Appendix IR2020-2.3-A

Opportunities to avoid or further reduce construction activities effects on SRKW

moffatt & nichol

Suite 301 - 777 West Broadway
Vancouver BC Canada V5Z 4J7

Tel +1 604-707-9004 | Fax +1 604-707-9005
www.moffattnichol.com

MEMORANDUM

To:	Vancouver Fraser Port Authority (port authority)
From:	Michael Cho, P.Eng and Alan Alcorn, P.E.
Date:	August 24, 2021
Subject:	IR 2020-2.3 – Opportunities to avoid or further reduce construction activities effects to SRKW
M&N Job No.:	9117

The proposed Roberts Bank Terminal 2, RBT2, Project Owner's Engineer (OE) has been requested by the Vancouver Fraser Port Authority (port authority) to re-evaluate feasible opportunities to mitigate the potential environmental effects of the proposed project on Southern Resident Killer Whales (SRKW). This work was conducted to support the port authority's response to the Minister of Environment and Climate Change (Minister) information request[1] regarding mitigation measures for project construction related to underwater noise and effects on SRKW. This memo focuses on key noise generating in-water construction activities, such as possible alternatives to impact piling and mattress rock densification, as well as the extent, duration, and timing of in-water activities to reduce underwater noise aggregation from multiple concurrent construction activities during the SRKW peak use period at Roberts Bank. Based on sightings data and recent information published by DFO, the SRKW peak use period at Roberts Bank has been identified as June 1 to September 30. Also, feasible marine construction shut-down times are provided to assist with construction acoustic effects modelling efforts.

Marine construction activities

The proposed RBT2 Project requires the construction of a marine terminal, the widening of the Roberts Bank causeway, and the expansion of the existing tug basin. The activities outlined in this section and referenced throughout this memo describe a feasible option to construct the in-water works, based on a preliminary reference concept design, or RCD (up to 30% complete). The preliminary design components and construction means and methods as outlined below form the basis for environmental assessments, and are not intended to provide definitive descriptions of how the project will be constructed.

The marine construction activities for the terminal and widened causeway require creating a reclaimed landmass using rock, granular material and sand delivered from sources using marine equipment. The first step in terminal construction is construction of the perimeter containment structures, or dykes, then

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[1] 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

filling of the interior basins formed by the dykes, and finally construction of the wharf structure and infilling behind the wharf to complete the terminal landmass.

The containment dykes would be constructed from granular material supplied by existing quarries, loaded onto barges, towed to the site, and unloaded using mainly temporary pile-supported barge ramp structures. The dykes would be constructed primarily using land-based equipment in a linear fashion until a fully enclosed containment structure is completed. This may be done in incremental cells or basins to allow fills to begin prior to surrounding the entire terminal footprint.

The interior fill material (sand) is sourced from multiple separate sources to meet the requirements of the proposed project. The fill sources include the onsite dredging of the dredge basin and tug basin, the annual Fraser River maintenance dredging program, and existing quarries, as required. Sand from the dredge basin would be pumped directly from the (cutter suction) dredge into the terminal and widened causeway landmass; sand from the tug basin would be dredged using a clamshell bucket, transported to the terminal by barges, and pumped directly into the terminal landmass. Sand from the Fraser River would be offloaded directly from a self-contained hopper dredge using the ship pumps. Sand from existing quarries would be offloaded from barges in a manner similar to construction of the rock containment dykes described above and use the same temporary barge ramps.

The terminal wharf structure is expected to consist of a series of concrete caissons, or rectangular boxes, that are placed end-to-end on top of a densified mattress rock foundation to create a continuous berthing face for the container vessels. At each end of the wharf structure, a smaller caisson, closure dyke and anchored sheet pile wall connect to the terminal dykes. The sheet pile wall would be mostly incorporated into the closure dyke with a relatively small exposure to the ocean and the (dead-man) anchor system may include land side piles that are not located within the marine environment. Once the gap between the caissons and the terminal dykes (wharf apron) is enclosed, sand would be placed to complete the terminal landmass. The east end of the wharf includes a mooring dolphin (in-water piled structure). For the expanded tug basin that is located at the east side of Deltaport, in-water piles are required to support the access ramps and mooring floats, and for navigation.

The types of marine equipment anticipated to be employed during the marine construction phase include dredges (cutter suction dredge and hopper dredge), clamshell buckets for dredging (for the tug basin), tugboats, barges for rock and sand transport, barges with mounted cranes (derrick) for rock placement, pile installation, and ground densification, as well as support boats for dredge operations, surveys and crew transport.

Alternatives to impact piling

The proposed project avoids the need for extensive in-water piles by incorporating a caisson wharf structure instead of a pile-supported wharf structure. A previous report[2] determined a pile-supported wharf structure would require over 1,100 in-water steel pipe piles (1,200 mm diameter), as well as a sheet pile bulkhead wall behind the wharf that runs the entire 1,300 m length of the wharf. In contrast, the caisson wharf structure does not require any piling except for the mooring dolphin piles and the 20 m of sheet piles for the closure dykes (the wharf closure is common to both the pile supported and caisson wharf structures).

The RCD includes a total of approximately 59 in-water temporary and permanent steel pipe piles, including approximately 24 pipe piles for the temporary barge ramps, approximately 29 pipe piles for the tug basin facilities, and approximately 6 pipe piles for the mooring dolphin. There are also approximately 34 sheet pile pairs[3] for the wharf closure dykes and 34 sheet pile pairs for the corresponding dead-man anchor. However, the dead-man anchor sheet pile pairs are not installed in-water. The dead-man anchor is a landside support that retains the sheet pile wall by engaging the capacity of the soils and anchor piles.

Vibratory pile driving methods will be used as much as technically possible. Impact pile driving methods are only anticipated to be required when the axial (vertical) capacity of the piles need to be verified using Pile Driving Analyzer (PDA) tests. The capacity verification test cannot be performed with a vibratory driving method. Another possible alternative method for capacity verification, such as static load test (e.g., Kentledge method[4]), is not feasible for the proposed project because the test requires a large support system, which would require additional pile installation.

Since the majority of the in-water piles do not carry a vertical load, only about 4 of the 59 pipe piles are likely to require axial load verification, one at each of the three barge ramp abutment locations and one at the mooring dolphin location. The majority of the in-water piles primarily carry lateral loads, and thus it is expected that these piles can be fully installed using vibratory driving (e.g., tug basin piles). If during detail design it is determined that piles require axial capacity verification, vibratory methods will be used to drive the pile for the majority of its length, and the impact driving method will be used for the final approximately 1 m for PDA tests.

The proposed caisson foundation includes rockfill mattress placed and then densified in-situ. As part of the Quality Control / Quality Assurance testing of the densified rockfill to confirm design specifications, a Becker Penetration Test (BPT) is expected to be required. BPT involves impact driving a relatively small (150 mm to 200 mm diameter) temporary steel casing through the approximately 8 m thick densified rockfill mattress and monitoring the resistance. A significantly smaller hammer[5] is used for the

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[2] WorleyParsons Canada (2011). Berth Structural System Study - Roberts Bank Terminal 2 (T2). Container Capacity Improvement Program (CCIP) Project Definition Report (PDR) Phase. Burnaby, BC.

[3] The sheet piles are expected to be installed in pairs

[4] The Kentledge technique involves loading large weights over the foundation and measuring the displacement, which is not feasible over water.

[5] The hammer used in BPT is a double-acting diesel hammer with a rated energy of 11 kJ and a ram weight of 780 kg, compared to 185 to 300 kJ and 6,200 kg to 10,000 kg expected for the PDA test for the barge ramp abutment and mooring dolphin foundation piles, respectively.

BPT compared for standard impact piling or that used for the PDA tests for a barge ramp abutment or mooring dolphin foundation pile. For the proposed project, BPT tests would likely be required at about 70 separate locations, roughly spread evenly throughout the densified mattress rock area. BPT at each location is anticipated to last up to 2 hours, although active impact driving would be approximately 15 to 30 minutes. The testing is anticipated to occur throughout the mattress rock densification, with approximately two tests expected to be completed within a single day. Other methods such as standard penetration test (SPT) is considered not feasible for testing in rockfill due to the size of the rock required to build the caisson mattress that will not allow SPT.

Refer to **Table 1** for additional details of the anticipated vibratory and impact piling requirements and refer to **Figure 1** for a map of the anticipated in-water impact pile driving locations.

TABLE 1: SUMMARY OF VIBRATORY AND IMPACT PILE INSTALLATION ACTIVITIES ANTICIPATED AT THE RBT2 TERMINAL AND TUG BASIN LOCATIONS

Pile installation activity	**Location**	**Approx. Size of piles**	**Approx. Number of piles / test location**		**Approx. Number of hours per installation day**		**Approx. Number of installation days**		**Approx. Total hours**		**Approx. # of blows**
			Vibratory	Impact	Vibratory	Impact [6]	Vibratory	Impact	Vibratory	Impact[7]	Impact
Barge ramps	Terminal	900 mm	24	3	3	2	24	3	72	6	45 [8]
Closure dykes sheet pile wall installation [9]	Terminal	580 mm	34	0	6	0	10	0	60	0	0
Mooring dolphin pile installation	Terminal	914 mm	6	1	5	2	6	1	30	2	15
Tug basin expansion	Expanded tug basin	450 mm	29	0	6-12 [10]	0	15	0	174	0	0
Test mattress rock density	Terminal	150 to 200 mm	0	70	0	2-4 [11]	0	35	0	140	39,200 [12]
								Total	336	148	39,260

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[6] The entire test including set up time is approximately 2 hours per location; active impact testing (continuous blows) is approximately 15 minutes of active pile driving per pile location

[7] The entire test including set up time

[8] PDA testing requires approximately 15 blows per pile (e.g. 3 piles x 15 blows per pile = 45 blows).

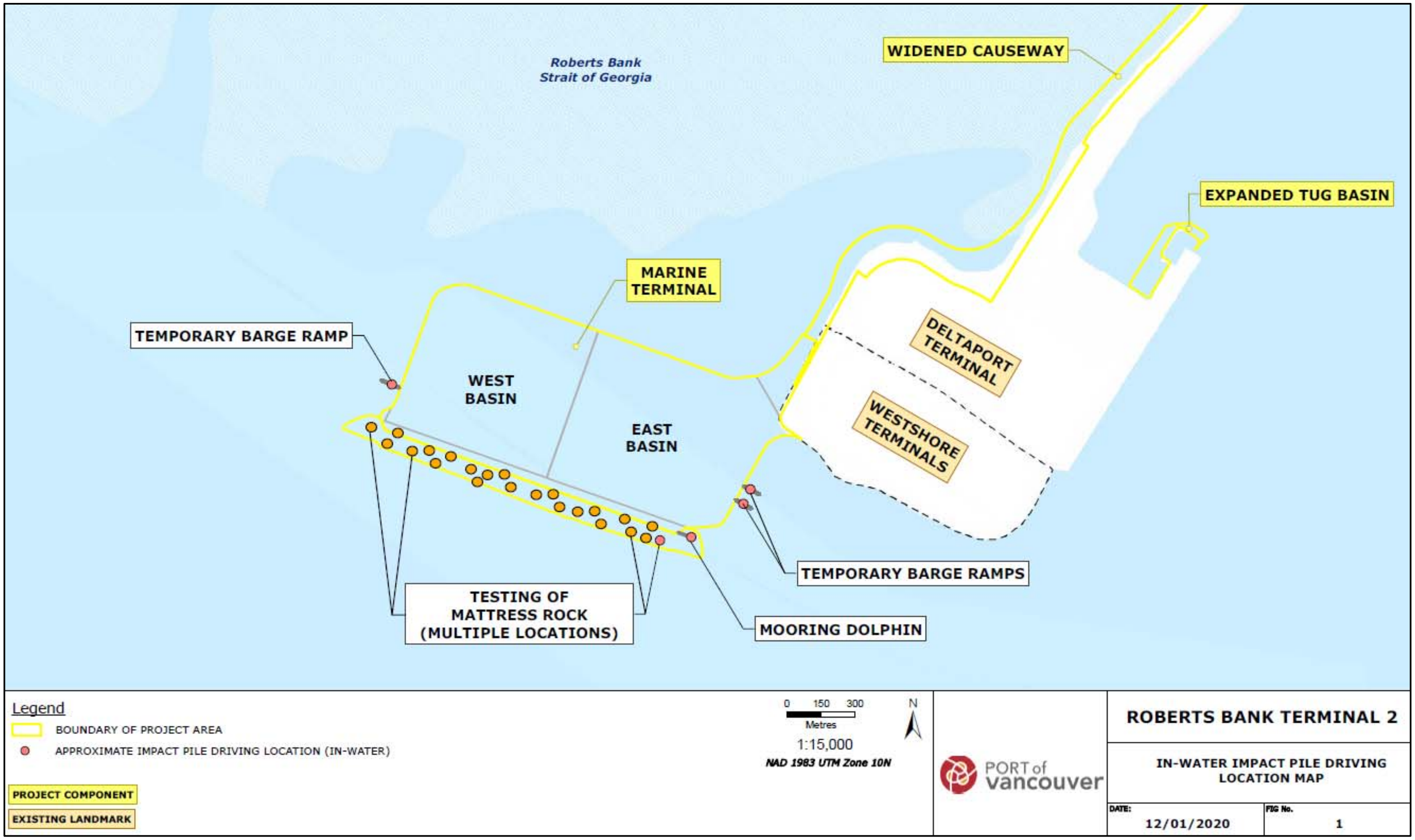
[9] Only the outer sheet pile wall of the 2 wall-system driven through the dyke is considered an activity partially occurring in-water. The outer wall has approximately 17 sheet pile pairs and there are two outer walls (one at each end of the wharf structure) for a total of approximately 34 sheet pile pairs. The interior dead-man anchor is not considered since it is installed on-land, in the dry.

[10] 1 to 2 tug basin piles may be installed per day, each approximately 6 hours

[11] 1 to 2 impact pile tests for the mattress rock may be completed per day, each approximately 2 hours, with 15-30 minutes of active impact driving

[12] Becker penetration testing would require an average of approximately 21 blows per 300 mm penetration, or 560 blows per test hole location based on an estimated 8,000 mm mattress rock layer thickness. This would translate to a total of 39,200 total blows for the project, based on an estimated 70 test locations.

FIGURE 1: MAP OF IMPACT PILE DRIVING



Extent and duration of key in-water noise generating activities

For the Environmental Impact Statement (EIS), key in-water construction activities and equipment generating in-water noise were identified, modelled and assessed (Wladichuk et al., 2014). These activities included vibratory and impact pile driving, dredging, and vibro-densification. Following the EIS, project design optimization resulted in changes in activities, which were reflected in the Project Construction Update[13] (PCU). This included the elimination of an intermediate transfer pit near the terminal to store Fraser River sand (FRS) and the need to dredge and transfer the stored sand to the terminal and causeway landmass. Instead, FRS would be pumped ashore directly from the hopper dredge into the terminal and causeway landmass.

Following the public hearings, the RCD construction schedule described in the PCU (herein referred to as the RCD schedule) was reviewed to identify anticipated in-water activities on a monthly basis during the construction phase of the proposed project in response to the Minister's information request. Further details were examined on the assumptions regarding activity location, anticipated timing, duration and constraints in terms of the critical path sequencing of construction activities. This work was also informed by previous construction works and activities associated with the Deltaport terminal. It is noted the RCD schedule did not have a constraint at that time for SRKW seasonal presence at Roberts Bank. The review on a more discrete task level was performed to allow a closer focus on the potential timing and duration of the activities, based on the following critical path in-water activity dependencies:

- Temporary pile-supported barge ramps must be constructed to receive containment dyke rock and granular material.
- Containment dykes must be constructed and closed to receive sand fill material.
- Rock, granular material and sand must be delivered in a continuous fashion via the barge ramps, along with sand pumped into the terminal and widened causeway landmass from the Fraser River annual maintenance dredge program.
- The berth pocket must be dredged, and sand pumped into the landmass prior to receiving caisson foundation materials.
- The caisson foundation mattress rock must be placed and densified prior to placing the caissons.
- The caissons must be placed to receive the sand fill behind it.
- The closure caissons, dykes and sheet pile walls must be placed to close the wharf apron.

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[13] CIAR Document #1210. From the Vancouver Fraser Port Authority to the Review Panel re: Project Construction Update. https://iaac-aeic.gc.ca/050/evaluations/document/122945

A key assumption in the RCD schedule is that two interdependent activities do not need to be linked 'Finish-to-Start', meaning one activity does not need to be completely finished before the next dependent activity starts. This minimizes the overall RCD schedule but creates an overlap between critical path construction activities. To assist with SRKW acoustic modelling, a total of 19 possible distinct activity scenarios were identified representing different activities or activity combinations, when considering seasons, some of which were only anticipated to occur for short periods. The results of this work informed the RCD schedule review described below.

Alternative timing for the RCD schedule

The RCD schedule was further reviewed to identify activities that overlap with SRKW peak use period (June 1 to September 30). Several of these activities were found to overlap in general location and time, primarily along the terminal dredge basin and barge ramps. Maintaining the critical path in-water construction dependencies, it was determined the following activities could be planned to avoid the SRKW peak use period without impacting the overall RCD schedule:

- All vibratory and impact piling;
- Vibro-densification of the caisson foundation mattress rock; and
- Removal of piles for the temporary barge ramps (using vibratory methods).

In addition, the overlap between the SRKW peak use period and dredging the dredge basin in construction year 3 could be reduced by approximately 2 months (avoiding August and September) if the prior dredging season was extended by approximately 1.5 months (from mid-October to November 30) in construction year 2, which coincides with the first 6 weeks of the Dungeness crab fisheries-sensitive window (October 15 – March 31). Extending the first dredging season in construction year 2 from 6.5 months to 8 months, followed by a second dredging season of 4 months in construction year 3, provides greater flexibility and increases the potential to mobilize a higher production rate (i.e., more efficient) international dredge or other means. A more efficient dredge could reduce the overall in-water construction duration, although this assumption was not included in the review. The modified RCD schedule incorporating these changes (Option 1) is shown on **Figure 2**.

A second modified RCD schedule (Option 2) was also identified that is the same as Option 1, except dredging does not extend into the crab fisheries-sensitive window in year 2. Mattress rock delivery and placement requires a certain amount of dredging be completed. In turn, the mattress rock vibro-densification requires a certain amount of rock placement. Therefore, dredging is a key constraint to the project RCD schedule. For each option, vibro-densification for the entire dredge basin will occur over an approximately 16 months period, start to finish, which includes 12 months of vibro-densification plus 4 months stoppage during the SRKW peak use period. Mattress rock production, delivery, and placement may occur continuously during this period. The result is that vibro-densification finishes approximately 6 months after the completion of dredging the entire dredge basin. In Option 2, the result is approximately a three-month delay to the overall RCD schedule. The second modified RCD schedule (Option 2) is shown on **Figure 3**.

The 4-month SRKW peak use period limits the contractor's ability to complete the overall construction faster since the critical path mattress rock vibro-densification cannot start until October 1. Similarly, the 4-month SRKW peak use period limits the flexibility of the contractor to make up for lost time due to unexpected weather and mechanical delays, and any additional work as the final design and technical specifications are developed. An additional 2 months is therefore reflected in the total duration of vibro-densification in Figure 2 and Figure 3 to provide a small contingency period for unexpected events.

Another major critical path activity is the installation of the pile-supported barge ramps in year 1 since it is required to allow delivery of containment dyke rock, granular material, and sand to the site. The piling for the barge ramps in the first year is scheduled to start as soon as possible in accordance with the salmon fisheries-sensitive window (March 1 – August 15) and is expected to last two to three weeks. The alternative of delaying all of the first-year pile driving by six weeks (starting October 1 instead of August 16) to avoid the SRKW peak use period reduces the amount of dyking that can be installed in the first season. A consequence is that dyking may need to be extended from two seasons to three. A potential option is to install the year 1 barge ramps prior to the construction of the year 1 dyking. The modified RCD schedules present this option for illustrative purposes.

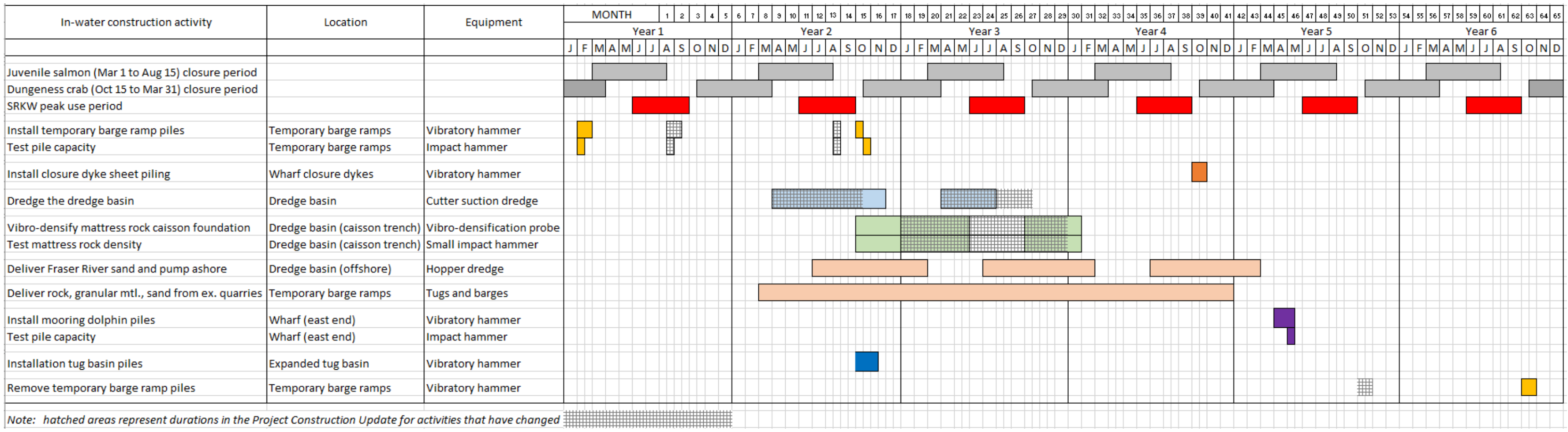
Several key in-water activities cannot be scheduled outside of the SRKW peak use period (in addition to the other environmental closure periods) since they are on the critical path. Delays to these key activities would result in significant extension of the overall RCD schedule duration, which would affect the overall feasibility of the project. The key in-water activities that remain within the SRKW peak use period are described below.

Delivering FRS and pumping it ashore for the terminal and expanded causeway landmass is critical to the overall RCD schedule since it provides approximately one-half of the overall sand requirements of the proposed project. Approximately 2 million m^3 of FRS from the annual maintenance dredging program is required for three seasons, for a total of approximately 6 million m^3. Subject to the scale of the freshet, the FRS is generally available between June 15 to February 28 (8.5 months). This results in the initial 3.5 months overlapping with the SRKW peak use period for each of the three seasons that FRS is delivered to the site. Dredging of the Fraser River is required to start as early as possible following the spring freshet, typically in mid-June, to maintain safe navigation of the Fraser River. The alternative of delaying the start of receiving the FRS from mid-June to October 1 (3.5 months) to avoid the SRKW peak use period would require that a significant portion of the sand material (approximately 0.8 million m^3 annually) would be wasted at the Sand Heads disposal site until the remainder of FRS is able to transit to the proposed project site for offloading starting October. The wasted FRS would therefore be unrecoverable and would directly delay the RCD schedule by at least two years due to a loss of at least two year's worth of sand in total. This is considered not feasible.

Delivery of rock, granular material and sand from existing quarries via the barge ramps is a critical path activity given the volume of fill material required to create the landmass for the terminal and expanded causeway. Approximately 3.6 million m^3 of sand and 1.8 million m^3 of containment dyke rock is expected to be sourced from existing quarries. Interruptions in delivery would directly delay the RCD schedule as continuous delivery of rock, granular material and sand is required for approximately 3 years, overlapping with the SRKW peak use period in those years.

Dredging the dredge basin is another critical path activity that is needed before placing and densifying the mattress rock caisson foundation. Approximately 3.2 million m^3 of sand comes from dredging of the dredge basin, which is anticipated to occur from April 1 to October 15 for two seasons, based on the Dungeness crab fisheries-sensitive window. Restricting dredging to outside of the SRKW peak use period (in addition to the Dungeness crab fisheries-sensitive window) would limit the dredging to only April 1 to May 31 per season. Dredging for 2 weeks between October 1 to October 15 is not feasible for RBT2 because of the significant mobilization and ramp-up effort compared to limited time allowed for dredging. Dredging would only occur for 2 months per season, a significant reduction from the 6.5 month season per the PCU assumptions. A 2 month dredging season is expected to add approximately four or more years to the overall construction duration, which is not feasible. In addition, a short dredging season allowing 2 months of dredging per year over multiple years would most likely preclude the use of international dredge equipment due to the need to remobilize over multiple seasons and significant downtime. Excluding the opportunity to use the anticipated higher capacity international dredging equipment is expected to result in higher pricing due to a lack of bid competition and increase the risk of construction delays since the local dredging capabilities will be stretched with little contingency for major equipment failures and lack of support from other resources.

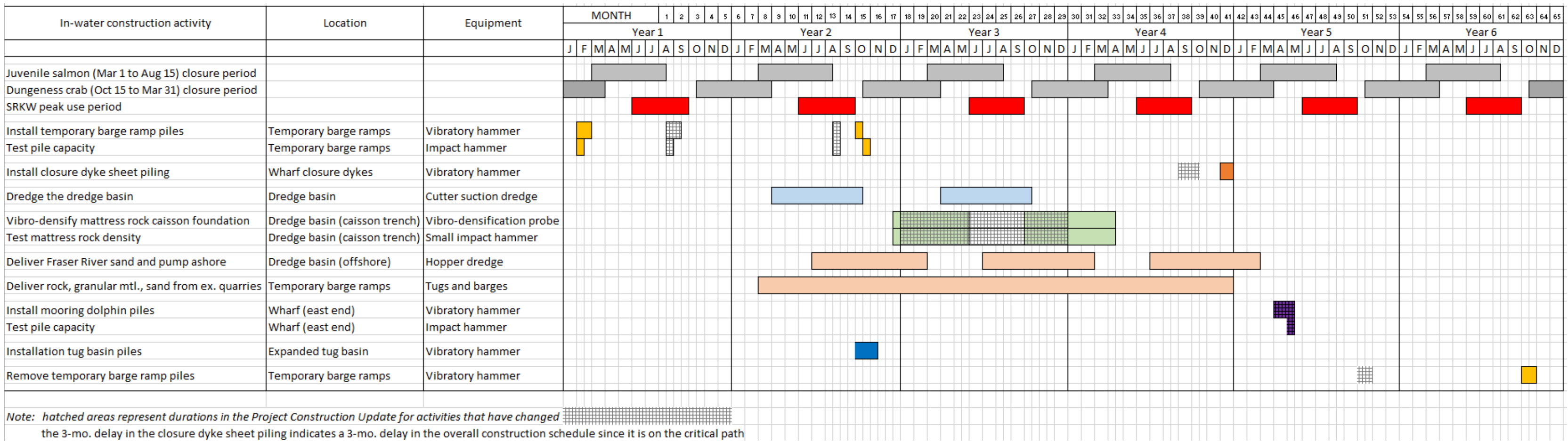
FIGURE 2: TIMING OF KEY IN-WATER NOISE GENERATING ACTIVITIES ANTICIPATED UNDER THE MODIFIED RCD SCHEDULE OPTION 1 BASED ON CONSTRUCTION AND ENVIRONMENTAL CONSTRAINTS AND DEPENDENCIES (WITH DREDGING EXTENSION IN YEAR 2)



In-water construction activity	Location	Equipment
Juvenile salmon (Mar 1 to Aug 15) closure period		
Dungeness crab (Oct 15 to Mar 31) closure period		
SRKW peak use period		
Install temporary barge ramp piles	Temporary barge ramps	Vibratory hammer
Test pile capacity	Temporary barge ramps	Impact hammer
Install closure dyke sheet piling	Wharf closure dykes	Vibratory hammer
Dredge the dredge basin	Dredge basin	Cutter suction dredge
Vibro-densify mattress rock caisson foundation	Dredge basin (caisson trench)	Vibro-densification probe
Test mattress rock density	Dredge basin (caisson trench)	Small impact hammer
Deliver Fraser River sand and pump ashore	Dredge basin (offshore)	Hopper dredge
Deliver rock, granular mtl., sand from ex. quarries	Temporary barge ramps	Tugs and barges
Install mooring dolphin piles	Wharf (east end)	Vibratory hammer
Test pile capacity	Wharf (east end)	Impact hammer
Installation tug basin piles	Expanded tug basin	Vibratory hammer
Remove temporary barge ramp piles	Temporary barge ramps	Vibratory hammer

Note: hatched areas represent durations in the Project Construction Update for activities that have changed

FIGURE 3: TIMING OF KEY IN-WATER NOISE GENERATING ACTIVITIES ANTICIPATED UNDER THE MODIFIED RCD SCHEDULE OPTION 2 BASED ON CONSTRUCTION AND ENVIRONMENTAL CONSTRAINTS AND DEPENDENCIES



In-water construction activity	Location	Equipment
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Dungeness crab (Oct 15 to Mar 31) closure period		
SRKW peak use period		
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Test pile capacity	Temporary barge ramps	Impact hammer
Install closure dyke sheet piling	Wharf closure dykes	Vibratory hammer
Dredge the dredge basin	Dredge basin	Cutter suction dredge
Vibro-densify mattress rock caisson foundation	Dredge basin (caisson trench)	Vibro-densification probe
Test mattress rock density	Dredge basin (caisson trench)	Small impact hammer
Deliver Fraser River sand and pump ashore	Dredge basin (offshore)	Hopper dredge
Deliver rock, granular mtl., sand from ex. quarries	Temporary barge ramps	Tugs and barges
Install mooring dolphin piles	Wharf (east end)	Vibratory hammer
Test pile capacity	Wharf (east end)	Impact hammer
Installation tug basin piles	Expanded tug basin	Vibratory hammer
Remove temporary barge ramp piles	Temporary barge ramps	Vibratory hammer

Note: hatched areas represent durations in the Project Construction Update for activities that have changed ▦
the 3-mo. delay in the closure dyke sheet piling indicates a 3-mo. delay in the overall construction schedule since it is on the critical path

Construction equipment shut down feasibility and response

To mitigate acoustic effects to SRKW, equipment operations or construction equipment will be altered or shut down before SRKW enter the activity(ies) specific exclusion zones. Response time for shutting down equipment can affect the effectiveness of this key mitigation measure. To further reduce potential acoustic effects to SRKW, the port authority proposes to apply a SRKW monitoring buffer to the respective behavioural disturbance exclusion zones to account for the time needed to modify and/or halt construction activities once a SRKW is detected. The operator's ability to shut down noise-generating activities that could impact SRKW, and how long safe shut-down would take, depends on the specific type of equipment and construction activity. For example, the cutter suction dredge while dredging the dredge basin and the hopper dredge while pumping ashore are expected to require 10-15 minutes to safely shut down the pumps and clear the discharge piping during standard shut-down procedures, although this may be quicker in case of an emergency. Other typical marine equipment shut-down times are shown below:

- Piling vibratory hammer: 2-3 minutes
- Piling impact hammer: 3-5 minutes
- Vibro-densification probe: 3-5 minutes

Marine vessels such as the dredges and tugs (especially while towing) cannot be completely shut down for safety reasons as they may lose navigational control. If not under tow, tugs can be slowed in 2-3 minutes but not completely shut down. Tugs are required to assist with the barge deliveries of imported quarry rock and sand. There can be approximately two to three barge deliveries per day during the SRKW peak use months during year 2 and 3 of construction, each trip requiring approximately 2-3 hours to transit the area of the largest anticipated SRKW exclusion zone, dock the loaded barge, pick up an empty barge, and transit outside of the zone. In addition, during the mattress rock densification, tugs are required to assist with positioning the densification rigs around the dredge pocket. Positioning to a new densification location is expected to require ~10-15 minutes for each rig.

This information was used in the modelling of acoustic effects on SRKW conducted for the proposed project to quantify the potential effects associated with anticipated response time for safely shutting down equipment once a SRKW is detected in the area[14].

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[14] Appendix IR2020-2.3-E

Appendix IR2020-2.3-B
Sound dampening technologies

Appendix IR2020-2.3-B Sound dampening technologies

The port authority conducted a review of available sound dampening technologies that could be implemented to reduce underwater noise from the limited impact pile driving anticipated for capacity testing for the Roberts Bank Terminal 2 (RBT2) Project. This involved conducting a literature review of the sound dampening technologies available or those in development and their documented effectiveness at reducing underwater noise from impact pile driving. The review included input from engineers, marine mammal scientists, and acoustic experts (**Table IR2020-2.3-B1**). In addition, the feasibility of these technologies was evaluated based on expected environmental and site conditions at Roberts Bank (e.g., currents, waves, water depth, substrate), project specifications (e.g., anticipated pile sizes; **Appendix IR2020-2.3-A**), and technology readiness level (e.g., commercially available or currently under development). Specifically, the technology had to meet four criteria to be considered feasible: suitable for RBT2 piles (<1 m diameter), suitable for the site conditions (nearshore, high current conditions similar to Roberts Bank), commercially available, and capable of achieving a minimum sound dampening effectiveness of 10 dB (sound exposure level (SEL)) at 10 m (**Appendix IR2020-2.3-C**). Technologies that met some of the criteria were considered either partially or potentially feasible while those that did not meet any or only met one criterion were considered not feasible or not likely feasible. Alternative hammer technologies were also evaluated as alternatives to impact hammers for installation and for potential use as sound dampening technology for the limited amount of capacity testing (i.e., approximately one hour anticipated over the six years of in-water construction). Sound dampening technology(ies) will be selected by the contractor depending on the circumstances (e.g., final design specifications and the environmental conditions at the time of impact piling).

Table IR2020-2.3-B1: Description of existing sound dampening technologies[1] for impact pile driving, their potential noise reduction effectiveness, and feasibility of use for RBT2 construction

Technique	Description and considerations	Potential effectiveness	Feasibility of use for RBT2
Confined bubble curtain	A bubble curtain is formed around a pile by injecting compressed air into the water through a ring of perforated pipes encircling the pile. Confined bubble curtains have a casing (plastic, fabric, or rigid pipe) around the bubbles.	Noise reduction ranges from 4–5 dB (SEL; Koschinski and Ludemann 2013; Weilgart 2019), 12–13 dB (SEL; Martin et al. 2012), and 5–15 dB (metric not specified; Buehler et al. 2015).	**Feasible**: suitable for RBT2 vertical piles and site conditions. Provides a solution to current disruption as the casing is used to guide bubbles and prevent bubble dispersion. Installation may be difficult in very high current conditions (which impact piling could be planned to avoid) due to amount of area to be contained and anchoring requirements.
Isolation casings	A simple isolation casing consists of a steel pipe around the pile typically installed using vibratory piling. More effective isolation casings have air between the pile and casing (i.e., evacuates the water) or have additional layers containing air (or foam, composites, or bubbles freely rising inside), making use of the impedance mismatch between water and air (see next three technologies). Air bubbles between	On their own, simple isolation casings provide minimal noise reduction. If water is evacuated between the pile and casing, noise can be reduced by up to ~15–25 dB (upwards of 20 dB peak, rms, and SEL) (Nehls et al. 2007; Spence et al. 2007; Saleem 2011).	**Feasible**: suitable for RBT2 piles and the site conditions. Effective when water can be evacuated from the space between the casing and the pile or additional insulating layers are used.

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[1] As many technologies are being commercially developed and are often kept confidential, some technologies that are under development are included to provide a more comprehensive summary of measures that may be operational in the near future.

Technique	Description and considerations	Potential effectiveness	Feasibility of use for RBT2
	the pile and isolation casing can improve noise reduction. Further dampening can be achieved by adding extra layers of foam.		
Double-walled pile (Reinhall piles; MCT 2020)	Hollow pile with mandrel and driving shoe. Pile has an outer wall, which is the structural pile that acts as the shield, while inside is a mandrel that takes the driving impacts, with an air pocket between the two piles. Driving shoe joins the inner and outer piles to limit noise propagation below the seafloor (i.e., sound transmission through the substrate that can partly re-enter the water column some distance from the source). This is the only method described in this table that has this advantage.	Noise reduction of 17–18 dB (SEL; both waterborne and ground transmission; CSA Ocean Sciences Inc. 2014; MCT 2020).	**Feasible**: suitable for RBT2 piles and site conditions. Some have been tested for similar applications in Washington State (MCT 2020) and are now available commercially.
IHC Noise Mitigation System (Noise mitigation screen; IHC 2019)	Double-walled steel pipe with an air gap between the two layers. A multi-layered bubble curtain is also used between the two piles.	Noise reduction of 5–17 dB (SEL; Koschinski and Ludemann 2013; Weilgart 2019).	**Not likely feasible**: not suitable for RBT2 piles or site conditions. Not currently sized or compatible to fit smaller pile sizes anticipated for the project. The screen has been commercially deployed as noise abatement system for offshore wind farms (depths up to 45 m); designed and used for very large piles required for wind turbine installation (size of the casings >3 m diameter).
BEKA shells	Two acoustically decoupled half-shells that are hydraulically movable relative to each other that close around the pile and reach the seabed.	Noise reduction of 6–8 dB (SEL; Koschinski and Ludemann 2013; Weilgart 2019).	**Not likely feasible**: potentially suitable for RBT2 piles and site conditions, but may not be sufficient to achieve anticipated underwater noise reductions and there is no known commercial application. The pilot stage is however complete.

Technique	Description and considerations	Potential effectiveness	Feasibility of use for RBT2
Vibratory pile driver (alternative hammer)	A pile driving system that vibrates the pile with a certain low vibrating frequency into the seabed. Proven technology for small piles, low anchoring depths (has also been used in offshore wind farm projects in water depths up to 45 m). Typically applied prior to impact pile driving.	Noise reduction of 10–20 dB (peak; Koschinski and Ludemann 2013; Weilgart 2019; Spence et al. 2007).	**Partially feasible**: suitable for RBT2 pile installation and the site conditions; adopted by the project (commitment #38, CIAR Document # 2001[2]). However, it is not suitable for capacity testing.
Smart Pile Driving and PULSE (Piling Under Limited Stress) (alternative hammer)	System that determines the necessary piling energy and the optimum Hydrohammer type. The piling approach (energy, repetition rate) is adjusted based on real time measurements. PULSE (add-on to standard hammer such as the Hydrohammer) is positioned between the piling hammer and sleeve and dampens the impact and noise with two hydraulic plungers.	Noise reduction of 3–9 dB (SEL), 9–12 dB (SPL) (IHC 2019; Weilgart 2019).	**Potentially partially feasible**: potentially suitable for RBT2 piles and site conditions by construction start. It is a relatively new technique, currently designed and used for larger piles. However, there are prototypes for smaller impact hammers. Not confirmed to be suitable for capacity testing.
BLUE piling technology hammers (alternative hammer)	An impact hammer with less noise emission compared to a conventional hydraulic hammer. Drives a pile using the weight of water.	Noise reduction >5 dB (SEL; Verfuss et al. 2019), 16–20 dB (SEL; Weilgart 2019), 25 dB (metric not specified; Koschinski and Ludemann 2015).	**Not feasible**: not suitable for RBT2 piles or site conditions. There is a lack of demonstrated commercial and serial deployment. The technology is not yet commercially available. Not likely suitable for capacity testing.
Pile caps (cushion blocks)	Caps of various materials are used between the impact piling head and the pile to reduce underwater sound. Commonly used for impact pile driving to avoid damaging piles. While piling cushions reduce the sound pressure level by prolonging the pulse duration, at the same time this prolongation is associated with a loss of force on the pile. As such, a negative effect on piling efficiency may result.	Noise reduction depends on the material of the piling cushion. Noise reduction ranging from 1 to 8 dB (peak; Spence et al. 2007). Noise reduction ~7 dB (SEL; Koschinski and Ludemann 2013).	**Partially feasible**: suitable for RBT2 piles and site conditions but on its own may not be sufficient to achieve anticipated underwater noise reductions (and not as effective for the steel piles required for RBT2 compared to concrete piles).

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[2] 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/evaluations/document/130776

Technique	Description and considerations	Potential effectiveness	Feasibility of use for RBT2
Cofferdams for piling	Cofferdams are rigid steel barriers surrounding the pile from seabed to surface. Dewatered cofferdams involve removing the water from inside the enclosed steel barrier that surrounds the pile (to remove the direct sound propagation path). Disadvantage is that large cofferdams generally require additional pile installation to create the barrier (e.g., sheet pile), which generates noise. Can be applied at water depths of up to 45 m at least.	Noise reduction ranges from 17–23 dB (SEL; Koschinski and Ludemann 2013, 2015; Weilgart 2019), ~20 dB (metric not specified; Stokes et al. 2010).	**Not feasible**: not suitable for RBT2 piles or site conditions. Have been applied in various commercial projects; however, this method is generally used for large or numerous piles. In the case of RBT2, the additional noise and longer duration of construction expected with installing cofferdams would likely negate noise reduction benefits for the limited number of piles and amount of impact pile driving anticipated.
Resonators (air-filled resonators, acoustic resonators)	Consist of an array of (solely or mainly) resonating units that are deployed around the pile to absorb the emitted sound. There are a variety of different ways to build resonators. Each supplier has its own resonating material and design (see the next two technologies that are specific examples). For example, underwater inverted air-filled cavities (static bubbles) with combinations of rigid and elastic wall membranes.	Noise reductions range ~15–20 dB (metric not specified; CSA Ocean Sciences Inc. 2014).	**Not likely feasible**: suitable for site conditions although not likely suitable for RBT2 piles (no specific examples found of use for piles of the size required for the project).
Hydro sound damper (resonator)	Consist of small gas-filled or foam balloons affixed to fishing nets around the pile. Dropped down into the water around the pile and collapse back up when pile is installed. The system does not affect the water flow or preclude fish from swim through. Technique involves scattering, absorption, and stimulation with the resonance frequency of the balloons. Foam elements act as impact absorbers. The attenuation frequencies can be adjusted by the size of balloons or foam pellets. This offers a system to selectively	Noise reduction of 4–14 dB (SEL; Koschinski and Ludemann 2013, 2015), up to 23 dB (SEL; Weilgart 2019).	**Not likely feasible**: suitable for site conditions, although not likely suitable for RBT2 piles (no specific examples found of use for piles of the size required for the project). Can be employed in areas with current, but in waters with strong tidal currents the attachment method must be robust enough to withstand the water flow and flexible enough to enable flow-through. Has been commercially deployed as noise abatement system for offshore wind farms. To date, the system has only been used for very large piles.

Technique	Description and considerations	Potential effectiveness	Feasibility of use for RBT2
	reduce noise at frequencies that are biologically important or at frequencies of maximum energy in pile strikes. Works for water depths of 40–60 m, pile diameters of 8–13 m, pile lengths of 80 m.		
AdBm-Noise Abatement System (resonator)	Uses rugged Helmholtz resonators whose acoustic properties can be modified or tuned to optimally treat noise. The resonators surround the sound source and passively absorb the noise. They have been designed to work to at least 400 m depth.	Noise reduction of 8 dB ($L_{p,pk}$; AdBm Technologies 2020).	**Not likely feasible**: suitable for site conditions, although not suitable for RBT2 piles given the small number of piles requiring impact piling and may not be sufficient to achieve anticipated underwater noise reductions. Completed full-scale test in 2018 and deployed commercially in an offshore wind farm project in 2019. However, there is a lack of demonstrated commercial and serial deployment.
Bubble curtain (single ring)	There are several types of bubble curtains, differing mainly in their design details (e.g., rate of airflow, size of airholes, number of manifolds, ring diameter, ring placement, and confined vs. unconfined). A bubble curtain is formed around a pile by injecting compressed air into the water through a ring of perforated pipes encircling the pile.	Noise reduction ranges from 0 to 5 dB (metric not specified; Buehler et al. 2015).	**Not likely feasible**: potentially suitable for RBT2 piles, although not suitable for site conditions. They are typically limited to use in shallow and calm coastal waters. Susceptible to currents, which can disrupt the continuity of the curtain, reducing noise attenuation effectiveness.
Multi-layered bubble curtain	Same principle as above but with additional rings of perforated pipes around the pile. Example, double big bubble curtain, where a set of two large perforated flexible tubes are positioned in concentric rings around the pile. More rings can be added as needed to meet thresholds (Cochrane, pers. comm. 2020).	Noise reduction ranges from 17 dB (SEL; Koschinski and Ludemann 2013; Weilgart 2019) to 5–20 dB (peak; Spence et al. 2007).	**Not likely feasible**: potentially suitable for RBT2 piles, although not suitable for site conditions. Similar to bubble curtains, this measure is also susceptible to currents, which can disrupt the continuity of the bubbles. Currents will disperse the bubbles unless they are confined by a barrier (e.g., confined bubble curtain). Multi-layered bubble curtains are typically limited to shallow and calm coastal waters (deployed in water depths ~20–40 m). Method most commonly used by local contractors (e.g., on the Fraser River).

Technique	Description and considerations	Potential effectiveness	Feasibility of use for RBT2
Pile-in-pipe piling	An example of a cofferdam where four cofferdams (protective pipes) are the four legs of the foundation. The cofferdam is part of the structure and remains in place after the installation. A foam coating of the supporting pile might offer additional noise reduction potential. More material is needed compared to conventional methods (more expensive). Can be safely anchored at water depths of 30 m.	Noise reduction ~27 dB (SEL; Koschinski and Ludemann 2013; Weilgart 2019).	**Not likely feasible**: suitable for site conditions, although not likely suitable for RBT2 piles (i.e., the types of piles/structures required for the project). Moreover, the measure has only been validated at the concept stage.

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Appendix IR2020-2.3-C

Underwater noise modelling of RBT2 construction to inform mitigation (technical data report)

Underwater Noise Modelling of RBT2 Construction to Inform Mitigation

Submitted to:

Pam Dinn
Ecofish Research Ltd.

Authors:

Zizheng Li
Zahra Alavizadeh
Xavier Mouy
Nicole E. Chorney
Alexander O. MacGillivray

16 September 2021

P001140-018
Document 01996
Version 6.0 Final

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:

Li, Z., Z. Alavizadeh, X. Mouy, N. E., Chorney, and A.O. MacGillivray. 2020. *Underwater Noise Modelling of RBT2 Construction to Inform Mitigation*. Document 01996, Version 5.6 DRAFT. 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

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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.

absorption
The reduction of acoustic pressure amplitude due to acoustic particle motion energy converting to heat in the propagation medium.

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.

attenuation
The gradual loss of acoustic energy from absorption and scattering as sound propagates through a medium.

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

audiogram weighting
The process of applying an animal’s audiogram to sound pressure levels to determine the sound level relative to the animal’s hearing threshold (HT). Unit: dB re HT.

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

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

cumulative distribution function
A function P(x) that indicates the probability (in the range 0-1) that a measured quantity, such as a sound level, is less than or equal to some value x.

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.

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

geoacoustic
Relating to the acoustic properties of the seabed.

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

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

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

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

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

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

median
The 50th percentile of a statistical distribution.

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

non-impulsive sound
Sound that is broadband, narrowband or tonal, brief or prolonged, continuous or intermittent, and typically does not have a high peak pressure with rapid rise time (typically only small fluctuations in decibel level) that impulsive signals have (ANSI/ASA S3.20-1995 R2008). For example, marine vessels, aircraft, machinery, construction, and vibratory pile driving (NIOSH 1998, NOAA 2015).

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.

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

otariid pinnipeds in water (OW)
The functional pinniped hearing group that represents eared seals under water.

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.

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

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

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

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

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

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

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*.

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

rms
root-mean-square.

shear wave
A mechanical vibration wave in which the direction of particle motion is perpendicular to the direction of propagation. Also called secondary wave or S-wave. Shear waves propagate only in solid media, such as sediments or rock. Shear waves in the seabed can be converted to compressional waves in water at the water-seabed interface.

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

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

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

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

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

For sound in water, the reference sound pressure is one micropascal (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 µPa^2·s·m (exposure level).

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

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

transmission loss (TL)
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. Also referred to as propagation loss.

Executive Summary

The Roberts Bank Terminal 2 project (RBT2 or project) is a proposed marine terminal at Roberts Bank in Delta, BC, that could provide 2.4 million TEUs (twenty-foot equivalent units) of additional container capacity annually. Underwater noise produced by construction and operation of RBT2 has the potential to disturb or injure nearby marine fauna. In 2015, JASCO Applied Sciences conducted a detailed modelling study (EIS Modelling Study) for the Vancouver Fraser Port Authority (port authority) to estimate underwater noise impacts from individual terminal construction and operations activities, as a part of Environmental Impact Statement (EIS) preparation (Wladichuk et al. 2014). The purpose of the current study is to provide additional modelling and analysis of underwater noise from combinations of terminal construction activities, in support of regulatory approvals for RBT2. Objectives of this study included modelling cumulative noise footprints from combinations of construction activities, and estimating Passive Acoustic Monitoring (PAM) detection ranges for Southern Resident Killer Whales (SRKW) near RBT2 during construction to inform mitigation and monitoring design.

Eight construction scenarios were modelled, which included sources from the EIS Modelling Study—vibratory piling, impact piling (with and without confined bubble curtain mitigation), vibro-densification, and cutter suction dredging—as well as newly modelled noise sources for pumping ashore with a trailing arm suction hopper dredge (TSHD) and material delivery and placement with tugs. A screening-level modelling assessment of underwater noise generated by the Becker Penetration Test (BPT), which tests mattress rock densification, concluded that this activity is unlikely to generate sound levels of sufficient intensity to cause injury or behavioural disturbance to marine mammals or to cause injury to fish. Multiple activities were combined, with support tugs (maneuvering or barge towing), to represent combinations of simultaneous activities from the proposed project construction schedule. The acoustic modelling considered the influences of local bathymetry, ocean sound speed profiles, and seabed geoacoustics on waterborne sound propagation.

The updated project construction approach (Moffatt and Nichol 2021) plans for in-water piles at the mooring dolphin and barge ramps to be driven using only vibratory piling and that use of impact hammers would be limited to Pile Driving Analyzer (PDA) tests to verify final load bearing capacity. Impact pile driving (using 123 kJ impact hammer) and PDA tests (using 185 kJ and 300 kJ impact hammers) were the only activities that had the potential to generate sound levels sufficiently high to injure marine mammals or fish. Injury thresholds for marine mammals were assessed in terms of current US National Marine Fisheries Service (NMFS) guidelines (2018). Injury thresholds for fish were assessed using a set of criteria developed by an ANSI-accredited working group that was established to determine broadly applicable sound exposure guidelines for fishes and sea turtles (Popper et al. 2014). For the PDA test using a 300 kJ hammer, without a confined bubble curtain, the temporary threshold shift (TTS) criteria for SRKW (mid-frequency cetaceans) was exceeded at a maximum range of 20 m and permanent threshold shift (PTS) criteria were not exceeded beyond 10 m range. For fish, the maximum injury range (peak pressure level (PK) threshold) was determined to be 50 m. The effectiveness of potential mitigation measures for impact pile driving was considered using the example of a confined bubble curtain, which attenuated the broadband SEL by 10.2 dB at a range of 10 m. The model results indicate that underwater sound levels generated by pile installation and PDA activities requiring an impact hammer could be substantially reduced by a confined bubble curtain, with the average distance to injury thresholds reduced by approximately 80% on average for marine mammals and fish.

The other construction activities associated with RBT2 were not expected to generate sound levels capable of causing injury to aquatic organisms; however, behavioural disturbance and masking of sounds used for foraging and communicating are possible. Although behavioural disturbance for marine mammals depends on many factors—including exposure duration, noise source type, habituation, and exposure context—the zone of potential disturbance is often considered as the area within which continuous sound levels exceed 120 dB re 1 µPa sound pressure level (SPL) (MMPA 2007, NOAA 2019). Behavioural thresholds specific to southern resident killer whales were modelled for 50% probability of low (129 dB re 1 µPa) and moderate (137 dB re 1 µPa) severity behavioural responses. Note that the 120 dB re 1 µPa SPL threshold is also the 10% probability threshold for low-severity behavioural responses for southern resident killer whales.

Seasonal variation in sound speed profiles (summer versus winter) affected the extent of the noise footprints. For example, for the material placement scenarios, the radii for the summer scenario (3A) were 15% smaller than for the winter scenario (3B). This is because the summer sound speed profile is more downward-refracting, causing more sound energy to be directed into the ocean bottom, resulting in more sound energy lost to seabed sediments (i.e., bottom loss). Differences in winter and summer sound speed profiles are mainly due to changes in the vertical temperature gradient (i.e., the thermocline), caused by cooling and heating in the upper 80 m of the water column.

As expected, combinations of activities have larger noise footprint extents than single activities. For example, the dredging and pumping ashore scenario (5) has a 95% threshold range of 2.68 km for the 120 dB re 1 µPa SPL threshold compared to the dredging only scenario (4), which has a 95% threshold range of 1.3 km. The addition of support tugs increased the noise footprint extents but usually not by a large amount. For example, the addition of seven tugs (Scenario 8B) to dredging, pumping ashore, and vibro-densification (Scenario 8A) increased the 95% threshold range for the 120 dB re 1 µPa SPL threshold from 4.10 to 4.36 km, an increase of less than 5%.

To estimate the ability to detect southern resident killer whales acoustically near the construction area for mitigation purposes, modelling was used to calculate the acoustic detection ranges of southern resident killer whales stereotyped vocalizations and whistles near RBT2 during construction. This analysis was based on the combination of two months of *in situ* passive acoustic recordings collected near Robert Bank in 2012 (Mouy et al. 2012), a previous modelling study of incremental contributions of project operations to underwater noise at Roberts Bank (MacGillivray et al. 2019), and the construction noise modelled in this report. The detection ranges of killer whale calls were estimated at three locations where passive acoustic monitoring (PAM) nodes could potentially be deployed for mitigation purposes during construction. The PAM locations were selected to be outside the major vessel traffic lanes and far enough from the construction zone (i.e., >6 km; Table 11) to maximize the ability to detect killer whales before they enter the general zone of construction acoustic effects.

Note that the detection range study was intended only to assess the feasibility of using PAM nodes for detecting SRKW at Roberts Bank. The PAM node layout evaluated in this study was not intended to reflect the actual design of a PAM array that would be deployed during construction of RBT2. It is anticipated that the actual design of a PAM array would be based on requirements identified during a formal engineering design process.

Results from this analysis show that 1) the detection range of stereotyped vocalizations is consistently higher than whistles, 2) the detection range is consistently higher at night than during the day, and 3) detection ranges during construction activities are similar to the detection range of the baseline (i.e., with no additional construction noise). For stereotyped vocalizations, the maximum night detection ranges that are reached 50% of the time (P = 0.5), based on the median detection range probability curves, are 1.32, 1.58, and 1.24 km at each of the three PAM locations considered in this study. The corresponding maximum day detection ranges (P = 0.5, median curve) are 0.76, 0.85, and 0.70 km, respectively.

1. Introduction

The Roberts Bank Terminal 2 project (RBT2 or project) is a proposed marine container terminal at Roberts Bank in Delta, BC, that could provide 2.4 million TEUs (twenty-foot equivalent units) of additional container capacity annually. An Environmental Impact Statement (EIS) for the proposed project was prepared by Vancouver Fraser Port Authority (port authority) and submitted to the Canadian Environmental Assessment Agency (CEAA) in 2015. During preparation of the EIS, JASCO Applied Sciences conducted a detailed modelling study (EIS Modelling Study) for the port authority to estimate underwater noise impacts from terminal construction and operations. The construction activities considered in this study included impact and vibratory pile driving, vibro-densification, and dredging (Wladichuk et al. 2014). The report of the Federal Review Panel for the RBT2 project concluded that the underwater noise modelling in the EIS was "state-of-the-art", "appropriate to the assessment", and "generally well applied" (IAAC 2020).

The purpose of this study is to provide additional modelling and analysis of potential underwater noise from terminal construction in support of regulatory approvals for RBT2. Additional analyses of underwater noise have been undertaken to further describe and assess anticipated effects of the project and to assist with the development of effective mitigation measures. The objectives of the new analyses reported here are as follows:

1. To build on existing noise modelling carried out for the RBT2 EIS (Wladichuk et al. 2014), which mainly considered each construction activity as a lone sound source, by modelling the cumulative noise footprints from combinations of construction activities, as identified in the proposed project construction schedule. This study also considers the effects of different water sound speed conditions (summer conditions versus the EIS Modelling Study’s winter conditions). Results of this analysis will be used to estimate potential noise effects on marine mammals and fish during project construction.
2. To use an acoustic model to estimate Passive Acoustic Monitoring (PAM) detection ranges for Southern Resident Killer Whales (SRKW) near RBT2 during construction. Results of this analysis will be used to determine potential effectiveness of PAM mitigation during project construction and assist with designing a robust detection system. This analysis is based on the methods used by JASCO during the 2012 baseline ambient monitoring project at Roberts Bank (Mouy et al. 2012). Note that the detection range analysis is intended only for evaluating feasibility of the method and is not intended to reflect the actual design of a PAM array that would be deployed during construction of RBT2.

Underwater noise was modelled for eight unique construction scenarios, each representing anticipated combinations of marine works that will occur concurrently during project construction. Details of the construction scenarios (see Section 2.2) were determined by reviewing the proposed project construction schedule for overlapping activities. New acoustic sources were modelled for a trailing arm suction hopper dredge (pumping ashore) and tugs (maneuvering and towing) to cover additional marine works that were not combined and included in the EIS Modelling Study. The level of tug activity associated with each scenario was determined by reviewing the details of the construction equipment peak analysis completed for the project construction update (VFPA 2018) and additional information from the Vancouver Fraser Port Authority (i.e., number of support tugs during different phases of construction)..

Acoustic propagation modelling was carried out using JASCO's Marine Operations Noise Model (MONM; Appendix A). The modelled noise footprints for each scenario were used to calculate distances to behavioural response and auditory injury thresholds for marine mammals and fish (see Section 2.1). The noise footprints were also used to calculate detection ranges of SRKW calls at three different locations where PAM nodes could potentially be deployed for mitigation purposes during construction (see Section 2.3). Detailed modelling results of the construction noise and PAM detection ranges are provided in Section 3. Noise footprint maps for each construction scenario are provided in Appendix B.

2. Methods

2.1. Acoustic Impact Criteria

Several acoustic impact criteria were used to determine where noise from marine works associated with the project would have potential to cause auditory injury or behavioural disturbance to marine mammals and fish. For marine mammals, this study uses three sources of criteria for acoustic injury and disturbance (described further in Section 2.1.1):

1. Species-group injury criteria from the US National Marine Fisheries Service (NMFS) (2018) guidelines (as opposed to the now-outdated criteria from Southall et al. (2007) used in the EIS Modelling Study).
2. Generic marine mammal behavioural disturbance criteria applied by the NMFS (MMPA 2007, NOAA 2019).
3. Species-specific behavioural response thresholds for SRKW (SMRU Canada Ltd. 2014), which are based on probabilities of low and moderate responses (described in Section 2.1.2).

Injury thresholds for fish were assessed using a set of criteria developed by an ANSI-accredited working group that was established to determine broadly applicable sound exposure guidelines for fishes and sea turtles (Popper et al. 2014). These are the most up-to-date guidelines on the effects of high-intensity noise exposure on fish. Behavioural thresholds for fish applied the criteria and methods from the EIS Modelling Study (described further in Section 2.1.3), that are relative to the hearing threshold for three species groups: flatfish, herring, and salmon.

The acoustic metrics used for these criteria are described in Appendix A.1 for continuous sources and Appendix A.2 for impulsive sources. The frequency weighting methods required for some of these criteria are provided in Appendix A.3 for marine mammals and Appendix A.4 for three fish species.

2.1.1. Impact Criteria for Marine Mammals

There are currently no statutory thresholds specified for underwater noise in Canada that are applicable to all types of noise sources and marine mammal species. To assess the model results in terms of potential for *injury* to marine mammals, this study applied the criteria recommended by NMFS (2018), using frequency weighting functions for five different species groups, given in Table 1. This differs from the approach of the EIS Modelling Study, which used the regulatory criteria applied by NMFS (MMPA 2007) and the now-outdated M-weighting functions of Southall et al. (2007).

The recent NMFS (2018) criteria are defined for two categories of auditory injury: permanent threshold shift (PTS), a physical injury to an animal's hearing organs; and temporary threshold shift (TTS), a temporary reduction in an animal's hearing sensitivity as the result of receptor hair cells in the cochlea becoming fatigued. The NMFS criteria for PTS and TTS onset are defined separately for six functional hearing groups of marine mammals (Table 1), five of which are used in the current study:

- Low-frequency (LF) cetaceans (e.g., humpback whales, grey whales)
- Mid-frequency (MF) cetaceans (e.g., killer whales)
- High-frequency (HF) cetaceans (e.g., harbour porpoises)
- Phocid pinnipeds underwater (PW) (e.g., harbour seals)
- Otariid pinnipeds underwater (OW) (e.g., Steller sea lions)

The frequency weighting functions associated with these functional hearing groups and criteria are described in detail in Appendix A.3.

Table 1. Injury criteria, TTS and PTS onset, for the marine mammal functional hearing groups considered in the current study as recommended by NMFS (2018). Non-impulsive sounds have a single criterion (weighted cumulative SEL over 24 hours, dB re 1 µPa^2·s), whereas impulsive sounds have dual criteria (weighted cumulative SEL over 24 hours, dB re 1 µPa^2·s; and unweighted peak pressure level (PK), dB re 1 µPa).

Hearing group	Impulsive				Non-impulsive*	
	TTS-onset		PTS-onset		TTS-onset	PTS-onset
	SEL (dB weighted)	PK (dB unweighted)	SEL (dB weighted)	PK (dB unweighted)	SEL (dB weighted)	SEL (dB weighted)
Low-frequency (LF) cetaceans	168	213	183	219	179	199
Mid-frequency (MF) cetaceans	170	224	185	230	178	198
High-frequency (HF) cetaceans	140	196	155	202	153	173
Phocid pinnipeds underwater (PW)	188	212	203	218	181	201
Otariid pinnipeds underwater (OW)	170	226	185	232	199	219

* None of these thresholds were reached, so they are omitted from the results in Section 3.

To assess the model results in terms of potential for behavioural disturbance to marine mammals, we use the same approach as the EIS Modelling Study—the NMFS criteria for behavioural disturbance (for level B harassment), shown in Table 2. These thresholds have also been used by Fisheries and Oceans Canada (DFO) as guidance for recent pile installation projects in British Columbia.

Table 2. Behavioural disturbance criteria (unweighted SPL, dB re 1 µPa) for marine mammals as defined by NMFS (for level B harassment) (MMPA 2007, NOAA 2019).

Hearing group	Continuous sounds	Impulsive sounds
	SPL (dB unweighted)	SPL (dB unweighted)
Cetaceans (LF, MF, and HF)	120	160
Pinnipeds in water		

2.1.2. Impact Criteria for SRKW Behavioural Disturbance

This study adopted the behavioural response thresholds for SRKW that were developed for the EIS. Killer whales are sensitive to sounds over a broad range of frequencies, from 600 Hz to 114 kHz based on a detection threshold of 100 dB re µPa (Branstetter et al., 2017). This frequency range expands to approximately 100 Hz to 120 kHz using a higher detection threshold of 120 dB re µPa. Highest hearing sensitivity by the killer whales in the Branstetter et al. (2017) study was found between 30 kHz and 40 kHz, where hearing thresholds ranged from 45–57 dB re µPa among the eight captive killer whales tested, and the composite model indicated the lowest threshold of 49 dB re µPa occurring at 34 kHz corresponding to the highest hearing sensitivity.

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 (SMRU Canada Ltd. 2014) (Table 3). For this study, radii were computed for SMRU's low- and moderate-severity response thresholds of 120 dB, 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 described in Section 2.1.1, 129 dB and 137 dB which correspond to the 50% probability of low- and moderate-severity behavioural responses, respectively.

Table 3. Behavioural response criteria (unweighted broadband SPL, dB re 1 µPa) for SRKWs (SMRU Canada Ltd. 2014). Note that 120 dB re 1 µPa (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

2.1.3. Impact Criteria for Fish

In 2006, the Working Group on the Effects of Sound on Fish and Turtles was formed to continue work begun by a panel convened by NOAA two years earlier to develop noise exposure criteria for fish and turtles. The resulting guidelines, published in 2014, included specific thresholds for different levels of effects and for different groups of species (Popper et al. 2014). These guidelines defined quantitative thresholds for three types of effects:

- Mortality, including injury leading to death.
- Recoverable injury, including injuries unlikely to result in mortality, such as hair cell damage and minor haematoma.
- TTS.

The Popper et al. (2014) criteria reflect the best-available science, at the time of writing, and supersede the interim criteria developed in 2008 by a panel of hydroacoustic and fisheries experts (FHWG 2008) that were applied in the EIS.

Masking and behavioural effects can be assessed qualitatively, by assessing relative risk rather than by specific sound level thresholds. These effects are not assessed in this report. Because the presence or absence of a swim bladder has a role in hearing, fish's susceptibility to injury from noise exposure varies depending on the species and the presence and possible role of a swim bladder in hearing. Thus, the Working Group proposed different thresholds for fish without a swim bladder (also appropriate for sharks and applied to whale sharks in the absence of other information), fish with a swim bladder not used for hearing, and fish that use their swim bladders for hearing. Fish eggs and fish larvae are considered separately. Table 4 lists relevant effects thresholds from Popper et al. (2014). In general, any adverse effects of pile driving on fish behaviour depends on the species and the state of the individuals exposed.

The SEL metric integrates noise intensity over some period of exposure. Because the period of integration for regulatory assessments is poorly defined for sounds without a clear start or end time, or for very long-lasting exposures, an accumulation period must be defined. This is done for marine mammals in the Southall et al. (2007) criteria, where it is 24 h or the duration of the activity, whichever is longest. Popper et al. (2014) recommend applying a standard period, where this is either defined as a justified fixed period or the duration of the activity; however, they also include caveats about how long the fish will be exposed because they can move (or remain in location) and so can the source. Popper et al. (2014) summarize that in all TTS studies considered, fish that showed TTS recovered to normal hearing levels within 18–24 h. Based on these findings, a period of accumulation of 24 h has been applied in this study for SEL, which is similar to that applied for marine mammals in Southall et al. (2007) and NMFS (2018).

Table 4. Criteria for impulse noise exposure for fish, adapted from Popper et al. (2014).

Type of animal	Mortality and Potential mortal injury	Impairment			Behaviour
		Recoverable injury	TTS	Masking	
Fish: No swim bladder (particle motion detection)	>219 dB SEL_{24h} or >213 dB PK	>216 dB SEL_{24h} or >213 dB PK	>>186 dB SEL_{24h}	(N) Low (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: Swim bladder not involved in hearing (particle motion detection)	210 dB SEL_{24h} or >207 dB PK	203 dB SEL_{24h} or >207 dB PK	>>186 dB SEL_{24h}	(N) Low (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: Swim bladder involved in hearing (primarily pressure detection)	207 dB SEL_{24h} or >207 dB PK	203 dB SEL_{24h} or >207 dB PK	186 dB SEL_{24h}	(N) Low (I) Low (F) Moderate	(N) High (I) High (F) Moderate
Fish eggs and fish larvae	>210 dB SEL_{24h} or >207 dB PK	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low

Notes: Peak sound level (PK) dB re 1 µPa; SEL_{24h} dB re 1µPa^2·s. All criteria are presented as sound pressure, even for fish without swim bladders, since no data for particle motion exist. Relative risk (high, moderate, or low) is given for animals at three distances from the source defined in relative terms as near (N), intermediate (I), and far (F).

To assess the model results in terms of behavioural disturbance to fish, we use audiogram-weighted sound levels thresholds of 90 dB re HT for three species groups—flatfish, herring, and salmon—where dB re HT is decibel level above the animal's hearing threshold (Nedwell et al. 2007). The frequency weighting functions associated with these criteria are described in Appendix A.4.

2.2. Modelling Terminal Construction Noise

In most respects, this study uses the same modelling methodology as the EIS Modelling Study, using JASCO's Marine Operations Noise Model (MONM; described in Appendix A.5) to compute propagation of underwater sounds produced by planned construction activities for RBT2. The EIS methodology was expanded for the purpose of this study to include:

- New acoustic sources representing pumping ashore with trailing arm suction hopper dredge and tug activities;
- Modelling combinations of activities rather than individual sources alone; and
- Sound speed profiles representing summer conditions for some scenarios.

Other details of the noise modelling were identical to those applied in the EIS Modelling Study and are described in Wladichuk et al. (2014).

2.2.1. Modelled Scenarios

Eight scenarios were modelled to represent noise generated by marine works during different phases of project construction. These scenarios represent a best estimate of construction equipment that would be operating simultaneously at the project site, based on the proposed construction schedule (VFPA 2018). Updated project construction plans (Moffatt and Nichol 2021) evaluated the opportunity to reduce the use of impact pile driving. It is anticipated that the piles would be installed using a vibratory hammer and that the use of an impact hammer would be limited to a few piles (approximately 4 in total) for Pile Driving Analyzer (PDA) testing for the temporary barge ramps and mooring dolphin, using larger hammers (185 kJ and 300 kJ, respectively) than were originally assumed in the Environmental Impact Statement (EIS) (123 kJ hammer). Scenarios 2A and 2B represent the base-case impact pile driving activities evaluated in the EIS (Wladichuk et al. 2014), whereas scenarios 2C through 2J represent the PDA tests specified in the updated project construction plans.

The modelled scenarios are not intended to capture the minute-by-minute details of equipment operations at the project site (nor would it be feasible to capture such detail in the model). Rather, these scenarios are intended to represent a noise footprint (at an arbitrary snapshot in time) of simultaneous noisy in-water activities occurring at various phases of project construction. The construction scenarios are as follows, with maneuvering tugs travelling at 3 knots (kts) and towing tugs travelling at 6 kts:

1. Vibratory piling a 914 mm steel cylindrical pile at the mooring dolphin;
2. Impact piling a 914 mm steel cylindrical pile at the mooring dolphin:
    2A. Pile installation using 123 kJ hammer without noise attenuation (summer);

    2B. Pile installation using 123 kJ hammer with a confined bubble curtain as a noise attenuation mitigation measure (summer);

    2C. PDA test using 185 kJ hammer without noise attenuation (summer)

    2D. PDA test using 185 kJ hammer with a confined bubble curtain as a noise attenuation mitigation measure (summer);

    2E. PDA test using 185 kJ hammer without noise attenuation (winter)

    2F. PDA test using 185 kJ hammer with a confined bubble curtain as a noise attenuation mitigation measure (winter);

    2G. PDA test using 300 kJ hammer without noise attenuation (summer)

    2H. PDA test using 300 kJ hammer with a confined bubble curtain as a noise attenuation mitigation measure (summer);

    2I. PDA test using 300 kJ hammer without noise attenuation (winter)

    2J. PDA test using 300 kJ hammer with a confined bubble curtain as a noise attenuation mitigation measure (winter);
3. Material placement with 4 tugs maneuvering near the terminal in:
    3A. Summer; and

    3B. Winter;
4. Dredging at the dredge basin with 2 tugs maneuvering;
5. Dredging and pumping ashore at the dredge basin with 3 tugs maneuvering and 1 tug towing a barge;
6. Pumping ashore at the dredge basin with 4 tugs maneuvering;
7. Pumping ashore and vibro-densification at the dredge basin with:
    7A. Four tugs maneuvering; and

    7B. Six tugs maneuvering and 1 tug towing a barge; and

8. Dredging, pumping ashore, and vibro-densification with:
    - 8A. No tugs; and
    - 8B. Six tugs maneuvering and 1 tug towing a barge.

Scenarios 1, 2A-D, 2G-H, 3A, 4, 5, 7B, and 8 were modelled with summer water conditions, and Scenarios 2E-F, 2I-J, 3B, 6, and 7A with winter water conditions. Figure 1 shows the locations of the acoustic sources. The source coordinates and depths are listed in Table 5. Table 6 lists the descriptions of modelled tug activities and Table 7 lists the details of each scenario.

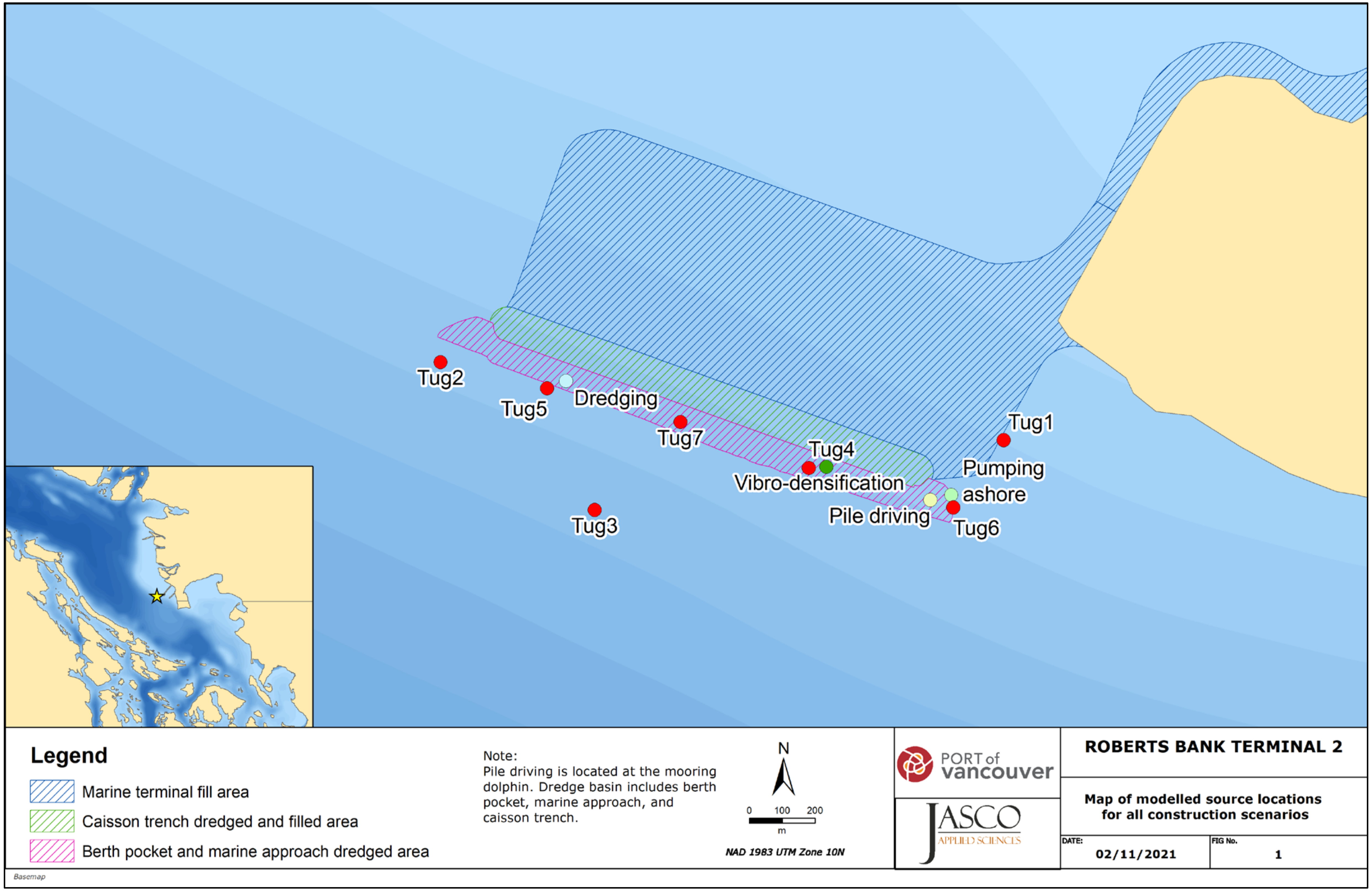

Figure 1. Map of modelled source locations for all construction scenarios.

Table 5. Specifications for each modelled sound source. Eastings/Northings are UTM Zone 10N. Figure 1 shows a map of these source locations. Note that the same MONM source location was used for modelling pile installation and PDA tests at the mooring dolphin and barge ramps, which is a reasonable assumption due to the close proximity of these activities.

Noise source	Latitude (N)	Longitude (W)	Easting (m)	Northing (m)	Source depth (m)
Vibratory hammering (APE 300/400B) at mooring dolphin and barge ramps	49°0.801'	123°10.652'	487018	5428956	7.7
Impact hammering (123 kJ hammer) at mooring dolphin and barge ramps					
PDA tests (185 and 300 kJ hammer) at mooring dolphin and barge ramps					
Dredger (vessel)	49°0.996'	123°11.567'	485903	5429319	2.14
Dredger (cutter head)					27.7
Pumping ashore (trailing arm suction hopper dredge FRPD309)	49°0.809'	123°10.599'	487081	5428971	4
6 Vibro-densifiers	49°0.855'	123°10.912'	486700	5429057	9.4
Tug 1 maneuvering at 3 kts	49°0.900'	123°10.468'	487242	5429139	3
Tug 2 maneuvering at 3 kts	49°1.026'	123°11.881'	485520	5429377	
Tug 3 towing at 6 kts	49°0.783'	123°11.494'	485992	5428926	
Tug 4 maneuvering at 3 kts	49°0.853'	123°10.957'	486646	5429054	
Tug 5 maneuvering at 3 kts	49°0.984'	123°11.614'	485846	5429298	
Tug 6 maneuvering at 3 kts	49°0.789'	123°10.594'	487089	5428934	
Tug 7 maneuvering at 3 kts	49°0.929'	123°11.279'	486255	5429194	

Table 6. Description of the modelled tug activities assumed for this study. Activities are based on the proposed project construction schedule and anticipated works and activities.

Number of modelled tugs	Relative tug activity level	Activity description
2	Low (25th percentile)	• 1 tug for maneuvering rig working on the rock face • 1 tug for either: o positioning pile driving rig for west basin barge ramp installation o or positioning pile driving rig for tug basin moorage pile installation o or positioning pump ashore pipelines o or positioning cutter suction dredge
4	Moderate (50th percentile)	• 1 tug for rock/material barges • 1 tug for pump ashore or cutter suction dredge • 1 tug for maneuvering rigs • 1 tug for positioning mattress rock densification rigs
7	High (75th percentile)	• 2 tugs for rock/material barges • 1 tug for cutter suction dredge at dredge basin • 2 tugs for maneuvering rigs placing either berm rock, caisson ballast, berm filter, scour protection or toe protection rock • 2 tugs for positioning mattress rock densification rigs

Table 7. Description of the modelled scenarios: Modelled noise sources, the applicable bathymetry data set (see Section 2.2.3.1), and the season of the sound speed profile (SSP) that represents the water conditions (see Section 2.2.3.3).

Scenario	Description	Noise source(s)	Bathymetry data set	SSP season
1	Vibratory piling 914 mm diameter cylindrical pile at mooring dolphin	Vibratory hammer	1	Summer
2A	Impact piling 914 mm diameter cylindrical pile, *without* confined bubble curtain mitigation, at mooring dolphin and barge ramps	123 kJ Impact hammer (without bubble curtain)	1	Summer
2B	Impact piling 914 mm diameter cylindrical pile, *with* confined bubble curtain mitigation, at mooring dolphin and barge ramps	123 kJ Impact hammer (with bubble curtain)	1	Summer
2C	PDA test 914 mm diameter cylindrical pile, *without* confined bubble curtain mitigation, at barge ramps	185 kJ Impact hammer (without bubble curtain)	1	Summer
2D	PDA test 914 mm diameter cylindrical pile, *with* confined bubble curtain mitigation, at barge ramps	185 kJ Impact hammer (with bubble curtain)	1	Summer
2E	PDA test 914 mm diameter cylindrical pile, *without* confined bubble curtain mitigation, at barge ramps	185 kJ Impact hammer (without bubble curtain)	1	Winter
2F	PDA test 914 mm diameter cylindrical pile, *with* confined bubble curtain mitigation, at barge ramps	185 kJ Impact hammer (with bubble curtain)	1	Winter
2G	PDA test 914 mm diameter cylindrical pile, *without* confined bubble curtain mitigation, at mooring dolphin	300 kJ Impact hammer (without bubble curtain)	1	Summer
2H	PDA test 914 mm diameter cylindrical pile, *with* confined bubble curtain mitigation, at mooring dolphin	300 kJ Impact hammer (with bubble curtain)	1	Summer
2I	PDA test 914 mm diameter cylindrical pile, *without* confined bubble curtain mitigation, at mooring dolphin	300 kJ Impact hammer (without bubble curtain)	1	Winter
2J	PDA test 914 mm diameter cylindrical pile, *with* confined bubble curtain mitigation, at mooring dolphin	300 kJ Impact hammer (with bubble curtain)	1	Winter
3A	Material placement and moderate tug activity in *summer*	Tugs 1, 2, 5, 6 maneuvering (3 kts)	4	Summer
3B	Material placement and moderate tug activity in *winter*	Tug 1, 2, 5, 6 maneuvering (3 kts)	4	Winter
4	Dredging the dredge basin* and low tug activity	Dredger (vessel) Dredger (cutter head) Tugs 2, 5 maneuvering (3 kts)	2	Summer
5	Dredging, pumping ashore combo, and moderate tug activity	Dredger (vessel) Dredger (cutter head) Trailing arm suction hopper dredge Tugs 2, 5, 6 maneuvering (3 kts) Tug 3 towing (6 kts)	2	Summer
6	Pumping ashore and moderate tug activity	Trailing arm suction hopper dredge Tugs 1, 4, 6, 7 maneuvering (3 kts)	2	Winter
7A	Pumping ashore, vibro-densification, and moderate tug activity at dredge basin in *winter*	Trailing arm suction hopper dredge 6 Vibro-densifiers	3	Winter

Scenario	Description	Noise source(s)	Bathymetry data set	SSP season
		Tugs 4–7 maneuvering (3 kts)		
7B	Pumping ashore, vibro-densification, and high tug activity at dredge basin in *summer*	Trailing arm suction hopper dredge	3	Summer
		6 Vibro-densifiers		
		Tugs 1, 2, 4–7 maneuvering (3 kts)		
		Tug 3 towing (6 kts)		
8A	Dredging, pumping ashore, and vibro-densification at dredge basin	Dredger (vessel)	3	Summer
		Dredger (cutter head)		
		Trailing arm suction hopper dredge		
		6 Vibro-densifiers		
8B	Dredging, pumping ashore, vibro-densification, and high tug activity at dredge basin	Dredger (vessel)	3	Summer
		Dredger (cutter head)		
		Trailing arm suction hopper dredge		
		6 Vibro-densifiers		
		Tugs 1, 2, 4–7 maneuvering (3 kts)		
		Tug 3 towing (6 kts)		

* Dredge basin includes berth pocket, marine approach, and caisson trench.

2.2.2. Acoustic Sources

Several construction activities were modelled including impact and vibratory piling of cylindrical piles, impact piling of cylindrical piles with and without confined bubble curtain as a mitigation measure, vibro-densification, dredging, pumping ashore with trailing arm suction hopper dredge, and tugs transiting (towing and maneuvering). The 1/3-octave-band source levels for each activity, discussed below, were derived from measurements collected by JASCO or obtained from a literature review. The source levels for pile driving (vibratory and impact), cutter suction dredge, and vibro-densification were the same as used in the EIS modelling study (Wladichuk et al. 2014). Source levels for pumping ashore with a trailing arm suction hopper dredge were obtained from a collection of underwater dredge measurements obtained in the North Sea by de Jong et al. (2010). Source levels for support tugs were adapted from a previous modelling study of cumulative regional vessel noise undertaken in support of the RBT2 EIS cumulative effects assessment (MacGillivray et al. 2014).

2.2.2.1. Impact Pile Driving (Cylindrical Pile)

Several sizes of cylindrical steel piles will be used during RBT2 construction, of which the largest is anticipated to be 914 mm in diameter. Impact piling source levels were based on the largest expected pile size for the project, which typically require the most hammer energy to drive the pile into the seabed and have higher source levels. At the time of the EIS modelling study, specifications of impact hammers that would be used during RBT2 construction had not been determined; therefore, estimated source levels were based on published measurements for similar piling activities. Impact piling is most often carried out using hydraulic or diesel impact hammers. A representative broadband source level for impact piling of 914 mm diameter steel cylindrical piles was based on measurements of impact piling of 914 mm diameter piles in 10 m of water using a Delmag diesel D36-32 hammer with ram weight of 3,600 kg (Humboldt Bay Bridges, Oestman et al. 2009). The maximum impact energy of the Delmag hammer is 123 kJ at a drop height of 3.4 m with a rate of 35 strikes/min.

The per-pulse sound exposure level measured at 10 m range was 183 dB re 1 µPa^{2}s. Assuming spherical spreading (20log*r*), the sound exposure source level would be 203 dB re 1 µPa^{2}m^{2}s. These measurements did not include 1/3-octave-band levels, so this broadband level was divided into 1/3-octave-band levels using the averaged spectrum for impact piling of 4 to 6 foot diameter piles (MacGillivray et al. 2011). The spectrum was extrapolated beyond 16 kHz using the trend of the spectrum from 6.3 to 16 kHz.

The updated project construction approach (Moffatt and Nichol 2021) plans for PDA testing of piles at the barge ramp and mooring dolphin, using larger hammers (185 kJ and 300 kJ, respectively) than were originally assumed for impact pile driving in the EIS but for a much shorter duration. A PDA test involves striking a single pile a small number of times to verify its load-bearing capacity. A conservative estimate is that each pile would be struck 17 times (15 strikes + 15% contingency added), with PDA testing limited to one pile per 24-hour period. To account for the larger hammer energy required for the PDA testing, source levels from the EIS scenarios were scaled according to the decibel ratio of the modelled and reference hammer energies. Figure 2 shows the resulting 1/3-octave-band source levels. The modelled source depth for all piling sources was taken to be the mid-water column depth at the piling location.

Bubble curtain mitigation may be used during pile driving, so the average attenuation from a confined bubble curtain on impact piling levels was applied to the unmitigated piling source levels. MacGillivray et al. (2011) averaged confined bubble curtain attenuation values from several studies. The 1/3-octave-band attenuation was extrapolated beyond 6.3 kHz with a constant value of attenuation of 6.3 kHz (i.e., 12.9 dB). Confined bubble curtains are more effective at attenuating high frequencies, so this approach is expected to be conservative. Source levels for mitigated impact piling of cylindrical piles were calculated by subtracting the attenuation from the source levels of unmitigated impact piling. Figure 2 shows the resulting 1/3-octave-band source levels (along with those of vibratory piling, which are described in the next section). At 10 m range, the modelling showed that the confined bubble curtain reduced the broadband SEL from impact pile driving by 10.2 dB (unweighted).

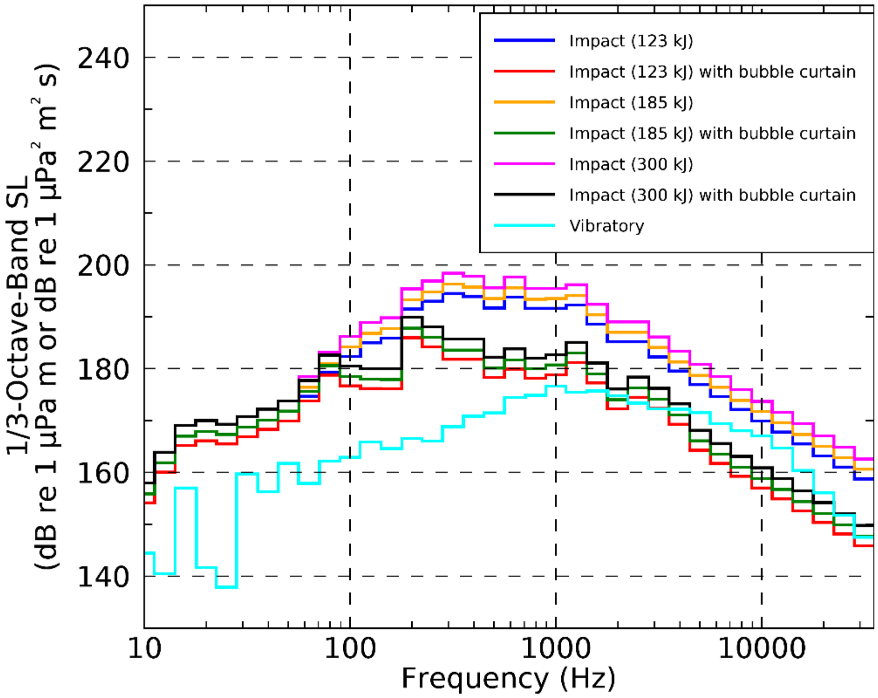

Figure 2. Source levels for impact (SEL) and vibratory (SPL) pile driving in 1/3-octave-bands.

2.2.2.2. Vibratory Pile Driving (Cylindrical Pile)

Specifications of vibratory hammers that will be used during RBT2 construction have not yet been determined; therefore, source levels for vibratory piling of the 914 mm diameter steel cylindrical piles were modelled based on published vibratory piling 1/3-octave-band source levels (Racca et al. 2007) and measurements for similarly sized piles (Blackwell 2005). The Racca at al. (2007) measurements were from an APE 300 vibro-hammer with 1,842 kilonewton (kN) centrifugal force driving a 900 mm diameter pile. The Blackwell measurements were from an APE model 400B hammer driving a 914 mm pile. The Blackwell measurements were back-propagated from 10 to 1 m using spherical spreading and were averaged with the Racca source level measurements over their common frequency range of 10 Hz to 5 kHz. The Blackwell measurements extended to 16 kHz so the levels between 6.3 and 16 kHz were shifted by +6.9 dB to match the trend of the averaged spectrum. The levels were then extrapolated to 63 kHz using the trend of the 12.5 and 16 kHz levels. Resulting 1/3-octave-band source levels are shown in Figure 2.

2.2.2.3. Vibro-densification

Source levels for two vibro-densifiers were measured at Roberts Bank during the Deltaport Third Berth project (DP3) for 1/3-octave-bands between 10 Hz and 40 kHz (Austin 2007). Source levels for vibro-densification in this study were taken from the maximum of the two measurements in each 1/3-octave-band. The source levels were extended to 63 kHz by extrapolating the trend of the source levels in the bands between 20 and 40 kHz (Figure 3). The modelled source depth for vibro-densification was taken to be mid-water column. The construction schedule anticipates that six vibro-densification rigs (1 vibratory head per rig) will be operating simultaneously at the project site (a single rig operating a single vibratory head was assumed in the EIS Modelling Study). Noise from the six rigs was assumed to be additive and radiating from a single location, because they are anticipated to be working in close proximity during vibro-densification. To reflect the increased noise generated by six rigs operating together, radiated sound power for a single rig was multiplied by a factor of six (corresponding to an incoherent increase in the source level of $10\log_{10}(6) = 7.8$ dB).

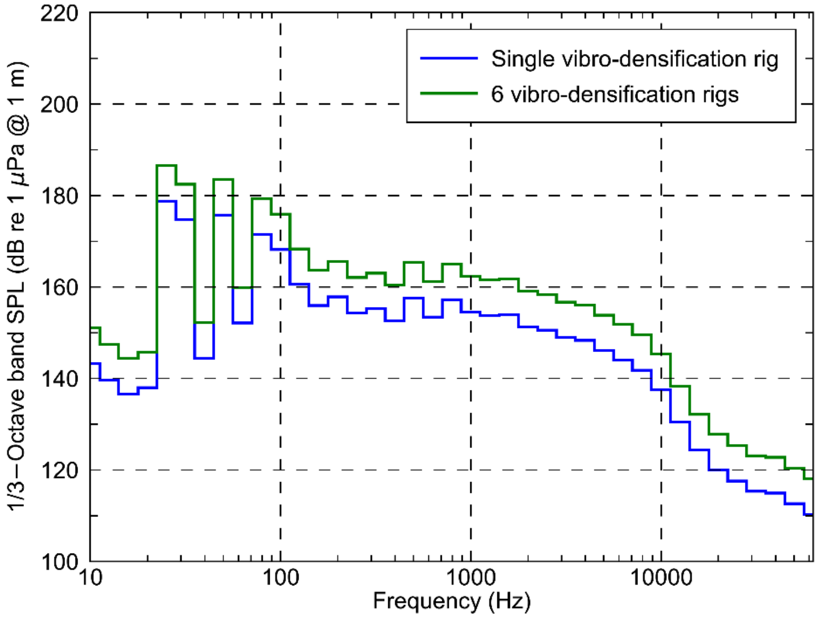

Figure 3. One-third-octave-band source levels for vibro-densification using a single rig (blue line, from the EIS Modelling Study) and 6 rigs (green line; used in the current study).

2.2.2.4. Cutter Suction Dredge

Source levels for dredging operations were derived from source level measurements of the *Columbia* dredger measured for DP3 (Zykov et al. 2007). Source levels were extrapolated beyond 40 to 63 kHz using the trend of source levels in bands between 20 and 40 kHz. Robinson et al. (2011) found that underwater noise from marine dredgers in the 1 to 2 kHz frequency range were generated near the cutter head on the seafloor and that below 500 Hz, noise levels were similar to those generated by transiting cargo ships. Modelled dredger source levels were therefore split between the vessel (below 1 kHz) and the cutter head (1 kHz and above) with the acoustic source depth for the vessel and cutter head at 2.14 m below the sea surface (the *Columbia's* draft) and 1 m above the seafloor, respectively (Figure 4).

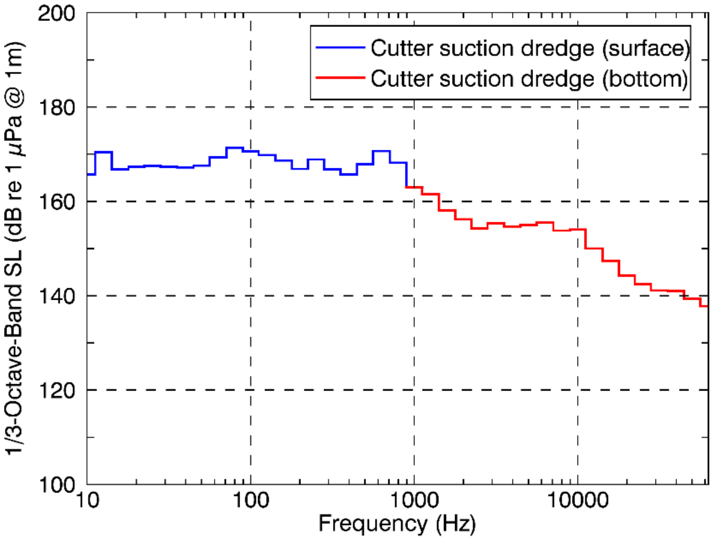

Figure 4. One-third-octave-band source levels for cutter suction dredging. Dredging source levels below 1000 Hz are assumed to originate from the dredge vessel hull near the surface, and levels at and above 1000 Hz are assumed to originate from the cutter head near the seafloor.

2.2.2.5. Pumping Ashore

For the project, a trailing arm suction hopper dredge (THSD) with pump-ashore capabilities is anticipated to be used to pump sand collected from the Fraser River directly into containment basins as a slurry to provide fill for the proposed terminal. The THSD planned for this activity is the FRPD309. According to a 2018 literature review by JASCO (Wladichuk and MacGillivray 2018), de Jong et al. (2010) provide the best surrogate measurements for the FRPD309 pumping ashore while anchored, based on dredge specifications and operations. The rainbowing measurements (which involved pumping of sediments by a similarly-sized dredger) were believed to be an appropriate surrogate for this activity. In the current study, the source levels for pumping ashore were averaged over Dredge 1 and 4 rainbowing from de Jong et al. (2010), and extrapolated to 10 Hz with a constant value, which was believed to be conservative (Figure 5). The source depth for the TSHD was assumed to be 4 m, as stated in de Jong et al. (2010).

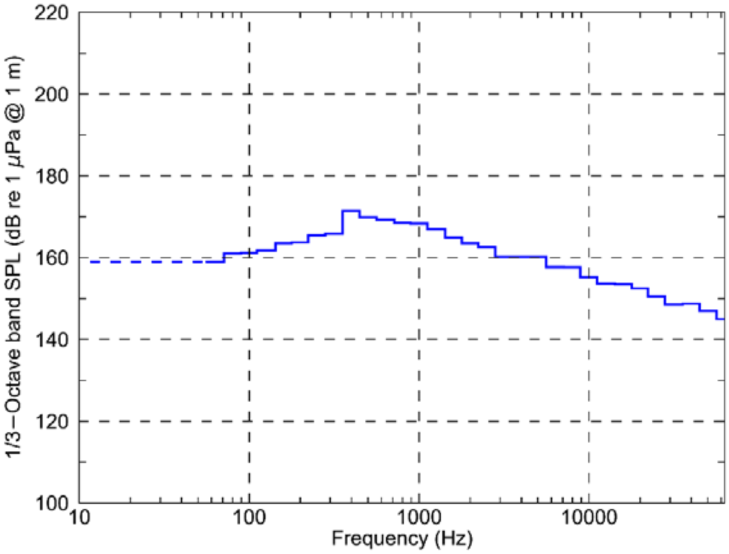

Figure 5. One-third-octave-band source levels for pumping ashore with a trailing arm suction hopper dredge (THSD).

2.2.2.6. Construction Tug Activity (Maneuvering and Barge Towing)

Various model scenarios included support tugs (see also Table 7). The speeds of the support tugs during maneuvering and barge towing activities were determined through consultation with the project's engineering team:

- Scenarios 3A and 3B: Four tugs performing material placement, operated at a maneuvering speed of 3 kts.
- Scenario 4: Two tugs assisting with dredging, operated at a maneuvering speed of 3 kts.
- Scenario 5: Four tugs assisting with dredging and pumping ashore with a THSD. Three were assumed at a maneuvering speed of 3 kts, and one towing a barge at 6 kts.
- Scenario 6: Four tugs assisting with pumping ashore with a THSD, all maneuvering at 3 kts.
- Scenarios 7A and 7B: Four tugs (winter Scenario 7A) or seven tugs (summer Scenario 7B) assisting with pumping ashore with a THSD and vibro-densification. For Scenario 7B, one tug was towing a barge at a speed of 6 kts. And all other tugs were maneuvering at 3 kts.
- Scenario 8B: Seven tugs assisting with dredging, pumping ashore with a THSD, vibro-densification. Six were maneuvering at 3 kts, and one was towing a barge at 6 kts.

The source levels (Figure 6) for the tugs were obtained from the RBT2 EIS Regional Commercial Vessel Traffic Underwater Noise Exposure Study (Vessel class 5 in MacGillivray et al. (2014), Wladichuk et al. (2014)) and adjusted to the speeds of 3 and 6 kts based on the classical power-law model of Ross (1987), which relates changes in source level (SL) to relative changes in speed:

$$\mathrm{SL} - \mathrm{SL}_{\mathrm{ref}} = C_v \times 10 \log_{10}\left(\frac{v}{v_{\mathrm{ref}}}\right). \tag{1}$$

In this equation, SL is the source level at a speed through water, v, $\mathrm{SL}_{\mathrm{ref}}$ is the source level at some reference speed v_{ref}, and C_v is a speed scaling coefficient. The speed scaling coefficient for tugs is C_v = 1.8 (MacGillivray et al. 2019). The source depth was selected as 3 m, which was based on the tug draft.

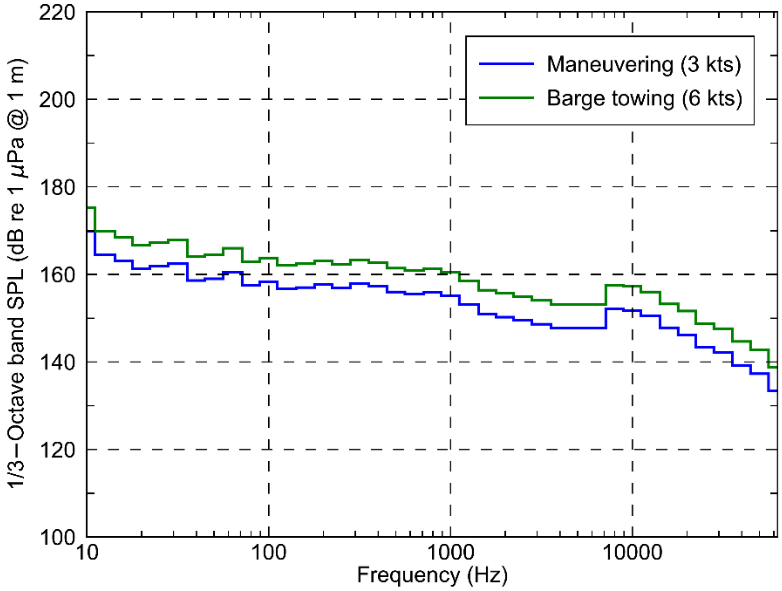

Figure 6. One-third-octave-band source levels for a tug maneuvering at speed of 3 kts and barge towing at speed of 6 kts.

2.2.2.7. Becker Penetration Test

The Becker penetration test (BPT) is a geotechnical sampling method that involves hammering a small diameter (15-20 cm) steel probe into the ground to measure the geotechnical properties of rocks, sand, or soil. During construction of RBT2, BPT would likely be used to confirm that rockfill mattress placed in the berth pocket conforms to design specifications. A literature review found no previous measurement or assessment of underwater noise from BPT, nor for impact driving of similar sizes of pipe piles. Therefore, a structural acoustic model for impact pile driving (MacGillivray 2014) was used to perform a screening level assessment of underwater noise predicted from this activity (see Appendix E for details).

2.2.3. Environmental Parameters

2.2.3.1. Bathymetry

Four data sets were used to represent the bathymetry over the course of construction. Data set 1, representing pre-construction conditions, is a combination of high-resolution (10 m) bathymetry data (within several kilometres of Roberts Bank, provided by Hemmera), data from the NOAA digital elevation model data (NGDC 2013) and the Canadian Hydrographic Service data provided by Nautical Data International Inc. These bathymetry data were re-projected onto a 20 × 20 m grid in UTM zone 10N.

Construction of the proposed project will involve changing the bathymetry for the construction of the proposed terminal (e.g., dredging). Data sets 2, 3, and 4 are modified versions of Data set 1 that represent the bathymetry at different phases of construction. Table 8 describes the four bathymetry data sets, including the construction activity associated with bathymetry changes, the corresponding modifications to the original bathymetry data set, and the model scenarios for which the data sets were used.

Table 8. Construction activities and the corresponding bathymetry modifications for the bathymetry data sets used for the scenarios. CD = chart datum.

Bathymetry data set	Description	Bathymetry modification	Applicable scenarios
1	Pre-construction	None	1–2
2	Dredge basin (berth pocket, approaches, and caisson trench) dredged to −30 m CD	Depth within berth pocket set to 26.7 m Depth within RBT2 set to 0 m (i.e., land)	4–6
3	Berth pocket filled to approx. −21.6 m	Depth within berth pocket set to 21.6 m Depth within RBT2 set to 0 m (i.e., land)	7–8
4	Perimeter dyke in place	Depth within RBT2 set to 0 m (i.e., land)	3

2.2.3.2. Geoacoustic Properties

This study used the seabed geoacoustic profile from the EIS Modelling Study, which was derived from a combination of geoacoustic inversion results from transmission loss measurements (Warner et al. 2013) and a review of typical properties for many common seabed materials (Hamilton 1980). Table 9 lists the seabed geoacoustic parameters used for all modelled scenarios in this study.

Table 9. Geoacoustic model of the seabed used for sound propagation modelling. Within each depth range, each parameter varies linearly within the stated range.

Depth below seafloor (m)	Material	Density (g/cm^3)	Compressional wave		Shear wave	
			Speed (m/s)	**Attenuation (dB/λ)**	Speed (m/s)	**Attenuation (dB/λ)**
0–100	Fluvial silt deposits	1.4–1.9	1502–1602	1.61–0.1	125	2.2
>100	Compact sand and rock	1.9	2275	0.1		

2.2.3.3. Sound Speed Profiles

The EIS Modelling Study used a single sound speed profile (SSP) that represented winter conditions at Roberts Bank. This was a conservative approach, because the more upward-refracting SSP in winter (compared to that measured in spring/summer (Warner et al. 2013)) allows for greater propagation of sound energy by reducing propagation loss due to bottom interactions. The present study uses both the winter SSP from the EIS Modelling Study and a second SSP to represent summer conditions.

The winter SSP was based on data measured near Roberts Bank in February 2007 that were collected during another previous modelling study for DP3 (McHugh et al. 2007). The profile reached 28 m depth and was extrapolated to 400 m (deeper than the maximum depth in the model area) using the depth-dependence of sound speed given by Coppens (1981):

$$c(z) = c(z_0) + 0.016(z - z_0) \tag{2}$$

where c is sound speed (m/s), z_0 is the reference depth (m), and z is the extrapolation depth (m). Figure 7 shows the extrapolated SSP used for this study.

The summer SSP is the average of numerous measurements collected in July near the proposed project from 2006 to 2010 by Fisheries and Oceans Canada (DFO) Institute of Oceans Sciences.

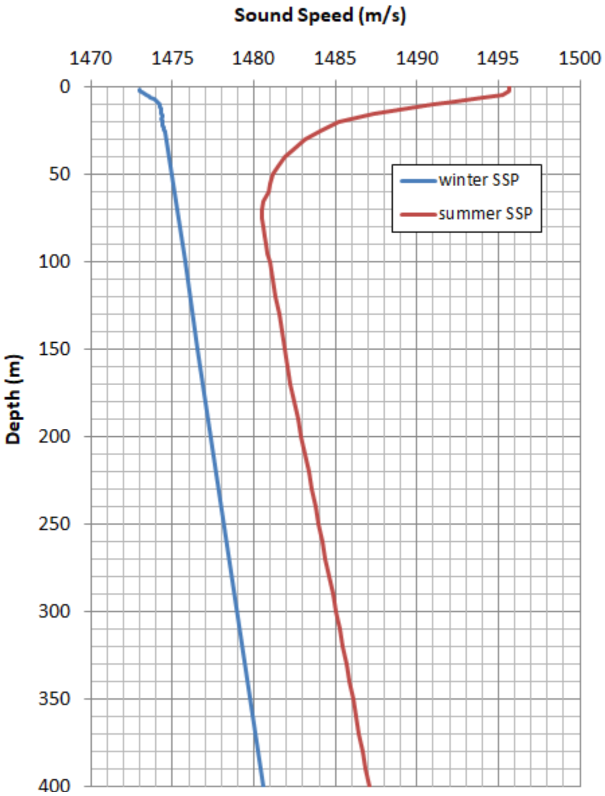

Figure 7. Sound speed profile extrapolated from a measurement near Roberts Bank (McHugh et al. 2007).

2.2.4. Calculating Distances to Threshold Levels (R_{max} and $R_{95\%}$)

Sound level contours were calculated based on the underwater sound fields predicted by the propagation models, sampled by taking the maximum value over all modelled depths above the seafloor for each location in the modelled region. The predicted distances to specific levels were computed from these contours. Two distances relative to the source are reported (in meters): (1) R_{max}, the maximum range to the given sound level, and (2) $R_{95\%}$, the range to the given sound level after the 5% farthest points were excluded (see examples in Figure 8).

The $R_{95\%}$ is used because sound field footprints are often irregular in shape. In some cases, a sound level contour might have small protrusions or anomalous isolated fringes. This is demonstrated in the image in Figure 8. In cases such as this, where relatively few points are excluded in any given direction, R_{max} (the maximum range to the given sound level) can misrepresent the area of the region exposed to such effects, and $R_{95\%}$ is considered more representative.

For the model scenarios with a single source (1, 2A, and 2B), the R_{max} and $R_{95\%}$ radii are calculated in terms of the radial distance from the source location. For scenarios (3–8), involving multiple activities at different locations, the R_{max} and $R_{95\%}$ radii were calculated relative to the centre of the berth face (Table 10) in the following two directions: (1) parallel to the berth face and (2) perpendicular to the berth face. Figure 9 shows an example of $R_{95\%}$ range to the 120 dB re 1 µPa SPL threshold in the perpendicular and parallel directions from the centre-berth-face reference point. The average of the parallel and perpendicular radii are also provided for scenarios 3–8.

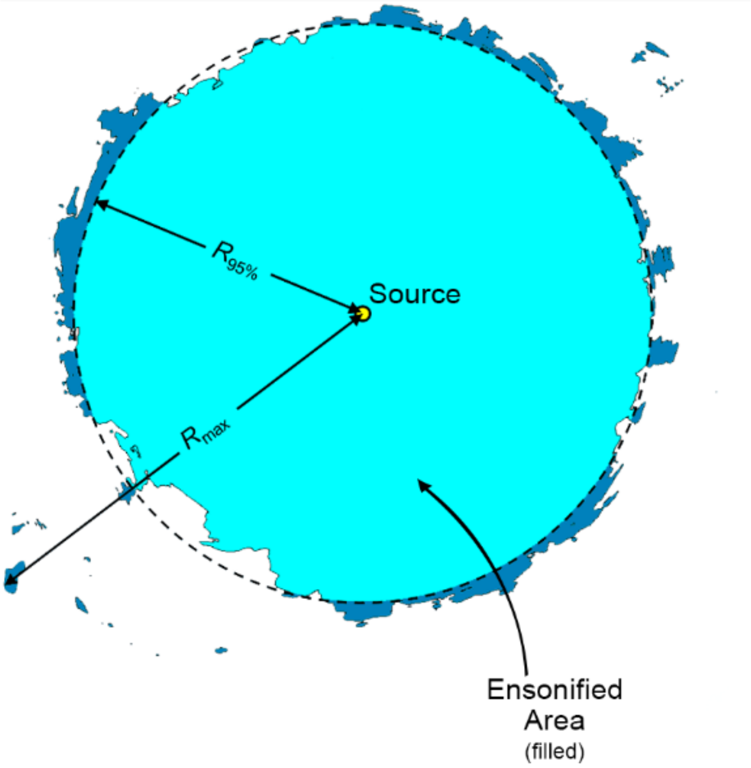

Figure 8. Sample areas ensonified to an arbitrary sound level with R_{max} and $R_{95\%}$ ranges shown. Light blue indicates the ensonified areas bounded by $R_{95\%}$; dark blue indicates the ensonified areas beyond $R_{95\%}$ that determine R_{max}.

Table 10. Coordinates of the centre of the berth face (i.e., mid berth face), the reference point for the R_{max} and $R_{95\%}$ radii provided for the multi-activity scenarios (Scenarios 3–8). Easting and Northing are in UTM Zone 10N.

Reference point	Latitude (N)	Longitude (W)	Easting (m)	Northing (m)
Centre of berth face	49°0.944'	123°11.214'	486333	5429222

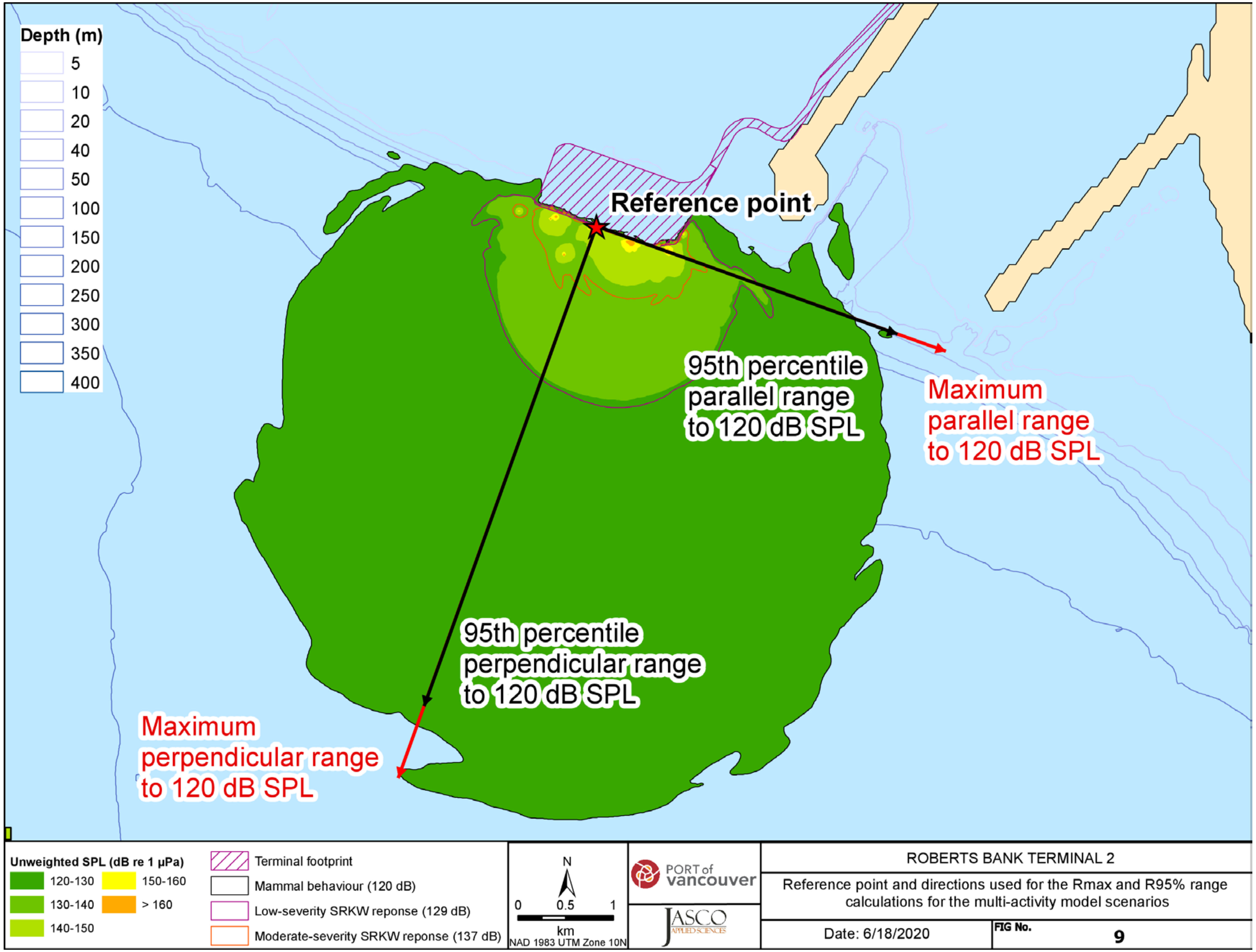

Figure 9. Reference point and directions used for the R_{max} and $R_{95\%}$ range calculations for the multi-activity model scenarios.

2.3. Modelling Detection Range of SRKW Vocalizations

Another major objective of this study was to calculate the acoustic detection ranges for SRKWs near RBT2 during construction. Results of this analysis will be used to determine potential effectiveness of PAM as a mitigation measure during project construction and the design of a PAM system. This analysis is based on the methods used by JASCO during the 2012 baseline ambient monitoring project at Roberts Bank (Mouy et al. 2012). The detection range analysis focused on the summer scenarios, since historical sightings data suggest that SRKW are mainly present in the study area from May to September (Hemmera 2014).

The acoustic detection range of killer whale vocalizations is estimated by calculating the distance from an acoustic recorder within which the received sound level of a vocalization is higher than a given detection threshold (DT) above the ambient noise level (NL) in the same frequency band. The received sound level of a whale vocalization (RL, in dB re 1 µPa) at a distance r and in the frequency band f, is the difference between the sound level at the source (i.e., the whale) and the transmission loss between the killer whale and the hydrophone (Urick 1983):

$$\mathrm{RL}(f,r) = \mathrm{SL}(f) + \mathrm{PL}(f,r) \ , \tag{3}$$

where, SL is the source level in dB re 1 µPa @ 1 m and PL is the transmission loss in dB re 1 m. It was assumed that sound levels of the whale vocalizations decayed according to a spherical spreading law at all frequencies and that killer whales are omnidirectional acoustic sources. Consequently, the propagation loss was defined as:

$$\mathrm{PL}(r) = 20\log_{10}(r) \ , \tag{4}$$

where, r is the distance between the killer whale and the recorder in metres. Absorption of sound in the water was negligible at the frequencies and distances measured (absorption coefficient ~0.002 dB/m) (François and Garrison 1982) and was therefore not taken into account.

The maximum distance where a vocalization can be detected is that at which the vocalization's received level, RL, exceeds the noise level, NL, at the recorder in the same frequency band by at least the detection threshold, DT:

$$\mathrm{RL}(f,r) \geq \mathrm{NL}(f) + \mathrm{DT} \ . \tag{5}$$

DT was set to 0 dB for this analysis, as automated detectors typically perform well above that signal-to-noise ratio (Mouy et al. 2012). The detection threshold used here strictly represents the signal processing detection threshold for automated detectors and is not related to the listening detection threshold of the animals. For this analysis, we obtained whale vocalizations source levels from published literature (Section 2.3.2) and baseline 24 hour (24 h) ambient and vessel noise levels from previous study of incremental changes at Roberts Bank due to terminal operations (MacGillivray et al. 2019) (Section 2.3.3).

The detection range was estimated separately for each frequency band of the vocalization and the final detection range was defined as:

$$R_{\max} = \arg max_f \left(R(f)\right) \ , \tag{6}$$

where $R(f)$ is the detection range at the frequency band f. As in Miller (2006), the detection range was estimated for each 1/3-octave-band from 0.5 Hz to 12.5 kHz.

The detection range was calculated for each minute of the ambient noise data. Here, we used 144,000 min of simulated noise data (see Section 2.3.3). The probability of detecting a killer whale vocalization at a given range was then taken to be the number of minutes with a detection range equal to or greater than that range divided by the total number of minutes. To estimate the detection range of the killer whale vocalization, a Monte-Carlo simulation was used to account for the measured variability in source levels. Detection ranges were calculated 1,000 times for all noise levels available (Section 2.3.3) by randomly choosing normally distributed source level values with the means and standard deviations described in Section 2.3.2. Each iteration of the Monte-Carlo process provided a probability of detection at each range from the hydrophone.

The distribution of the 1,000 detection probabilities obtained at the end of the Monte-Carlo simulation are represented for each range by the 25th, 50th, and 75th percentile probability curves (Figure 10). To facilitate the interpretation of the results, discrete detection range values reached 90%, 50%,10%, and 0.1% of the time (i.e., detection probabilities of 0.9, 0.5, 0.1, and 0.001, respectively) are reported separately for the 50th percentile probability curve (red dots in Figure 10) and the 75th percentile probability curve (green dots in Figure 10). Note that the detection range obtained 0.1% of the time is considered the maximum detection range possible reached under the most optimal conditions (i.e., loudest source level possible and lowest noise level possible).

The killer whale detection range was estimated separately for stereotyped calls and whistles (see Section 2.3.2), and for day (i.e., 06:00 to 21:59 PDT) and night (i.e., 22:00 to 05:59 PDT).

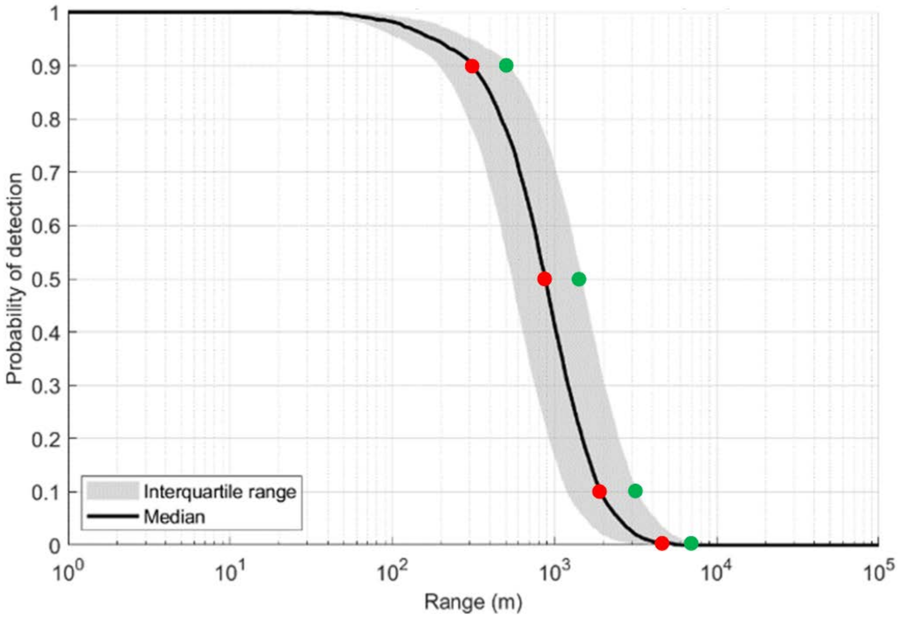

Figure 10. Representation of the detection range results: Distribution of detection probabilities at each range described by its interquartile range (grey shading), and its median (solid line). Red and green dots represent the discrete detection range values that are reported (see Tables 27 and 28) based on the median and 75th percentile probabilities, respectively.

2.3.1. Study Locations

The detection ranges of killer whale calls were estimated at three locations (PAM 1, 2, and 3) where PAM nodes could potentially be deployed for mitigation purposes during construction. These PAM locations are listed in Table 11 along with the distances between them and their distance from the mid berth face (the reference point at the centre of the berth face from which the R_{max} and $R_{95\%}$ radii are calculated; see Section 2.2.4). The locations are mapped in Figure 11, which also shows the location of the Autonomous Multichannel Acoustic Recorder (AMAR) that was deployed in 2012 and AIS vessel tracking data that were collected during the same period (Mouy et al. 2012). The data from this AMAR were used in the background sound level characterization described below in Section 2.3.3. The PAM locations were selected to be outside the major vessel traffic lanes and far enough from the construction zone (i.e., >6 km; Table 11) to maximize the ability to detect killer whales before they enter the general zone of construction acoustic effects.

Table 11. Coordinates of the detection range modelling locations and their distances (km) from the RBT2 construction site (mid berth face) and from each other.

PAM location	Latitude (N)	Longitude (W)	Approx. depth (m)	Distance to mid berth face (km)	Distance to PAM 1 (km)	Distance to PAM 2 (km)	Distance to PAM 3 (km)
1	49°3.035’	123°16.509’	30	7.53	0.	13.81	5.66
2	48°59.276’	123°6.746’	50	6.26	13.79	0.	11.37
3	49°0.000’	123°6.000’	100	6.09	5.66	11.37	0.

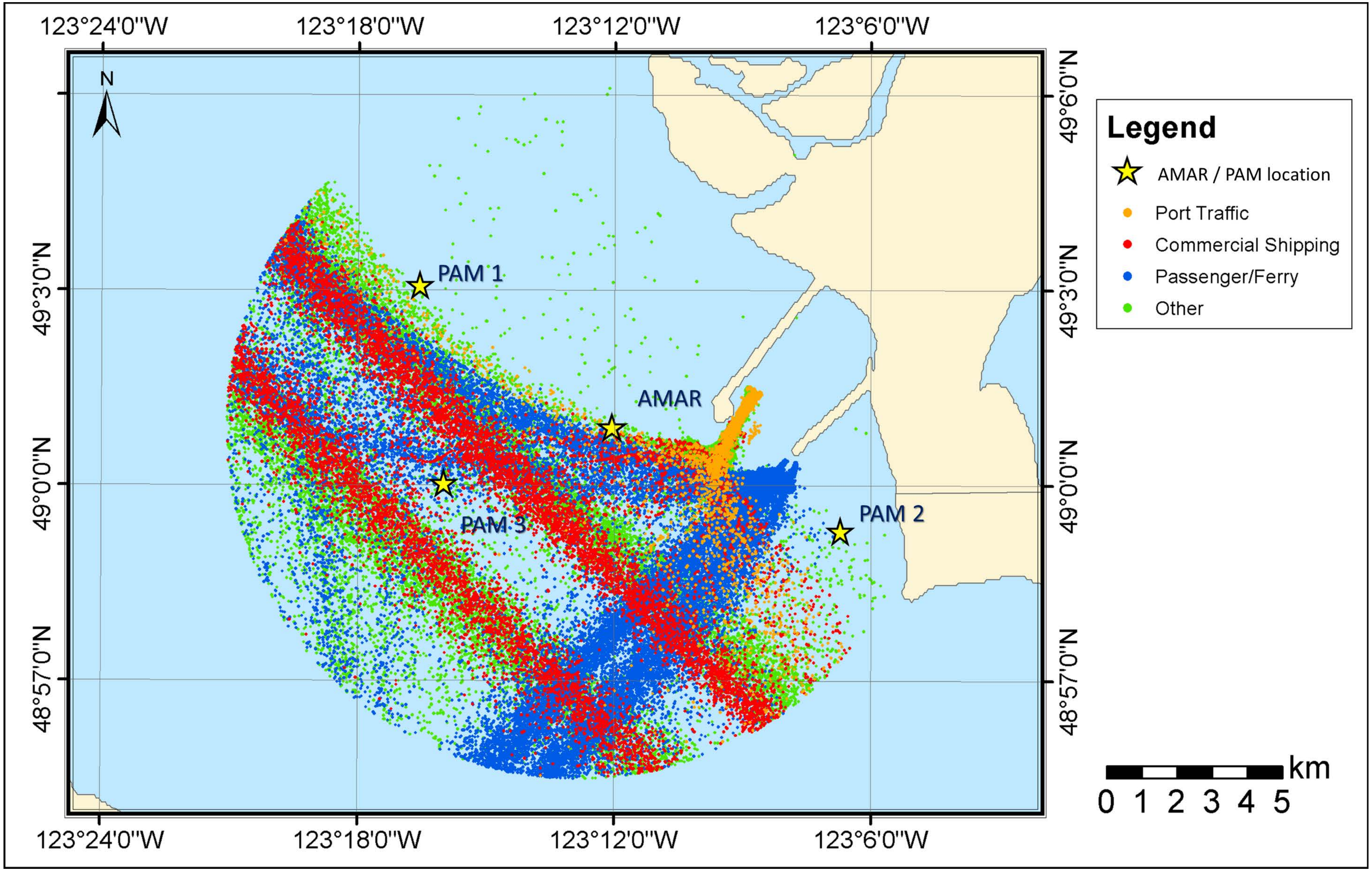

Figure 11. Detection range modelling locations and AIS ship tracking signals recorded at Roberts Bank From 22 Jul to 24 Sep 2012.

2.3.2. Source Levels of Killer Whale Vocalizations

As described above, the estimation of detection ranges requires knowledge of the call source levels. Source levels of various killer whale calls were obtained from the literature and are summarized in Table 12. Detection ranges were calculated independently for whistles and stereotyped calls. The source levels for whistles were taken from (Miller 2006) and for stereotyped calls from Holt et al. (2011). Because the literature did not provide source levels in 1/3-octave-bands as required, we assumed that the sound energy from the calls was equally partitioned across the 1/3-octave-bands from 0.5 Hz to 12.5 kHz.

Table 12. Source levels (mean ± SD broadband levels) of killer whale sounds from the literature. Bolded values were used in the present study for determination of detection ranges.

Study area	Population	Call type	Source level (dB **re 1 µPa** @ 1 m)	Source
Johnstone Strait, BC	Northern resident	Whistles	140.2 ± 4.1	Miller (2006)
		Variable calls	146.6 ± 6.6	
		Stereotyped calls	152.6 ± 5.9	
San Juan Islands, WA	Southern resident (J pod)	Stereotyped calls	155.3 ± 7.4	Holt et al. (2009)
	Southern resident (J, K, and L pods)	Stereotyped calls	155.1 ± 6.5	Holt et al. (2011)

2.3.3. Background Sound Level Characterization

The estimation of detection ranges requires knowledge of the background sound levels. Since no *in situ* passive acoustic measurements were available at the three PAM locations, we estimated background sound levels at these three locations based on a baseline 24 h ambient and vessel noise model that was used for a previous study of incremental contributions of project operations at Roberts Bank (MacGillivray et al. 2019). AIS data used in the 2019 model simulations were from 30 Jul 2015. To ground-truth the model, baseline sound levels were adjusted based on sound level measurements obtained from *in situ* AMAR data collected off Roberts Bank in summer (July to September) 2012 (Mouy et al. 2012). The noise model provided noise levels in 1/3-octave-bands from 0.5 to 12.5 kHz for each minute of a simulated 24 h period. Noise levels from the model were then adjusted based on the *in situ* AMAR data to provide more accurate noise levels for the detection range analysis.

Estimates of the background sound levels were estimated as follows. Sound levels from the 24 h model were extracted for the AMAR location where the *in situ* data were collected in summer 2012 (see Figure 11). A normally distributed, random correction factor, in decibels, was added to the broadband (0.44–14.0 kHz) sound levels of each of the 1 min sound levels from the model. The mean (μ) and standard deviation (σ) of the distribution from which the correction factors were randomly sampled, were defined by minimizing the difference between the cumulative distribution functions (CDF; see Glossary) of the adjusted model levels and the *in situ* measurements. Correction factors were defined independently for day (06:00 to 21:59 PDT) and night (22:00 to 05:59 PDT). Using normally distributed correction factors (μ ± σ) of 4.6 ±4 dB and 0 ±4 dB for day and night, respectively, yielded a good match between the adjusted model levels and the *in situ* measurements (Figure 12). Figure 13 shows an example of a time series of adjusted model levels for a 24 h period (1440 min) at the AMAR location. Normally distributed correction factors with the same mean and standard deviation were applied to the sound levels from the model at locations PAM 1, 2, and 3 and were used for the detection range analysis. The model adjustment process was repeated 100 times to effectively simulate 100 days (144,000 min) of sound level data at each PAM location.

To assess how construction noise at the RBT2 site affects the detection range of killer whale calls, the 1/3-octave-band noise level from each construction scenario (see Section 2.2) was added to the adjusted 24 h model levels.

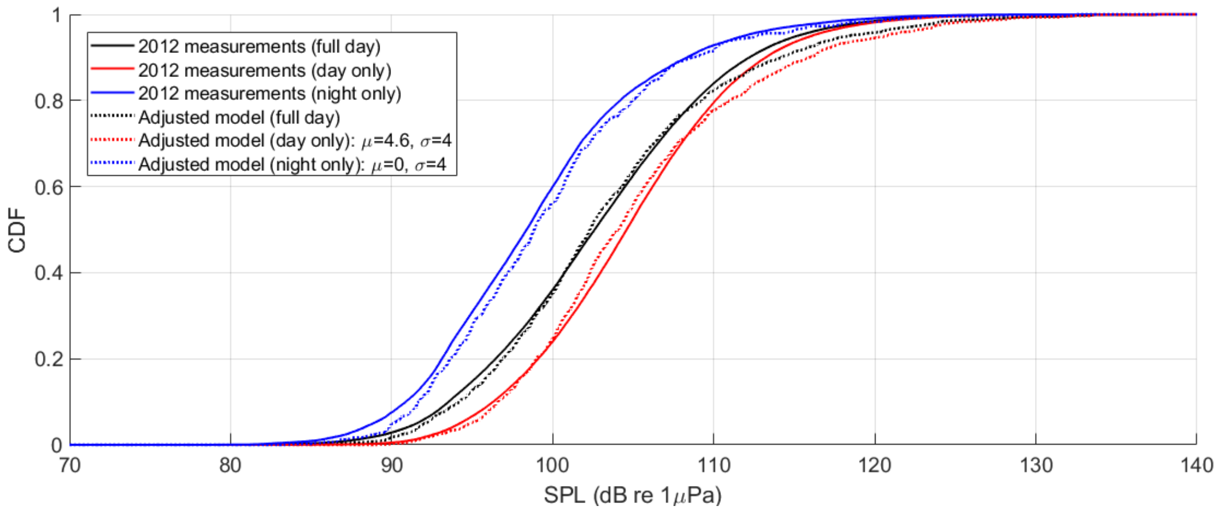

Figure 12. Comparison of the cumulative distribution functions (CDF) of sound levels (0.44–14.0 kHz) from the *in situ* 2012 measurements (solid lines) and the adjusted 24 h model outputs (dotted lines) at Roberts Bank (Mouy et al. 2012). CDFs are broken down by full day (black; 24 hours), day only (red; 06:00–21:59 PDT), and night only (blue; 22:00–05:59 PDT).

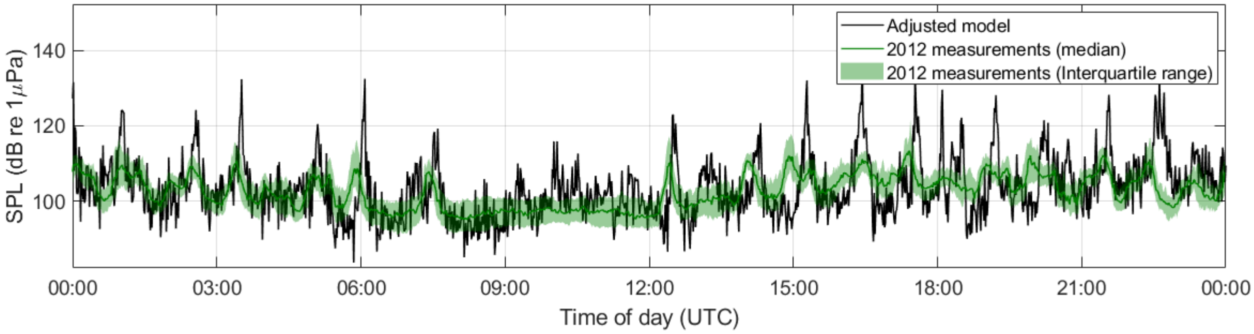

Figure 13. Time series of 1 min sound levels (0.44–14.0 kHz) from the adjusted 24 h model (black line) and from the *in situ* 2012 AMAR measurements (green line and shading) at Roberts Bank.

3. Results

The model results for the construction scenarios during summer and winter are presented as both SEL and SPL isopleth maps for the impact pile driving (an impulsive noise source) and as SPL isopleths for the other activities (all non-impulsive noise sources) (Appendix B). The results are also provided as tables of behavioural response and auditory injury radii for marine mammals and fish ($R_{95\%}$ and R_{max}). Audiogram-weighted SPL radii for all scenarios are presented in the tables in Appendix C.

3.1. Terminal Construction Modelled Noise Levels

3.1.1. Pile Driving Installation: Scenarios 1, 2A, and 2B

Table 13 presents the radii to disturbance and behavioural response thresholds for vibratory pile driving during summer months (Scenario 1). Note that updated project construction plans (Moffat and Nichol 2021) no longer anticipate the need for pile installation using impact pile driving. Instead, piles would be installed with vibratory hammers and impact hammering would be limited to PDA testing to verify final pile load bearing capacity (see Section 3.1.2). Nonetheless, base-case results for impact pile driving installation are included to help evaluate the effectiveness of the reduced use of impact hammer. Tables 14 to 18 present the radii for the 24 h cumulative SEL injury thresholds for impact pile driving during summer without and with confined bubble curtain mitigation (Scenarios 2A and 2B, respectively). Three total durations of pile driving are considered for SEL injury thresholds: 1, 10, and 100 min, respectively. Table 20 presents the radii for the SPL disturbance thresholds for marine mammals for impact pile driving (per strike). Table 21 shows peak sound level radii for marine mammals and fish to injury thresholds for the impact pile driving. Corresponding isopleth maps are provided in Appendix B.

Guidelines provided by NMFS (2018) only recommend consideration of injury thresholds for non-impulsive sounds, such as vibratory pile driving, if their peak pressures exceed the corresponding impulsive injury threshold. While vibratory pile driving (Scenario 1) is not expected to generate PK levels exceeding the minimum 202 dB re 1 µPa injury threshold for marine mammals, preliminary analyses were nonetheless carried out to verify that this activity did not have the potential to exceed auditory injury thresholds for SRKW. Model calculations showed that this activity would not exceed MF-weighted injury thresholds for non-impulsive sound from NMFS (2018) at 10 m, even after 6 hours of continuous activity. As vibratory driving generally has a higher source level than other non-impulsive activities, we conclude that non-impact piling-construction activities do not have the potential to cause auditory injury.

Table 13. Radii to general marine mammal disturbance (120 dB re 1 µPa) and SRKW behavioural response thresholds (129 and 137 dB re 1 µPa, corresponding to the 50% probability of low and moderate-severity) for vibratory pile driving (Scenario 1): Maximum and 95th percentile radii (R_{max} and $R_{95\%}$ in km) to unweighted SPL thresholds.

Scenario	Description	SPL threshold (dB re 1 µPa)	R_{max} (km)	$R_{95\%}$ (km)
1	Vibratory piling 914 mm diameter cylindrical pile at mooring dolphin	137	0.79	0.63
		129	2.38	1.65
		120	8.54	7.25

Table 14. Radii to SEL injury thresholds for 1 min of impact piling for marine mammals: maximum and 95th percentile radii (R_{max} and $R_{95\%}$ in km) to the 24 h cumulative SEL injury thresholds for PTS and TTS (weighted) for 1 min of impact piling without (Scenario 2A) and with (Scenario 2B) confined bubble curtain mitigation. A dash "–" indicates that the threshold was not reached.

Hearing group	SEL threshold (dB re 1 µPa²s)	Scenario 2A		Scenario 2B	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
Low-frequency cetaceans	183 (PTS)	0.10	0.10	0.02	0.02
	168 (TTS)	0.85	0.71	0.18	0.16
Mid-frequency cetaceans	185 (PTS)	–	–	–	–
	170 (TTS)	0.01	0.01	–	–
High-frequency cetaceans	155 (PTS)	0.11	0.10	0.01	0.01
	140 (TTS)	0.77	0.66	0.15	0.14
Phocid pinnipeds in water	185 (PTS)	0.03	0.03	–	–
	170 (TTS)	0.22	0.20	0.05	0.05
Otariid pinnipeds in water	203 (PTS)	–	–	–	–
	188 (TTS)	0.02	0.02	–	–

Table 15. Radii for 24 h cumulative SEL injury threshold for fish (unweighted) for 1 min of impact piling: maximum and 95th percentile radii (R_{max} and $R_{95\%}$ in km). Impact piling without (Scenario 2A) and with (Scenario 2B) confined bubble curtain mitigation. A dash "–" indicates that the threshold was not reached.

Marine fauna group	SEL_{24h} threshold ($L_{E,24h}$; dB re 1 µPa²·s)	Scenario 2A		Scenario 2B	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
Mortality and potential mortal injury					
I	219	–	–	–	–
II, fish eggs and fish larvae	210	–	–	–	–
III	207	–	–	–	–
Fish recoverable injury					
I	216	–	–	–	–
II, III	203	–	–	–	–
Fish TTS					
I, II, III	186	0.08	0.07	0.01	0.01

Fish I–No swim bladder; Fish II–Swim bladder not involved with hearing; Fish III–Swim bladder involved with hearing

Table 16. Radii to SEL injury thresholds for 10 min of impact piling for marine mammal: maximum and 95th percentile radii ($R_{\max}$ and $R_{95\%}$ in km) to the 24 h cumulative SEL injury thresholds for PTS and TTS (weighted) for 10 min of impact piling without (Scenario 2A) and with (Scenario 2B) confined bubble curtain mitigation. A dash “–” indicates that the threshold was not reached.

Hearing group	SEL threshold (dB re 1 µPa^{2}s)	Scenario 2A		Scenario 2B	
		$R_{\max}$ (km)	$R_{95\%}$ (km)	$R_{\max}$ (km)	$R_{95\%}$ (km)
Low-frequency cetaceans	183 (PTS)	0.43	0.40	0.09	0.09
	168 (TTS)	3.38	3.13	0.67	0.54
Mid-frequency cetaceans	185 (PTS)	–	–	–	–
	170 (TTS)	0.11	0.09	0.01	0.01
High-frequency cetaceans	155 (PTS)	0.40	0.36	0.08	0.07
	140 (TTS)	3.29	2.36	0.64	0.58
Phocid pinnipeds in water	185 (PTS)	0.12	0.11	0.02	0.02
	170 (TTS)	0.92	0.78	0.18	0.16
Otariid pinnipeds in water	203 (PTS)	–	–	–	–
	188 (TTS)	0.09	0.08	0.01	0.01

Table 17. Radii for criteria for pulsed noise exposure for fish for 10 min of impact piling: maximum and 95th percentile radii ($R_{\max}$ and $R_{95\%}$ in km). Scenario A is no bubble curtain and scenario B is with a confined bubble curtain. A dash “–” indicates that the threshold was not reached.

Marine fauna group	SEL$_{24h}$ threshold ($L_{E,24h}$; dB re 1 µPa^2·s)	Scenario 2A		Scenario 2B	
		$R_{\max}$ (km)	$R_{95\%}$ (km)	$R_{\max}$ (km)	$R_{95\%}$ (km)
Mortality and potential mortal injury					
I	219	–	–	–	–
II, fish eggs and fish larvae	210	–	–	–	–
III	207	0.01	0.01	–	–
Fish recoverable injury					
I	216	–	–	–	–
II, III	203	0.03	0.03	–	–
Fish TTS					
I, II, III	186	0.31	0.28	0.08	0.08

Fish I–No swim bladder; Fish II–Swim bladder not involved with hearing; Fish III–Swim bladder involved with hearing

Table 18. Radii to SEL injury thresholds for 100 min of impact piling for marine mammals: maximum and 95th percentile radii (R_{max} and $R_{95\%}$ in km) to the 24 h cumulative SEL injury thresholds for PTS and TTS (weighted) for 100 min of impact piling without (Scenario 2A) and with (Scenario 2B) confined bubble curtain mitigation. A dash "–" indicates that the threshold was not reached.

Hearing group	SEL_{24h} threshold (dB re 1 µPa²s)	Scenario 2A		Scenario 2B	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
Low-frequency cetaceans	183 (PTS)	1.60	1.42	0.34	0.31
	168 (TTS)	23.88	17.83	2.82	2.52
Mid-frequency cetaceans	185 (PTS)	0.04	0.04	–	–
	170 (TTS)	0.37	0.33	0.08	0.07
High-frequency cetaceans	155 (PTS)	1.66	1.13	0.31	0.27
	140 (TTS)	9.13	7.23	2.67	1.69
Phocid pinnipeds in water	185 (PTS)	0.49	0.40	0.10	0.09
	170 (TTS)	3.71	3.20	0.82	0.63
Otariid pinnipeds in water	203 (PTS)	0.04	0.04	–	–
	188 (TTS)	0.29	0.27	0.06	0.06

Table 19. Radii for criteria for pulsed noise exposure for fish for 100 min of impact piling: maximum and 95th percentile radii (R_{max} and $R_{95\%}$ in km). Scenario A is no bubble curtain and scenario B is with a confined bubble curtain. A dash "–" indicates that the threshold was not reached.

Marine fauna group	SEL_{24h} threshold ($L_{E,24h}$; dB re 1 µPa²·s)	Scenario 2A		Scenario 2B	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
Mortality and potential mortal injury					
I	219	0.01	0.01	–	–
II, fish eggs and fish larvae	210	0.04	0.04	–	–
III	207	0.07	0.07	0.01	0.01
Fish recoverable injury					
I	216	0.02	0.02	–	–
II, III	203	0.12	0.11	0.03	0.03
Fish TTS					
I, II, III	186	1.04	0.92	0.28	0.26

Fish I–No swim bladder; Fish II–Swim bladder not involved with hearing; Fish III–Swim bladder involved with hearing

Table 20. Radii to marine mammal disturbance thresholds for impact piling: maximum and 95th percentile radii (R_{max} and $R_{95\%}$ in km) to unweighted per-strike SPL disturbance thresholds for impact piling without (Scenario 2A) and with (Scenario 2B) confined bubble curtain mitigation.

Criterion	SPL threshold (dB re 1 µPa)	Scenario 2A		Scenario 2B	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
Behavioural disturbance (impulsive)	160	1.11	0.99	0.36	0.32

Table 21. Radii to PK injury, PTS, and TTS thresholds for impact piling for marine mammals and fish: Maximum radii (R_{max} in km) to unweighted PK level per strike for impact piling without (Scenario 2A) and with (Scenario 2B) confined bubble curtain mitigation. Zones of effects are assumed to be uniform therefore separate $R_{95\%}$ radii are not given. A dash "–" indicates that the threshold was not reached.

Hearing group	PK threshold (dB re 1 µPa)	R_{max} (km)	
		Scenario 2A	Scenario 2B
I	213	0.01	–
II, III, Fish Eggs and Fish Larvae	207	0.03	0.01
Low-frequency cetaceans	219 (PTS)	<0.01	<0.01
	213 (TTS)	0.01	<0.01
Mid-frequency cetaceans	230 (PTS)	<0.01	–
	224 (TTS)	<0.01	<0.01
High-frequency cetaceans	202 (PTS)	0.05	0.01
	196 (TTS)	0.11	0.03
Phocid pinnipeds in water	218 (PTS)	<0.01	<0.01
	212 (TTS)	0.01	<0.01
Otariid pinnipeds in water	232 (PTS)	<0.01	–
	226 (TTS)	<0.01	<0.01

Fish I–No swim bladder; Fish II–Swim bladder not involved with hearing; Fish III–Swim bladder involved with hearing

The time to exceed the 203 dB re 1 µPa^{2}s SEL fish injury threshold at a distance of 10 m was also calculated for unmitigated and mitigated impact pile driving. For Scenario 2A (unmitigated) the SEL injury threshold would be exceeded after 2.1 minutes at 10 m. For Scenario 2B (mitigated) the SEL injury threshold would be exceeded after 21.9 minutes at 10 m.

3.1.2. Pile Driving Analyzer (PDA) Tests: Scenarios 2C-2J

Based on updated project construction plans (Moffatt and Nichol 2021), impact hammering will be limited to PDA tests which will be used to verify final pile load bearing capacity. Table 22 and Table 23 present the radii for the 24 h cumulative SEL injury thresholds for PDA tests using two different hammer energies (185 kJ and 300 kJ), during summer and winter without and with confined bubble curtain mitigation. SEL injury thresholds were calculated assuming a total of 17 hammer strikes for a single pile during a 24-hour period. Table 24 presents the radii for the SPL disturbance thresholds for marine mammals for the PDA tests (per strike). Table 25 shows peak sound level radii to injury thresholds for marine mammals and fish for the PDA tests. Corresponding isopleth maps are provided in Appendix B.

Table 22. Radii to SEL injury thresholds for PDA tests for marine mammals: maximum and 95th percentile radii (R_{max} and $R_{95\%}$ in km) to the 24 h cumulative SEL injury thresholds for PTS and TTS (weighted) for PDA tests without (Scenarios 2C, 2E, 2G, and 2I) and with (Scenarios 2D, 2F, 2H, and 2J) confined bubble curtain mitigation. A dash "–" indicates that the threshold was not reached.

Hearing group	SEL threshold (dB re 1 µPa²s)	Scenario 2C		Scenario 2D		Scenario 2E		Scenario 2F		Scenario 2G		Scenario 2H		Scenario 2I		Scenario 2J	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
Low-frequency cetaceans	183 (PTS)	0.08	0.08	0.01	0.01	0.09	0.09	0.01	0.01	0.11	0.11	0.02	0.02	0.13	0.12	0.02	0.02
	168 (TTS)	0.70	0.56	0.15	0.14	0.79	0.68	0.15	0.14	0.89	0.78	0.20	0.18	1.10	0.94	0.20	0.19
Mid-frequency cetaceans	185 (PTS)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	170 (TTS)	0.01	0.01	–	–	0.01	0.01	–	–	0.02	0.02	–	–	0.02	0.02	–	–
High-frequency cetaceans	155 (PTS)	0.10	0.09	0.01	0.01	0.10	0.09	0.01	0.01	0.12	0.11	0.01	0.01	0.12	0.12	0.01	0.01
	140 (TTS)	0.73	0.63	0.13	0.12	0.97	0.72	0.13	0.12	0.79	0.68	0.16	0.16	1.54	0.97	0.20	0.16
Phocid pinnipeds in water	185 (PTS)	0.02	0.02	–	–	0.02	0.02	–	–	0.03	0.03	–	–	0.03	0.03	–	–
	170 (TTS)	0.18	0.17	0.03	0.03	0.22	0.20	0.03	0.03	0.24	0.22	0.05	0.05	0.30	0.27	0.05	0.05
Otariid pinnipeds in water	203 (PTS)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	188 (TTS)	0.01	0.01	–	–	0.01	0.01	–	–	0.02	0.02	–	–	0.02	0.02	–	–

Table 23. Radii for 24 h cumulative SEL injury threshold for fish (unweighted) for PDA tests: maximum and 95th percentile radii (R_{max} and $R_{95\%}$ in km). PDA tests without (Scenarios 2C, 2E, 2G, and 2I) and with (Scenarios 2D, 2F, 2H, and 2J) confined bubble curtain mitigation. A dash "–" indicates that the threshold was not reached.

Marine fauna group	SEL_{24h} threshold ($L_{E,24h}$; dB re 1 µPa²·s)	Scenario 2C		Scenario 2D		Scenario 2E		Scenario 2F		Scenario 2G		Scenario 2H		Scenario 2I		Scenario 2J	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
Mortality and potential mortal injury																	
I	219	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
II, fish eggs and fish larvae	210	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
III	207	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Fish recoverable injury																	
I	216	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
II, III	203	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Fish TTS																	
I, II, III	186	0.06	0.06	0.01	0.01	0.07	0.07	0.01	0.01	0.08	0.08	0.02	0.02	0.09	0.08	0.02	0.02

Fish I–No swim bladder; Fish II–Swim bladder not involved with hearing; Fish III–Swim bladder involved with hearing
m bladder involved with hearing

Table 24. Radii to marine mammal disturbance thresholds for PDA tests: maximum and 95th percentile radii (R_{max} and $R_{95\%}$ in km) to unweighted per-strike SPL disturbance thresholds for PDA tests without (Scenarios 2C, 2E, 2G, and 2I) and with (Scenarios 2D, 2F, 2H, and 2J) confined bubble curtain mitigation.

Criterion	SPL threshold (dB re 1 µPa)	Scenario 2C		Scenario 2D		Scenario 2E		Scenario 2F		Scenario 2G		Scenario 2H		Scenario 2I		Scenario 2J	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
Behavioural disturbance (impulsive)	160	1.56	1.40	0.43	0.40	2.07	1.67	0.48	0.42	2.15	1.74	0.52	0.47	2.65	2.22	0.62	0.55

Table 25. Radii to PK injury, PTS, and TTS thresholds for PDA tests for marine mammals and fish: Maximum radii (R_{max} in km) to unweighted PK level per strike for PDA tests without (Scenarios 2C, 2E, 2G, and 2I) and with (Scenarios 2D, 2F, 2H, and 2J) confined bubble curtain mitigation. Zones of effects are assumed to be uniform therefore separate $R_{95\%}$ radii are not given. A dash "–" indicates that the threshold was not reached.

Hearing group	PK threshold (dB re 1 µPa)	R_{max} (km)							
		Scenario 2C	Scenario 2D	Scenario 2E	Scenario 2F	Scenario 2G	Scenario 2H	Scenario 2I	Scenario 2J
I	213	0.01	<0.01	0.01	<0.01	0.02	<0.01	0.02	<0.01
II, III, Fish Eggs and Fish Larvae	207	0.03	0.01	0.03	0.01	0.04	0.01	0.05	0.01
Low-frequency cetaceans	219 (PTS)	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.01	<0.01
	213 (TTS)	0.01	<0.01	0.01	<0.01	0.02	<0.01	0.02	<0.01
Mid-frequency cetaceans	230 (PTS)	<0.01	–	<0.01	–	<0.01	<0.01	<0.01	<0.01
	224 (TTS)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
High-frequency cetaceans	202 (PTS)	0.06	0.01	0.07	0.01	0.08	0.02	0.08	0.02
	196 (TTS)	0.13	0.03	0.14	0.03	0.16	0.05	0.18	0.05
Phocid pinnipeds in water	218 (PTS)	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.01	<0.01
	212 (TTS)	0.01	<0.01	0.02	<0.01	0.02	<0.01	0.02	<0.01
Otariid pinnipeds in water	232 (PTS)	<0.01	–	<0.01	–	<0.01	–	<0.01	–
	226 (TTS)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Fish I–No swim bladder; Fish II–Swim bladder not involved with hearing; Fish III–Swim bladder involved with hearing

3.1.3. Combined Construction Activities: Scenarios 3–8

Table 26 presents the radii for scenarios involving combinations of the following construction activities: material placement, dredging, pumping ashore, vibro-densification, and tug activity. Appendix B provides isopleth maps showing SPL contours for these scenarios. Note that sound levels associated with Scenarios 3–8 were insufficiently high to exceed auditory injury thresholds for marine mammals and fish at any appreciable distance. Thus, only disturbance and behavioural response radii are provided for these scenarios.

The extent of the modelled noise footprints was greatest for those scenarios involving the largest number of concurrent activities (i.e., Scenarios 7 and 8). Furthermore, the extent of the noise footprints was greater for activities occurring in winter than in summer. Model results for Scenarios 7 and 8 indicated that vibro-densification, dredging, and pumping ashore were the key contributors to underwater noise from project construction. Noise originating from these three activities generally determined the extent of the combined SPL footprints. Noise from tugs was of secondary importance, under these scenarios.

Table 26. Radii to general marine mammal disturbance (120 dB re 1 µPa) and SRKW behavioural response thresholds (129 and 137 dB re 1 µPa, corresponding to the 50% probability of low and moderate-severity) for combined construction activities (Scenarios 3–8): Maximum and 95th percentile radii (R_{max} and $R_{95\%}$ in km) are provided for unweighted SPL thresholds. Since all scenarios listed in this table involve multiple noise sources, the radii are calculated in two directions: (1) parallel to the centre line running through the berth face, and (2) perpendicular to the berth face (as described in Section 2.2.4). The average of these two radii are also listed in the table.

Scenario	Description	SPL threshold (dB re 1 µPa)	Parallel		Perpendicular		Average	
			R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
3A	Material placement and moderate tug activity in *summer*	137	0.94	0.92	0.26	0.24	0.60	0.58
		129	1.00	0.96	0.32	0.28	0.66	0.62
		120	1.22	1.14	0.64	0.56	0.93	0.85
3B	Material placement and moderate tug activity in *winter*	137	0.94	0.92	0.28	0.24	0.61	0.58
		129	1.08	1.00	0.38	0.30	0.73	0.65
		120	1.58	1.34	0.84	0.62	1.21	0.98
4	Dredging the dredge basin and low tug activity	137	0.86	0.82	0.26	0.22	0.56	0.52
		129	1.00	0.92	0.48	0.42	0.74	0.67
		120	1.50	1.26	1.52	1.34	1.51	1.30
5	Dredging, pumping ashore combo, and moderate tug activity	137	1.02	0.96	0.50	0.42	0.76	0.69
		129	1.42	1.26	0.76	0.62	1.09	0.94
		120	3.10	2.56	3.18	2.80	3.14	2.68
6	Pumping ashore and moderate tug activity	137	1.08	1.04	0.28	0.24	0.68	0.64
		129	1.64	1.50	0.82	0.72	1.23	1.11
		120	7.92	4.30	3.76	3.32	5.84	3.81
7A	Pumping ashore, vibro-densification, and moderate tug activity at dredge basin in *winter*	137	1.36	1.10	0.88	0.78	1.12	0.94
		129	2.38	2.00	2.08	1.82	2.23	1.91
		120	8.42	5.36	8.50	7.46	8.46	6.41
7B	Pumping ashore, vibro-densification, and high tug activity at dredge basin in *summer*	137	1.26	1.02	0.72	0.54	0.99	0.78
		129	2.06	1.52	1.76	1.54	1.91	1.53
		120	4.04	3.30	5.42	4.88	4.73	4.09
8A	Dredging, pumping ashore, and vibro-densification at dredge basin	137	1.22	1.02	0.64	0.52	0.93	0.77
		129	2.04	1.50	1.74	1.54	1.89	1.52
		120	4.00	3.26	5.52	4.94	4.76	4.10
8B	Dredging, pumping ashore, vibro-densification, and high tug activity at dredge basin	137	1.26	1.00	0.72	0.56	0.99	0.78
		129	2.06	1.52	1.76	1.56	1.91	1.54
		120	4.06	3.36	6.16	5.36	5.11	4.36

3.1.4. Becker Penetration Test

A model-based analysis (see Appendix E) indicated that impact hammering associated with BPT would likely not generate sound levels exceeding injury thresholds for marine mammals or fish at any distance.

Furthermore, this activity would not generate sound levels exceeding the behavioural response threshold for marine mammals (160 dB re 1 µPa SPL) beyond 2 m range. While the model-based analysis indicated that BPT is unlikely to be an activity of concern for marine mammals or fish, it is nonetheless recommended that sound emissions generated by this activity be measured during construction, given the absence of *in situ* validation data.

3.2. Modelled Detection Ranges of Killer Whale Vocalizations

Detection range probabilities for killer whale stereotyped vocalizations and whistles were determined for each PAM location for all summer scenarios (i.e., reflecting times when SRKW are most likely to be present, as discussed in Section 2.3).

3.2.1. Stereotyped Vocalizations

Figure 14 shows the detection range probabilities of killer whale stereotyped vocalizations at the three PAM locations under baseline noise condition (i.e., no construction noise). Detection range probability curves for all summer construction scenarios can be found in Appendix D.1. Table 27 summarizes the detection range values for each construction scenario, location, and time of day. Figure 15 illustrates the key detection range values from the table. The rings on the map show the smallest detection range values (bolded values in Table 27) for each location and time of day at each PAM location for the summer scenarios, based on the maximum (dashed lines) and $P = 0.5$ (solid lines) probabilities of the median detection range during the night (blue) and day (orange).

The detection range of stereotyped vocalizations is consistently higher at night than during the day for all locations and scenarios. This is because background noise levels are lower during night-time when there is less vessel traffic (particularly passenger ferries). All locations are at least 6.5 km away from the construction site (see Table 11) and receive little to no noise contribution from the construction activities. Consequently, detection ranges during construction activities are similar to the detection range of the baseline. The maximum possible detection ranges, based on the median detection range probability curves, are 4.6, 4.9, and 4.4 km at PAM locations 1, 2, and 3, respectively. These detection ranges are mostly theoretical and are almost never reached (i.e., median probabilities almost equal to zero). The maximum night detection ranges that are reached 50% of the time ($P = 0.5$), based on the median detection range probability curves, are 1.32, 1.58, and 1.24 km at PAM locations 1, 2, and 3, respectively. The corresponding day detection ranges (P = 0.5, median curve) are 0.76, 0.85, and 0.70 km, respectively.

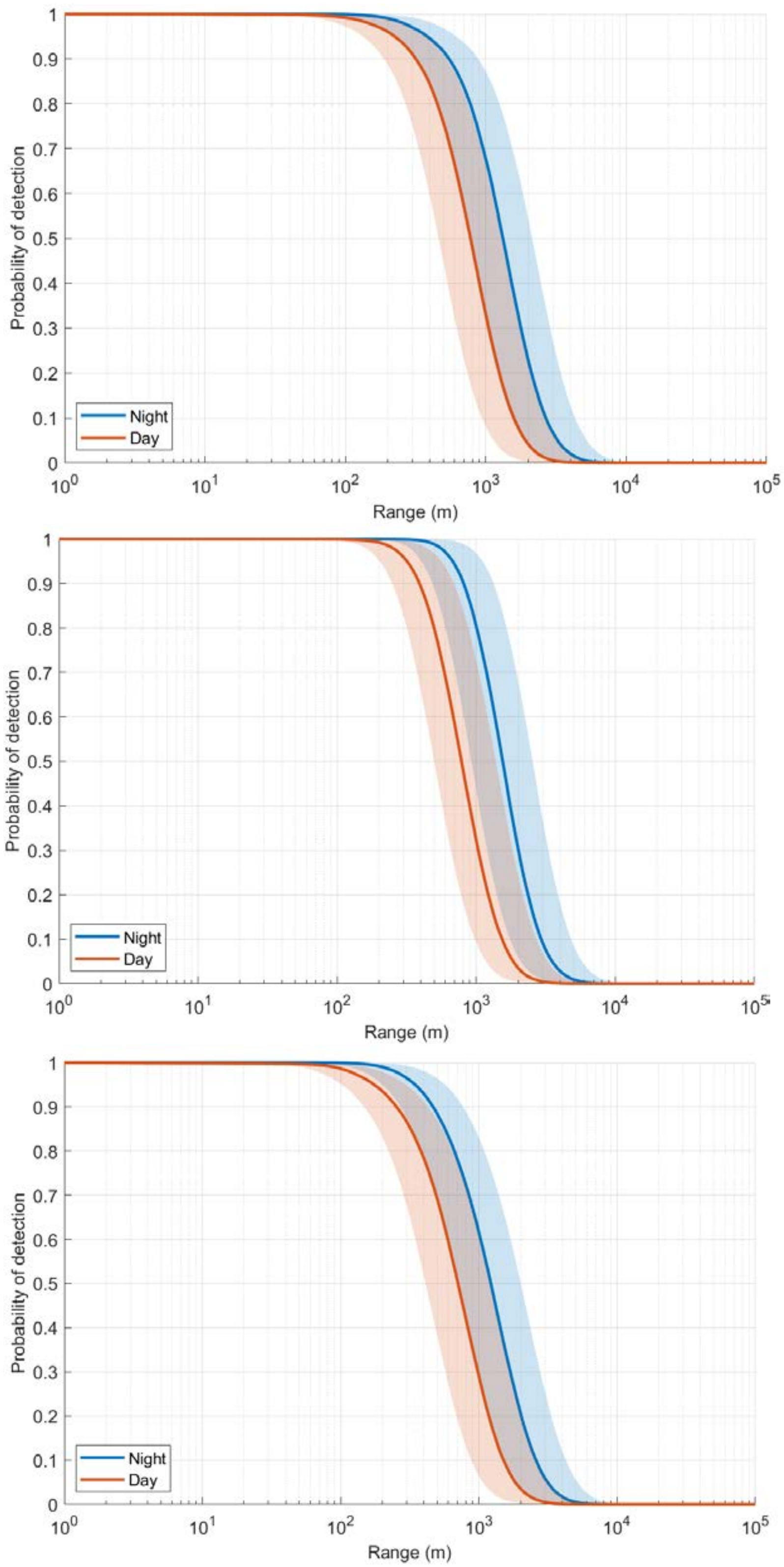

Figure 14. Detection range probabilities of killer whale stereotyped vocalizations for the baseline scenario: Summer detection range probabilities of killer whale stereotyped calls during the day (orange) and night (blue) at the locations PAM 1 (top), PAM 2 (center), and PAM 3 (bottom), with no construction activities at the terminal (i.e., baseline scenario). The solid lines are the median values and the shaded areas define the 25th and 75th percentiles.

Table 27. Detection ranges of killer whale stereotyped vocalizations for the summer scenarios: At each PAM location, median and 75th percentile detection range (in metres) for day (06:00–21:59 PDT) and night (22:00–05:59 PDT) for various probabilities of detection (*P*). The detection ranges for scenarios with the smallest night *P* = 0.5 detection range (bolded) are represented as rings in Figure 15. Values in this table were extracted from the detection range probability curves (see illustration in Figure 10).

Scenario	Period	Median detection range (m)				75th percentile detection range (m)			
		Max.	*P* = 0.1	*P* = 0.5	*P* = 0.9	Max.	*P* = 0.1	*P* = 0.5	*P* = 0.9
Location PAM 1									
Baseline	Day	2707	1584	779	317	4472	2618	1287	523
	Night	4602	2677	1324	547	7423	4323	2138	883
1	Day	2582	1511	743	302	4341	2539	1248	508
	Night	4598	2674	1322	546	7380	4298	2125	878
3A	Day	2636	1544	759	309	4456	2607	1281	522
	Night	4486	2609	1290	533	7303	4245	2099	867
4	Day	**2581**	1510	**742**	302	4352	2547	1252	509
	Night	**4282**	2495	**1234**	510	7409	4315	2133	882
5	Day	2654	1553	763	311	4341	2540	1249	508
	Night	4473	2602	1286	531	7227	4204	2079	859
7B	Day	2631	1540	757	308	4253	2486	1222	497
	Night	4444	2584	1278	528	7287	4236	2093	865
8A	Day	2613	1529	751	306	4431	2595	1275	519
	Night	4291	2498	1235	511	7502	4361	2155	891
8B	Day	2560	1498	737	300	4283	2505	1231	501
	Night	4447	2586	1278	528	7371	4290	2122	877
Location PAM 2									
Baseline	Day	2600	1535	783	391	4589	2708	1382	689
	Night	4915	2930	1550	812	8069	4810	2543	1333
1	Day	2639	1588	817	408	4451	2677	1378	688
	Night	4472	2819	1527	806	7423	4683	2538	1340
3A	Day	2629	1554	794	396	4275	2523	1289	643
	Night	4987	2979	1576	826	8112	4845	2565	1345
4	Day	2585	1528	780	389	4358	2576	1315	656
	Night	4808	2880	1527	801	7877	4725	2505	1313
5	Day	2553	1538	791	395	4340	2611	1343	671
	Night	4376	2762	1497	790	7298	4599	2493	1315
7B	Day	2730	1642	845	422	4400	2649	1363	681
	Night	4488	2836	1538	812	7544	4766	2584	1364
8A	Day	2812	1664	850	424	4659	2755	1408	702
	Night	4755	2855	1514	794	8197	4915	2607	1367
8B	Day	**2723**	1640	**845**	422	4252	2561	1318	659
	Night	**4301**	2723	**1478**	780	7402	4686	2543	1343

Scenario	Period	Median detection range (m)				75th percentile detection range (m)			
		Max.	*P* = 0.1	*P* = 0.5	*P* = 0.9	Max.	*P* = 0.1	*P* = 0.5	*P* = 0.9
Location PAM 3									
Baseline	Day	2632	1505	705	253	4450	2542	1191	427
	Night	4425	2585	1220	465	7272	4260	2009	766
1	Day	2539	1452	681	244	4183	2393	1122	403
	Night	4346	2547	1202	459	6793	3973	1877	716
3A	Day	2617	1500	703	252	4172	2391	1121	402
	Night	4211	2480	1173	448	7157	4199	1987	759
4	Day	2419	1394	656	235	3965	2285	1074	385
	Night	4228	2530	1205	461	7049	4218	2010	769
5	Day	2390	1380	649	233	3928	2271	1069	384
	Night	4182	2517	1202	460	6857	4140	1977	757
7B	Day	2533	1462	688	247	4052	2341	1102	395
	Night	4205	2531	1208	462	6960	4176	1994	763
8A	Day	2592	1483	695	249	4173	2390	1120	402
	Night	4305	2524	1193	455	7062	4151	1960	748
8B	Day	2428	1404	661	237	4110	2375	1118	401
	Night	4301	2592	1238	474	6816	4105	1961	751

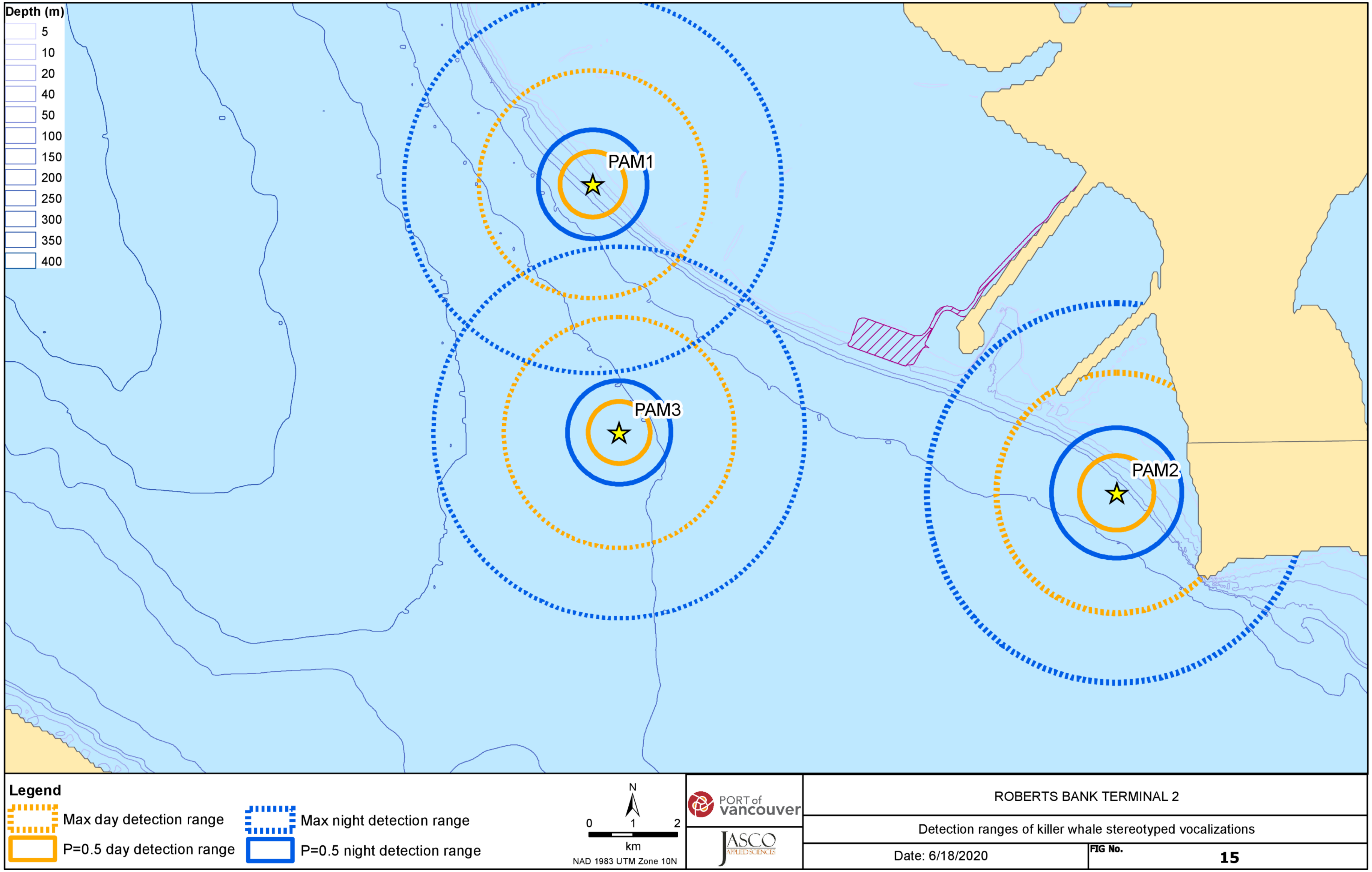

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Figure 15. Detection ranges of killer whale stereotyped vocalizations.

3.2.2. Whistles

Figure 16 shows the detection range probabilities of killer whale whistles at the three PAM locations under the baseline noise conditions (i.e., no construction noise). Detection range probability curves for all summer construction scenarios can be found in Appendix D.2. Table 28 summarizes the detection range values for each scenario, location, and time of day. Figure 17 illustrates the key detection range values from the table. The rings on the map show the smallest detection range values (bolded values in Table 28) for each location and time of day at each PAM location for the summer scenarios based on the maximum (dashed lines) and *P* = 0.5 (solid lines) probabilities of the smallest median detection range during the night (blue) and day (orange).

Similar to stereotyped vocalization, the detection range of whistles is consistently higher at night than during the day for all locations and scenarios, due to lower background noise levels. Given the low source level of whistles (see Table 12), their detection range is much lower than for stereotyped vocalizations. As is the case for stereotyped vocalizations, detection ranges during construction activities are similar to the detection ranges of the baseline. The maximum possible detection ranges, based on the median detection range probability curves, are 800, 900, and 770 m at PAM locations 1, 2, and 3, respectively. These detection ranges are mostly theoretical and are almost never reached (i.e., median probabilities almost equal to zero). The maximum detection ranges that are reached 50% of the time (*P* = 0.5), based on the median detection range probability curves, are 230, 280, and 210 m at PAM locations 1, 2, and 3, respectively.

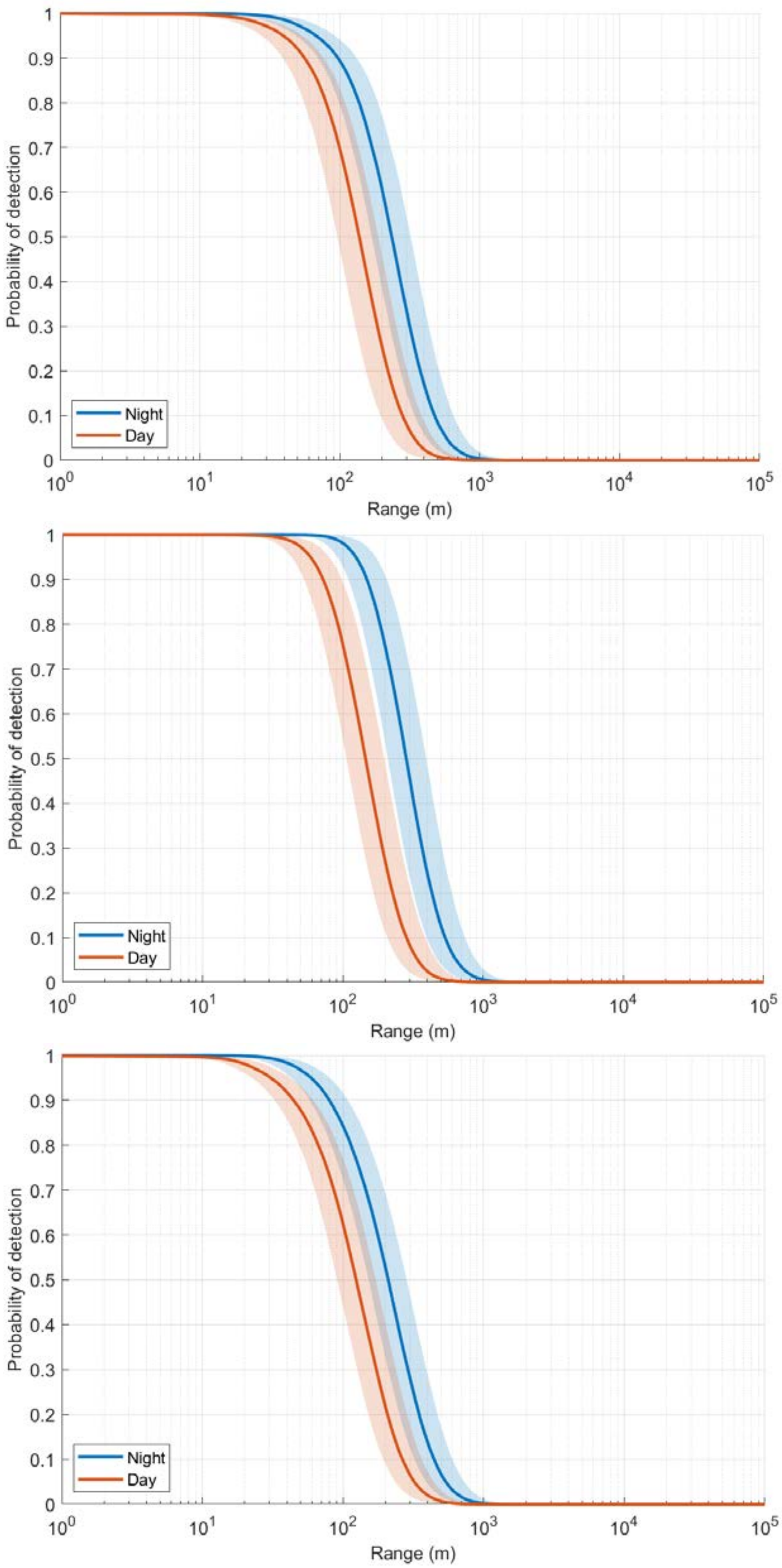

Figure 16. Detection range probabilities of killer whale whistles for the baseline scenario: Summer detection range probabilities of killer whale whistles during the day (orange) and night (blue) at the locations PAM 1 (top), PAM 2 (center), and PAM 3 (bottom), with no construction activities at the terminal (i.e., baseline scenario). The solid lines are the median values, and the shaded areas define the 25th and 75th percentiles.

Table 28. Detection ranges of killer whale whistles for the summer scenarios: At each PAM location, median and 75th percentile detection range (in metres) for day (06:00–21:59 PDT) and night (22:00–05:59 PDT) for various probabilities of detection (*P*). The detection ranges for scenarios with the smallest night *P* = 0.5 detection range (bolded) are represented as rings in Figure 17. Values in this table were extracted from the detection range probability curves (see illustration in Figure 10).

Scenario	Period	Median detection range (m)				75th percentile detection range (m)			
		Max.	*P* = 0.1	*P* = 0.5	*P* = 0.9	Max.	*P* = 0.1	*P* = 0.5	*P* = 0.9
Location PAM 1									
Baseline	Day	479	280	138	56	654	383	188	77
	Night	817	475	235	97	1114	648	320	132
1	Day	470	275	135	55	650	381	187	76
	Night	804	468	231	96	1074	625	309	128
3A	Day	471	276	136	55	653	382	188	76
	Night	815	474	234	97	1131	658	326	135
4	Day	463	271	133	54	641	375	184	75
	Night	798	464	230	95	1101	641	317	131
5	Day	478	279	137	56	647	378	186	76
	Night	802	467	231	95	1123	654	323	134
7B	Day	**462**	270	**133**	54	642	376	185	75
	Night	**791**	460	**227**	94	1083	630	311	129
8A	Day	478	280	137	56	640	375	184	75
	Night	794	462	228	94	1086	631	312	129
8B	Day	464	271	133	54	649	380	187	76
	Night	834	485	240	99	1152	669	331	137
Location PAM 2									
Baseline	Day	481	284	145	72	653	386	197	98
	Night	898	535	283	148	1244	742	392	206
1	Day	482	290	149	74	656	395	203	102
	Night	795	502	272	143	1097	692	375	198
3A	Day	491	290	148	74	675	399	204	102
	Night	873	521	276	145	1194	713	377	198
4	Day	497	294	150	75	680	402	205	102
	Night	856	513	272	143	1174	704	373	196
5	Day	467	281	145	72	642	386	199	99
	Night	793	501	271	143	1082	683	370	195
7B	Day	**478**	288	**148**	74	654	394	203	101
	Night	**784**	496	**269**	142	1074	678	368	194
8A	Day	492	291	149	74	668	395	202	101
	Night	880	528	280	147	1241	745	395	207
8B	Day	472	284	146	73	642	387	199	99
	Night	804	509	276	146	1107	701	380	201

Scenario	Period	Median detection range (m)				75th percentile detection range (m)			
		Max.	*P* = 0.1	*P* = 0.5	*P* = 0.9	Max.	*P* = 0.1	*P* = 0.5	*P* = 0.9
Location PAM 3									
Baseline	Day	463	265	124	44	637	364	171	61
	Night	761	444	210	80	1029	602	284	108
1	Day	460	263	123	44	616	352	165	59
	Night	772	452	213	81	1043	610	288	110
3A	Day	438	251	118	42	610	349	164	59
	Night	773	454	215	82	1056	622	294	112
4	Day	455	262	123	44	614	354	166	60
	Night	748	448	213	81	986	589	281	107
5	Day	449	259	122	44	610	352	166	60
	Night	736	442	211	81	998	602	287	110
7B	Day	462	267	126	45	629	363	171	61
	Night	726	437	208	80	999	601	287	110
8A	Day	**450**	258	**121**	43	614	352	165	59
	Night	**739**	433	**205**	78	1041	610	288	110
8B	Day	439	254	120	43	605	350	165	59
	Night	726	438	209	80	964	583	278	107

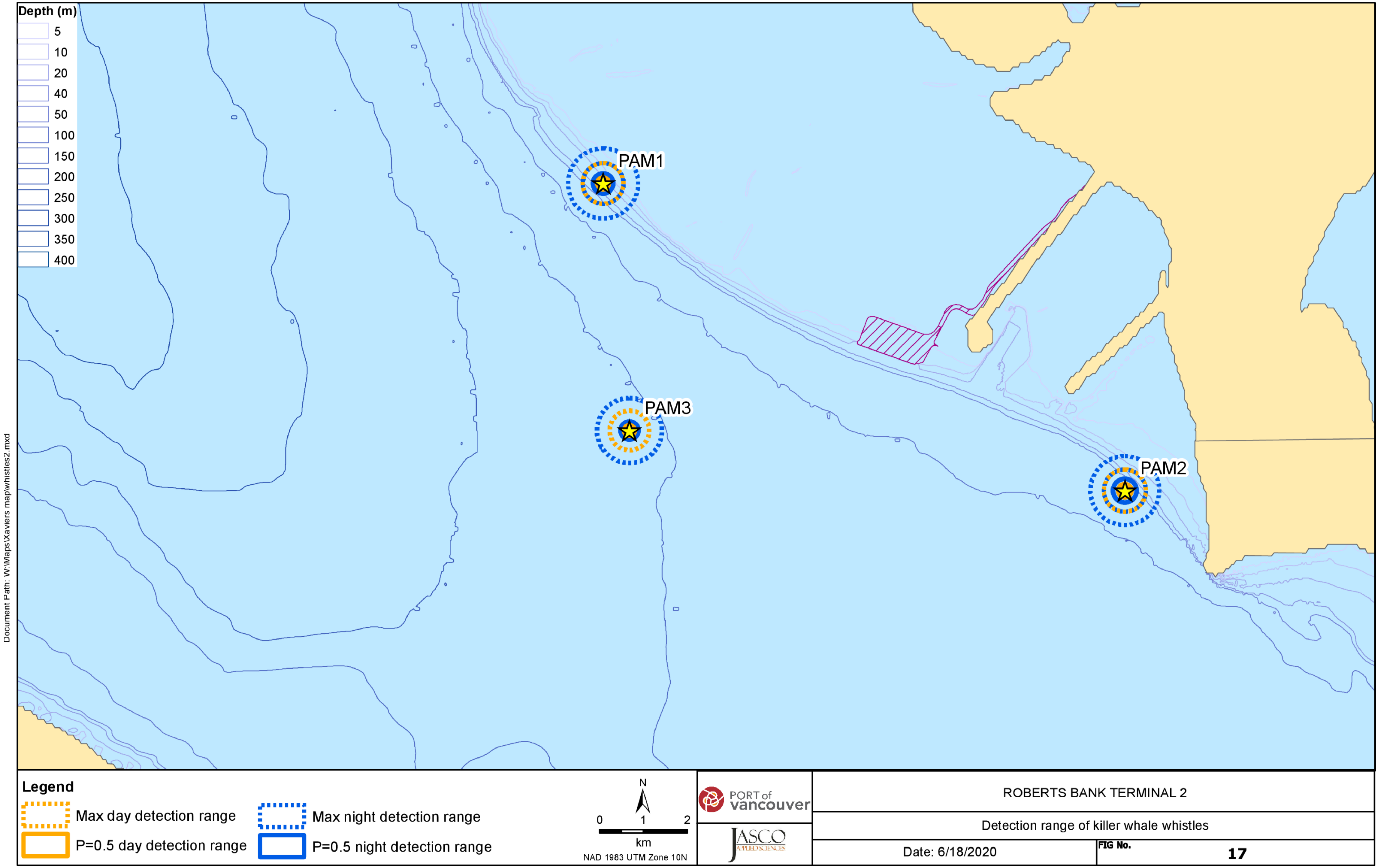

Figure 17. Detection ranges of killer whale whistles.

4. Discussion and Conclusion

4.1. Terminal Construction Noise Modelling

The acoustic modelling showed that the limited impact pile driving associated with PDA tests generally had smaller injury radii for marine mammals and fish than the base impact pile driving cases considered in the EIS. This is because the injury radii are related to total sound exposure (i.e., SEL), and PDA tests only involve a small number of hammer strikes per pile. However behavioural disturbance radii were greater for PDA tests due to the larger hammer energies involved, compared to the EIS scenarios (300 kJ maximum energy, compared to 123 kJ in the EIS). For the PDA tests, the 300 kJ hammer had slightly larger PTS and TTS radii than the 185 kJ hammer. For example, for Scenario 2C (PDA test in summer using 185 kJ hammer, without bubble curtain mitigation), the distance to the TTS threshold for MF cetaceans (170 dB SEL) reached 0.01 km, but for Scenario 2G (PDA test in summer using 300 kJ hammer, without bubble curtain mitigation), the distance to the TTS threshold reached 0.02 km.

Scenarios with confined bubble curtain mitigation had substantially reduced radii compared to scenarios without mitigation. For example, for the PDA test using a 300 kJ hammer in summer (Scenarios 2G and 2H), the presence of the confined bubble curtain reduced the $R_{95\%}$ of the fish SEL TTS threshold (186 dB SEL) from 0.08 to 0.02 km. Likewise, the presence of the confined bubble curtain reduced the $R_{95\%}$ of the mid-frequency cetaceans SEL TTS threshold (170 dB SEL) from 0.02 km to effectively zero range (i.e., less than the model resolution). The model results indicate that underwater sound levels generated by impact pile driving could be substantially reduced by bubble curtain mitigation, with the average distance to injury thresholds reduced by approximately 80% on average for marine mammals and fish. For PK injury thresholds, all PDA testing scenarios produced injury (PTS) radii less than 80 m. Note that the potential for injury exists whenever either of the SEL or PK dual-criteria are exceeded.

Other activities associated with marine construction would not generate sound levels of sufficient intensity to cause injury in marine mammals or fish and were therefore not included in this report. Guidelines provided by NMFS (2018) only recommend consideration of injury thresholds for non-impulsive sounds if their peak pressures exceed the corresponding impulsive injury threshold. Peak pressure levels generated by activities other than impact pile driving are not expected to exceed the minimum 202 dB re 1 µPa PK injury threshold for marine mammals under any circumstance. Furthermore, preliminary analyses for vibratory pile driving (Scenario 1) verified that PTS thresholds would not be exceeded for SRKW at 10 m range. Thus, the construction activities generating non-impulsive noise are not expected to have any potential to induce auditory injury in SRKW. Likewise, a screening assessment of the Becker penetration test (Appendix E) indicated that this activity likely does not have the potential to induce auditory injury in SRKW or fish.

Seasonal variation in sound speed profiles (summer versus winter) also had an impact on sound propagation. Threshold radii for construction activities in summer were generally smaller than radii for the same activities in winter. This is because the summer sound speed profile at Roberts Bank is more downward-refracting than the winter profile and thus causes more sound energy to be directed into the bottom, resulting in more energy lost to seabed sediments (i.e., bottom loss). Differences in winter and summer sound speed profiles are mainly due to changes in the vertical temperature gradient (i.e., the thermocline), caused by cooling and heating in the upper 80 m of the water column. For example, the $R_{95\%}$ to the 160 dB SPL threshold for Scenario 2A (impact pile driving) was 0.99 km in summer, compared to 1.32 km in winter calculated and presented in the EIS Modelling Study (Wladichuk et al. 2014, Tab. 6-B). Similarly, for the material placement scenarios, the radii for summer (3A) were 15% less than for winter (3B).

For the construction scenarios, combinations of activities increased the noise footprint compared to a single activity. For example, comparing Scenario 4 (dredging with support tugs) and Scenario 5 (dredging and pumping ashore with support tugs), the average $R_{95\%}$ (between the perpendicular and parallel directions to the berth face) to the 120 dB SPL threshold increased from 1.30 to 2.68 km.

The addition of support tugs increased the noise footprint extents but only by a small amount. For example, the addition of seven tugs (Scenario 8B) to dredging, pumping ashore, and vibro-densification (Scenario 8A) increased the $R_{95\%}$ for the 120 dB threshold from 4.10 to 4.36 km, an increase of less than 5%. This indicates pile driving, dredging and vibro-densification are likely to be the dominant noise sources during construction of the project.

The fish audiogram-weighted SPL radii presented in Appendix C show that impact pile driving produced the largest radii compared to the other construction scenarios. Impact piling with a confined bubble curtain mitigation (Scenario 2B) had substantially reduced radii compared to the scenario without a confined bubble curtain (Scenario 2A) by up to 63% for 50 dB re HT and 16% for 90 dB re HT thresholds. In addition, the radii for fish audiogram-weighted SPL for impact piling scenarios were also reduced compared to the radii in the EIS Modelling Study, which was modelled with a winter sound speed profile. For example, the $R_{95\%}$ for 50 dB re HT of salmon audiogram-weighted SPL was 1.60 km for the current study, compared to 2.10 km for the previous EIS Modelling Study, for impact pile driving without confined bubble curtain.

4.2. Detection Range of Killer Whale Vocalizations

Sounds produced by killer whales at the three proposed PAM locations are rapidly masked by the noise of existing shipping traffic. Stereotyped vocalizations have a higher source level than whistles and can consequently be detected at further ranges. All potential PAM locations are at least 6 km away from the RBT2 construction site, and sound levels at these locations are mostly driven by vessel traffic rather than construction noise. Consequently, the modelled sounds from construction activities did not substantially reduce the detection range of killer whale vocalizations at the PAM locations. PAM detection ranges were consistently higher at night than during the day, due to lack of passenger ferry traffic during nighttime. In the modelled PAM configuration, the detection ranges at each of the hypothetical PAM locations did not overlap. Consequently, more than three PAM nodes would likely be required to acoustically detect SRKWs at Roberts Bank during project construction. Additional analysis would be needed to determine the number of PAM nodes that would be needed to achieve specific detection rate and spatial coverage targets.

All detection range estimates are based on source levels of killer whale vocalizations reported in the literature. In noisy environments, however, killer whales have been reported to produce sounds with higher source levels (i.e., the Lombard effect (Holt et al. 2009)). This effect was not considered in this study because it is difficult to model this vocal behaviour, but it could result in greater detection ranges than those reported here.

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Appendix A. Acoustic Metrics and Modelling Methodology

This section provides detailed descriptions of the acoustic metrics relevant to the modelling study, the frequency weighting required for some of the impact criteria, and the modelling methodology.

A.1. Acoustic Metrics for Continuous Sounds

Continuous sound is characterized by gradual changes of sound pressure levels over time (e.g., propeller noise from a transiting vessel). Given a measurement of the time-varying sound pressure, $p(t)$, for a given noise source, the root-mean-square sound pressure level (SPL, symbol L_p) is computed according to the following formula:

$$L_p = 10\, log_{10} \frac{1}{T} \int_T p(t)^2 dt \,/ {P_{ref}}^2 \,. \tag{A-1}$$

In this formula, T is the time over which the measurement was obtained. Figure A-1 shows an example of a continuous sound pressure waveform and the corresponding root-mean-square (rms) sound pressure.

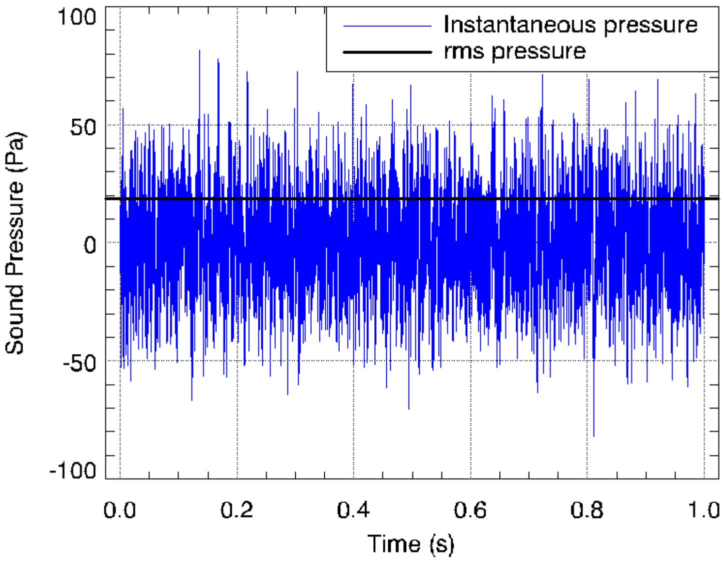

Figure A-1. Example waveform of a continuous noise measurement and the corresponding SPL (rms pressure).

A.2. Acoustic Metrics for Impulsive Sounds

Sounds with short durations (less than a few seconds) are referred to as impulsive, and are typically characterized by abrupt increases of sound pressure (less than a second), followed by rapid decay back to pre-existing levels (within a few seconds). Noise from impact pile driving is typically considered impulsive.

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

$$L_{\mathrm{pk}} = 20\log_{10}(\max|p(t)|\,/p_0)\,. \tag{A-2}$$

In this formula, $p(t)$ is the instantaneous sound pressure as a function of time, measured over the pulse duration $0 \leq t \leq T$. This PK metric is commonly quoted for impulsive sounds, but does not take into account the duration or bandwidth of the noise. At high sound pressures (e.g., for shock fronts), PK can be a valid criterion for assessing whether a sound is potentially injurious; however, because PK does not consider pulse duration, it is not a good indicator of perceived loudness.

The SPL of an impulsive sound can be calculated using the same equation as a continuous source (Equation A-1); however, some ambiguity remains in how the duration T is defined because the beginning and end of a pulse can be difficult to identify precisely. In studies of impulsive noise, T is often accepted as the interval over which the cumulative energy curve rises from 5% to 95% of the total energy. This interval contains 90% of the total pulse energy (T_{90}), and the SPL computed over this interval is commonly referred to as the 90% rms SPL (L_{p90}, dB re 1 µPa). The energy, $E(t)$, of the pulse is computed from the time integral of the square pressure by:

$$E(t) = \int_0^t p(\tau)^2 \, d\tau \quad . \tag{A-3}$$

According to this definition, if the time corresponding to n% of the total energy of the pulse is denoted t_n, then the 90% energy window is defined such that $T_{90} = t_{95}–t_5$. Figure A-2 shows an example of an impulsive noise pressure waveform, with the corresponding peak pressure, rms pressure, and 90% energy time interval.

Sound exposure level (SEL) measures the total sound energy contained in one or more pulses. SEL (L_E, dB re 1 µPa^2·s) for a single pulse is computed from the time-integral of the squared pressure over the full pulse duration (T_{100}) according to the formula:

$$L_E = 10\log_{10}\left(\int_{T_{100}} p(t)^2 \, dt / P_{ref}^2 t_{ref} \right) = 10\log_{10}\left(E(t_{100}) / E_{ref} \right) . \tag{A-4}$$

SEL for impulsive noise sources (i.e., impact pile driving) presented may refer to single pulse or multiple pulse SEL. Total SEL from a train of N pulses may be calculated by summing the sound energy (in linear units) of the N individual pulses (L_{Ei}) as follows:

$$L_E = 10\log_{10}\left(\sum_{i=1}^{N} 10^{\frac{L_{Ei}}{10}} \right) , \tag{A-5}$$

where N is the total number of pulses and L_{Ei} is the SEL of the ith pulse event. Alternatively, given the mean (or expected) SEL for single pulse events, $\overline{L}_E$, the cumulative SEL from N pulses may be computed according the following formula:

$$L_E = \overline{L}_E + 10\log_{10}\left(N\right) . \tag{A-6}$$

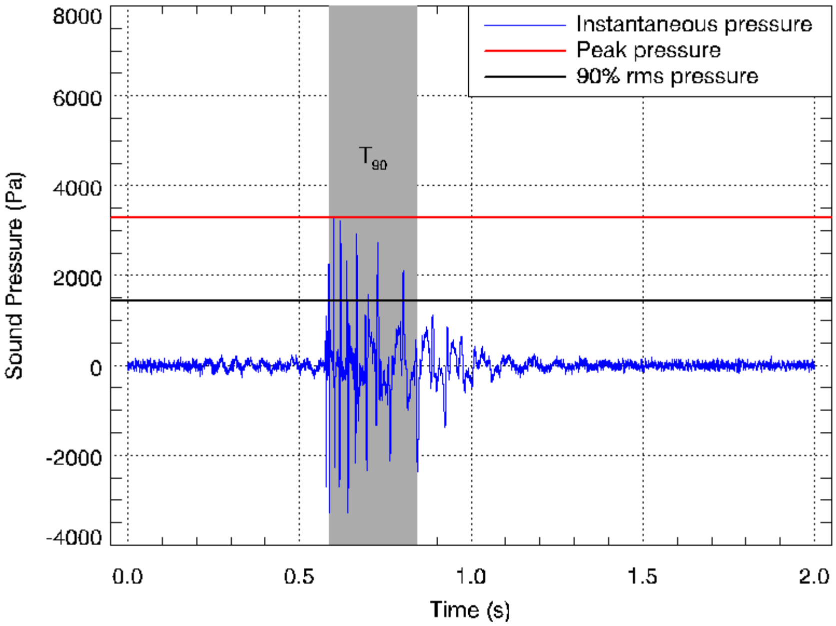

Figure A-2. Example waveform showing an impulsive noise measurement (horizontal lines indicate the peak pressure and 90% rms pressure for this pulse. The grey area indicates the 90% energy time interval (T_{90}) over which the rms pressure is computed.)

A.3. Auditory Frequency Weighting for Marine Mammals

Some of the acoustic impact criteria for marine mammals (described in Section 2.1) involve frequency weighting according to the auditory range of the animals. The EIS Modelling Study used the M-weighting functions defined by Southall et al. (2007). The current study, however, uses more recent weighting functions adopted by NOAA’s technical guidance for assessing noise impacts on marine mammals (NMFS 2018), which are described here.

The overall shape of the auditory weighting functions is similar to human A-weighting functions, which follows the sensitivity of the human ear at low sound levels. The new frequency-weighting function is expressed as:

$$G(f) = K + 10\log_{10}\left[\left(\frac{(f/f_{lo})^{2a}}{\left[1+(f/f_{lo})^2\right]^a \left[1+(f/f_{hi})^2\right]^b}\right)\right]. \qquad \text{(A-7)}$$

Finneran (2015) proposed five functional hearing groups for marine mammals in water: low-, mid-, and high-frequency cetaceans; phocid pinnipeds, and otariid pinnipeds. The parameters for these frequency-weighting functions were further modified the following year (Finneran 2016) and were adopted in NOAA’s technical guidance that assesses noise impacts on marine mammals (NMFS 2018). Table A-1 lists the frequency-weighting parameters for each hearing group. Figure A-3 shows the resulting frequency-weighting curves. The PTS- and TTS-onset threshold levels for each hearing group (Southall et al. 2007) are listed in Table 1.

Table A-1. Parameters for the auditory weighting functions recommended by NMFS (2018).

Hearing group	a	B	f_{lo} (Hz)	f_{hi} (Hz)	K (dB)
Low-frequency cetaceans	1.0	2	200	19,000	0.13
Mid-frequency cetaceans	1.6	2	8,800	110,000	1.20
High-frequency cetaceans	1.8	2	12,000	140,000	1.36
Phocid pinnipeds in water	1.0	2	1,900	30,000	0.75
Otariid pinnipeds in water	2.0	2	940	25,000	0.64

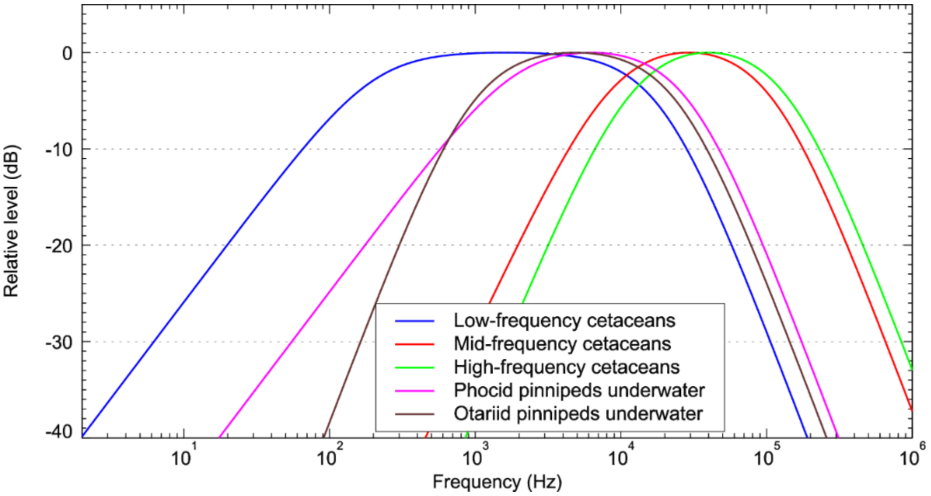

Figure A-3. Auditory weighting functions for functional marine mammal hearing groups as recommended by NMFS (2018).

A.4. Auditory Frequency Weighting for Fish Species Groups

Audiogram-weighted levels represent sound levels above an animal's hearing threshold (dB re HT), and they cannot be directly compared with unweighted levels. Sound levels less than 0 dB re HT are below the typical hearing threshold for a species (or species group) and are expected to be inaudible. Sound levels 0 dB re HT represent auditory sensation levels, which relate to the perceived loudness of different sounds by a particular species.

In this study, audiogram weighting was applied for three groups of marine fish species: flatfish, herring, and salmon. The audiogram for herring was measured by Enger (1967) and for salmon by Hawkins and Johnstone (1978). The flatfish audiogram is a composite of dab audiogram data below 200 Hz (Chapman and Sand 1974) and sole audiogram data above 200 Hz (Zhang et al. 1998). For calculating weighted sound levels outside the measured audiogram range, flatfish, herring, and salmon thresholds were extrapolated to the lower and upper modelled frequencies by fixing the threshold at the most extreme value, which is highly a conservative approach. Figure A-4 shows the estimated audiograms for the three fish species groups.

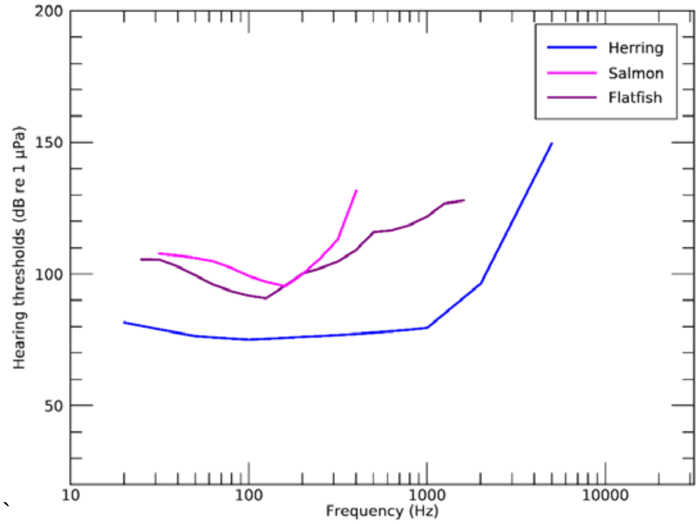

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Figure A-4. Audiograms for the three fish species groups considered in this study: herring (Enger 1967), salmon (Hawkins and Johnstone 1978), and flatfish (Chapman and Sand 1974, Zhang et al. 1998).

A.5. Marine Operations Noise Model

Sound levels for each noise source of concern were modelled using JASCO's Marine Operations Noise Model (MONM). MONM predicts underwater sound propagation in range-varying acoustic environments through a wide-angled parabolic equation (PE) solution to the acoustic wave equation (Collins 1993). The PE method has been extensively benchmarked and is widely employed in the underwater acoustic community. The PE code used by MONM is based on a version of the Naval Research Laboratory's Range-dependent Acoustic Model (RAM), which has been modified to account for an elastic seabed.

MONM computes acoustic fields in three dimensions by modelling transmission loss (TL) along evenly spaced 2-D radial traverses covering a 360° swath from the source, an approach commonly referred to as *N* × 2-D (Figure A-5 left). The model fully accounts for depth and/or range dependence of several environmental parameters including bathymetry and sound speed profiles for the water column and the seafloor. It also accounts for the additional reflection loss at the seabed due to partial conversion of incident compressional waves to shear waves at the seabed and sub-bottom interfaces through a complex density approximation (Zhang and Tindle 1995). Wave attenuation in all layers is also included. The acoustic environment is sampled at a fixed range step along radial traverses. MONM treats frequency dependence by computing acoustic TL at the centre frequencies of 1/3-octave-bands. Broadband received levels are summed over the received 1/3-octave-band levels, which are computed by subtracting band TL values from the corresponding source levels. MONM's predictions have been validated against experimental data from several underwater acoustic measurement programs (Aerts et al. 2008, Funk et al. 2008, Ireland et al. 2009, O'Neill et al. 2010, Warner et al. 2010, Hannay et al. 2013). For this study, MONM was used to compute TL for the 28 1/3-octave-bands centred between 10 Hz and 5 kHz.

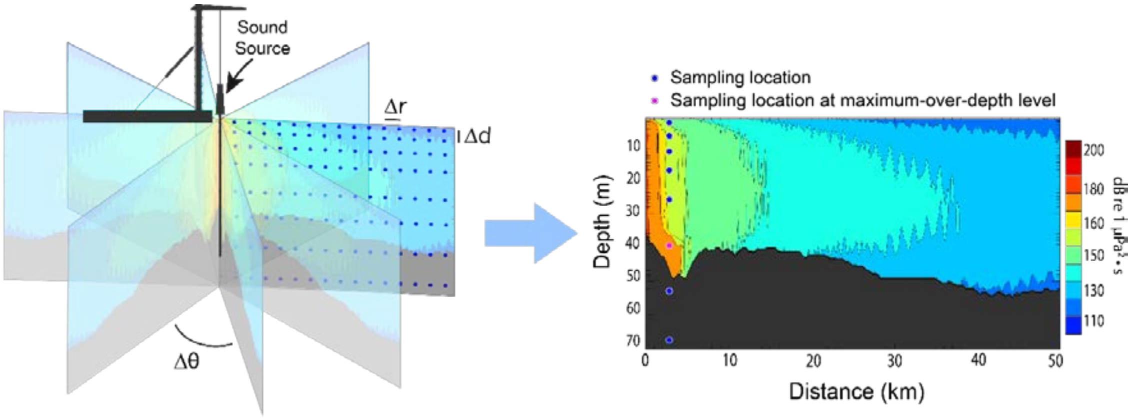


Figure A-5. The *N*×2-D and maximum-over-depth modelling approach used by MONM.

The TL computed by MONM was further corrected to account for attenuation of acoustic energy by molecular absorption in seawater. The volumetric sound absorption is quantified by an attenuation coefficient, expressed in units of decibels per kilometre (dB/km). The absorption coefficient depends mainly on the sound frequency, but also on the temperature, salinity, and hydrostatic pressure of the water. In general, the absorption coefficient increases with the square of frequency. The absorption of acoustic wave energy has a noticeable effect (>0.05 dB/km) at frequencies above 1 kHz. At 10 kHz, the absorption loss over 10 km distance can exceed 10 dB. The absorption coefficient for seawater can be computed according to the formulae from François and Garrison (1982) which consider the contribution of pure seawater, magnesium sulfate, and boric acid. In this study, absorption coefficients were calculated based on water temperature at 7.5 C and salinity of 29 parts per thousand (ppt) and a depth of 10 m, and applied to the modelled TL (Table A-2).

Table A-2. Frequency-dependent attenuation of sound in seawater.

Frequency (Hz)	Absorption (dB/km)	Frequency (Hz)	Absorption (dB/km)
10	0.000	1000	0.060
12.5	0.000	1250	0.075
16	0.000	1600	0.093
20	0.000	2000	0.112
25	0.000	2500	0.135
31.5	0.000	3150	0.168
40	0.000	4000	0.218
50	0.000	5000	0.290
63	0.000	6300	0.406
80	0.001	8000	0.594
100	0.001	10000	0.869
125	0.002	12500	1.289
160	0.003	16000	2.011
200	0.005	20000	3.002
250	0.007	25000	4.443
315	0.011	31500	6.551
400	0.016	40000	9.509
500	0.024	50000	13.001
630	0.034	63000	17.233
800	0.046		

Because it is computationally inefficient to use the PE method to model TL above several Kilohertz, TL was approximated for bands between 6.3 and 63 kHz by computing the TL at 5 kHz and applying the correct frequency-dependent absorption coefficient to each band. This approach is valid because high-frequency predictions from the PE model will approach a limiting value that is consistent with geometrical absorption.

A 10 m radial step size was used for the PE model computational grid, and sound levels were modelled at 18 receiver depths, distributed vertically in the water column, as follows:

- Five receivers were spaced 2 m apart, 2 to 10 m below the water's surface;
- Nine receivers were spaced 10 m apart, 20 to 100 m below the water's surface;
- Three receivers were spaced 100 m apart, 200 to 400 m below the water's surface; and
- One receiver was on the seafloor.

Modelled received levels were gridded separately in each horizontal plane (i.e., at each modelled receiver depth). To generate a conservative estimate, the modelled results in this study were obtained by collapsing the stack of grids into a single plane using a maximum-over-depth rule, which means that the sound levels at each planar point are taken to be the maximum value from all modelled depths in the water column for that point (Figure A-5 right).

To model continuous sources such as container ships, tugs, dredgers, and vibratory pile drivers, MONM predicted the SPL on the *N*×2-D grid. For impulsive sources (i.e., impact pile driving), MONM modelled the single-strike SEL and then converted the SEL to SPL based on a range-dependent conversion curve.

Predicted received SPL (in dB re 1 µPa) were contoured to show the estimated acoustic footprint (area of ensonification) for each scenario, and noise contours were converted to GIS layers for rendering on thematic maps. For each scenario, the 95th percentile radius, $R_{95\%}$, and the maximum radius, $R_{\max}$, for each noise threshold level were tabulated. The $R_{95\%}$ is the radius of a circle that encompasses 95% of grid points whose value equals, or is greater than, the threshold value. For a given threshold level, this radius always provides a range beyond which no more than 5% of a uniformly distributed population would be exposed to sound at or above that level, regardless of the geometrical shape of the noise footprint. The $R_{\max}$ is the maximum distance from the source to the given noise threshold in any direction (equivalent to $R_{100\%}$). $R_{\max}$ can be a reference for the most conservative case compared to using $R_{95\%}$. For cases where the isopleth of a specific sound level is discontinuous and small pockets of higher received levels occur far beyond the main ensonified volume (e.g., due to convergence of sound rays), $R_{\max}$ would be much larger than $R_{95\%}$ and could be misleading if not given alongside $R_{95\%}$.

Appendix B. Isopleth Maps of Modelled Terminal Construction Noise Scenarios

Section 3.1 summarizes the model results, providing tables of radii to various sound level thresholds associated with the eight modelled construction scenarios. This appendix provides maps for each of the modelled scenarios. For all scenarios, we provide a map of unweighted SPL, including cetacean disturbance (120 dB re 1 µPa) and behavioural response thresholds (129 and 137 dB re 1 µPa, corresponding to the 50% probability of low and moderate-severity behavioural response for SRKW). For each impact pile driving scenarios (Scenarios 2A and 2B for impact piling), we provide two additional maps: (1) fish injury thresholds (unweighted 24 h SEL) and (2) mid-frequency (MF) cetacean injury thresholds (weighted 24 h SEL).

B.1. Scenario 1

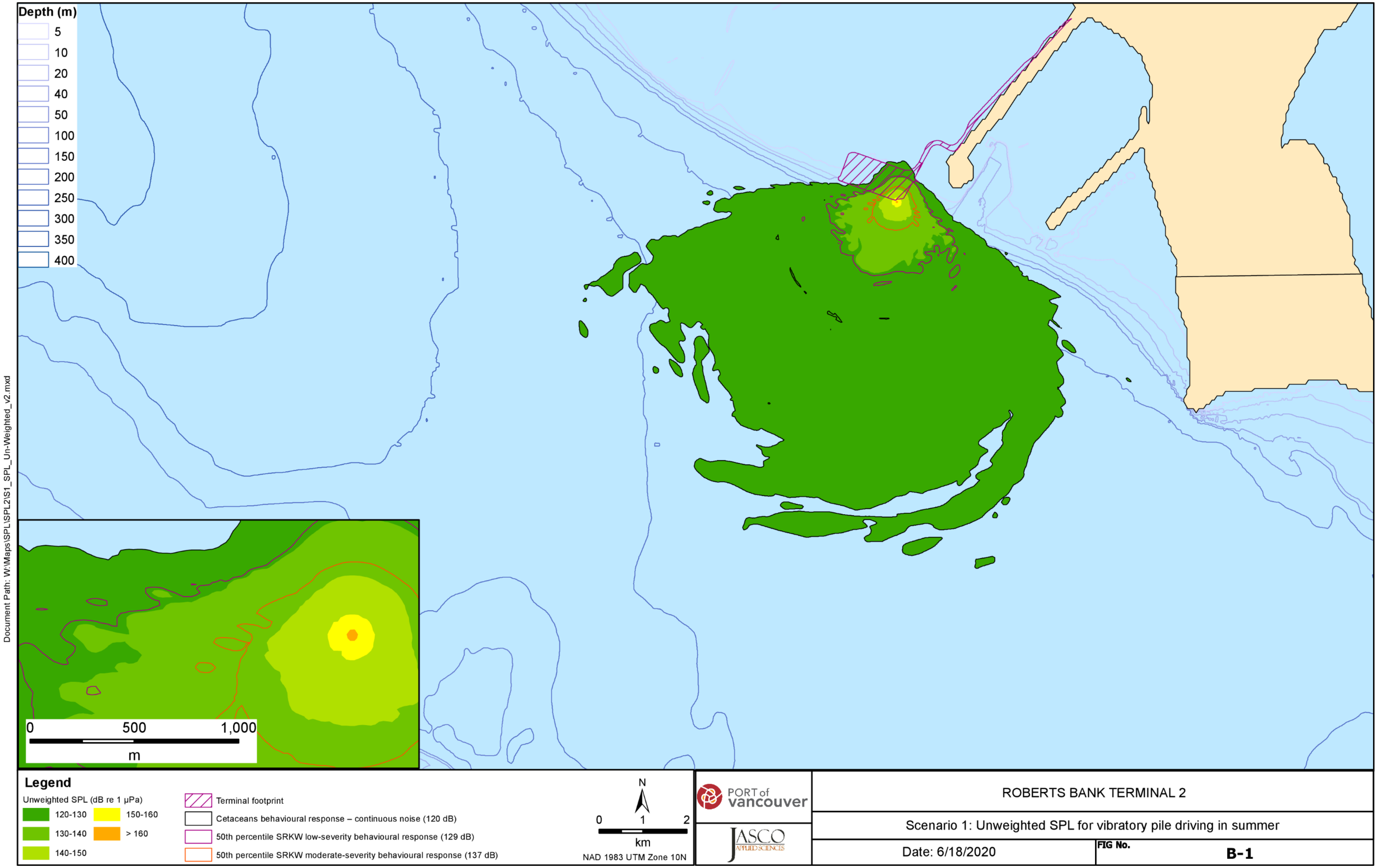


Figure B-1. Scenario 1: Unweighted SPL for vibratory pile driving in summer.

B.2. Scenario 2A Fish

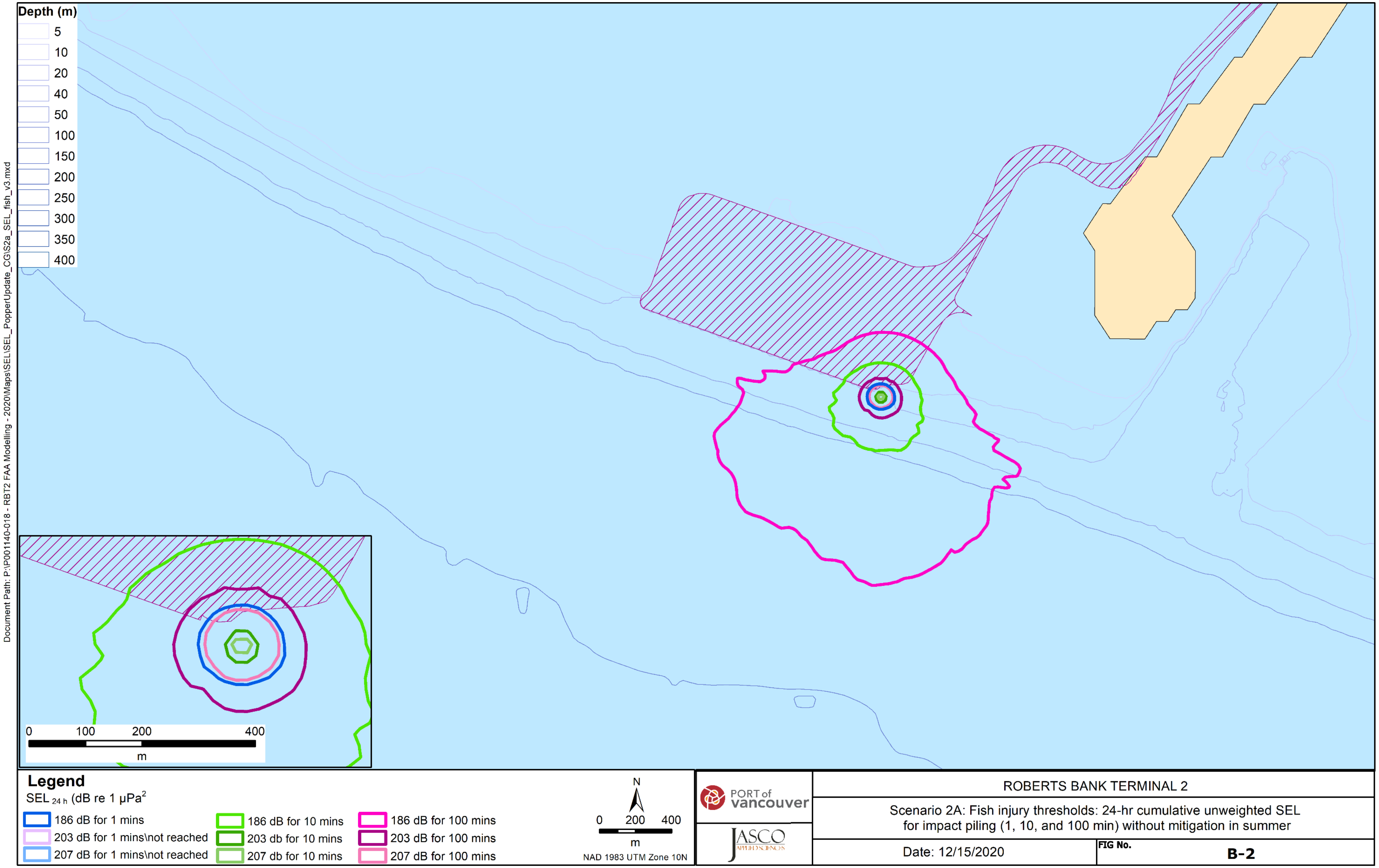


Figure B-2. Scenario 2A: Fish injury thresholds: 24 h cumulative unweighted SEL for impact piling (1, 10, and 100 min; 123 kJ hammer) without mitigation in summer.

B.3. Scenario 2A MFC

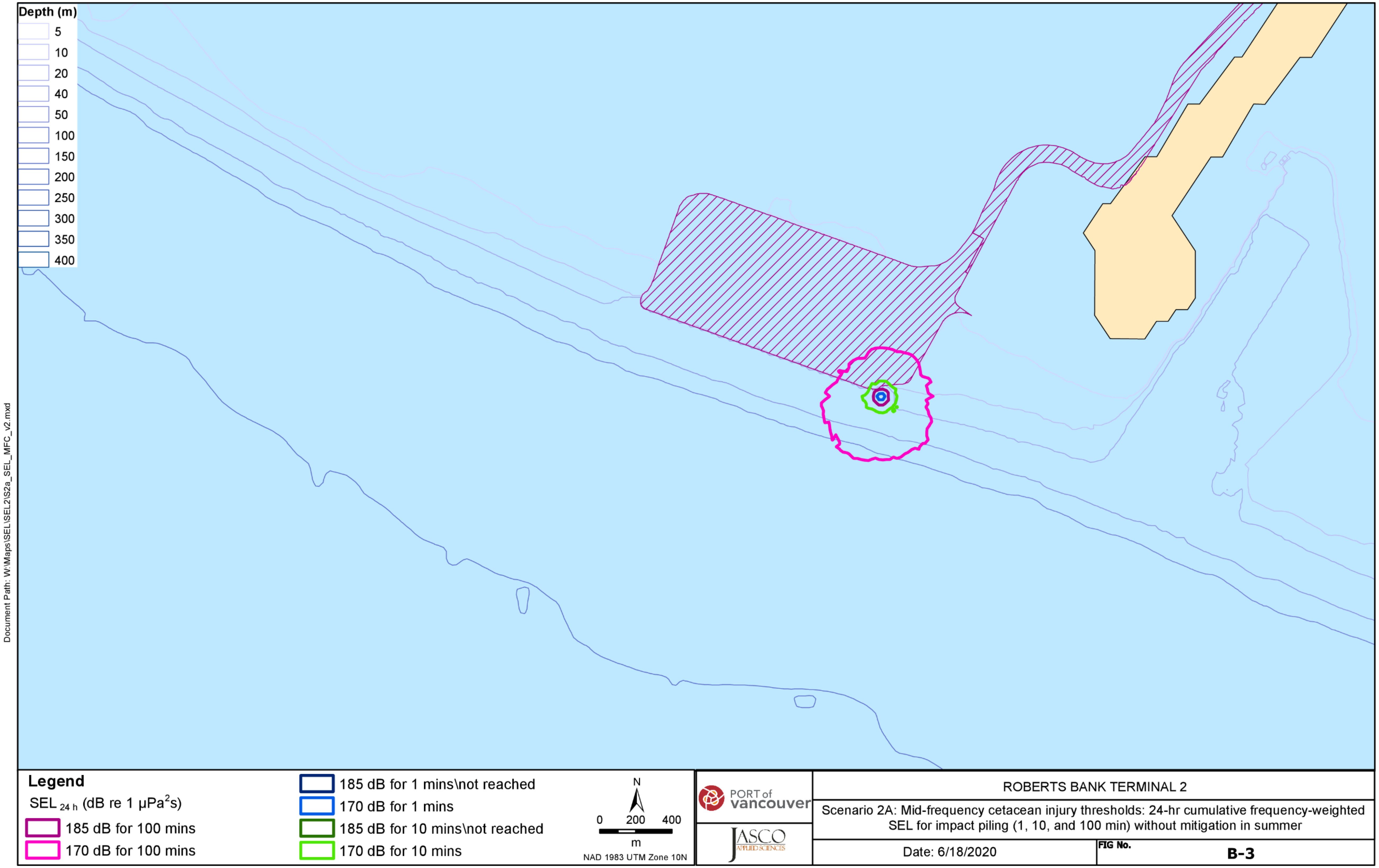


Figure B-3. Scenario 2A: Mid-frequency cetacean injury thresholds: 24 h cumulative frequency-weighted SEL for impact piling (1, 10, and 100 min; 123 kJ hammer) without mitigation in summer.

B.4. Scenario 2A SPL

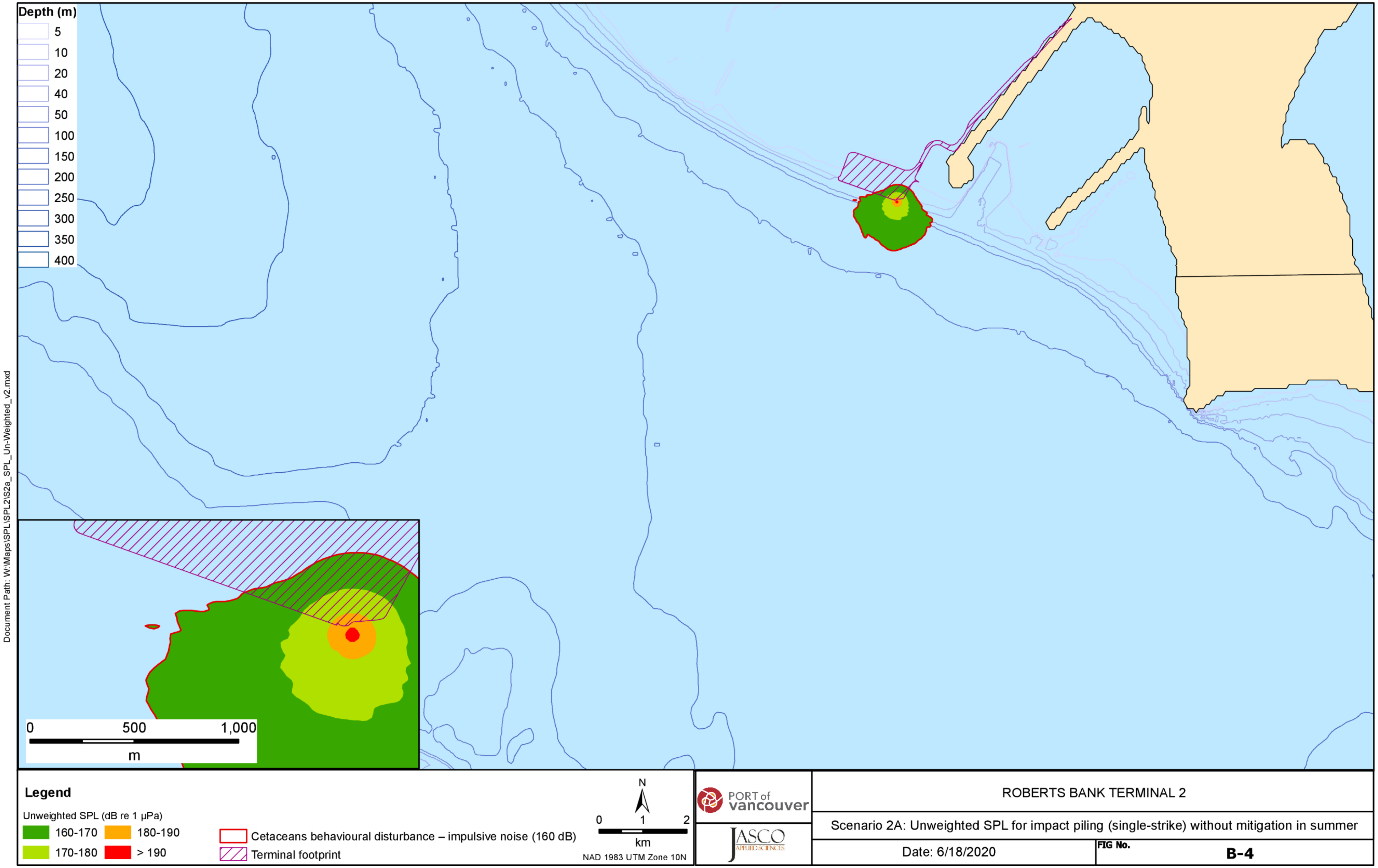


Figure B-4. Scenario 2A: Unweighted SPL for impact piling (single-strike; 123 kJ hammer) without mitigation in summer.

B.5. Scenario 2B Fish

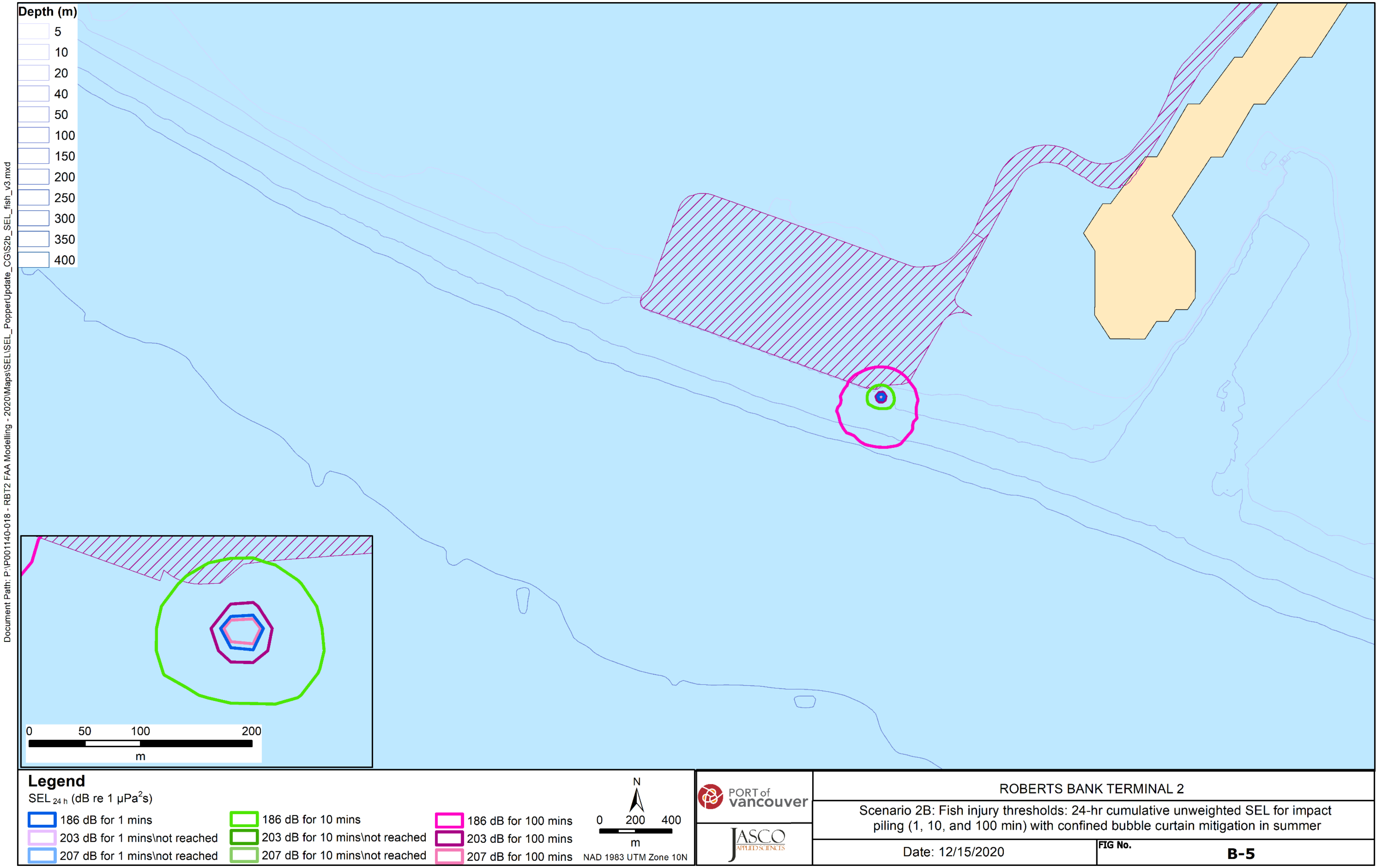


Figure B-5. Scenario 2B: Fish injury thresholds: 24 h cumulative unweighted SEL for impact piling (1, 10, and 100 min; 123 kJ hammer) with confined bubble curtain mitigation in summer.

B.6. Scenario 2B MFC

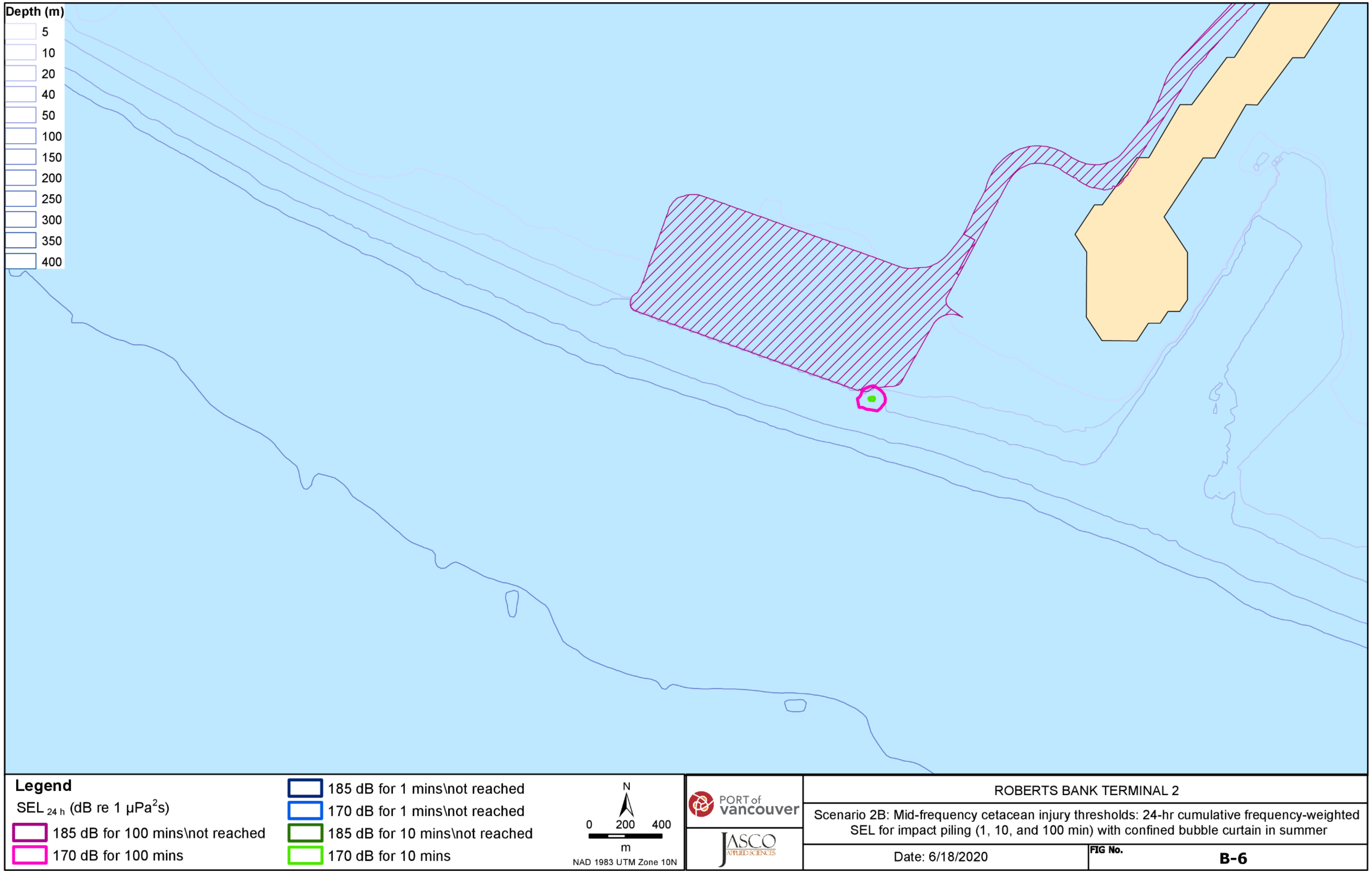


Figure B-6. Scenario 2B: Mid-frequency cetacean injury thresholds: 24 h cumulative frequency-weighted SEL for impact piling (1, 10, and 100 min; 123 kJ hammer) with confined bubble curtain mitigation in summer.

B.7. Scenario 2B SPL

Document Path: W:\Maps\SPL\SPL2\S2b_SPL_Un-Weighted_v2.mxd

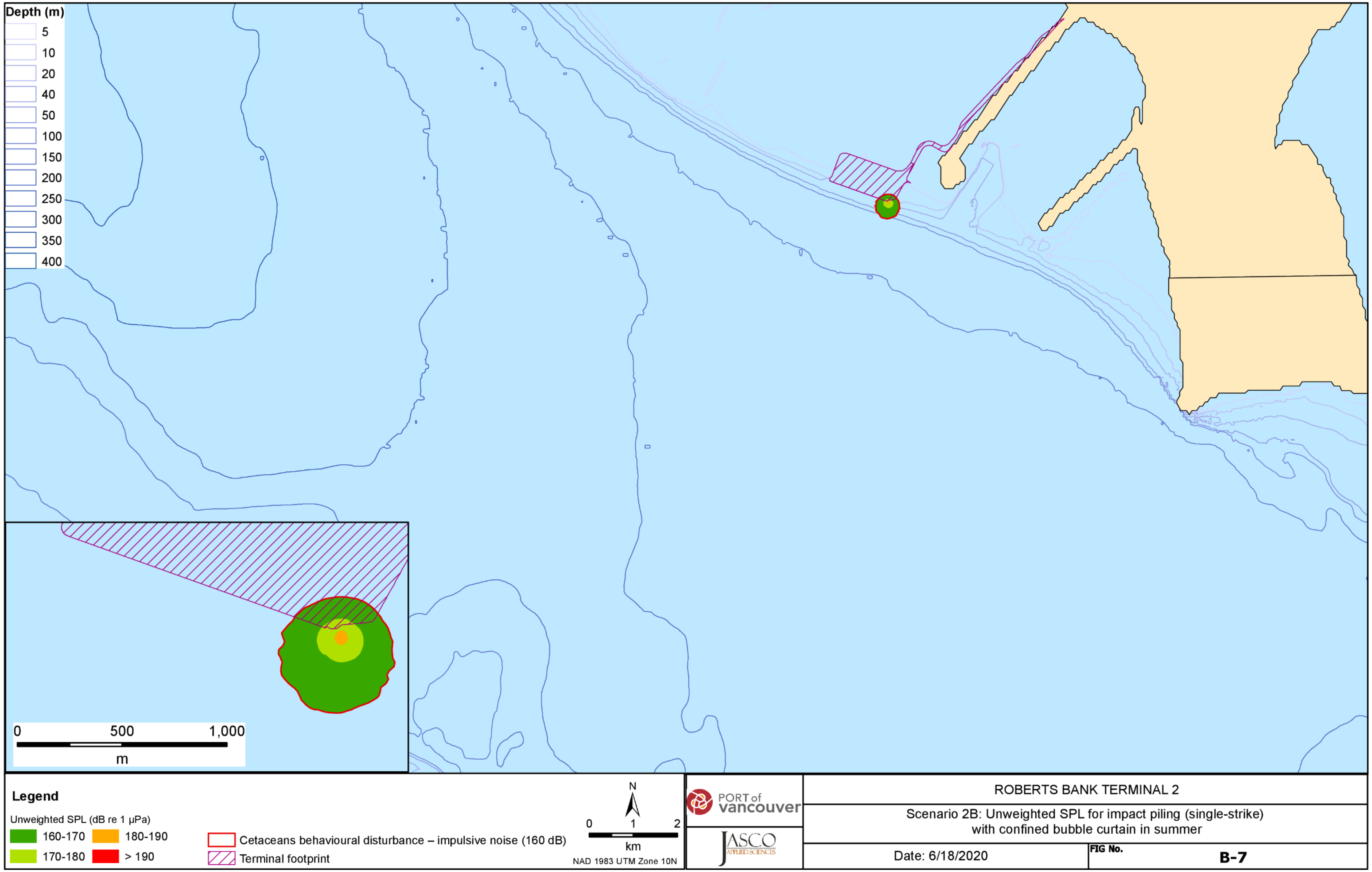


Figure B-7. Scenario 2B: Unweighted SPL for impact piling (single-strike; 123 kJ hammer) with confined bubble curtain mitigation in summer.

B.8. Scenario 3A

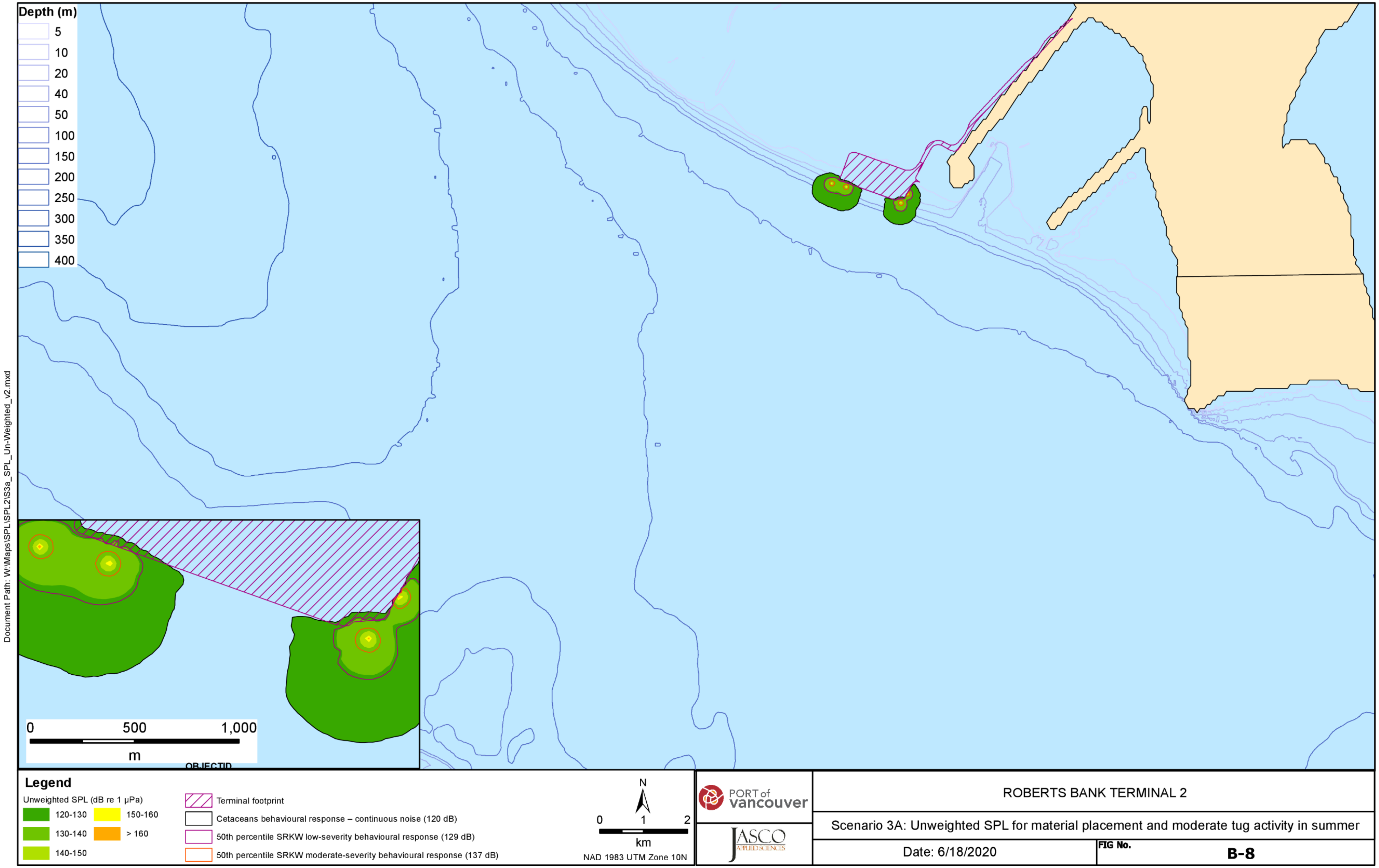
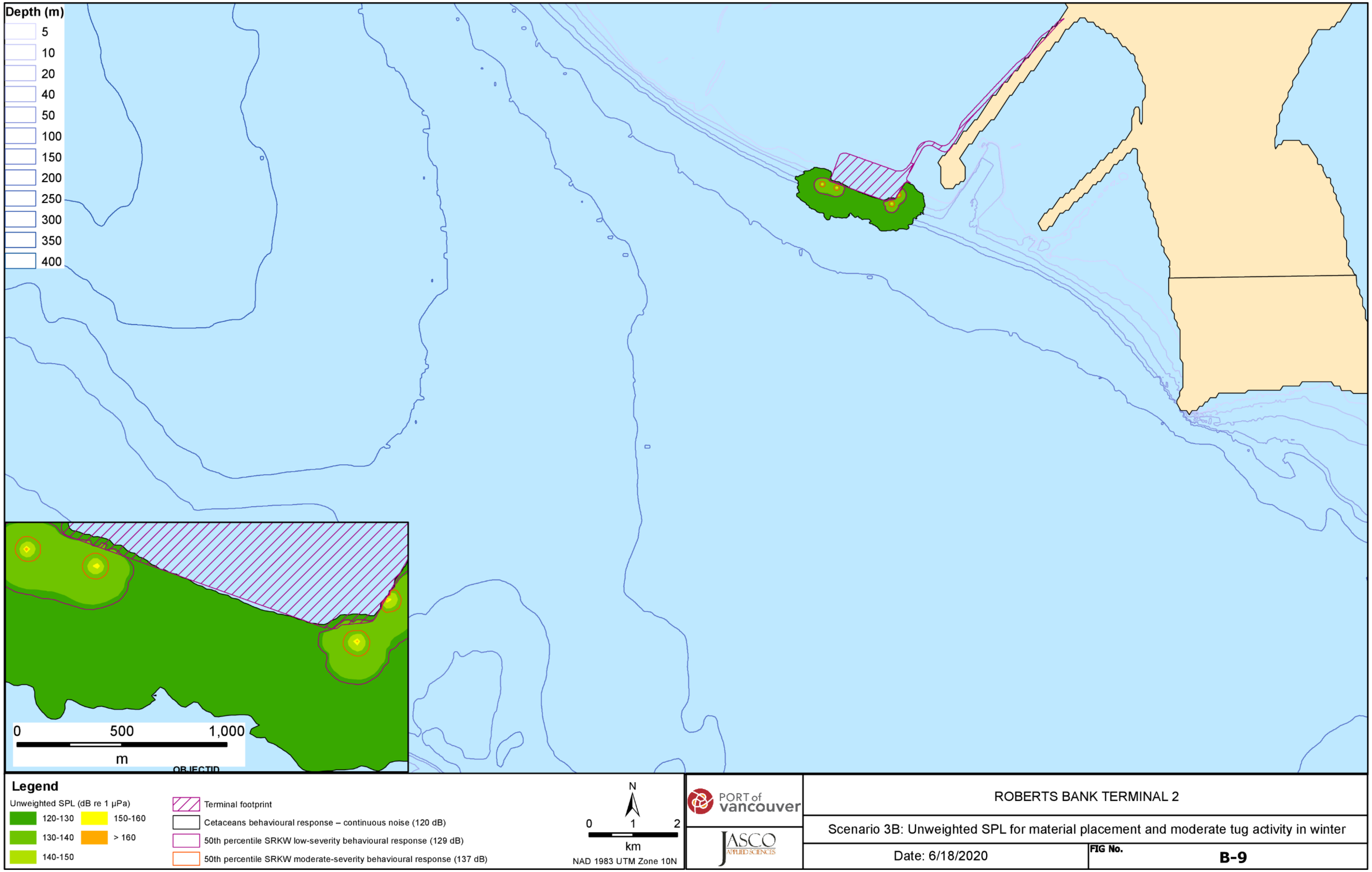


Figure B-8. Scenario 3A: Unweighted SPL for material placement and moderate tug activity in summer.

B.9. Scenario 3B



Document Path: W:\Maps\SPL\SPL2\S3b_SPL_Un-Weighted_v2.mxd

Figure B-9. Scenario 3B: Unweighted SPL for material placement and moderate tug activity in winter.

B.10. Scenario 4

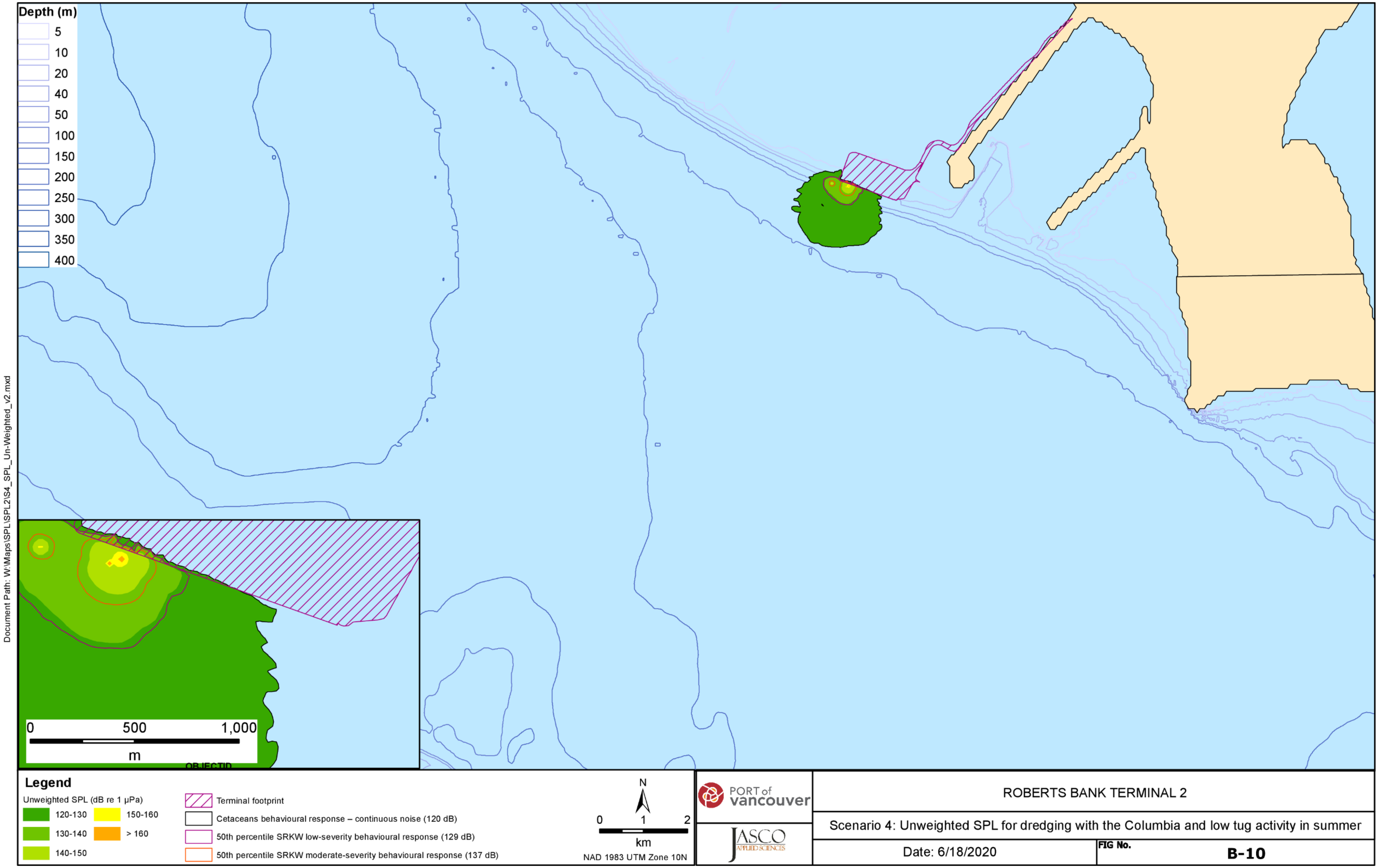


Figure B-10. Scenario 4: Unweighted SPL for dredging with the *Columbia* and low tug activity in summer.

B.11. Scenario 5

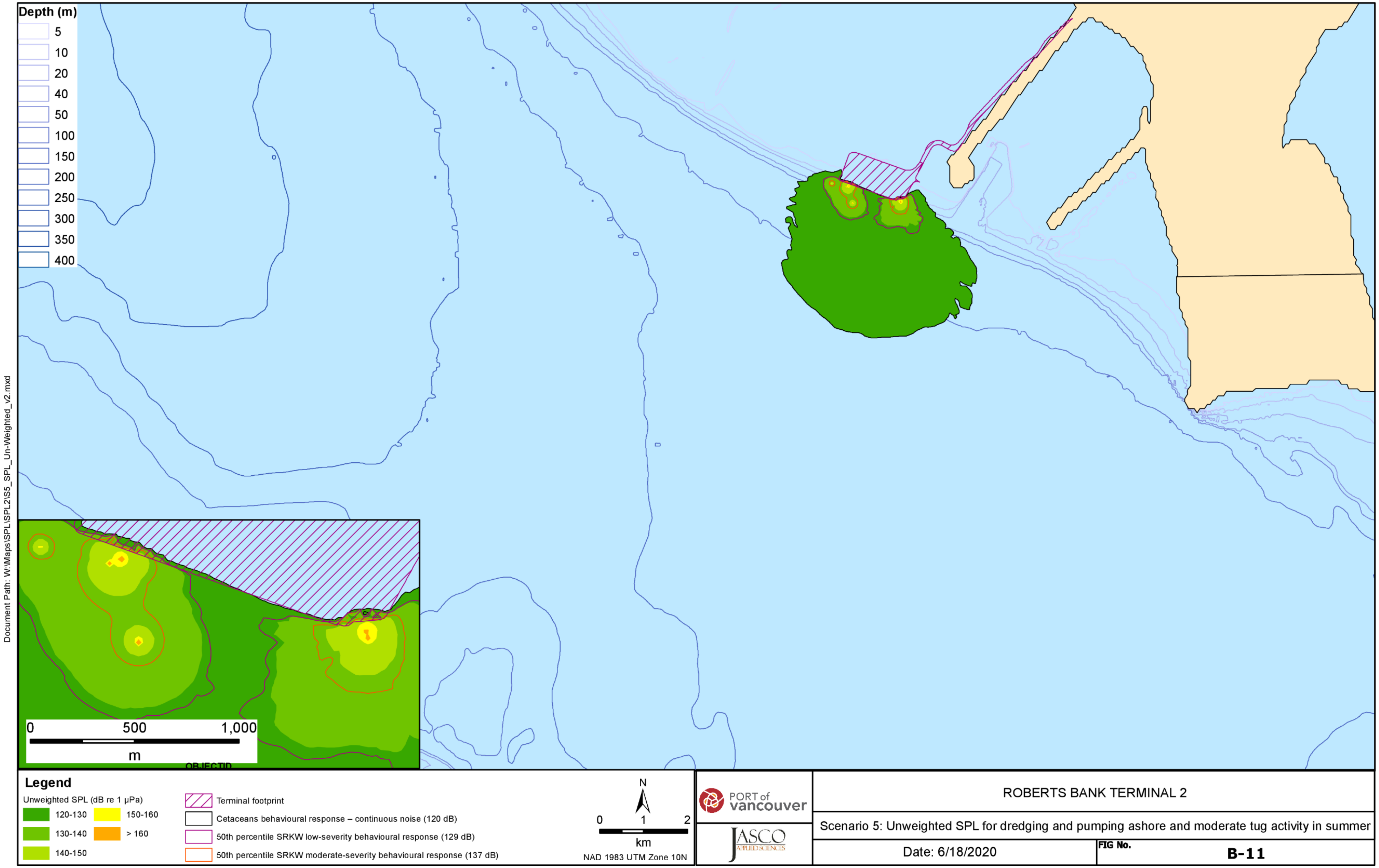
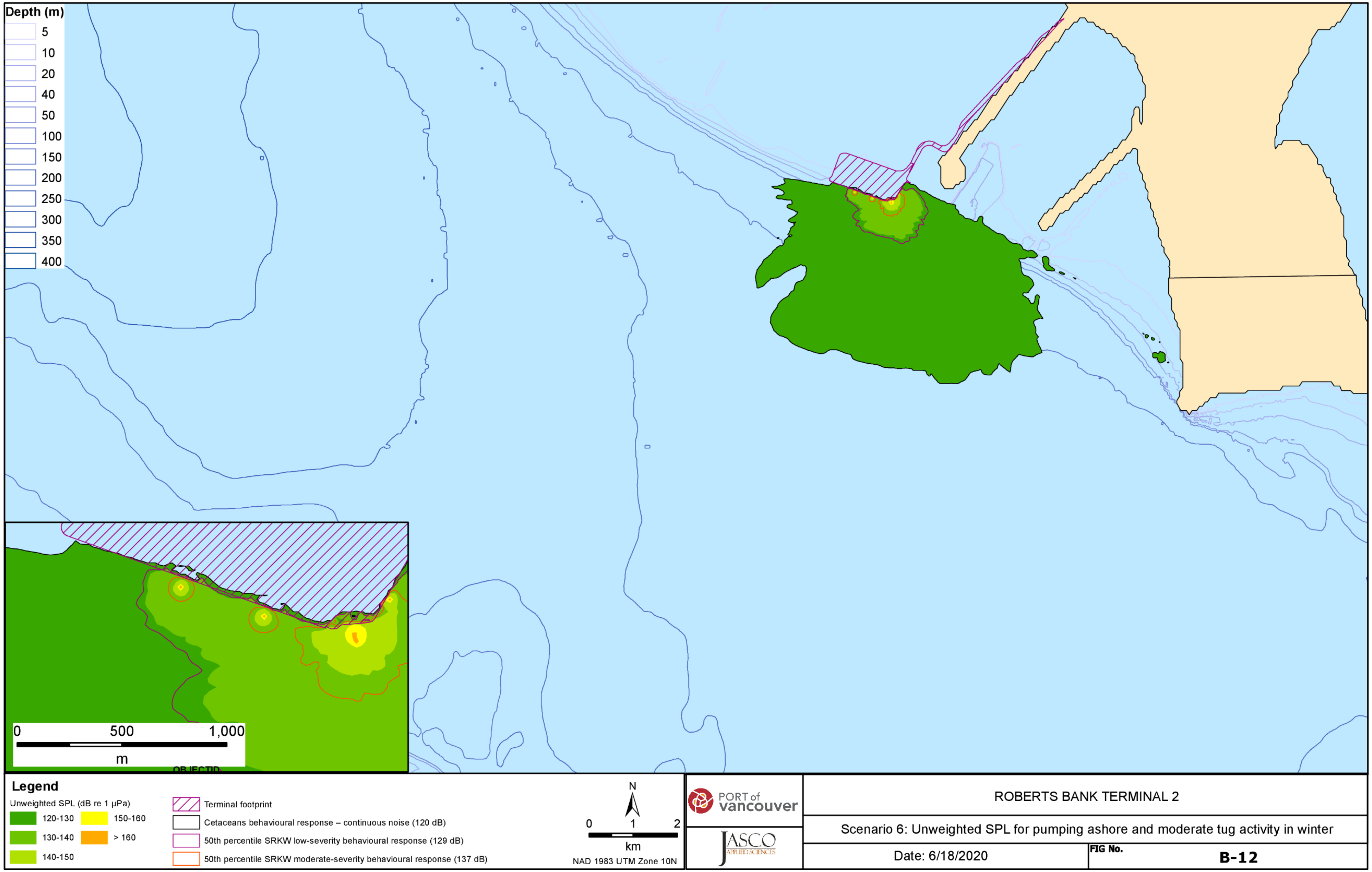


Figure B-11. Scenario 5: Unweighted SPL for dredging and pumping ashore and moderate tug activity in summer.

B.12. Scenario 6



Document Path: W:\Maps\SPL\SPL2\S6_SPL_Un-Weighted_v2.mxd

Figure B-12. Scenario 6: Unweighted SPL for pumping ashore and moderate tug activity in winter.

B.13. Scenario 7A

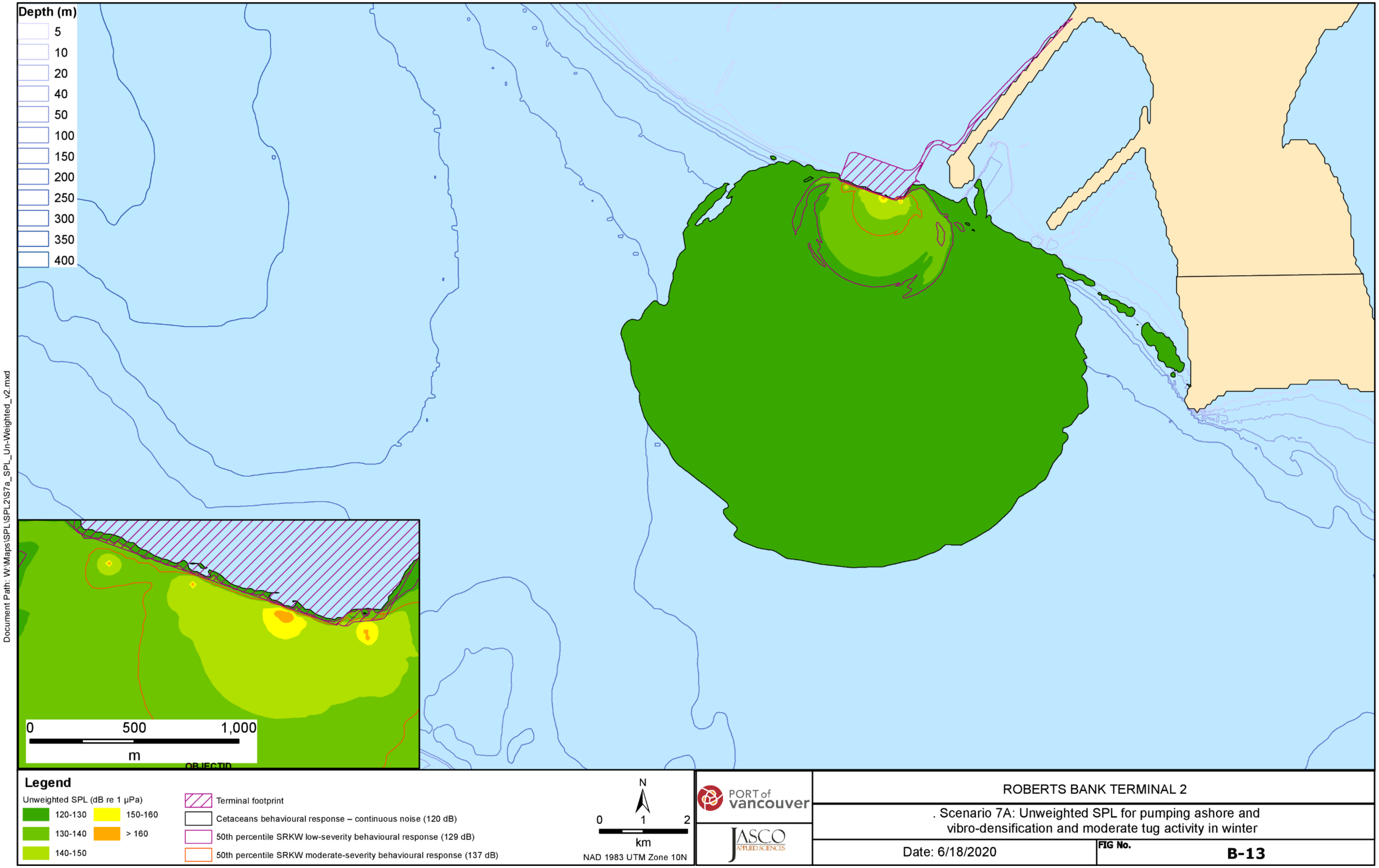


Figure B-13. Scenario 7A: Unweighted SPL for pumping ashore and vibro-densification and moderate tug activity in winter.

B.14. Scenario 7B

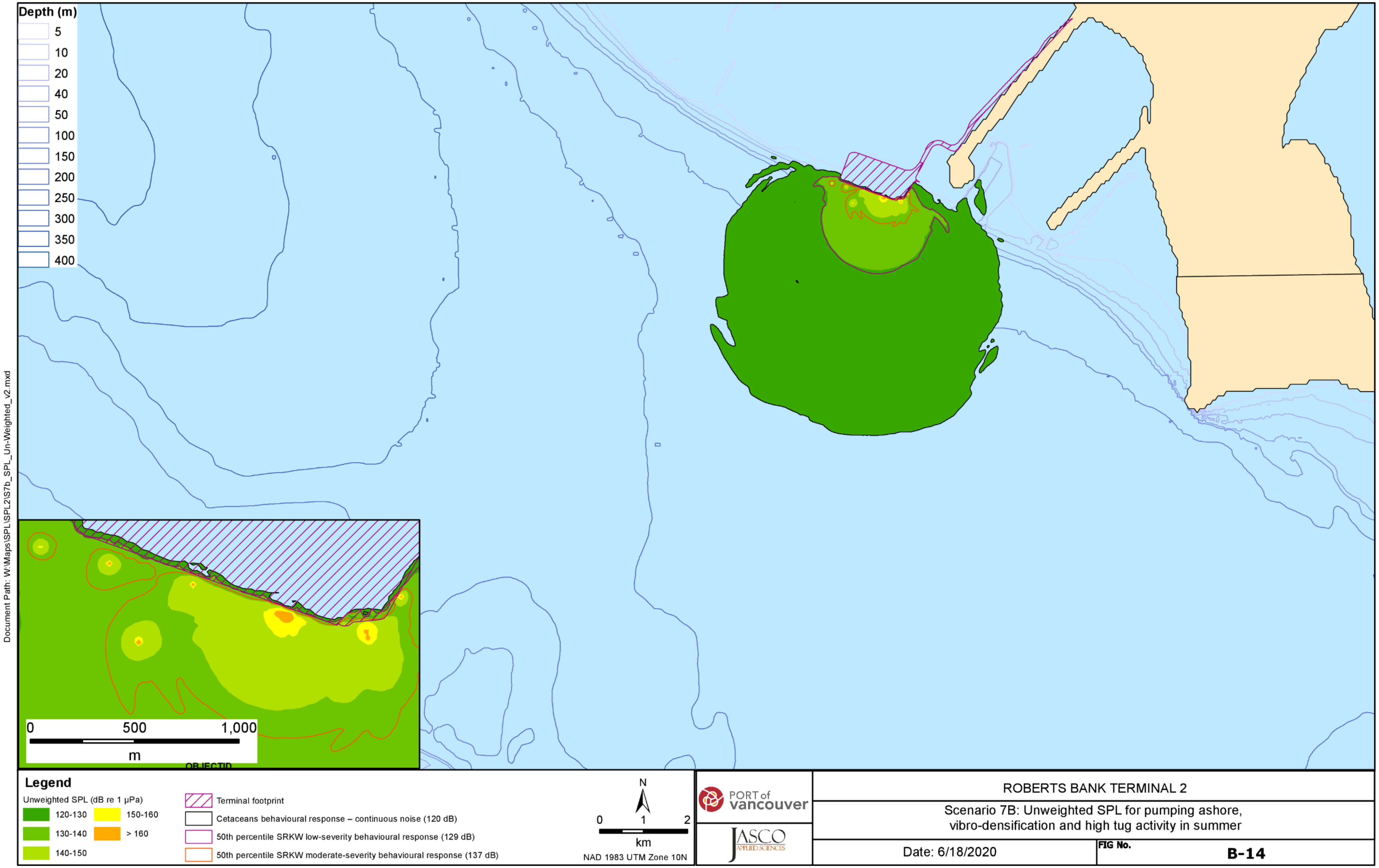


Figure B-14. Scenario 7B: Unweighted SPL for pumping ashore, vibro-densification and high tug activity in summer.

B.15. Scenario 8A

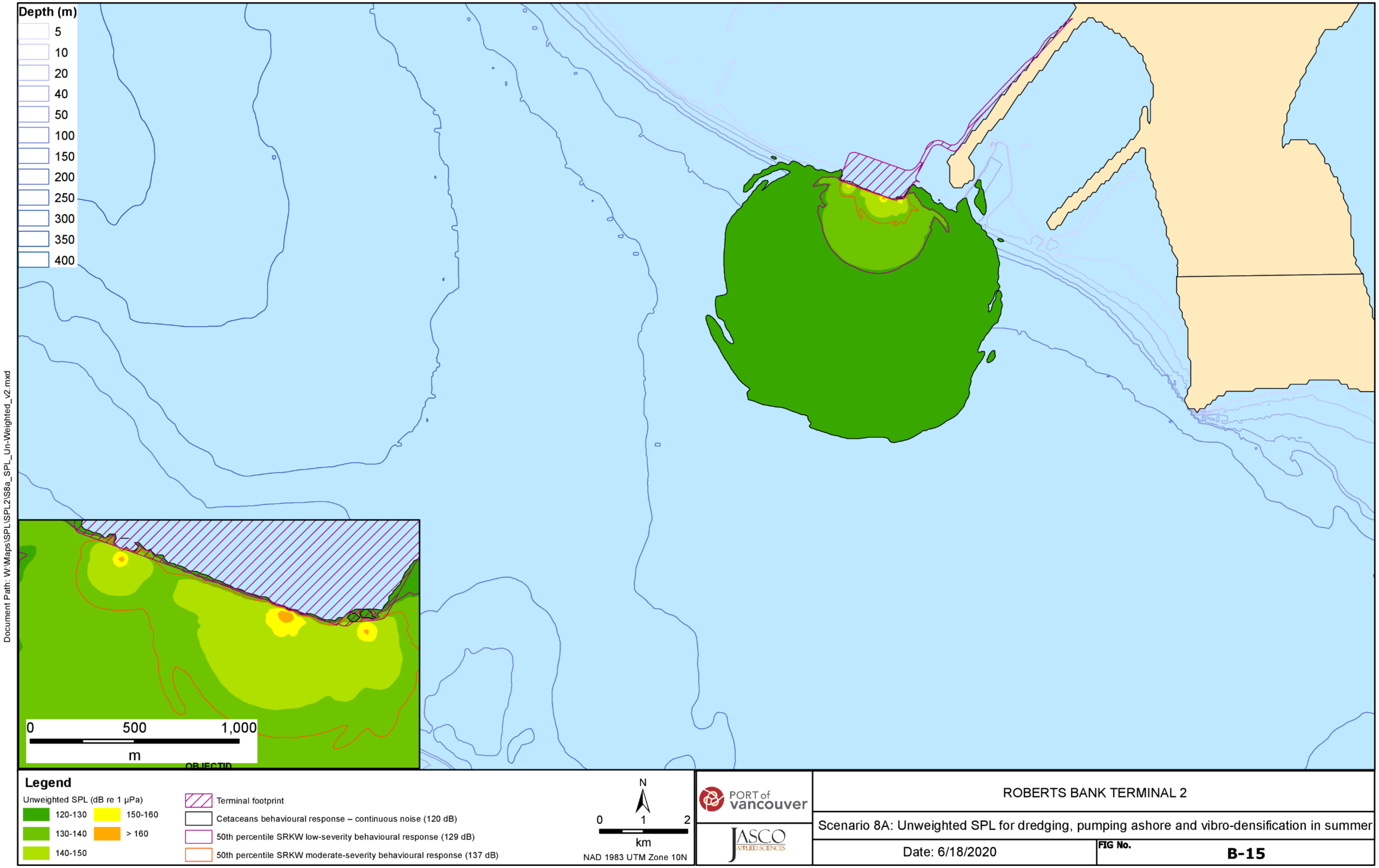


Figure B-15. Scenario 8A: Unweighted SPL for dredging, pumping ashore and vibro-densification in summer.

B.16. Scenario 8B

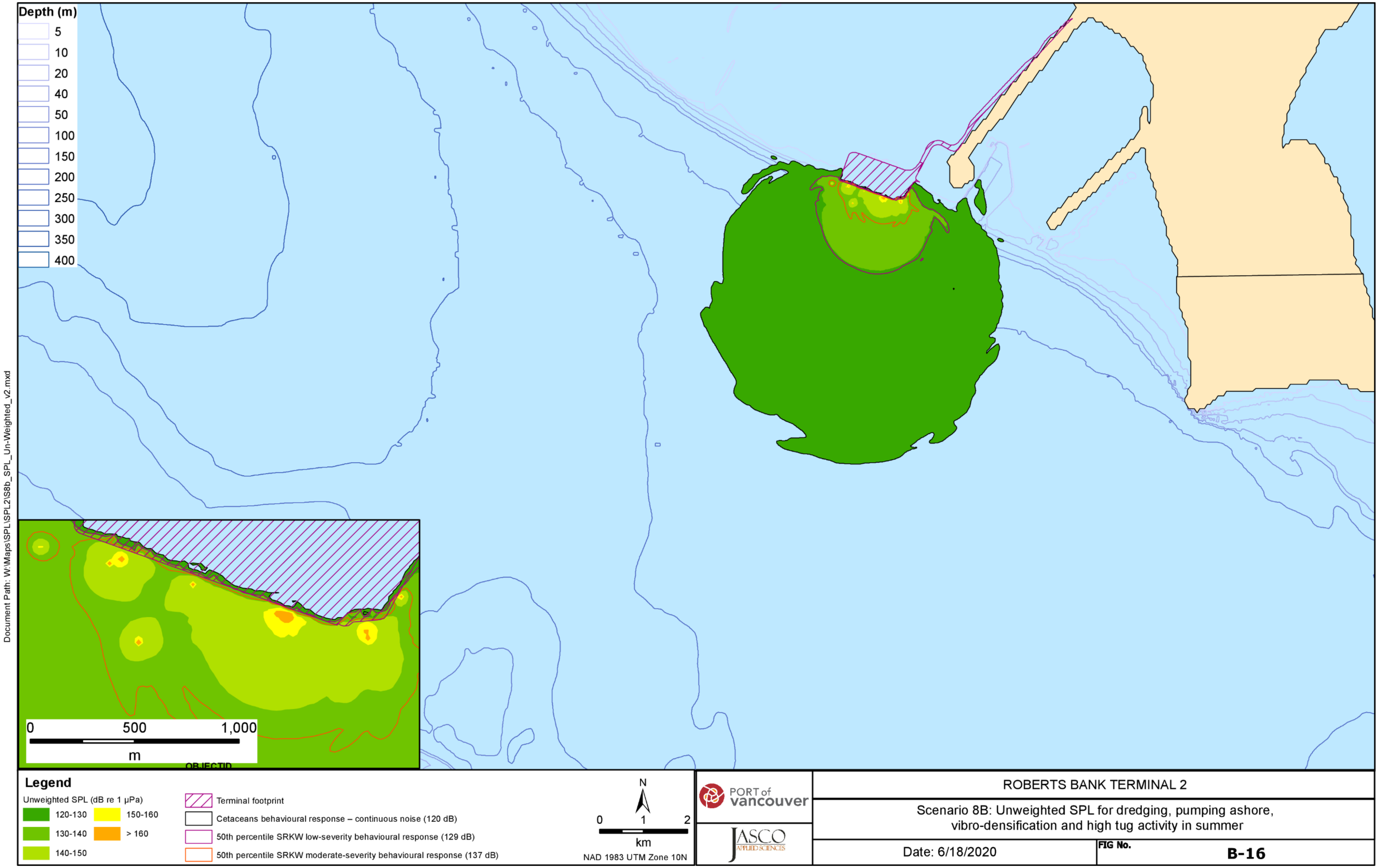


Figure B-16. Scenario 8B: Unweighted SPL for dredging, pumping ashore, vibro-densification and high tug activity in summer.

B.17. Scenarios 2C–2F Fish

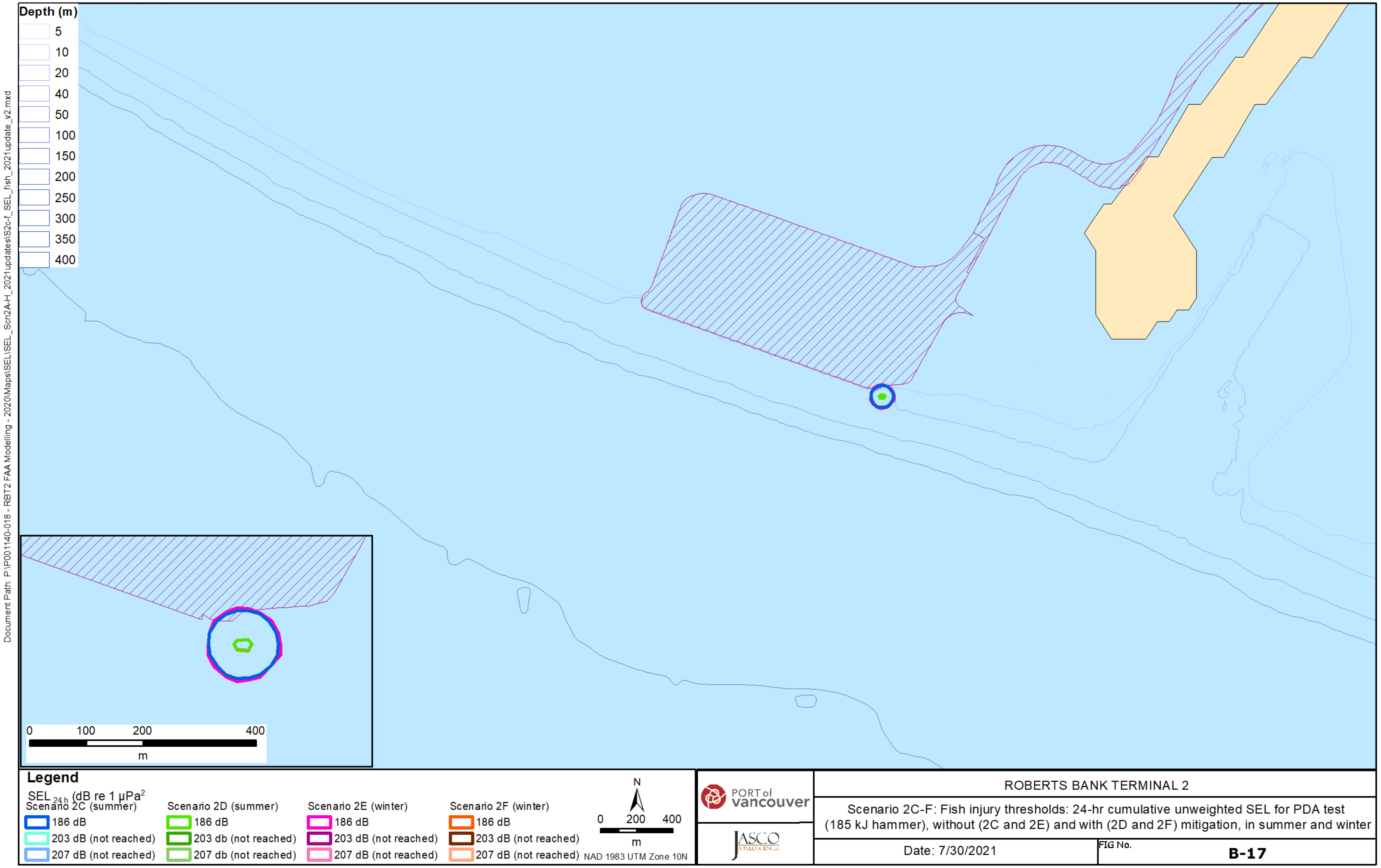


Figure B-17. Scenarios 2C–2F: Fish injury thresholds: 24 h cumulative unweighted SEL for PDA test (17 strikes, 185 kJ hammer) without and with confined bubble curtain mitigation in summer and winter, respectively.

B.18. Scenarios 2G–2J Fish

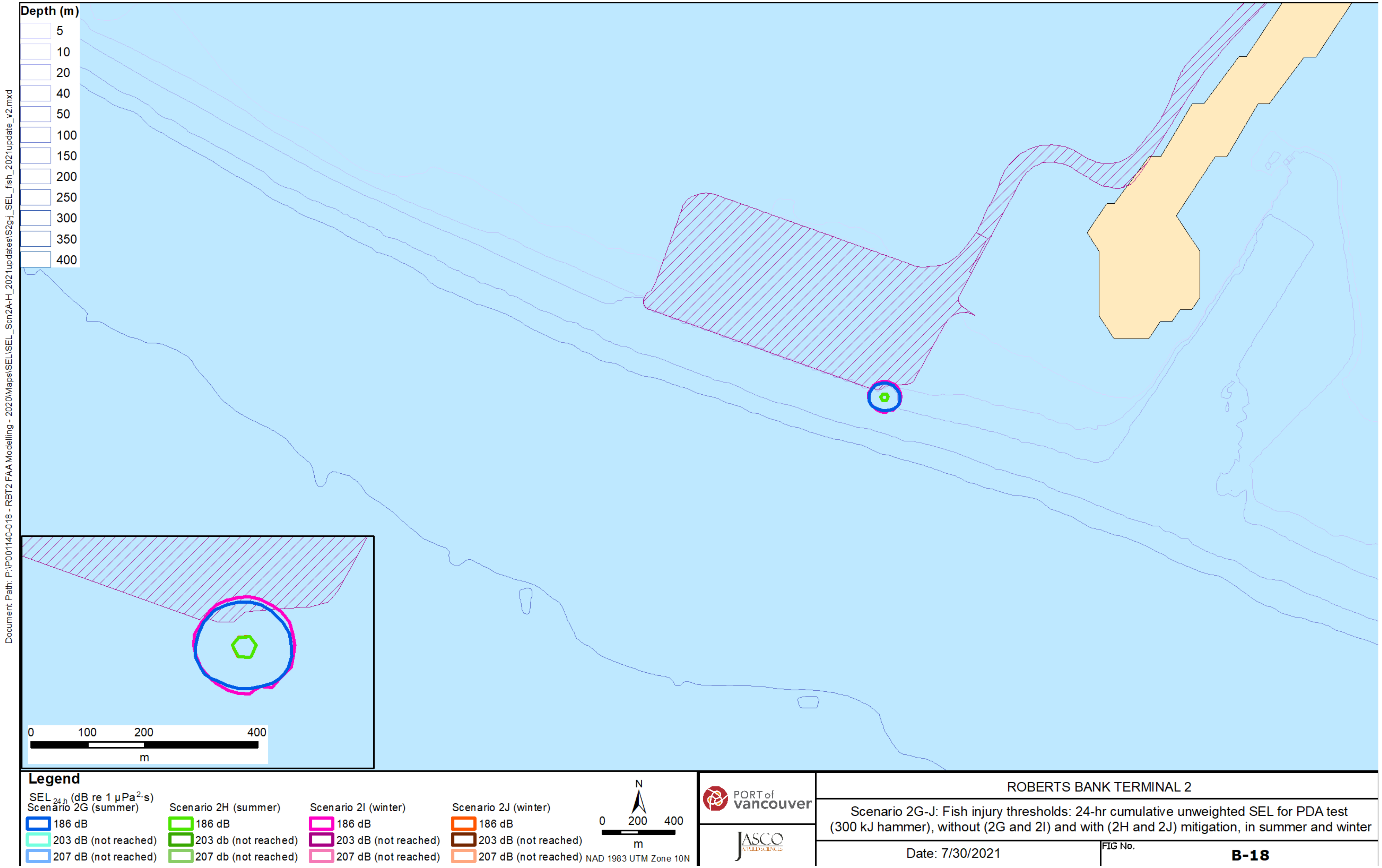


Figure B-18. Scenarios 2G–2J: Fish injury thresholds: 24 h cumulative unweighted SEL for PDA test (17 strikes; 300 kJ hammer) without and with confined bubble curtain mitigation in summer and winter, respectively.

B.19. Scenarios 2C–2F MFC

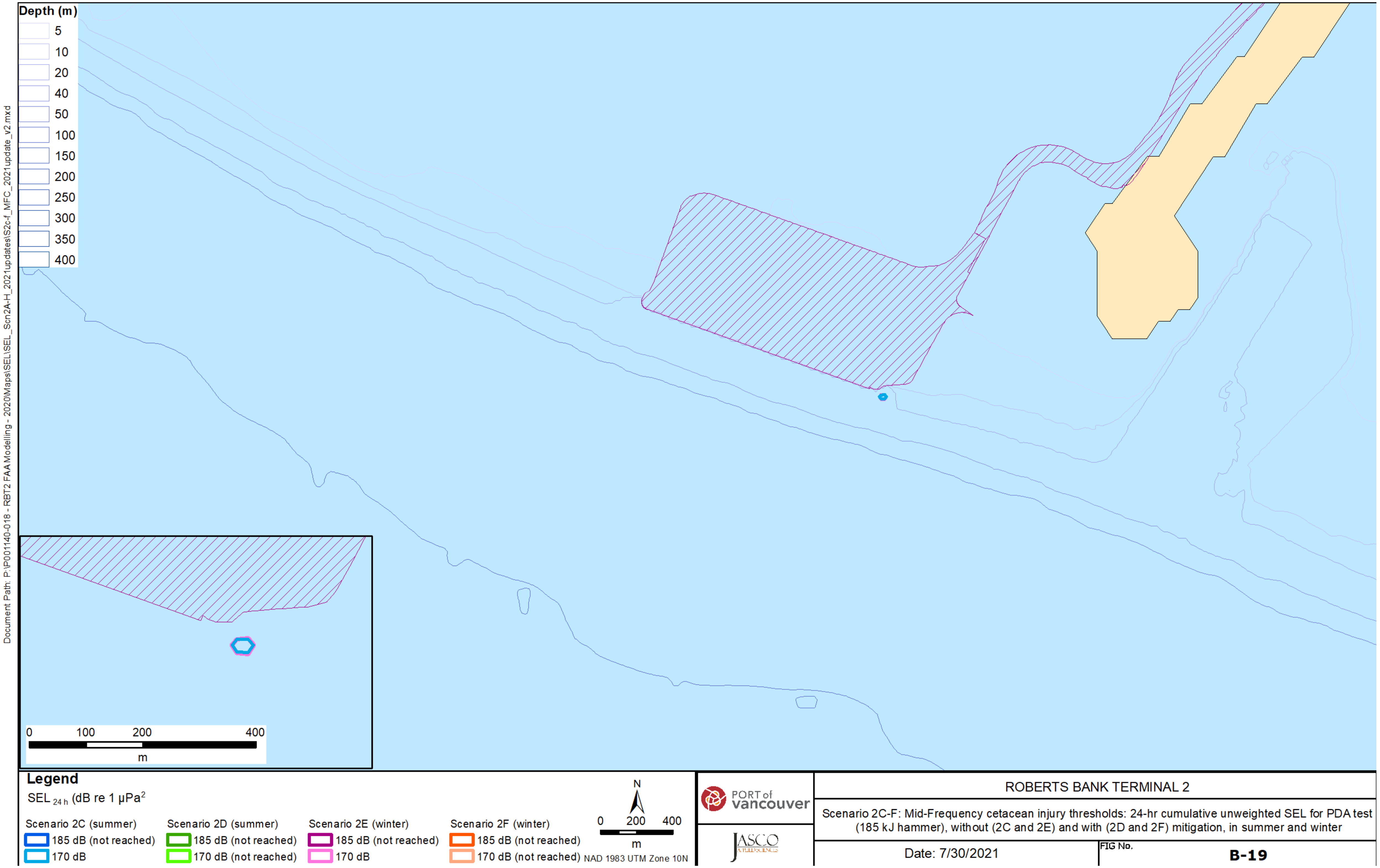


Figure B-19. Scenarios 2C–2F: Mid-frequency cetacean injury thresholds: 24 h cumulative frequency-weighted SEL for PDA test (17 strikes; 185 kJ hammer) without and with confined bubble curtain mitigation in summer and winter, respectively.

B.20. Scenarios 2G–2J MFC

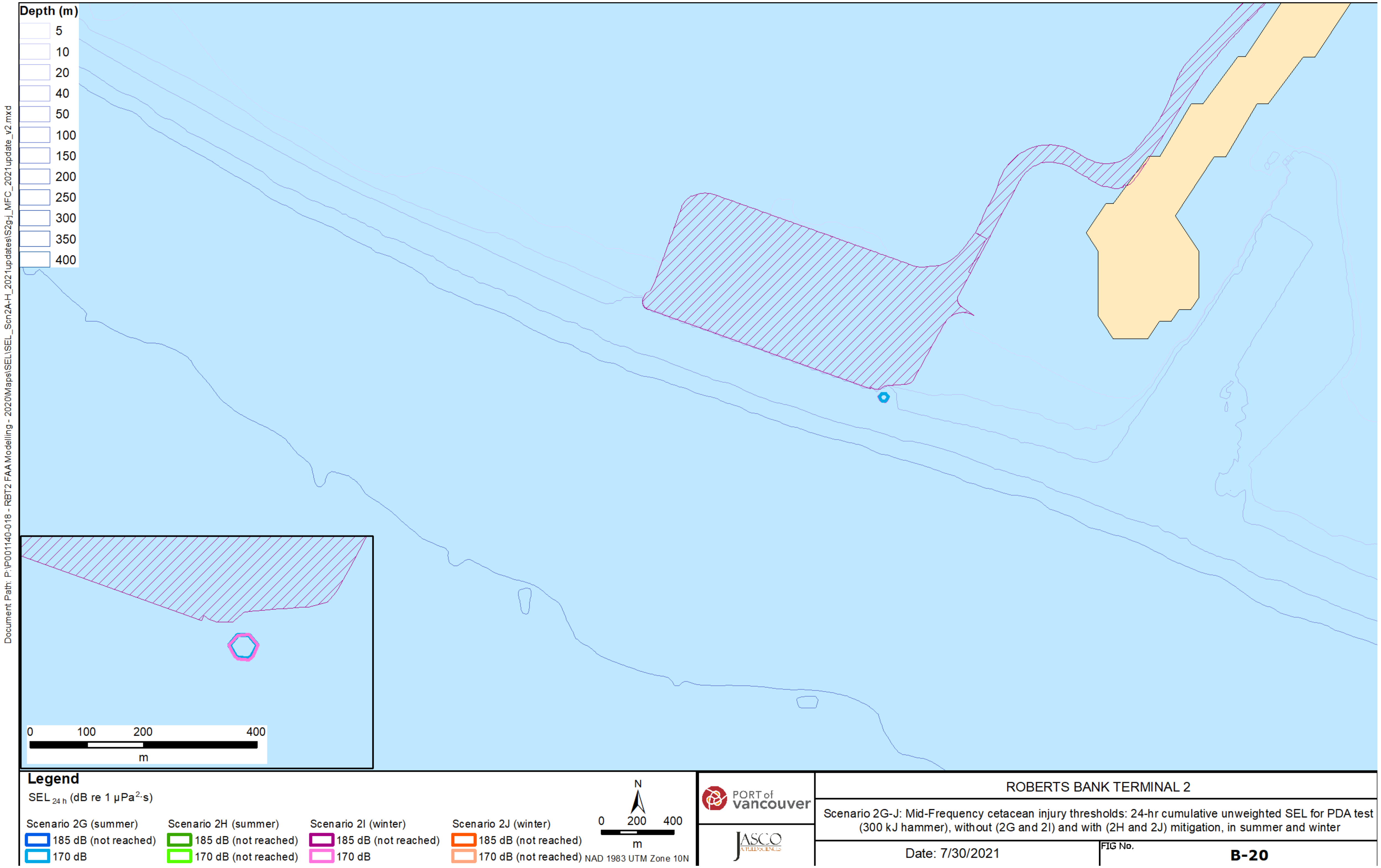


Figure B-20. Scenarios 2G–2J: Mid-frequency cetacean injury thresholds: 24 h cumulative frequency-weighted SEL PDA test (17 strikes; 300 kJ hammer) without and with confined bubble curtain mitigation in summer and winter, respectively.

B.21. Scenarios 2C–2F SPL

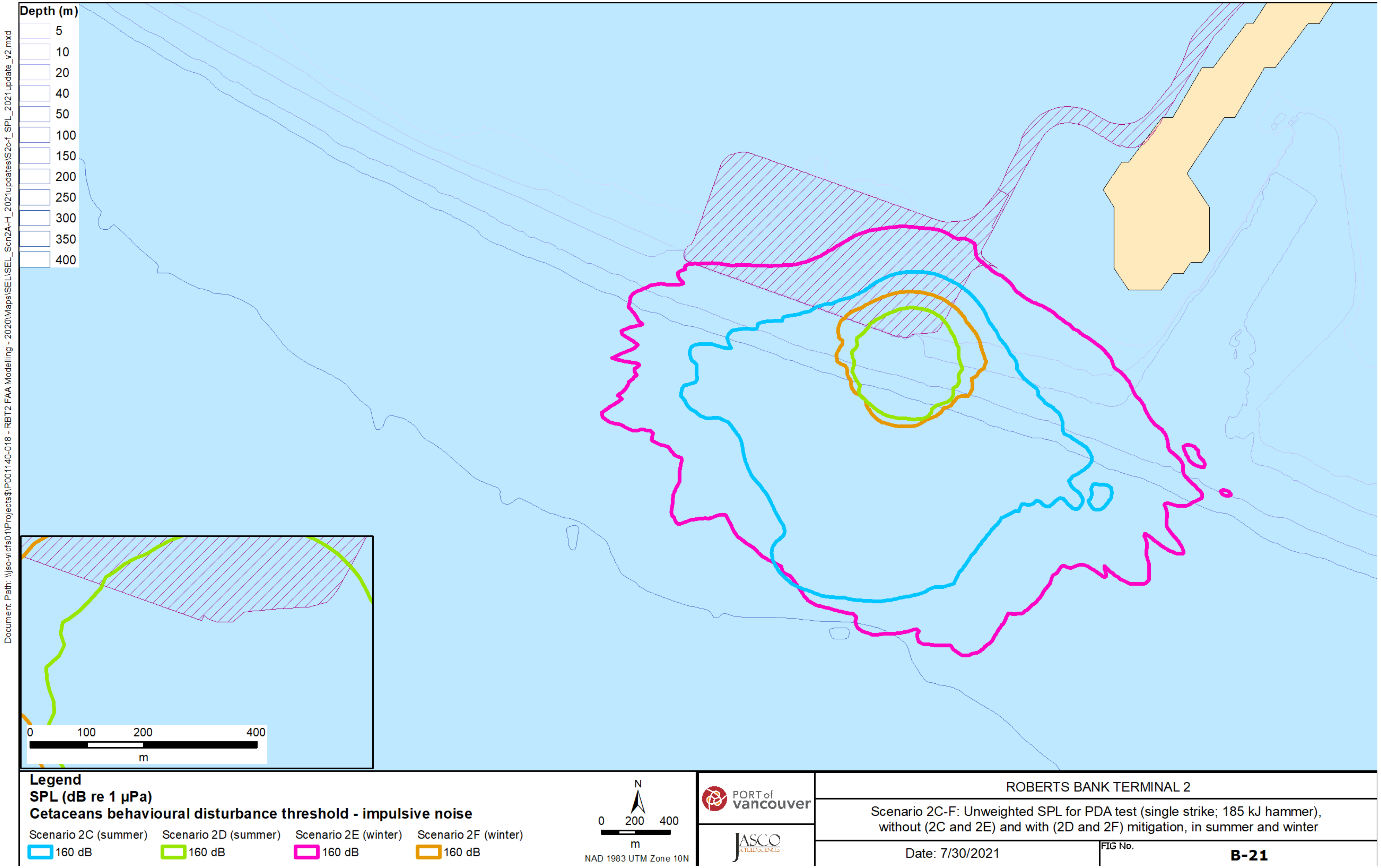


Figure B-21. Scenarios 2C–2F: Unweighted SPL for PDA test (single-strike; 185 kJ hammer) without and with confined bubble curtain mitigation in summer and winter, respectively.

B.22. Scenarios 2G–2J SPL

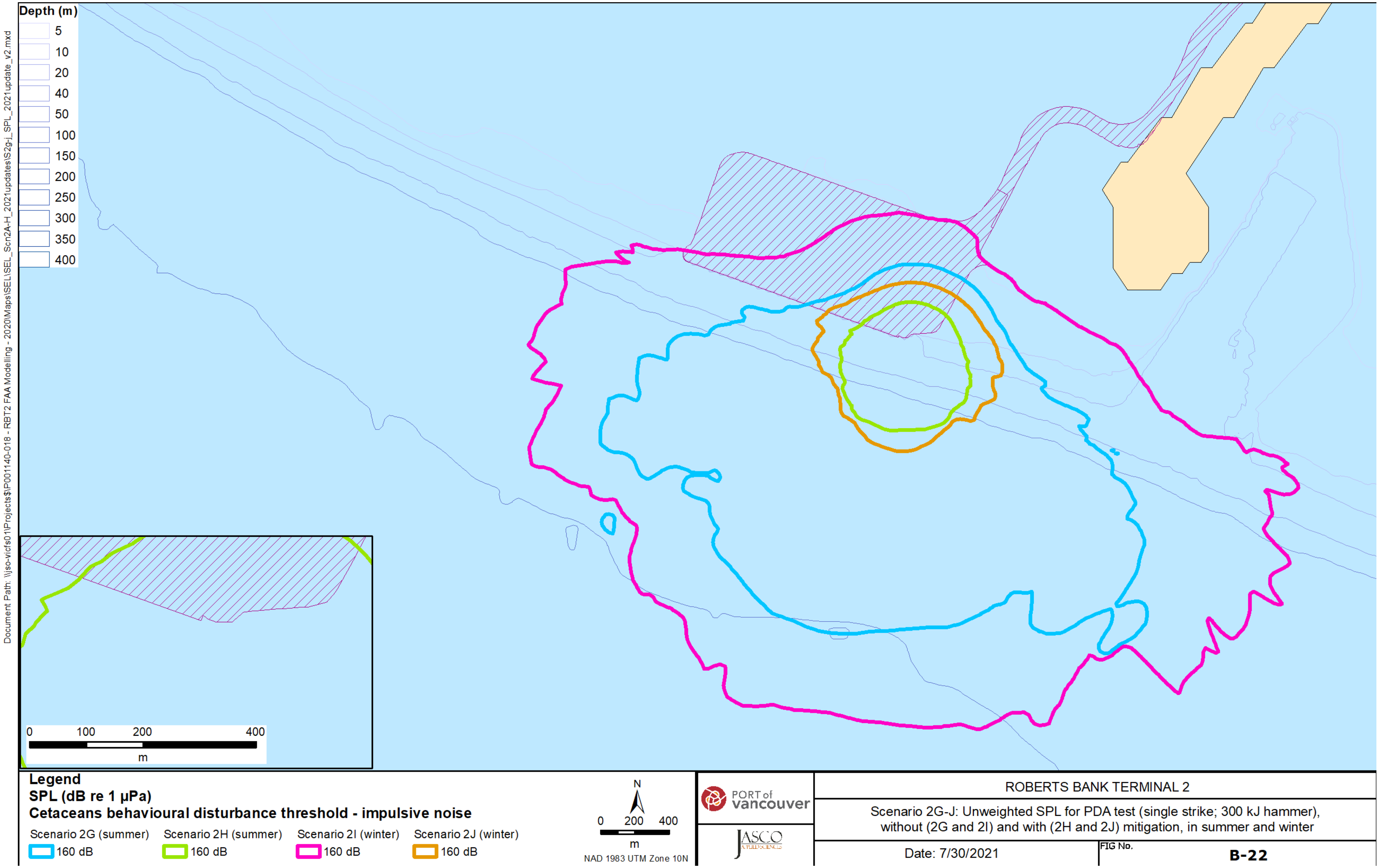


Figure B-22. Scenarios 2G–2J: Unweighted SPL for PDA test (single-strike; 300 kJ hammer) without and with confined bubble curtain mitigation in summer and winter, respectively.

Appendix C. Radii Tables for Fish Audiogram-weighted SPL

Table C-1. Radii to audiogram-weighted SPL thresholds (R_{max} and $R_{95\%}$ in km) for vibratory pile driving (Scenario 1) for three fish species.

SPL	*90 dB* re HT		*50 dB* re HT		*10 dB* re HT	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Flatfish	0	0	0.05	0.05	10.24	9.35
Herring	0	0	1.49	1.24	57.84	43.21
Salmon	0	0	0.03	0.03	5.67	5.20

Table C-2. Radii to audiogram-weighted SPL thresholds (R_{max} and $R_{95\%}$ in km) for impact pile driving (Scenarios 2A and 2B) for three fish species.

SPL	Scenario 2A						Scenario 2B					
	90 dB re HT		*50 dB* re HT		*10 dB* re HT		*90 dB* re HT		*50 dB* re HT		*10 dB* re HT	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Flatfish	0.02	0.02	2.57	2.37	57.40	43.08	0	0	0.94	0.89	52.76	36.58
Herring	0.51	0.46	51.72	34.19	64.10	48.74	0.16	0.15	29.47	19.84	61.97	45.27
Salmon	0.01	0.01	1.77	1.60	56.03	41.65	0	0	0.66	0.59	50.29	35.04

Table C-3. Radii to audiogram-weighted SPL thresholds (R_{max} and $R_{95\%}$ in km) for PDA testing (Scenarios 2C and 2D) for three fish species.

SPL	Scenario 2C						Scenario 2D					
	90 dB re HT		*50 dB* re HT		*10 dB* re HT		*90 dB* re HT		*50 dB* re HT		*10 dB* re HT	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Flatfish	0.03	0.03	3.21	2.91	57.69	43.29	0.01	0.01	1.21	1.09	54.62	38.48
Herring	0.58	0.51	54.08	36.19	64.37	49.06	0.20	0.18	35.01	23.50	62.76	45.92
Salmon	0.02	0.02	2.21	2.02	56.10	42.60	0	0	0.82	0.76	52.66	36.68

Table C-4. Radii to audiogram-weighted SPL thresholds (R_{max} and $R_{95\%}$ in km) for PDA testing (Scenarios 2E and 2F) for three fish species.

SPL	Scenario 2E						Scenario 2F					
	90 dB re HT		*50 dB* re HT		*10 dB* re HT		*90 dB* re HT		*50 dB* re HT		*10 dB* re HT	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Flatfish	0.03	0.03	4.58	3.97	67.09	52.93	0.01	0.01	1.52	1.41	63.99	47.65
Herring	0.67	0.61	67.07	50.95	67.98	53.66	0.20	0.18	56.41	36.05	67.63	53.36

Salmon	0.02	0.02	2.88	2.58	65.15	50.96	0	0	1.14	1.04	62.98	45.94

Table C-5. Radii to audiogram-weighted SPL thresholds (R_{max} and $R_{95\%}$ in km) for PDA testing (Scenarios 2G and 2H) for three fish species.

SPL	Scenario 2G						Scenario 2H					
	90 dB re HT		*50 dB* re HT		*10 dB* re HT		*90 dB* re HT		*50 dB* re HT		*10 dB* re HT	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Flatfish	0.04	0.04	3.95	3.58	57.97	43.63	0.01	0.01	1.58	1.46	55.89	40.53
Herring	0.74	0.63	54.96	38.63	64.63	49.44	0.25	0.23	41.95	27.15	62.94	46.83
Salmon	0.03	0.03	2.85	2.56	57.38	43.09	0.01	0.01	1.08	0.98	54.57	39.02

Table C-6. Radii to audiogram-weighted SPL thresholds (R_{max} and $R_{95\%}$ in km) for PDA testing (Scenarios 2I and 2J) for three fish species.

SPL	Scenario 2I						Scenario 2J					
	90 dB re HT		*50 dB* re HT		*10 dB* re HT		*90 dB* re HT		*50 dB* re HT		*10 dB* re HT	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Flatfish	0.04	0.04	6.70	5.90	67.13	51.78	0.01	0.01	2.02	1.86	64.57	48.68
Herring	0.87	0.79	67.12	52.28	68.09	53.75	0.27	0.24	58.98	40.10	67.68	53.53
Salmon	0.03	0.03	3.90	3.55	65.87	51.48	0.01	0.01	1.49	1.34	63.49	47.29

Table C-7. Radii to audiogram-weighted SPL thresholds for combined construction activities (Scenarios 3-8): Maximum and 95th percentile radii (R_{max} and $R_{95\%}$ in km) to flatfish weighted SPL thresholds for all non-impulsive scenarios. Since all scenarios listed in this table involve multiple noise sources, the radii are calculated in two directions: (1) parallel to the centre line running through the berth face, and (2) perpendicular to the berth face (as described in Section 2.2.4). The average of these two radii are also listed in the table.

Scenario	SPL Threshold (dB re 1 µPa s)	Parallel		Perpendicular		Average	
		R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
3A	90	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	50	0.90	0.90	0.24	0.24	0.57	0.57
	10	1.98	1.66	1.88	1.58	1.93	1.62
3B	90	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	50	0.90	0.90	0.24	0.24	0.57	0.57
	10	2.68	2.20	2.34	2.08	2.51	2.14
4	90	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	50	0.82	0.80	0.12	0.10	0.47	0.45
	10	2.64	2.18	4.36	3.86	3.5	3.02
5	90	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Scenario	SPL Threshold (dB re 1 µPa s)	Parallel		Perpendicular		Average	
		R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
	50	0.82	0.82	0.40	0.38	0.61	0.60
	10	4.08	3.34	6.42	5.58	5.25	4.46
6	90	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	50	0.90	0.90	0.24	0.24	0.57	0.57
	10	6.54	5.56	7.20	6.38	6.87	5.97
7A	90	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	50	0.82	0.80	0.18	0.16	0.50	0.48
	10	38.38	24.54	21.38	18.26	29.88	21.4
7B	90	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	50	0.90	0.80	0.40	0.24	0.65	0.52
	10	22.62	14.90	20.80	17.50	21.71	16.20
8A	90	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	50	0.80	0.76	0.16	0.14	0.48	0.45
	10	22.62	14.98	20.80	17.52	21.71	16.25
8B	90	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	50	0.90	0.80	0.40	0.16	0.65	0.48
	10	22.64	15.12	20.82	17.54	21.73	16.33

Table C-8. Radii to SPL thresholds for the combined construction activities scenarios: Maximum and 95th percentile radii (R_{max} and $R_{95\%}$ in km) to herring weighted SPL thresholds for all non-impulsive scenarios. Since all scenarios listed in this table involve multiple noise sources, the radii are calculated in two directions: (1) parallel to the centre line running through the berth face, and (2) perpendicular to the berth face (as described in Section 2.2.4). The average of these two radii are also listed in the table.

Scenario	SPL Threshold (dB re 1 µPa s)	Parallel		Perpendicular		Average	
		R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
3A	90	0.82	0.82	0.12	0.12	0.47	0.47
	50	1.00	0.96	0.34	0.30	0.67	0.63
	10	35.84	26.34	21.10	18.20	28.47	22.27
3B	90	0.82	0.82	0.12	0.12	0.47	0.47
	50	1.04	0.98	0.36	0.32	0.70	0.65
	10	55.2	40.06	29.42	22.9	42.31	31.48
4	90	0.42	0.42	0.04	0.04	0.23	0.23
	50	1.00	0.92	0.50	0.44	0.75	0.68
	10	43.88	29.60	25.32	19.10	34.60	24.35
5	90	0.82	0.82	0.38	0.38	0.60	0.60
	50	1.44	1.26	0.80	0.64	1.12	0.95
	10	51.48	37.6	27.46	21.38	39.47	29.49
6	90	0.80	0.80	<0.01	<0.01	0.40	0.40

Scenario	SPL Threshold (dB re 1 µPa s)	Parallel		Perpendicular		Average	
		R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
	50	1.64	1.48	0.86	0.76	1.25	1.12
	10	61.18	48.38	33.72	26.46	47.45	37.42
7A	90	0.82	0.82	0.08	0.08	0.45	0.45
	50	2.40	2.04	2.72	2.40	2.56	2.22
	10	61.18	48.4	33.72	26.40	47.45	37.40
7B	90	0.82	0.82	0.38	0.38	0.6	0.6
	50	2.12	1.74	2.32	2.06	2.22	1.90
	10	51.60	38.56	27.62	21.6	39.61	30.08
8A	90	0.42	0.42	0.04	0.04	0.23	0.23
	50	2.12	1.70	2.30	2.04	2.21	1.87
	10	51.56	38.42	27.58	21.64	39.57	30.03
8B	90	0.82	0.82	0.38	0.38	0.60	0.60
	50	2.14	1.74	2.36	2.06	2.25	1.90
	10	51.60	38.44	27.62	21.66	39.61	30.05

Table C-9. Radii to SPL thresholds for the combined construction activities scenarios: Maximum and 95th percentile radii (R_{max} and $R_{95\%}$ in km) to salmon weighted SPL thresholds for all non-impulsive scenarios. Since all scenarios listed in this table involve multiple noise sources, the radii are calculated in two directions: (1) parallel to the centre line running through the berth face, and (2) perpendicular to the berth face (as described in Section 2.2.4). The average of these two radii are also listed in the table.

Scenario	SPL Threshold (dB re 1 µPa s)	Parallel		Perpendicular		Average	
		R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
3A	90	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	50	0.88	0.88	0.22	0.22	0.55	0.55
	10	1.44	1.28	1.08	0.88	1.26	1.08
3B	90	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	50	0.88	0.88	0.22	0.22	0.55	0.55
	10	1.72	1.46	1.40	1.20	1.56	1.33
4	90	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	50	0.44	0.44	0.06	0.06	0.25	0.25
	10	1.80	1.50	2.38	2.12	2.09	1.81
5	90	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	50	0.82	0.82	0.38	0.38	0.60	0.60
	10	2.52	2.08	2.88	2.48	2.70	2.28
6	90	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	50	0.90	0.90	0.24	0.24	0.57	0.57
	10	3.78	3.36	3.10	2.78	3.44	3.07
7A	90	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Scenario	SPL Threshold (dB re 1 µPa s)	Parallel		Perpendicular		Average	
		R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
	50	0.82	0.80	0.10	0.08	0.46	0.44
	10	22.60	12.44	20.94	17.88	21.77	15.16
7B	90	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	50	0.90	0.82	0.38	0.36	0.64	0.59
	10	9.04	6.18	16.34	12.54	12.69	9.36
8A	90	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	50	0.80	0.80	0.08	0.08	0.44	0.44
	10	9.12	6.22	16.82	12.74	12.97	9.48
8B	90	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	50	0.90	0.82	0.38	0.24	0.64	0.53
	10	9.34	6.36	16.88	13.00	13.11	9.68

Appendix D. Detection Ranges of Killer Whale Vocalizations for Summer Model Scenarios

D.1. Detection Ranges of Stereotyped Vocalizations

D.1.1. Scenario 1

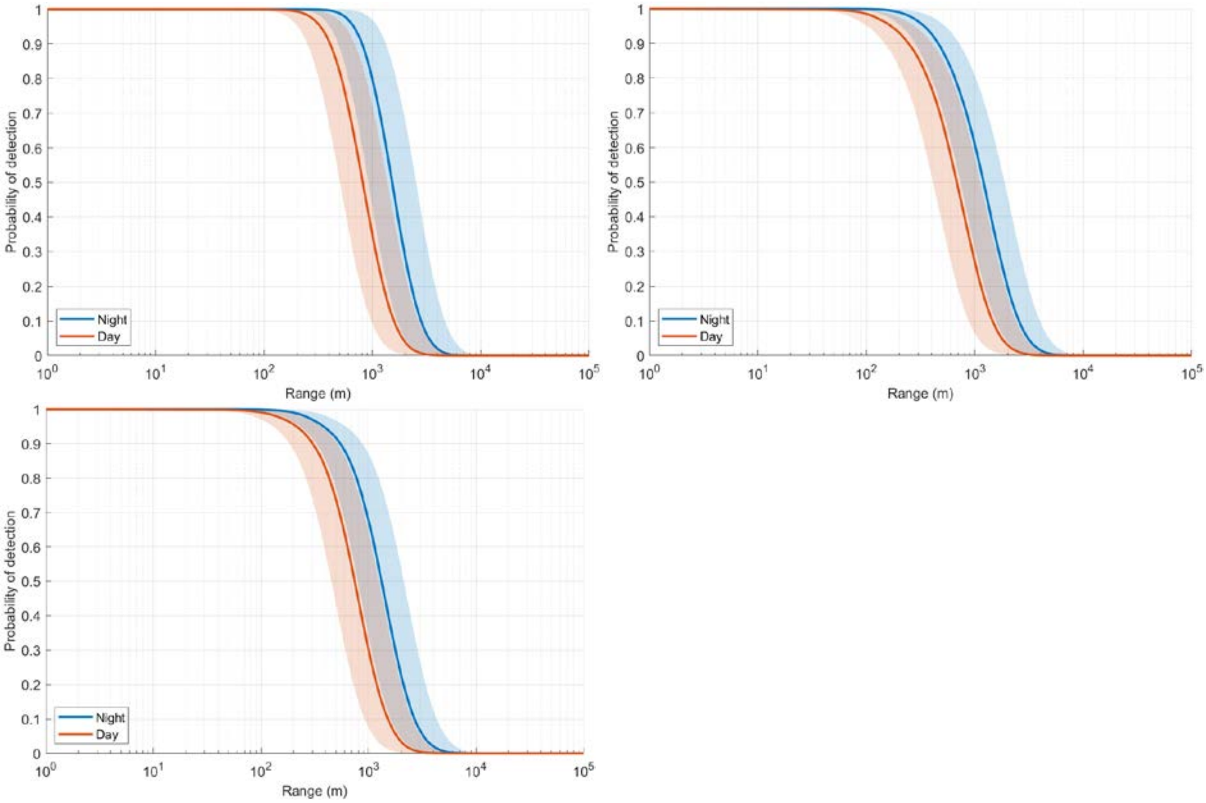


Figure D-1. Detection ranges of killer whale stereotyped vocalizations for Scenario 1: Vibratory piling 914 mm diameter cylindrical pile at mooring dolphin. Summer detection range probabilities of killer whale stereotyped calls during the day and night at the locations PAM 1 (top left), PAM 2 (top right), and PAM 3 (bottom left), during construction Scenario 1. The solid lines are the median values and the shaded areas define the 25th and 75th percentiles.

D.1.2. Scenario 3A

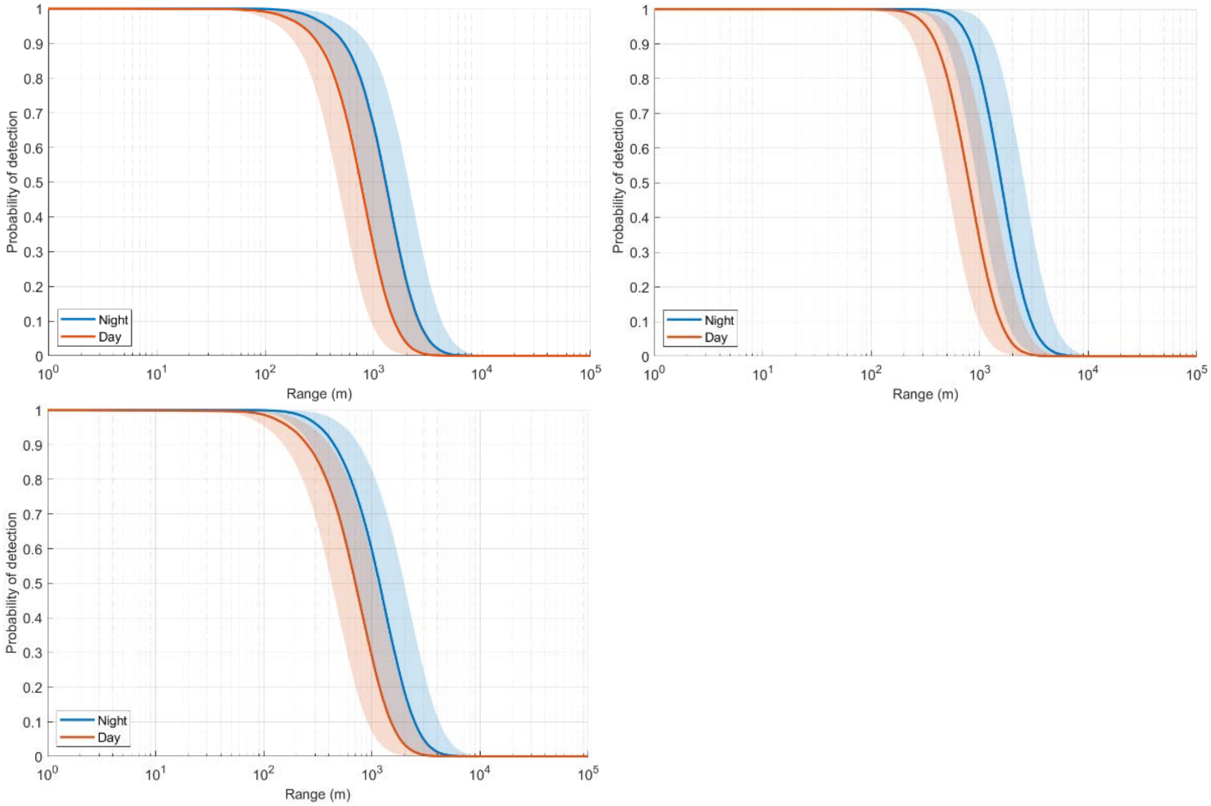


Figure D-2. Detection ranges of killer whale stereotyped vocalizations for Scenario 3A: Material placement and moderate tug activity. Summer detection range probabilities of killer whale stereotyped calls during the day and night at the locations PAM 1 (top left), PAM 2 (top right), and PAM 3 (bottom left), during construction Scenario 3A. The solid lines are the median values and the shaded areas define the 25th and 75th percentiles.

D.1.3. Scenario 4

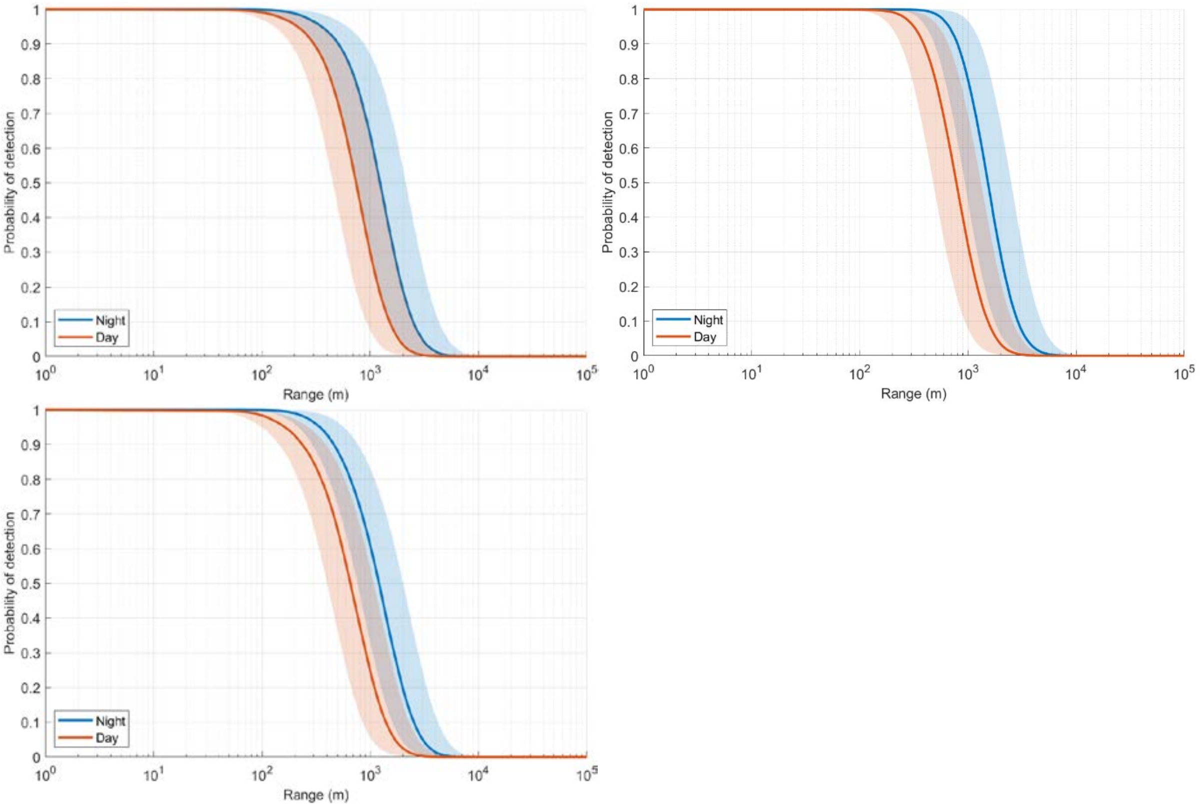


Figure D-3. Detection ranges of killer whale stereotyped vocalizations for Scenario 4: Dredging the dredge basin and low tug activity. Summer detection range probabilities of killer whale stereotyped calls during the day and night at the locations PAM 1 (top left), PAM 2 (top right), and PAM 3 (bottom left), during construction Scenario 4. The solid lines are the median values and the shaded areas define the 25th and 75th percentiles.

D.1.4. Scenario 5

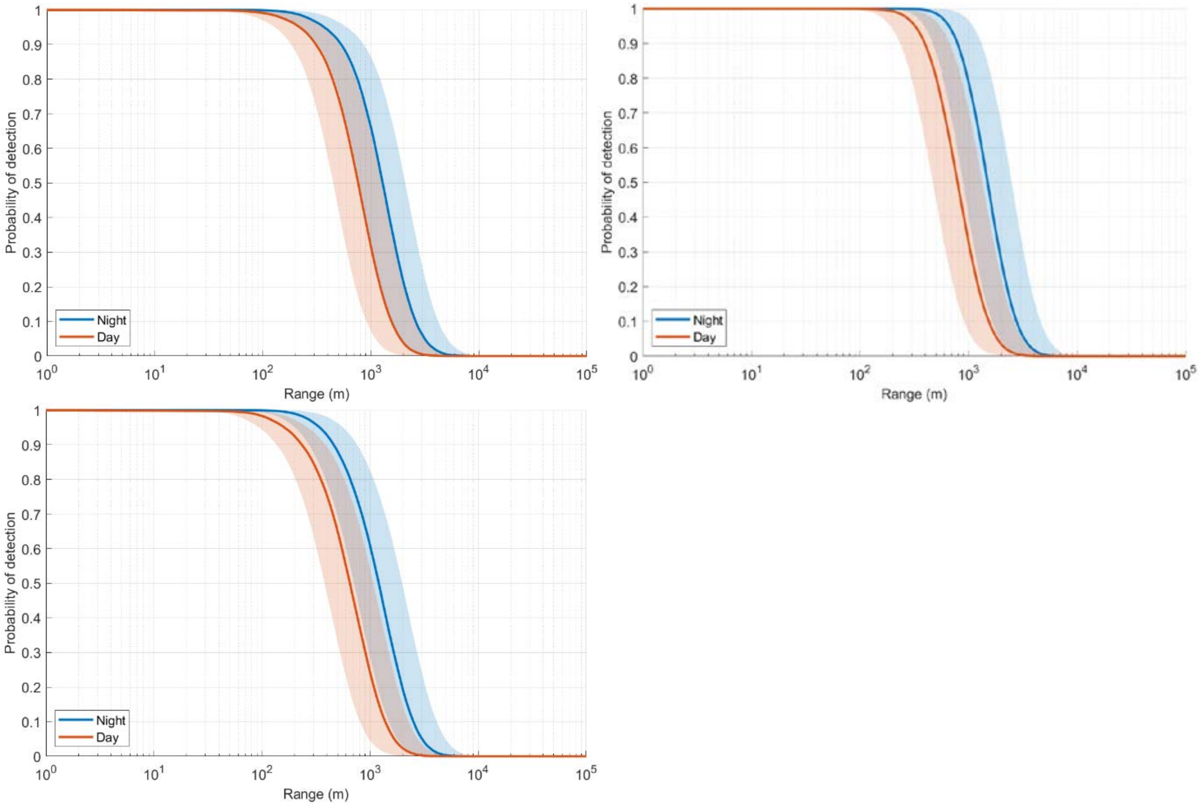


Figure D-4. Detection ranges of killer whale stereotyped vocalizations for Scenario 5: Dredging, pumping ashore combo, and moderate tug activity. Summer detection range probabilities of killer whale stereotyped calls during the day and night at the locations PAM 1 (top left), PAM 2 (top right), and PAM 3 (bottom left), during construction Scenario 5. The solid lines are the median values and the shaded areas define the 25th and 75th percentiles.

D.1.5. Scenario 7B

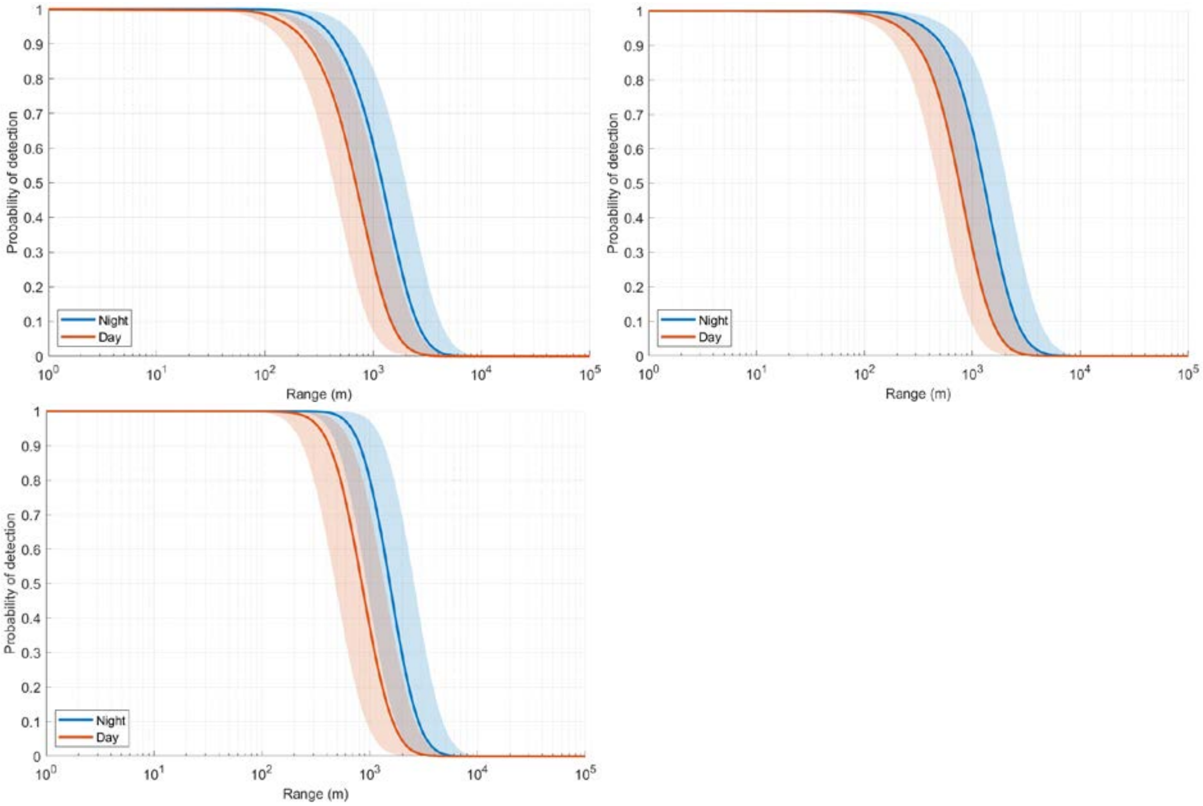


Figure D-5. Detection ranges of killer whale stereotyped vocalizations for Scenario 7B: Pumping ashore, vibro-densification, and high tug activity at dredge basin. Summer detection range probabilities of killer whale stereotyped calls during the day and night at the locations PAM 1 (top left), PAM 2 (top right), and PAM 3 (bottom left), during construction Scenario 7B. The solid lines are the median values and the shaded areas define the 25th and 75th percentiles.

D.1.6. Scenario 8A

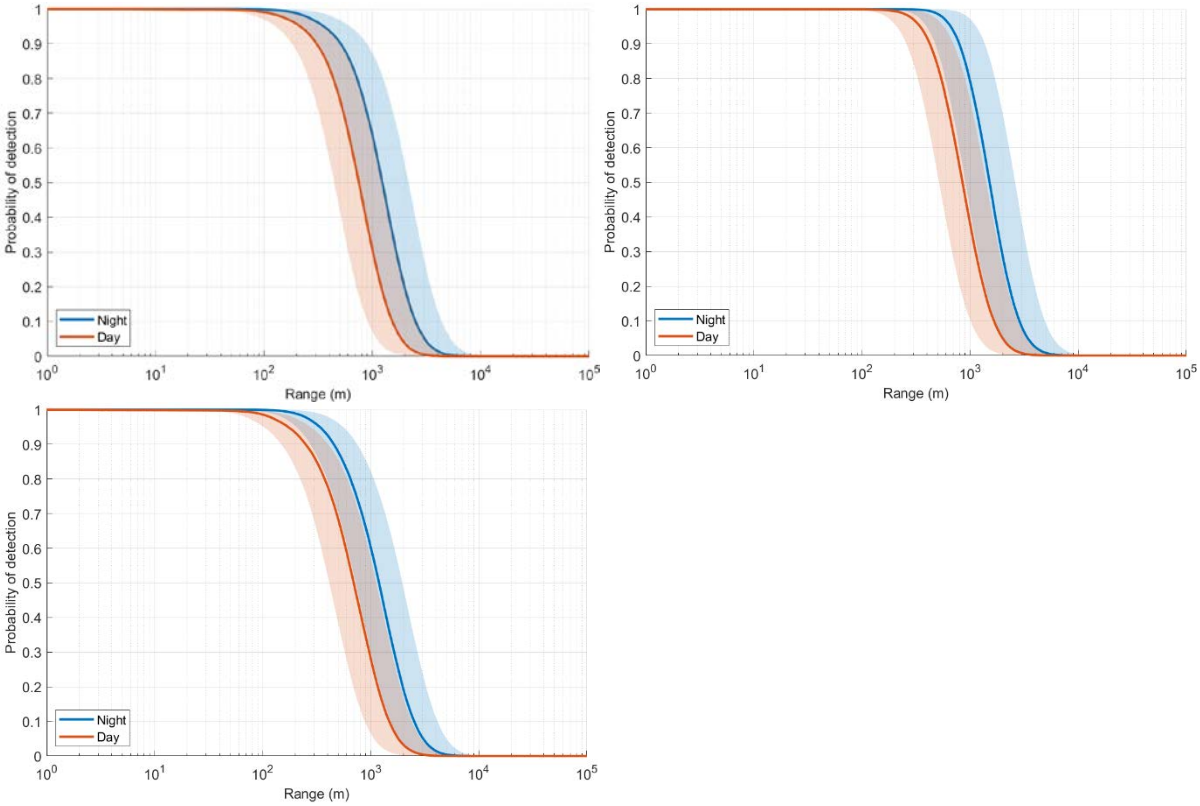


Figure D-6. Detection ranges of killer whale stereotyped vocalizations for Scenario 8A: Dredging, pumping ashore, and vibro-densification at dredge basin. Summer detection range probabilities of killer whale stereotyped calls during the day and night at the locations PAM 1 (top left), PAM 2 (top right), and PAM 3 (bottom left), during construction Scenario 8A. The solid lines are the median values and the shaded areas define the 25th and 75th percentiles.

D.1.7. Scenario 8B

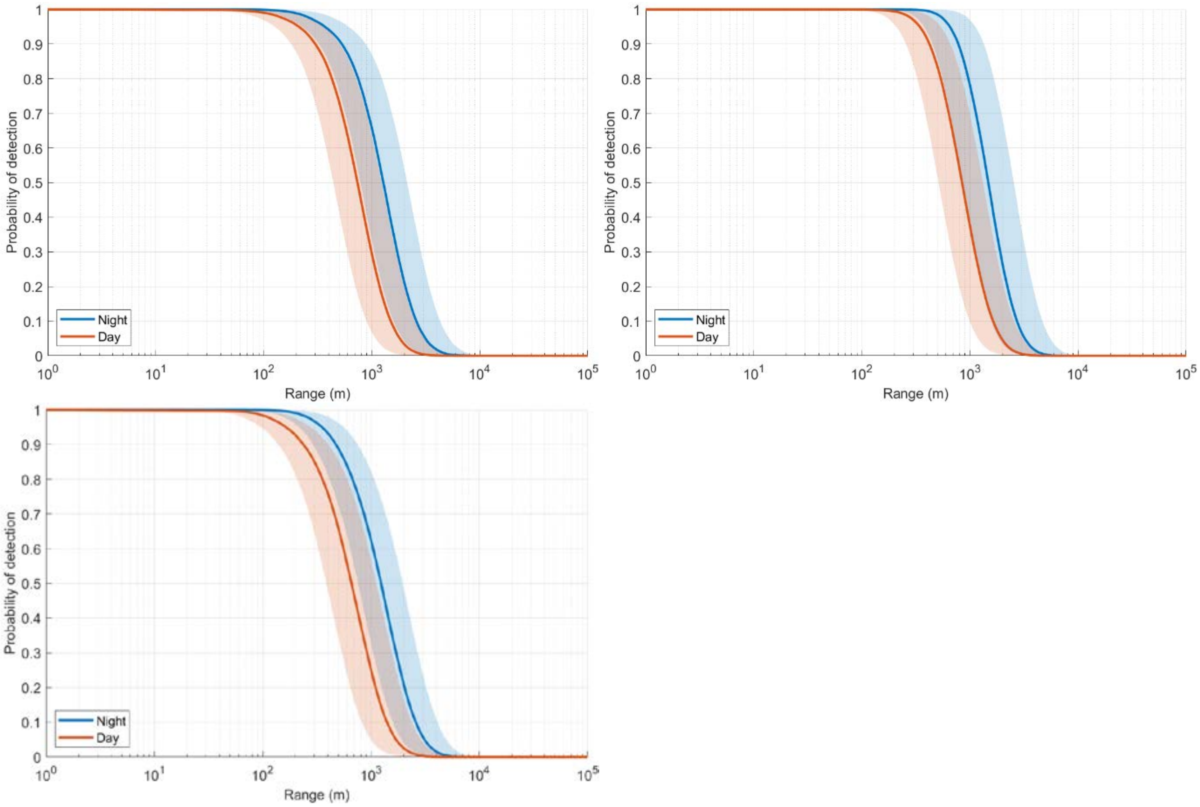


Figure D-7. Detection ranges of killer whale stereotyped vocalizations for Scenario 8B: Dredging, pumping ashore, vibro-densification, and high tug activity at dredge basin. Summer detection range probabilities of killer whale stereotyped calls during the day and night at the locations PAM 1 (top left), PAM 2 (top right), and PAM 3 (bottom left), during construction Scenario 8B. The solid lines are the median values and the shaded areas define the 25th and 75th percentiles.

D.2. Detection Ranges of Whistles

D.2.1. Scenario 1

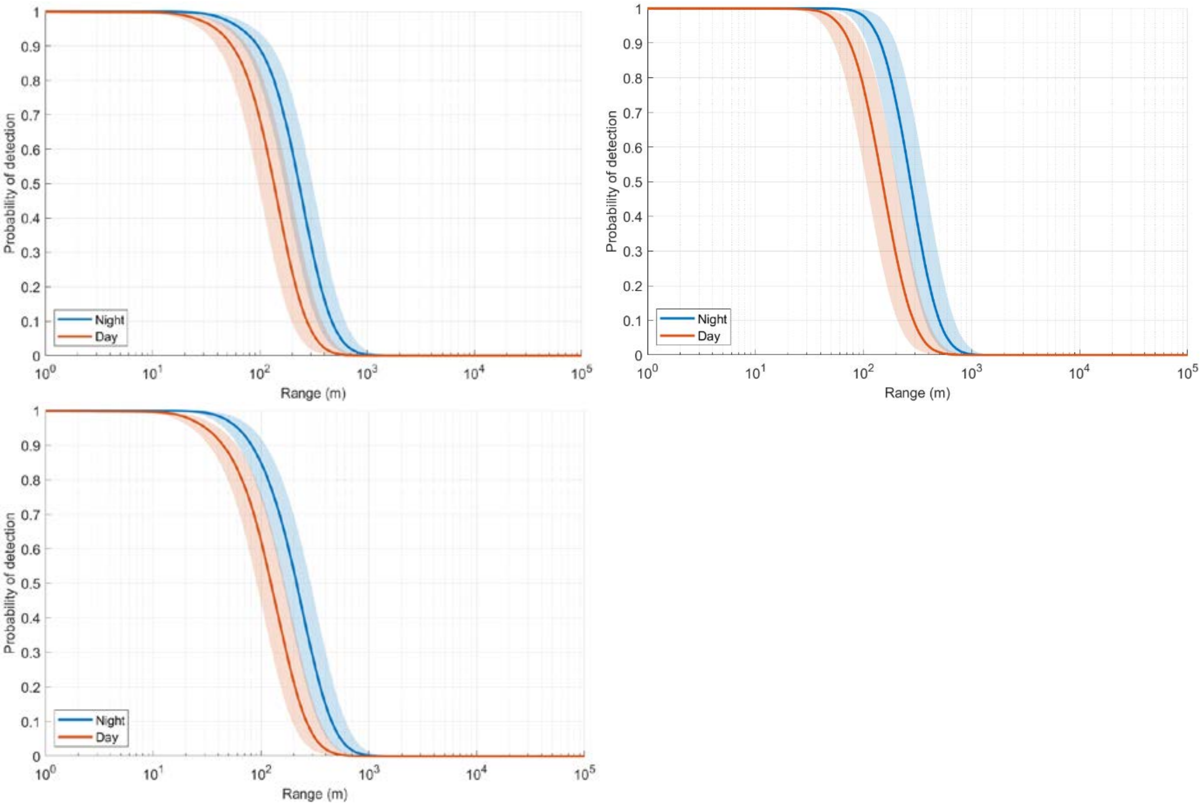


Figure D-8. Detection ranges of killer whale whistles for Scenario 1: Vibratory piling 914 mm diameter cylindrical pile at mooring dolphin. Summer detection range probabilities of killer whale whistles during the day and night at the locations PAM 1 (top left), PAM 2 (top right), and PAM 3 (bottom left), during construction Scenario 1. The solid lines are the median values and the shaded areas define the 25th and 75th percentiles.

D.2.2. Scenario 3A

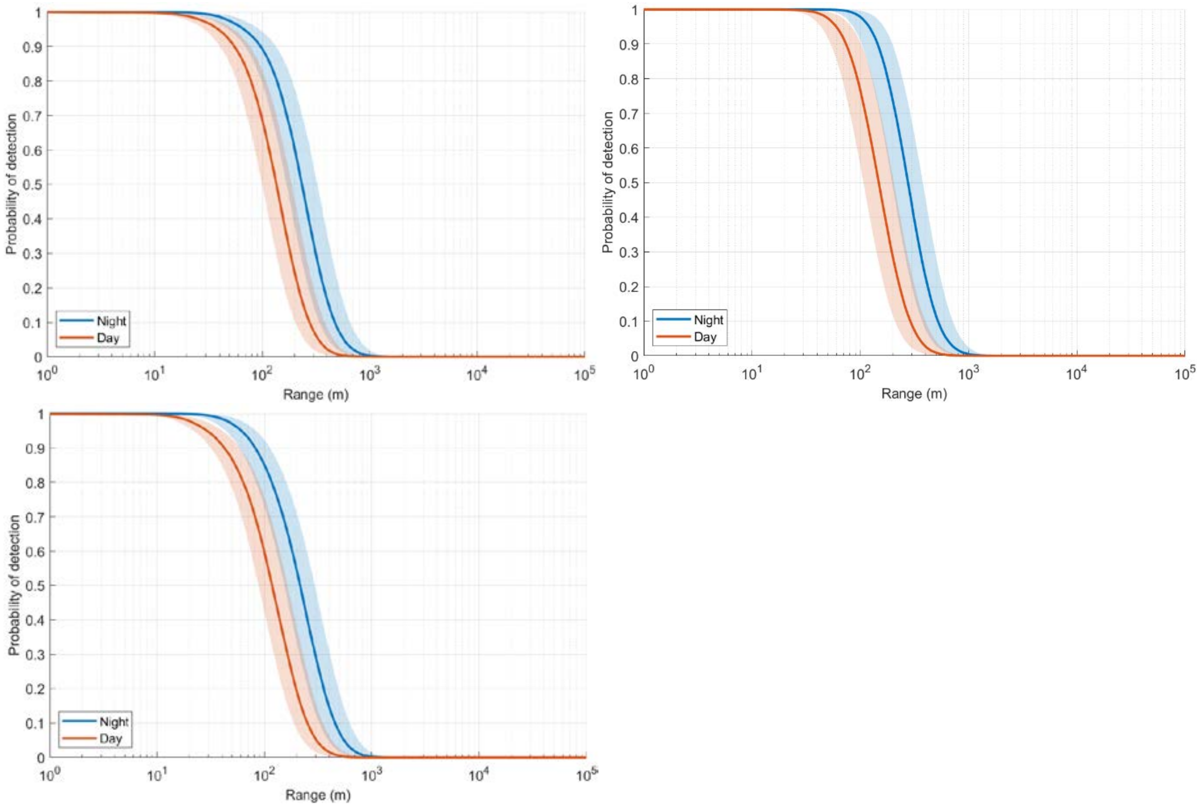


Figure D-9. Detection ranges of killer whale whistles for Scenario 3A: Material placement and moderate tug activity. Summer detection range probabilities of killer whale whistles during the day and night at the locations PAM 1 (top left), PAM 2 (top right), and PAM 3 (bottom left), during construction Scenario 3A. The solid lines are the median values and the shaded areas define the 25th and 75th percentiles.

D.2.3. Scenario 4

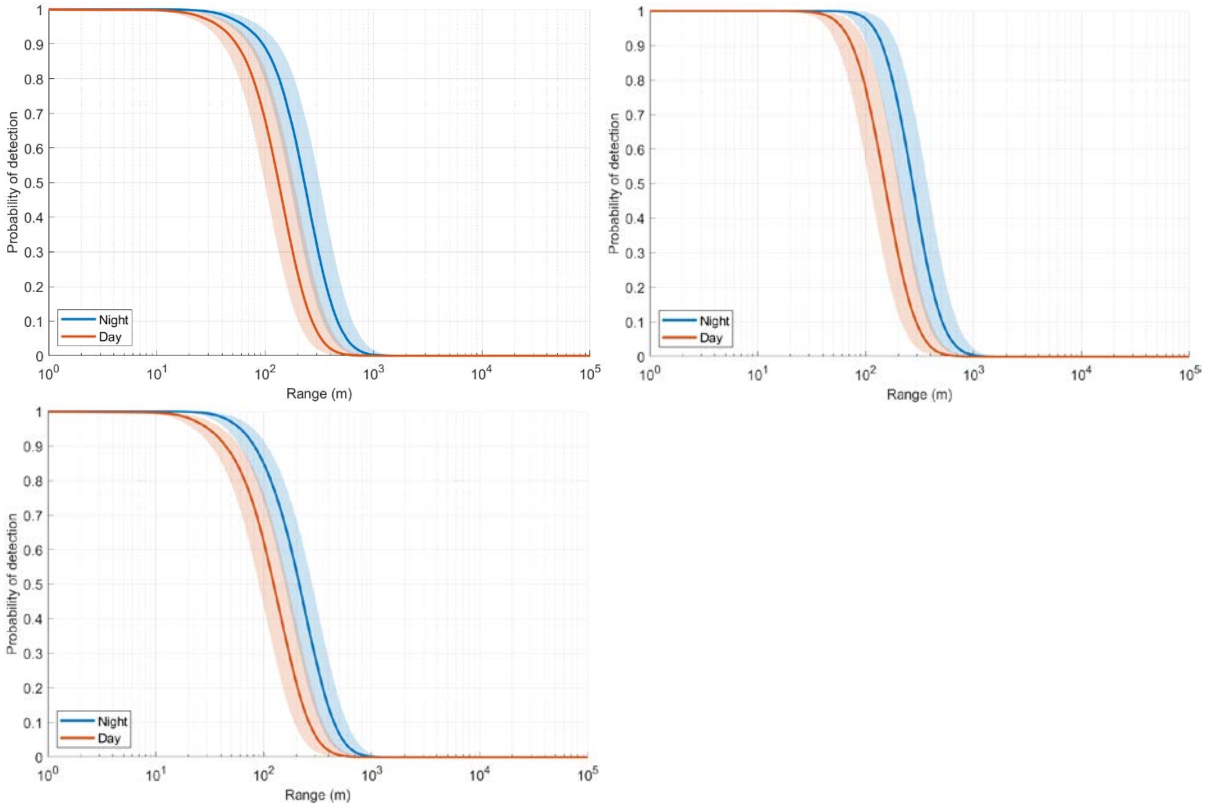


Figure D-10. Detection ranges of killer whale whistles for Scenario 4: Dredging the dredge basin and low tug activity. Summer detection range probabilities of killer whale whistles during the day and night at the locations PAM 1 (top left), PAM 2 (top right), and PAM 3 (bottom left), during construction Scenario 4. The solid lines are the median values and the shaded areas define the 25th and 75th percentiles.

D.2.4. Scenario 5

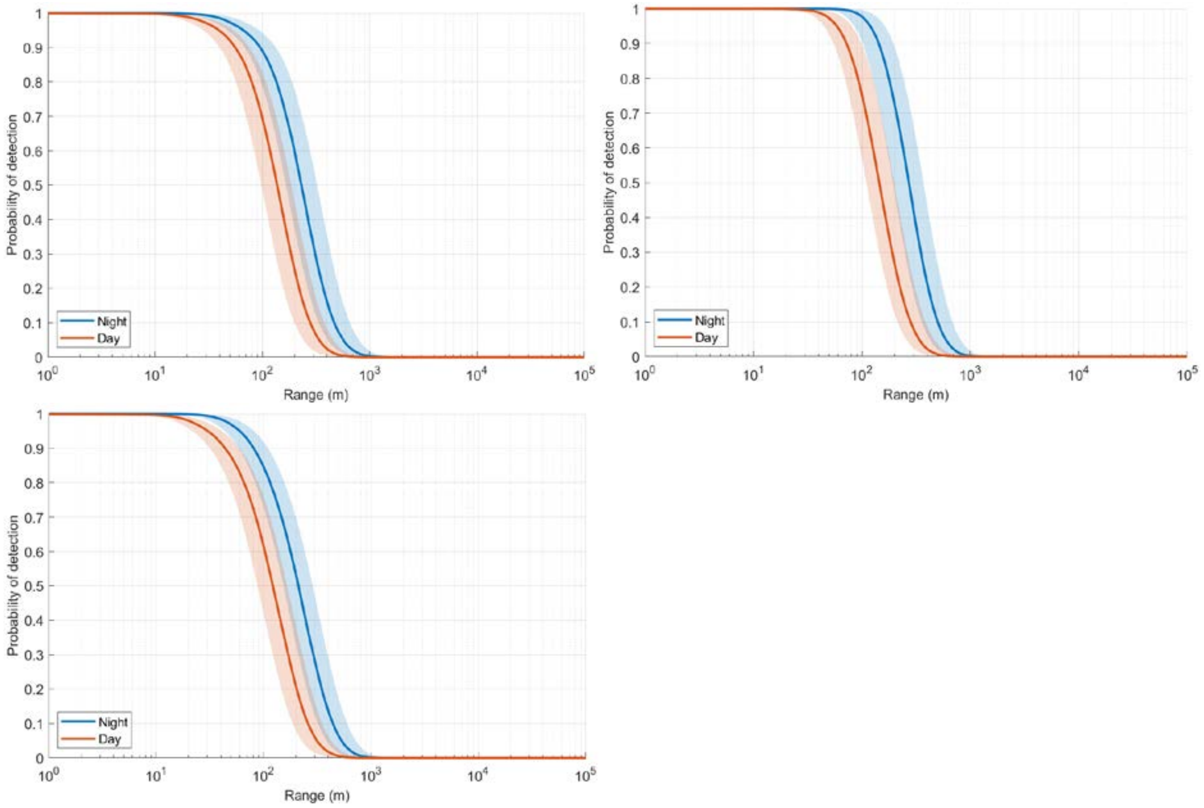


Figure D-11. Detection ranges of killer whale whistles for Scenario 5: Dredging, pumping ashore combo, and moderate tug activity. Summer detection range probabilities of killer whale whistles during the day and night at the locations PAM 1 (top left), PAM 2 (top right), and PAM 3 (bottom left), during construction Scenario 5. The solid lines are the median values and the shaded areas define the 25th and 75th percentiles.

D.2.5. Scenario 7B

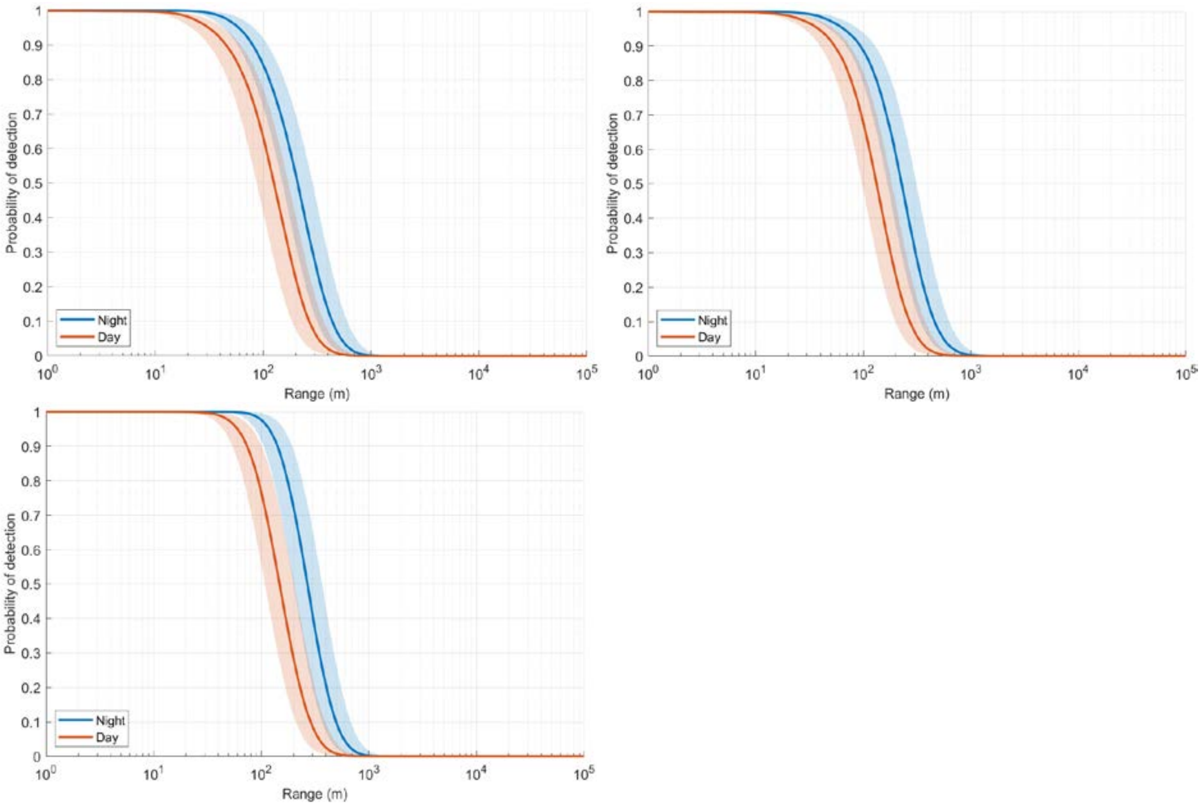


Figure D-12. Detection ranges of killer whale whistles for Scenario 7B: Pumping ashore, vibro-densification, and high tug activity at dredge basin. Summer detection range probabilities of killer whale whistles during the day and nigh at the locations PAM 1 (top left), PAM 2 (top right), and PAM 3 (bottom left), during construction Scenario 7B. The solid lines are the median values and the shaded areas define the 25th and 75th percentiles.

D.2.6. Scenario 8A

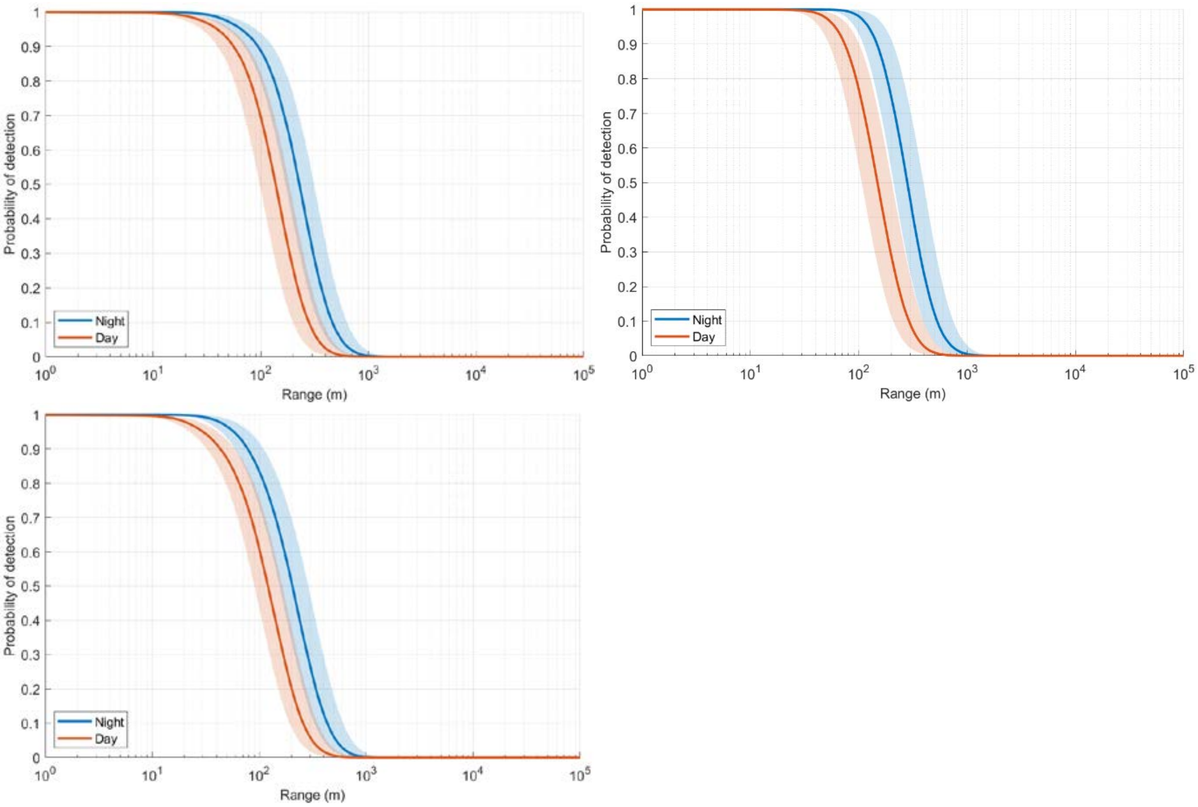


Figure D-13. Detection ranges of killer whale whistles for Scenario 8A: Dredging, pumping ashore, and vibro-densification at dredge basin. Summer detection range probabilities of killer whale whistles during the day and night at the locations PAM 1 (top left), PAM 2 (top right), and PAM 3 (bottom left), during construction Scenario 8A. The solid lines are the median values and the shaded areas define the 25th and 75th percentiles.

D.2.7. Scenario 8B

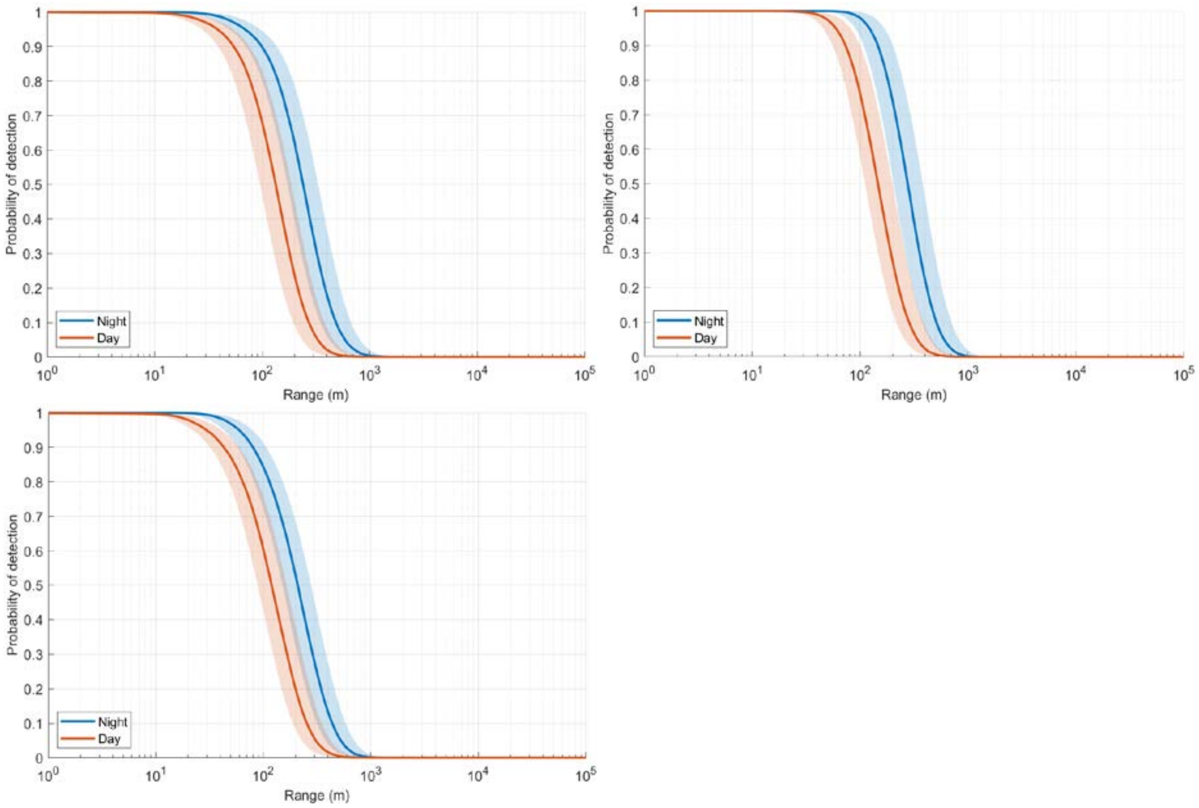


Figure D-14. Detection ranges of killer whale whistles for Scenario 8B: Dredging, pumping ashore, vibro-densification, and high tug activity at dredge basin. Summer detection range probabilities of killer whale whistles during the day and night at the locations PAM 1 (top left), PAM 2 (top right), and PAM 3 (bottom left), during construction Scenario 8B. The solid lines are the median values and the shaded areas define the 25th and 75th percentiles.

Appendix E. Screening Assessment of the Becker Penetration Test

The Becker penetration test is described in Appendix IR2020-2.3-A as follows:

> The proposed caisson foundation includes rockfill mattress placed and then densified in-situ. As part of the Quality Control / Quality Assurance testing of the densified rockfill to confirm design specifications, a Becker Penetration Test (BPT) is expected to be required. BPT involves impact driving a relatively small (150 mm to 200 mm diameter) temporary steel casing through the approximately 8 m thick densified rockfill mattress and monitoring the resistance. A significantly smaller hammer is used for the BPT compared to that used for the PDA [Pile Driving Analyzer] tests for a barge ramp abutment or mooring dolphin foundation pile. For the proposed project, BPT tests at about 70 separate locations, roughly spread evenly throughout the densified mattress rock area are anticipated. BPT at each location is anticipated to last up to 2 hours, although active impact driving would be 15 to 30 minutes. The testing is anticipated to occur throughout the approximately 12 months of mattress rock densification, with approximately two tests expected to be completed within a single day.

A literature review found no references to pre-existing measurements or assessments of underwater noise from BPT. Therefore, a model-based approach was employed to assess potential noise levels from this activity, to determine whether it has the potential to induce injury or behavioural response impacts in marine mammals or fish. Underwater noise from BPT was analyzed using a structural acoustic model for marine impact pile driving, developed by JASCO (MacGillivray 2014). The predictions of this model have been validated against field data and benchmarked against other structural acoustic models and are considered highly accurate (Lippert et al. 2016). The structural acoustic model was used to calculate underwater noise emissions generated by impact hammering of a 20 cm diameter steel pipe using an 11 kJ impact hammer, which was taken to be a suitable representation of BPT based on the engineering specifications of this activity. The impact force of an ICE 180 double-acting diesel hammer on the steel pipe was simulated using GRLWEAP (Pile Dynamics 2010), which is an industry-standard model for performing driveability analysis of structural piles. Other details of the acoustic model used for assessing noise emissions from BPT are provided in Table E-1.

Table E-1. Structural acoustic model parameters used for calculating underwater noise levels from the Becker penetration test.

Parameter description	Parameter value
Pipe outer diameter (mm)	200
Pipe outer wall thickness (mm)	8.12
Pipe length (m)	32
Penetration into seabed (m)	8
Water depth (m)	24
Hammer model	ICE 180
Hammer energy (kJ)	11
Hammer ram mass (kg)	780
Hammer strikes per test	560
Tests per 24-hour period	2

Sound level versus range predictions from the structural acoustic model are shown in Figures E-1 and E-2. The modelling results suggest that impact hammering associated with BPT would not generate sound levels exceeding injury thresholds for marine mammals or fish at any distance (Tables E-2 and E-3). Furthermore, this activity would not generate sound levels exceeding the behavioural response threshold for marine mammals beyond 2 m range (Table E-4).

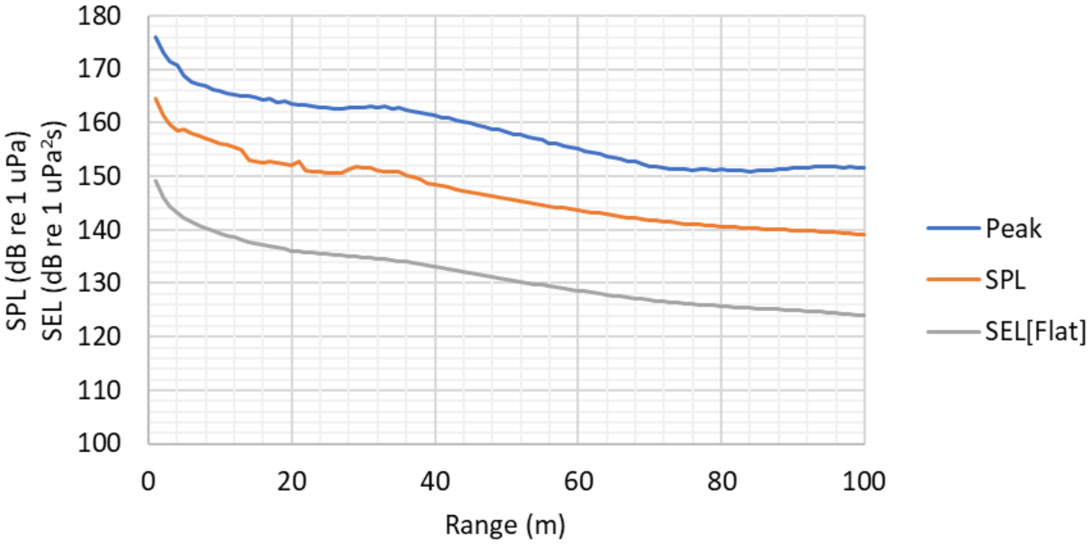


Figure E-1. Unweighted sound levels versus range (peak, SPL, and per-strike SPL) for a Becker penetration test, as calculated by the structural acoustic model.

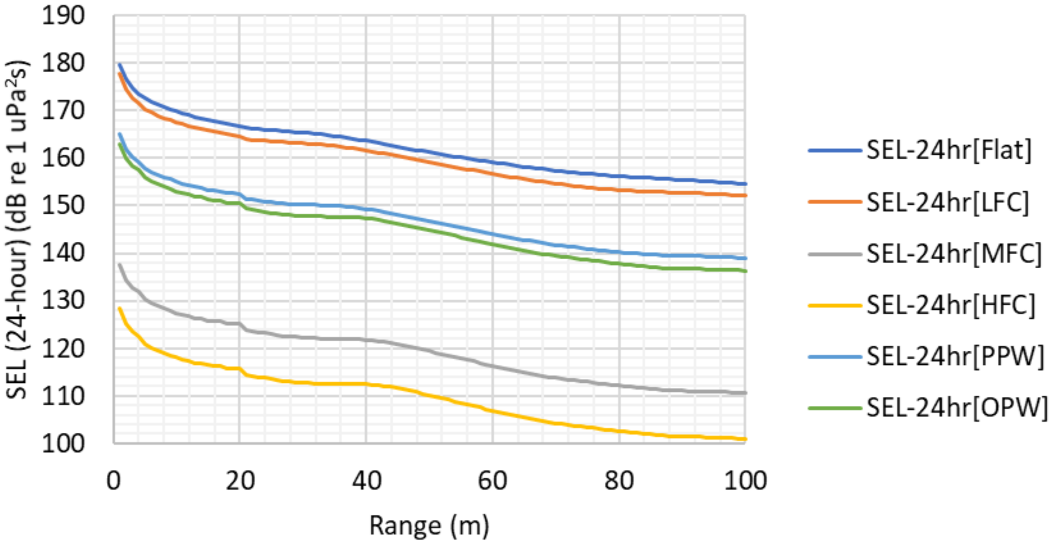


Figure E-2. 24 h cumulative SEL versus range (unweighted and marine-mammal weighted) for two complete Becker penetration tests (1520 total strikes), as calculated by the structural acoustic model.

Table E-2. Radii for 24 h cumulative SEL injury thresholds for marine mammals for two complete Becker penetration tests (1520 total strikes). A dash "–" indicates that the threshold was not reached.

Hearing group	SEL threshold (dB re 1 µPa^{2}s)	Range to threshold (m)
Low-frequency cetaceans	183 (PTS)	–
	168 (TTS)	8
Mid-frequency cetaceans	185 (PTS)	–
	170 (TTS)	–
High-frequency cetaceans	155 (PTS)	–
	140 (TTS)	–
Phocid pinnipeds in water	185 (PTS)	–
	170 (TTS)	–
Otariid pinnipeds in water	203 (PTS)	–
	188 (TTS)	–

Table E-3. Radii for 24 h cumulative SEL injury threshold for fish (unweighted) for two Becker penetration tests. A dash "–" indicates that the threshold was not reached.

Marine fauna group	SEL$_{24h}$ threshold ($L_{E,24h}$; dB re 1 µPa^2·s)	Range to threshold (m)
Mortality and potential mortal injury		
I	219	–
II, fish eggs and fish larvae	210	–
III	207	–
Fish recoverable injury		
I	216	–
II, III	203	–
Fish TTS		
I, II, III	186	–

Fish I–No swim bladder; Fish II–Swim bladder not involved with hearing; Fish III–Swim bladder involved with hearing

Table E-4. Radii to marine mammal disturbance thresholds for a Becker penetration test.

Criterion	SPL threshold (dB re 1 µPa)	Range to threshold (m)
Behavioural disturbance (impulsive)	160	2

Appendix IR2020-2.3-D

Table of proposed mitigation measures

Appendix IR2020-2.3-D Table of proposed mitigation measures

Table IR2020-2.3-D1: The Vancouver Fraser Port Authority (VFPA) new and updated proposed mitigation measures related to southern resident killer whales (SRKW). Previous project commitments are presented for comparison.

Note: Individual commitments are sub-divided to demonstrate how mitigation measures in previous commitments (CIAR Document #2001[1]) correspond to the revised measures. **Bold** text indicates additional or enhanced mitigation measures to further avoid and reduce potential effects of construction on SRKW. Blue text indicates clarification or additional detail with respect to commitments included in CIAR Document #2001.

Number	Phase			Previous project commitment (as of July 2019)[1]	New and updated proposed mitigation measures
	Design	Construction	Operation		
13	✓	✓		The VFPA will ensure the Project is designed to reduce the combined number of dredge equipment and tug/barge movements to the satisfaction of a qualified professional(s).	The VFPA will ensure the Project is designed to limit the number of dredge equipment and tug/barge movements required for dredging activities **when SRKW are confirmed to be present in the Salish Sea** to the extent feasible as determined by a qualified professional(s).
30		✓		Prior to the start of construction, the VFPA will develop a Dredging and Sediment Discharge Plan to the satisfaction of a qualified professional(s). The plan will be implemented during construction. The plan must include at a minimum the following: • Roles and responsibilities for implementation and monitoring; • Measures to reduce the combined number of dredge equipment and tug/barge movements; • A description of how material dredged will be handled and managed; • Measures to ensure that material dredged from the tug basin is placed within the terminal footprint as fill for the Project land development; • Site-specific water quality objectives and thresholds based on turbidity or total suspended solids models; • Criteria for the location of real-time monitoring of turbidity; • Measures related to the protection of marine species and relevant EMPs (i.e., sub-plans); and • Criteria, protocol, and procedures to stop construction activities to address non-compliances. The plan will be developed in consultation with the following parties: CEA Agency, ECCC, DFO, and Indigenous groups. The VFPA will provide the draft plan to the parties for review a minimum of 90 days prior to the start of construction.	Prior to the start of construction, the VFPA will develop a Dredging and Sediment Discharge Plan to the satisfaction of a qualified professional(s). The plan will be implemented during construction. The plan must include at a minimum the following: • Roles and responsibilities for implementation and monitoring; • Measures to limit the number of dredge equipment and tug/barge movements required for dredging activities **when SRKW are confirmed to be present in the Salish Sea** to the extent feasible; • A description of how material dredged will be handled and managed; • Measures to ensure that material dredged from the tug basin is placed within the terminal footprint as fill for the Project land development; • Site-specific water quality objectives and thresholds based on turbidity or total suspended solids models; • Criteria for the location of real-time monitoring of turbidity; • Measures related to the protection of marine species and relevant EMPs (i.e., sub-plans); and • Criteria, protocol, and procedures to stop construction activities to address non-compliances. The plan will be developed in consultation with the following parties: ECCC, DFO, and Indigenous groups. The VFPA will provide the draft plan to the parties for review a minimum of 90 days prior to the start of construction.
33		✓		Prior to the start of construction activities with the potential to impact marine mammals, the VFPA will develop a Marine Mammal Management Plan to the satisfaction of a qualified professional(s). The plan will be implemented during construction. The plan will describe at a minimum the following:	Prior to the start of construction activities with the potential to impact marine mammals, the VFPA will develop a Marine Mammal Management Plan to the satisfaction of a qualified professional(s). The plan will be implemented during construction. The plan will describe at a minimum the following:
				• The one kilometre buffer zone wherein water dredging activities will be shut down if marine mammals (other than harbour seals and sea lions[2]) enter it; • The other activity-specific buffer zones where relevant non-dredging activities will be shut down if marine mammals (other than harbour seals and sea lions) enter it;	• Exclusion zones where, **before SRKW enter them** or if other marine mammals enter them, underwater noise generating construction activities will be shut down or modified. **Exclusion zones will be determined based on construction-related underwater noise boundaries using the following criteria:** – **Injury thresholds and behavioural disturbance thresholds for impulsive and continuous (i.e., non-impulsive) noise, respectively, for SRKW; and** – **Species or hearing group-specific injury thresholds for impulsive noise for other marine mammal species.**
				• The role of trained Marine Mammal Observers (MMOs) to monitor the prescribed buffer zone when construction is occurring or will occur in the areas and record the location and behaviour of observed marine	• **Roles and responsibilities for implementation and monitoring**. **This will include:** – The role of **the marine mammal detection team (e.g., marine mammal observers (MMOs), passive acoustic monitoring (PAM) system operators, and other detection technology**

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[1] CIAR Document #2001 Updated Project Commitments, at Appendix A, Table A1: Compilation of Proposed Mitigation Measures and Other Project Commitments – RBT2 Project

[2] A 150 m exclusion zone will be established for harbour seals and sea lions based on their relative abundance in the Project construction area and their inquisitiveness.

Number	**Phase**			**Previous project commitment (as of July 2019)**[1]	**New and updated proposed mitigation measures**
	Design	**Construction**	**Operation**		
				mammals. This includes the requirement for the MMOs to coordinate with whale sighting networks to receive advance warning of marine mammals approaching the construction area;	**operators),** to field-verify the applicable exclusion zone(s), monitor for the presence of marine mammals, including SRKW, record the location and behaviour of observed marine mammals, and notify the contractor when marine mammals are detected; – The minimum training **and experience** requirements of **the marine mammal detection team, including** MMOs; and – The requirement for the **marine mammal detection team** to coordinate with whale sighting networks to receive advance warning of marine mammals approaching the project site.
				• During dredging or discharge of dredgeate in southern resident killer whale (SRKW) critical habitat, an MMO (during the period from May 1 to October 31) or Officer of the Bridge (during the period from November 1 to April 30) will be dedicated to maintaining constant observations for detection of SRKWs within one kilometre of the ship's vicinity prior to and during dredging and/or loading of dredgeate conducted in VFPA jurisdiction;	• **A year-round marine mammal detection team for the duration of the in-water construction period**;
				• The methodology by which the observation and acoustic monitoring will be conducted;	• The methodology by which marine mammal observation and acoustic monitoring will be conducted. **This includes a SRKW detection system and monitoring program which integrates multiple, complementary detection techniques (e.g., early detection sources[3], MMOs, PAM systems, infrared or other feasible technologies);**
					• **A multiple step notification system which establishes different actions to be taken depending on the proximity of SRKW to the project site (e.g., alert equipment operators to be on standby for a potential modification or shutdown of construction activity);**
					• **A SRKW monitoring buffer to account for the time needed to modify or shut down underwater noise generating construction activities before SRKW enter the applicable exclusion zone;**
					• **Procedures to adjust MMO coverage if SRKW are determined to be approaching the exclusion zone(s) or monitoring buffer;**
				• Communication and documentation protocols when marine mammals are observed and notifications sent to DFO;	• Protocols to document cetaceans observed and communicate these observations **to B.C. Cetacean Sightings Network** and DFO;
				• MMOs' authority to stop work when marine mammals enter the prescribed buffer zone;	• Authority for members of the **marine mammal detection team** (at a minimum MMOs) to initiate stop work procedures; • **Communication protocols to facilitate stop work procedures**;

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[3] Available data on SRKW sightings and acoustic detections from scientists, non-profit organizations, and the public such as shared sightings by the Canadian Coast Guard (i.e., Marine Mammal Desk) to track when SRKW are approaching Roberts Bank.

Number	Phase			Previous project commitment (as of July 2019)[1]	New and updated proposed mitigation measures
	Design	Construction	Operation		
				• Specify the construction activities that must stop or not start if a marine mammal is sighted in the prescribed buffer zone, and not restart until the marine mammal (other than harbour seals and sea lions) has moved out of the buffer zone for 30 minutes. This includes the requirement that if any marine mammal is observed in distress, construction activities producing underwater noise will stop immediately, DFO will be notified, and construction activities producing underwater noise will not resume until the marine mammal has moved out of the area of potential injury to the satisfaction of a qualified professional(s);	• Specify stop work procedures for in-water construction activities that, if safe to do so, must stop, be modified, or not start: – **Before SRKW enter the applicable exclusion zone(s), and not restart until it has been confirmed that the SRKW has moved out of the monitoring buffer, or if a minimum of 30 minutes has elapsed since the SRKW was last detected within the monitoring buffer; and** – If any marine mammal is detected in the applicable exclusion zone(s), and not restart until it has been confirmed that the marine mammal has moved out of the applicable exclusion zone(s) or if a minimum of 30 minutes has elapsed since the marine mammal was last detected within the applicable exclusion zone(s); • If any marine mammal is observed in distress, stop work procedures will be implemented and DFO will be notified. Mitigation to address the situation of marine mammal distress will be directed by and implemented to the satisfaction of a qualified professional(s);
				• Timing of impact pile driving, including daytime-only impact piling to ensure detection of all marine mammals within the prescribed buffer zone, and seasonal timing of impact pile driving activities to avoid periods of marine mammal occurrence (other than harbour seals and sea lions), if deemed technically feasible; and	• Timing of impact pile driving, including impact pile driving during daylight hours only, to ensure detection of marine mammals within the applicable exclusion zone(s);
					• **Avoiding the following construction activities from June 1 or the date when SRKW are confirmed to be present in the Salish Sea, whichever is later,[4] to September 30:** – **All vibratory and impact pile driving;** – **Vibro-densification of the caisson foundation mattress rock; and** – **Removal of the piles for the temporary barge ramps.**
				• The use of hydrophone monitoring of the buffer zone in periods of darkness or poor visibility, and the use of additional technologies to detect marine mammals in darkness and in poor conditions, such as infrared automated detection systems, if deemed technically feasible by the onset of construction.	• **Use of combined monitoring systems** to detect marine mammals and monitor applicable exclusion zone(s) or the applicable SRKW monitoring buffer **during daylight**, in darkness and in poor conditions, **such as hydrophone monitoring and/or** infrared automated detection systems, if feasible and deemed by a qualified professional(s) to improve marine mammal detection**;** and
					• **Implementation of DFO management measures to protect SRKW, in place at the time, if feasible and when safe to do so, to reduce SRKW disturbance from construction vessels.**
				The plan will be developed in consultation with the following parties: CEA Agency, DFO, and Indigenous groups. The VFPA will provide the draft plan to the parties for review a minimum of 90 days prior to the start of construction.	The plan will be developed in consultation with the following parties: DFO and Indigenous groups. The VFPA will provide the draft plan to the parties for review a minimum of 90 days prior to the start of construction.
37		✓		Prior to the start of construction activities with the potential to impact marine mammals and marine fish, the VFPA will develop an Underwater Noise Management Plan to the satisfaction of a qualified professional(s) and in consultation with DFO. The plan will be implemented during construction. With regard to marine mammals and marine fish, the plan will describe at a minimum the following:	Prior to the start of construction activities generating underwater noise with the potential to impact marine mammals and marine fish, the VFPA will develop an Underwater Noise Management Plan to the satisfaction of a qualified professional(s). The plan will be implemented during construction. With regard to marine mammals and marine fish, the plan will describe at a minimum the following:
				• Roles and responsibilities for implementation and monitoring;	• Roles and responsibilities for implementation and monitoring;
					• **In-water construction activities that are predicted to generate impulsive and continuous (non-impulsive) underwater noise;**

---

[4] If SRKW are not present in the Salish Sea by June 1, the activities could continue until the date that SRKW are confirmed present in the Salish Sea by hydrophone data or Enhancing Cetacean Habitat and Observation Program (ECHO) Program marine mammal observers (or equivalent).

	Phase				
Number	**Design**	**Construction**	**Operation**	**Previous project commitment (as of July 2019)[1]**	**New and updated proposed mitigation measures**
					• **Procedures to verify the extent of the SRKW exclusion zone(s)[5] at the start of each new underwater noise-generating activity to confirm it is of appropriate size. This includes:** – **Real-time field verification monitoring for activities that generate impulsive noise; and** – **Validation of predicted exclusion zones (e.g., updated acoustic model) for continuous (non-impulsive) noise generated by construction activities.**
				• The monitoring parameters and methods to ensure sound levels remain below prescribed thresholds for marine fish and marine mammals;	• The monitoring parameters and methods to ensure impulsive noise sound levels remain below the following prescribed injury thresholds for marine fish and marine mammals; – **A threshold of below 206 decibels at a reference pressure of one micropascal within 10 m of in-water impact pile driving for finfish;** – **Species or hearing group-specific injury thresholds for all marine mammals.**
					• **Sequencing of in-water construction activities to limit underwater noise aggregation, where feasible;**
				• Apply gradual start-up or ramping of construction activities, such as pile driving, to allow marine species to habituate or temporarily leave the area;	• Apply gradual start-up or ramping of construction activities, such as pile driving, to allow marine species to habituate or temporarily leave the area;
				• Requirement for the deployment of hydrophones; and	• Requirement for the deployment of hydrophones;
				• Procedures in cases of sound exceedances, and mitigation measures that will prevent injury to marine fish and hearing injury and behavioural changes to marine mammals during impact pile driving, including but not limited to sound reduction or dampening methods or technologies.	• Procedures in cases of sound exceedances during impulsive noise generating activities, **including stopping or modifying work, and implementing modified or additional mitigation measures, which may include expanding the exclusion zone(s)**; and • **Procedures to notify IAAC in the event of an exceedance of the injury threshold and the corrective action implemented;** and • Use of feasible sound attenuation methods and/or technologies when impact pile driving underwater that will prevent injury to marine fish and hearing injury and behavioural changes to marine mammals**.**
				The plan will be developed in consultation with the following parties: CEA Agency, DFO, and Indigenous groups. The VFPA will provide the draft plan to the parties for review a minimum of 90 days prior to start of construction.	The plan will be developed in consultation with the following parties: DFO and Indigenous groups. The VFPA will provide the draft plan to the parties for review a minimum of 90 days prior to start of construction.
88		✓			**The VFPA will ensure that crab salvage activities are conducted, as part of the Marine Species Management Plan, prior to dredging during the fisheries-sensitive window for Dungeness crabs (October 15 to March 31)[6], including deployed baited closed-traps to lure Dungeness crabs (including gravid females) away from the dredge area.**
89	✓	✓	✓		**The VFPA will work collaboratively with Musqueam Indian Band and Tsawwassen First Nation on a stewardship initiative to retrieve and dispose of lost or discarded fishing gear in the Roberts Bank area.**

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[5] **'Exclusion zones' as defined and established in the Marine Mammal Management Plan.**

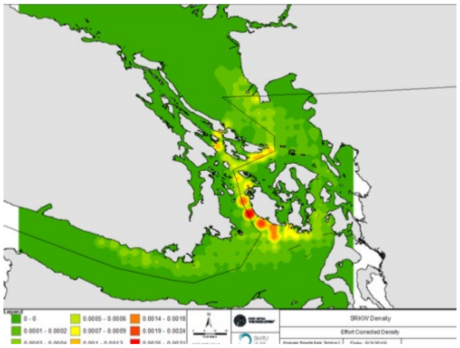
[6] If **agreed to by DFO and mitigation is developed and implemented to the satisfaction of a qualified professional(s).**

Appendix IR2020-2.3-E

Assessing effectiveness of mitigation to reduce potential acoustic effects on Southern Resident Killer Whales from project construction (technical data report)

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



Prepared for:

Vancouver Fraser Port Authority
100 The Pointe, 999 Canada Place
Vancouver, BC, V6C3T4
September 8, 2021

Prepared by:

Ecofish Research Ltd.

SMRU Consulting North America

JASCO Applied Sciences Ltd.

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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, 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. September 8, 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

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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). In-water construction works and activities are anticipated to occur continuously for approximately five years of the anticipated six-year construction period required to build the Project. 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 review panel appointed for the RBT2 Project concluded that construction acoustic effects to SRKW could be mitigated but that this would depend on the effectiveness of the detection methods and mitigation measures proposed. The Minister of Environment and Climate Change (the Minister) requested information on mitigation measures for SRKW during Project construction and their effectiveness. In response, this study examined the effectiveness of previously proposed, as well as enhanced and newly proposed mitigation measures and detection methods, coupled with in-water construction activity shutdowns, in reducing potential acoustic effects on SRKW from Project construction. This study considered and addressed the information request by quantifying potential acoustic effects with and without these mitigation measures. The approach considered review panel recommendations and feedback received from Fisheries and Oceans Canada (DFO) prior to and during the public hearing. Further, this study reflects input received by Indigenous groups and DFO during consultation of materials for the Minister's information request.

To estimate potential acoustic effects on SRKW due to in-water construction activities, we synthesized monthly SRKW presence within 20 km of the proposed terminal and SRKW seasonal use of the area. We simulated individual SRKW transits through the study area and estimated their spatiotemporal overlap with the acoustic footprints associated with noise-generating in-water construction activities planned to build the proposed terminal. We classified the potential effects on SRKW as acoustic injury and behavioural disturbance (i.e., responses). We quantified acoustic injury as the likelihood of SRKW spending time within injury zones. We conservatively assumed that behavioural responses to underwater noise above the behavioural disturbance threshold would lead to cessation of feeding, and therefore quantified their effects in terms of potential lost foraging time and potential lost prey captures per SRKW. 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 Environmental Impact Statement (EIS), but also assessed the effect to SRKW if the probability of behavioural responses is higher than assumed in the EIS.

We simulated mitigation strategies during construction to assess their potential effectiveness in reducing acoustic effects on SRKW. The mitigation measures and strategies integrate the following previously proposed mitigation measures with newly augmented and additional measures proposed by

the port authority since the public hearing, in response to the Minister's information request. These are to:

1. Refine, since the panel hearing, the reference concept design schedule described in the Project Construction Update (referred herein as reference concept design schedule) to avoid or reduce the noisiest construction activities (i.e., vibro-densification and pile installation) during the period of SRKW peak use of the study area.
2. Employ noise attenuation for impact pile driving as previously proposed (e.g., use of confined bubble curtains) (Commitment #37, VFPA 2019).
3. Integrate previously committed to SRKW detection methods (Commitment #33, VFPA 2019), which since public hearing have been augmented and supplemented, coupled with shutdown or modifications of relevant in-water construction activities if SRKW are present (accounting for delays in equipment shutdown).

The acoustic effects model was implemented within a Monte Carlo framework, which allowed the assessment of uncertainties in predicted acoustic effects on SRKW.

Refining the Timing of In-water Activities

Since the public hearing, the port authority has evaluated the construction timing to identify activities that could be planned to avoid the SRKW seasonal habitat use of Roberts Bank to reduce acoustic effects on SRKW. Construction activities that contribute disproportionately to acoustic effects on SRKW were identified and modifications to the in-water construction timing were developed to avoid or further reduce acoustic effects to SRKW. In particular, opportunities to avoid or reduce activities during the SRKW peak use period of Roberts Bank (June 1 to September 30) were considered. We focused on the construction activities predicted to cause the largest potential acoustic effects on SRKW. These were pile installation activities and combined construction activities including vibro-densification. Two modified reference concept design schedules (Option 1 and Option 2) were developed and evaluated based on input from the RBT2 engineering team (Moffatt and Nichol 2021). These options (i.e., Option 1 and Option 2) plan both impact and vibratory piling and vibro-densification of the mattress rock for the caisson foundation outside the SRKW peak use period. Under Option 1, in year 2, the six-month season for dredging the dredge basin is planned to continue for an additional 1.5 months (from October 15 to November 30) which means that in construction year 3 dredging avoids August and September (i.e., a portion of the SRKW peak use period). The extended dredging period coincides with the first 6 weeks of the Dungeness crab fisheries-sensitive window (October 15 – March 31) (Commitment #49; VFPA 2019). Option 2 is similar to Option 1 except that dredging does not extend into the Dungeness crab fisheries-sensitive window in year 2. The acoustic effects model quantified the reduction in predicted effects on SRKW of the two options compared to the reference concept design schedule and Option 1 is expected to reduce effects to SRKW more than Option 2.

Over the entire period of in-water construction under the reference concept design schedule (i.e., ~56 months), prior to implementing any mitigation, the acoustic effects model estimated a median of ~42 hours of potential lost foraging time per SRKW (95% CI: 35.1 hours – 49.3 hours). The largest amount of potential lost foraging time occurred in construction year 3 (particularly April-October) (accounting for ~50% of the total potential lost foraging time) and year 2 (particularly June-September) (~20% of total potential lost foraging time). The incurred potential lost foraging time was mostly due to three construction activities planned during the summer period: 1) combination of dredging, pumping ashore, and vibro-densification, 2) combination of dredging and pumping ashore, and 3) vibratory pile installation. The SRKW pod that is predicted to lose the most foraging time is J pod (due to higher presence in the area). Pods K and L would lose smaller (and similar) amounts of foraging time. The distribution of potential lost foraging time as a function of distance from RBT2 follows the same pattern as the distribution of transits, i.e., there is a peak at around 1.5 km from the terminal, a subsequent decline, and a second peak starting at around 5 km from the terminal. The pattern of variation in the estimated potential prey losses per SRKW mirrors the patterns of variation in potential lost foraging time per SRKW.

Implementing construction schedule Option 1 resulted in a substantial reduction in potential lost foraging time per SRKW compared to the reference concept design schedule: ~30% reduction over the entire span of construction and ~45% reduction in year 3, the year found to dominate overall acoustic effects. On the other hand, implementing Option 2 resulted in a smaller reduction in potential lost foraging time: ~20% overall reduction and ~35% reduction in construction year 3. Given the reductions in acoustic effects that can be achieved by implementing the modified schedule (Option 1), this option was used to further to evaluate the effectiveness of the mitigation strategy of detecting SRKW and halting in-water construction activities.

Sound Dampening Technology for Impact Pile Installation

The only construction activity anticipated to have the potential to produce onset of acoustic injury to SRKW (either Permanent or Temporary Threshold Shifts (PTS and TTS)) is impact pile driving. During the public hearing, the port authority had not specified the amount of impact piling anticipated to be required. Upon further review of the requirements, impact piling is now anticipated to be limited to testing pile capacity (for ~4 piles) with approximately 15 minutes of active impact hammer per pile. The port authority committed to implement sound dampening technology and planned the activity to occur during daytime only (Commitment #33, VFPA 2019). Acoustic modelling scenarios implementing confined bubble curtains as an example of an effective sound dampening method during impact piling were also modelled for impact piling and pile capacity testing. The largest acoustic injury zones modelled were conservatively used to evaluate the anticipated effectiveness of the mitigation measure for acoustic injury and results are therefore considered precautionary.

Firstly, the acoustic effects model found the likelihood of in-water construction noise causing acoustic injury to SRKW, without considering the use of a sound dampening technology or other mitigation, is small. We found a median of 1 transit within the injury zone per year in construction years 1, 2, 4, and 5. Each transit within the PTS injury zone took a median of 3 minutes and 20 seconds (0 minutes - 4 minutes), and within the TTS injury zone took a median of 4 minutes and 50 seconds (0 minutes - 7 minutes). These estimates are much lower than the reference time used to calculate the sound exposure level (100 minutes) injury radii, indicating that even if a SRKW were exposed to noise from impact pile driving, exposure will likely not reach the energy level threshold for acoustic injury. The potential for acoustic injury can be completely mitigated by implementing sound dampening technologies for impact pile driving (e.g., by confined bubble curtains which reduce the area of potential injury to the immediate proximity of the pile) and monitoring for SRKW and temporarily halting impact pile driving if a SRKW is detected, irrespective of the construction timing refinements made to plan this activity outside the SRKW peak use period.

Confined bubble curtains can reduce the range of potential behavioural disturbance effects. This mitigation measure was conservatively assumed not to be in place when estimating behavioural disturbance effects in the simulation model and evaluating the effectiveness of other mitigation measures.

SRKW Detection Mitigation Strategies

Since the public hearing, the port authority has updated its previous marine mammal observer (MMO) commitment, which was to have an MMO (during the period from May 1 to October 31) or Officer of the Bridge (during the period from November 1 to April 30) dedicated to maintaining constant observations to detect SRKW within 1 km of dredging or the ship (Commitment #33, VFPA 2019). The port authority is now committing to having a year-round marine mammal detection team (including MMOs) for the duration of the in-water construction period. Using the acoustic effects model, we assessed the effectiveness of individual and combined observation and acoustic detection mitigation strategies to detect SRKW and halting or modifying in-water activities to avoid or reduce acoustic effects to SRKW from in-water activities if SRKW are present. We evaluated two commonly used detection methods: MMOs and passive acoustic monitoring (PAM), and their combination. We developed MMO project-specific SRKW detection probability functions, assuming two different levels of effort or use of technologies (a standard level of effort based on typical construction monitoring industry practices (MMO Industry protocols) and an enhanced level of effort to increase long range detection based on National Oceanic and Atmospheric Administration (NOAA) marine mammal survey protocols (MMO NOAA protocols)), and for three different weather conditions recognizing that sea-state conditions influence detectability. The port authority previously committed to acoustic monitoring but did not describe the intended level of effectiveness. The port authority now anticipates that an acoustic array of hydrophones will be deployed (augmented effort) to achieve higher SRKW detection especially at night. In evaluating the effectiveness of PAM, we assumed that each SRKW transit had a realistic 75% chance of being detected by a PAM system (i.e., an array with multiple hydrophones), immediately outside of a radial distance of 6 km from the RBT2 terminal (which coincides with the maximum anticipated MMO detection distance). A PAM workshop with the participation of international leading experts in acoustic monitoring and Killer Whale acoustic behaviour was held in July 2020 to seek advice on feasibility and design of a system that would be in place during construction to maximize detection effectiveness for Killer Whales. Participants agreed that installing a high-performance PAM system is feasible. The port authority will continue to seek input from DFO on the design of an effective PAM system to monitor and mitigate effects of construction activities on SRKW and other marine mammals.

Additional SRKW detection methods will be employed to increase the effectiveness of mitigation strategies. The port authority committed to employing infrared and other technologies if feasible by the time of construction, as well as the MMO coordinating with whale sightings networks (Commitment #33, VFPA 2019). The port authority will also use early detection sources and available data on SRKW sightings and acoustic detections from scientists, non-profit organizations, and the public such as shared sightings by the Canadian Coast Guard (i.e., Marine Mammal Desk) to track when SRKW are approaching Roberts Bank. Based on available information, feasibility, and detection rates of these methods, and therefore their efficacy, cannot be quantified at this stage. To obtain a theoretical estimate of mitigation effectiveness for these combined detection methods (i.e., including MMOs and PAM) with the refined construction timing, we implemented a model scenario where all SRKW transits were detected and all construction activities that can be halted were halted prior to the whales entering the exclusion zones. This scenario provides an upper bound for potential mitigation effectiveness. The scenario that includes only MMO Industry protocols can be viewed as a lower bound for mitigation effectiveness.

In addition to using Monte Carlo simulation to derive confidence intervals on expected acoustic effects, we also assessed the uncertainty in the severity of acoustic effects on SRKW by deriving more conservative probabilities that SRKW will cease feeding when exposed to noise within each acoustic effect zone. This provides an upper bound for expected acoustic effects on SRKW.

The effectiveness of the different SRKW detection methods coupled with in-water construction activity shutdowns varied. The acoustic effects model suggests that:

- The mitigation strategy employing MMO Industry protocols is effective at reducing potential lost foraging time within the first few kilometers. However, it is not effective at reducing it beyond this range, and as a result, there is a percentage of lost foraging time that is not mitigated using this MMO mitigation strategy.
- The mitigation strategies employing PAM and MMO NOAA protocols are more effective at reducing potential lost foraging time beyond 4 km from the terminal than the strategy employing MMO Industry protocols.
- Combined mitigation strategies (detection by PAM and MMO NOAA protocols coupled with relevant in-water construction activity shutdown or modification) was most effective at reducing potential lost foraging time up to 6 km from RBT2. Even when accounting for delays in halting construction activities (thus providing realistic expectations of mitigation effectiveness), combined mitigation strategies remained very effective at reducing acoustic effects.

- Implementing detections using PAM or MMO NOAA protocols and construction shutdowns, in addition to the modified schedule (Option 1), reduced potential lost foraging time per SRKW over 6 years of construction to:
    - MMO NOAA protocols: 11.3 hours (8.7 – 14.1 hours) (i.e., 73% reduction compared to base case schedule with no mitigation strategy);
    - PAM: 10.0 hours (6.8 - 13.7 hours) (i.e., 76% reduction); and
    - PAM and MMO NOAA protocols combined: 5.6 hours (3.7 - 7.6 hours) (i.e., 87% reduction).
- Using more conservative probabilities of response to noise (i.e., assuming that whales will cease feeding at lower noise levels) led to an increase in estimates of lost foraging time per SRKW on average by 23% (range 19-26%), resulting in an upper bound estimate of less than 10 hours of potential lost foraging time per SRKW over the whole 6-year in-water construction period (when assuming a combined mitigation strategy including the use of the modified schedule (Option 1) and combined detection by PAM and MMO NOAA protocols with construction shutdowns). A large proportion of the added potential lost foraging time was accrued within the quietest (120-129 dB) acoustic effect zone, where the probability of construction noise eliciting behavioural responses is lowest.

The maximum theoretical potential reduction in lost foraging time that would be achieved with all the detection measures committed to by the port authority (i.e., if all whales are detected prior to entering the exclusion zones or all construction activities that can be halted are halted before SRKW enter the activity based exclusion zone), was 94%, yielding an estimated potential lost foraging time of 2.3 hours (1.2 - 3.6 hours) per SRKW over the 6 years of construction. Acknowledging that perfect detection may not always be achieved, and all construction activities may not be halted before SRKW enter the exclusion zone, we estimate that a realistic range of potential lost foraging time per SRKW is approximately 2.3 h – 7.6 h over the 6 years of in-water construction.

Conclusion

This study assessed the effectiveness of potential mitigation measures and detection methods, coupled with in-water construction activity shutdowns, in reducing potential acoustic effects to SRKW from Project construction. Key study results indicate that:

- The potential for acoustic injury (PTS and TTS) can be completely mitigated by implementing sound dampening technologies for impact pile driving (e.g., confined bubble curtains and monitoring for SRKW and stopping impact pile driving if a Killer Whale is detected).
- The effects of construction noise eliciting behavioural responses can be mitigated (87% reduction), by implementing a combined mitigation strategy of refining the in-water construction timing and monitoring for SRKW and halting construction when a Killer Whale is detected using both PAM and enhanced MMO protocols only. Acoustic effects will persist

due to construction activities that cannot be halted due to safety reasons, but these are expected to be small.

The integration of early detection sources and infrared or other feasible technologies, proposed monitoring of a buffer outside the exclusion zone and shutting down or altering activities before SRKW enter exclusion zones to reduce potential effects associated with delays in equipment shutdowns, as proposed by the port authority, is predicted to have the potential to reduce the expected acoustic effects by up to 94% to 2.3 hours (95% CI: 1.2 - 3.6 hours) per SRKW over the six-year span of the construction period. While still based on conservative assumptions (e.g., Killer Whales forage 100% of the time), and therefore considered precautionary, the results from the model demonstrate that the combined mitigation measures proposed by the port authority for construction can be effective at mitigating construction acoustic effects to SRKW as concluded by the review panel.

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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). Project construction is estimated to take approximately six years including approximately five years of continuous in-water construction. Project construction is anticipated to start in the second half of the first year of construction (year 1) and to be completed approximately six years later in the second half of year 7 (VFPA 2018).

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 and is sufficient for effective acoustic social signaling and echolocation to locate 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 acoustic injury, behavioural effects (including potential displacement 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).

The federal review panel appointed to assess the Project concluded in its report that, during construction, the combination of mitigation measures such as noise dampening methods, the adoption of a buffer zone also referred to as an exclusion zone (i.e., a zone monitored for presence of marine mammals and where relevant equipment shutdowns or other actions (e.g., delay or modification of activities to reduce underwater noise) will be implemented if a marine mammal enters it), use of marine mammal observers, and avoidance of impact pile driving at night would fully mitigate the potential adverse effects of construction noise on SRKW (The Review Panel for the Roberts Bank Terminal 2 Project 2020). However, the review panel noted that the ability of the mitigation measures to eliminate residual effects will depend on the effectiveness of the monitoring methods in detecting SRKW in the buffer zones (The Review Panel for the Roberts Bank Terminal 2 Project 2020).

In a letter received on August 24, 2020, the Minister of Environment and Climate Change (the Minister) requested information regarding avoidance and mitigation measures for Project construction (MECC 2020). As part of this request, the port authority was asked to provide additional information on sound dampening technologies for impact pile driving, timing of activities to avoid seasonal use by SRKW, and methods to detect SRKW entry into exclusion zones based on all noise generating activities.

Guided by consultation with Indigenous groups, engagement with government agencies, and recommendations made by the review panel, the port authority identified mitigation measures since the review panel's report to further reduce impacts to SRKW from underwater noise during Project construction. The mitigation measures integrate the following previously proposed mitigation measures with newly augmented and additional measures proposed by the port authority since the public hearing. These are to:

1. Refine, since the panel hearing, the reference concept design schedule described in the Project Construction Update to avoid or reduce the noisiest construction activities (i.e., vibro-densification and pile installation, respectively) during the period of SRKW peak use of the study area.
2. Employ sound dampening technology for impact pile driving as previously proposed (e.g., use of confined bubble curtains) (Commitment #37, VFPA 2019).
3. Integrate previously committed to SRKW detection methods (Commitment #33, VFPA 2019), which since public hearing have been augmented and supplemented, coupled with shutdown or modifications of relevant in-water construction activities if SRKW are present (accounting for delays in equipment shutdown).

This study was conducted to assess the predicted effectiveness of updated and new mitigation measures from the port authority in avoiding or reducing acoustic effects on SRKW from Project construction. The mitigation measures were assessed by developing an acoustic effects model that incorporated key factors in the interaction between underwater noise from construction activities and the seasonal presence of SRKW to quantitatively evaluate the effectiveness of these measures.

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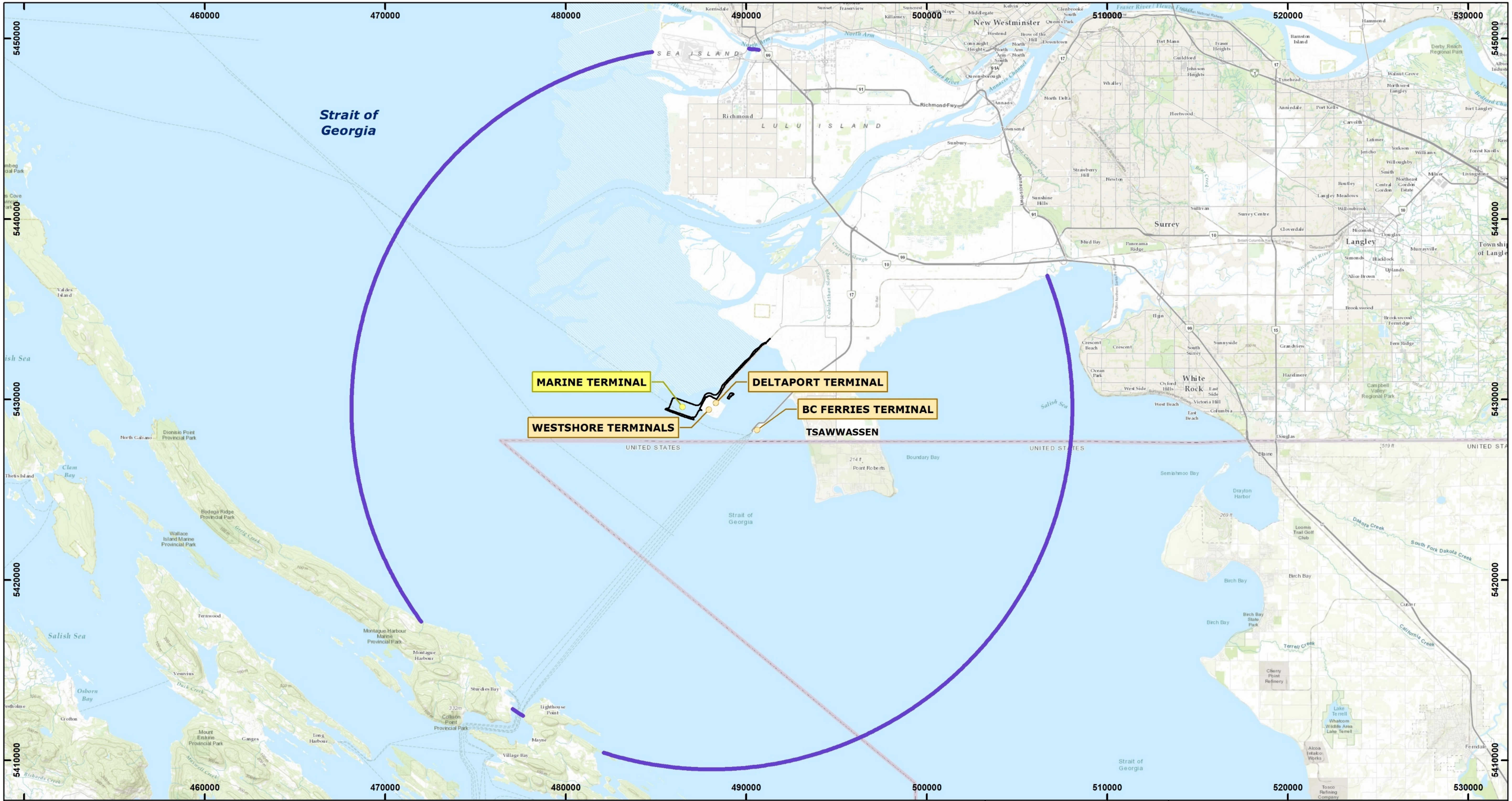


Legend

▭ BOUNDARY OF PROJECT AREA

━ 20 KM STUDY AREA

PROJECT COMPONENT

EXISTING LANDMARK

0 2.5 5
Kilometres

N

1:200,000

NAD 1983 UTM Zone 10N

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

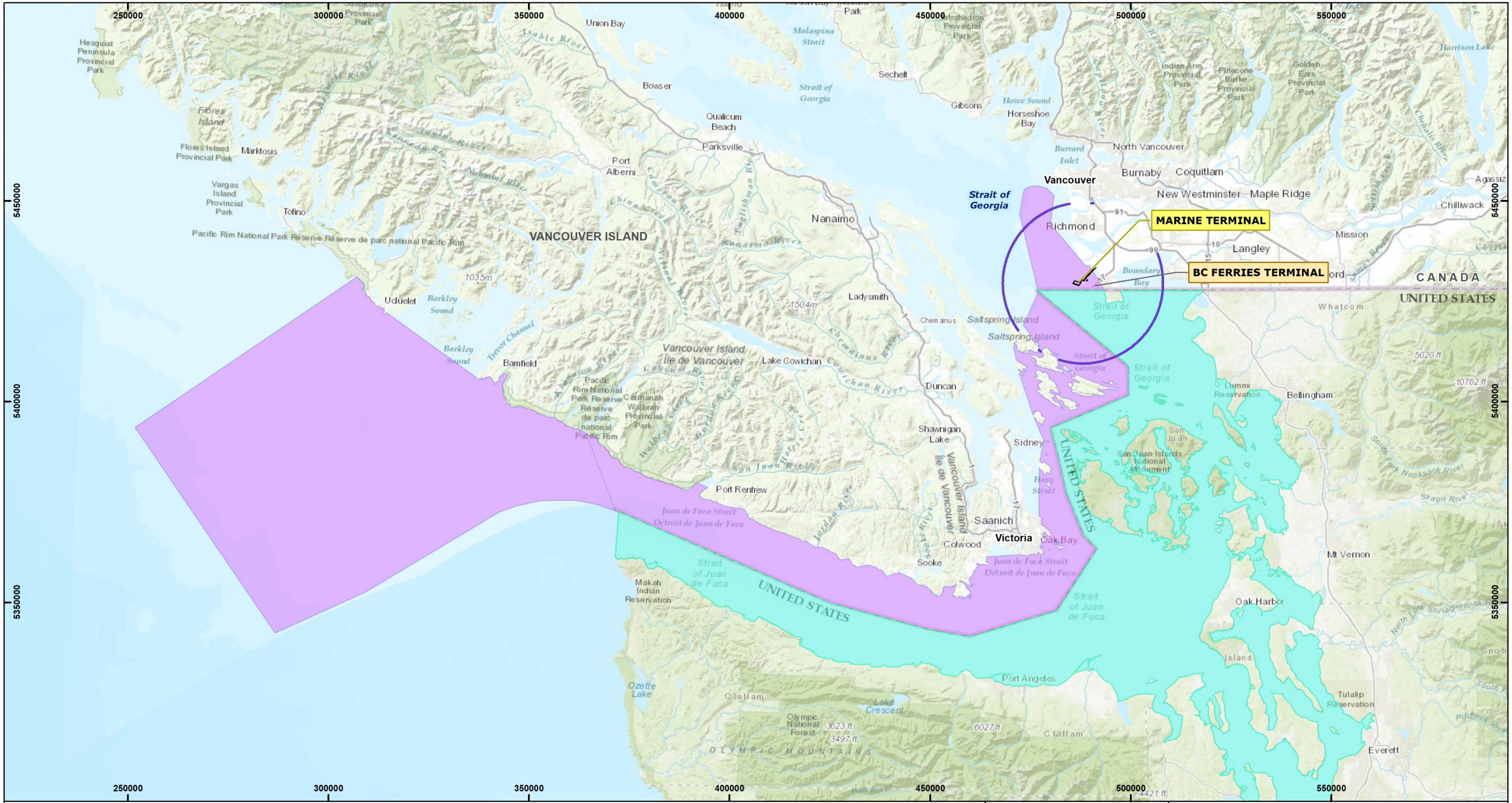
ROBERTS BANK TERMINAL 2

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: 02/16/2021

FIG No. 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

1.1. Objectives

The purpose of this study is to evaluate the effectiveness of the mitigation measures identified since the public hearing (i.e., measures that were not considered by the review panel) for reducing acoustic effects to SRKW from Project construction 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 on SRKW (e.g., by considering changes in the size of acoustic effect zones over time, as well as spatial and temporal variations in SRKW use) from Project construction;
- Quantify the effectiveness of construction timing changes as avoidance measures to reduce the predicted acoustic effects on SRKW;
- Quantify the effectiveness of different mitigation measures, including marine mammal monitoring methods, to avoid or reduce the anticipated acoustic effects on SRKW (e.g., detect SRKW and temporarily shutdown relevant activities) and identify best measures for implementation;
- Quantify the anticipated acoustic effects before and after the implementation of mitigation measures;
- 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; and
- Estimate the frequency and duration of anticipated construction halts (i.e., shutdowns) to inform project planning and management.

The subsequent sections present the methods applied to evaluate potential acoustic effects of key underwater noise generating activities during Project construction 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 construction, 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 construction and to assess the effectiveness of the mitigation measures identified since the RBT2 public hearing, while accounting for uncertainties in the estimates. The approach selected also considered the federal review panel recommendations, DFO's comments provided in support of the public hearing, and clarifications provided on the Minister's information request (MECC 2020) by IAAC. The methods also consider feedback received during consultation with Indigenous groups and DFO on the approach and assumptions. This section describes the approaches taken and data used to quantify acoustic effects and evaluate the effectiveness of the mitigation measures to avoid or reduce acoustic effects to SRKW from Project construction.

In developing the modelling approach, we considered the following sources of information:

- The fine-scale spatiotemporal use of the study area by SRKW;
- Modelled acoustic footprints of key noise generating activities during construction;
- Behavioural response to disturbance; and
- Sound exposure levels thresholds for acoustic injury.

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 study area) (Map 1).

The sources of information considered were synthesized in a simulation model (acoustic effects model) to quantify potential acoustic effects on SRKW from Project construction and evaluate changes to them when mitigation is implemented. The size of acoustic effect zones and likelihood of exposure of SRKW depends upon the type, location, and duration of construction activities and their potential overlap with SRKW transiting through the area. The approach used in this study provides an estimate of potential effects per SRKW over time for different construction activities. The acoustic effects model was developed to consider and reflect the areas of high SRKW use that would be temporarily degraded acoustically during Project construction (Recommendation #26, DFO 2019). We also partitioned effects by activity to assess the effectiveness of different mitigation measures.

The acoustic effects model was developed to simulate SRKW transits through the study area and to assess their spatio-temporal overlap with Project construction activities. In cases where there was overlap, we calculated the length of time that SRKW were exposed to underwater noise from Project construction, and then converted this to SRKW potential lost foraging time (Section 2.3) using 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 to estimate prey capture rates per hour of foraging (Section 2.3.1). The number of SRKW transits per month (described in Section 2.1.1), and the distance from the proposed RBT2 terminal at which transits 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. Acoustic footprints were determined for key noise generating construction activities (and combined activities) during the in-water construction period when underwater noise is anticipated (Li *et al.* 2021). Acoustic effect zones for construction noise were defined combining globally recognized received level acoustic disturbance thresholds with behavioural response thresholds developed specifically for continuous noise effects on SRKW (Section 2.2). We assessed the efficacy of each mitigation measure identified to reduce potential lost foraging time and missed prey captures, including methods for evaluating frequency and duration of construction halts (i.e., shutdowns) (Section 2.4.5). We also evaluated uncertainties in severity of behavioural responses (Section 2.5) by applying more conservative behavioural dose-response coefficients (i.e., by considering the case where SRKW's behavioural response is more acute 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), this 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 this 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 previously used for the EIS to reflect six additional years, following the approach from Hemmera and SMRU (2014). The mean number of days SRKW were sighted per month within the study area a 20 km radius of RBT2 (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 sightings network data 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 undertaken by the port authority near the proposed Project in 2012 and 2013 (SMRU 2014b). These passive acoustic monitoring 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 (Table 1, Figure 1) per year.

Peak transit months were identified as June to August with a mean of ~14 to 17 estimated transits per month, followed by April and September which both had a mean of ~11 estimated transits per month (Table 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 (Figure 1) that were 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).

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). This longer SRKW peak use period was used as the period to avoid, where feasible, when evaluating alternative timing for noisiest construction activities described under mitigation evaluation in Section 2.4.4.

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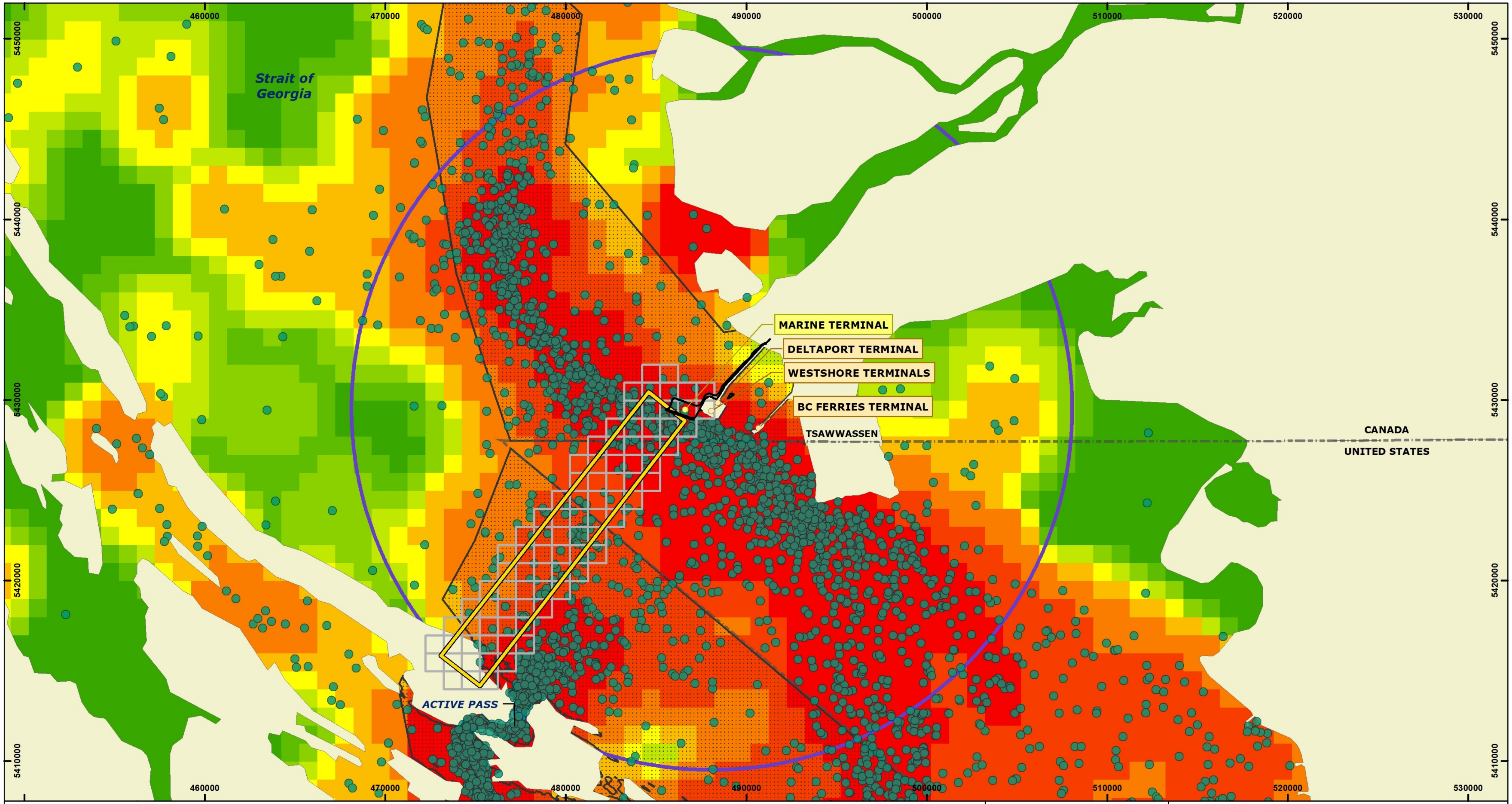


Legend

- ● 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: 07/28/2021

FIG No. Map 3

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 transit correction
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 transit, 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).**

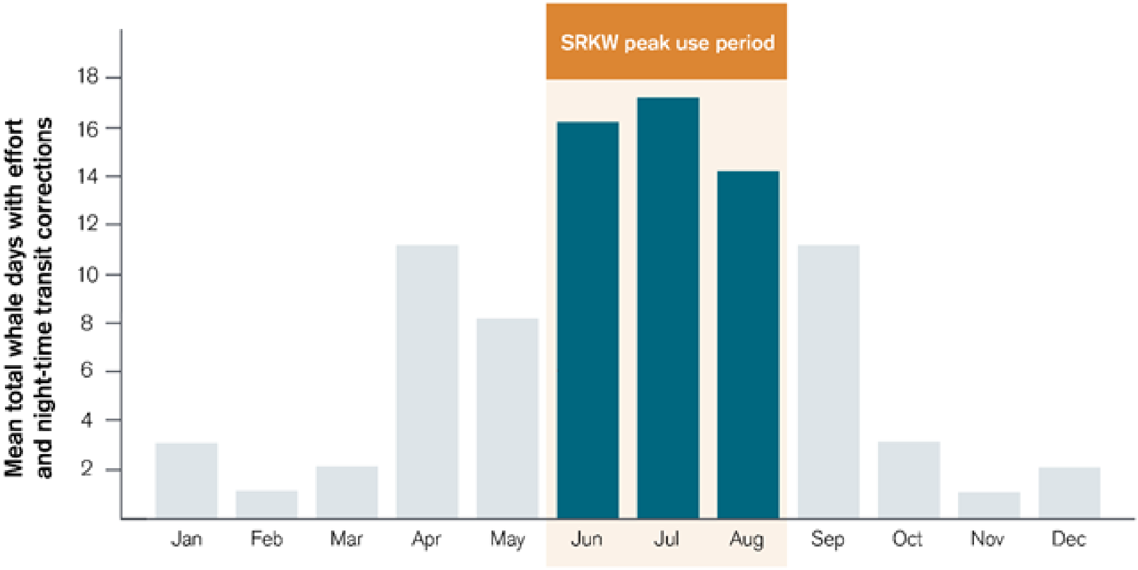
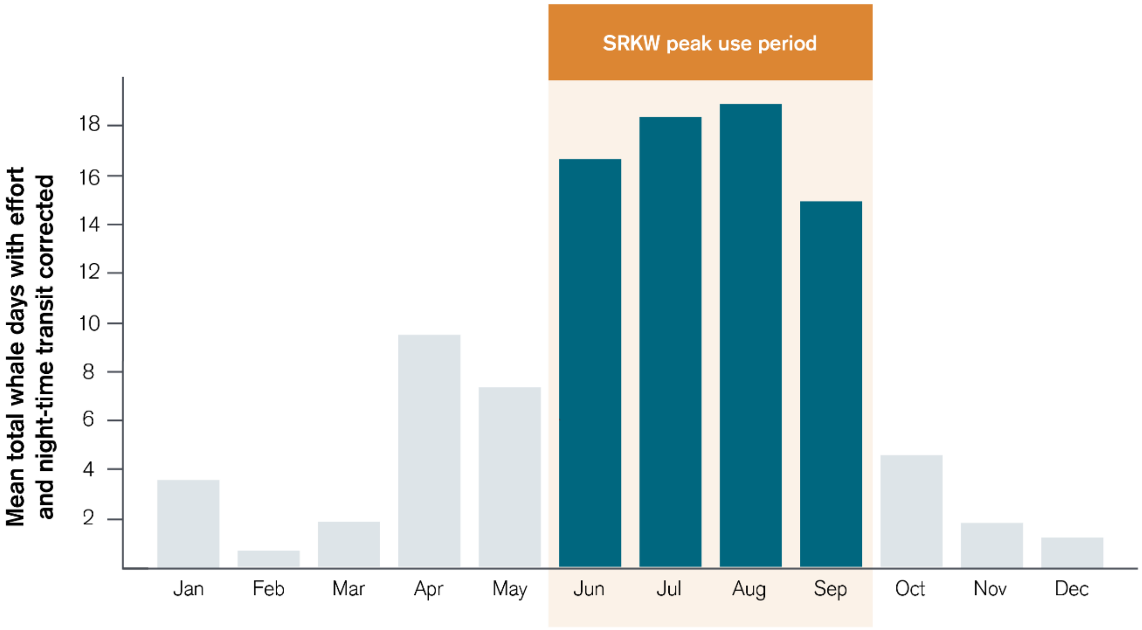


Figure 2. **Average monthly SRKW sightings from 2009 to 2017 corrected for seasonal effort and night-time transit, within the study area (20 km of the proposed RBT2 terminal), showing SRKW peak use from June to September. Original, uncorrected data were compiled from the B.C. Cetacean Sightings Network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



2.1.2. Anticipated SRKW Pod Size Per Transit

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 animals 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 sighting encounters, 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 encounters. 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.

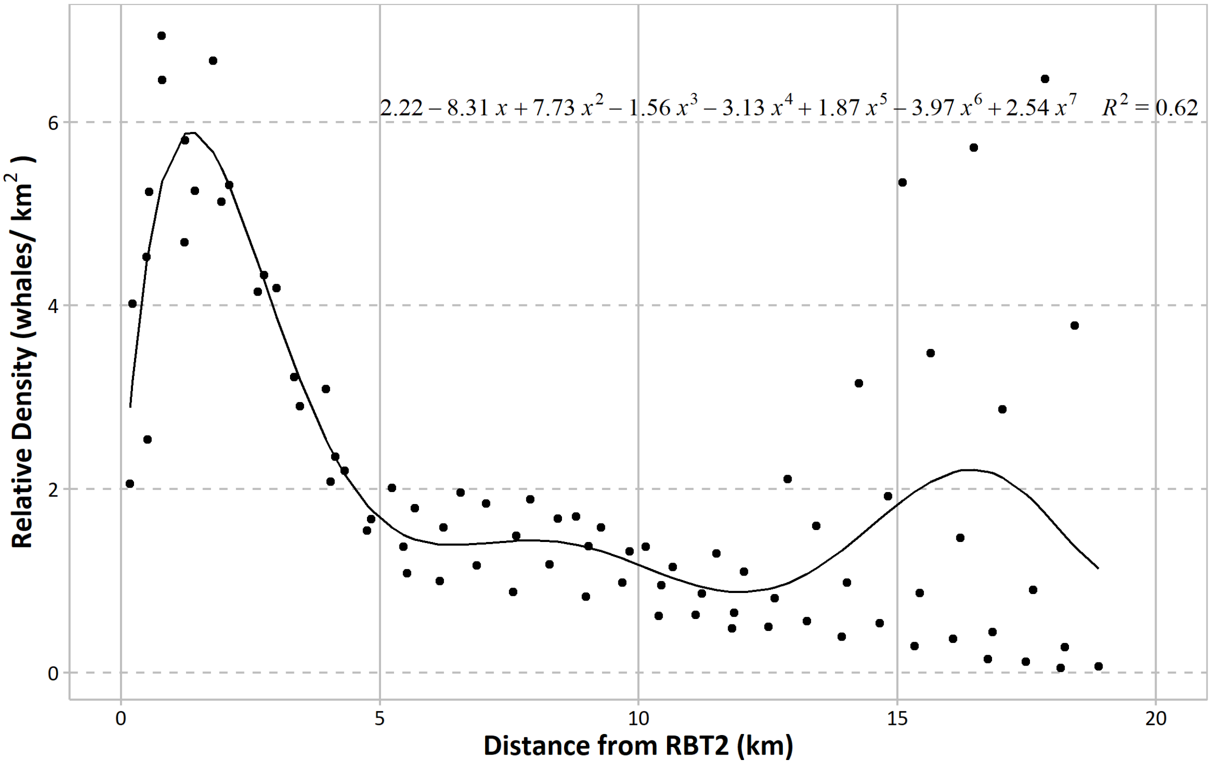
Pod assemblage	Summer (May-Oct) breakdown	Winter (Nov-Apr) breakdown	# of individuals (2019) per pod or pod assemblage[1]
J	36.40%	59.30%	23
JK	16.60%	16.90%	32
JKL	26.20%	6.80%	61
JL	9.20%	3.40%	35
K	2.50%	0.00%	19
KL	0.00%	0.00%	26
L	1.20%	1.70%	17
SRKW	7.90%	11.90%	23

[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. First, the effort-corrected 2002-2017 sightings database (described in Section 2.1.1) was 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 (echolocation click masking), conspecific communications (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).

The Minister requested that the port authority provide more information on avoidance and mitigation measures to address acoustic effects such as acoustic injury and behavioural disturbance

(MECC 2020). In the following sections, we present some of the elements incorporated into the acoustic effects model developed to address the Minister's request, specifically the noise exposure criteria used to assess acoustic injury and behavioural response.

2.2.1. Acoustic Injury

Noise-induced threshold shifts are increases in hearing thresholds within a certain frequency range (Yost 2000). Threshold shifts can be temporary (TTS) or permanent (PTS) and can consist of both temporary and permanent components. Several important factors relate to the type and magnitude of hearing loss, including exposure level, frequency content, duration, and temporal pattern of exposure. Threshold shifts can occur as a result of exposure to impulsive or continuous (non-impulsive) noise sources. In the case of the Project, only impact pile driving has the potential to cause acoustic injury to SRKW. A limited number of piles (approximately 59 piles and 34 sheet piles) will be installed in water as part of temporary and permanent structures at the terminal and tug basin as described in Moffatt and Nichol (2021). Piles will be installed using a vibratory hammer to reduce noise levels but impact pile driving may be required to test the axial (vertical) capacity of a small number of piles (~4 piles: 3 for the temporary barge ramps and 1 for the mooring dolphin), using a Pile Driving Analyzer (PDA) test to confirm infrastructure stability and safety (Moffatt and Nichol 2021).

Recently revised injury thresholds (NMFS 2018) are recognized as the best available science for acoustic injury. They are used globally and have therefore been selected for this study. Impulsive sounds have dual criteria (i.e., a weighted cumulative sound exposure level (SEL) over 24 hours, dB re 1 $\mu Pa^2 \cdot s$; and unweighted peak pressure level (PK), dB re 1 µPa). Injury zone radii for impulsive noise sources were defined based on the largest of the SEL and PK estimates for PTS and TTS. The SEL metric is a cumulative measure of acoustic energy that accounts for both the received level and the duration of exposure. Hearing sensitivity filters (or weightings) that are specific to different marine mammal hearing groups are applied to the noise source prior to calculating SEL. Following recommendations in Southall *et al.* (2019), a relevant exposure time of 100 minutes (based on EIS assumptions) and actual number of strikes (i.e., ~15) anticipated for impact hammer scenarios for testing pile capacity was used to calculate what areas exceeded SEL thresholds for the relevant hearing group (i.e., mid-frequency in the case of SRKW) (Li *et al.* 2021). The 100-minute duration also coincides with reasonable SRKW transit time through the study area. Based on a mean travel speed of 1.6 m/s (Williams and Noren 2009), Killer Whales could travel over approximately 10 km during a 100-minute period. The largest isopleths modelled were conservatively selected to assess likelihood of acoustic injury. Probability of response coefficients for all impulsive noise zones were considered to be 1.0, the highest severity of effect possible (i.e., exposure time equals potential lost foraging time).

2.2.2. 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 effect zones where SRKW could respond to both continuous and impulsive noise by potentially ceasing to forage. We used the NOAA behavioural disturbance thresholds of 120 and 160 dB re 1 μPa (broadband, unweighted, root-mean-square (rms)) for continuous and impulsive noise respectively (NOAA 2019). These thresholds have 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 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. Mean response probabilities for the behavioural response used in this study were derived using the low severity curve (Figure 3) using 120, 129 and 137 dB as thresholds. These reflect decreasing probability (severity) of SRKW behavioural response to continuous noise from Project construction. The highest probability of behavioural response is associated to the highest broadband unweighted received level of noise (closest to sound source), and the probability of response decreases with received noise level (increasing distance from the noise source). 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.

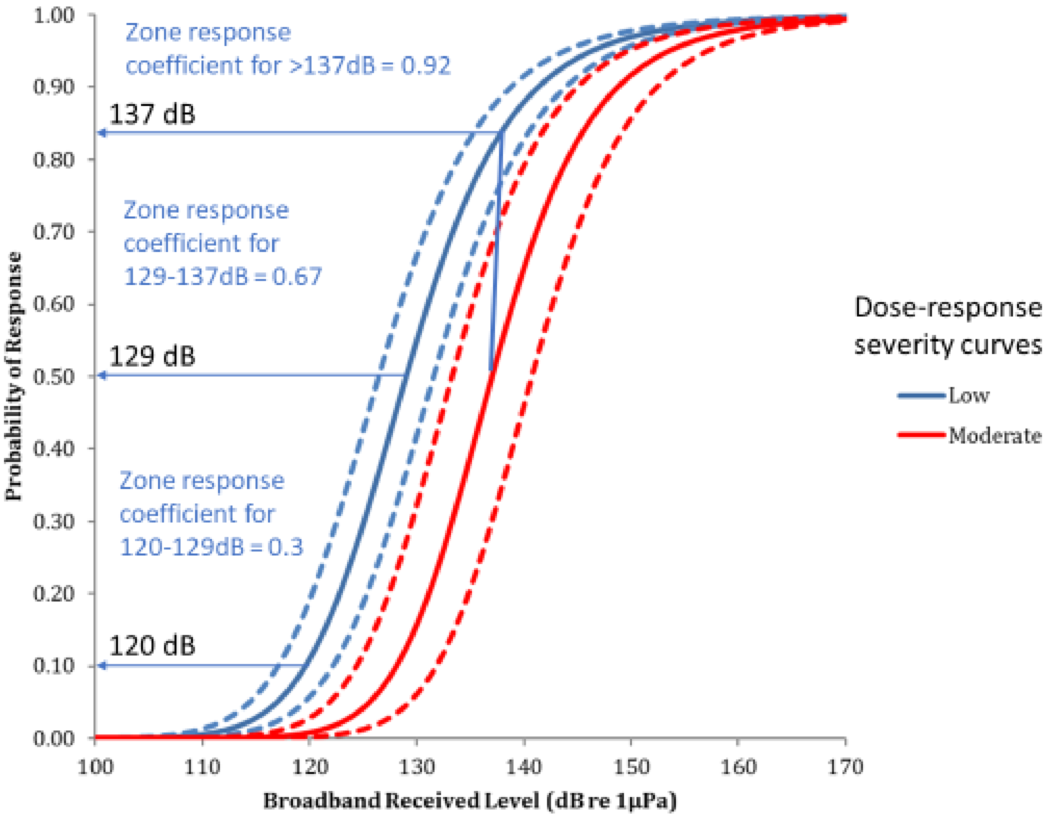
To partially address uncertainty in the contextual severity of the effect, we adopted more conservative (higher) probability of response coefficients than for the EIS, by basing them on the low behavioural dose-response curve (blue curve in Figure 4) rather than basing the coefficients on the moderate dose-response curve (red curve in Figure 4). These response coefficients are used to convert exposure time 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 to convert noise exposure time to potential lost foraging time. 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 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 lost foraging time when transiting through that zone;

- 0.67 (67th percentile response) for the acoustic zone encompassing 129 to 137 dB, representing the mid-point between a 50th percentile and 84th percentile probability of response; and
- 0.30 (30th percentile response) for the acoustic zone encompassing 120 to 129 dB, representing the mid-point between the 10th percentile and 50th percentile probability of response.

Figure 4. Dose-response behavioural response probabilities used to derive potential lost foraging time coefficients associated with 120, 129, and 137 dB broadband received level. 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.

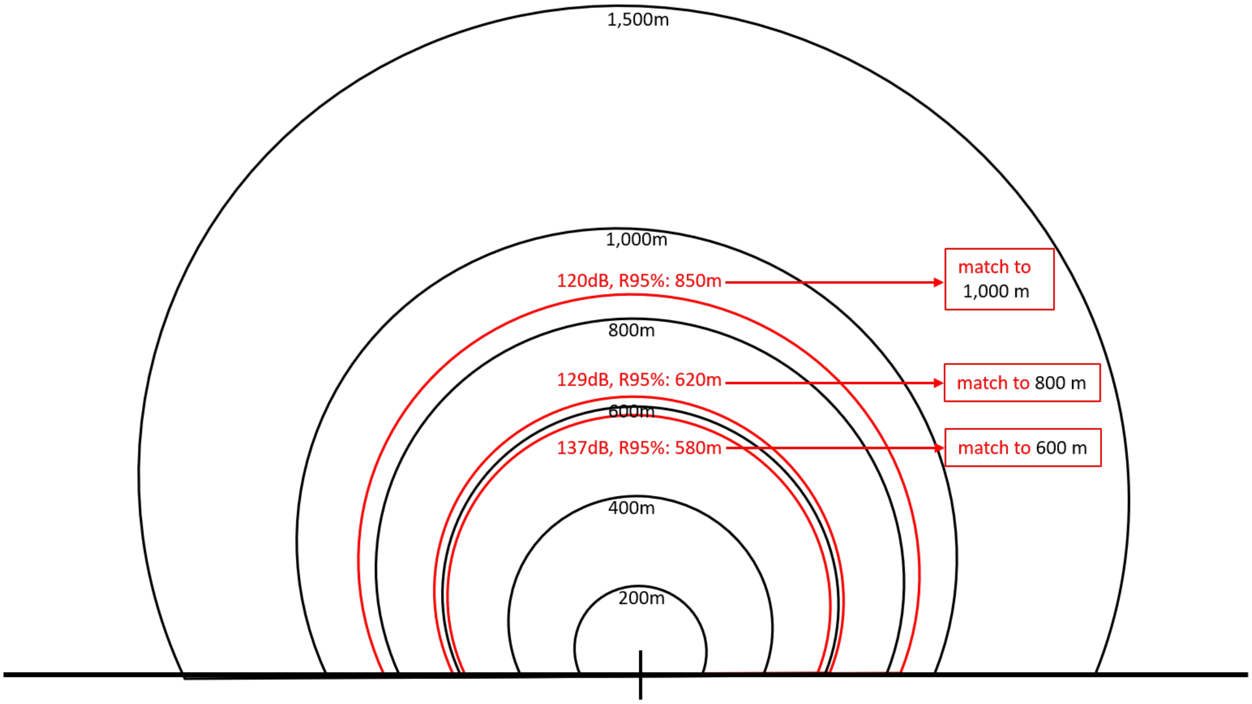


2.3. Quantification of Lost Foraging Time

The estimation of potential lost foraging time is a two-step process. We first estimated the time SRKW travel through acoustic effect zones and subsequently transformed this exposure time to potential lost foraging time by applying the probability of response coefficients described in Section 2.2.2.

A systematic pre-defined set of semi-circular areas centered at the RBT2 terminal were used and prescribed to the most appropriate acoustic effect zones based on threshold radii from final noise modelling results and construction timing (Figure 5). The radii of the systematic pre-defined set of areas ranged from 200 m to 1,000 m (in increments of 200 m), then increasing in increments of 500 m to 4,000 m, followed by increments of 1,000 m to the maximum radius of potential behavioural disturbance effects (19,000 m). This was done to provide a greater resolution in estimated lost foraging time incurred within portions of the acoustic effect zones prior to implementing mitigation measures to quantify their effectiveness.

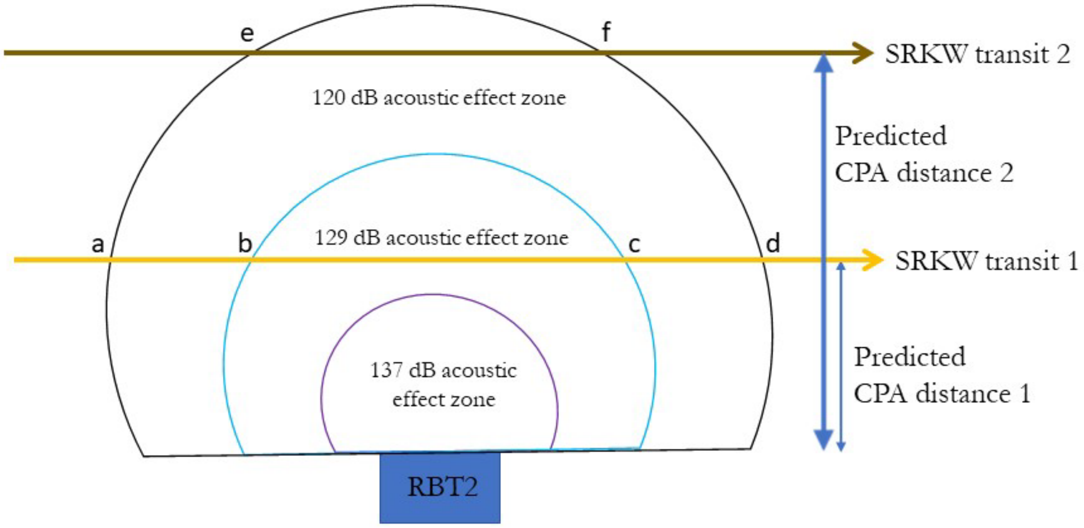
Figure 5. Diagram showing systematic pre-defined set of semi-circular areas centered at the RBT2 terminal (black lines), semi-circular areas derived from acoustic modelling (red lines), and how the former were prescribed to represent the appropriate acoustic effect zones.



The time spent in each zone during each predicted transit was calculated based on the distance through the zone divided by the average speed of a foraging Killer Whale (i.e., 1.6 m/s, Williams and Noren 2009). A graphical depiction of an example is provided in Figure 6. In this example, SRKW transit 1 occurs at predicted CPA distance 1 when construction activities are being undertaken. In this case the transit does not pass through the 137 dB acoustic effect 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 effect zone (i.e., zone radii) based on acoustic thresholds modelled (Li *et al.* 2021). The CPA of each transit is generated as described in Section 2.1.3.

Figure 6. Diagram and table with equations showing how predicted time exposure to underwater noise is calculated based on closest point of approach (CPA) during transits of SRKW in the area affected by underwater noise generated by Project construction activities. Acoustic effect zones are represented by the semi-circles originating from the sound source.

	Distance travelled (m) in each acoustic effect zone		
SRKW transit number	**137 dB**	**129 dB**	**120 dB**
1	0	(distance b to c)/speed	((distance a to b)+(distance c to d))/speed
2	0	0	(distance e to f)/speed



2.3.1. Number of Lost Prey Captures Conversion

The number of lost prey captures was 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 (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 modeling 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. Construction Acoustic Effects

To estimate the potential acoustic effects on SRKW during construction, prior to the implementation of mitigation, we developed an acoustic effects model based on key in-water activities anticipated in the reference concept design schedule described in the Project Construction Update (referred herein as reference concept design schedule; VFPA 2018) and the predicted acoustic effect zones during Project construction using different acoustic scenarios. We first defined the key noise generating activities during Project construction, then developed representative activity scenarios and modelled their acoustic footprints to characterize the predicted acoustic effect zones. We used these as inputs in the acoustic effects model simulating the overlap of transiting SRKW and Project construction noise to estimate acoustic effects on SRKW. We evaluated the effectiveness of mitigation measures for reducing underwater noise and/or interactions and used the acoustic effects model to quantify the effectiveness for reducing potential lost foraging time on SRKW. The following sections describes the methods related to each step of the acoustic effects model.

2.4.1. Reference Concept Design Schedule

To support the modelling of acoustic effects on SRKW throughout the construction period, a schedule of applicable construction activity scenarios (represented by acoustic models) was developed to represent noise variation over time and potential range of acoustic effects on SRKW transiting and feeding through the study area. This process included the following three general steps described in more detail in the following sections:

1. Identification of representative in-water construction activity scenarios;
2. Development of acoustic models representative of the activity scenarios to determine acoustic effect zones; and
3. Development of a schedule of acoustic effect zones corresponding to representative activity scenarios defined based on the reference concept design schedule (i.e., Project Construction Update) for the duration of in-water construction.

2.4.1.1. Representative In-Water Construction Activity Scenarios

The proposed Project requires the construction of a marine terminal, the widening of the Roberts Bank causeway, and the expansion of the existing tug basin. For the EIS, key in-water construction activities and equipment generating underwater noise were identified, modelled, and assessed (Wladichuk *et al.* 2014). Activities included vibratory and impact pile driving, dredging and vibro-densification. A total of 14 construction activity scenarios were modelled for the EIS (Wladichuk *et al.* 2014), focused primarily on single activities and modelled under conservative winter conditions when sound propagates farther (Wladichuk *et al.* 2014). Project design optimization resulted in changes in activities, which were reflected in the Project Construction Update (VFPA 2018). This included the elimination of an intermediate transfer pit near the terminal to store Fraser River sand and the need to dredge and transfer the stored sand to the terminal containment dykes. Sand would instead be pumped ashore directly from the dredge into the containment dykes (VFPA 2018). Pumping ashore was therefore considered in this study as a noise source. For this study, we reviewed the Peak Equipment Analysis completed for the Project Construction Update (VFPA 2018) which provides details on projected equipment use on a monthly basis throughout construction. This information, along with additional assumptions and details from the RBT2 engineering team, was used to identify the anticipated in-water construction schedule for the Project. This schedule reflects the reference concept design schedule described in the Project Construction Update presented at the public hearing.

The following key activities, and associated equipment[1] that generate underwater noise, were identified and assessed as part of this study:

- Vibratory pile or sheetpile installation (vibratory hammer);
- Impact pile or sheetpile driving if required to seat or test piles and sheet piles (impact hammer);

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[1] The actual equipment to be used, e.g., for dredging of the dredge basin and pumping ashore of sand from the Fraser River, may vary depending on equipment availability at the time of construction but noise levels would be expected to be comparable to those assumed during the environmental assessment process based on measurements of equipment available locally.

- Dredging of the dredge basin (encompassing the berth pocket, marine approach areas and caisson trench) (assumed for the study as the cutter suction dredge *Columbia*);
- Material delivery (using tugs and barges) and placement (simply referred to as material placement for the study);
- Pumping ashore of dredgeate from the Fraser River (assumed for the study as the trailing suction hopper dredge FRPD309);
- Vibro-densification of marine sediment and rock mattress in open-water (i.e., excludes densification behind dykes or through the dyke or fill material) including testing the density of the mattress rock using the Becker Penetration Test; and
- Support tugs associated with activities described above.

Several of these activities were found to overlap in general location and time, primarily along the dredge basin. A total of 19 possible distinct activity scenarios were identified representing different activities or activity combinations, when considering seasons, some of which were only anticipated to occur for short periods. In summary, the reference concept design schedule was assumed to range over six calendar years, starting in August of year 1 and ending in March of year 6, for a total of approximately 56 months (~five years of continuous in-water activities, noting that not all years have the same number of months of construction).

2.4.2. Acoustic Models

The study relied on acoustic models representing each construction activity scenario identified. Of the 19 new possible activity scenarios, seven were determined to be suitably represented by either previous acoustic models developed for the EIS (e.g., vibratory pile installation at the tug basin) or, because they occurred for a short period, could be adequately represented by another scenario (i.e., proxy scenario with larger or similar acoustic effect zone). Several new acoustic models were therefore developed to represent anticipated construction noise on a monthly basis considering concurrent activities, season, different impact hammers and potential use of mitigation measures to reduce noise during impact pile driving (e.g., confined bubble curtain) (Li *et al.* 2021) (Table 3, Table 4). Each model was developed collaboratively with acousticians (i.e., JASCO Applied Sciences Ltd., herein referred to as JASCO) and the RBT2 engineering team to be representative of anticipated activity on an average day each month, taking into account assumptions made for the basis of design and professional experience (e.g., number of pieces of equipment likely to be used at a time, representative locations for the equipment, and representative numbers, activities and locations of support and delivery tugs in the construction area) (Li *et al.* 2021).

The acoustic models assumed the zones of injury and behavioural effects to be a semi-circle centered on the berth face of the proposed terminal, with radii R95%. The R95% radii represent the radius of a circle centered at the source that encompasses 95% of the area ensonified above the threshold value (e.g., SRKW behavioural disturbance threshold). However, for several scenarios, the assumption of the acoustic effect zones (i.e., isopleths) being semi-circular was violated. Hence, JASCO provided an

R95% value in two directions: i) perpendicular to the berth face and ii) parallel to the center line running through the berth face. Considering both the parallel R95% and perpendicular R95% independently or the averaged R95% yields similar results. For this study, we used the averaged R95% for each construction activity scenario associated with continuous noise and a range of behavioural disturbance thresholds (Table 3). For impulsive noise scenarios, we considered threshold values for acoustic injury (PTS and TTS) and behavioural disturbance (Table 4).

For each month of the construction schedule, at least one applicable acoustic model (i.e., construction activity scenario) was selected to be representative of the anticipated level of activity during that month. The acoustic model(s) representing the activity scenario(s) that month, or best available proxy, was selected for each month to predict acoustic effects of in-water construction.

The selection of the most applicable acoustic model for each month of the construction schedule also considered time of year (i.e., seasonality), time of day (day or night) and duration of activities. The applicability of winter and summer acoustic models was extrapolated to other months (SMRU 2014c). Winter acoustic models were assumed to apply from November to March (i.e., five "winter" months each year) while the summer models were applied from April to October (i.e., seven months of "summer" each year). Duration of activities (i.e., the number of hours per day) was informed by professional advice and experience from the RBT2 engineering team. The following construction activity assumptions were made under the reference concept design schedule:

- Vibratory and impact pile installation occurs in daytime only (as per the port authority's Commitments #33 and 38 (VFPA 2019)) using one hammer (vibratory or impact) at a time. Because of their higher sound levels, these scenarios were selected during periods of pile installation. The majority of pile installation hours is vibratory. For the environmental assessment, the port authority had not estimated the amount of impact piling anticipated to be required. For the reference concept design schedule in this study, we conservatively assumed that some impact pile driving would occur for all pile installation activities and assumed the following installation hours on a given pile installation day based on a maximum of 10 hours of daytime available and considering set-up time required outside active installation:
    - Temporary barge ramps piles: vibratory: 7 hours, impact: 1 hour;
    - Closure dykes sheet piles: vibratory: 6 hours, impact: 1 hour; and
    - Mooring dolphin piles: vibratory: 5 hours, impact: 2 hours.
- Vibratory pile removal of temporary piles is assumed to generate the same noise levels as vibratory installation (i.e., same acoustic models used) and to occur for approximately 8 hours per removal day.

- For months when intermittent pile installation occurs, other activity scenario(s) are included outside pile installation activities, where applicable, to represent underwater noise occurring for the remaining portion of the month.
- Dredging occurs 24 hours per day, seven days per week using one dredger[2] (i.e., *Columbia* or similar for this study) for the duration of dredging.
- Vibro-densification will take place during the daytime using six vibratory heads operating simultaneously in close proximity. Although vibro-densification is anticipated to occur six days per week, for simplicity, it was assumed to take place seven days a week.
- Different daytime and nighttime scenarios were used during months with vibro-densification to reflect that vibro-densification is generally expected to occur for about 10 hrs a day.
- Pumping ashore will be a regular activity occurring during day and night but not occurring continuously (i.e., three to four trips per day, ~2 hours of pumping per trip for 6-8 hours per day). However, for simplicity, it was assumed to take place continuously.
- Only a portion of the sheet pile installation will occur in direct contact with water because the majority of the sheet pile wall will be embedded within the closure dykes; thus, noise is anticipated to be largely attenuated by the dyke material. However, to be conservative, noise levels from sheet pile installation (impact and vibratory) of the sheet pile walls, which have some contact with water, were assumed to be the same as for pile installation.
- Pile installation in the tug basin was excluded from this analysis since the zone of potential acoustic effects does not extend in an area with SRKW transits, based on EIS acoustic modelling (Wladichuk *et al.* 2014).

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[2] This was deemed reasonable by the port authority as there would be little space to add other dredging equipment.

Table 3. R95% radii (m) for selected behavioural (SPL) effect threshold values for in-water construction activity scenarios associated with continuous noise.

Scenario ID	Acoustic Model / Construction Activity Scenario	Season	Number of tugs	120 dB	129 dB	137 dB
1	Vibratory pile installation at terminal	Summer	0	7,253	1,651	627
3A	Material placement	Summer	4	850	620	580
3B	Material placement	Winter	4	980	650	580
4	Dredging with Columbia	Summer	2	1,300	670	520
5	Dredging and pumping ashore combo	Summer	4	2,680	940	690
6	Pumping ashore	Winter	4	3,810	1,110	640
7A	Pumping ashore and vibro-densification	Winter	4	6,410	1,910	940
7B	Pumping ashore and vibro-densification	Summer	7	4,090	1,530	780
8A	Dredging, pumping ashore and vibro-densification	Summer	0	4,100	1,520	770
8B	Dredging, pumping ashore, vibro-densification, and high tug activity	Summer	7	4,360	1,540	780

Table 4. **R95% radii (m) for selected threshold values for in-water construction activity scenarios associated with impulsive noise (i.e., for impact pile driving (assumed for EIS) and for pile driving analyzer (PDA) testing) without and with sound dampening technology. Unweighted peak (PK_{PTS} and PK_{TTS}) pressure level and sound exposure level (SEL_{PTS} and SEL_{TTS}) refer to radii of injury acoustic zones, and 160 dB refers to radius of behavioural response acoustic zones. A dash "–" indicates that the threshold was not reached.**

Scenario ID	Acoustic Model / Construction Activity Scenario	Season	PK_{PTS}	PK_{TTS}	SEL[1]$_{PTS}$[2]	SEL_{TTS}[3]	160 dB
2A	Impact pile driving without sound dampening technology	Summer	< 10	< 10	38	331	993
2B	Impact pile driving with sound dampening technology	Summer	–	< 10	–	72	324
2C	PDA test – moderate[4] size hammer without sound dampening	Summer	< 10	< 10	–	11	1,395
2D	PDA test – moderate size hammer with sound dampening technology	Summer	–	< 10	–	–	396
2G	PDA test – large size hammer without sound dampening technology	Summer	< 10	< 10	–	19	1,743
2H	PDA test – large size hammer with sound dampening technology	Summer	< 10	< 10	–	–	474

[1] Sound Exposure Levels (SEL) were calculated over 100 minutes of exposure for scenarios 2A and 2B and for 17 hammer strikes (i.e., 15 strikes + 15% contingency for added conservatism) for scenarios 2C, 2D, 2G and 2H as durations anticipated over a 24-hour period.

[2] PTS: Permanent Threshold Shift

[3] TTS: Temporary Threshold Shift

[4] The barge ramps and mooring dolphin PDA tests are anticipated to require a 185 kJ and 6,200 kg (moderate) and 300 kJ and 10,000 kg (large) hammers, respectively

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 medians, with 95% confidence intervals.

Here, we describe the pseudo-code implemented to calculate potential lost foraging time. For each of the 89.2 SRKW transits per year (Table 1), and for the approximately 56 months of the reference concept design schedule, we:

1) Randomly chose a CPA, proportional to the relative density of SRKW in Figure 3.
2) Randomly chose a SRKW pod/assemblage, proportional to the seasonal occurrence presented in Table 2.
3) Randomly chose a construction activity scenario, proportional to the number of hours and days each construction activity is planned to occur per month and period (i.e., day or night). We ensured that all construction scenarios were included at least once when it is planned to occur in a month. This precaution was taken to ensure that pile installation was included in the simulation (given that its planned total time is low compared to other scenarios).
4) Designated acoustic effect zones, based on the size of the acoustic footprints of construction activities (see Figure 5). To do this, we matched the R95% for 120 dB, 129 dB, and 137 dB behavioural response effect thresholds (for continuous noise sources, Figure 4), or 160 dB, SEL_{PTS}, and SEL_{TTS} effects thresholds (for pulse noise sources) of the corresponding construction activity scenario with a systematic pre-defined set of semi-circular areas centered at the RBT2 terminal. The R95% radii represent the radius of a circle centered at the source that encompasses 95% of the area ensonified above the threshold value. In cases where the R95% radius falls between two predetermined radii, the R95% was conservatively matched to the higher radius (e.g., if R95% was 370 m, it falls between the 200 m and 400 m predetermined radii, and was thus matched to 400 m, as shown on Figure 5).
5) Calculated the distance of each SRKW transit within each of the acoustic effect zones.
6) Converted the distance travelled within the relevant acoustic effect zones to potential lost foraging time and potential lost prey capture.
7) Repeated steps 1 to 6, 10,000 times.
8) Calculated the median and 95% confidence intervals of potential lost foraging time and potential lost prey capture over the 10,000 Monte Carlo iterations.

2.4.4. Mitigation Evaluation

We examined three mitigation measures and strategies, designed to reduce construction noise effects on SRKW. The measures are to: 1) refine the timing of in-water activities to avoid the noisiest construction activities during the SRKW peak use period, 2) implement sound dampening technology during impact piling, and 3) adopt stop work procedures before SRKW enter activity specific exclusion zones. We evaluated the effectiveness of different detection methods, specifically marine mammal observers (MMO), passive acoustic monitoring (PAM) system, and the combination of MMOs and PAM system considering the estimated size of the activity specific exclusion zones and time required for construction activities and associated equipment to shutdown.

2.4.4.1. Construction Timing Refinements

For this study, the reference concept design schedule (based on the Project Construction Update) was developed considering timing and duration of activities as described above (Section 2.4.1.1). Acoustic effects model results were then examined to identify periods and construction activities contributing disproportionately to the total potential lost foraging time. The time period from June 1 to September 30 was identified as a key period to reduce acoustic effects to SRKW given their peak use of the area (Figure 1, Figure 2). Pile installation activities and combined or concurrent activities including vibro-densification (Construction Activity scenario 8B; Table 3) planned in the summer were identified as having large potential acoustic effect zones and therefore contributed a large proportion of the total estimated potential lost foraging time for the modelled reference concept design schedule . Opportunities to avoid or reduce construction activities during the SRKW peak use period were examined by the RBT2 engineering team (Moffatt and Nichol 2021). This included revisiting assumptions around the requirements for impact piling to further reduce impact pile driving and avoid potential risks of acoustic injury.

Two modified reference concept design construction schedules (Option 1 and Option 2) were developed and evaluated to reduce effects on SRKW. The modified schedules are described in more detail in Moffatt and Nichol (2021). Table 5 shows the differences between the modified schedules and the reference concept design schedule. Under both modified schedules, the following construction activities are avoided from June 1 or the date when SRKW are confirmed to be present in the Salish Sea, whichever is later[3], to September 30:

- All vibratory and impact pile driving;
- Vibro-densification of the caisson foundation mattress rock; and
- Removal of the piles for the temporary barge ramps (using vibratory methods).

A key difference in the modified schedules compared to the reference concept design schedule is that both Options 1 and 2 plan barge ramp pile installation to avoid the SRKW peak use period (i.e., planned for some time between October 1 and February 29) (Table 5). For this study, to be precautionary, barge ramp installation was modelled during the month of October (when potential

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[3] If SRKW are not present in the Salish Sea by June 1, the activities could continue until the date that SRKW are confirmed present in the Salish Sea by hydrophone data or ECHO Program marine mammal observers (or equivalent).

SRKW presence is highest between October 1 and February 29) to assess the worst-case scenario for both year 1 and 2. For Options 1 and 2, barge ramp pile removal was also assumed to occur in October of year 6 instead of October of year 5 under the reference concept design schedule, thus coinciding with other concurrent in-water activities). These minor changes in timing resulted in modelling two additional months of in-water construction activities for the modified schedules compared to the reference concept design schedule.

The two modified reference concept design schedule options also differ from each other in their timing of vibro-densification and dredging. To construct the terminal wharf structure, the berth pocket must first be dredged. Caisson foundation mattress rock must then be placed sequentially in the dredged area and vibro-densified prior to placing the caissons to form the berth face. Table 5 presents the differences in the predicted timing of dredging and vibro-densification between the two modified schedules and the reference concept design schedule (i.e., based on the Project Construction Update). In summary, for Option 1, the overlap between the SRKW peak use period and dredging the dredge basin in construction year 3 could be reduced by approximately 2 months (avoiding August and September) if the year 2 six months dredging season continued for an additional 1.5 months (from October 15 to November 30). The extended dredging period coincides with the first 6 weeks of the Dungeness crab fisheries-sensitive window (October 15 – March 31) (Commitment #49; VFPA 2019). In Option 2, dredging would not extend into the Dungeness crab fisheries-sensitive window in year 2.

Table 5. Summary of the different assumptions, for this study, in the timing of barge ramp pile installation, dredging of the dredge basin, and vibro-densification of the caisson foundation mattress rock for the two modified reference concept design schedule options and the reference concept design schedule (based on the Project Construction Update)[1].

In-water Construction Activity	Construction Schedule		
	Option 1	Option 2	Reference concept design
Barge ramp pile installation	Year 1: barge ramp 1 and 2 pile installation in January[2] (2-3 weeks) Year 2: barge ramp 3 pile installation in October (2-3 weeks)	Year 1: barge ramp 1 and 2 pile installation in January[2] (2-3 weeks) Year 2: barge ramp 3 pile installation in October (2-3 weeks)	Year 1: barge ramp 1 and 2 pile installation in August to September (2-3 weeks) Year 2: barge ramp 3 pile installation in August (2-3 week)
Dredging	Year 2: dredge from April to end of November (8 months) Year 3: dredge from April to July (4 months)	Year 2: dredge from April to October 15[3,4] (6.5 months) Year 3: dredge from April to October 15[23,4] (6.5 months)	Year 2: dredge from April to October 15[3,4] (6.5 months) Year 3: dredge from April to October 15[3,4] (6.5 months)
Vibro-densification	Period 1: October of Year 2 to May of Year 3 (8 months) Period 2: October of Year 3 to January of Year 4 (4 months)	Period 1: mid-December of Year 2 to May of Year 3 (5.5 months) Period 2: October of Year 3 to mid-April of Year 4 (6.5 months)	Year 3: January to December (12 months)

[1] The in-water construction schedules presented in this table are based on a preliminary reference concept design (up to 30% complete). The preliminary design components and construction means and methods was developed for the environmental assessment and are not intended to provide definitive descriptions of how the project will be constructed.

[2] Activity was conservatively modelled in October considering potential higher acoustic effects compared to other months between October and

[3] Dredging ends prior to the Dungeness crab fisheries-sensitive window (October 15 to March 31) (Commitment #49 (VFPA 2019))

[4] Duration of dredging includes timing and duration of mattress rock production, delivery and installation in light of shorter initial dredging time period.

In addition to identifying these timing modifications (Moffatt and Nichol 2021), the assumptions around the duration of impact and vibratory pile installation (number of days and hours per day) were also refined. It was determined that the use of an impact hammer (impulsive noise) could be reduced to one pile per barge ramp and one pile at the mooring dolphin (~4 piles in total) for engineering testing of the axial (vertical) capacity of the piles using Pile Driving Analyzer (PDA) (Moffatt and Nichol 2021). PDA tests the piles to confirm infrastructure stability and safety. These tests require larger hammers than what is typically required for impact pile installation and assumed for the reference concept design schedule. However, PDA testing only requires a few strikes, as such the activity takes less time. For this study, for both modified schedule options, we conservatively assumed that each PDA test for the barge ramps would occur over approximately 2 hours (even though the ~15 hammer strikes are anticipated to be completed within a shorter time frame of ~15 minutes of active impact hammer for each test) and the tests would occur on separate days (i.e., one pile per day). For vibratory piling, it was assumed that installation would occur for 3 hours per day instead of 7 hours a day as previously assumed for the reference concept design schedule. For this study, further refinements identified by Moffatt and Nichol (2021)[4] indicated that impact piling is no longer anticipated to be required to install sheet piles as previously assumed under the reference concept design schedule. Therefore, this activity was removed when modelling the modified schedules (i.e., Option 1 and Option 2). For the mooring dolphin steel piles, for both modified schedules, we conservatively assumed the same impact piling duration and number of piles as the reference concept design schedule. This overestimated the potential acoustic injury from impact piling as it does not reflect the refinements identified by Moffatt and Nichol (2021)[5] to limit impact piling to PDA testing one pile to install the mooring dolphin.

As described for the reference concept design schedule, construction activity scenarios and associated acoustic models were assigned to reflect the two modified schedule options. The SRKW acoustic effects model quantified the estimated change in potential lost foraging time (relative to the reference concept design schedule) and compared the potential reductions in lost foraging time from the modified schedules (i.e., Option 1 and Option 2) to identify a preferred schedule to use to further evaluate the effectiveness of other mitigation strategies.

2.4.4.2. Sound Dampening Technology for Impact Pile Installation

A sound dampening or technology, or a combination of technologies, if necessary, will be implemented to ensure the Project does not exceed the SRKW permanent acoustic injury thresholds and other relevant acoustic thresholds, as previously committed to by the port authority (Commitment #37, VFPA 2019). Various technologies exist that can effectively attenuate sound from impact pile driving (reviewed in e.g., Martin *et al.* 2012, Koschinski and Ludemann 2015, Weilgart 2019). Underwater noise reductions of at least 10–15 dB (SEL) at 10 m could be achieved by methods or technologies deemed feasible for the Project. These include: confined bubble curtains (4-15 dB, Martin *et al.* 2012, Koschinski and Ludemann 2013), isolation casings (up to ~15-25 dB; Spence *et al.* 2007, Saleem 2011), and double-walled piles (17-18 dB, CSA Ocean Sciences Inc. 2014, MCT 2020). These measures can inhibit sound transmission through water due to density mismatch and concomitant reflection and absorption of sound waves (Würsig *et al.* 2000).

JASCO developed acoustic models representative of sound dampening during impact pile driving. The acoustic models assumed the use of a confined bubble curtain (acoustic model scenarios 2B, 2D, and 2H in Table 4), as a representative example of the low to mid-range of noise reduction effectiveness (i.e., a 10 dB reduction in SEL) that could be achieved by sound dampening technologies to be implemented by the contractor to reduce underwater noise and meet relevant acoustic

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[4] The port authority has confirmed that all the sheet piles for the closure dykes and the vast majority of the 59 steel pipe piles will be driven using only a vibratory hammer and anticipates that impact piling will only be required for testing pile capacity (PDA tests) of 1 of the 6 mooring dolphin piles and 3 of the 24 piles required for the three temporary barge ramps for a total of ~4 piles (Moffatt and Nichol 2021).

[5] Table 1 of Moffatt and Nichol (2021) presents a summary of vibratory and impact pile installation activities anticipated at the RBT2 terminal and tug basin locations, including approximate number of piles, number of hours per installation day and number of installation days.

thresholds. To examine the effectiveness of this mitigation measure for acoustic injury, we selected the scenarios with the largest potential acoustic injury zones, which was the impact piling acoustic model scenario based on EIS assumptions (scenario 2A and 2B; Table 4). To evaluate the effectiveness of sound dampening technology, we replaced the acoustic model for pile driving without sound dampening (acoustic model scenario 2A, Table 4) in the reference concept design schedule with the acoustic model of pile driving with a confined bubble curtain (scenario 2B), which is anticipated to reduce the radius of the predicted acoustic effect zone for injury (by 100% from 38 m to 0 m for PTS and by 78% from 331 to 72 m for TTS), and recalculated the likelihood of acoustic injury.

The use of a confined bubble curtain would also reduce the behavioural disturbance zone for all the impact hammer scenarios modelled (Table 4; e.g., for scenario 2A, the behavioural disturbance zone would be reduced by 67% from 993 m to 324 m). However, this mitigation measure was conservatively assumed not to be in place when estimating behavioural disturbance effects and the effectiveness of other mitigation measures.

2.4.4.3. Monitoring for SRKW and Associated Shutdowns

Marine Mammal Observers

Monitoring by marine mammal observers (MMO) to detect marine mammals and avoid or reduce acoustic effects from in-water activities is a standard mitigation strategy for construction. During the public hearing, the port authority committed to have a MMO (during the period from May 1 to October 31) or an Officer of the Bridge (during the period from November 1 to April 30) dedicated to detect the presence of SRKWs (Commitment #33, VFPA 2019). To further reduce potential effects to SRKW, this analysis assumed that MMOs will be employed year-round for the duration of in-water works near the works and activities, and that construction activities will be halted or modified as soon as a SRKW is detected within applicable exclusion zones. Detection effectiveness could vary depending on several factors including the number and position (e.g., height) of the MMOs, optical equipment used and weather conditions. Naturally, the probability that a SRKW will be detected by MMOs is a decreasing function of the distance from the observer, in this case at the terminal, and this function will be affected by visibility conditions. Barlow (2015) provides information on Killer Whale detection functions (i.e., the probability of sighting an animal depending on its distance from a survey track line) for line transect surveys. Distance sampling line-transect surveys (Buckland *et al.* 2001) are commonly used to estimate cetacean abundance. Key parameters that are usually reported under this framework include the probability of detecting animals on the transect line (known as g_0) and the effective strip width (ESW) which is a metric of the distance from the transect line to which animals are detected.

The probability of detection at 0 km (g_0) was shown to vary by sea state by Barlow (2015). For this study, we used Killer Whale specific data from Table 3 of Barlow (2015). In perfect calm conditions (i.e., Beaufort scale[6] 1), this value is 1 or 100% chance of a sighting. On average, between

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[6] The Beaufort scale is an empirical measure that relates wind speed to observed conditions at sea.

Beaufort state 0 and 3, SRKW detection probability at zero distance (g_0) was 0.948 (or ~95%; Table 6). Detection probability was reduced to 0.491 (or 49%) for Beaufort states between 4 and 6, corresponding to wind conditions of 20-50 km/h (Table 6). The ESW is the distance where as many animals are detected at a distance greater than ESW (but less than the maximum detection distance) as are missed between the terminal and the ESW (Buckland *et al.* 2001) (see Figure 5.3 in Buckland *et al.* 2015). Barlow (2015) reported Beaufort state specific ESW for Killer Whale surveys. We binned weather conditions in three categories: good (Beaufort state 0 to 3), regular (Beaufort state 4 to 6), and bad (Beaufort state higher than 6), and obtained the average ESW by weather condition from Table 2 in Barlow (2015). There are no published data for sightings probabilities or ESW at Beaufort states higher than 6; however, given data from Barlow (2015), we assumed a linear reduction from Beaufort state 4 through 6, and developed an average estimate for Beaufort 7-8, resulting in an estimate of $g_0 = 0.22$ and ESW = 2.09 km (Table 6).

Table 6. Detection probability at 0 km (g_0), and mean effective strip width, under differing Beaufort states.

Beaufort State	Weather condition	Mean g_0	Mean effective strip width (ESW) km
0 to 3	Good	0.948	4.45
4 to 6	Regular	0.491	3.16
> 6	Bad	0.22	2.09

Project-specific SRKW Detection Probability Functions

For this study, we calculated the detection probability as a decreasing sigmoidal function of distance from the terminal as:

$$p_{detection} = \frac{g_0}{1 + e^{k(x - x_0)}}$$

where g_0 is the detection probability at 0 km reported by Barlow (2015) (Table 6), k is the rate of decrease of the probability of detection with distance from the terminal, x is the perpendicular distance from RBT2, and x_0 is the distance from the terminal at which the probability is reduced by 50% (based on the ESW reported by Barlow (2015); Table 6). We chose a value of k (0.002) that would yield smooth curves that are characteristic of detection functions for Killer Whales (e.g., Zerbini *et al.* 2007).

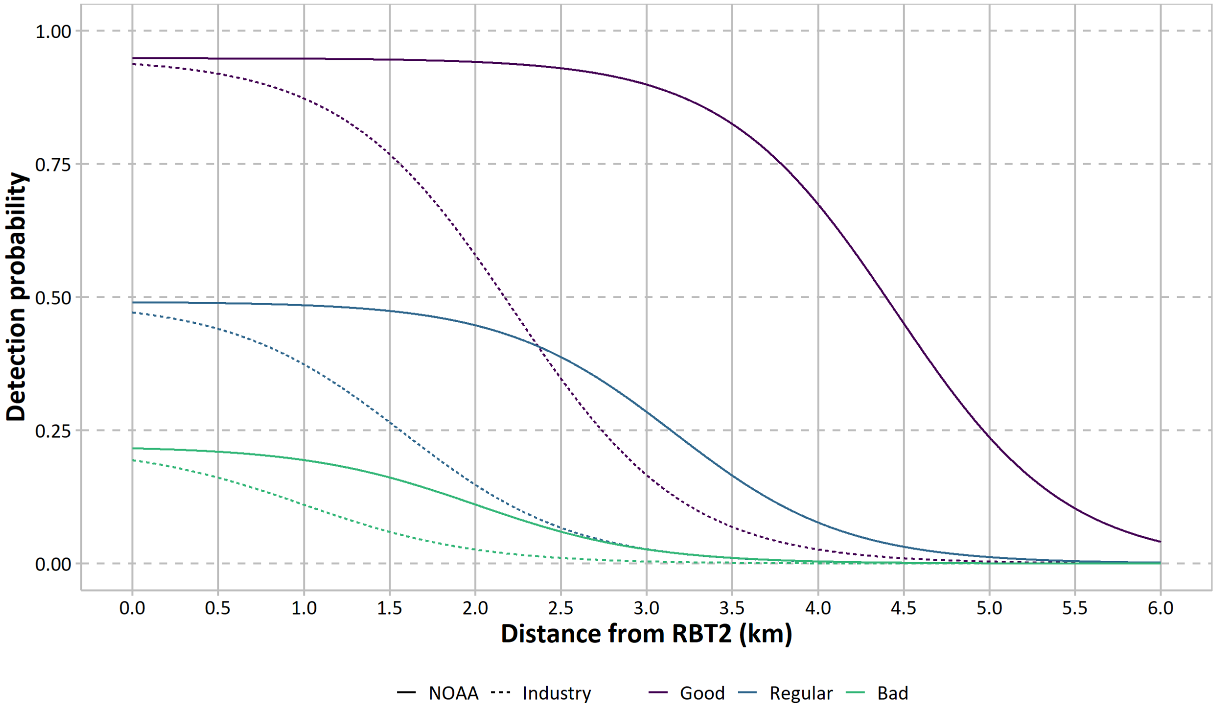
We assessed the effectiveness of two MMO mitigation strategies (i.e., detection method coupled with construction activity shutdowns): 1) typical MMO effort based on industry practices for construction monitoring (hereafter referred to as MMO Industry protocols) and 2) enhanced MMO effort assuming NOAA vessel survey protocols (hereafter referred to as MMO NOAA protocols). The scenario that includes only MMO Industry protocols can be viewed as a lower bound for mitigation effectiveness but is above what was initially proposed at the public hearing. For the MMO NOAA protocols, we used the values of parameters provided by Barlow (2015), which were obtained using state-of-the-art MMO methodology, which consists of experienced field technicians searching from the bridge deck of a research vessel (10 m above sea level) using two pedestal-mounted 25X binoculars (big-eyes) from port and starboard observation stations while a third observer searches with unaided eyes (and, occasionally, 7X binoculars) from a center observation and data recording station (Kinzey *et al*. 2000, Barlow 2016). For the Industry protocols, we assumed that the MMOs would be located at the center of the semi-circular acoustic effect zone but would consist of different level of effort (number of observers) or use of technologies (i.e., no big-eyes). This will likely not impact the detection probability at 0 km (g_0), but rather the distance from the terminal at which the probability is reduced by 50%, and therefore we assumed x_0 for the Industry protocols to be half the effective strip width reported by Barlow (2015).

Recognizing that sea-state conditions influence detectability, we developed detection probability curves for 3 different weather conditions. We defined weather conditions based on average wind speed and minimum visibility due to the occurrence of fog:

- Good weather: mean wind speed is less than 18.5 km/hr (Beaufort scale 0-3);
- Regular weather: mean wind speed is between 18.5 and 50 km/hr (Beaufort scale 4-6); and
- Bad weather: mean wind speed is more than 50 km/hr, or minimum visibility is less than 1,000 m.

The resulting detection probability curves are presented in Figure 7, for both MMO mitigation strategies and the three different Beaufort states.

Figure 7. Probability of detecting SRKW following Industry (dotted line) and NOAA protocols (full line) for MMOs, as a function of perpendicular distance from RBT2 in three weather conditions.



MMO Mitigation Effectiveness

We applied the weather-specific detection functions to each SRKW surfacing available to be detected by MMOs. To achieve this, we calculated the number of times a SRKW is predicted to surface along a transit within a radial distance of 6 km from the MMO (i.e., the maximum anticipated detection distance based on Figure 6), assigned the proportion of those surfacings that would be available to be detected based on distance from the MMO, and probabilistically assigned a weather condition to each transit using weather data for the Vancouver area during the last 8 years (ECCC 2020).

To assign weather conditions over the anticipated scheduled construction, we obtained weather data for the Vancouver area from May 2013 to March 2020 from the Canada Weather Stats website (ECCC 2020, https://www.weatherstats.ca/) with good, regular and bad weather conditions as defined above, where we randomly assigned the foggy days to days with either good or regular weather, thus changing its definition to bad weather. We then randomly assigned a weather condition to each SRKW transit, proportional to the proportions depicted in Figure 8.

We calculated the number of times a SRKW would surface along the transit considering their mean swimming speed (1.6 m/s; Williams and Noren 2009) and dive durations based on 30 tagged fish-eating Killer Whales (Northern Resident Killer Whales; Wright *et al.* 2017). We assumed that in each transit (in each Monte Carlo iteration), whales surfaced at a distance of 6 km radial distance from the MMO, and then calculated the position of the next surfacing by multiplying the mean swimming speed of Killer Whales by a dive duration randomly drawn from the distribution of dive durations data from Northern Resident Killer Whales (data provided by B. Wright (DFO, Pacific Biological Station) (Figure 9). Median number of surfacings along the transit, within a radial distance of 6 km, varied from 1 to 212, depending on the perpendicular distance from the RBT2 terminal at which the simulated transits occurred (Figure 10). Given the dynamics of the transiting SRKWs and that of MMOs, only a proportion of surfacings will be available to be detected (i.e., taking into account that MMOs are sweeping the area for SRKW and may be delayed in intersecting a transiting SRKW). Given the typical scanning rate for an area represented by 180-degrees and up to 6 km from land, it would take about 10 minutes to cover the monitoring area. Hence, we assumed that 10% of the surfacings that occur at radial distances larger than 2 km would be available to be detected, whereas a larger proportion (25%) would be available at radial distances smaller than 2 km. The probability that each SRKW available surfacing will be detected ($p_{detection}$) was calculated, given its radial distance from the MMOs, and weather condition. For each transit, we drew a random number from a binomial distribution with probability of success equal to $p_{detection}$.

We also interviewed five experienced MMOs (with experience in Killer Whale sightings) to obtain their professional opinion on the proportion of SRKW transits that they would be able to detect under different weather conditions, given use of powerful binoculars and a raised viewing platform (i.e., similar to NOAA protocols). All interviewees consistently responded that they would be able to detect ~50% of SRKW transits under bad weather conditions, and between 95% and 100% of SRKW transits under good weather conditions. In the Monte Carlo simulation, the percentage of available transits to be detected by MMOs (i.e., daytime transits that occur within a radial distance of 6 km of the berth face of the RBT2 terminal) varied by MMO strategy and weather conditions between ~40% (MMO Industry protocols) and ~60% (MMO NOAA protocols) for bad weather conditions, and ~90% (MMO Industry protocols) and 99% (MMO NOAA protocols) for good weather conditions. These detection rates are consistent with expected rates from the MMO expert elicitation.

To evaluate the effectiveness of each MMO mitigation strategy, we assumed that once a SRKW transit is detected, in-water construction activity would be immediately halted or modified to prevent or reduce adverse acoustic exposure to SRKW. This implies that during the section of the transit that occurs prior to MMO detection the SRKW would be impacted by construction noise, and the potential lost foraging time during the later section of the transit (i.e., after being detected) would be reduced to zero. The proportion of transits that are detected by MMOs decreases with distance from the berth face of the RBT2 terminal. Thus, we assumed that the majority of transits that occur close to the terminal (i.e., location of the observer) would be detected before they reach the perpendicular, whereas transits that occur further from the terminal would have a higher likelihood of transiting a longer trajectory prior to being detected (Figure 11, Figure 12).

Figure 8. Mean proportion of days by month (May 2013 to March 2020) with good, regular, and bad weather conditions.

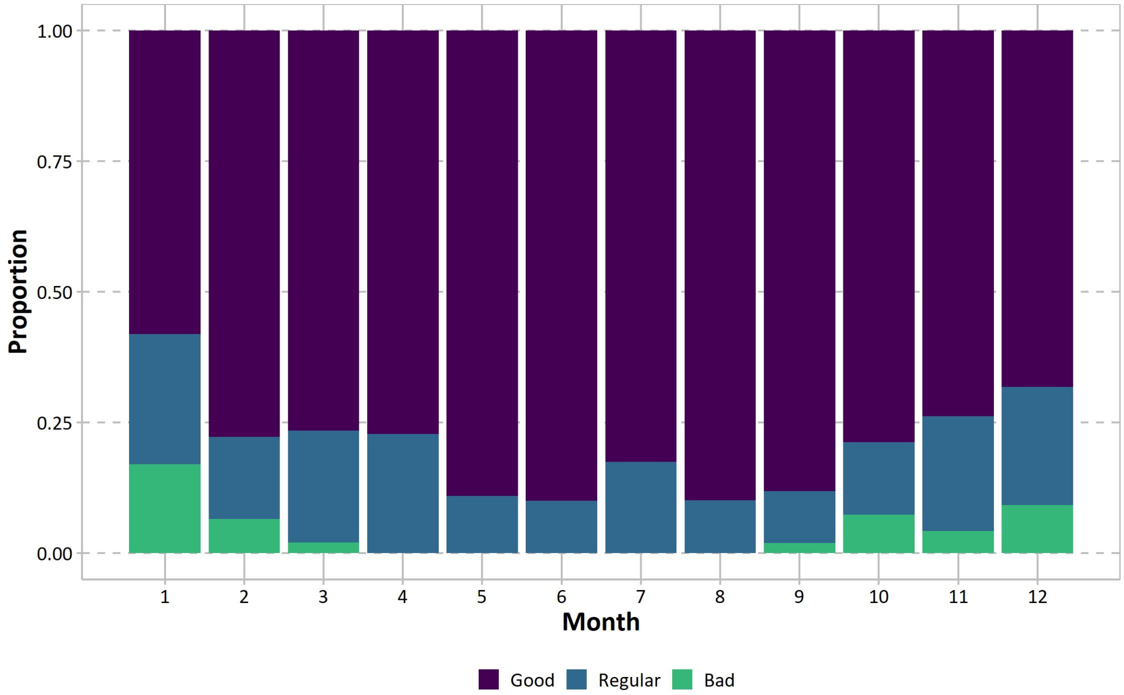
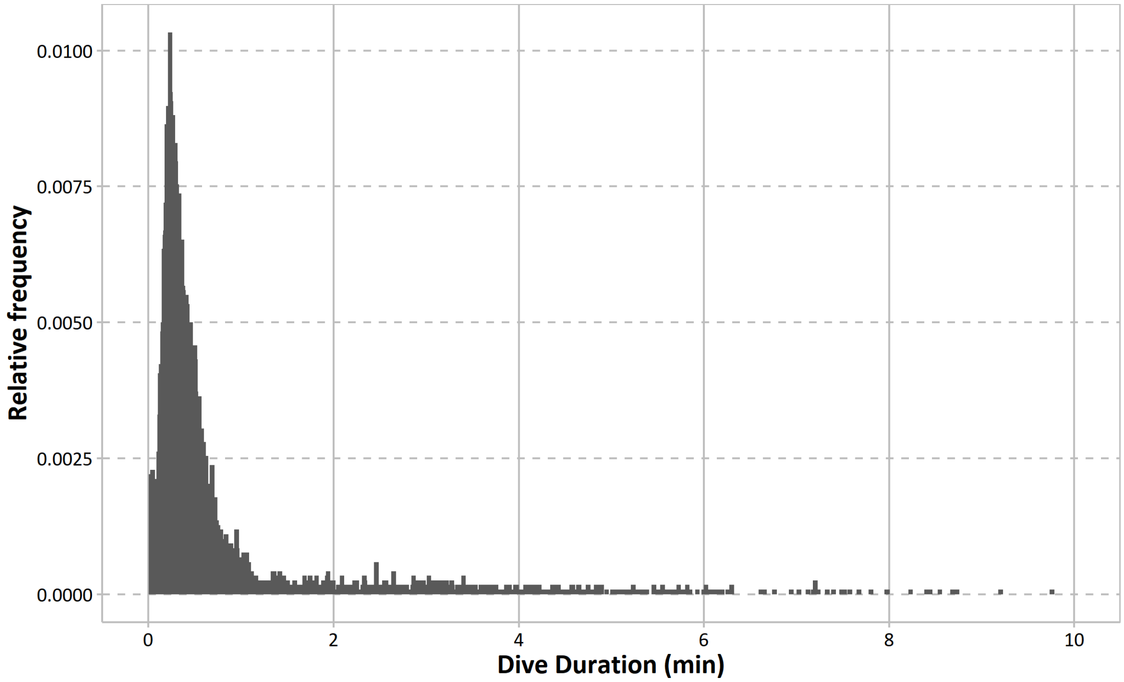


Figure 9. Relative frequency of dive durations of 30 tagged Northern Resident Killer Whales. Data presented in Figure 3 of Wright *et al.* (2017).



Data courtesy of B. Wright (DFO, Pacific Biological Station)

Figure 10. Number of anticipated SRKW surfacings for a single SRKW transit within a radial distance of 6 km, as a function of perpendicular distance from the RBT2 terminal. The line represents the median distance, and the shaded area represents the minimum and maximum number of expected surfacings.

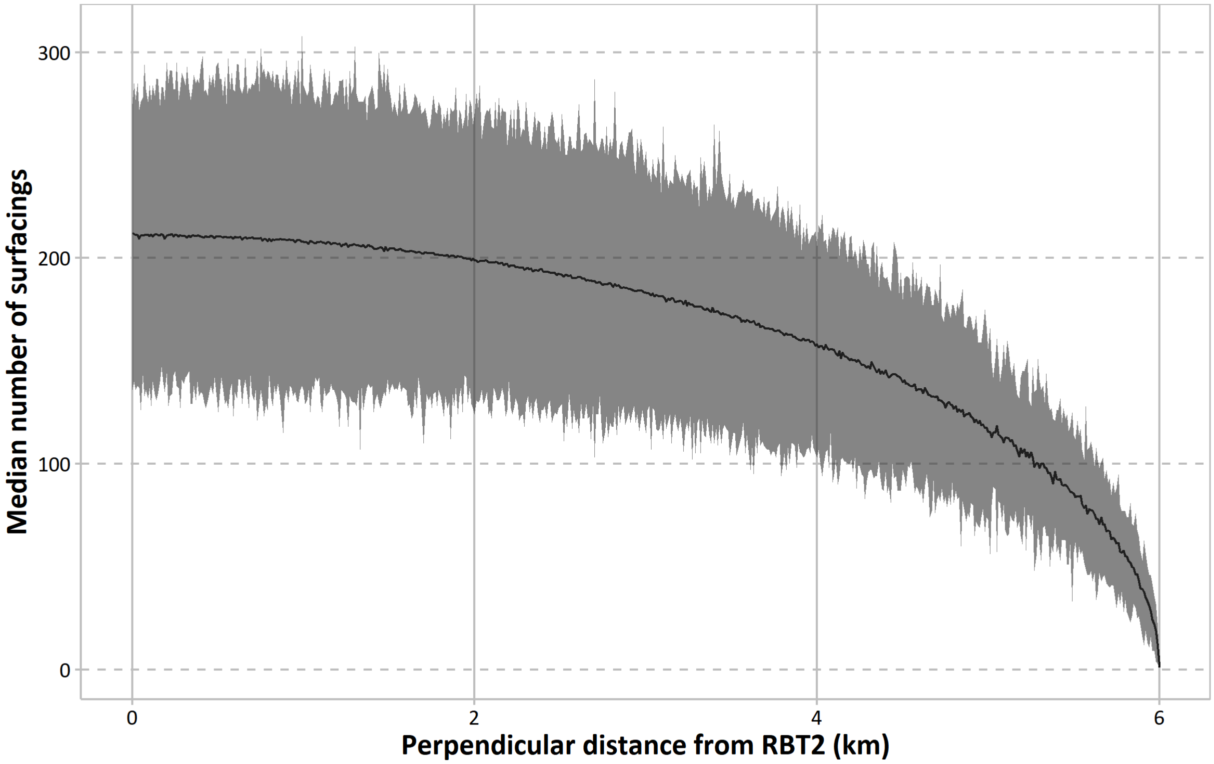


Figure 11. **Positions of SRKW transit detections applying the MMO Industry protocols (N Monte Carlo simulations: 10,000), as a function of perpendicular distance, and distance along the RBT2 terminal. The solid line represents the direction of the transits, and the shading represents the density of points.**

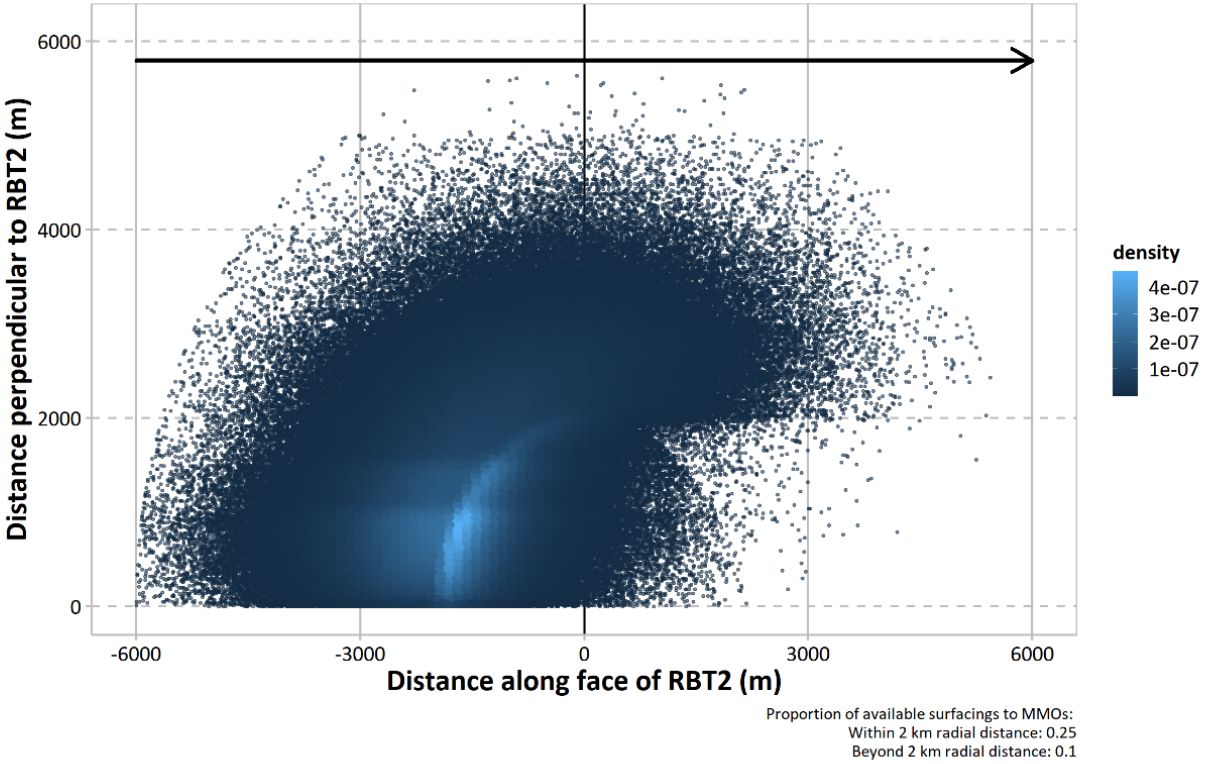
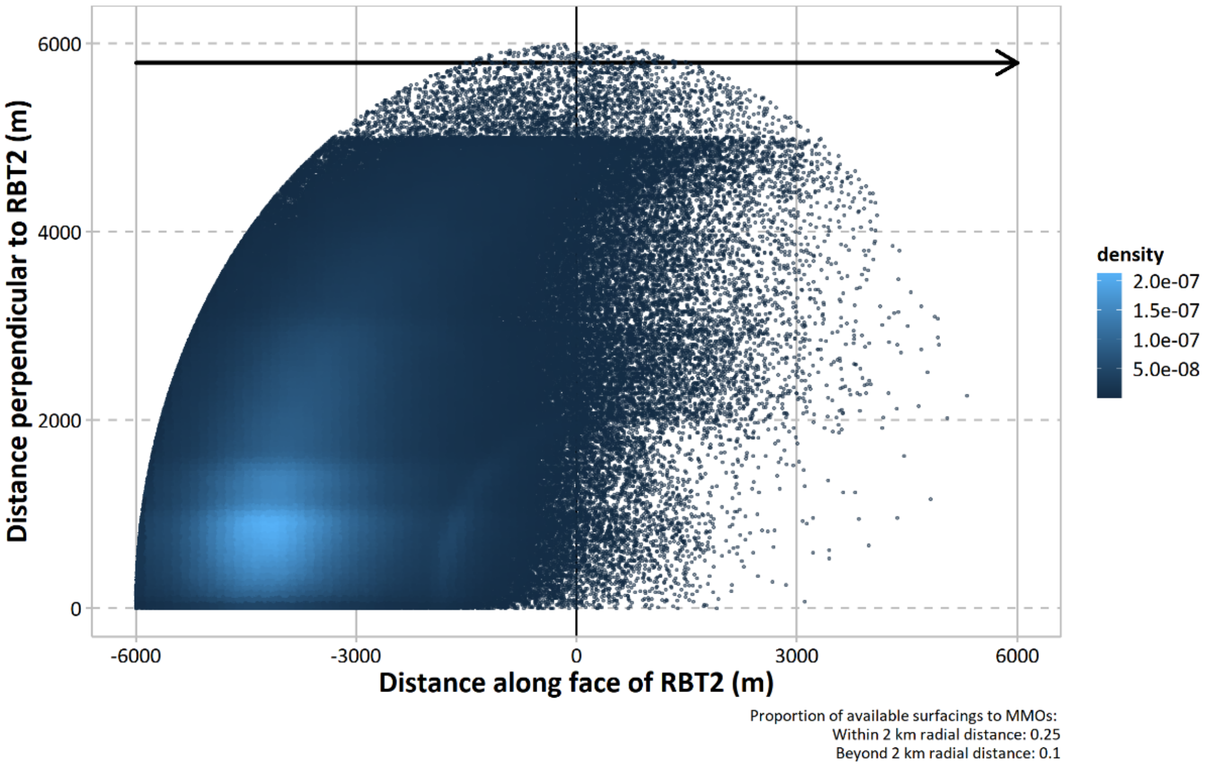


Figure 12. Positions of SRKW transit detections applying the MMO NOAA protocols (N Monte Carlo simulations: 10,000), as a function of perpendicular distance, and distance along the RBT2 terminal. The solid line represents the direction of the transits, and the shading represents the density of points.



We implemented the MMO mitigation as described above on the SRKW acoustic effects model, assuming the modified reference concept design schedule option with the greatest reductions in effects to SRKW (herein referred to as the modified schedule (Option 1)), to quantify and compare the effectiveness of the two mitigation strategies in reducing potential lost foraging time and potential prey captures.

Passive Acoustic Monitoring

Passive acoustic monitoring (PAM) is a monitoring method commonly used during seismic surveys (Compton *et al.* 2008, DFO 2015, Verfuss *et al.* 2018) and sometimes used for construction monitoring to complement MMOs during periods of low visibility and darkness. When used in combination with other monitoring methods, it can increase overall marine mammal detection (Smith *et al.* 2020). Its effectiveness, however, depends on marine mammal vocalizing when present in the area and their detectability over ambient noise conditions.

We evaluated a PAM mitigation measure assuming each SRKW transit has a 75% chance of being detected by the PAM system, immediately outside of a radial distance of 6 km from the RBT2 terminal.

Detections of SRKW transits will occur during both day and night, as opposed to MMOs who will only be able to effectively detect daytime transits. The port authority previously committed to acoustic monitoring but did not describe the intended level of effectiveness. This mitigation strategy assumed that as soon as a SRKW is detected, in-water construction activities will be halted or modified to prevent or reduce adverse acoustic exposure to SRKW. Hence, for detected SRKW transits no lost foraging time was assumed to be incurred within 6 km of radial distance from the terminal.

Details on the design, installation and use of the PAM system capable of achieving at least a 75% detection rate was discussed at a PAM workshop held on July 27, 2020, hosted by the port authority, with the participation of various leading experts in acoustic monitoring and Killer Whale acoustic behaviour. The objective of the workshop was to seek expert advice and collaboration on: i) the most effective PAM design and ii) the expected performance for a real-time PAM network to be implemented during the construction phase of the Project. Participants indicated that several factors can influence the effectiveness of a PAM system including ambient noise and the behaviour of the whales but confirmed that installing a high performance PAM system is feasible. Advice received will inform the design of a system that would be in place during construction to optimize detection effectiveness for Killer Whales.

We evaluated the PAM mitigation using the SRKW acoustic effects model, using the modified schedule (Option 1), to quantify the effectiveness of the mitigation strategy in reducing potential lost foraging time and potential prey captures.

Combined PAM and MMO

We also evaluated the effectiveness of combining PAM and MMOs detection measures in reducing lost foraging time for SRKW. We assumed that as soon as a SRKW is detected, in-water construction activities will be halted or modified to prevent or reduce adverse acoustic exposure to SRKW. Given the geographical location of where detections occur (i.e., PAM detection occurs immediately outside of a radial distance of 6 km from the RBT2 terminal), the strategies are applied sequentially for each transit, starting with the PAM followed by MMOs. Hence, each transit has a 75% chance of being detected by a PAM system, immediately outside of a radial distance of 6 km from the RBT2 terminal. Those transits not detected by the PAM system are then subjected to potential detection by the MMOs. Given that there are two MMO mitigation strategies (Industry and NOAA protocols), the combined strategy results in two different mitigation strategies: PAM + MMO Industry protocols, and PAM + MMO NOAA protocols. We evaluated the combined PAM and MMO mitigation using the SRKW acoustic effects model, assuming the modified schedule (Option 1), to quantify the associated effectiveness of each mitigation strategy in reducing potential lost foraging time and potential prey captures.

Delays in Shutdowns

Response time for shutting down equipment can affect the effectiveness of the aforementioned detection measures. The contractor's ability to shut down or modify noise generating activities and how long safe shut-down would take depends on the specific type of equipment and construction activity (Moffatt and Nichol 2021). Marine vessels such as tugs (especially while towing) cannot be completely shut down for safety reasons as they may lose navigational control. If not under tow, tugs can be slowed in 2-3 minutes but are unlikely able to completely shut down. To assess how potential delays in halting or modifying in-water noise-generating activities may affect the estimates of potential lost foraging time once a SRKW is detected, we calculated potential lost foraging time following two strategies: i) Ten-minute delay: assume that the shutdown of each in-water construction activity would take 10 minutes and ii) Variable delay: assume that the shutdown of each in-water construction activity would take a random uniformly distributed value within the range estimated by the RBT2 engineering team (Table 7). This implied calculating the position along the transit where the SRKW would be when noise from construction activity(ies) would be reduced to zero. To calculate this position, we took the position where the transit was detected and adjusted the position by the distance that would be travelled by a SRKW swimming in a straight line at a mean swimming speed of 1.6 m/s.

Table 7. Limits of delays in halting construction activities by construction activity scenario once a SRKW is detected.

Scenario ID	**Acoustic Model / Construction Activity Scenario**	**Season**	**Delay in shutdown (minutes)**	
			Lower Limit	**Upper Limit**
1	Vibratory pile installation at terminal	Summer	2	3
2A	Impact pile driving without sound dampening technology	Summer	3	5
2B	Impact pile driving with sound dampening technology	Summer	3	5
2C, 2G	PDA test without sound dampening technology	Summer	3	5
2D, 2H	PDA test with sound dampening technology	Summer	3	5
3A	Material placement	Summer	∞	∞
3B	Material placement	Winter	∞	∞
4	Dredging with Columbia	Summer	10	15
5	Dredging and pumping ashore combo	Summer	10	15
6	Pumping ashore	Winter	10	15
7A	Pumping ashore and vibro-densification	Winter	10	15
7B	Pumping ashore and vibro-densification	Summer	10	15
8A	Dredging, pumping ashore and vibro-densification	Summer	10	15
8B	Dredging, pumping ashore, vibro-densification, and high tug	Summer	10	15

∞ denotes that the noise generating activity does not stop. Conservative assumption: no tugs would be able to shut down because towing tugs cannot turn off or idle engines for safety reasons. However, tugs not towing can temporarily disengage props if not in the main navigation channel

Other SRKW Detection Methods

Additional SRKW detection methods will be employed to increase the effectiveness of mitigation strategies such as early detection methods and infrared (e.g., Verfuss *et al.* 2018, Smith *et al.* 2020) or other feasible technologies. The port authority committed to coordinating with whale sighting networks to receive advance warning and to use infrared automated detection system if deemed technically feasible (Commitment #33, VFPA 2019). Early detection methods could include shared sightings by the Canadian Coast Guard (i.e., Marine Mammal Desk), community groups (e.g., Saturna Islanders), near real-time tracking by vessel operators via the BC Cetacean Sightings Network's Whale Report Alert System application, or detections by non-Project 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). These sources could provide additional information on whale observations, individual whale detection, and movement trends to inform early detection and implement appropriate mitigation.

Limitations of infrared detection methods include reduced effectiveness in high sea states (Beaufort wind force ≥ 5), dense fog, heavy rain, snow, aerosols, high water temperature, and glare (Zitterbart *et al.* 2013, 2020, Verfuss *et al.* 2018, Smith *et al.* 2020). Some disadvantages that would likely need to be overcome before implementation for construction monitoring may include reduction of false positives (e.g., birds and vessels; location-specific detection algorithms and false alert suppression could help filter out false positives (Smith *et al.* 2020, Zitterbart *et al.* 2020, Zitterbart and Richter 2021)) and species classification which is typically into broad categories only (based on size and movement and behavioural patterns; higher focal lengths may facilitate the ability to classify infrared video clips to species level (Smith *et al.* 2020)).

The port authority is continuing to monitor the literature and evaluate scientific advances in infrared and other detection technologies for Killer Whales, including recent trials in the Strait of Georgia, to determine feasibility and effectiveness of these measures as additional detection methods during construction. A pilot test using land-based uncooled fixed infrared cameras is underway to assess the effectiveness of infrared at detecting killer whales in BC (Sturdies Bay Terminal, Active Pass and Saturna Island, Boundary Pass) as part of the Government of Canada's Oceans Protection Plan. Preliminary results include reliable detection ranges for SRKW from 600 m to 2,300 m, depending on the camera's elevation (~10 m to 25 m; Zitterbart and Richter 2021). In addition, the port authority has investigated the feasibility and applicability of using drones, underwater autonomous vehicles (e.g., unmanned gliders), and/or active acoustic monitoring to detect SRKW during construction. While these detection methods are relatively novel and untested with SRKW, gliders have been effective at acoustically detecting North Atlantic right whales in shipping lanes in eastern Canada and the United States in near real-time to inform vessel speed restrictions (Baumgartner *et al.* 2020, Kowarski *et al.* 2020), while active acoustic monitoring can detect whales that are not vocalizing (Verfuss *et al.* 2018).

Based on available information, feasibility and detection rates of these methods, and therefore their efficacy, cannot be quantified at this stage. We estimated the potential lost foraging time for all the feasible SRKW detection methods, systems, and information combined by assuming that they would achieve a 100% detection rate. The scenario assumed that all SRKW transits were detected and all in-water construction activities that can be halted (i.e., all construction activity scenarios except for Material Placement, Table 7) were halted prior to the whales entering the exclusion zones. We named this scenario "Perfect Detection".

2.4.5. Frequency and Duration of Construction Shutdowns

It is of interest to estimate the frequency and duration of halts (i.e., shutdowns) that are likely to occur during the construction phase due to SRKW presence in the applicable acoustic effect zones because this informs the evaluation of feasibility of the proposed mitigation measure. To estimate the duration of each in-water construction shutdown, we calculated the length of time that it would take a transiting SRKW to travel from the point of detection (i.e., via PAM or MMOs) to outside the applicable acoustic effect zones. We then calculated the median and 95% confidence intervals of the number of shutdowns and length of shutdowns over the 10,000 Monte Carlo iterations, assuming the modified schedule (Option 1).

2.5. Assessing Uncertainty in SRKW Response

For acoustic effects modelled without mitigation (i.e., reference concept design schedule) and with mitigation measures, uncertainty in the severity of the effect was further explored by re-running the acoustic effects model where we assumed that the SRKW's behavioural response is more acute than the mean (i.e., the probability of response occurs at a lower noise received level). Thus, the probability of response coefficients were derived from the upper confidence interval (dashed lines to the left of the mean response in Figure 4) of the low behavioural response dose-response curve (as opposed to the mean values used in the mid-point case). 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 that 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; and
- 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.

This more conservative scenario was termed "Upper Confidence Interval" and is considered by this study an upper bound estimate of potential acoustic effects to SRKW.

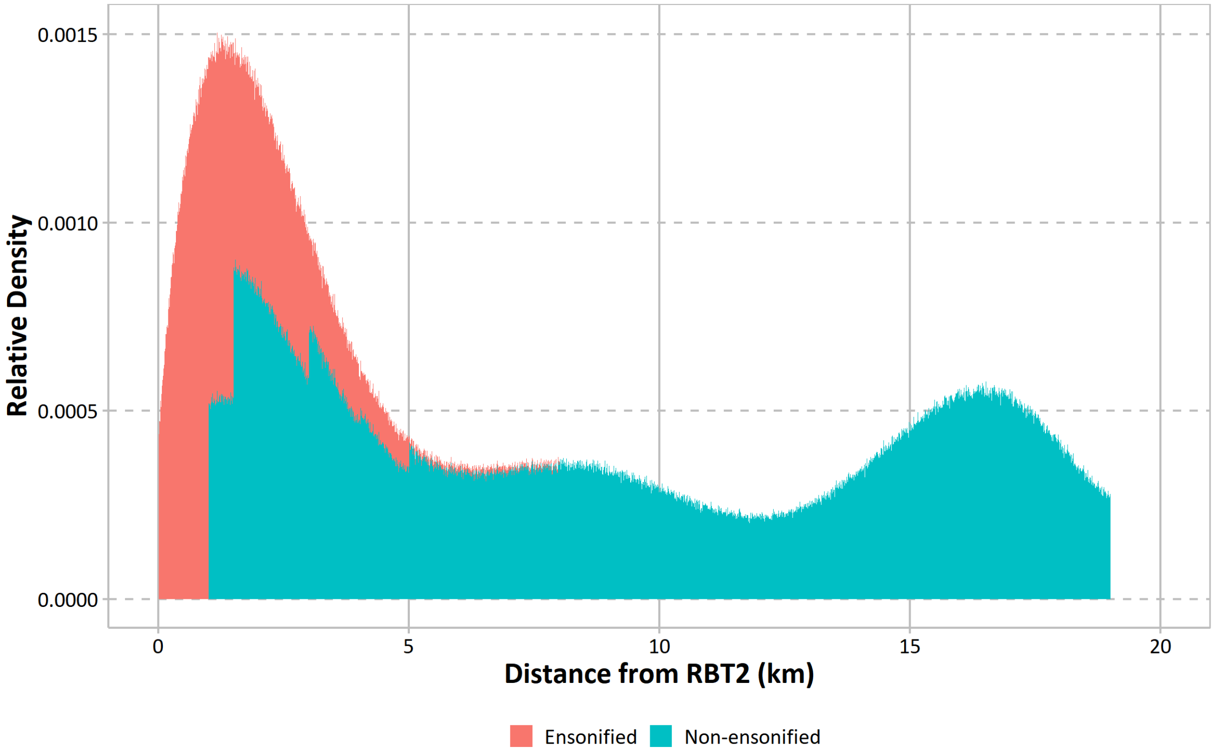
3. RESULTS

This section presents results of the SRKW acoustic effects model for construction. We compared unmitigated expected acoustic effects (acoustic injury and behavioural response), to expected acoustic effects under different and combined mitigation strategies. We also present the assessment of uncertainties in the contextual severity of the behavioural response effects, the effects of including delays in equipment shutdown, and estimates of frequency and duration of construction shutdowns associated with the detection of SRKW.

3.1. Reference Concept Design Schedule

We modelled potential acoustic effects to SRKW using the reference concept design schedule, which is based on the Project Construction Update. Whales are exposed to underwater noise when there is spatiotemporal overlap between the SRKW transit and the acoustic footprint of in-water construction activities (i.e., ensonified transit; acoustic footprints vary depending on the construction activity, Section 2.4). The proportion of realized SRKW transits that were predicted to be ensonified before implementing mitigation decreased with perpendicular distance from the face of the terminal. All transits that occurred within up to 1 km of perpendicular distance were ensonified, between 1 km and 1.5 km, around 65% of the realized transits were ensonified, the proportion changes quickly beyond 1.5 km to about 35%, and then gradually declines until reaching zero by 8 km of perpendicular distance from the face of the terminal (i.e., beyond the largest construction acoustic effect zone (vibratory pile installation acoustic model scenario 1; Table 3, Figure 13).

Figure 13. Relative density of realized SRKW transits as a function of distance from RBT2. Colours represent when whale transits and underwater noise from construction activities overlap in time and space prior to mitigation.



3.2. Acoustic Injury

Given the estimates of sound exposure levels for the planned construction activities (Li *et al.* 2021, Section 2.4), the only construction activity anticipated to have the potential to produce onset of acoustic injury is impact pile driving. The results of the acoustic effects model for the reference concept design schedule, which used the largest potential injury zones modelled for the impact hammer scenarios (Table 1), indicated there was a very small chance that SRKW transits occur within impact pile driving injury (PTS and TTS) zones. We found a median of 1 transit within the injury zone per year in construction years 1, 2, 4, and 5. Each transit within the PTS injury zone took a median of 3 minutes and 20 seconds (0 minutes – 4 minutes), and within the TTS injury zone took a median of 4 minutes and 50 seconds (0 minutes – 7 minutes). It is worth noting that this is much lower than the reference time used to calculate the sound exposure level (100 minutes) injury radii.

To avoid overestimating the likelihood of spatiotemporal overlap between SRKW transits and injury zones (PTS and TTS), we did not force the simulation to include pile driving construction scenarios when estimating acoustic injury. Rather, to estimate the likelihood and duration of overlap, we randomly chose a construction scenario, proportional to the number of hours and days each construction activity is planned to occur per month and period (i.e., day or night).

3.3. Behavioural Response

We quantified the effects of behavioural responses elicited by underwater noise (impulsive and continuous) caused by construction activities assuming that SRKW forage 100% of the time and that behavioural response to noise would lead to cessation of feeding, and therefore measured it in terms of potential lost foraging time and potential lost prey captures.

Under the reference concept design schedule, prior to implementing any mitigation, the acoustic effects model estimated a median of ~42 hours of potential lost foraging time per SRKW (95% CI: 35.1 hours – 49.3 hours) over the approximately 56 months in-water construction schedule spread over six calendar years. The largest amount of potential lost foraging time occurred in construction year 3, which corresponds to the year predicted to have the most concurrent in-water construction activities (particularly April-October) (accounting for ~50% of the total potential lost foraging time) and year 2 (particularly June-September) (~20% of total potential lost foraging time) (Figure 14). The smallest potential losses of foraging time occurred in year 6 (~0.2% of total potential lost foraging time; noting that limited in-water construction is anticipated to occur that year from January to March). The pattern of variation in the estimated potential prey losses per SRKW mirrors the patterns of variation in potential lost foraging time per SRKW (Figure 14).

The incurred potential lost foraging time was mostly due to three summer construction activity scenarios: i) scenario 8B: dredging, pumping ashore and vibro-densification combination (~40% of total potential lost foraging time), ii) scenario 5: dredging and pumping ashore combination (~18% of total potential lost foraging time), and iii) scenario 1: vibratory pile installation (~18% of total potential lost foraging time) (Figure 15). Given the seasonal use of the area by SRKW with the peak use between June 1 to September 30 (Figure 1), a large proportion of the potential lost foraging time (68%) was incurred during the peak use period (Figure 15). The SRKW pod that is predicted to lose the most foraging time is J pod (due to higher presence in the area). Pods K and L would lose smaller (and similar) amounts of foraging time (Figure 16).

Figure 14. Potential lost foraging time per SRKW in hours (h) (A), and potential lost prey captures per SRKW (B), as functions of construction year for the reference concept design schedule, prior to mitigation.

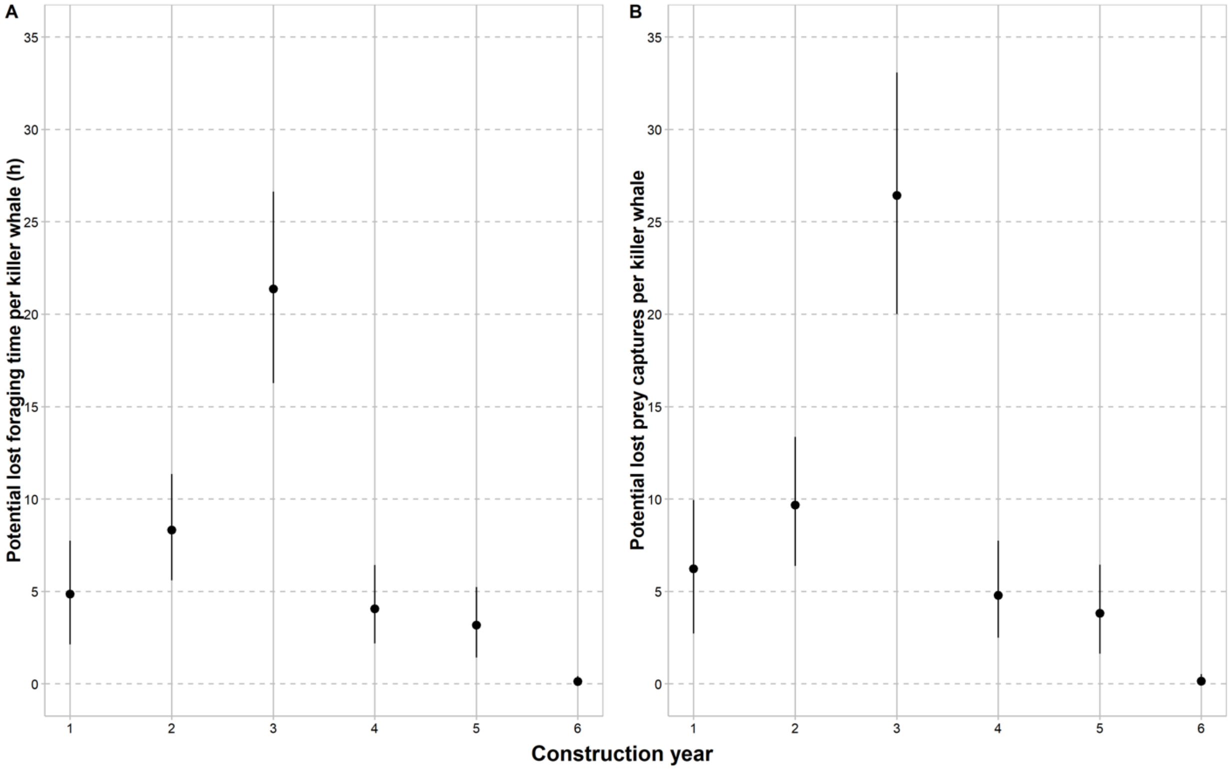


Figure 15. Potential lost foraging time per SRKW in hours (h) as function of calendar month for the reference concept design schedule, prior to mitigation. Colours represent scheduled construction year, and columns refer to construction activity scenarios used to characterize construction activities.

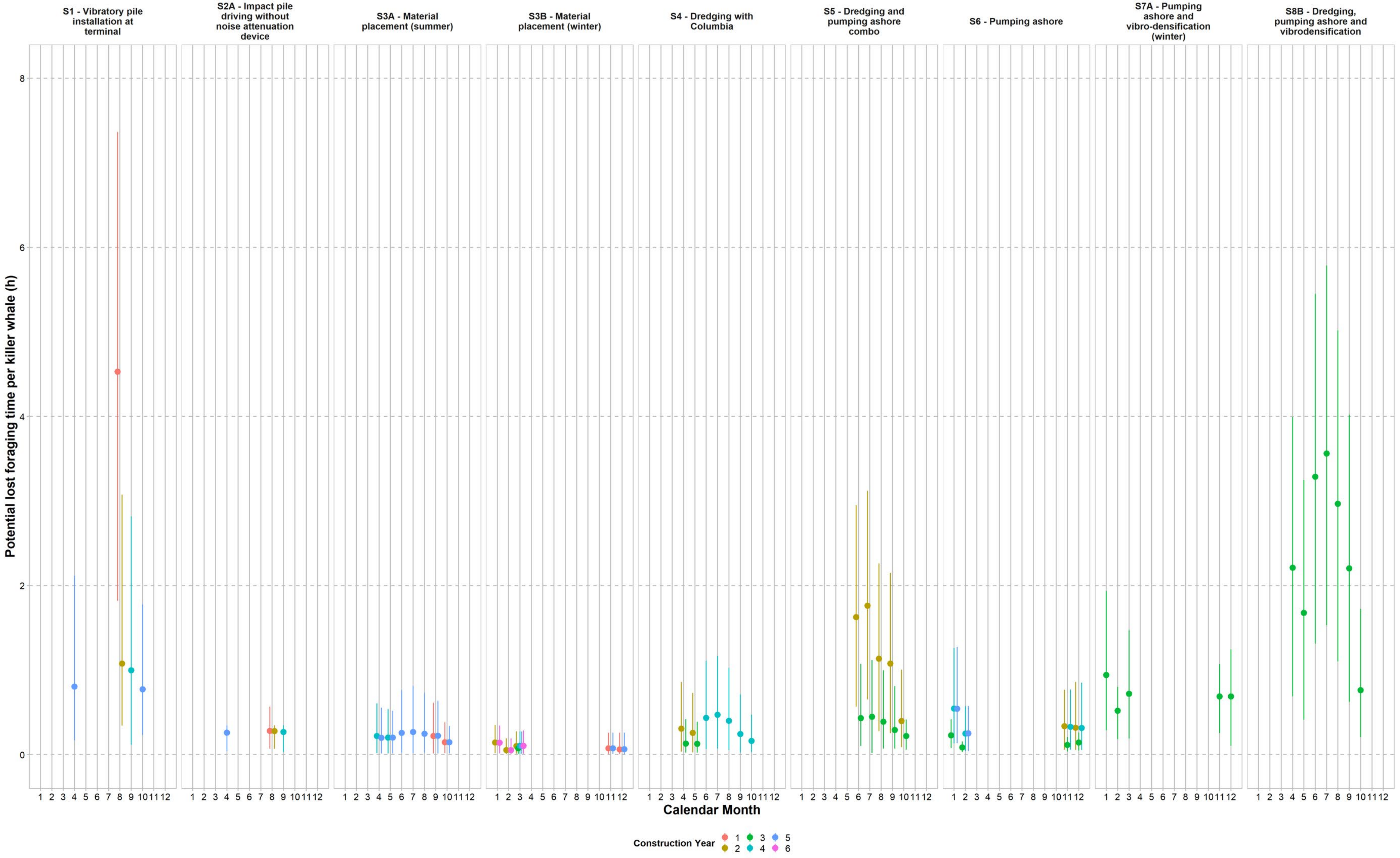
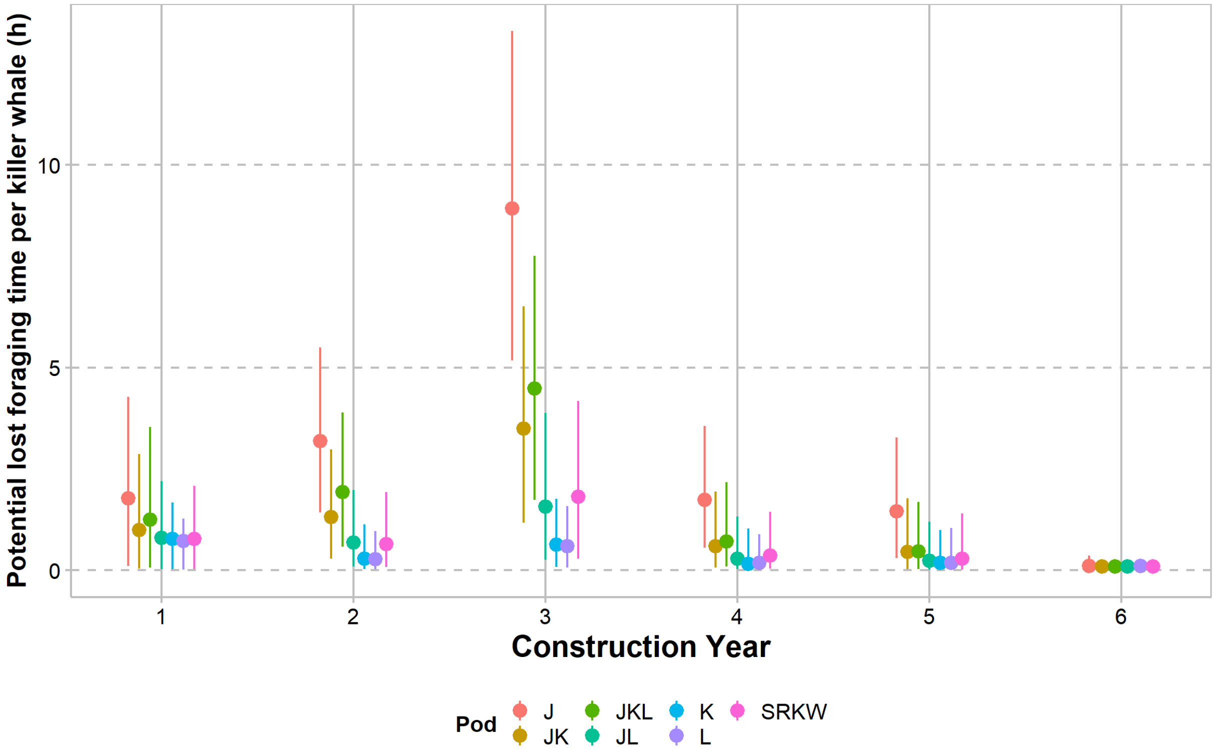


Figure 16. **Potential lost foraging time per SRKW (median and 95% CI) in hours (h) as a function of scheduled construction year for the reference concept design schedule, prior to mitigation. Colours represent individual and combinations of the three SRKW pods (J, K and L). SRKW represent unknown pods or assemblages.**



3.4. Mitigation Evaluation

3.4.1. Construction Timing Refinements

We identified two modified schedule options that avoid or reduce activities during the SRKW peak use period (June 1 to September 30) (Section 2.4.4.1). Both options reduce acoustic effects on SRKW, but they differ in the amount of reduction.

Implementing Option 1 resulted in the most reduction in potential lost foraging time per SRKW; ~30% overall reduction and ~45% reduction in year 3 (Figure 17). Year 3 coincides with the year found to dominate overall acoustic effects. Implementing Option 2 resulted in a smaller reduction in potential lost foraging time; it caused ~20% overall reduction and ~35% reduction in year 3. Modified schedule (Option 1) requires dredging in year 2 to continue from mid-October to the end of November coinciding with the first six weeks of the Dungeness crab fisheries-sensitive window (October 15 to March 31), which plans the noisiest activities outside the period of SRKW peak and moderate use of Roberts Bank, consequently further reducing potential effects to SRKW.

Both modified schedule options resulted in substantial decreases in lost foraging time in years 1 and 3, a minor decrease in year 5, and minor increases in potential lost foraging time in years 2, 4, and 6 (Figure 17). For example, in year 1, installing the piles for the barge ramps outside the SRKW peak use period, assumed under both modified schedules (Figure 18, Figure 19), reduced potential lost foraging time by ~4 hours (Figure 17) from the reference concept design schedule. The minor increases in years 2 and 4 are a result of vibro-densification (construction activity scenario 7A) being planned to occur during winter months of both years (Table 5). In the case of year 6, the minor increase in potential lost foraging time is a result of temporary pile removal (construction activity scenario 1) being planned in year 6 rather than year 5 as assumed for the reference concept design schedule.

Given the reductions in acoustic effects that can be achieved by implementing the modified schedule (Option 1), this option was used when evaluating the effectiveness of other potential mitigation.

Figure 17. Potential lost foraging time per SRKW in hours (h) by construction year, prior to other mitigation. Colours represent the reference concept design schedule and modified schedules.

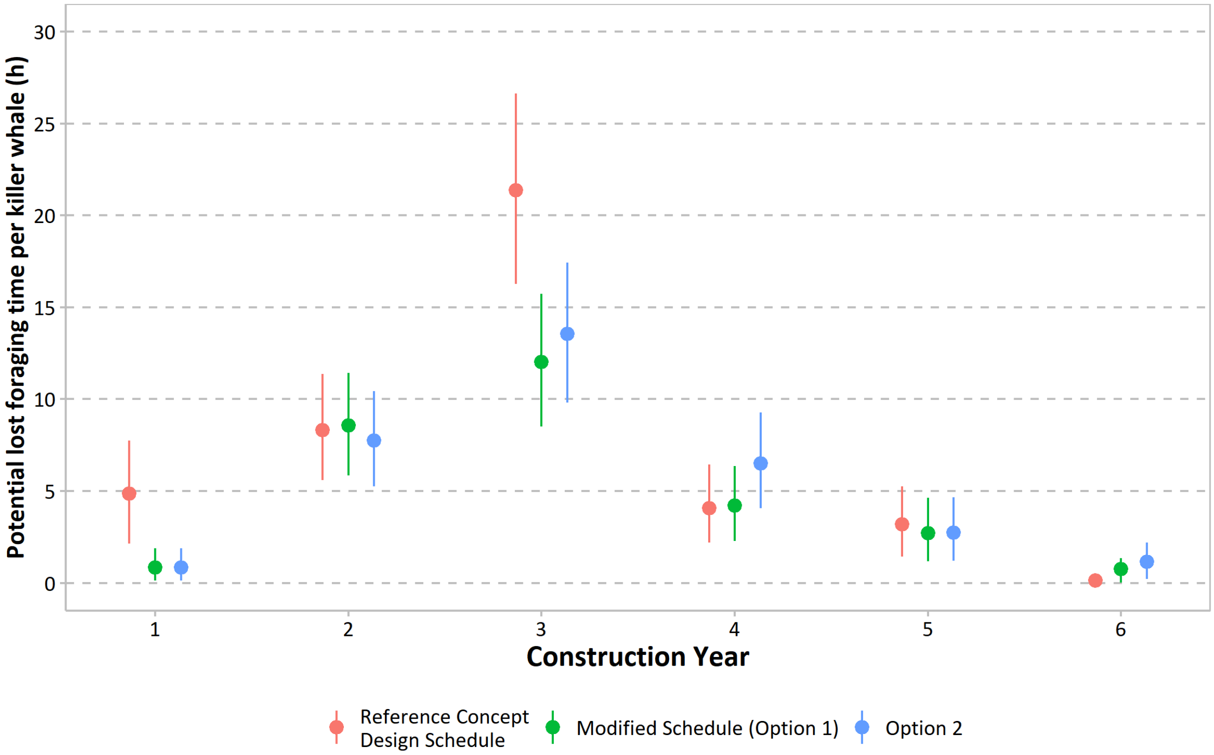


Figure 18. Potential lost foraging time per SRKW as function of calendar month for the modified schedule (Option 1), prior to other mitigation. Colours represent construction year, and columns refer to construction activity scenarios used to characterize construction activities.

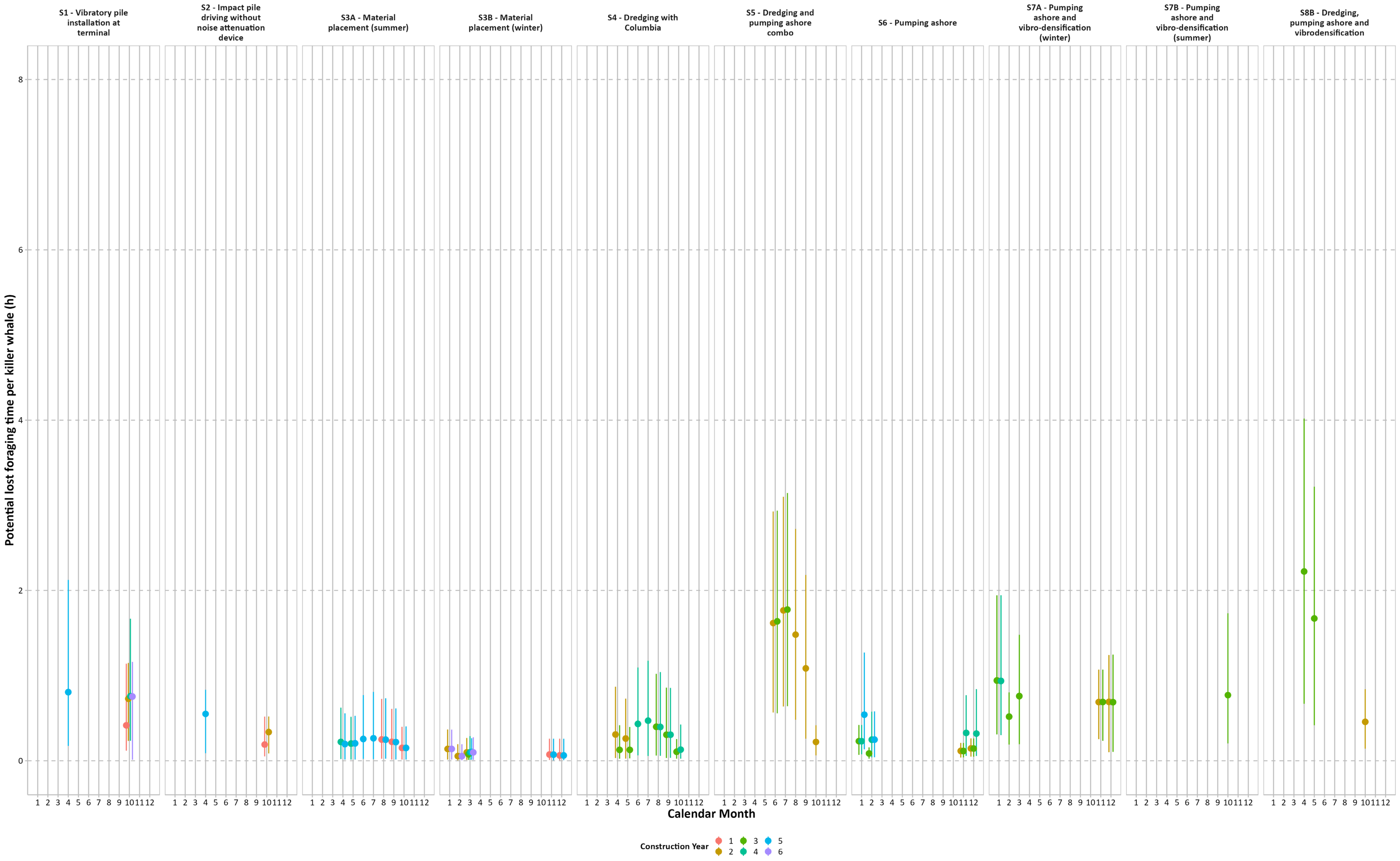
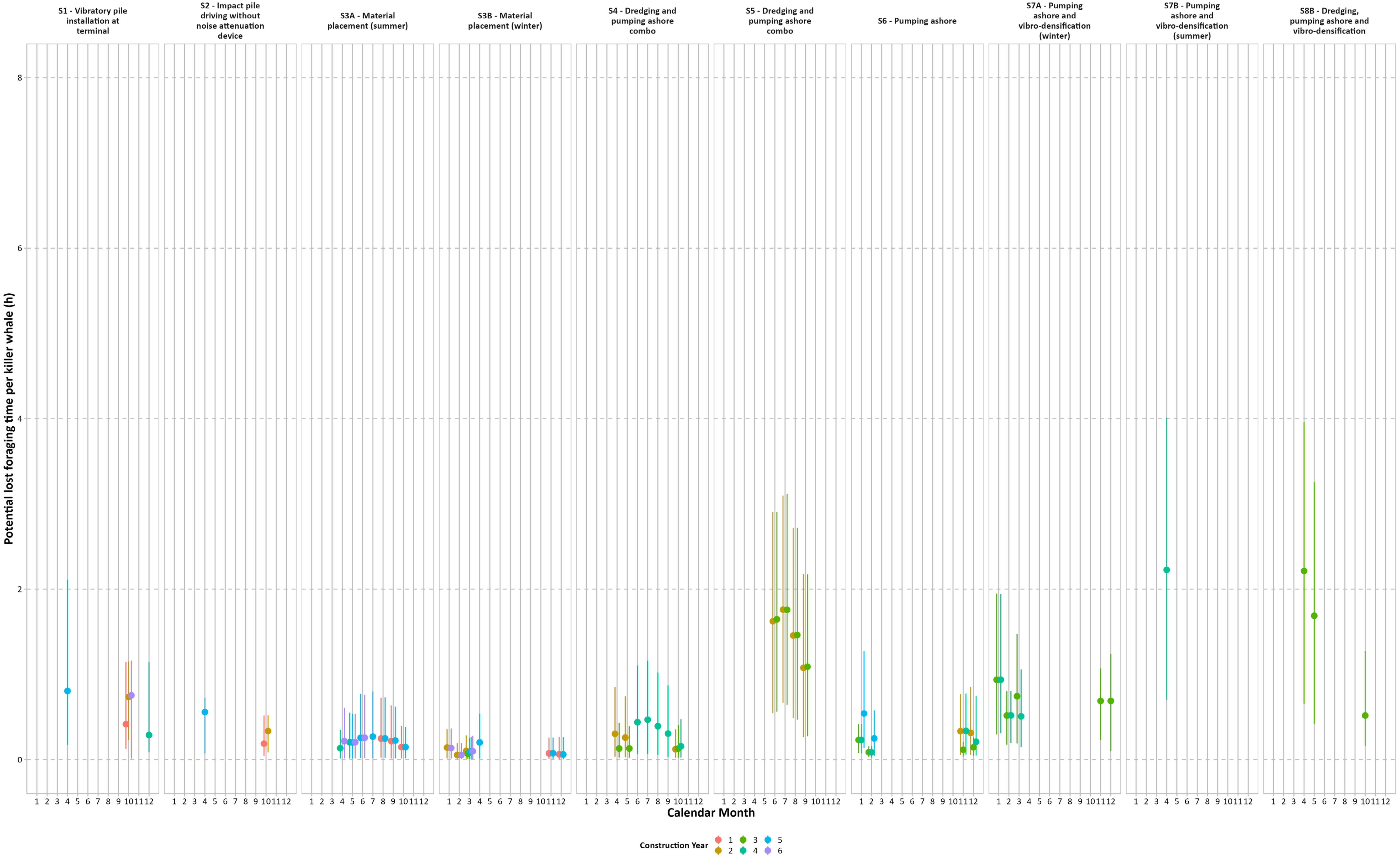


Figure 19. Potential lost foraging time per SRKW in hours (h) as function of calendar month for modified schedule Option 2, prior to other mitigation. Colours represent construction year, and columns refer to construction activity scenarios used to characterize construction activities.



3.4.2. Sound Dampening Technology for Impact Piling

The implementation of sound dampening technology during the impact piling to install all piles, as assumed under the reference concept design schedule (i.e., the scenario that has the largest acoustic injury zone of all impact pile driving scenarios), can completely mitigate the potential for PTS and largely mitigate the potential for TTS (Scenario 2B; Li *et al.* 2021). Given that PTS injury threshold is not reached with the use of sound dampening technology, the risk of these potential injuries is completely mitigated, whereas the radius of the TTS injury zone is reduced to 72 m (i.e., within the 200 m radius closest to RBT2). Therefore, the time spent in the TTS injury zone with the use of sound dampening technology is the same as the time spent in the PTS injury zone without the use of sound dampening technology. Given the small radii of acoustic injury zones, the implementation of sound dampening technology in conjunction with monitoring for SRKW and shutdown of pile driving can completely mitigate the potential for acoustic injury (PTS and TTS). These results are consistent irrespective of the construction schedule considered. However, planning the required impact piling for testing piles outside of the SRKW peak use period in modified schedule Options 1 and 2 and the reduced acoustic injury zones associated with PDA testing are added precautions and further reduce the likelihood of interactions, potential injury, and reliance on other mitigation strategies. Confined bubble curtains can also reduce the range of potential behavioural disturbance effects. However, this mitigation measure was conservatively assumed not to be in place when estimating behavioural disturbance effects and the effectiveness of other mitigation measures under the modified schedule (Option 1) (Section 3.4.3). Therefore, this mitigation measure is not reflected in the following results section when discussing mitigation effectiveness on behavioural disturbance.

3.4.3. Monitoring for SRKW and Associated Shutdown

We assessed the effectiveness of individual and combined observation and acoustic detection mitigation strategies, including in-water construction activity shutdown or modification. The implementation of combined and enhanced mitigation strategies (i.e., use of more effective MMO NOAA protocols instead of MMO Industry protocols to enhance long range detection and year-round MMOs) showed increasing effectiveness in reducing potential lost foraging time and potential prey captures, assuming the modified schedule (Option 1) (Figure 20). Patterns of variation in potential lost foraging time and potential prey captures are largely identical. Thus, from this point on we will describe the effectiveness of mitigation strategies in terms of potential lost foraging time, except where patterns of variation differ. It is worth noting that the assessment of the relative effectiveness of the mitigation strategies described in this section takes the modified construction schedule as a basis, thus effectiveness presented here is not the overall effectiveness of the combined strategy (i.e., using reference concept design schedule as the baseline for comparisons - this will be described in Section 3.6).

MMOs (Industry protocols) coupled with in-water construction activity shutdowns can reduce the accrued potential lost foraging time by about 57% (Table 8). Effectiveness of detection using MMO NOAA protocols or PAM, coupled with shutdowns, in terms of reducing potential lost foraging time were almost identical estimated at approximately 73%, whereas effectiveness of

MMO NOAA protocols in terms of reducing potential lost prey captures is higher than that of PAM (~78% vs ~73%, Table 9). The MMO NOAA protocols coupled with shutdown mitigation strategy is more effective because MMOs can detect SRKW transits exclusively during the day when SRKW prey capture is highest. Combined mitigation strategies (PAM and MMOs coupled with shutdown) were shown to reach effectiveness of ~87-88% (MMO Industry protocols) and ~91-92% (MMO NOAA protocols), in terms of reducing both potential lost foraging time and prey captures (Figure 20, Table 8, Table 9).

In general, the distribution of potential lost foraging time as a function of distance from RBT2 follows the same pattern as the distribution of transits (Figure 3). There is a peak at around 1.5 km from the terminal, a subsequent decline, and a second peak starting at around 5 km from the terminal (Figure 21). The MMO Industry protocols coupled with shutdown mitigation is effective at reducing potential lost foraging time within the first few kilometres, where there is a clear peak of potential lost foraging time. However, it is not effective at reducing potential lost foraging time beyond the first peak, and as a result, there is a percentage of lost foraging time that is not mitigated using this MMO mitigation strategy (Figure 21). The PAM and MMO NOAA protocols coupled with shutdown mitigation strategies are more effective at reducing potential lost foraging time beyond 4 km from the terminal berth face. Combined mitigation strategies (PAM and MMO NOAA protocols coupled with shutdown) are very effective at reducing potential lost foraging time up to 6 km from RBT2, given the assumed placement and modelled effectiveness of PAM and MMO strategies, respectively.

Table 8. **Potential lost foraging time per SRKW (median and 95% confidence intervals) in hours (h) as function of construction year as well as the percent reductions for the detection and shutdown mitigation strategies compared to the modified schedule (Option 1).**

Construction Year	Modified Schedule (Option 1)	MMO Industry		MMO NOAA		PAM		PAM & MMO Industry		PAM & MMO NOAA	
	Potential lost foraging time per killer whale (h)	Potential lost foraging time per killer whale (h)	Percent reduction (%)	Potential lost foraging time per killer whale (h)	Percent reduction (%)	Potential lost foraging time per killer whale (h)	Percent reduction (%)	Potential lost foraging time per killer whale (h)	Percent reduction (%)	Potential lost foraging time per killer whale (h)	Percent reduction (%)
1	0.8 (0.1 - 1.9)	0.3 (0.0 - 1.0)	67.3	0.2 (0.0 - 0.7)	74.9	0.2 (0.0 - 1.1)	77.9	0.1 (0.0 - 0.6)	89.9	0.1 (0.0 - 0.5)	91.9
2	8.6 (5.9 - 11.4)	3.6 (2.2 - 5.3)	57.5	2.4 (1.2 - 3.8)	72.1	2.2 (0.8 - 4.1)	74.2	1.0 (0.3 - 2.1)	88.3	0.7 (0.1 - 1.6)	92.0
3	12.0 (8.5 - 15.7)	5.4 (3.6 - 7.4)	55.3	3.0 (1.7 - 4.5)	75.4	3.1 (1.2 - 5.7)	74.0	1.5 (0.6 - 2.9)	87.5	0.9 (0.3 - 1.9)	92.5
4	4.2 (2.3 - 6.3)	1.8 (0.7 - 3.0)	58.2	1.3 (0.5 - 2.3)	69.3	1.1 (0.2 - 2.6)	73.8	0.5 (0.1 - 1.4)	87.7	0.4 (0.1 - 1.1)	90.1
5	2.7 (1.2 - 4.6)	1.0 (0.3 - 2.1)	62.5	0.7 (0.2 - 1.6)	72.7	0.7 (0.0 - 2.0)	74.6	0.3 (0.0 - 1.1)	89.4	0.2 (0.0 - 0.8)	91.5
6	0.8 (0.0 - 1.3)	0.3 (0.0 - 0.8)	56.0	0.2 (0.0 - 0.7)	73.2	0.1 (0.0 - 1.1)	84.9	0.1 (0.0 - 0.7)	85.4	0.1 (0.0 - 0.5)	85.4
All years	29.1 (23.8 - 34.6)	12.5 (9.7 - 15.5)	57.0	7.9 (5.8 - 10.3)	72.8	7.9 (4.8 - 11.5)	73.0	3.8 (2.2 - 5.8)	87.1	2.6 (1.4 - 4.2)	91.1

Percent reductions are calculated based on the median values

Table 9. **Potential lost prey captures per SRKW (median and 95% confidence intervals) as function of construction year as well as the percent reductions for the detection and shutdown mitigation strategies compared to the modified schedule (Option 1).**

Construction Year	Modified Schedule (Option 1)	MMO Industry		MMO NOAA		PAM		PAM & MMO Industry		PAM & MMO NOAA	
	Potential lost prey captures per killer whale	Potential lost prey captures per killer whale	Percent reduction (%)	Potential lost prey captures per killer whale	Percent reduction (%)	Potential lost prey captures per killer whale	Percent reduction (%)	Potential lost prey captures per killer whale	Percent reduction (%)	Potential lost prey captures per killer whale	Percent reduction (%)
1	1 (0 - 2)	0 (0 - 1)	72.6	0 (0 - 1)	80.3	0 (0 - 1)	78.6	0 (0 - 1)	91.9	0 (0 - 1)	92.8
2	10 (7 - 13)	4 (2 - 5)	63.5	2 (1 - 3)	79.8	3 (1 - 5)	74.3	1 (0 - 2)	89.7	1 (0 - 2)	93.6
3	15 (10 - 19)	6 (4 - 8)	58.4	3 (2 - 5)	79.6	4 (1 - 7)	74.0	2 (1 - 3)	88.3	1 (0 - 2)	93.5
4	5 (3 - 8)	2 (1 - 3)	63.5	1 (0 - 2)	75.7	1 (0 - 3)	73.8	1 (0 - 2)	89.1	0 (0 - 1)	91.5
5	3 (1 - 6)	1 (0 - 2)	68.1	1 (0 - 2)	79.0	1 (0 - 2)	74.8	0 (0 - 1)	90.8	0 (0 - 1)	92.8
6	1 (0 - 2)	0 (0 - 1)	56.2	0 (0 - 1)	73.6	0 (0 - 1)	84.8	0 (0 - 1)	85.3	0 (0 - 1)	85.4
All years	35 (28 - 42)	13 (10 - 17)	61.3	8 (5 - 10)	78.4	9 (6 - 14)	72.9	4 (2 - 7)	88.0	3 (1 - 4)	92.3

Percent reductions are calculated based on the median values

Figure 20. Potential lost foraging time per SRKW in hours (h) (A), and potential lost prey captures per SRKW (B), as functions of construction year, for the modified schedule (Option 1), with detection and shutdown mitigation strategies applied. Colours represent the different mitigation strategies.

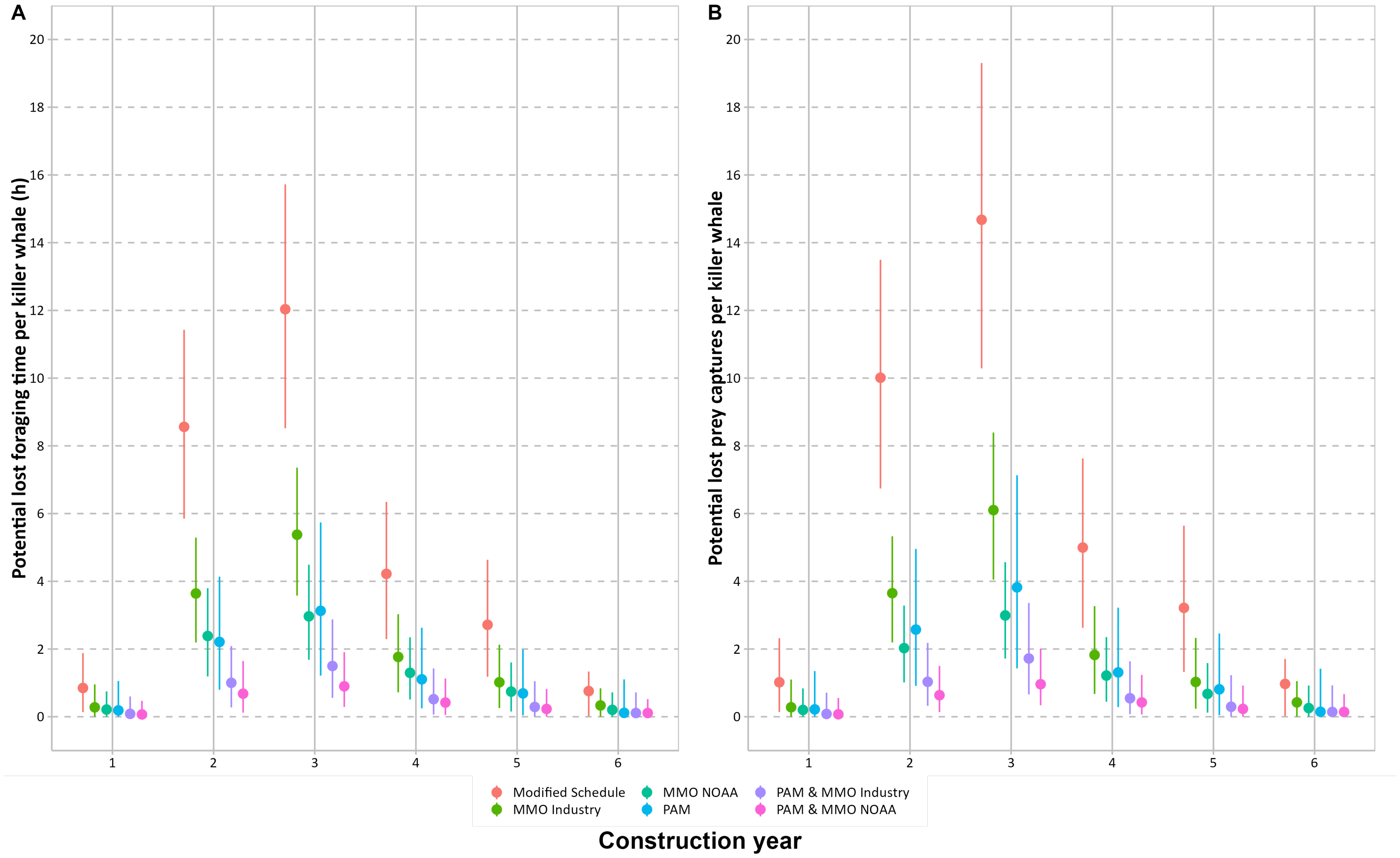
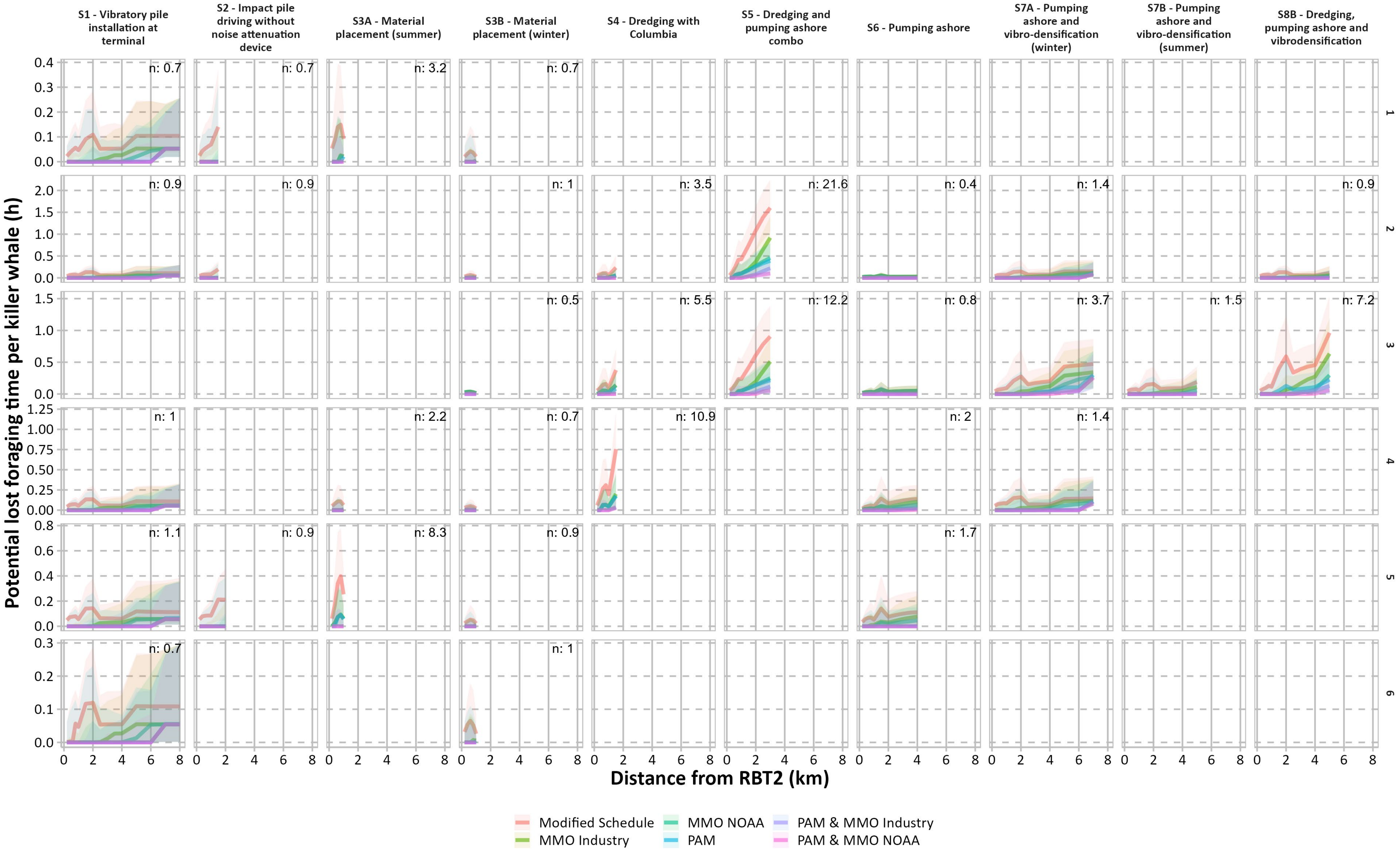


Figure 21. Potential lost foraging time per SRKW as a function of distance from RBT2 for the modified schedule (Option 1), with detection and shutdown mitigation strategies applied. Columns refer to construction activity scenarios representative of construction activities, rows refer to construction year, and colours represent the different mitigation strategies. Sample sizes in each panel represent mean number of ensonified SRKW transits.



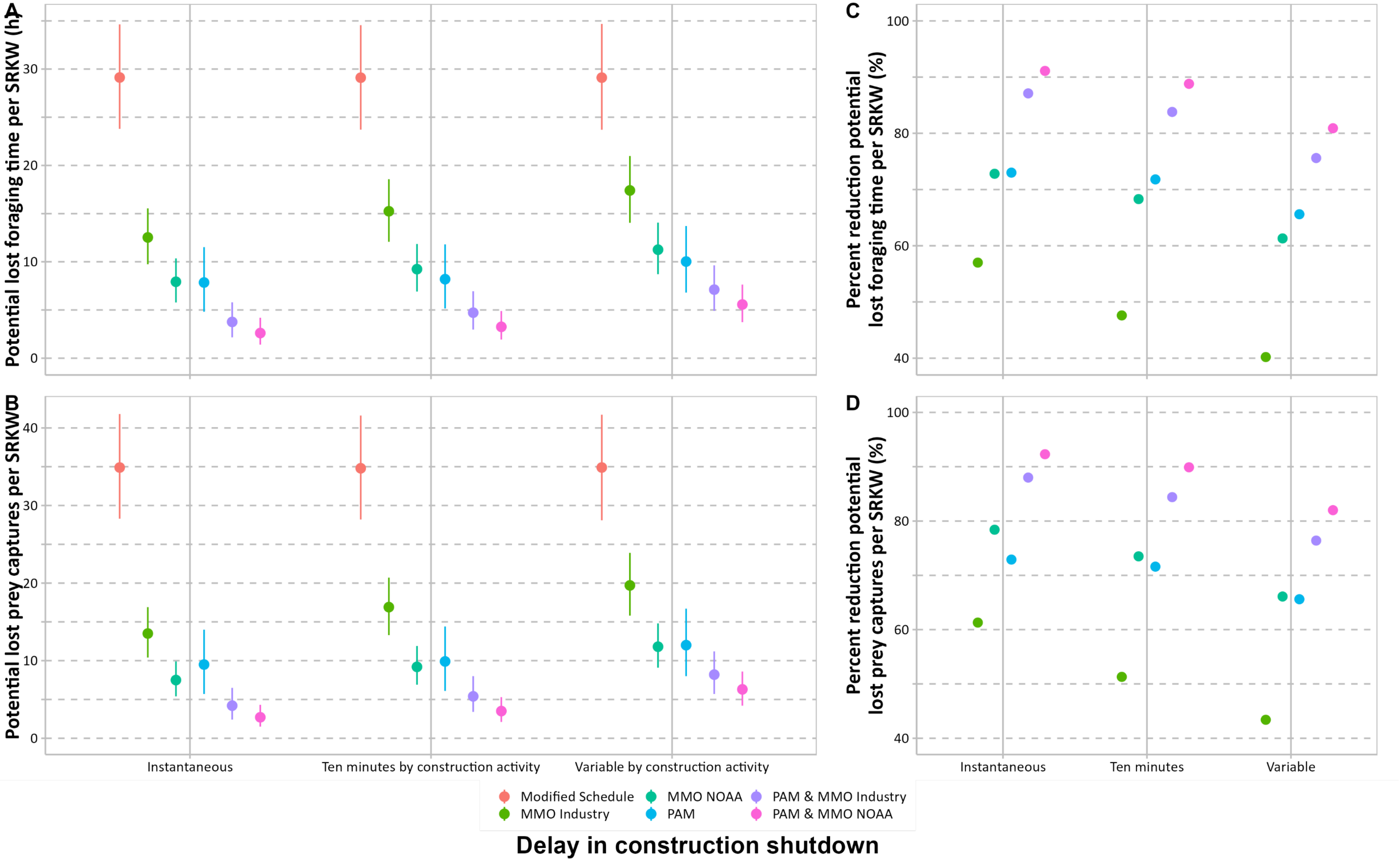
3.4.3.1. Delays in Shutdowns

Mitigation results presented up to this point have assumed that in-water construction activity shutdowns occur instantly as a SRKW transit is detected. However, the response time for shutting down activities depends on the type of equipment and construction activity, and some activities cannot be completely shut down for safety reasons (e.g., tugs while towing) (Moffatt and Nichol 2021). Here we present the assessment of how delays in halting (or modifying) noise generating activities affect the estimates of potential lost foraging time once a SRKW is detected. Delays in shutting down construction activities increased residual (i.e., after mitigation) potential lost foraging time and prey captures consistently irrespective of mitigation strategy (Figure 22). The percent reductions in lost foraging time that monitoring for SRKW would bring were about 5% smaller (i.e., monitoring mitigation strategies are less efficient once delays in shutdown are considered) if a 10-minute delay by construction activity was assumed, and about 10% if we assumed that each construction activity took a variable time to be halted as described in Table 7.

3.4.3.2. Other SRKW Detection Methods

The port authority has committed to applying additional detection methods (e.g., early detection sources and other technologies such as infrared once feasible) to increase SRKW detection effectiveness, where feasible, and to modify or halt activities before they enter the applicable exclusion zones. Assuming these combined measures would achieve perfect SRKW detection prior to entering acoustic effect zones and all construction activities that can be shut down (i.e., all construction activity scenarios except for scenario 3 (material placement; Table 7) were halted prior to SRKW entering the exclusion zones, SRKWs would accrue an estimate of 2.3 hours (95% CI: 1.2 hour - 3.5 hours) of potential lost foraging time per SRKW over 6 years of construction. Over 50% of this potential lost foraging time would be incurred in year 5 of construction, ~20% in year 1, and ~15% in year 4 of construction. This potential lost foraging time would be caused by tugs towing barges (i.e., construction activity scenarios 3A and 3B associated with material placement), which cannot turn off or idle engines for safety reasons.

Figure 22. Potential lost foraging time per SRKW (A), potential lost prey captures per SRKW (B), and percent reductions in potential lost foraging time per SRKW (C), and potential lost prey captures per SRKW (D), as functions of assumed delays in halting construction activities for the modified schedule (Option 1), with detection and shutdown mitigation strategies applied. Colours represent the different mitigation strategies.



3.5. Frequency and Duration of Construction Shutdowns

The number of predicted construction shutdowns due to SRKW detections under the modified schedule (Option 1) varied by construction year, whereas it was somewhat consistent across individual mitigation strategies (within years, Figure 23A, Table 10). The number of expected shutdowns was small during years 1 and 6 (all corresponding to partial construction years). There was a notable increase during year 2, reaching the highest number of expected shutdowns in year 3, and decreased during years 4 and 5.

A similar pattern (i.e., variable by construction year, and more consistent across mitigation strategies) was observed in the expected duration of shutdowns (Figure 23B, Table 11). The shortest median duration of shutdowns occurred during years 1 and 5. The predicted length of shutdowns is calculated as the time that it would take a transiting SRKW to traverse the acoustic effect zone of the relevant construction activity scenario.

Note that to obtain the total number of potential shutdowns due to combined mitigation strategies that use both PAM and MMO detection methods, the number of predicted shutdowns due to both the PAM and MMO components must be added. Thus, for example in year 2, the median total of shutdowns was estimated at 30 (95% CI: 18 – 43) (Table 10); 24 (95% CI: 16 – 32) due to PAM detections and 6 (95% CI: 2 – 11) due to MMO detections (MMO NOAA protocols). Each of the shutdowns due to SRKW detection by PAM in year 2 is expected to last a median of 1 hour and 54 minutes (95% CI: 1 hour and 6 minutes - 3 hours and 24 minutes), whereas shutdowns due to SRKW detection by MMOs in the combined mitigation strategy (NOAA protocols) in year 2 are expected to last a median of 1 hour and 30 minutes (95% CI: 36 minutes – 3 hours) (Table 11).

Note that the shutdown information presented is based on implementation of mitigation using the detection methods evaluated in the study. It is possible that early detection of SRKW may trigger construction shutdowns more frequently and for longer duration. In addition, detection of Transient Killer Whales and other cetaceans in the applicable exclusion zones will also likely cause additional stoppages that are not quantified in this study. Given that Transient Killer Whales vocalize less frequently than SRKW (Deecke *et al.* 2005), detection rates via PAM will be smaller than for SRKW and detections will likely be via MMOs. Visual distinction between the two Killer Whale ecotypes is difficult at long distances, and thus it is highly likely that presence of Transient Killer Whales in the area will lead to construction work being halted.

Table 10. Number of construction shutdowns (median and 95% confidence interval), as function of construction year for the modified schedule (Option 1).

Mitigation Strategy	Construction Year					
	1	2	3	4	5	6
MMO Industry	3 (1 - 7)	21 (14 - 29)	22 (15 - 30)	13 (7 - 19)	9 (4 - 15)	1 (1 - 3)
MMO NOAA	3 (1 - 7)	23 (16 - 31)	26 (19 - 34)	14 (8 - 20)	9 (4 - 15)	2 (1 - 4)
PAM	3 (1 - 7)	24 (16 - 32)	26 (18 - 35)	15 (8 - 22)	10 (5 - 16)	1 (0 - 4)
MMO component of PAM & MMO Industry	1 (1 - 3)	5 (2 - 10)	5 (2 - 10)	3 (1 - 7)	2 (1 - 6)	1 (1 - 2)
MMO component of PAM & MMO NOAA	1 (1 - 3)	6 (2 - 11)	6 (2 - 12)	3 (1 - 7)	2 (1 - 6)	1 (1 - 2)

Note that to obtain the total number of shutdowns for combined mitigation strategies, the number of shutdowns due to PAM detections must be summed to the number of shutdowns associated with the MMO component.

Table 11. Duration of construction shutdowns in hours (median and 95% confidence interval), as function of construction year for the modified schedule (Option 1).

Mitigation Strategy	Construction Year					
	1	2	3	4	5	6
MMO Industry	0.6 (0.3 - 3.1)	1.1 (0.3 - 2.7)	1.3 (0.4 - 2.7)	0.8 (0.3 - 2.8)	0.6 (0.3 - 3.0)	2.5 (0.2 - 3.3)
MMO NOAA	1.0 (0.4 - 3.4)	1.5 (0.6 - 3.0)	1.7 (0.7 - 3.1)	1.1 (0.5 - 3.2)	1.0 (0.5 - 3.4)	2.8 (0.4 - 3.7)
PAM	1.3 (1.1 - 3.7)	1.9 (1.1 - 3.4)	2.0 (1.2 - 3.4)	1.5 (1.1 - 3.5)	1.3 (1.1 - 3.7)	3.3 (1.1 - 3.8)
MMO component of PAM & MMO Industry	0.6 (0.3 - 3.0)	1.1 (0.3 - 2.7)	1.3 (0.4 - 2.7)	0.8 (0.3 - 2.8)	0.6 (0.3 - 3.0)	2.5 (0.2 - 3.3)
MMO component of PAM & MMO NOAA	1.0 (0.4 - 3.4)	1.5 (0.6 - 3.0)	1.7 (0.7 - 3.1)	1.1 (0.5 - 3.2)	1.0 (0.5 - 3.4)	2.8 (0.4 - 3.6)

3.6. Summary of Mitigation Effectiveness for Behavioural Response

In this section we present a summary of the effectiveness of the tiered approach to mitigate behavioural response effects to construction noise on SRKW, where refinements to the in-water construction timing represented the first tier and monitoring for SRKW and shutting down construction represented the second tier. We focus on the mitigation strategies that are predicted to yield the largest reduction in potential lost foraging time; hence, the adoption of a modified schedule (Option 1) and the use of PAM and MMO NOAA protocols to detect SRKW coupled with in-water construction activity shutdowns. Potential lost foraging time and prey captures per SRKW are calculated considering the mid-point dose-response behavioural response coefficients and assumed time to shutdown is variable by construction activity. We present results taking the unmitigated potential lost foraging time and prey captures (i.e., using the reference concept design schedule) as baseline. We also present a comparison to the maximum potential mitigation that could be achieved (hypothetical scenario) by implementing additional SRKW detection methods such as integration of early detection sources and infrared or other feasible technologies assuming they would increase SRKW detections to 100% (Section 2.4.4.3).

Median potential lost foraging time incurred in the reference concept design schedule was 42 hours (95% CI: 35.1 hours – 49.3 hours) (Figure 24, Table 12) over 6 years of construction. The implementation of the modified schedule (Option 1) reduced lost foraging time by ~31% to

29.1 hours (23.7 – 34.7 hours). Implementing PAM or MMO (NOAA protocols) detection coupled with in-water construction activity shutdown mitigation strategy, under the modified schedule (Option 1), further reduced potential lost foraging time per SRKW to similar amounts: 11.3 hours (8.7 - 14.1 hours) for MMO NOAA protocols (i.e., 73% reduction), and 10 hours (6.8 – 13.7 hours) for PAM (i.e., 76% reduction). The accumulated effectiveness of implementing both detection methods PAM and MMO NOAA protocols, under the modified schedule (Option 1), coupled with halting in-water construction activity), decreased lost foraging time by 87% to 5.6 hours per SRKW (3.7 - 7.6 hours) over the 6 years of construction. The maximum potential reduction in lost foraging time if detection of SRKW was perfect was 94% to 2.3 hours per SRKW (1.2 - 3.6 hours) over 6 years of construction. Patterns in potential lost prey captures per SRKW by mitigation strategy mirror those of potential lost foraging time per SRKW (Figure 24, Table 12).

Table 12. Mitigation effectiveness compared to the reference concept design schedule for combined mitigation strategies, including implementing the modified schedule (Option 1) and mitigation strategies (detection coupled with shutdown). Effectiveness is expressed in terms of potential lost foraging time and potential lost prey captures per SRKW over ~6 years of construction.

Mitigation Strategy	Potential lost foraging time per killer whale				Potential lost prey captures per killer whale			
	Median (h)	LCI (h)	UCI (h)	Percent reduction (%)	Median (prey)	LCI (prey)	UCI (prey)	Percent reduction (%)
Reference Concept Design Schedule	42.0	35.1	49.3	-	51	43	60	-
Modified Schedule (Option 1) (MS)	29.1	23.7	34.7	31	35	28	42	32
MS + MMO NOAA	11.3	8.7	14.1	73	12	9	15	77
MS + PAM	10.0	6.8	13.7	76	12	8	17	77
MS + PAM & MMO NOAA	5.6	3.7	7.6	87	6	4	9	88
MS + Perfect Detection	2.3	1.2	3.6	94	3	1	4	95

Percent reductions are calculated based on the median values

Figure 23. Number (A) and duration (B) of construction shutdowns, as functions of construction year for the modified schedule (Option 1). Colours represent detection and shutdown mitigation strategies. Note that to obtain the total number of shutdowns for combined mitigation strategies, the number of shutdowns due to PAM detections (light blue) must be summed with the number of shutdowns associated with MMO detections.

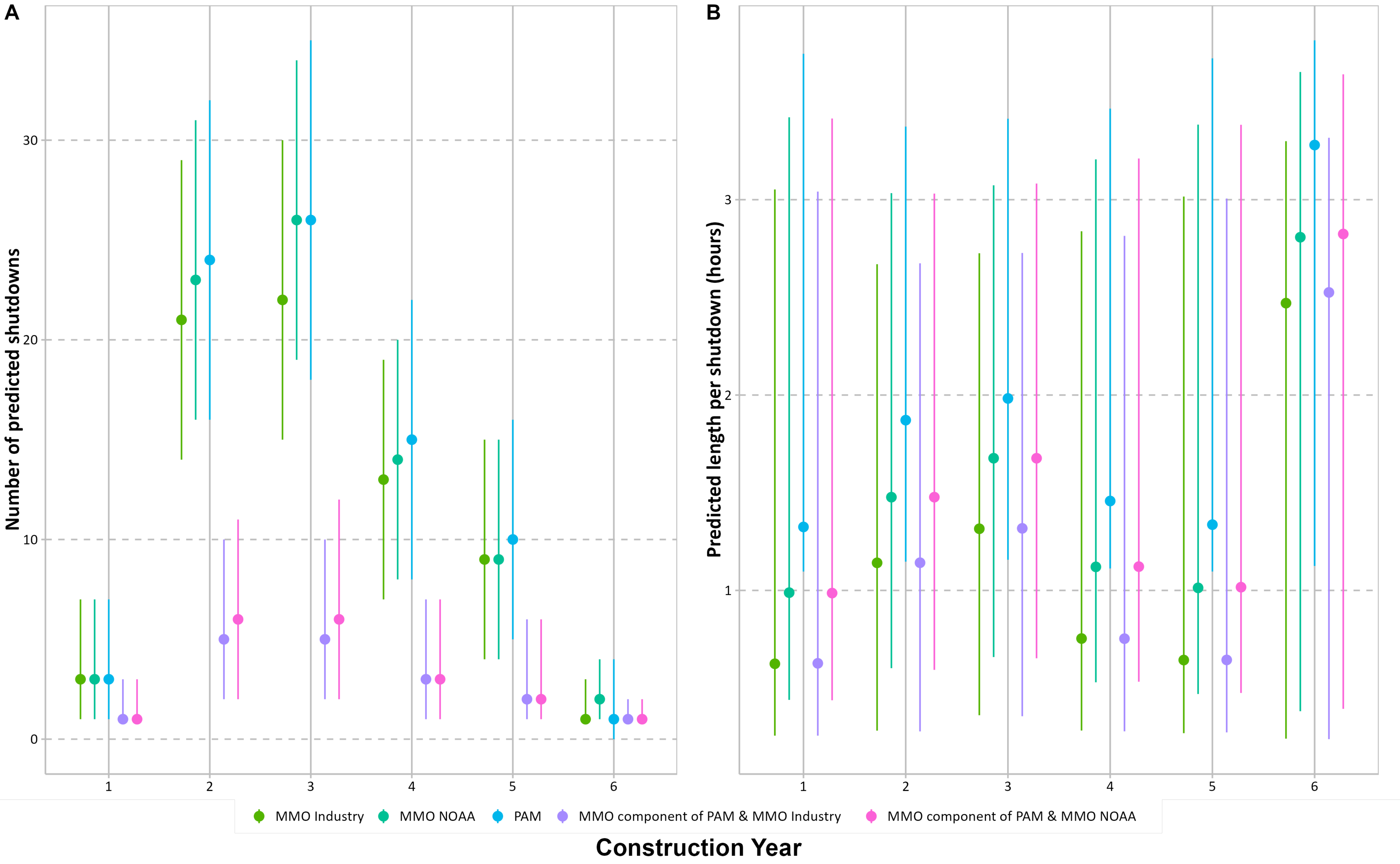


Figure 24. Potential lost foraging time per SRKW (A), potential lost prey captures per SRKW (B), and percent reductions in potential lost foraging time per SRKW (C), and potential lost prey captures per SRKW (D), as functions of different detection and shutdown mitigation strategies based on the modified schedule (Option 1) (referred below as MS). Potential lost foraging time and prey captures per SRKW are calculated considering the Mid-Point dose-response behavioural response coefficients, and assuming time to shutdown is variable by construction activity. Percentages are calculated considering the reference concept design schedule as the baseline.

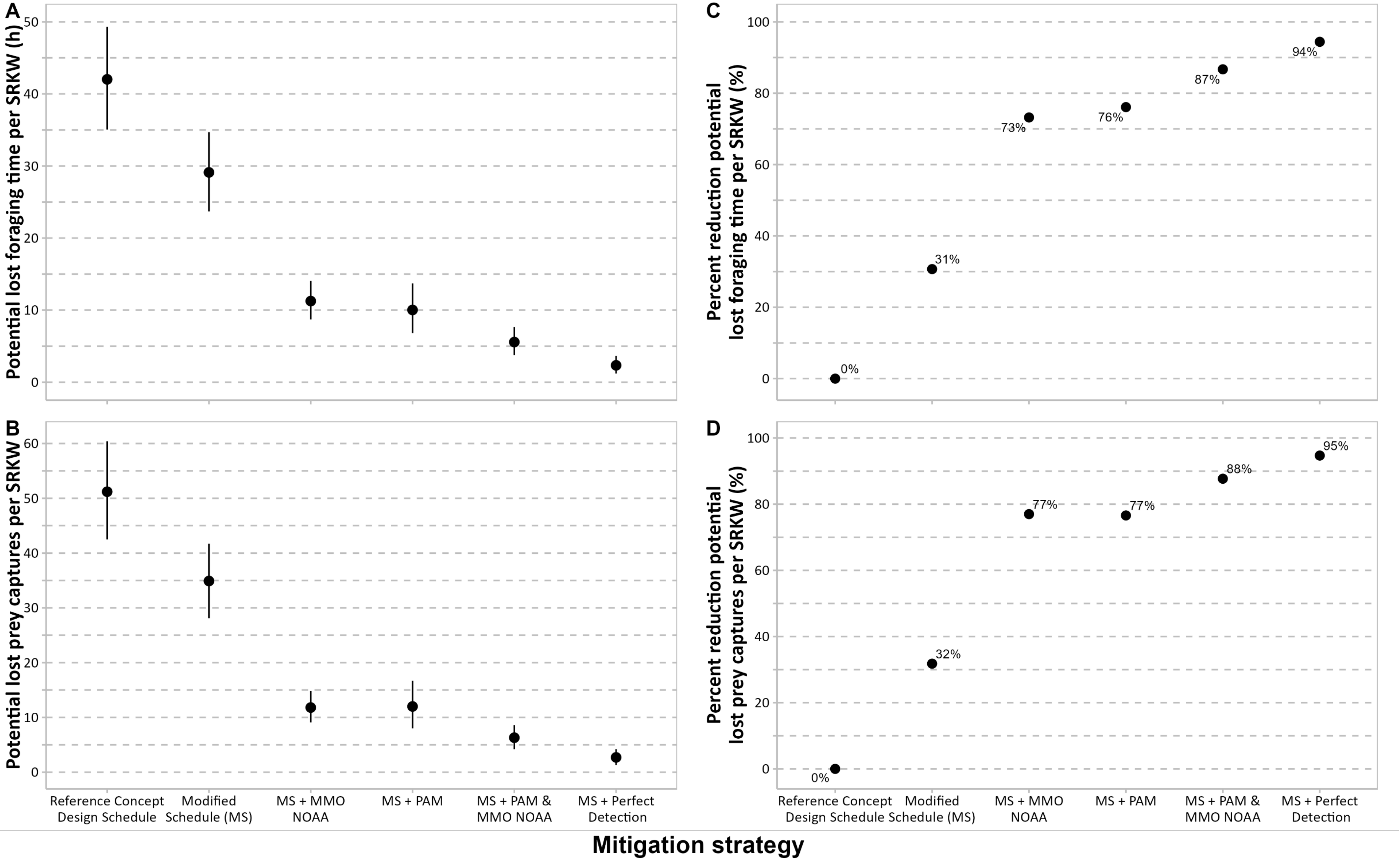
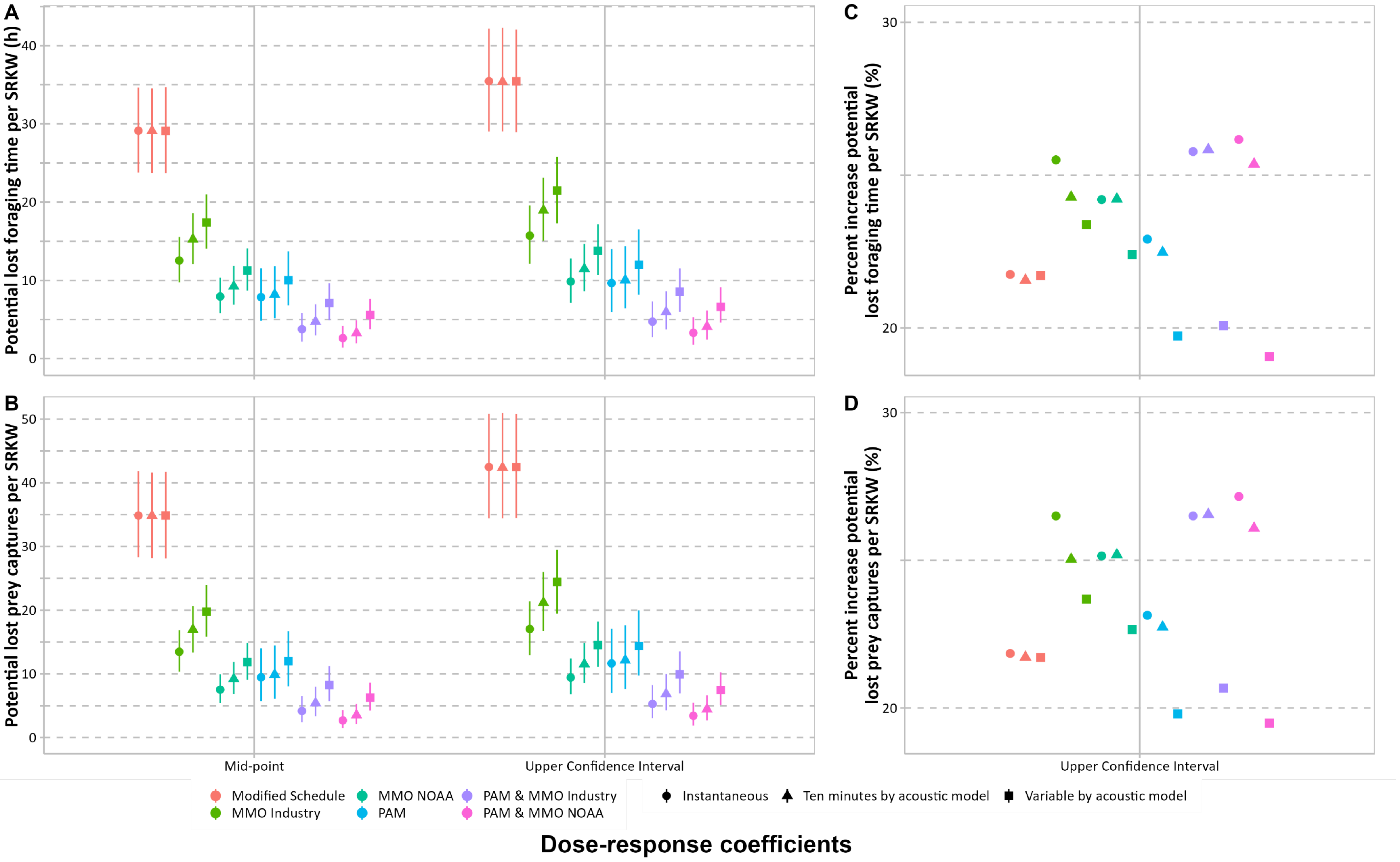


Figure 25. Potential lost foraging time per SRKW (A), potential lost prey captures per SRKW (B), percent increases in potential lost foraging time per SRKW (C), and potential lost prey captures per SRKW (D), as functions of alternate dose-response behavioural response probabilities for the modified schedule (Option 1), with detection and shutdown mitigation strategies applied. Colours represent mitigation strategies and shapes represent assumed delays in halting construction activities.



3.7. Assessing Uncertainty in SRKW Response

This section presents results on the assessment of uncertainty in the severity of the behavioural response elicited by in-water construction noise. To obtain an upper bound estimate of acoustic effects on SRKW, we calculated potential lost foraging time assuming that SRKW's response to underwater noise was greater than the mean response (i.e., the probability of response occurs at a lower noise received level) for the modified schedule (Option 1) (i.e., "Upper Confidence Interval" scenario presented in Section 2.5).

When considering uncertainty, the percent increase in potential lost foraging time and lost prey captures per SRKW was consistent irrespective of mitigation strategies and delays in construction shutdowns (Figure 25). Potential lost foraging time increased on average by approximately 23%, with some variability around that average value, but all were contained within the range of 19%-26%. A large proportion of the additional potential lost foraging time, when assessing for uncertainty, was accrued within the 120-129 dB acoustic effect zone, where the probability of construction noise eliciting behavioural responses is lower compared to the other zones. Percent increases were smaller (below average) for the PAM detection and construction shutdown mitigation strategy, and for the case when the time to halt construction was variable by construction activity. The estimated total lost foraging time per SRKW over the 6-year construction period remained below ~10 hours when using combined mitigation strategies if the probability of response is higher than assumed for the SRKW acoustic effects model.

4. DISCUSSION

This study examined the effectiveness of mitigation measures and detection methods combined under various mitigation strategies in reducing potential acoustic effects to SRKW from constructing the RBT2 Project. The potential acoustic effects that were considered included acoustic injury and behavioural disturbance. We considered the information requests by the Minister, review panel recommendations, feedback received from DFO prior to and during the public hearing, and input received by Indigenous groups and DFO during consultation of materials for the Minister's information request. We quantified potential effects (including metrics of uncertainty) within a simulation framework (i.e., acoustic effects model) to address the Minister's information request.

The acoustic effects model was based on conservative assumptions, such as the assumptions that SRKW forage 100% of the time, acoustic effect zones are larger than the acoustic footprints, and the behavioural responses coefficients are more acute than implied by the logarithmic nature of sound propagation. Therefore, estimates of potential lost foraging time and prey capture (metrics of behavioural response effects) presented are considered precautionary.

The likelihood of in-water construction noise causing acoustic injury to SRKW (either PTS or TTS), without considering mitigation, is small. With the use of sound dampening technology (e.g., confined bubble curtain), the potential for PTS acoustic injury was completely mitigated, while the potential for TTS acoustic injury was reduced from 331 m to 72 m based on impact piling assumptions from the

EIS (assumed under the reference concept design schedule). This is considered a precautionary estimate of acoustic injury zones for the refined reference concept design schedule which indicates impact piling is only required for PDA testing. For PDA testing, the area associated with the potential for TTS is reduced to <10 m. The potential for acoustic injury can be completely mitigated by implementing sound dampening technologies for impact pile driving (e.g., confined bubble curtains), and monitoring for SRKW and halting impact pile driving if a SRKW is detected. Further, planning this activity outside of the SRKW peak use period is an added precaution that further reduces the likelihood of any acoustic injury.

We assessed the effectiveness of a tiered approach of combined mitigation that could further reduce behavioural response effects of construction noise on SRKW. The first tier consisted of recent modifications to the timing of in-water construction to plan the noisiest activities and activities that could lead to acoustic injury outside the SRKW peak use period. The second tier represented detecting SRKW and shutting down in-water construction once SRKW are detected in a construction acoustic effect zone. We examined a series of monitoring methods to detect SRKW, which included MMOs with two different levels of effort based on 1) typical industry practices for construction monitoring and 2) enhanced effort based on NOAA protocols; PAM system; and their combination. The MMOs mitigation strategies assumed that detection functions are based on three weather states and are specific to SRKW. Parameters for the detection functions following NOAA protocols were derived from data reported by Barlow (2015). These parameters were modified, based on expert opinion, to create detection functions for MMO Industry protocols. The values implemented were validated and corroborated by interviewing experienced MMOs. We assumed that a PAM system can detect 75% of the transits within 6 km of the terminal berth face. This assumption was based on detection rates considered realistic given the uncertainties remaining without a final PAM design, and it does not necessarily reflect the maximum detection rates achievable by PAM systems. Advice from the PAM expert workshop will inform the design of a system that would be in place during construction to maximize detection effectiveness for SRKW. The port authority will continue to seek input from DFO on the design of an effective PAM system to monitor and mitigate effects of construction activities on SRKW and other marine mammals.

Modifications to the timing of construction activities led to a reduction in potential lost foraging time per SRKW from a median of ~42 hours (35.1 hours – 49.3 hours) over the six years of construction for the reference concept design schedule presented at the public hearing to ~29 hours (i.e., ~13-hour decrease or ~30%) for the modified schedule Option 1, before implementing any other mitigation measure. Construction timing modifications in Option 2 led to a reduction in potential lost foraging time per SRKW from the median of ~42 hours for the reference concept design schedule to ~33 hours (i.e., ~9-hour decrease or ~20%) over the 6 years of construction, before implementing any other mitigation measure. For this study, modified schedule Option 1 was used for evaluating the effectiveness of other mitigation strategies (monitoring for SRKW and associated construction shutdown).

The different SRKW detection methods (coupled with relevant in-water construction activity shutdown) varied in level of effectiveness. MMO NOAA protocols was ~20% more effective than MMO Industry protocols. The MMO NOAA protocols or PAM were similarly effective in reducing lost foraging time, but MMO NOAA protocols was more effective in reducing potential lost prey captures because MMOs can better detect SRKW transits in the day, when SRKW prey capture is highest. The addition of either MMO NOAA protocols or PAM to the modified schedule decreased lost foraging time by an additional ~40% over the reductions achieved by the modified schedule (Option 1) alone. When considering potential delays in shutting down in-water construction activities due to equipment constraints, mitigation strategies are ~10% less effective than if instantaneous shutdowns are assumed. Regardless, SRKW detection using combined detection methods and shutdown protocols achieved extensive reductions in acoustic effects after the implementation of the modified schedule (Option 1). The combined strategy of implementing the modified schedule and both PAM and MMOs NOAA protocols detection methods coupled with in-water construction shutdown led to an overall 87% reduction in potential lost foraging time per SRKW to 5.6 h (3.7 h-7.6 h) over the 6 years of construction compared to the reference concept design schedule without other mitigation measures. It is worth noting that, when considering the design and performance of the PAM system, the model suggests that increasing PAM efficiency to 90%, which is unlikely technically feasible, would increase effectiveness of the combined mitigation strategy by 7% (from 87% to 94%). The port authority will adopt a PAM system with the ability to detect vocalizing SRKW when transiting through the dominant acoustic footprints and adopting a marine mammal detection team using NOAA protocols to detect SRKW year-round.

During the public hearing, the port authority committed to employing infrared and other technologies if feasible by the time of construction (Commitment #33, VFPA 2019). Integrating early detection sources in addition to the other detection methods (i.e., MMO NOAA protocols and PAM), including adopting other feasible technologies, could theoretically improve effectiveness up to the maximum case modelled. In the case that all SRKW are detected, mitigation effectiveness would be improved by an additional 7% to a maximum of 94% reduction; to 2.3 h (1.2 h-3.6 h). This indicates that mitigation strategies that are currently feasible have the potential to reduce behavioural response effects from underwater noise on SRKW to low levels, close to the maximum possible. The port authority now proposes a year-round marine mammal detection team for the duration of the in-water construction period to integrate multiple, complementary detection techniques (e.g., early detection sources, MMO NOAA protocols, PAM system, or other feasible technologies) to detect SRKW before they enter applicable exclusion zones. Based on input received during consultation, the port authority now also proposes to monitor a buffer outside the exclusion zones to reduce potential effects associated with delays in equipment shutdowns. Nevertheless, there will be a small acoustic effect on SRKW remaining (see Table 12) as not all construction activities can cease due to safety reasons (e.g., tugs when towing). Acknowledging that perfect detection may not always be achieved, and all construction activities may not be halted before SRKW enter the exclusion zone, we estimate that a realistic range of potential lost foraging time per SRKW is likely to be 2.3 h – 7.6 h over the 6 years of in-water construction.

We evaluated the sensitivity of estimates of potential lost foraging time to uncertainties in the severity of behavioural responses to underwater noise on SRKW using more conservative probabilities that SRKWs will cease feeding when exposed to noise within each acoustic effect zone. Instead of using the median (50th percentile) dose-response probability of response, we used the 97.5th percentile (or upper confidence interval) to generate an upper bound estimate of behavioural disturbance effects to SRKW. With the application of the more conservative values, estimates increased on average by 23% (range 19-26%), resulting in potential lost foraging time of < 10 hours per SRKW for the 6 years of construction.

In summary, mitigation of potential acoustic effects to SRKW from constructing the proposed RBT2 Project can be highly effective. The potential for SRKW acoustic injury can be completely mitigated by implementing sound dampening technologies for impact pile driving and monitoring for SRKW and stopping impact pile driving if SRKW is detected. The effects of construction noise eliciting behavioural responses can be largely mitigated by implementing a combination of planning the noisiest in-water construction activities outside of the SRKW peak use period and monitoring for SRKW and halting in-water construction activities if a SRKW is detected.

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Appendix IR2020-2.3-F

RBT2 Southern Resident Killer Whale Construction Mitigation: Proposed construction schedule changes to reduce effects to SRKW and potential resulting interactions with Dungeness crabs

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RBT2 Southern Resident Killer Whale Construction Mitigation

Proposed construction schedule changes to reduce effects to SRKW and potential resulting interactions with Dungeness crabs

Executive summary

The Vancouver Fraser Port Authority (port authority) identified two construction schedule options to further avoid and reduce construction underwater noise effects on southern resident killer whales (SRKW). Both options would reduce potential effects to SRKW, especially in Year 3 of construction. Option 1 is predicted to be more effective at reducing potential effects to SRKW compared to Option 2. However, under Option 1, dredging would continue into the initial portion of the Year 2 Dungeness crab fisheries-sensitive window, which may affect brooding Dungeness crabs. These potential additional effects to crab are anticipated to be relatively low in magnitude, of short duration, and localized since dredging would occur for a limited time early in the window in Year 2 following a salvage and a period of continuous work in the same area.

Adopting Option 1 would require the port authority to adjust commitment #41 (CIAR Document #2001[1]) to enable dredging during the Dungeness crab fisheries-sensitive window in Year 2 from October 15 to November 30 (i.e., alter the duration to December 1 – March 31 for Year 2 only).

The port authority is continuing to seek feedback from Indigenous groups and Fisheries and Oceans Canada (DFO) on the two potential schedule options. We look forward to ongoing discussions on these possible schedule modifications.

Introduction

The port authority has been evaluating additional mitigation measures to further avoid and/or reduce effects to SRKW from underwater noise from in-water construction activities for the proposed Roberts Bank Terminal 2 (RBT2) Project. This included reviewing the six year in-water construction schedule[2] (base-case schedule presented to the review panel at the public hearing) to schedule the noisiest in-water activities outside the period of SRKW peak use of Roberts Bank (June 1 – August 31). The port authority focused on activities with the potential for acoustic injury (i.e., impact pile driving) and those that have the largest potential acoustic behavioural disturbance footprints for SRKW (e.g., vibro-densification and vibratory pile installation).

Through this work, we identified two options to further reduce potential effects on SRKW by modifying the timing of in-water activities while also considering the potential effects to other important species, such as Dungeness crabs, as a result of the modified timing.

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[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

[2] CIAR Document #1210 From the Vancouver Fraser Port Authority to the Review Panel re: Project Construction Update (See Reference Document #995) (NOTE: Updated June 13, 2018). https://iaac-aeic.gc.ca/050/documents/p80054/122934E.pdf

Two updated construction schedule options were identified. Option 1 is predicted to be more effective at reducing potential effects on SRKW than Option 2.

- **Option 1** proposes, in Year 2 of the six year construction schedule, to continue the dredging period for an additional month and a half, which would coincide with the first six weeks of the Dungeness crab fisheries-sensitive window (October 15 – March 31). Option 1 would allow dredging to end sooner in Year 3 of construction and for vibro-densification to begin and end earlier, resulting in less overlap between noise from in-water activities and months when SRKW are more often present at Roberts Bank. Based on the activity proposed, the port authority believes potential effects to Dungeness crab can be mitigated. In Option 1, activities are concentrated in months where SRKW are least present at Roberts Bank.
- **Option 2** does not extend dredging in Year 2 of construction for an additional six weeks. Thus, there is no overlap with the Dungeness crab-sensitive window. However, more noise from in-water activities would occur in Year 3 during times when SRKW are more often present; therefore, there is a smaller reduction in potential effects to the endangered whales.

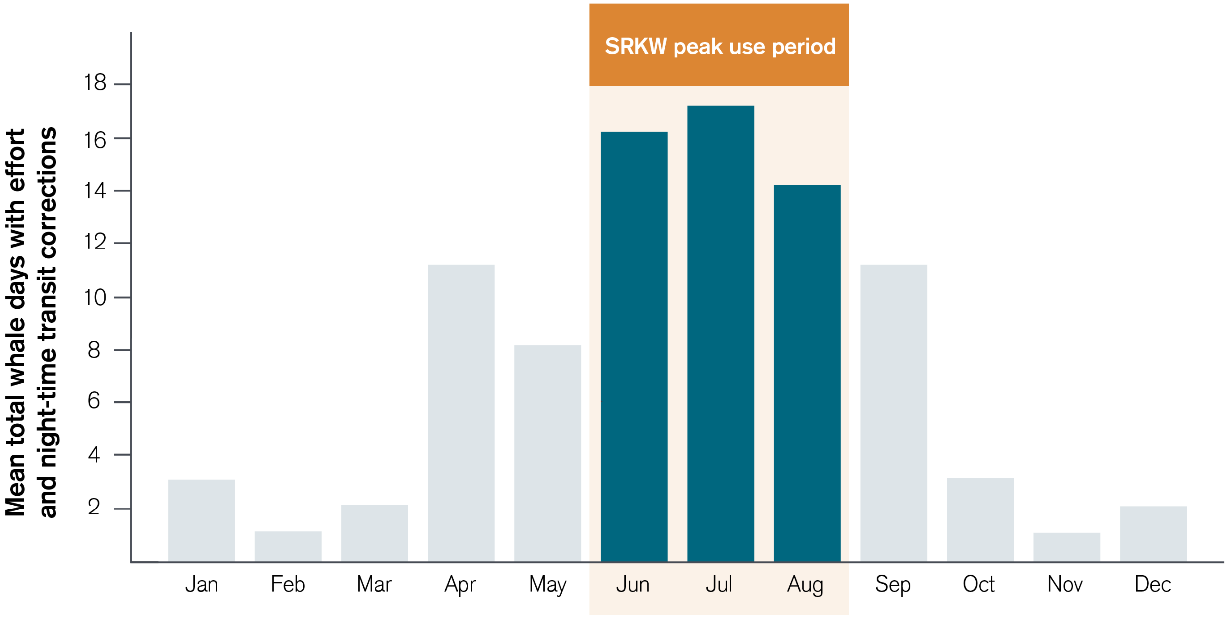
Feedback requested

The port authority has started seeking feedback from Indigenous groups and DFO on the two potential schedule options. To support discussions, the memorandum describes in further detail the two construction schedule options, the reductions in potential effects to SRKW and the potential implications to Dungeness crabs.

Construction schedule options

Two updated construction schedule options were identified. Both schedules time impact pile installation and vibro-densification to avoid the SRKW peak use period. SRKW typically visit Roberts Bank from April to September and the peak use period is from June to August (based on 16 years of data, 2002-2017) (**Figure IR2020-2.3-F1**).

Figure IR2020-2.3-F1: Average monthly SRKW sightings, with estimated seasonal effort and night-time transit corrections,[3] within 20 km of the proposed RBT2 terminal. Based on a comprehensive dataset of SRKW sightings between 2002 and 2017 from the BC Cetacean Sightings Network and Orca Master sightings databases



The two options differ primarily in the predicted timing of vibro-densification and dredging. **Figure IR2020-2.3-F2** below illustrates the anticipated timing of dredging and vibro-densification for each of the two updated schedule options and the base-case schedule shown alongside the environmental constraints considered in schedule development: the SRKW peak use period, the Dungeness crab fisheries-sensitive window, and the juvenile salmon fisheries-sensitive window.[4] The difference in timing of vibro-densification and dredging is based on the sequencing of these activities in each option. Dredging is required to construct the terminal wharf structure. Caisson foundation mattress rock must then be placed sequentially as the dredge basin is progressively dredged and then densified (i.e., vibro-densified) prior to placing the caissons required for the berth face.

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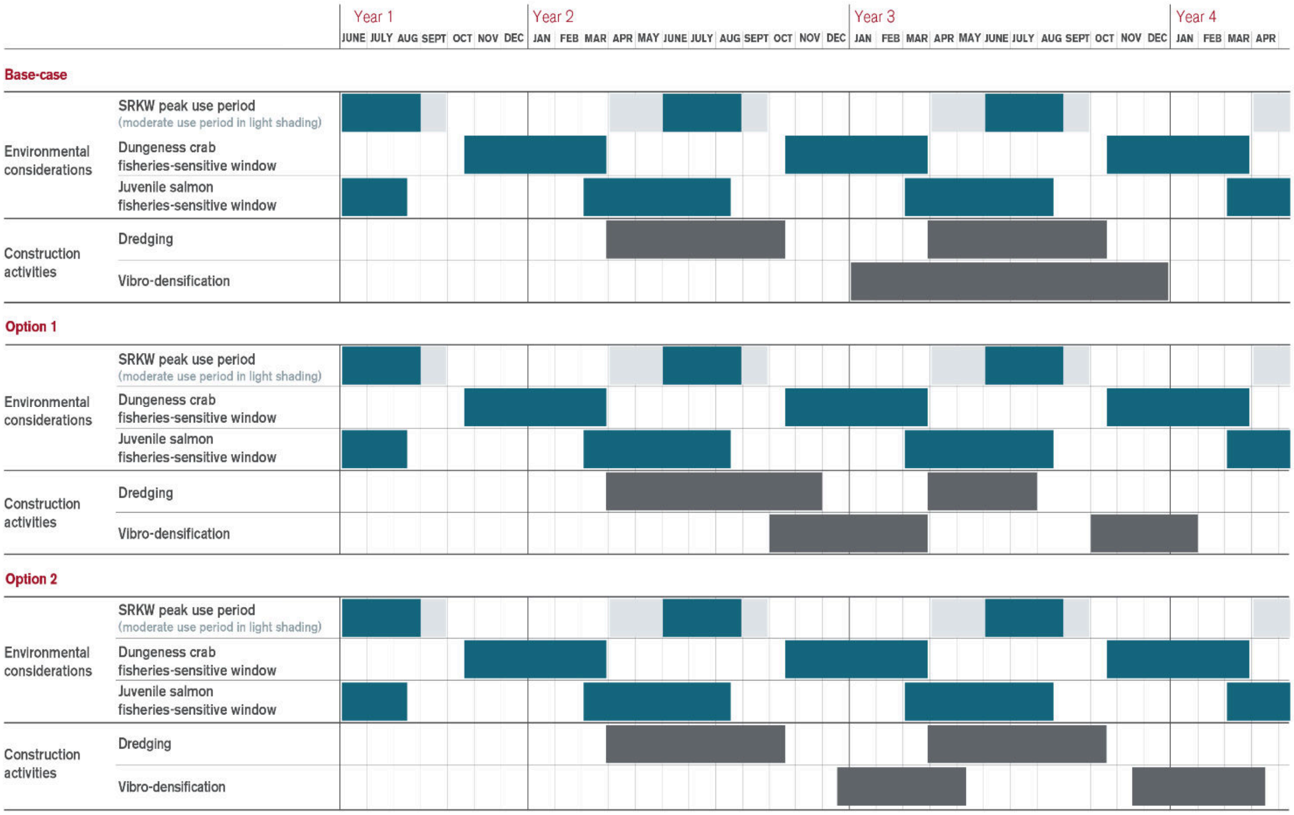
[3] Data from passive acoustic monitoring undertaken by the port authority near the proposed project in 2012 and 2013 was used to calculate a correction coefficient (i.e., 1.3) to represent the number of additional days that night-time transits likely occur.

[4] Note that the Dungeness crab fisheries-sensitive window constraint was applied to dredging of the dredge basin below –5 m chart datum (commitment #49, CIAR Document #2001), while the juvenile salmon fisheries-sensitive window constraint was applied to in-water activities above –5 m chart datum (commitment #53, CIAR Document #2001), which are not depicted in **Figure IR2020-2.3-F2** but affect the overall schedule.

Figure IR2020-2.3-F2: Timing of dredging and vibro-densification for the base-case, Option 1, and Option 2 schedules based on construction and environmental constraints and dependencies



For **Option 1**, dredging would take place for eight consecutive months in Year 2, stopping at the end of November (**Figure IR2020-2.3-F2**). This is six weeks longer than in Option 2 (and the base-case). By extending dredging in Year 2, the remaining dredging in Year 3 would require less time (four months) and would end earlier, by the end of July. Additional dredging in Year 2 also allows vibro-densification of the mattress rock to begin earlier (October of Year 2). The ~10 months vibro-densification schedule is partitioned over two stages: 1) October of Year 2 to March of Year 3, and 2) October of Year 3 to January of Year 4.

For **Option 2**, dredging would take place for 6.5 consecutive months in Year 2 and would stop by October 14. To complete the dredging works, an additional 6.5 months of dredging would likely be required over the same period (April 1 – October 14) in Year 3. Vibro-densification of the mattress rock (~10 months) would similarly be partitioned over two stages but could not begin as early in Year 2[5] and thus would end later in Year 4: 1) mid-December of Year 2 to mid-May of Year 3, and 2) mid-November of Year 3 to mid-April of Year 4 (**Figure IR2020-2.3-F2**).

Reductions in potential acoustic effects to SRKW

Because SRKW presence at Roberts Bank changes seasonally, the predicted reduction in potential effects from underwater noise to SRKW of each schedule option differs based on the time of year when these underwater

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[5] Interdependencies of in-water construction activities associated with the dredge basin is described in **Appendix IR2020-2.3-A**

activities are planned. As illustrated in **Figure IR2020-2.3-F2**, Option 1 has dredging and vibro-densification overlapping the fewest number of months when SRKW are most often present.

The modified dredging schedule as part of Option 1 reduces potential effects to SRKW by avoiding dredging during August and September of Year 3, which are months of SRKW peak and moderate use, respectively. Also, extending dredging in Year 2 permits vibro-densification to take place earlier and consequently entirely outside the periods of SRKW peak and moderate use (**Figure IR2020-2.3-F2**). Option 1 is predicted to reduce potential SRKW lost foraging time from a median of ~42 hours for the base-case schedule[6] to ~28 hours over the six years of construction (i.e., reducing ~14 hours or ~30% overall, and ~60% in Year 3).

In contrast, Option 2 predicts a reduction in potential lost foraging time per SRKW from the median of ~42 hours in the base-case to ~34 hours over the six years of construction (i.e., reducing effects by ~8 hours or ~20% overall, and ~40% in Year 3). The difference in potential effects to SRKW is primarily based on the predicted timing of dredging and vibro-densification (**Figure IR2020-2.3-F2**). In Option 2, there is no change in the dredging schedule from the base-case and thus no reduction in overlap with the SRKW peak use or moderate use periods. Vibro-densification also does not completely avoid months of SRKW moderate use (April and May; **Figure IR2020-2.3-F1**), in both Year 3 and 4, compared to Option 1 (**Figure IR2020-2.3-F2**).

When comparing both options, Option 1 is more effective in reducing effects to SRKW than Option 2. The Option 1 schedule is predicted to result in the fewest instances when SRKW individuals or pods transiting through Roberts Bank may be exposed to construction related underwater noise potentially causing behavioural disturbance. Note, these reductions in estimated effects are only related to proposed schedule changes and do not reflect other mitigation measures we have committed to implement to avoid and reduce construction acoustic effects to SRKW.

Potential interactions with Dungeness crabs

The port authority has committed to employing several mitigation measures to avoid and reduce project effects to Dungeness crabs. One of the most important measures is to conduct crab salvages (commitment #51, CIAR Document #2001) of the dredge basin prior to the start of dredging in each year (i.e., Year 2 and Year 3). The port authority also committed to working with Indigenous groups and specifically collaborating with Tsawwassen First Nation and Musqueam Indian Band to pilot salvaging methods that minimize the handling of crabs prior to construction. The port authority committed to avoiding in-water activities (in waters below –5 m chart datum), which would disturb the native subtidal seabed (i.e., dredging) from October 15 to March 31. Project offsetting will also create high suitability habitat for juvenile crabs. In addition to mitigation measures, which includes offsetting, the port authority also committed, as part of the RBT2 follow-up program, to verify the project effects predictions regarding Dungeness crab (CIAR Document #2001).

As noted earlier, the Option 1 construction schedule includes continuing dredging during the initial portion of the Dungeness crab fisheries-sensitive window in Year 2, whereas Option 2 would not. The port authority developed and committed to a fisheries-sensitive window to protect brooding female Dungeness crabs that may bury during this time of year. We assume that female crabs actively use the project footprint area (including the dredge basin) to brood based on data confirming their presence at Roberts Bank. We adopted a precautionary approach in selecting the period from October 15 to March 31 as the fisheries-sensitive window. The time of year reflects literature for the entire Pacific coast (i.e., not limited to the Strait of Georgia). Moreover, the duration of the

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[6] Since the public hearing, the port authority developed an acoustic effects model to evaluate the potential effectiveness of different construction mitigation options. The model estimates lost foraging time as the metric of time within which a transiting SRKW may be exposed to underwater noise exceeding acoustic injury and behavioural disturbance thresholds for impulse noise (e.g., impact piling) or behavioural disturbance thresholds for continuous noise (e.g., vibro-densification) assuming that SRKW foraging 100% of the time.

fisheries-sensitive window (lasting 22 weeks or ~165 days) is longer than the time required by crabs to brood, which is estimated at ~65 to 130 days (O'Clair et al. 1996).

If schedule Option 1 is adopted, we anticipate, with mitigation, continuing dredging into the early portion of the Dungeness crab fisheries-sensitive window is unlikely to cause measurable additional effects to Dungeness crab. The port authority expects that because active dredging will be underway in the dredge basin starting in April that brooding females are likely to choose to brood in other nearby suitable habitats[7] or delay brooding instead of burying in the dredge basin. Further, dredging would be limited to the initial portion of the window likely allowing sufficient time for female crabs to brood.

References

O'Clair, C. E., T. C. Shirley, and S. J. Taggart. 1996. Dispersion of Adult Cancer magister at Glacier Bay, Alaska: Variation with Spatial Scale, Sex, and Reproductive Status. Pages 209–227 in. High latitude crabs: Biology, management, and economics. University of Alaska Sea Grant, AK-SG-96-02, Fairbanks, Alaska.

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[7] Habitat suitability modelling conducted specifically for the gravid life stage indicates that substantial amounts (over 700 ha, ~85%) of suitable brooding habitat will remain available to gravid crab at Roberts Bank post-project construction. In the literature, brooding habitat is simply characterized as highly permeable, well oxygenated sandy sediment and this type of habitat is abundant in the region, as the entire delta foreslope is comprised of sand (EIS Section 12.6.3.3, Table 12-9, CIAR Document #181).