121 whale sighting days).

Table 2. Mean (Standard Deviation, SD) SRKW whale sighting days for the six-month study period, in the study area (Roberts Bank) per month (2002-2017).

Month	Mean (SD) SRKW whale sighting days in study area
May	20.5 (8.0)
June	25.9 (5.8)
July	27.6 (6.1)
August	25.0 (6.9)
September	25.6 (3.2)
October	17.1 (3.7)

2.2.2 Container vessel acoustic footprint

a) Number of container vessels:

Container vessel projections, as presented at the public hearing, were used to predict the number of container vessels that would call at the RBT2 terminal (Mercator International 2018). The projection of 234 annual calls was assumed to translate into 117 calls (234 transits) to RBT2 across the six-month study period (May to October). This analysis was then extrapolated based on updated container vessel projections considered a range of annual container vessel calls from most-realistic (208) to high-case (260) scenarios (Mercator International 2021).

b) Acoustic footprint predictions:

The acoustic impact zone for this SRKW acoustic exposure analysis was defined as the 120 dB re 1µPa isopleth (broadband, unweighted, rms). The use of this threshold for a comparative noise effects analysis is well supported by empirical data and widely used globally and within Canada to assess the effects of continuous (non-pulsed) underwater noise on marine mammals (see Buren et al. 2021; Appendix IR2020-3-D). This 120 dB threshold is currently recommended by the US regulator, the National Marine Fisheries Service, to assess ‘level B’ acoustic disturbance from continuous sound sources like container vessels (US Government 2020), where level B is defined as “acts that have the potential to disturb (but not injure) a marine mammal or marine mammal stock in the wild by disrupting behavioral patterns”. Additionally, the killer whale specific behavioural dose-response thresholds developed for RBT2 were based on data that included both behavioural observations and acoustic behavioural changes in response to vessel noise (SMRU 2014) and these also highlight 120 dB as a robust single isopleth effect threshold for use for SRKW. It represents the 1st percentile and 10th percentile probability of the moderate and low behavioural dose-response thresholds respectively used in the RBT2 Environmental Impact Statement (SMRU 2014). The ninety-five percentile radii of 120 dB acoustic footprints were calculated in R (statistical and modeling software) from EIS noise propagation modelling undertaken by JASCO Applied Sciences (MacGillivray et al. 2019) or using a statistical representation of a container vessel source level collected on the ECHO Program Underwater Listening Station in Georgia Strait (see Hannay et al. 2016). Summer propagation conditions were used throughout, as this reflects the summer study period. Table 3 provides information on the 120 dB isopleth radii for each model run. Using ArcGIS 10.1, radii for each model run were overlaid onto predicted container vessel routes arriving and departing the proposed RBT2 terminal. Radii were centered on the mid-point of inbound and outbound shipping lanes. Land masses were excluded, and the resulting 120 dB acoustic footprints are provided in Figures 3-4 and then incorporated with SRKW habitat use and presence data and the number of container vessel movements (i.e., container vessel and tugs) as described in section 2.3 below.

Table 3. Radii (m) to broadband 120 dB re 1µPa (rms, unweighted) isopleths (acoustic footprints) for different model scenarios (data provided by request from JASCO Applied Sciences). Container vessel radii were based on a composite dataset of different sized container vessels.

Container vessel speed (knots)	**Container vessel radii in Haro Strait and Boundary Pass (m)**	**Container vessel radius in Strait of Georgia (m)**	**Container vessel berthing/unberthing radius at RBT2 (m)**	**Tug escort (n=3) supporting container vessel radius at RBT2 (m)**
-	-	-	3850	-
-	-	-	-	915
11.0	1544	-	-	-
14.5	2913	-	-	-
15.0	-	1963		-
18.0	5741	-	-	-
Model run use	#3-8	#1-2	#1-2	#1-2

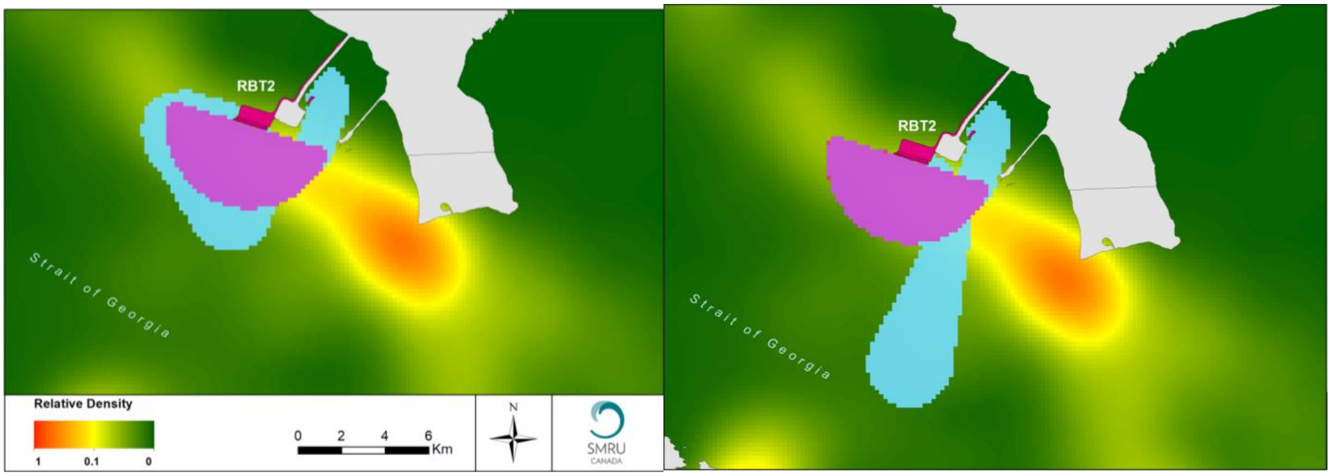


Figure 3. RBT2 operations scenario showing 120 dB acoustic footprint of predicted container vessel arrival and berthing (model run #1, left panel) and unberthing and departure (model run #2, right panel) at RBT2 terminal (pink footprint). The purple semi-circular footprint represents berthing and unberthing underwater noise radii, with blue depicting the acoustic footprint for the mix of container vessel and tug movements. The underlying SRKW habitat use layer depicts relative summer density (see Figure 2 for details).

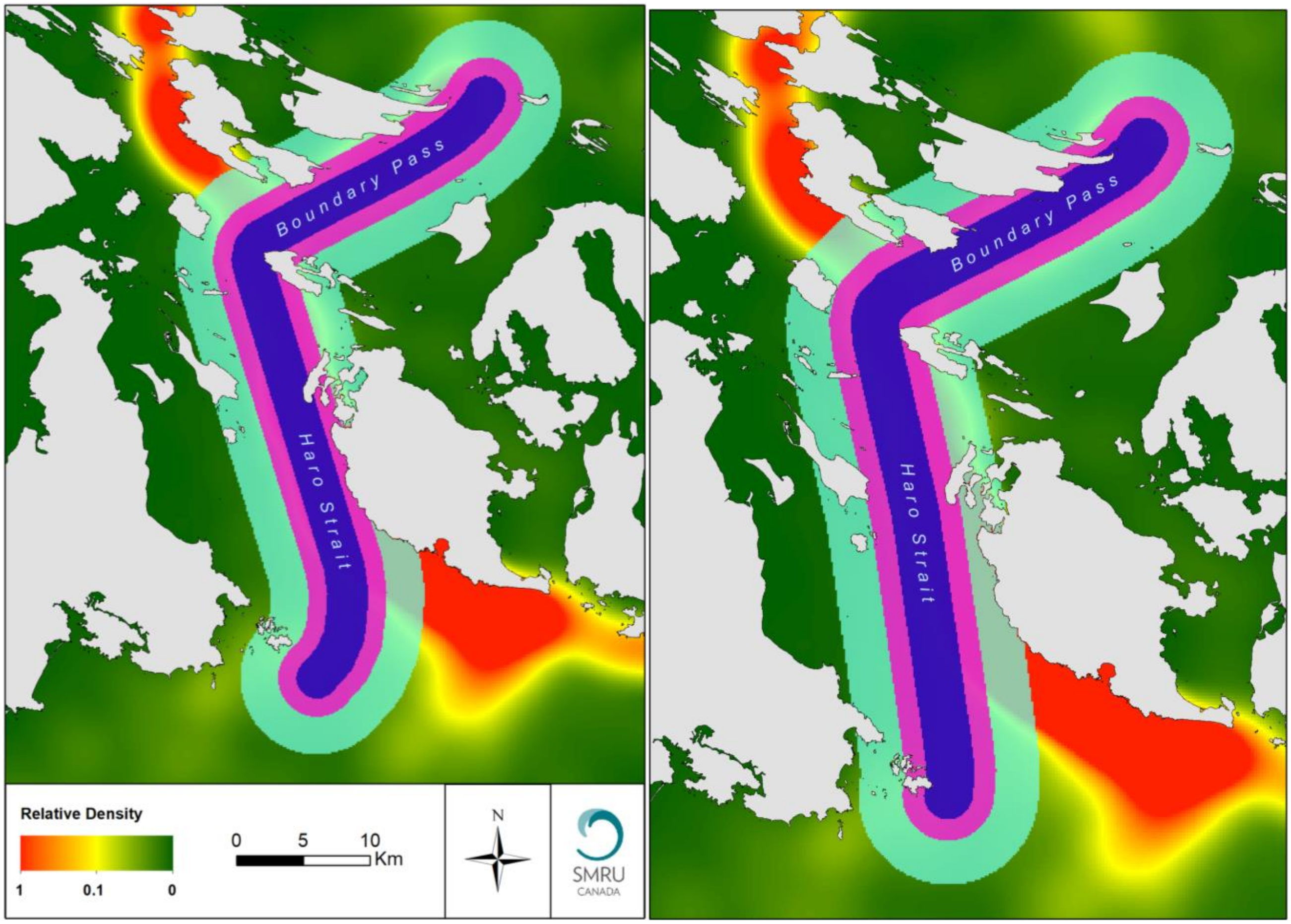


Figure 4. Container vessel slowdown scenarios showing 120 dB acoustic footprints of a container vessel travelling at 18 (teal), 14.5 (magenta) and 11 (blue) knots inbound to (left panel, model runs #3, #5 and #7) and outbound from (right panel, model runs #4, #6 and #8) RBT2 through Haro Strait and Boundary Pass.

2.3 Exposure model simulation methodology

For this study, we used the July 1, 2020 population estimates from the Center for Whale Research. Each of the three SRKW pods (J, K, and L) contributed 22, 17, and 33 individuals toward the total population size of 72 SRKWs assumed for the simulation. The number of total sighting days that whales were placed into the model averaged to 141.8 days (see Table 2), which when broken down by pod corresponded to 66.3, 35.3, and 40.2 days for each of J, K, and L pods.

If the pod was present according to stochastic occurrence probabilities, each pod was assigned a centroid location around which all pod members were distributed (Joy et al. 2019). The centroid location was weighted according to the spatial aggregate of historical sightings for each of the months between May and October, with higher probabilities in regions of high historical occupancy. The resolution of the gridded surface was 200 m by 200 m grid and all whales within each pod were located within 5 km of the pod's centroid location and distributed according to an isotropic bivariate normal distribution (i.e., like a symmetrical mountain). The number of unique pod centroids was determined based on the historic monthly observations of pods being sighted with one another versus on their own (section 2.2.1). The historic co-location of pods informs the marginal probabilities of a multivariate copula distribution that allow the simulation to maintain statistical properties that mirror SRKW social behaviour (Nelson 2006).

The whale's location was fixed within each day of the simulation and changed between days as described above. The whale was considered to have been exposed above the 120 dB acoustic threshold (or experienced an acoustic exposure) if the individual was located within the boundary of the acoustic footprint on any day the whale was present. The whale was limited to experiencing one exposure for each day it was present and exposed. The rationale for this assumption is the differential speed of container vessels and killer whales. Container vessels typically travel at above 15 knots, whereas killer whales typically travel at 3-4 knots (Williams and Noren 2009), other than when pursuing prey or short-term social activities. Thus, once a container vessel has interacted with a whale and travelled on, it is considered highly unlikely for the whale to catch up to the container vessel, even if taking a different route through the Gulf Islands towards RBT2.

SRKW acoustic exposures were accumulated over the 184-day period between May 1st and October 31st for each of the simulated periods of exposure. Counts of 'SRKW acoustic exposures' were then summarized over the six-month study period and were also broken down by month for each model run. The number of exposures facilitates a relative comparison between different slowdown scenarios as mitigation for the increased exposure to underwater noise due to RBT2 Project operation. Each model run simulation was run 500 times to generate the 95% quantiles or confidence intervals (CIs) for all model run output metrics of the simulation model. Median values were used to determine the estimated exposure totals for each scenario.

2.3 Estimating annual SRKW acoustic exposures and resulting mitigation efficacy under different container vessel forecast scenarios and ECHO Program vessel slowdown participation rate scenarios

Assuming summer and winter SRKW spatial habitat use are similar, one can coarsely estimate the mitigation for year-round Project operation. We used the summer-winter ratio of relative frequency of spatiotemporal overlaps between Project operation and SRKW transits estimated by Buren et al. (2021). This study used the equivalent of 234 annual container vessel calls (4.5 per week, Mercator International 2018) to estimate SRKW acoustic exposures. Model results were extrapolated to provide mitigation efficacy information based on the most-realistic scenario of 208 annual container vessel calls, as well as a less likely high-case scenario of 260 container vessel calling RBT2 annually (Mercator International 2021). These are equivalent to 4 container vessel calls per week and 5 container vessel calls per week respectively.

The study initially assumed 100% of container vessels were available to participate in the container vessel slowdown through Haro Strait and Boundary Pass to mitigate SRKW acoustic exposures from Project operation. However, at present a large proportion of container ships already voluntarily participate in the ECHO Program slowdown initiatives (VFPA 2021), which currently has a maximum duration of five months. To estimate the anticipated effectiveness of a Project-specific slowdown measure compared to voluntary participation, we assumed that RBT2-bound container vessels could achieve a 95% participation rate compared to 80% based on composite container vessel participation rates modelled for the ECHO Program 2020 slowdown (VFPA 2021). A 95% participation rate was selected considering that under some circumstances the container vessel may not be able to participate due to safety or schedule constraints.

3. Results

3.1 Summer SRKW acoustic exposures based on 234 annual container vessel calls per year

SRKW acoustic exposure estimates for each of the eight model runs with 95% confidence intervals are provided in Table 4 for the six-month summer study period. The modeled approach estimated that RBT2 operations (arrival, berthing, unberthing, and departure) would result in a total of 47 acoustic exposures to SRKW over the six-month period, with unberthing and departure contributing slightly more compared to arrival and berthing (Table 4). The model predicted a total of 1,715 acoustic exposures for RBT2-bound container vessels travelling 18 knots inbound and outbound through Haro Strait and Boundary Pass slowdown area (scenario #3 and #4 combined) (Table 4), 1.53 (1,119 exposures) and 2.64 (650 exposures) times higher than estimated for container vessels travelling 14.5 and 11 knots through those areas, respectively. This is expected as source levels (and the associated acoustic footprint) of container vessels increase with vessel speed (MacGillivray et al. 2018). Acoustic exposures associated with inbound transits through this area were consistently higher than outbound transits (Table 4) reflecting the SRKW habitat hotspots on the west side of San Juan Island in Haro Strait (Figure 2). Variance in all SRKW acoustic exposure estimates as depicted by the estimated 95% confidence intervals was relatively high (Table 4).

Median SRKW acoustic exposure data from the eight model runs (Table 4) were used to determine the reduced number of exposures (inbound, outbound, both combined totals, and combined totals per SRKW for each scenario) for **i)** RBT2-bound container vessels transiting at slower speed from 18 knots to 14.5 knots in Haro Strait and Boundary Pass and **ii)** RBT2-bound container vessels transiting at slower speed from 18 knots to 11 knots in Haro Strait and Boundary Pass (Table 5). A mitigation ratio comparing the 47 total SRKW acoustic exposures due to RBT2 Project operation with each of these two scenarios was calculated to assess the potential effectiveness of container vessel slowdowns (Table 5). A mitigation ratio of -1.0 is equivalent to counterbalancing 100% of the acoustic exposures resulting from RBT2 Project operation. Total SRKW acoustic exposures for RBT2 Project operation and the two slowdown scenarios are also presented graphically in Figure 5. Slowdowns in the months of July, August, and September contributed the most to mitigating the total SRKW acoustic exposure mitigation from RBT2 Project operation (see Appendix), partly reflecting a higher proportion of multi-pod assemblages occurring in these months in this portion of the marine shipping area.

Table 4. Median SRKW acoustic exposure totals by model run with upper and lower 95th confidence intervals (CI) based on the 120 dB acoustic footprints for six-month study period (see the Appendix for monthly breakdowns).

Scenario	**Model run #**	**Description of model run**	**Total SRKW acoustic exposures (May-Oct, 120 dB footprint)**		
			Median (50%ile)	Lower 95th CI	Upper 95th CI
RBT2 Project operation (117 calls)	1	Depart shipping lane - berthing at RBT2	22	0	67
	2	Unberthing from RBT2 - return shipping lane	25	0	74
RBT2 bound container vessel slowdown (117 calls)	3	Haro-Boundary (18 knots) – inbound	914	626	1,234
	4	Haro-Boundary (18 knots) – outbound	801	544	1,100
	5	Haro-Boundary Slowdown (14.5 knots) – inbound	638	432	881
	6	Haro-Boundary Slowdown (14.5 knots) – outbound	481	319	694
	7	Haro-Boundary Slowdown (11 knots) – inbound	381	251	541
	8	Haro-Boundary Slowdown (11 knots) – outbound	269	174	395

The study estimates a reduction of 596 SRKW acoustic exposures across the six-month study period with all RBT2 Project-associated container vessels slowing down from 18 to 14.5 knots, equating to a reduction of 8.2 exposures per SRKW (i.e., 596 divided by 72 individuals). Without taking into account year-round Project operation or ECHO program slowdown participation, the predicted mitigation ratio is a median of -12.7 or in other words a 14.5 knot container vessel slowdown would counterbalance the median 47 summer Project operation SRKW acoustic exposures nearly thirteen times. Under the assumption that 100% of RBT2 Project-associated container vessels slow down from 18 to 11 knots results in a reduction of 1,065 SRKW acoustic exposures across the six-month study period, equating to a reduction of 14.8 exposures per SRKW. The predicted mitigation ratio is a median of -22.7 or in other words the 11 knot container vessel slowdown would counterbalance the median 47 summer Project operation SRKW acoustic exposures nearly twenty-three times (Figure 5, Table 5).

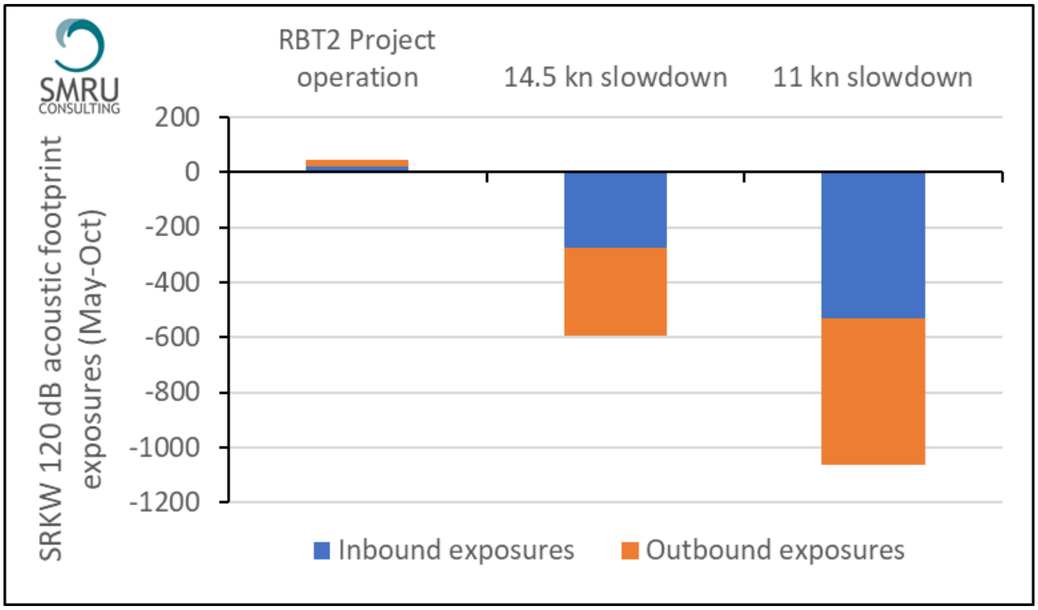


Figure 5. Median SRKW acoustic exposures (120 dB acoustic footprint, six-month study period) for RBT2 operations and the estimated reduction in SRKW acoustic exposures with RBT2-bound container vessels slowing down from 18 knots to 14.5 or 11 knots (see Table 5).

Table 5. Median SRKW acoustic exposures (120 dB acoustic footprint, six-month study period) for RBT2 Project operation (grey shaded) as well as the model predicted reduction (delta) due to RBT2-bound container vessels slowing down from 18 knots to 14.5 knots or 11 knots in Haro Strait and Boundary Pass. An acoustic exposure mitigation ratio that compares the estimated total SRKW acoustic exposure for each mitigation scenario to the RBT2 Project operation estimate. An acoustic exposure mitigation is fully achieved at a ratio value of -1.0 or less.

Scenario	**SRKW acoustic exposures (RBT2 inbound container vessels)**	**SRKW acoustic exposures (RBT2 outbound container vessels)**	**SRKW acoustic exposures (RBT2 inbound + outbound container vessels)**	**Acoustic exposures per SRKW (RBT2 inbound + outbound container vessels)**	**Acoustic exposure mitigation ratio (mitigation scenario exposures/ RBT2 operations exposures)**
RBT2 Project operation	22	25	47	0.65	NA
Haro-Boundary slowdown (14.5 knots) (difference between 18 knot exposures and 14.5 knot exposures in Table 4)	-276	-320	-596	-8.23	-12.7
Haro-boundary slowdown (11 knots) (difference between 18 knot exposures and 11 knot exposures in Table 4)	-533	-532	-1,065	-14.79	-22.7

An alternative viewpoint to presenting the above results is to estimate how many of the 234 RBT2-bound container vessels transiting through Haro Strait and Boundary Pass (117 calls) would need to slow down to mitigate the 47 SRKW acoustic exposures predicted from RBT2 Project operation in the summer. This can be estimated for the entire six months by dividing 234 by the exposure mitigation ratio. Dividing by the number of weeks (26) also provides weekly values (median, 95% Confidence Intervals, CI) which are provided in Table 6. Without taking into account year-round Project operation or ECHO program slowdown participation, results indicate summer RBT2 Project operation could be mitigated by slowing 18.4 (95% CI: 0-55.3) container vessel transits to 14.5 knots through Haro Strait and Boundary Pass or slowing 10.3 (95% CI: 0-30.9) container vessel transits to 11 knots through those areas.

Table 6. Median number of summer container vessel transits and 95% Confidence Interval (CI) to mitigate SRKW acoustic exposures due to RBT2 Project operation across the summer six-months and per week assuming RBT2-bound container vessel slow down from 18 knots to 14.5 knots or to 11 knots in Haro Strait and Boundary Pass and assuming 4.5 RBT2-bound container vessel calls per week.

Container vessel speed in Haro Strait and Boundary Pass	**Median number of summer container vessel transits across the summer 6 months required to mitigate SRKW acoustic exposures due to summer RBT2 Project operation (95% CI)**	**Median number of summer container vessel transits per week required to mitigate SRKW acoustic exposures due to summer RBT2 Project operation (95% CI)**
14.5 knots	18.4 (0-55.3)	0.71 (0-2.13)
11.0 knots	10.3 (0-30.9)	0.40 (0-1.19)

3.2 Estimating annual SRKW acoustic exposures and resulting mitigation efficacy under different container vessel forecast scenarios and ECHO Program participation rate scenarios

The study results reported prior to this section relate specifically to the effectiveness of six summer months of container vessel slowdowns to mitigate SRKW acoustic exposures due to summer Project operation for the baseline case of 4.5 RBT2-bound container vessel calls per week (234 calls per year). This extrapolation analysis uses these baseline results and other sources of information to coarsely estimate the conditions required to mitigate year-round Project operations, when using a range of different Project container vessel call forecast scenarios and taking into account current ECHO Program slowdown participation rates and temporal duration.

The summer-winter ratio (78.7:21.3) of relative frequency of Project operation spatiotemporal overlaps estimated by Buren et al. (2021) results in a prediction of an additional 13 acoustic exposures occurring due to RBT2 Project operation in the remaining six winter months (November to April), for a total of 60 (95% CI: 0-180) SRKW acoustic exposures across an entire year of RBT2 Project operation when 234 container vessels call annually at the terminal. If one extrapolates these 60 SRKW acoustic exposures, then for 208 RBT2 container vessels calls annually (the most-realistic scenario), then mitigation of an entire year of RBT2 Project operation is predicted by a median reduction of 53.3 (95% CI: 0-160) SRKW acoustic exposures due to slowdowns (Table 7). If 260 RBT2 container vessel calls occur annually (the less likely high-case scenario), then mitigation of an entire year of RBT2 Project operation if predicted by a median reduction of 66.7 (95% CI: 0-200) SRKW acoustic exposures due to slowdowns (Table 7).

Based on this coarse year-round estimate, when there are 4.5 weekly calls (or 9 weekly transits) the median number of acoustic exposures of SRKW at Roberts Bank from Project operation over the entire year could be mitigated by slowing approximately 24 container vessel transits (95% CI: 0-71) to 14.5 knots, the equivalent of 10.1% (95% CI: 0-30.2%) of all container vessel summer transits (Table 7) or approximately 13 container vessel transits (95% CI: 0-39) to 11 knots, the equivalent of 5.6% (95% CI: 0-16.9%) of all container vessel summer transit to 11 knots through Haro Strait and Boundary Pass (Table 8).

Extrapolation to the most-realistic container vessel call scenario (4 weekly container vessel calls, or 8 weekly transits) (Mercator International 2021), mitigation of the median SRKW acoustic exposures at Roberts Bank from Project operation over the entire year could be achieved by slowing approximately 21 (95% CI: 0-63) container vessel transits to 14.5 knots or alternately 12 (95% CI: 0-35) container vessel transits to 11 knots. Under the high-case scenario (5 weekly container vessel calls, or 10 weekly transits), it would require slowing approximately 26 (95% CI: 0-78) container vessel transits to 14.5 knots or alternately 15 (95% CI: 0-61) container vessel transits to 11 knots. These median estimated values of container vessel numbers equate to either 10.1% (for 14.5 knots) or 5.6% (for 11 knots) of the six-month total of predicted number of transits that occur over the summer period (Tables 7 and 8).

Currently, the maximum duration of ECHO program slowdowns is five months. Over just a five-month period, to realize the same median number of container vessel transits to counterbalance year-round Project operation SRKW acoustic exposures requires 12.1% (95% CI: 0-36.2%) of container vessel transits at 14.5 knots and 6.7% (95% CI: 0-20.2%) of container vessel transits at 11 knots (Table 9).

A median 10.1% (six-month slowdown) or 12.1% (five-month slowdown) of container vessel transits are predicted to need to slow down to 14.5 knots from 18 knots during the summer to counterbalance the year round effects of Project operation SRKW acoustic exposures. If we assume that 15% more RBT2-bound container vessel transits will slow down due to the contractual requirement to do so (in addition to the voluntary participation in the ECHO program slowdown, assumed to be 80% (based on 2020 ECHO-modelled participation rates)) then this 14.5 knots slowdown measure is predicted to mitigate the effects of project operations by approximately 1.5 times (six-month slowdown) or 1.2 times (five-month slowdown) respectively. When viewed from the more precautionary perspective of upper 95% confidence intervals, slowdowns of 14.5 knots mitigate the effects of project operations by approximately 0.5 times (six-month slowdown) or 0.42 times (five-month slowdown) respectively (Tables 7 and 9), highlighting uncertainty in the model’s prediction of Project operation mitigation. Put another way, to achieve Project operation mitigation using upper 95% confidence interval Project operation SRKW acoustic exposures would require an additional 30.2% of container vessels to slow down to 14.5 knots over six months (or 36.2% over five months). This represents 63-78 container vessel transits depending on container vessel call forecast scenarios (Table 7).

Confidence in Project operation mitigation increases under 11 knot container vessel slow down with mitigation ratio predicted at 2.68 times (six-month slowdown) or 2.24 times (five-month slowdown), noting resulting upper 95% confidence interval values remain below one, at 0.89 times (six-month slowdown) or 0.74 times (five-month slowdown), again indicating a level of uncertainty in achieving Project operation mitigation (Tables 8 and 9). To achieve Project operation mitigation using upper 95% confidence interval Project operation SRKW acoustic exposures would require an additional 16.9% of container vessels to slow down to 11 knots over six months (or 20.2% over five months). This represents 35-41 container vessel transits depending on the different container vessel call forecast scenarios (Table 8).

Table 7. Mitigation efficacy assessment for RBT2 Project container vessel slowing down to 14.5 knots in Haro Strait and Boundary Pass to mitigate the estimated median number of annual SRKW acoustic exposures due to year-round Project operations under a range of container vessel call scenarios and ECHO Program slowdown participation rates. An acoustic exposure mitigation ratio of -1 and lower represents mitigation of Project operation.

Container vessel Call forecast scenarios	**Number of container vessel calls per week (calls per year) to RBT2**	**Estimated median number of SRKW exposures (95% CI) due to Project operations per year**	**Estimated median number of container vessel transits (95% CI) slowing to 14.5 knots[1] across summer months[2] to mitigate annual SRKW exposures estimated for Project operations**	**Estimated median percentage of container vessel transits (95% CI) slowing to 14.5 knots[1] across summer months[2] to mitigate annual SRKW exposures estimated for Project operations**	**Estimated median acoustic exposure mitigation ratio (upper 95% CI) if 15% of RBT2 container vessels slow to 14.5 knots[1] across summer months[2]. Assuming 80% ECHO Program participation with 95% RBT2 container vessel participation[3]**
Mercator 2018	4.5 (234)	60 (0-180)	23.5 (0-70.6)	10.1% (0-30.2%)	-1.49 (-0.5)
Mercator 2021 most-realistic	4 (208)	53.3 (0-160)	20.9 (0-62.7)	10.1% (0-30.2%)	-1.49 (-0.5)
Mercator 2021 high-case	5 (260)	66.7 (0-200)	26.1 (0-78.4)	10.1% (0-30.2%)	-1.49 (-0.5)

[1] slowing down to 14.5 knots through Haro Strait and Boundary Pass. [2] six summer months, May through October. [3] Assumed that RBT2-bound container vessels would achieve a 95% participation rate (considering that due to safety reasons there may be times container vessels will not be able to participate) as the port authority is proposing to contractually require the terminal operator to require RBT2-bound container vessels to participate in applicable initiatives of the ECHO Program (or future equivalent program).

Table 8 Mitigation efficacy assessment for RBT2 Project container vessel slowing down to 11 knots in Haro Strait and Boundary Pass to mitigate the estimated median number of annual SRKW acoustic exposures due to year-round Project operations under a range of container vessel call scenarios and ECHO Program slowdown participation rates. An acoustic exposure mitigation ratio of -1 and lower represents mitigation of Project operation.

Container vessel Call forecast scenarios	**Number of container vessel calls per week (calls per year) to RBT2**	**Estimated median number of SRKW exposures (95% CI) due to Project operations per year**	**Estimated median number of container vessel transits (95% CI) slowing to 11 knots[1] across summer months[2] to mitigate annual SRKW exposures estimated for Project operations**	**Estimated median percentage of container vessel transits (95% CI) slowing to 11 knots[1] across summer months[2] to mitigate annual SRKW exposures estimated for Project operations**	**Estimated median acoustic exposure mitigation ratio (upper 95% CI) if 15% of RBT2 container vessels slow to 11 knots[1] across summer months[2]. Assuming 80% ECHO Program participation with 95% RBT2 container vessel participation[3]**
Mercator 2018	4.5 (234)	60 (0-180)	13.2 (0-39.5)	5.6% (0-16.9%)	-2.68 (-0.89)
Mercator 2021 most-realistic	4 (208)	53.3 (0-160)	11.7 (0-35.1)	5.6% (0-16.9%)	-2.68 (-0.89)
Mercator 2021 high-case	5 (260)	66.7 (0-200)	14.6 (0-43.9)	5.6% (0-16.9%)	-2.68 (-0.89)

[1] slowing down to 11 knots through Haro Strait and Boundary Pass. [2] six summer months, May through October. [3] Assumed that RBT2-bound container vessels would achieve a 95% participation rate (considering that due to safety reasons there may be times container vessels will not be able to participate) as the port authority is proposing to contractually require the terminal operator to require RBT2-bound container vessels to participate in applicable initiatives of the ECHO Program (or future equivalent program).

Table 9. Summary information to mitigate the estimated median (upper 95% confidence interval, CI) number of annual SRKW acoustic exposures due to year-round Project operations under the upper most-realistic container vessel forecast scenario of four RBT2 container vessel calls per week.

Container vessel speed in Haro Strait and Boundary Pass	Six-month slowdown: Percent of total summer 6 month RBT2-bound transits required slow down[1] to mitigate SRKW acoustic exposures due to annual RBT2 Project operation (upper 95% CI)	Five-month slowdown: Percent of total summer 6 month RBT2-bound transits required to slow down[1] mitigate SRKW acoustic exposures due to annual RBT2 Project operation (upper 95% CI)	Median number of RBT2-bound container vessel transits across the summer 6 months required slow down[1] to mitigate SRKW acoustic exposures due to annual RBT2 Project operation (upper 95% CI)
14.5 knots	10.1% (30.2%)	12.1% (36.2%)	20.9 (62.7)
11.0 knots	5.6% (16.9%)	6.7% (20.2%)	11.7 (35.1)

[1] slowing down through Haro Strait and Boundary Pass.

4. Discussion

The operation of the proposed RBT2 Project, specifically, the arrival, berthing, unberthing, and departure of container vessels assisted by tugs and container vessels at berth, is predicted to increase underwater noise and in turn cause potential acoustic effects to SRKW utilizing Roberts Bank. Since the public hearing, the Minister requested additional information regarding mitigation measures to avoid or reduce acoustic effects to SRKW from Project operation and their anticipated effectiveness. To support the port authority's response to the Minister's information request, SMRU Consulting conducted a noise footprint modelling study to assess the potential to mitigate acoustic effects on SRKW by reducing the number of acoustic exposures from container vessel noise from Project operation at Roberts Bank with container vessel speed reductions of Project-associated container vessels in Haro Strait and Boundary Pass, specifically the ECHO Program-led voluntary inshore 29.6 nm slowdown area. This mitigation assessment differs from previous assessments as it evaluates mitigation action outside the Project operation area.

The modelling study estimated total SRKW acoustic exposures using an approach considering acoustic footprints from vessel activities and the overlap with SRKW summer habitat use. It compared model-predicted numbers of SRKW acoustic exposures due to RBT2 Project operation with reduced numbers of exposures predicted from various potential mitigation scenarios outside the area of Project operation. Specifically, the reduction in exposures predicted by slowing down container vessels transiting SRKW high use areas, Haro Strait and Boundary Pass, at two speeds, 14.5 knots and 11 knots.

The initial modelling study relied on 2018 container vessel forecasts (Mercator International 2018), forecasting 4.5 weekly container vessel calls to RBT2 or 234 calls per year. These results were extrapolated based on updated container vessel forecasts using both the most-realistic (4 weekly container vessel calls or 208 calls per year) and a less likely high-case (5 weekly container vessel calls or 260 calls per year) container vessel call projection scenario (Mercator International 2021). Each call represents two transits, inbound and outbound. Estimates of SRKW acoustic exposures by Project operation in summer months were also extrapolated to provide a coarse estimate of year-round exposures. The initial model results assumed 100% of RBT2-bound container vessels participate and slowdown in Haro Strait and Boundary Pass (providing a maximum benefit of the action), but this assumes no RBT2-bound container vessels would otherwise voluntarily participate in ECHO Program. Recognizing that voluntary participation in ECHO Program initiatives or equivalent already occurs for a high proportion of container vessels, we also assessed the additional benefit of a near-maximum participation condition that might be required for RBT2 container vessels (i.e., 95%), over and above the current voluntary participation to a speed of 14.5 knots (assumed to be 80%).

Container vessel (and tug) acoustic footprints, based on a single behavioural disturbance threshold of 120 dB re 1 µPa (broadband, root mean square, unweighted), were integrated with SRKW summer habitat use and monthly SRKW presence data collated over 16 years (2002-2017). This SRKW acoustic footprint exposure model assumes the selected broadband threshold is representative of continuous noise effects on SRKW (Buren et al. 2021) and the underlying effort-corrected opportunistic data derived SRKW habitat use map is representative. It also assumes container vessel-SRKW pod interactions per model scenario can occur only once per day (considered reasonable given the respective speeds and the number of Project container vessels transiting either inbound and outbound is unlikely to be more than one per day), and that inbound and outbound container vessels transit on different days, as currently occurs with container traffic at Roberts Bank. The noise generated by container vessels at berth has a relatively small footprint (approximately 500 m in summer, MacGillivray et al. 2021) and would be captured by any in motion Project operation activity that would occur on that day. Additional at berth acoustic exposures are therefore expected to be small given the predicted spatiotemporal overlap with SRKW (Buren et al. 2021).

The modelling study firstly estimated the total number of SRKW acoustic exposures associated with RBT2 Project operation in the summer by assuming that 117 container vessels will call at RBT2 over the six-month summer period (May to October). The model estimated a median total of 47 (95% CI: 0-141) SRKW acoustic exposures (the equivalent of 0.65 median exposures per SRKW). The results reflect the relatively low density of SRKW around the proposed terminal within the 120 dB acoustic footprint associated with Project operation. The total exposures estimated by this SRKW acoustic footprint exposure model do not consider the other mitigation measures proposed by the port authority to avoid or reduce noise exposure to SRKW during Project operation (e.g., delayed unberthing and departure, during daylight hours, when SRKW are present).

Vessel slowdowns in Haro Strait have been demonstrated to reduce vessel source levels and ambient noise levels during transits, leading to reductions in predicted disturbance to SRKW (Joy et al. 2019, Burnham et al. 2021, VFPA 2021). The modelling study also predicted that slowing down all 234 Project-associated container vessels transits through Haro Strait and Boundary Pass, regions with relatively high density of SRKW (Cominelli et al. 2018, Olson et al. 2018, DFO 2021), would substantially reduce the number of SRKW acoustic exposures. The initial study, based on 4.5 weekly container vessel calls, predicted 1,715 SRKW acoustic exposures (23.82 per SRKW) in the scenario that container vessels are transiting Haro Strait and Boundary Pass at normal 18 knots container vessel speeds. Reducing Project-associated container vessel speed to 14.5 knots, within these two areas in the marine shipping area, led to a median of 596 fewer SRKW acoustic exposures across the six summer months (8.23 per SRKW), while reducing to 11 knots led to a median of 1,065 fewer SRKW acoustic exposures (14.8 per SRKW). Consequently, using an assumption that 100% of Project-associated container vessels slow down to the specified target speed, RBT2 Project operation SRKW acoustic exposure effects were predicted to be reduced by nearly thirteen times for a slowdown to 14.5 knots through Haro Strait and Boundary Pass and nearly twenty-three times for a slowdown to 11 knots through those same areas. These reductions equate to counterbalancing the 47 SRKW acoustic exposures during RBT2 summer Project operation by slowing approximately 18 (95% CI: 0-55) container vessel transits to 14.5 knots or 10 (95% CI: 0-31) container vessel transits to 11 knots. The months of July, August, and September contributed the most to mitigating SRKW acoustic exposures from Project operation.

Numbers of SRKW acoustic exposures reflect the high historic presence of SRKW in the study area in the summer from 2002-2017. It is worth noting that inter-annual variability in SRKW presence was observed to be relatively high, largely reflecting that in the last few years, long-term summer average presence has been substantially (~15%) lower than assumed in this study. Exploratory model runs reducing whale sighting days by ~50% resulted in model predictions of mitigation ratios that were similar to those presented here. In other words, the mitigation ratio of RBT2 operation is not sensitive to the number of days SRKW are predicted to be present across the study period. Mitigation ratios are also considered unlikely to change appreciably using a different SRKW population number to the 72 individuals used for this study.

Assuming summer and winter SRKW spatial habitat use are similar, one can coarsely estimate the annual number of SRKW acoustic exposures required to mitigate year-round Project operation. We used the summer-winter ratio of relative frequency of spatiotemporal overlaps between Project operation and SRKW transits estimated by Buren et al. (2021). Applying this summer versus winter ratio results in an additional 13 SRKW acoustic exposures occurring due to RBT2 Project operation at Roberts Bank in the remaining winter months (November – April), resulting in an annual median total of 60 SRKW acoustic exposures, 47 in summer and 13 in winter (based on 4.5 weekly container vessel calls). This simple extrapolation suggests that for the 4.5 weekly container vessel forecast scenario the median number of SRKW acoustic exposures at Roberts Bank from Project operation over the entire year could be mitigated by slowing approximately 24 container vessel transits (95% CI: 0-71) to 14.5 knots, the equivalent of 10.1% (95% CI: 0-30.2%) of all container vessel summer transits or approximately 13 vessel transits (95% CI: 0-39) to 11 knots, the equivalent of 5.6% (95% CI: 0-16.9%) of all container vessel summer transit to 11 knots through Haro Strait and Boundary Pass.

Extrapolation to the most-realistic container vessel call scenario (4 weekly container vessel calls, or 8 weekly transits) (Mercator International 2021), mitigation of the median SRKW acoustic exposures at Roberts Bank from Project operation over the entire year could be achieved by slowing approximately 21 (95% CI: 0-63) container vessel transits to 14.5 knots or alternately 12 (95% CI: 0-35) container vessel transits to 11 knots. Under the high-case scenario (5 weekly container vessel calls, or 10 weekly transits), it would require slowing approximately 26 (95% CI: 0-78) container vessel transits to 14.5 knots or alternately 15 (95% CI: 0-61) container vessel transits to 11 knots. These median values equate to approximately 10.1% (for 14.5 knots) and 5.6% (for 11 knots) of the six-month total of predicted number of transits that occur over the summer period. This percent of total six-month summer transits is logically considered scalable, because if container vessel calls are higher or lower, then both Project operation and slowdown mitigation action for acoustic exposures would scale proportionally.

Currently, the maximum duration of ECHO program slowdowns is five months (VFPA 2021). Over just a five-month period, to realize the exact same median number of container vessel transits quoted above to still counterbalance year-round Project operation SRKW acoustic exposures requires 12.1% (95% CI: 0-36.2%) of container vessel transits at 14.5 knots and 6.7% (95% CI: 0-20.2%) of container vessel transits at 11 knots.

Thus, at 14.5 knots, a median 10.1% (six-month slowdown) or 12.1% (five-month slowdown) of container vessel transits are predicted to need to slow down during the summer through the ECHO Program 29.6 nm slowdown area of Haro Strait and Boundary Pass in the marine shipping area to counterbalance the year round SRKW acoustic exposures (to noise above the 120 dB re 1 µPa broadband) due to Project operation. At present a large proportion of container ships already voluntarily participate in the ECHO Program slowdown initiatives (VFPA 2021). If we assume that 15% more RBT2-bound container vessel transits will slow down due to the contractual requirement to do so (in addition to the voluntary participation in the ECHO program slowdown, assumed to be 80% (based on 2020 ECHO-modelled participation rates, VFPA 2021) then this 14.5 knot slow down measure is predicted to mitigate the SRKW acoustic exposure effects of project operations by approximately 1.5 times (six-month slowdown) or 1.2 times (five-month slowdown) respectively.

High variance around median Project operation SRKW acoustic exposures (related largely to how SRKW are distributed by the simulation model across the study area's habitat each month (concurrently noting that effort-correcting opportunistic sightings data is an evolving science (e.g., Harvey et al. 2018, Watson et al. 2019) result in a residual level of uncertainty in these Project operation mitigation predictions. For example, to achieve Project operation mitigation using upper 95% confidence intervals would require an additional 30.2% of container vessels to slow down to 14.5 knots over six months (or 36.2% over five months). This represents 63-78 container vessel transits depending on container vessel call forecast scenarios. Clearly, if a portion of the 80% of container vessels already slowing down to 14.5 knots due to ECHO Program participation slowed down their speed even further, this would reduce the speed and/or the participation rate required by the additional RBT2-bound container vessels. Results for container vessel with slow down speeds of 11 knots clearly provided improved certainty in mitigating Project operations when considering upper 95% confidence intervals.

In summary, the model estimated annual median SRKW acoustic exposures (to noise above the 120 dB re 1 µPa broadband, rms, unweighted behavioural disturbance threshold) from year-round RBT2 Project operation is predicted by this study to be mitigated by slowing approximately 10% (95% CI: 0-30%) of RBT2 Project-associated container vessel transits from 18 knots to 14.5 knots through the ECHO Program-led voluntary inshore 29.6 nm slowdown area of Haro Strait and Boundary Pass in the marine shipping area across six summer months. Across five months, approximately 12% (95% CI: 0-36%) of container vessel transits are required to slow down from 18 to 14.5 knots to mitigate year-round RBT2 Project operation SRKW acoustic exposures. The predicted mitigation potential for container vessel slowdowns reflects the relatively low density of SRKW habitat use within the relatively small Project operation footprint at Roberts Bank compared to the relatively high SRKW density habitat use in the well documented hotspots along the shipping lanes within the much larger Haro Strait and Boundary Pass slowdown area, coupled with the clear reduction in the acoustic footprint when container vessels slow down from their normal average speed. High variance in Project operation SRKW acoustic exposures estimates and a notably high voluntary participation rates of a five-month ECHO Program slowdown provide a positive but relatively small opportunity for Project operation SRKW acoustic exposure mitigation at RBT2 container vessel slowdown speeds of 14.5 knots, noting that upper 95% confidence intervals result in a residual level of uncertainty in these predictions of Project operation mitigation. Model results indicated a larger opportunity for Project operation SRKW acoustic exposure mitigation and improved certainty when container vessel slow down to speeds of 11 knots through Haro Strait and Boundary Pass.

5. Acknowledgements

We acknowledge the financial support of Vancouver Fraser Port Authority under a contract to Ecofish Research Ltd. We thank BC Cetacean Sightings Network (BCCSN) and the Whale Museum for provision of long-term SRKW sightings data. We thank staff at Ecofish and JASCO Applied Sciences for their input into the development of this approach and members of Ecofish and VFPA who provided constructive reviews of earlier drafts, as well as the ECHO Program and JASCO Applied Science who made available and provided by request a statistical representation of container vessel source level and related acoustic data.

6. References

Buren, A.D., D.J. Tollit, M. Gilbert, A. Johnson, J. Wood, K. Akaoka, H. Regehr, A. MacGillivray, Z. Li, and D. Lacroix. (2021). Roberts Bank Terminal 2 Project Technical Data Report - Assessing effectiveness of mitigation at the terminal to reduce potential acoustic effects on Southern Resident Killer Whales from project operation – Draft V1. Consultant’s report prepared for Vancouver Fraser Port Authority by Ecofish Research Ltd., SMRU Consulting North America, and JASCO Applied Sciences Ltd. April 9, 2021.

Burnham, R.E., Vagle, S., O’Neill, C., Trounce, K. (2021). The efficacy of management measures to reduce vessel noise in critical habitat of southern resident killer whales in the Salish Sea. Fisheries and Oceans Canada. 50 pp.

Cominelli, S., Devillers, R., Yurk, H., MacGillivray, A., McWhinnie, L., and Canessa, R. (2018). Noise exposure from commercial shipping for the southern resident killer whale population. Marine Pollution Bulletin: 136, 177–200. doi: 10.1016/j.marpolbul.2018.08.050

DFO (2011). Recovery Strategy for the Northern and Southern Resident Killer Whales (*Orcinus orca*) in Canada. *Species at Risk Act* Recovery Strategy Series, Fisheries & Oceans Canada, Ottawa, ix + 80 pp.

DFO (2017). Action Plan for the Northern and Southern Resident Killer Whales (*Orcinus orca*) in Canada. *Species at Risk Act* Action Plan Series. Fisheries and Oceans Canada, Ottawa. iii + 32 pp.

DFO (2021). Identification of areas for mitigation of vessel related threats to survival and recovery for SRKW. Canadian Science Advisory Secretariat Science Advisory Report 2021/025 Accessed here: https://waves-vagues.dfo-mpo.gc.ca/Library/40979817.pdf

Hannay, D., X. Muoy, and Z. Li. (2016). An automated real-time vessel sound measurement system for calculating monopole source levels using a modified version of ANSI/ASA S12.64-2009". Canadian Acoustics: 44(3), 166-167.

Harvey, G., T.A. Nelson, P.C. Paquet, C.J. Ferster and C.H. Fox. (2018). Comparing citizen science reports and systematic surveys of marine mammal distributions and densities. Biological Conservation 226:92-100. doi:10.1016/j.biocon.2018.07.024

Hemmera and Sea Mammal Research Unit (SMRU) Consulting Canada Ltd (2014). Roberts Bank Terminal 2 Technical Data Report. Marine Mammal Habitat Studies. Part 1. Southern Resident Killer Whale (SRKW) relative density and distribution: Network sightings synthesis. Accessed here: http://www.robertsbankterminal2.com/wp-content/uploads/RBT2-Marine-Mammals-Habitat-Use-Studies-TDR.pdf

JASCO Applied Sciences and SMRU Consulting. (2020). ECHO Program 2019 Voluntary Vessel Slowdown Hydroacoustic Studies: Final Report. Document 01994, Version 1.0. Technical report by JASCO Applied Sciences and SMRU Consulting for Vancouver Fraser Port Authority. Available at: https://www.portvancouver.com/wp-content/uploads/2020/08/ECHO-Program-2019-voluntary-vessel-slowdown-in-Haro-Strait-and-Boundary-Pass-final-report.pdf

Joy, R., Tollit, D.J. Wood, J., MacGillivray, A., Zizheng L., Trounce, K. and Robinson, O. (2019). Potential benefits of vessel slowdowns on endangered southern resident killer whales. Frontiers in Marine Science, 6. doi: 10.3389/fmars.2019.00344

MacGillivray, A., M. Wood, S. Li, A. Allen and D. Hannay (2016). Regional Ocean Noise Contributors Analysis. ECHO Program. Document 01195. Technical report by JASCO Applied Sciences for VFPA. Report accessed here: https://www.portvancouver.com/wp-content/uploads/2017/01/Regional-Ocean-Noise-Contributors.pdf

MacGillivray, A. O., and Li, Z. (2018). 'Reductions in underwater radiated noise from shipping during the 2017 Haro Strait vessel slowdown trial'. Journal of the Acoustical Society of America. 144, 1731–1731. doi: 10.1121/1.5067678

MacGillivray, A., Z. Li, J. Wladichuk, and G. Warner (2019). Mercator Projections Underwater Noise Modelling Update: Roberts Bank Terminal 2 Project. Document 01759, Version 1.0. Technical report by JASCO Applied Sciences for Hemmera.

MacGillivray, A., C. Grooms and Z. Li. (2021). Appendix IR2020-3-C: RBT2 Project Operation Underwater Noise Modelling: Document 02360, Version 3.1. Technical report by JASCO Applied Sciences for Ecofish Research Ltd.

Mercator International (2018). Roberts Bank Terminal 2 Container Vessel Call Forecast Study. Available at Canadian Impact Assessment Registry (Document #1362): https://www.iaac-aeic.gc.ca/050/documents/p80054/126252E.pdf

Mercator International (2021). Appendix IR2020-3-B: Updated RBT2 Container Vessel Call Forecast Study. Report to the Vancouver Fraser Port Authority.

National Marine Fisheries Service (NMFS). (2018). 2018 Revisions to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-59, 167 p.

Nelson, R.B. (2006). An introduction to Copulas. New York. Springer. ISBN 978-1-14419-2109-3.

Olson, J.K., J. Wood, R.W. Osborne, L. Barrett-Lennard and S. Larson (2018). Sightings of southern resident killer whales in the Salish Sea 1976–2014: the importance of a long-term opportunistic dataset. Endangered Species Research 37:105–118. doi: 10.3354/esr00918

Quakenbush, L.T., Citta, J.J., George, J.C., Small, R.J., and Heide-Jørgensen, M.P. (2010). Fall and Winter Movements of Bowhead Whales (Balaena mysticetus) in the Chukchi Sea and Within a Potential Petroleum Development Area. Arctic. 63 (3): 289-307.

Rechsteiner, E.U., Birdsall, C.F.C., Smith, I.U., Sandilands, D.W.D., Phillips, A.V., and Barrett-Lennard, L.G. (2013). Quantifying observer effort for opportunistically-collected wildlife sightings. Report of the Vancouver Aquarium Cetacean Research Program. 49pp. Accessible here: http://killerwhale.vanaqua.org/document.doc?id=140

SMRU Consulting, Canada Ltd. (SMRU). (2014). Determination of Behavioral Effect Noise Thresholds for Southern Resident Killer Whales. Technical report prepared for the proposed Roberts Bank Terminal 2 project for Port Metro Vancouver. Available online at https://iaac-aeic.gc.ca/050/documents/p80054/118046E.pdf. Accessed September 14, 2020.

United States Government (2020). Federal Register. The Daily Journal of the United States Government. Taking of Marine Mammals. Available online at: https://www.federalregister.gov/taking-of-marine-mammals. Accessed September 2020.

Vancouver Fraser Port Authority (VFPA) (2015). Roberts Bank Terminal 2 Project, Roberts Bank, Delta, B.C., Environmental Impact Statement. Vancouver Fraser Port Authority, Vancouver, B.C. CIAR Document #181. Available at https://iaac-aeic.gc.ca/050/evaluations/document/101482?culture=en-CA. Accessed March 9, 2021.

Vancouver Fraser Port Authority (VFPA) (2021). ECHO Program 2020 voluntary vessel slowdown in Haro Strait and Boundary Pass. Available at https://www.portvancouver.com/wp-content/uploads/2021/06/2021-06-11-Summary-Report-2020-Haro-Boundary-slowdown.pdf. Accessed August 2021.

Watson, J., R. Joy, D. Tollit, S.J. Thornton and M. Auger-Méthé. (2019). Estimating animal utilization distributions from multiple data types: a joint spatio-temporal point process framework. arXiv preprint arXiv:1911.00151

Williams R., and Noren D. P. (2009). Swimming speed, respiration rate, and estimated cost of transport in adult Killer Whales. Marine Mammal Science. 25 327–350.

7. Appendix

Monthly median SRKW acoustic exposures for each model run (including upper and lower 95th quantiles, see Table 1 for scenario details). Note medians are calculated each individual month, whereas six-month median exposures presented in Table 4 of the results accumulate data from all six months and subsequently calculate a median value and 95% confidence intervals.

Model run #1 (departure from shipping land with approach to RBT2 and berthing)	Median	L 95th quantile	U 95th quantile
	50%	2.50%	97.50%
May	0	0	18
June	0	0	22
July	0	0	28
August	1	0	32
September	2	0	35
October	0	0	23

Model run #2 (RBT2 unberthing and return to shipping lane)	Median	L 95th quantile	U 95th quantile
	50%	2.50%	97.50%
May	0	0	18
June	0	0	19
July	0	0	26
August	0	0	29
September	0	0	32
October	0	0	22

Model run #3 (18 knot inbound)	Median	L 95th quantile	U 95th quantile
	50%	2.50%	97.50%
May	81	16	161
June	141	42	262
July	168	63	326
August	195	56	338
September	208	75	393
October	123	30	242

Model run #4 (18 knot outbound)	Median	L 95th quantile	U 95th quantile
	50%	2.50%	97.50%
May	69	10	145
June	124	33	243
July	147	46	298
August	167	49	310
September	179	67	354
October	106	18	222

Model run #5 (14.5 knot slowdown inbound)	Median	L 95th quantile	U 95th quantile
	50%	2.50%	97.50%
May	54	3	119
June	96	25	201
July	115	30	241
August	131	33	251
September	144	41	287
October	83	14	176

Model run #6 (14.5 knot slowdown outbound)	Median	L 95th quantile	U 95th quantile
	50%	2.50%	97.50%
May	41	0	96
June	72	13	165
July	88	20	198
August	101	19	200
September	105	33	222
October	60	7	143

Model run #7 (11 knot slowdown inbound)	Median	L 95th quantile	U 95th quantile
	50%	2.50%	97.50%
May	32	0	78
June	58	10	122
July	69	17	145
August	78	20	155
September	87	22	177
October	49	6	115

Model run #8 (11 knot slowdown outbound)	Median	L 95th quantile	U 95th quantile
	50%	2.50%	97.50%
May	23	0	58
June	40	5	96
July	49	9	114
August	57	10	116
September	59	17	130
October	33	1	81

Appendix IR2020-3-G

Proposed mitigation measures – project operation and marine shipping incidental to the project

Appendix IR2020-3-G Table of proposed mitigation measures

Table IR2020-3-G1: The Vancouver Fraser Port Authority (VFPA) new and updated proposed mitigation measures related to further reducing potential effects of project operation and marine shipping incidental to the project on southern resident killer whales (SRKW)

Note: **Bold** text indicates additional or enhanced mitigation measures to previous project commitments (as of July 2019, Appendix A, CIAR Document #2001[1]) to further avoid and reduce potential effects of project operation on SRKW. Blue text indicates clarification or additional detail with respect to commitments included in CIAR Document #2001.

Number	**Phase**			**New and updated proposed mitigation measures**
	Design	**Construction**	**Operation**	
16			✓	Prior to the start of operation, the VFPA will develop an Operation Environmental Management Plan (OEMP) to the satisfaction of a qualified professional(s). The OEMP will be implemented during operation. The OEMP will include at a minimum the following sub-plans, developed in consultation with the parties identified below. • Operation Compliance Management Plan (City of Delta[2], ECCC, DFO, Indigenous groups) • Air Emission Management Plan (B.C. Ministry of ECCS, City of Delta, ECCC, Health Canada, Metro Vancouver, Indigenous groups) • Archaeological Monitoring and Management Plan (B.C. Archaeology Branch, Parks Canada, Indigenous groups) • Communications Plan (B.C. Environmental Assessment Office, City of Delta, DFO, Transport Canada, Indigenous groups) • Environmental Training Plan (Indigenous groups) • Health and Safety and Emergency Response Plan (B.C. Ambulance Service, City of Delta, Coast Guard, Delta Fire and Emergency Services, Delta Police Department, ECCC, WorkSafeBC, Indigenous groups) • Light Management Plan (City of Delta, ECCC, DFO, Indigenous groups) • Noise and Vibration Management Plan (B.C. Ministry of Health, City of Delta, ECCC, Health Canada, Indigenous groups) • **Operational Marine Mammal Management Plan (Coast Guard, DFO, Pacific Pilotage Authority, Transport Canada, and Indigenous groups)** • Spill Preparedness and Response Plan (B.C. Ambulance Service, City of Delta, Coast Guard, Delta Fire and Emergency Services, Delta Police Department, ECCC, DFO, Transport Canada, WorkSafeBC, Indigenous groups)

---

[1] Canadian Impact Assessment Registry (CIAR) Document #2001 Updated Project Commitments, at Appendix A, Table A1: Compilation of Proposed Mitigation Measures and Other Project Commitments – RBT2 Project.

[2] The VFPA will ask the City of Delta to identify which additional OEMP sub-plans may be of interest for their review and consultation.

Number	Phase			New and updated proposed mitigation measures
	Design	Construction	Operation	
				• Terrestrial Vegetation and Wildlife Management Plan (B.C. Ministry of FLNRORD, ECCC, Indigenous groups) • Waste and Hazardous Materials Management Plan (ECCC, Metro Vancouver, Indigenous groups) • Water Quality Management Plan (ECCC, DFO, Indigenous groups) The VFPA will provide the draft sub-plans to the parties for review a minimum of 90 days prior to start of operation. The OEMP and its associated sub-plans will also be made publicly available on the RBT2 website.
81	✓	✓	✓	The VFPA is committed to developing and implementing a Follow-up Program (FUP) for RBT2 to verify the accuracy of residual effect predictions made in the EIS, and determine the effectiveness of measures taken to mitigate the adverse environmental effects of the Project. The RBT2 FUP will include the following elements: • Current Use of Lands and Resources for Traditional Purposes Effects Prediction and Mitigation Effectiveness (Table C1); • Coastal Geomorphic Process Evaluation and Associated Effects Prediction (Table C2); • Roberts Bank Ecosystem Model Evaluation of Marine Vegetation Forecasts and Associated Effects Verification (Table C3); • Roberts Bank Ecosystem Model Evaluation of Infauna/Marine Invertebrates Forecasts and Associated Effects Verification (informed by element described in Table C14); • Roberts Bank Ecosystem Model Evaluation of Rockfish and Lingcod Forecasts and Associated Effects Verification (informed by element described in Table C11); • Roberts Bank Ecosystem Model Evaluation of Blue Heron Forecasts and Associated Effects Verification (Table C4); • Eelgrass Habitat Offset Effectiveness (Table C5); • Intertidal Marsh Habitat Offset Effectiveness (Table C6); • Juvenile Crab Nursery Habitat Effects Prediction (Table C7); • Orange Sea Pen Transplantation Effectiveness (Table C8); • Juvenile Salmon Density Effects Prediction (Table C9); • Sandy Gravel Beach Habitat Offset Effectiveness (Table C10); • Subtidal Rock Reefs Habitat Offset Effectiveness (Table C11); • Caisson Refuge Habitat Mitigation Effectiveness (Table C12); • Underwater Noise Evaluation and Associated Effects Prediction (Table C13);

Number	Phase: Design	Phase: Construction	Phase: Operation	New and updated proposed mitigation measures
				- Western Sandpiper Prey Effects Prediction (Table C14); - Salinity Model Evaluation and Associated Effects Prediction (Table C15); - Barn Owl Nest Box Mitigation Effectiveness (Table C16); - Barn Owl Productivity Effects Prediction (Table C17); - Diving Birds Abundance Effects Predictions (Table C18); - Avian Risk from Artificial Light Effects Prediction (Table C19); - Light Trespass and Sky Glow Effects Prediction and Mitigation Effectiveness (Table C20); - Human Health Air Quality Effects Predictions (Table C21); - Human Health Noise Effects Predictions (Table C22); **and** - **Marine Shipping Effects Predictions (Table C23).** The VFPA will provide each draft FUP element to parties listed in Tables C1 through **C23** (current drafts provided in Appendix C) for review a minimum of 90 days prior to the start of construction.
83			✓	**Prior to the start of operation, the VFPA will develop an Operational Marine Mammal Management Plan to the satisfaction of a qualified professional(s). The plan will be implemented during operation. The plan must include the following:** - **Roles and responsibilities for implementation and monitoring; and** - **Criteria and procedures to delay the unberthing and departure of container vessels during daylight hours in the presence of southern resident killer whales (SRKW), if safe to do so. This includes communication protocols, and methods for detecting SRKW, and criteria for determining SRKW presence near the RBT2 terminal. Criteria and procedures will also include safety, regulatory requirements, and technical and economic feasibility.** **The plan will be developed in consultation with the following parties: Coast Guard, DFO, Pacific Pilotage Authority, Transport Canada, and Indigenous groups.** **The VFPA will provide the draft plan to the parties for review a minimum of 90 days prior to start of operation.**
84			✓	**The VFPA will contractually require the terminal operator to require RBT2-bound container vessels to participate in applicable initiatives of the Enhancing Cetacean Habitat and Observation (ECHO) Program (or equivalent).**

Number	**Phase**			**New and updated proposed mitigation measures**
	Design	**Construction**	**Operation**	
85	✓	✓	✓	**The VFPA will evaluate technologies to reduce underwater noise from support tugs associated with project operation (e.g., electric tugs) and implement the use of them when it becomes technically and economically feasible to do so safely and in a manner which effectively reduces underwater noise.**
86	✓	✓	✓	**The VFPA will provide shore power connections for container vessels berthed at the RBT2 terminal to reduce usage of diesel-powered auxiliary engines.**
87		✓	✓	**The VFPA will sign on to an additional five years of the *Species at Risk Act* (SARA) Section 11 Conservation Agreement, to support the recovery of the SRKW and the reduction of the potential effects of commercial vessel traffic on cetacean species throughout the southern coast of British Columbia, if the other parties to that agreement also agree.**

Table IR2020-3-G2: The Vancouver Fraser Port Authority new and updated proposed mitigation measures related to further reducing effects of marine shipping incidental to the project on SRKW

Note: **Bold** text indicates additional or enhanced mitigation measures to previous project commitments (as of July 2019, Appendix B CIAR Document #2001[3]) to further avoid and reduce potential effects of marine shipping incidental to the project on SRKW.

Number	Phase			Project commitments
	Design	Construction	Operation	
4		✓	✓	**The VFPA will sign on to an additional five years of the *Species at Risk Act* (SARA) Section 11 Conservation Agreement, to support the recovery of the SRKW and the reduction of the potential effects of commercial vessel traffic on cetacean species throughout the southern coast of British Columbia, if the other parties to that agreement also agree.**

---

[3] Canadian Impact Assessment Registry (CIAR) Document #2001 Updated Project Commitments, at Appendix B, Table B1: Compilation of Proposed Mitigation Measures and Other Project Commitments – Marine Shipping Associated with the Project.

Appendix IR2020-3-H

Gomez et al. ’s (2016) findings relevant to 2020 Minister’s information request regarding avoidance and other mitigation measures for Southern Resident Killer Whales from RBT2 operations and marine shipping associated with the project

Ecofish Research Ltd.
Suite 906 – 595 Howe Street
Vancouver, B.C. V6C 2T5
Phone: 604-608-6180

SMRU Consulting
55 Water Street, Suite 604
Vancouver, BC, V6B 1A1
Phone: 604-737-7678

MEMORANDUM

TO: **Vancouver Fraser Port Authority**
FROM: **Dr. Dominic Tollit, SMRU Consulting**
Dr. Alejandro Buren, Ecofish Research Ltd.
DATE: **April 14, 2021**
FILE: **1384 Roberts Bank Terminal 2 Project**
RE: **Gomez *et al.*'s (2016) findings relevant to 2020 Minister's information request regarding avoidance and other mitigation measures for Southern Resident Killer Whales from RBT2 operations and marine shipping associated with the project**

1. SUMMARY

- Gomez *et al.* (2016)[1] is a systematic review and meta-analysis of behavioural responses (BR) of marine mammals to anthropogenic underwater noise that presented several important factors and uncertainties to consider when setting appropriate BR thresholds for impact assessment.
- The review concluded that context of exposure plays a critical and complex role in modulating the severity of BR of marine mammals to noise. Based on the information available in the literature, the analysis emphasized that BR in cetaceans were best explained by the interaction between sound source type and functional hearing group (species grouping based on hearing capabilities). Furthermore, the authors cautioned against solely relying on 'generic' multispecies noise thresholds for addressing behavioural disturbance effects.
- To reduce uncertainty in predicting noise effects, Gomez *et al.* (2016) recommended a species-specific and sound source-specific approach and the use of both observational and acoustic data. The authors also highlighted the importance of contextual factors such as previous exposure experience, proximity, and demographic factors in setting appropriate BR thresholds.
- The environmental assessment (EA) for the Roberts Bank Terminal 2 (RBT2) Project incorporated the relevant contextual factors in setting Southern Resident Killer Whales (SRKW) specific BR thresholds to estimate acoustic effects of Project operation and

---

[1] Dr. A. Buren and Dr. D. Tollit, both key members of the RBT2 marine mammal team, were paper co-authors

associated marine shipping on the species. Data used to derive SRKW-specific BR thresholds were from resident Killer Whales (correct species) exposed to vessel noise (correct sound source type) collected from individuals with previous exposure to this sound source type and captured at various distances (proximities) to noise sources from likely different demographics (e.g., sex and age). Resulting Killer Whale-specific data from both observed behavioural and acoustic response data showed an increase in response severity with increasing received noise levels, supporting the EA 'dose-response' approach for setting Killer Whale noise thresholds.

- To respond to the minister's information request, a fine scale acoustic effects model was developed to quantify effects and mitigation effectiveness (Buren *et al.* 2021). The simulation model is more conservative and adaptable than those used for the EA. The model continues to employ the basic 'dose-response' premise that an animal is more likely to respond negatively to loud noise than to quiet noise, as supported by published Killer Whale studies (Miller *et al.* 2014, Williams *et al.* 2014), but can also evaluate the range in effects by varying the severity or probability of BR.
- In conclusion, the RBT2 studies appropriately considered the findings from Gomez *et al.* (2016). The acoustic effects model developed to quantify the effectiveness of new proposed mitigation measures, as requested by the minister, can also evaluate uncertainty in BR of SRKW to anthropogenic noise (Buren *et al.* 2021).

2. INTRODUCTION

The minister of Environment and Climate Change (the minister) requested additional information regarding project avoidance and other mitigation measures related to underwater noise and effects on Southern Resident Killer Whales (SRKW) associated with project operation and marine shipping incidental to the project (CIAR Document #2067[2]). Specifically, the minister's request was to update the assessment of behavioural response rates of SRKW to continuous noise exposure from vessels during operations and marine shipping associated with the Project to address uncertainties identified in Gomez *et al.* 2016. The objective of this memorandum is to provide an overview of key findings and recommendations from Gomez *et al.* (2016) related to behavioural responses (BR) of cetaceans to underwater noise and relevance for the Roberts Bank Terminal 2 (RBT2) Project studies to support the response to the information request on this topic.

Gomez *et al.* (2016)[3] is a pertinent review and meta-analysis of BR of marine mammals to underwater noise that presented a number of important factors and uncertainties to consider when setting BR

---

[2] CIAR Document #2067 From the Minister of Environment and Climate Change to the Vancouver Fraser Port Authority re: Information Request. https://www.ceaa-acee.gc.ca/050/documents/p80054/135827E.pdf

[3] Dr. A. Buren and Dr. D. Tollit, both key members of the RBT2 marine mammal team, were paper co-authors

thresholds for the purpose of monitoring and regulating acoustic effects on cetaceans. The results, based on a review of 370 papers, showed that generic underwater noise BR thresholds typically used in assessments are not a 'one size fits all', and that a variety of contextual factors are important and should be considered when interpreting the severity of BR.

This memorandum therefore focuses on the aspects of Gomez *et al.* (2016) that relate to noise thresholds. It describes the key findings and recommendations of the scientific paper such as the important factors affecting BR and the uncertainty related to how best to incorporate context and the resulting variability in BR reported in cetaceans. The memorandum also describes how Gomez *et al.* (2016) findings were considered in developing and implementing resident Killer Whale-specific BR (disturbance) thresholds for the RBT2 project and used to evaluate effectiveness of new mitigation measures for project operation and marine shipping associated with the project at reducing underwater noise and potential effects to SRKW.

3. KEY FINDINGS & RECOMMENDATIONS

3.1. Optimal approaches to assess noise effects requires both observational and acoustic data that are specific to the species under review and uses a sound source that is appropriate

The Gomez *et al.* (2016) study highlighted that the optimal approach to assess noise effects on cetaceans requires both observational and acoustic data that are specific to the species under review and uses a sound source type that is appropriate. The authors recommend "a species-by-species approach to management when sufficient data are available".

This optimal approach was undertaken for the RBT2 environmental assessment (EA). Killer Whale behavioural disturbance thresholds for RBT2 relied on data from suitable studies (further described below) identified by a Technical Advisory Group comprising experts on SRKW and underwater noise (Compass Resource Management Ltd. 2013). The Killer-Whale-specific behavioural disturbance thresholds were based on data that included both behavioural observations and acoustic behavioural changes in response to vessel noise. The three datasets provided before-after disturbance information on resident Killer Whale surface behaviours, underwater dive behaviour, and acoustic vocalization data (SMRU 2014b). Similar to published studies on single species and sound sources (e.g., Miller *et al.* 2014, Williams *et al.* 2014), the data showed an increase in response severity as received noise levels increased. The RBT2 EA used the BR severity scale to define acoustic thresholds to estimate the range of acoustic effects on SRKW from the project, using a species-specific approach as supported by Gomez *et al.* (2016).

3.2. The context of exposure plays a critical and complex role in modulating the severity of behavioural responses of marine mammals to noise and generic multispecies noise thresholds should be used with caution

Gomez *et al.* (2016) concluded that context of exposure plays a critical and complex role in modulating the severity of BR of marine mammals to noise. The analysis emphasized that BR in cetaceans (measured via a linear severity scale) were best explained by the interaction between sound source type and functional hearing group (proxy for species with similar hearing capabilities). Furthermore, when combining multiple studies and species without additional contextual information, received noise levels do not always linearly predict how severe BR are in cetaceans. Thus, the authors caution against solely relying on 'generic' multispecies noise thresholds for addressing behavioural disturbance effects. In addition to sound source type and functional hearing group, the review provided evidence that a range of additional contextual factors can be important in determining the severity of a response. These were previous exposure experience, proximity of the sound source, demographic factors (e.g., age, sex, or reproductive state of the animal), or behavioural state (e.g., migrating vs. foraging). Behavioural state was identified as an important factor for migrating large baleen whales that responded more to noise than foraging whales (which are thought to be more motivated to remain in the area). Lastly, the data presented by Gomez *et al.* (2016) for mid-frequency cetaceans (which includes Killer Whales) responding to continuous noise sources, highlight that a very important secondary contextual factor is likely past experience of the sound source, given reports of naïve Arctic Beluga strongly responded to relatively low received levels of drilling noise (see Southall *et al.* 2007).

The RBT2 studies did not rely on generic multispecies thresholds. Rather, resident Killer Whale-specific behavioural disturbance thresholds were developed, using the appropriate sound source. DFO described this approach as superior to using generic thresholds (DFO 2017). BR thresholds developed for the EA considered the influence of the most important factors from Gomez *et al.* (sound source type and appropriate hearing group). As noted above, the SRKW-specific thresholds were based on BR of resident Killer Whales (i.e., based on correct species) to large vessel noise (appropriate sound source type), including BR observed in three studies on resident Killer Whales to define thresholds and estimate potential noise effects (SMRU 2014a). The resulting Killer Whale responses collected were from a range of different noise source proximity distances, background noise levels, and likely different demographic (sex, age, reproductive state) groupings. In addition, SRKW are not a species that migrates and they are typically feeding in their critical habitat, minimizing the potential influence of behavioural state. The Killer Whale-specific thresholds developed for RBT2 used data collected from animals already very familiar with anthropogenic activities, including being in proximity of different vessels (e.g., whale watch boats and large commercial vessels). Datasets were collected in the inland waters of British Columbia and Washington State and are therefore representative of the areas in which the assessment was conducted. The port authority's RBT2 technical team have thus developed disturbance thresholds and methods that aim to address the key contextual factors raised by Gomez *et al.* (2016).

3.3. Addressing variability and uncertainty in severity of BR

In recognition of uncertainties, such as defining severity of BR across different field study datasets (e.g., probability of an individual to respond at a given noise level), the technical team has adopted an adaptable approach to assess variability in the severity of BR and the associated potential effects to SRKW from underwater noise generated during project operation.

Since the public hearing, the RBT2 technical team has developed a more conservative, fine-scale, and adaptable acoustic effects model for quantifying project operation acoustic effects and mitigation effectiveness at Roberts Bank (Buren *et al.* 2021). The approach allows uncertainty in BR to be explored within various zones of acoustic effects using repeated simulations (e.g., scenarios include 95% confidence effect levels) and by running various 'what if' scenarios, where response probabilities (i.e., severity) were increased to upper 95% bounds. It also derived BR probabilities based on the more conservative ('low') dose-response curve developed for the EA, and then conservatively used an arithmetic mean BR probability for each acoustic effect zone, despite the fact that sound levels decrease exponentially with distance from the source. This approach was used together with updated, fine-scale SRKW transit information to estimate potential lost foraging time and subsequently lost prey captures of individuals exposed to different noise levels from vessels and effectiveness of proposed mitigation measures, assuming more conservative SRKW behavioural response (Buren *et al.* 2021). The adaptable approach developed by the RBT2 technical team allows the assessment of varying the severity of BR. As one means to assess the potential effects of the uncertainties identified by Gomez *et al.* (2016), the acoustic effects model was used to explore a scenario where the probability of underwater noise eliciting a BR was assumed to be more acute than the mean (Buren *et al.* 2021).

4. CONCLUSION

In conclusion, the RBT2 EA considered the recommendations from Gomez *et al.* (2016) by applying a species-specific behavioural response threshold using both observational and acoustic data and relevant sound source type (e.g., vessel noise) and considering a number of key contextual factors that influence the severity of BR. The fine-scale acoustic effects model, developed since the public hearing, aims to quantify the effectiveness of new proposed mitigation measures, as requested by the minister, and explores uncertainties identified by Gomez *et al.* (2016) related to variability in the severity of BR of SRKW to anthropogenic underwater noise. The model has also been developed to be adaptable, allowing further variability in key input parameters, including dose-response severity assumptions, to be explored.

Yours truly,

SMRU Consulting and Ecofish Research Ltd.

Prepared by:

Signed

Dominic Tollit, Ph.D.

Principal Scientist

Signed

Alejandro Buren, Ph.D.

Senior Scientist

Reviewed by:

Signed

Deborah Lacroix, M.Sc., R.P.Bio.

Senior Ecologist, Project Director

Disclaimer:

5. REFERENCES

Buren, A.D., D.J. Tollit, M. Gilbert, J. Wood, A. MacGillivray, Z. Li and D. Lacroix. 2021. Roberts Bank Terminal 2 Project Technical Data Report - Quantifying potential acoustic effects on Southern Resident Killer Whales from project operation and assessing mitigation effectiveness. Consultants report prepared for Vancouver Fraser Port Authority by Ecofish Research Ltd., SMRU Consulting North America, and JASCO Applied Sciences Ltd. March 2021.

Compass Resource Management Ltd. 2013. Roberts Bank Terminal 2 Technical Advisory Group (TAG) process report: Southern resident killer whales – Final report. Prepared for Port Metro Vancouver, Vancouver, B.C. Available at: http://www.robertsbankterminal2.com/wp-content/uploads/RBT2-TAG-Summary-Report-SRKW-November-2013.pdf

DFO (Fisheries and Oceans Canada). 2017. DFO Canadian Science Advisory Secretariat. Technical review of Roberts Bank Terminal 2 Environmental Impact Statement and Marine Shipping Supplement Report: Effects on Marine Mammals. At p. 10. Available online at https://iaac-aeic.gc.ca/050/evaluations/document/117102. Accessed on June 6, 2020.

Gomez, C., Lawson, J.W., Wright, A.J., Buren, A.D., Tollit, D., Lesage, V. 2016. A systematic review on the behavioural responses of wild marine mammals to noise: the disparity between science and policy. Can. J. Zoo. 94 (12): 801-819.

Miller, P., Antunes, R., Wensveen, P., Samarra, F., Alves, A., Tyack, P., Kvadsheim, P., Kleivane, L., Lam, P., Ainslie, M., and Thomas, L. 2014. Dose-response relationships for the onset of avoidance of sonar by free-ranging killer whales. J. Acoust. Soc. Am. 135 (2): 975–93.

SMRU (Sea Mammal Research Unit Canada Ltd.). 2014a. Determination of Behavioral Effect Noise Thresholds for Southern Resident Killer Whales. Appendix 14-C. Technical report prepared for the proposed Roberts Bank Terminal 2 project for Port Metro Vancouver. Available online at https://iaac-aeic.gc.ca/050/documents/p80054/118046E.pdf. Accessed February 25, 2020.

SMRU. 2014b. Southern Resident Killer Whale Noise Exposure and Acoustic Masking Technical Report. Appendix 14-B. Technical report prepared for the proposed Roberts Bank Terminal 2 project for Port Metro Vancouver Available online at: https://iaac-aeic.gc.ca/050/documents/p80054/101359E.pdf. Accessed February 25, 2021.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, Jr., D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals 33:411-521.

Williams, R., Erbe, C., Ashe, E., Beerman, A., and Smith, J. 2014. Severity of killer whale behavioral responses to ship noise: A dose-response study. Mar. Poll. Bull. 80 (1-2): 254–60.

Appendix IR2020-3-I

Marine shipping follow-up program element framework

Appendix IR2020-3-I Marine shipping follow-up program element framework

Table IR2020-3-I1: Roberts Bank Terminal 2 (RBT2) marine shipping follow-up program (FUP) element to verify predictions of potential effects of container vessels calling at the Port of Vancouver on southern resident killer whales (SRKW) and current use of lands and resources for traditional purposes (current use) in the marine shipping area

Characteristics	Description
Objective (*Why/What?*)	**Rationale**: Verify project effect predictions **Program purpose**: The marine shipping FUP element has two purposes: 1. Verify predictions of underwater noise from container vessels calling at the Port of Vancouver and manage unanticipated project-related additional acoustic effects on SRKW. 2. Verify predictions of container vessel numbers and/or size classes calling at the Port of Vancouver and manage unanticipated additional effects on current use in the marine shipping area in the event there is an exceedance of container vessel numbers and/or size classes that is attributable to the project.
Responsibility (*Who?*)	**Consultation:** Follow-up Advisory Committee, Indigenous Advisory Committee, representatives of Indigenous groups with interests that overlap with the marine shipping area, Transport Canada (including the Pacific Pilotage Authority), Fisheries and Oceans Canada (DFO) (including the Canadian Coast Guard), and other relevant federal authorities. The Vancouver Fraser Port Authority (the port authority) is also responsible for commitments #1 to 3 of Appendix B of the Updated Project Commitments (CIAR Document #2001[1]), and the port authority will also actively contribute to, support, and/or participate in regional federal initiatives, policies, and programs that relate to the effects of marine shipping generally within the marine shipping area on SRKW and current use, and will coordinate its consultation with Indigenous groups and other federal authorities on this marine shipping FUP element in alignment with those non-project-specific initiatives. The port authority will also collaborate with Indigenous groups and relevant federal authorities to support dialogue, issue resolution, and opportunities related to marine shipping incidental to the project. **Implementation:** The port authority, Transport Canada (including the Pacific Pilotage Authority), and DFO (including the Canadian Coast Guard), collaborating with Indigenous groups.
Approach / Methods (*How?*)	**Approach:** The port authority will monitor the number of vessel calls and size classes for container vessels calling at the Port of Vancouver and use that information to model the underwater noise from container vessels. If underwater noise generated by container vessels exceeds predictions for the most-realistic vessel scenario presented in IR2020-3, then the port authority will assess whether the exceedance is attributable to the project. If the vessel number or size exceedance is attributable to the project, then the port authority will determine whether the increased underwater noise resulted in increased sound exposures to SRKW.

---

[1] CIAR Document #2001 From the Vancouver Fraser Port Authority to the Review Panel re: Updated Project Commitments (See Reference Documents #1738 and #1934). https://iaac-aeic.gc.ca/050/documents/p80054/130776E.pdf

Characteristics	Description
	The port authority, in consultation with Indigenous groups, will also monitor if project-related changes in numbers and/or size classes of container vessels calling at the Port of Vancouver are affecting interactions with current use beyond the potential effect predictions in the marine shipping area presented in Section 9.5.5 of the marine shipping addendum (CIAR Document #316[2]). The identification of interactions with current use will be based on inputs received by the port authority from affected Indigenous groups in the course of consultation. The results of this FUP element will be reported annually, as part of the RBT2 FUP. **Methods:** In the RBT2 FUP, the port authority proposes a FUP element requiring implementation of the following: *Underwater noise* 1. The port authority will collect noise source level measurements from container vessels calling at the Port of Vancouver to confirm the model assumptions. For example, sound source level measurements would be collected using Transport Canada's underwater listening station in Boundary Pass, provided it is still in operation. If the Boundary Pass underwater listening station is not available, the port authority would seek an alternative station or deploy alternative hydrophones, if needed, to verify container vessel underwater noise source levels. 2. The port authority currently collects data on container vessels calling at the Port of Vancouver. The port authority would use a modelling approach to monitor underwater noise from container vessels calling at the Port of Vancouver If an exceedance is detected, then the port authority would assess whether the increase is attributable to the project.[3] 3. If the increase is attributable to the project, then the port authority will assess whether these project-related changes in container vessel call numbers or size result in increases in acoustic effects to SRKW in the marine shipping area. Changes would be verified using a modelling approach to estimate associated sound exposure to SRKW in the marine shipping area using metrics such as L_{eq} and/or exceedance hours (time above SRKW acoustic disturbance threshold of 120 dB re 1 µPa broadband sound pressure level). The temporal and spatial nature of the potential increase in underwater noise would also consider the overlap with temporal and spatial use of the marine shipping area by SRKW. 4. If unanticipated additional project-related acoustic effects to SRKW occur from container vessels, then modified or additional measures would be identified and implemented in collaboration with Indigenous groups, Transport Canada, DFO, and relevant federal authorities to mitigate the effect.

---

[2] CIAR Document #316 Marine Shipping Addendum to the Environmental Impact Statement (see reference document # 181). https://iaac-aeic.gc.ca/050/evaluations/document/103783

[3] For example, if more Mega-Max container vessels call at RBT2 than predicted, shifting the overall size distribution of all container vessels calling at the Port of Vancouver to the larger end, the shift would presumably be attributable to the project. However, if the number of container vessels calling at other terminals within the Port of Vancouver starts to increase, that may not be due to the project.

Characteristics	Description
	Current use 1. The container vessel data routinely collected by the port authority will be used to monitor the numbers, size classes, and destination of container vessels within the Port of Vancouver. If there is an increase in the number of container vessels is attributable to the project beyond predictions identified in Section 9.5.5 of the marine shipping addendum, then the port authority would monitor, in consultation with Indigenous groups, whether these project-related increases in container vessel calls are resulting in increased interactions with current use in the marine shipping area, including the specific nature and characteristics of the interactions. The identification of interactions with current use will be based on inputs received by the port authority from affected Indigenous groups in the course of consultation. 2. If there is a consequential adverse effect on current use from container vessels in the marine shipping area that is attributable to the project, the port authority will work with the affected Indigenous group(s) and relevant federal authorities to identify modified or additional mitigation measures (e.g., enhanced communication procedures with affected Indigenous groups). The selected mitigation measure(s) may be implemented through regional initiatives (e.g., policies or programs under Transport Canada's Oceans Protection Plan, such as the Cumulative Effects of Marine Shipping initiative and Enhanced Maritime Situational Awareness system).
Study Area (*Where?*)	The study area will include the marine shipping area (the area outside the port authority jurisdiction to the 12 nautical mile limit of Canada's territorial sea).
Timing (*When?*)	The FUP element will be developed prior to operation, in consultation with Indigenous groups. The Follow-up Advisory Committee, Indigenous Advisory Committee, and engagement process with representatives of Indigenous groups with interests that overlap with the marine shipping area will be established prior to the start of operation and will dissolve when the RBT2 FUP element has met its objectives. The FUP element will require monitoring container vessel traffic calling at the Port of Vancouver annually starting the first year of RBT2 operation and continue until it can be demonstrated that conditions are stable.[4]
Connection with Other FUP Elements	Proposed follow-up on project-related changes in underwater noise at the terminal and effects on current use in the proposed marine terminal area are described under separate RBT2 FUP elements and do not apply to the marine shipping area. See Appendix A of the Updated Project Commitments (CIAR Document #2001), commitment #81, Table C1 for the current use of lands and resources for traditional purposes (including intangible cultural heritage) effects prediction and mitigation effectiveness FUP element, and Table C13 for the underwater noise evaluation and associated effects predictions.

---

[4] Based on current projections (Mercator International 2021, Appendix IR2020-3-B), the RBT2 terminal is assumed to be operating at the design capacity, of on average 2.4 million twenty-foot equivalent units per year, by 2040 and the redistribution of container vessel traffic calling at the Port of Vancouver will have stabilized; hence, no further project-related change in container vessel traffic would be expected beyond this time period.