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ECHO Program

2020 voluntary vessel slowdown in Haro Strait and Boundary Pass

Vancouver Fraser Port Authority

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Executive summary

This report summarizes the development, implementation and results of the 2020 voluntary vessel slowdown in Haro Strait and Boundary Pass. The slowdown was coordinated and implemented by the Vancouver Port Authority-led Enhancing Cetacean Habitat and Observation (ECHO) Program, with the ECHO Program's vessel operators committee and advisory working group members providing valuable input and advice throughout the development, implementation and evaluation of the slowdown.

Context for and purpose of the voluntary vessel slowdown

The southern resident killer whale (SRKW) population has decreased over the last several years but saw the birth of two calves in 2020, bringing the population to 74 individuals, as of December 31, 2020 (Center for Whale Research). Research indicates that underwater vessel noise can interfere with the whales' ability to navigate, communicate and find their prey.

Historical data indicates that southern resident killer whales are most frequently detected in Salish Sea waters, including Haro Strait and Boundary Pass, between June and October.

The seasonal slowdowns that have been in place since 2017 have demonstrated that reducing the speeds of vessels can be effective in reducing the underwater noise generated at the vessel source and total underwater noise in nearby habitats, which may benefit the behaviour and feeding success of the southern resident killer whales.

In May 2019, the Government of Canada entered into a first-of-its-kind *Species at Risk Act*, Section 11 conservation agreement with Vancouver Fraser Port Authority, Pacific Pilotage Authority and five marine transportation industry partners to support the recovery of the southern resident killer whales. In an effort to provide additional benefits to the behaviour and foraging of the SRKW, in 2019 the slowdown area was expanded to include both Haro Strait and Boundary Pass, and vessel speed targets were further reduced. These parameters were maintained for the 2020 voluntary slowdown.

Operations and monitoring

When safe and operationally feasible to do so, operators of vehicle carrier and container ships were encouraged to transit Haro Strait and Boundary Pass at 14.5 knots or less speed through water. Bulk cargo vessels, tankers and government vessels were asked to transit at 11.5 knots or less speed through water. At the outset of the 2020 voluntary vessel slowdown, more than 80 organizations indicated their support of the underwater noise reduction initiative and their intention to participate.

Due to the global pandemic, all cruise ships and Washington State Ferries transits in the slowdown area were cancelled.

The initiation and conclusion of the slowdown was determined by presence of the SRKW, confirmed by trusted observers and hydrophone data. The slowdown began on July 1, 2020 and ended on October 31, 2020.

Changes in ambient noise were measured with hydrophones, and computer models were run to predict underwater noise reductions throughout the slowdown region, and how these reductions may benefit the

behaviour and foraging of killer whales. Killer whale presence was monitored through both visual observations from shore and acoustic detections via hydrophones in Haro Strait and Boundary Pass.

Results

The Pacific Pilotage Authority (PPA) reported that 91% of ship transits (1,803 of 1,980 transits) participated during the slowdown, compared to 82% in 2019, 87% in 2018 and 61% in 2017. Although not all participating vessels could accurately achieve the speed targets, 68% of transits came within one knot of the target speeds.

The SRKW were present in the slowdown area on 40 of the 123 days (or 33%) that the slowdown was active.

Evaluation of the total ambient noise levels indicated a median reduction in underwater broadband received sound pressure level (SPL) of 2.5 dB (a 44% reduction in sound intensity) near Lime Kiln in Haro Strait, and 2.8 dB (a 48% reduction in sound intensity) at the hydrophone station near the shipping lanes in Boundary Pass, when compared to the pre-slowdown baseline period. These values include times when large vessels were present, filtered to exclude confounding noise factors such as small vessel presence and periods of high wind and current.

Modelling of southern resident killer whale behaviour and foraging predicted a ~17% improvement in foraging time on an average traffic day during the 2020 slowdown for the full model area (including Haro Strait, Boundary Pass and the Gulf Islands). When focusing only on the Haro Strait region, the improvement in foraging time was modelled to be 20%.

The results of the 2020 vessel slowdown further demonstrate that voluntary measures are an effective way of managing threats to at-risk whales. Lower ship speeds reduce the underwater noise generated at the vessel source as well as total underwater noise in nearby habitats, improving foraging conditions for the SRKW. Despite longer transit times, the vessel speeds and participation rates achieved during the 2020 slowdown indicated a quantifiable reduction in underwater noise, and predicted a reduction in affected foraging time for the SRKW, when compared to baseline conditions. The duration of the 2020 slowdown combined with the high participation rate appears to have provided the greatest predicted benefit to SRKW foraging and behaviour of all of the ECHO Program voluntary vessel slowdowns to date.

Future vessel slowdowns will build on the learnings of the slowdown initiatives to date.

1. Background

This report summarizes the development, implementation and results of the 2020 voluntary vessel slowdown in Haro Strait and Boundary Pass. The slowdown was coordinated and implemented by the Enhancing Cetacean Habitat and Observation (ECHO) Program, with the ECHO Program's vessel operators committee and advisory working group members providing valuable input and advice throughout the development, implementation and evaluation of the slowdown.

The purpose of the slowdown was to help reduce underwater vessel noise impacts in known areas of importance to the southern resident killer whale (SRKW) in Haro Strait and Boundary Pass. Data collection and analysis was undertaken to help measure the level of voluntary vessel participation and speeds achieved as well as the level of underwater noise reduction achieved by slowing vessels.

The slowdown took place between July 1 and October 31, 2020, and involved speed reductions for large commercial vessels transiting the shipping lanes of Haro Strait and Boundary Pass (Figure 1).

1.1. The ECHO Program

The ECHO Program is a Vancouver Fraser Port Authority-led initiative aimed at better understanding and managing the effects of large commercial vessel-related activities on at-risk whales throughout the southern coast of British Columbia (B.C.).

The geographic scope of the port authority's jurisdiction is limited; therefore, in order to adequately understand and address the cumulative effects of commercial ship activity on whales regionally, a collaborative approach is required. To this end, since 2014 the port authority has been collaborating with an advisory working group and technical committees made up of Canadian and U.S government agencies, marine transportation organizations, Indigenous communities, conservation and environmental groups, and scientists to advance ECHO Program projects within the Salish Sea. The long-term goal of the program is to quantifiably reduce threats to at-risk whales as a result of large commercial vessel-related activities.

1.2. Context for the voluntary vessel slowdown

A number of at-risk species of cetaceans (whales, dolphins and porpoises) inhabit the Pacific waters of southern B.C. and northern Washington State. Key among these species is the endangered southern resident killer whale, with a population of 74 individuals as of December 31, 2020 (Center for Whale Research, 2021). The key threats to SRKW and other at-risk whales in this region include acoustic disturbance (underwater noise), physical disturbance (presence and proximity of vessels), environmental contaminants and availability of prey. Acoustic disturbance related to shipping traffic is a priority focus area for the ECHO Program.

Fisheries and Oceans Canada's recovery strategy (Fisheries and Oceans Canada 2011; 2016; 2017) designates much of the Salish Sea as SRKW critical habitat—the habitat necessary for the survival or recovery of the species. Under the *Endangered Species Act*, critical habitat has also been designated in much of the U.S. waters of the Salish Sea. Killer whales use sound to navigate, communicate and locate prey via echolocation, and underwater noise generated by vessels can impede these functions.

Since its inception, the ECHO Program's advisory working group and vessel operators committee have provided the ECHO Program team with input and advice during the development and implementation of the voluntary vessel slowdowns. The composition of the advisory working group and the vessel operators committee is described in section 2.1.

Results from the 2017, 2018 and 2019 slowdowns demonstrated that reducing ship speeds is an effective way of reducing both the underwater noise generated at the ship source (MacGillivray et al, 2018a) and total underwater noise in nearby habitats, which is in turn predicted to benefit the behaviour and feeding success of the southern resident killer whale (SMRU, 2018b, 2019a, 2019b).

In May 2019, the Government of Canada entered into a first-of-its-kind *Species at Risk Act*, Section 11 conservation agreement with Vancouver Fraser Port Authority, Pacific Pilotage Authority and five marine transportation industry partners to support the recovery of the southern resident killer whales. The agreement formalizes the role of the ECHO Program and the participation of the marine industry and government to continue working collaboratively over a five-year term, with a focus on reducing acoustic and physical disturbance of large commercial vessels operating in southern resident killer whale critical habitat. The Advisory Working Group selected key Conservation Agreement measures to be Key Performance Indicators (KPIs) to evaluate the overall effectiveness of the agreement. The slowdown vessel participation rate, reduced ambient noise levels in SRKW foraging areas and affected foraging time in Haro Stait were selected as KPIs for the Conservation Agreement.

Due to the uncertainty of the global COVID-19 pandemic, the Advisory Working Group recommended the 2020 slowdown parameters including location, speed targets and dynamic start/stop approach, remain consistent with 2019. Marine mammal observers began monitoring Haro Strait and Boundary Pass on June 1 for SRKW presence. SRKW were first visually confirmed in Haro Strait on July 1, triggering the start of the slowdown, which remained active until October 31, 2020.

In 2019 Transport Canada recognized that reducing vessel speeds over the extended distance through Boundary Pass could have cost implications for vessel owners, operators and agents, with increased pilotage fees identified as one possible source of increased costs. To reduce the financial risk of participating in the expanded voluntary slowdown, Transport Canada created a reimbursement program to cover additional pilotage costs incurred as a result of participating in the 2019 slowdown. In 2020, vessels that experienced slippage into the next hour of pilotage time, exceeded eight hours of pilotage time, or required double pilotage due to participation in the slowdown, were again eligible for a reimbursement.

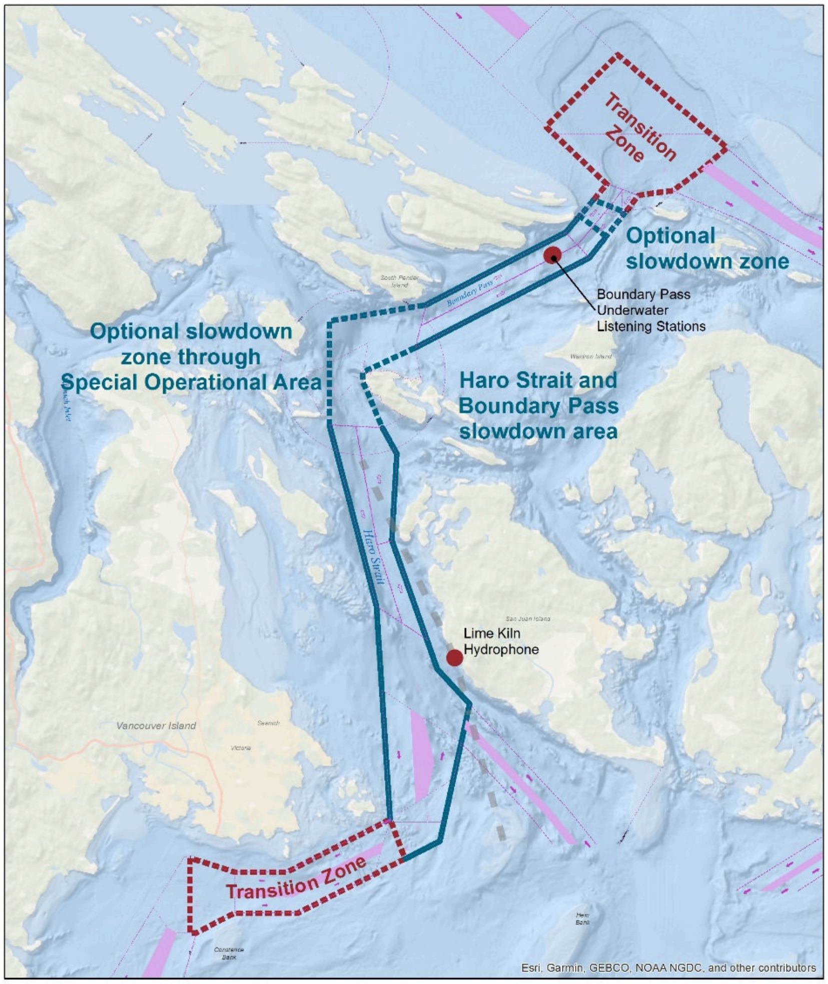
Throughout this report, vessel types are grouped together based on business sector, cargo type and vessel size and shape. Bulker refers to bulk carriers and general cargo vessels carrying bulk, breakbulk and project cargo. Tanker refers to tanker vessels carrying liquid bulk cargo. Other includes yachts, tugs and heavy lift vessels subject to pilotage. Government vessels, such as those belonging to the Royal Canadian Navy or Fisheries and Oceans Canada, frequently participated in the slowdown, but are not included in the statistics of piloted commercial vessels. Due to COVID-19, all cruise ship and Washington State Ferry transits through the slowdown area were cancelled in 2020, and are not reflected in this year’s study.

1.3. Development of the slowdown parameters

1.3.1. Slowdown area

The slowdown area in Haro Strait and Boundary Pass—from Discovery Island to the south and the eastern tip of Saturna Island to the north—was unchanged from 2019 and is a total of 29.6 nautical miles (Figure 1). The slowdown area included two optional slowdown zones where those operating the vessel were encouraged to participate, only if it was navigationally safe to do so. The transition zones before and after the slowdown area were marked to encouraged vessel operators to slow down to the appropriate speed prior to entering the slowdown area.

Figure 1: 2020 voluntary vessel slowdown area



Source: Vancouver Fraser Port Authority

1.3.2. Slowdown speeds

Due to the uncertainties and challenges of COVID-19, the vessel operators committee and advisory working group recommended that the 2020 slowdown speeds remain the same as those set in 2019.

When it was safe and operationally feasible to do so, vehicle carriers and container vessel operators were encouraged to transit the slowdown area at 14.5 knots or less speed through water. Bulkers, tankers and government vessel operators were asked to transit at 11.5 knots or less.

Transiting at the 2020 slowdown target speeds of 14.5 and 11.5 knots was estimated to add between 16 and 28 minutes to the total transit time, depending on the vessel type. Table 1 shows the average predicted increase in transit time for vessels transiting the slowdown area during the 2020 slowdown, relative to typical vessel speeds.

Table 1: Predicted average increases in transit time during 2020 slowdown

Vessel type	Target speed through water (knots)	Average speed through water (knots)	Average increase in transit time (minutes)
Vehicle carrier	14.5	17.3	16
Container	14.5	18.9	28
Bulker	11.5	13.5	23
Tanker	11.5	13.7	27

1.3.3. Dynamic start and end dates

To provide the most potential benefit to the SRKW while limiting slowdown impacts to industry, the 2020 slowdown timing was set to begin any time after June 1 once SRKW came into either Haro Strait or Boundary Pass, and end any time between September 30 and October 31, depending on whale presence. This timeframe was proposed based on historical information indicating SRKW annual presence in the area is highest between June and September.

The SRKW monitoring period began on June 1, 2020. SRKW were confirmed present in Haro Strait by trusted observers and hydrophone data on July 1, 2020 thus initiating the slowdown. The official start to the slowdown was communicated to mariners through a Navigational Warning (NAVWARN), via email to the Pacific Pilotage Authority, BC Coast Pilots, shipping associations and agents, and ECHO Program newsletter distribution list, and posted to the ECHO Program webpage.

Vessel operators were advised that the slowdown would continue until at least September 30, 2020, and that if the whales were still confirmed present at that time, would be extended for two week periods to no later than October 31, 2020. This process of monitoring, evaluation and adaptive two week extensions resulted in a slowdown period of 123 days, from July 1 to October 31, 2020.

2. Implementation

The implementation of the voluntary vessel slowdown initiative required the preparation of materials, communication and engagement with stakeholders, and technical aspects of evaluating the success of the slowdown through vessel participation and underwater noise monitoring. The following section provides further details on the implementation of the 2020 voluntary vessel slowdown initiative.

2.1. Engagement and communications

The ECHO Program advisory working group convened six times in 2020 to share input and advice during the development, implementation and evaluation phases of the slowdown. The advisory working group includes members from the following organizations:

- BC Coast Pilots
- BC Ferries
- Canadian Coast Guard
- Chamber of Shipping
- Council of Marine Carriers
- Cruise Lines International Association – North West & Canada
- Department of National Defence and the Canadian Armed Forces
- Fisheries and Oceans Canada
- Indigenous individuals
- National Oceanic and Atmospheric Administration (NOAA)
- Natural Resources Defense Council
- Ocean Wise
- Pacific Pilotage Authority
- Shipping Federation of Canada
- Transport Canada
- Vancouver Fraser Port Authority
- Washington State Ferries
- WWF-Canada

The ECHO Program vessel operators committee convened seven times throughout the year to assist in the development of parameters for the 2020 slowdown and support monitoring of participation and results. The vessel operators committee includes members from the following organizations:

- BC Coast Pilots
- BC Ferries
- Canadian Coast Guard
- Chamber of Shipping
- Council of Marine Carriers
- Cruise Lines International Association – North West and Canada
- Hapag-Lloyd
- Holland America Group
- International Ship-Owners Alliance of Canada (ISAC)
- Marine Exchange of Puget Sound
- Pacific Merchant Shipping Association
- Pacific Northwest Ship & Cargo Services
- Pacific Pilotage Authority
- Royal Canadian Navy
- Shipping Federation of Canada
- Transport Canada
- U.S. Coast Guard
- Vancouver Fraser Port Authority
- Washington State Ferries

A number of communication tools including backgrounders, maps, presentations, decision matrices and a webpage were developed and shared to raise awareness about the 2020 voluntary vessel slowdown initiative. A Canadian Coast Guard navigational warning (NAVWARN) was issued on the start and end date of the slowdown. Email newsletters from the ECHO Program were sent biweekly throughout the slowdown and included updates on participation rates.

The Pacific Pilotage Authority dispatch system was amended to include tracking of the vessel owner or agent’s intent to participate and to allow reporting from the BC Coast Pilots after each vessel transit to indicate whether the vessel slowed down and whether it was eligible for reimbursement. The Pacific Pilotage Authority’s vessel participation and reimbursement eligibility data were provided to the ECHO Program team. The ECHO Program team then communicated this data to industry participants and others through bi-weekly newsletters and vessel operators committee meetings and, where relevant, reimbursement payments.

A virtual recognition event was held on December 1, 2020 with zoologist and marine mammal scientist Dr. Anna Hall as a guest speaker. In addition, certificates of appreciation, letters of thanks and a small gift were mailed to each organization that supported, or participated in, the 2020 ECHO Program initiatives.

2.2. Monitoring

Automated identification system (AIS) receivers stationed at the Lime Kiln State Park on San Juan Island, Washington, and at a property on Cliffside Road, Saturna Island, B.C., provided information such as vessel type, name, speed and draught on each AIS-enabled vessel transiting the slowdown area. This data was used to assess rates of vessels achieving target vessel speeds through the slowdown area.

Since February 2016, SMRU Consulting North America (SMRU) has been conducting continuous monitoring of total ambient underwater noise using a hydrophone installed at a water depth of 23 metres, approximately 70 metres in front of the Lime Kiln lighthouse. This particular location is within key summer foraging habitat for the SRKW and provides a representation of sound levels that may be received by the whales when they are in this part of Haro Strait. The Lime Kiln hydrophone also provided acoustic detections of killer whales during the slowdown period.

JASCO Applied Sciences Ltd. has maintained autonomous hydrophone deployments in Boundary Pass since August 2018, which were retrieved and redeployed approximately every three months. In June, 2020, these autonomous deployments were replaced with a long-term, real-time underwater listening station (ULS) consisting of two tetrahedral hydrophone arrays, cabled to shore on Saturna Island. Both the autonomous deployments and the cabled ULS are located near the shipping lanes at an approximate depth of 190 metres to measure vessel source levels and ambient noise, and to acoustically detect marine mammals.

The data collected at the two hydrophone sites were used to evaluate reductions in total ambient underwater noise from slowdown efforts, as well as to supplement the visual observations of marine mammals collected by observers. On San Juan Island, marine mammal observers from the Whale Museum, in collaboration with SMRU, were stationed at Lime Kiln overlooking Haro Strait. On Saturna

Island, a Simon Fraser University student was engaged in collaboration with Saturna Island Marine Research and Education Society (SIMRES) to observe marine mammals from East Point Park, overlooking Boundary Pass and the Strait of Georgia.

In addition to the monitoring of underwater noise levels, ship traffic and whale presence in Haro Strait and Boundary Pass as described above, computer modelling of vessel underwater noise and SRKW behaviour was also conducted to evaluate the effectiveness of the slowdown. Significant improvements to the noise and behavioural response models were completed in conjunction with the 2019 slowdown analysis (JASCO and SMRU, 2020), and the 2020 program maintained these model improvements. Results of these monitoring and modelling activities are described in sections 5 and 6.

3. Evaluation and results: industry participation

All commercial vessels over 350 gross tonnes and pleasure craft over 500 gross tonnes are subject to compulsory pilotage in B.C.'s coastal waters. The BC Coast Pilots embark and guide vessels coming in or out of B.C.'s ports to ensure safety, efficiency and environmental protection. In this report, we refer to these types of commercial and pleasure craft as "piloted vessels."

The ECHO Program slowdown monitoring and reporting efforts targeted these piloted vessels transiting through the Haro Strait and Boundary Pass slowdown area. Some piloted vessels transited only one of the Haro Strait or Boundary Pass slowdown zones because they were destined for, or repositioning to, anchorages in the southern Gulf Islands.

During the 18-week slowdown period, between 00:01 July 2, 2020 and midnight on October 31st, 2020, the Pacific Pilotage Authority reported 1,980 piloted vessel transits through Haro Strait and/or Boundary Pass. Of those piloted vessels, 1,623 vessels passed through both Haro Strait and Boundary Pass, 108 through Haro Strait only, and 249 through Boundary Pass only.

Due to the global pandemic, some vessel movements were interrupted. All cruise vessels were prohibited from entering Canadian waters during the slowdown season, and Washington State Ferries cancelled their ferry route between Anacortes, WA and Sidney, BC. These vessel types are not included in the 2020 slowdown analysis.

Using the same approach as the 2017, 2018 and 2019 slowdowns, the Pacific Pilotage Authority modified their dispatch system so shipping agents could indicate the vessel owner's intention to participate in the slowdown at the time a pilot order was placed. Orders could be flagged as 'yes' (full commitment), 'yes-conditional' (based on prevailing conditions during the transit such as schedule and weather), or 'no' (would not participate). The Pacific Pilotage Authority dispatch system was also modified to allow pilots to report at the end of their assignment on whether the vessel was able to participate in the slowdown or not.

In addition to the pilot-reported vessel participation rates, the ECHO Program also considered participation rates from the perspective of vessels achieving speed through water targets. ECHO Program consultants evaluated speed through water (STW) using the Automatic Identification System (AIS) data to determine vessels speed over ground and then correcting to STW based on localized current modelling.

3.1. Intent to participate

At the outset of the 2020 voluntary vessel slowdown, more than 80 organizations indicated their support of the ECHO Program's suite of voluntary underwater noise reduction initiatives, when safe and operationally:

- ACGI Shipping Inc.
- American Waterways Operators
- BC Coast Pilots
- Canadian Coast Guard
- Canadian Hydrographic Service
- Canpotex Shipping Service
- Canship Ugland Ltd.
- Chamber of Shipping

- China Navigation Co. Pte. Ltd.
- CMA CGM
- Colley West Shipping Ltd.
- COSCO Shipping Canada Inc.
- Council of Marine Carriers
- Cruise Lines International Association – North West & Canada
- CSL Americas
- Evergreen Shipping Agency (America) Corporation
- Fairmont Shipping (Canada) Ltd.
- Fednav Limited
- G2 Ocean Shipping Canada Ltd.
- Gowlland Towing
- Hapag-Lloyd
- HMM
- Hudson Shipping Lines, Inc.
- Inchcape Shipping Services Inc.
- International Ship-owners Alliance of Canada
- Island Tug and Barge Ltd.
- ‘K’ Line America, Inc.
- LBH Canada
- Ledcor Resources and Transportation
- Maersk Line
- Marine Exchange of Puget Sound
- Mason Agency Ltd.
- McLean Kennedy
- MOL (Americas) LLC
- Montship Inc.
- MSC Mediterranean Shipping Company
- Navitrans Shipping Agencies West
- Norton Lilly International
- NYK Bulk & Projects Carriers Ltd.
- Oak Maritime
- Ocean Network Express Inc.
- Oldendorff Carriers
- OOCL (Canada)
- Pacific Basin Shipping
- Pacific Industrial & Marine Ltd.
- Pacific Merchant Shipping Association
- Pacific Northwest Ship & Cargo Services
- Pacific Pilotage Authority
- Puget Sound Partnership
- Puget Sound Pilots
- Ravensdown Shipping Services Pty Ltd.
- Robert Reford
- Royal Canadian Navy
- Saga Welco AS
- Seaspan
- Shipping Federation of Canada
- Sinotrans Canada Inc.
- SM Line Corporation
- Swire / CNC Shipping
- Teekay Shipping
- Tormar Shipping Agency
- Trans Mountain
- Trans-Oceanic Shipping
- Transport Canada
- U.S. Coast Guard
- Valles Steamship (Canada) Ltd.
- Vancouver Island Agencies
- Varamar Shipping & Trading
- Washington State Ferries
- Waterfront Shipping Company Ltd.
- Westward Shipping Ltd.
- Westwood Shipping Lines
- Wheelhouse Shipping Agency
- Wilhelmsen Ships Service
- Yang Ming Shipping (Canada) Ltd.

During the slowdown period, shipping agents were responsible for relaying a vessel’s intent to participate when placing an order for a pilot through the Pacific Pilotage Authority’s dispatch system.

The Pacific Pilotage Authority-reported data indicated that 94% (1,858 of 1,980) of vessel transits intended to participate. Of these, 959 vessel transits indicated ‘yes’, they would participate without conditions, and 899 vessels transits indicated ‘yes, conditional’, i.e., they would participate subject to conditions such as being able to meet schedule, meet tidal windows and not incur excess costs. Only 6% (122 transits) indicated that they did not intend to participate.

Table 2 provides details of intent to participate by vessel type for 2020. The response totals from the 2017, 2018 and 2019 slowdowns are also included in Table 2 for comparison and indicate fewer ‘No’ responses and more ‘Yes’ responses in 2020.

Table 2: Intent to participate as reported by Pacific Pilotage Authority in 2020, 2019, 2018 and 2017

Vessel type	Yes		Conditional		No	
Bulker	37%	450 of 1209	57%	684 of 1209	6%	75 of 1209
Car carrier	73%	101 of 138	18%	25 of 138	9%	12 of 138
Container	75%	382 of 511	20%	102 of 511	5%	27 of 511
Tanker	16%	15 of 95	76%	72 of 95	8%	8 of 95
Other	41%	11 of 27	59%	16 of 27	0%	0 of 27
Totals (2020)	**48%**	**959 of 1980**	**45%**	**889 of 1980**	**6%**	**122 of 1980**
Totals (2019)	39%	612 of 1,551	52%	807 of 1,551	9%	132 of 1,551
Totals (2018)	49%	822 of 1,678	42%	703 of 1,678	9%	153 of 1,678
Totals (2017)	38%	366 of 951	41%	386 of 951	21%	199 of 951

3.2. Participation as reported by Pacific Pilotage Authority

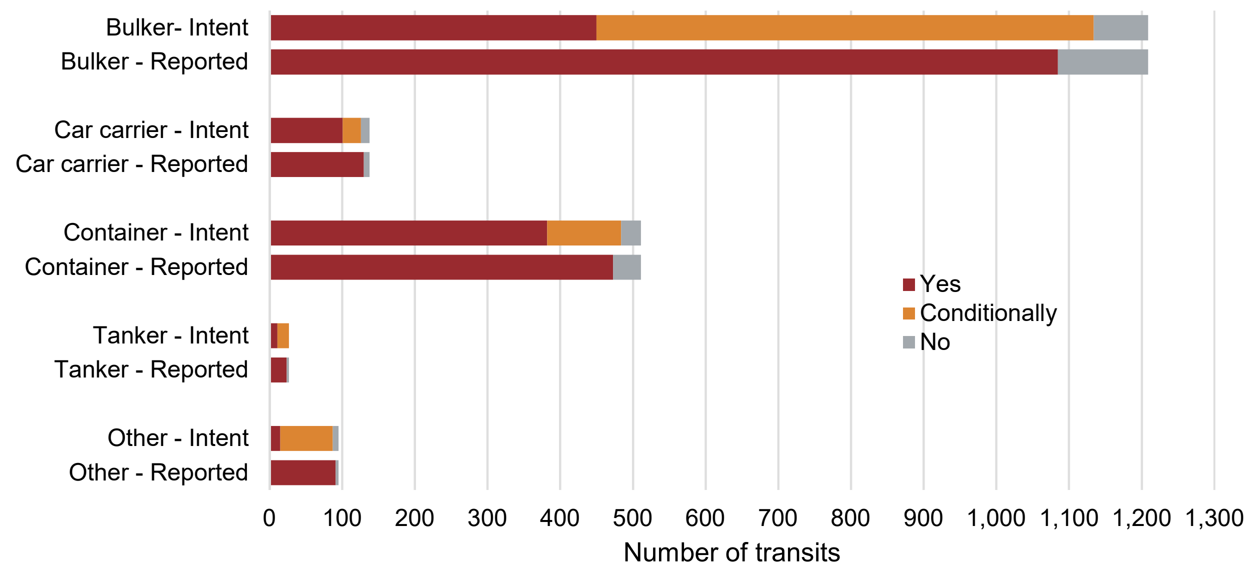
Of the 1,980 piloted vessel transits through Haro Strait and Boundary Pass during the 2020 slowdown period, the Pacific Pilotage Authority reported that 91% (1,803 of 1,980) participated in the slowdown. The key reason for vessels not being able to slow down (as noted by the BC Coast Pilots to Pacific Pilotage Authority dispatch at the end of each job) related to schedule concerns. A breakdown of participation as reported by the pilots at the end of each transit is included in Table 3. The participation totals from the 2017, 2018 and 2019 slowdowns are also included in Table 3 for comparison and indicate an increase in vessels reporting 'Yes' to participation and a decrease in reporting 'No' to participation in 2020.

Table 3: Participation as reported by Pacific Pilotage Authority

Vessel type	Yes		No	
Bulker	90%	1085 of 1209	10%	124 of 1209
Car carrier	94%	130 of 138	6%	8 of 138
Container	93%	473 of 511	7%	38 of 511
Tanker	96%	91 of 95	4%	4 of 95
Other	89%	24 of 27	11%	3 of 27
Totals (2020)	**91%**	**1,803 of 1,980**	**9%**	**177 of 1,980**
Totals (2019)	82%	1,279 of 1,551	18%	272 of 1,551
Totals (2018)	87%	1,467 of 1,678	13%	211 of 1,678
Totals (2017)	61%	578 of 951	39%	373 of 951

Figure 2 provides an overview of intended participation based on agent reporting versus pilot reported participation by vessel type.

Figure 2: Intent to participate versus Pacific Pilotage Authority-reported participation by vessel type



An evaluation of vessels achieving slowdown speed through the water targets, accounting for localized currents (otherwise referred to as 'calculated vessel participation rate'), is discussed in section 3.4.

3.3. Inbound versus outbound reported participation

The BC Coast Pilot boarding station located near Victoria, B.C., is also referred to as Brotchie Ledge (Brotchie). For inbound transits, the pilot boards at Brotchie, and for outbound transits the pilot disembarks at Brotchie. An evaluation of pilot-reported participation for inbound versus outbound transits was conducted for all vessels that either started or ended their transit at Brotchie. For all vessel types, reported participation rates were higher during outbound transits, as shown in Table 4.

Table 4: Inbound versus outbound reported participation

PPA reported participation for transits starting or ending at Brotchie				
Vessel type	Inbound		Outbound	
Bulker	86%	565 of 654	94%	520 of 555
Car carrier	88%	60 of 68	100%	70 of 70
Container	88%	226 of 256	97%	247 of 255
Tanker	92%	44 of 48	100%	47 of 47
Other	79%	11 of 14	100%	13 of 13
All	**87%**	**906 of 1040**	**95%**	**897 of 940**

3.4. Calculated vessel speed through the water participation rates

Understanding each vessel's actual speed through water (STW) is an important factor in evaluating the slowdown and subsequent modelling of vessel noise. Vessel captains and pilots typically work together to set the vessel engine speed in revolutions per minute (RPM) in an attempt to achieve a target speed through the water. Owing to the considerable momentum of the vessels combined with complex, strong local tidal currents and wind, the actual speed through water can vary considerably while the vessel engine speed may be constant. An evaluation of speed through water participation rates calculated by ECHO Program consultants (SMRU and JASCO) and the pilot-reported participation rates provided by the Pacific Pilotage Authority are discussed in this section.

3.4.1. Speed through water calculation approaches

Vessel movements were tracked using AIS data which provides vessel position and speed over ground. Speed over ground values were then used by ECHO Program consultants in combination with tidal current modelling to calculate the vessel's speed through water across the slowdown area.

SMRU and JASCO estimated STW in Haro Strait and Boundary Pass, respectively, using AIS speed over ground data corrected for current. Using several locations from the DFO WebTide current/tidal prediction model, AIS speed over ground data points were corrected for current speed and direction. An average of these current-corrected data points was calculated over the Haro Strait and Boundary Pass slowdown areas separately to represent the average speed through water for each slowdown area.

3.4.2. Calculated versus pilot-reported participation

As described in section 3.4.1, for each transit, STW values were calculated by SMRU for Haro Strait and JASCO for Boundary Pass and averaged to get an overall speed through water value in the slowdown area. These values were compared to the speed targets for each vessel category. Based on the overall mean STW evaluation and comparison to targets, 68% of all vessels were within one knot of their respective target speeds.

Table 5 provides details of the speed through water achievement rates by vessel type. This information is presented graphically in Figure 3. Figure 4 provides an overview of how the participation, both calculated and reported, varied by week.

It should be noted that the total transit numbers for calculated speed through water in Table 5 differ slightly from the total pilot-reported participation numbers. This is due to erroneous or missing speed data from the AIS receivers for 59 piloted transits, bringing the total number of transits evaluated from 1,980 to 1,921.

Table 5: Reported and calculated speed through water participation rates by vessel type

Vessel type	Pilot-reported participation % evaluated for STW (number of transits of vessel type total)	Calculated STW participation % (number of transits of vessel type total)
		Within 1 knot of target STW
Bulker	90% (1044 of 1163)	67% (778 of 1163)
Car carrier	94% (128 of 136)	60% (81 of 136)
Container	92% (464 of 502)	72% (361 of 502)
Tanker	96% (89 of 93)	72% (67 of 93)
Other	89% (24 of 27)	78% (21 of 27)
All	91% (1749 of 1921)	68% (1308 of 1921)

Figure 3: Pilot-reported participation versus calculated speed through water participation by vessel type

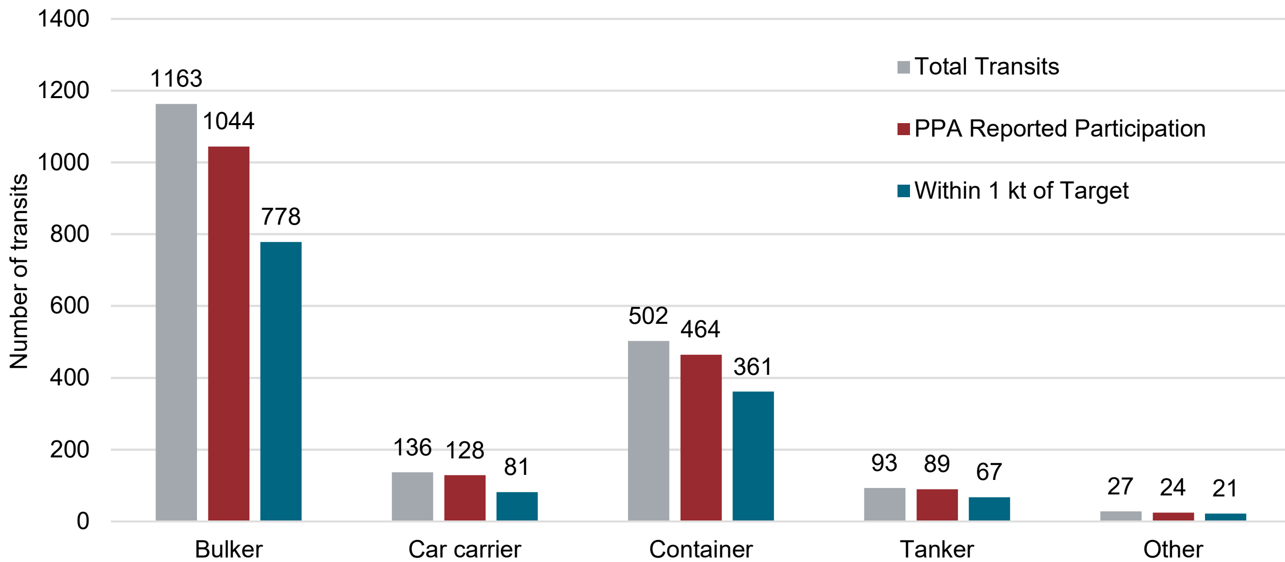
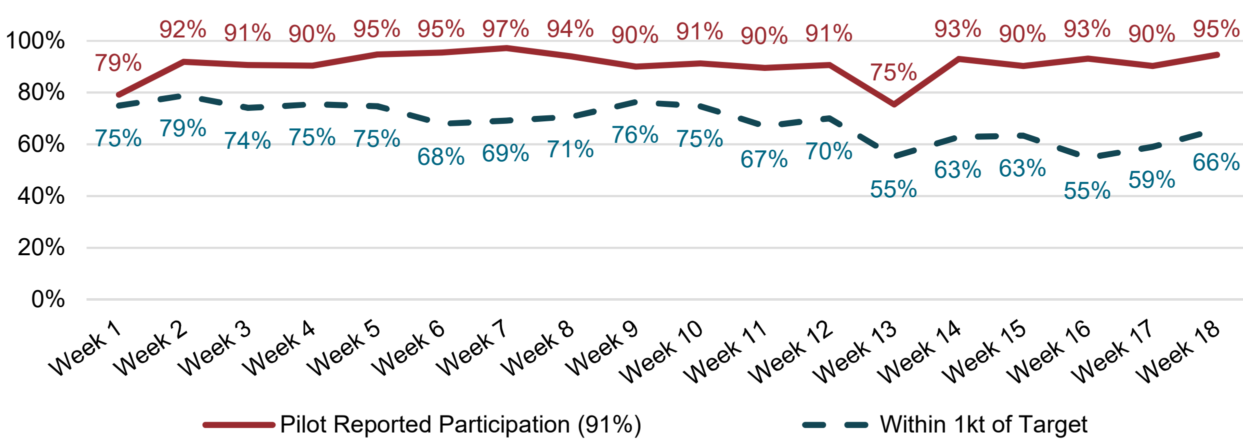


Figure 4: Pilot-reported participation versus speed through water participation within one knot of target speed by week



End of season feedback interviews and discussions were conducted with the shipping associations who represent the participating ship owners and agents, and BC Coast Pilots. Feedback indicated that in general the slowdown had little impact on day to day operations and ECHO Program communications were effective.

4. Transport Canada reimbursement program

In 2019 Transport Canada recognized that reducing vessel speeds over the extended distance through Boundary Pass could have cost implications for vessel owners, operators and agents, with increased pilotage fees identified as one possible source of increased costs. To reduce the financial risk of participating in the expanded voluntary slowdown, Transport Canada created a reimbursement program to cover additional pilotage costs incurred as a result of participating in the 2019 slowdown.

Any vessel that participated in the ECHO Program's 2020 voluntary vessel slowdown and incurred additional pilotage fees as a result of the slowdown was again eligible for the reimbursement.

Three types of potential additional pilotage costs were covered by the reimbursement program:

1. **Time slippage** occurs when extra transit time shifts total time from a one-hour block to the next (e.g., travel time slips from 4 hr 40 min to 5 hr 05 min) resulting in costs for an additional hour of pilotage
2. **Double pilotage to avoid excess** occurs when a vessel, which would normally transit under eight piloting hours with one pilot, runs the risk of exceeding the eight hour limit for the total job as a result of participation in the slowdown and therefore orders two pilots for the job
3. **Excess** occurs when a vessel unexpectedly exceeds the eight piloting hour limit with only one pilot on board

Eligible additional pilotage costs were confirmed by the Pacific Pilotage Authority at the end of each transit and communicated directly to the Vancouver Fraser Port Authority who then provided reimbursement to ship owners, operators or agents, on behalf of Transport Canada. There was no application process required of the ship owner, operator or agent to be eligible for reimbursement.

The reimbursement program was activated on the first day of the slowdown, July 1, 2020 and remained in place until the conclusion of the slowdown on October 31, 2020.

Of the 1,803 participating vessel transits that transited while the reimbursement program was active, ~68% did not incur additional pilotage costs as a result of participating in the slowdown. A breakdown of how the remaining ~32% of participating vessels incurred additional pilotage costs is provided in Table 6.

Table 6: Breakdown of 2020 participating vessels and associated reimbursement types

Reimbursement type	Number of participating vessels	Percentage of total participating vessels
No additional pilotage costs	1218	67.6%
Slippage to an additional hour	537	29.8%
Slippage to an additional hour with two pilots onboard	15	0.8%
Excess hours	33	1.8%
Total	1803	-

A total of $184,686 additional pilotage costs were incurred as a result of the slowdown and paid out as reimbursements.

Over the 18 weeks of the slowdown trial there were 177 vessel transits that reported as not participating at the end of their transit. Of these, 49% cited the reason for not participating as being due to scheduling concerns, 15% as being due to tidal/current concerns and 9% as being due to additional costs not related to pilotage.
Only 8 vessel transits (4.5%) cited the reason for not participating as being due concerns of incurring excess pilotage costs, which is a significant reduction from 2019 when 20% of non-participating vessel transits cited this as a reason. In 2019 it was not clear if the reason behind this 20% of non-participating vessels was due to a lack of communication about the reimbursement program, a lack of understanding and/or trust in this new program, or a concern about the delay in reimbursement payments.

The 2020 results suggest that the levels of communication, understanding, trust and familiarity with the reimbursement program may have contributed to further reducing concerns about additional pilotage costs and improving the overall voluntary slowdown participation rates from 82% to 91%.

5. Evaluation and results: acoustics

The ECHO Program contracted SMRU and JASCO to monitor changes in ambient underwater noise at Haro Strait and Boundary Pass, respectively, during the slowdown. JASCO also conducted regional underwater noise modelling based on the speeds and participation rates achieved in 2019. The modelled distribution of underwater noise for the area was then used as an input to SMRU's killer whale behavioural response model (section 6.3). Results of the acoustic studies are presented in this section.

5.1. Ambient noise in Haro Strait and Boundary Pass

The complete technical report on ambient underwater noise levels in Haro Strait and Boundary Pass, prepared jointly by SMRU and JASCO, is provided as Chapter 1 of Appendix A to this summary report. Generalized results are provided below.

5.1.1. Received levels

The depth and location of the Lime Kiln hydrophone makes it an appropriate representation of underwater noise levels that may be received by whales feeding in Haro Strait, in particular the important foraging habitat off the west coast of San Juan Island. In Boundary Pass, the hydrophone system was located adjacent to the international shipping lanes, and provides a good representation of the overall underwater noise reduction closer to vessels participating in the slowdown.

Received underwater noise levels at the Lime Kiln hydrophone and Boundary Pass stations were analyzed for a representative baseline period before the 2020 slowdown for comparison to the slowdown time period. For analysis, the baseline time period was considered from May 3 to July 1, 2020, immediately preceding the slowdown time period of July 2 to October 31, 2020. As the slowdown was enacted mid-day on July 1, the acoustic analysis began at 00:01 PDT on July 2.

The Boundary Pass hydrophone station transitioned from an autonomous multichannel acoustic recorder (AMAR) deployment, to the long-term cabled Underwater Listening Station (ULS) on June 9, 2020. During acoustic analysis of the baseline period for Boundary Pass, it was found that the AMAR experienced sporadic and unusual increases in low-frequency noise, thought to be attributed to the AMAR mooring. As such, the decision was taken to use only data from the cabled ULS for evaluation of the noise reduction during the slowdown for this location. The baseline period used for acoustic evaluation at Boundary Pass was therefore limited to June 9 to July 1, 2020.

To evaluate potential changes in ambient underwater noise resulting from the slowdown, a comparison of filtered ambient underwater noise data for the pre-slowdown baseline versus slowdown time period was conducted. The filtered data set aimed to better evaluate changes in ambient underwater noise that could be attributed to the vessel slowdown. The filtered data set included only time periods when a large AIS-enabled vessel was within six kilometres of the hydrophone and was the closest vessel to the hydrophone, and excluded time periods when there were other factors that could be significantly contributing to the received underwater noise. The filtered data set excluded:

- Time periods of elevated wind greater than 5 metres per second at the Lime Kiln hydrophone and elevated wind speed greater than 10 metres per second at the Boundary Pass ULS
- Time periods with high tidal current greater than 0.25 metres per second at Lime Kiln and greater than 0.5 metres per second at Boundary Pass; analysis of the effects of tidal current on received levels at each of the hydrophones were used to determine the appropriate filter values
- Time periods with small boats present and dominating the received noise levels at both the Boundary Pass and Lime Kiln hydrophones

Statistical analysis of the sound pressure levels (SPL) received at the hydrophones were conducted for the baseline period and the slowdown period using exceedance cumulative distribution functions (CDF). Use of CDF controls for the number of vessel transits and accounts for variability in underwater noise exposure time versus underwater noise amplitude. Note that using exceedance CDF plots, L95 indicates the value that would be exceeded 95% of the time (therefore the quietest 5% level), and L50 would be the median value.

Table 7 presents the differences in sound pressure levels measured between baseline and slowdown periods at Lime Kiln. These differences are presented for filtered broadband, by decade bands, and what are referred to as the CORI bands. The CORI bands indicate the frequency ranges for SRKW communication and echolocation as defined through a group of technical experts convened by the Coastal Ocean Research Institute (CORI) of Oceanwise Conservation Association (Heise et. al, 2017). Broadband is the full frequency range the hydrophone can measure (10–100,000 Hz for this study), while a decade band covers a frequency range equal to an order of magnitude. Note that a negative value in Tables 7 and 8 indicate a reduction in underwater noise.

Table 7: Ambient underwater noise differences (dB) at Lime Kiln

Frequency range	SPL (dB) difference between slowdown and baseline		
	L95 (quietest 5% of the time)	L50 Median	L5 (loudest 5% of the time)
Broadband 10–100,000 Hz	−2.5	−2.5	−1.9
1st Decade 10–100 Hz	−2.9	−2.8	−2.2
2nd Decade 100–1,000 Hz	−1.4	−1.9	−1.3
3rd Decade 1,000–10,000 Hz	−3.9	−4.0	−2.8
4th Decade 10,000–100,000 Hz	−0.4	−2.2	−1.9
CORI Communication 500–15,000 Hz	−2.5	−3.1	−1.9
CORI Echolocation 15,000–100,000 Hz	−0.4	−1.2	−1.8

Results indicate a median reduction in broadband received sound pressure level of 2.5 dB (a 44% reduction in sound intensity) at the Lime Kiln hydrophone for the filtered data, compared to the pre-slowdown baseline period. For all frequency ranges, and all time metrics evaluated (including quietest and loudest times) a decrease in underwater noise was noted during the slowdown, when compared to baseline noise levels.

Table 8 presents the differences in sound pressure levels between baseline and slowdown periods at Boundary Pass. A median noise reduction of 2.8 dB (a 48% reduction in sound intensity) was measured at Boundary Pass. Similar to the Lime Kiln station, a decrease from baseline conditions was measured during the slowdown for all frequency ranges and time metrics evaluated.

Table 8: Ambient underwater noise differences (dB) at Boundary Pass

Frequency range	SPL (dB) difference between slowdown and baseline		
	L95 (quietest 5% of the time)	L50 Median	L5 (loudest 5% of the time)
Broadband 30–64,000 Hz	−2.9	−2.8	−3.4
1st Decade 30–100 Hz	−4.0	−3.3	−3.9
2nd Decade 100–1,000 Hz	−1.5	−1.7	−2.0
3rd Decade 1,000–10,000 Hz	−3.7	−2.6	−2.9
4th Decade 10,000–64,000 Hz	−0.4	−1.8	−3.6
CORI Communication 500–15,000 Hz	−2.6	−1.8	−2.3
CORI Echolocation 15,000–64,000 Hz	−0.2	−1.0	−3.6

These measured data sources indicate the 2020 slowdown was successful in reducing the ambient underwater noise in Haro Strait and Boundary Pass for greater than 90% of the time when large vessels are present, and across all measured frequency ranges, despite longer transit times.

Improvements in the filters used to evaluate the potential underwater noise reduction were made in 2019 and carried forward to the 2020 slowdown. As a result, direct comparison of 2019 and 2020 data to previous slowdown years is not recommended.

The raw, unfiltered sound pressure level data from the Lime Kiln hydrophone was also input to a Generalized Additive Mixed Model (GAMM) framework to determine which covariates explained changes in underwater noise levels at the Lime Kiln hydrophone. Some selected predictions from this model were evaluated (see Chapter 1 of Appendix A for details). Predictions included evaluation of changes in underwater noise levels with distance from the hydrophone between the baseline and slowdown periods, for container and bulk vessel types.

The GAMM model predictions identified clear trends for decreased received sound pressure level with increased distance, as well as the slowdown period being quieter than the baseline period. At an example distance of 2.3 kilometres (the distance between the middle of the northbound shipping lane and the Lime Kiln hydrophone) the model predicted a 1.7 dB reduction in received level at the Lime Kiln hydrophone for a passing bulk or container vessel during the 2020 slowdown. These predicted differences in received levels are attributed to both the source levels of the vessels, as well as their average speed reductions.

5.1.2. Evaluation of “quiet times” at Lime Kiln and Boundary Pass

Knowing that slowing a vessel down will result in the vessel being in an area longer and may impact “quiet times” between vessel transits, a comparison of quiet times was conducted. This analysis included all acoustic data (unfiltered), both natural and anthropogenic. Two broadband thresholds were selected as representative quiet time thresholds for comparing the baseline and slowdown time periods. These included:

- 110 dB re 1 µPa, which is the broadband noise level below which SRKW behavioural response is not anticipated (SMRU 2014)
- 102.8 dB re 1 µPa, which is the broadband L95 received underwater noise level (underwater noise level exceeded 95% of the time) at Lime Kiln during the 2017 baseline period (SMRU, 2018a)

Evaluation of quiet times was completed for both Lime Kiln and Boundary Pass data. Using the thresholds described above and when comparing the baseline time period with the slowdown time period, quiet time analysis revealed:

- At Lime Kiln, for the L95 threshold of 102.8 dB re 1 µPa, the percentage of quiet time during baseline period was approximately 30%, and during the slowdown period was approximately 28%, indicating a very minor decrease in the percentage of quiet time during the slowdown for this threshold
- For the L95 threshold at Boundary Pass, the percentage of quiet time was approximately 48% during the baseline and 47% during the slowdown, also indicating a very minor decrease during the slowdown.
- At Lime Kiln for the behavioural threshold of 110 dB re 1 µPa, both the baseline period and the slowdown period measured approximately 53%, indicating no change in the amount of quiet time during the slowdown for this threshold
- For the behavioural threshold at Boundary Pass, the percentage of quiet time was approximately 65% during the baseline and 66% during the slowdown, indicating a very minor increase in quiet time during the slowdown.
- At Lime Kiln there was a slight increase in quiet times during 2020 for both the quiet time thresholds when compared to the acoustic results from 2019. Percentage of quiet times in 2019

were on the order of 25% and 50% for the two thresholds, whereas these increased slightly to ~28-30% and 53% in 2020.

It appears, given the selected quiet time thresholds, that the Boundary Pass location experiences a higher percentage of quiet time than the Lime Kiln location. This may be due to the presence of small recreational vessel traffic proximate to the Lime Kiln hydrophone causing elevated noise levels, as opposed to the louder, but less frequent passes of large commercial vessels proximate to the Boundary Pass hydrophone.

Overall, these analyses indicate that the differences in duration of quiet times and overall percentage of quiet time resulting from vessel slowdowns remain relatively unchanged in the whale foraging habitat near Lime Kiln as well as under the shipping lane in Boundary Pass. It should be noted that these analyses are very sensitive to the values selected for quiet time thresholds.

5.2. Underwater noise modelling

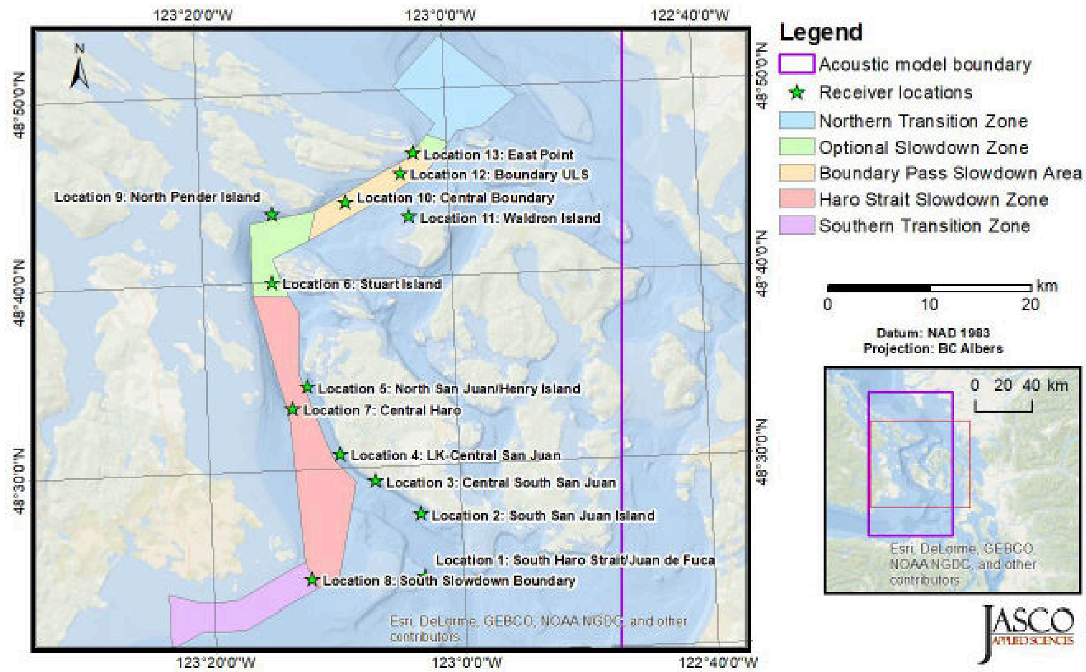
An evaluation of the expected changes in total underwater noise based on the 2020 slowdown was conducted by JASCO, using the existing regional acoustic model of vessel traffic that has been used by the ECHO Program since 2017. The model area was expanded to include Boundary Pass and surrounding area in 2019. The speed scaling relationships (i.e., the relationship between speed and underwater noise) for different vessel types, which were developed in the 2017 slowdown trial (MacGillivray et al, 2018a), were used in conjunction with the achieved speeds and participation rates of the 2020 slowdown to predict the changes in total underwater noise in the Haro Strait and Boundary Pass area during the slowdown.

The modelled distribution of underwater noise from vessels during the slowdown was then used as an input to SMRU's SRKW behavioural response model (section 6.3). The complete technical report on noise modelling from JASCO is provided as Chapter 2 in Appendix A.

The area covered by the acoustic model is provided in Figure 5, and includes the expanded slowdown area and a buffer region to capture underwater noise from vessel traffic outside the designated slowdown zones. The model generates sequences of two-dimensional maps, or "snapshots", of the dynamic sound field, providing cumulative sound pressure level as a function of easting, northing, frequency and time. For the purposes of this study, the underwater noise model was run to provide sound pressure level data over a 24-hour period in the model area, to feed into the SMRU behavioural response model.

In 2019, sound propagation curves were updated using sound speed profile data collected in Haro Strait and Boundary Pass, and these updates were carried forward into 2020 modelling. Although this model update affected absolute values for predicted sound pressure levels, the changes in underwater noise attributed to slowdowns may be compared to the results of previous years of modelling.

Figure 5: Underwater noise modelling area and receiver locations



Source: JASCO Applied Sciences

The model scenarios include vessel traffic counts based on data provided through AIS, as well as through reports from the Pacific Pilotage Authority. Vessel counts for an average and high traffic day, as well as for the speeds and participation rates achieved during the 2020 slowdown are provided in Table 9. As the underwater noise and behavioural response models use a 24-hour (daily) time period, the participation rates used for modelling vary slightly from the actual participation rates reported by the pilots, and the rates of achievement within one knot for the slowdown (as described in sections 3.2 and 3.4).

For example, an average traffic day has four container transits (Table 9), a reported slowdown participation rate of 93%, and a 72% rate of achieving within one knot of the target speed. As a portion of a vessel cannot be modelled, a 75% participation rate (three of four containers) was represented in the model. This scaling of participation rates for a 24-hour time period resulted in a modelled participation rate of 79% and 76%, respectively, for average and high traffic days.

Table 9: 24-hour vessel traffic counts in Haro Strait and Boundary Pass

Vessel type		Average traffic day		High traffic day	
	Average slowdown speed achieved (knots)	Baseline vessel count	2020 modelled count of participating vessels	Baseline vessel count	2020 modelled count of participating vessels
Bulker	11.98	8	6 of 8	10	8 of 10
Container	14.97	4	3 of 4	6	5 of 6
Tanker	11.83	1	1 of 1	2	2 of 2
Vehicle carrier	15.14	1	1 of 1	2	1 of 2
Passenger	N/A*	0	0 of 0	0	0 of 0
Total		**14**	**11 of 14 (79%)**	**20**	**16 of 20 (80%)**

**Cruise vessels were absent from the slowdown area in 2020 due to the pandemic, thus were not included in 2020 modelling*

In order to assess the potential changes in underwater noise from the various vessel traffic scenarios, specific receiver locations were selected to provide examples of the model outputs. The modelled receiver locations were selected to be in key SRKW foraging areas as well as locations in the slowdown and transition zones, as shown on Figure 5. With the addition of Boundary Pass to the slowdown area, thirteen receiver locations were selected.

The differences in the number of vessels transiting in a given day (average day 14 vessels, high traffic day 20 vessels) can affect the underwater noise levels at the different receiver locations, as shown in Table 10. For example, the values shown for receiver location #4, proximate to Lime Kiln, indicate a median underwater noise reduction of 0.634 dB re 1 µPa on an average traffic day, and a 1.225 dB re 1 µPa median reduction on a high traffic day. The model indicates median noise reductions at receiver location #12 proximate to the Boundary Pass ULS of 0.558 dB re 1 µPa on an average traffic day, and 0.891 dB re 1 µPa on a high traffic day.

Table 10: Modelled difference between baseline and slowdown sound pressure levels

Receiver location		Median difference in dB average traffic day				Median difference in dB high traffic day			
#	***Name***	***2017***	***2018***	***2019***	***2020***	***2017***	***2018***	***2019***	***2020***
1	South Haro	-0.369	-0.311	-0.102	−0.111	-0.117	−0.385	-0.353	−0.35
2	Southern San Juan	-0.403	-0.123	-0.182	−0.182	-0.456	−0.394	-0.408	−0.258
3	Salmon Banks	0.054	0.089	0.016	0.009	0.018	0.065	0.178	0.15
4	**Lime Kiln**	**-0.639**	**-0.324**	**-0.642**	**−0.634**	**-1.536**	**−0.799**	**-1.248**	**−1.225**
5	Northern San Juan	-0.891	-0.397	-0.984	−0.945	-0.932	−0.591	-1.199	−1.204
6	Stuart Island	-0.877	-0.451	-0.586	−0.586	-0.324	0.030	-0.010	−0.06
7	Central Haro	-0.734	-0.383	-0.544	−0.553	-1.014	−0.592	-0.629	−0.571
8	Southern Haro	-0.116	0.021	0.059	0.057	-0.206	−0.015	-0.340	−0.234
9	North Pender	--	--	-0.151	−0.176	--	--	-0.880	−0.955
10	Central Boundary	--	--	-0.050	−0.05	--	--	-0.251	−0.487
11	Waldron Island	--	--	-0.525	−0.537	--	--	-0.522	−0.633
12	**Boundary ULS**	**--**	**--**	**-0.548**	**−0.558**	**--**	**--**	**-0.637**	**−0.891**
13	East Point Saturna	--	--	-0.569	−0.603	--	--	-0.706	−0.851

Every model has inherent uncertainty, and thus the focus of evaluation should be on the relative change in underwater noise levels as a result of vessel slowdowns, rather than the absolute values. The transmission loss curves used in the model were updated in 2019, which affects the way underwater noise from the vessel source is distributed through the model space. These results indicate that 2020 speeds and participation rates clearly provide an underwater noise reduction in most locations over a 24-hour period. Note that the underwater noise model represents sound over a 24-hour period, both when vessels are and are not present, but does not account for the presence of small vessel traffic, due to the lack of AIS data from small vessels. Small vessels can have a significant impact on received underwater noise at Lime Kiln (SMRU, 2018a), and is the reason that small vessel traffic is filtered out of the evaluation of slowdown benefits to ambient noise as measured by hydrophones (Section 5.1.1).

6. Evaluation and results: SRKW presence and behaviour

Observers were stationed on San Juan Island, Washington, and Saturna Island, B.C., to monitor whale presence in Haro Strait and Boundary Pass, respectively, during the 2020 slowdown. Passive acoustic monitoring (PAM) was also conducted to detect marine mammals throughout the slowdown period using the hydrophones in Haro Strait and Boundary Pass. PAM uses auto-detection software to identify species of marine mammals. Behavioural response modelling was undertaken to compare how the slowdown reduced the amount of time SRKW foraging may be affected by vessel underwater noise.

The results of monitoring for whale presence, as well as the behavioural response modelling using the predicted/modelled underwater noise levels described in section 5.2 are discussed in this section.

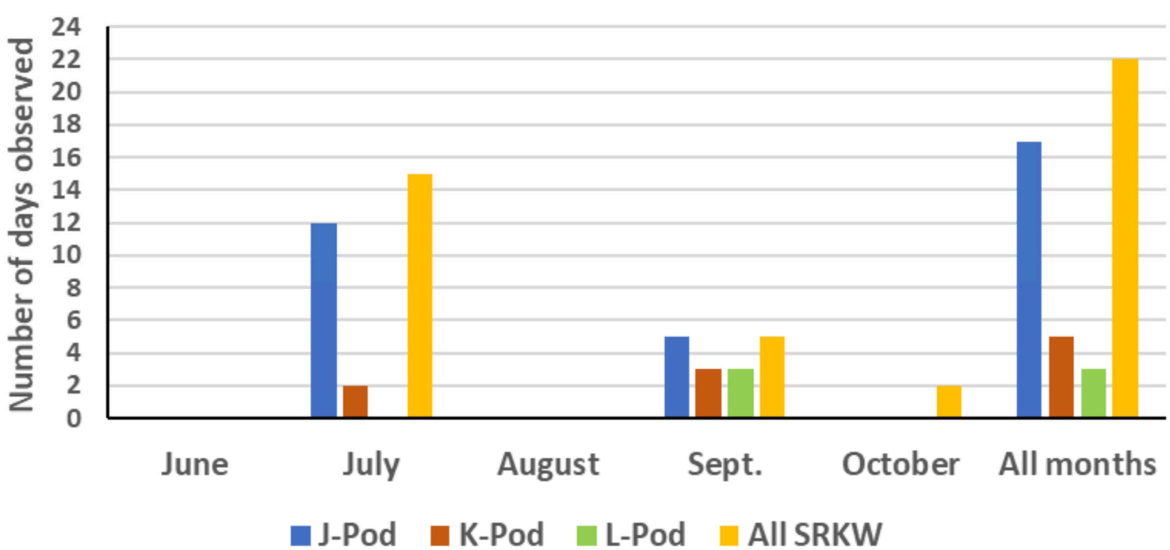
6.1. SRKW presence at Lime Kiln

Both visual observations and acoustic detections at Lime Kiln were used for a general evaluation of killer whale presence during the slowdown period, and for triggering the start and end dates of the slowdown. The analysis of whether slower vessels had a positive effect on the behaviour and foraging of killer whales in 2020 was undertaken using computer modelling of behavioural response to underwater noise from vessels as described in section 6.3, and included in Chapter 3, Appendix A. Further information on acoustic and visual detections of SRKW at Lime Kiln, and in the Haro Strait region, can be found in Appendix A and B.1.

Daily scientific observations of SRKW presence and absence were conducted by Ms. Jeanne Hyde stationed at or near the lighthouse in Lime Kiln Point State Park on San Juan Island between June 1 and October 31, 2020. Over the course of this monitoring period, SRKW were visually confirmed from the Lime Kiln station on 22 days.

SRKWs are made up of three pods—J, K and L—which are often seen travelling separately but can be seen travelling together or in various combinations. Members of J pod were observed on 17 days, K pod on 5 days and L pod on 3 days. On 3 occasions, the particular pod was not identified beyond confirmation of the transiting whales being SRKW. The sightings were concentrated in July (15 days, mainly J pod) and September (5 days). In June and August, no SRKW sightings occurred. In September, J pod was present during all five days while K and L pod were also present on three of those days. Figure 6 shows the SRKW sightings at Lime Kiln by pod and by month.

Figure 6: Days southern resident killer whales were visually observed at Lime Kiln



Source: SMRU Consulting North America
"All SRKW" indicates the total number of days SRKW were sighted per month.
Acoustic detections of SRKW were also collected during the slowdown period through passive acoustic monitoring and subsequent human validation of the acoustic detections, using the Lime Kiln hydrophone. During the slowdown period, a total of 70 killer whale events were detected at the Lime Kiln hydrophone, mainly in July and September. Of those events, 53 unique events were confirmed to be SRKW over 34 days.

In addition to visual observations made at Lime Kiln, supplementary information on SRKW presence in the greater Haro Strait region during the 2020 slowdown was provided by other trusted observers. Overall, SRKW were visually confirmed from the Lime Kiln station on 22 days and acoustically detected on 12 additional days, for a total of 34 days in Haro Strait during the 2020 monitoring period.

6.2. SRKW presence at Boundary Pass

Between June 4 to October 6, 2020, scientific observations of cetaceans, with a focus on SRKW, were made by Ms. Lucy Quayle stationed near East Point Park, Saturna Island, overlooking the northern region of Boundary Pass.. Further information on animal behaviour and vessel presence was also captured and can be found in Appendix B.2..

During this time, four SRKW events were visually confirmed in Boundary Pass on three days, all in the month of July. Three of the four events included J pod members, and one event included a large group of K and L pod members. During all events, SRKW demonstrated travelling behavior.

Vessel presence was also recorded by the observer throughout the study period. Small vessels were present during two of the four SRKW events, while large commercial vessels were present for one of the four SRKW events. During one of the four events, vessels were absent.

The Saturna Sighters Network, a citizen science group, captured visual observations of SRKW on two additional days, when the primary observer was not present. These additional observations make for a total of five visual detection days of SRKW in Boundary Pass.

In addition to the visual observations, acoustic detections were collected through passive acoustic monitoring at the Boundary Pass hydrophone station. A total of 31 killer whale events were detected, 17 of which were confirmed to be SRKW. The 17 SRKW acoustic events took place over 15 days. All five of the SRKW visually detected days were also detected acoustically, while 10 additional SRKW days were detected by the hydrophones, outside of regular observation hours.

Based on both the visual and acoustic detections in Boundary Pass, SRKW were present for 15 days during the slowdown period.

6.3. SRKW behavioural response modelling

Studying SRKW behaviour in the presence of vessels is challenging, and reliant upon the two being present at the same time. As such, behavioural response modelling is the key metric used to evaluate the potential benefits of the slowdown to the behaviour and foraging of SRKW. The complete results of the SMRU behavioural response modelling are provided as Chapter 3 in Appendix A.

To evaluate the potential effects of reduced underwater noise on SRKW, the results of the 24-hour noise modelling conducted by JASCO (described in section 5.2) were used as input for a behavioural response model developed by SMRU (SMRU 2014). The behavioural response model uses SRKW sightings data to determine habitat use, coupled with two functions that affect foraging. The first is a dose-response function that determines the likelihood of a change in behaviour by the whale (e.g., stops foraging, moves away) for a given broadband received level of underwater noise (in dB re 1uPa), and the second is an echolocation click masking (i.e., the whale may not be able to use echolocation to detect prey) model that proportionally reduces foraging efficiency with increased high frequency (50 kHz) received underwater noise level. Both a change in behavior and echolocation click masking could result in 'potential lost foraging time' for the SRKW, a relative combined effect metric used for evaluating the benefits of the slowdown.

The behavioural response model was run for baseline or typical traffic counts and speeds for both an average and a high volume traffic day, and then run using the actual speeds and estimated daily participation rates (see section 5.2) achieved during the 2020 slowdown. In 2019, improvements were made to the behavioural response model, including an updated SRKW density estimate using more recent sightings data from 2002 to 2017 (Wood et. al, 2019) and modifying the number of animals in the model to reflect the SRKW population of the time (73 individuals). These improvements were carried forward into the 2020 modelling. These model modifications, coupled with the extension of the model area into Boundary Pass and changes to the vessel noise model described in section 5.2, make it challenging to directly compare 2019 and 2020 results to previous slowdown years.

Over the 122 day period used to acoustically evaluate the 2020 voluntary vessel slowdown (July 1 was excluded from analysis as the slowdown was not enacted until mid-day), the behavioural response model predicted SRKW would be present in the full model region for 43.2 days. The predicted improvements in foraging time during the 2020 slowdown, over the entire model region (which includes Haro Strait, Boundary Pass and the Gulf Islands as shown in Figure 7) were predicted to be approximately 17% on an average traffic day and 20% on a high traffic day, resulting in an additional ~20 to ~30 hours of foraging time per whale over the duration of the slowdown period, for average and high traffic days respectively.

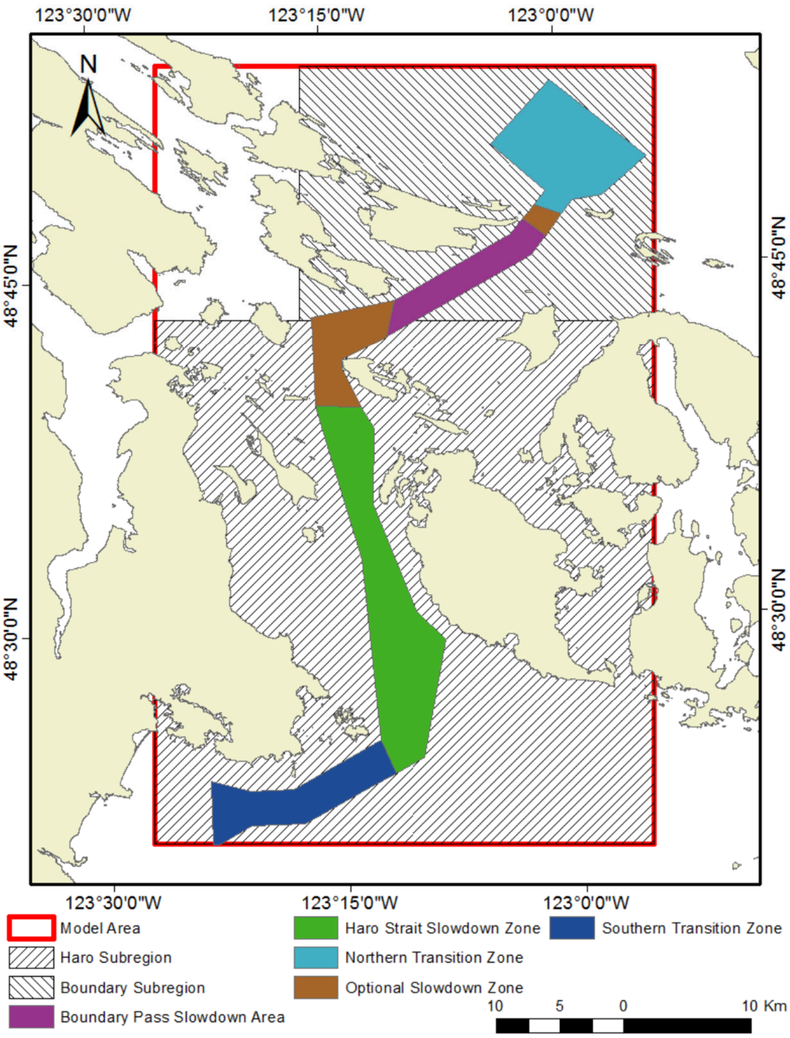
When evaluating the Haro sub-region only, over the 122 days of the slowdown, improvements in foraging time were estimated at ~20% on an average traffic day and ~23% on a high traffic day. To provide an year-over year comparison of benefits, an evaluation of the Haro sub-region was also conducted for the original 2017 slowdown time period of 61 days (August 7 – October 6), which yielded the same percentage benefits of ~20% and ~23% on average and high traffic days, respectively.

As noted previously, the modifications made to the behavioural response model in 2019 make it challenging to directly compare 2019 results to previous years; however, a relative comparison was conducted. For this relative comparison, behavioural response modelling for the same model area (Haro Strait sub-region only) over the 61-day period of the initial 2017 slowdown trial, was conducted for each of the three years of the slowdown, as shown in Table 11. Chapter 3 of Appendix A provides additional detail on the modelling

Table 11: Modelled difference in improved foraging time: Haro Strait only, 61-day slowdown

Slowdown year	Improvements in affected foraging time High traffic day	Improvements in affected foraging time Average traffic day
2020	22.8%	19.9%
2019	24.3 %	19.9%
2018	16.3%	15.3%
2017	23.6%	22.2%

Figure 7: Behavioural response modelling area and subregions



Source: SMRU Consulting

Although the values used to calculate the changes presented in Table 11 are not strictly comparable due to the modifications made to the noise and behavioural response models in 2019, the relative reduction in affected foraging time from baseline speeds provides an assessment of the relative benefit of each of the slowdowns to the key foraging area of Haro Strait. The daily improvements to affected foraging time for SRKW modelled in Haro Strait, using the speeds and participation rates achieved in 2020, are estimated to provide a similar benefit to those achieved during the original 2017 slowdown trial.

The comparison provided in Table 11, the expansion of the overall slowdown area into Boundary Pass, as well as the longer 122-day duration of the slowdown in 2020 suggest that the best overall gains in foraging time across the four years of voluntary vessel slowdowns were achieved in 2020.

7. Key findings and conclusions

Working closely with members of the ECHO Program's vessel operators committee and advisory working group, slowdown parameters were developed, and the 2020 voluntary vessel slowdown was coordinated and managed by the ECHO Program. The slowdown was conducted between July 1 and October 31, 2020, over an approximately 29.6 nautical mile area through Haro Strait and Boundary Pass, key foraging habitat for southern resident killer whales. The goal of the 2020 slowdown was to provide underwater noise reduction benefit to SRKW.

The key findings of the 2020 voluntary vessel slowdown are:

- A 91% vessel participation rate was reported by the Pacific Pilotage Authority (1,803 of 1,980 piloted transits) over the slowdown period
- 68% (1308 of 1921) of all piloted transits came within one knot of the vessel-specific speed through water targets
- SRKW were present in the Haro Strait and/or Boundary Pass regions on 40 of the 123 slowdown days
- When filtered to include only times when a large commercial vessel was the closest vessel to the hydrophone, and to remove times of elevated wind and tidal current effects and small boat presence, the median reduction in broadband received sound pressure level for the 2019 slowdown, was 2.5 dB (a 44% reduction in sound intensity) near Lime Kiln in Haro Strait, and 2.8 dB (a 48% reduction in sound intensity) at the hydrophone station near the shipping lanes in Boundary Pass
- Regional underwater noise modelling predicted that the vessel speeds and participation rates achieved during the 2020 slowdown likely resulted in median total underwater noise reductions (unfiltered) of 0.634 dB and 0.558 dB on an average traffic day at receiver locations near Lime Kiln and the Boundary Pass hydrophone station, respectively
- An evaluation of whether “quiet time” was impacted during the slowdown within Haro Strait and Boundary Pass showed that, although statistically significant, the differences in duration of “quiet time” and overall percentage of “quiet time” resulting from the 2020 vessel slowdown were relatively unchanged when compared to the baseline time period
- The SRKW behavioural response model predicted that the vessel speeds and participation rates achieved during the slowdown could result in a ~17% improvement in foraging time for SRKW on an average traffic day for the full model area (including Haro Strait, Boundary Pass and the Gulf Islands). When focusing only on the Haro Strait sub-region, the improvement in foraging time is modelled to be ~20% on an average traffic day.

The following conclusions are drawn from the 2020 slowdown:

- High voluntary participation rates were maintained in 2020, despite the uncertainties of the global COVID-19 pandemic and maintaining the reduced speed targets and expanded slowdown area which were introduced in 2019
- Slower vessel speeds and associated reduced underwater vessel noise resulted in quieter ambient noise conditions in key SRKW foraging habitats during the slowdown, when compared to baseline conditions
- Modelling indicates that underwater noise reductions achieved as a result of slower vessel speeds can lessen the amount of time SRKW behaviour and foraging is affected by vessel noise
- The underwater noise levels measured and modelled, and the predicted reductions in affected foraging time, indicate an overall reduction in underwater noise and improved SRKW foraging, despite the longer duration of vessel transits
- The duration of the 2020 slowdown combined with the high participation rate, decreased speed targets and expanded slowdown area appears to have provided the greatest predicted benefit to SRKW foraging and behaviour of all the ECHO Program voluntary vessel slowdowns to date.

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Appendix A

JASCO Applied Sciences and SMRU Consulting: ECHO Program 2020 Voluntary Vessel Slowdown Hydroacoustic Studies

ECHO Program 2020 Voluntary Vessel Slowdown Hydroacoustic Studies

Final Report

Submitted to:

Krista Trounce
Vancouver Fraser Port Authority
Contract: 19-0226

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1.1. Introduction

JASCO Applied Sciences (JASCO) and SMRU Consulting (SMRU) were contracted by the Vancouver Fraser Port Authority (VFPA) to analyze acoustic data for the Enhancing Cetacean Habitat and Observation (ECHO) Program's 2020 voluntary Slowdown initiative in Haro Strait and Boundary Pass. This study involves analyzing data collected at Lime Kiln (Haro Strait) and in Boundary Pass during the 60 day Baseline period and the 122 day Slowdown period (Table 1) in order to measure the effect of the Slowdown on underwater noise levels and to document the occurrence of killer whales. Data collected during the 2020 Slowdown included hydroacoustic data, water current velocity, wind speed, and automatic identification system (AIS) data from vessels. In addition, temperature and salinity profiles (for measuring speed of sound in seawater) were sampled approximately once a month at several locations in Boundary Pass and Haro Strait. The goals of this study were as follows:

- To quantify changes in sound levels due to vessels participating in the voluntary Slowdown, while controlling for confounding factors such as water current speed, wind speed, and other non-participating vessel presence using both distribution comparisons (Cumulative Distribution Functions) and statistical models (Generalized Additive Mixed Models);
- To quantify changes in "quiet time" (i.e., times when broadband sound levels are below two sound pressure level (SPL) thresholds) between the Baseline and Slowdown periods; and
- To document the presence of killer whales as determined by acoustic detectors and comparing results to visual observations.

This chapter presents methods, results, and conclusions for the 2020 hydroacoustic studies.

Table 1. Baseline and Slowdown periods for 2020.

Period	Start date/time (PDT)	End date/time (PDT)	Duration (days)
Baseline	2020 May 3 00:00	2020 Jul 1 23:59	60
Slowdown	2020 Jul 2 00:00	2020 Oct 31 23:59	122

1.2. Methods

1.2.1. Hydroacoustic Measurements

1.2.1.1. Lime Kiln

Underwater sound was recorded with a Reson TC4032 hydrophone (Teledyne Reson; −170 ± 3 dB re 1 V/µPa sensitivity) that was diver deployed and cabled ashore to the Lime Kiln Lighthouse (Figure 1). The hydrophone was commissioned on 15 Sep 2018 and is still in use at the time of this report (Table 2). The hydrophone was protected by a hydrophone cage, which was covered with a shroud to minimize noise artifacts from water flow. Data were digitized with a high-quality data acquisition board (St. Andrews Instrumentation Ltd., http://www.sa-instrumentation.com/) at a sample rate of 250,000 samples per second (10 Hz to 125 kHz recording bandwidth) and a 16-bit resolution, and they were stored by PAMGUARD (https://www.pamguard.org/) as 1 minute WAV files.

The system was calibrated on 29 May 2019 and 3 Dec 2020 using a Pistonphone Type 42AC precision sound source (G.R.A.S. Sound & Vibration A/S) and was found to be stable. The pistonphone calibrator produces a constant tone at 250 Hz at the hydrophone sensor. The level at which the Lime Kiln system recorded the reference tone yields the total pressure sensitivity for the instrumentation, i.e., the conversion factor between digital units and pressure.

Table 2. Hydrophone location at Lime Kiln. The system recorded continuously, with a few periods of down time during the Baseline and Slowdown periods (system uptime was 99%).

Reson serial #	Latitude	Longitude	Water depth (m)	Hydrophone height above seafloor (m)	Start date/ time (PDT)	End date/ time (PDT)	Period
0217071	48° 30.930' N	123° 9.174' W	23	1	2018 Sep 21 14:55	Ongoing	Baseline & Slowdown

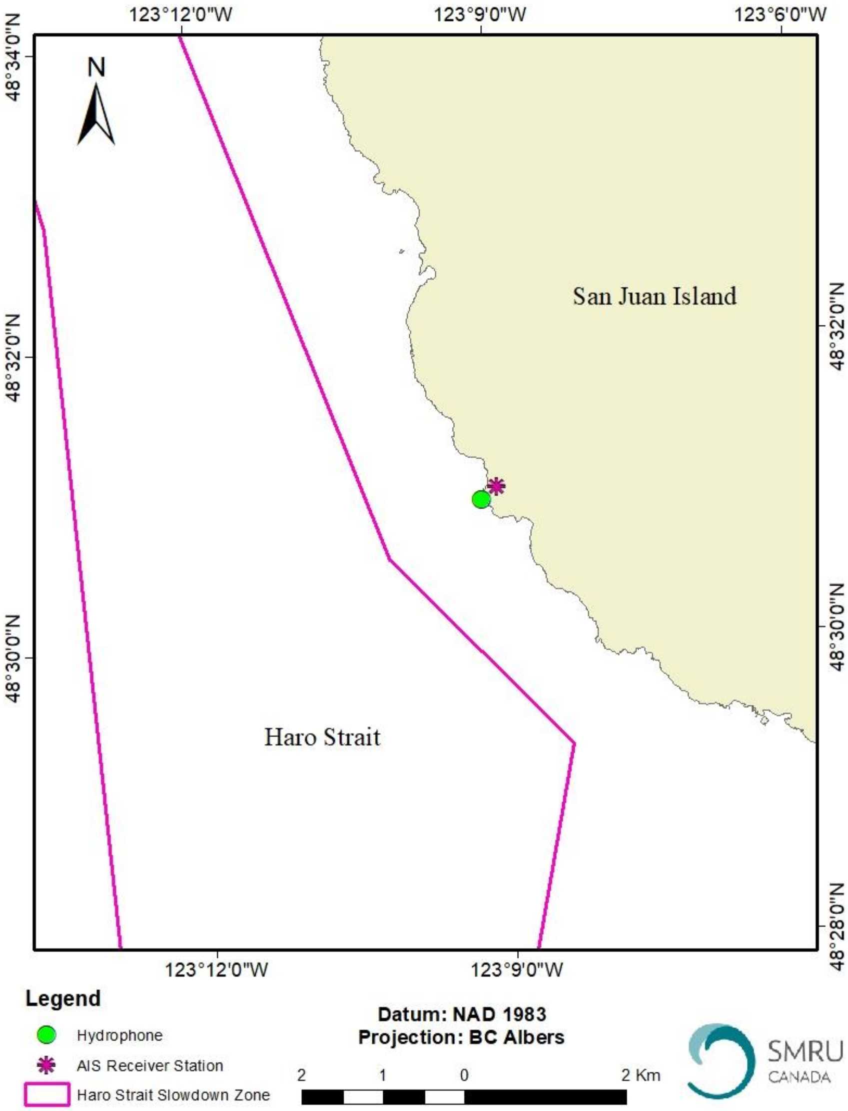

Figure 1. Map of Haro Strait with the location of the Lime Kiln hydrophone.

1.2.1.2. Boundary Pass

Underwater sound was recorded with one Autonomous Multichannel Acoustic Recorder Generation 4 (AMAR G4; JASCO) until 9 Jun 2020, after which time sound was recorded with Frame A of the cabled Underwater Listening Station (ULS; JASCO) in Boundary Pass. Table 3 lists the sensor deployment locations and the recording periods. The AMAR and ULS were deployed on sub-sea moorings between the international shipping lanes in Boundary Pass, within approximately 300 m of each other. The AMAR mooring incorporated back-up retrieval measures, including tandem acoustic releases and satellite beacons (Figure 2). The ULS mooring consisted of two tetrahedral frames (A and B) that were deployed using a remotely operated vehicle (ROV) (Figure 3). The AMAR and Frame A of the ULS were equipped with M36-V35 omnidirectional hydrophones (GeoSpectrum Technologies Inc; −165 ± 3 dB re 1 V/µPa sensitivity). The AMAR had one GeoSpectrum hydrophone, and Frame A of the ULS had four. Only one of the four GeoSpectrum hydrophone channels from Frame A were analyzed for this study. The hydrophones were protected by a hydrophone cage, which was covered with a shroud to minimize noise artifacts from water flow. The AMAR recorded sound at 128,000 samples per second (10 Hz to 64 kHz recording bandwidth) with 24 bit resolution and 1.8 TB storage memory, and the ULS recorded sound at 512,000 samples per second (10 Hz to 256 kHz recording bandwidth) with 24 bit resolution on each channel. ULS data was recorded at a shore station on Saturna Island. Figure 4 shows an AMAR mooring on the aft deck of the MV *Moving Experience*, and Figure 5 shows one of the cabled ULS frames being deployed.

Table 3. Acoustic recorder locations and periods used for analysis. ULS data were used during time periods when the AMAR and ULS recorded simultaneously, because the ULS recordings had less mooring noise.

Sensor	Latitude	Longitude	Water depth (m)	Hydrophone height above seafloor (m)	Start date/ time (UTC)	End date/ time (UTC)	Period
AMAR 629	48° 45.59152' N	123° 3.90083' W	193	3.6	2020 Jan 31 3:20	2020 Jun 13 14:57	Baseline
ULS Frame A	48° 45.64598' N	123° 3.663361' W	193	2.2	2020 Jun 9 2:07	Ongoing	Baseline & Slowdown

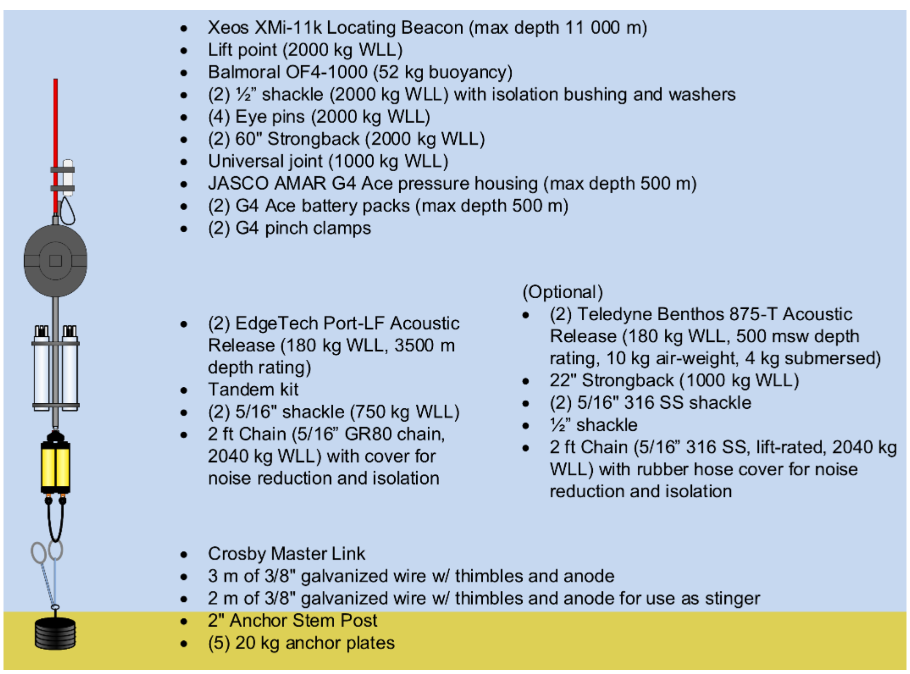

Figure 2. Boundary Pass AMAR G4 mooring (JASCO design 202). The hydrophone was located a few metres above the seabed, inside the cage at the top of the Autonomous Multichannel Acoustic Recorder (AMAR).

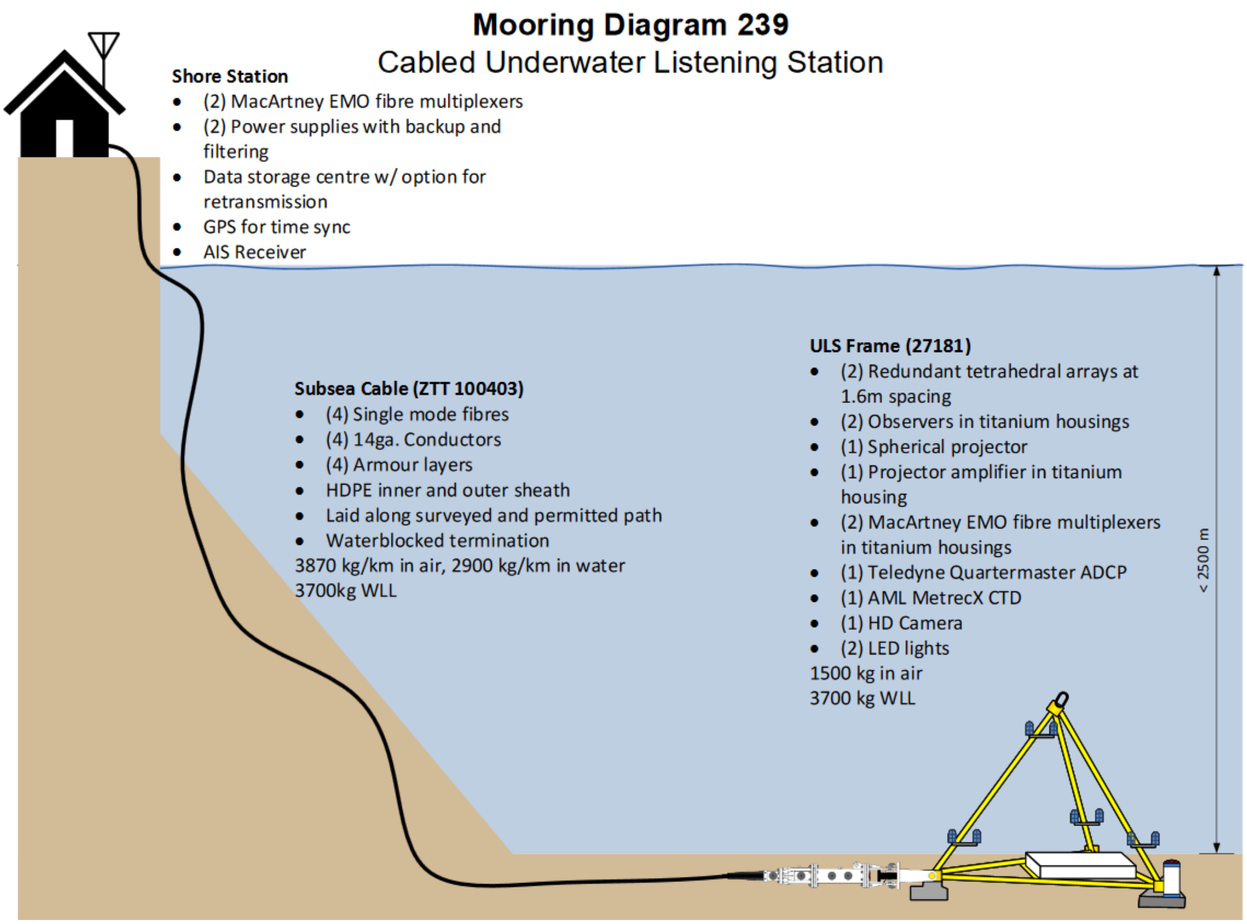

Figure 3. Boundary Pass Underwater Listening Station (ULS) mooring (JASCO design 239). The hydrophones were mounted on the tetrahedral frame and the upper hydrophone was 2.2 m above the seabed, inside an acoustically transparent shroud.

Figure 4. Autonomous Multichannel Acoustic Recorder (AMAR) mooring ready for deployment on the back deck of MV *Moving Experience*.

Figure 5. Boundary Pass Underwater Listening Station (ULS) frame connected to cable termination and being deployed.

The AMAR was accurately localized on the seabed by measuring ranges to the acoustic releases at four surface GPS waypoints using an acoustic transducer. The estimated easting and northing accuracy after localization was approximately 3 m. The location of the ULS was accurately measured during deployment using the ROV and an ultra-short baseline acoustic positioning system (USBL). Figure 6 shows the locations of the recorders.

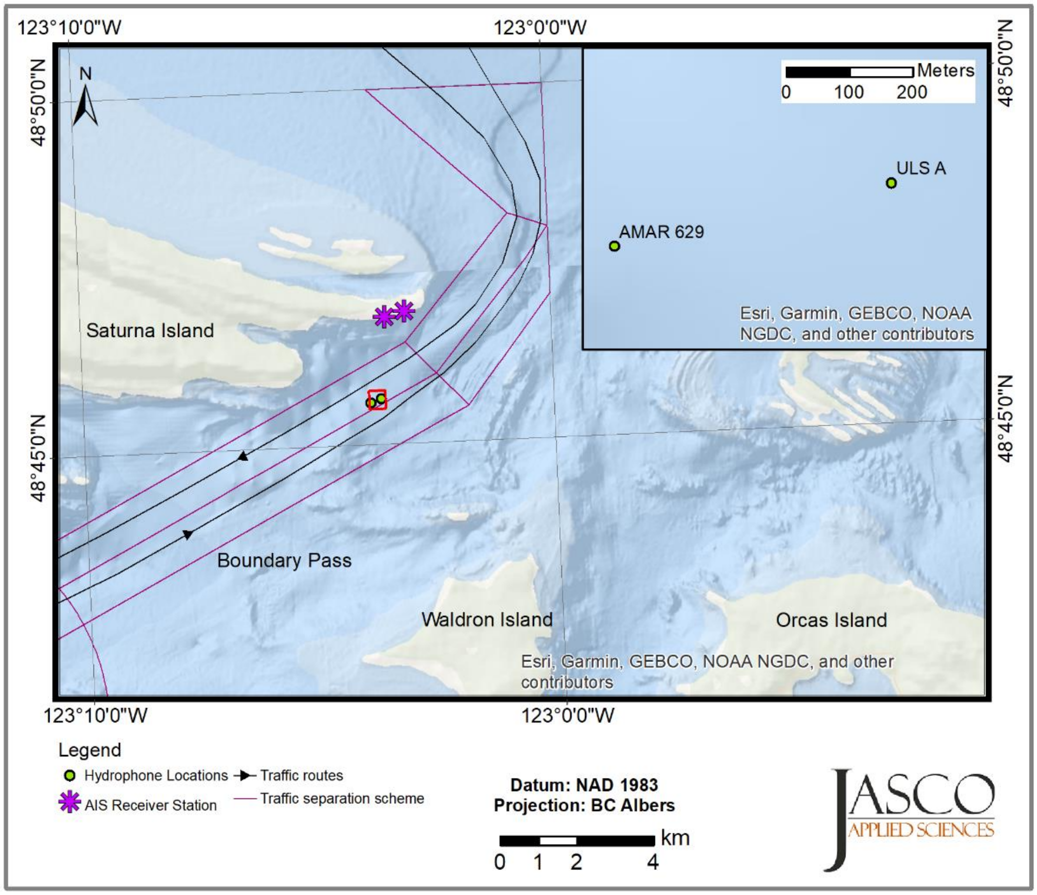

Figure 6. Map of Boundary Pass with locations for the hydrophones and Automatic Identification System (AIS) receivers. An Acoustic Doppler Current Profiler (ADCP) was mounted on ULS Frame A.

The laboratory calibrations of the AMAR at a single frequency were verified to within 0.5 dB before deployment and after retrieval using a Pistonphone Type 42AA precision sound source (G.R.A.S. Sound & Vibration A/S). Before deployment, the laboratory calibrations of the ULS at a single frequency were verified in the same way as the AMAR. The pistonphone calibrator produces a constant tone at 250 Hz at the hydrophone sensor. The level at which the instrument record the reference tone yields the total pressure sensitivity for the instrument, i.e., the conversion factor between digital units and pressure. In addition to the absolute sound level calibration checks, relative sound level calibration checks were also performed between the ULS hydrophones and between the primary ULS hydrophone and the AMAR.

Although the AMAR and ULS were deployed within 300 m of each other, there were differences in the ambient noise levels for the concurrent recording period. Figures 7 and 8 shows example waveforms and spectrograms for simultaneous 3 minute recordings from the Baseline period measured on the AMAR and ULS, respectively. A large vessel was present during the time period shown in these figures and the water current speeds were less than 0.5 m/s (large vessel traffic is discussed in Sections 1.2.3 and current speeds in Section 1.2.5). The AMAR mooring noise was strongest at frequencies below 100 Hz, but also extended to higher frequencies. There was a rhythmic nature to the noise, but it was also intermittent over relatively short timescales where we do not expect water currents changed substantially.

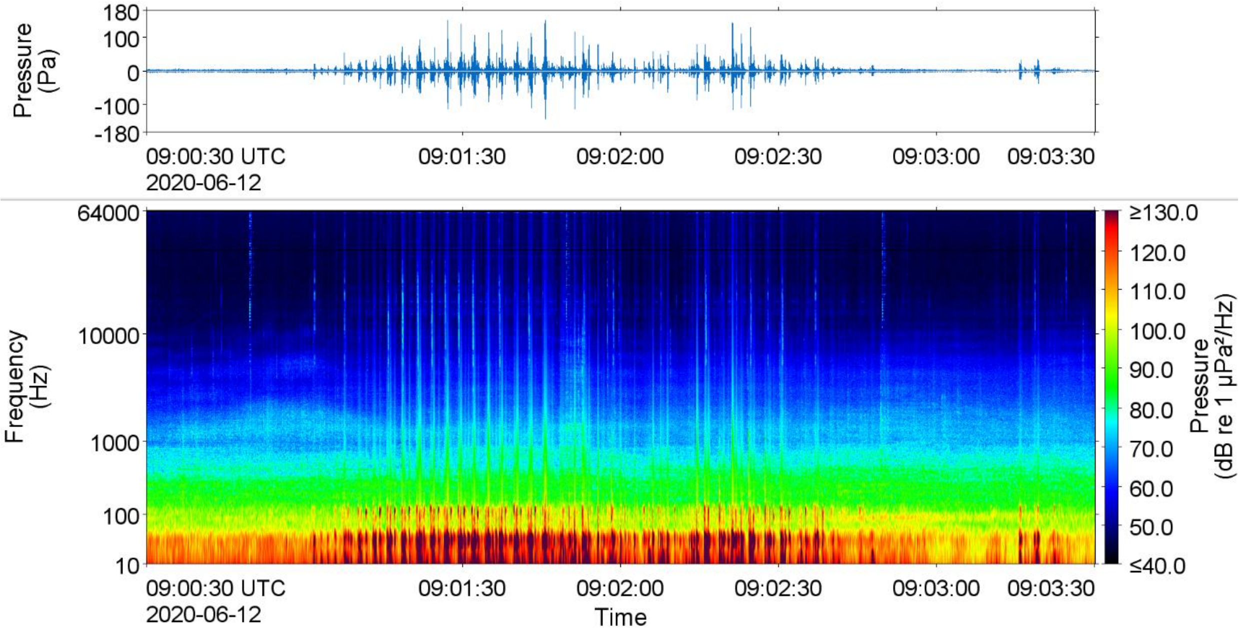

Figure 7. AMAR 629 waveform (top) and spectrogram (bottom) showing intermittent mooring noise below 100 Hz.

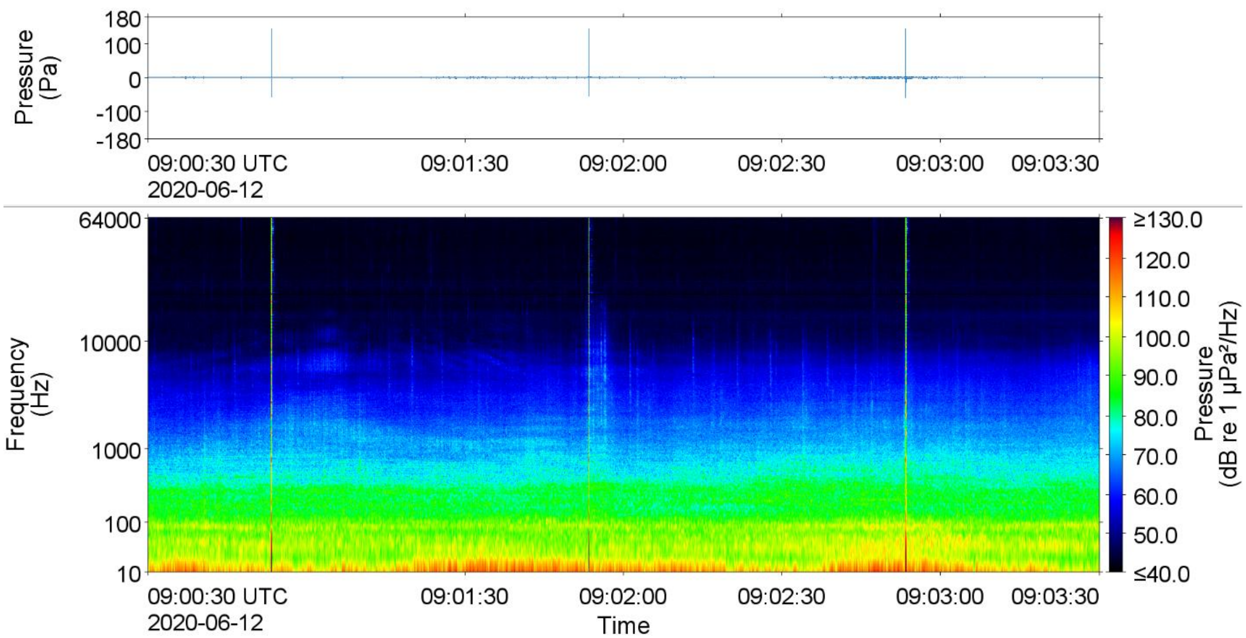

Figure 8. ULS Frame A waveform (top) and spectrogram (bottom) from the same time as AMAR 629 recorded mooring noise (see Figure 7).

AMAR data for the Baseline period were discarded from the Slowdown analysis because mooring noise in the recordings could not easily be filtered out of the data. Discarding these data avoided introducing noise-related bias into sound levels measured during the Baseline period. Furthermore, Baseline period vessel traffic composition was found to be consistent before and after the ULS commissioning, so we do not expect that removing the earlier portion of the Baseline period would influence the Baseline sound level statistics. Thus, only data from the ULS were used for analysis, which limited the effective Baseline period in Boundary Pass to 22.6 days (Table 4).

Table 4. Baseline and Slowdown periods used for analysis in Boundary Pass.

Period	Start date/time (PDT)	End date/time (PDT)	Duration (days)
Baseline	2020 Jun 9 10:07	2020 Jul 1 23:59	22.6
Slowdown	2020 Jul 2 00:00	2020 Oct 31 23:59	122

1.2.2. CTD Measurements

Conductivity, temperature, and depth (CTD) measurements were made on an approximately monthly basis using an RBR*concerto*[3] CTD logger (https://rbr-global.com/) in Boundary Pass and Haro Strait from May to October 2020. An intensive day of data collection in Haro Strait with CTD casts every ~45 minutes occurred in August. Note that salinity is derived from conductivity measurements. The logger was fastened to a weight and line and then lowered by hand from a research vessel. The data logger sampled temperature, salinity, and depth eight times per second. Only data collected during the downcast were used for calculating sound speed profiles, as is standard for these measurements, which ensures that the sensor samples from water undisturbed by the unit. Figure 9 shows a map of the CTD cast locations, and Table 5 lists the coordinates of the CTD casts.

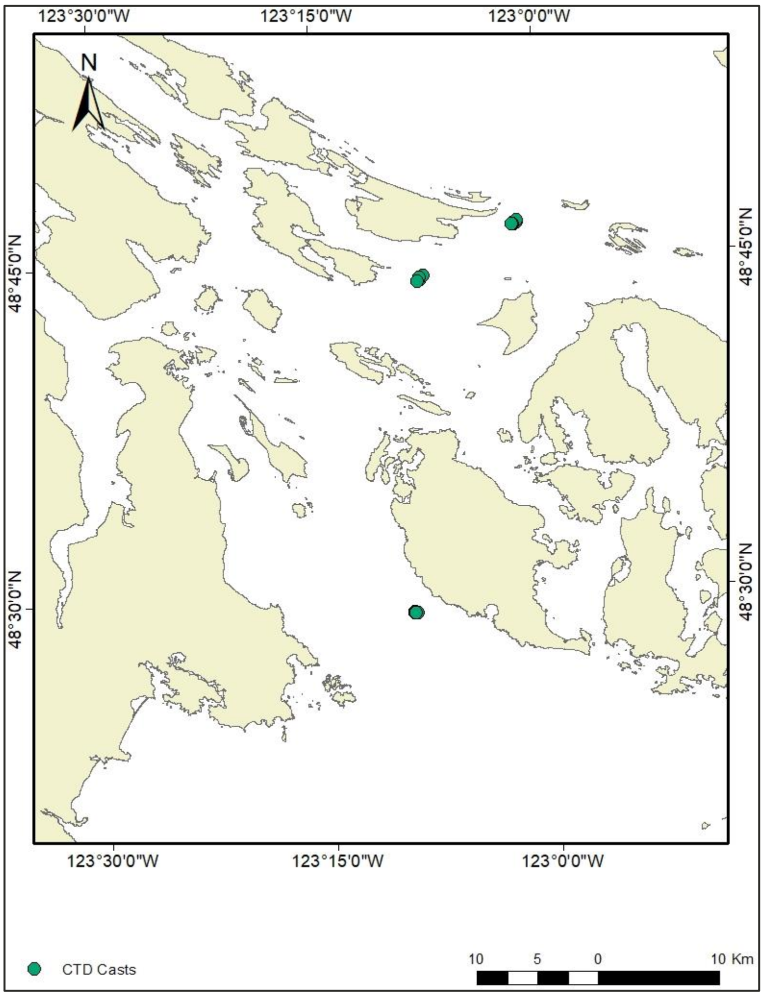

Figure 9. Locations of conductivity, temperature, and depth (CTD) casts in Haro Strait and Boundary Pass.

Table 5. Location and times of the conductivity, temperature, and depth (CTD) casts in Haro Strait and Boundary Pass.

Location	Latitude	Longitude	Date and time (PDT)
Haro Strait	48° 29.223' N	123° 09.257' W	2020 May 15 13:01
	48° 29.211' N	123° 09.232' W	2020 Jun 18 11:23
	48° 29.224' N	123° 09.236' W	2020 Jul 15 12:56
	48° 29.196' N	123° 09.059'W	2020 Aug 20 09:19
	48° 29.196' N	123° 09.059' W	2020 Aug 20 10:00
	48° 29.196' N	123° 09.059' W	2020 Aug 20 10:46
	48° 29.196' N	123° 09.059' W	2020 Aug 20 11:21
	48° 29.196' N	123° 09.059' W	2020 Aug 20 12:13
	48° 29.196' N	123° 09.059' W	2020 Aug 20 13:06
	48° 29.196' N	123° 09.059' W	2020 Aug 20 13:41
	48° 29.196' N	123° 09.059' W	2020 Aug 20 14:24
	48° 29.196' N	123° 09.059' W	2020 Aug 20 15:15
	48° 29.196' N	123° 09.059' W	2020 Aug 20 16:00
	48° 29.196' N	123° 09.059' W	2020 Aug 20 16:45
	48° 29.196' N	123° 09.059' W	2020 Aug 20 17:29
	48° 29.191' N	123° 09.214' W	2020 Aug 28 14:31
	48° 29.195' N	123° 09.193' W	2020 Sep 21 11:35
Boundary Pass	48° 46.388' N	123° 01.612' W	2020 May 15 11:12
	48° 44.057' N	123° 07.984' W	2020 May 15 11:35
	48° 44.206' N	123° 07.820' W	2020 Jun 18 12:44
	48° 46.427' N	123° 01.677' W	2020 Jun 18 13:23
	48° 46.433' N	123° 01.405' W	2020 Jul 15 14:00
	48° 46.522' N	123° 01.377' W	2020 Jul 15 14:27
	48° 46.387' N	123° 01.657' W	2020 Aug 28 12:42
	48° 44.136' N	123° 08.098' W	2020 Aug 28 13:25
	48° 43.985' N	123° 08.200' W	2020 Sep 21 01:06
	48° 46.360' N	123° 01.723' W	2020 Sep 21 01:35

1.2.3. Large Vessel Traffic

For traffic safety reasons, vessels over 300 tons (excluding fishing vessels) and passenger vessels over 150 tons carrying over 12 passengers are required to broadcast AIS information at regular intervals. AIS messages are a reliable data source about large vessel traffic in Boundary Pass and Haro Strait, so the messages were recorded using AIS receivers and logging computers. AIS transmissions from vessel traffic in Boundary Pass were recorded using land-based AIS receivers located near East Point on Saturna Island (Figure 6), while those in Haro Strait were recorded using a land-based AIS receiver located at the Lime Kiln Lighthouse. The receivers were connected to computers that recorded data throughout the Baseline and Slowdown periods. The computers were connected to an uninterruptible power supply (UPS) in case of power outages.

Vessel classification data transmitted over AIS are sometimes invalid or incorrect. To ensure that vessels that were potential participants in the Slowdown were properly identified, the AIS data recorded in Boundary Pass and Haro Strait were compared to data from the Pacific Pilotage Association (https://www.ppa.gc.ca/vessel-movement-data) and corrected (if needed). The data sets were compared using each vessel's the International Maritime Organization (IMO) number and/or Maritime Mobile Service Identity (MMSI) number.

Vessel speed through water was calculated by adding or subtracting (as appropriate) the water current from the AIS transmitted speed over ground. In Haro Strait, speed through water was assessed on a per-minute basis for the closest vessel within 6 km to the hydrophone using currents measured at Lime Kiln (see Section 1.2.5).

In Boundary Pass, speed through water was assessed for each vessel transit through the Pass. Modelled currents at seven locations along the international shipping lanes from the WebTide Tidal Prediction Model (v0.7.1) (Foreman et al. 2000, Institute of Ocean Sciences 2015) were used to determine each vessel’s time-dependent speed through water as the vessel transited through Boundary Pass. The mean speed through water, calculated over the course of the transit, was used to summarize the vessel’s speed through water for the transit. The mean speed through water was then used to calculate statistics by vessel class and period (i.e., Baseline vs. Slowdown).

1.2.4. Small Boat Detections

1.2.4.1. Lime Kiln

An energy band detector was used to detect periods when boats (defined in this report as non-AIS enabled small vessels) might be present at Lime Kiln. This detector used four thresholds (Table 6) and based those thresholds on the hourly median SPL rather than a fixed threshold. The boat detector was triggered when either:

- Thresholds 1, 2, and 3 were exceeded or
- Threshold 2 was exceeded and Threshold 4 was not.

These two triggers allowed for detections of boats passing near the hydrophone at a fast speed (i.e., they produced high amplitudes in the 100–1,000 Hz, 1–10 kHz, and 10–100 kHz frequency bands), or when a boat passed at a slower speed. For this latter case, Threshold 4 was used to avoid detecting large commercial ships (i.e., slow boats tend not to produce much sound in the 100–1,000 Hz band, but ships do). To avoid night false positives, detections earlier than 08:00 and later than 18:00 PDT were discarded.

Table 6. The thresholds used in the boat detector used on the Lime Kiln data.

Threshold number	Decade band	Threshold (dB above the median hourly SPL in this decade band)
1	100–1,000 Hz	6
2	1–10 kHz	5
3	10–100 kHz	23
4	100–1,000 Hz	9

1.2.4.2. Boundary Pass

The boat (i.e., small vessel) and ship (i.e., large vessel) detectors were applied to the Boundary Pass AMAR data by comparing sound levels in established frequency ranges to criteria values. If the criterion was met, a 'shippingFlag' value of either 1 (boat/ship is present) or 4 (boat/ship is nearby) was set. The highest sound level within the minutes flagged as having a vessel present is assigned as the closest point of approach (CPA). The criteria values are outlined in Table 7; criteria names are shown in italics in the description below. The ship and boat detector settings used here are the same as those determined last year to provide optimal detection rates by comparing detector output to visual observations (see Chapter 1 in JASCO Applied Sciences and SMRU Consulting 2020). The criteria are:

- The background SPL within the frequency range is calculated as a long-term average over the *background window duration*.
- Each minute's SPL (within the frequency range) must be greater than the background value by the *Shipping to background threshold*.
- Each minute's SPL (within the frequency range) must exceed the total broadband SPL by *Shipping to RMS Threshold.*
- Each minute's SPL must be greater than the *min broadband SPL.*
- The average number of tonals detected over a *Min shipping duration* minute window must be greater than *Min # of shipping tonals.*
- The duration of the shipping detection must be greater than *Min shipping duration* and less than *Max shipping duration.*

If all of the criteria are met, the 'shippingFlag' is set to 1, indicating that a boat or ship is present in that minute of data. We then assume that the anthropogenic shoulder before and after the shipping detection flag '1' values have energy from the vessel that did not meet the criteria and should not be considered as 'ambient'. This window is given a value of 4 for the shipping detection flag. This system of 1 and 4 attempts to distinguish between ship/boats that are nearer and farther from the AMAR, i.e., for large vessels the sequence is typically a series of flags of 4 (approach), then 1 (over/nearest), and then 4 (departure).

Table 7. Parameters of the vessel detectors used on the Boundary Pass data.

Parameter	Ship detector	Boat detector
f_{min} flag (Hz)	40	315
f_{max} flag (Hz)	315	2000
Min broadband SPL (dB)	105	95
Min # of shipping tonals	3	0.49
Background window duration (min)	720	720
Min shipping duration (min)	5	3
Max shipping duration (min)	360	60
Typical shipping passing duration (min)	30	10
Shipping to background threshold (dB)	3	3
Shipping to RMS threshold (dB)	12	15
Anthropogenic shoulder (min)	15	15

1.2.5. Water Current Measurements

On 9 Jul 2019 at Lime Kiln, divers installed an Infinity current meter (Infinity-EM AEM-USB) on a stand adjacent to (~2 m from) and at the same depth (23 m) as the hydrophone. Every few months, divers recovered and redeployed the unit to download data and replace batteries. The current meter was set to record measurements every 10 minutes. At each 10 minute measurement, an electro-magnetic burst of 10 pulses spaced out by 0.5 seconds was produced to measure currents. The average of these 10 measurements was stored and used for further analysis.

In Boundary Pass, water current speed and direction were recorded with a Quartermaster 150 kHz Acoustic Doppler Current Profiler (ADCP; Teledyne) that was attached to and integrated with the ULS Frame A (Figure 6). The ADCP was configured to measure currents every minute (ping) and record averaged measurements every 15 minutes. The ADCP sampled current speed and direction over the water column in 8 m depth bins. Upwards-facing ADCPs cannot measure currents at very shallow depths, and the measurements in the upper ~15 m of the water column were unreliable. The ADCP recorded data at the same time as acoustic data were recorded.

1.2.6. Wind Speed Measurements

For Lime Kiln, wind speed data were collected with a Davis Instruments Vantage Pro 2 weather station (https://www.davisinstruments.com/vantage-pro2/) mounted on a utility pole behind the Lime Kiln light house.

For Boundary Pass, hourly wind speed measurements from Environment Canada were downloaded to investigate the effect of wind speed. Wind speed measurements were obtained from the Saturna Island CS weather station, located at East Point on Saturna Island, approximately 3 km from the hydrophones. Wind speed measurements from the Kelp Reefs weather station, located in Haro Strait, were used for times when the Saturna Island CS weather station data were unavailable. Weather data from the Eastsound Orcas Island Airport were used when weather data from the Saturna Island CS and Kelp Reefs stations were unavailable.

1.2.7. Ambient Cumulative Distribution Functions

Cumulative Distribution Functions (CDFs) of ambient noise levels were used to investigate the effect of the Slowdown on ambient sound levels. The CDFs represent the cumulative probability of measured sound levels exceeding a given sound level. CDF plots can be used to find the probability of exceeding (being above) or below a value, or of being within, or outside, a particular range. The use of exceedance CDFs were recommended by the ECHO Program's Acoustic Technical Committee to detect trends in ambient noise and were recently used in a similar slowdown noise assessment in Glacier Bay National Park (Frankel and Gabriele 2017), as well as being used in the Fisheries and Oceans Canada (DFO) Canadian Science Advisory Secretariat noise mitigation working paper (see DFO 2017).

To investigate the effect of the slowdown, exceedance CDFs were created for periods when non-slowdown related factors were minimized. This filtering was applied because changes in covariate data can have large effects on ambient noise levels compared to those from vessels participating in the Slowdown initiative. For example, private yachts often transit near the Lime Kiln hydrophone and generate some of the highest amplitude noise levels recorded at this location. Using unfiltered data in the CDF analysis would therefore include a large confounding covariate and potentially skew CDF results. Likewise, the effect of a slowdown on ambient noise levels can only be measured when the vessels that are potentially slowing down are present. Otherwise, the data could be skewed by differing amounts of low-amplitude noise levels.

For the CDF analysis, we focused on time periods when all of the following conditions were satisfied:

- Potential Slowdown participants (i.e., vessels in the categories of Bulk Carrier, Car Carrier, Container Ship, General Cargo, Passenger, and Tanker) were within 6 km of the hydrophone,
- Potential Slowdown participants were the nearest of all AIS broadcasting vessels to the hydrophone,
- Near-seafloor water current speed was less than a site-specific threshold to minimize flow noise effects (using currents collected as described in Section 1.2.5),
- Wind speed was less than a site-specific threshold to minimize wind-driven ambient noise effects, and
- Small boats, which often do not broadcast AIS messages, were unlikely to mask sounds from potential participants, as determined by the small boat detectors (see Section 1.2.4).

The amount of data affected by this filtering varied by site.

CDF results are presented for SPL calculated in several frequency bands (Table 8). These included broadband SPL, decade-band SPL (between 10 Hz and 100 kHz), and SPL in communication and echolocation bands identified by an expert work group convened by the Coastal Ocean Research Institute (Heise et al. 2017b) as being particularly relevant to the acoustic quality of Southern Resident Killer Whale (SRKW) habitat.

Table 8. Sound pressure level (SPL) frequency bands used for Cumulative Distribution Function (CDF) analysis of ambient noise measurements at Lime Kiln in Haro Strait and at the Underwater Listening Station (ULS) in Boundary Pass.

Frequency band	Frequency range
Broadband	10–100,000 Hz
1st decade band	10–100 Hz
2nd decade band	100–1000 Hz
3rd decade band	1–10 kHz
4th decade band	10–100 kHz
CORI SRKW communication band	500–15,000 Hz
CORI SRKW echolocation band	15–100 kHz

1.2.8. Quiet Times

As a direct result of a vessel slowdown, the noise exposure duration time will increase, in theory reducing the amount of "quiet time" between vessel transits. The value of quiet time to SRKWs is that there is little or no anthropogenic noise interference with acoustic behaviours (Heise et al. 2017a). Clearly, natural environmental conditions (such as waves or rain) can also interfere with killer whale communication (Miller 2006). There is sparse data on what threshold might represent "quiet time".

This study assessed variability in the proportion of time when SPL was less than two broadband thresholds. The first threshold was 110 dB re 1µPa, below which behavioural dose response curves for SRKW (Hemmera Envirochem Inc. et al. 2014) predict that noise related behavioural responses are unlikely. The second threshold was 102.8 dB re 1µPa, which was the L_{95} for the Baseline months of the 2017 Slowdown trial in Haro Strait for time periods when AIS vessels were within 6 km of Lime Kiln and times with high currents, winds, and small boat presence were removed. The L_{95} has been used to represent "natural ambient", and this assumption has been previously confirmed by analyzing acoustic data from Lime Kiln in 2012 that removed periods with no detections of vessels, small boats, and associated depth sounders (the three major anthropogenic noise sources at this location) and found a broadband median (L_{50}) SPL of ~101 dB re 1µPa (Hemmera Envirochem Inc. et al. 2014). The same broadband thresholds are used for this 2020 Slowdown study in Haro Strait and Boundary Pass for consistency with past Slowdown analyses.

SPL data used in the quiet time analysis included all acoustic data and therefore multiple noise sources, both natural and anthropogenic. We calculated the number of minutes (duration) of every quiet period below the two selected thresholds.

1.2.9. GAMM Analysis

Statistical analysis of broadband SPL was only conducted on Lime Kiln data. The analysis used a Generalized Additive Mixed Model (GAMM) framework to determine which covariates explained changes in noise levels (SPL) at the hydrophone. A main factor of interest was whether noise levels at Lime Kiln were significantly reduced during the Slowdown period compared to the Baseline period, but the GAMM also provides information on the contributions of other key variables. A GAMM approach was taken for two reasons. Firstly, the relationship between covariates and SPL may not always be linear and therefore a model that also allows for non-linear effects was needed. Secondly, successive SPL measurements at 1-minute intervals are not independent, thus a model that allowed for random effects was needed to account for temporal autocorrelation in the data series. This fine temporal scale analysis used the same data (Lime Kiln only) as was used for the CDF analysis but did not filter out confounding factors, nor restrict the data set to vessel detections within 6 km. The GAMM analysis was conducted in R (a programming language and software environment for statistical computing) using the mgcv package (Wood 2004).

The statistical analysis included the key co-variates of interest: period of initiative (Baseline or Slowdown), and a number of additional regression covariates that would help control for the variation in noise levels received at Lime Kiln. These covariates included:

- The range to the closest AIS-broadcasting vessel,
- Speed through water of the closest AIS-broadcasting vessel,
- Number of AIS-broadcasting vessels within 6 km of Lime Kiln,
- AIS-broadcasting vessel type,
- Presence of a small boat (based on the acoustic detector),
- Wind velocity, and
- Current velocity

Due to the large number of AIS-broadcasting vessel types in the original data set (10), some of these types were condensed into broader categories (reflecting similar speeds and size) so that the GAMM model would run effectively. Container vessels and car carriers were combined into a 'Containerized' category. Bulk carriers, general cargo, and tankers were combined into a Bulk category. Yacht, sail, naval, tugs and passenger were added to the 'other' vessel type. For each category, we then fit separate estimates for the relationship of range to the closest vessel in that category, and separate estimates for the speed through water for vessels in that category. To deal with the lack of independence of successive 1-minute SPL data, we included an auto-correlation function in the model to down-weight adjacent data and avoid pseudo-replication and the inflation of p-values. Independence was assumed only after a four-hour time window based on an empirical examination of the data series.

1.2.10. Killer Whale PAM Detectors

Acoustic detections of killer whales using data from the Lime Kiln hydrophone were assessed during the Slowdown period, as this did not start until after SRKW had returned to Haro Strait for summer. Each day of data was initially processed using PAMGuard software (64-bit Version: 1.15.11; Gillespie et al. 2008). PAMGuard was configured with customized click classifiers that were parameterized to classify impulsive signals as porpoise, killer whale, 50 kHz echosounders, and ship noise, as well as a whistle and moan detector to automatically detect tonal signals. This post-processing resulted in 'binary files' (a PAMGuard filetype) and a populated SQLite database that could be used to further analyze data with PAMGuard's ViewerMode. PAMGuard ViewerMode was then used to identify and log killer whale, porpoise, and anthropogenic events. Events were identified using a combination of the click detection time/bearing display, a scrolling spectrogram, and the Data Map (condensed display showing all of the click and whistle and moan detections for the day). An event was defined as a period of time in which the sound type was present continuously with less than a 30 minute inter-detection interval. Event logs were then exported for each day of data and combined by event type for each month of data using a custom R script.

An automated detector and classifier developed by JASCO was used to detect and classify killer whale vocalizations from acoustic recordings obtained at the ULS hydrophones in Boundary Pass across the four months of the Slowdown (July to October). The algorithm was similar to the one described in Moloney et al. (2014) and Dewey et al. (2015). Figure 10 shows the various processing steps of the detector.

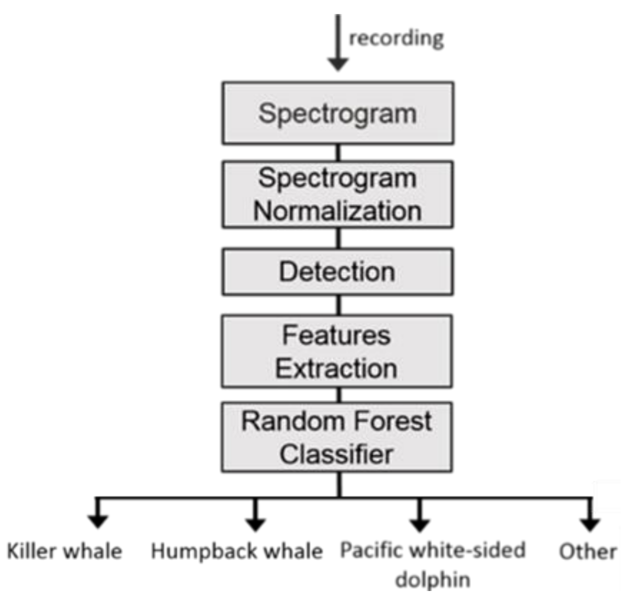

Figure 10. Automatic detection of killer whale, humpback whale, and Pacific white-side dolphin.

The algorithm first calculated the spectrogram and normalized it for each frequency band. Next, the spectrogram was segmented to detect acoustic events between 10 Hz and 8 kHz. For each event, a set of 40 features representing salient characteristics of the spectrogram were extracted, several of which were calculated following Fristrup and Watkins (1993) and Mellinger and Bradbury (2007), and were based on the spectrogram, frequency envelope, and amplitude envelope of the signal.

Extracted features were presented to a classifier to determine the class of the sound detected. The classification was performed using a random forest classifier (Breiman 2001), which was trained using several thousands of manually annotated vocalizations in recordings collected at different locations in British Columbia (Mouy et al. 2015). The random forest was defined with these four classes: “killer whale”, “humpback whale”, “Pacific white-side dolphin”, or “other”. Figure 11 illustrates the key processing steps of the detector on a recording that contained killer whale vocalizations.

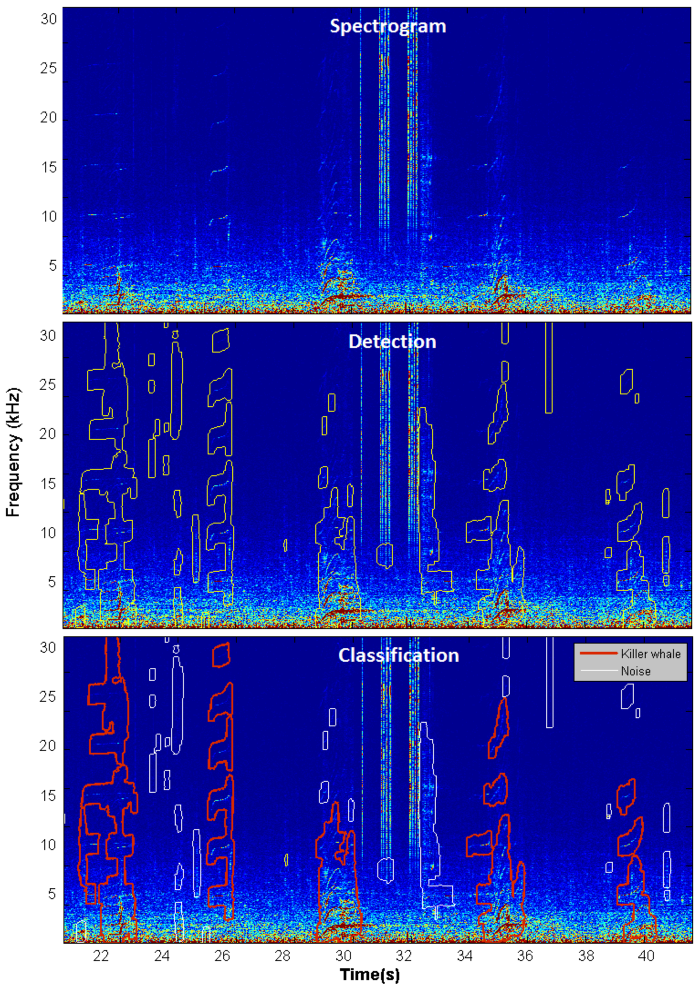

Figure 11. Key processing steps of the detector. Top panel: Spectrogram with killer whale vocalizations. Middle panel: Acoustic events detected in the spectrogram. Bottom panel: Killer whale vocalizations classified using a random forest classifier.

1.2.11. Killer Whale Manual Analysis

All automated detections from killer whale vocalizations obtained at Boundary Pass were manually verified by an experienced analyst (Héloïse Frouin-Mouy, JASCO) using the web application PAMview (Figure 12). All false detections for these species were discarded, and a log of killer whale detections was created. Another experienced analyst (Tina M. Yack, EcoSound Bioacoustics) reviewed these killer whale detections from Boundary Pass to identify the ecotype (SRKW, Transient, or unknown). For Lime Kiln data, Tina Yack identified killer whale events by processing all wav files from the Slowdown period in PAMGuard and then used PAMGuard's ViewerMode to identify start and end times for each event. An event was defined as a period of time in which the sound type was present continuously with less than a 30 minute inter-detection interval. Each unique killer whale event was given an ID, and accurate start and end times from PAMGuard ViewerMode were documented in an Excel worksheet. Killer whale events were reviewed a final time aurally and visually to provide a final ecotype identification (SRKW, Transient, unknown ecotype) when possible.

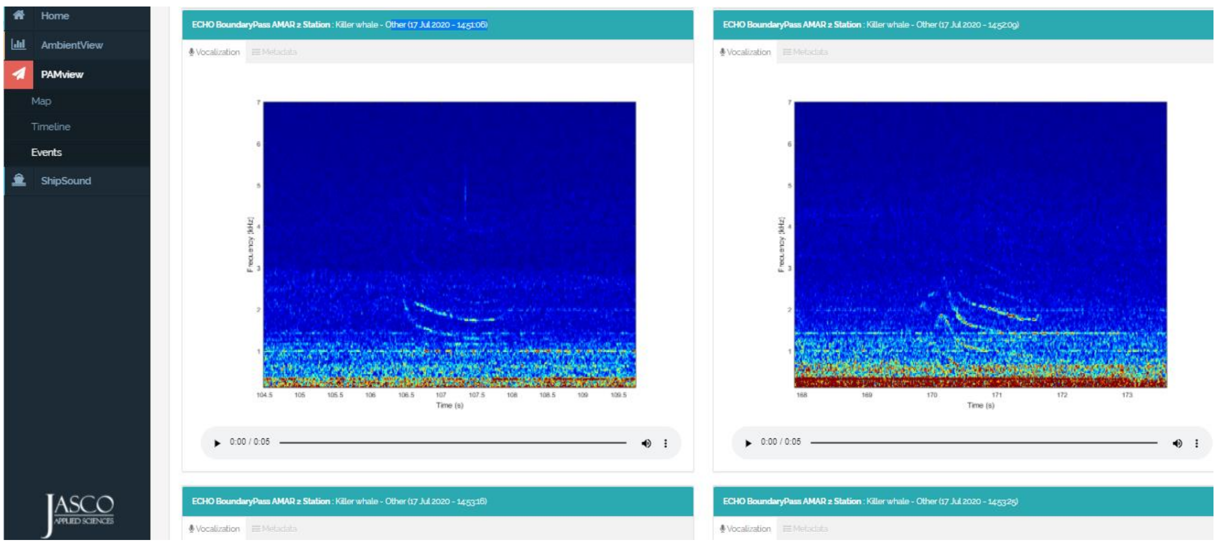

Figure 12. JASCO's Web Portal platform (PAMview). Example of spectrograms with killer whale vocalizations.

1.3. Results

1.3.1. CTD Measurements

A total of 27 CTD casts were collected from May to October 2020: 17 casts in Haro Strait and 10 in Boundary Pass. Figures 13–15 show the temperature, salinity, and sound speed profiles, respectively. Profiles measured in Boundary Pass exhibited a stronger thermocline than those measured in Haro Strait. As a result, the Haro Strait profiles were more uniform with depth. The approximately 1.5 degree change in temperature on 20 Aug 2020, during the day of intensive data collection, likely corresponds to the movement of a tidally-driven front between two different water masses through Haro Strait (Turner 2020). CTD sampling on 20 Aug 2020 started several hours before low tide and continued until high tide. During most of the sampling period, the sound speed profile followed a typical summer profile with highest sound speeds near the surface. However, near the high tide mark, mixing of the water column was such that salinity and temperature were consistent through the water column creating a sound speed profile that increased with depth. This suggests that changes in sound propagation conditions in the Slowdown area are more frequent than previously estimated.

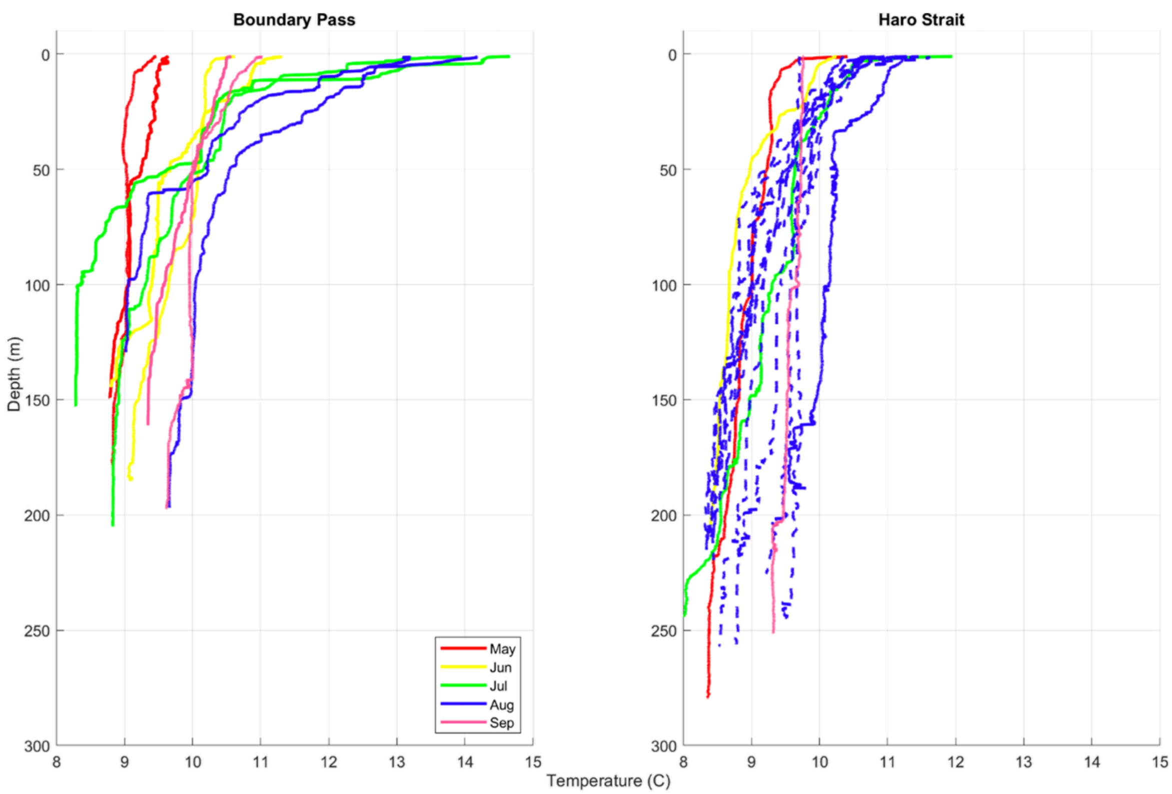

Figure 13. Water temperature profiles from the conductivity, temperature, and depth (CTD) measurements in Boundary Pass and Haro Strait. Dashed blue lines indicate the intensive day of collection in August.

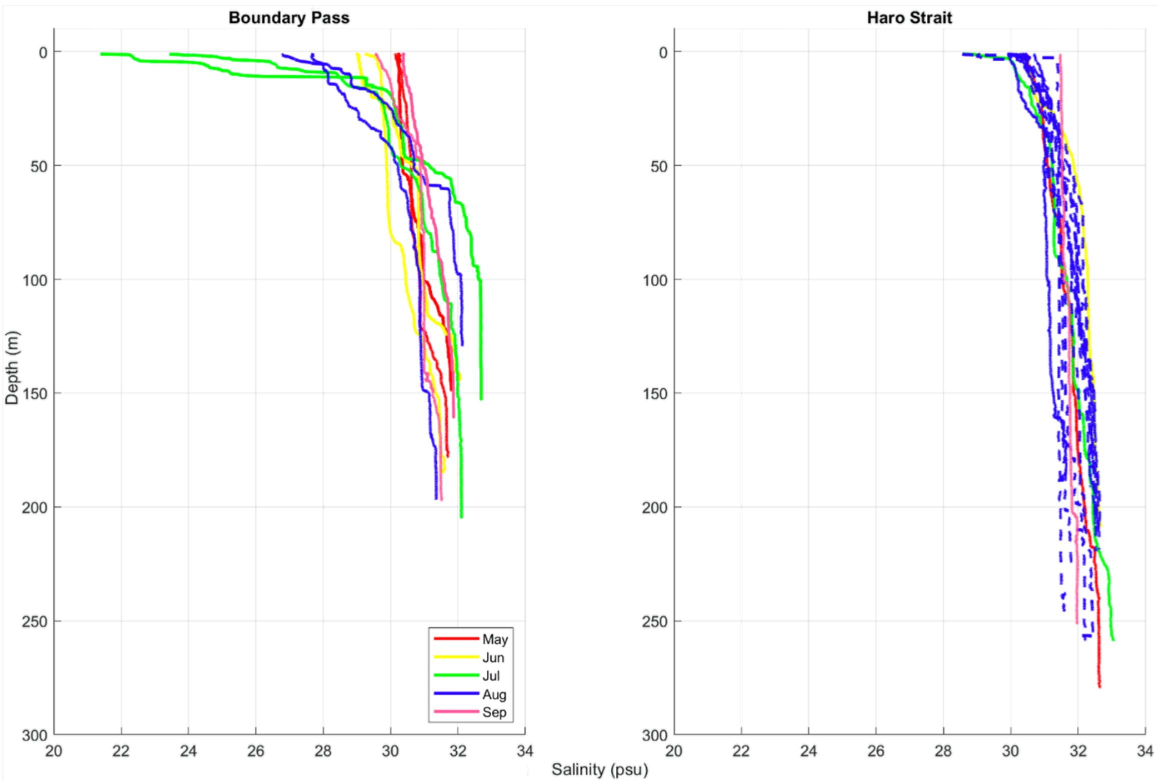

Figure 14. Water salinity profiles from the conductivity, temperature, and depth (CTD) measurements in Boundary Pass and Haro Strait. Dashed blue lines indicate the intensive day of collection in August.

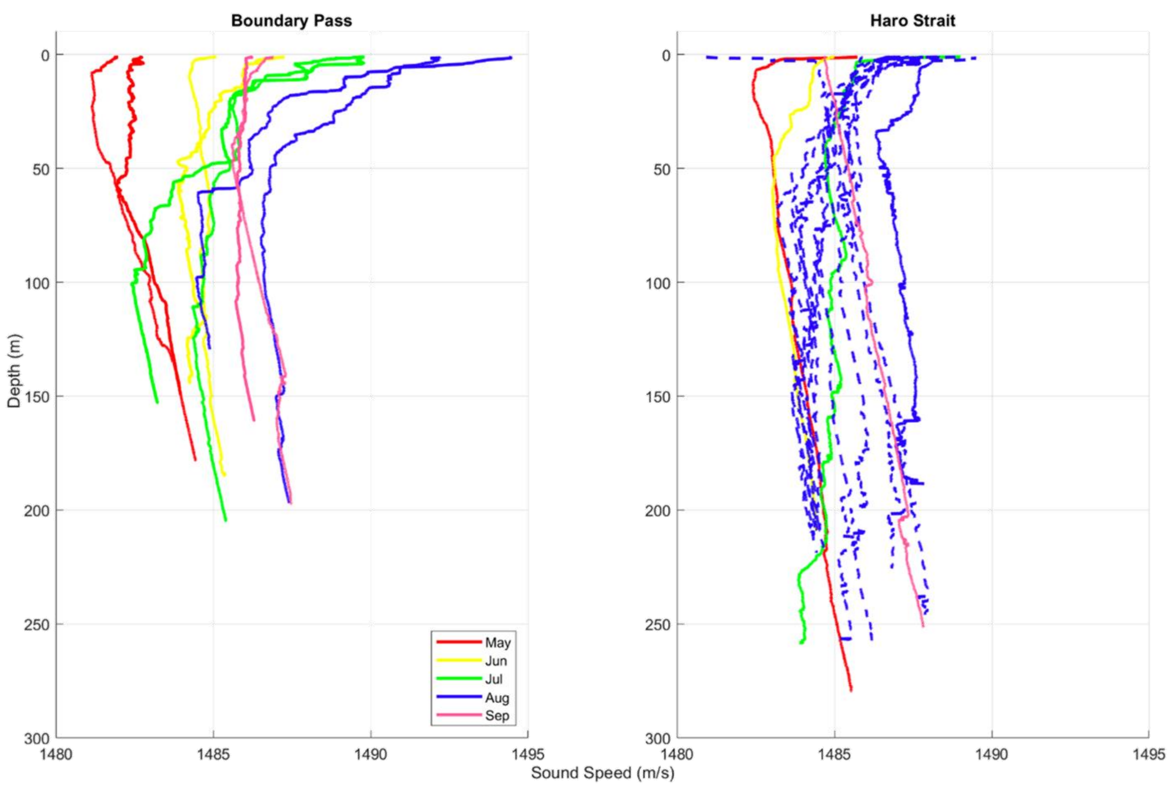

Figure 15. Sound speed profiles calculated from conductivity, temperature, and depth (CTD) measurements in Boundary Pass and Haro Strait. Dashed blue lines indicate the intensive day of collection in August.

1.3.2. Large Vessel Traffic

1.3.2.1. Lime Kiln

Vessel type composition based on the closest AIS-enabled vessel to the Lime Kiln hydrophone in each 1 minute increment within the acoustic 6 km monitoring area was similar (typically within 1–4% across vessel types) between Baseline and Slowdown periods (Figure 16), with Bulk carriers (12–15%), Container Vessels (9%), and General Cargo (14–18%) the most frequently identified piloted vessel types in both periods. Car Carriers, and Tankers each contributed approximately 2–4% of the total minutes. There were no cruise ships (passenger) in the data this year due to the COVID-19 pandemic. The Slowdown period had almost double the percent of yachts and a small increase in sailing vessels. This is also likely due to the pandemic, with private boaters assuming a boating holiday was safe and because US private vessels were not allowed into Canada during this period.

Note that these per minute values reflect not only the number of each type of vessel that transits the area but also the duration of each transit, which varies with speed. The absolute number of minutes with AIS-enabled vessels within 6 km of Lime Kiln was higher during the Slowdown as it lasted 122 days while the Baseline lasted 60 days.

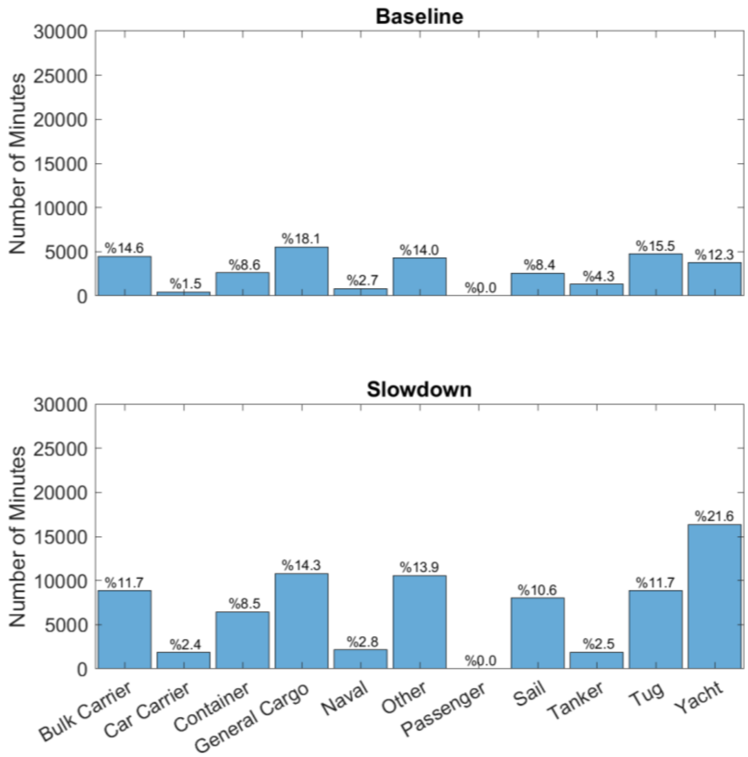

Figure 16. Proportion of Automatic Identification System (AIS) vessel traffic within 6 km of the Lime Kiln hydrophone by vessel category: (Top) Baseline period (30,618 minutes) and (bottom) Slowdown (75,691 minutes) period.

Speed through water (AIS-derived speed over ground corrected for tidal currents as measured at the Lime Kiln hydrophone; see Section 1.2.3 for details) of the nearest vessel was calculated for each minute of Lime Kiln data. For each vessel type, the median speed through water was calculated during the Baseline period. This median speed through the water was subtracted from each 1-minute measure of speed through the water for both the Baseline and Slowdown time periods, to estimate a vessel type specific difference in speed from the median Baseline. Figure 17 shows the distribution of the difference in speed for Baseline and Slowdown periods. These speeds were calculated using vessels contained in the Pacific Pilotage Authority (PPA) data set, which lists all vessels subject to mandatory pilotage in the region (i.e., all speed changes, not just those vessels that participated in the Slowdown initiative). As expected, the Baseline period shows an even distribution around zero (shown with a red dashed line), i.e., half the differences in speed are negative, half are positive. The Slowdown period shows a clear shift in distribution to the left of the Baseline median speed (red dashed line at zero) and thus a clear reduction in speed during the Slowdown. Plotting the distribution of speed through water for key vessel types during Baseline and Slowdown (Figure 18; again using all PPA vessels, not just those who participated) clearly shows which vessel classes slowed down the most, noting that pilots reported to the ECHO Program that 91% of all piloted vessel participated in the Slowdown.

Based on median speed through the water, estimated speed reductions for the different vessel types were as follows for Haro Strait: Bulk carriers 1.1 knots, General cargo 1.1 knots, Tankers 1.1 knots, Container vessels 3.9 knots, and Car carriers 2.2 knots. Passenger vessels (which only included cruise ships in this case) were not present in the data this year due to the pandemic.

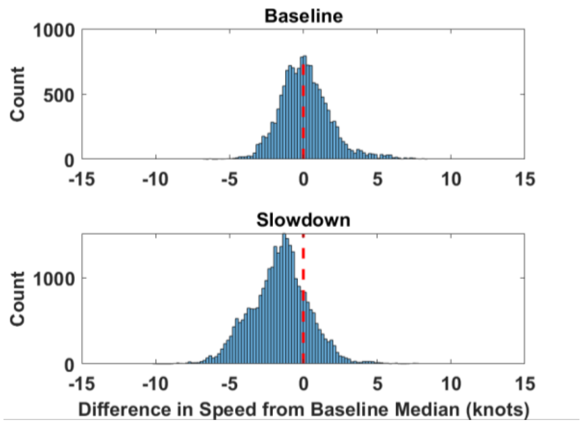

Figure 17. By minute distribution of the difference (by vessel type) between Baseline median speed through water (knots) and vessel speeds recorded during Baseline and Slowdown periods.

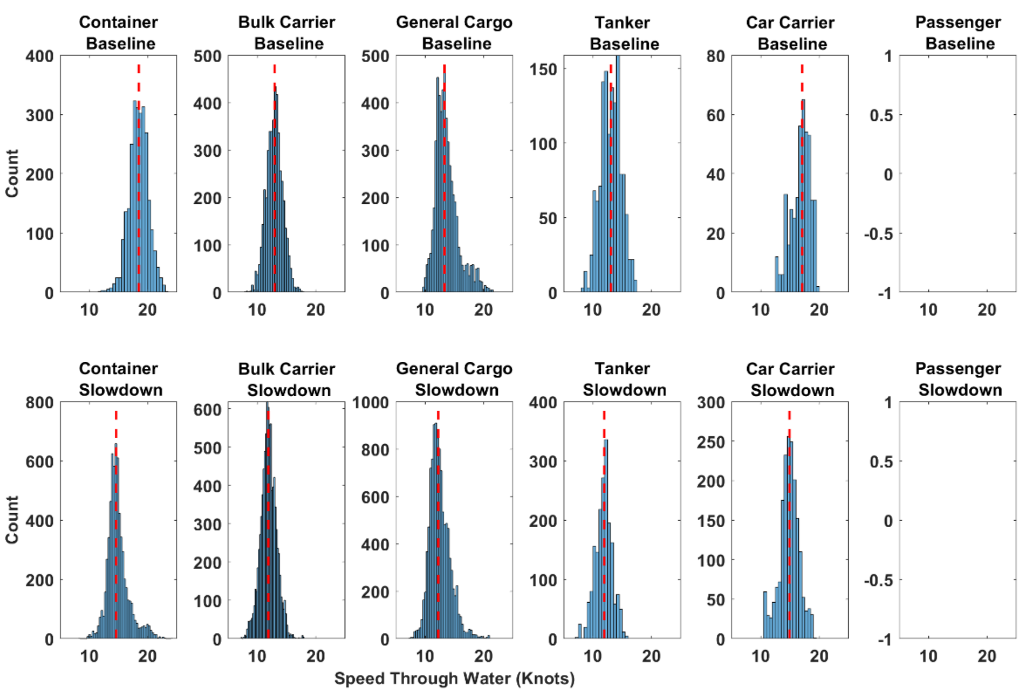

Figure 18. By minute distribution of vessel speed through water (knots) for key vessel types across Baseline and Slowdown periods. The vertical dashed red line represents the median speed for the vessel type in each period.

1.3.2.2. Boundary Pass

Vessel type composition was also similar between the Baseline and Slowdown periods in Boundary Pass. The AIS data collected for Boundary Pass was analyzed to determine the proportion of time when each vessel class was nearest to the hydrophone. This analysis was performed in 1-minute increments to align with the time resolution of the sound level data and considered AIS vessel traffic within 6 km of the hydrophone where the propagation path was not blocked by land. Only AIS data acquired for periods with analyzed acoustic data were used for this analysis (Table 4). Bulk carriers (42–47%) and Container ships (15–17%) were the most frequently identified piloted vessel types. General Cargo, Car carriers, and Tankers each contributed approximately 2–5% of the total minutes. Note that these per minute counts reflect not only the number of each type of vessel that transits the area but also the duration of each transit, which varies with speed.

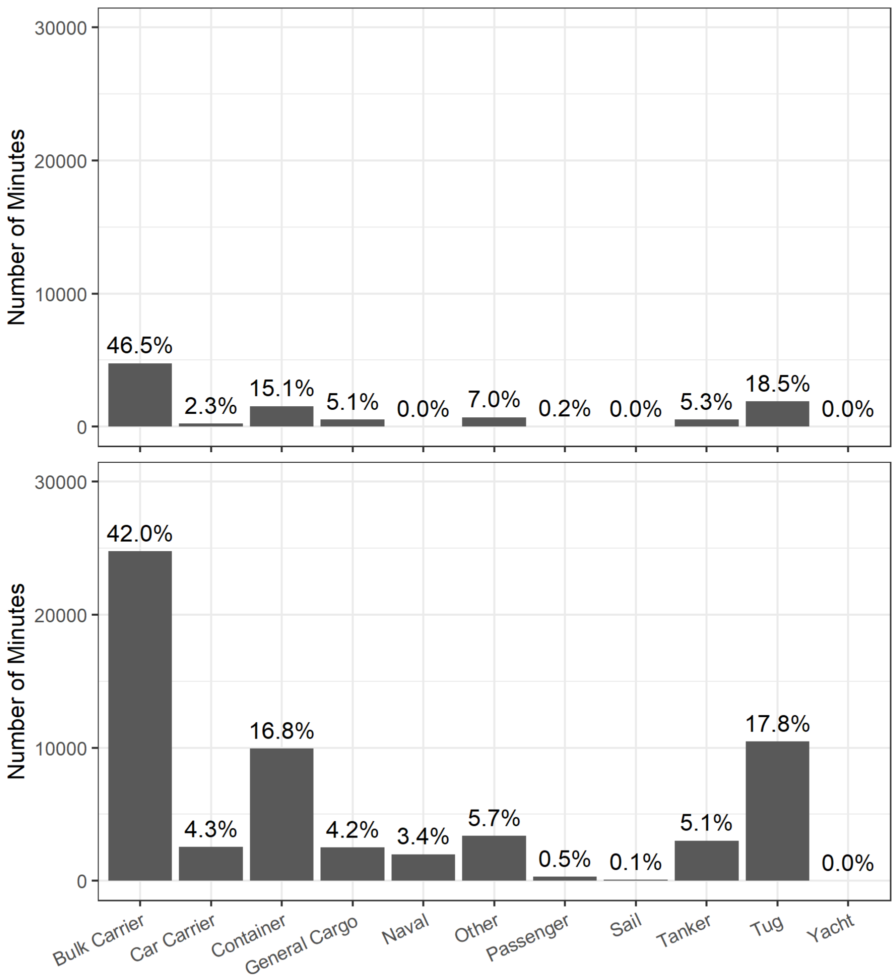

Figure 19. Proportion of Automatic Identification System (AIS) vessel traffic within 6 km of the Boundary Pass hydrophone by vessel category: (Top) Baseline period and (bottom) Slowdown period (Table 4).

Mean speed through water (AIS-derived speed over ground corrected for modelled tidal current effects; see Section 1.2.3 for details) was calculated for each vessel transit through Boundary Pass. For each vessel type, the median speed through water was calculated during the Baseline period from all vessel transits. This Baseline median speed through water was subtracted from each vessel's mean speed through the water for both the Baseline and Slowdown periods, to estimate the vessel-type-specific change in speed from the median Baseline speed. Figure 20 shows the distributions of the difference in speeds for Baseline and Slowdown periods, aggregated over all vessel types. These speeds were calculated using vessels contained in the Pacific Pilotage Authority (PPA) data set, which lists all vessels subject to mandatory pilotage in the region (i.e., all speed changes, not just those vessels that participated in the Slowdown initiative). As expected, the Baseline period shows an even distribution around zero (shown with a red dashed line), i.e., half the differences in speed are negative, half are positive. The Slowdown period shows a clear shift in distribution to the left of the Baseline median speed (red dashed line at zero) and thus a clear reduction in speed during the Slowdown. Plotting the distribution of speed through water for key vessel types during Baseline and Slowdown (Figure 21; again using all PPA vessels, not just those who participated) clearly shows which vessel classes slowed down the most, noting that pilots reported to the ECHO Program that 91% of all piloted vessel participated in the Slowdown.

Based on median speed through the water, estimated speed reductions for the different vessel types were as follows for Boundary Pass: Bulk carriers 1.7 knots, General cargo 1.4 knots, Tankers 0.9 knots, Container vessels 3.9 knots, and Car carriers 2.3 knots.

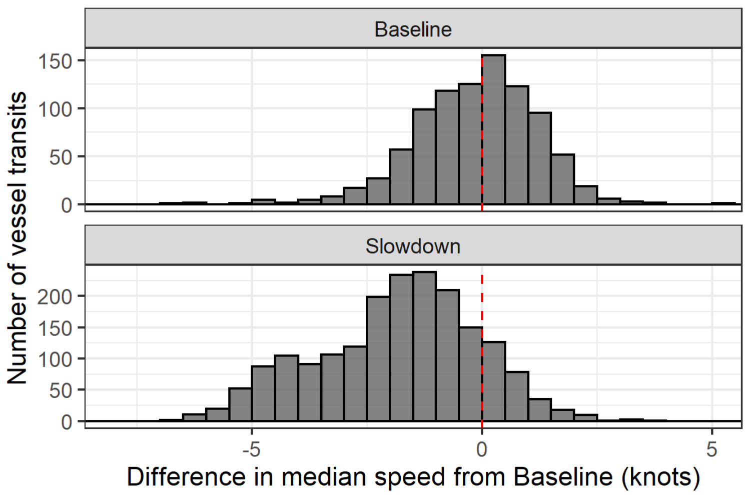

Figure 20. Boundary Pass aggregated over all vessel types: Distributions of the difference between mean vessel speed and the median of the mean Baseline speeds through water for the corresponding vessel category. A negative value indicates a vessel travelling slower than the median vessel of the same type from the Baseline period.

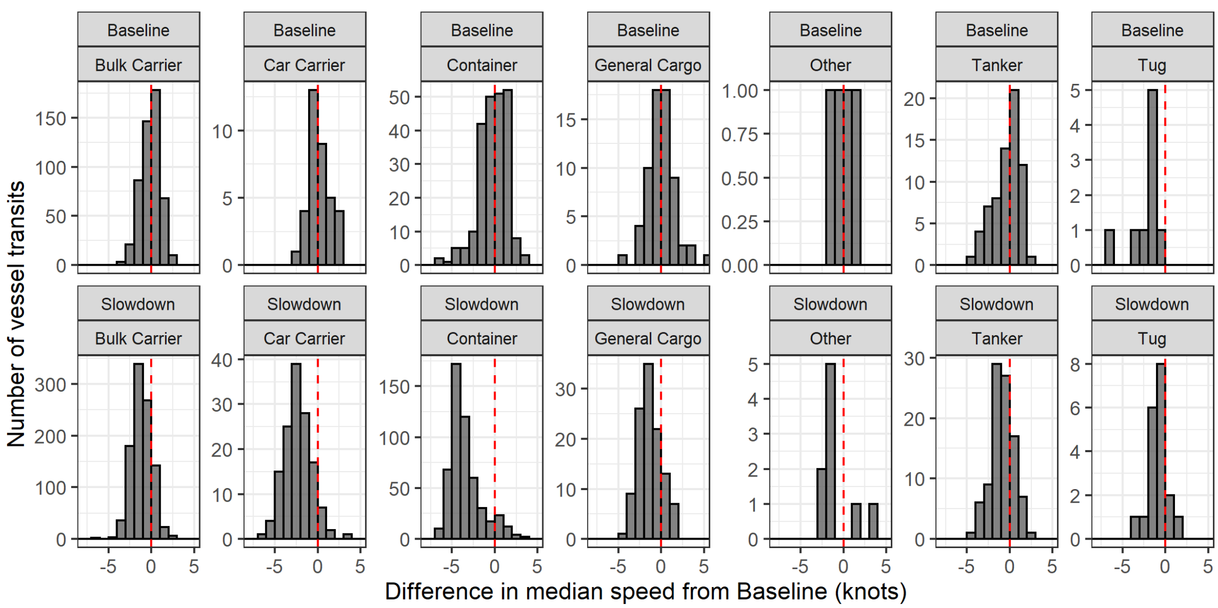

Figure 21. Boundary Pass distributions of the difference between mean vessel speed and the median of the mean Baseline speeds through water for the corresponding vessel category. A negative value indicates a vessel travelling slower than the median vessel of the same type from the Baseline period.

1.3.3. Small Boat Detections

1.3.3.1. Lime Kiln

Figure 22 shows the daily average minutes per hour of small boat presence at Lime Kiln during Baseline and Slowdown periods. Average minutes per hour were likely lower in the Baseline period as it is earlier in the boating season and due to pandemic-related restrictions on human movement.

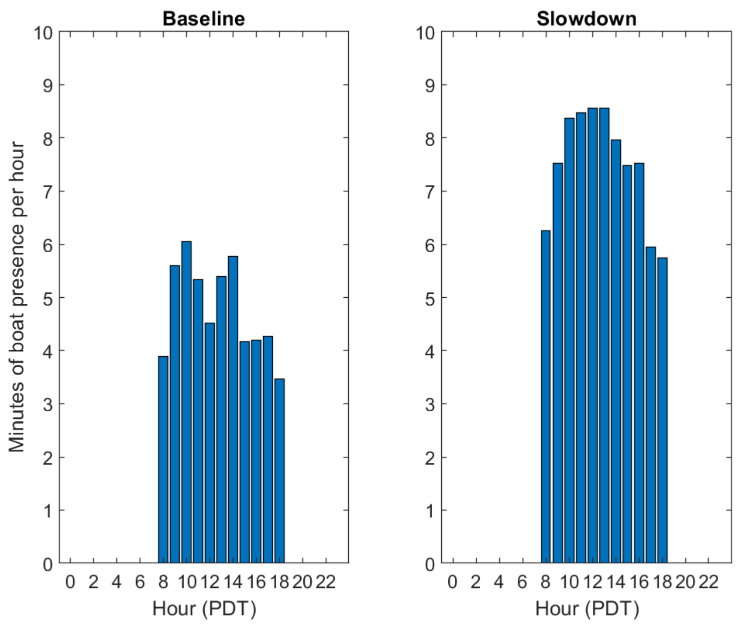

Figure 22. Daily average minutes of small boat detections at Lime Kiln, broken down by hour of day (PDT): (Left) Baseline period and (right) Slowdown period.

1.3.3.2. Boundary Pass

Figure 23 shows the small boat detections at Boundary Pass by minutes of presence per hour. These were only for times when a small boat was detected, but no large vessels were detected. Times with large vessels were excluded because large vessels are much louder than small boats and can generate sound at frequencies similar to small boats. This means they could cause the ship detector and the boat detector to both be flagged. The distributions of small boat detections in Figure 23 show the expected trend of more presence in daytime hours than at night; however, there is not a significant change between Baseline and Slowdown time periods. Figure 24 provides an example spectrogram of a time when there was a small boat detection.

There were 2–3 times more frequent small boat detections in Boundary Pass (Figure 23) than in Haro Strait (Figure 22). These differences may not be representative of small boat density, however, as there are many reasons why the detection rates could differ aside from differences in small boat traffic. The small boat detection algorithms were different between sites, and had different thresholds, sensitivities, and performance. The Boundary Pass hydrophone was centred between the international shipping lanes and was several kilometres from shore, whereas the Lime Kiln hydrophone was several kilometres from the shipping lanes and close to shore. The closer shoreline at Lime Kiln limited the effective listening area in Haro Strait to a much larger degree than the land surrounding the Boundary Pass hydrophone. The small boat detections during the night in Boundary Pass likely contain some false detections, however, the small boat detector may have been triggered by smaller AIS-broadcasting vessels such as tugs or fishing vessels, which are known to transit through Boundary Pass in the night (Warner et al. 2019).

The small boat detection rate in Boundary Pass was slightly higher in 2020 than in 2019, which could have been caused by a change in boat traffic or increased detection range in 2020 due to the lower mooring noise on the ULS. In 2019, the precision of the small boat detector was 95% and the same detector and settings were used in 2020, so we expect similar precision in 2020.

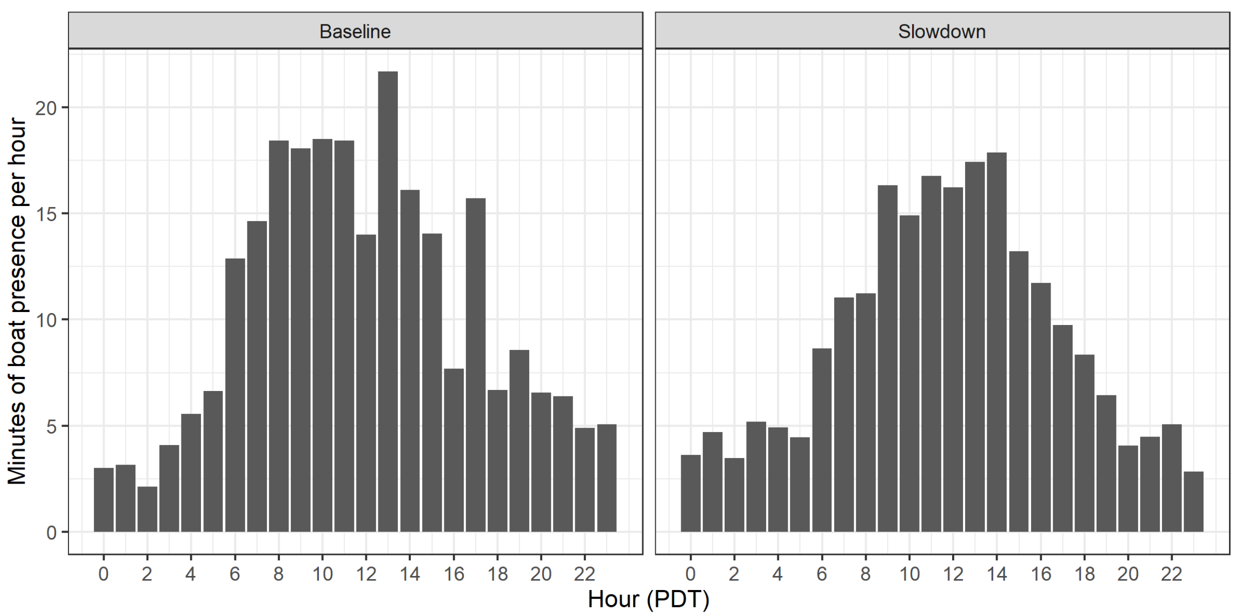

Figure 23. Daily average minutes of small boat detections, by hour of day (PDT): (Left) Baseline period, and (right) Slowdown period.

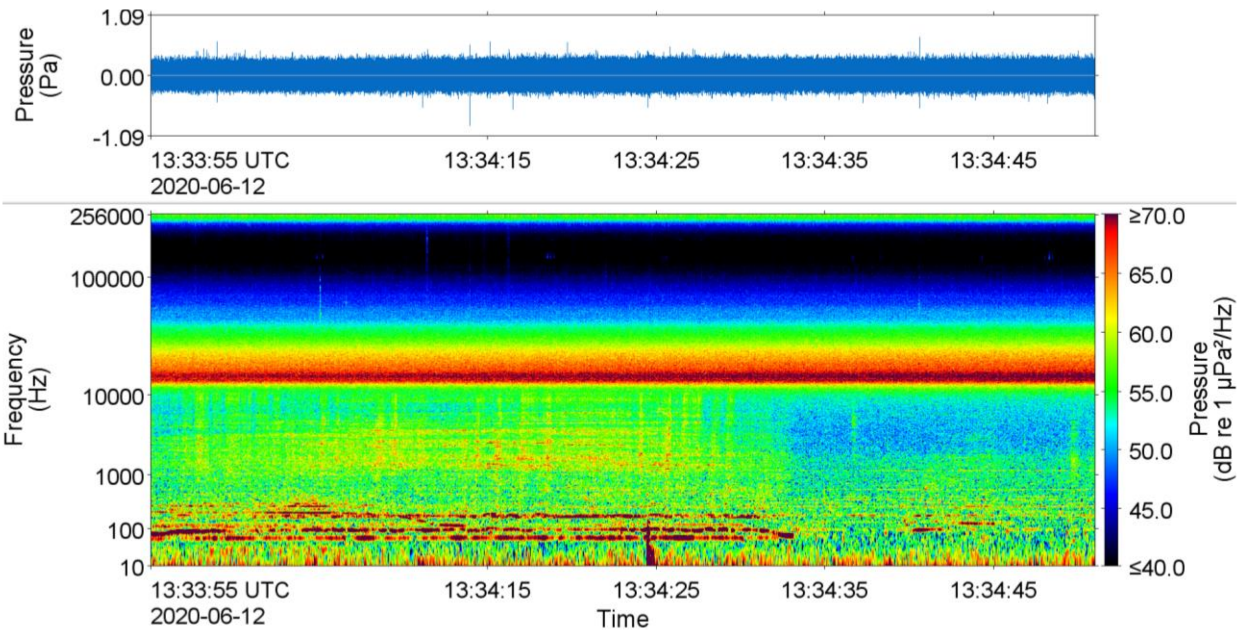

Figure 24. Example of a small boat detection at 13:34 UTC (or 06:34 PDT) at Boundary Pass.

1.3.4. Ambient Noise Cumulative Distribution Functions

1.3.4.1. Lime Kiln

The filtering that was applied to the Lime Kiln data followed the protocol of previous Slowdown analyses with time periods with currents >25 cm/s and wind speeds >5 m/s being removed. Filtering the data removed a large proportion of the data (Table 9), with the AIS filter, which removes time periods with no large vessels/potential Slowdown participants proximate to the hydrophone, removing the most, and the wind filter the least. Because the wind filter was applied to weather data collected at Lime Kiln (this year), instead of from the middle if Haro Strait (as in previous years), less data was excluded from this analysis.

Table 9. Number of minutes as a result of filtering by Automatic Identification System (AIS) data, current speed, wind speed, and small boat detections at Lime Kiln. Each filter also includes the previous filter (e.g., numbers provided for Current also include AIS). Percentages are shown relative to the total number of minutes of acoustic data for each period.

Period	Total number of minutes with acoustic data	AIS filtering			
			Current filtering		
				Wind filtering	
					Small boat filtering
Baseline	86,357	14,403 (17%)	9152 (11%)	9137 (11%)	8728 (10%)
Slowdown	175,572	29,798 (17%)	20,470 (12%)	20,437 (12%)	19,876 (11%)

Figures 25 through 31 show the exceedance CDFs after applying filtering on the Baseline and Slowdown period data, and Table 10 lists sound level exceedance statistics. The differences between the L_5, L_{50}, L_{95}, and L_{eq} metrics from the two periods are listed in Table 11. There was a clear decrease in SPL from the Baseline to the Slowdown period. The median broadband level decreased by 2.5 dB and the broadband L_{eq} decreased by 2.4 dB during the Slowdown period.

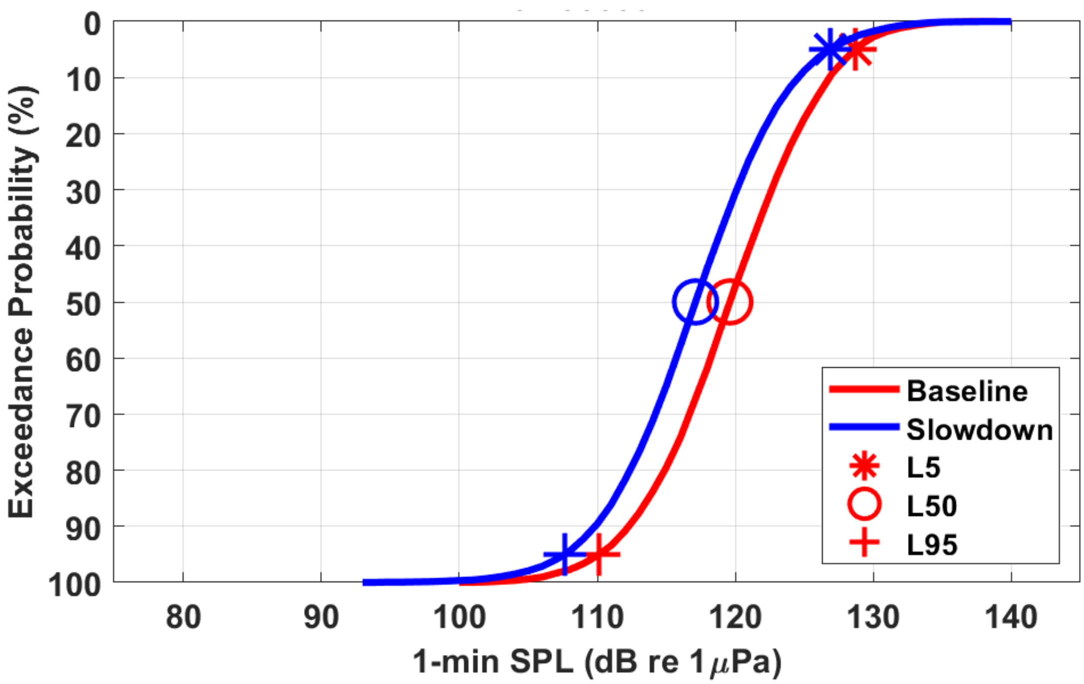

Figure 25. Lime Kiln broadband (10–100,000) exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

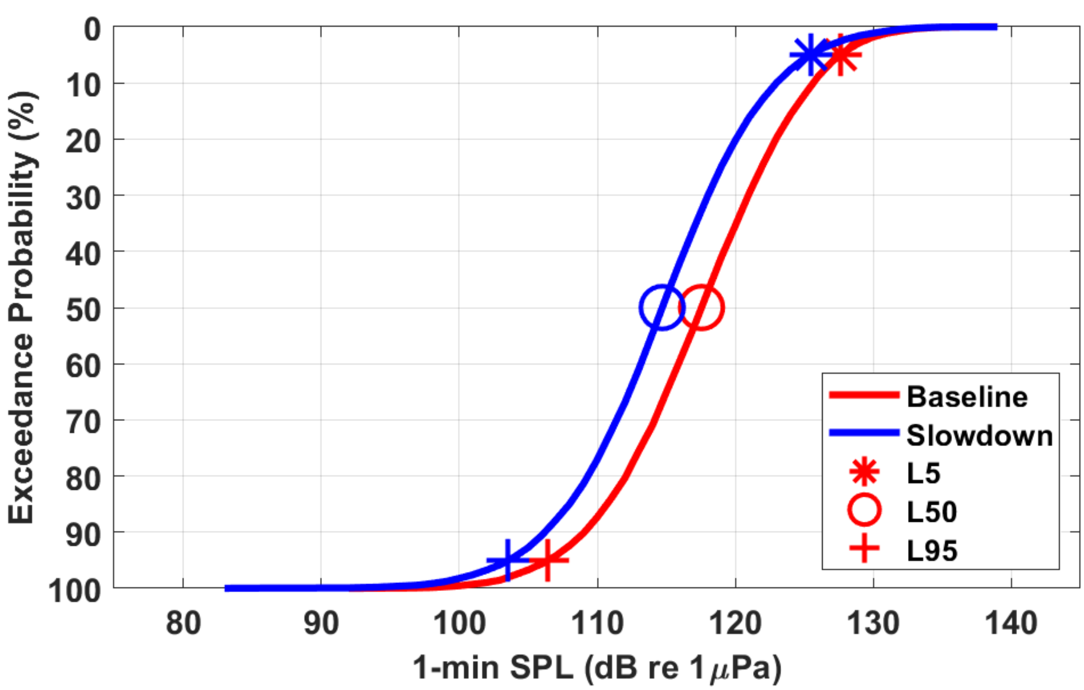

Figure 26. Lime Kiln 10–100 Hz band exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

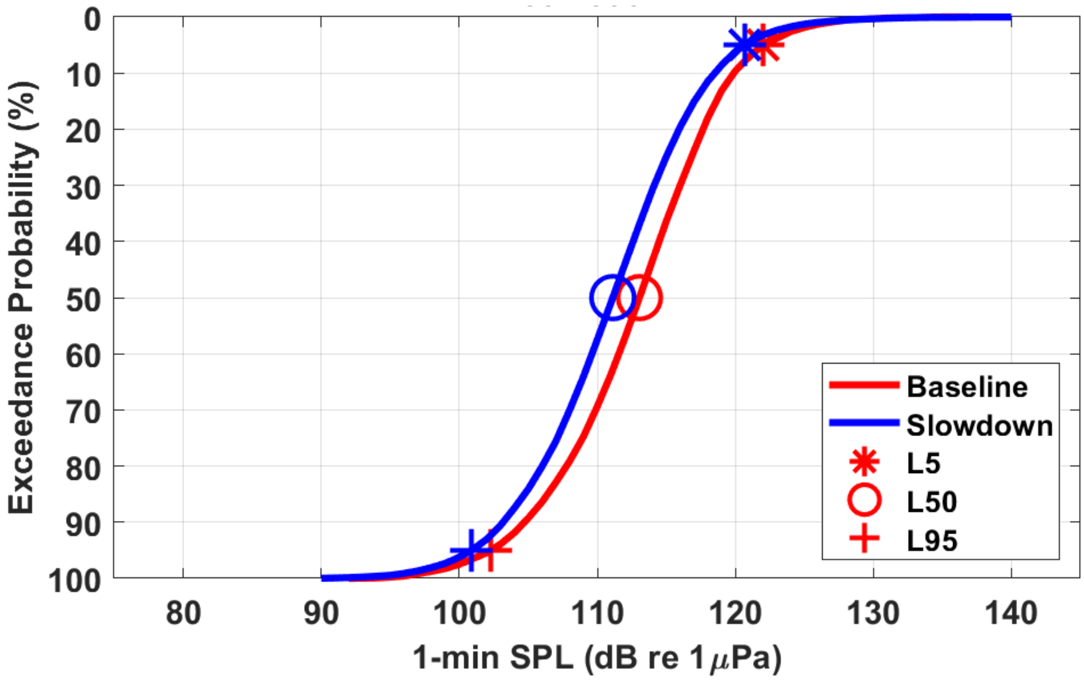

Figure 27. Lime Kiln 100–1000 Hz band exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

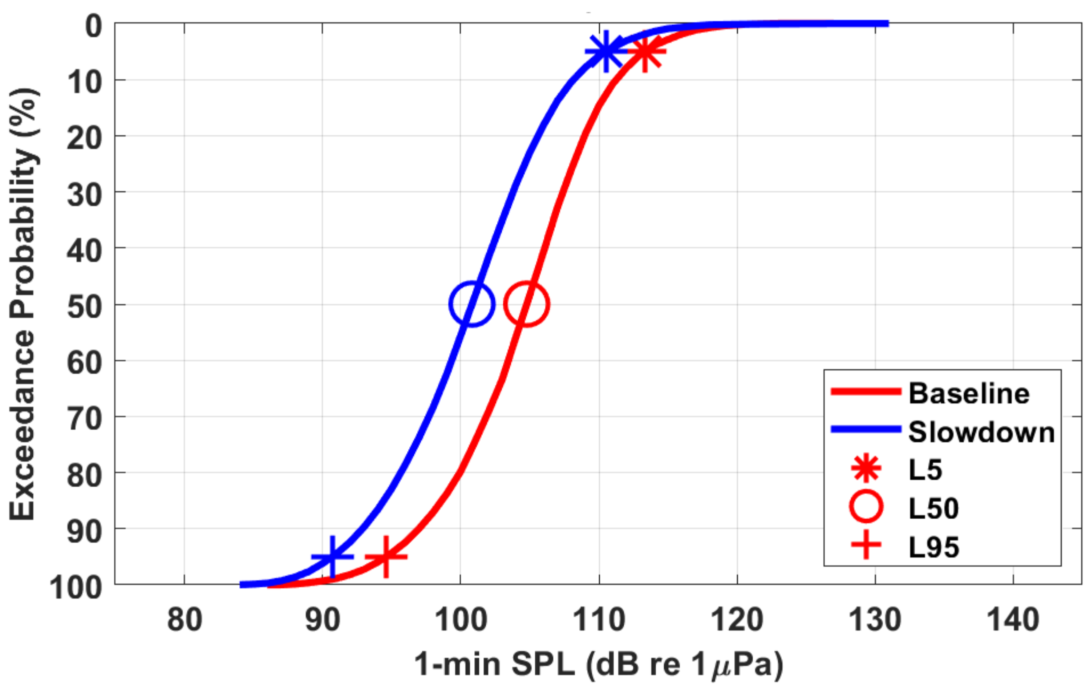

Figure 28. Lime Kiln 1–10 kHz band exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

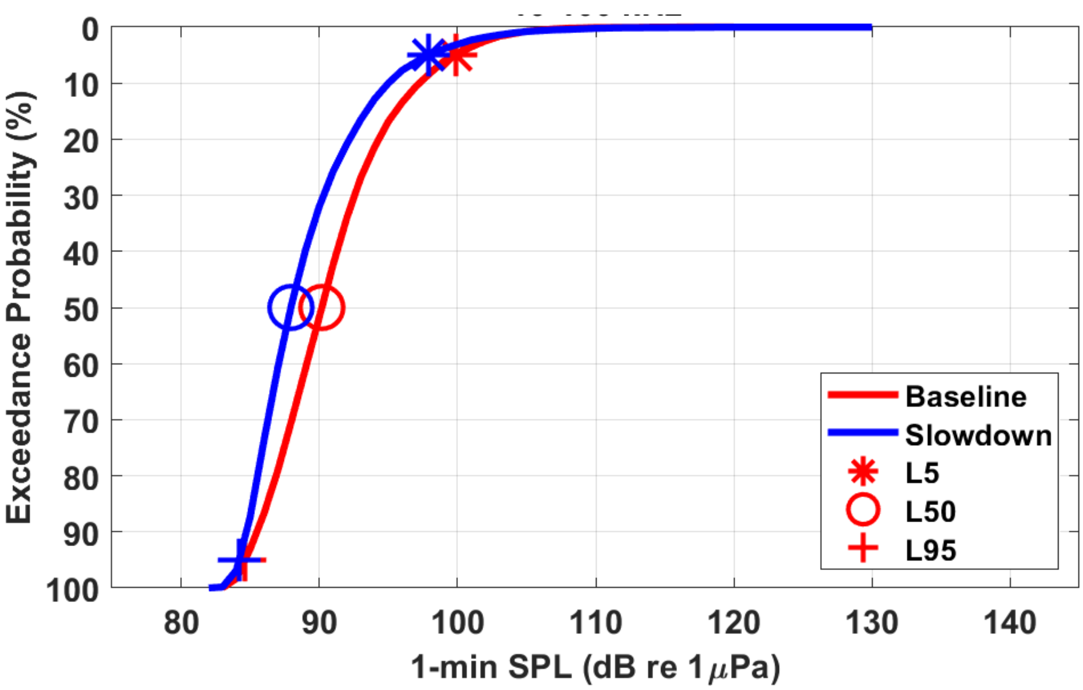

Figure 29. Lime Kiln 10–100 kHz band exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

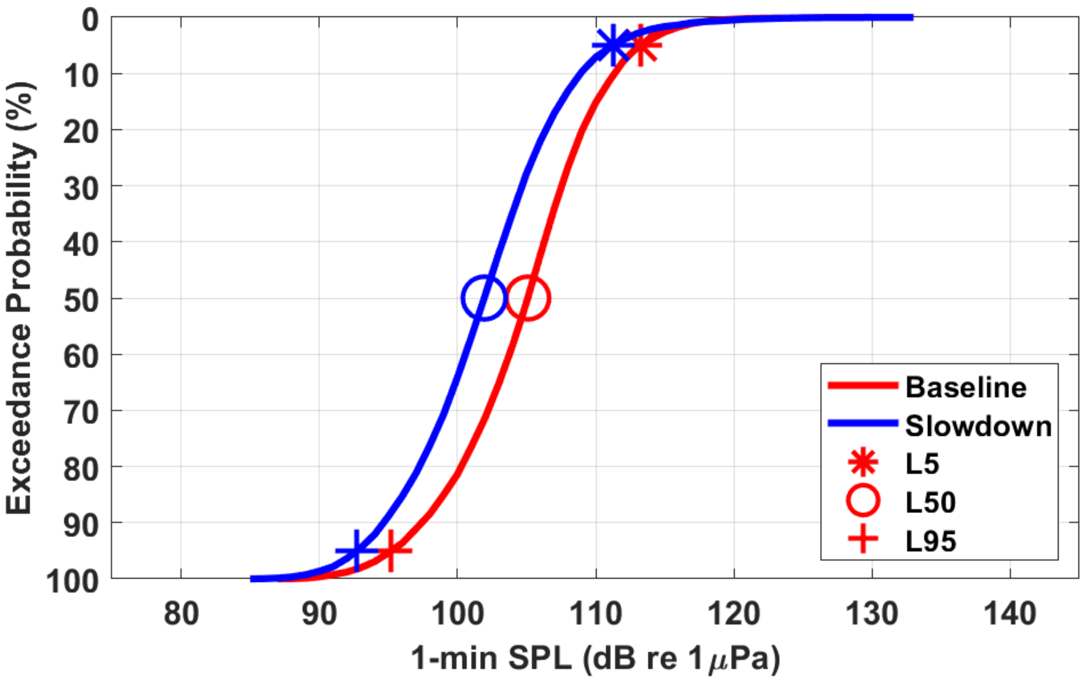

Figure 30. Lime Kiln 500–15,000 Hz band (CORI Communication) exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

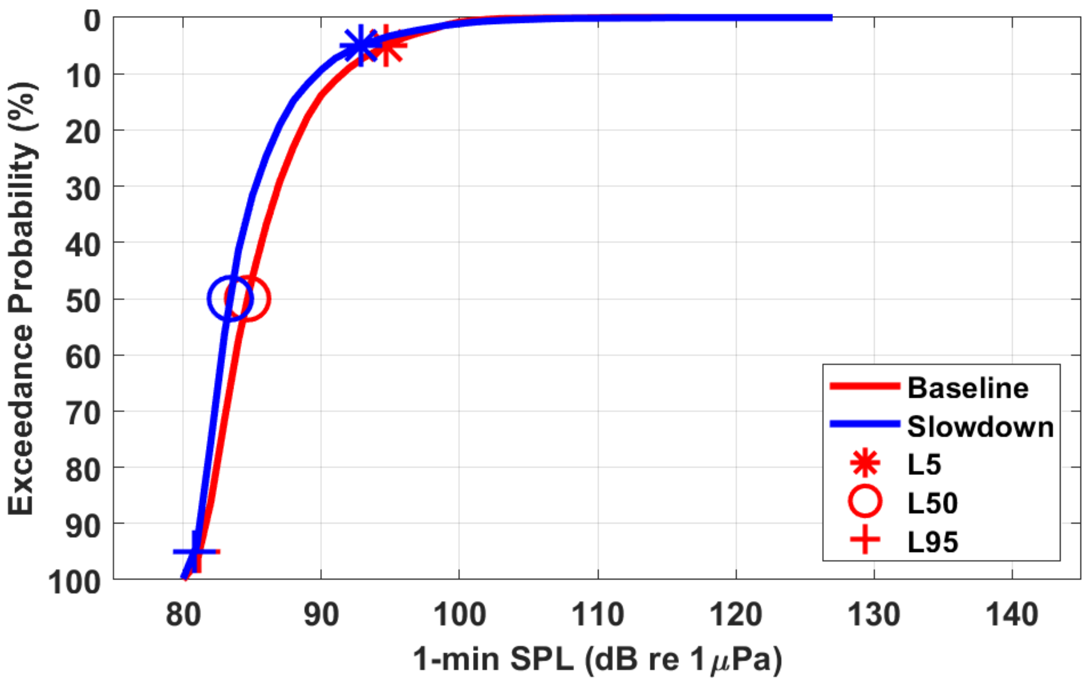

Figure 31. Lime Kiln 15–100 kHz band (CORI Echolocation) exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

Table 10. Ambient noise statistics (L_{95}, L_{50}, L_5, and L_{eq}) during the Baseline and Slowdown periods at Lime Kiln.

Frequency range	Baseline SPL (dB re 1 µPa)				Slowdown SPL (dB re 1 µPa)			
	L_{95}	L_{50}	L_5	L_{eq}	L_{95}	L_{50}	L_5	L_{eq}
Broadband 10–100,000 Hz	110.1	119.6	128.7	120.1	107.6	117.1	126.9	117.6
1st Decade 10–100 Hz	106.4	117.6	127.6	117.9	103.6	114.7	125.4	115.1
2nd Decade 100–1000 Hz	102.3	113.1	122.0	113.2	100.9	111.1	120.7	111.5
3rd Decade 1–10 kHz	94.6	104.8	113.3	105.0	90.7	100.8	110.5	101.2
4th Decade 10–100 kHz	84.6	90.2	99.9	91.4	84.2	87.9	97.9	89.6
CORI Communication 500–15,000 Hz	95.2	105.1	113.3	105.2	92.7	101.9	111.3	102.5
CORI Echolocation 15–100 kHz	81.2	84.7	94.7	86.3	80.8	83.4	92.9	85.2

Table 11. Comparison of Slowdown versus Baseline period ambient noise statistics (L_{95}, L_{50}, L_5, and L_{eq}) at Lime Kiln. A negative value denotes that the Slowdown period was quieter than the Baseline period.

Frequency range	SPL difference (dB) between Slowdown and Baseline periods			
	L_{95}	L_{50}	L_5	L_{eq}
Broadband 10–100,000 Hz	−2.5	−2.5	−1.9	−2.4
1st Decade 10–100 Hz	−2.9	−2.8	−2.2	−2.8
2nd Decade 100–1000 Hz	−1.4	−1.9	−1.3	−1.7
3rd Decade 1–10 kHz	−3.9	−4.0	−2.8	−3.7
4th Decade 10–100 kHz	−0.4	−2.2	−1.9	−1.8
CORI Communication 500–15,000 Hz	−2.5	−3.1	−1.9	−2.8
CORI Echolocation 15–100 kHz	−0.4	−1.2	−1.8	−1.1

1.3.4.2. Boundary Pass

The first step in comparing Baseline and Slowdown period sound level CDFs in Boundary Pass was to filter out time periods when potential participants were farther than other AIS broadcasting vessels to the hydrophone or were more than 6 km away. Applying this filtering retained 23–25% of the original data.

The effect of water currents on sound levels was then analyzed with the remaining data. Figure 32 shows broadband sound level distributions for different current speed intervals. The distributions agreed up to 0.5 m/s but at higher speeds, the distributions differed and were presumed affected by current-induced flow noise. For subsequent analysis, time periods when current speeds were greater than 0.5 m/s were discarded. Applying this filtering on the AIS-filtered data retained 20–22% of the original data.

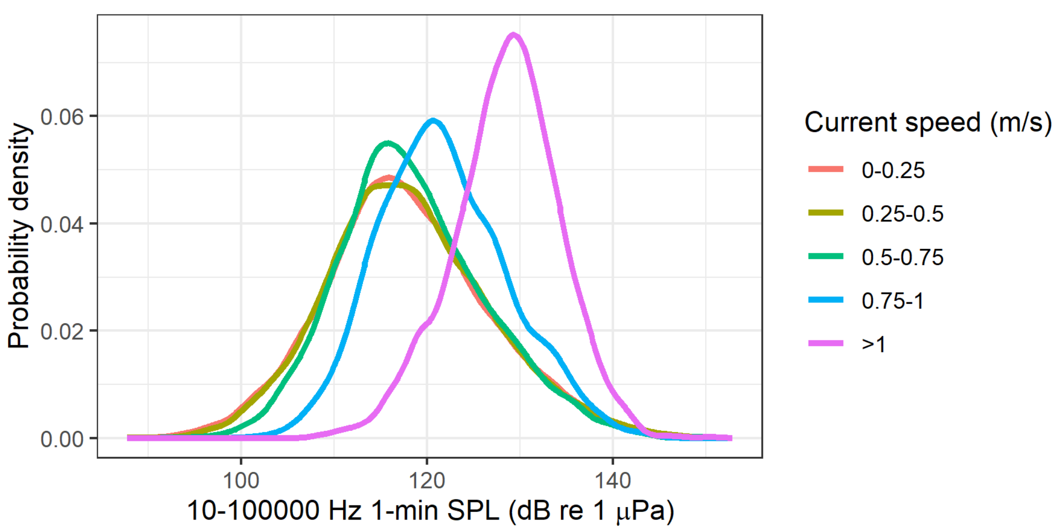

Figure 32. Broadband (10–100,000 Hz) sound pressure level (SPL) distributions after Automatic Identification System (AIS) filtering for different current speed intervals.

The effect of wind speed on sound levels was then analyzed with the remaining data. Figure 33 shows 2-D histograms of SPL as a function of wind speed in different frequency bands. For subsequent analysis, time periods when wind speeds were greater than 10 m/s were discarded. Appling this filtering reduced the total amount of data for the CDF by a small amount, leaving 20–21% of the original data.

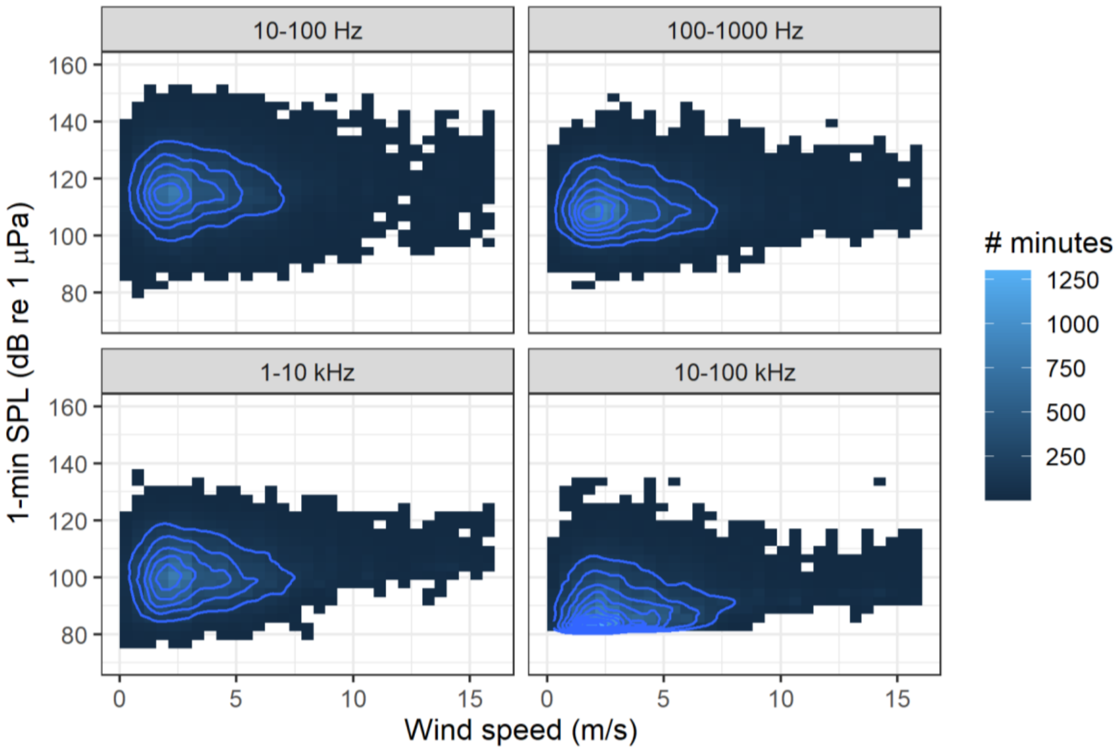

Figure 33. Two-dimensional histograms of sound levels as a function of windspeed after Automatic Identification System (AIS) and current speed filtering.

The final factor used for filtering was small boat detections (Section 1.3.3.2). The detector was occasionally triggered by large vessels (i.e., a false detection), so data when potential participants were near the hydrophone (within 2 km) and the boat detector was triggered were not filtered out. The boat detector filtering was applied only when potential participants were at least 2 km from the hydrophone. Appling this filtering reduced the total amount of data for the CDF by a small amount, leaving 20–21% of the original data. Table 12 summarizes the effect of these filters for the Boundary Pass data in terms of the number of minutes retained for the CDF analysis.

Table 12. Number of minutes as a result of filtering by Automatic Identification System (AIS) data, current speed, wind speed, and small boat detections at Boundary Pass. Each filter also includes the previous filter (e.g., numbers provided for Current also include AIS). Percentages are shown relative to the total number of minutes of acoustic data for each period.

Period	Total number of minutes with acoustic data	AIS filtering			
			Current filtering		
				Wind filtering	
					Small boat filtering
Baseline	32,455	7603 (23%)	6458 (20%)	6424 (20%)	6373 (20%)
Slowdown	170,544	42,910 (25%)	37,506 (22%)	36,594 (21%)	36,049 (21%)

Figures 34 to 40 show the exceedance CDFs after applying the filtering on the Baseline and Slowdown period data, and Table 13 lists sound level exceedance statistics. The differences between the L_5, L_{50}, L_{95}, and L_{eq} metrics from the two periods are listed in Table 14. There was a clear decrease in SPL from the Baseline to the Slowdown period for almost all sound level statistics and frequency bands. The median and L_{eq} broadband levels decreased by 2.8 dB during the Slowdown period.

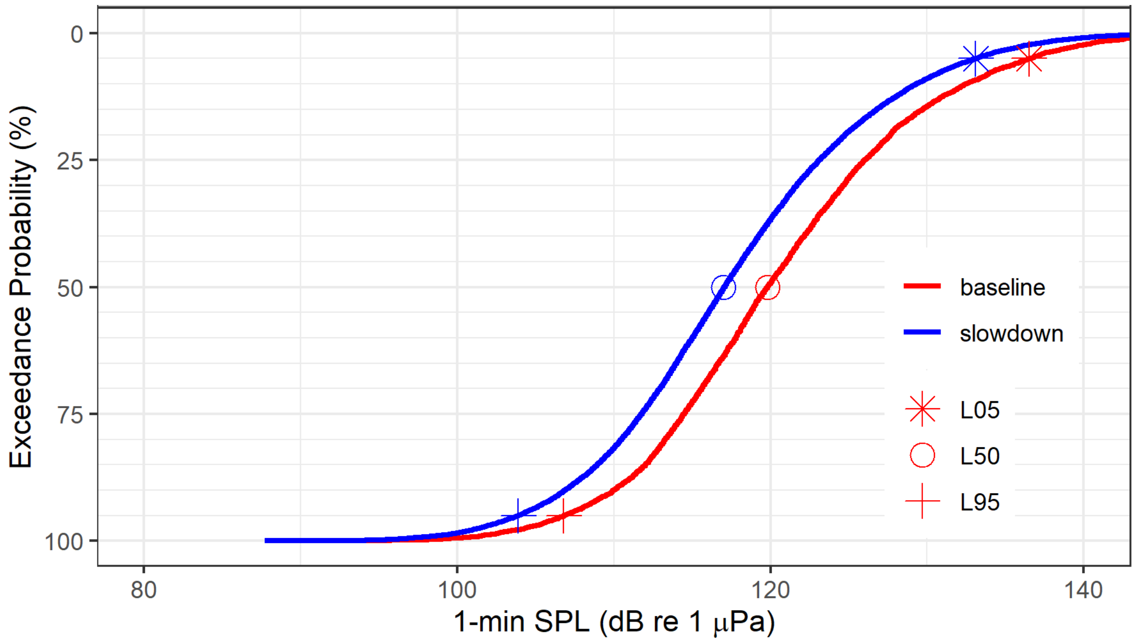

Figure 34. Boundary Pass broadband (10–100,000) exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

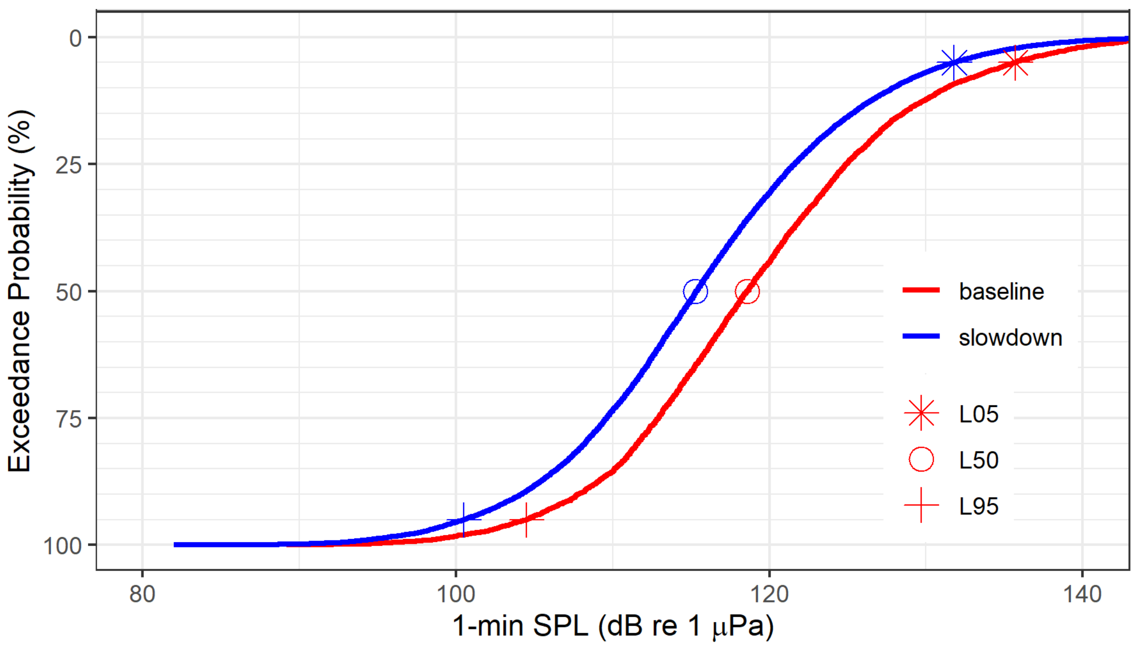

Figure 35. Boundary Pass 10–100 Hz exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

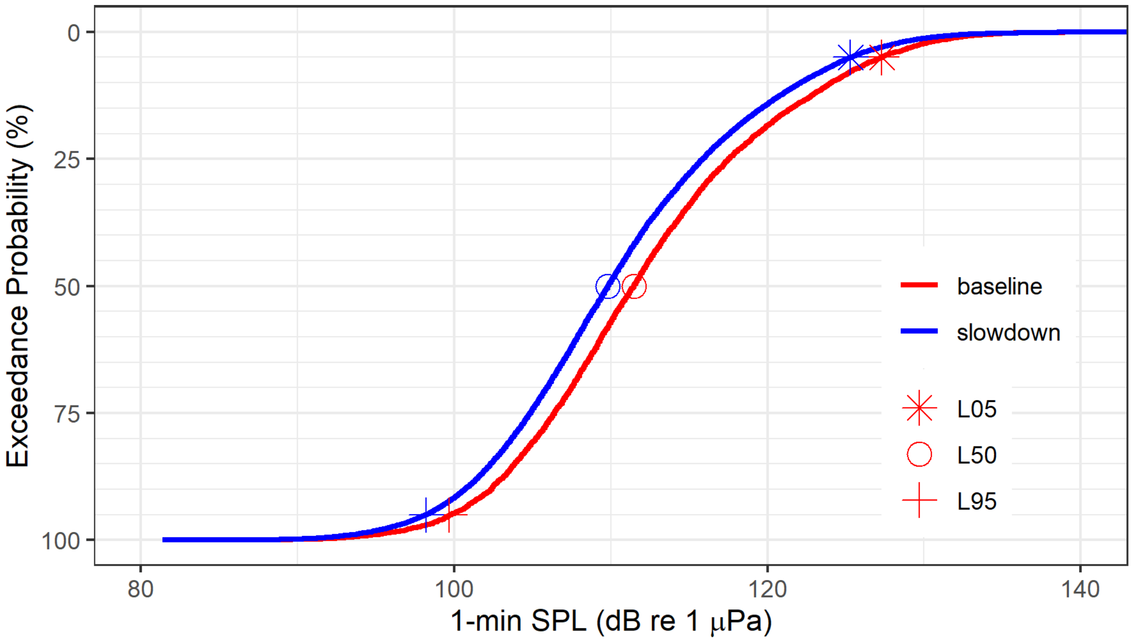

Figure 36. Boundary Pass 100–1000 Hz band exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

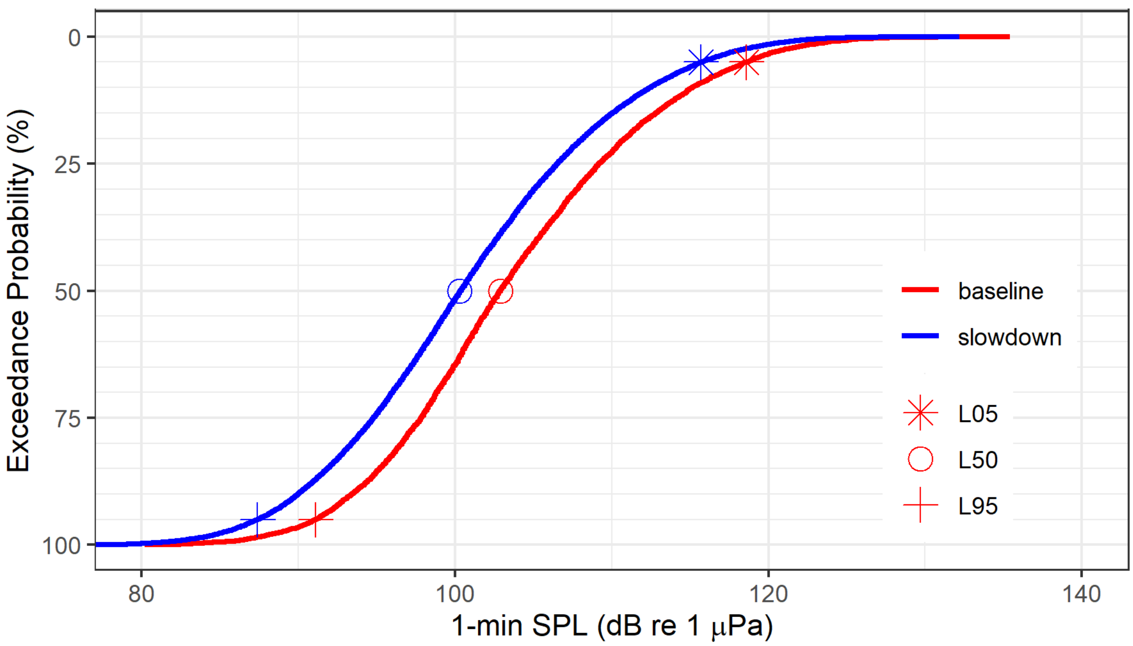

Figure 37. Boundary Pass 1–10 kHz band exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

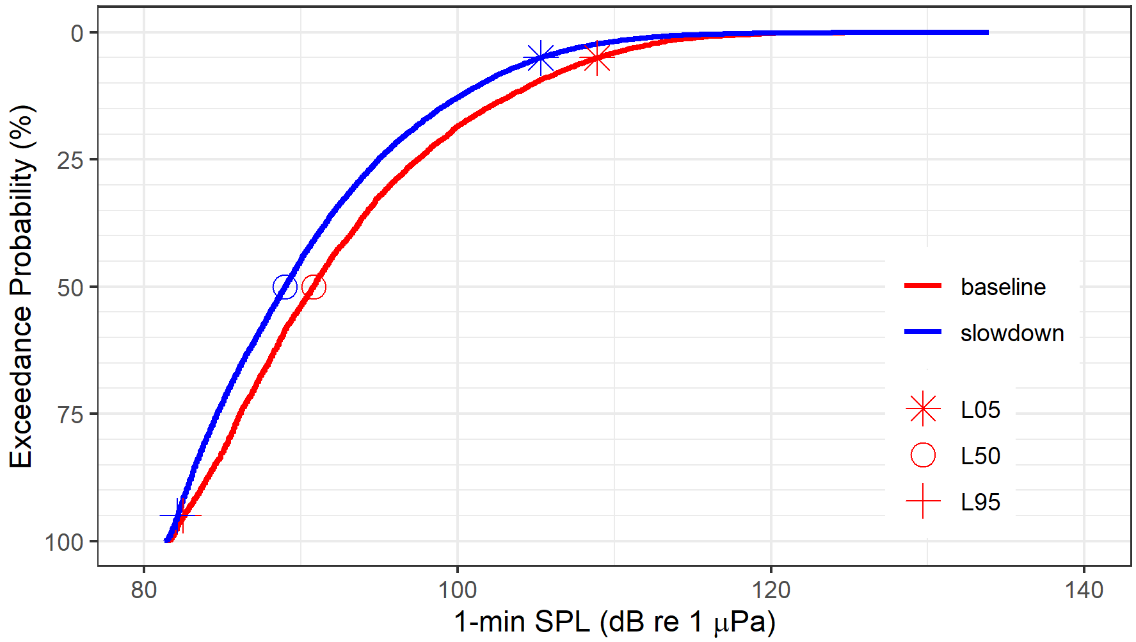

Figure 38. Boundary Pass 10–100 kHz band exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

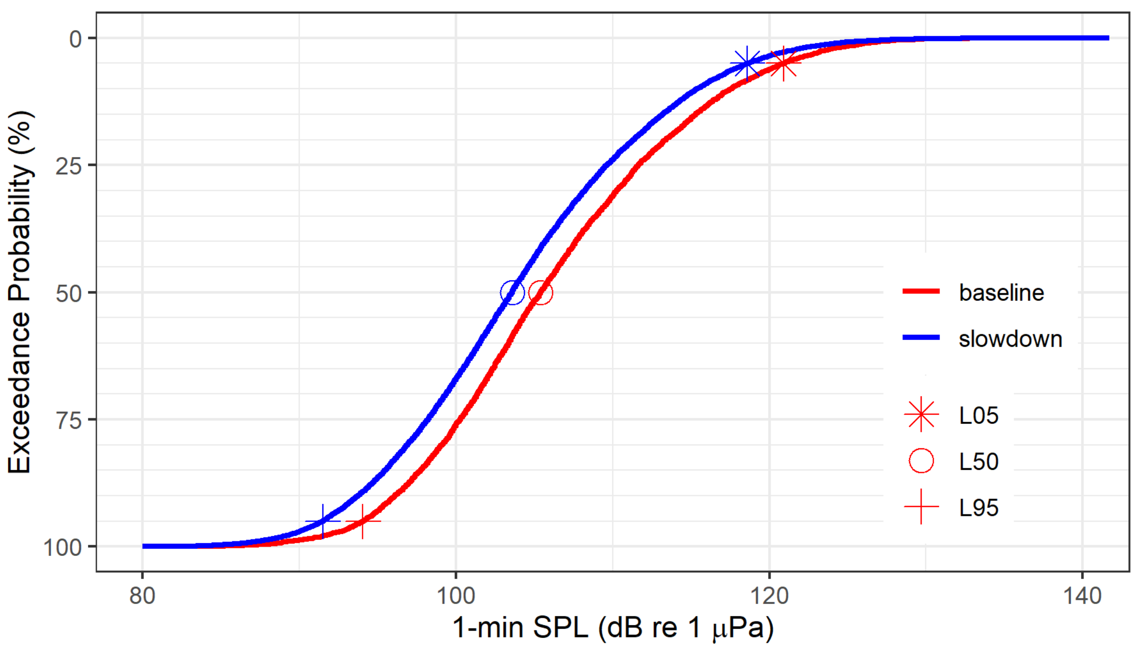

Figure 39. Boundary Pass 500–15,000 Hz band (CORI Communication) exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

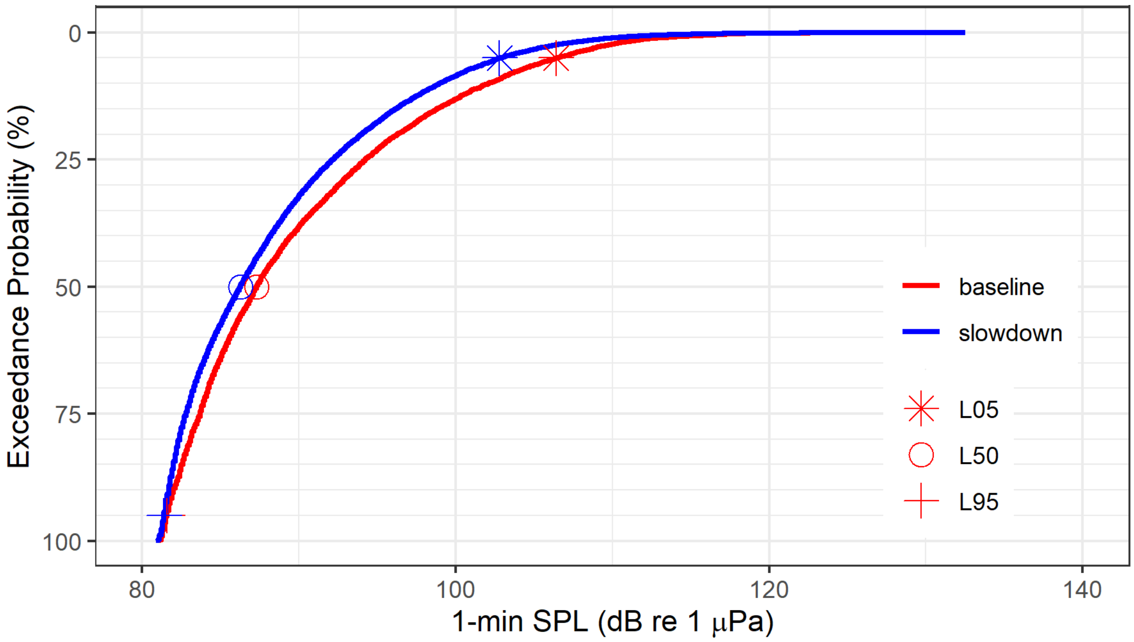

Figure 40. Boundary Pass 15–100 kHz band (CORI Echolocation) exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

Table 13. Ambient noise statistics (L_{95}, L_{50}, L_5, and L_{eq}) during the Baseline and Slowdown periods at Boundary Pass.

Frequency range	Baseline SPL (dB re 1 µPa)				Slowdown SPL (dB re 1 µPa)			
	L_{95}	L_{50}	L_5	L_{eq}	L_{95}	L_{50}	L_5	L_{eq}
Broadband 10–100,000 Hz	106.8	119.8	136.5	130.2	103.9	117.0	133.1	127.4
1st Decade 10–100 Hz	104.5	118.6	135.7	129.5	100.5	115.3	131.8	126.5
2nd Decade 100–1000 Hz	99.7	111.5	127.3	120.9	98.2	109.8	125.3	119.5
3rd Decade 1–10 kHz	91.1	102.9	118.6	112.3	87.4	100.3	115.7	109.4
4th Decade 10–100 kHz	82.5	90.8	108.9	104.0	82.1	89.0	105.3	102.8
CORI Communication 500–15,000 Hz	94.1	105.4	120.9	114.6	91.5	103.6	118.6	113.0
CORI Echolocation 15–100 kHz	81.6	87.3	106.4	101.6	81.4	86.3	102.8	101.2

Table 14. Comparison of Slowdown versus Baseline period ambient noise statistics (L_{95}, L_{50}, L_5, and L_{eq}) at Boundary Pass. A negative value denotes that the Slowdown period was quieter than the Baseline period.

Frequency range	SPL difference (dB) between Slowdown and Baseline periods			
	L_{95}	L_{50}	L_5	L_{eq}
Broadband 10–100,000 Hz	−2.9	−2.8	−3.4	−2.8
1st Decade 10–100 Hz	−4.0	−3.3	−3.9	−3.0
2nd Decade 100–1000 Hz	−1.5	−1.7	−2.0	−1.5
3rd Decade 1–10 kHz	−3.7	−2.6	−2.9	−2.8
4th Decade 10–100 kHz	−0.4	−1.8	−3.6	−1.1
CORI Communication 500–15,000 Hz	−2.6	−1.8	−2.3	−1.6
CORI Echolocation 15–100 kHz	−0.2	−1.0	−3.6	−0.4

1.3.5. Quiet Times

1.3.5.1. Lime Kiln

Broadband (10–100,000 Hz) sound levels were below the 102.8 and 110 dB re 1 µPa thresholds 28–30% and 53% of the time, respectively, during the Baseline and Slowdown periods. The duration of quiet periods (consecutive minutes with broadband SPL less than the threshold) were often less than 3 or 4 minutes for both thresholds and both periods. The maximum duration of quiet times was up to 150 and 168 minutes for Baseline and Slowdown periods, respectively, using the 102.8 dB threshold, and up to 263 and 433 minutes for Baseline and Slowdown periods, respectively, using the 110 dB threshold. Table 15 summarizes these statistics, and Figure 41 shows the distributions of quiet time durations.

Figure 42 shows examples of broadband SPL as a function of time over different periods during the Baseline period. Over relatively short time scales (hours), SPL oscillated above and below the thresholds several times, resulting in the (typically) short duration quiet periods described above. This oscillation was caused by varying anthropogenic, environment-driven, and biological noise, each of which has its own time scale. It is also related to the analytical methods used. The acoustic data are averaged within a minute with no overlap between minutes. This caused less-smooth transitions between minutes.

Table 15. Statistics of the duration of "quiet time" for two sound pressure level (SPL) thresholds at Lime Kiln. 'Quiet time (%)' is the total duration of quiet times divided by the duration of the Slowdown period.

Period	Quiet threshold (dB re 1 µPa)	Median duration (min)	Maximum duration (min)	Quiet time (%)
Baseline	102.8	3	150	29.81
	110	4	263	52.54
Slowdown	102.8	3	168	27.74
	110	3	433	52.73

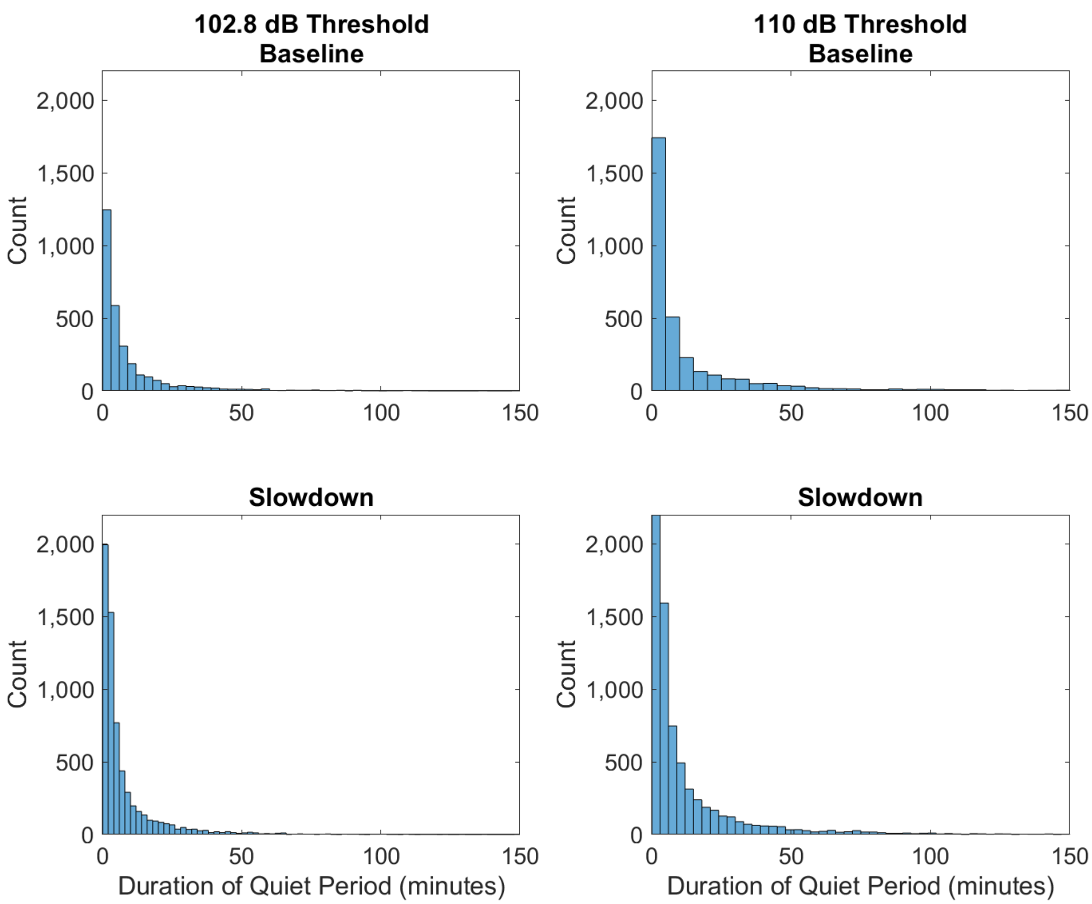

Figure 41. Histograms of quiet time durations during the Baseline and Slowdown periods Lime Kiln for the two broadband sound pressure level (SPL) thresholds.

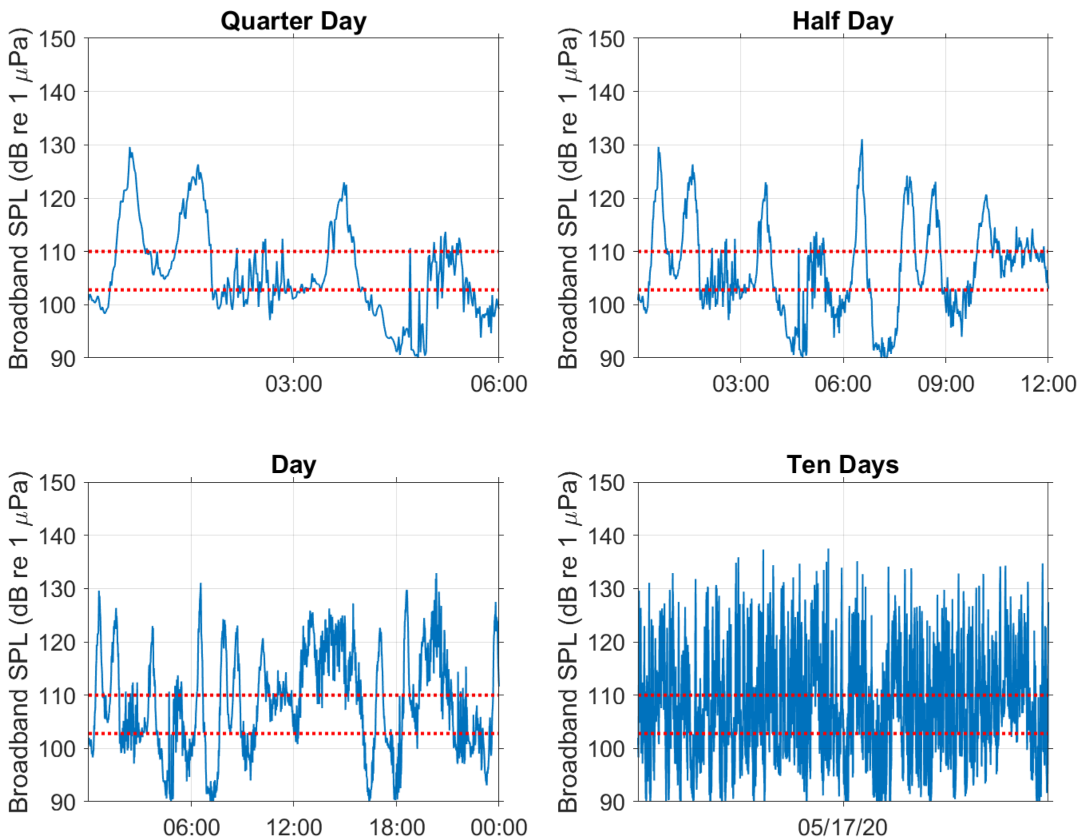

Figure 42. Plots of 1-minute broadband (10–100,000 Hz) sound pressure level (SPL) at Lime Kiln for (top left) quarter day, (top right) half day, (bottom left) one day, and (bottom right) 10 day periods. All plots start at 0:00 (PDT) on 12 May 2020. Red dotted lines indicate the two quiet thresholds used. Due to the high degree of oscillation in the data, quiet periods do not typically last long.

1.3.5.2. Boundary Pass

Broadband (10–100,000 Hz) sound levels were below the 102.8 and 110 dB re 1 μPa thresholds 47–48% and 65–66% of the time, respectively, during the Baseline and Slowdown periods. The duration of quiet periods (consecutive minutes with broadband SPL less than the threshold) was often less than 6 minutes for the 102.8 dB threshold for both Baseline and Slowdown periods, and often less than ~10 minutes for the 110.0 dB threshold. The maximum duration of quiet times was up to 279 and 317 minutes for Baseline and Slowdown periods, respectively, using the 102.8 dB threshold, and up to 314 and 523 minutes for Baseline and Slowdown periods, respectively, using the 110 dB threshold. Table 16 summarizes these statistics, and Figure 43 shows the distributions of quiet time durations.

Figure 44 shows examples of broadband SPL as a function of time over different periods during the Slowdown period. Over relatively short time scales (hours), SPL oscillated above and below the thresholds several times, resulting in the (typically) short duration quiet periods described above. This oscillation is caused by varying anthropogenic, environment-driven, and biological noise, each of which has its own time scale. It is also related to the analytical methods used. The acoustic data are averaged within a minute with no overlap between minutes. This caused less-smooth transitions between minutes.

Table 16. Statistics of the duration of “quiet time” for two sound pressure level (SPL) thresholds in Boundary Pass. ‘Quiet time (%)’ is the total duration of quiet times divided by the duration of the Slowdown period.

Period	Quiet threshold (dB re 1 µPa)	Median duration (min)	Maximum duration (min)	Quiet time (%)
Baseline	102.8	6	279	48.35
	110	11	314	64.71
Slowdown	102.8	6	317	47.39
	110	9	523	65.71

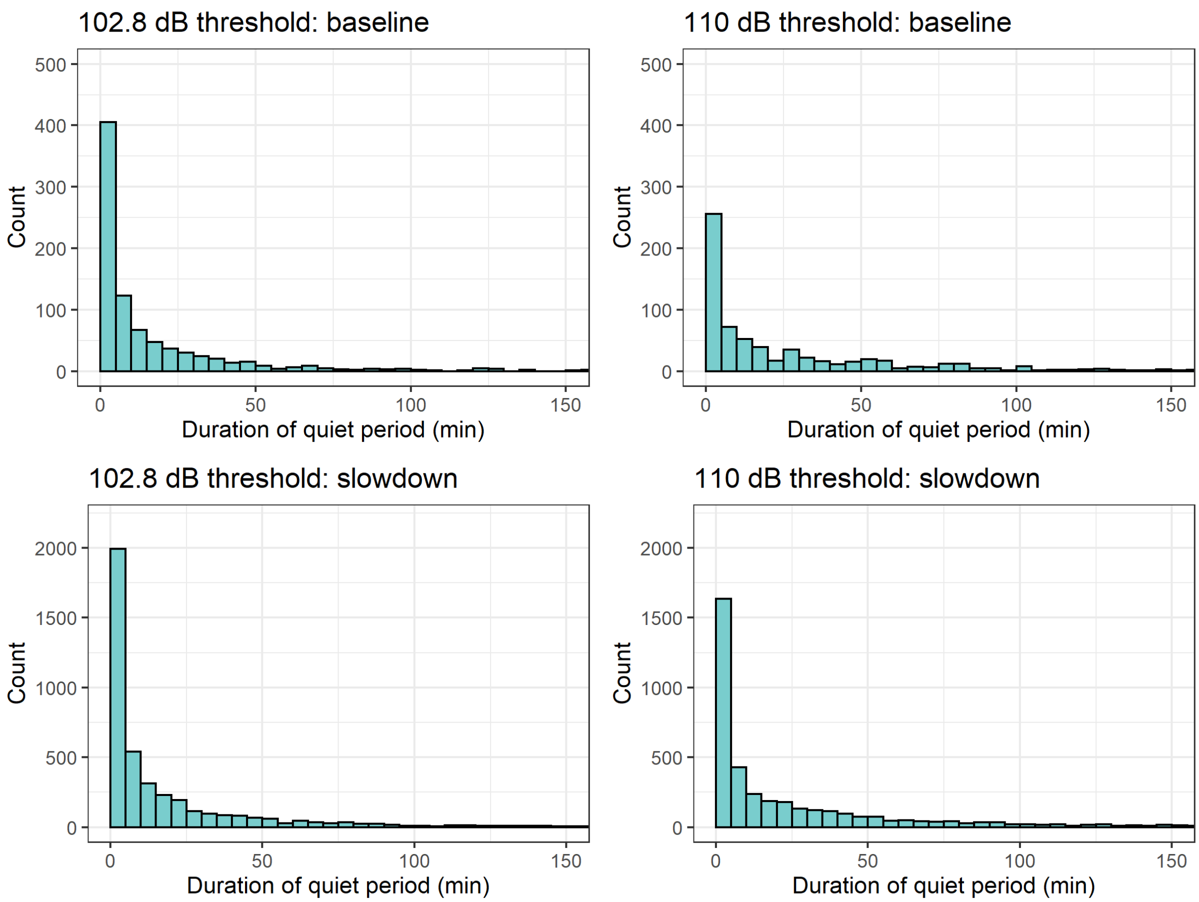

Figure 43. Histograms of quiet time durations during the Baseline and Slowdown periods in Boundary Pass for the two broadband sound pressure level (SPL) thresholds.

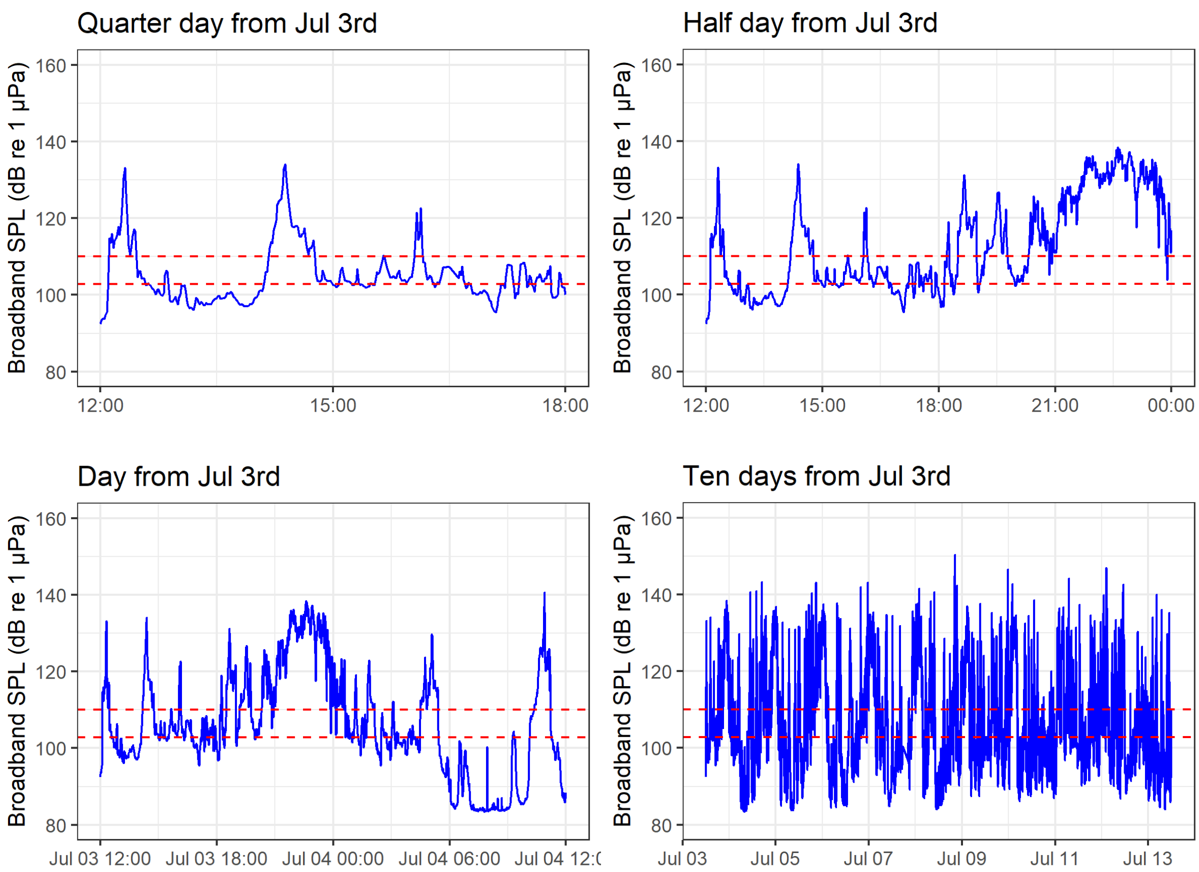

Figure 44. Plots of 1-minute broadband (10–100,000 Hz) sound pressure level (SPL) in Boundary Pass for (top left) quarter day, (top right) half day, (bottom left) one day, and (bottom right) 10 day periods. All plots start at 12:00 UTC (05:00 PDT) on 3 Jul 2020. Red dotted lines indicate the two quiet thresholds used. Due to the high degree of oscillation in the data, durations of quiet periods are typically short.

1.3.6. GAMM Analysis

Akaike Information Criterion (AIC) scores were used to select between various GAMMs. A GAMM was initially fit that included only the main effects. These included the period (Slowdown versus Baseline), AIS-broadcasting vessel presence, small boat presence, wind, current, and number of AIS-broadcasting vessels. Additional covariates were then added to the model to see if the model fit improved as indicated by a drop in the model's AIC score. An iterative approach was used to select and deselect different covariates, to test interaction terms, and to test linear versus non-linear relations such that the final GAMM selected (Tables 17 and 18) resulted in the model with the lowest AIC score.

Table 17. Results of the best fitting Generalized Additive Mixed Model (GAMM) model. The parametric coefficients include all the categorical covariates, linear fits and any of their interactions included in the model.

Parametric coefficients (i.e., Linear)	Estimate (dB)	Standard error	t value	p-value
Intercept	113.54	0.14	795.99	<0.001
Period (Slowdown)	−1.63	0.16	−10.04	<0.001
Vessel type (Bulk)	3.32	0.21	15.95	<0.001
Vessel type (Containerized)	3.87	0.50	7.69	<0.001
Boat detector (Present)	2.39	0.04	57.63	<0.001

The best fitting GAMM included the following covariates and interactions:

- Slowdown initiative period (as a categorical variable).
- The interaction of range by AIS-broadcasting vessel type (modelled as a smoothed cubic regression spline).
- The interaction of speed through water by AIS-broadcasting vessel type (modelled as a smoothed cubic regression spline).
- AIS-broadcasting vessel type (as a categorical variable).
- Small boat presence (as a categorical variable).
- Current velocity (modelled as a smoothed cubic regression spline).

These are not listed in order of their magnitude of effect or importance in the model, as ranking the order of their magnitude of effect in this complex model that has non-linear, linear, and factor level covariates is not possible. All of these terms in the GAMM were statistically significant (i.e., p-values < 0.05) (Tables 17 and 18) and explained 33% of the variance in the data.

Table 18. Results of the best fitting Generalized Additive Mixed Model (GAMM) model. The smooth terms are the covariates that were fit with non-linear splines. The p-values are the probability of obtaining results at least as extreme as these observed results.

Approximate significance of smooth terms	Effective degrees of freedom	Reference degrees of freedom	F (test statistic)	p-value
Range by vessel type (Other)	2.99	2.99	404.74	<0.001
Range by vessel type (Bulk)	1.76	1.76	473.47	<0.001
Range by vessel type (Containerized)	1	1	719.08	<0.001
Speed through water by vessel type (Other)	1.95	1.95	34.06	<0.001
Speed through water by vessel type (Bulk)	1.91	1.91	105.86	<0.001
Speed through water by vessel type (Containerized)	1.82	1.82	86.67	<0.001
Current	3.97	3.97	534.23	<0.001

The interpretation of the GAMM outputs in Tables 17 and 18 is not simple because of the complexity of the statistical model. This statistical complexity is warranted by the multiple and complicated covariates, which explain the large and dynamic fluctuations in the soundscape at Lime Kiln. The best fitting GAMM used both linear (i.e., parametric) coefficients and non-linear (i.e., smooth) terms to model the fluctuations in ambient noise.

1.3.6.1. Interpreting Linear Covariates

Focusing first on the linear coefficients and the 'Estimates' column in Table 17, it is important to note that these are in units of decibels and that factor (i.e., categorical) covariates are always compared to a 'reference' of that covariate. For example, the factor of Period in Table 17 is set to Slowdown. Because there are only two periods (Baseline and Slowdown), the estimate reported in Table 17 for Period is the difference (in dB) between Slowdown and Baseline periods. From the results in Table 17, we can make the following interpretations:

- **Intercept**: This is the model y-axis intercept as per any simple linear regression.
- **Period**: There was a significant difference in ambient noise from Baseline to Slowdown periods. While there is an estimated 1.63 dB decrease in ambient noise from Baseline to Slowdown, this is not the entire reduction in noise level that occurred from the Slowdown because this does not include other covariates that changed between Baseline and Slowdown periods (namely vessel speed through water and vessel type). To estimate reductions in noise levels from the Slowdown, these other covariates need to be added in and the GAMM used to make predictions. This is done in Section 1.3.6.3.
- **Vessel type**: Containerized and Bulk vessel types were significantly different from the Other vessel type. The interaction of vessel type with speed through the water and range were also significant. In addition, the main reason for including vessel type in the model was to control for the variance in noise level due to vessel type (and its interaction with other covariates), not to test if there is a difference in noise levels between vessel types (Veirs et al. 2016).
- **Boat detector**: There was a significant increase (2.39 dB without including other covariate effects) in noise levels at Lime Kiln when small boats were detected acoustically (when compared to no small boats being detected).

1.3.6.2. Interpreting Non-linear Covariates

For the non-linear covariates reported in Table 18, these are all significant. The following interpretation from these non-linear covariates can be drawn:

- **Range by vessel type**: The range from a vessel to Lime Kiln can have a large effect on noise levels at Lime Kiln. Noise levels are highest when the vessel is closest to Lime Kiln. Noise levels decrease approximately 10 dB as vessels move to 6 km from Lime Kiln.
- **Speed through water by vessel type**: Increases in speed through water lead to increased noise levels at approximately 1 dB for every additional knot of speed.
- **Current**: Current can have a large effect on noise levels at Lime Kiln. There can be an increase of over 10 dB in noise levels as currents increase from 0 to 1.4 m/s. Current velocity effects also justified the removal of high current speeds in the CDF analysis in Section 1.3.4.

1.3.6.3. Select GAMM Predictions

As discussed above, looking at any one covariate in isolation can be misleading when interpreting the GAMM output, especially for such a complex model. Therefore, some select predictions using the GAMM model are provided. Figure 45 shows the predicted relationship between noise levels at Lime Kiln and the range from Lime Kiln of Bulk and Containerized vessel types for both Baseline and Slowdown periods when no small boats were present while current was zero. Two trends can be seen. Noise levels dropped as the range increased, and Slowdown noise levels were lower than Baseline noise levels. At the range of 2.3 km (distance from Lime Kiln to the centre of northbound shipping lane), the predictions in Figure 45 are 118.3 and 116.6 dB re 1 µPa for Bulk vessel types and 120.8 and 119.1 dB re 1 µPa for Containerized vessel types for Baseline and Slowdown periods, respectively. This is a decrease of 1.7 dB for Bulk and Containerized vessel types from Baseline to Slowdown. This is similar to the Slowdown 2019 GAMM predicted reductions of 0.9 for Bulk vessel types and 2.2 dB for Containerized.

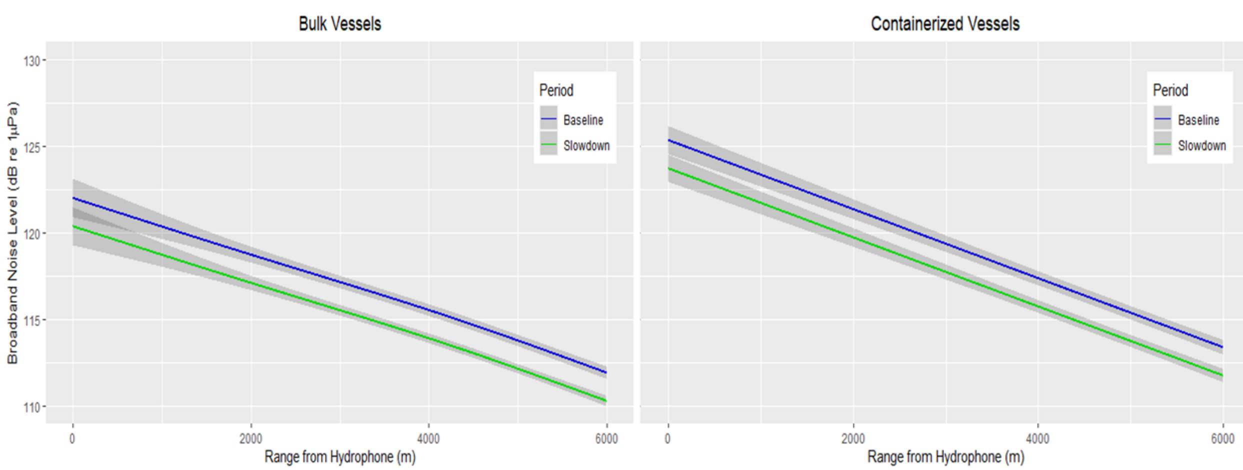

Figure 45. Model predictions for (left) Bulk vessel type and (right) Containerized vessel type modelled as a non-linear function of distance from the hydrophone. Depicted are the expected values of the model and its 95% confidence regions for broadband noise levels received at Lime Kiln assuming median vessel speeds through the study area during Baseline (blue) and Slowdown periods (green). Noise levels contributed from current and small boats were assumed to be zero in both figure panels.

1.3.7. Killer Whale PAM Detections

1.3.7.1. Lime Kiln

During the 2020 ECHO Program vessel Slowdown monitoring period between 1 Jul and 31 Oct, a total of 70 killer whale events were detected by Passive Acoustic Monitoring (PAM) using PAMGuard software at the Lime Kiln hydrophone, mainly in July and September (Figure 46). This total includes the SRKW detection made on 1 Jul 2020 that initiated the start of the ECHO vessel Slowdown. PAM protocols also permitted collating summary monthly detections of porpoise and other odontocetes (dolphins) or baleen whales. A total of 148 porpoise events occurred mainly in September, while one other odontocetes or baleen detections occurred in October (Table 19).

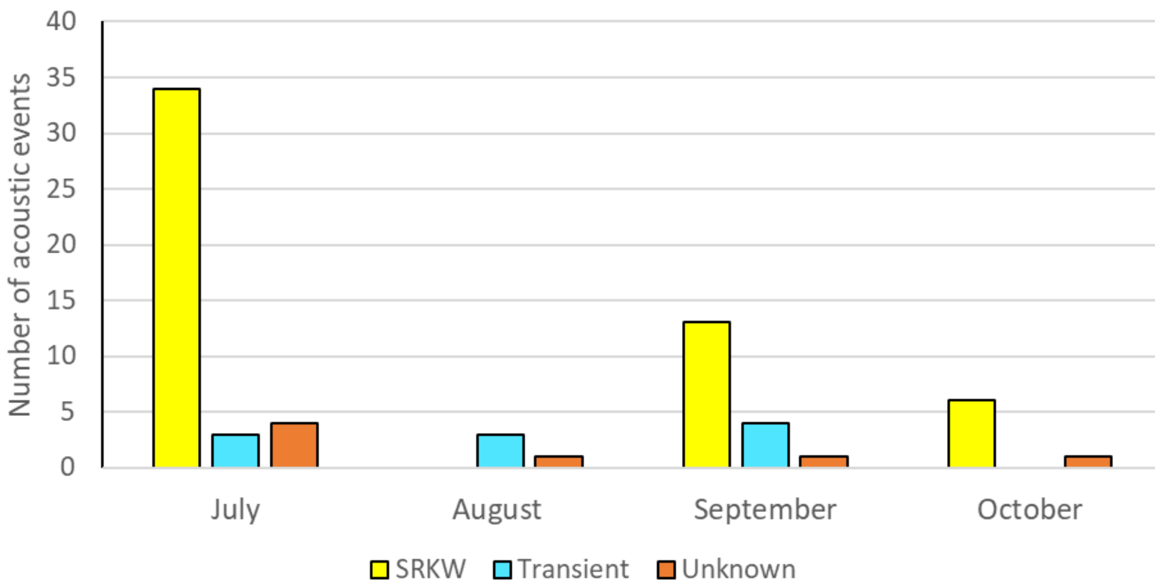

Figure 46. Monthly breakdown of killer whale events detected and identified by PAM protocols (1 Jul to 31 Oct 2020) using PAM data from the Lime Kiln hydrophone.

Table 19. Monthly breakdown of species events detected and identified by passive acoustic monitoring (PAM) protocols (1 Jul to 31 Oct 2020) using PAM data from the Lime Kiln hydrophone.

Month	Southern Resident killer whales	Transient killer whales	Unknown killer whales	All killer whales	Porpoises	Unidentified odontocetes, dolphins, or baleens
July	34	3	4	41	20	0
August	0	3	1	4	25	0
September	13	4	1	18	71	0
October	6	0	1	7	32	1
All months	**53**	**10**	**7**	**70**	**148**	**1**

In total, confirmed SRKW were detected by PAM using PAMGuard software on 34 days across 53 unique events. Most of these were in July (19 days or 34 events) or September (10 days or 13 events; Table 20). There were no SRKW detected at Lime Kiln at all in August 2020.

Ten transient killer whale and seven unknown killer whale ecotype events were also detected, with most in July but detections also in August, September, and October (Table 20). Notably, lack of ecotype definition was due to the presence of only echolocation clicks that were not discernible to ecotype. A total duration of 67 hours of SRKW detections was recorded with an average duration of 1 hour 17 minutes. Transients were detected for <3 hours with an average duration of 13 minutes. In all months, SRKW were present during daylight periods more than night-time periods (Figures 47 through 50).

We compared killer whale PAM detection events made in 2020 with those made by local Marine Mammal Observers (MMOs), typically but not exclusively observing from approximately 9 am to 5 pm (Table 21) (Tollit and Wood 2019). On 100% of the 22 days SRKW were observed by MMOs, PAM also detected a killer whale transit. PAM also detected 12 additional days of SRKW presence, consisting of 32 additional transit events, 28 of which occurred during periods without MMOs being present (i.e., late evening to early morning transits) and four daytime events where PAM detected transit events that were not seen by observers. This includes on one day, a PAM detection by one of the MMOs, Jeanne Hyde (rather than via the PAMGuard analysis presented here). There was just one occasion that MMOs recorded a 2 minute SRKW event that had no concurrent PAM detection and one other occasion that MMOs recorded an SRKW event (with K12s observed) but where PAM methods instead determined an unknown ecotype killer whale (i.e., SRKW not confirmed by the PAM analyst, but killer whale detected). In both cases, SRKW were identified that day by PAM during other events. Overall, when combining these two additional events, there were 56 confirmed SRKW transit events (across 34 different days) recorded by either PAM or MMOs at Lime Kiln from 1 Jul to 31 Oct 2020 (Tables 21 and 22). There were also 7 unknown ecotype events that occurred across this period, three of which were on days where no SRKW were detected (Table 22).

Data from this study were combined with a similar assessment (1 Jul to 31 Oct) undertaken during the vessel Slowdown in 2019 to compare PAM and MMO combined detection information across years at Lime Kiln (Figure 51). SRKW were detected on 55% more days in 2020 than 2019, as well as 40% more transits and more than double the transit duration.

Table 20. Passive acoustic monitoring (PAM) identifications of killer whales detected on the Lime Kiln hydrophone (1 Jul to 31 Oct 2020), with details of time, event duration and ecotype classification. Southern Resident Killer Whale (SRKW) detections are in bold.

Date	Start time (Local PDT)	Event duration (h:min:sec)	Killer whale ecotype classification (Vocalization notes)
2020 Jul 1	**8:34:06**	**0:30:15**	**SRKW**
	13:50:16	0:04:01	Unknown
2020 Jul 2	**15:48:22**	**0:33:36**	**SRKW**
2020 Jul 3	3:12:39	0:07:48	Transient
2020 Jul 4	**17:55:48**	**3:56:46**	**SRKW**
	23:53:35	0:07:27	Transient
2020 Jul 5	**15:52:50**	**4:54:51**	**SRKW**
2020 Jul 6	**4:39:22**	**1:07:44**	**SRKW**
2020 Jul 7	**9:20:50**	**0:28:52**	**SRKW**
	12:48:25	**7:32:19**	**SRKW**
2020 Jul 8	**2:37:29**	**0:35:55**	**SRKW**
	17:00:47	**0:59:50**	**SRKW**
	20:18:43	**2:03:46**	**SRKW**
2020 Jul 9	**6:23:59**	**1:17:51**	**SRKW**

	12:42:36	**0:24:32**	**SRKW**
	20:19:07	**2:51:04**	**SRKW**
	0:34:33	0:09:45	Transient
	16:58:14	0:00:07	Unknown
2020 Jul 10	**0:40:35**	**0:30:59**	**SRKW**
	17:50:44	**4:04:11**	**SRKW**
2020 Jul 11	**0:09:02**	**0:10:40**	**SRKW**
	3:35:14	**0:06:18**	**SRKW**
	4:58:31	**0:40:45**	**SRKW**
	6:44:15	**0:57:58**	**SRKW**
	18:18:19	**0:32:17**	**SRKW**
	11:35:58	0:08:20	Unknown
	14:06:37	0:03:25	Unknown
2020 Jul 12	**13:17:30**	**1:09:09**	**SRKW**
	15:54:50	**0:00:00**	**SRKW**
	22:23:05	**0:11:56**	**SRKW**
2020 Jul 14	**16:12:20**	**1:30:00**	**SRKW**
2020 Jul 15	**20:55:36**	**1:11:42**	**SRKW**
2020 Jul 16	**18:38:01**	**0:07:01**	**SRKW**
2020 Jul 17	**4:17:27**	**0:28:19**	**SRKW**
	10:00:08	**5:56:47**	**SRKW**
	17:00:00	**1:30:05**	**SRKW**
	22:51:26	**0:23:39**	**SRKW**
2020 Jul 18	**6:23:21**	**0:45:35**	**SRKW**
2020 Jul 24	**20:05:01**	**1:20:58**	**SRKW**
2020 Jul 25	**21:57:14**	**0:31:33**	**SRKW**
2020 Jul 30	**8:08:40**	**0:00:15**	**SRKW**
2020 Aug 9	19:58:53	0:07:15	Unknown (likely Transient)
2020 Aug 14	23:52:07	0:06:11	Transient
2020 Aug 22	22:27:57	0:00:00	Transient
2020 Aug 30	22:17:26	1:25:54	Transient
2020 Sep 1	**14:12:28**	**5:09:38**	**SRKW**
2020 Sep 3	**15:16:19**	**0:26:15**	**SRKW**
2020 Sep 5	**18:55:57**	**1:34:40**	**SRKW**
	1:05:42	0:00:00	Transient
2020 Sep 8	2:36:10	0:00:00	Transient
	21:09:53	0:00:37	Transient
2020 Sep 10	8:50:39	0:16:53	Transient
2020 Sep 11	**15:23:33**	**0:44:49**	**SRKW**
	18:31:19	**0:00:00**	**SRKW**
	20:29:06	**1:11:00**	**SRKW**
2020 Sep 13	**12:05:59**	**1:44:18**	**SRKW**

2020 Sep 19	**14:11:27**	**0:30:02**	**SRKW**
	17:08:02	**0:00:14**	**SRKW**
2020 Sep 23	20:48:35	0:27:54	Unknown
2020 Sep 24	**2:49:51**	**0:31:37**	**SRKW**
2020 Sep 27	**20:16:35**	**0:12:19**	**SRKW**
2020 Sep 28	**19:42:15**	**0:34:59**	**SRKW**
2020 Sep 30	**2:18:31**	**0:37:40**	**SRKW**
2020 Oct 4	**11:20:20**	**0:56:12**	**SRKW**
2020 Oct 6	**22:09:01**	**0:41:39**	**SRKW**
2020 Oct 7	**2:45:48**	**1:22:59**	**SRKW**
	7:53:17	**0:20:38**	**SRKW**
2020 Oct 19	**20:30:26**	**0:49:58**	**SRKW**
2020 Oct 20	**1:06:21**	**0:14:37**	**Likely SRKW**
2020 Oct 30	3:02:26	0:44:57	Unknown

Table 21. Summary of Southern Resident Killer Whale (SRKW) passive acoustic monitoring (PAM) and marine mammal observer (MMO) detection events made in 2020 at Lime Kiln 1 Jul to 31 Oct 2020. SRKW detections made by only one method are in bold.

Date	Start time (Local PDT)	Event duration (h:min:sec)	PAM versus daylight MMO detections of SRKW at Lime Kiln
2020 Jul 1	**8:34:06**	**0:30:15**	**PAM only** (out of MMO observation period)
	13:50:16	0:04:01	MMO and PAM UK killer whale
2020 Jul 2	15:48:22	0:33:36	Both PAM and MMO
2020 Jul 4	17:55:48	3:56:46	Both PAM and MMO
2020 Jul 5	15:52:50	4:54:51	Both PAM and MMO
2020 Jul 6	**18:00:00**	**0:00:02**	**MMO only**
	4:39:22	**1:07:44**	**PAM only** (out of MMO observation period)
2020 Jul 7	9:20:50	0:28:52	Both PAM and MMO
	12:48:25	7:32:19	Both PAM and MMO
2020 Jul 8	**2:37:29**	**0:35:55**	**PAM only** (out of MMO observation period)
	17:00:47	0:59:50	Both PAM and MMO
	20:18:43	**2:03:46**	**PAM only** (out of MMO observation period)
2020 Jul 9	**6:23:59**	**1:17:51**	**PAM only** (out of MMO observation period)
	12:42:36	0:24:32	Both PAM and MMO
	20:19:07	**2:51:04**	**PAM only** (out of MMO observation period)
2020 Jul 10	**0:40:35**	**0:30:59**	**PAM only** (out of MMO observation period)
	17:50:44	4:04:11	Both PAM and MMO

2020 Jul 11	**0:09:02**	**0:10:40**	**PAM only** (out of MMO observation period)
	3:35:14	**0:06:18**	**PAM only** (out of MMO observation period)
	4:58:31	**0:40:45**	**PAM only** (out of MMO observation period)
	6:44:15	0:57:58	Both PAM and MMO
	18:18:19	0:32:17	Both PAM and MMO
2020 Jul 12	13:17:30	1:09:09	Both PAM and MMO
	15:54:50	**0:00:00**	**PAM Only**
	22:23:05	**0:11:56**	**PAM only** (out of MMO observation period)
2020 Jul 14	16:12:20	1:30:00	Both PAM and MMO
2020 Jul 15	**20:55:36**	**1:11:42**	**PAM only** (out of MMO observation period)
2020 Jul 16	**18:38:01**	**0:07:01**	**PAM only** (out of MMO observation period)
2020 Jul 17	**4:17:27**	**0:28:19**	**PAM only** (out of MMO observation period)
	10:00:08	5:56:47	Both PAM and MMO
	17:00:00	**1:30:05**	**PAM only** (out of MMO observation period)
	22:51:26	**0:23:39**	**PAM only** (out of MMO observation period)
2020 Jul 18	6:23:21	0:45:35	Both PAM and MMO
2020 Jul 24	20:05:01	1:20:58	Both PAM and MMO
2020 Jul 25	**21:57:14**	**0:31:33**	**PAM only** (out of MMO observation period)
2020 Jul 30	**8:08:40**	**0:00:15**	**PAM only** (out of MMO observation period)
2020 Sep 1	14:12:28	5:09:38	Both PAM and MMO
2020 Sep 3	15:16:19	0:26:15	Both PAM and MMO
2020 Sep 5	18:55:57	1:34:40	Both PAM and MMO
2020 Sep 11	15:23:33	0:44:49	Both PAM and MMO
	18:31:19	**0:00:00**	**PAM only** (out of MMO observation period)
	20:29:06	**1:11:00**	**PAM only** (out of MMO observation period)
2020 Sep 13	12:05:59	1:44:18	PAM only
	21:30:00	**0:00:00**	**PAM only** (out of MMO observation period)
2020 Sep 19	**14:11:27**	**0:30:02**	**PAM only**
	17:08:02	0:00:14	Both PAM and MMO
2020 Sep 24	**2:49:51**	**0:31:37**	**PAM only** (out of MMO observation period)
2020 Sep 27	**20:16:35**	**0:12:19**	**PAM only** (out of MMO observation period)

2020 Sep 28	**19:42:15**	**0:34:59**	**PAM only** (out of MMO observation period)
2020 Sep 30	**2:18:31**	**0:37:40**	**PAM only** (out of MMO observation period)
2020 Oct 4	11:20:20	0:56:12	**PAM only** (out of MMO observation period)
2020 Oct 6	**22:09:01**	**0:41:39**	**PAM only** (out of MMO observation period)
2020 Oct 7	**2:45:48**	**1:22:59**	**PAM only** (out of MMO observation period)
	7:53:17	0:20:38	**PAM only** (out of MMO observation period)
2020 Oct 19	**20:30:26**	**0:49:58**	**PAM only** (out of MMO observation period)
2020 Oct 20	**1:06:21**	**0:14:37**	**PAM only** (out of MMO observation period)

Table 22. Summary performance of passive acoustic monitoring (PAM) Southern Resident Killer Whale (SRKW) detections from Lime Kiln hydrophone compared against marine mammal observer (MMO) detections based at Lime Kiln (1 Jul to 31 Oct 2020).

Detections of SRKW during Slowdown period	Days with SRKW detections	SRKW transit events
PAM detections	34	54
MMO detections	22	30
PAM detection only, not during MMO monitoring period	22	28
PAM detection only, during MMO monitoring period	4	4
MMO detection, no PAM detection	2 (1 unknown killer whales detected by PAM)	2 (1 unknown killer whales detected by PAM)
Total SRKW classifications combined PAM and MMOs	34	56
Total unknown ecotype detected by PAM with no other SRKW detected	3	7

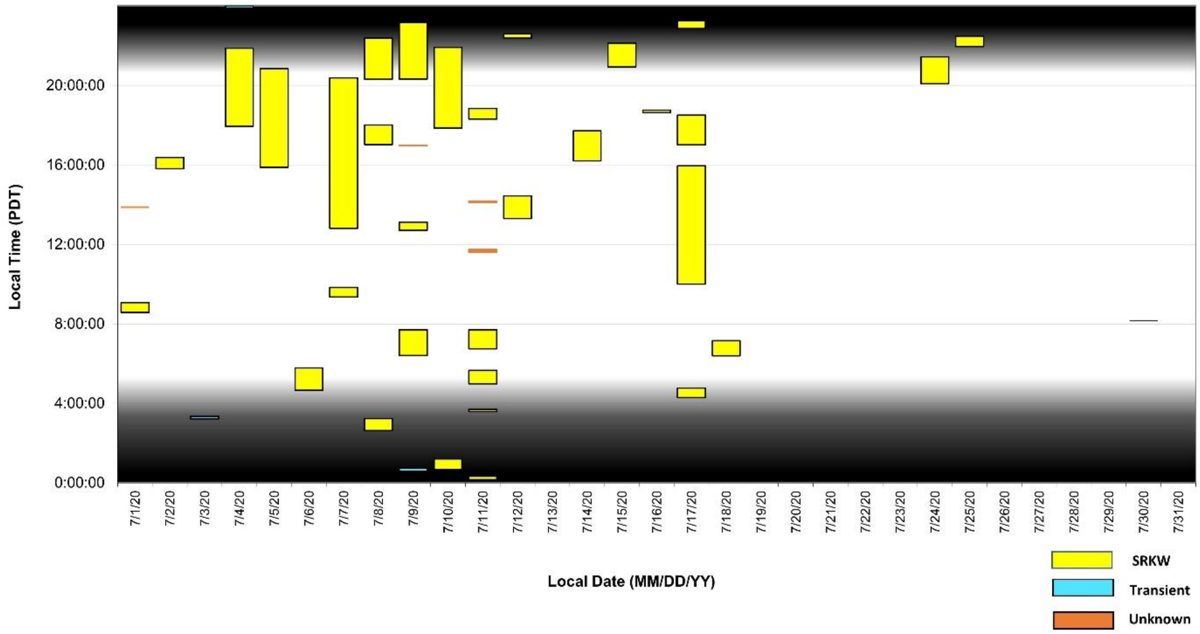

Figure 47. 1–31 Jul 2020: Date and timing of killer whale vocal events detected at Lime Kiln hydrophone using PAMGuard software.

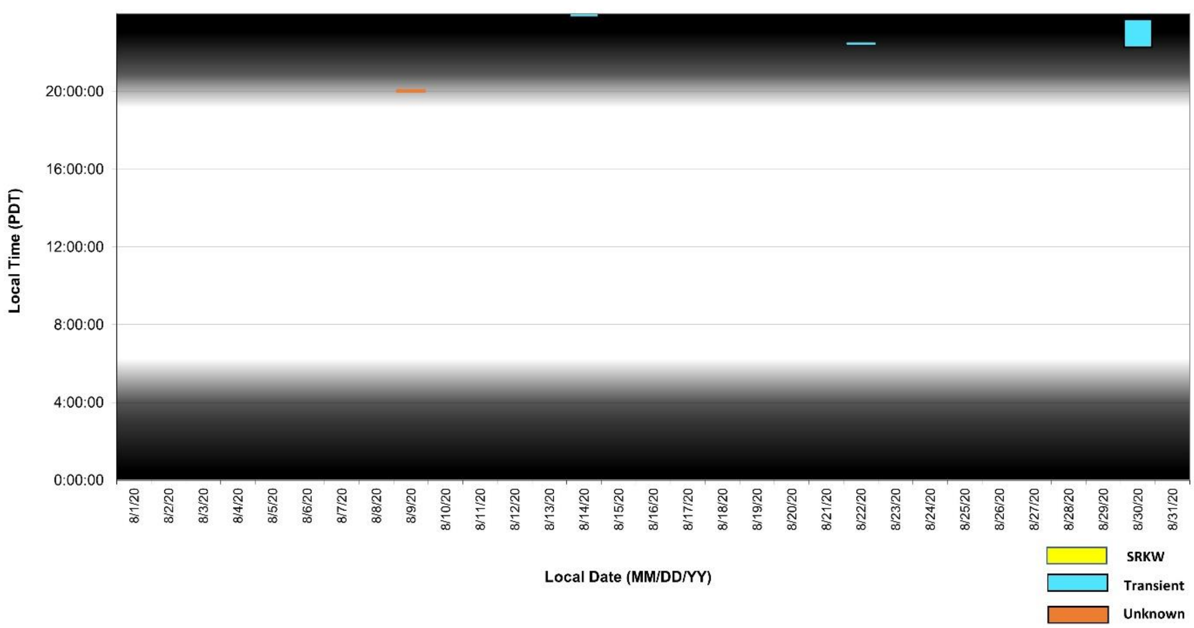

Figure 48. 1–31 Aug 2020: Date and timing of killer whale vocal events detected at Lime Kiln hydrophone using PAMGuard software.

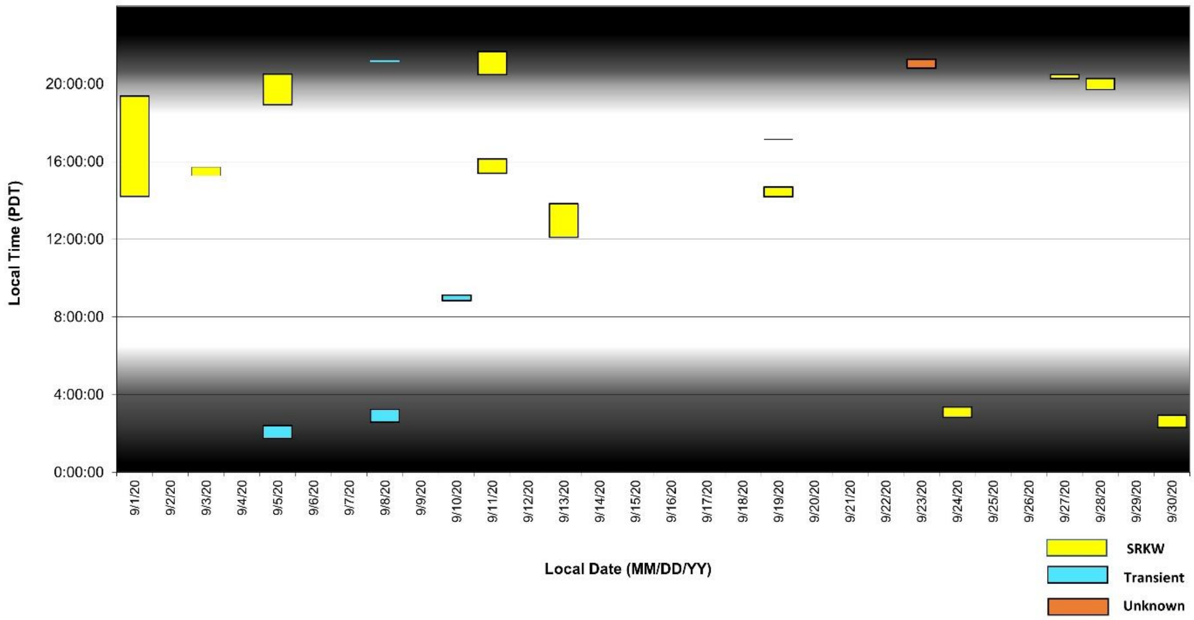

Figure 49. 1–30 Sep 2020: Date and timing of killer whale vocal events detected at Lime Kiln hydrophone using PAMGuard software.

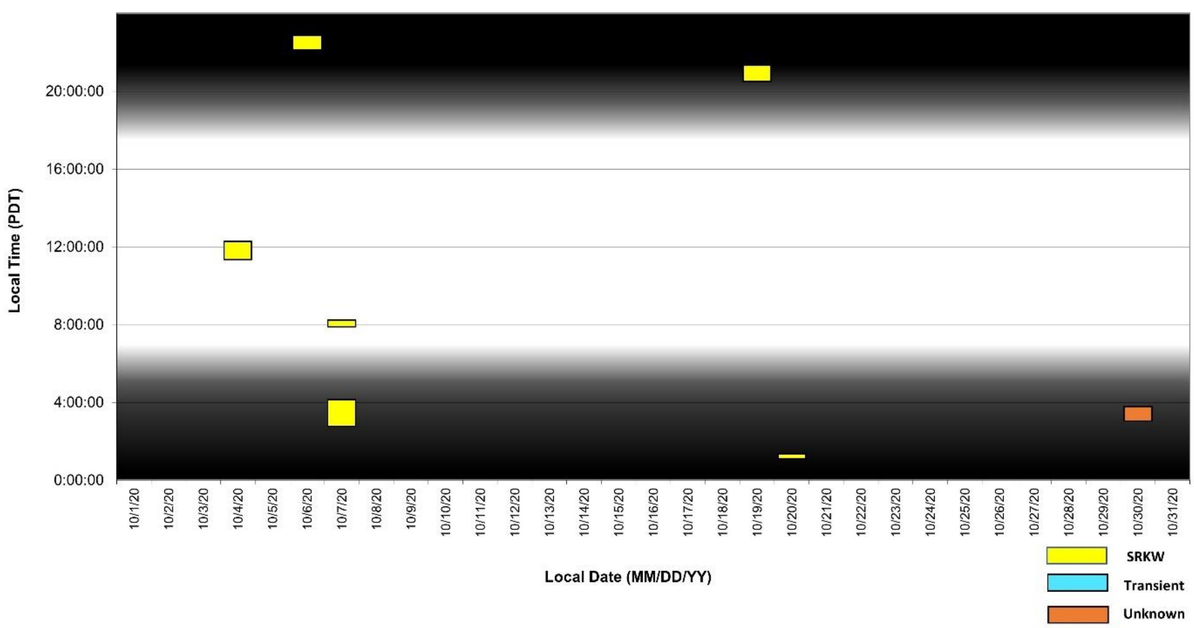

Figure 50. 1–31 Oct 2020: Date and timing of killer whale vocal events detected at Lime Kiln hydrophone using PAMGuard software.

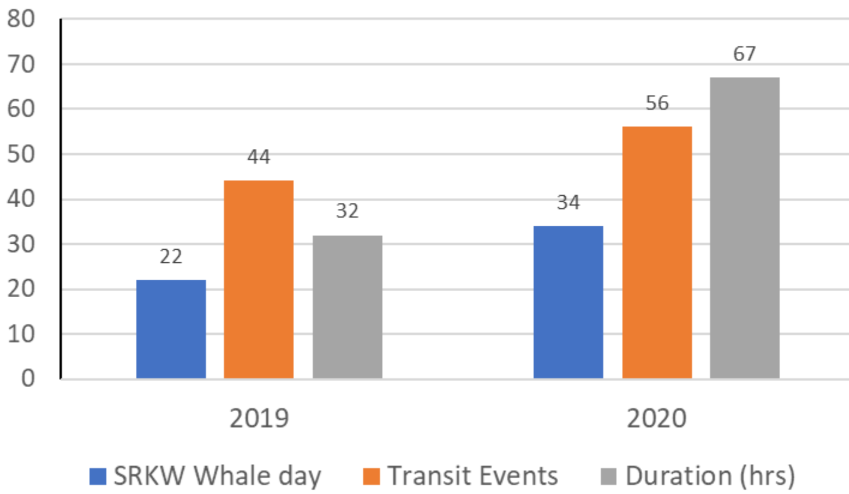

Figure 51. Southern Resident killer whale (SRKW) days, transit events and transit durations (h) based on combined SRKW Passive Acoustic Monitoring (PAM) and Marine Mammal Observer (MMO) detection events made during Slowdown periods 2019–2020 at Lime Kiln.

1.3.7.2. Boundary Pass

In total, killer whales were detected by PAM on 24 days across 31 unique events in Boundary Pass. Most of these were in July (10 days and 14 events) and September (7 days and 9 events). A total of 17 SRKW, 12 transient killer whale, and 1 unknown killer whale ecotype events (examples of spectrograms: Figure 53) were detected, respectively (Table 23). A total duration of >22 hours of killer whale detections (19:55 hours and minutes of SRKW, 2:42 hours and minutes of transient killer whale, and 0:04 minutes of unknown killer whale) was recorded. Both transient killer whales and SRKW were present during daylight periods and during nighttime periods (Figures 52, 54, 55, and 56). SRKW were not detected in August. Details of the killer whale PAM detection events are provided in Table 24.

Table 23. Summary information of passive acoustic monitoring (PAM) detection events of killer whales (KW) made at Boundary Pass between 1 Jul and 31 Oct 2020.

Date	Number of KW days			Number of KW events			Mean duration (hr:min)			Total duration (hr:min)		
	SRKW	Transient	Unknown	SRKW	Transient	Unknown	SRKW	Transient	Unknown	SRKW	Transient	Unknown
2020 Jul 1–31	7	3	0	9	5	0	0:44	0:12	0	6:42	1:03	0
2020 Aug 1–31	0	3	1	0	4	1	0	0:02	0:04	0:00	0:11	0:04
2019 Sep 1–30	4	3	0	6	3	0	1:15	0:29	0	7:33	1:27	0
2019 Oct 1–31	3	0	0	3	0	0	1:53	0	0	5:39	0	0
Total	**14**	**9**	**1**	**18**	**12**	**1**	**N/A**	**N/A**	**N/A**	**19:54**	**2:41**	**0:04**

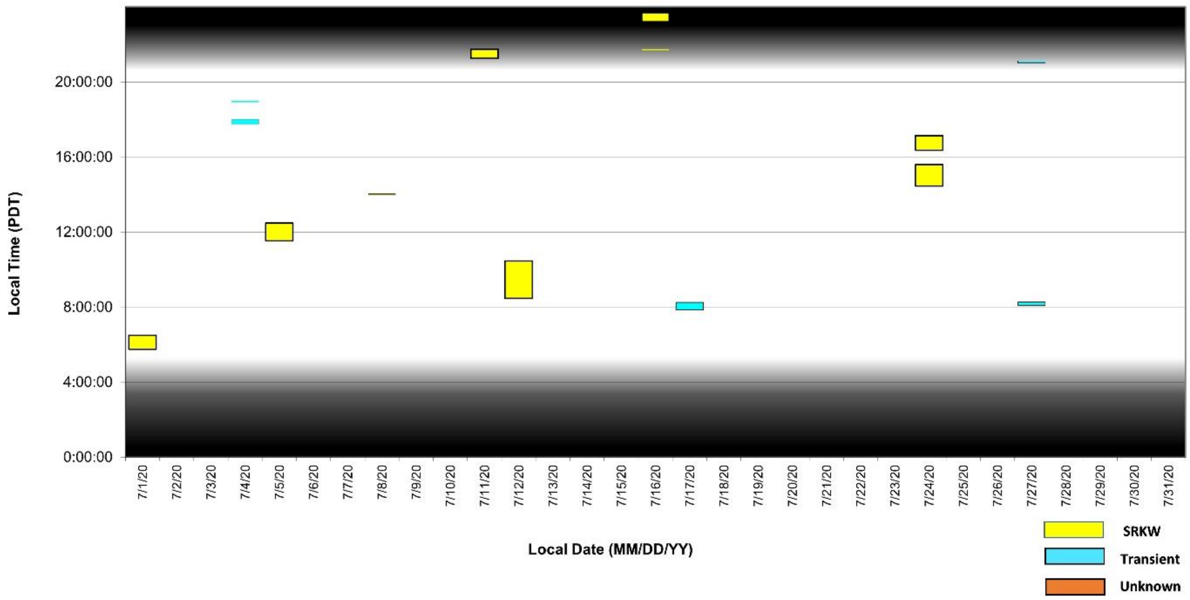

Figure 52. 1–31 Jul 2020: Date, time, and duration of killer whale (by ecotype) Passive Acoustic Monitoring (PAM) detections made at Boundary Pass.

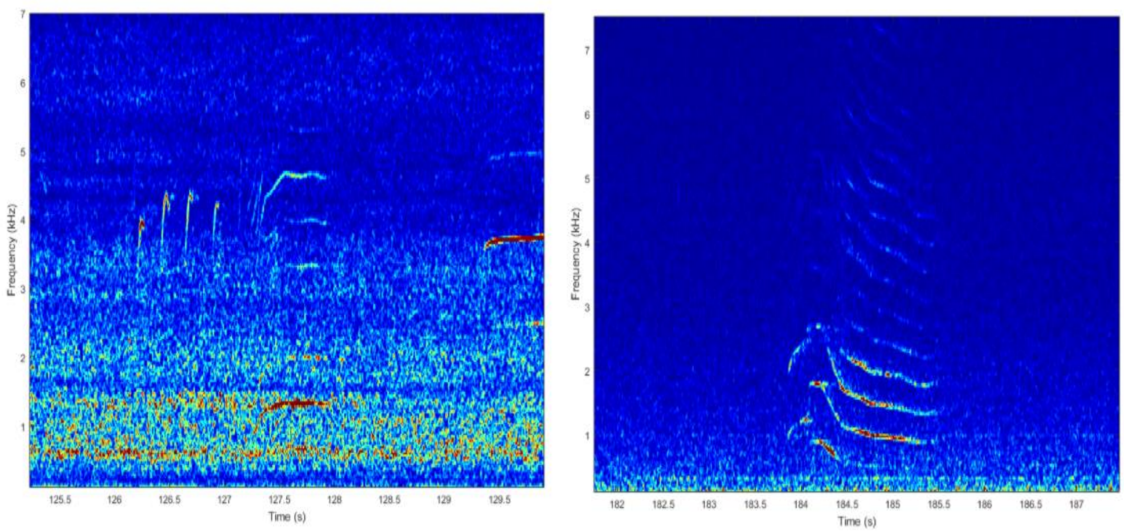

Figure 53. Spectrograms of killer whale sounds (left: SRKW (L pod) S18 call on 24 Jul 2020, right: Transient sound on 17 Jul 2020).

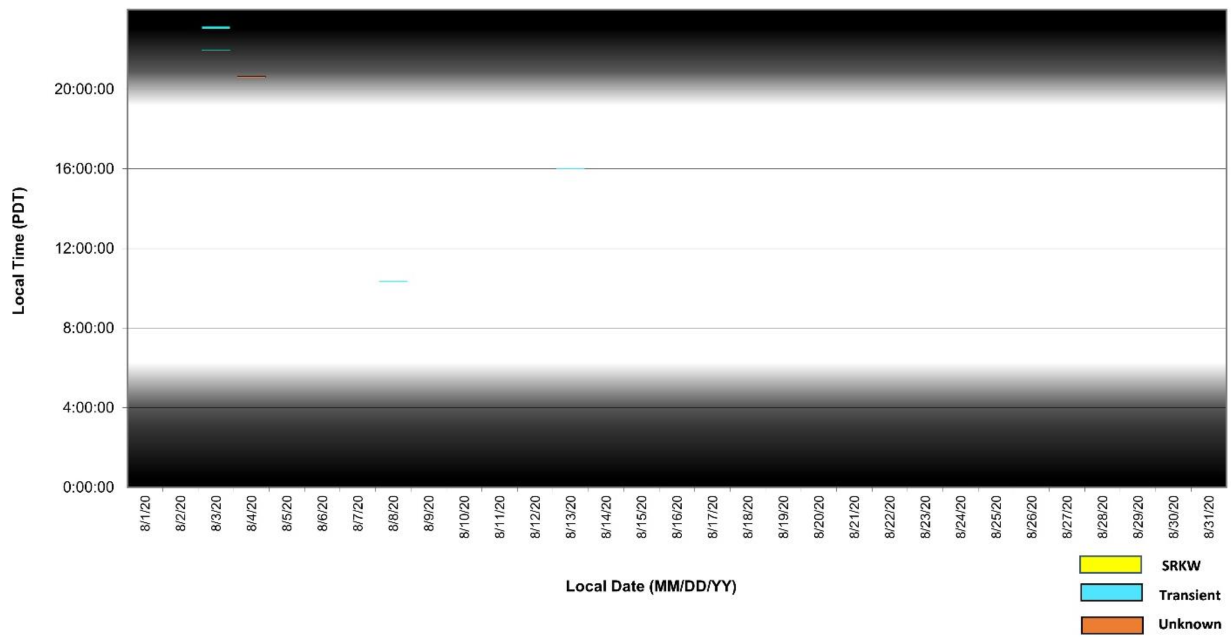

Figure 54. 1–31 Aug 2020: Date, time, and duration of killer whale (by ecotype) passive acoustic monitoring (PAM) detections made at Boundary Pass.

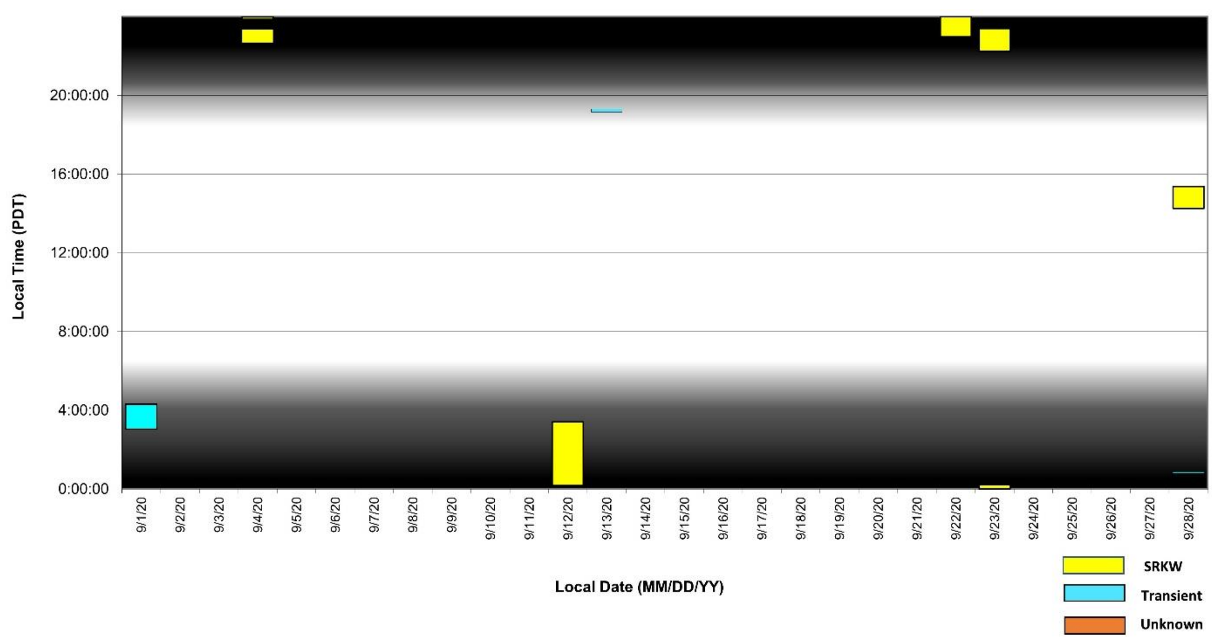

Figure 55. 1–30 Sep 2020: Date, time and duration of killer whale (by ecotype) passive acoustic monitoring (PAM) detections made at Boundary Pass.

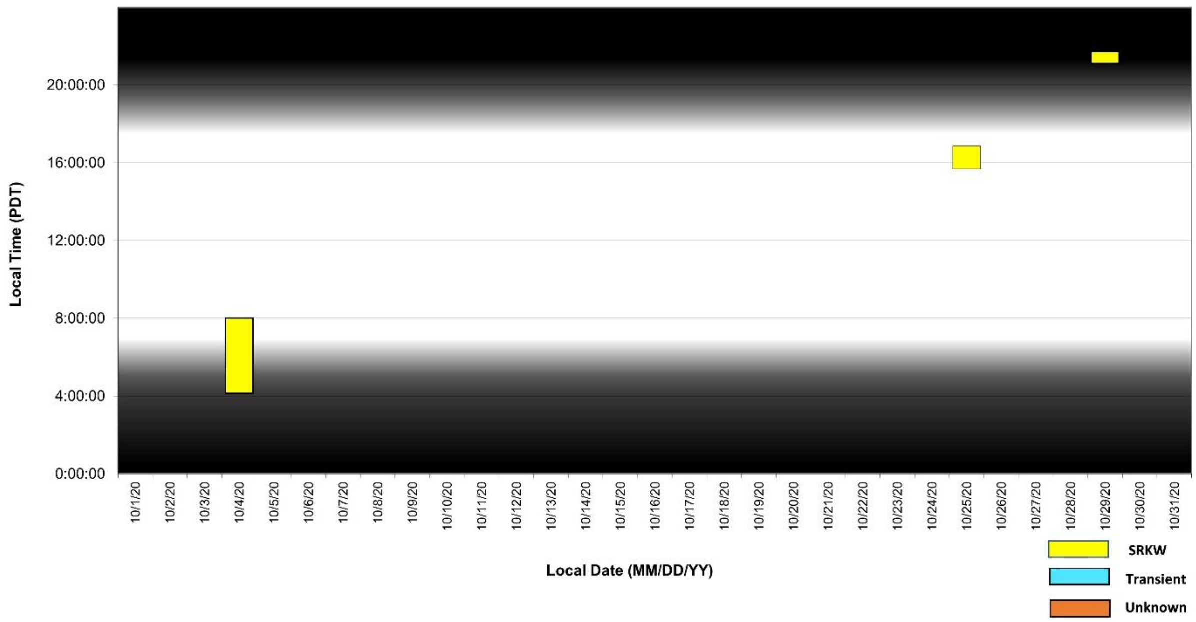

Figure 56. 1–31 Oct 2020: Date, time, and duration of killer whale (by ecotype) passive acoustic monitoring (PAM) detections made at Boundary Pass.

Table 24. Passive acoustic monitoring (PAM) identifications of killer whales detected on the Boundary Pass hydrophone (1 Jul to 31 Oct 2020), with details of time, event duration and ecotype classification. Southern Resident Killer Whale (SRKW) detections are in bold.

Date	Start time (Local PDT)	Event duration (hr:min:sec)	Killer whale ecotype classification (Vocalization notes)
2020 Jul 1	**5:44:55**	**0:45:00**	**SRKW**
2020 Jul 4	17:44:00	0:15:48	Transient
	18:54:47	0:04:46	Transient
2020 Jul 5	**11:31:42**	**0:57:20**	**SRKW**
2020 Jul 8	**13:58:45**	**0:03:38**	**SRKW**
2020 Jul 11	**21:15:23**	**0:28:55**	**SRKW**
2020 Jul 12	**8:27:21**	**2:00:12**	**SRKW**
2020 Jul 16	**21:41:55**	**0:03:27**	**SRKW**
	23:12:34	**0:28:42**	**SRKW**
2020 Jul 17	7:49:52	0:24:43	Transient
2020 Jul 24	**14:26:54**	**1:09:01**	**SRKW**
	16:21:16	**0:46:33**	**SRKW**
2020 Jul 27	8:05:40	0:10:36	Transient
	21:00:46	0:07:16	Transient
2020 Aug 3	21:57:46	0:01:13	Transient
	23:02:03	0:07:15	Transient
2020 Aug 4	20:34:34	0:04:16	Unknown
2020 Aug 8	10:19:14	0:02:09	Transient
2020 Aug 13	15:59:31	0:01:07	Transient
2020 Sep 1	3:02:40	1:15:22	Transient

2020 Sep 4	**22:41:04**	**0:39:40**	**SRKW**
	23:52:02	**0:07:15**	**SRKW**
2020 Sep 12	**0:10:19**	**3:14:49**	**SRKW**
2020 Sep 13	19:09:10	0:09:25	Transient
2020 Sep 22	**22:58:47**	**1:14:07**	**SRKW**
2020 Sep 23	**22:14:05**	**1:09:55**	**SRKW**
2020 Sep 28	0:49:19	0:02:20	Transient
	14:15:03	**1:07:31**	**SRKW**
2020 Oct 4	**4:08:45**	**3:51:43**	**SRKW**
2020 Oct 25	**15:41:34**	**1:10:36**	**SRKW**
2020 Oct 29	**21:06:34**	**0:36:43**	**SRKW**

1.4. Discussion

The 2020 Slowdown initiative in Haro Strait and Boundary Pass was found to reduce ambient sound levels during periods when potentially participating vessels (Bulk Carrier, Car Carrier, Container Ship, General Cargo, Passenger, and Tanker) were the closest vessel within 6 km of the hydrophones. Median broadband sound levels measured by the hydrophones decreased by 2.5 dB in Haro Strait and 2.8 dB in Boundary Pass, relative to the baseline period, after filtering for confounding factors. Generally, the sound level reductions were larger at lower frequencies at the Boundary Pass hydrophones and were larger at higher frequencies at the Lime Kiln hydrophone. Controlling other cofounding factors such as water current speed, and to a lesser degree, wind speed and small boat presence, was required to quantify the Slowdown effect at both sites.

The GAMM analysis of SPL data from Lime Kiln found supporting evidence that there were statistically significant reductions in ambient sound levels during the Slowdown period, and that these were related to vessel speed reductions from participating vessels.

The sound level reductions were calculated using data collected during 11% and 21% of the Slowdown period (2 Jul to 31 Oct 2020) in Haro Strait and Boundary Pass, respectively. The true proportion of the time when the Slowdown reduced sound levels are greater than these percentages would suggest, however, because periods with high current speeds (and the resulting high flow noise) were filtered out of the analysis. The difference in sound level reductions between sites was primarily attributed to differences in the proximity of the hydrophones to large and small vessel traffic. At Lime Kiln, the hydrophone was relatively close to shore and several kilometres from the international shipping lanes. Small (mostly recreational) vessels frequently transited close to shore, which required filtering (using both AIS and the boat detector) out more of the acoustic data for quantifying the Slowdown effect on sound levels. In Boundary Pass, the hydrophone was several kilometres from shore and positioned between the international shipping lanes. Small vessel traffic infrequently passed close to the hydrophone, so more acoustic data could be used to quantify the Slowdown effect.

The duration of quiet time (i.e., time broadband sound levels were below 102.8 and 110 dB re 1 μPa) changed very little between Baseline and Slowdown periods. The total quiet time and median quiet time duration in Boundary Pass was longer than in Haro Strait. This is likely driven by differences in use of these areas by recreational boats.

During the 2020 Slowdown, there were 53 SRKW PAM events recorded at Lime Kiln and 18 SRKW PAM events recorded in Boundary Pass. This is in line with historical sightings of SRKW in the Salish Sea (see Chapter 3). The Slowdown was triggered by the return of SRKW to Haro Strait, thus PAM data for the Baseline period were not evaluated. No visual sightings of SRKW were reported in the Baseline period. In contrast to SRKW PAM events during the Slowdown period, there were 10 transient killer whale events recorded at Lime Kiln and 12 in Boundary Pass. This suggests higher use of Boundary Pass by transient killer whales; however, transient killer whales are not very vocal and can therefore be missed by PAM systems. No SRKW were detected in August at Lime Kiln or Boundary Pass.

1.4.1. Comparison to Previous Years

In Boundary Pass, the 512 kHz sample rate of the ULS in 2020 compared to the 128 kHz sample rate of the AMARs in 2019 allowed for extending the maximum frequency limit from 64 kHz to 100 kHz in 2020. Furthermore, the lower mooring noise from the ULS in 2020 compared to the AMAR mooring noise in 2019 allowed the lower frequency limit to be reduced from 30 Hz (2019) to 10 Hz (2020). The larger bandwidth in 2020 allowed for the same frequency bands to be analyzed in Boundary Pass as in Haro Strait. The quieter ULS mooring may also have contributed to the detection of increased sound levels for times with high wind speed in 2020, which was not observed in the 2019 AMAR data.

Compared to 2019, overall sound levels were generally consistent at Lime Kiln but decreased by a small amount in Boundary Pass (median levels averaged 1.3 dB lower in 2020 than in 2019 across the decade and CORI bands). Sound level reductions were slightly smaller in 2020, despite the increase in pilot-reported participation rate from 82% in 2019 to 91% in 2020. The acoustic differences between years, however, were relatively small and could be related to differences in the relative proportions of different vessel types. When the vessels subject to the 14.5 knot voluntary speed limit (cruise, car carriers, and container ships) participated, they slowed down more than the vessels subject to the 11.5 knot voluntary speed limit (general cargo, bulkers, tankers) so it is expected that the sound level reductions on a per-transit basis would be greater for participants in the 14.5 knot Slowdown group. A larger proportion of vessels in the 11.5 knot Slowdown group during the Slowdown could therefore reduce the overall mean sound level reduction. The reductions observed in 2020 are considered robust and show consistent decreases in SPL during the Slowdown period compared to the Baseline.

1.5. Conclusions

- Median broadband (10–100,000 Hz) sound levels measured at Lime Kiln in Haro Strait decreased by 2.5 dB during the Slowdown period compared to the Baseline period, when filtered for confounding factors.
- Median broadband (10–100,000 Hz) sound levels measured between the international shipping lanes in Boundary Pass decreased by 2.8 dB during the Slowdown period compared to the Baseline period, when filtered for confounding factors.
- The Slowdown period also showed reductions in broadband noise for the mean (L_{eq}) and L_5 in both locations, with slightly larger reductions in Boundary Pass (L_{eq} decreased by 2.8 dB) than in Haro Strait (L_{eq} decreased by 2.4 dB).
- Median ambient noise reductions were largest in the 10–100 Hz decade band in Boundary Pass and in the 1–10 kHz band in Haro Strait.
- Temperature and salinity profile measurements showed stronger seasonal gradients in the surface water properties (up to 50 m depth) in Boundary Pass than in Haro Strait.
- Based on median speed through water (AIS speed over ground corrected for current using the Lime Kiln current meter) recorded at Lime Kiln, Container vessels reduced their speed through water the most during the Slowdown (3.9 knots), followed closely by Car carriers (2.2 knots).
- Large vessel traffic in Boundary Pass and Haro Strait was largely composed of bulk carriers, container ships, general cargo vessels, and tugs.
- Small boats were frequently detected in Haro Strait. Including the sail and yacht categories in the AIS data during the Slowdown, they were the closest AIS-enabled vessels within 6 km of Lime Kiln 33.3% of the time and therefore had the potential to dominate sound levels when potential Slowdown participants were present.
- Small boat detections in Boundary Pass were concentrated during daytime hours but infrequently dominated sound levels when vessels that were potential Slowdown participants were present.
- Filtering out time periods with small boat presence for the CDF analysis was more important in Haro Strait than in Boundary Pass because small boats in Haro Strait frequently pass close to the near-shore Lime Kiln hydrophone, whereas small boats rarely pass the Boundary Pass hydrophone (which is located between the international shipping lanes).
- The median duration of quiet time for both the 102.8 and 110 dB re 1 µPa thresholds was 3–4 minutes during both the Baseline and Slowdown periods at Lime Kiln. SPL were below the 102.8 dB threshold approximately 29% of the time, and below the 110 dB threshold approximately 53% of the time. There was no significant difference in quiet time between the Baseline and Slowdown periods at Lime Kiln.
- In Boundary Pass, the median duration of quiet time was 6 minutes for the 102.8 dB threshold during the Baseline and Slowdown periods and was around 10 minutes for the 110 dB threshold. SPL were below the 102.8 dB threshold approximately 48% of the time, and below the 110 dB threshold approximately 65% of the time. There was no significant difference in quiet time between the Baseline and Slowdown periods in Boundary Pass.
- The GAMM analysis found statistically significant reductions in SPL from the vessel speed reductions of the Slowdown period. While controlling for other covariates and at a range of 2.3 km from Lime Kiln (distance from Lime Kiln to centre of northbound shipping lane), the model predicted a decrease of 1.7 dB for Bulk and Containerized vessel types from Baseline to Slowdown periods, respectively.
- Through passive acoustic monitoring only, killer whales (all ecotypes) were detected acoustically 70 times in Haro Strait and 31 times in Boundary Pass during 1 Jul to 31 Oct 2020). Of these total killer whale detection events, 53 were confirmed SRKW in Haro Strait, and 18 were confirmed SRKW in Boundary Pass. Transient killer whale events were acoustically detected 10 and 12 times in Haro Strait and Boundary Pass, respectively. The remaining detections were unknown killer whale ecotypes.

1.6. Acknowledgements

We thank Greg Bellavance and the crew of the *Moving Experience* for their assistance with deploying and retrieving the autonomous underwater monitoring equipment. We thank David Osborne for allowing us to install our shore-based AIS logger at his home on Saturna Island. JASCO's field teams included Connor Grooms, Héloïse Frouin-Mouy, Jennifer Wladichuk, and Graham Warner. The cabled ULS was designed by JASCO's engineering personnel: John Moloney, Art Cole, Craig Hillis, Ron Burke, and Jack Hennessey, several of whom participated in its final assembly, testing and deployment in May 2020. JASCO's IT team led by Jason Reym set up the data management and backup systems at Saturna Island. We are grateful to Mike Shaw and the crew at Island Tug and Barge, who provided cable lay services including the safe lowering of the ULS hydrophone frames to the seabed.

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Chapter 2. Cumulative Vessel Noise Modelling

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2.1. Introduction

During 2020, the Vancouver Fraser Port Authority's (VFPA) Enhancing Cetacean Habitat and Observation (ECHO) Program carried out a voluntary slowdown initiative to reduce vessel noise in sensitive Southern Resident Killer Whale (SRKW) habitat in Haro Strait and Boundary Pass. This was the fourth year of voluntary slowdowns undertaken by the ECHO Program, after a successful trial in Haro Strait during 2017 demonstrated that reducing vessel speeds significantly reduced underwater radiated noise in SRKW habitat. During the 2020 Haro Strait and Boundary Pass slowdown, vehicle carriers, and container ships were requested to slow to 14.5 knots speed through water, while bulker carriers, general cargo vessels, and tankers were requested to slow to 11.5 knots speed through water (cruise vessels were absent from the slowdown area in 2020, due to pandemic-related restrictions). The 2020 initiative achieved an overall reported voluntary participation rate of 91%, as reported by the Pacific Pilotage Authority, over an 18 week period.

As in previous years, JASCO Applied Sciences (JASCO) performed acoustic modelling to estimate changes in SRKW noise exposures in 2020 resulting from implementing voluntary speed reductions inside the slowdown areas. The methods applied in this study were based on those used for previous-years' slowdown modelling studies (MacGillivray et al. 2018a, MacGillivray and Li 2019). Time-snapshots of underwater noise levels were simulated, based on historical ship movement data, using JASCO's ARTEMIS (Acoustic Real-Time Exposure Model for In-motion Sources) model. The outputs of the noise simulation were then input to SMRU's behavioural response model for estimating behavioural effects on SRKW in critical habitat areas. Simulated noise exposures were used to compare potential behavioural disturbances and lost foraging opportunities for SRKW under baseline and slowdown conditions (see Chapter 3). The area covered by the acoustic model includes the slowdown areas in Haro Strait and Boundary Pass plus a buffer region to capture noise from vessel traffic outside the slowdown zone (Figure 57).

Four 24 h model scenarios were devised to simulate average-traffic and high-traffic days under baseline and slowdown conditions. These scenarios were based on vessel speeds and participation rates observed during the 2020 slowdown initiative. Sound propagation (i.e., transmission loss) curves were updated based on sound speed profile data collected in Haro Strait and Boundary Pass during the 2019 slowdown (see Chapter 1). Model results for the 2020 slowdown were compared to the previous years slowdowns and to baseline conditions. Other details of the modelling, such as source levels and speed scaling coefficients, were identical to those used in the vessel noise models for the 2017–2019 slowdowns (i.e., as described in MacGillivray et al. (2018b)).

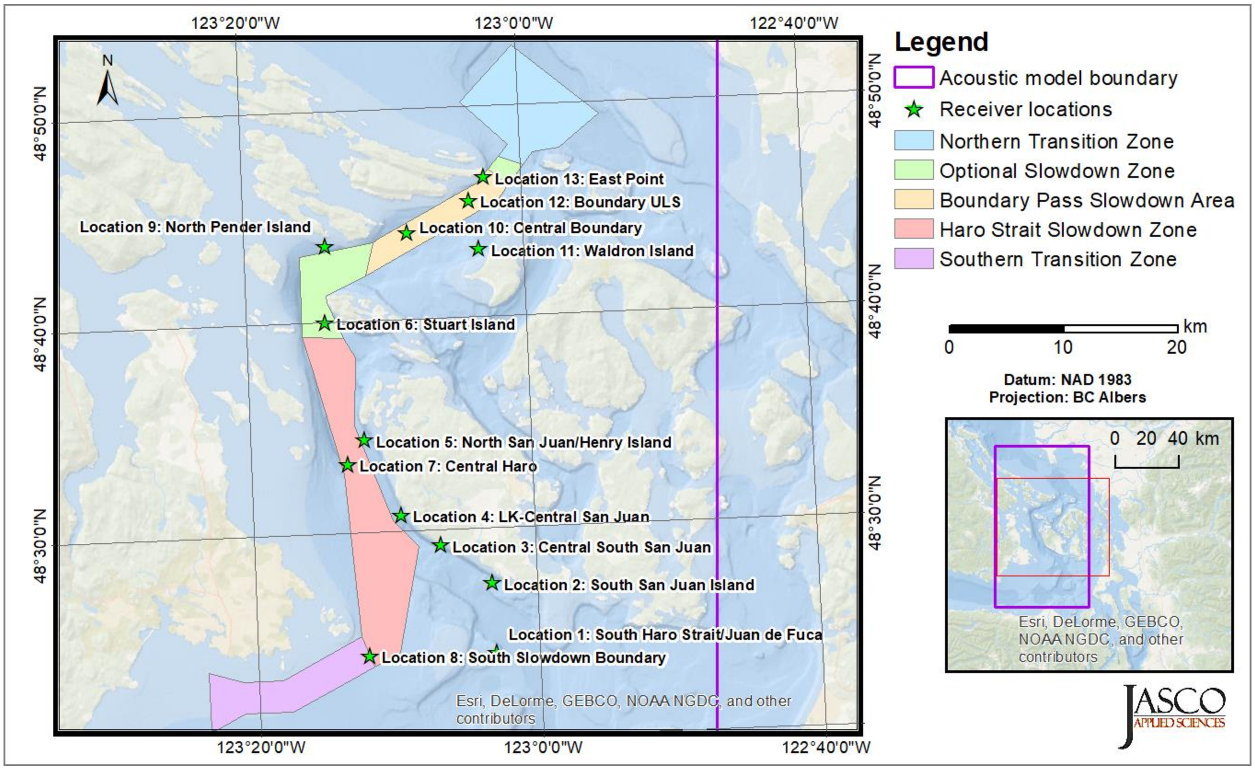

Figure 57. Map of the modelling area and receivers for 2020 slowdown evaluation. Vessels are assumed to reduce their speed inside the slowdown zones.

2.2. Methods, Data Sources, and Model Inputs

JASCO's ARTEMIS can simulate underwater sound levels generated by large ensembles of vessels on a regional scale. The model combines information from several sources—including vessel tracking data, noise emission data, and environmental data—to predict marine environmental noise from ship traffic. Vessel sound emissions are determined by referencing a database of source levels (according to vessel type and speed). The transmission of sound from each vessel is determined according to a database of pre-computed transmission loss curves for the study area. When run in time-lapse mode, the model generates sequences of 2-dimensional (2-D) maps, or "snapshots", of the dynamic sound field, yielding sound pressure level (SPL) as a function of easting, northing, frequency, and time.

Most details of the cumulative vessel noise modelling for the 2020 slowdown were identical to those for the 2017–2019 slowdown modelling. This included the baseline traffic data, source levels, speed scaling coefficients, wind-driven ambient noise levels, and the computational models themselves, as described in MacGillivray et al. (2018b). Details of the 2020 model scenarios that were different from the previous years' studies are described in Sections 2.2.1–2.2.3.

2.2.1. Model Scenarios

This study simulated vessel noise in Haro Strait and Boundary Pass during a single day (24 h) in July. Baseline vessel traffic was based on historical AIS data for the study area. Four model scenarios were used to simulate different vessel traffic and slowdown conditions (Table 25). The number of piloted vessel transits through Haro Strait and Boundary Pass was based on daily vessel counts provided by the Pacific Pilotage Authority (PPA). Table 26 summarizes the number of simulated vessel movements during 24 h for the baseline and 2020 slowdown model scenarios. Scenarios S1 and S2 considered baseline conditions for average and high traffic with no vessel slowdowns. Scenarios S3 and S4 considered slowdown conditions for average and high traffic with slowdowns according to actual participation rates observed during 2020. The number of slowdown transits in the model was chosen to match as realistically as possible the actual overall participation rate, subject to the restriction that the model must consider whole numbers of vessel movements. In this study, slowdowns were only applied to piloted vessels transiting through Haro Strait and Boundary Pass and to the Washington State Ferries (WSF) trips between Sidney and Anacortes, which conduct a short east-west transit across the northern boundary of the Haro Strait slowdown area. All other vessels were assumed to be unaffected by the voluntary slowdown, and their movements were taken to be identical between the four model scenarios. These included non-piloted vessels and cargo vessel traffic transiting to and from the USA.

As a result of the global pandemic, 2020 was a unique year for ferry (and recreational) traffic. Elimination or reduction of some ferry routes occurred in both British Columbia and Washington State waters, but was variable over the time frame of the slowdown. Although there is only one ferry route that transits across the slowdown area, other ferry traffic contributed underwater noise to the 24 h noise model area (Figure 59). Despite the complexity and differences in ferry traffic in 2020 compared to previous years, the decision was taken to maintain consistency in the noise model by not amending ferry traffic routes and the resulting contribution to the noise model. This decision allows for better understanding of the potential underwater noise benefits of the participation rates and speeds achieved for the 2020 slowdown of large commercial vessel traffic and allows for more accurate comparison to previous years noise reduction and resultant behavioural response benefits.

Table 25. Summary of model scenarios for the 2020 voluntary slowdown evaluation.

Scenario	Piloted ship speeds	Slowdown participation rate (%)	Number of ship transits
S1	Baseline	n/a	Average
S2	Baseline	n/a	High
S3	Slowdown/baseline	Actual trial rate	Average
S4	Slowdown/baseline	Actual trial rate	High

Table 26. Mean speed through water of slowdown participants and numbers of daily piloted vessel transits in Haro Strait and Boundary Pass, representing the traffic conditions in the model. Average and high traffic conditions represent median and 95th percentile vessel counts, respectively.

Vessel category	Mean speed through water of slowdown participants (kn)	Baseline total transits		2020 slowdown transits	
		Average traffic (ships per 24 h)	High traffic (ships per 24 h)	Average traffic (ships per 24 h)	High traffic (ships per 24 h)
Bulker*	11.98	8	10	6	8
Containership	14.97	4	6	3	5
Tanker	11.83	1	2	1	2
Vehicle Carrier	15.14	1	2	1	1
Cruise	N/A**	0	0	0	0
	Total	**14**	**20**	**11**	**16**

* The Bulker category includes both bulk carriers and general cargo vessels.
** Cruise vessels were absent from Haro Strait and Boundary Pass during the 2020 slowdown due to pandemic-related restrictions.

2.2.2. Vessel Traffic

Movements of piloted vessels through Haro Strait and Boundary Pass were simulated differently for each model scenario, based on the assumed slowdown participation rate and the number of ship transits. Both the time of departure and the choice of inbound or outbound route were randomly selected for each simulated vessel movement. Baseline speeds for each category were based on average historical vessel speeds along the inbound and outbound routes, as determined from historical AIS data (Figure 58). For scenarios S3 and S4 (i.e., the slowdown scenarios), speeds of participating vessels inside the slowdown zone were taken to be the trial-mean speed through water values (using actual AIS speed over ground data, corrected for currents) for each category. Acceleration and deceleration times in the transition zones were assigned on a category-specific basis, in consultation with pilots from the BC Coast Pilots. Participating vessels were assumed to maintain their slower speeds though the transition zone between Haro Strait and Boundary Pass, based on observed vessel behaviour during 2020. Each simulated trip was displaced slightly from the centre of the route, in a randomized fashion, to more realistically represent the observed distribution of traffic along the traffic routes.

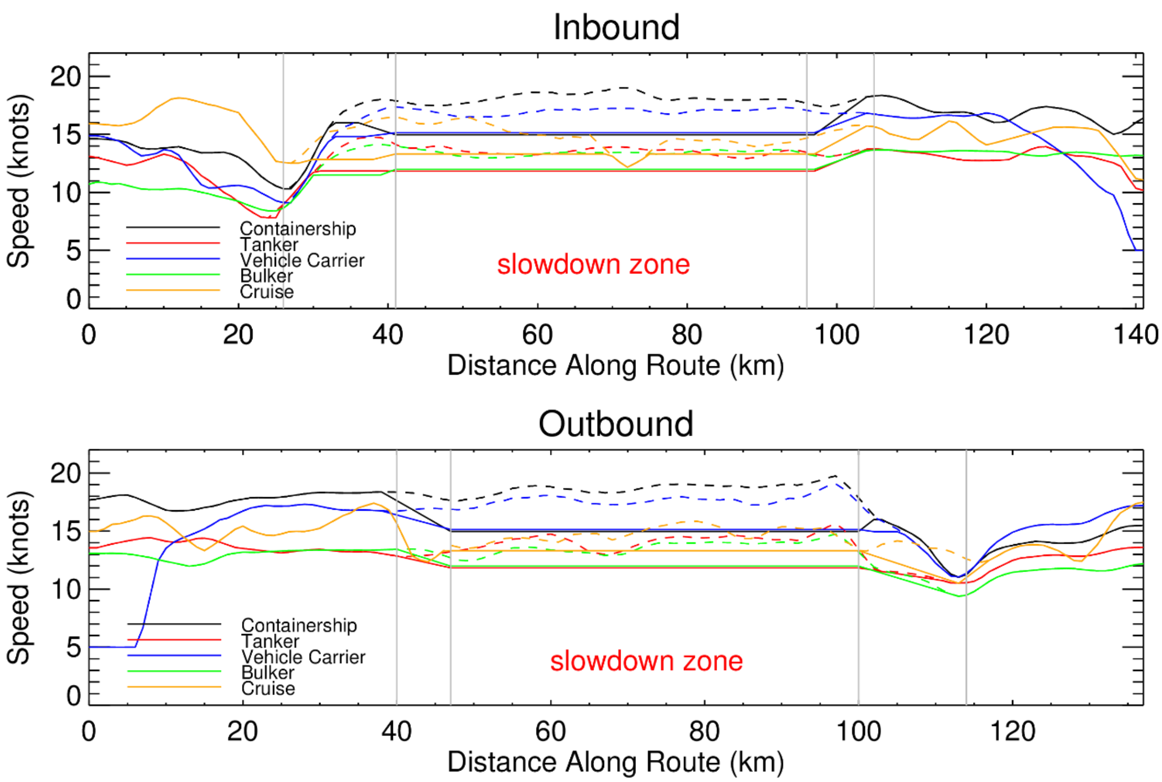

Figure 58. Speeds of piloted vessels along route based on slowdown speeds measured during the trial Dashed = baseline speed, solid = slowdown speed. Vertical grey lines indicate the boundaries of the transition zones. Baseline speeds outside the slowdown zone are based on mean historical AIS data for each vessel category. Speeds inside the slowdown zone are based on average speeds, by category, recorded during the trial. The distance along each route is relative to a start point just outside the model boundary.

Baseline vessel traffic, which included non-piloted vessels and piloted vessels bound to and from the USA, were simulated based on actual AIS vessel tracks for a single day in July (Figure 59)[1]. We selected this day (30 Jul 2015) because the total number of hours of non-piloted vessel traffic over the 24 h period was close to the median daily value for the month (i.e., it represented an average day). Vessel tracks

[1] The AIS dataset included only vessels carrying AIS transceivers. Only moving vessels were included in the model. In Canada, federal regulations require every vessel of 500 deadweight tons or more to carry AIS, except fishing vessels. In practice, many smaller craft and fishing vessels also carry AIS for safety.

were assigned to an appropriate source level category based on their type classification. These AIS data were previously used to generate shipping density maps for a study of noise contributors in the Salish Sea; additional details regarding these data and the vessel categories in the model may be found in the final report for that study (MacGillivray et al. 2016). Baseline traffic was held constant between scenarios, except for the WSF sailing between Sidney and San Juan, which was assumed to reduce speed to 11 knots where it intersected the slowdown zone.

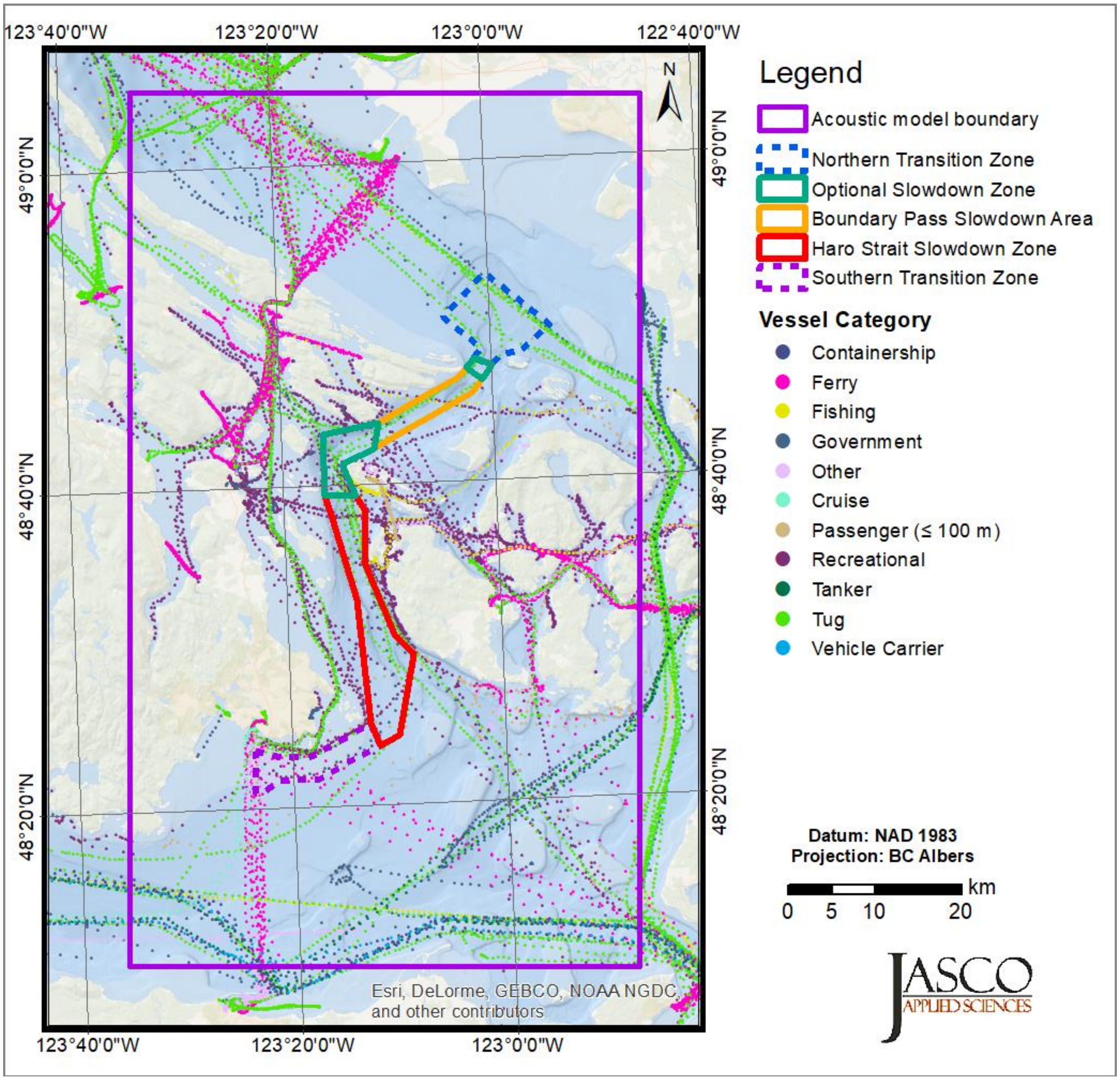

Figure 59. Baseline vessel traffic included in the model, based on Automated Information System (AIS) vessel tracks for 30 Jul 2015. Each point on the map represents a time-stamped vessel position report. The total amount of vessel hours on this day was approximately equal to the median 24 h value for July 2015. A total of 230 AIS vessels were included in the baseline.

2.2.3. Sound Propagation

JASCO's Marine Operations Noise Model (MONM) was used to simulate frequency-dependent sound transmission curves (i.e., transmission loss) for the study area. This model was previously validated via field tests using a controlled sound source at several different locations within the study area (Warner et al. 2014). MONM accounts for the different environmental factors that influence underwater sound propagation, including the sound speed profile of the water, the water depth, and the seabed sediment layering. The details for the bathymetry and seabed geoacoustics were presented in MacGillivray et al. (2016). The water sound speed profiles (SSP) were based on CTD measurements from Haro Strait and Boundary Pass collected during May to October 2019 (Figure 60).

The model included 25 environmental zones, to account for differences in sound speed profile conditions between Boundary Pass and Haro Strait (Figure 61). A set of 150 sound-transmission-versus-range curves was used to represent noise propagation in different parts of the study area. Different curves were used to represent different combinations of frequency, water depth, and source depth (Figure 62). More details regarding the methods used to generate the sound transmission curves for the study area are described in Section 3.3 of MacGillivray et al. (2016).

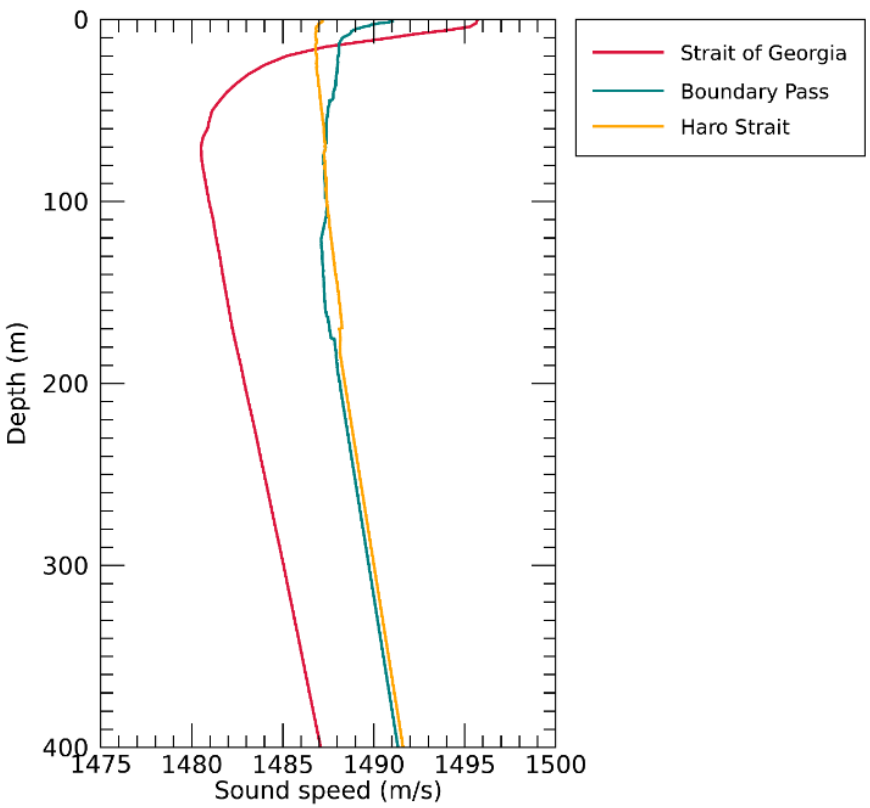

Figure 60. Sound speed profiles (SSP) used for modelling underwater sound propagation in Boundary Pass, Haro Strait, and Strait of Georgia. Sound speed profiles for Boundary Pass and Haro Strait were based on Conductivity, Temperature, Depth (CTD) data collected during 2019. The sound speed profile for Georgia Strait were based on historical CTD data from Fisheries and Oceans Canada (DFO).

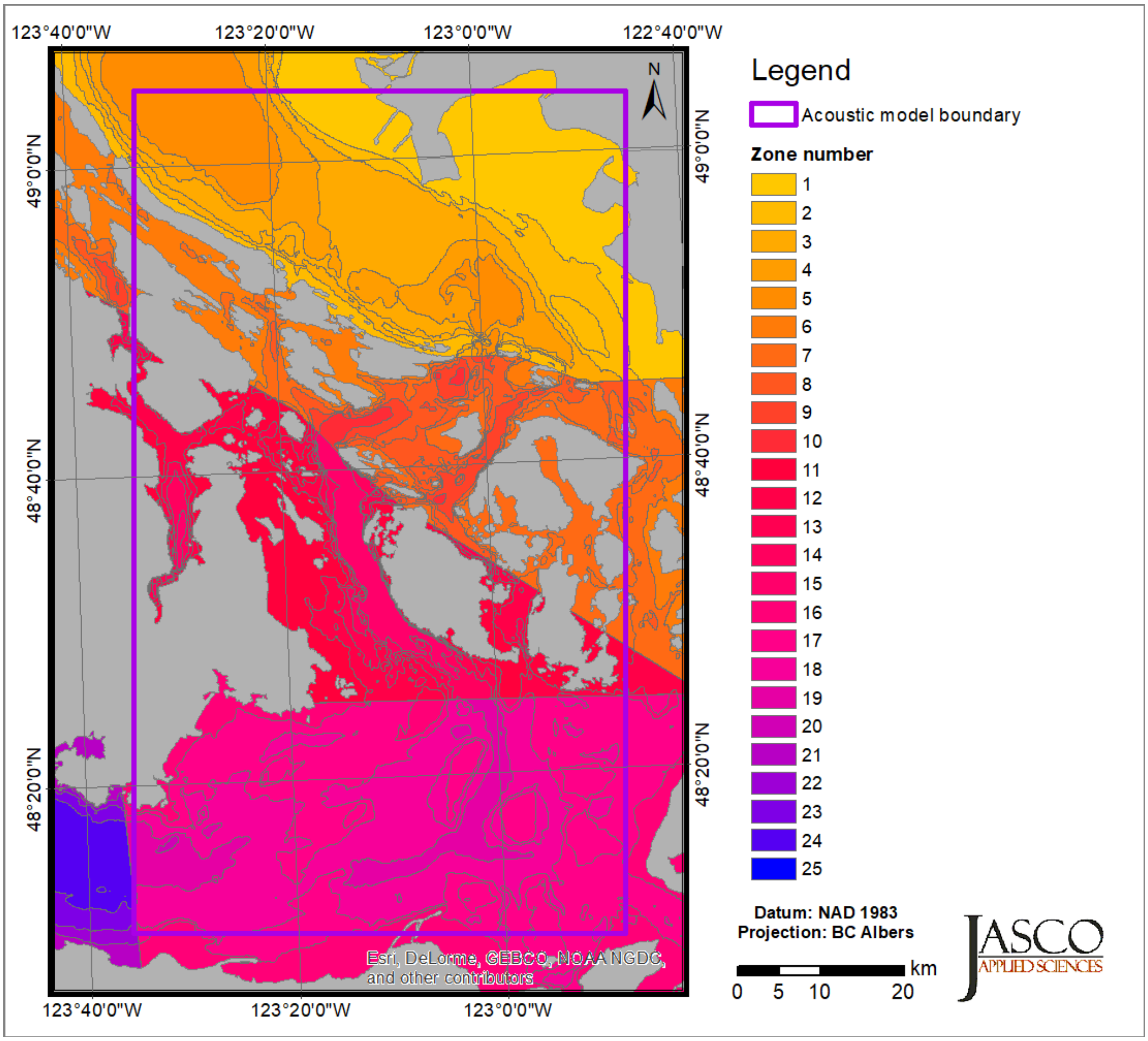

Figure 61. Environmental zones used to compute transmission loss in the modelling area. Divisions between zones are based on water depth, seabed geoacoustics, and sound speed profile conditions.

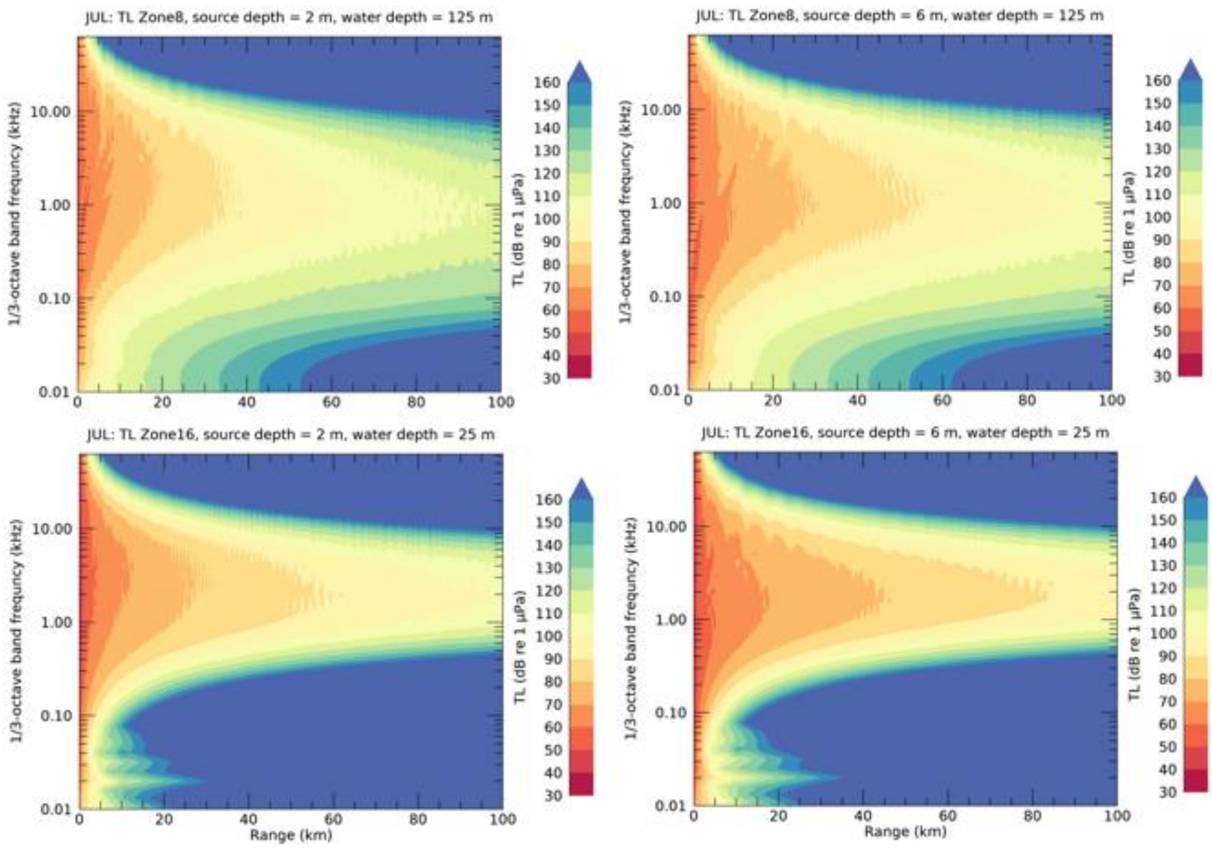

Figure 62. Frequency-dependent sound transmission versus range curves, for zones 8 and 16 (Figure 61), for Haro Strait in July, as calculated by JASCO's Marine Operations Noise Model (MONM). The modelled receiver depth is 10 m, which is near the sea surface because marine mammals spend most of their time in this zone.

2.3. Results

For each model scenario, a set of time-dependent sound pressure level (SPL) grids were generated that represented 1 min snapshots of vessel traffic noise over a 24 h period. The SPL snapshots from the model simulations (examples shown in Figure 63) were rendered as animations to show the time evolution of the vessel traffic noise in the study area. Digital files of SPL from the vessel noise model were used as input to a model of potential behavioural effects of noise on SRKW. Results from the behavioural response and masking study are described in Chapter 3.

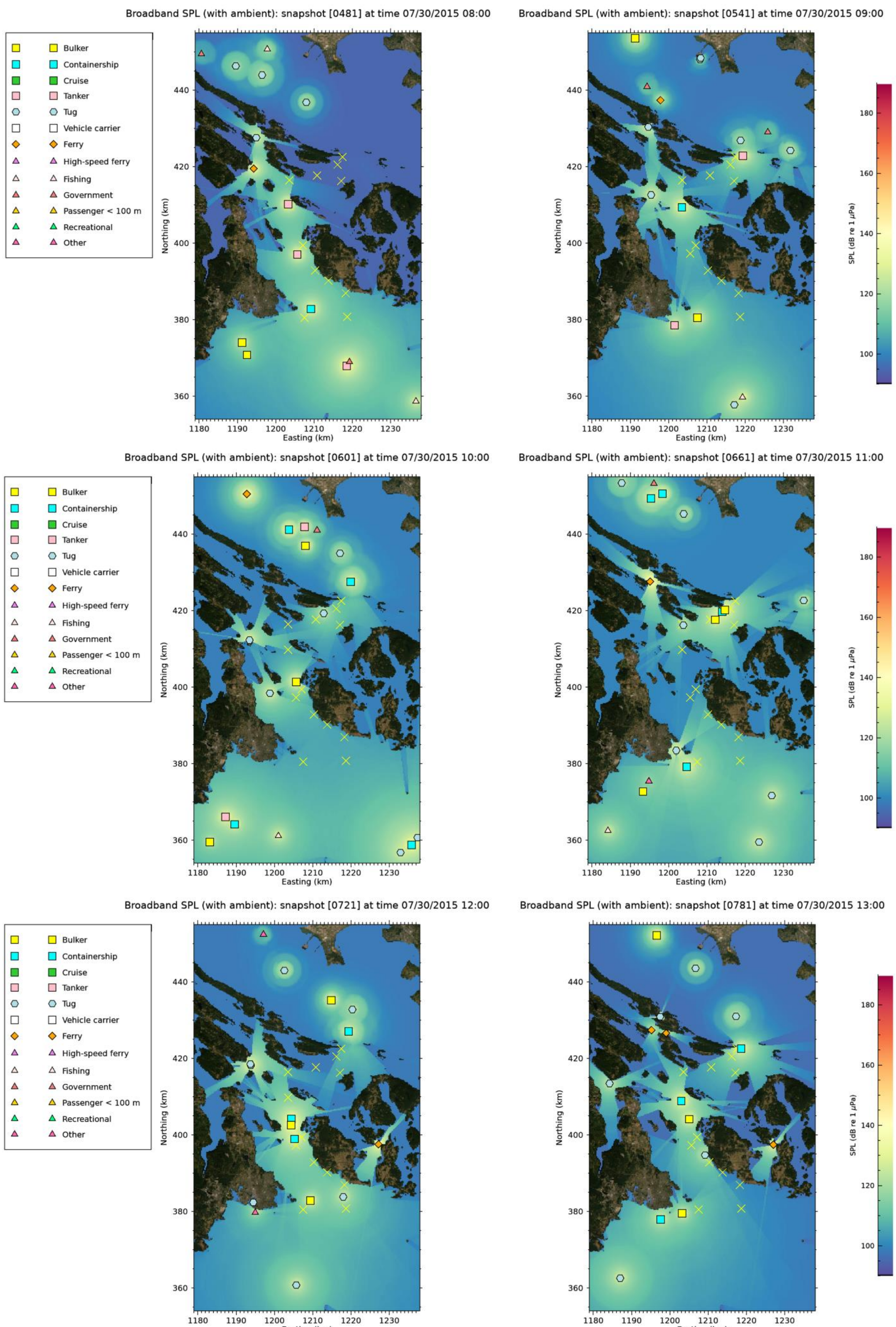

Figure 63. Time snapshots of broadband sound pressure level (SPL; 9 to 70,800 Hz) for the study area for scenario S4 (slowdown, high traffic conditions) from 08:00 to 13:00 UTC (01:00–08:00 PDT) in 1 h increments. Easting and northing are BC Albers projected coordinates.

Thirteen receiver locations were selected to sample the modelled SPL in key SRKW habitat areas within Haro Strait (1–8) and Boundary Pass (9–13) (see Figure 57). Time-dependent sound levels were extracted from the model output at these locations for all model scenarios. The extracted sound levels were plotted versus time, both for broadband noise and for the 50 kHz frequency band, to show how noise levels varied over the 24 h period of simulation (Figure 64). Peaks in the SPL versus time plots correspond to passes of individual vessels by the receiver location. Away from the shipping lanes (i.e., at receiver locations 1–5), levels in the 50 kHz frequency band were seldom above wind-driven ambient because of the strong high-frequency sound attenuation in seawater (the attenuation coefficient in seawater at 50 kHz at this location is estimated to be 13 dB/km in summer based on the formulae of François and Garrison (1982)).

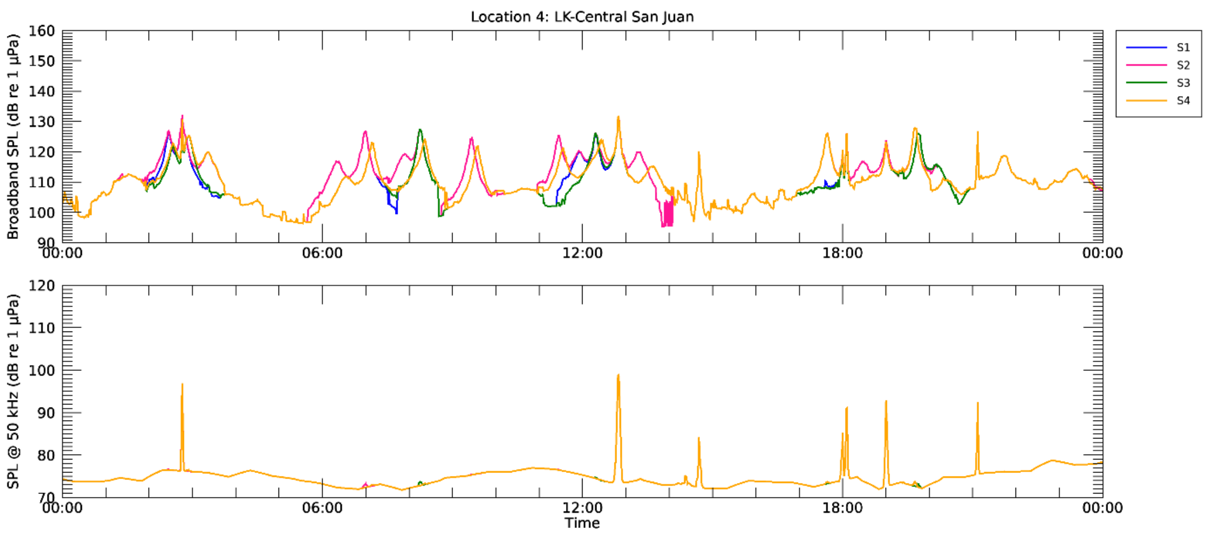

Figure 64. Modelled sound pressure level (SPL) versus time at receiver location 4 (Lime Kiln - Central San Juan). The plot shows both broadband (top) and 50 kHz 1/3-octave band (bottom) sound levels for the four model scenarios.

To interpret the time-varying model outputs, a statistical analysis was applied to the modelled noise levels. Figure 65 and 66 compare cumulative distribution function (CDF) curves for the 2020 baseline and slowdown periods in Haro Strait and Boundary Pass, respectively. Sampled sound levels were used to generate CDFs at each location, showing the percent of time that modelled sound levels were below a specified threshold level. The following example illustrates how to interpret the CDF curves. At location 4 (near Lime Kiln), the SPL was 109.1 dB at the 50th percentile level for scenario S1; this means that, 50% of the time, baseline sound levels were at or below 109.1 dB near Lime Kiln, under average traffic conditions.

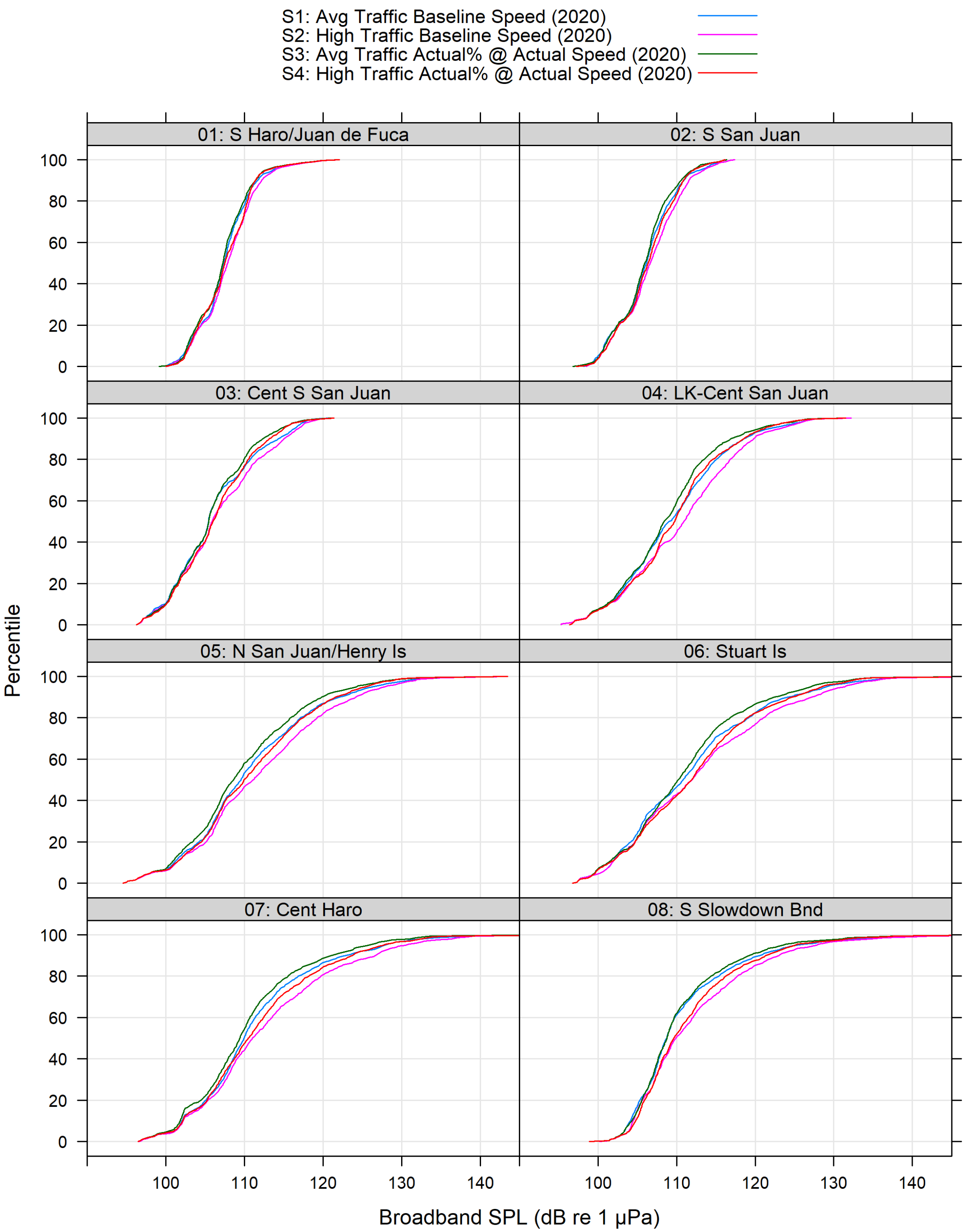

Figure 65. Cumulative distribution function (CDF) curves of time-dependent sound pressure level (SPL) for scenarios S1 to S4 for Haro Strait receiver locations.These charts show the percent of time that SPL falls below a specified decibel level for a particular receiver location and model scenario.

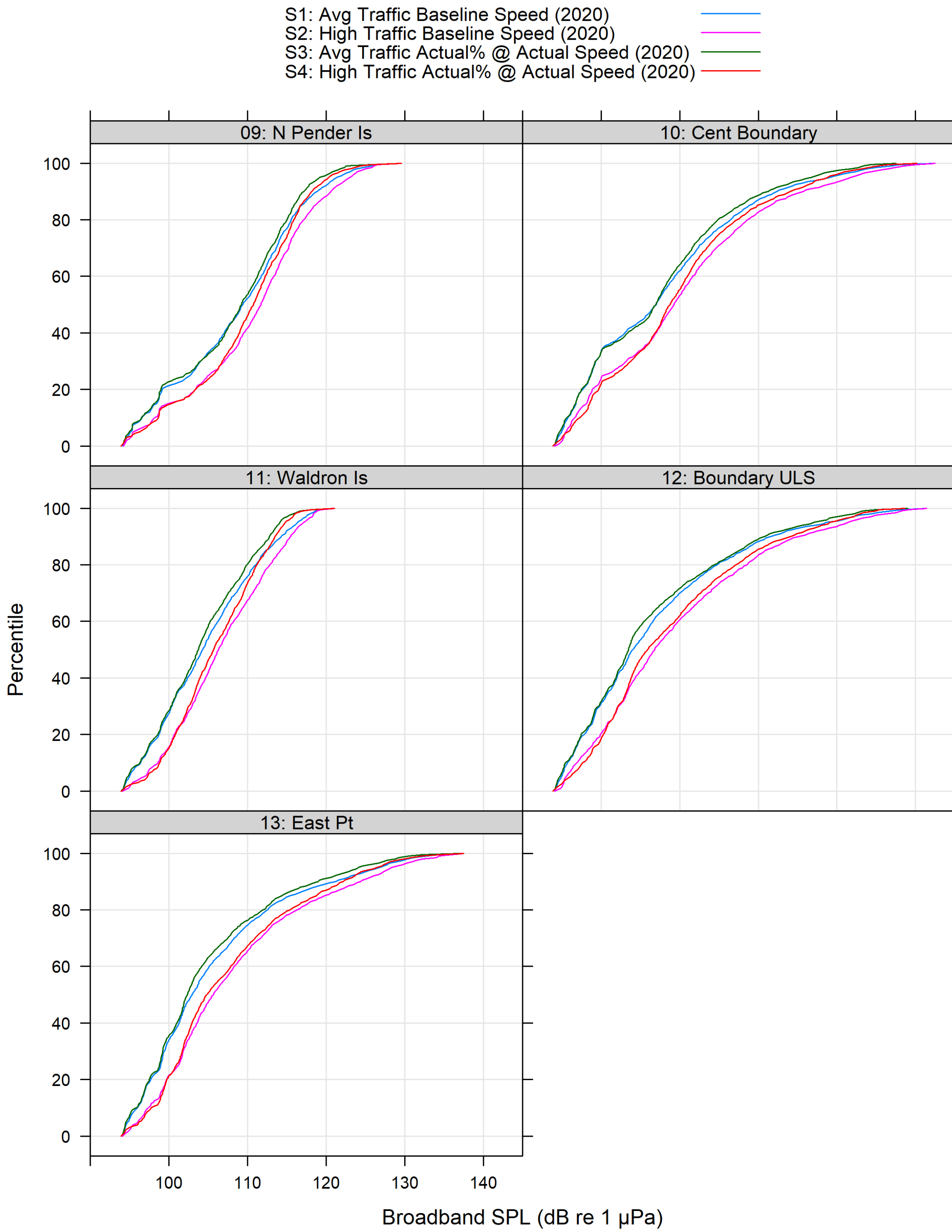

Figure 66. Cumulative distribution function (CDF) curves of time-dependent sound pressure level (SPL) for scenarios S1 to S4 for Boundary Pass receivers.These charts show the percent of time that SPL falls below a specified decibel level for a particular receiver location and model scenario.

2.4. Discussion

2.4.1. Slowdown Differences

Differences between the CDFs were used to calculate how slowdown participation affected noise levels in the study area (Figures 67 and 68). All scenarios were based on the same baseline vessel data, so the differences were attributable to changes associated with vessel slowdowns in Haro Strait and Boundary Pass. For example, the difference in CDFs between scenarios S1 and S3 at location 4 (near Lime Kiln) was −0.63 dB at the 50th percentile level, meaning the modelled effect of slowdown participation during average traffic conditions was to reduce the median (i.e., 50th percentile) noise level by 0.63 dB near Lime Kiln. One potential downside of the slowdown mitigation is that, while the intensity of vessel noise emissions is reduced, the duration of noise exposure is increased because of longer transit times. This is evident in the CDF differences (see Figure 67) where noise levels at the lowest exposure levels (i.e., low percentiles) were predicted to either decrease by a small amount or, in some instances, increase relative to the current baseline. For example, the lowest 5th percentile of noise levels at Lime Kiln (location 4), were predicted to increase by 0.05 dB under average traffic conditions and 0.08 dB under high traffic conditions. However, such increases were generally limited to times when the modelled SPL was below 105 dB re 1 μPa.

The greatest changes in medial sound levels were predicted to be in Haro Strait on the west side of San Juan Island (locations 4 and 5) and on the traffic lanes inside the slowdown zone (location 7). The modelled effect of the slowdowns was generally greater in Haro Strait than in Boundary Pass. At all locations, the predicted changes were generally greatest for the higher percentiles (75%, 95%) and smallest for the lower percentiles noise levels (5%, 25%). This reflects the fact that changes in noise levels were most strongly affected by the slowdowns during those times when piloted vessels were present near the receivers.

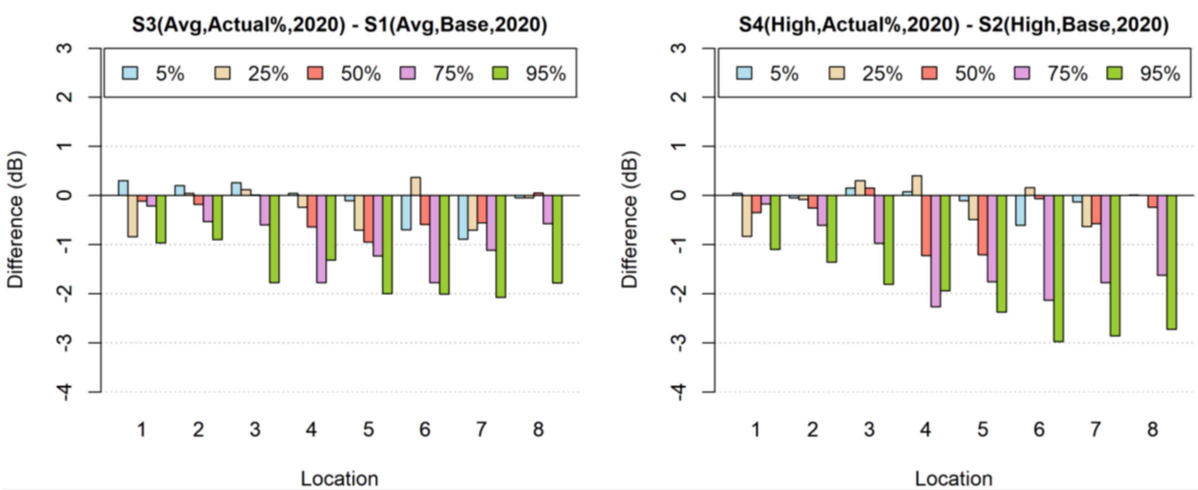

Figure 67. Haro Strait: Predictions of changes in sound levels at the receiver locations due to the 2020 slowdown. The reductions were calculated by subtracting the modelled cumulative distribution functions (CDFs) curves for the different model scenarios at the 5th, 25th, 50th (median), 75th, and 95th percentile levels. The *n*th percentile level is the sound level that is exceeded (100 – *n*) percent of the time (e.g., the 95% level is exceeded 5% of the time). A negative change corresponds to a reduction in SPL due to vessel slowdowns.

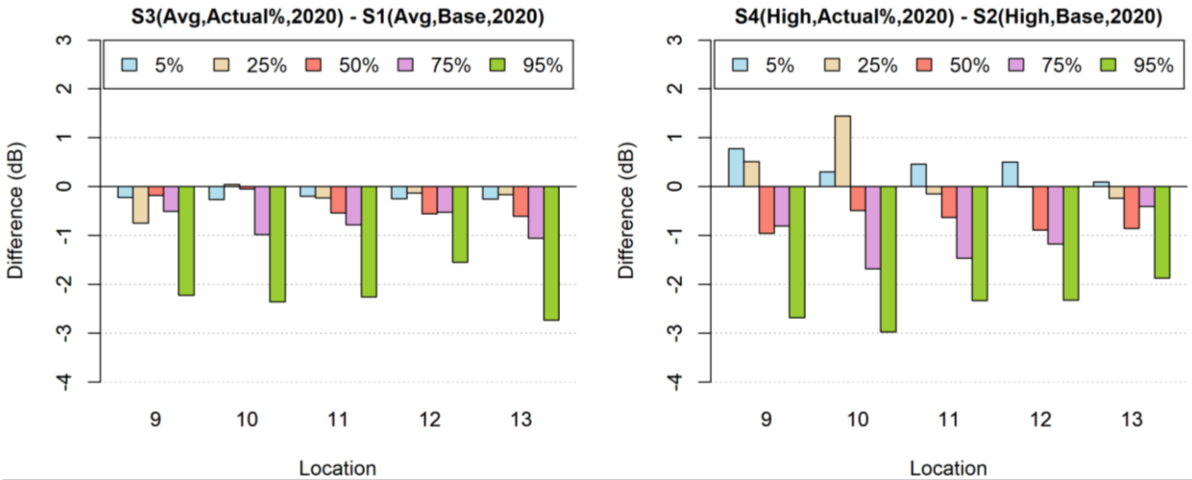

Figure 68. Boundary Pass: Predictions of changes in sound levels at the receiver locations due to the 2020 slowdown. The reductions were calculated by subtracting the modelled cumulative distribution functions (CDFs) curves for the different model scenarios at the 5th, 25th, 50th (median), 75th, and 95th percentile levels. The *n*th percentile level is the sound level that is exceeded (100 – *n*) percent of the time (e.g., the 95% level is exceeded 5% of the time). A negative change corresponds to a reduction in SPL due to vessel slowdowns.

2.4.2. Comparison to Previous Years

Modelled sound levels were very similar between the 2020 and 2019, as there were only small differences in assumed vessel speeds and participation rates between the two years. Speeds of participating vessels were nearly identical in the 2019 and 2020 models (less than 0.2 kn difference in all categories). Vessel counts and participation rates were unchanged for the average-traffic scenarios (S1 and S3) and only slightly different for the high-traffic scenarios (S2 and S4). The latter scenarios had one fewer vessel (no cruise ship) and one more participant (a bulker) in 2020. In all other respects, the 2019 and 2020 model scenarios were identical.

As a result, the modelled SPL reductions were nearly identical between the two years (Figures 69 and 70). The median (50th percentile) SPL reductions were marginally greater in 2020 than 2019 (by <0.04 dB) for the average traffic scenarios (S1 and S3). For the high-traffic scenarios (S2 and S4), median SPL reductions were greater in 2020 compared to 2019, by values of 0.26 dB or less. Notably, removing a cruise ship from the high-traffic scenarios did not significantly reduce 2020 sound levels. Thus, while the participation rates were slightly higher during 2020, the modelled slowdown reductions were largely unchanged from 2019.

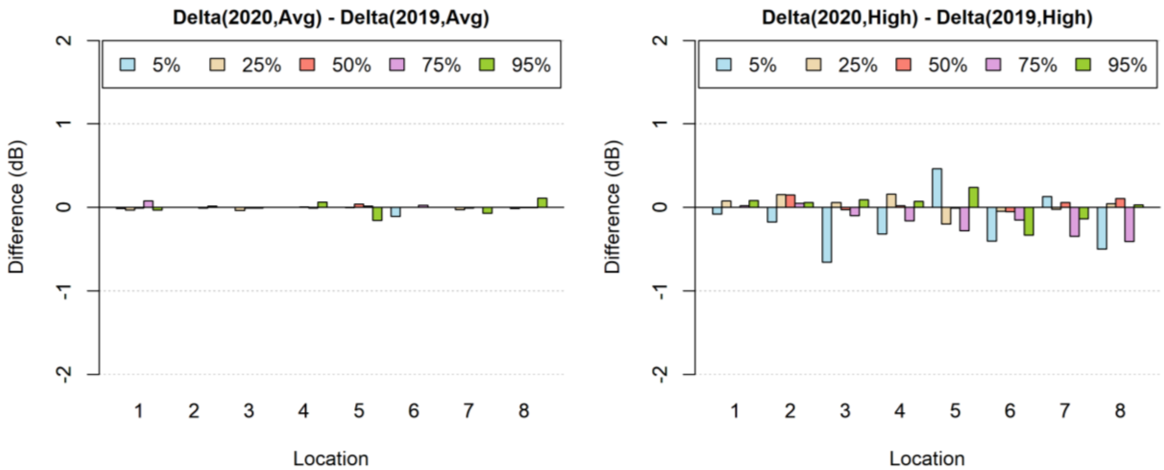

Figure 69. Differences between modelled sound level reductions (i.e., Deltas) between 2020 and 2019 at the receiver locations in Haro Strait. Differences in the reductions were calculated by subtracting differences in the modelled cumulative distribution functions (CDFs) (baseline – slowdown) at the 5th, 25th, 50th (median), 75th, and 95th percentile levels. The *n*th percentile level is the sound level that is exceeded (100 – *n*) percent of the time (e.g., the 95% level is exceeded 5% of the time). A negative difference indicates that the SPL reduction was greater in 2020 than in 2019, at the specified percentile level.

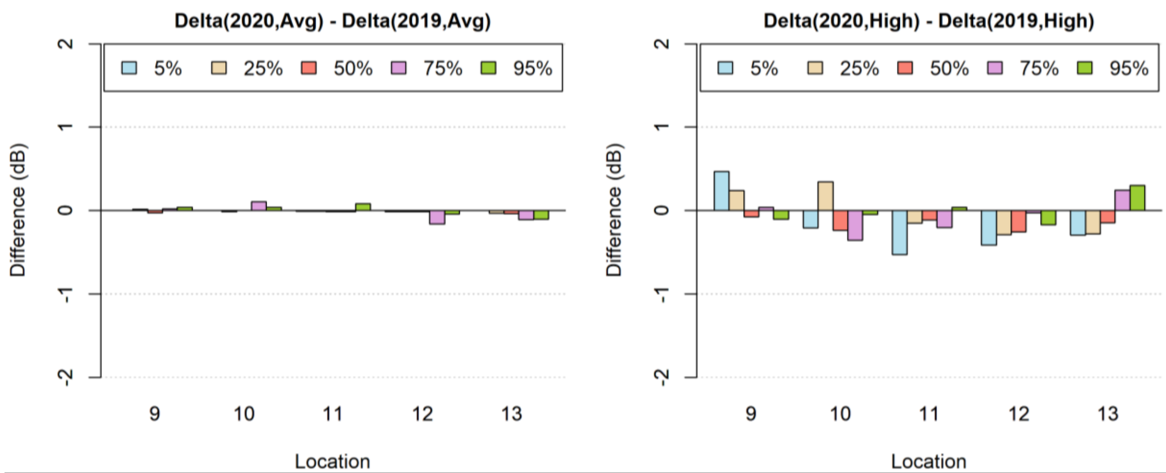

Figure 70. Differences between modelled sound level reductions (i.e., Deltas) between 2020 and 2019 at the receiver locations in Boundary Pass. Differences in the reductions were calculated by subtracting differences in the modelled cumulative distribution functions (CDFs) (baseline – slowdown) at the 5th, 25th, 50th (median), 75th, and 95th percentile levels. The *n*th percentile level is the sound level that is exceeded (100 – *n*) percent of the time (e.g., the 95% level is exceeded 5% of the time). A negative difference indicates that the SPL reduction was greater in 2020 than in 2019, at the specified percentile level.

2.4.3. Assumptions and Sources of Uncertainty

The historical Marine Traffic database may underestimate marine traffic density and consequently noise at some locations inside the study area, due to lack of positional information for small vessels such as ecotourism and recreational boats that do not transmit their position on AIS. Source levels of small boats are relatively low, so errors introduced by neglecting their contribution to underwater noise is expected to be geographically limited to specific areas with high concentration of small boats.

Changes to small boat traffic and ferry traffic due to the pandemic are difficult to accurately quantify and are not reflected in the noise model outputs provided herein. This adds an element of additional uncertainty to the 2020 results, while maintaining the ability to quantify the underwater noise benefits of the large commercial vessel slowdown.

This study considered only sound contributions from large, AIS-enabled vessels and wind-driven ambient noise. Other potential sources of underwater noise such as biological sources, sonars, seismic activity, terminal operations, and aircraft were not included.

2.5. Conclusion

- Results from the vessel noise modelling showed that implementing a slowdown zone in Haro Strait and Boundary Pass reduced noise levels in key SRKW habitat. This study predicted that median SPL near Lime Kiln (receiver location 4) were decreased by 0.63 dB during average traffic conditions and by 1.23 dB during high-traffic conditions over a 24 h period.
- As in previous years, the greatest reductions in noise levels were achieved near the west side of San Juan Island (locations 4 and 5). For all scenarios, greater reductions were generally observed in Haro Strait than in Boundary Pass.
- At some locations, the slowdowns also increased minimum noise levels by a small amount, due to overall increases in vessel transit time. These increases, however, were limited to periods when modelled noise levels were below 105 dB re 1 µPa. Thus, the modelling predicted that implementing a slowdown zone would reduce noise levels in Haro Strait and Boundary Pass most of the time.
- Modelled sound level reductions in Haro Strait and Boundary Pass in 2020 were very similar to 2019, due to similar vessel speeds and voluntary participation rates between the two years. The absence of cruise ships in 2020 did not appear to have a significant affect on the modelled sound levels, due to their relatively low noise emissions.

Appendix A. Modelled Sound Levels

Figures 71 to 83 show modelled SPL (top = broadband, bottom = 1/3-octave-band @ 50 kHz) versus time for scenarios S1 to S4 at each of the eight receiver locations in the study area (see Figure 57 for a map of the receiver locations).

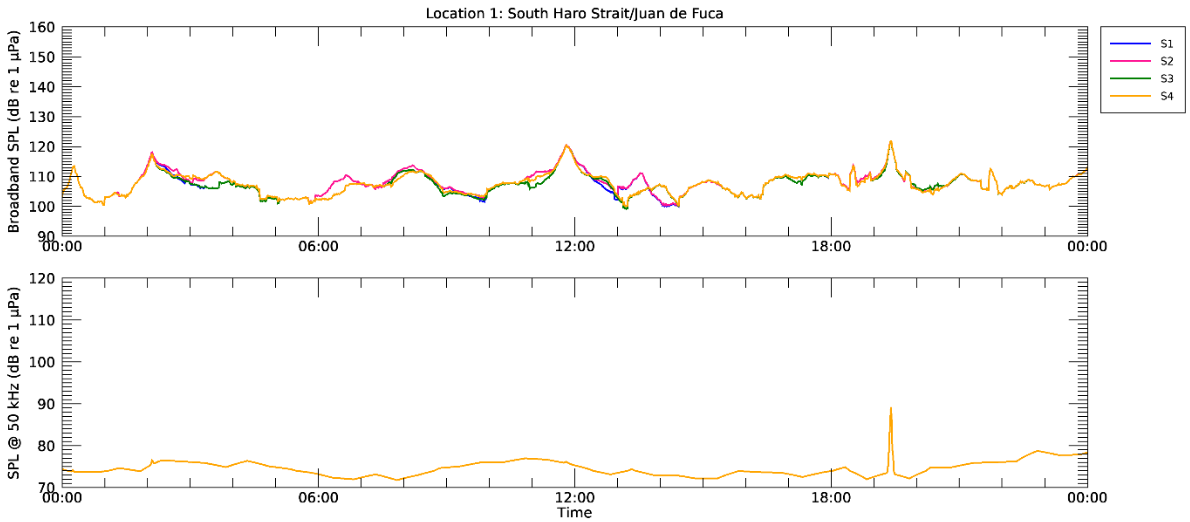

Figure 71. Modelled sound pressure level (SPL) versus time at receiver location 1. The plot shows both broadband (top) and 50 kHz 1/3-octave band (bottom) sound levels for the four model scenarios.

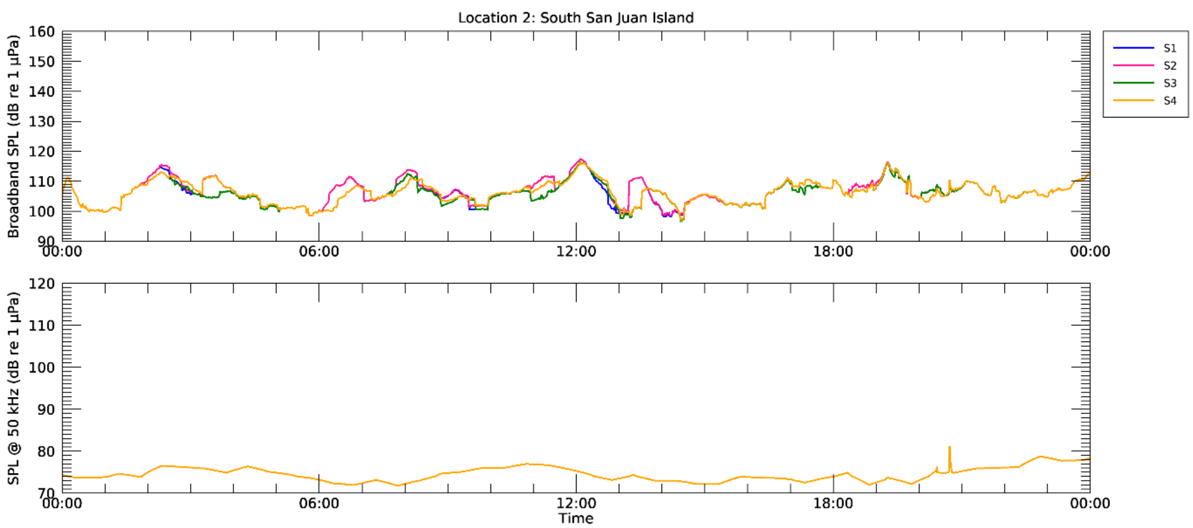

Figure 72. Modelled sound pressure level (SPL) versus time at receiver location 2. The plot shows both broadband (top) and 50 kHz 1/3-octave band (bottom) sound levels for the four model scenarios.

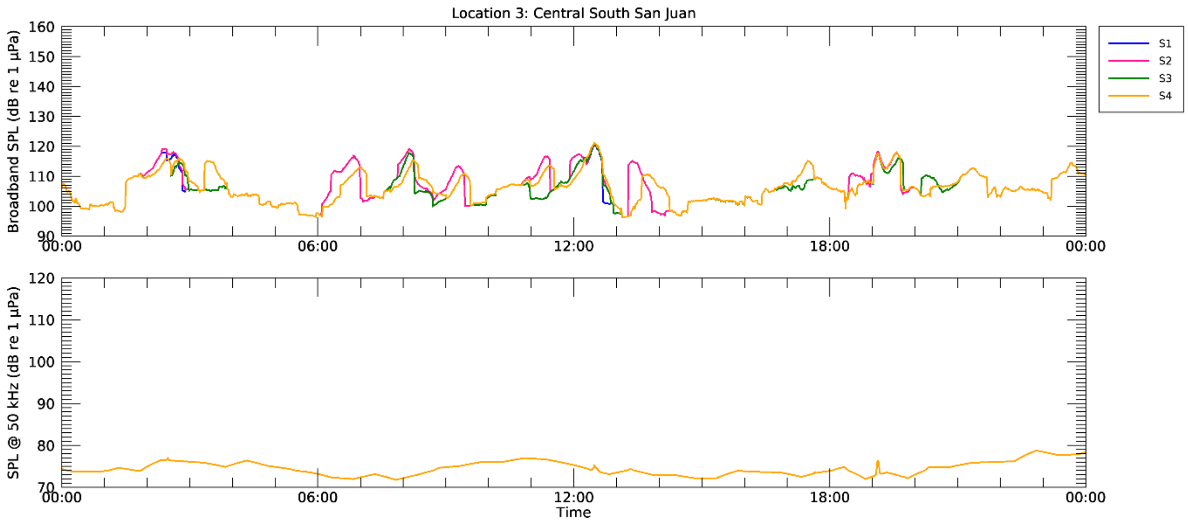

Figure 73. Modelled sound pressure level (SPL)versus time at receiver location 3. The plot shows both broadband (top) and 50 kHz 1/3-octave band (bottom) sound levels for the four model scenarios.

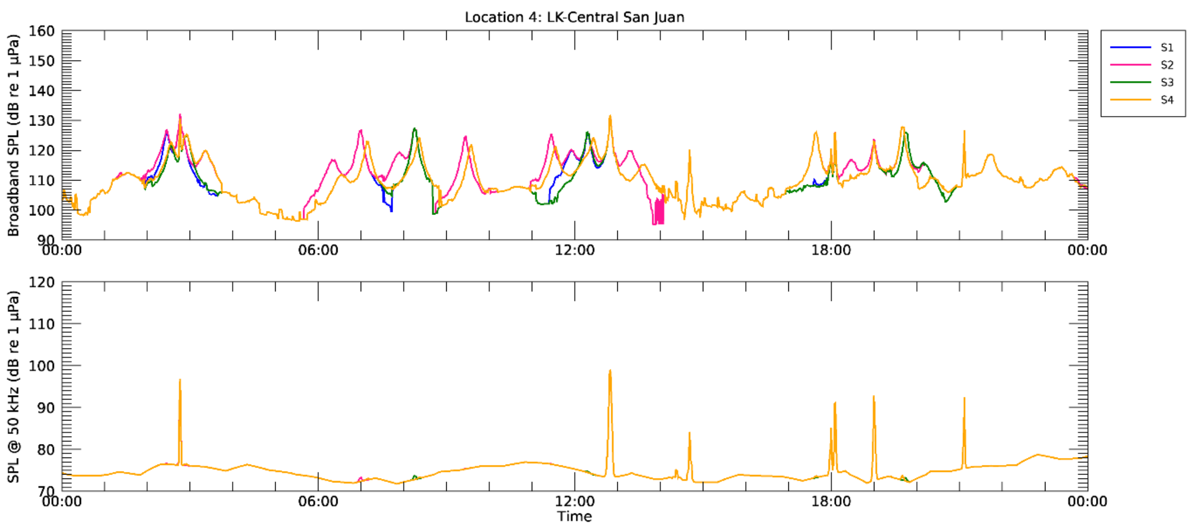

Figure 74. Modelled sound pressure level (SPL) versus time at receiver location 4. The plot shows both broadband (top) and 50 kHz 1/3-octave band (bottom) sound levels for the four model scenarios.

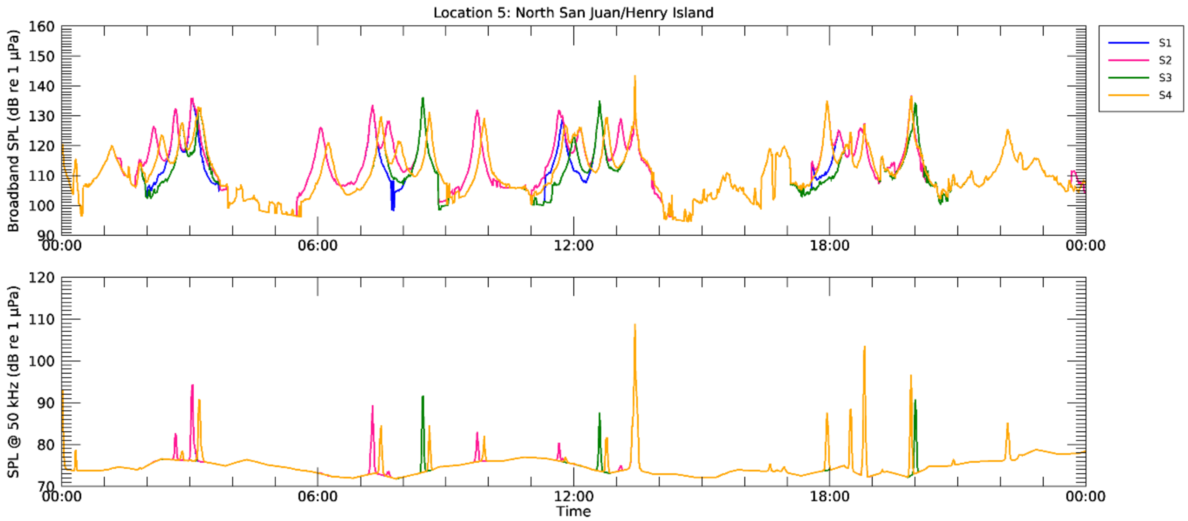

Figure 75. Modelled sound pressure level (SPL) versus time at receiver location 5. The plot shows both broadband (top) and 50 kHz 1/3-octave band (bottom) sound levels for the four model scenarios.

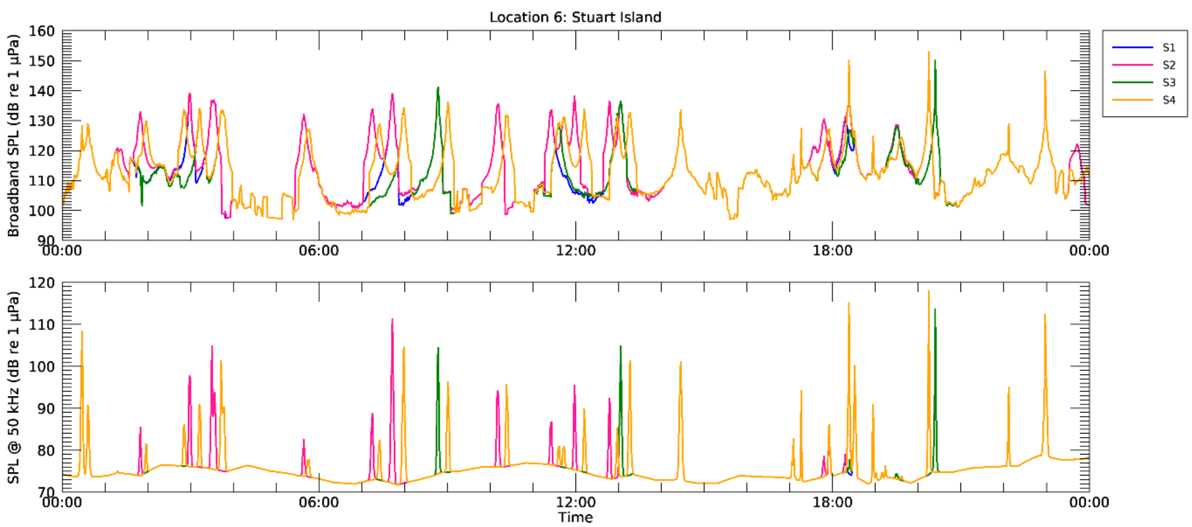

Figure 76. Modelled sound pressure level (SPL) versus time at receiver location 6. The plot shows both broadband (top) and 50 kHz 1/3-octave band (bottom) sound levels for the four model scenarios.

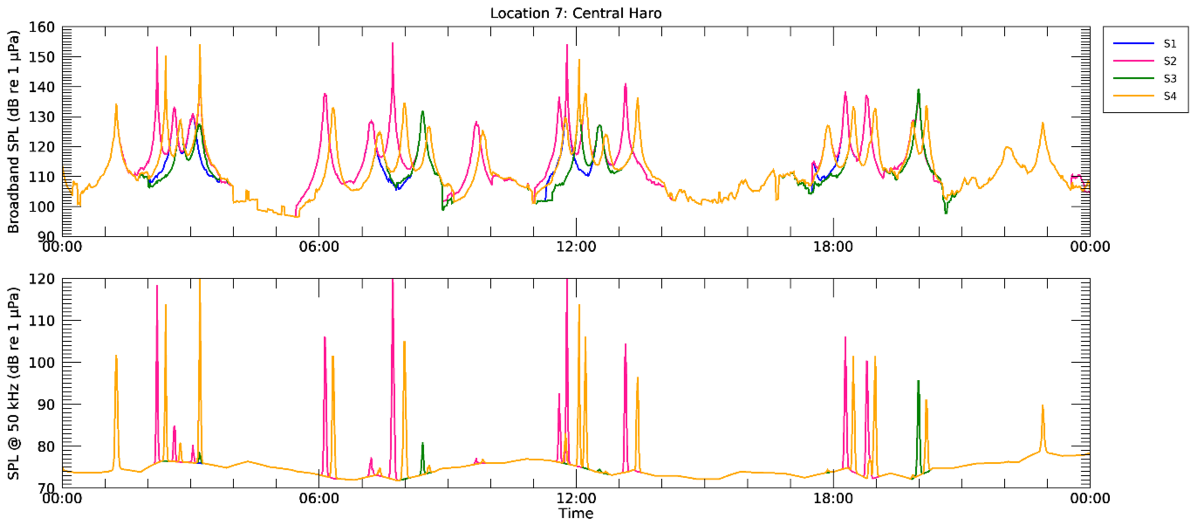

Figure 77. Modelled sound pressure level (SPL) versus time at receiver location 7. The plot shows both broadband (top) and 50 kHz 1/3-octave band (bottom) sound levels for the four model scenarios.

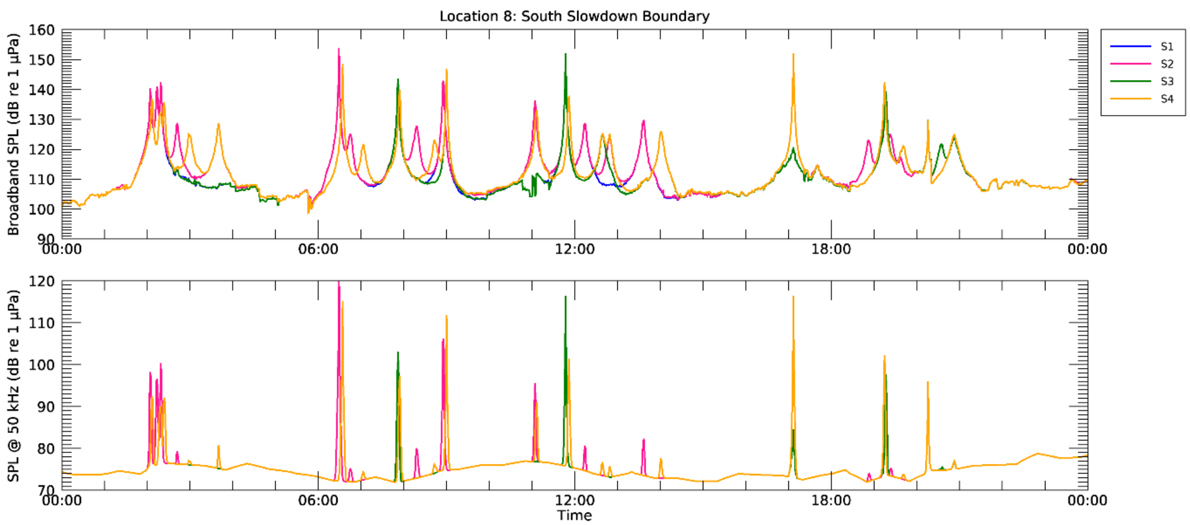

Figure 78. Modelled sound pressure level (SPL) versus time at receiver location 8. The plot shows both broadband (top) and 50 kHz 1/3-octave band (bottom) sound levels for the four model scenarios.

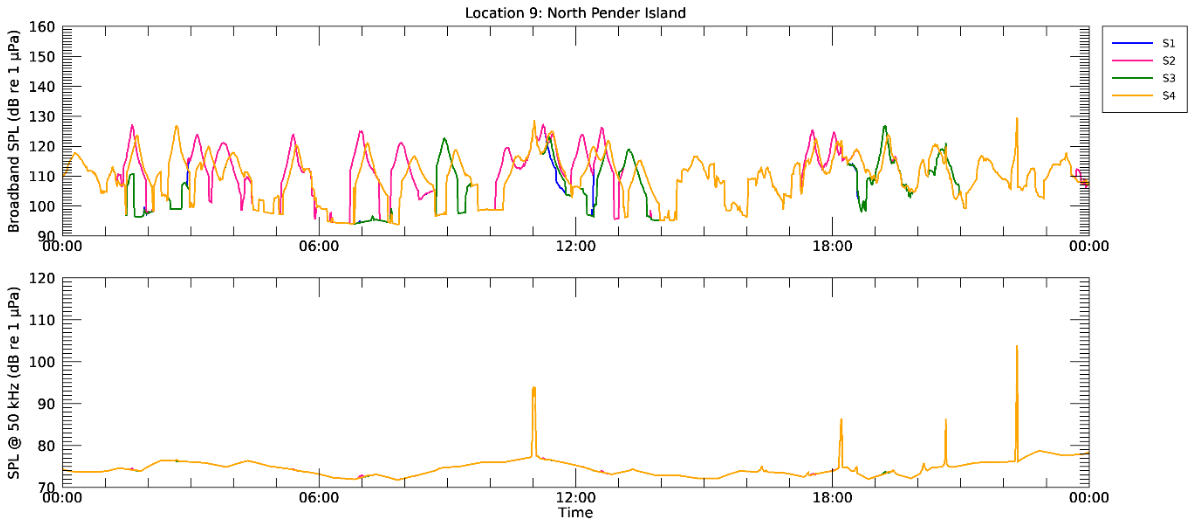

Figure 79Modelled sound pressure level (SPL) versus time at receiver location 9. The plot shows both broadband (top) and 50 kHz 1/3-octave band (bottom) sound levels for the four model scenarios.

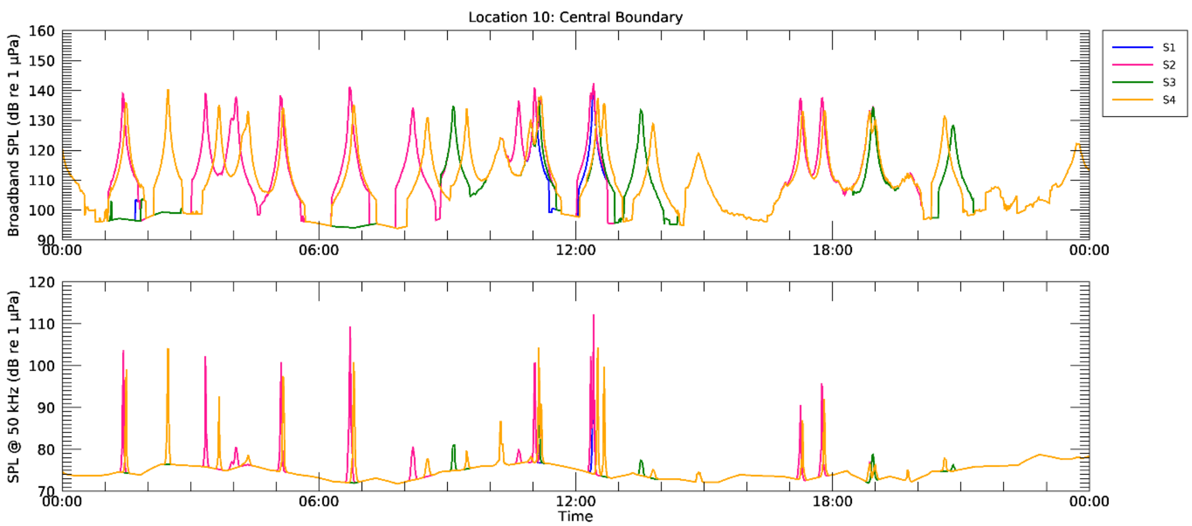

Figure 80. Modelled sound pressure level (SPL) versus time at receiver location 10. The plot shows both broadband (top) and 50 kHz 1/3-octave band (bottom) sound levels for the four model scenarios.

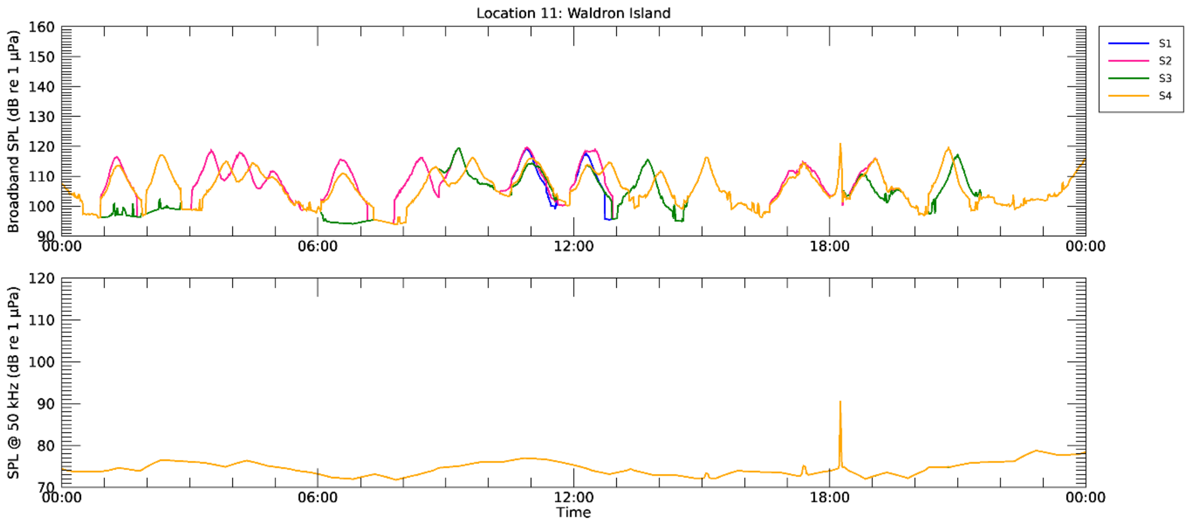

Figure 81. Modelled sound pressure level (SPL) versus time at receiver location 11. The plot shows both broadband (top) and 50 kHz 1/3-octave band (bottom) sound levels for the four model scenarios.

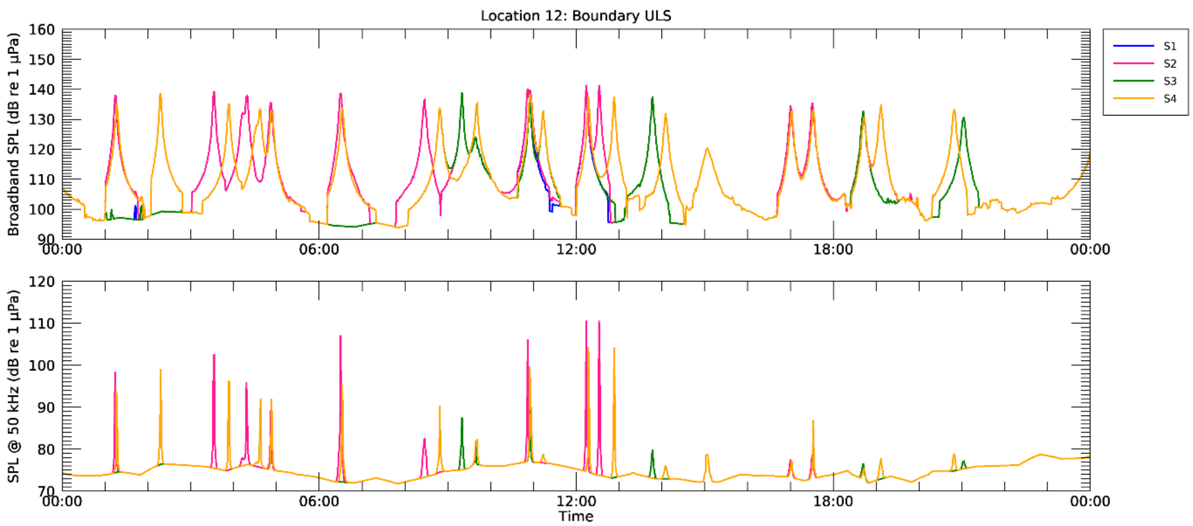

Figure 82. Modelled sound pressure level (SPL) versus time at receiver location 12. The plot shows both broadband (top) and 50 kHz 1/3-octave band (bottom) sound levels for the four model scenarios.

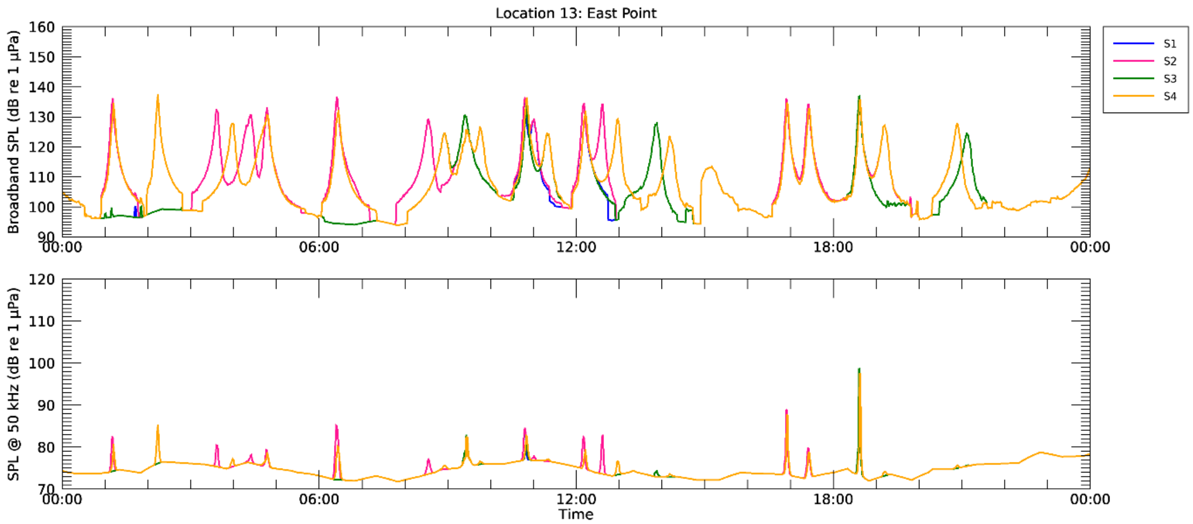

Figure 83. Modelled sound pressure level (SPL) versus time at receiver location 13. The plot shows both broadband (top) and 50 kHz 1/3-octave band (bottom) sound levels for the four model scenarios.

Appendix B. Tabulated Slowdown Differences

Table 27. The differences in modelled sound pressure level (SPL) at each receiver location in the study area (see Figure 57) for selected pairs of scenarios under different traffic conditions and rates of slowdown participation. The differences are calculated from the decibel difference of the CDF curves at the 5th, 25th, 50th, 75th, and 95th percentile levels, where the *n*th percentile level is the sound level that is exceeded (100 – *n*) percent of the time (e.g., the 95th percentile SPL is exceeded 5% of the time).

Location	SPL difference at *n*th percentile level (dB)				
	5th	25th	50th	75th	95th
Slowdown differences: Average traffic actual% participation at actual speeds (S3 – S1)					
1	0.304	−0.837	−0.111	−0.21	−0.961
2	0.207	0.046	−0.182	−0.53	−0.9
3	0.264	0.12	0.009	−0.594	−1.774
4	0.049	−0.237	−0.634	−1.77	−1.309
5	−0.102	−0.708	−0.945	−1.227	−1.992
6	−0.7	0.369	−0.586	−1.775	−2.002
7	−0.885	−0.703	−0.553	−1.114	−2.071
8	−0.046	−0.043	0.057	−0.572	−1.778
9	−0.224	−0.746	−0.176	−0.503	−2.22
10	−0.26	0.043	−0.05	−0.982	−2.354
11	−0.194	−0.226	−0.537	−0.777	−2.252
12	−0.248	−0.131	−0.558	−0.525	−1.545
13	−0.256	−0.159	−0.603	−1.053	−2.73
Slowdown differences: High traffic actual% participation at actual speeds (S4 – S2)					
1	0.046	−0.828	−0.35	−0.172	−1.094
2	−0.044	−0.077	−0.258	−0.608	−1.357
3	0.151	0.304	0.15	−0.971	−1.804
4	0.083	0.408	−1.225	−2.263	−1.938
5	−0.102	−0.484	−1.204	−1.753	−2.373
6	−0.607	0.163	−0.06	−2.128	−2.972
7	−0.132	−0.63	−0.571	−1.767	−2.851
8	0.013	0.002	−0.234	−1.62	−2.719
9	0.783	0.513	−0.955	−0.806	−2.676
10	0.302	1.445	−0.487	−1.678	−2.975
11	0.463	−0.146	−0.633	−1.46	−2.333
12	0.508	−0.001	−0.891	−1.167	−2.32
13	0.096	−0.234	−0.851	−0.404	−1.868

Chapter 3. Modelling Behavioural Responses and Masking from Vessel Noise Exposure

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3.1. Introduction

The Vancouver Fraser Port Authority-led Enhancing Cetacean Habitat and Observation (ECHO) Program has been managing a seasonal voluntary vessel slowdown (the Slowdown) of large commercial vessel traffic in key foraging habitat for the Southern Resident killer whale (SRKW) since 2017. In 2017 and 2018, the slowdown area was limited to Haro Strait, and expanded to include Boundary Pass in 2019 and 2020.

Following methods described in Joy et al. (2019), we used the Southern Resident killer whale (SRKW)-noise exposure model to predict how Slowdown related reductions in noise levels in Haro Strait and Boundary Pass might affect SRKW behaviour and foraging. This spatially explicit probabilistic model aims to accumulate how many minutes each whale is inhibited or disrupted from its ability to forage as a result of high received noise levels; either from an associated change in behavioural state (i.e., a behavioural response, or BR, such as switching from foraging to traveling, e.g., Lusseau et al. 2009), or the degree of masking of echolocation clicks from high frequency noise. The number of SRKW behavioural responses (BRs) and degree of residual echolocation click masking combines to create a relative cumulative effects metric termed ‘potential lost foraging time’. ‘Potential lost foraging time’ can be integrated across time, or averaged by day for each SKRW, and then compared between scenarios to better understand the potential benefits of slowing vessels on SRKW.

This report presents a comparison of two baseline simulation scenarios (average and high traffic days), and two scenarios that mimic the 2020 Slowdown conditions across the 122-day period (2 Jul to 31 Oct). An important input into the SRKW-noise exposure model is the SRKW density layer that parameterizes when and where whales are placed in the model space. Given changes in SRKW residency patterns in the model area, the model runs (baseline average traffic, baseline high traffic, slowdown average traffic, slowdown high traffic) were completed using SRKW density estimate using sightings data from 2002–2017 (Wood et al. 2019). The goal of this study was quantifying the efficacy of the Slowdown on reducing SRKW potential lost foraging time.

3.2. Methods

The SRKW-noise exposure model requires several inputs and assumptions. This section outlines these inputs (with more details in Joy et al. 2019) by examining 1) the model area, 2) cumulative vessel noise modelling, 3) SRKW density, 4) the biological transfer functions (i.e., dose-response curve and echolocation click masking model), and 5) the scenarios captured by the modelled scenarios. We explored different combinations of assumptions and model inputs, to create a set of SRKW-noise exposure models that characterize two regional shipping scenarios (Table 28) for a total of four scenarios over the 122 day Slowdown between 2 Jul and 31 Oct 2020. In this chapter we build our scenarios around the 73 SRKW alive and counted by the Center for Whale Research at the time of model creation (J-pod = 22, K-pod = 17, L-pod = 34). However, results are provided on a per whale basis so that total estimates could be scaled to changing population size.

3.2.1. Model Area

The 2020 Slowdown had the same spatial extent as the 2019 Slowdown. These include Haro Strait and Boundary Pass (Figure 84).

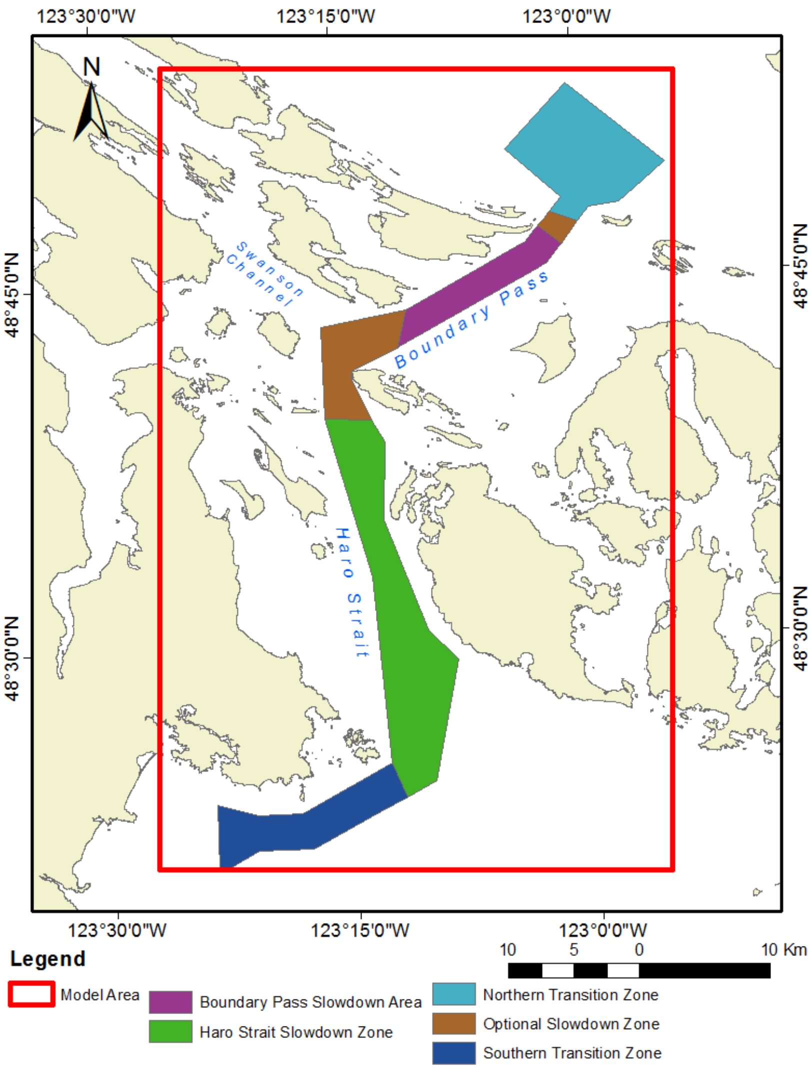

Figure 84. Map of the SRKW-noise exposure Model Area and the ECHO 2020 Slowdown zones.

3.2.2. Cumulative Vessel Noise Modelling

The cumulative vessel noise modelling was conducted by JASCO within the model area at a spatial resolution of 200 m by 200 m and a temporal resolution of 1-minute over a 24-hour period. Noise model outputs were converted to 5-minute periods by taking the maximum value in each 5-minute period and these were used as input into the SRKW-noise exposure model. Details pertaining to the vessel noise model are provided in Chapter 2.

3.2.3. SRKW Density

Voluntary SRKW sightings were provided by the BC Cetacean Sightings Network (BCCSN) and The Whale Museum in Washington State. These were effort corrected to generate relative SRKW density estimates following the methods in Olson et al. (2018). SRKW density was calculated using sightings data from 2002–2017 (Wood et al. 2019), as was used in the 2019 Slowdown analysis and reporting (Figure 85). Evaluation of the 2017/2018 Slowdown was conducted using a previous version of the SRKW density (Joy et al. 2020).

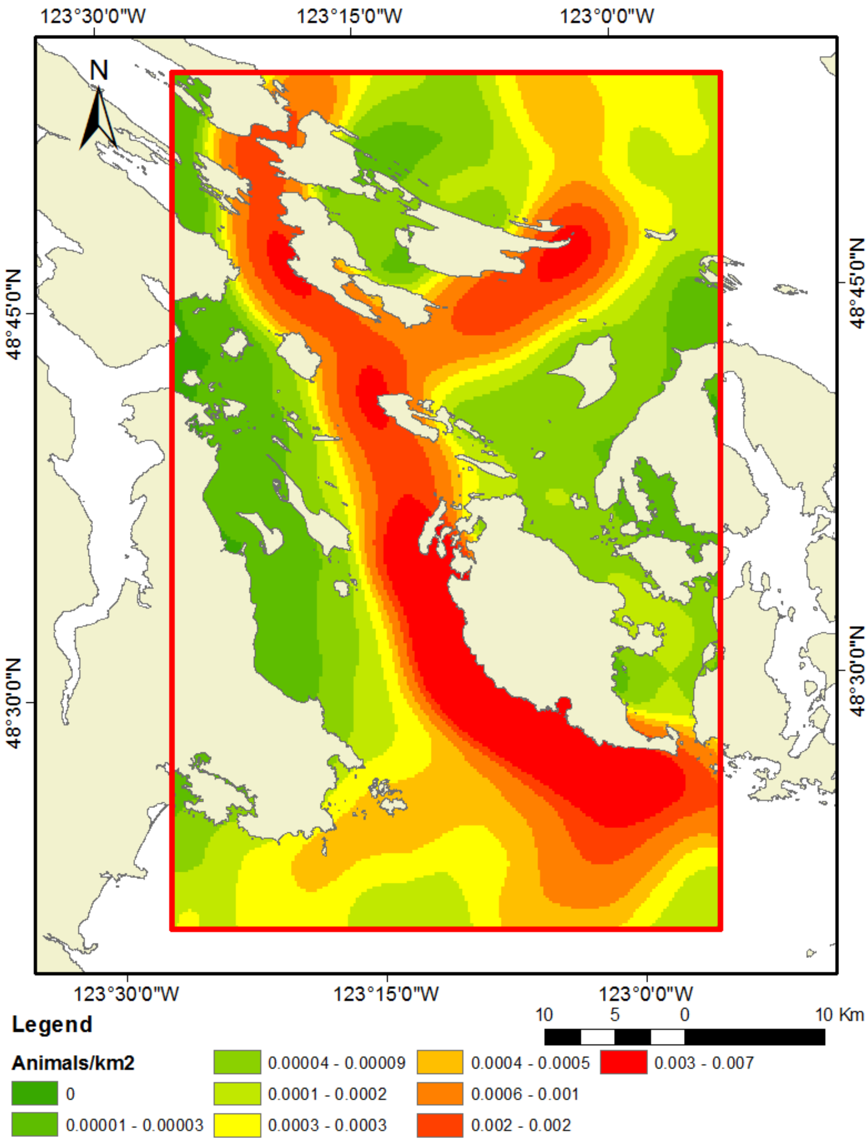

Figure 85. SRKW density per unit effort based on effort corrected sightings 2002–2017 in the broader regional area (Wood et al. 2019), where red denotes higher and green lower density probabilities. The red box depicts the extent of the SRKW-noise exposure model. This SRKW density layer is used in the SRKW-noise exposure model to determine occupancy of pods within the SRKW-noise exposure model.

3.2.4. Biological Transfer Functions

The SRKW-noise model accumulates over time, for each whale, the number of minutes the whale is inhibited or disrupted from its ability to forage due to received noise levels; either from a broadband noise induced behavioural state change or the degree of masking of echolocation clicks from high frequency noise bands. The severity of a single BR (i.e., low vs moderate) determines the length of time the individual whale is disrupted from foraging. The same dose-response curves as used in previous Slowdowns were used (Joy et al. 2019); (Figure 86).

The intensity of the high-frequency (50 kHz Power Spectral Density band) sound levels determines the degree of residual high frequency masking implied by a proportional reduction from 250 m in the distance that echolocation is fully inhibited (Au et al. 2004, Joy et al. 2019). The same residual echolocation click-masking model as used in previous Slowdowns was used (Joy et al. 2019). These BRs and residual masking minutes are subsequently converted into a relative effect metric termed ‘potential lost foraging time’. The amount of ‘potential lost foraging time’ can then be integrated or summarized as a cumulative effect over time and/or over a spatial area and compared between scenarios. With a comparison of the cumulative ‘potential lost foraging time’ between the 4 scenarios it is possible to better understand the potential benefits of slowing vessels on SRKW foraging. All model output metrics in this report are reported on a “per whale” basis which controls for changes in population size. For each scenario, 95% confidence intervals are derived using re-sampling of 100 repeated bootstrapped simulations.

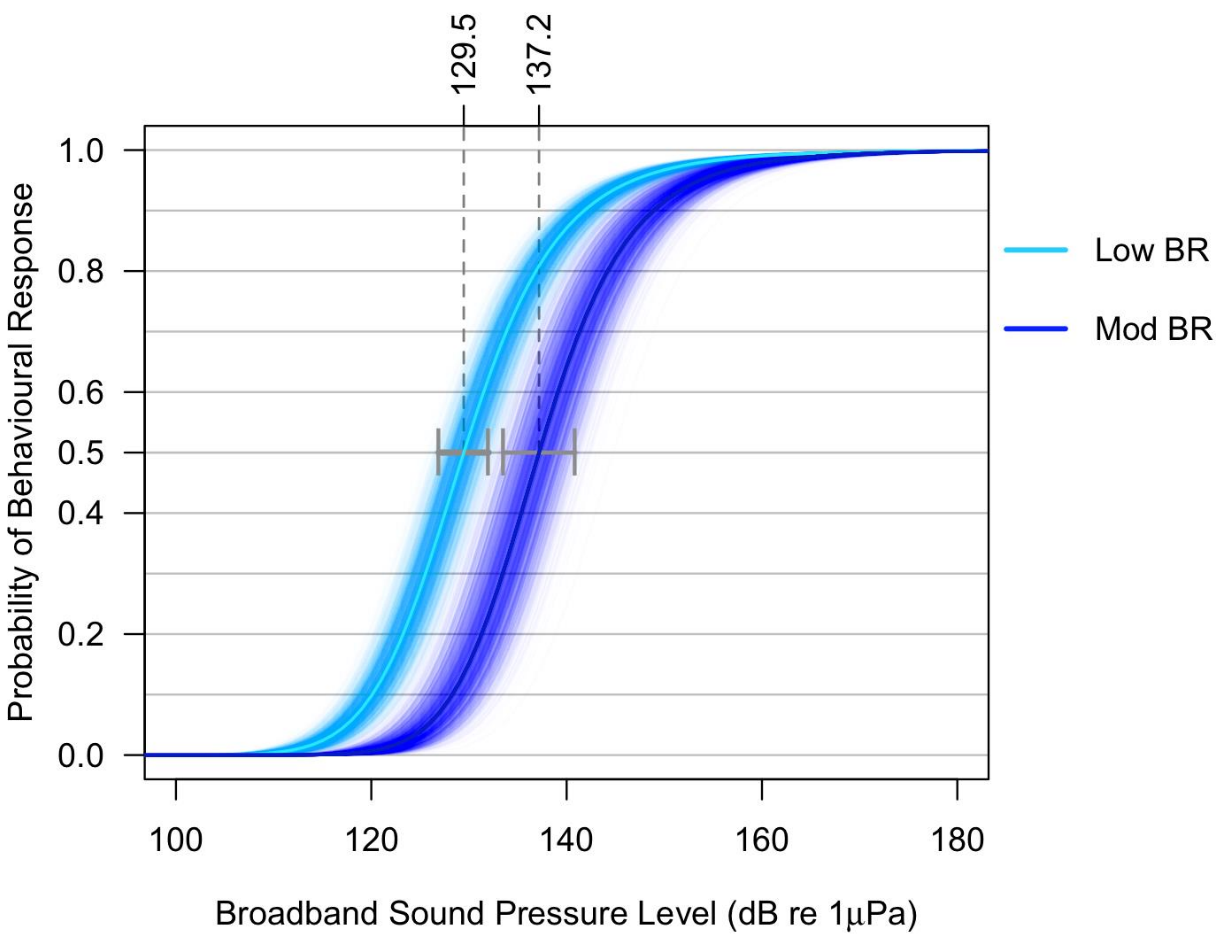

Figure 86. Dose-response curves for low and moderate severity responses. Variability in the dose-response relationship was included in the noise-exposure model as seen in this figure. The 95% CI are shown as grey horizontal error bars at 50% probability of a Low and Mod behavioural response (BR) and are derived from a regression equation of Northern and Southern Resident killer whales responding to large vessel noise.

3.2.5. Modelled Scenarios

We created four scenarios to explore combinations of Baseline/Slowdown, and Average/High traffic volume. These scenarios were run for 122 days to match with the 2020 Slowdown that occurred between 2 Jul and 31 Oct 2020. In order to allow more direct comparisons to previous Slowdown years, we provide results accumulated for the 61 days between 7 Aug and 5 Oct (the timeline of the 2017 Slowdown). The 4 scenarios modelled in this SRKW-noise exposure model are documented in Table 28.

As a result of the global pandemic, 2020 was a unique year for ferry (and recreational) traffic. Elimination or reduction of some ferry routes in both British Columbia and Washington State waters occurred, but was variable over the time frame of the slowdown. Although there is only one ferry route which transits across the Slowdown area, other ferry traffic contributes underwater noise to the 24-hour noise model area (Figure 84). Despite the complexity and differences in ferry traffic in 2020 compared to previous years, the decision was taken to maintain consistency in the noise model (Chapter 2) that provides the basis for the behavioural response model, by not amending ferry traffic routes and the resulting contribution to the noise model. This decision allows for better understanding of the potential underwater noise benefits of the participation rates and speeds achieved for the 2020 slowdown of large commercial vessel traffic, and allows for more accurate comparison to previous years noise reduction and resultant behavioural response benefits.

Table 28. Scenarios included in the Southern Resident Killer Whale (SRKW) noise exposure modeling.

Scenario number	Model vessel speed scenario	Traffic volume of piloted ship transits	SRKW density	Reported Slowdown participation rate	Modelled* Slowdown participation rate
S1	Baseline speed	Average (50th %ile)	2002–2017	n/a	n/a
S2	Baseline speed	High (95th %ile)	2002–2017	n/a	n/a
S3	2020 Slowdown participation speed	Average (50th %ile)	2002–2017	91%	79%
S4	2020 Slowdown participation speed	High (95th %ile)	2002–2017	91%	80%

* Modelled participation rate based on number of vessel transits per 24-hour period in the vessel noise model, rounded to the nearest whole vessel (i.e., average traffic 11 of 14 vessels, high traffic 16 of 20 vessels slowing down - see Table 26).

3.3. Results

The results section is broken into two sub-sections: The first explores the 4 scenarios over the 2020 Slowdown of 122-days; the second section examines a 61-day sub-period extracted from the 2020 Slowdown to compare to similar 61-day Slowdown periods from 2017–2019.

3.3.1. Potential Lost Foraging Time (122 days)

The 'potential lost foraging time' (PLFT) for the 122-day Slowdown run between 2 Jul and 31 Oct 2020 is dependent on the number of days these whales are in the model area. We report the 122-day Slowdown results for the Full Region as well as the Haro Subregion (Figure 87). The number of whale days in the Full Region was 43.2 days. In the Haro Subregion there were 32.0 whale days.

Full Region: The total accumulation of PLFT per whale was highest (i.e., effect is worst) at baseline speeds, totalling 119.5 hours for average traffic volume (S1) and 146.2 hours for baseline speeds and high traffic (S2; Table 29). The final columns of Table 29 provide lost foraging time (in hours or % time) per study day or whale day. In this case, there were 122 study days. Whale days are those days of the study when whales were in the model area. In this case there were 43.2 whale days.

We compared difference in PLFT between two Baseline and two Slowdown scenarios (Figure 88). The gains in foraging time, were ~17% for average traffic volumes and ~20% for high traffic volumes.

Haro Subregion: Again, the total accumulation of PLFT per whale was highest (i.e., effect is worst) at baseline speeds, totalling 87.3 hours for average traffic volume (S1) and 108.3 hours for baseline speeds and high traffic (S2; Table 30).

We compared difference in PLFT between two Baseline and two Slowdown scenarios (Figure 89). The gains in foraging time, were ~20% for average traffic volumes and ~23% for high traffic volumes.

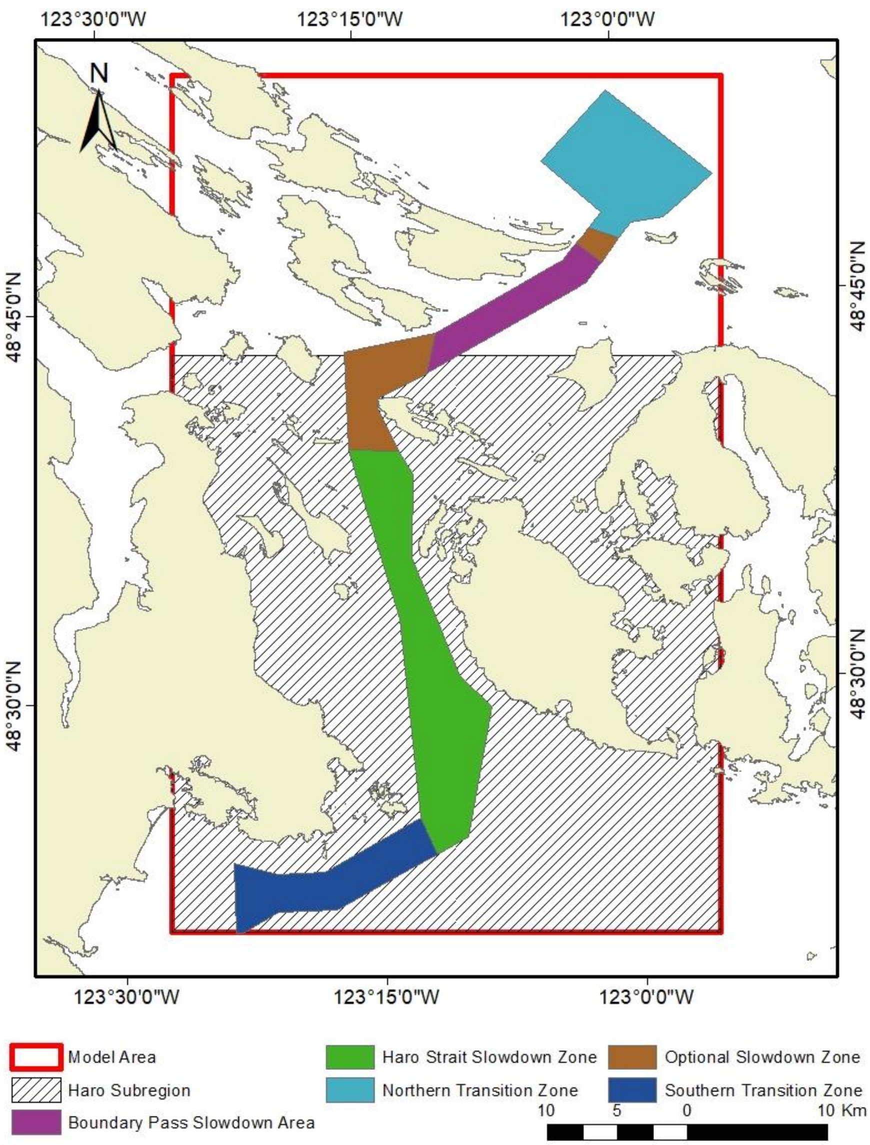

Figure 87. Model subregions in which Potential Lost Foraging Time is reported. Full Region encompasses the entire model area (red box) and is the same area used in the 2019 model. Haro Subregion matches the extent of the 2017/2018 model areas, indicated by the hatched area.

Table 29. Lost foraging time accumulated in the Full Region over 122 days.

Scenario	Summary traffic conditions	Lost foraging time (min) due to Low BR (95% CI)	Lost foraging time (min) due to Moderate BR (95% CI)	Sum of lost foraging time (min) due to Low and Moderate BR	Lost foraging time (min) due to click masking (95% CI)	Sum of all lost foraging time (h)	Lost foraging time (h) per study day	Lost foraging time (h) per whale day	Lost foraging time as a % of whale day
S1	**Baseline** – **average** vessel speed and **average** vessel numbers	2110 (1230, 3180)	4075 (1950, 7175)	6185	986 (614, 1385)	119.5	1.0	2.8	11.5
S2	**Baseline** – **average** vessel speed and **high** vessel numbers	2610 (1530, 3855)	5150 (2500, 8638)	7760	1011 (633, 1421)	146.2	1.2	3.4	14.1
S3	**Slowdown** 79% participation **14.5- and 11.5-knot speeds** **average** vessel numbers	1800 (1025, 2778)	3150 (1400, 6000)	4950	1013 (630, 1421)	99.4	0.8	2.3	9.6
S4	**Slowdown** 80% participation **14.5- and 11.5-knot speeds** **high** vessel numbers	2160 (1240, 3270)	3775 (1775, 6800)	5935	1048 (656, 1463)	116.4	1.0	2.7	11.2

Table 30. Lost Foraging time accumulated in the Haro Subregion over 122 days.

Scenario	Summary traffic conditions	Lost foraging time (min) due to Low BR (95% CI)	Lost foraging time (min) due to Moderate BR (95% CI)	Sum of lost foraging time (min) due to Low and Moderate BR	Lost foraging time (min) due to click masking (95% CI)	Sum of all lost foraging time (h)	Lost foraging time (h) per study day	Lost foraging time (h) per whale day	Lost foraging time as a % of whale day
S1	**Baseline** – **average** vessel speed and **average** vessel numbers	1585 (905, 2440)	2875 (1300, 5100)	4460	779 (463, 1131)	87.3	0.7	2.7	11.4
S2	**Baseline** – **average** vessel speed and **high** vessel numbers	1970 (1135, 3018)	3725 (1675, 6375)	5695	801 (477, 1157)	108.3	0.9	3.4	14.1
S3	**Slowdown** 79% participation **14.5- and 11.5-knot speeds** **average** vessel numbers	1320 (745, 2080)	2075 (925, 4075)	3395	805 (478, 1164)	70.0	0.6	2.2	9.1
S4	**Slowdown** 80% participation **14.5- and 11.5-knot speeds** **high** vessel numbers	1595 (900, 2490)	2575 (1150, 4725)	4170	836 (497, 1204)	83.4	0.7	2.6	10.9

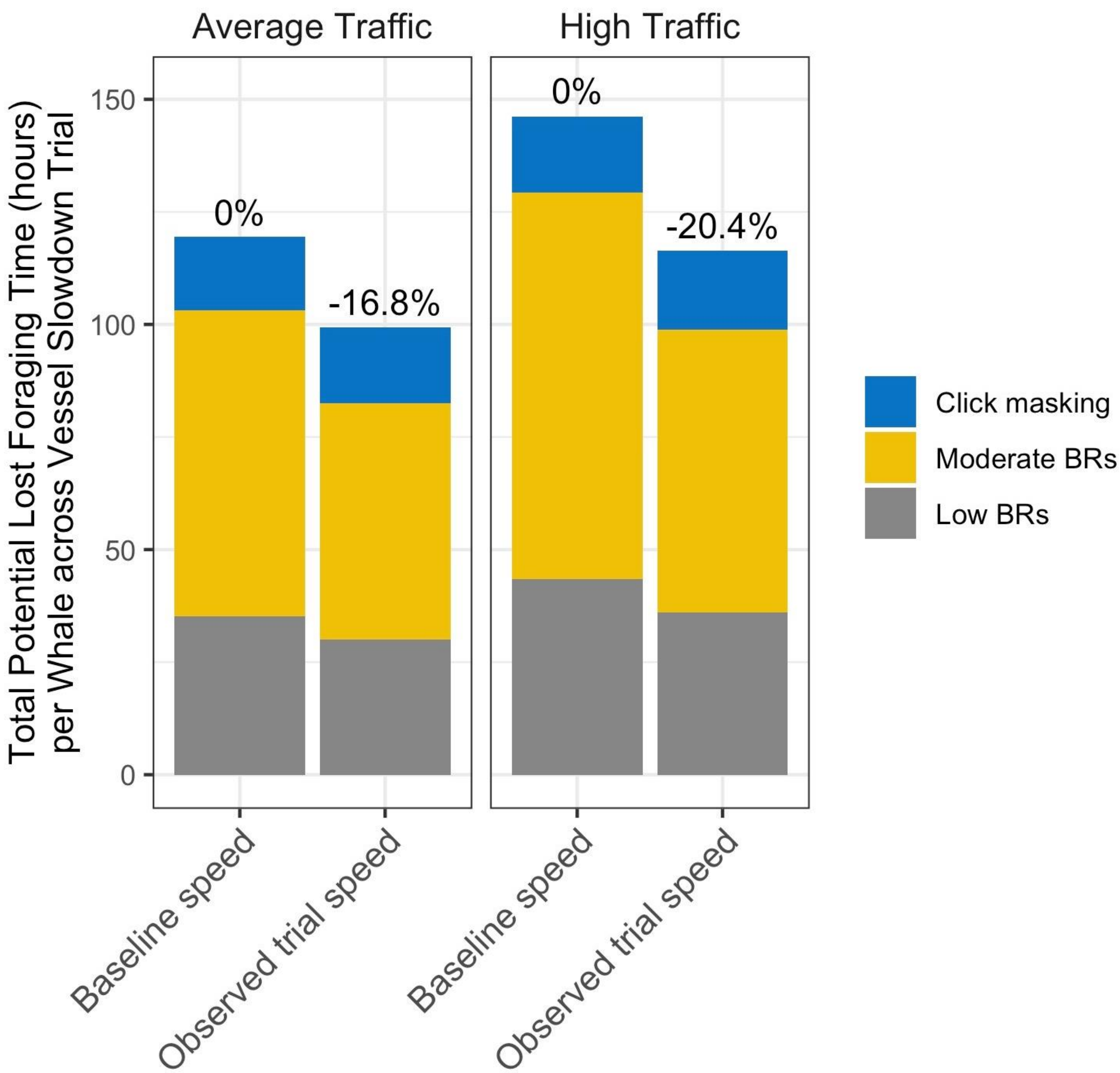

Figure 88. The accumulated amount of Potential Lost Foraging Time in hours per Whale in the Full Region across the 122-day 2020 Slowdown. Each bar represents the cumulative lost foraging time associated with Low BRs (5 mins), Mod BRs (25 mins), and lost foraging due to high-frequency masking. The paired bars represent the Baseline Speed relative to the Slowdown Speeds in scenarios that reflect average and high commercial traffic volumes.

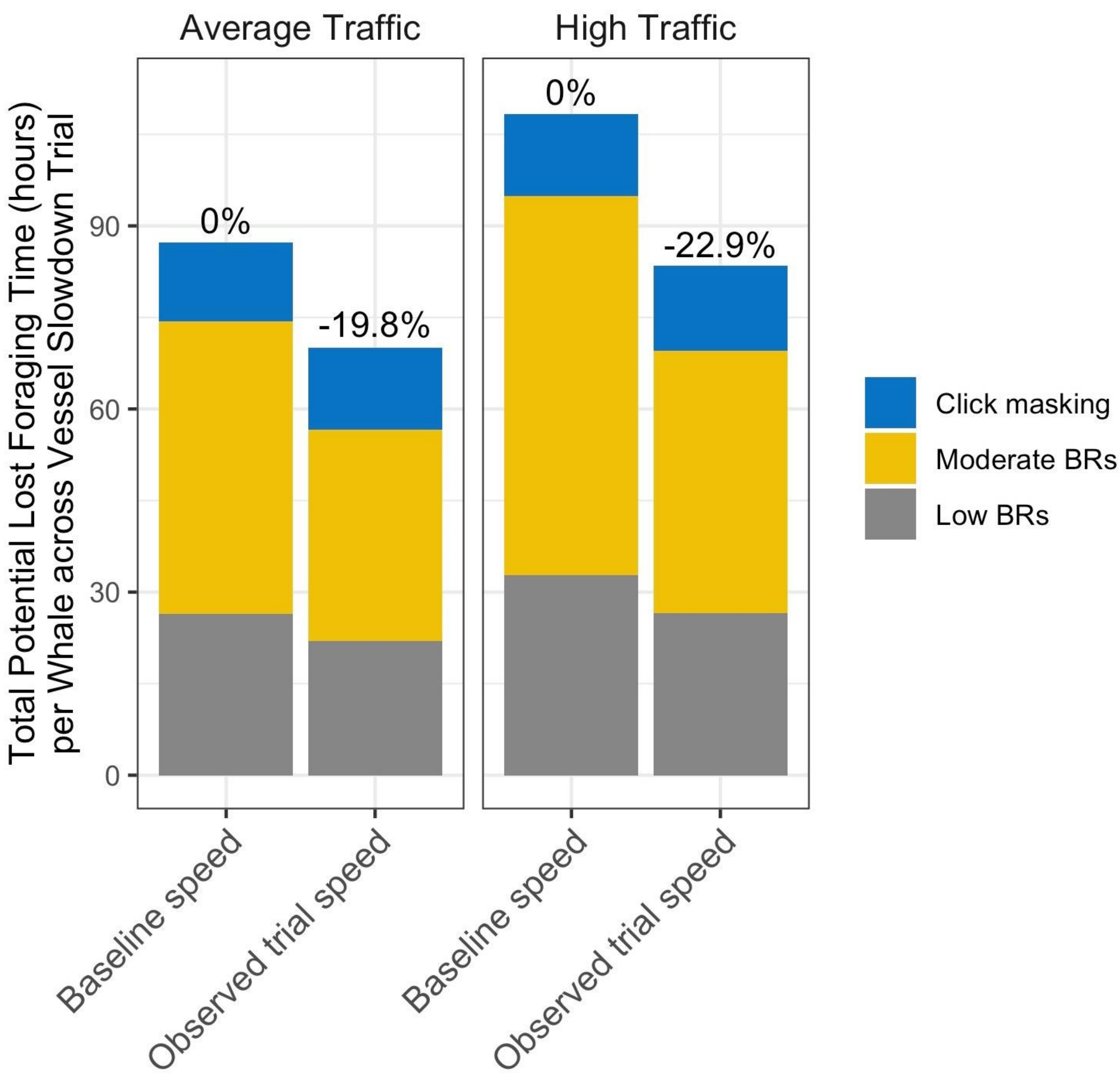

Figure 89. The accumulated amount of Potential Lost Foraging Time in hours per Whale in the Haro Subregion across the 122-day 2020 Slowdown. Each bar represents the cumulative lost foraging time associated with Low BRs (5 mins), Mod BRs (25 mins), and lost foraging due to high-frequency masking. The paired bars represent the Baseline Speed relative to the Slowdown Speeds in scenarios that reflect average and high commercial traffic volumes.

3.3.2. Potential Lost Foraging Time (61 days)

To compare the efficacy (in terms of PLFT) of ECHO Program-led Slowdowns across years we use a standardized 61-day period from 7 Aug to 6 Oct in 2017, 2018, 2019, and 2020. In the 2017 and 2018 noise exposure models, there were 15.4 whale days in the model. This increased to 16.2 in 2019 and 16.9 in the 2020 noise exposure model for the same Haro Subregion (Figure 87). There have been changes to SRKW density estimates as well as acoustic noise modeling over time that mean these comparisons across years need to be interpreted with caution.

Haro Subregion: During the 61-day period, the total accumulation of PLFT per whale was highest (i.e., effect is worst) at baseline speeds. The total accumulation of PLFT per whale totalled 45.9 hours at baseline speeds for average traffic volume (S1), and 57.0 hours for baseline speeds and high traffic volume (S2; Table 31).

We compared difference in PLFT between two Baseline and two Slowdown scenarios (Figure 90). The gains in foraging time were ~20% for average traffic volumes and ~23% for high traffic volumes.

Table 32 provides a synopsis of the efficacy of Slowdowns across 2017-2020. Controlling for area and time and therefore focusing on the Haro Subregion, the standard 61-day period, and average traffic volumes, the percent improvement in PLFT was highest in 2017 (22.2%) and lowest in 2018 (15.3%). Under high traffic volumes, 2019 had the highest improvement in PLFT (24.3%) and 2018 the lowest (16.3%). The interplay between slowdown speeds and participation rates are what drive these comparisons across years within the Haro Subregion and the 61-day standard period. However, if one considers the entire duration and spatial extent of each Slowdown then 2020 had the highest estimates of additional hours of foraging that could have potentially occurred (Table 32). This amounted to 20.1 hours per whale under average traffic volumes and 29.8 hours under high traffic volumes. The numbers of additional hours of foraging are driven by slowdown speeds, participation rate, duration of the Slowdowns and the spatial extent of the Slowdowns.

As a reminder, the comparison between the 2017/2018 Slowdowns and 2019/2020 Slowdown total PLFT are complicated by changes in the model area (due to the additional slowdown in Boundary Pass), the cumulative vessel noise modelling, and changes in SRKW density used in modeling.

Table 31. Lost Foraging time accumulated in the Haro Subregion over 61 days in 2020.

Scenario	Summary traffic conditions	Lost foraging time (min) due to Low BR (95% CI)	Lost foraging time (min) due to Moderate BR (95% CI)	Sum of lost foraging time (min) due to Low and Moderate BR	Lost foraging time (min) due to click masking (95% CI)	Sum of all lost foraging time (h)	Lost foraging time (h) per study day	Lost foraging time (h) per whale day	Lost foraging time as a % of whale day
S1	**Baseline** – **average** vessel speed and **average** vessel numbers	835 (420, 1450)	1500 (550, 3150)	2335	419 (231, 634)	45.9	0.8	2.7	11.3
S2	**Baseline** – **average** vessel speed and **high** vessel numbers	1040 (520, 1800)	1950 (700, 3925)	2990	429 (238, 647)	57.0	0.9	3.4	14.0
S3	**Slowdown** 79% participation **14.5- and 11.5-knot speeds** **average** vessel numbers	700 (345, 1235)	1075 (400, 2550)	1775	432 (239, 653)	36.8	0.6	2.2	9.1
S4	**Slowdown** 80% participation **14.5- and 11.5-knot speeds** **high** vessel numbers	845 (410, 1475)	1350 (475, 2925)	2195	446 (250, 674)	44.0	0.7	2.6	10.9

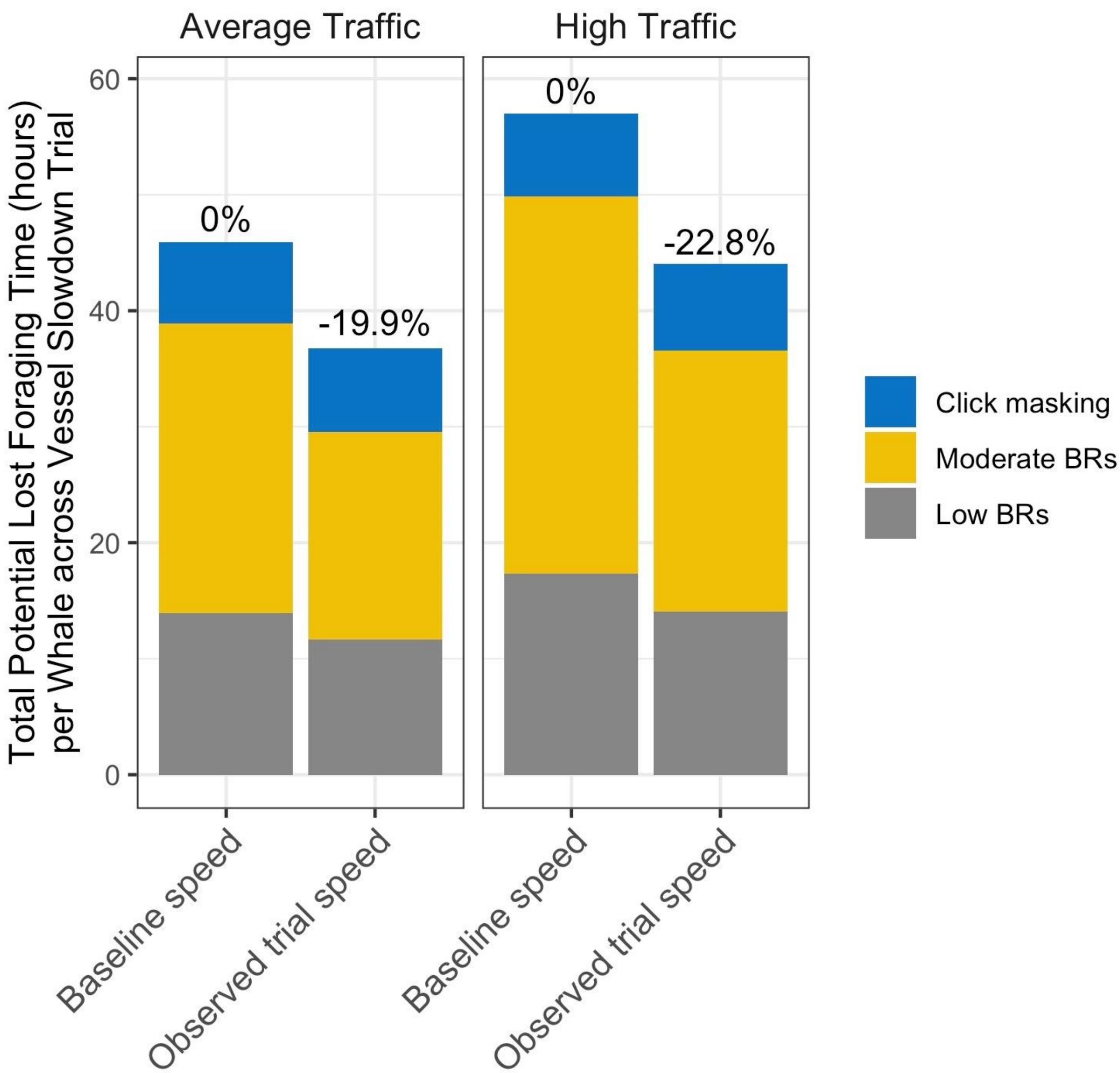

Figure 90. The accumulated number of ‘potential lost foraging time’ from noise exposure due to Low BRs, Moderate BRs and click masking for a 61-day slowdown trial period (7 Aug to 6 Oct 2020) for the Haro Subregion.

Table 32. Comparison of Slowdown efficacy across years.

Slowdown year	61-day Haro Subregion percent improvement in PLFT		Days of slowdown	Full Slowdown Region* additional hours of foraging	
	Average traffic	High traffic		Average traffic	High traffic
2017	22.2	23.6	61	8.4	11.5
2018	15.3	16.3	111	8.5	12.7
2019	19.9	24.3	102	17.6	26.0
2020	19.9	22.8	122	20.1	29.8

* The Full Slowdown Region in 2017/2018 was the Haro Subregion. In 2019/2020, the Full Slowdown Region was the Haro Subregion and Boundary Pass.

3.4. Discussion

The goal of this chapter was to evaluate the efficacy of the 2020 Slowdown on reducing SRKW 'potential lost foraging time' (PLFT) and compare this to previous Slowdowns. However, any direct comparisons to 2017/2018 are difficult because of changes in the acoustic modeling, SRKW density and the model area. Therefore, comparisons to previous years should be considered rough comparisons and should focus on relative changes.

3.4.1. Efficacy of the Slowdown

Improvements in 'potential lost foraging time' (PLFT) from the 2020 Slowdown (122-day, Full Region) resulted in an additional 20.1 hours and 29.8 hours of foraging time (i.e., S1 vs S3 and S2 vs S4) per whale. This corresponds to a 9.7 hour difference in total PLFT between average traffic volumes compared to high traffic volumes across the 122-day trial and the Full Region. We estimate that the Slowdown reduced the lost foraging time as a % of a whale day from 11.5% to 9.6% under average traffic volumes, and 14.1% to 11.2% under high traffic volumes. As in modelling from previous years, moderate behavioural responses comprised the largest portion of PLFT.

Comparing gains in foraging time for each whale between the 61-days of Slowdowns in the Haro Subregion only, corresponds to a percent improvement of PLFT of 22.2%, 15.3%, 19.9% and 19.9% for each of 2017–2020. These numbers provide the most standardized comparisons of the relative effectiveness within the Haro Subregion and over the same period (61 days). However, each year of slowdowns have been of variable duration, and in 2019, the Boundary Pass slowdown zone was added. Across the entire slowdown area and over the duration of the Slowdowns in each year, on a per whale basis, and average traffic volumes, the 2017 Slowdown resulted in a gain of 8.4 hours in PLFT across 61-days, the 2018 Slowdown resulted in a gain of 8.5 hours across 111-days, the 2019 Slowdown resulted in a gain of 17.6 hours across 102-days, and the 2020 Slowdown resulted in a gain of 20.1 hours across 122-days. As a reminder, the 2019/2020 Slowdown noise exposure model used slightly different inputs (changed sound speed profile for the acoustic model, changed SRKW density, changed model area) and **therefore the absolute differences between the 2019/2020 Slowdown and those in 2017/2018 should be treated with caution**. Despite this caution, it is clear that, due to combinations of Slowdown speeds, Slowdown participation, Slowdown duration and Slowdown area, the 2020 Slowdown has resulted in the largest gains in PLFT to date.

3.5. Conclusions

- Under assumptions of average traffic volume, the 2020 Slowdown resulted in an additional 20.1 hours of foraging time per whale, over the 43.2 days whales were present in the model for the 122-day Slowdown. Assuming high traffic volumes, this number increased to 29.8 hours per whale.
- Using the standardized 61-day period, average traffic volume and Haro Subregion, there were gains in foraging time of 22.2%, 15.3%, 19.9% and 19.9% per whale from the 2017–2020 Slowdowns, respectively. Therefore, the best gain in foraging time for an equivalent number of days in this Subregion was achieved during the 2017 Slowdown.
- Using the full duration and area of each Slowdown as well as average traffic volumes, there were gains in foraging time of 8.4 hours, 8.5 hours, 17.6 hours, and 20.1 hours per whale from the 61-day 2017 Slowdown, 111-day 2018 Slowdown, 102-day 2019 Slowdown, and 122-day Slowdown, respectively. Therefore, the best overall gain in foraging time was the 2020 Slowdown, remembering there are caveats with absolute comparisons between Slowdown years.

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Appendix B.1.

SMRU Consulting: SRKW sightings at Lime Kiln State Park (Haro Strait) in summer 2020

SRKW sightings at Lime Kiln State Park in summer 2020

Jan 13, 2021

SMRU Consulting North America

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SRKW sightings at Lime Kiln State Park in summer 2020

13 January 2021

Prepared by SMRU Consulting NA

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Submitted to ECHO Program, Vancouver Fraser Port Authority

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Data were collected and kindly provided by Dr. Bob Otis and Jeanne Hyde. We also thank Melanie Knight and Krista Trounce (ECHO Program) for their continued support and report review.

Study Aims

The goal of this report is to provide summary comparative information on SRKW sightings made by two voluntary observers during summer 2020 from Lime Kiln State Park.

Methods

Observers (led by Dr. Bob Otis and Jeanne Hyde) stationed at Lime Kiln State Park recorded individual transits by SRKW from **June 1** to **October 31 2020.** Observations (9:00-17:00, within ½ mile) by Bob Otis were made from July 1 to August 10 and supplemented with observations by Jeanne Hyde (June 1 to October 31) that included observations made earlier and later in the day. Date, time, transit duration and direction and pod groupings (where possible) were collected. A new transit is defined if no whales were observed in the study area for 30 minutes or more.

Observations have been summarized by pod and overall. While often only one transit by a single “individual” pod occurred on any sighting day, up to three transits by a single pod were sometimes observed in a single day, highlighting movement of that pod up and down the coast on that day.

Results

Summer 2020 observations (June 1 – October 31):

SRKW were visually observed on 22 days in total in summer 2020 (June 1 to October 31, 2020) at Lime Kiln. There was a total of 30 confirmed SRKW transits encompassing a total of 36 “individual” pod transits (i.e., when transits by each pod were counted separately, despite potentially occurring concurrently with another pod). Pod transits did not always include all members of a particular pod, but only certain matrilines. L87 is considered a de facto member of J-Pod as it has been travelling with this pod since 2010.

Members of J-Pod were observed on 17 days (23 pod transits), K-Pod on 5 days (7 pod transits) and L-Pod on 3 days (3 pod transits) (Table 1, Figure 1). On three occasions the particular pod ID was not identified beyond confirmation of the transiting whales being SRKW. Observations were concentrated in July (15 days, mainly J-Pod), and September (5 days). No sightings were made in either June or August 2020. Members of J-Pod alone were observed 14 times, K-pod alone 2 times and L-Pod alone no times. All three pods transited together on 3 days in September (Figure 2). This would be counted as 3 SRKW transits and 9 “individual” pod transits.

Summary sightings days across each month and overall are presented for 2020 in Figure 1. Information on temporal distribution of all transits through the period are presented in Figure 2. The duration of observed pod transits has been provided for 2020 (Figure 3). Overall SRKW or pod transit times averaged 81.4 minutes (standard deviation = 101.3 minutes, min. = 2 minutes, max. = 390 minutes). A total of 66% of transits were 60 minutes in duration or less.

Table 1. Summary of Lime Kiln SRKW and individual pod sightings data by individual pod and overall (June 1 to October 31, 2020)

Metric	J-Pod	K-Pod	L-Pod	Unknown Pod	SRKW
Detection days	17	5	3	3	22
Number of transits	23	7	3	3	30

Figure 1. Number of days SRKW observed at Lime Kiln in summer 2020 (June 1 to October 31, 2020).

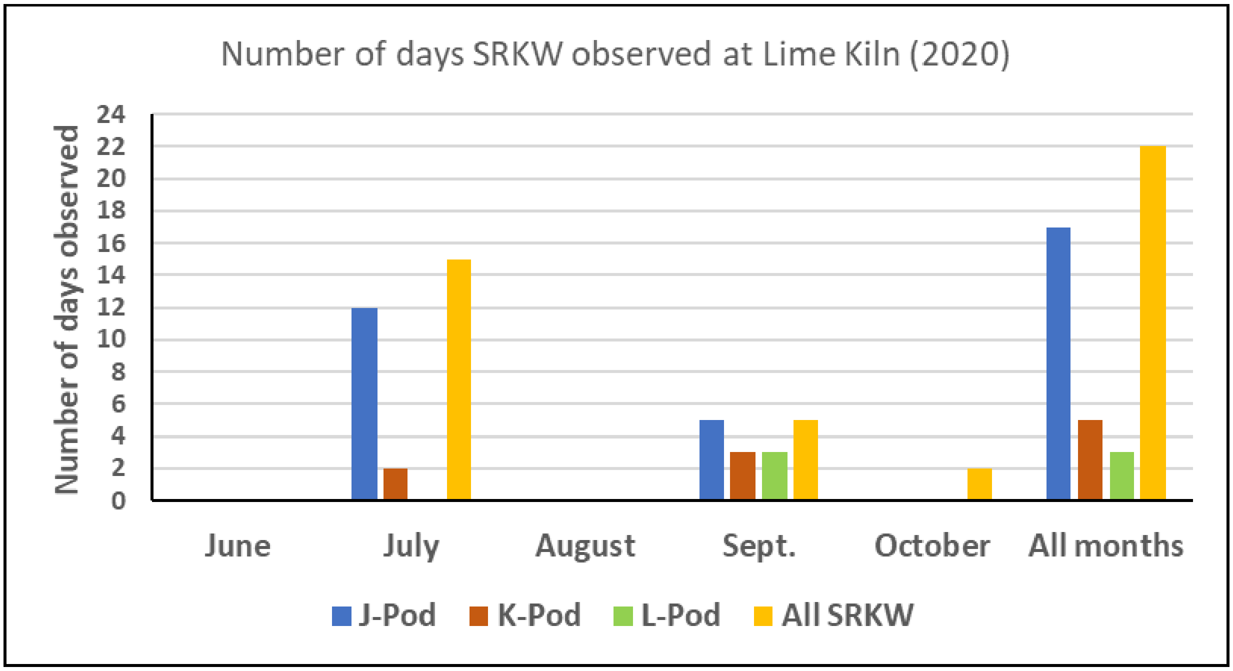


Figure 2. Observed SRKW pod transits per days past Lime Kiln in summer 2020 (June 1 to October 31, 2020).

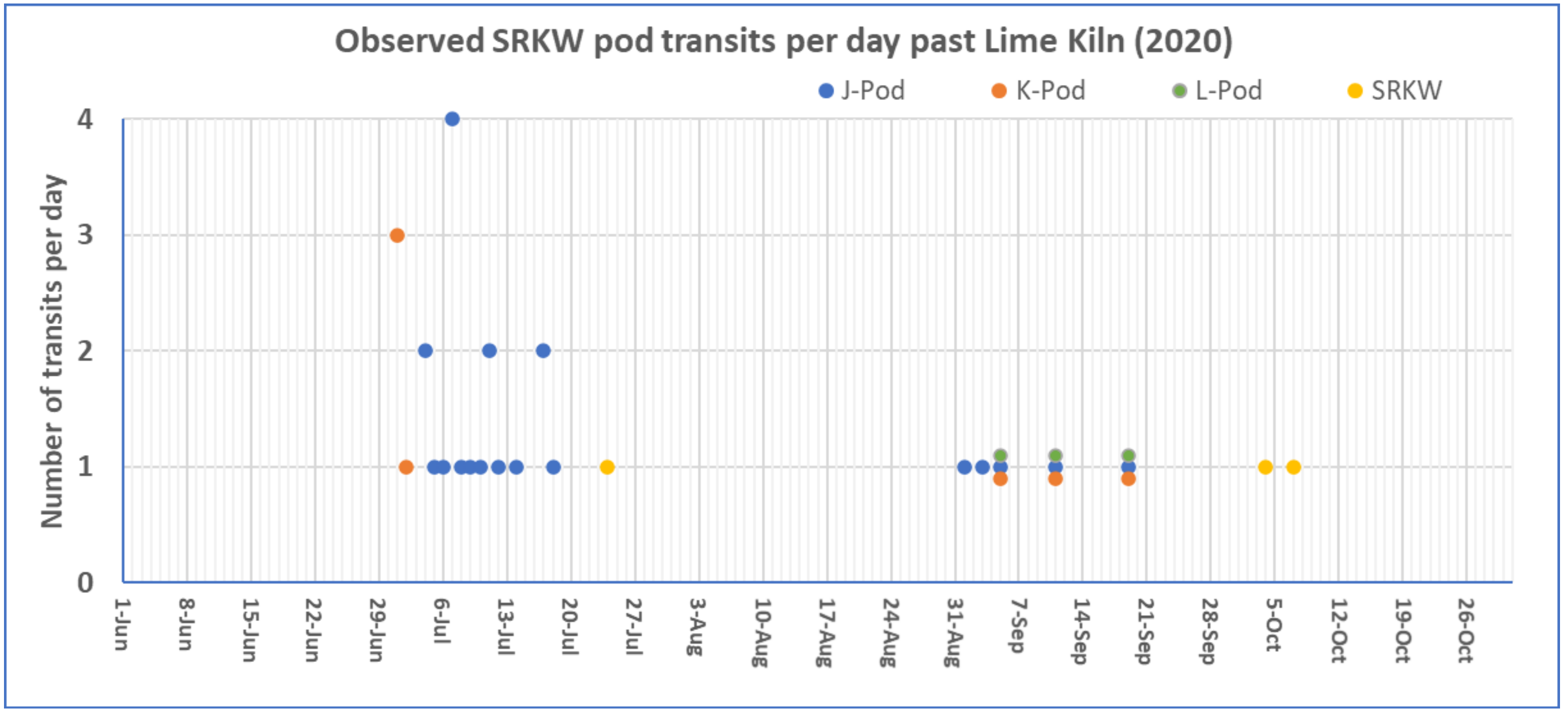
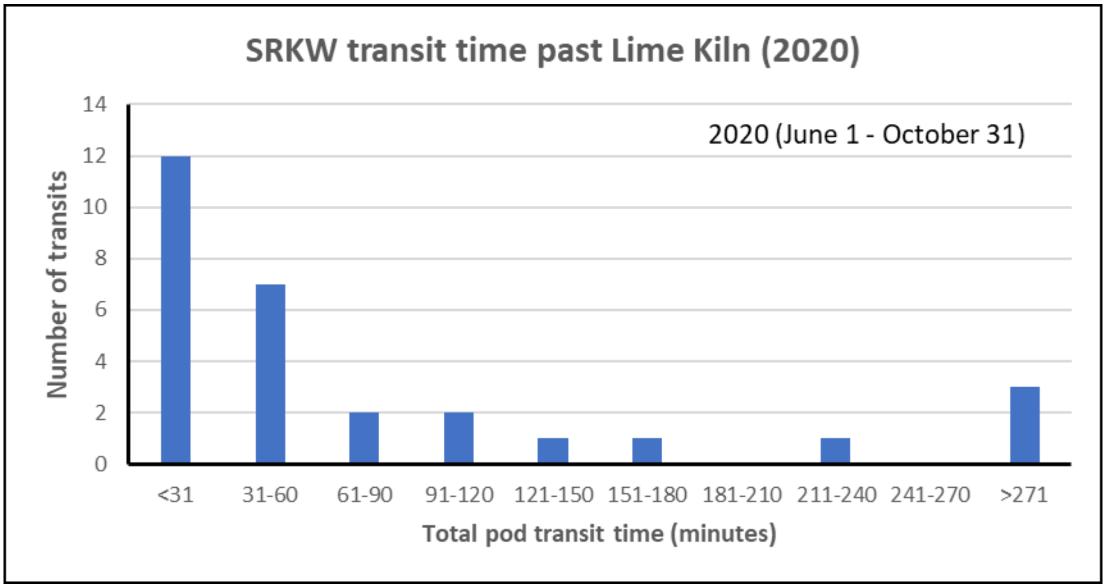


Figure 3. SRKW pod transit times past Lime Kiln in 2020 (June 1 to October 31, 2020)



Discussion

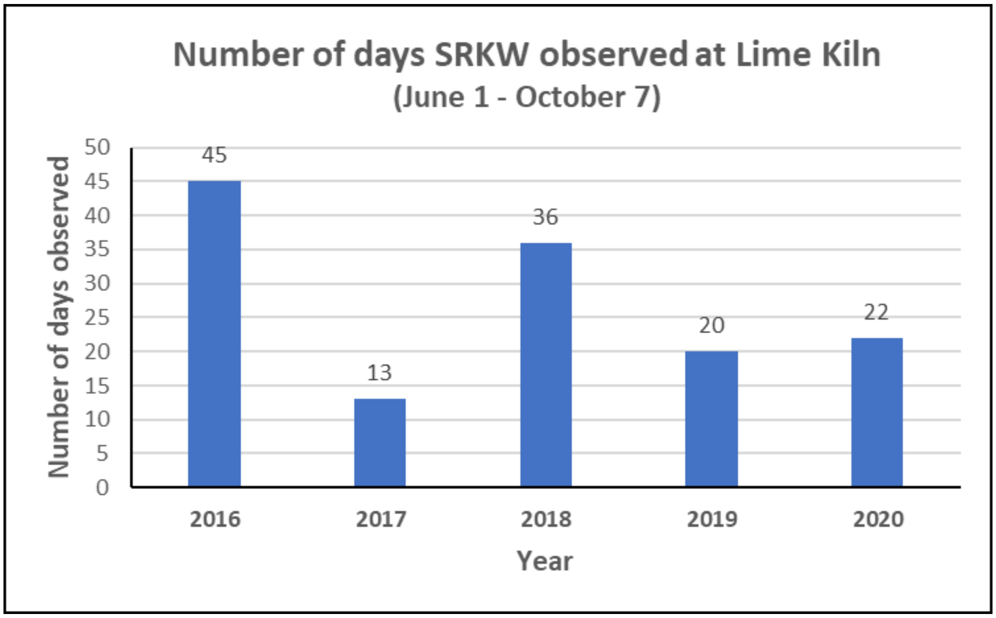
Datasets of SRKW sightings made during summer 2020 (June 1 to October 31) at Lime Kiln State Park were kindly provided by two long-term experienced observers, Dr. Bob Otis and Jeanne Hyde. SRKW were sighted on 22 days, with J-pod sighted on 17 (77%) of those days. Sightings were mostly from July and to a lesser degree September, with very low sighting rates in early October and no SRKW sighted in either June or August. The lack of sightings in June 2020 mirrored June 2019, compared with 4-5 sightings recorded 2016 through 2018. The lack of sightings in August 2020 mirrored August 2017, noting just 1 sighting occurred in August 2018. In contrast, in 2016 and 2019, sightings rates were relatively high in August (Tollit and Wood 2017; 2018; 2019). Use of the area clearly varies temporally by year and by month, presumably linked to the availability and abundance of salmon.

No SRKW sightings were made after October 7th therefore we are able to reasonably compare data collected by the same observers in 2016-2019. The number of Lime Kiln visual sightings days (June 1 - October 7) in 2020 was 22, similar to 2019 (20 days), considerably higher than 2017 (13 days), but considerably less than 2018 (36 days) and 2016 (45 days) (Table 2, Figure 4). Transit numbers show a very similar between-year pattern, while transit durations are more variable, with average duration in 2020 approximately twice that of 2019 (SMRU Consulting 2017; 2018; 2019). In 2020, more than 65% of transits were 60 minutes or less in duration. Short transits times of an hour or less have thus dominated in all observation years.

Table 2. Days, transits and transit durations SRKW were observed during June 1 through October 7 2016-2020 by land-based observers at Lime Kiln State Park

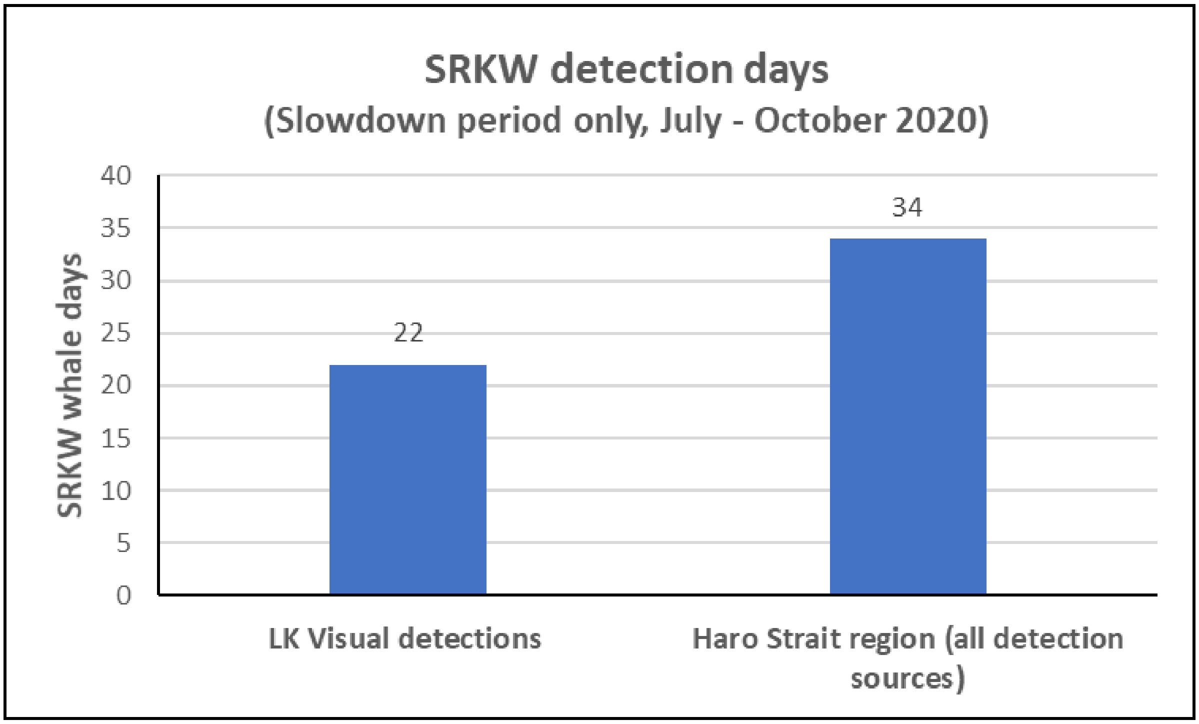
Year	Number of days	Number of transits	Average transit duration (minutes)
2020	22	30	81
2019	20	29	42
2018	36	53	67
2017	13	21	48
2016	45	68	72

Figure 4. Days SRKW were observed during June 1 through October 7 2016-2020 by land-based observers at Lime Kiln.



In addition to visual observations made by Bob Otis and Jeanne Hyde at Lime Kiln State Park, Jeanne also provided supplementary information on SRKW presence based on passive acoustic monitoring (PAM) detections from the Lime Kiln hydrophone and observations from other trusted observers in the greater Haro Strait area. PAM detection data was also compiled by SMRU Consulting from July 1 to October 31 using PAMGuard software using data from the Lime Kiln hydrophone. Based on this supplementary information, from July 1 to October 31, there were 34 SRKW 'whale days' in Haro Strait (Figure 5). This total includes 22 days of confirmed visual sightings made solely at Lime Kiln during this slowdown period (see Figure 2), and an additional 12 days SRKW were detected acoustically. 100% of the 22 days with confirmed visual sightings also had acoustic detections. Two acoustic night-time detections of SRKW were also made on June 4th and 26th but no visual confirmations were subsequently made. Thus, from June 1 to October 31 2020, an overall total of 36 SRKW detections were made. Supplemental information provided here are preliminary as data from all data sources, including BC Cetacean Sightings Networks and OrcaMaster are not yet fully compiled.

Figure 5. Days SRKW were detected during 2020 vessel slowdown period (July 1 – October 31) based solely on visual observations at Lime Kiln and from all combined available detection data sources. Note: BC Cetacean Sightings Networks and OrcaMaster data are not yet fully compiled.



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Appendix B.2.

Boundary Pass 2020 Land-based Cetacean Observations

Boundary Pass 2020 Land-based Cetacean Observations

ECHO Program 2020 Slowdown Evaluation

Submitted to:
Vancouver Fraser Port Authority, ECHO Program

Authors:
Lucy Quayle and Ruth Joy
19 February 2021

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1. Introduction

Boundary Pass is an important passageway for both marine vessels and marine mammals. Boundary Pass includes the international commercial shipping lane that connects Haro Strait to the Strait of Georgia. Due to its location between the Canadian Gulf Islands and the American San Juan Islands, it is also popular among recreational boaters. Many marine mammals use Boundary Pass, including resident and transient (Biggs) ecotypes of killer whales (*Orcinus orca*), humpback whales (*Megaptera novaeangliae*), and harbour porpoises (*Phocoena phocoena*). As little is known about how marine mammal species currently use Boundary Pass, it is of great importance to better understand how they behave in this area.

Historically, the endangered southern resident killer whales (SRKW) were known to consistently spend time in the summer and fall in the inner waters of the Salish Sea (Olson et al. 2018). This led Boundary Pass, Haro Strait and parts of the Strait of Georgia to be designated as critical habitat (DFO 2018). In recent years however, changes in both SRKW movement and duration in these areas have been documented showing deviations from historical trends (Olson 2018). According to the Center for Whale Research, 2020 was the first year in recorded history that SRKW were undetected in the Salish Sea for the entire month of August (CWR 2020).

Changes in the presence of other species in the Salish Sea have also been noted in recent years, including the increase in transient killer whale and humpback whale presence (Nordstrom and Birdsall 2018, Shields et al. 2018). Understanding these recent changes allows us to prepare for increased spatial overlap between species and marine vessels, in order to mitigate disturbance on the water.

Beginning in 2017, the Enhancing Cetacean Habitat and Observation (ECHO) Program has coordinated a seasonal large vessel slowdown in Haro Strait and more recently, since 2019, in Boundary Pass as well. The vessel slowdown project aims to better understand the relationship between commercial vessel speed and underwater noise, and to reduce underwater noise in key SRKW foraging habitat. On June 1, 2020, monitoring began in Haro Strait and Boundary Pass, by engaging trusted observers to monitor SRKW presence in the slowdown area. On July 1, 2020, SRKWs were detected in Haro Strait triggering the start of the slowdown in both Haro Strait and Boundary Pass. SRKWs were observed multiple times in the slowdown area in the month of October so the slowdown was extended to its maximum of October 31, 2020 - a total of 123 slowdown days.

To support the activation and extension of the slowdown and inform the ECHO Program and marine transportation stakeholders of how large marine mammals use the area of Boundary Pass during the summer, land-based surveys were conducted between June and October. A primary observer was stationed on Saturna Island, collecting marine mammal observations and noting the presence of vessels in the vicinity of cetaceans. In addition, a citizen science volunteer group, the Saturna Sighting Network, aided in observations in the study area. While other methods are in place in Boundary Pass for detecting marine mammal presence, e.g., hydrophones and time-lapse cameras, the presence of an observer allows accurate and detailed behavioural information to be collected. Species of interest include killer whales (both resident and transient ecotypes) and humpback whales, though other large marine mammal species, such as minke whales (*Balaenoptera acutorostrata*) were also recorded if observed.

This study was commissioned by the Vancouver Fraser Port Authority's ECHO Program, in support of the voluntary vessel slowdown to reduce noise exposure from large vessels on southern resident killer whales. Collaborators include the Saturna Island Marine Research & Education Society (SIMRES) and SMRU Canada Ltd.

2. Methods

2.1. Study Area

This study was based on the east side of Saturna Island, overlooking the northern section of Boundary Pass and the Strait of Georgia. The primary observer, Lucy Quayle, conducted visual surveys from East Point Park (48.782985 N, 123.045580 W) (Site 1, Figure 1a, b). Opportunistic observations from the Saturna Sighting Network (SSN), a local citizen scientist group, are also included in this report though they did not have the same level of 'effort' as from the primary observer. Observations from this group were based out of two general areas, Tumbo Channel Road with a north/northeast outlook (Figure 1b, Site 2 and 3) and Cliffside Road overlooking the south (Figure 1b, Site 4-6).

Specific locations of additional sites are as follows:

Site 2 – Tumbo Channel Road (48.783300 N, 123.065378 W)

Site 3 – Tumbo Channel Road (48.783728 N, 123.054335 W)

Site 4 – Cliffside Road (48.780997 N, 123.051562 W)

Site 5 – Cliffside Road (48.779814 N, 123.058331 W)

Site 6 – Cliffside Road (48.779779 N, 123.064329 W)

The observer (primary, or Saturna Sighting Network) and observer location were recorded in respective columns in marine mammal observation event table (see Appendix A).

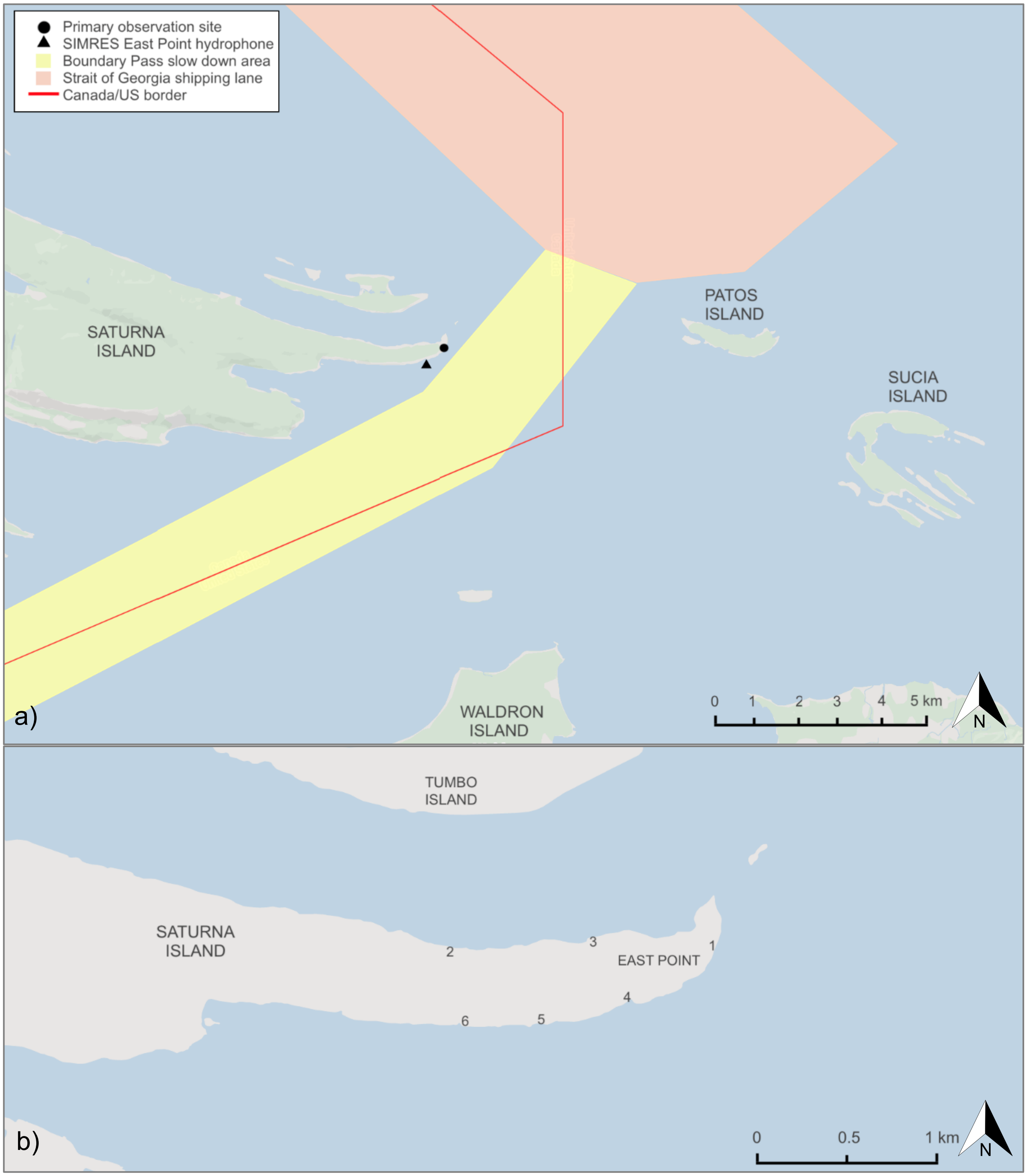

Figure 1. a) Primary observation site, SIMRES hydrophone location, shipping lanes and approximate field of view from East Point, Saturna Island. b) Primary observation site (1), and additional Saturna Sighting Network observation locations (2-6) on Saturna Island. Map modified from Le Baron et al. 2019.

2.2. Land-based Marine Mammal Observations

From June 4 to October 6, 2020, land-based observations of marine mammals were conducted by the primary observer from Site 1 at East Point Park, Saturna Island. To detect whales, visual scans were conducted every 15 minutes between 9:00 am and 5:00 pm PST, following similar methods to Lusseau et al. (2009), Di Clemente et al. (2018) and Le Baron et al. (2019). Occasionally, due to extended work hours or reports of incoming whales, some observations were recorded outside of the normal survey hours between 7:00 am and 8:00 pm. Equipment to facilitate visual scans include binocular, and a DSLR (Sony α7R IV) with a telephoto lens (Sony 200-600 mm). A laser range finder (Newcon LRM 3500M-35BT) was used to gain experience visually estimating distances so that it could be recorded when whales were in the shipping lane.

Although visual scans were performed every 15 minutes, one of the main ways that whales were detected included hearing a loud exhale or splash of a whale. As such, the primary observer also performed near constant aural monitoring during observation hours except for eight days between September 8 and 18. Due to heavy smoke from forest fires in Canada and the US in September 2020, air quality was too poor for normal surveys and visibility was sometimes as low as 300 m. Surveys were still conducted during this time but modified to only three-minute scans every 15 minutes instead of the normal near constant visual and aural observation method. Days that used the modified survey protocol are indicated in the notes section in Appendix A, and include the estimated visibility distance on the day.

Other methods for improving whale detection include communication with citizen scientists and researchers, real-time hydrophone broadcasts from San Juan Island and the presence of ecotourism vessels within the area. The SSN observations that were included in this report were opportunistic, rather than adhering to an organised schedule, therefore observations were recorded between 6:30 am to 10:30 pm. In most cases, the SSN reported their observations in the SSN WhatsApp group chat forum which included the primary observer and others. Due to the layout of the Whale Report App, the information recorded by SSN observers was more of a snapshot of an event rather than recording the same information collected by primary observer. For example, only a single time stamp and location was recorded along with species information rather than including event duration, travel path, usage of shipping lane or vessel presence.

When possible, whale sightings were reported by the primary observer when first detected to the BC Cetacean Sightings Network (BCCSN) Whale Report mobile application. Reports were sometimes delayed due to data collection taking priority or a lack of cell coverage. SSN observers reported whale sightings to the Whale Report App wherever possible as well. All sightings were submitted to the BCCSN by the end of November 2020.

When a target species was visually confirmed, the following information was recorded by the primary observer and information collected by SSN observers has been denoted with a '*'. Observation data is provided in Appendix A.

- The start and end time of observation event
- Daily observation number
- Species and ecotype*
- Number of individuals*
- Identified individuals including pods/matrilines where applicable
- Behaviour (i.e., travel, forage, social) *
- Direction of travel *
- Estimated distance from survey position
- Presence within the shipping lane (Boundary Pass or Strait of Georgia)
- Vessels present (within 1000 m and estimated distance to whale) and
- Observer and location of observer *

An observation event began as soon as a target species was detected and was terminated when the species travelled out of view or went undetected for more than 20 minutes. When multiple individuals were observed, they would be deemed as part of a single event if all sighted within 10 body lengths of each other (Lusseau et al. 2009).

For killer whales, ecotype was determined by examining the dorsal-fin saddle patch and the shape of the dorsal fin (Figure 2). These distinguishing features were also used to identify individuals as each individual has a unique combination of saddle patch colouration, nicks and scratches. Knowledge of recent sightings within the general area of the Salish Sea also helped to determine ecotype and individuals. When possible, verification of SRKW presence through acoustic recordings collected from SIMRES' East Point Hydrophone network was conducted by Jeanne Hyde. Humpback whales were identified by the markings on the underside of the fluke or by the dorsal fin. If possible, the classification between adult or calf/juvenile was also identified. Photographs and videos were taken during each event of the target species to increase the chance of identification and data collection. The identification process often required multiple photographs from different angles of an individual to enable a positive identification.

Marine mammal behaviour was categorized into resting, traveling, foraging, and socializing behaviour modified from Lusseau et al. (2009) and Di Clemente et al. (2018). The behaviour or activity of a marine mammal was distinguished as follows, though resting behaviour was not observed during this study:

- *Resting*: Little or no clean movement by individual
- *Traveling*: Forward linear movement of an individual
- *Foraging*: Back and forth movement, jumping on, or surging/charging a specific area.
- *Socializing*: Breaching, tail slaps, spy hop, or aerial displays from humpback whales.

To get information on how large marine mammals use the waters of Boundary Pass, information on the direction traveled, the general zone of movement and whether the marine mammals spent time inside the shipping lane was recorded. When vessels were present within 1000 m of a whale during an event, the total number of large vessels (i.e., those required to use the shipping lane), and the total number of smaller vessels (i.e., those not required to use the shipping lane) were recorded (Appendix B).

Figure 2. (a) Southern resident killer whale with ‘open’ saddle patch behind dorsal fin. (b) Transient killer whale with nicks and scratches on dorsal fin and saddle patch. (c) Minke whale with small pointy dorsal fin and small body. (d) Humpback whale (identified individuals: Heather (BCY0160) and calf Neowise) with large body and prominent ‘humpback’ dorsal fin.
Credit: Lucy Quayle.

3. Results

3.1. Number of Survey Days and Observation Events

Between June 4 and October 6, 2020, 106 surveys were conducted by primary observer, including 102 full days (more than six hours) and four half days (less than six hours) (Table 1). This constituted over 839 hours of observation effort across the 106 observation days. During this period, whales were observed on 54 of the total 106 survey days (Figure 3) with 115 unique whale events recorded. During the survey period, 15 days were non-survey days due to vacation time and 8 days were obstructed by heavy smoke resulting in a modified survey protocol. Observations were collected from the SSN between June 1 and October 31 and have been included in Table 1. Combining primary observer observations with SSN observations, whales were detected on 77 of the 153 calendar days between June and October 2020 with a total of 174 unique events. The SSN contributed 119 days of opportunistic effort that resulted in additional sightings of all four species of cetaceans that were the focus of this report.

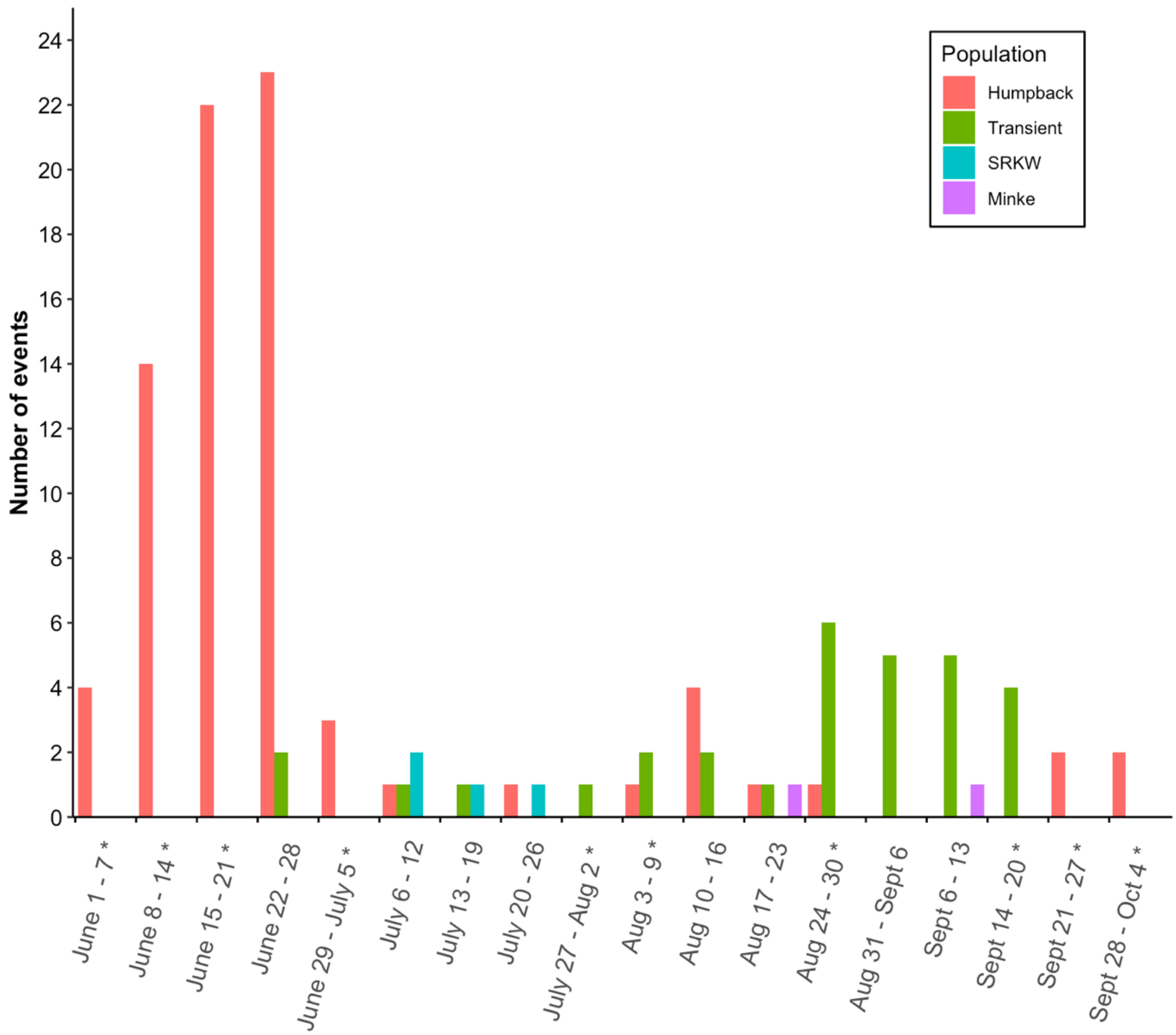

Figure 3. Number of large marine mammal events broken down by week per species from June 1 to October 6 2020. Weeks with less than 7 days of observations are indicated with a '*'. Only events that were seen by the primary observer are included in this figure.

The primary observer detected four SRKW events in Boundary Pass in July 2020. Two events occurred on July 12 when most of J pod travelled south through Boundary Pass towards Haro Strait and an hour later, a single individual followed the first group. The third event occurred on July 24 when approximately 18 members from K and L pod were observed travelling south through Boundary Pass. An additional J pod sighting was detected on July 13 travelling over 12 km away through the Strait of Georgia to Rosario Strait but did not pass through Boundary Pass. SSN observers detected SRKW on two additional days, when the primary observer was off Island. Approximately 18 members from K pod were observed on September 28 and between 18 and 30 members from at least J pod were observed on October 25. In total, five SRKW events were visually detected on four days during the study period in Boundary Pass. SRKW were not detected in June or August.

An additional SRKW event was detected through acoustic methods using recordings from the SIMRES East Point hydrophone and confirmed by Jeanne Hyde. This event occurred outside of survey hours at 2:00 am on September 12 and was discovered after a report of J and K pod northbound in Haro Strait the night before. Though hydrophone detections were out of the scope this project, this event has been included in Table 1 but will not be discussed in the Section 3.2 or 3.3.

Transient killer whales were observed every month throughout the study period except October, with presence greatest in September and August (Figure 3). At least 13 different matriline family groups were detected throughout the course of this study. Some family groups were seen multiple times, for example the T018s/T019s were seen in at least six different events. Other family groups, such as the T099s were only observed on one occasion. Unfortunately, many observations collected by the SSN did not have sufficient detail or photographic evidence to provide enough information to allow positive identification, so the number of matriline family groups is likely larger than reported.

Humpback whales were observed the most in June (Figure 3) and less frequently for all other months. The high number of observation events in June was mostly due to the presence of Heather (BCY0160) and her calf Neowise, born in 2020. This pair were first seen as early as mid-May by SSN and last seen on July 4, 2020 before moving north towards Galiano Island. In total, 27 of 64 humpback events observed by the primary observer in June included Heather and Neowise as did a further 18 additional events by the SSN. In total, there were 11 individual humpback whales positively identified during this study. Due to distance from observation, weather or lack of fluke display many individuals were unable to be identified so the number of individuals that used Boundary Pass during the survey was likely much higher.

Minke whales were observed twice (August, September) by the primary observer and were recorded on two other occasions by SSN observers (July, September). This species is not as common in this area as the other species and is much harder to detect. They are smaller than the humpback whale, with a small dorsal fin and spend less time at the surface. These sightings were reported to the “Northeast Pacific Minke Whale Project”, led by Dr Frances Robertson.

Table 1. Monthly totals of survey days (and number of observation events) of marine mammal presence from June 1 to October 31, 2020.

		June	July	Aug	Sept	Oct	Total
Number of calendar days		30	31	31	30	31	153
Number of slowdown days		0	31	31	30	31	123
Number of survey days by primary observer		24	27	29	22	4	106
Number of survey days by primary + SSN opportunistic sighting days		26	30	29	24	10	119
SRKW	Number of whale days by primary observer (Number of events observed by primary)	0 (0)	3 (4)*^	0 (0)	0 (0)	0 (0)	3 (4)*^
	Number of whale days by primary + SSN (Number of events observed by primary + SSN)	0 (0)	3 (4)	0 (0)	2 [H] (2 [H])	1 (1)	6 [H] (7 [H])
Transient	Number of whale days by primary observer (Number of events observed by primary)	1 (2)	2 (2)	9 (14)	12 (14)	0 (0)	24 (32)
	Number of whale days by primary + SSN (Number of events observed by primary + SSN)	4 (5)	4 (6)	11 (16*)	15 (17)	1 (1)	35 (45*)
Humpback	Number of whale days by primary observer (Number of events observed by primary)	20 (64* *)	4 (4)	5 (5)	2 (2)	1 (2)	32 (77* *)
	Number of whale days by primary + SSN (Number of events observed by primary + SSN)	26 (91)	8 (12)	6 (6)	3 (3)	5 (6)	48 (118)
Minke	Number of whale days by primary observer (Number of events observed by primary)	0 (0)	0 (0)	1 (1)	1 (1)	0 (0)	2 (2)
	Number of whale days by primary + SSN (Number of events observed by primary + SSN)	0 (0)	1 (1)	1 (1)	2 (2)	0 (0)	4 (4)
All species	Number of whale days by primary observer (Number of events observed by primary)	20 (66)	7 (10)	12 (20)	14 (17)	1 (2)	54 (115)
	Number of whale days by primary + SSN (Number of events observed by primary + SSN)	26 (96)	11 (23)	15 (23)	18 (24)	7 (8)	77 (174)

Data collected by primary observer (Lucy Quayle) and sightings collected by Saturna Sighting Network (SSN) are included. As SSN observation data was opportunistic rather than following a strict survey protocol, there is no specific estimation of survey days though it is likely that one or more SSN members were observing each day.

* Event was detected over 10 km away from observation location and was seen travelling between Rosario Strait and Strait of Georgia.

^ Two events recorded on one day on July 12 where 21 individuals from J pod went through Boundary Pass and single individual followed after one hour later.

[H] One of two events in September was an acoustic detection from hydrophone recordings provided by SIMRES' East Point Hydrophone of SRKWs travelling northbound through Boundary Pass at 2:00 am confirmed by Jeanne Hyde and Lucy Quayle.

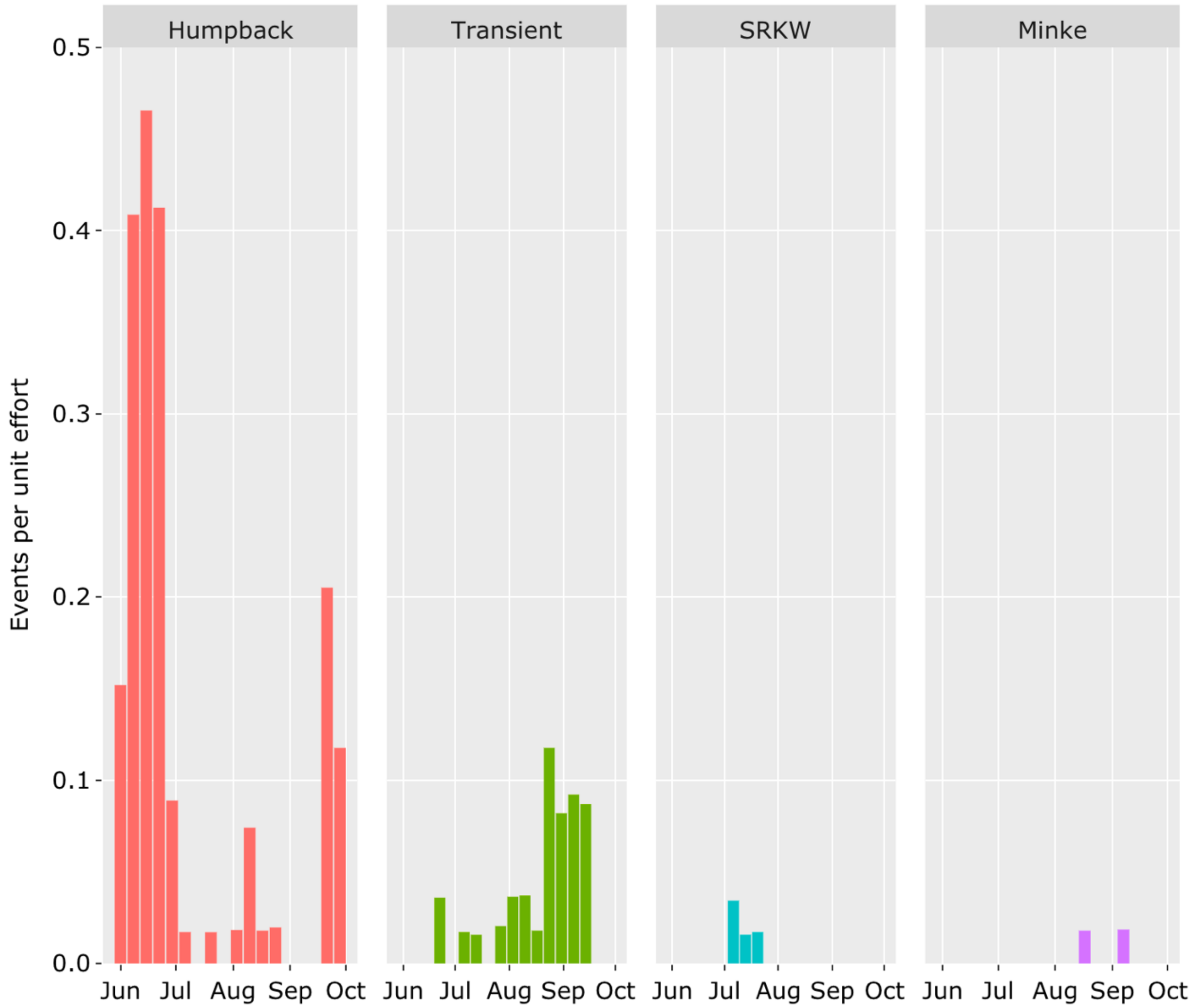

Figure 4. Number of large marine mammal events per species scaled by number of survey hours conducted per week (i.e., whale sightings per unit effort). Data cover the time period from June 4 to October 6 2020 for observation effort made by the primary observer at Boundary Pass, Saturna Island.

Whale sightings per unit effort are depicted in Figure 4. Effort was relatively stable across the months June to mid-September (Figure 5), there are only minor adjustments to the overall pattern of sightings are made across months. Sightings in late September and early October were upweighted relative to earlier in the season (e.g., compare the relative bar height of humpback whales sighted with (Figure 4) and without (Figure 3) effort correction. Whale sightings evaluated both with and without effort correction, humpback whales were the most commonly sighted whale in the region. This was particularly true during the month of June. Transient killer whales were the 2nd most common species seen in Boundary Pass, with numbers peaking from mid-August to mid-September.

The location of all cetaceans sighted across the monitoring period from East Point by the primary observer are shown in Figure 6.

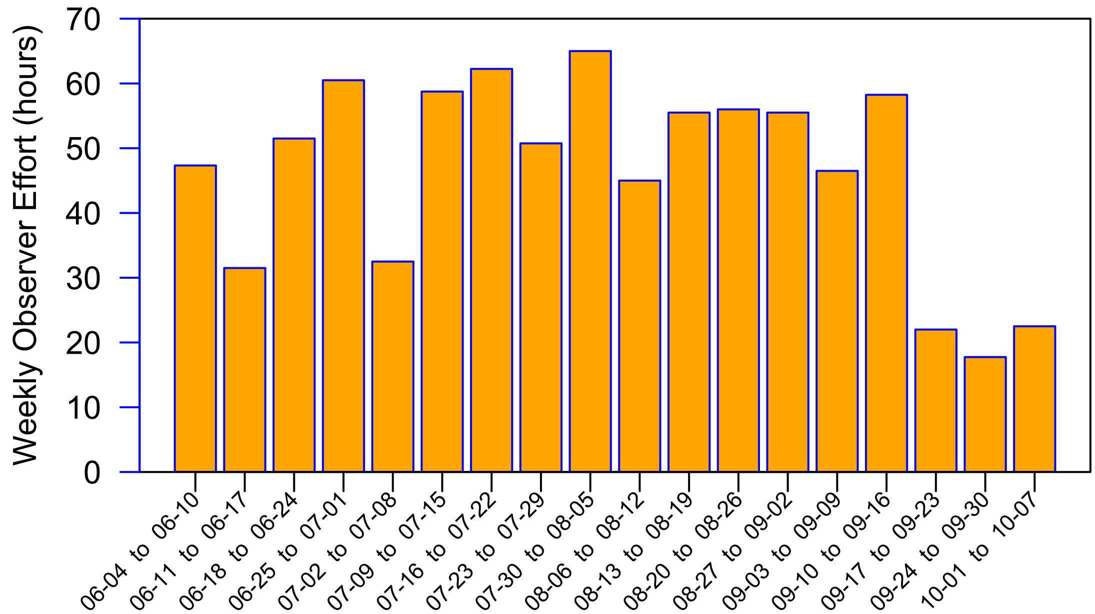

Figure 5. Weekly sum of survey effort by the primary observer from East Point Park, Saturna Island between June 4 and October 6, 2020.

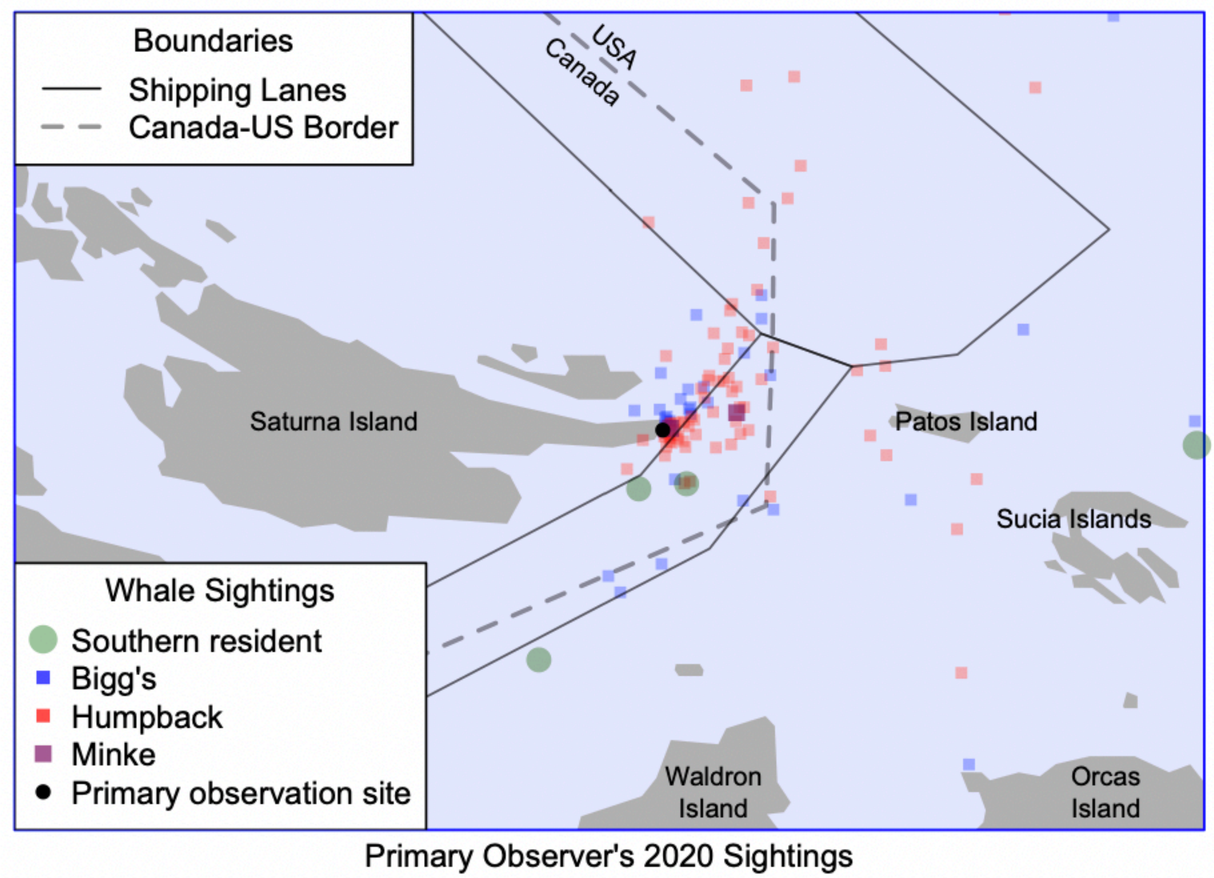

Figure 6. All cetaceans sighted across the monitoring period from East Point by the primary observer between June 4 and October 6, 2020. Sightings are shown relative to the international shipping lanes and the Canada-US Border.

Though not a part of this project, other species of note observed during the study include harbour porpoise (*Phocoena phocoena*), harbour seals (*Phoca vituline*) and an elephant seal (*Mirounga angustirostris*). A small group of harbour porpoise were seen most days throughout the season, traveling in singles or groups of two within 400 m from shore. They were found to be mostly associated with the movement of the tide, often tracing the flood tideline as it came past East Point. In August, a mother calf pair were observed and were still seen in the area at the end of the survey period. Harbour seals were also present throughout the season as they have a haul out on nearby Boiling Reef. More than 50 individuals were observed on the reef throughout the season though it appeared that their numbers were fluctuating through this time. The harbour seal pupping season started in mid-July and pups were seen accompanied by their mothers for the next 1-2 months. An elephant seal was seen at least three times during the week of August 18. This individual was seen close to shore on two occasions and once in the Boundary Pass shipping lane. It appeared to be diving for long durations in the area as it was only seen once or twice per day taking deep breaths before disappearing below the surface.

3.2. Behaviour and Location

Each species utilized unique spatial distributions in Boundary Pass and displayed varying types of behaviour over the study period. Over 55% of all observation events included travel within the Boundary Pass shipping lane and a further 19% transited through the Strait of Georgia shipping lane (Table 2).

For the three visually detected SRKW events that travelled past East Point (two on July 12 and one on July 24), all pods were observed spread out across Boundary Pass, either in small groups or as singles. J pod was estimated to have travelled as close as 20 m of the shoreline during the events on July 12, whereas K and L pod were estimated further out at 200 m on July 24. Members from all three pods also used the Boundary Pass shipping lane and took between one and two hours for all individuals to pass East Point. While all three pods displayed both travel and social behaviour (both breaching and tail slapping), no specific foraging behaviour was detected. The fourth SRKW event did not travel through Boundary Pass, instead, they travelled from Strait of Georgia near Point Roberts towards Rosario Strait. Due to the distance from East Point, no behaviour information was collected.

In contrast to the SRKW, transient killer whales travel in small family groups of 3-8 individuals, though on occasion, smaller groups would join together to make bigger groups. Most travel for transient killer whales involved hugging the shoreline, sometimes touching the shore. Over half of the transient killer whale events (53%) used Boundary Pass either transiting between Saturna Island and Waldron Island or Patos Island, or less frequently linear travel within Boundary Pass shipping lane (Table 2). Foraging behaviour was observed in 10 of 32 observation events for transient killer whales and at least four successful harbour seal captures were seen. Successful seal capture was determined when either a seal was seen in killer whale mouth and/or repetitive interactions with seal. Socialising behaviour was less common with only one breaching event when multiple family groups combined. Event duration for transient killer whales ranged from three minutes (observation time limited by heavy smoke) to over 5.5 hours. Long events were usually associated with travel far from shore, for example heading along the US side of Boundary Pass close to Orcas Island.

As previously mentioned, almost half of the humpback whale events observed by the primary observer included Heather and Neowise. This mother/calf pair displayed different movement patterns in Boundary Pass compared to the other individuals observed. Where other individuals tended to travel within the shipping lane either north towards Strait of Georgia or south towards Haro Strait, Heather and Neowise travelled closer to shore, often outside of the shipping lane. In total, over half of the humpback whale events involved movement within Boundary Pass shipping lane and a further 23% travelled within the Strait of Georgia shipping lane (Table 2). All events included travel behaviour, with general patterns of 3-5 breaths ~ 10 seconds apart followed by a long deep dive. Socialising behaviour (breaching, tail lobbing and pectoral fin slaps) were observed in 18 of 77 events. The maximum number of breaches in one event was over 60 breaches. For humpbacks, feeding behaviour was more challenging to identify since in this region of the Salish Sea these behaviours occur mostly underwater out of view. As such, foraging behaviour was not recorded for humpbacks. Observation events ranged from the detection of a single blow, to over a 3.5-hour event.

During both minke whale events, only fast travelling behaviour was observed. In both events, travel was observed through Boundary Pass and Strait of Georgia shipping lanes (Table 2). Breathing/diving pattern was more spread out (breath followed by one-minute dive) compared to humpbacks. Due to detection difficulty associated with this species' small profile and short breath cycles, events were short (from 5 minutes to just over 30 minutes) in duration.

Table 2. Marine mammal observation event locations in relation to shipping lanes observed by primary observer

Species	In shipping lanes	Outside shipping lanes		Total count of observation events
		Only near shore*	Only far channel^	
SRKW	3	-	1	4
Transient	21	7	4	32
Humpback	59	13	5	77
Minke	2	-	-	2
Total	**85**	**20**	**10**	**115**

*Movement within "only near shore" refers to movement between Saturna Island and the shipping lanes (i.e., within 300 m of shore, west of the shipping lanes).
^Movement within 'only far channel' refers to movement east of the shipping lanes, in US waters.
Only events that were seen by the primary observer are included in this table.

3.3. Vessel Presence During Marine Mammal Events

Vessels were present during 75 of the 115 (65%) marine mammal observations events recorded by primary observer (Table 3). Fifty two percent of marine mammal events included small vessels within 1000 m of a whale and 29% of events had large vessels present, thus both large and small vessels were present for 16% of observed marine mammal events. A breakdown of vessel types for both small and large vessels can be found in Appendix B. Three of four SRKW events had vessels present, however only one recreational vessel was determined to be whale watching during this time within Canadian waters.

Table 3. Number of whale observation events that had vessels within 1000 m of the whale observed by the primary observer.

Species	Vessel presence		Total number of events with vessels present **	Total number of observation events (percentage of events vessels were present)
	Count of small vessels* (no. of events with small vessels)	Count of large vessels^ (no. of events with large vessels)		
SRKWs	8 (2)	1 (1)	3	4 (75%)
Transient killer whales	154 (22)	8 (6)	24	32 (75%)
Humpback whales	84 (35)	43 (26)	47	77 (61%)
Minke whale	1 (1)	0 (0)	1	2 (50%)
All species	**247 (60)**	**52 (33)**	**75**	**115 (65%)**

*Small vessels include ecotourism, recreational, sailboat motoring, government and research boats
^Large vessels include container ship, bulk carrier, tanker, tug and Navy vessels.
**Multiple events had both small and large vessels present
Only events that were seen by the primary observer are included in this table.

4. Discussion

Summer monitoring in 2020 for SRKW in Boundary Pass began on June 4 by the primary observer. No SRKW were observed in Boundary Pass during June 2020. In 2019, using similar field methodology, Le Baron et al. (2019) reported no SRKW in June in Boundary Pass. The first day in 2020 that SRKW were reported in the Salish Sea was on July 1 in southern Haro Strait. This sighting triggered the start of ECHO Program slowdown in both Haro Strait and Boundary Pass. SRKW were not observed in Boundary Pass on this day, neither by the primary observer nor by the Saturna Sighting Network. The first detection of SRKW presence in Boundary Pass was 11 days later on July 12, 2020. This is comparable with the first SRKW in Boundary Pass in 2019 which occurred on July 6.

Historically, SRKW were known to consistently spend time in the summer and fall in the inner waters of the Salish Sea (Olson et al. 2018), and Boundary Pass was considered important foraging habitat within these inshore waters. The low number of SRKW sighting events in 2019 and 2020 in Boundary Pass is not consistent with historical spatial habitat use. In 2020, SRKW transiting Boundary Pass were observed on only 2 days (3 events) in July, between June and September. This differed from the 2019 sighting reports which reported 6 SRKW days (1 day in July, 4 days in August, and 1 day in September). Similar to 2019, all 2020 sighting events included SRKW transiting through the shipping lanes. In 2019 foraging behaviour was observed, but in 2020 SRKW transited quickly through Boundary Pass, displaying socializing (breaching and tail slaps) but no obvious foraging behaviour was observed.

When we consider occupancy at the pod level and include sightings from both the primary observer and the SSN, members from all three pods were seen in Boundary pass between June 1 and October 31, 2020. J pod was first detected travelling southbound in Boundary Pass on July 12 and again on October 25, 2020. Members from both K and L pod were observed on July 24 and K pod were seen again on September 28 by the SSN. Many times, SRKW were reported to be in Haro Strait and other areas of the Salish Sea, but were not seen earlier or later on the same day in Boundary Pass.

In 2019, Le Baron et al. (2019) observed, at least on one occasion, 18 small vessels in the vicinity of SRKW and 58 in total for all recorded events in 2019. In the 2020 study during the COVID-19 pandemic, a maximum of five small vessels were observed in the vicinity of SRKW at one time, and no persistent whale watching activity was recorded in Canadian waters. This is likely due to the new regulations that Canadian whale watching companies were required to follow. These new approach distances of 400 m in Canada as well as an effort by whale watch operators to shift their tours to viewing other cetaceans besides SRKW may have had some effect on the number of small vessels observed. Likely, one of the major contributing factors in 2020 to reduction in numbers of small vessels would be attributable to the COVID-19 Canadian/US border restrictions. These restrictions prohibited American ecotourism and recreational vessels to cross the border for the entire summer 2020 monitoring period.

In 2020, 32 transient killer whale (TKW) events were observed on 24 separate survey days by the primary observer, and a further 10 days by SSN observers. These numbers are comparable to the 35 TKW sightings on 28 days of effort reported by the observer in 2019 (Le Baron et al 2019). This indicates that Boundary Pass is an area that transient killer whales are consistently using. The transient killer whales were most present in August and September of 2020, roughly one month after the harbour seal (one of their main prey species) began pupping. To further support this, transients were observed displaying hunting behaviours around Boiling Reef, the location of seal haul out, in 10 of 32 events, four of which were deemed successful.

Interestingly, the temporal presence of transient killer whales in Boundary Pass in 2020 was not consistent with the timings of the 2019 observations in Le Baron et al. (2019). In 2019, the highest numbers of transients were seen in June and July whereas these months had the lowest numbers of sightings in 2020. This indicates that transient killer whale movement is dynamic throughout the seasons and from year to year. Each family group likely uses this area differently, perhaps depending on prey availability, movement patterns of other family groups and even presence of SRKW.

Humpback whales had the highest daily presence out of all cetaceans observed in Boundary Pass. They were detected on 32 of the survey days by the primary observer and a further 16 by SSN observers. Humpback whale detections were particularly concentrated in June 2020 where whales were seen on 19 of the days. Furthermore, 60 of a total 72 humpback events, or 83% occurred in this month. One mother humpback was consistently present with her newborn calf throughout the month including spending a significant amount of time in the shipping lanes. The 2020 high prevalence of events in June is consistent with 2019 observations in which Le Baron et al (2019) similarly reported a high number of humpback whale events in June (24 events), many of which were found to be in the shipping lanes. Humpback numbers in September were higher in 2019 (16 events) compared to the single sighting for September of 2020. Recent reports from the SSN indicate that humpback whale events increased during late November/early December in 2020, often including three or more individuals per day.

No active lunge feeding by humpbacks was observed during the study period, likely due to the strong currents that are prevalent in the area. Boundary Pass is an important transit route for humpback whales moving through to the Strait of Georgia. As there were relatively few humpback whale observations after July, this may indicate low food availability in the nearby areas or a relative higher availability elsewhere. Local reports from ecotourism companies, other citizen scientist initiatives including happywhale.com, indicate that during the summer when humpbacks were rarely seen in Boundary Pass, high densities of humpback whales were located in the Strait of Georgia near Galliano Island and in Juan de Fuca Strait, south of Victoria.

In 2020, the primary observer spotted two solitary minke whale sightings near East Point, one in August and one in September. The SSN doubled this number to 4 sightings. This species was not reported in 2019 and the species remains rare in the region (Dr Frances Robertson, personal communication).

Limitations of this study included weather conditions that contributed to poor visibility, such as dense fog, forest fire smoke, strong winds and rough sea state, and/or heavy rain. Increased distance of marine mammals from shore decreased detectability confidence (i.e., the detection function; see Buckland et al. 2004), and this likely resulted in some unseen surfacing of whales. Observations in the far channel, east of the shipping lanes were usually detected because ecotourism vessels were present. Additionally, observations could not be conducted during all daylight hours since there was only one observer present at a time. The primary observer found capturing detailed behavioural information on SRKW when present in large group sizes challenging, particularly when the individuals were widely spatially distributed from one another.

Working with the SSN resulted in benefits besides additional sightings. This synergy of efforts contributed to a collaborative alert system for whales approaching Boundary Pass. This ensured that whales were spotted sooner, and their movement could be monitored for longer in the vicinity of the shipping lanes.

5. Conclusions and Recommendations

Since little information on current area usage, behaviour, and general presence is available for marine mammals in Boundary Pass, this study aimed to gain further understanding of this area through land-based surveys from June 4 to October 6, 2020. It also provided insights into the relationship that exists between marine mammal presence and vessel activity in this area. This study found that:

- Between June 4 and October 6 2020, whales were observed on 54 of the total 106 survey days and during this time, 115 unique whale events were recorded.
- Members from all three SRKW pods were seen in Boundary pass during the ECHO Program voluntary vessel slowdown monitoring period between June 1 and October 31, 2020. During the slowdown, five SRKW events were observed in Boundary Pass over four days by the primary observer and/or the Saturna Sighting Network, indicating SRKW presence for 3% of the slowdown days. SRKW were observed travelling within the shipping lane and close to Saturna Island shoreline. No SRKW foraging events were recorded.
- Marine mammal species utilized unique spatial distributions in Boundary Pass and displayed varying types of behaviour over the study period. Over 74% of all whale events viewed by the primary observer included travel within the shipping lanes.
- Of the whale species observed, the greatest number of events were recorded for humpback whales, most frequently detected in June 2020, displaying travelling and socializing behaviour, followed by transient killer whales who were frequently present in Boundary Pass, seen travelling, socializing and foraging on harbour seals.
- Vessels, both large and small, were seen to be within 1,000 metres of whales for 65% of the events viewed by the primary observer. Of note is that a maximum of three small vessels at a time were observed proximate to SRKW in Canadian waters, and none of these were identified as persistent or extended whale watching.
- The collaboration with the Saturna Sighting Network greatly enhanced the observations both outside of survey hours and during primary observer vacation days.

Based on the findings of this study, with consideration to previous use of Boundary Pass, continuation of this study would enable the comparison of data from multiple summers, which would help distinguish whether the similarities and differences between spatial and behavioural observations in 2019 and 2020 are consistent or are changing year to year. The COVID-19 pandemic and associated vessel restrictions may have influenced behaviour and movement within the Salish Sea for all species through a change or reduction in ecotourism traffic, recreational and commercial vessels.

It is recommended that a more detailed reporting protocol may be developed with the Saturna Sighting Network, to improve detail of observations collected by this volunteer group, allowing for more analysis to be conducted.

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Appendix A. Marine Mammal Observation Event Data

Note: Observations were collected by primary observer Lucy Quayle, between June 4 and October 6 2020, indicated by "LQ" in Group column. Saturna Sighting Network observations were collected between June 1 and October 31 and are indicated by "SSN" in Group column. As SSN observation data were collected by citizen scientists, not all columns were filled out, and as such, gaps are denoted with 'ND' meaning No Data. Direction of travel: for LQ sightings north is heading towards Strait of Georgia and south is generally heading to Haro Strait, for SSN sightings, directions are relative to their site location. Zone: Near zone: to the east of shipping lanes closest to Saturna Island, Far zone: to the west side of shipping lanes in US waters, BP: Boundary Pass shipping lane, SoG: Strait of Georgia shipping lane. When there was limited visibility due to fog or heavy smoke, the 'modified survey protocol' was followed and is indicated in notes column. Coordinates of survey sites (1-6) are provided in Section 2.1.

Date	Group	Daily event no.	Start time	End time	Species/ Population	Pod, matriline or individual ID	No. of individuals	Travel direction	Closest est. distance (m)	Zone	Behaviour	Vessel present	Notes	Site
06-01-20	SSN	1	13:29	13:40	Humpback	KEY0002	1	S	100	ND	Travel	ND		Cliffside 4
06-01-20	SSN	2	20:26	21:01	Humpback	Unknown	2	V	ND	ND	Travel	ND		East Point 1
06-02-20	SSN	1	8:40	-	Transient	Unknown	ND	N/NE	100	ND	Travel	ND		Cliffside 4
06-02-20	SSN	2	9:58	-	Humpback	Unknown	1	E	ND	ND	Travel	ND		Cliffside 4
06-02-20	SSN	3	12:16	-	Humpback	Unknown	3	E	ND	ND	Travel, Social	ND		Cliffside 5
06-02-20	SSN	4	13:48	-	Humpback	Unknown	1	W	ND	ND	Travel	ND		Cliffside 4
06-02-20	SSN	5	19:20	-	Humpback	Unknown	2	SW	200	ND	Travel	No		Cliffside 4
06-03-20	SSN	1	8:59	11:20	Humpback	Unknown	2	S	200	ND	Travel	ND		Cliffside 4/6
06-03-20	SSN	2	11:00	-	Humpback	Unknown	3	V	ND	ND	Travel	ND		Cliffside 4/6
06-04-20	SSN	1	21:35	-	Humpback	Unknown	2	V	ND	ND	Travel, Social	ND	Some breaching	Cliffside 4
06-04-20	LQ		No events											East Point 1

Date	Group	Daily event no.	Start time	End time	Species/ Population	Pod, matriline or individual ID	No. of individuals	Travel direction	Closest est. distance (m)	Zone	Behaviour	Vessel present	Notes	Site
06-05-20	LQ	1	15:44	16:30	Humpback	BCY0160, Neowise	2	N	50	Near zone	Travel, Social	Yes		East Point 1
06-05-20	SSN	2	21:09	-	Humpback	BCY0160, Neowise	2	S	200	ND	Travel	ND		Cliffside 4
06-06-20	SSN	1	7:30	-	Humpback	BCY0160, Neowise	2	SW	ND	ND	Travel	ND		Cliffside 6
06-06-20	LQ	2	14:55	15:15	Humpback	BCY0160, Neowise	2	E	100	BP	Travel, Social	No	Some breaching	East Point 1
06-06-20	SSN	3	21:52	-	Humpback	BCY0160, Neowise	2	SW	ND	ND	Travel	ND		Cliffside 4
06-06-20	SSN	4	22:28	-	Transient	Unknown	4 to 9	W	ND	ND	Travel	ND	Heard but not seen	Cliffside 5
06-07-20	SSN	1	9:06	-	Humpback	BCY0160, Neowise	2	N	200	ND	Travel	ND		Cliffside 4
06-07-20	LQ	2	12:00	12:20	Humpback	Unknown	1	N	10000	Far zone	Travel	Yes	Seen travelling from direction of Rosario Strait towards Strait of Georgia	East Point 1
06-07-20	LQ	3	13:30	14:15	Humpback	BCY0160, Neowise	2	N	150	BP	Travel, Social	Yes		East Point 1
06-07-20	SSN	4	21:07	-	Humpback	BCY0160, Neowise	2	N	200	ND	Travel	ND		Cliffside 4
06-08-20	SSN	1	7:05	-	Humpback	BCY0160, Neowise	2	N	200	ND	Travel, Social	ND		Cliffside 4
06-08-20	LQ	2	9:21	9:30	Humpback	BCY0160, Neowise	2	SW	100	Near zone	Travel	No		East Point 1
06-08-20	LQ	3	14:57	15:16	Humpback	BCY0160, Neowise	2	NE/N	100	BP	Travel	No		East Point 1
06-08-20	SSN	4	18:34	-	Humpback	Unknown	1	E	ND	ND	Travel	ND		Cliffside 4
06-09-20	SSN	1	7:40	-	Humpback	Unknown	1	W	ND	ND	Travel	ND		Cliffside 4

Date	Group	Daily event no.	Start time	End time	Species/ Population	Pod, matriline or individual ID	No. of individuals	Travel direction	Closest est. distance (m)	Zone	Behaviour	Vessel present	Notes	Site
06-09-20	LQ	2	15:10	15:30	Humpback	BCY0160, Neowise	2	N	100	BP	Travel	No		East Point 1
06-10-20	LQ	1	9:20	9:36	Humpback	Unknown	1	NW	5000	SoG	Travel	NA		East Point 1
06-10-20	LQ	2	9:52	10:50	Humpback	BCY0160, Neowise	2	S	100	BP	Travel	Yes		East Point 1
06-10-20	LQ	3	12:44	12:47	Humpback	Unknown	1	S	100	Near zone	Travel	No		East Point 1
06-10-20	LQ	4	13:05	13:15	Humpback	Unknown	1	N	300	Near zone	Travel	No		East Point 1
06-10-20	LQ	5	13:37	14:00	Humpback	BCY0160, Neowise	2	N	100	Near zone	Social, Travel	No		East Point 1
06-10-20	SSN	6	16:53	-	Humpback	BCY0160, Neowise	2	V	ND	ND	Travel	ND		East Point 1
06-11-20	LQ		No events											East Point 1
06-12-20	LQ	1	9:07	11:17	Humpback	BCY0160, Neowise	2	~SW-NE-SW	100	Near zone	Social, Travel	Yes		East Point 1
06-12-20	LQ	2	9:24	10:15	Humpback	BCX1210	1	S	200	BP	Travel	Yes		East Point 1
06-12-20	LQ	3	12:40	12:45	Humpback	BCX1210	1	N/SW	400	Near zone	Travel	No		East Point 1
06-12-20	LQ	4	15:00	15:20	Humpback	BCY0160, Neowise	2	N	300	BP	Travel	Yes		East Point 1
06-12-20	LQ	5	15:04	15:20	Humpback	Unknown	1	S	300	Near zone	Travel	No		East Point 1
06-12-20	LQ	6	15:08	15:08	Humpback	Unknown	1	NW	2500	Near zone	Travel	Yes		East Point 1
06-12-20	SSN	7	15:42	-	Humpback	BCX1210	1	W	500	ND	Travel	NA		Cliffside 4

Date	Group	Daily event no.	Start time	End time	Species/ Population	Pod, matriline or individual ID	No. of individuals	Travel direction	Closest est. distance (m)	Zone	Behaviour	Vessel present	Notes	Site
06-12-20	SSN	8	16:16	-	Humpback	BCY0160, Neowise	2	S	1500	ND	Travel, Social	NA		Cliffside 4
06-13-20	SSN	1	9:24	-	Humpback	BCY0160, Neowise	2	W	ND	ND	Travel	NA		Cliffside 4
06-13-20	LQ		No survey conducted										Primary observer not on Island	
06-14-20	SSN	1	8:48	-	Humpback	BCY0160, Neowise	2	W	ND	ND	Travel, Social	NA		Cliffside 4
06-14-20	LQ		No survey conducted										Primary observer not on Island	
06-15-20	LQ		No survey conducted										Primary observer not on Island	
06-16-20	LQ	1	10:39	13:05	Humpback	BCY0160, Neowise	2	N	1000	BP, SoG	Travel, Social	Yes		East Point 1
06-16-20	LQ	2	15:31	16:05	Humpback	BCY0160, Neowise	2	S	4000	BP	Travel	No		East Point 1
06-16-20	LQ	3	17:02	17:45	Humpback	BCY0160, Neowise	2	S	100	BP	Travel, Social	Yes		East Point 1
06-16-20	SSN	4	22:20	-	Humpback	BCY0160, Neowise	2	E	ND	ND	Travel, Social	ND	Some breaching	East Point 1
06-17-20	LQ	1	9:26	10:15	Humpback	Unknown	1	NE	2500	SoG	Travel	No		East Point 1
06-17-20	LQ	2	10:17	11:15	Humpback	BCY0160, Neowise	2	N	100	SoG	Travel, Social	Yes		East Point 1
06-17-20	LQ	3	10:50	11:14	Humpback	Unknown	1	NE	5000	SoG	Travel	No		East Point 1
06-17-20	LQ	4	18:20	18:30	Humpback	BCY0160, Neowise	2	S	100	Near zone	Travel	No		East Point 1
06-17-20	SSN	5	21:18	-	Humpback	BCY0160, Neowise	2	E	ND	ND	Travel	NA		Cliffside 4

Date	Group	Daily event no.	Start time	End time	Species/ Population	Pod, matriline or individual ID	No. of individuals	Travel direction	Closest est. distance (m)	Zone	Behaviour	Vessel present	Notes	Site
06-18-20	LQ	1	13:33	13:33	Humpback	Unknown	1	N	5000	SoG	Travel	No		East Point 1
06-18-20	LQ	2	15:04	15:22	Humpback	BCY0160, Neowise	2	N	200	Near zone	Travel	No		East Point 1
06-18-20	SSN	3	15:28	-	Humpback	Unknown	1	E	ND	ND	Travel	ND		Tumbo Ch. 3
06-19-20	LQ	1	9:20	11:00	Humpback	MMZ0004	1	N	4500	BP, SoG	Travel	Yes		East Point 1
06-19-20	LQ	2	10:00	10:44	Humpback	Unknown	1	N	6000	SoG	Social	Yes	Many breaches	East Point 1
06-19-20	LQ	3	11:09	11:50	Humpback	BCX1251	1	N	500	BP	Travel	Yes		East Point 1
06-19-20	LQ	4	12:22	12:42	Humpback	BCY0160, Neowise	2	N	100	Near zone	Travel	Yes		East Point 1
06-19-20	LQ	5	13:24	13:50	Humpback	BCY0160, Neowise	2	N	4000	SoG	Travel	Yes		East Point 1
06-19-20	LQ	6	13:30	14:10	Humpback	MMZ0004	1	SE	4000	SoG	Travel, Social	Yes		East Point 1
06-19-20	LQ	7	19:20	20:05	Humpback	MMZ0004	1	S	100	BP, SoG	Travel	No		East Point 1
06-20-20	LQ	1	9:14	9:36	Humpback	BCX1251	1	N	600	BP	Travel	Yes		East Point 1
06-20-20	SSN	2	9:45	-	Humpback	Unknown	1	W	ND	ND	Travel	ND		Cliffside 4/5
06-20-20	LQ	3	11:56	12:15	Humpback	MMZ0004	1	N	300	SoG	Travel	Yes		East Point 1
06-20-20	LQ	4	13:25	13:55	Humpback	Unknown	1	NE	10000	Far zone	Travel	Yes	Seen travelling from direction of Rosario Strait towards Strait of Georgia	East Point 1
06-20-20	LQ	5	14:48	14:49	Humpback	Unknown	1	N	3000	SoG	Travel	No		East Point 1

Date	Group	Daily event no.	Start time	End time	Species/ Population	Pod, matriline or individual ID	No. of individuals	Travel direction	Closest est. distance (m)	Zone	Behaviour	Vessel present	Notes	Site
06-21-20	LQ	1	9:30	12:10	Humpback	BCX1251	1	N	600	BP, SoG	Travel	Yes		East Point 1
06-21-20	LQ	2	12:10	14:30	Humpback	MMZ0004	1	N	800	BP, SoG	Travel	Yes		East Point 1
06-21-20	SSN	3	18:53	-	Humpback	Unknown	1	V	ND	ND	Travel	ND		East Point 1
06-22-20	LQ	1	9:18	11:25	Humpback	MMZ0004	1	N	400	BP, SoG	Travel	Yes		East Point 1
06-22-20	LQ	2	9:18	11:35	Humpback	BCX1251	1	N	400	BP, SoG	Travel	Yes		East Point 1
06-22-20	LQ	3	12:21	13:57	Humpback	MMZ0004	1	S	1000	BP, SoG	Travel	Yes		East Point 1
06-22-20	LQ	4	12:47	12:54	Humpback	BCX1251	1	N	100	SoG	Travel	Yes		East Point 1
06-22-20	SSN	5	16:24	-	Transient	Unknown	4	E	ND	ND	Travel	ND		Tumbo Ch. 2/3
06-23-20	LQ	1	9:20	9:20	Humpback	Unknown	1	NE	7000	SoG	Travel	Yes		East Point 1
06-23-20	LQ	2	9:43	9:43	Humpback	BCY0160, Neowise	2	N	3000	SoG	Travel	No		East Point 1
06-23-20	LQ	3	9:53	9:53	Humpback	MMZ0004	1	NE	3000	SoG	Travel	No		East Point 1
06-23-20	LQ	4	10:40	11:15	Humpback	BCX1251	1	NE	3500	SoG	Social	Yes		East Point 1
06-23-20	LQ	5	11:38	12:17	Humpback	BCY0160, Neowise	2	S	1000	BP	Travel	Yes		East Point 1
06-23-20	LQ	6	14:38	15:20	Humpback	BCY0160, Neowise	2	N	500	BP, SoG	Travel	No		East Point 1
06-23-20	LQ	7	14:45	15:20	Humpback	MMZ0004	1	N	400	BP, SoG	Travel	No		East Point 1

Date	Group	Daily event no.	Start time	End time	Species/ Population	Pod, matriline or individual ID	No. of individuals	Travel direction	Closest est. distance (m)	Zone	Behaviour	Vessel present	Notes	Site
06-24-20	LQ	1	10:40	11:19	Transient	T049As	4	N/NE	5	BP	Travel, Forage	Yes		East Point 1
06-24-20	LQ	2	11:21	11:35	Humpback	Unknown	2	S	5000	Far zone	Social	Yes		East Point 1
06-24-20	LQ	3	11:57	11:57	Humpback	Unknown	1	S	2500	SoG	Travel	No		East Point 1
06-24-20	LQ	4	12:25	13:00	Humpback	BCY0160, Neowise	2	N	400	BP, SoG	Travel, Social	Yes		East Point 1
06-24-20	LQ	5	13:09	13:16	Humpback	BCX1251	1	N	400	BP, SoG	Travel	Yes		East Point 1
06-24-20	LQ	6	14:03	14:07	Humpback	BCY0160, Neowise	2	N	6000	SoG	Social	No	Some breaching	East Point 1
06-24-20	LQ	7	14:32	15:00	Humpback	MMZ0004	1	N	450	BP	Travel	No		East Point 1
06-24-20	LQ	8	15:55	17:01	Transient	T049As	4	~NW	100	BP	Travel, Forage	No	Likely successful kill of harbour seal.	East Point 1
06-25-20	LQ	1	9:25	11:06	Humpback	MMZ0004	1	V	700	BP, SoG	Travel	Yes		East Point 1
06-25-20	LQ	2	11:51	15:30	Humpback	MMZ0004	1	V-S	1500	BP	Travel	Yes		East Point 1
06-26-20	LQ		No events											East Point 1
06-27-20	LQ	1	9:30	13:10	Humpback	BCY0160, Neowise	2	~S	200	BP, SoG	Travel, Social	Yes		East Point 1
06-27-20	LQ	2	16:10	18:15	Humpback	BCY0160, Neowise	2	N/S	200	BP	Travel	Yes		East Point 1
06-28-20	LQ	1	13:04	14:47	Humpback	BCY0160, Neowise	2	~S	2000	BP, SoG	Travel, Social	Yes	Many breaches	East Point 1
06-28-20	LQ	2	16:01	17:06	Humpback	BCY0160, Neowise	2	N	100	BP, SoG	Travel, Social	Yes		East Point 1

Date	Group	Daily event no.	Start time	End time	Species/ Population	Pod, matriline or individual ID	No. of individuals	Travel direction	Closest est. distance (m)	Zone	Behaviour	Vessel present	Notes	Site
06-29-20	LQ	1	10:09	11:01	Humpback	BCY0409	1	S	600	BP	Travel	Yes		East Point 1
06-30-20	LQ		No events											East Point 1
07-01-20	LQ	1	7:09	7:10	Humpback	Unknown	1	SE	6000	Far zone	Travel	No		East Point 1
07-02-20	LQ	1	12:00	12:01	Humpback	Unknown	1	Unknown	3000	BP	Travel	Yes		East Point 1
07-02-20	SSN	2	20:33	-	Humpback	BCY0160, Neowise	2	S/W	ND	ND	Travel	NA		Cliffside 5
07-03-20	SSN	1	14:34	-	Humpback	Unknown	1	NE	500	ND	Travel	NA		Cliffside 4
07-03-20	LQ		No survey conducted										Primary observer not on Island	
07-04-20	SSN	1	6:51	-	Transient	T037As	5~10	ND	ND	ND	Travel	NA		Cliffside 4
07-04-20	SSN	2	7:30	-	Humpback	BCY0160, Neowise	2	ND	ND	ND	Travel	NA		Cliffside 4
07-04-20	SSN	3	10:00	14:03	Humpback	BCY0160, Neowise	2	ND	ND	ND	Travel, Social	NA		Cliffside 5
07-04-20	SSN	4	19:00	-	Transient	Unknown	5~7	SE	ND	ND	Travel	NA		Cliffside 5
07-04-20	SSN	5	19:47	-	Humpback	BCY0160, Neowise	2	SW	ND	ND	Travel	NA		Cliffside 6
07-04-20	LQ		No survey conducted										Primary observer not on Island	
07-05-20	SSN	1	11:14	12:10	Transient	Unknown	5~10	SW	ND	ND	Travel	Yes		Cliffside 4
07-05-20	SSN	2	14:25	-	Minke	Unknown	1	E	ND	ND	Travel	NA		Tumbo Ch. 2

Date	Group	Daily event no.	Start time	End time	Species/ Population	Pod, matriline or individual ID	No. of individuals	Travel direction	Closest est. distance (m)	Zone	Behaviour	Vessel present	Notes	Site
07-05-20	LQ		No survey conducted										Primary observer not on Island	
07-06-20	LQ	2	12:25	18:00	Transient	T034s, T036s, T046s, T122s.	~15	NNE	4500	SoG	Travel, Social, Forage	Yes		East Point 1
07-07-20	LQ		No events											East Point 1
07-08-20	LQ		No events											East Point 1
07-09-20	LQ		No events											East Point 1
07-10-20	LQ		No events											East Point 1
07-11-20	LQ		No events											East Point 1
07-12-20	LQ	1	8:50	9:59	SRKW	J pod	~21	SSW	20	BP, SoG	Travel, Social	No	Very spread out across Boundary Pass, some breaches	East Point 1
07-12-20	LQ	2	11:25	11:37	SRKW	J pod	1	SSW	500	BP, SoG	Travel	Yes	One individual following behind main pod	East Point 1
07-12-20	LQ	3	14:25	15:14	Humpback	Unknown	1	N	300	BP	Travel	Yes		East Point 1
07-13-20	LQ	1	15:00	15:01	SRKW	J pod	~22	SE	12300	Far zone	Travel, Social	Yes	Far away, first seen Active pass 7:15, Pt Roberts 10:30 then Rosario Strait.	East Point 1
07-14-20	LQ		No events											East Point 1
07-15-20	LQ		No events											East Point 1
07-16-20	LQ		No events											East Point 1

Date	Group	Daily event no.	Start time	End time	Species/ Population	Pod, matriline or individual ID	No. of individuals	Travel direction	Closest est. distance (m)	Zone	Behaviour	Vessel present	Notes	Site
07-17-20	SSN	1	9:19	-	Humpback	Unknown	1	E	ND	ND	Travel	ND		Cliffside 4
07-17-20	LQ	2	15:27	16:20	Transient	T065As, T037As	~8	NW	2000	BP, SoG	Travel	Yes		East Point 1
07-18-20	LQ		No events											East Point 1
07-19-20	LQ		No events											East Point 1
07-20-20	LQ		No events											East Point 1
07-21-20	LQ		No events											East Point 1
07-22-20	SSN	1	21:23	-	Humpback	Unknown	2	NW	2000	-	Travel	No		Tumbo Ch. 2
07-22-20	LQ		No events											East Point 1
07-23-20	LQ		No events											East Point 1
07-24-20	LQ	1	14:30	16:30	SRKW	K pod, L pod	18	S	200	BP, SoG	Travel, Social	Yes		East Point 1
07-24-20	LQ	2	17:44	18:08	Humpback	BCX0870	1	N	2000	BP, SoG	Travel	Yes		East Point 1
07-24-20	SSN	3	19:29	-	Humpback	Unknown	1	SE	ND	ND	Travel	ND		Tumbo Ch. 2
07-25-20	LQ		No events											East Point 1
07-26-20	LQ		No events											East Point 1
07-27-20	LQ		No events											East Point 1

Date	Group	Daily event no.	Start time	End time	Species/ Population	Pod, matriline or individual ID	No. of individuals	Travel direction	Closest est. distance (m)	Zone	Behaviour	Vessel present	Notes	Site
07-28-20	LQ		No survey conducted										Primary observer day off	
07-29-20	LQ		No events											East Point 1
07-30-20	LQ		No events											Cliffside 4
07-31-20	LQ		No events											Cliffside 4
08-01-20	LQ	1	14:51	17:22	Transient	T099s	4	SE/SW	1	BP, SoG	Travel, Forage	Yes	Likely successful seal hunt	East Point 1
08-02-20	LQ		No events											East Point 1
08-03-20	LQ		No events											East Point 1
08-04-20	LQ		No events											East Point 1
08-05-20	LQ	1	9:45	10:15	Humpback	BCX0915, Unknown	2	N	300	BP	Travel	No		East Point 1
08-05-20	LQ	2	11:40	11:55	Transient	T018, T019, T019B, T019C	4	NE	50	BP	Travel	Yes		East Point 1
08-05-20	LQ	3	15:00	16:30	Transient	T018, T019, T019B, T019C	4	NW	400	BP	Travel	Yes		East Point 1
08-06-20	LQ		No survey conducted										Primary observer day off	
08-07-20	SSN	1	8:07	-	Transient	Unknown	4	W	ND	ND	Travel	ND		Cliffside
08-07-20	LQ		No events											East Point 1

Date	Group	Daily event no.	Start time	End time	Species/ Population	Pod, matriline or individual ID	No. of individuals	Travel direction	Closest est. distance (m)	Zone	Behaviour	Vessel present	Notes	Site
08-08-20	SSN	1	14:38	-	Transient	Unknown	4	N	ND	ND	Travel	ND		East Point 1
08-08-20	LQ		No events											Cliffside 4
08-09-20	LQ		No events											Cliffside 4
08-10-20	LQ		No events											Cliffside 4
08-11-20	LQ		No events											Cliffside 4
08-12-20	LQ	1	11:15	12:00	Transient	T036As	3	NNW	400	SoG	Travel	Yes		East Point 1
08-13-20	LQ	1	11:00	12:00	Transient	T018s, T036As	~7	SE/NW	3300	SoG	Travel	Yes		East Point 1
08-13-20	LQ	2	14:10	15:20	Transient	T018s, T036As	~15	SE	2300	BP, SoG	Travel, Social	Yes		East Point 1
08-13-20	LQ	3	16:20	17:00	Transient	T065As, T137As	~6	NE	4500	Far zone	Travel	Yes		East Point 1
08-13-20	LQ	4	17:00	17:36	Humpback	Unknown	2	NNW	3000	BP, SoG	Travel	No		East Point 1
08-14-20	LQ		No events											East Point 1
08-15-20	LQ		No events											East Point 1
08-16-20	LQ	1	9:12	9:30	Humpback	Unknown	1	NE	4500	Far zone	Travel	Yes		East Point 1
08-17-20	LQ	1	13:23	13:54	Humpback	Unknown	1	N	8000	SoG	Travel	Yes		East Point 1
08-18-20	SSN	1	13:53	-	Humpback	Unknown	1	E	ND	ND	Travel	ND		Cliffside 4

Date	Group	Daily event no.	Start time	End time	Species/ Population	Pod, matriline or individual ID	No. of individuals	Travel direction	Closest est. distance (m)	Zone	Behaviour	Vessel present	Notes	Site
08-18-20	LQ		No events											East Point 1
08-19-20	LQ		No events											East Point 1
08-20-20	LQ	1	10:45	10:50	Minke	Unknown	1	N	300	BP	Travel	No		East Point 1
08-21-20	LQ		No events											East Point 1
08-22-20	LQ	1	10:55	13:00	Transient	T065As, T137A	4	SE	12000	Far zone	Travel	Yes	Travelled from Strait of Georgia to Rosario Strait	East Point 1
08-23-20	LQ		No events											East Point 1
08-24-20	LQ	1	13:00	14:00	Transient	T100s	4	NW/SW	10600	Far zone	Travel	Yes	Travelled from Clarke Island to Orcas Island through to President Channel	East Point 1
08-25-20	LQ	1	10:59	11:33	Transient	T065Bs	3	SW	20	Near zone	Travel, Forage	Yes		East Point 1
08-25-20	LQ	2	15:45	16:30	Transient	T065Bs	3	ESE	4500	BP	Travel	Yes		East Point 1
08-25-20	LQ	3	15:45	18:15	Transient	T046s, T137A, T137B	4+	N	5000	Far zone	Travel	Yes		East Point 1
08-26-20	LQ	1	14:08	14:48	Humpback	MMZ0004	1	NW	1200	BP, SoG	Travel	Yes		East Point 1
08-26-20	LQ	2	15:33	15:54	Transient	T037As	5	SSW	5	BP	Forage, Travel, Social	Yes	Successful hunt of seal, interrupted by small vessel	East Point 1
08-27-20	LQ		No events											East Point 1
08-28-20	LQ	1	18:00	20:00	Transient	T037As	5	N/S	5	BP	Forage, Travel	Yes	Reduced visibility due to fog until 11am	East Point 1

Date	Group	Daily event no.	Start time	End time	Species/ Population	Pod, matriline or individual ID	No. of individuals	Travel direction	Closest est. distance (m)	Zone	Behaviour	Vessel present	Notes	Site
08-29-20	LQ		No events										Sea state very rough in am (Beaufort 5), very windy	East Point 1
08-30-20	LQ		No survey conducted										Primary observer day off	
08-31-20	LQ		No events											East Point 1
09-01-20	LQ	1	16:59	17:51	Transient	T065Bs, T036As	6	S	100	BP	Travel	No		East Point 1
09-02-20	LQ		No events											East Point 1
09-03-20	SSN	1	7:34	-	Transient	Unknown	6	W	ND	ND	Travel	ND		Cliffside 4
09-03-20	LQ		No events										Reduced visibility due to fog until 11am	East Point 1
09-04-20	LQ	1	10:57	12:46	Transient	T065Bs	3	VS	5	Near zone	Forage, Travel	Yes	At least one successful seal hunt	East Point 1
09-05-20	LQ	1	7:00	7:36	Transient	Unknown	12	N	200	SoG	Travel	No		East Point 1
09-05-20	LQ	2	13:50	14:08	Transient	T065Bs	3	S	200	BP	Travel	Yes		East Point 1
09-06-20	LQ	1	16:30	17:40	Transient	T018, T019, T019B, T019C	4	N	5	BP	Travel	Yes	Half day of survey	East Point 1
09-07-20	LQ	1	11:00	11:15	Transient	T018, T019, T019B, T019C	4	S	5	Near zone	Travel	Yes	Half day of survey	East Point 1
09-08-20	LQ		No events										Reduced visibility (10km) due to smoke.	East Point 1
09-09-20	LQ	1	18:45	19:00	Transient	T100s	4	W	200	BP	Travel	No	Reduced visibility (10km) due to smoke.	Tumbo Ch. 2

Date	Group	Daily event no.	Start time	End time	Species/ Population	Pod, matriline or individual ID	No. of individuals	Travel direction	Closest est. distance (m)	Zone	Behaviour	Vessel present	Notes	Site
09-10-20	LQ	1	8:30	8:45	Transient	T100s	4	W	200	Near zone	Travel	No	Reduced visibility (20km) due to smoke.	Tumbo Ch. 2
09-10-20	LQ	2	15:05	15:36	Minke	Unknown	1	VN	150	BP	Travel	Yes	Reduced visibility (10km) due to smoke.	East Point 1
09-11-20	LQ	1	11:46	11:54	Transient	T123s	4	NE	20	Near zone	Travel	No	Reported North of Sucia Island 1400. Reduced visibility (4km) due to smoke.	East Point 1
09-12-20	SSN	1	2:11	3:11	SRKW	Unknown	Unknown	N	ND	ND	ND	Yes	Only acoustic detection. Reduced visibility (300m) due to smoke/fog. Modified survey protocol used.	East Point 1
09-12-20	LQ	2	8:50	9:20	Transient	T065Bs	3	S	5	BP	Travel, Forage	No	Reduced visibility (300m) due to smoke/fog. Modified survey protocol used	East Point 1
09-13-20	LQ		No events										Restricted visibility <1500m due to smoke/fog. Modified survey protocol used	East Point 1
09-14-20	LQ		No events										Reduced visibility <1000m due to smoke/fog. Modified survey protocol used	East Point 1
09-15-20	LQ		No events										Reduced visibility 400m due to smoke/fog. Modified survey protocol used	East Point 1
09-16-20	LQ	1	10:42	10:49	Transient	T100s	3	N	200	Near zone	Travel	No	Reduced visibility 1500-2500m due to smoke/fog. Modified survey protocol used	East Point 1
09-17-20	LQ	1	9:00	9:23	Transient	Unknown	3	N	0	Near zone	Travel, Forage	Yes	Reduced visibility 400-1000m due to smoke/fog. Modified survey protocol used	East Point 1
09-18-20	LQ		No events										Fog/smoke lifting. Reduced visibility < 5000m. Modified survey protocol used	East Point 1
09-19-20	LQ	1	13:39	14:03	Transient	T065Bs	3	SE	50	BP	Travel	Yes		East Point 1
09-19-20	LQ	2	14:06	14:37	Transient	Unknown	4	ESE	3000	BP	Travel	Yes		East Point 1
09-20-20	SSN	1	19:16	-	Transient	Unknown	4	E	ND	ND	Travel	ND		Cliffside 4

Date	Group	Daily event no.	Start time	End time	Species/ Population	Pod, matriline or individual ID	No. of individuals	Travel direction	Closest est. distance (m)	Zone	Behaviour	Vessel present	Notes	Site
09-20-20	LQ		No survey conducted										Primary observer not on Island	
09-21-20	SSN	1	12:26	-	Humpback	Unknown	1	S	ND	ND	Travel	ND		Tumbo Ch. 2
09-21-20	SSN	2	15:29	-	Minke	Unknown	1	NW	ND	ND	Travel	ND		Cliffside 5
09-21-20	LQ		No survey conducted										Primary observer not on Island	
09-22-20	LQ		No survey conducted										Primary observer not on Island	
09-23-20	LQ		No survey conducted										Primary observer not on Island	
09-24-20	LQ		No events											East Point 1
09-25-20	LQ	1	14:26	15:08	Humpback	BCY0771, MMY0038	2	N	800	BP, SoG	Travel	No	Half day of survey	East Point 1
09-25-20	SSN	2	14:28	-	Transient	Unknown	3	NE	ND	ND	Travel	ND		Cliffside 5
09-26-20	LQ		No events											East Point 1
09-27-20	LQ	1	9:45	10:18	Humpback	Unknown	2	N	600	Near zone	Travel	Yes		East Point 1
09-28-20	SSN	1	13:40	15:12	SRKW	K pod	~12	S	ND	BP	Travel, Social	ND	Some breaching, spread out across Boundary Pass	Cliffside 5
09-28-20	LQ		No survey conducted										Primary observer not on Island	
09-29-20	LQ		No survey conducted										Primary observer not on Island	
09-30-20	LQ		No events											East Point 1

Date	Group	Daily event no.	Start time	End time	Species/ Population	Pod, matriline or individual ID	No. of individuals	Travel direction	Closest est. distance (m)	Zone	Behaviour	Vessel present	Notes	Site
10-01-20	LQ		No events										Half day of survey	East Point 1
10-02-20	SSN	1	16:36	-	Humpback	Unknown	1	E	ND	ND	Travel	ND		Cliffside 5
10-02-20	LQ		No survey conducted										No Survey by LQ	East Point 1
10-03-20	LQ		No survey conducted										No Survey by LQ	East Point 1
10-04-20	LQ	1	9:50	10:00	Humpback	Unknown	2	N	500	BP	Travel	No	Not seen, only heard (in fog)	East Point 1
10-04-20	LQ	2	14:03	14:17	Humpback	Unknown	2	N	2500	BP	Travel	Yes		East Point 1
10-05-20	LQ		No events											East Point 1
10-06-20	LQ		No events										Final survey day by LQ	East Point 1
10-07-20	SSN		No known events											
10-08-20	SSN		No known events											
10-09-20	SSN		No known events											
10-10-20	SSN		No known events											
10-11-20	SSN		No known events											
10-12-20	SSN		No known events											
10-13-20	SSN		No known events											

Date	Group	Daily event no.	Start time	End time	Species/ Population	Pod, matriline or individual ID	No. of individuals	Travel direction	Closest est. distance (m)	Zone	Behaviour	Vessel present	Notes	Site
10-14-20	SSN		No known events											
10-15-20	SSN		No known events											
10-16-20	SSN	1	12:43	-	Transient	Unknown	3	NE	300	Near zone	Travel	ND		Cliffside 4
10-17-20	SSN		No known events											
10-18-20	SSN		No known events											
10-19-20	SSN		No known events											
10-20-20	SSN		No known events											
10-21-20	SSN		No known events											
10-22-20	SSN	1	8:25	-	Humpback	Unknown	1	W	ND	ND	Travel	ND		Cliffside 4
10-23-20	SSN		No known events											
10-24-20	SSN		No known events											
10-25-20	SSN	1	15:55	-	SRKW	J pod	18~30	SW	ND	BP	Travel, Social	ND	Breaching and spread out across Boundary Pass	Cliffside 4/5
10-26-20	SSN		No known events											
10-27-20	SSN	1	13:49	-	Humpback	Unknown	1	E	ND	ND	Travel	ND		Cliffside 5
10-28-20	SSN	1	8:29	-	Humpback	Unknown	3	E	ND	ND	Travel	ND		Tumbo Ch. 3

Date	Group	Daily event no.	Start time	End time	Species/ Population	Pod, matriline or individual ID	No. of individuals	Travel direction	Closest est. distance (m)	Zone	Behaviour	Vessel present	Notes	Site
10-29-20	SSN		No known events											
10-30-20	SSN		No known events											
10-31-20	SSN		No known events											

Appendix B. Vessels Present During Marine Mammal Observations

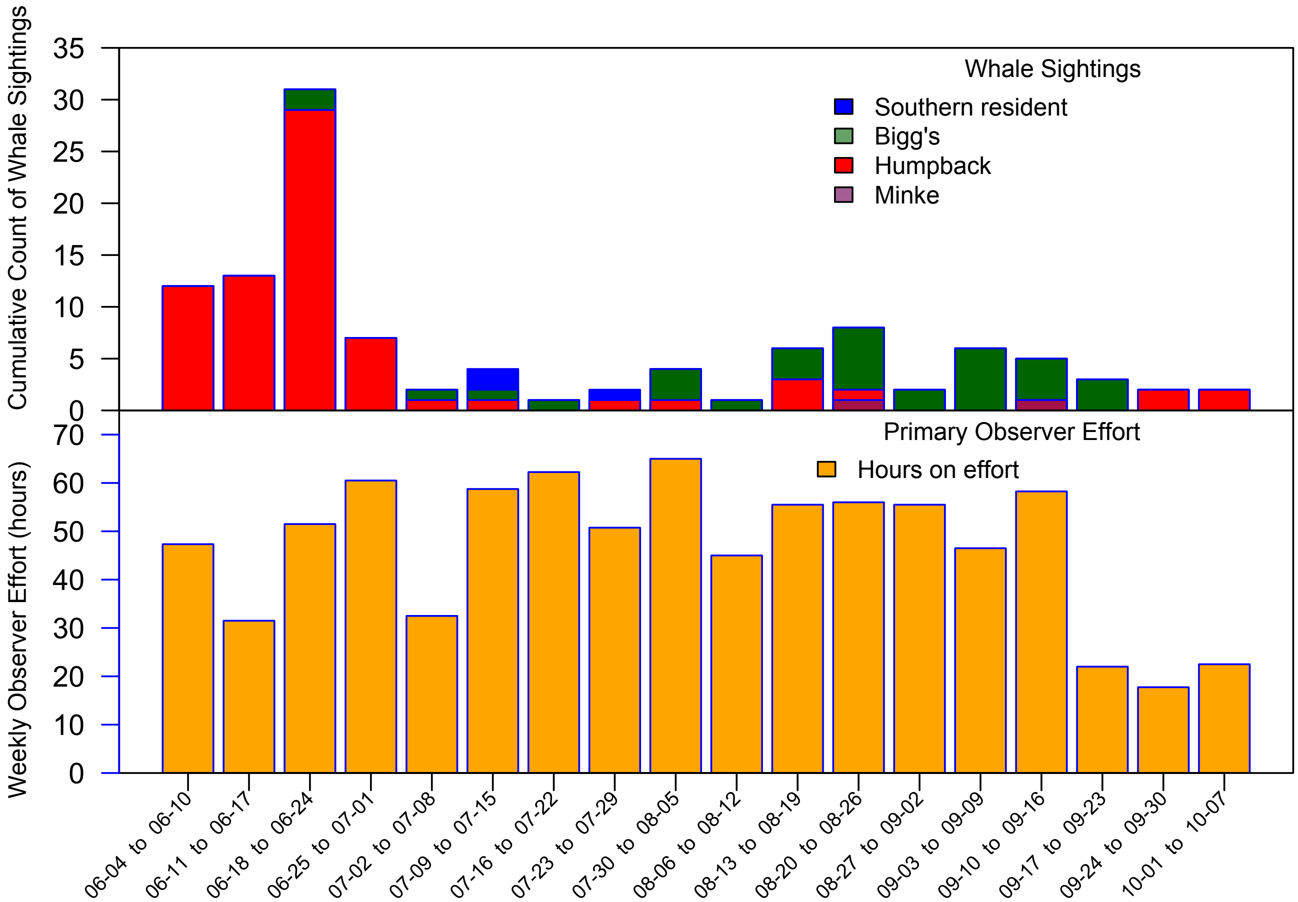
Total count of vessels within 1000 m of marine mammals during marine mammal events, broken down into small vessels (ecotourism, recreational, sailboat motoring, government, research boats) and large vessels (container ship, bulk carrier, tanker, tug and Navy vessels).

Date	Daily event no.	Species/ population	Large vessel no.	Small vessel no.	Total vessel count	Notes
06-05-20	1	Humpback	0	1	1	1 DFO vessel
06-07-20	2	Humpback	1	0	1	1 tug towing
06-07-20	3	Humpback	2	0	2	2 bulk carriers
06-10-20	2	Humpback	0	1	1	1 recreational boat
06-12-20	1	Humpback	2	0	2	1 container ship, 1 bulk carrier
06-12-20	2	Humpback	2	0	2	1 container ship, 1 bulk carrier
06-12-20	4	Humpback	2	0	2	1 tanker and tug escort
06-12-20	6	Humpback	2	0	2	1 tanker and tug escort
06-16-20	1	Humpback	1	0	1	1 bulk carrier
06-16-20	3	Humpback	1	1	2	1 container ship, 1 ecotourism vessel
06-17-20	2	Humpback	0	2	2	2 recreational vessels
06-19-20	1	Humpback	0	1	1	1 RCMP vessel
06-19-20	2	Humpback	0	2	2	1 police vessel, 1 sailboat motoring
06-19-20	3	Humpback	0	1	1	1 recreational vessel
06-19-20	4	Humpback	1	1	2	1 container ship, 1 recreational vessel
06-19-20	5	Humpback	2	3	5	1 car carrier, 1 bulk carrier, 1 RCMP, 1 Soundwatch, 1 ecotourism vessel
06-19-20	6	Humpback	2	3	5	1 car carrier, 1 bulk carrier, 1 RCMP, 1 Soundwatch, 1 ecotourism vessel
06-20-20	1	Humpback	1	1	2	1 RCMP, 1 tug and barge
06-20-20	3	Humpback	0	1	1	1 sailboat motoring
06-20-20	4	Humpback	0	3	3	3 ecotourism vessels
06-21-20	1	Humpback	0	2	2	1 sailboat motoring, 1 recreational vessel
06-21-20	2	Humpback	2	8	10	1 container ship, 1 bulk carrier,1 fishery patrol, 7 ecotourism vessels
06-22-20	1	Humpback	1	2	3	1 container ship, 2 recreational vessels
06-22-20	2	Humpback	1	2	3	1 container ship, 2 recreational vessels
06-22-20	3	Humpback	1	3	4	1 bulk carrier, 1 ecotourism vessel, 2 recreational vessels
06-22-20	4	Humpback	1	1	2	1 container ship, 1 ecotourism vessel

Date	Daily event no.	Species/ population	Large vessel no.	Small vessel no.	Total vessel count	Notes
06-23-20	1	Humpback	1	0	1	1 bulk carrier
06-23-20	4	Humpback	1	0	1	1 tug towing
06-23-20	5	Humpback	0	1	1	1 ecotourism vessel
06-24-20	1	Transients	0	5	5	1 Parks vessel, 3 ecotourism vessels, 1 recreational vessel
06-24-20	2	Humpback	0	2	2	2 recreational vessels
06-24-20	4	Humpback	0	3	3	1 Straitwatch, 1 sailboat motoring, 1 recreational vessel
06-24-20	5	Humpback	0	1	1	1 RCMP
06-25-20	1	Humpback	3	1	4	1 container ship, 2 bulk carriers, 1 sailboat motoring
06-25-20	2	Humpback	3	7	10	1 container ship, 1 tanker with tug escort, 4 ecotourism vessels, 2 recreational vessels, 1 sailboat motoring
06-27-20	1	Humpback	2	13	15	1 container ship, 1 tanker, 6 ecotourism vessels, 2 recreational vessels, 3 Government vessels, 2 sailboats motoring
06-27-20	2	Humpback	1	0	1	1 bulk carrier
06-28-20	1	Humpback	0	2	2	2 recreational vessels
06-28-20	2	Humpback	1	2	3	1 bulk carrier, 1 recreational vessel, 1 sailboat motoring
06-29-20	1	Humpback	0	1	1	1 recreational vessel
07-02-20	1	Humpback	1	0	1	1 container ship
07-06-20	2	Transient	0	16	16	14 ecotourism vessels, 2 recreational vessels
07-12-20	2	SRKW	1	0	1	1 bulk carrier
07-12-20	3	Humpback	0	2	2	2 recreational vessels
07-13-20	1	SRKW	0	5	5	5 ecotourism vessels (in US waters)
07-17-20	2	Transient	2	11	13	1 tanker with tug escort, 9 ecotourism vessels, 1 fishery patrol and 1 recreational vessel
07-24-20	1	SRKW	0	3	3	1 fishery patrol, sailboat motoring, 1 ecotourism vessel
07-24-20	2	Humpback	5	0	5	1 bulk carrier, 1 container ship, 3 Navy vessels
08-01-20	1	Transient	0	13	13	9 ecotourism vessels, 4 recreational vessels
08-05-20	2	Transient	0	2	2	2 ecotourism vessels
08-05-20	3	Transient	0	13	13	11 ecotourism vessels, 2 recreational vessels
08-12-20	1	Transient	0	3	3	2 ecotourism vessels, 1 recreational vessel
08-13-20	1	Transient	0	5	5	4 ecotourism vessels, 1 recreational vessel
08-13-20	2	Transient	1	17	18	1 bulk carrier, 1 Straitwatch,1 Soundwatch, 8 ecotourism vessels, 7 recreational vessels

Date	Daily event no.	Species/ population	Large vessel no.	Small vessel no.	Total vessel count	Notes
08-13-20	3	Transient	0	3	3	3 ecotourism vessels
08-16-20	1	Humpback	0	1	1	1 recreational vessel
08-17-20	1	Humpback	0	5	5	4 ecotourism vessels, 1 sailboat motoring
08-22-20	1	Transient	0	10	10	Many Ecotourism vessels (only estimate due to distance)
08-24-20	1	Transient	0	10	10	Many Ecotourism vessels (only estimate due to distance)
08-25-20	1	Transient	0	3	3	2 Parks vessels, 1 RCMP
08-25-20	2	Transient	0	4	4	2 ecotourism vessels, 1 RCMP, 1 Border Patrol
08-25-20	3	Transient	0	10	10	Many ecotourism vessels (only estimate due to distance)
08-26-20	1	Humpback	0	2	2	1 Parks vessel, 1 recreational vessel
08-26-20	2	Transient	1	3	4	3 recreational vessels, 1 container ship
08-28-20	1	Transient	0	5	5	4 ecotourism vessels, 1 Parks vessel
09-04-20	1	Transient	0	4	4	3 recreational vessels, 1 sailboat motoring
09-05-20	2	Transient	1	0	1	1 bulk carrier
09-06-20	1	Transient	0	12	12	1 Soundwatch/Straitwatch, 4 ecotourism vessels, 6 recreational vessels, 1 sailboat motoring
09-07-20	1	Transient	0	1	1	1 sailboat motoring
09-10-20	2	Minke	0	1	1	1 recreational vessel
09-17-20	1	Transient	0	1	1	1 ecotourism vessel
09-19-20	1	Transient	2	0	2	1 container ship, 1 bulk carrier
09-19-20	2	Transient	1	3	4	1 Navy, 1 recreational vessel, 2 ecotourism vessels
09-27-20	1	Humpback	0	1	1	1 recreational vessel
10-04-20	2	Humpback	0	1	1	1 recreational vessel

Appendix C. Weekly whale count and observer effort



Top Panel: Weekly count summaries of whale events (sightings) recorded by the primary observer from East Point Park, Saturna Island between June 4, 2020 and October 6, 2020. Bottom Panel: Weekly sum of the number of hours of effort of the Primary observer.