# ECHO Program

## Summary report: 2021 voluntary vessel slowdown in Haro Strait and Boundary Pass

Vancouver Fraser Port Authority

June 2022

# Contents

# List of figures



# List of tables



# List of appendices

# Acknowledgements

The ECHO Program would like to thank the Pacific Pilotage Authority, the BC Coast Pilots, Canadian Coast Guard, Fisheries and Oceans Canada and Transport Canada for their contributions to this report; the ECHO Program's vessel operators committee and advisory working group members for their valuable input, advice and support throughout the development, implementation and evaluation of the slowdown; and the Canadian and U.S. marine transportation organizations for their participation in the slowdown.

# Executive summary

This report summarizes the development, implementation and results of the 2021 voluntary vessel slowdown in Haro Strait and Boundary Pass. The slowdown was coordinated and implemented by the Vancouver Fraser 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.

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. Research indicates that underwater vessel noise can interfere with the whales' ability to navigate, communicate and find their prey. 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.

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 knots or less speed through water – half a knot slower than in 2020. At the outset of the 2021 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 slowdown began on July 1, 2021 and ended on November 30, 2021. Killer whale presence was monitored through both visual observations from shore and acoustic detections via hydrophones in Haro Strait and Boundary Pass. The SRKW were present in the slowdown area on 29 of the 152 days (or ~20%) that the slowdown was active.

The Pacific Pilotage Authority (PPA) reported that 90% of ship transits (2,074 of 2,295 transits) participated during the slowdown, compared to 91% in 2020, 82% in 2019, 87% in 2018 and 61% in 2017. Although not all participating vessels could accurately achieve the speed targets, 61% of transits came within one knot of the target speeds.

Evaluation of the total ambient noise levels indicated a median reduction in underwater broadband received sound pressure level (SPL) of 3.7 dB (a 57% reduction in sound intensity) near Lime Kiln in Haro Strait, and 3.2 dB (a 52% reduction in sound intensity) at the hydrophone station near the shipping lanes in Boundary Pass, during the July to October time period when compared to the pre-slowdown baseline period. Lesser noise reductions were measured in November when compared to baseline, however there were multiple environmental and equipment factors that contribute to this difference in noise reduction. 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.

The results of the 2021 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 2021 slowdown indicated a quantifiable reduction in underwater noise and predicted an improvement in foraging time for the SRKW, when compared to baseline conditions.

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 2021 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 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 were 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 November 30, 2021 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 reducing 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, 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, representatives from 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 73 individuals as of December 31, 2021 (Center for Whale Research, 2022). 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 previous four years of seasonal slowdowns in Haro Strait and Boundary Pass 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, 2020).

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 Strait were selected as KPIs for the Conservation Agreement.

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 2021 and are not reflected in this year's study.

## 1.3. Development of the slowdown parameters

### 1.3.1. Slowdown area

The 2021 slowdown area in Haro Strait and Boundary Pass was unchanged from 2019 and 2020 and is a total of 29.6 nautical miles (Figure 1). The slowdown area includes 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 encourage vessel operators to slow down to the appropriate speed prior to entering the slowdown area.

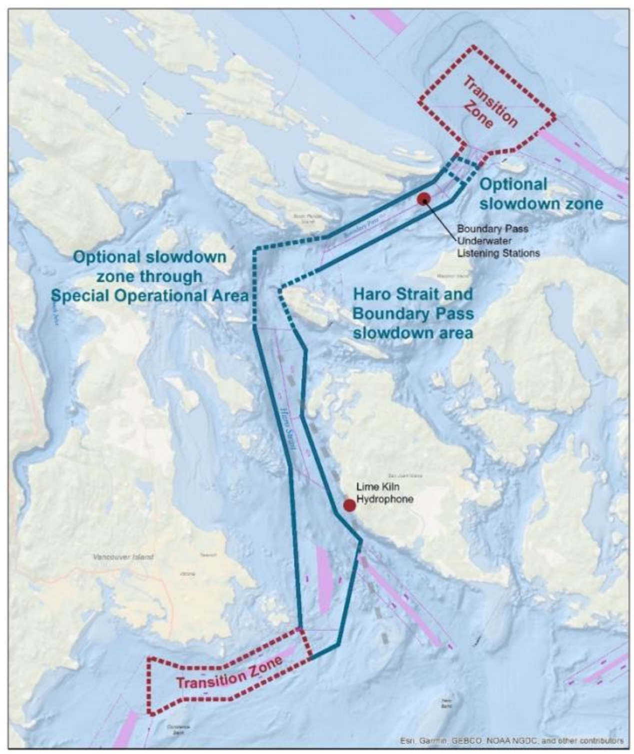



**Figure 1: 2021 voluntary vessel slowdown**

### 1.3.2. Slowdown speeds

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 knots or less. Eleven knots is half a knot slower than the target speed for 2019 and 2020 for bulkers, tankers and government vessels.

Transiting at 11 and 14.5 knots was estimated to add between 16 and 34 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 2021 slowdown, relative to typical vessel speeds.

**Table 1: Predicted average increases in transit time during 2021 slowdown**

| Vessel type | Slowdown target speed through water (knots) | Average speed through water – normal conditions (knots) | Average increase in transit time due to slowdown (minutes) |
|---|---|---|---|
| Bulker | 11 | 13.5 | 29 |
| Vehicle carrier | 14.5 | 17.3 | 16 |
| Container | 14.5 | 18.9 | 28 |
| Tanker | 11 | 13.7 | 34 |

### 1.3.3. Dynamic start and end dates

To provide the most potential benefit to the SRKW while limiting slowdown impacts to industry, the 2021 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 October 31 and November 30, 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, 2021. SRKW were confirmed present in Haro Strait by trusted observers and hydrophone data on July 1, 2021, thus initiating the slowdown. The official start to the slowdown was communicated to mariners through a Canadian Coast Guard Navigational Warning (NAVWARN), US Coast Guard Notice to Mariners (NOTMAR), 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 October 31, 2021, and that if the whales were still confirmed present at that time, would be extended for two-week periods to no later than November 30, 2021. This process of monitoring, evaluation and adaptive two-week extensions resulted in a slowdown period of 152 days, from July 1 to November 30, 2021.

# 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 2021 voluntary vessel slowdown initiative.

## 2.1. Engagement and communications

The ECHO Program advisory working group convened five times in 2021 to share input and advice during the development, implementation, and evaluation phases of the slowdown. The ECHO Program vessel operators committee also convened five times throughout the year to assist in the development of parameters for the 2021 slowdown and support monitoring of participation.

A list of the advisory working group and vessel operators committee members can be found here.

A number of communication tools including background documents, maps, presentations, decision matrices and a webpage were developed and shared to raise awareness about the 2021 voluntary vessel slowdown initiative. A Canadian Coast Guard navigational warning (NAVWARN) and US Coast Guard Notice to Mariners (NOTMAR) were active for the duration 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 Transport Canada's reimbursement program (see Section 4). 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.

Certificates of appreciation and letters of thanks were mailed to each organization that supported, or participated in, the 2021 ECHO Program initiatives.

## 2.2. Monitoring

Automatic 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. These data were 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 represents 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.

# 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.

The SRKW arrived in the area on July 1, prompting the start of the slowdown, however, acoustic and participation analysis began on July 2, allowing time for notification to all parties. During the 21-week slowdown period, between 00:01 July 2, 2021, and midnight on November 30th, 2021, the Pacific Pilotage Authority reported 2,295 piloted vessel transits through Haro Strait and/or Boundary Pass. Of those piloted vessels, 1,887 vessels passed through both Haro Strait and Boundary Pass, 167 through Haro Strait only, and 241 through Boundary Pass only.

Each slowdown year since 2017, the Pacific Pilotage Authority has 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 2021 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 feasible. A list of the companies who confirmed their intention to participate in the 2021 slowdown can be found Appendix A.

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 96% (2,201 of 2,295) of vessel transits intended to participate. Of these, 60% (1,367 vessel transits) indicated 'yes', they would participate without conditions, and 36% (834 vessel 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 4% (94 transits) indicated that they did not intend to participate.

Table 2 provides the response totals from the past five years of the slowdowns. There was a significant increase in "Yes" response in 2021 over previous years. Feedback from advisors indicates this may be because of changes to the Transport Canada pilotage reimbursement program in 2021 which eliminated agent payment processing and delays. The Transport Canada pilot reimbursement is discussed further in section 4.

**Table 2 Intent to participate as reported by Pacific Pilotage Authority - 2017 to 2021**

| Total per year | Yes | | Conditional | | No | |
|---|---|---|---|---|---|---|
| **2021** | **60%** | **1367 of 2,295** | **36%** | **834 of 2,295** | **4%** | **94 of 2,295** |
| 2020 | 48% | 959 of 1,980 | 45% | 889 of 1,980 | 6% | 122 of 1,980 |
| 2019 | 39% | 612 of 1,551 | 52% | 807 of 1,551 | 9% | 132 of 1,551 |
| 2018 | 49% | 822 of 1,678 | 42% | 703 of 1,678 | 9% | 153 of 1,678 |
| 2017 | 38% | 366 of 951 | 41% | 386 of 951 | 21% | 199 of 951 |

## 3.2. Participation as reported by Pacific Pilotage Authority

Of the 2,295 piloted vessel transits through Haro Strait and Boundary Pass during the 2021 slowdown period, the Pacific Pilotage Authority reported that 90% (2,074 of 2,295) 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) are related to schedule concerns, many of which are related to navigation or safety and cannot be avoided (62%). A breakdown of participation as reported by the pilots at the end of each transit is included in Table 3. The participation totals from 2017 - 2020 slowdowns are also included in Table 3 for comparison and indicate a marginal decrease in vessels reporting 'Yes' to participation.

**Table 3: Participation as reported by Pacific Pilotage Authority – 2017 to 2021**

| Vessel type | Yes | | No | |
|---|---|---|---|---|
| Bulker | 89% | 1,245 of 1,397 | 11% | 152 of 1,397 |
| Vehicle carrier | 90% | 137 of 152 | 10% | 15 of 152 |
| Container | 93% | 500 of 539 | 7% | 39 of 539 |
| Tanker | 93% | 127 of 137 | 7% | 10 of 137 |
| Other | 93% | 65 of 70 | 7% | 5 of 70 |
| **Total (2021)** | **90%** | **2,074 of 2,295** | **10%** | **221 of 2,295** |
| Total (2020) | 91% | 1,803 of 1,980 | 9% | 177 of 1,980 |
| Total (2019) | 82% | 1,279 of 1,551 | 18% | 272 of 1,551 |
| Total (2018) | 87% | 1,467 of 1,678 | 13% | 211 of 1,678 |
| Total (2017) | 61% | 578 of 951 | 39% | 373 of 951 |

## 3.3. Inbound versus outbound reported participation

For all vessel types, reported participation rates were higher during outbound transits, as shown in Table 4. In most cases outbound transits would include vessels leaving from the Port of Vancouver or Howe Sound areas travelling west through Boundary Pass and south through Haro Strait. Inbound transits would be those travelling in the opposite direction, north through Haro Strait and east through Boundary Pass. In 2021, 17% of vessel transits (400 of 2,295) navigated through only one of the two slowdown areas, either Haro Strait or Boundary Pass. These partial transits are normally repositioning transits of a vessel to or from the Port of Vancouver to a Vancouver Island terminal or Gulf Island anchorage.

**Table 4: Inbound versus outbound reported participation**

| PPA reported participation for transits starting or ending at Brotchie pilot station | | | | |
|---|---|---|---|---|
| **Vessel type** | **Inbound** | | **Outbound** | |
| Bulker | 84% | 642 of 763 | 95% | 603 of 634 |
| Vehicle carrier | 86% | 66 of 77 | 95% | 71 of 75 |
| Container | 88% | 241 of 274 | 98% | 259 of 265 |
| Tanker | 87% | 59 of 68 | 99% | 68 of 69 |
| Other | 86% | 31 of 36 | 100% | 34 of 34 |
| **All** | 85% | 1,039 of 1,218 | 96% | 1,035 of 1,077 |

## 3.4. Calculated vessel speed through the water participation rates

Understanding each vessel's actual speed through water is an important factor in evaluating the slowdown. 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. As such, speed through water participation is calculated based on a vessel transiting within one knot of the speed through water target averaged over the length of the transit.

SMRU Consulting and JASCO Applied Sciences (consultants to the ECHO Program) calculated speed through water in Haro Strait and Boundary Pass, respectively, using AIS speed over ground data corrected for current using several locations in 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. Based on the overall mean speed through water evaluation and comparison to targets, 61% of all vessel transits were within one knot of their respective 2021 target speeds.

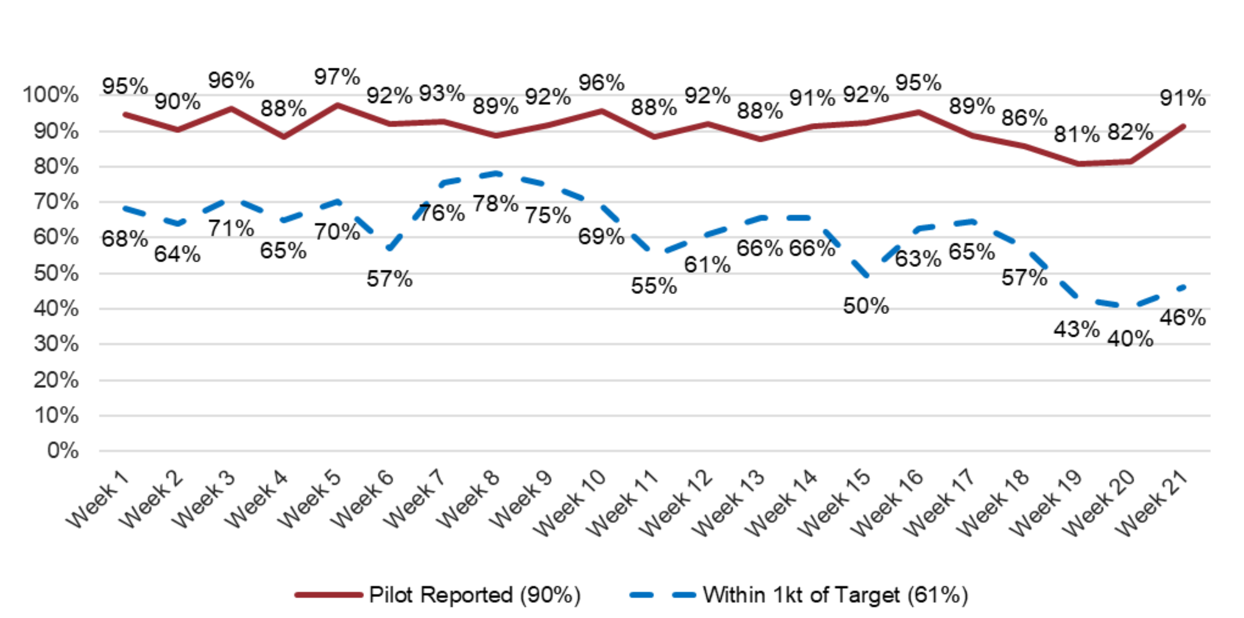
Table 5 provides details of the pilot reported and the speed through water achievement rates by vessel type. Figure 2 provides an overview of how the participation varied during the slowdown, both calculated and reported.

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

| Vessel type | Pilot-reported participation | Transits within 1 kt of target speed through water * |
|---|---|---|
| Bulker | 1230 of 1381 (89%) | 778 of 1381 (56%) |
| Vehicle carrier | 137 of 152 (90%) | 89 of 152 (59%) |
| Container | 498 of 537 (93%) | 383 of 537 (71%) |
| Tanker | 127 of 137 (93% | 102 of 137 (74%) |
| Other | 65 of 70 (93%) | 41 of 70 (59%) |
| All | 2057 of 2277 (90%) | 1393 of 2277 (61%) |

* Owing to occasional missing AIS data, there are only 2,277 (18 fewer) speed through water participation transits than pilot reported transits. This table shows only the pilot reported transits where AIS data was available.

**Figure 2: Reported and speed through water participation by week**




## 3.5. Non-participating vessels

End of season feedback interviews and discussions were conducted with the shipping associations who represent the participating ship owners and agents, and with BC Coast Pilots. Feedback indicated that in general the slowdown had little impact on day-to-day operations and ECHO Program communications were effective. Feedback from the pilots and shipping associations indicated the extra month of slowdown into November caused engagement fatigue and resulted in a drop in participation.

Over the 21 weeks of the slowdown there were 221 vessel transits reported as not participating at the end of their transit. Of these, 62% cited the reason for not participating as being due to scheduling concerns, 5% as being due to tidal/current concerns, 9% as being due to additional costs not related to pilotage and 20% was "other". Of the 221 vessels reporting as not participating, 179 (81%) were inbound.

# 4. Transport Canada reimbursement program

Since the addition of Boundary Pass to the slowdown area in 2019, Transport Canada has implemented a reimbursement program to cover additional pilotage costs incurred as a result of participating in the ECHO Program Haro Strait and Boundary Pass slowdown.

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 due to participation in the slowdown and therefore orders two pilots for the job
3. **Excess** occurs when a vessel unexpectedly exceeds the eight-hour piloting 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. On behalf of Transport Canada, Vancouver Fraser Port Authority provided a reimbursement to the Pacific Pilotage Authority. 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, 2021, and remained in place until the conclusion of the slowdown on November 30, 2021.

Of the 2,074 vessel transits reported as participating in the slowdown, ~68% did not incur additional pilotage costs due to participation. A breakdown of how the remaining ~32% of participating vessels incurred additional pilotage costs is provided in Table 6.

**Table 6: 2021 participating vessels and associated reimbursement types**

| Reimbursement type | Number of participating vessels | Percentage of total participating vessels |
|---|---|---|
| No additional pilotage costs | 1401 | 68% |
| Slippage to an additional hour | 588 | 28% |
| Slippage to an additional hour with two pilots onboard | 34 | 1.5% |
| Excess hours | 56 | 2.5% |
| Total | 2,074 | |

A total of $258,140 additional pilotage costs were incurred as a result of the slowdown and paid out as reimbursements.

# 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. 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 Appendix B to this summary report.

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 is 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 station were analyzed for a representative baseline period before the 2021 slowdown for comparison to the slowdown period. For analysis, the baseline period was considered from May 3 to July 1, 2021, representing 60 days immediately preceding the slowdown period of July 2 to November 30, 2021. As the slowdown was enacted mid-day on July 1, the acoustic analysis began at 00:01 PDT on July 2. In 2021, the extension of the slowdown into November caused challenges for acoustic evaluation, including:

- confusion on the part of participants, resulting in decreased participation rates in November
- changes in ocean conditions (most notably temperature) which affect the propagation of sound differently than the “spring/summer” conditions from May to October
- a significant number of unusual storm events affecting vessel behaviour; and
- maintenance to the ULS, resulting in the use of different hydrophones for late October and November

The Boundary Pass hydrophone station transitioned to a long-term cabled ULS on June 9, 2020, and was the only station used for evaluation of the 2021 slowdown in Boundary Pass. This ULS was serviced between October 6 and October 9, 2021, resulting in data not being analysed for that period, and different hydrophones were used to record data for the latter part of October and November. There are always slight differences in the characteristics of hydrophones, even those of the same make and model. As such, this change of equipment during the slowdown may have influenced noise level comparisons between the baseline period and November. To account for the potential differences in November underwater sound conditions noted above, analysis of the benefits of the slowdown were calculated between the baseline period and the July through October slowdown separately from November slowdown conditions.

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 the July through October slowdown and November slowdown time periods 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 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 five 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 July to October and November slowdown periods 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.

Tables 7 and 8 present the differences in sound pressure levels measured between baseline and slowdown periods at Lime Kiln and Boundary Pass, respectively. The median broadband value is highlighted in each table. These differences are presented for filtered broadband, frequency decade band 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). Note that a negative value in Tables 7 and 8 indicate a reduction in underwater noise.

**Table 7: Ambient underwater noise differences at Lime Kiln**

| Frequency range | SPL difference (dB) Slowdown (Jul-Oct) | | | SPL difference (dB) Slowdown (Nov) | | |
|---|---|---|---|---|---|---|
| | $L_{95}$ (quietest 5%) | $L_{50}$ Median | $L_5$ (loudest 5%) | $L_{95}$ (quietest 5%) | $L_{50}$ Median | $L_5$ (loudest 5%) |
| Broadband 10–100,000 Hz | -2.9 | -3.7 | -3.0 | -0.8 | -2.5 | -2.3 |
| 1st Decade 10–100 Hz | -3.6 | -4.2 | -3.1 | -1.9 | -3.2 | -2.8 |
| 2nd Decade 100–1000 Hz | -1.5 | -2.4 | -2.7 | -0.2 | -1.8 | -1.7 |
| 3rd Decade 1–10 kHz | -3.0 | -3.5 | -3.2 | 2.4 | -0.2 | -0.9 |
| 4th Decade 10–100 kHz | -0.2 | -1.7 | -1.4 | 1.7 | 1.1 | 1.2 |
| CORI Communication 500–15,000 Hz | -2.2 | -3.2 | -3.0 | 1.8 | -0.5 | -0.9 |
| CORI Echolocation 15–100 kHz | 0.1 | -0.8 | -0.3 | 1.0 | 0.5 | 3.0 |

**Table 8: Ambient underwater noise differences at Boundary Pass**

| Frequency range | SPL difference (dB) Slowdown (Jul-Oct) | | | SPL difference (dB) Slowdown (Nov)* | | |
|---|---|---|---|---|---|---|
| | $L_{95}$ (quietest 5%) | $L_{50}$ Median | $L_5$ (loudest 5%) | $L_{95}$ (quietest 5%) | $L_{50}$ Median | $L_5$ (loudest 5%) |
| Broadband 10–100,000 Hz | -4.4 | -3.2 | -3.2 | -1.5 | -1.0 | -1.4 |
| 1st Decade 10–100 Hz | -6.3 | -3.6 | -3.4 | -1.6 | -1.0 | -1.1 |
| 2nd Decade 100–1000 Hz | -3.2 | -2.1 | -2.2 | -1.3 | -0.6 | -0.2 |
| 3rd Decade 1–10 kHz | -3.1 | -2.7 | -2.5 | 0.4 | -1.0 | -1.5 |
| 4th Decade 10–100 kHz | -0.1 | -1.9 | -3.1 | 0.9 | 0.9 | -0.9 |
| CORI Communication 500–15,000 Hz | -2.8 | -2.2 | -2.2 | 0.0 | -0.8 | -0.5 |
| CORI Echolocation 15–100 kHz | 0.0 | -1.3 | -2.9 | 1.2 | 1.6 | -0.3 |

**Note that due to the ULS maintenance in October 2021, direct comparison of November data at Boundary Pass to the May-June baseline period should be considered with caution*

When comparing baseline levels to the July through October portion of the slowdown for both Lime Kiln and Boundary Pass, all frequency ranges, and all time metrics showed a decrease in underwater noise, with the exception of the quietest time (L95) at the highest frequency range (>15 kHz), which showed no change in noise levels. Median noise levels were reduced by 3.7 dB at Lime Kiln and 3.2 dB at Boundary Pass for the July through October slowdown indicating reductions in sound intensity of 57% and 53%, respectively.

The noise level differences measured in November compared to baseline levels, still indicate noise reductions during the slowdown the majority of the time. However, these noise level reductions in November are less than those measured in July through October, and the November slowdown did not make ambient noise conditions quieter in the higher frequency ranges. It should be noted that due to the hydrophone maintenance conducted in Boundary Pass in October 2021, direct comparison of the November slowdown to the May through June baseline period should be made with caution.

These measured data sources indicate the 2021 slowdown from July to October was very successful in reducing the ambient underwater noise in Haro Strait and Boundary Pass 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 and 2021 slowdown evaluations. Considerable underwater noise reductions in the range of ~3 dB have been measured during the slowdowns in both Haro Strait and Boundary Pass since 2019.

## 5.2. Evaluation of "quiet times" in Haro Strait 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 period with the slowdown July through October and November periods, the change in quiet times is provided in Table 9 below.

**Table 9: Evaluation of quiet times**

| | Baseline to slowdown July-October | | Baseline to slowdown November | |
|---|---|---|---|---|
| | 110 dB threshold | 102.8 dB threshold | 110 dB threshold | 102.8 dB threshold |
| Lime Kiln/ Haro Strait | 4.9% increase in quiet time | 0.3% increase in quiet time | 1.7% decrease in quite time | 8% decrease in quite time |
| Boundary Pass | 1.6% increase in quiet time | 0.7% increase in quiet time | 7.7% decrease in quiet time | 4.3% decrease in quiet time |

During baseline and slowdown (July – October) time periods at Lime Kiln in Haro Strait, quiet time below the 102.8 dB thresholds is ~34% of the time, and below 110 dB ~60% of the time.

Boundary Pass appears to experience a slightly higher percentage of quiet time with around ~47% below the 102.8 dB threshold and ~65% below the 110 dB threshold during the baseline and July-October slowdown period. 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.

These analyses indicate that during the July through October slowdown period, quiet times were slightly increased over baseline conditions. However, when evaluating the November slowdown period, quiet times were decreased compared to the baseline. As outlined previously, various factors (largely environmental factors such as water temperature and storms) contribute to changes in underwater sound conditions in November, thus comparison of quiet times in November data to the May through June baseline period must be done with caution.

## 5.3. Underwater noise and behavioural response modelling

In previous years of the voluntary vessel slowdowns, underwater noise modelling and subsequent modelling of SRKW behavioural response and lost foraging time were conducted. This effort involved utilizing a 24-hour noise model of the region of interest (Haro Strait and Boundary Pass) which generates sequences of two-dimensional snapshots of the dynamic sound field, providing cumulative sound pressure levels as a function of easting, northing, frequency and time. The model scenarios compared speeds and vessel counts for an average vessel traffic day (14 ships) and high traffic day (21 ships) operating under normal speed conditions, against the same number of vessels operating at slowdown conditions.

Because the 24-hour model must round participation rates to the nearest "whole ship" in a day, the model is inherently insensitive to minor changes in participation rates and speeds. Table 10 below shows a comparison of the average participation rates and speeds for 2020 and 2021.

**Table 10: Participation rates and speeds 2020 - 2021**

| Vessel type | 2020 | | 2021 | |
|---|---|---|---|---|
| | Average slowdown speed achieved (knots) | 2020 reported participation rates | Average slowdown speed achieved (knots) | 2021 reported participation rates |
| Bulker | 11.98 | 90% | 11.84 | 89% |
| Vehicle carrier | 15.14 | 94% | 15.53 | 90% |
| Container | 14.97 | 93% | 15.04 | 93% |
| Tanker | 11.83 | 96% | 11.23 | 93% |
| Passenger | N/A* | NA* | NA* | NA* |

Due to the similarities between 2020 and 2021 participation rates and speeds, and the insensitivity of the noise model to minor changes, the decision was taken to not repeat the acoustic modelling and behavioural response modelling, as the results would be essentially the same. Included in the modelling results are "unfiltered" times when there are no vessels present, unlike the actual ambient noise measurements described in Section 5.1.

The 2020 results (JASCO and SRMU, 2021) indicated that the median broadband total noise level at Boundary Pass would be reduced by 0.56 dB as a result of the slowdown on an average traffic day and by 0.89 dB on a high traffic day. For Lime Kiln, these reductions were modelled to be 0.63 dB on an average traffic day and 1.2 dB on a high traffic day. These modelling results indicate an overall reduction in underwater noise levels in the key SRKW areas, despite longer transit times.

To evaluate the potential effects of reduced underwater noise on SRKW, the results of the 24-hour noise modelling conducted by JASCO would be 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.

As the behavioural response model utilizes the 24-hour vessel noise model, similar noise model results will provide similar behavioural response model results. The 2020 results (JASCO and SRMU, 2021) indicated an improvement in foraging time for the SRKW in the full model area of ~17% on an average traffic day and ~20% on a high traffic day, with improvements in foraging in key habitat in Haro Strait of ~20% on an average traffic day and ~23% on a high traffic day. As the participation rates and achieved speeds of the 2021 slowdown were similar to those of 2020, the modelling results would also be similar. The extended duration of the 2021 slowdown would, however, increase the number of days that these foraging benefits would be experienced by the SRKW

# 6. Evaluation and results: SRKW presence

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 2021 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.

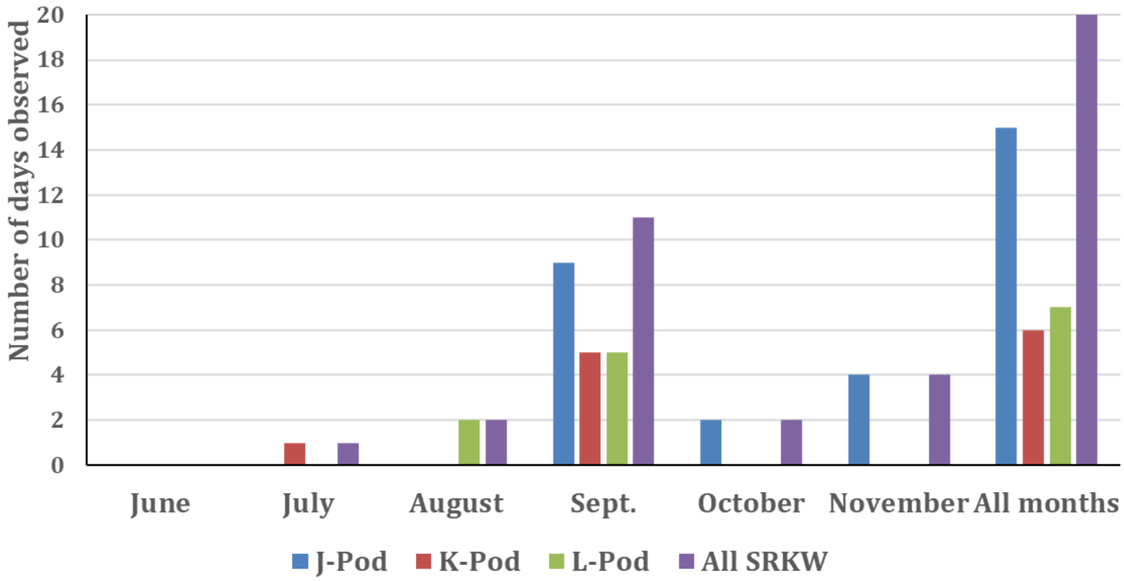
## 6.1. SRKW presence at Lime Kiln

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. Further information on acoustic and visual detections of SRKW at Lime Kiln, and in the Haro Strait region, can be found in Appendix B and Appendix C.1.

Daily scientific observations of SRKW presence were conducted by Ms. Jeanne Hyde at or near the lighthouse in Lime Kiln Point State Park on San Juan Island between June 1 and November 30, 2021. Over the course of this monitoring period, SRKW were visually confirmed from the Lime Kiln station on 20 days.

SRKWs are made up of three pods (J, K, L) which are often seen travelling separately but can be seen travelling together or in various combinations. Members of J pod were observed on 15 days, K pod on six days and L pod on seven days. On two days the particular pod was not identified beyond confirmation of the transiting whales being SRKW. Additionally, SRKWs were observed on one additional day by other observers in Haro Strait. Figure 3 shows the SRKW sightings at Lime Kiln by pod and by month.

**Figure 3: SRKW observations at Lime Kiln, by pod and by month**




*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, there were 41 unique detection events of SRKW across 27 days using the Lime Kiln hydrophone. Additionally, there were five (5) detections of unknown killer whale ecotype.

Collectively, there were a minimum of 44 SRKW transit events over 29 'whale days' in Haro Strait during the 2021 monitoring period.

## 6.2. SRKW presence at Boundary Pass

Between June 1 and August 30, 2021, scientific observations of cetaceans, with a focus on SRKW, were made by observers from Simon Fraser University, 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 C.2.

During this time, SRKWs were visually confirmed on one day in Boundary Pass on August 30. Although they were observed from a distance, it was later confirmed that four individuals from L pod were present and most likely demonstrating a mixture of travelling and socialising behaviour. No vessels were present during the event.

The Saturna Sighters Network, a citizen science group, captured visual observations of SRKW on five additional days between September and October 2022, after the field season for the primary observers was complete. Therefore, there were a minimum of six visual detection days of SRKW in Boundary Pass during the monitoring period.

In addition to the visual observations, acoustic detections were collected through passive acoustic monitoring at the Boundary Pass hydrophone station between June and November. A total of 14 SRKW events were detected over 13 days.

Based on both the visual and acoustic detections in Boundary Pass, SRKW were present for 13 days during the monitoring period.

# 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 2021 voluntary vessel slowdown was coordinated and managed by the ECHO Program. The slowdown was conducted between July 1 and November 30, 2021, over an approximately 29.6 nautical mile area through Haro Strait and Boundary Pass, in key foraging habitat for southern resident killer whales. The goal of the 2021 slowdown was to provide underwater noise reduction benefit to SRKW.

The key findings of the 2021 voluntary vessel slowdown are:

- A 90% vessel participation rate was reported by the Pacific Pilotage Authority (2,057 of 2,277 piloted transits) over the slowdown period
- 61% (1,393 of 2,277) 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 29 of the 152 slowdown days
- The filtered median reduction in broadband received sound pressure level for the 2021 slowdown (July - October), was 3.7 dB (a 57% reduction in sound intensity) near Lime Kiln in Haro Strait, and 3.2 dB (a 52% reduction in sound intensity) at the hydrophone station near the shipping lanes in Boundary Pass.
- The acoustic benefits of the slowdown were lesser when comparing the November slowdown time frame to the May-June 2021 baseline period, with median filtered broadband noise reductions of 2.5 dB (a 44% reduction in sound intensity) in Haro Strait. Due to station maintenance in October 2021, there is uncertainty when comparing November slowdown data for Boundary Pass to the baseline period.
- A comparison of available "quiet time" during the baseline period versus the slowdown showed minor increases in quiet time resulting from the 2021 vessel slowdown from July to October, and minor decreases in quiet time during the November slowdown, when compared to the May-June baseline period.

The following conclusions are drawn from the 2021 slowdown:

- High voluntary participation rates were maintained in 2021, despite reduced speed targets for the slower vessels from 11.5 knots to 11 knots, a longer duration into November and the ongoing uncertainties of the global COVID-19 pandemic and its impact on shipping.
- 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.
- The underwater noise levels measured, 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.

# 8. References

Center for Whale Research. Orca Population as of December 31, 2021. Accessed online, March 22, 2022. Available at: https://www.whaleresearch.com/orca-population

Fisheries and Oceans Canada. 2011. Recovery Strategy for the Northern and Southern Resident Killer Whales (Orcinus orca) in Canada. Species at Risk Act Recovery Strategy Series, Fisheries & Oceans Canada, Ottawa, ix + 80 pp.

Fisheries and Oceans Canada. 2016. Report on the Progress of Recovery Strategy Implementation for the Northern and Southern Resident Killer Whales (Orcinus orca) in Canada for the Period 2009 – 2014. Species at Risk Act Recovery Strategy Report Series. Fisheries and Oceans Canada, Ottawa. Iii + 51 pp.

Fisheries and Oceans Canada. 2017. Action Plan for the Northern and Southern Resident Killer Whale (Orcinus orca) in Canada. Species at Risk Act Action Plan Series. Fisheries and Oceans Canada, Ottawa. v + 33 pp.

Heise, K., L.G. Barrett-Lennard, R. Chapman, T. Dakin, C. Erbe, D.E. Hannay, N.D. Merchant, J. Pilkington, S.Thornton, et al. 2017. Proposed Metrics for the Management of Underwater Noise for Southern Resident Killer Whales. Coastal Ocean Report Series. Volume 2017/2. Report for the Coastal Ocean Research Institute. © Ocean Wise 2017, Vancouver, BC, Canada. 31 p.

JASCO Applied Sciences and SMRU Consulting. 2021. ECHO Program 2020 Voluntary Vessel Slowdown Hydroacoustic Studies: Final Report. Document 02363, Version 1.0. Technical report by JASCO Applied Sciences and SMRU Consulting for Vancouver Fraser Port Authority.

JASCO Applied Sciences and SMRU Consulting. 2020. ECHO Program 2019 Voluntary Vessel Slowdown Hydroacoustic Studies: Final Report. Document 01994, Version 1.0. Technical report by JASCO Applied Sciences and SMRU Consulting for Vancouver Fraser Port Authority.

MacGillivray, A. and Z. Li. 2018a. Vessel Noise Measurements from the ECHO Slowdown Trial: Final Report. Document 01518, Version 3.0. Technical report by JASCO Applied Sciences for Vancouver Fraser Port Authority ECHO Program.

MacGillivray, A., Z. Li, and H. Yurk. 2018b. Modelling of Cumulative Vessel Noise for Haro Strait Slowdown Trial: Final Report. Document 01577, Version 2.0. Technical report by JASCO Applied Sciences for Vancouver Fraser Port Authority ECHO Program.

MacGillivray, A.O. and Z. Li. 2019. Vessel Noise Modelling Update for 2018 Haro Strait Slowdown Initiative: Final Report. Document Number 01767, Version 2.0. Technical report by JASCO Applied Sciences for Vancouver Fraser Port Authority ECHO Program.

SMRU Consulting North America. 2014. Proposed Roberts Bank Terminal 2 technical report: Southern Resident killer whale underwater noise exposure acoustic masking study. Prepared for Port Metro Vancouver, B.C. in Port Metro Vancouver (PMV). 2015. Roberts Bank Terminal 2 Environmental Impact Statement: Volume 3. Appendix 14-B. Environmental Assessment by Review Panel. Submitted to Canadian Environmental Assessment Agency. Document is available at https://www.ceaa-acee.gc.ca/050/documents/p80054/101359E.pdf

SMRU Consulting North America. 2018a. ECHO Slowdown Trial: Ambient Noise and SRKW Acoustic Detections – Final. Prepared for Vancouver Fraser Port Authority.

SMRU Consulting North America. 2018b. Modelling of SRKW Behavioural Responses and Masking from Vessel Noise Exposure during the Haro Strait Slowdown Trial. Prepared for the ECHO Program of Vancouver Fraser Port Authority.

SMRU Consulting North America. 2019a. Reductions in Potential Lost Foraging Time from Vessel Noise Exposure: Haro Strait 2018 Slowdown (with a comparison with 2017 Slowdown trial) Prepared for the ECHO Program of Vancouver Fraser Port Authority.

SMRU Consulting North America. 2019b. Addendum: Modelling of SRKW Behavioural Responses and Masking from Vessel Noise Exposure during the Haro Strait 2017 Slowdown Trial. Prepared for the ECHO Program of Vancouver Fraser Port Authority.

SMRU Consulting North America. 2019c. ECHO Slowdown 2018: Ambient Noise and SRKW Acoustic Detections - Report. Prepared on behalf of the Vancouver Fraser Port Authority ECHO Program. SMRU Consulting North America.

Vancouver Fraser Port Authority. ECHO Program partners and advisors webpage 2021. Accessed online, March 22, 2022. Available at: https://www.portvancouver.com/environmental-protection-at-the-port-of-vancouver/maintaining-healthy-ecosystems-throughout-our-jurisdiction/echo-program/partners-advisors/

Vancouver Fraser Port Authority. ECHO Program participants webpage 2021. Accessed online, March 22, 2022. Available at: https://www.portvancouver.com/environmental-protection-at-the-port-of-vancouver/maintaining-healthy-ecosystems-throughout-our-jurisdiction/echo-program/projects/thankyou/

Wood, J.D., R. Joy, and D.J. Tollit. 2019. Southern Resident Killer Whale Habitat Use Phase II and Salmon Data Synthesis. Technical report by SMRU Consulting for [DFO] Fisheries and Oceans Canada. 51 p.

## Appendix A

List of organizations that confirmed their intent to participate in the ECHO Program’s 2021 Haro Strait and Boundary Pass slowdown

ACGI Shipping Inc.
Amix Marine Services
Canpotex Shipping Service
CMA CGM
Colley West Shipping Ltd
COSCO Shipping Lines (Canada) Inc.
CSL Americas
Evergreen Shipping Agency (America) Corp
Fairmont Shipping (Canada) Ltd
Fednav Limited
Fisheries and Oceans Canada
G2 Ocean
GFY Marine Group Inc.
Hapag-Lloyd
HMM America Shipping Agency, Inc.
Kirby Offshore Marine
LBH Shipping Canada Inc.
Ledcor Resources & Transportation
Maersk Line
Mason Agency Ltd.
Mclean Kennedy Inc.
MOL (Americas) LLC
MOL Chemical Tankers
MOL Chemical Tankers America Inc
MONTSHIP INC.
MSC Geneva S.A.
MSC MEDITERRANEAN SHIPPING COMPANY
Navitrans Shipping Agencies West Inc.
Neptune Bulk Terminals (Canada) Ltd.
Nickel Bros Industrial Ltd
"K" Line
NOAA Olympic Coast National Marine Sanctuary
NORTON LILLY
Oak Maritime
Ocean Network Express (Canada) Inc
Ocean Network Express Inc
Oldendorff Carriers
OOCL (CANADA) INC
Pacific Basin Shipping (Canada) Ltd.
Pacific Northwest Ship & Cargo Services
Pinnacle Renewable Energy
Ravensdown Shipping Services Pty Ltd
RCI
Robert Reford
SAAM Towage
Saga Welco AS
Saturna Cetacean Sighting Network
Seaspan ULC
Seaward Engineering and Research LTD.
Swire Bulk Pte Ltd
Teekay
Trans Mountain
Ocean Tugs
Trans-Oceanic Shipping
V.Ships USA LLC (Boston)
Valles Steamship (Canada) Ltd
VANCOUVER ISLAND AGENCIES
Varamar Group
SM Line Corporation
Westward Shipping Ltd
Westwood Shipping Lines
Wheelhouse Shipping Agency Ltd.
Wilhelmsen Ships Service
Yang Ming Shipping(Canada) Ltd.
Zim Integrated Shipping Services

**Appendix B**

2021 Voluntary vessel slowdown hydroacoustic studies

# ECHO Program 2021 Voluntary Vessel Slowdown Hydroacoustic Studies

## Hydroacoustic Monitoring


JASCO Applied Sciences (Canada) Ltd
SMRU Consulting


28 March 2022

Submitted to:

Krista Trounce
Vancouver Fraser Port Authority
Contract 19-0226 P001494-001


Authors:

Connor H. Grooms (JASCO)
Chloe E. Malinka (SMRU)
Graham A. Warner (JASCO)
Jason D. Wood (SMRU)
April E. Houweling (JASCO)
Jennifer L. Wladichuk (JASCO)
Alexander O. MacGillivray (JASCO)
Dominic J. Tollit (SMRU)
Tina M. Yack (EcoSound Bioacoustics)



P001494-001
Document 02626
Version 1.0

Suggested citation:

Grooms, C.H., C.E. Malinka, G.A. Warner, J.D. Wood, A.E. Houweling, J.L. Wladichuk, A.O. MacGillivray, D.J. Tollit, and T.M. Yack. 2022. ECHO Program 2021 Voluntary Vessel Slowdown Hydroacoustic Studies: Hydroacoustic Monitoring. Document 02626, Version 1.0. Technical report by JASCO Applied Sciences and SMRU Consulting for Vancouver Fraser Port Authority.

Author Affiliations:

*JASCO Applied Sciences*

Connor H. Grooms
Graham A. Warner
April E. Houweling
Jennifer L. Wladichuk
Alexander O. MacGillivray

*SMRU Consulting*

Chloe E. Malinka
Dominic J. Tollit
Jason D. Wood

*EcoSound Bioacoustics*

Tina M. Yack

# Contents

# Figures

# Tables

# 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 2021 voluntary Slowdown initiative in Haro Strait and Boundary Pass. This study involves analyzing data collected at two hydrophone sites: Lime Kiln hydrophone (Haro Strait) and Transport Canada underwater listening station (Boundary Pass), during the 60 day Baseline period and the 122 day Slowdown period (Table 1). The purpose of the analyses performed here was to assess the effectiveness of the Slowdown initiative for reducing underwater noise levels from ships and to document the occurrence of killer whales. In previous years, the Slowdown period in this area occurred from the first arrival of Southern Resident killer whales (SRKW) after 1 Jun and ending 31 Oct. Due to the extended presence of SRKW in 2021, the Slowdown period was extended into November for an additional 30 days. This November Slowdown period was analyzed separately due to a change in participation rate and environmental factors including sustained high winds and storms that influenced ambient noise levels.

Data collected during the 2021 Slowdown included hydroacoustic data, water current velocity, wind speed, and automatic identification system (AIS) data from vessels. In addition, water temperature and salinity profiles (for measuring speed of sound in seawater) were sampled approximately once per month at several locations in Haro Strait and Boundary Pass.

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 were 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 report presents the methods (Section 2), results (Section 3), and conclusions (Section 5) for the 2021 hydroacoustic studies.

Table 1. Baseline and Slowdown periods for 2021.

| Period | Start date/ time (PDT) | End date/ time (PDT) | Duration (days) |
|---|---|---|---|
| Baseline | 2021 May 3 00:00 | 2021 Jul 1 11:59 | 60 |
| Slowdown (Jul-Oct) | 2021 Jul 2 00:00 | 2021 Oct 31 11:59 | 122 |
| Slowdown (Nov) | 2021 Nov 1 00:00 | 2021 Nov 31 11:59 | 30 |

# 2. Methods

## 2.1. Hydroacoustic Measurements

### 2.1.1. Lime Kiln

Underwater sound was recorded with a Reson TC4032 hydrophone (Teledyne Reson; −170 ± 3 dB re 1 V/µPa sensitivity) at Lime Kiln. The hydrophone was diver deployed and is cabled ashore to the Lime Kiln Lighthouse, on the west side of San Juan Island (Figure 1). The cabled hydrophone is located ~70 m offshore and at 23 m depth. It is mounted approximately 1 m above the seafloor. The hydrophone was commissioned on 15 Sep 2018 and was used until 23 Feb 2022 (Table 2). The hydrophone is protected by a hydrophone cage, which is covered with a shroud to minimize non-acoustic noise caused by water flow over the hydrophone transducer, often referred to as 'flow noise'.

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) with 16 bit resolution. Data were stored by PAMGUARD (https://www.pamguard.org/) as 1 min WAV files.

The system was calibrated on 29 May 2019, 3 Dec 2020, and 14 May 2021 using a Pistonphone Type 42AC precision sound source (G.R.A.S. Sound & Vibration A/S). The system was found to be stable during each calibration. 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.

Acoustic data at Lime Kiln were successfully recorded for 99.53% of the period evaluated in this report. Throughout the entire period (from the start of Baseline to the end of the November 2021 Slowdown period), there was a total of only 0.47% of the time (equivalent to 23 h, 45 m) during which no acoustic data were available.

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 |

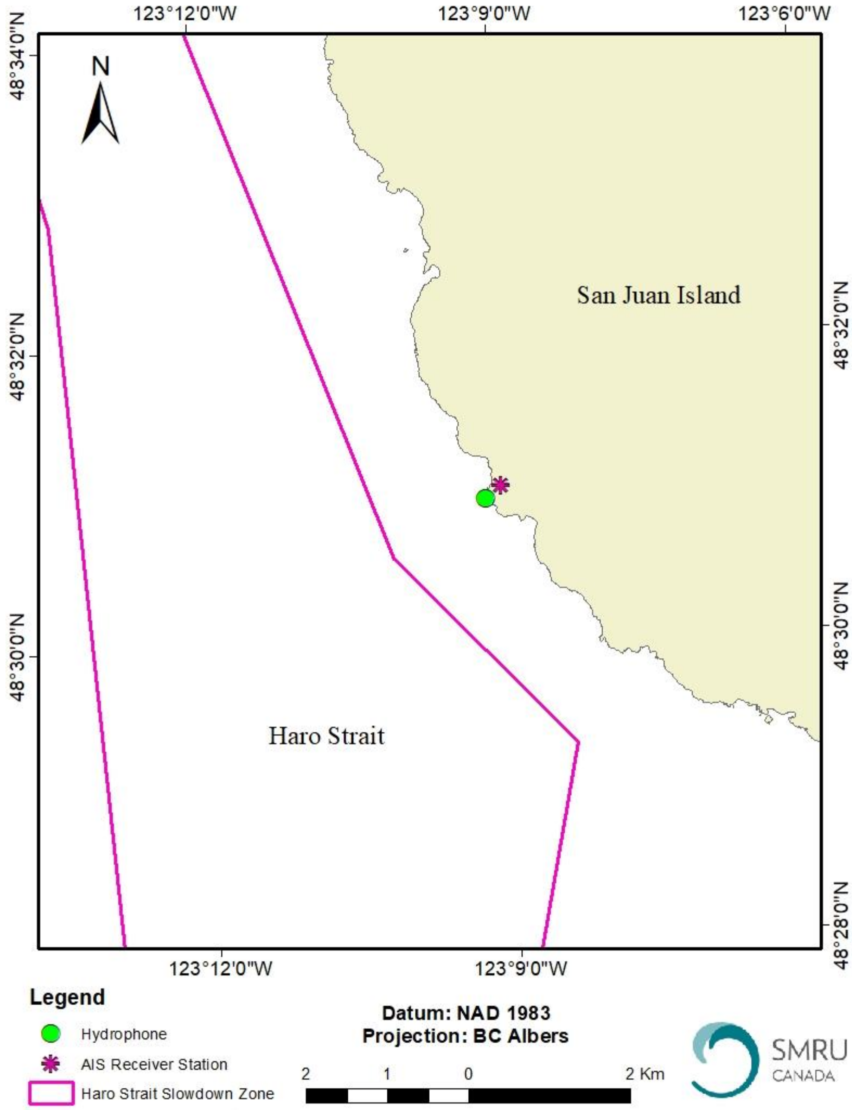



Figure 1. Map of Haro Strait with the location of the Lime Kiln hydrophone.

### 2.1.2. Boundary Pass Underwater Listening Station

Underwater sound was recorded at the cabled Underwater Listening Station (ULS; JASCO) in Boundary Pass. The ULS was deployed on two sub-sea moorings between the international shipping lanes in Boundary Pass, spaced approximately 300 m of each other. The ULS consisted of two tetrahedral frames (Frames A and B) that were deployed using a cable-lay vessel and remotely operated vehicle (ROV) (Figure 2). Each frame is independently connected to shore by a fiber-optic and electrical cable running 2.5 km along the seabed.

Each frame of the ULS has eight hydrophones: four are M36-V35 omnidirectional hydrophones (GeoSpectrum Technologies Inc; −165 ± 3 dB re 1 V/µPa sensitivity) and four are HTI-99-HF (High Tech, Inc, −165 dB re 1 V/µPa sensitivity). For the Slowdown evaluation study, data from the GTI M36-V35 hydrophones were used for analyzing ambient sound levels. Individual hydrophone channels are denoted as A1 to A4 for Frame A and B1 to B4 for Frame B. Table 3 lists the sensor deployment locations and the recording periods. Each hydrophone is protected by a hydrophone cage, which is covered with a shroud to minimize noise from water flow over the acoustic transducers. The ULS recorded sound at a sample rate of 512,000 samples per second (10 Hz to 256 kHz recording bandwidth) with 24 bit resolution on each channel using JASCO OceanObserver™ data acquisition systems (www.jasco.com/oceanobserver). ULS data were transmitted to and processed in real-time at the ULS shore station on Saturna Island. Figure 3 shows one of the cabled ULS frames being deployed. The location of the ULS hydrophone frames were accurately measured during deployment using the ROV and an ultra-short baseline acoustic positioning system (USBL). Figure 4 shows the locations of the recorders.

In June 2021, ULS Frame B stopped recording due to a component failure. Frame A continued operating. While a ULS servicing operation was being planned, a JASCO AMAR G4 with a GeoSpectrum M36-V35 hydrophone was deployed near the location of Frame B as a back-up system (data from the latter instrument were not needed for the present study). In October 2021, both ULS frames were replaced during a servicing operation. Both frames are still recording data as of March 2022. Figure 4 shows a map of the instrument locations. To assist with interpretating acoustic data, water current speed profiles, wind speed, and vessel traffic data were also collected as part of this measurement program

Data from the time of servicing (6 Oct 07:00 UTC to 9 Oct 07:00 UTC) were not analyzed due to noise contamination from barges and equipment involved in the servicing operation.

Table 3. Underwater Listening Station (ULS) frame locations and time periods used for analysis. A map of the ULS frame locations is shown in Figure 4.

| ULS Frame | Latitude | Longitude | Water depth (m) | Hydrophone channel | Start date/ time (UTC) | End date/ time (UTC) | Period |
|---|---|---|---|---|---|---|---|
| Frame A Dep 1 | 48°45.55800' N | 123°3.87600' W | 193 | 1 | 2021 Jan 1 00:00 | 2021 Oct 6 07:00 | Baseline & Slowdown |
| Frame B Dep 2 | 48°45.65731' N | 123°3.65912' W | 195 | 2/3 | 2021 Oct 9 07:00 | Ongoing | Slowdown |

Dep 1 = deployment 1 and Dep 2 = deployment 2.

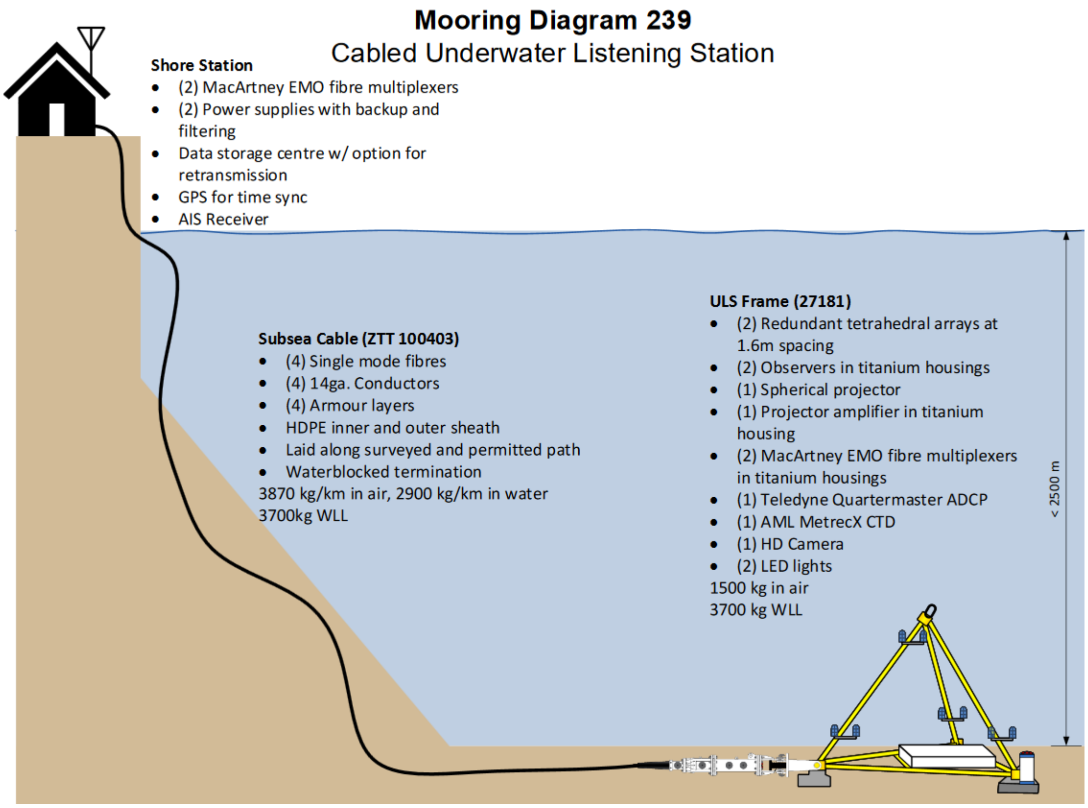



Figure 2. Boundary Pass Underwater Listening Station (ULS) mooring (JASCO design 239). The hydrophones were mounted on a tetrahedral frame, and the upper hydrophone was 2.2 m above the seabed, inside an acoustically transparent shroud.

Figure 3. Boundary Pass Underwater Listening Station (ULS) frame connected to the cable termination and being deployed.

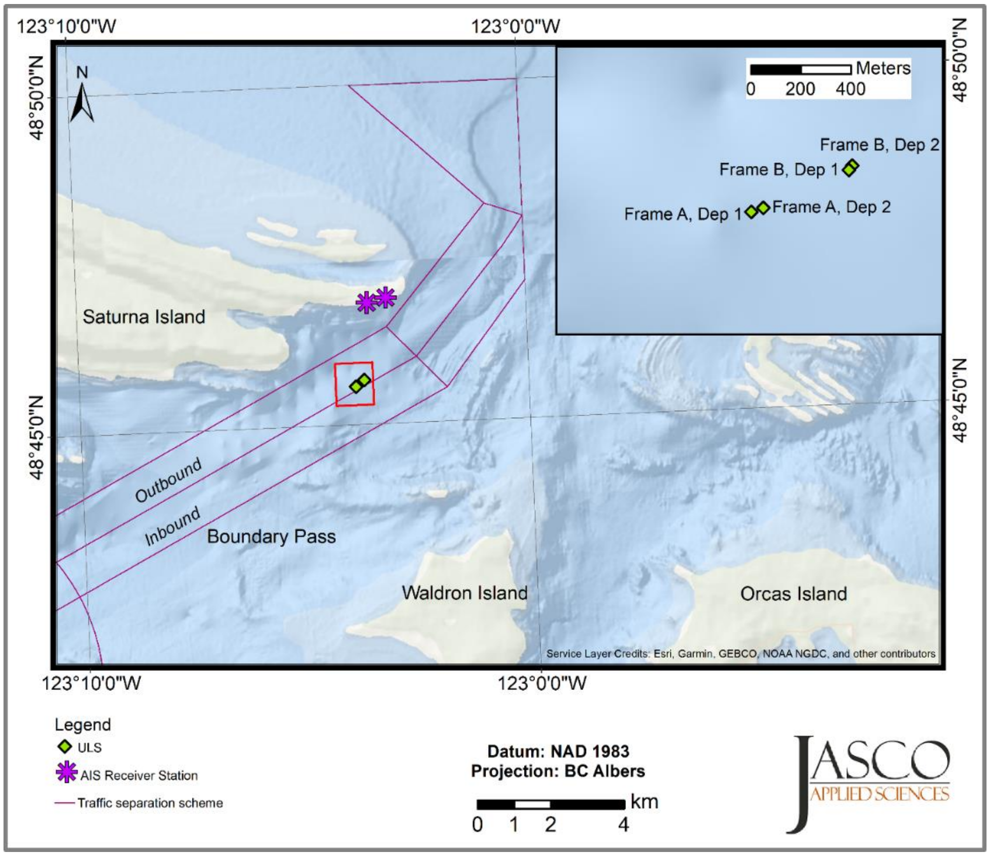



Figure 4. Map of Boundary Pass with locations of the hydrophones and Automatic Identification System (AIS) receivers. An Acoustic Doppler Current Profiler (ADCP) mounted on Frame A experienced an outage from 6–20 May 2021 and was then operational until the underwater listening station (ULS) servicing event. After servicing, the ADCP was no longer operational.

The laboratory calibrations of each hydrophone element of the ULS 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). The pistonphone calibrator produces a constant tone at 250 Hz at the hydrophone sensor. The level at which the instrument records the reference tone yields the total pressure sensitivity for the instrument, i.e., the conversion factor between digital units and pressure.

Analysis of the post-servicing ambient data determined the noise floor on channel 1 of ULS Frame B was elevated compared to the pre-servicing period. An investigation determined the most likely cause of the elevated noise floor was increased vibration-induced pseudonoise below 100 Hz and additional high-frequency tonal noise above 10 kHz (Figure 5). To prevent this issue from affecting the results of the Slowdown hydroacoustic analysis, the other channels of ULS Frame B were analyzed to determine which had the lowest noise floor (Figures 6 and 7). Based on the results of this analysis, channel 2 was selected for frequencies <10 kHz and channel 3 for frequencies >10 kHz for the post-servicing period. For future analysis, this is not expected to pose an issue because the Baseline comparison data will have the same background/instrument noise present.

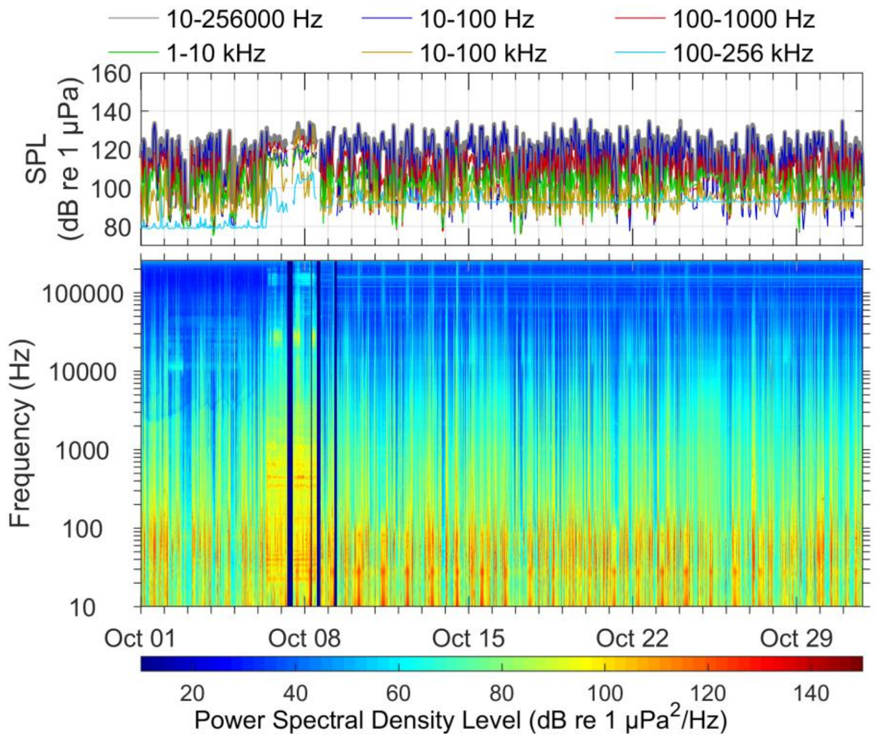



Figure 5. ULS (top) time series and (bottom) spectrogram using a combination of pre- and post-servicing data from channel 1 on Frames A and B. Servicing occurred between 6 and 9 Oct 2021. Servicing vessel noise is apparent during this time, and small data gaps are associated with servicing and testing. After servicing, additional tones at high frequencies (>100 kHz) and increased low-frequency (<100 Hz) noise occurs.

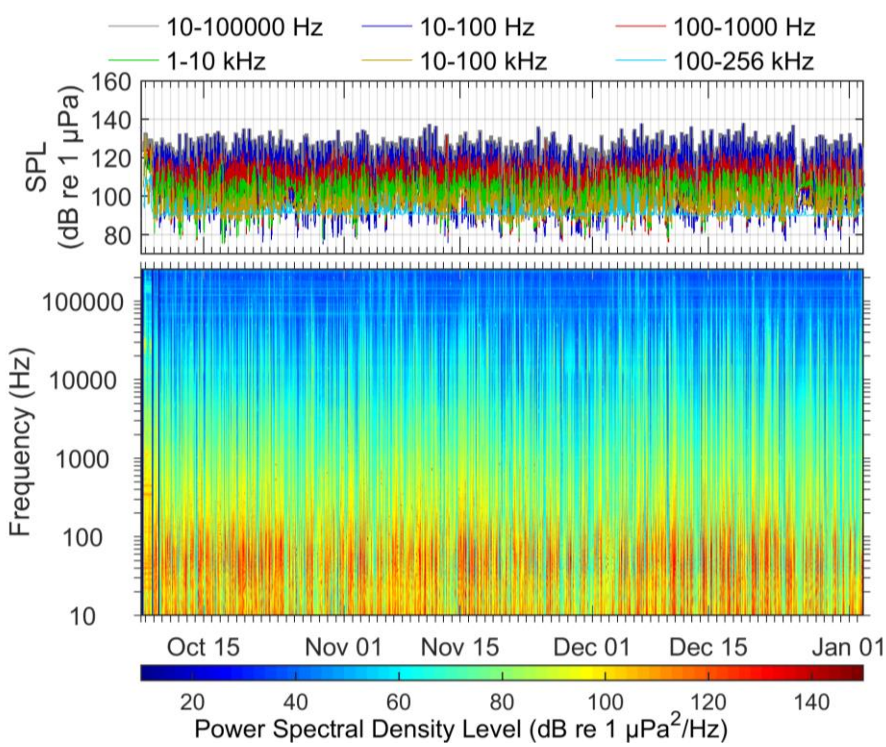



Figure 6. ULS Frame B channel 2 (top) time series and (bottom) spectrogram for the post-servicing period. Low-frequency self-noise performance more closely matches data from the pre-servicing period for frequencies <10 kHz.

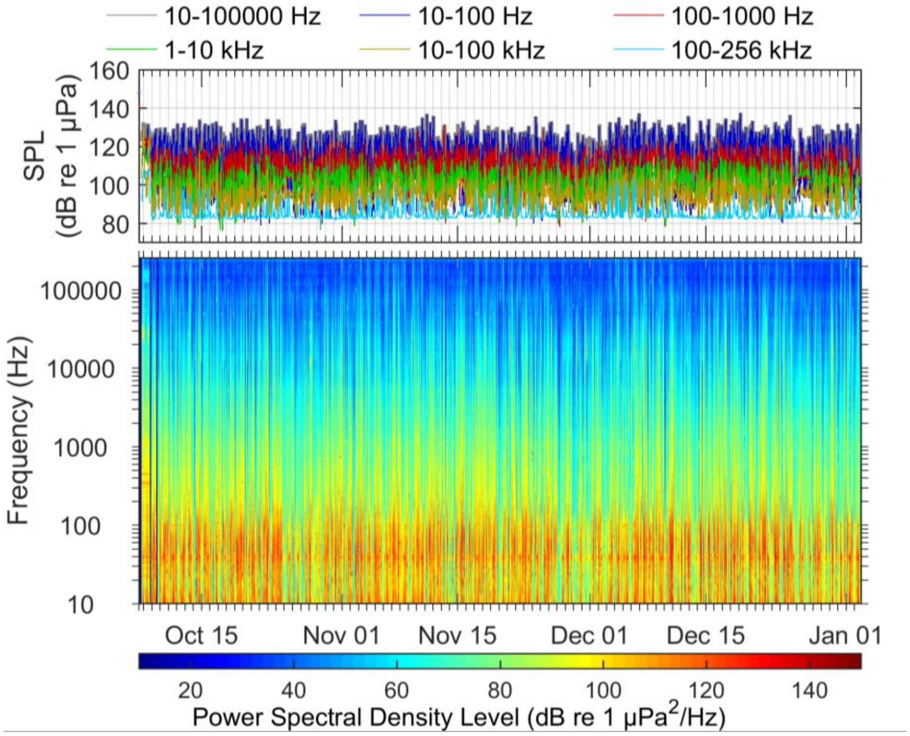



Figure 7. ULS Frame B channel 2 (top) time series and (bottom) spectrogram for full post servicing period. High-frequency self-noise performance more closely matches data from the pre-servicing period for frequencies >10 kHz.

## 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 Haro Strait and Boundary Pass from April to November 2021. 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 8 shows a map of the CTD cast locations, and Table 4 lists the coordinates of the CTD casts.

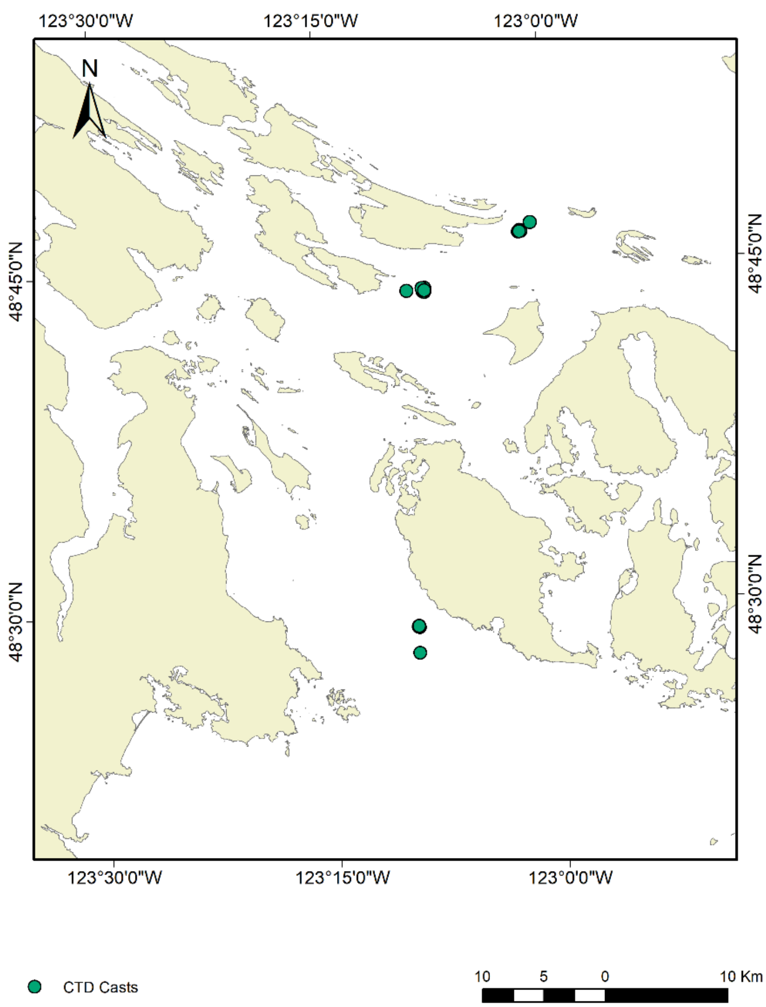



Figure 8. Locations of conductivity, temperature, and depth (CTD) casts in Boundary Pass and Haro Strait.

Table 4. 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° 28.002' N | 123° 09.304' W | 2021 Apr 28 09:53 |
| | 48° 29.130' N | 123° 09.268' W | 2021 Jun 02 12:17 |
| | 48° 29.170' N | 123° 09.336' W | 2021 Jun 23 10:50 |
| | 48° 29.160' N | 123° 09.295'W | 2021 Jul 06 14:43 |
| | 48° 29.202' N | 123° 09.300' W | 2021 Aug 25 10:36 |
| | 48° 29.198' N | 123° 09.333' W | 2021 Oct 01 14:43 |
| | 48° 29.198' N | 123° 09.309' W | 2021 Nov 12 12:25 |
| Boundary Pass | 48° 46.467' N | 123° 01.598' W | 2021 Apr 23 11:32 |
| | 48° 44.057' N | 123° 08.095' W | 2021 Apr 23 13:05 |
| | 48° 46.379' N | 123° 01.670' W | 2021 Jun 02 10:43 |
| | 48° 43.983' N | 123° 09.268' W | 2021 Jun 02 11:08 |
| | 48° 43.943' N | 123° 08.204' W | 2021 Jun 23 12:02 |
| | 48° 46.438' N | 123° 01.558' W | 2021 Jun 23 12:35 |
| | 48° 46.380' N | 123° 01.705' W | 2021 Jul 06 13:07 |
| | 48° 44.086' N | 123° 08.099' W | 2021 Jul 06 13:39 |
| | 48° 46.410' N | 123° 01.548' W | 2021 Aug 25 08:57 |
| | 48° 44.082' N | 123° 08.262' W | 2021 Aug 25 09:36 |
| | 48° 46.391' N | 123° 01.635' W | 2021 Oct 01 12:26 |
| | 48° 44.082' N | 123° 08.262' W | 2021 Oct 01 13:39 |
| | 48° 46.790' N | 123° 00.898' W | 2021 Nov 12 10:33 |
| | 48° 43.982' N | 123° 08.097' W | 2021 Nov 12 11:11 |

## 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 Haro Strait and Boundary Pass, so the messages were recorded using AIS receivers and logging computers.

AIS transmissions from vessel traffic in Haro Strait were recorded using a land-based AIS receiver located at the Lime Kiln Lighthouse, while those in Boundary Pass were recorded using land-based AIS receivers located near East Point on Saturna Island (see Figure 4). 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 Haro Strait and Boundary Pass 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 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 each 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 versus Slowdown).

## 2.4. Small Boat Detections

### 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 5) 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, when boat traffic is far less, detections earlier than 08:00 and later than 18:00 PDT were discarded.

Table 5. 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 |

### 2.4.2. Boundary Pass

The boat (i.e., small vessel) and ship (i.e., large vessel) detectors were applied to the Boundary Pass data by comparing sound levels in established frequency bands to criteria values. If a 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 6; criteria names are shown in italics in the description below. The ship and boat detector settings used here are the same as those determined in previous years 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 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 ULS, 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 6. 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 |

## 2.5. Water Current Measurements

Accurate seafloor current speeds are required for filtering out time periods when flow noise can substantially contaminate sound level measurements. Flow noise contamination has been observed on the Lime Kiln and Boundary Pass hydrophones when the measured current speeds exceed 25 cm/s and 50 cm/s, respectively (Warner et al. 2021).

### 2.5.1. Lime Kiln

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 the batteries.

The current meter was set to record measurements every 10 min. At each 10 min measurement, an electro-magnetic burst of 10 pulses spaced out by 0.5 s was produced to measure currents. The average of these 10 measurements was stored and used for further analysis.

During a battery replacement dive on 27 Oct 2021, divers removed growth on the sensor. The period of reduced sensitivity prior to this cleaning is visible in the reduced magnitude of the current speed measurements from approximately late September to the end of October (see Figure 9). This means that for October 2021, there were underestimations of current speed. This could have led to more data being included in the CDF analysis (Table 9; see Section 3.4.1) than should have been, though the data being excluded at this final step is a minor proportion of data.

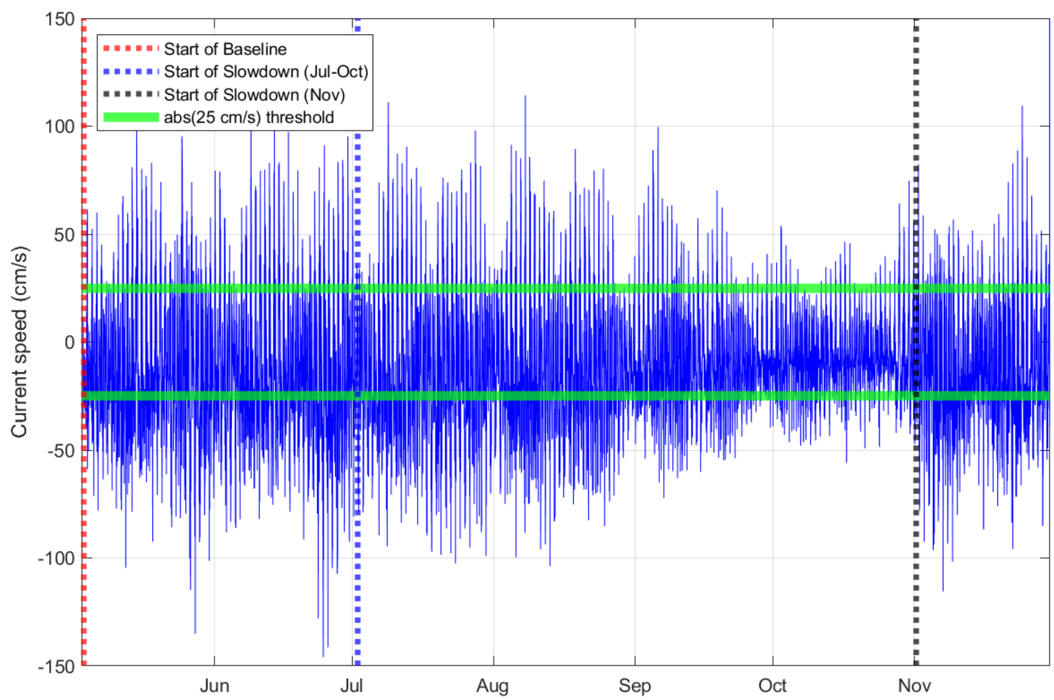



Figure 9. Time series of current speed measurements (cm/s) throughout 2021 Baseline and Slowdown periods at Lime Kiln. The periods are denoted with vertical dotted lines, and the green horizontal lines show the positive and negative threshold cut-off of 25 cm/s at Lime Kiln, below which data could be included in Cumulative Distribution Function (CDF) analysis.

### 2.5.2. Boundary Pass

Water current was measured using a Quartermaster Acoustic Doppler Current Profiler (ADCP; Teledyne) mounted on the ULS Frame A and integrated into the power supply (of ULS A1) and the data cable of the ULS (see Figure 2). The ADCP was oriented vertically to measure water current profiles. It operated at 150 kHz. The ADCP was deployed approximately 1 m above the seafloor and measured currents from near the seabed (~190 m depth) to near the surface.

In May, a USB adapter for the ADCP failed, resulting in a two-week data gap. After the October ULS servicing operation, power circuit 1 on Frame A was nonoperational. ADCP current measurements have been unavailable since that time. Table 7 summarizes the available ADCP data. Predictions from the WebTide model, adjusted based on actual seabed current measurements, were thus used to fill in missing periods when ADCP data were unavailable.

Table 7. Acoustic Doppler Current Profiler (ADCP) recorder location (on ULS Frame A) and recording periods during Year 3 (2021).

| ADCP serial number | Centre frequency (kHz) | Latitude | Longitude | Water depth (m) | Start (UTC) | End (UTC) |
|---|---|---|---|---|---|---|
| 24647 | 150 | 48°45.55800' N | 123°3.87600' W | 193 | 2021 Jan 1 00:00 | 2021 May 6 16:36 |
| | | | | | 2021 May 20 07:41 | 2021 Oct 7 06:07 |

The WebTide Tidal Prediction Model (v0.7.1) (Foreman et al. 2000, Institute of Ocean Sciences 2015) predicts northing and easting current speeds as a function of time and location. WebTide does not provide depth-dependent current predictions. To investigate the accuracy of the WebTide model, we compared the ADCP measurements from the first ULS deployment to the model. The WebTide model was found to agree reasonably well with measured currents near the surface but did not agree as well with measured currents near the seafloor. However, features of the WebTide predictions were nonetheless found to correlate with the ADCP measurements of seabed currents.

ADCP-measured seafloor current magnitude was found to be correlated with WebTide current predictions along a principal axis oriented 45° clockwise from northing (i.e., the southwest-northeast axis). Figure 10 shows the magnitude of the measured seafloor current versus the WebTide predictions along the southwest-northeast axis. The comparisons showed that, for 87% of the time, measured seafloor current magnitude exceeded 0.5 m/s when the WebTide prediction along the southwest-northeast axis exceeded +0.5 m/s. Thus, this criterion was used as a proxy for predicting when seafloor current speeds exceeded 0.5 m/s for time periods when ADCP data were unavailable at the Boundary Pass ULS.

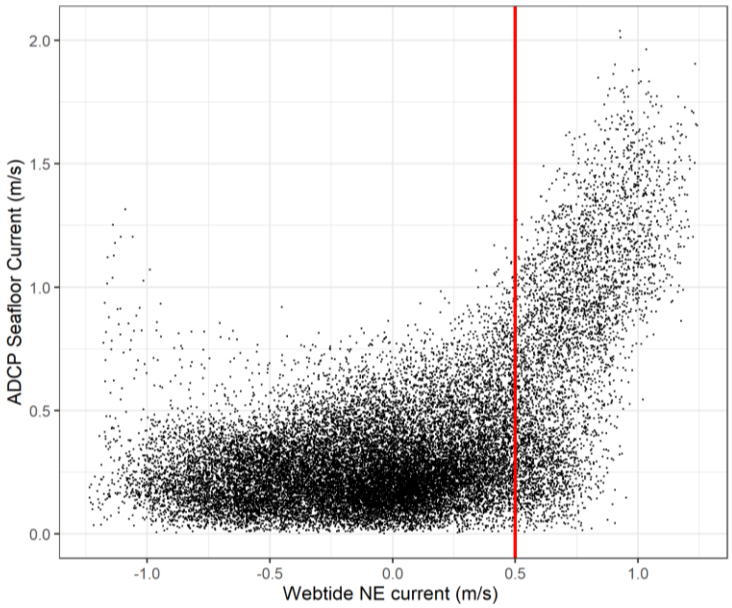



Figure 10. Magnitude of the Acoustic Doppler Current Profiler (ADCP)-measured seafloor current speed compared with WebTide-predicted current speed along a principal axis oriented 45° clockwise from northing (i.e., in the southwest-northeast direction). Positive WebTide current speeds indicate water travelling in the northeast direction; negative WebTide current speeds indicate water travelling in the SW direction

## 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 used to investigate the effect of wind speed. Environment Canada 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.

## 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 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 they 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 would potentially skew CDF results. Likewise, the effect of a slowdown on ambient sound 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 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 to the hydrophone of all AIS broadcasting vessels;
- Near-seafloor water current speed was less than a site-specific threshold to minimize flow noise effects (using currents collected as described in Section 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 and so confound sounds from potential participants, as determined by the small boat detectors (see Section 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. 2017) 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 |

## 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. 2017). 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 2021 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.

## 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. The GAMM also provides information on the contributions of other key variables. A GAMM approach was taken for two reasons. First, the relationship between covariates and SPL may not always be linear and therefore a model that also allows for non-linear effects was needed. Second, successive SPL measurements at 1 min 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, Slowdown (Jul-Oct) or Slowdown (Nov)), and a number of additional regression covariates that would help explain the variation in noise levels received at Lime Kiln. These covariates included the following:

- 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 min 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 4 h time window based on an empirical examination of the data series.

## 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 min 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 five months of the entire Slowdown (Jul-Nov). The algorithm was similar to the one described in Moloney et al. (2014) and Dewey et al. (2015). Figure 11 shows the various processing steps of the detector.

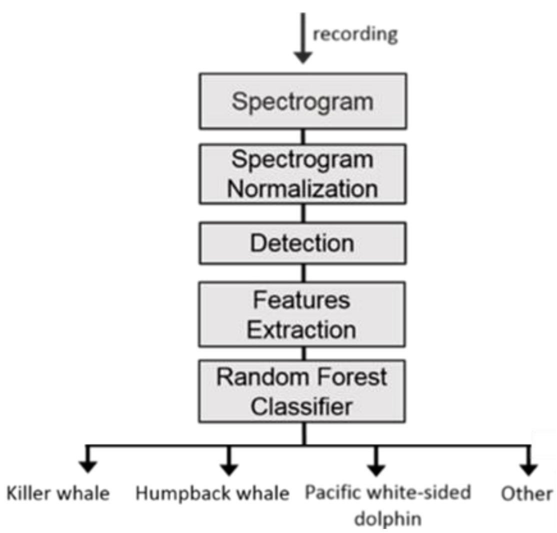



Figure 11. Automatic detection of killer whale, humpback whale, and Pacific white-side dolphin.

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', and 'other'. Figure 12 illustrates the key processing steps of the detector on a recording that contained killer whale vocalizations.

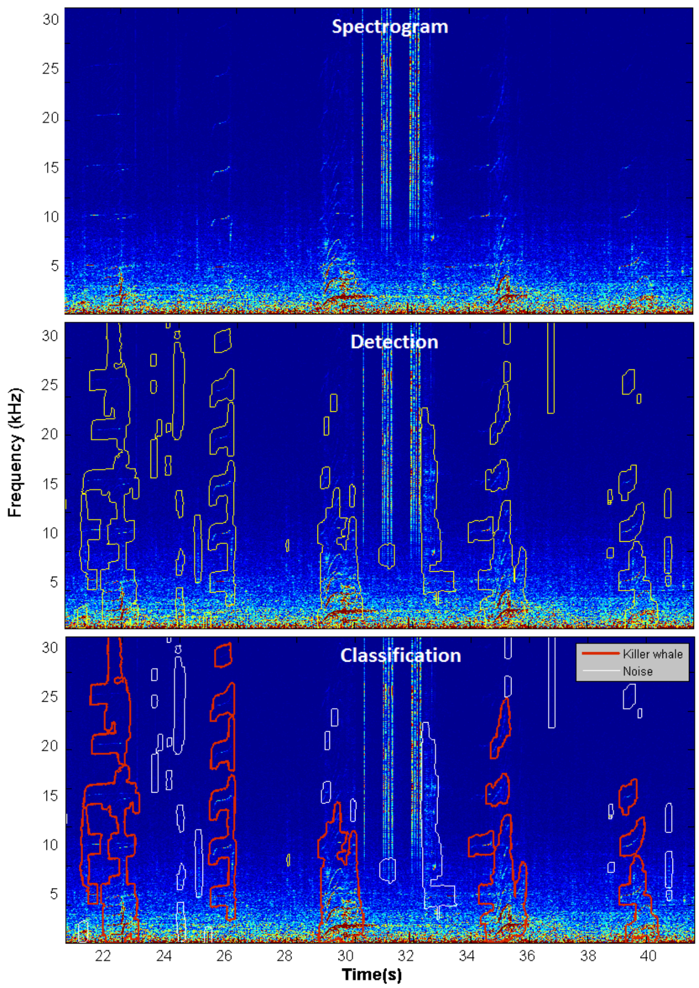



Figure 12. Key processing steps of the detector. Top panel: Spectrogram with killer whale vocalizations. Middle panel: Acoustic events detected in the spectrogram. Bottom panel: Killer whale vocalizations classified using a random forest classifier.

## 2.11. Killer Whale Manual Analysis

All automated detections from killer whale vocalizations obtained at Boundary Pass were manually verified by experienced analysts (Jennifer Wladichuk and April Houweling, JASCO) using the web application PAMview (Figure 13). 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 reviewing all PAMView detections identified as killer whale from the Slowdown period to provide initial ecotype identification and identify initial start and end times. Subsequently, the associated wav files were processed using PAMGuard software (Gillespie et al. 2009) and then PAMGuard's ViewerMode was used to identify final start and end times for each event when warranted (e.g., echolocation clicks or faint calls were determined to be present). An event was defined as a period of time in which the sound type was present continuously with less than a 30 min inter-detection interval. Each unique killer whale event was assigned 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).

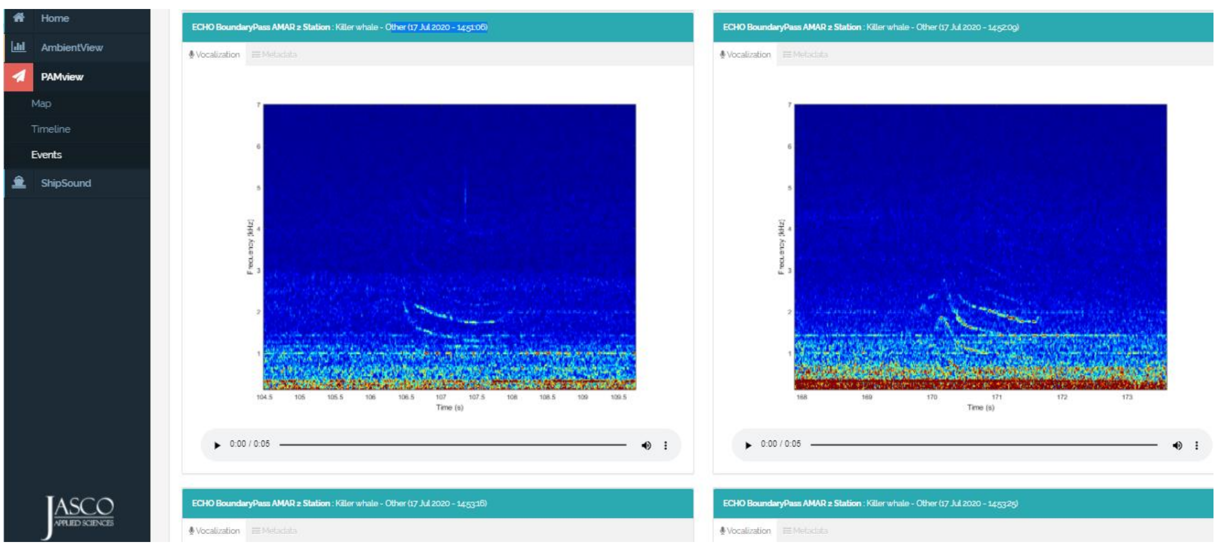



Figure 13. JASCO's Web Portal platform (PAMview). Example of spectrograms with killer whale vocalizations.

# 3. Results

## 3.1. CTD Measurements

A total of 21 CTD casts were collected from April to November 2021: 7 casts in Haro Strait and 14 in Boundary Pass (see Table 4). Figures 14–16 show the temperature, salinity, and sound speed profiles, respectively. Profiles measured in Boundary Pass tended to exhibit a stronger thermocline than those measured in Haro Strait. As a result, the Haro Strait profiles were more uniform with depth. Likewise, June through October exhibited stronger thermoclines in both bodies of water. As a result, the sound speed profiles in May and November were more uniform with depth (see Figure 16).

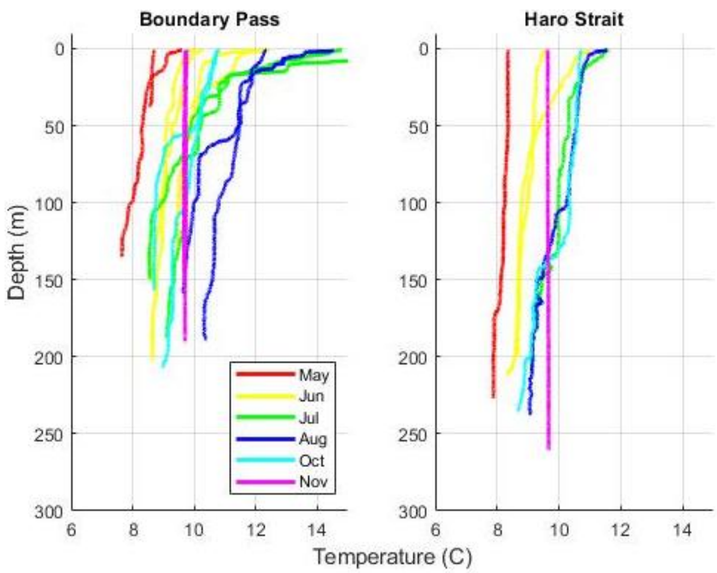



Figure 14. Water temperature profiles from the conductivity, temperature, and depth (CTD) measurements in (left) Boundary Pass and (right) Haro Strait.

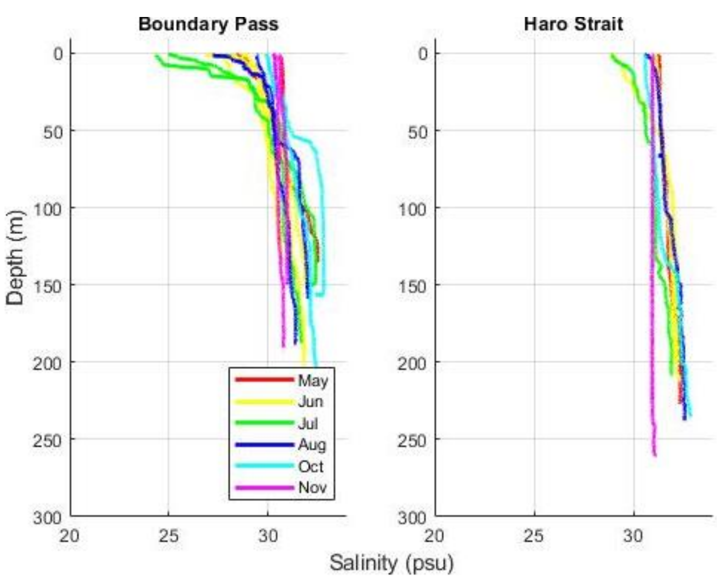



Figure 15. Water salinity profiles from the conductivity, temperature, and depth (CTD) measurements in (left) Boundary Pass and (right) Haro Strait.

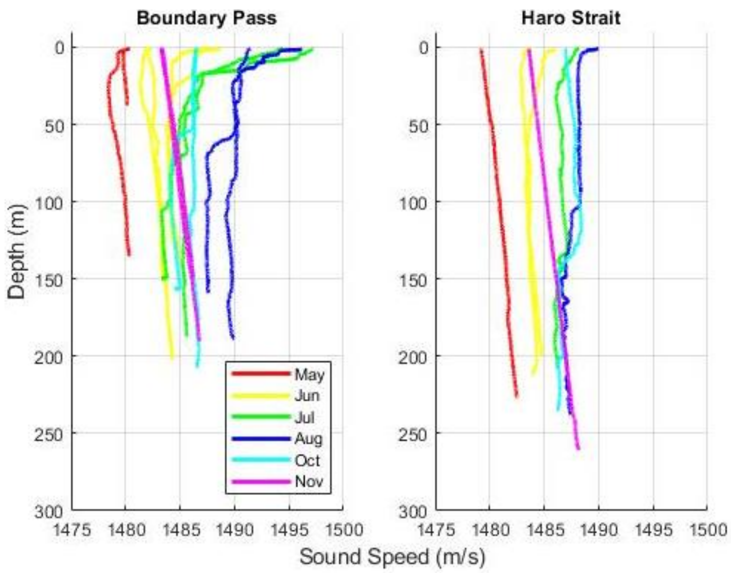



Figure 16. Sound speed profiles calculated from conductivity, temperature, and depth (CTD) measurements in (left) Boundary Pass and (right) Haro Strait.

## 3.2. Large Vessel Traffic

### 3.2.1. Lime Kiln

Vessel-type composition based on the closest AIS-enabled vessel to the Lime Kiln hydrophone in each 1 min increment within the acoustic 6 km monitoring area was similar (typically within 1–2% across vessel types) between Baseline and Slowdown (Jul-Oct) periods (Figure 17). Bulk carriers (9–11%), Container Vessels (7%), and General Cargo (14–16%) were the most frequently identified piloted vessel types in both periods, while Car Carriers and Tankers each contributed approximately 2–3% of the total minutes. There was a low number of cruise ships (passenger) in the data this year due to the ongoing COVID-19 pandemic. The Slowdown (Jul-Oct) period had a similar percent of yachts (~20–21%) and sailing vessels (~12–13%) when compared to Baseline. Sailing vessels and yachts decreased by 12 and 15 percentage points in Slowdown (Nov), respectively, compared to Baseline due to recreational boating activity decreasing with season change. This lack of recreational traffic in November resulted in larger proportional changes between Baseline and Slowdown (Nov) periods, with increases of 7 and 11 percentage points for Bulk carriers and General Cargo, respectively.

Note that these per minute vessel presence 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 (Jul-Oct) as it lasted for 122 days, while the Baseline lasted 60 days. Slowdown (Nov) lasted 30 days (see Table 1).

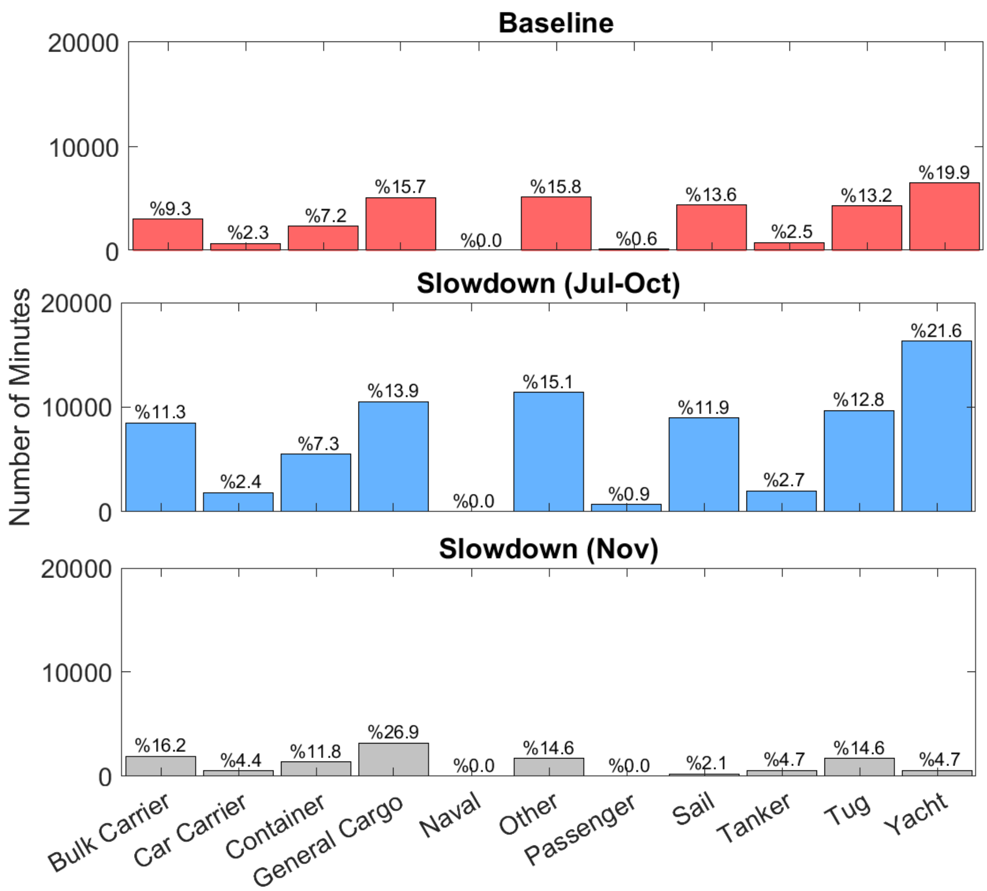



Figure 17. Proportion of Automatic Identification System (AIS) vessel traffic within 6 km of the Lime Kiln hydrophone by vessel category: (Top) Baseline period (middle) Slowdown (Jul-Oct), and (bottom) Slowdown (Nov) period.

Speed through water (AIS-derived speed over ground corrected for tidal currents as measured at the Lime Kiln hydrophone; see Section 2.5.1 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-min measure of speed through the water for the Baseline and both Slowdown time periods, to estimate a vessel type specific difference in speed from the median Baseline. Figure 18 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 (red dashed line in Figure 18), i.e., half the differences in speed are negative and half are positive. The Slowdown (Jul-Oct) period shows a clear shift in distribution to the left of the Baseline median speed (red dashed line at zero in Figure 18), and thus a clear reduction in speed during the Slowdown (Jul-Oct). There is also a reduction in speed during the Slowdown (Nov), compared to Baseline, but as participation was lower here, the reduction observed was also less pronounced. Plotting the distribution of speed through water for key vessel types during Baseline and Slowdown periods (Figure 19; again, using all PPA vessels not just those who participated) clearly shows which vessel classes slowed down the most. The pilots reported to the ECHO Program that 92% of all piloted vessel participated in the Slowdown (Jul-Oct) in Haro Strait and 85% participated in Slowdown (Nov) in Haro Strait.

Based on median speed through the water, estimated speed reductions for the different vessel types were as follows for Haro Strait, during Slowdown (Jul-Oct) and compared to Baseline: Bulk carriers 1.4 knots, General cargo 1.6 knots, Tankers 2.0 knots, Container vessels 3.9 knots, and Car carriers 2.5 knots. During the Slowdown (Jul-Oct) period, Passenger vessels had a greater median speed through water (by 0.1 knots) compared to Baseline. The estimated speed reductions for these vessels for Haro Strait, during Slowdown (Nov) and compared to Baseline, were: Bulk carriers 1.0 knots, General cargo 1.2 knots, Tankers 1.6 knots, Container vessels 3.8 knots, and Car carriers 1.7 knots. No Passenger vessels (which only included cruise ships in this case) were present in the Slowdown (Nov) data.

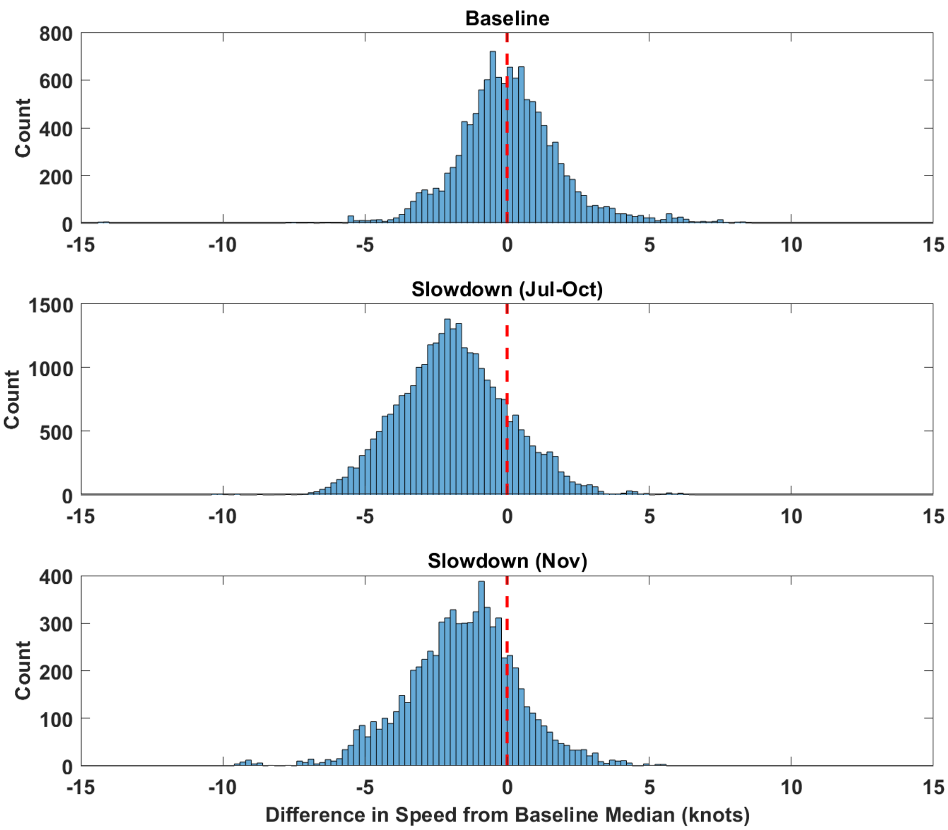



Figure 18. By minute distribution of the difference (by all vessel types) between Baseline median speed through water (knots) and vessel speeds recorded during Baseline and both Slowdown periods. Red dashed line indicates no difference in vessel speed.

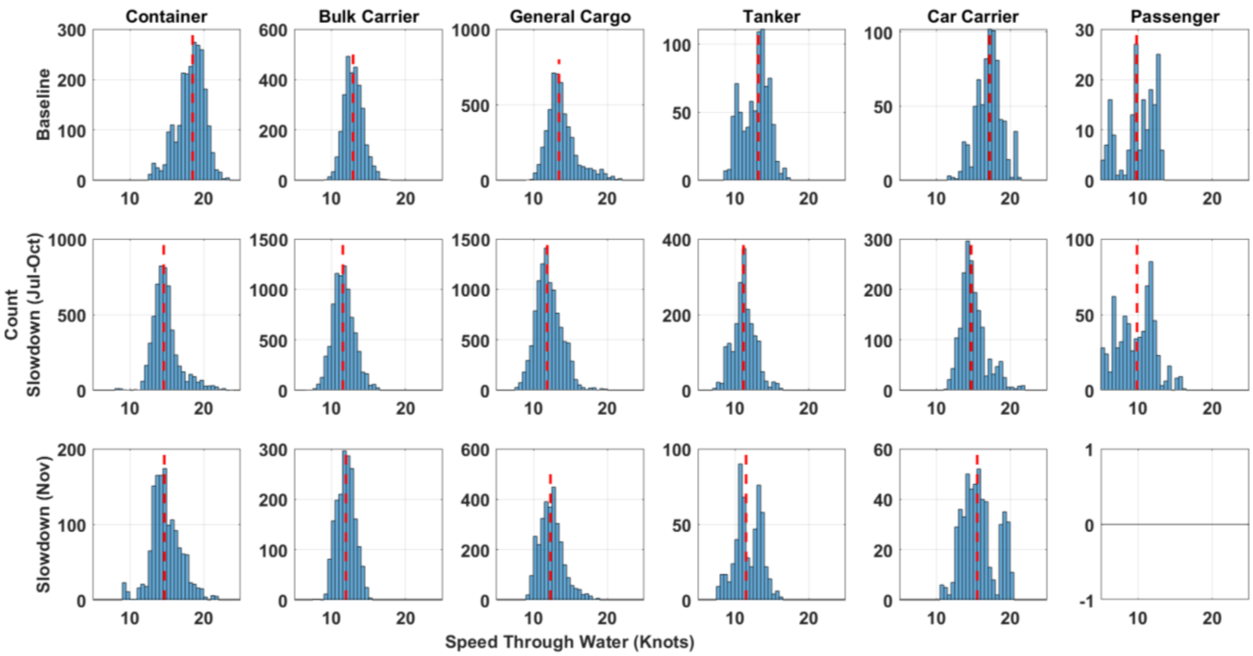



Figure 19. By minute distribution of vessel speed through water (knots) for key vessel types across Baseline and both Slowdown periods. The vertical dashed red line represents the median speed for the vessel type in each period.

## 3.2.2. Boundary Pass

Vessel type composition was 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 the hydrophone. This analysis was performed in 1 min 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 (Figure 20). Bulk carriers (38–40%) and Container ships (13–15%) were the most frequently identified piloted vessel types. General Cargo, Car carriers, and Tankers each contributed approximately 4–5% of the total minutes. Note that these per minute vessel presence 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.

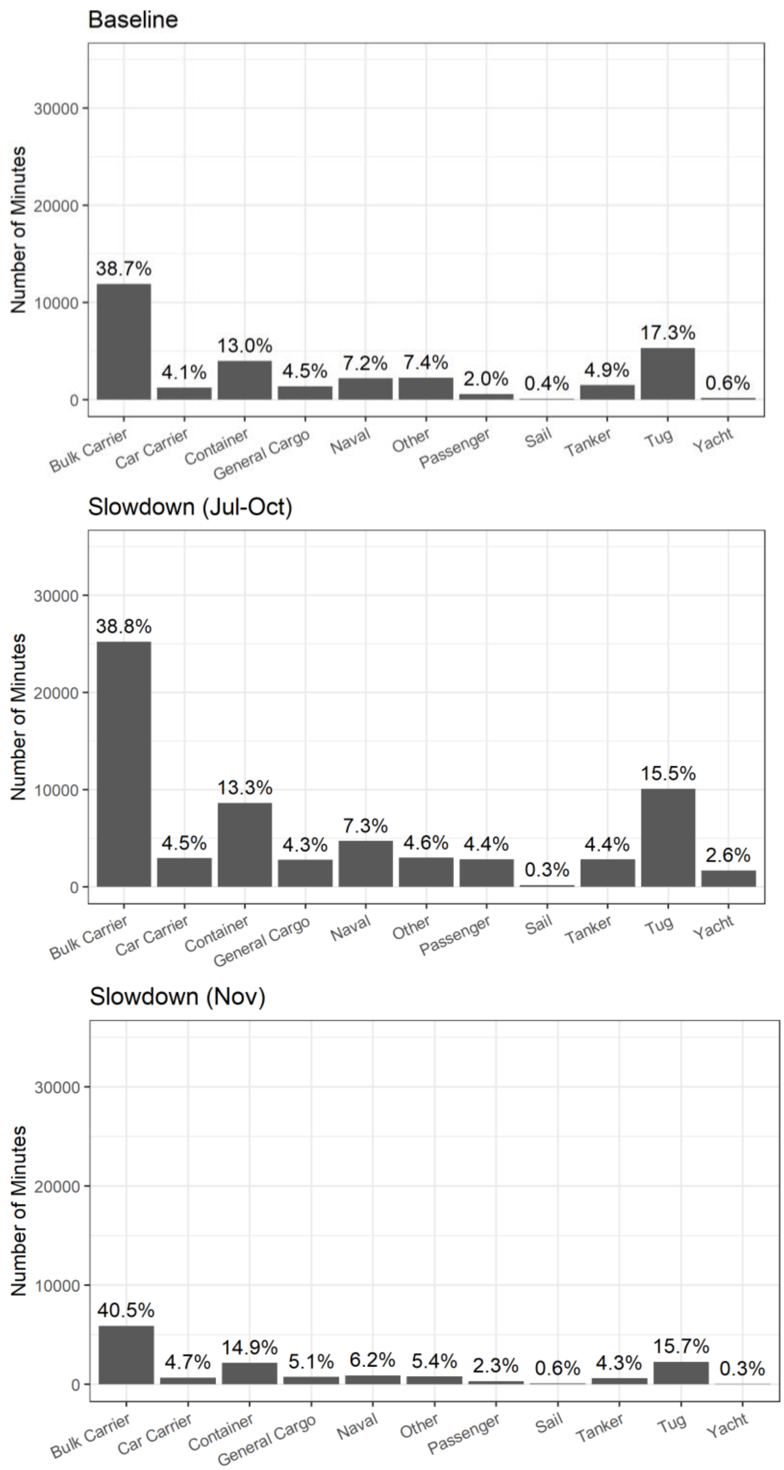



Figure 20. Proportion of Automatic Identification System (AIS) vessel traffic within 6 km of the Boundary Pass hydrophone by vessel category: (Top) Baseline period, (middle) Slowdown period (Jul-Oct), and (bottom) Slowdown period (Nov).

The mean speed through water (AIS-derived speed over ground corrected for modelled tidal current effects; see details in Section 2.5.1) was calculated for 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 only vessels that participated in the Slowdown initiative) 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 the Baseline and Slowdown periods, to estimate the vessel-type-specific change in speed from the median Baseline speed. Figure 21 shows the distributions of the difference in speeds for Baseline and Slowdown periods, aggregated over all vessel types. As expected, the Baseline period shows an even distribution around zero (Figure 21 in red dashed line), i.e., half the differences in speed are negative, half are positive. The Slowdown periods show a clear shift in distribution to the left of the Baseline median speed (Figure 21 in red dashed line at zero) and thus a clear reduction in speed during the Slowdown for both November and July to October time periods. Plotting the distribution of speed through water for key vessel types during Baseline and Slowdown periods (Figure 22; again using all PPA vessels, not only who participated) clearly shows which vessel classes slowed down the most.

Based on median speed through the water, estimated speed reductions for the different vessel types were as follows for Slowdown (Jul-Oct) in Boundary Pass: Bulk carriers 1.4 knots, General cargo 1.6 knots, Tankers 1.6 knots, Container vessels 4.0 knots, and Car carriers 2.8 knots. For Slowdown (Nov) in Boundary Pass, the decreases in vessel speed were: Bulk carriers 0.7 knots, General cargo 1.2 knots, Tankers 1.6 knots, Container vessels 3.8 knots, and Car carriers 1.8 knots.

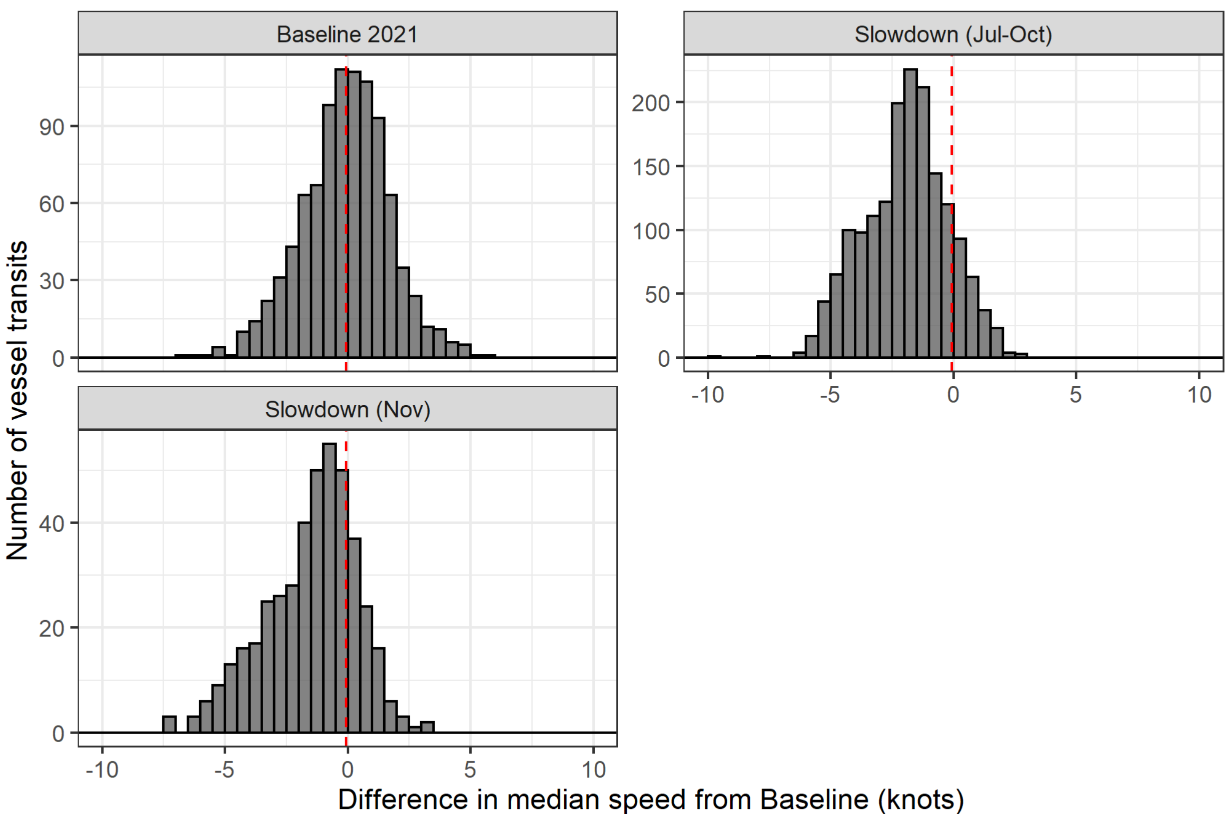



Figure 21. Boundary Pass aggregated over all vessel types: Distributions of the difference between mean vessel speed and the median of the Baseline speeds through water for the corresponding vessel category. A negative value indicates a vessel travelling slower than the median vessel of the same type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

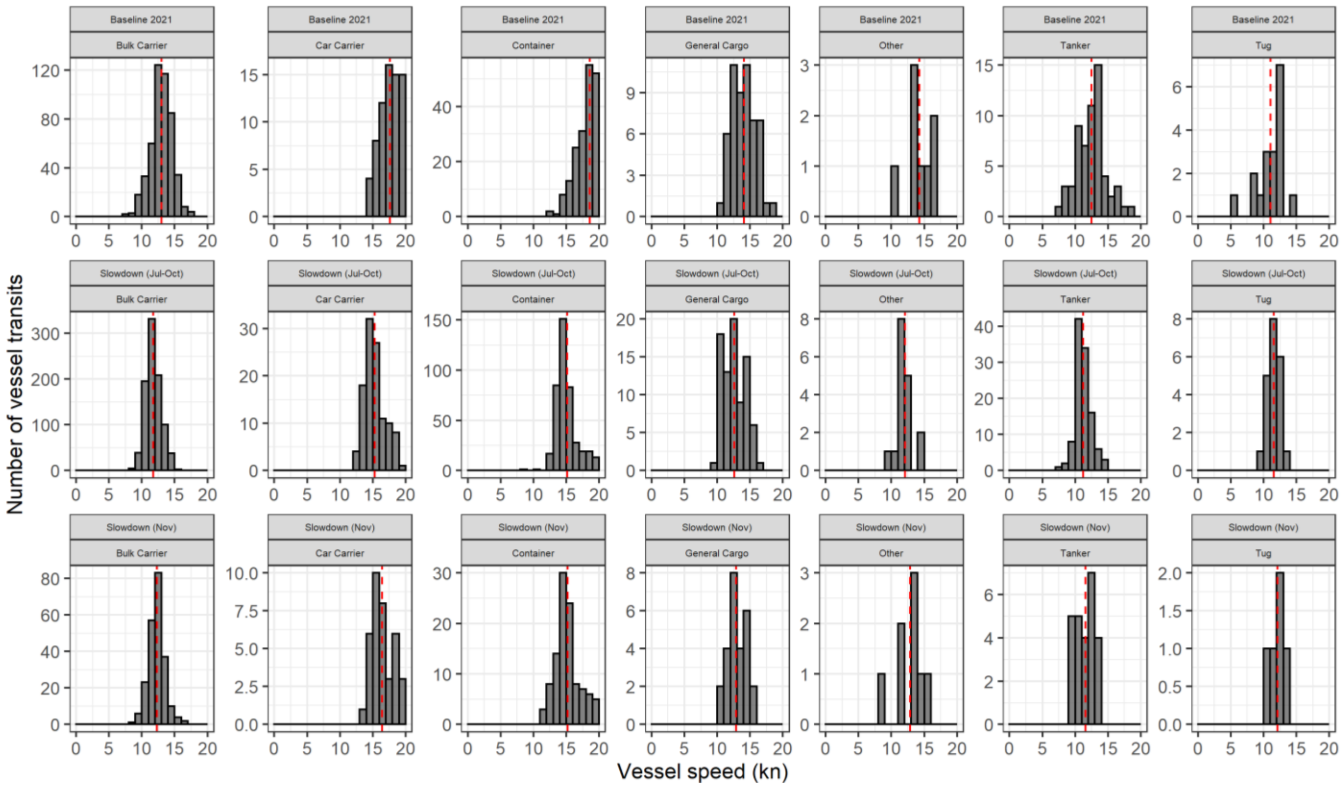



Figure 22. Boundary Pass histograms of speed through water by vessel category and time period. Red dashed lines show the median Baseline speeds through water for each category. Speed through water for each vessel transit was calculated from the time-average value through the Boundary Pass slowdown area.

## 3.3. Small Boat Detections

### 3.3.1. Lime Kiln

Figure 23 shows the daily average minutes per hour of small boat daytime presence at Lime Kiln during Baseline, Slowdown (Jul-Oct), and Slowdown (Nov) periods. Average minutes per hour were likely lower in the Baseline period, compared to the Slowdown (Jul-Oct) period, as it is earlier in the boating season and due to ongoing pandemic-related restrictions on human movement. Average minutes per hour were likely lower in the Slowdown (Nov) period due to cold and stormy weather in November.

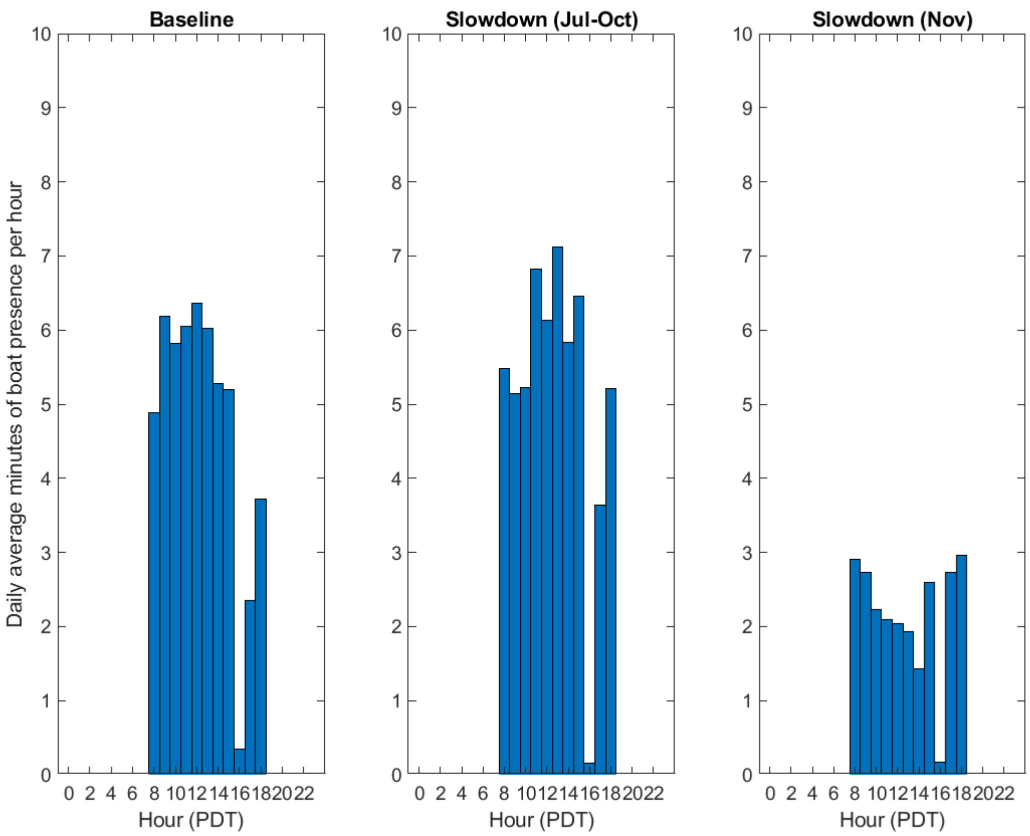



Figure 23. Daily average minutes of small boat daytime detections at Lime Kiln, broken down by hour of day (PDT): (Left) Baseline, (middle) Slowdown (Jul-Oct), and (right) Slowdown (Nov) periods.

### 3.3.2. Boundary Pass

Figure 24 shows the small boat detections at Boundary Pass by daily average minutes of presence per hour. These were only for times when a small boat was detected. 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 24 show the expected trend of more presence in daytime hours than at night; there was no significant change between Baseline and Slowdown (Jul-Oct) periods. Figure 25 provides an example spectrogram of a time when there was a small boat detection.

Daytime small boat detections were 2–3 times more frequent in Boundary Pass (Figure 24) than in Haro Strait (Figure 23). 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 detection rate in Boundary Pass was slightly lower in 2021 than in 2020, which could have been caused by reduced traffic due to COVID-19.

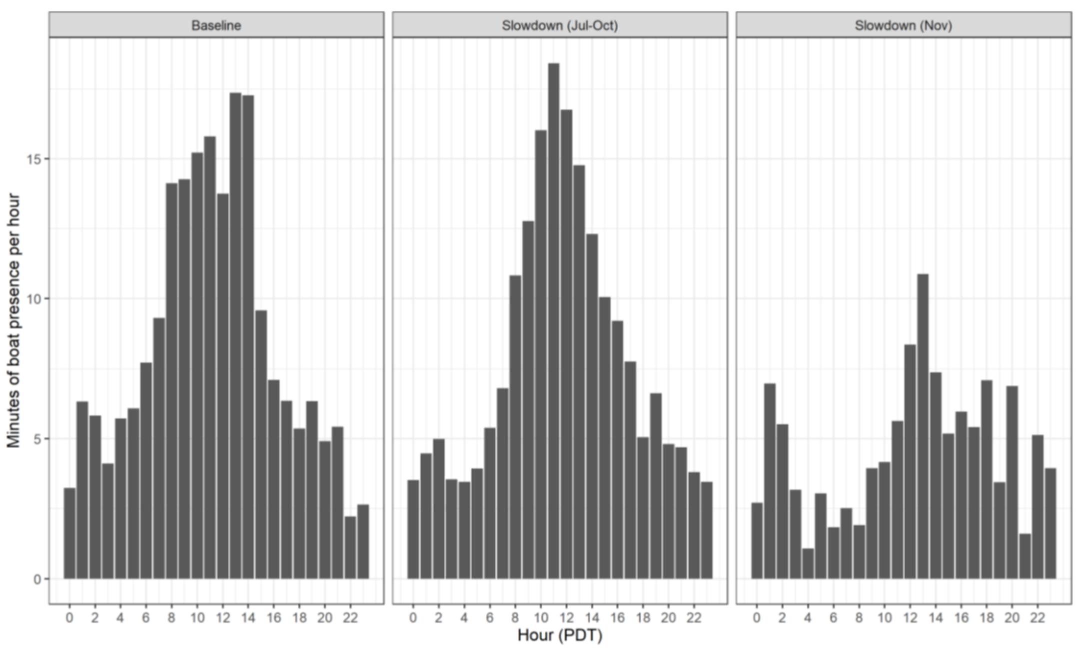



Figure 24. Daily average minutes of small boat detections, by hour of day (PDT): (Left) Baseline period, (middle) Slowdown (Jul-Oct), and (right) Slowdown (Nov) period.

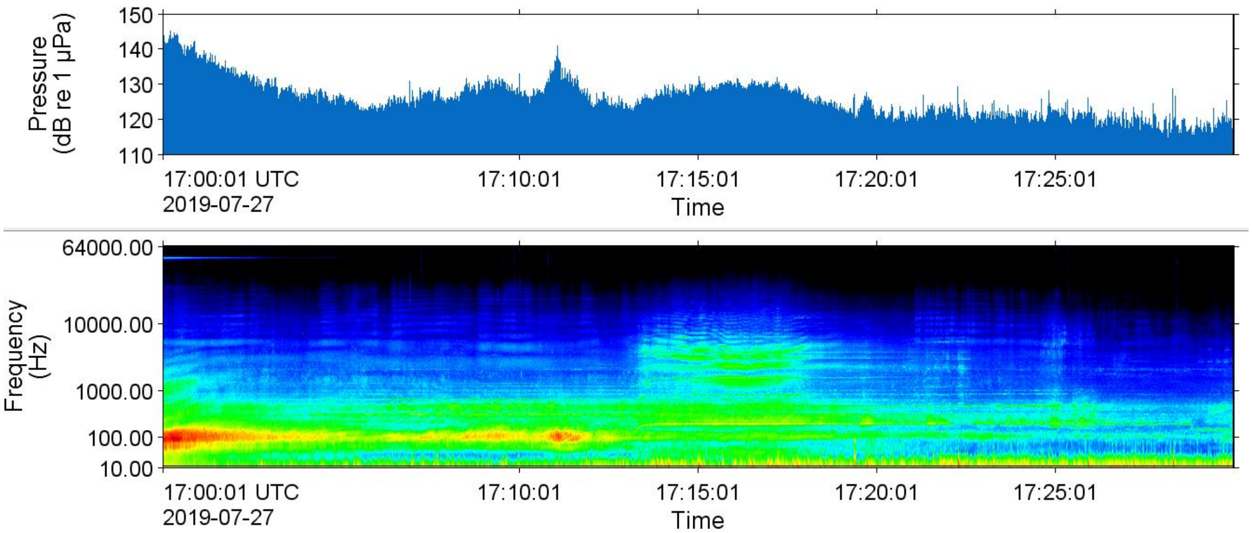



Figure 25. Example of a small boat detection at 27 Jul 2019 17:15 UTC (or 10:15 PDT) at Boundary Pass.

## 3.4. Ambient Noise Cumulative Distribution Functions

### 3.4.1. Lime Kiln

The required 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. Data were again first filtered to only include potential Slowdown participants, identified as being both within 6 km of the hydrophone and being the nearest of all AIS-broadcasting vessels to the hydrophone (i.e., the closest AIS-broadcaster was the participant). An automated acoustic detector also identified key times in which small boats were present (see Section 2.4.1), and these periods were filtered out of subsequent CDF analyses. 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 greatest proportion, leaving only 14–18% of the data, followed by current filtering, which leaves 8–11% of the data. The subsequent wind filter had the least effect and only really affected the Slowdown (Nov) period.

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 | 86,288 | 12,053 (14.0%) | 6,568 (7.6%) | 6,556 (7.6%) | 6,381 (7.4%) |
| Slowdown (Jul-Oct) | 174,480 | 28,177 (16.2%) | 19,604 (11.2%) | 19,511 (11.2%) | 18,824 (10.8%) |
| Slowdown (Nov) | 43,147 | 7,547 (17.5%) | 4,196 (9.7%) | 4,133 (9.6%) | 4,010 (9.3%) |

Figures 26 through 32 show the exceedance CDFs after applying filtering on the data from Baseline and both Slowdown periods. Table 10 lists respective sound level exceedance statistics. The differences between the $L_5$, $L_{50}$, $L_{95}$, and $L_{eq}$ metrics from the three periods are listed in Table 11. There was a clear decrease in SPL from the Baseline to both Slowdown periods. The median broadband level decreased by 3.7 dB, and the broadband $L_{eq}$ decreased by 3.5 dB during the Slowdown (Jul-Oct) period. There was a smaller decrease in SPL during Slowdown (Nov) of 2.5 and 2.2 dB (broadband $L_{50}$ and $L_{eq}$, respectively).

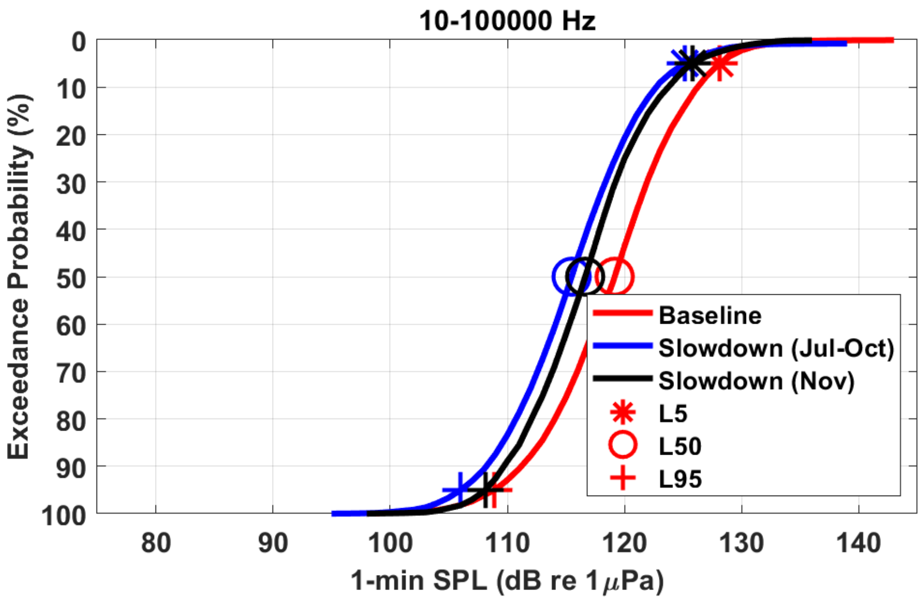



Figure 26. Lime Kiln broadband (10–100,000 Hz) exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

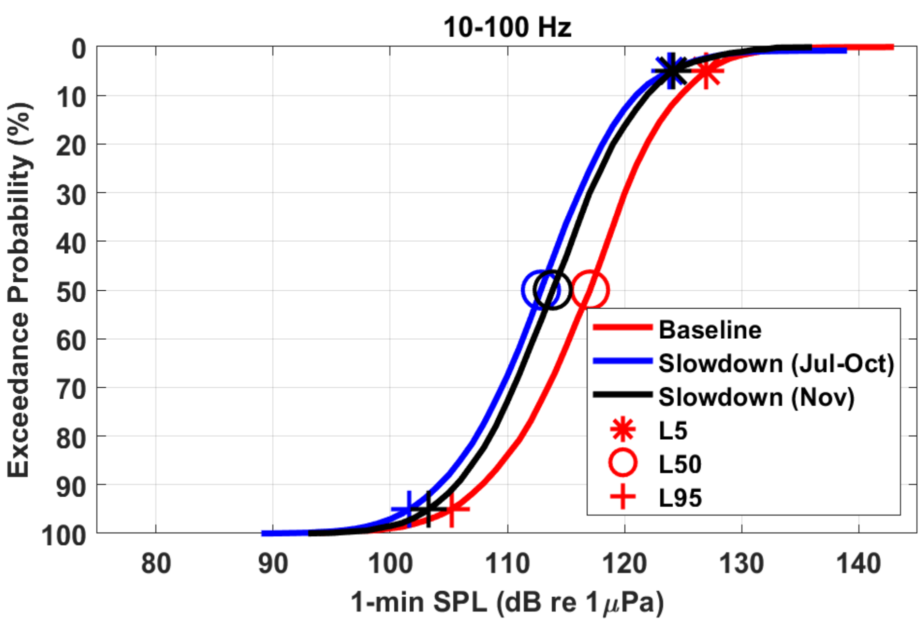



Figure 27. Lime Kiln 10–100 Hz band exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

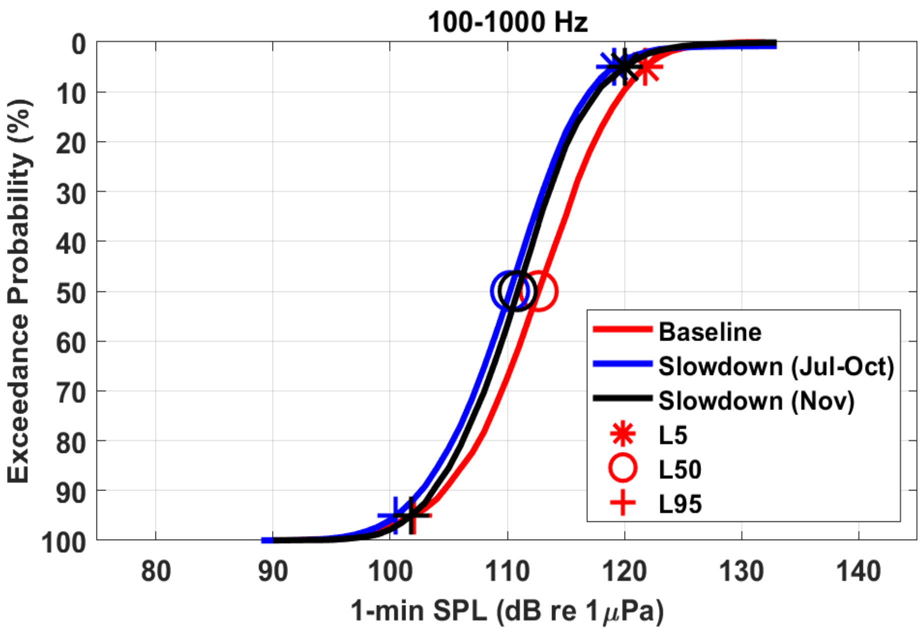



Figure 28. Lime Kiln 100–1000 Hz band exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

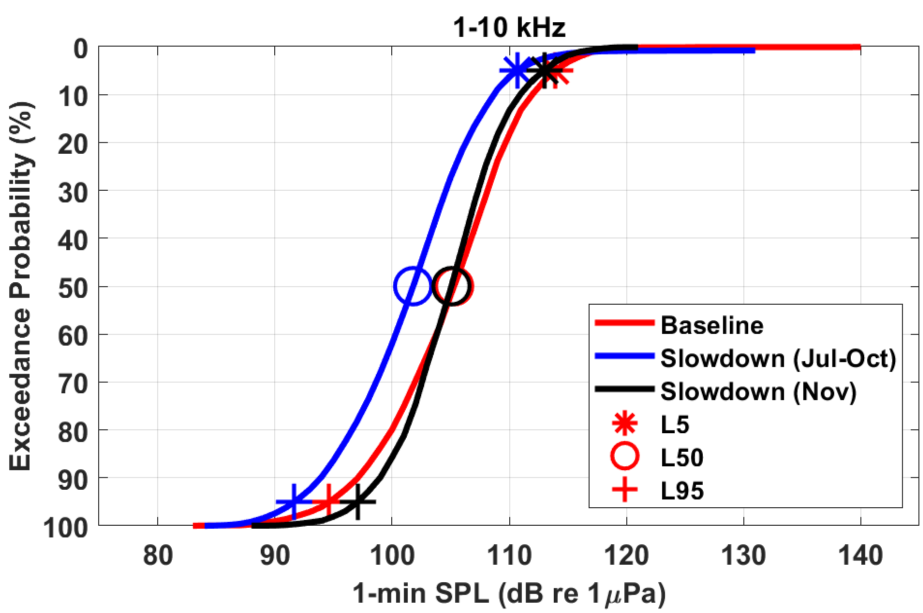



Figure 29. Lime Kiln 1–10 kHz band exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

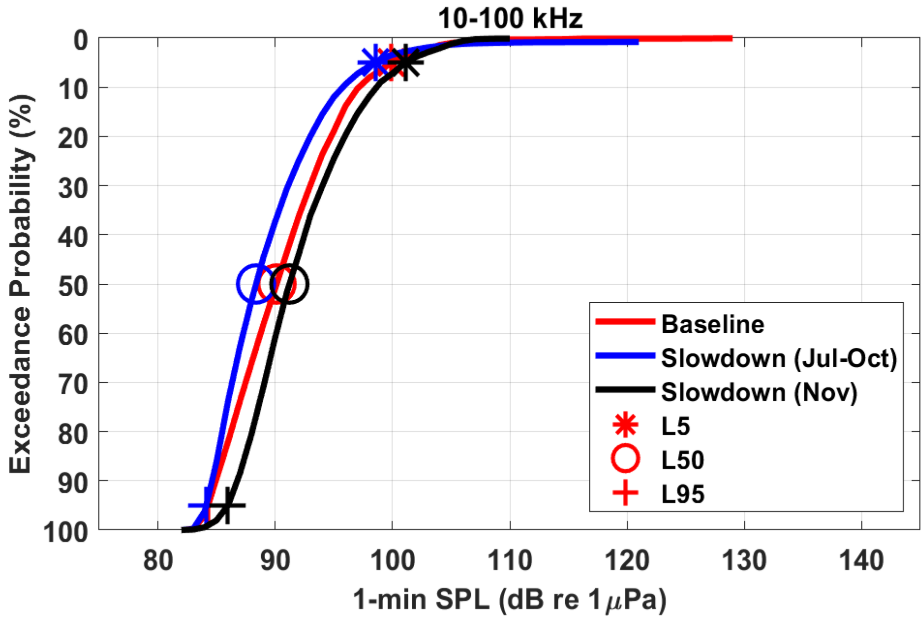



Figure 30. Lime Kiln 10–100 kHz band exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

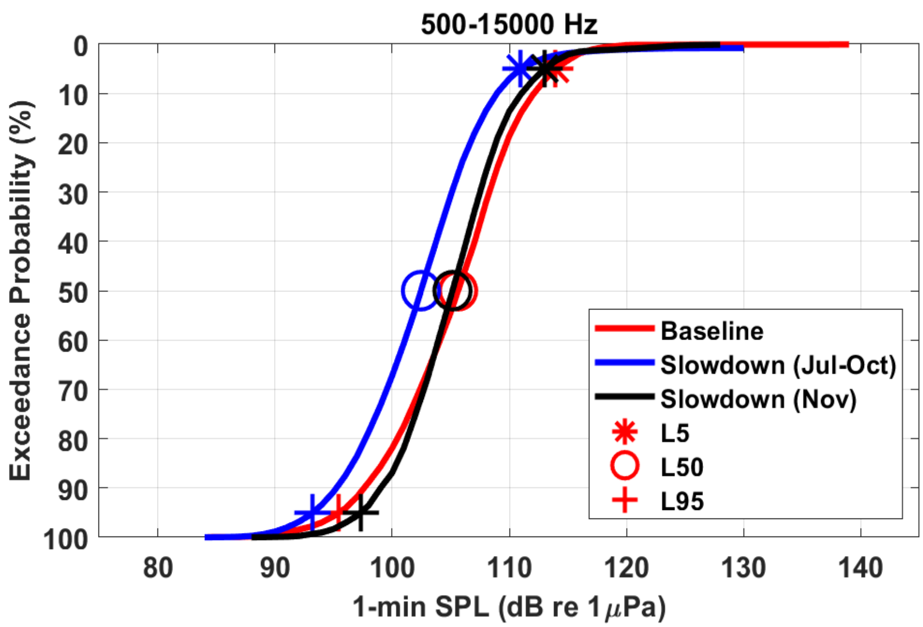



Figure 31. Lime Kiln 500–15,000 Hz band (CORI Communication) exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

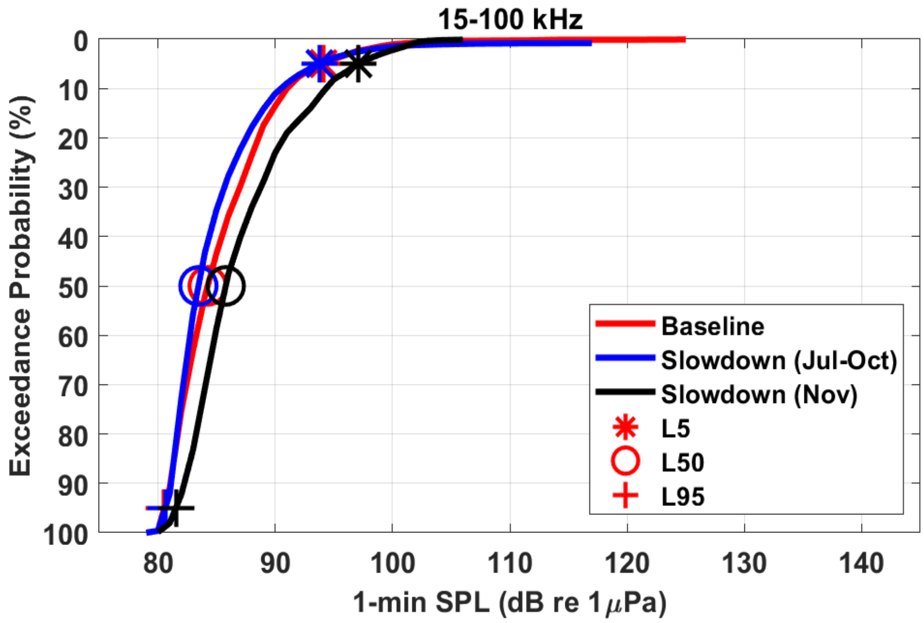



Figure 32. Lime Kiln 15–100 kHz band (CORI Echolocation) exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

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 (Jul-Oct) SPL (dB re 1 µPa) | | | | Slowdown (Nov) SPL (dB re 1 µPa) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $L_{95}$ | $L_{50}$ | $L_5$ | $L_{eq}$ | $L_{95}$ | $L_{50}$ | $L_5$ | $L_{eq}$ | $L_{95}$ | $L_{50}$ | $L_5$ | $L_{eq}$ |
| Broadband 10–100,000 Hz | 108.9 | 119.2 | 128.2 | 119.4 | 106.0 | 115.5 | 125.2 | 115.9 | 108.1 | 116.6 | 125.8 | 117.2 |
| 1st Decade 10–100 Hz | 105.2 | 117.1 | 127.0 | 117.1 | 101.7 | 112.9 | 123.9 | 113.2 | 103.3 | 113.9 | 124.1 | 114.3 |
| 2nd Decade 100–1000 Hz | 102.0 | 112.7 | 121.8 | 112.9 | 100.5 | 110.2 | 119.1 | 110.4 | 101.8 | 110.9 | 120.1 | 111.3 |
| 3rd Decade 1–10 kHz | 94.6 | 105.3 | 113.9 | 105.3 | 91.7 | 101.8 | 110.7 | 101.9 | 97.1 | 105.1 | 113.0 | 105.5 |
| 4th Decade 10–100 kHz | 84.3 | 90.1 | 99.9 | 91.3 | 84.1 | 88.4 | 98.5 | 89.8 | 86.0 | 91.2 | 101.2 | 92.6 |
| CORI Communication 500–15,000 Hz | 95.5 | 105.6 | 114.0 | 105.7 | 93.2 | 102.5 | 111.0 | 102.7 | 97.3 | 105.2 | 113.0 | 105.6 |
| CORI Echolocation 15–100 kHz | 80.5 | 84.2 | 94.1 | 85.9 | 80.6 | 83.5 | 93.8 | 85.2 | 81.5 | 85.8 | 97.1 | 87.7 |

Table 11. Comparison of Slowdown versus Baseline period ambient noise statistics ($L_{95}$, $L_{50}$, $L_5$, and $L_{eq}$) at Lime Kiln, highlighting greater sound pressure level (SPL) reductions during the Slowdown (Jul-Oct) period compared to the Slowdown (Nov) period. A negative value denotes that the Slowdown periods were quieter than the Baseline period.

| Frequency range | SPL difference (dB) between Slowdown (Jul-Oct) and Baseline periods | | | | SPL difference (dB) between Slowdown (Nov) and Baseline periods | | | |
|---|---|---|---|---|---|---|---|---|
| | $L_{95}$ | $L_{50}$ | $L_5$ | $L_{eq}$ | $L_{95}$ | $L_{50}$ | $L_5$ | $L_{eq}$ |
| Broadband 10–100,000 Hz | -2.9 | -3.7 | -3.0 | -3.5 | -0.8 | -2.5 | -2.3 | -2.2 |
| 1st Decade 10–100 Hz | -3.6 | -4.2 | -3.1 | -3.9 | -1.9 | -3.2 | -2.8 | -2.7 |
| 2nd Decade 100–1000 Hz | -1.5 | -2.4 | -2.7 | -2.5 | -0.2 | -1.8 | -1.7 | -1.6 |
| 3rd Decade 1–10 kHz | -3.0 | -3.5 | -3.2 | -3.4 | 2.4 | -0.2 | -0.9 | 0.1 |
| 4th Decade 10–100 kHz | -0.2 | -1.7 | -1.4 | -1.4 | 1.7 | 1.1 | 1.2 | 1.3 |
| CORI Communication 500–15,000 Hz | -2.2 | -3.2 | -3.0 | -3.0 | 1.8 | -0.5 | -0.9 | 0.0 |
| CORI Echolocation 15–100 kHz | 0.1 | -0.8 | -0.3 | -0.7 | 1.0 | 0.5 | 3.0 | 1.8 |

## 3.4.2. Boundary Pass

The first step in comparing sound level CDFs for Baseline and Slowdown periods 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 24–27% of the original data. The effect of water currents on sound levels was then analyzed with the remaining data. Figure 33 shows broadband sound level distributions for different current speed intervals. The distributions agreed up to 0.5 m/s. 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 19–23% of the original data.

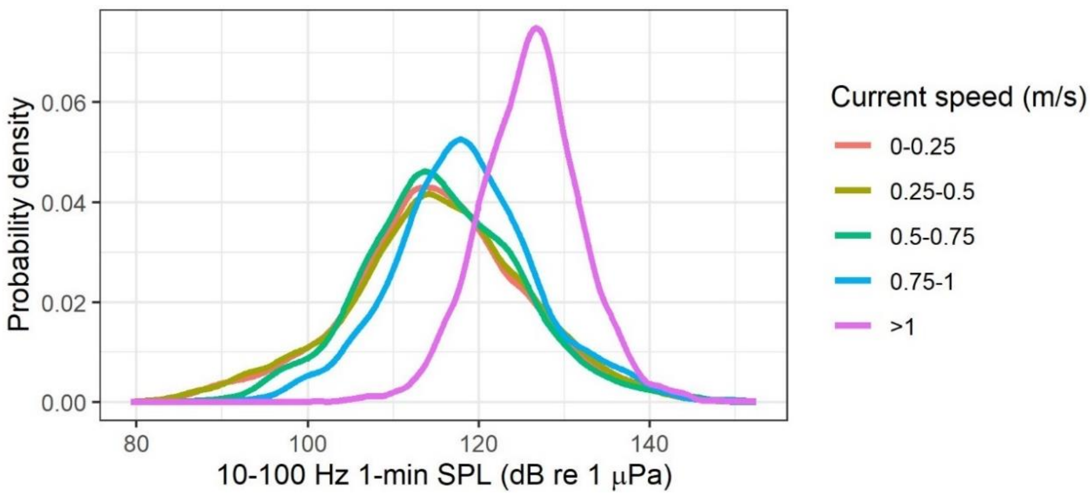



Figure 33. Low-frequency 10–100 Hz sound pressure level (SPL) distributions after Automatic Identification System (AIS) filtering for different current speed intervals. Highlight effects of flow noise by looking at lower frequency bands of system. Results presented for time periods when the Acoustic Doppler Current Profiler (ADCP) was operational (3 May to 8 Oct 2021).

The effect of wind speed on sound levels was then analyzed with the remaining data. Figures 34–35 shows 2-D histograms of SPL as a function of wind speed in different frequency bands. For subsequent analysis, durations when wind speeds were greater than 10 m/s were discarded. Appling this filtering during the Baseline and Slowdown (Jul-Oct) periods reduced the total amount of data for the CDF analysis by a small amount (~1% change). Applying wind filtering to Slowdown (Nov) reduced the total amount of data by a greater amount (~3% change) due to the higher sustained winds during this latter period. Inspections of the SPL versus windspeed data for November (Figure 36) indicates that sound levels were elevated at frequencies above 500 Hz, even after >10 m/s wind speed filtering was applied to the data. After applying wind filtering, 17–22% of the original data were retained.

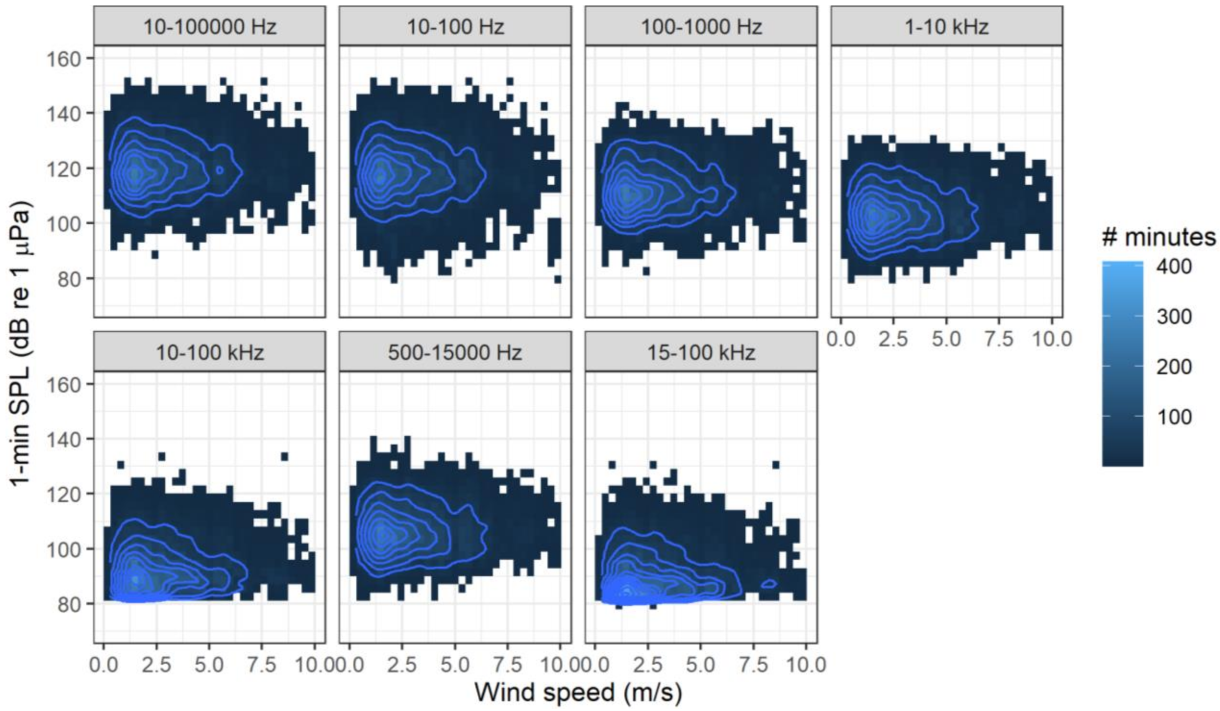



Figure 34. Baseline period: Two-dimensional (2-D) histograms of sound levels as a function of windspeed after Automatic Identification System (AIS) and current speed filtering.

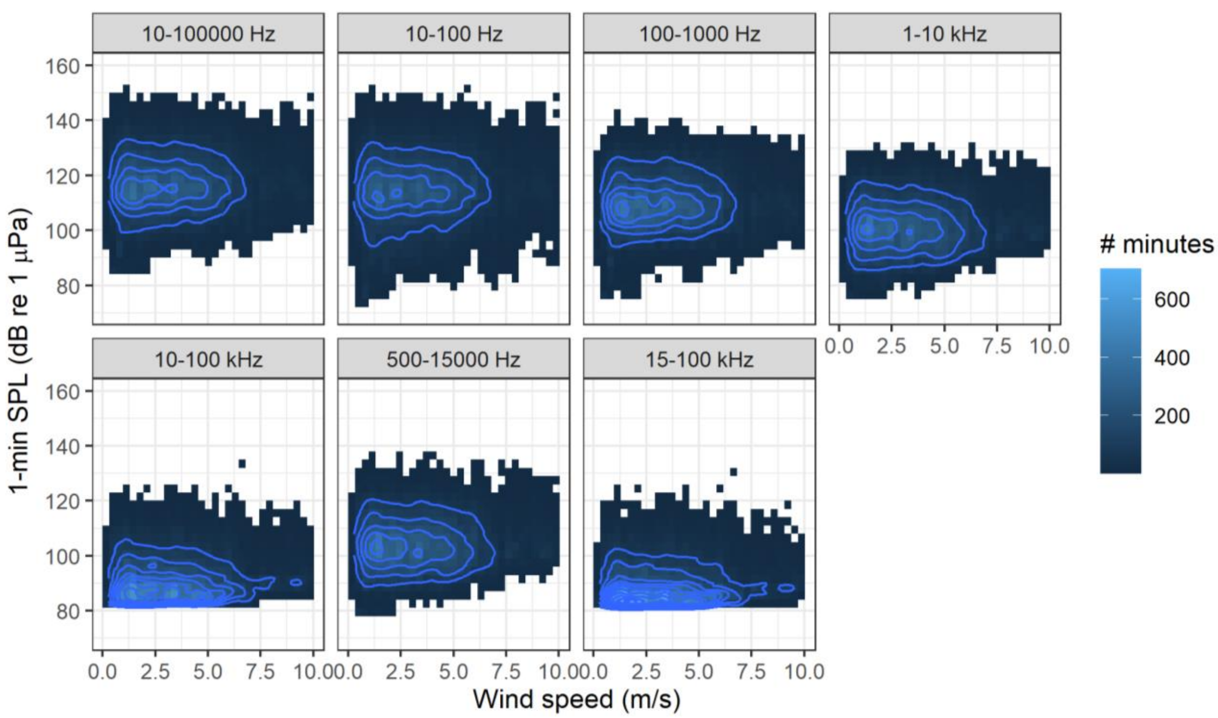



Figure 35. Slowdown (Jul-Oct) period: Two-dimensional (2-D) histograms of sound levels as a function of windspeed after Automatic Identification System (AIS) and current speed filtering.

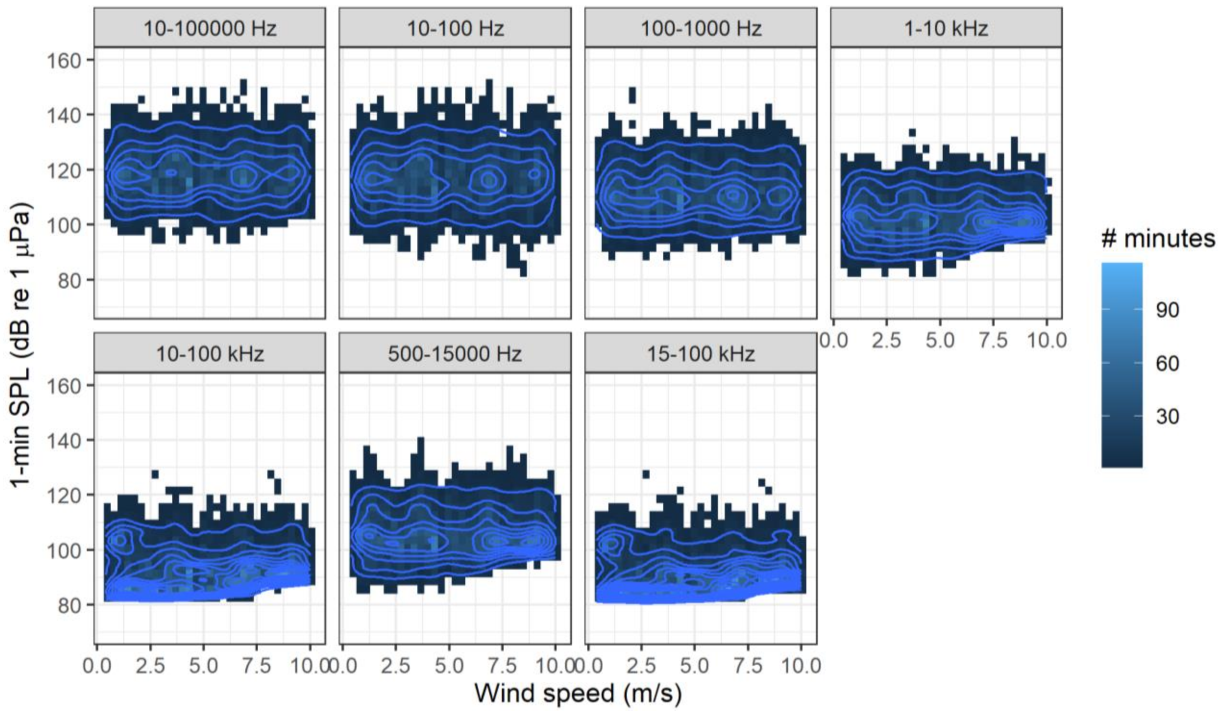



Figure 36. Slowdown (Nov) period: Two-dimensional (2-D) histograms of sound levels as a function of windspeed after Automatic Identification System (AIS) and current speed filtering.

The final factor used for filtering was small boat detections (see Section 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 17–21% 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 | 86311 | 20717 (24%) | 16752 (19%) | 16629 (19%) | 16299 (19%) |
| Slowdown (Jul-Oct) | 170872 | 45378 (27%) | 38739 (23%) | 37006 (22%) | 35803 (21%) |
| Slowdown (Nov) | 43034 | 10480 (24%) | 8627 (20%) | 7248 (17%) | 7215 (17%) |

Figures 37 to 43 show the exceedance CDFs after applying the filtering on the Baseline, Slowdown (Jul-Oct), and Slowdown (Nov) period data. Table 13 lists sound level exceedance statistics. The differences between the $L_5$, $L_{50}$, $L_{95}$, and $L_{eq}$ metrics from the periods are listed in Table 14. There was a clear decrease in SPL from the Baseline to the Slowdown (Jul-Oct) periods for all sound level statistics and frequency bands. The median and $L_{eq}$ broadband levels decreased by 3.2 and 3.1 dB, respectively during the Slowdown (Jul-Oct) period. The median and $L_{eq}$ broadband levels decreased by 1.0 and 1.3 dB, respectively, during the Slowdown (Nov) period. The 10–100 kHz band shows the Slowdown (Nov) period having higher sound levels when compared to the Baseline. This was due to the equipment change following the October ULS servicing, where high-frequency tones from the electronics were present in the November time period but not present in the Baseline.

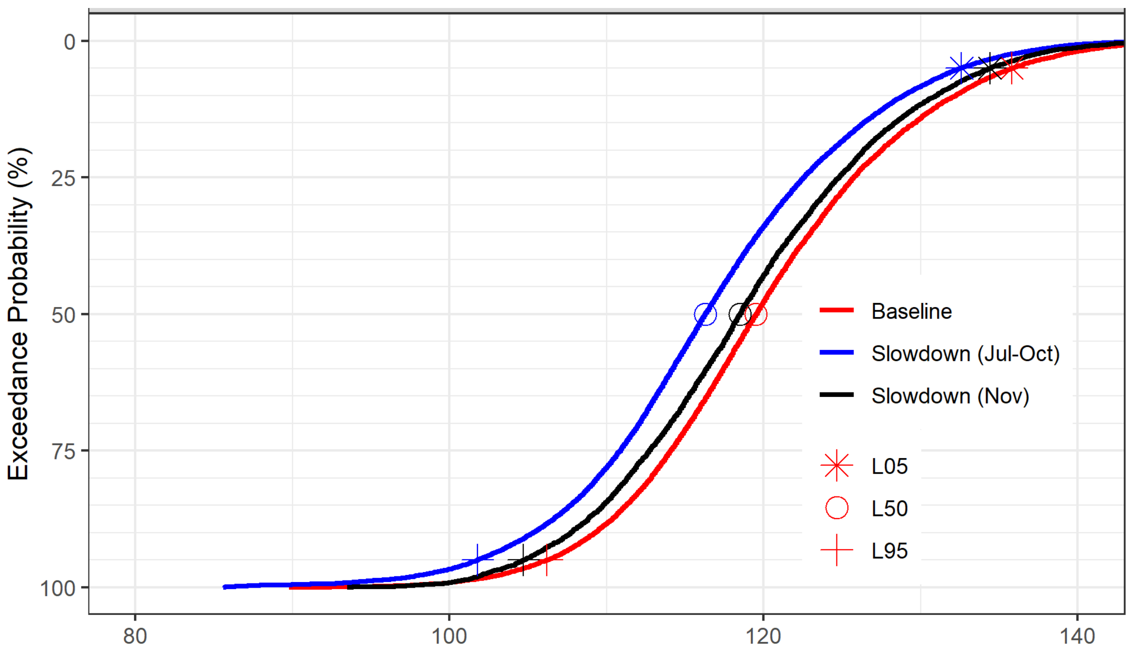



Figure 37. Boundary Pass broadband (10–100,000) exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

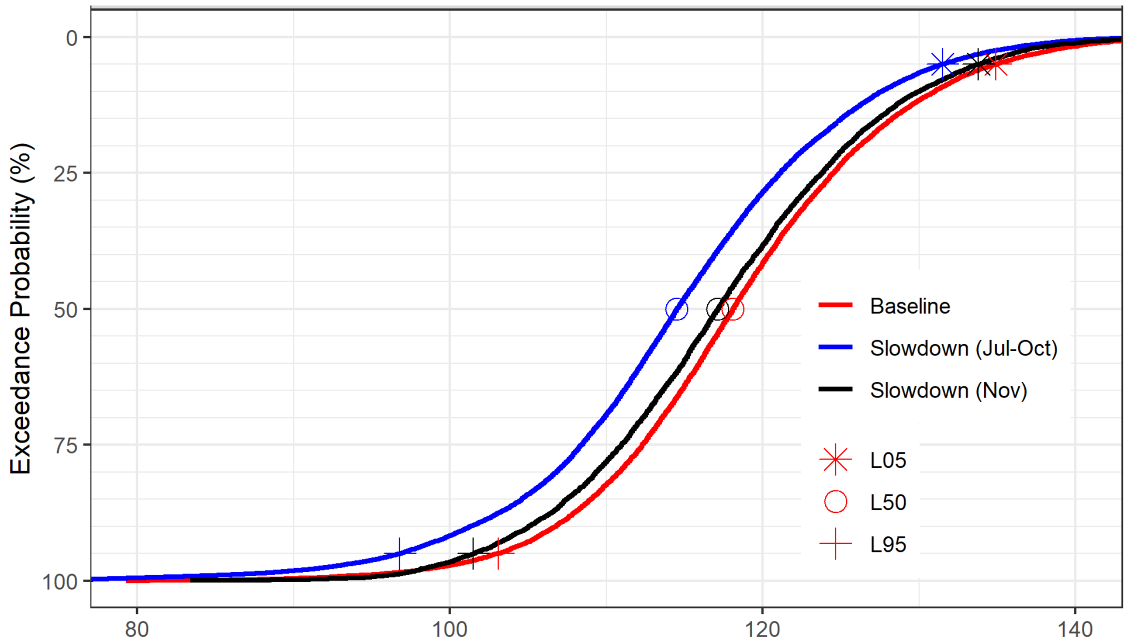



Figure 38. Boundary Pass 10–100 Hz exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

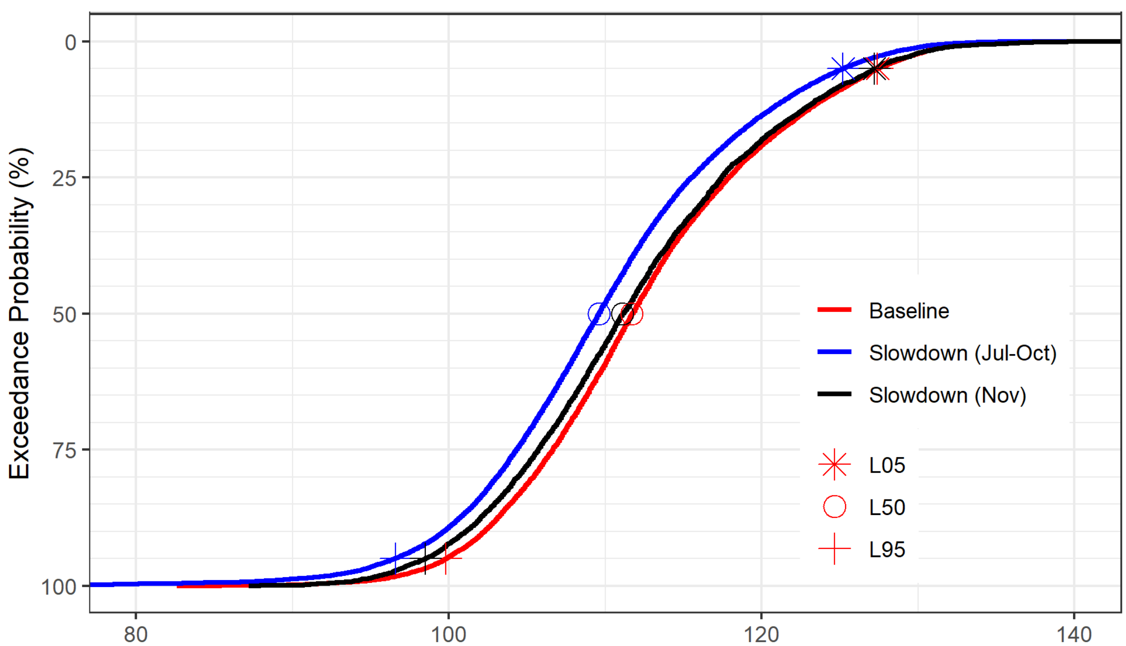



Figure 39. Boundary Pass 100–1000 Hz band exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

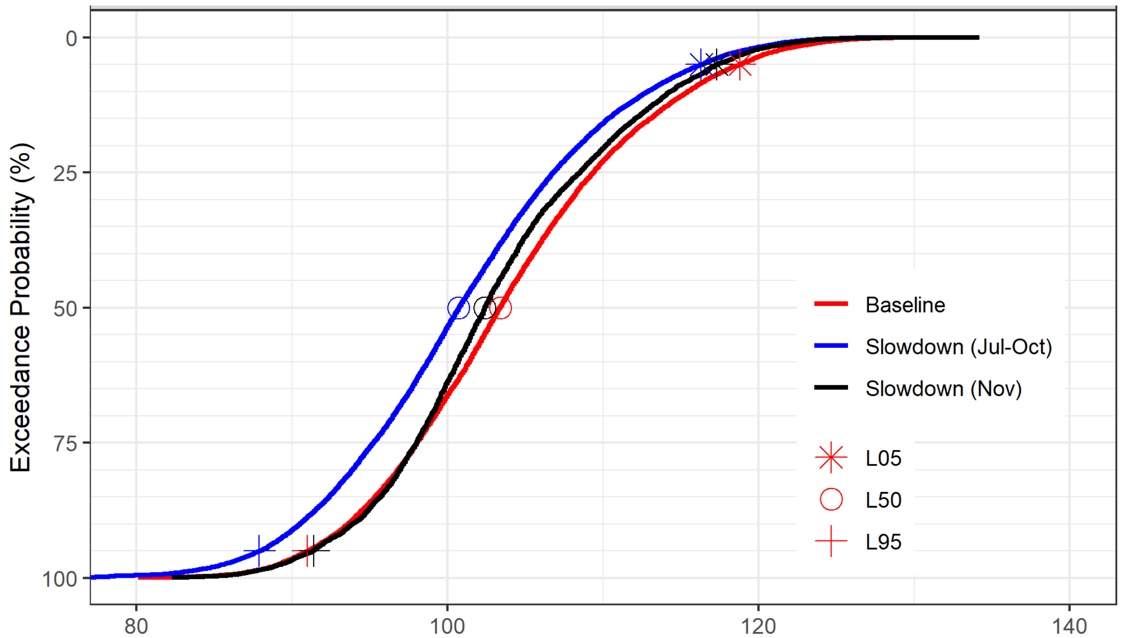



Figure 40. Boundary Pass 1–10 kHz band exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

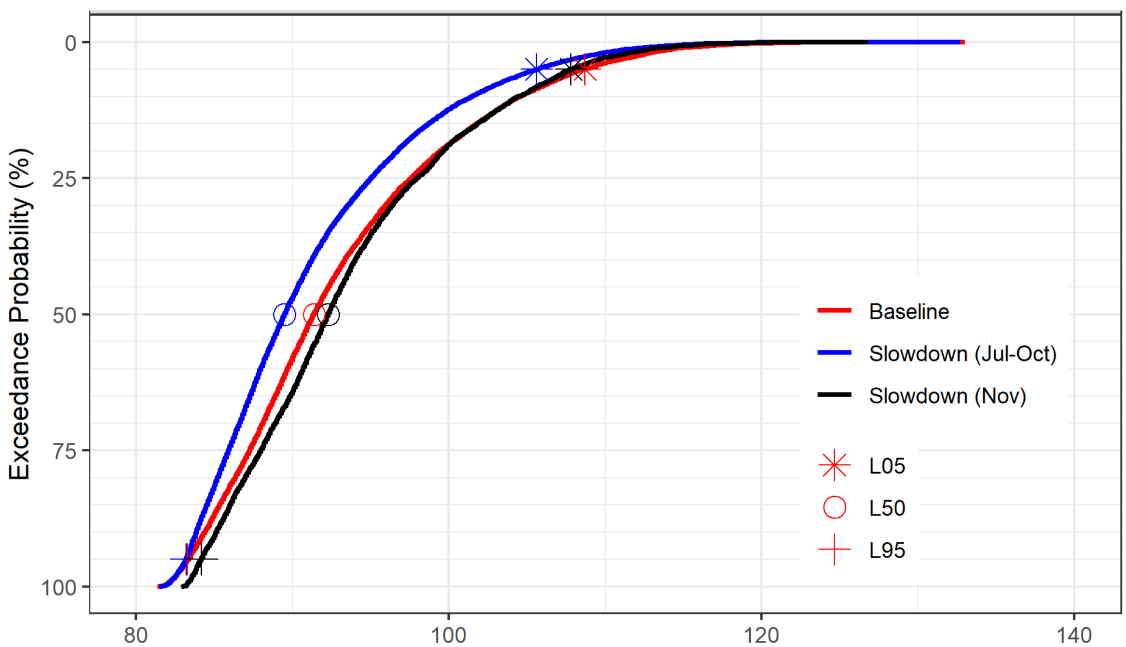



Figure 41. Boundary Pass 10–100 kHz band exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

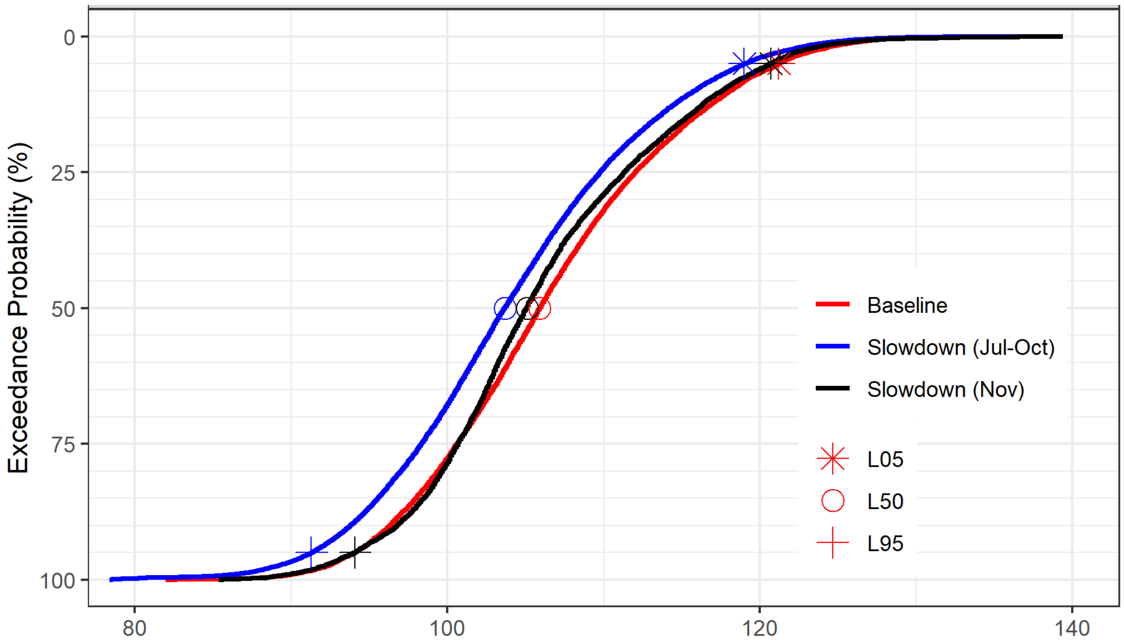



Figure 42. Boundary Pass 500–15,000 Hz band (CORI Communication) exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

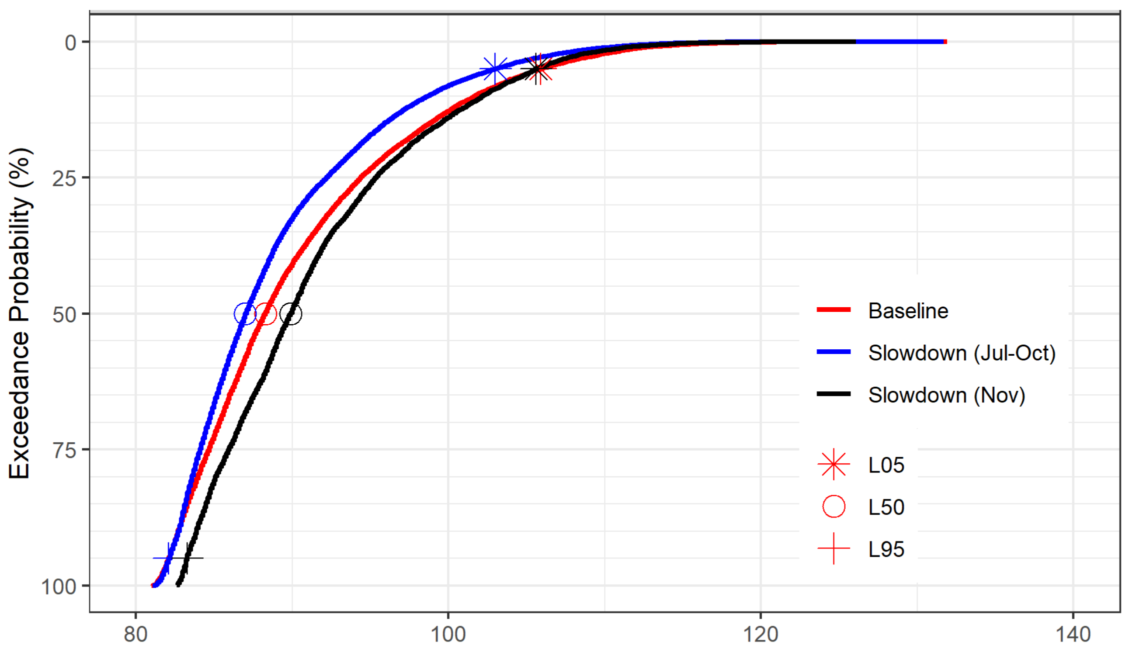



Figure 43. Boundary Pass 15–100 kHz band (CORI Echolocation) exceedance Cumulative Distribution Functions (CDFs) for the Baseline and Slowdown periods.

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 (Jul-Oct) SPL (dB re 1 µPa) | | | | Slowdown (Nov) SPL (dB re 1 µPa) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $L_{95}$ | $L_{50}$ | $L_5$ | $L_{eq}$ | $L_{95}$ | $L_{50}$ | $L_5$ | $L_{eq}$ | $L_{95}$ | $L_{50}$ | $L_5$ | $L_{eq}$ |
| Broadband 10–100,000 Hz | 106.3 | 119.5 | 135.8 | 129.8 | 101.9 | 116.4 | 132.6 | 126.8 | 105.1 | 118.4 | 134.3 | 128.5 |
| 1st Decade 10–100 Hz | 103.0 | 118.1 | 134.9 | 129.2 | 96.9 | 114.7 | 131.6 | 126.1 | 101.1 | 117.1 | 133.7 | 128.1 |
| 2nd Decade 100–1000 Hz | 99.8 | 111.7 | 127.4 | 120.6 | 96.7 | 109.6 | 125.2 | 118.6 | 99.0 | 111.1 | 127.0 | 120.9 |
| 3rd Decade 1–10 kHz | 91.0 | 103.4 | 118.8 | 112.0 | 88.1 | 101.0 | 116.3 | 109.7 | 91.8 | 102.7 | 117.3 | 110.9 |
| 4th Decade 10–100 kHz | 83.3 | 91.4 | 108.6 | 103.5 | 83.2 | 89.8 | 105.6 | 100.4 | 84.3 | 92.9 | 107.7 | 102.1 |
| CORI Communication 500–15,000 Hz | 94.1 | 105.9 | 121.2 | 115.0 | 91.5 | 103.9 | 119.0 | 113.0 | 94.6 | 105.3 | 120.5 | 115.0 |
| CORI Echolocation 15–100 kHz | 82.1 | 88.3 | 105.9 | 101.4 | 82.2 | 87.3 | 103.0 | 98.3 | 83.4 | 90.5 | 105.5 | 100.0 |

Table 14. Comparison of Slowdown versus Baseline period ambient noise statistics ($L_{95}$, $L_{50}$, $L_5$, and $L_{eq}$) at Boundary Pass, highlighting greater sound pressure level (SPL) reductions during the Slowdown (Jul-Oct) period compared to the Slowdown (Nov) period. A negative value denotes that the Slowdown periods were quieter than the Baseline period.

| Frequency range | SPL difference (dB) between Slowdown (Jul-Oct) and Baseline periods | | | | SPL difference (dB) between Slowdown (Nov) and Baseline periods | | | |
|---|---|---|---|---|---|---|---|---|
| | $L_{95}$ | $L_{50}$ | $L_5$ | $L_{eq}$ | $L_{95}$ | $L_{50}$ | $L_5$ | $L_{eq}$ |
| Broadband 10–100,000 Hz | -4.4 | -3.2 | -3.2 | -3.1 | -1.5 | -1.0 | -1.4 | -1.3 |
| 1st Decade 10–100 Hz | -6.3 | -3.6 | -3.4 | -3.2 | -1.6 | -1.0 | -1.1 | -1.0 |
| 2nd Decade 100–1000 Hz | -3.2 | -2.1 | -2.2 | -2.0 | -1.3 | -0.6 | -0.2 | 0.6 |
| 3rd Decade 1–10 kHz | -3.1 | -2.7 | -2.5 | -2.4 | 0.4 | -1.0 | -1.5 | -1.1 |
| 4th Decade 10–100 kHz | -0.1 | -1.9 | -3.1 | -3.1 | 0.9 | 0.9 | -0.9 | -1.4 |
| CORI Communication 500–15,000 Hz | -2.8 | -2.2 | -2.2 | -1.9 | 0.0 | -0.8 | -0.5 | 0.3 |
| CORI Echolocation 15–100 kHz | 0.0 | -1.3 | -2.9 | -3.1 | 1.2 | 1.6 | -0.3 | -1.3 |

## 3.5. Quiet Times

### 3.5.1. Lime Kiln

Broadband (10–100,000 Hz) sound levels were below the 102.8 dB re 1 µPa thresholds 33, 34, and 26% of the time, respectively, during the Baseline and Slowdown (Jul-Oct) and Slowdown (Nov) periods. Broadband sound levels were below the 110 dB re 1 µPa thresholds 59, 66, and 60% of the time for the three respective Baseline and Slowdown periods. The duration of quiet periods (consecutive minutes with broadband SPL less than the threshold) were often less than 3 or 5 min for both thresholds and across all three periods. The maximum duration of quiet times, using the 102.8 dB threshold, was 177 mins, and this occurred during the Slowdown (Jul-Oct) period. The maximum duration of quiet times, using the 110 dB threshold, was 321 mins, and this also occurred during the Slowdown (Jul-Oct) period. Table 15 summarizes these statistics, and Figure 44 shows the distributions of quiet time durations.

Figure 45 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 period.

| Period | Quiet threshold (dB re 1 µPa) | Median duration (min) | Maximum duration (min) | Quiet time (%) |
|---|---|---|---|---|
| Baseline | 102.8 | 3 | 142 | 33.6 |
| | 110 | 5 | 307 | 58.7 |
| Slowdown (Jul-Oct) | 102.8 | 3 | 177 | 33.9 |
| | 110 | 5 | 321 | 63.6 |
| Slowdown (Nov) | 102.8 | 3 | 131 | 25.6 |
| | 110 | 4 | 248 | 60.4 |

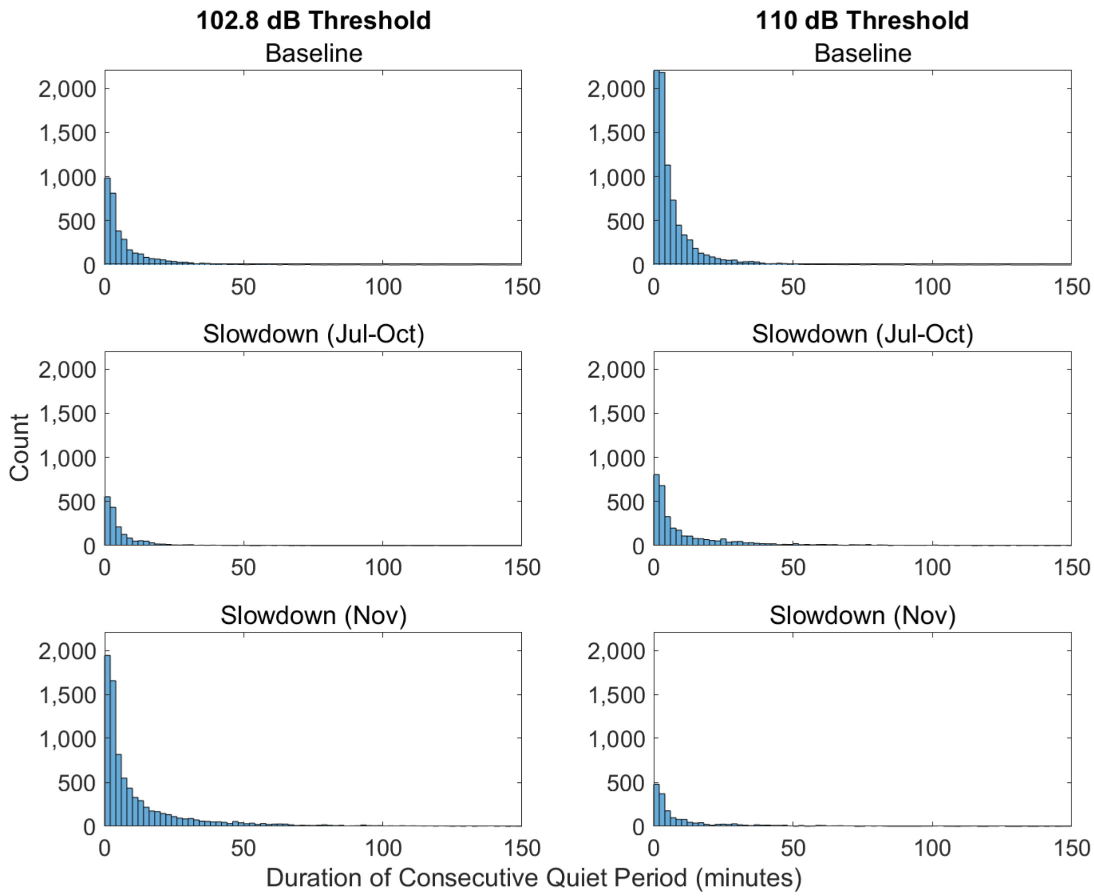



Figure 44. Histograms of quiet time durations during the Baseline and both Slowdown periods at Lime Kiln for the two broadband sound pressure level (SPL) thresholds.

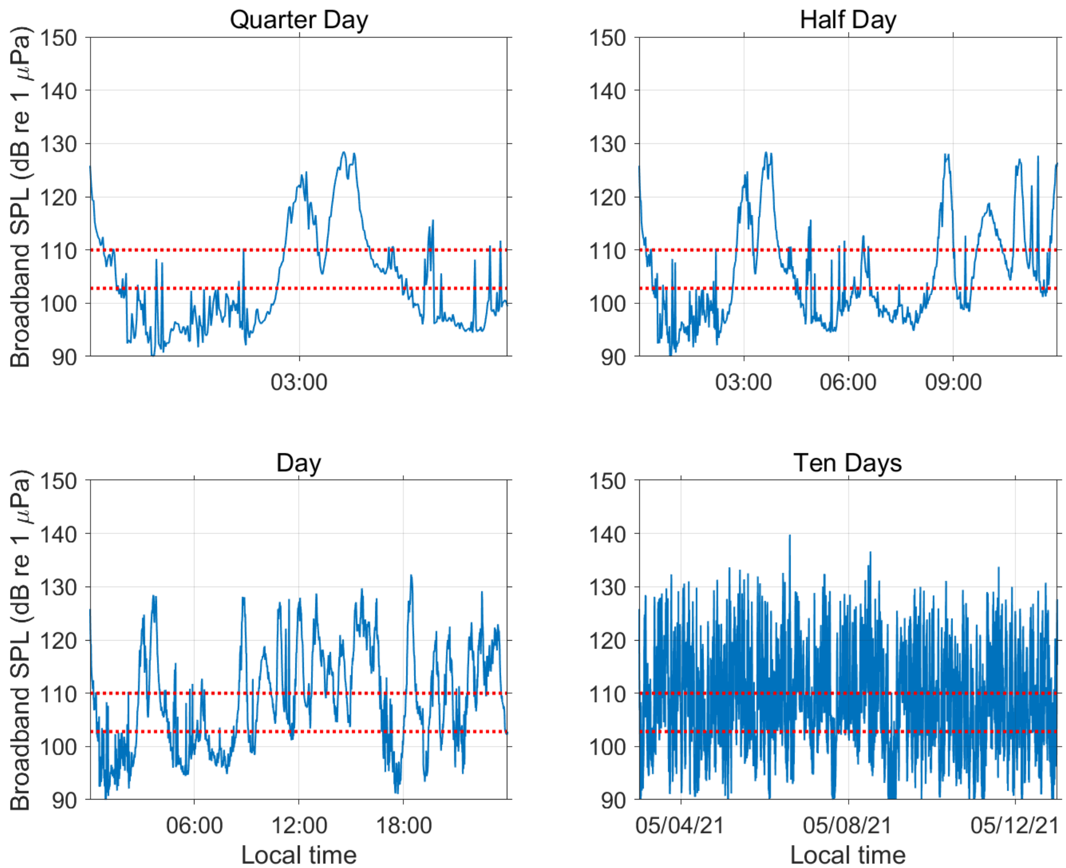



Figure 45. Plots of 1 min broadband (10–100,000 Hz) sound pressure level (SPL) at Lime Kiln for (top left) quarter day, (top right) half day, (bottom left) one day, and (bottom right) 10 day periods. All plots start at 7:00 (PDT) on 3 May 2020. Red dotted lines indicate the two quiet thresholds used. Due to the high degree of oscillation in the data, quiet periods do not typically last long.

### 3.5.2. Boundary Pass

Broadband (10–100,000 Hz) sound levels were below the 102.8 dB re 1 µPa thresholds 47, 48, and 39% of the time, respectively, during the Baseline and Slowdown (Jul-Oct) and Slowdown (Nov) periods. Broadband sound levels were below the 110 dB re 1 µPa thresholds 65, 66, and 60% of the time for the three respective Baseline and Slowdown periods. The duration of quiet periods (consecutive minutes with broadband SPL less than the threshold) was often less than 7 min for the 102.8 dB threshold for both the Baseline and Slowdown periods and was often less than 10 min for the 110.0 dB threshold. The maximum duration of quiet times was up to 416, 417, and 402 min for Baseline and Slowdown (Jul-Oct) and Slowdown (Nov) periods, respectively, using the 102.8 dB threshold, and up to 405, 420, and 405 min for Baseline and Slowdown (Jul-Oct) and Slowdown (Nov) periods, respectively, using the 110 dB threshold. Table 16 summarizes these statistics, and Figure 46 shows the distributions of quiet time durations.

Figure 47 shows examples of broadband SPL as a function of time over different durations during the Slowdown period. Over relatively short time scales (i.e., 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. As a result, sound levels can vary substantially from one minute to the next (minutes do not contain overlapping sound pressure data).

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 | 416 | 46.96 |
| | 110 | 10 | 405 | 64.83 |
| Slowdown (Jul-Oct) | 102.8 | 7 | 417 | 47.68 |
| | 110 | 9 | 420 | 66.38 |
| Slowdown (Nov) | 102.8 | 5 | 402 | 39.23 |
| | 110 | 5 | 405 | 60.49 |

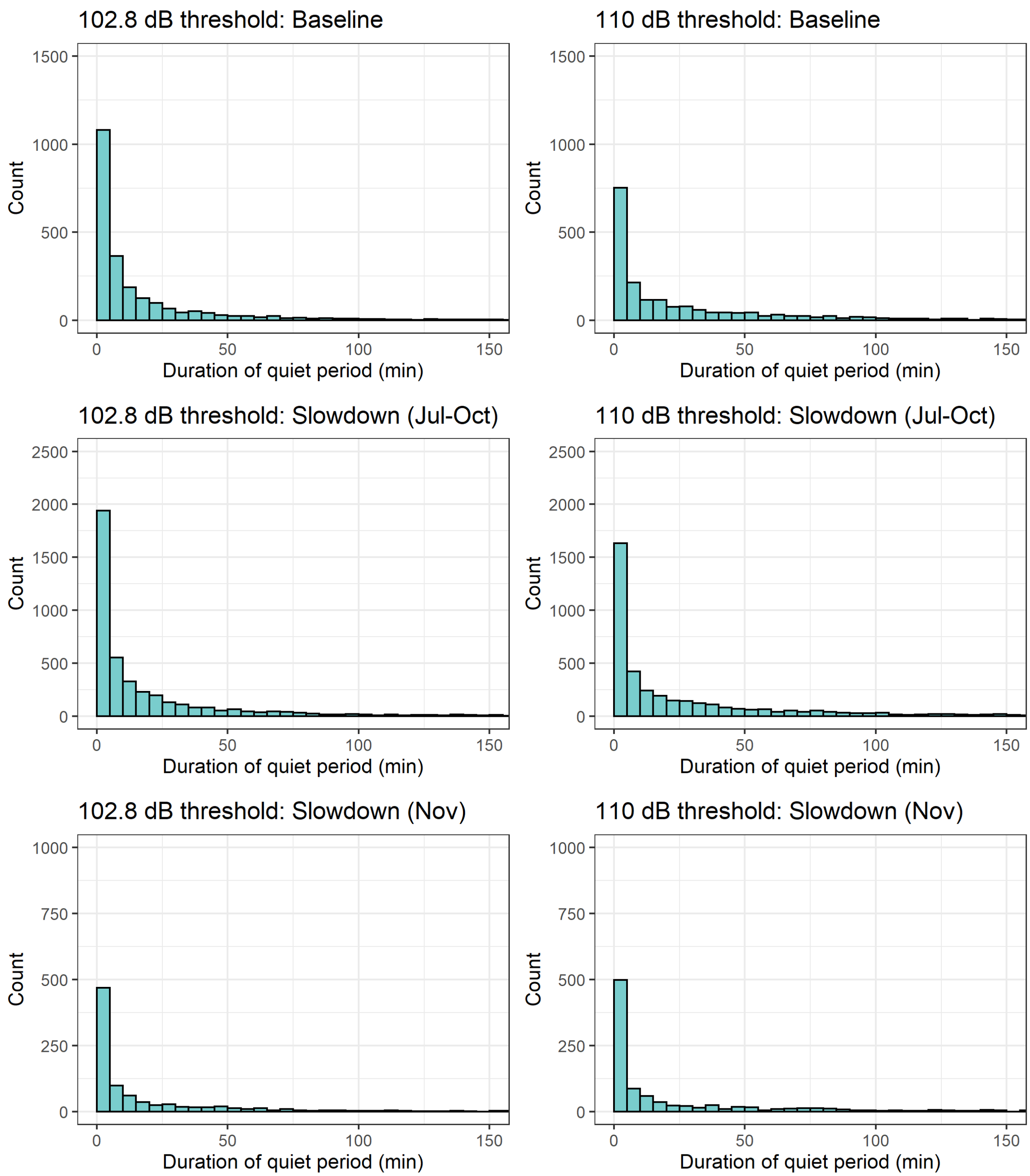



Figure 46. Histograms of quiet time durations during the Baseline and Slowdown periods in Boundary Pass for the two broadband sound pressure level (SPL) thresholds.

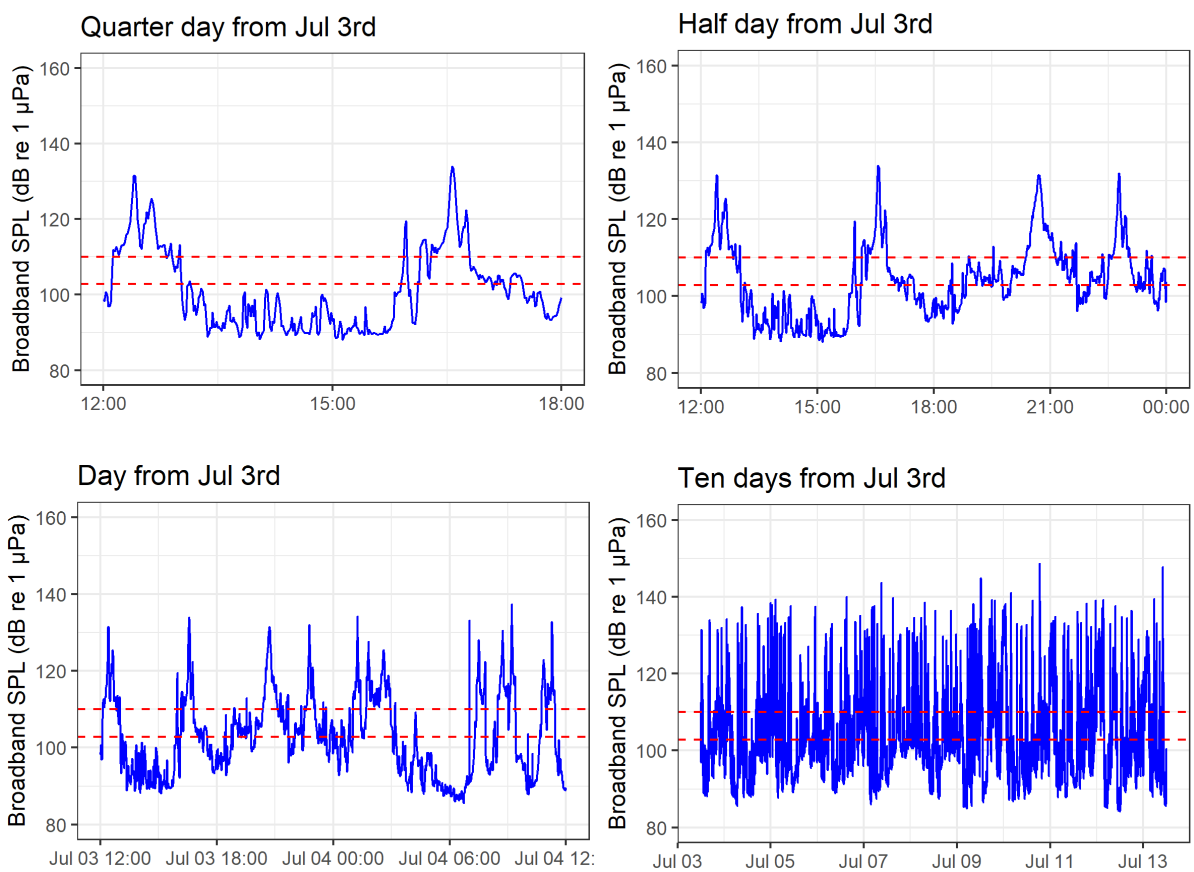



Figure 47. Plots of 1 min broadband (10–100,000 Hz) sound pressure level (SPL) in Boundary Pass for (top left) quarter day, (top right) half day, (bottom left) one day, and (bottom right) 10 day periods. All plots start at 12:00 UTC (05:00 PDT) on 3 Jul 2021. Red dotted lines indicate the two quiet thresholds used. Due to the high degree of oscillation in the data, durations of quiet periods are typically short.

## 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 (Baseline versus Slowdown), 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 decrease 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. Linear relations: 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 | 113.29 | 4.94 | 22.93 | <0.001 |
| Period (Slowdown (Jul-Oct)) | -1.08 | 0.17 | -6.31 | <0.001 |
| Period (Slowdown (Nov)) | 1.62 | 0.27 | 5.95 | <0.001 |
| Vessel type (Bulk) | 1.67 | 4.94 | 0.34 | 0.735 |
| Vessel type (Containerized) | 3.22 | 4.96 | 0.65 | 0.516 |
| Boat detector (Present) | 1.85 | 0.04 | 44.69 | <0.001 |
| Wind | -0.04 | 0.02 | -2.01 | 0.044 |
| Number of AIS broadcasting vessels | -0.03 | 0.01 | -3.11 | 0.002 |

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);
- Wind (as a linear variable); and
- Number of AIS broadcasting vessels within 6 km of Lime Kiln (as a linear variable).

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. Except for vessel type, all these terms in the GAMM were statistically significant (i.e., p-values < 0.05; see Tables 17 and 18) and explained 30% of the variance in the data. Vessel type was included in the GAMM model because it was needed as an interaction term with range and speed through water.

Table 18. Non-linear relations: 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 | 3 | 3 | 0.93 | <0.001 |
| | Bulk | 3 | 1 | 0.93 | <0.001 |
| | Containerized | 3 | 1 | 0.93 | <0.001 |
| Speed through water by vessel type | Other | 2 | 1.95 | 0.95 | <0.001 |
| | Bulk | 2 | 1.91 | 0.95 | <0.001 |
| | Containerized | 2 | 1.91 | 0.95 | <0.001 |
| Current | | 3 | 3.97 | 0.98 | 0.12 |

The interpretation of the GAMM outputs in Tables 17 and 18 is not simple because the statistical model is complex. 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.

## 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 first Period factor in Table 17 is set to Slowdown (Jul-Oct). The estimate reported in Table 17 for Period (Slowdown (Jul-Oct)) is the difference (in dB) between the Baseline and Slowdown (Jul-Oct) 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 (Slowdown (Jul-Oct))**: There was a significant difference in ambient noise from Baseline to Slowdown (Jul-Oct) periods. While there was an estimated 1.08 dB decrease in ambient noise from Baseline to Slowdown periods, this was not the entire reduction in noise level that occurred from the Slowdown (Jul-Oct) because it 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 (Jul-Oct), these other covariates need to be added and the GAMM must be used to make predictions. See Section 3.6.3 for details. Compared to Baseline, the Slowdown (Nov) period increased by 1.62 dB. Again, this does not include the other covariates, so results should not be taken to mean the Slowdown (Nov) was higher amplitude than the Baseline period, which it was not.
- **Vessel type**: Containerized and Bulk vessel types were not significantly different from the Other vessel type. The interaction of vessel type with speed through the water and range was 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 (1.85 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).

### 3.6.2. Interpreting Non-linear Covariates

All non-linear covariates reported in Table 18 were significant, except for current velocity. 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 were highest when a vessel was 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, in spite of not being a significant factor in this year's model. 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 (see Section 3.4).

### 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 48 shows the predicted relationship between noise levels at Lime Kiln and the range from Lime Kiln of Bulk and Containerized vessel types for Baseline and Slowdown (Jul-Oct) periods when no small boats were present while current and wind were zero and only one AIS broadcasting vessel was within 6 km of Lime Kiln.

Two trends can be seen. Noise levels decreased as the range increased and Slowdown (Jul-Oct) noise levels were lower than Baseline noise levels. At a 2.3 km range (distance from Lime Kiln to the centre of northbound shipping lane), the predictions in Figure 48 are 117.8 and 116.7 dB re 1 µPa for Bulk vessel types and 120.4 and 119.3 dB re 1 µPa for Containerized vessel types for Baseline and Slowdown (Jul-Oct) periods, respectively. This is a decrease of 1.1 dB for Bulk and Containerized vessel types from Baseline to Slowdown periods. This is similar to previous Slowdown GAMM predicted reductions of 1.7 dB (2020) and 0.9 dB (2019) for Bulk vessel types and 1.7 dB (2020) and 2.2 dB (2019) for Containerized vessels.

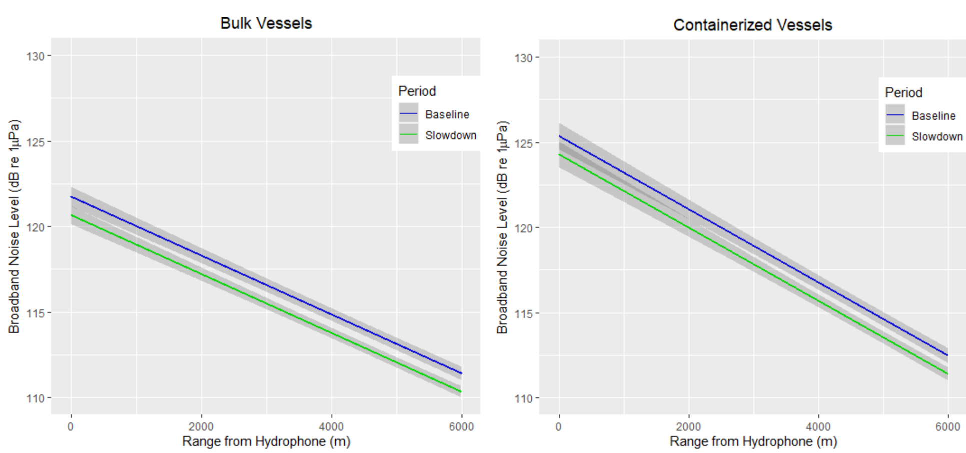



Figure 48. Model predictions for (left) Bulk vessel type and (right) Containerized vessel type modelled as a non-linear function of distance from the hydrophone. Depicted are the expected values of the model and their 95% confidence regions for broadband noise levels received at Lime Kiln, assuming median vessel speeds through the study area during Baseline (blue) and Slowdown (Jul-Oct) periods (green). Noise levels contributed from current, wind, and small boats were assumed to be zero, and only one vessel was broadcasting AIS within 6 km of Lime Kiln, in both figure panels.

## 3.7. Killer Whale PAM Detections

### 3.7.1. Lime Kiln

During the 2021 ECHO Program vessel Slowdown monitoring period between 1 Jul and 30 Nov, a total of 52 killer whale events across 37 separate days were detected by Passive Acoustic Monitoring (PAM) using PAMGuard software at the Lime Kiln hydrophone, occurring mainly in September and to a lesser extent August and November (Figure 49). PAM protocols also permitted collating summary monthly detections of porpoise and other odontocetes (dolphins) or baleen whales. A total of 105 porpoise events occurred across 58 days mainly in November, August, and September. Eighteen other odontocetes or baleen whale detections occurred across 12 days (all but one were identified as humpback whales) with most detections of this species of baleen whale occurring in October and November (Table 19).

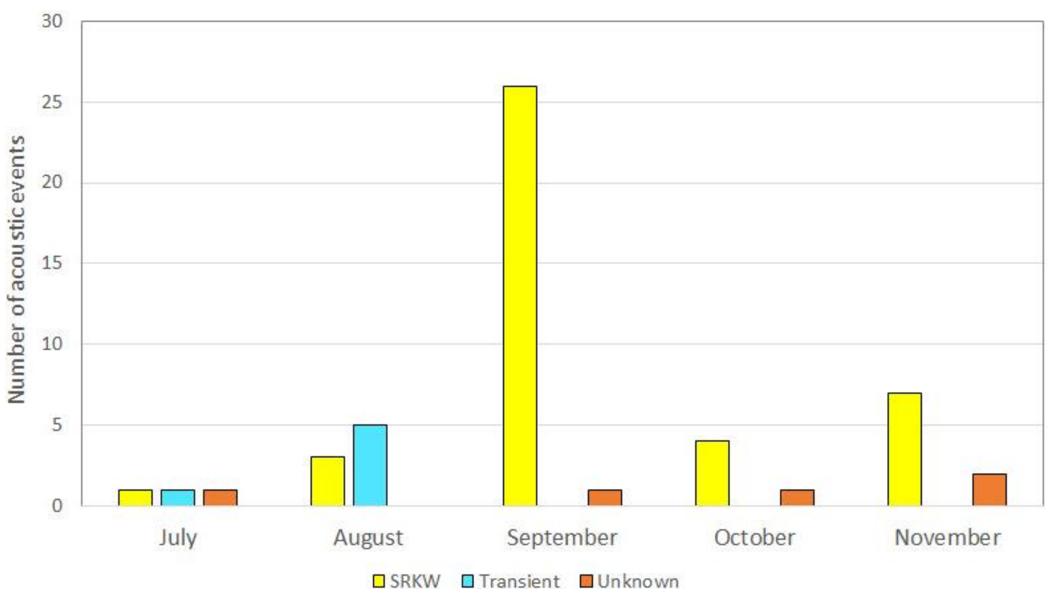



Figure 49. Monthly breakdown of killer whale events detected and identified by PAM protocols (1 Jul to 30 Nov 2021) using PAM data from the Lime Kiln hydrophone.

Table 19. Monthly breakdown of species events detected and identified by passive acoustic monitoring (PAM) protocols (1 Jul to 30 Nov 2021) using PAM data from the Lime Kiln hydrophone.

| Month | SRKW | Transient killer whales | Unknown killer whales | All killer whales | Porpoises | Unidentified odontocetes, dolphins, or baleens |
|---|---|---|---|---|---|---|
| July | 1 | 1 | 1 | **3** | 10 | 1 |
| August | 3 | 5 | 0 | **8** | 24 | 0 |
| September | 26 | 0 | 1 | **27** | 25 | 0 |
| October | 4 | 0 | 1 | **5** | 12 | 6 |
| November | 7 | 0 | 2 | **9** | 34 | 11 |
| **Total** | **41** | **6** | **5** | **52** | **105** | **18** |

In total, confirmed SRKW were detected by PAM and PAMGuard software for 41 unique events across 27 days. SRKW were detected in all months, but most occurred in September (26 events across 13 days), and November (7 events across 7 days; Figure 49, Table 19).

Six transient killer whale and five unknown killer whale ecotype events were also detected across a total of 10 separate days, with transient killer whale detections only in July and August (Figure 49, Table 19). Lack of ecotype definition was often due to the presence of only echolocation clicks, which are not discernible to ecotype. A total duration of 61 h of SRKW detections were recorded with an average duration of 1 h 29 min. Transients were detected for ~4 h in total, with an average duration of 42 min (Table 20). In all months, as was also seen in 2020, SRKW were present during daylight periods more than night-time periods (Figures 50–54; Table 20).

Table 20. Passive acoustic monitoring (PAM) identifications of killer whales detected on the Lime Kiln hydrophone (1 Jul to 30 Nov 2021), 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:s) | Killer whale ecotype classification |
|---|---|---|---|
| 2021 Jul 15 | 3:35:54 | 0:02:02 | Transient |
| 2021 Jul 19 | 22:14:01 | 0:03:01 | Unknown |
| 2021 Jul 27 | **18:18:47** | **2:31:08** | **SRKW** |
| 2021 Aug 2 | 17:05:07 | 0:05:20 | Transient |
| | 17:45:32 | 0:05:20 | Transient |
| 2021 Aug 13 | 1:37:57 | 0:53:14 | Transient |
| 2021 Aug14 | 22:03:38 | 1:48:44 | Transient |
| 2021 Aug 25 | **18:35:07** | **1:05:42** | **SRKW** |
| 2021 Aug 28 | 22:00:29 | 1:19:20 | Transient |
| 2021 Aug 30 | **17:17:04** | **0:08:54** | **SRKW** |
| | **19:52:11** | **0:21:20** | **SRKW** |
| 2021 Sep 1 | **2:07:11** | **1:57:28** | **SRKW** |
| 2021 Sep 5 | **19:29:54** | **1:03:26** | **SRKW** |
| 2021 Sep 6 | **3:50:18** | **0:34:06** | **SRKW** |
| | **7:06:38** | **0:46:37** | **SRKW** |
| | **16:01:09** | **0:55:07** | **SRKW** |
| | **19:50:44** | **0:21:32** | **SRKW** |
| 2021 Sep 8 | **17:01:48** | **1:27:28** | **SRKW** |
| | **20:35:49** | **0:32:02** | **SRKW** |
| 2021 Sep 9 | **16:35:35** | **0:45:47** | **SRKW** |
| 2021 Sep 11 | **16:08:36** | **2:18:21** | **SRKW** |
| 2021 Sep 12 | **6:36:56** | **1:47:06** | **SRKW** |
| | **9:54:17** | **2:27:33** | **SRKW** |
| 2021 Sep 14 | **14:27:07** | **2:10:08** | **SRKW** |
| 2021 Sep 15 | **8:56:55** | **1:28:25** | **SRKW** |
| | **15:11:15** | **1:45:57** | **SRKW** |
| 2021 Sep 17 | **6:48:07** | **1:06:21** | **SRKW** |
| | 10:48:27 | 0:06:06 | Unknown |
| 2021 Sep 18 | **6:26:30** | **1:34:09** | **SRKW** |
| | **12:05:31** | **3:51:39** | **SRKW** |
| | **17:30:30** | **0:46:26** | **SRKW** |
| | **20:00:02** | **0:35:01** | **SRKW** |
| 2021 Sep 19 | **12:10:51** | **1:52:53** | **SRKW** |
| | **16:11:02** | **2:46:31** | **SRKW** |
| 2021 Sep 30 | **6:07:10** | **0:22:12** | **SRKW** |

| | | | |
|---|---|---|---|
| | **10:17:46** | **0:27:52** | **SRKW** |
| | **11:31:22** | **0:34:13** | **SRKW** |
| | **16:28:22** | **0:44:10** | **SRKW** |
| 2021 Oct 4 | **12:42:30** | **3:37:45** | **SRKW** |
| | 17:35:46 | 0:11:04 | Unknown |
| 2021 Oct 5 | **2:04:44** | **0:26:52** | **SRKW** |
| 2021 Oct 24 | **15:04:58** | **0:14:16** | **SRKW** |
| 2021 Oct 27 | **18:28:19** | **0:01:00** | **SRKW** |
| 2021 Nov 2 | **12:50:49** | **2:55:22** | **SRKW** |
| 2021 Nov 5 | **4:36:05** | **0:24:20** | **SRKW** |
| 2021 Nov 9 | **15:56:22** | **0:46:16** | **SRKW** |
| 2021 Nov 16 | **12:30:00** | **3:44:18** | **SRKW** |
| 2021 Nov 18 | **6:45:25** | **6:05:42** | **SRKW** |
| 2021 Nov 19 | **8:42:27** | **2:25:46** | **SRKW** |
| 2021 Nov 22 | 23:25:49 | 0:01:00 | Unknown |
| 2021 Nov 29 | 0:02:51 | 0:44:38 | Unknown |
| | **3:11:34** | **1:09:41** | **SRKW** |

Finally, we compared killer whale PAM detection events in 2021 with those made by local Marine Mammal Observers (MMOs), typically but not exclusively observed from approximately 9 am to 5 pm (Table 22). Due to the COVID-19 pandemic, observation days and hours and exact observation location from 11 Aug 2021 were more irregular (Tollit and Wood 2021). On 100% of the 20 days SRKW were observed by MMOs, PAM also detected a SRKW transit. There was one occasion when MMOs recorded an SRKW event that had no concurrent PAM detection, though SRKW were identified earlier in the day by PAM analysis. The behaviour was recorded as slow group travel, a behaviour state known to be sometimes associated with lack of vocalizations. PAM also detected 9 additional unique days of SRKW presence, consisting of 16 additional transit events, 12 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 two days when a PAM SRKW detection event was reported by long-term MMO, Jeanne Hyde, who actively monitors the Lime Kiln hydrophone. One was subsequently verified, while the other was uncertain.

Overall, when combining all events, there were a minimum of 44 confirmed SRKW transit events (across 29 different days) recorded by either PAM or MMOs at Lime Kiln during the Slowdown study period 1 Jul to 30 Nov 2021. There were also two unknown ecotype events that occurred on days when no SRKW were detected (Tables 22 and 23).

Data from this study were combined with a similar assessment undertaken during the vessel Slowdowns in 2019 and 2020 to compare PAM and MMO combined detection information (days, pod transits, and hours) across years at Lime Kiln State Park (Figure 57). Noting that in 2021 the vessel Slowdown was a longer period than previous years, SRKW were detected at slightly lower levels than in 2020, but at notably higher levels than 2019, irrespective of the metric used (Figure 57).

We further explored time of day presence and monthly patterns using PAMGuard software detection event data collected across ~608 days of acoustic monitoring during summer and fall 2016 through 2021 at the Lime Kiln Hydrophone (Table 21). Across the entire data set, SRKW were detected significantly more during the day than at night (ANOVA, $F = 11.2$, $P < 0.003$), with an obvious peak in the afternoon (Figure 55). Conversely, transient killer whales and porpoise event detections were higher during the night than the day (Figure 55). Across these 608 days of vessel Slowdown acoustic monitoring, there were 321 killer whale events, with 77% SRKW (N = 246) and 11% (N = 36) transient killer whales, as well as 624 porpoise detection events (Table 21). While acoustic coverage in 2016 was lower (33 days) than in subsequent years (94–153 days) (Table 21), there was clear inter- and intra-annual variability in SRKW presence across summer. Detection events in July 2018 and 2020 were higher than in 2017, 2019, and 2020. Detection events in August 2017, 2020, and 2021 were higher than 2016, 2018, and 2019. Overall, September had the most consistent contribution of SRKW events (Figure 56). Killer whale summer presence was clearly lowest in 2017 and highest in 2018 (Table 21). Porpoise activity was generally highest in August and September and decreased somewhat in October, with notably high presence in 2019 compared to other years (Figure 56). Notably, observed porpoise presence peaked in 2019 (Table 21).

Table 21. Summary of vessel Slowdown acoustic monitoring periods 2016–2021 at the Lime Kiln hydrophone, and killer whale and porpoise detection events detected using PAMGuard software.

| Year | Date range (Days) | Killer whale events (SRKW) | Porpoise events |
|---|---|---|---|
| 2016 | Aug 14 to Sep 14 (32) | 48 (38) | 67 |
| 2017 | Jul 5 to Oct 6 (94) | 17 (17) | 61 |
| 2018 | Jul 12 to Oct 21 (102) | 79 (66) | 43 |
| 2019 | Jul 5 to Oct 16 (104) | 51 (31) | 232 |
| 2020 | Jul 1 to Oct 31 (123) | 74 (53) | 116 |
| 2021 | Jul 1 to Nov 30 (153) | 52 (41) | 105 |
| **Total** | **(608)** | **321 (246)** | **624** |

Table 22. Summary of Southern Resident killer whale (SRKW) passive acoustic monitoring (PAM) and marine mammal observer (MMO) detection events made at Lime Kiln from 1 Jul to 30 Nov 2021.

| Date | Start time (Local PDT) | Event duration (h:min:s) | SRKW detections: PAM versus daylight MMO at Lime Kiln State Park |
|---|---|---|---|
| 2021 Jul 27 | 18:18:47 | 2:31:08 | PAM and MMO |
| 2021 Aug 25 | 18:35:07 | 1:05:42 | PAM and MMO |
| 2021 Aug 30 | 17:17:04 | 0:08:54 | PAM and MMO |
| | 19:52:11 | 0:21:20 | PAM and MMO |
| 2021 Sep 1 | 2:07:11 | 1:57:28 | PAM (outside of MMO observation period) |
| 2021 Sep 5 | 19:29:54 | 1:03:26 | PAM and MMO |
| 2021 Sep 6 | 3:50:18 | 0:34:06 | PAM (outside of MMO observation period) |
| | 7:06:38 | 0:46:37 | PAM (outside of MMO observation period) |
| | 16:01:09 | 0:55:07 | PAM |
| | 19:50:44 | 0:21:32 | PAM (outside of MMO observation period) |
| 2021 Sep 8 | 17:01:48 | 1:27:28 | PAM and MMO |
| | 20:35:49 | 0:32:02 | PAM (outside of MMO observation period) |
| 2021 Sep 9 | 16:35:35 | 0:45:47 | PAM and MMO |
| 2021 Sep 11 | 16:08:36 | 2:18:21 | PAM and MMO |
| 2021 Sep 12 | 6:36:56 | 1:47:06 | PAM and MMO |
| | 9:54:17 | 2:27:33 | PAM and MMO |
| | 16:00:00 | 3:21:00 | MMO |
| 2021 Sep 14 | 14:27:07 | 2:10:08 | PAM and MMO |
| | 8:56:55 | 1:28:25 | PAM and MMO |
| 2021 Sep 15 | 15:11:15 | 1:45:57 | PAM and MMO |
| 2021 Sep 17 | 6:48:07 | 1:06:21 | PAM and MMO |
| 2021 Sep 18 | 6:26:30 | 1:34:09 | PAM and MMO |
| | 12:05:31 | 3:51:39 | PAM and MMO |
| | 17:30:30 | 0:46:26 | PAM |
| | 20:00:02 | 0:35:01 | PAM and MMO |
| 2021 Sep 19 | 12:10:51 | 1:52:53 | PAM and MMO |
| | 16:11:02 | 2:46:31 | PAM and MMO |
| 2021 Sep 30 | 6:07:10 | 0:22:12 | PAM (outside of MMO observation period) |
| | 10:17:46 | 0:27:52 | PAM |
| | 11:31:22 | 0:34:13 | PAM and MMO |
| | 16:28:22 | 0:44:10 | PAM and MMO |
| 2021 Oct 4 | 12:42:30 | 3:37:45 | PAM and MMO |
| 2021 Oct 5 | 2:04:44 | 0:26:52 | PAM (outside of MMO observation period) |
| 2021 Oct 24 | 15:04:58 | 0:14:16 | PAM and MMO |
| 2021 Oct 27 | 18:28:19 | 0:01:00 | PAM (outside of MMO observation period) |
| 2021 Oct 30 | 2:00:00 | 0:01:00 | PAM – unverified report by J. Hyde (outside of MMO observation period) |
| 2021 Nov 2 | 12:50:49 | 2:55:22 | PAM and MMO |
| 2021 Nov 5 | 4:36:05 | 0:24:20 | PAM (outside of MMO observation period) |
| 2021 Nov 9 | 15:56:22 | 0:46:16 | PAM |
| 2021 Nov 16 | 12:30:00 | 3:44:18 | PAM and MMO |
| 2021 Nov 18 | 6:45:25 | 6:05:42 | PAM and MMO |
| 2021 Nov 19 | 8:42:27 | 2:25:46 | PAM and MMO |
| 2021 Nov 27 | 21:00:00 | 0:07:00 | PAM – verified report by J. Hyde (outside of MMO observation period) |
| 2021 Nov 29 | 3:11:34 | 1:09:41 | PAM (outside of MMO observation period) |

Table 23. 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 30 Nov 2021).

| Detections of SRKW | Day of occurrences | Total number of SRKW events |
|---|---|---|
| PAM detections | 29 | 43* |
| MMO detections (see Tollit and Wood 2021) | 20 | 27 |
| PAM detection only but outside MMO monitoring period | 10 | 12 |
| PAM detection only but during MMO monitoring period | 4 | 4 |
| MMO detection but no SRKW-specific PAM detection | 1 | 1 |
| Total SRKW classifications combined PAM and MMOs | 29 | 44 |
| Total unknown ecotype detected by PAM with no other SRKW detected | 2 | 2 |

Includes two PAM detections noted by Jeanne Hyde not detected by PAMGuard software.

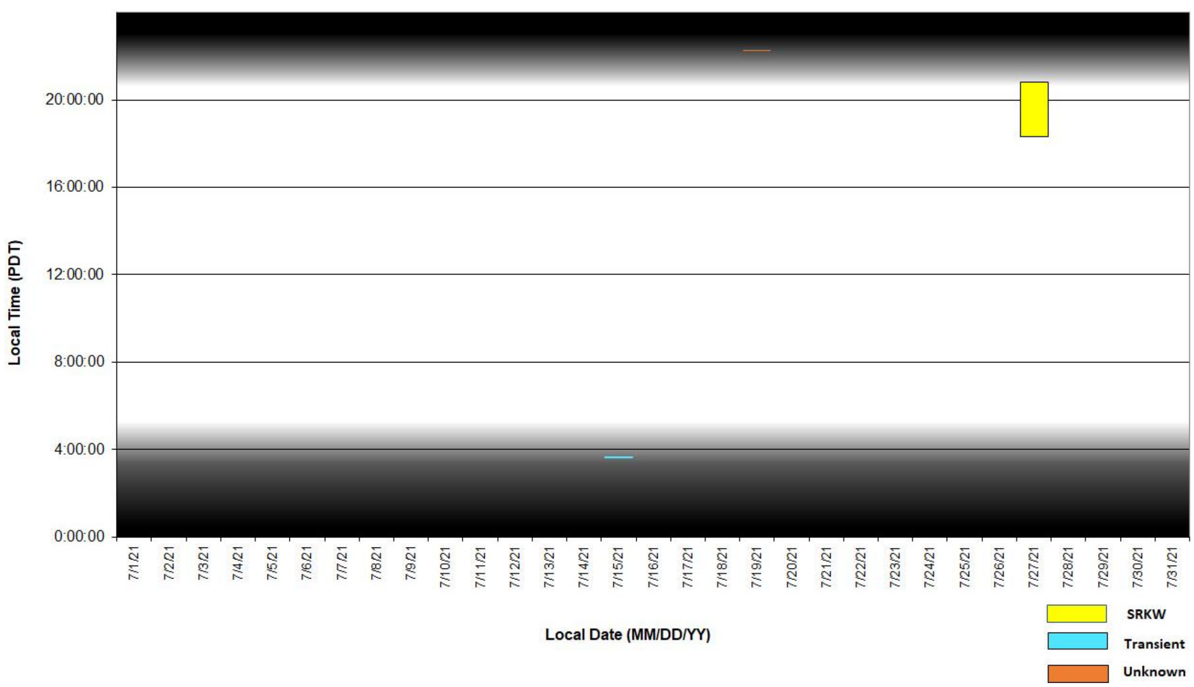



Figure 50. 1–31 Jul 2021: Date and timing of killer whale vocal events detected at Lime Kiln hydrophone using PAMGuard software.

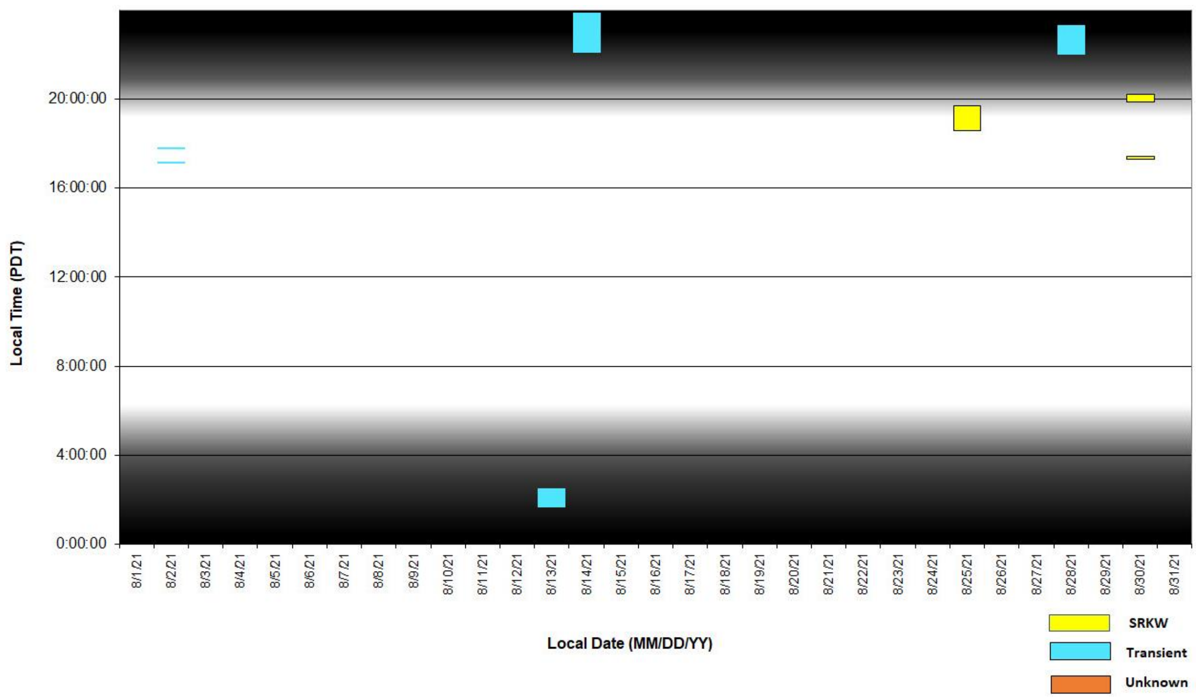



Figure 51. 1–31 Aug 2021: Date and timing of killer whale vocal events detected at Lime Kiln hydrophone using PAMGuard software.

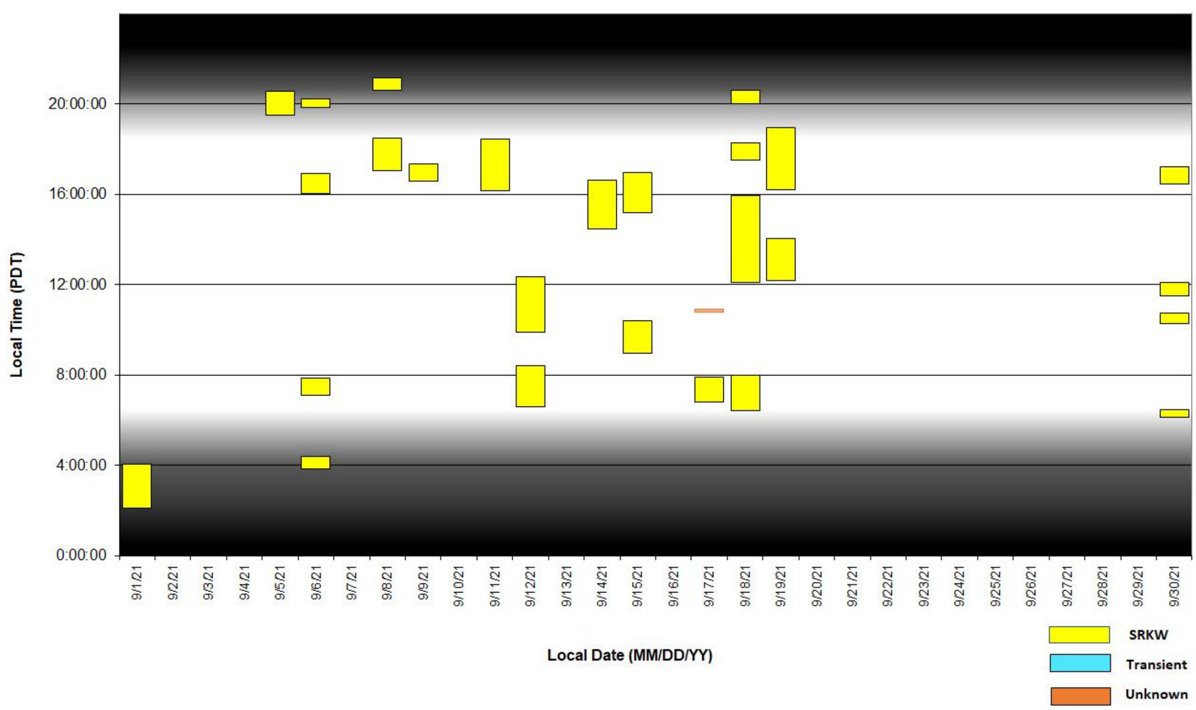



Figure 52. 1–30 Sep 2021: Date and timing of killer whale vocal events detected at Lime Kiln hydrophone using PAMGuard software**.**

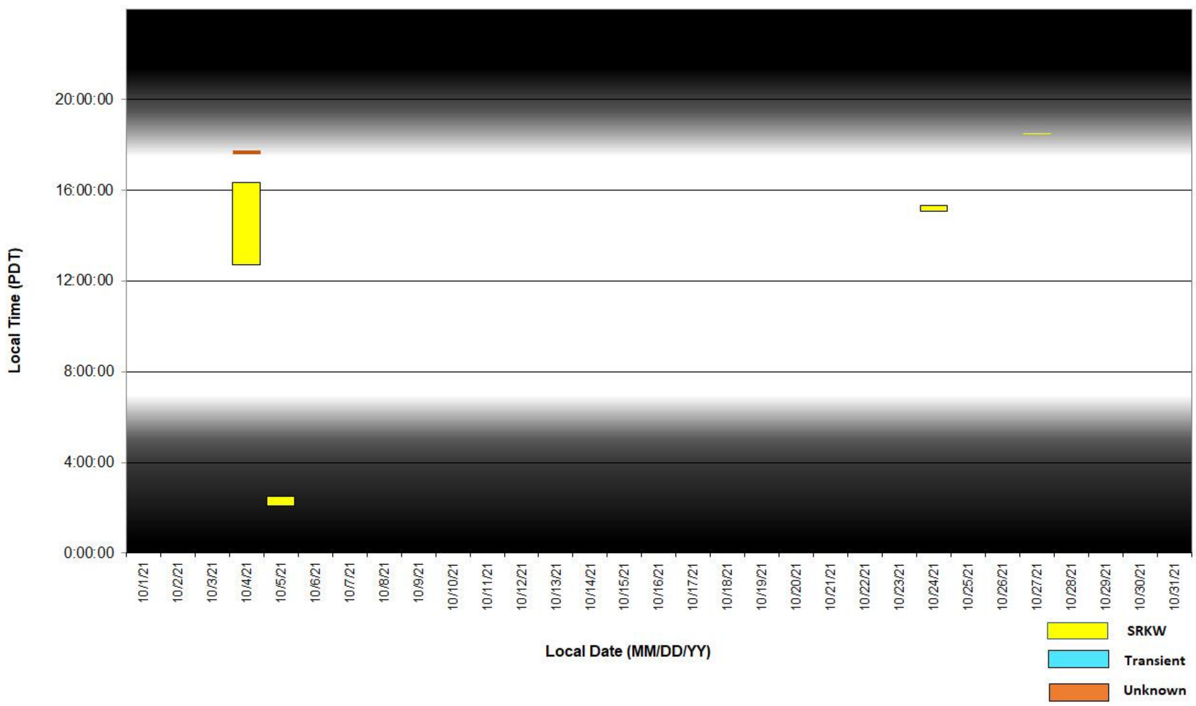



Figure 53. 1–31 Oct 2021: Date and timing of killer whale vocal events detected at Lime Kiln hydrophone using PAMGuard software.

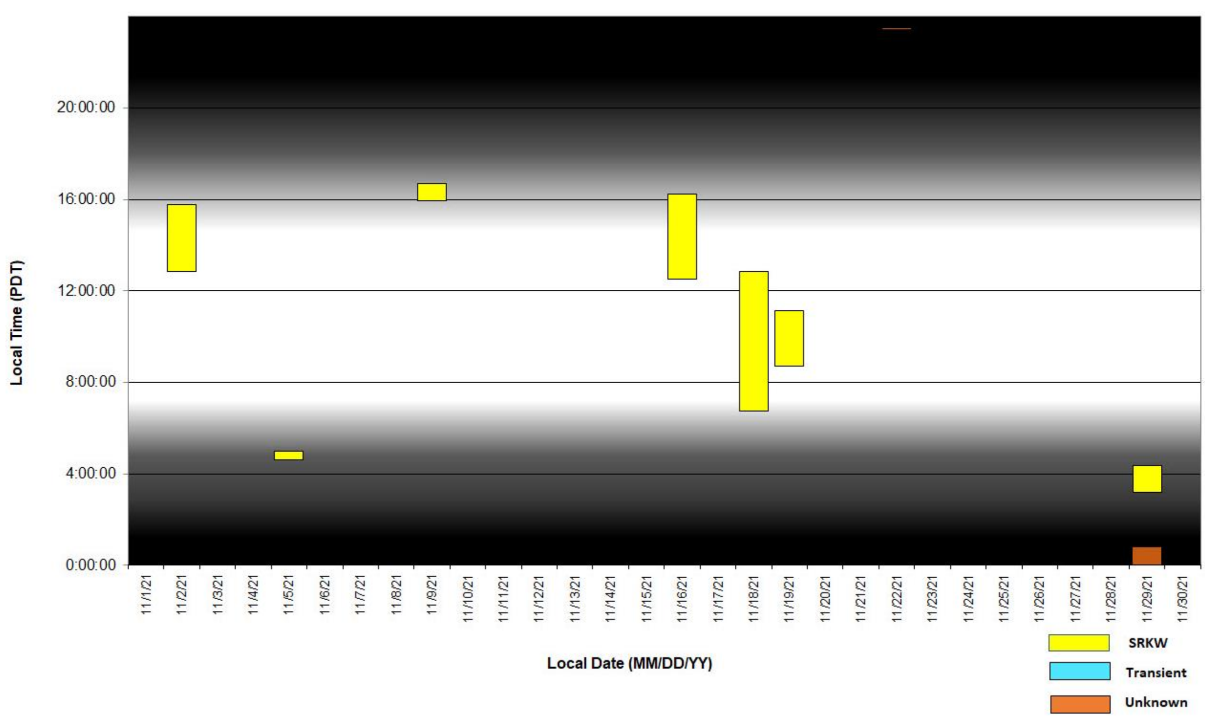



Figure 54. 1–30 Nov 2021: Date and timing of killer whale vocal events detected at Lime Kiln hydrophone using PAMGuard software.

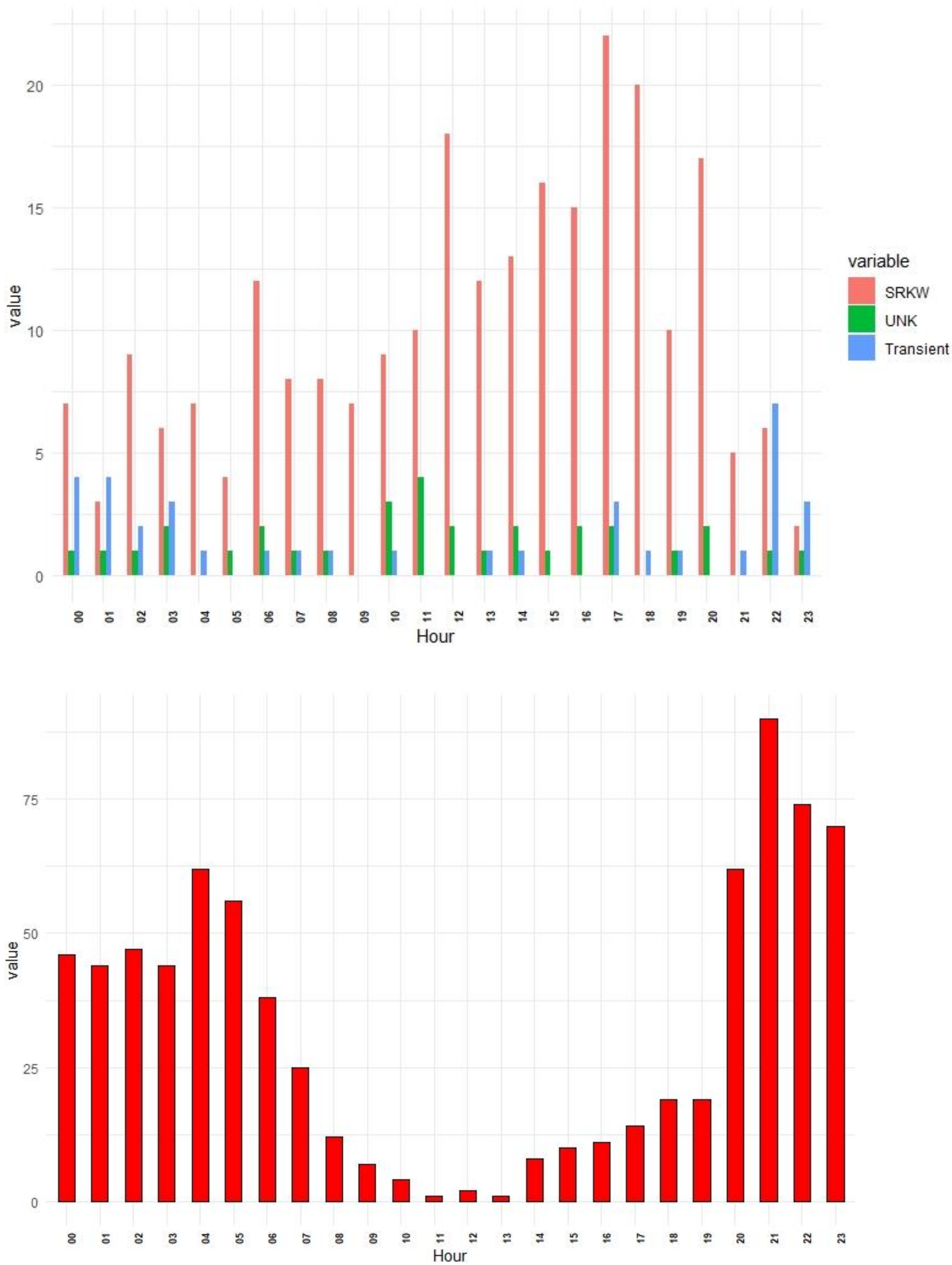



Figure 55. Time of day (local time) presence of (upper panel) Southern Resident killer whale (SRKW), transient, and unknown killer whales and (lower panel) porpoise vocal events based on combined acoustic data sets collected summer and fall 2016–2021 detected using PAMGuard software at Lime Kiln hydrophone.

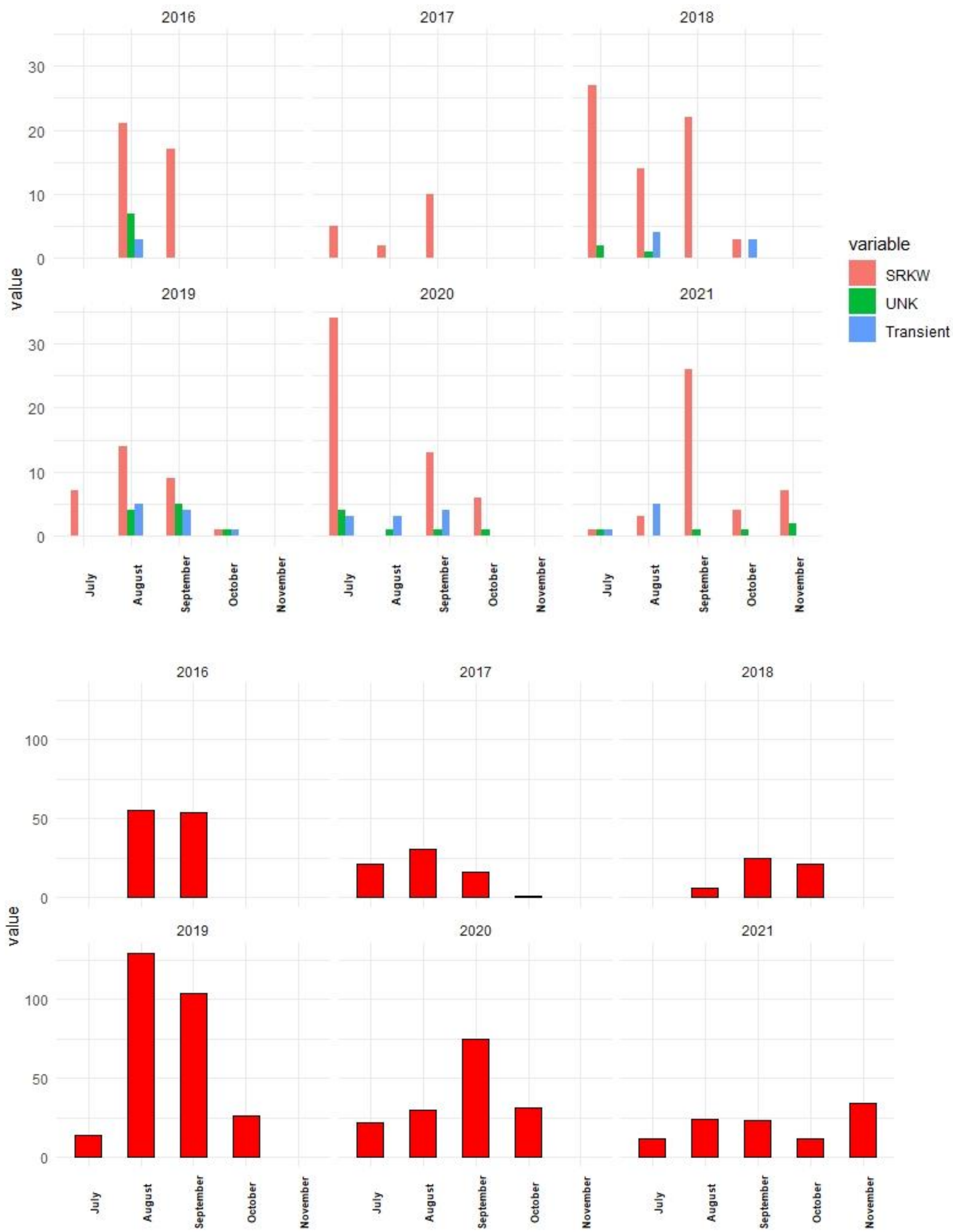



Figure 56. Monthly (upper panel) Southern Resident killer whale (SRKW), transient, and unknown killer whales and (lower panel) porpoise vocal events based on acoustic data sets collected 2016–2021 detected using PAMGuard software at Lime Kiln hydrophone.

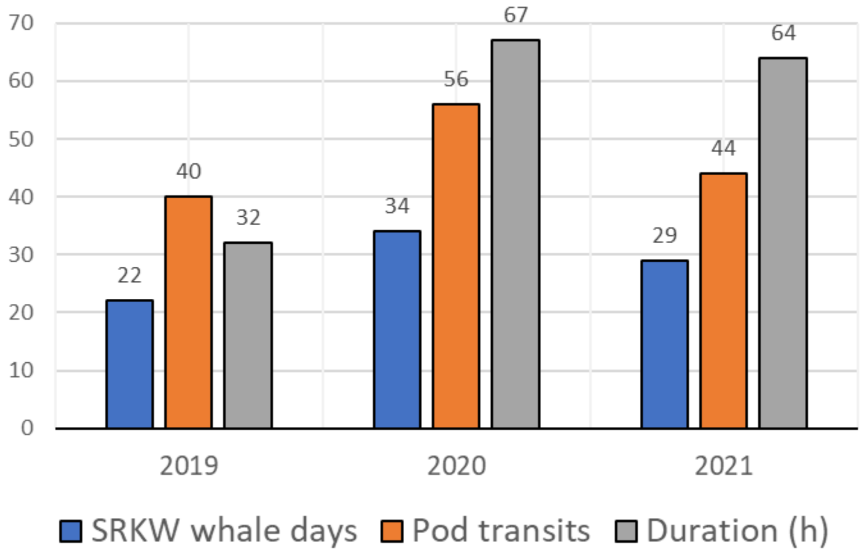



Figure 57. Southern Resident killer whale (SRKW) days, transit events and transit durations (h) based on combined SRKW Passive Acoustic Monitoring (PAM) and Marine Mammal Observer (MMO) detection events made during Slowdown periods 2021–2022 at Lime Kiln.

## 3.7.2. Boundary Pass

In total, killer whales were detected by PAM on 28 days across 35 unique events in Boundary Pass. Most detections were in September (9 days, 12 events). A total of 14 SRKW and 21 transient killer whale events were detected (Table 24; see examples of spectrograms in Figure 59). A total of >32 h of killer whale detections were recorded (20 h 39 min of SRKW and 12 h 40 min of transient killer whale). SRKW and transient killer whales were present during daylight periods and nighttime periods (Figures 60, 61, 62, and 63). No SRKW were detected in July, and no transient killer whales were detected in October. Details of the killer whale PAM detection events for 2021 are provided in Table 25. A summary of all killer whale PAM detection events for the 2019–2021 Slowdowns is provided in Table 26.

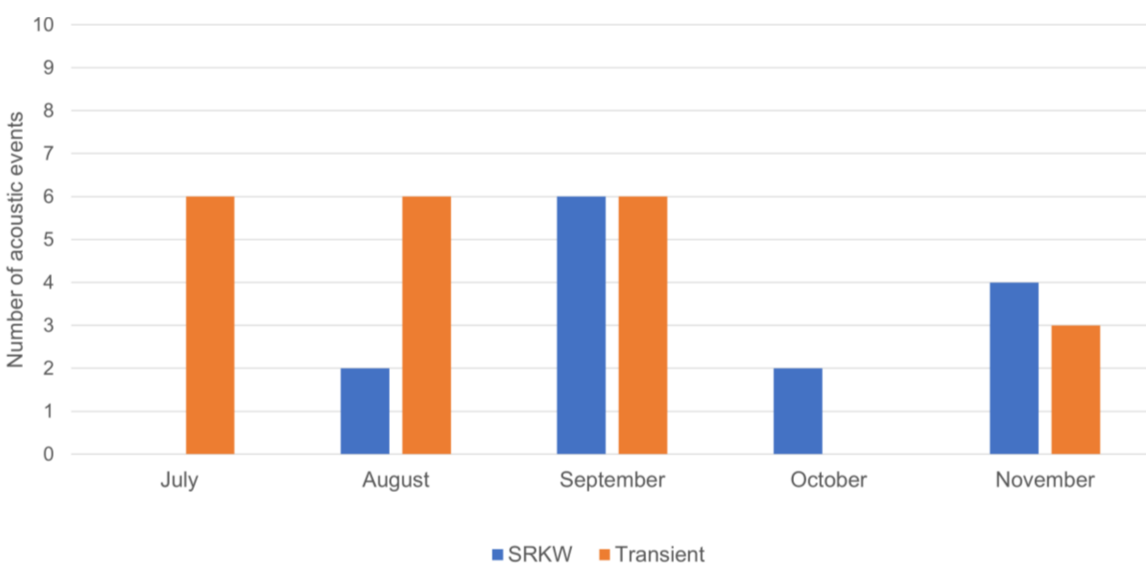



Figure 58. Monthly breakdown of killer whale events detected and identified by PAM protocols (4 Jul to 30 Nov 2021) using passive acoustic monitoring (PAM) data from the Boundary Pass hydrophone.

Table 24. Summary information of passive acoustic monitoring (PAM) detection events of killer whales (KW) made at Boundary Pass between 4 Jul and 30 Nov 2021.

| Date | Number of KW days | | Number of KW events | | Mean duration (h:min) | | Total duration (h:min) | |
|---|---|---|---|---|---|---|---|---|
| | SRKW | Transient | SRKW | Transient | SRKW | Transient | SRKW | Transient |
| July | 0 | 5 | 0 | 6 | 0:00 | 0:47 | 0:00 | 4:42 |
| August | 2 | 4 | 2 | 6 | 0:50 | 0:41 | 1:41 | 4:06 |
| September | 6 | 4 | 6 | 6 | 1:58 | 0:30 | 11:48 | 3:03 |
| October | 2 | 0 | 2 | 0 | 1:39 | 0:00 | 3:18 | 0:00 |
| November | 3 | 2 | 4 | 3 | 0:58 | 0:16 | 3:52 | 0:49 |
| **Total** | **13** | **15** | **14** | **21** | **5:25** | **2:14** | **20:39** | **12:40** |

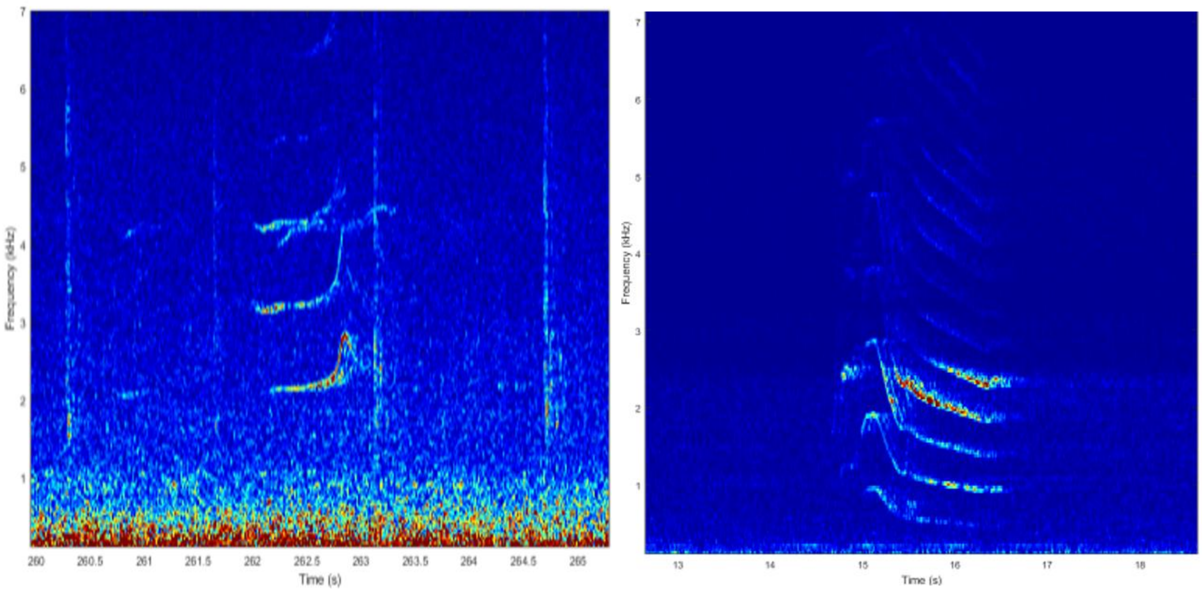



Figure 59. Spectrograms of killer whale vocalizations (left: SRKW (J pod) S1 call on 27 Oct 2021, right: Transient vocalization on 5 Jul 2021).

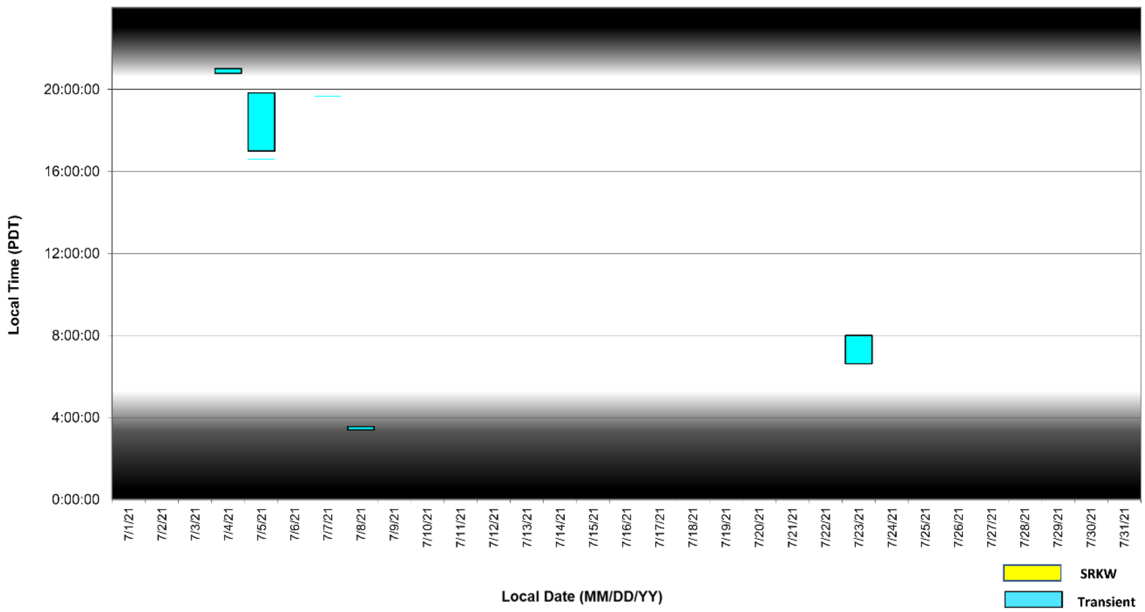



Figure 60. 1–31 Jul 2021: Date, time, and duration of killer whale (by ecotype) Passive Acoustic Monitoring (PAM) detections made at Boundary Pass.

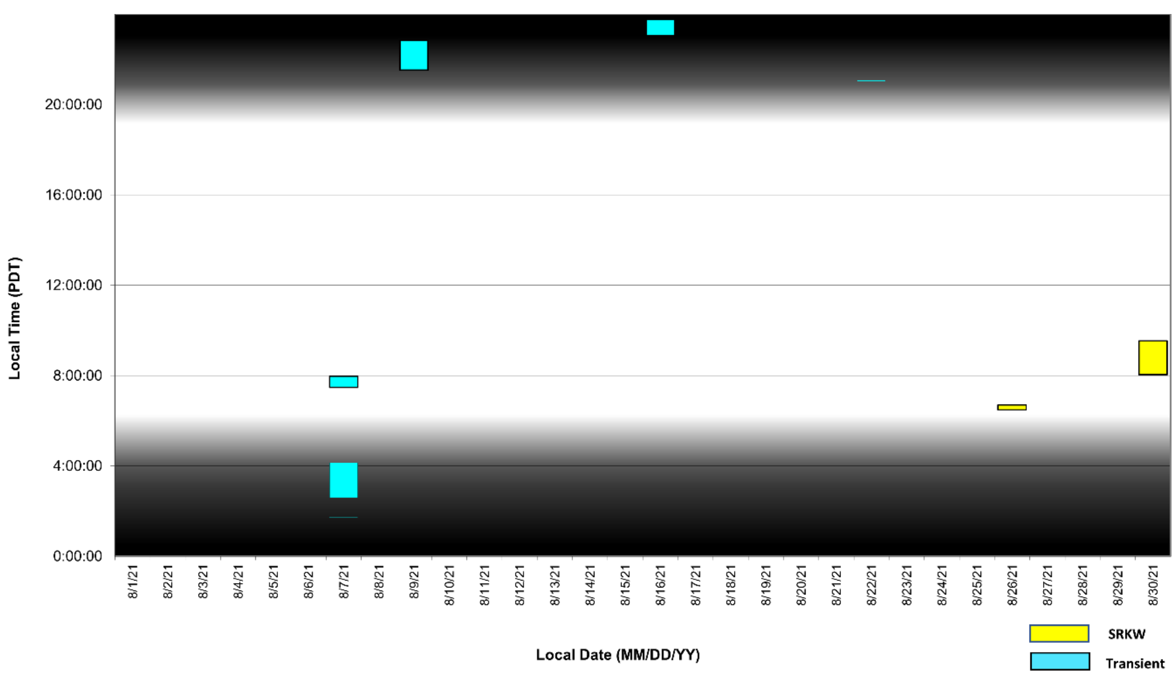



Figure 61. 1–30 Aug 2021: Date, time, and duration of killer whale (by ecotype) passive acoustic monitoring (PAM) detections made at Boundary Pass.

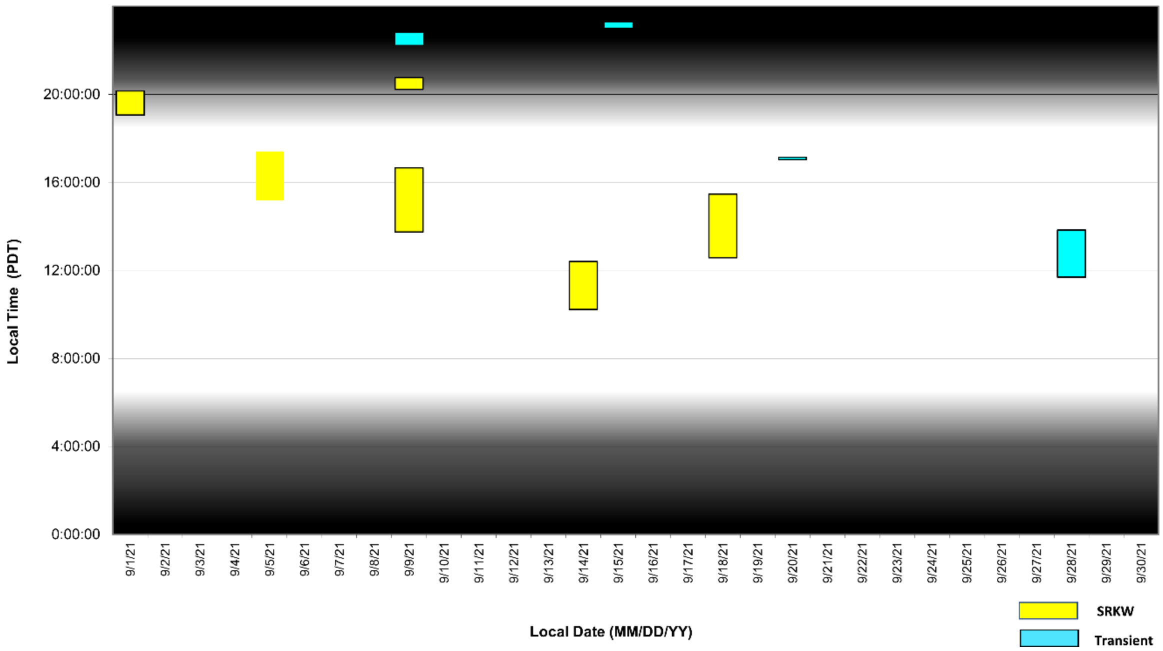



Figure 62. 1–30 Sep 2021: Date, time and duration of killer whale (by ecotype) passive acoustic monitoring (PAM) detections made at Boundary Pass.

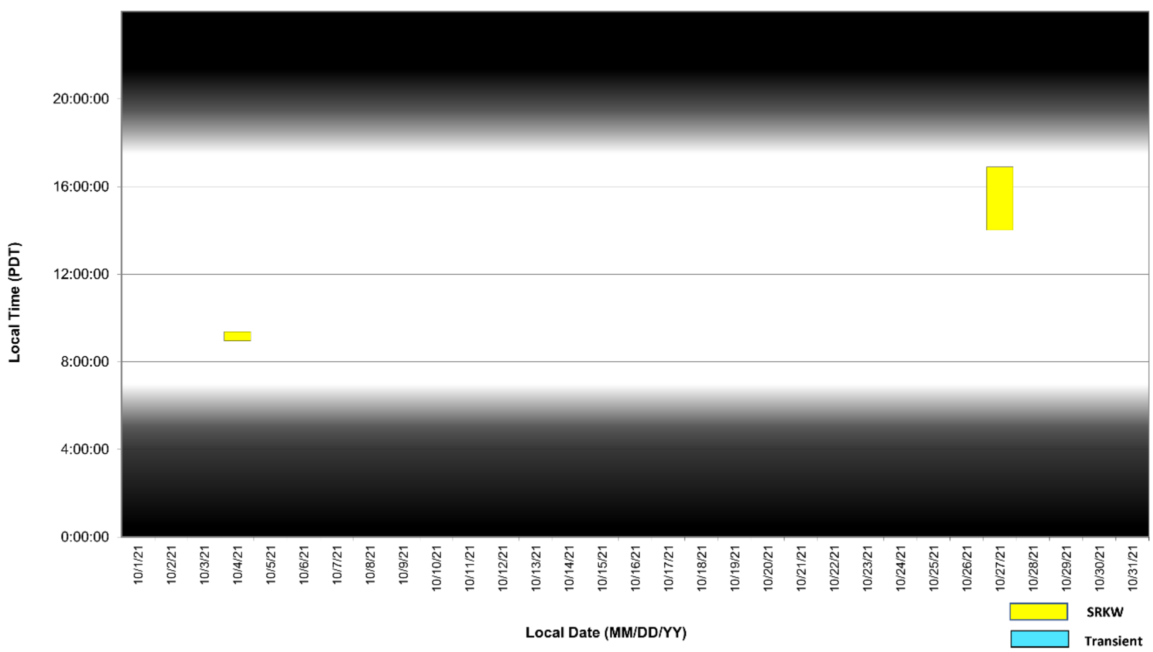



Figure 63. 1–31 Oct 2021: Date, time, and duration of killer whale (by ecotype) passive acoustic monitoring (PAM) detections made at Boundary Pass.

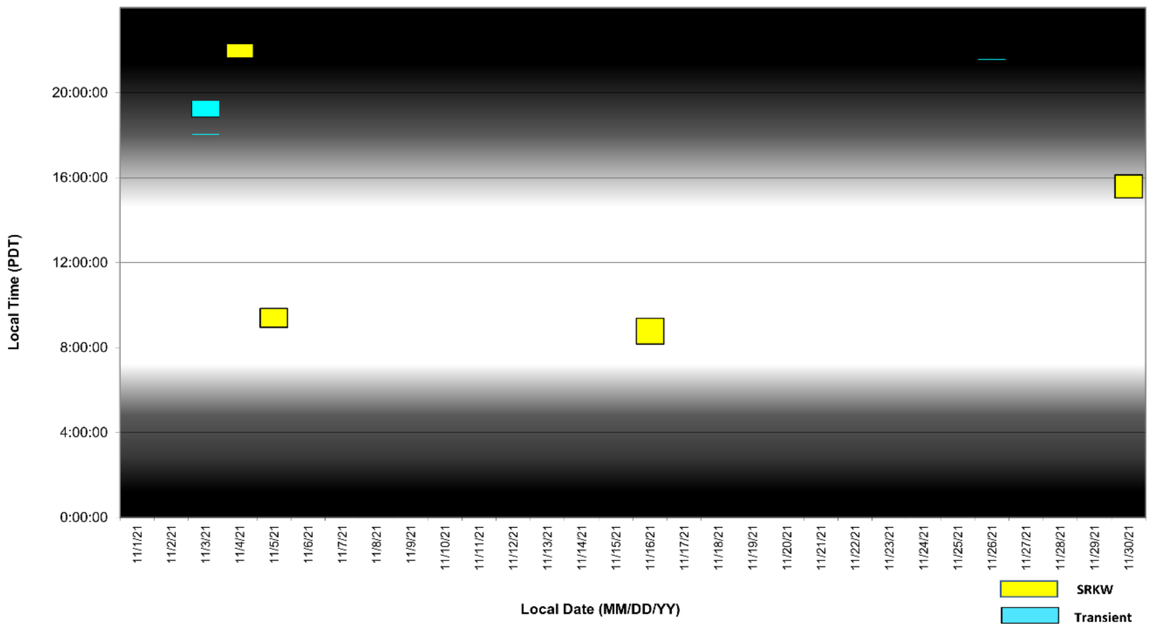



Figure 64. 1–30 Nov 2021: Date, time, and duration of killer whale (by ecotype) passive acoustic monitoring (PAM) detections made at Boundary Pass.

Table 25. Passive acoustic monitoring (PAM) identifications of killer whales detected on the Boundary Pass hydrophone (4 Jul to 30 Nov 2021), 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:s) | Killer whale ecotype classification (Vocalization notes) |
|---|---|---|---|
| 2021 Jul 4 | 20:47 | 0:13:48 | Transient |
| 2021 Jul 5 | 16:34 | 0:03:53 | Transient |
| | 17:00 | 2:50:00 | Transient |
| 2021 Jul 7 | 19:39 | 0:02:01 | Transient |
| 2021 Jul 8 | 3:23 | 0:09:39 | Transient |
| 2021 Jul 23 | 6:37 | 1:22:51 | Transient |
| 2021 Aug 7 | 1:41 | 0:01:43 | Transient |
| | 2:35 | 1:32:08 | Transient |
| | 7:28 | 0:29:59 | Transient |
| 2021 Aug 9 | 21:31 | 1:18:23 | Transient |
| 2021 Aug 16 | 23:03 | 0:43:34 | Transient |
| 2021 Aug 22 | 21:02 | 0:00:25 | Transient |
| 2021 Aug 26 | **6:28** | **0:12:54** | **SRKW** |
| 2021 Aug 30 | **8:02** | **1:28:57** | **SRKW** |
| 2021 Sep 1 | **19:03** | **1:05:34** | **SRKW** |
| 2021 Sep 5 | **15:11** | **2:12:23** | **SRKW (porpoise present)** |
| 2021 Sep 9 | **13:44** | **2:55:19** | **SRKW** |
| | **20:13** | **0:31:33** | **SRKW (distant calls)** |
| | 22:15 | 0:31:41 | Transient |
| 2021 Sep 14 | **10:13** | **2:10:36** | **SRKW** |
| 2021 Sep 15 | 22:27 | 0:01:00 | Transient (single call) |
| | 23:00 | 0:14:37 | Transient |
| 2021 Sep 16 | 12:35 | 0:00:58 | Transient |
| 2021 Sep 18 | **12:34** | **2:53:22** | **SRKW** |
| 2021 Sep 20 | 17:01 | 0:07:07 | Transient |
| 2021 Sep 28 | 11:41 | 2:08:22 | Transient |
| 2021 Oct 4 | **8:57** | **0:25:37** | **SRKW** |
| 2021 Oct 27 | **14:01** | **2:52:58** | **SRKW** |
| 2021 Nov 3 | 18:00 | 0:02:49 | Transient |
| | 18:51 | 0:45:48 | Transient |
| 2021 Nov 4 | **21:37** | **0:41:38** | **SRKW** |
| 2021 Nov 5 | **8:56** | **0:53:22** | **SRKW** |
| 2021 Nov 16 | **8:10** | **1:12:53** | **SRKW** |
| 2021 Nov 26 | 21:33 | 0:00:58 | Transient |
| 2021 Nov 30 | **15:02** | **1:05:01** | **SRKW** (event ctd. into 1 Dec 2021) |

Table 26. Summary of Vessel Slowdown acoustic monitoring periods 2019–2021 at the Boundary Pass hydrophone, and killer whale detection events detected using PAMview software.

| Year | Date range (Days) | Killer whale days (SRKW) | Killer whale events (SRKW) |
|---|---|---|---|
| 2019 | Jul 5 to Oct 13 = 101 days | 30 (8) | 34 (8) |
| 2020 | Jul 1 to Oct 31 = 123 days | 24 (14) | 31 (18) |
| 2021 | Jul 4 to Nov 30 = 150 days | 28 (13) | 35 (14) |
| **Total** | **374 days** | **82 (35)** | **100 (40)** |

# 4. Discussion

## 4.1. Sources of Error

In Boundary Pass, the lack of ADCP coverage during some periods was expected to introduce only a small amount of error into the CDF analysis. This is because the current filtering criterion (current magnitude >0.5 m/s) could be estimated with 87% accuracy using a proxy variable based on the WebTide model (see Section 2.5.2). It is nonetheless expected that the accuracy of the proxy estimate could be improved, since WebTide only predicts average current speeds with depth. A current model that includes depth dependence would presumably allow for a more accurate filtering during periods with missing ADCP data. Missed time periods of higher currents could elevate measured sound levels in the lower frequency bands (10–100 and 100–1000 Hz) due to including data with higher flow-induced pseudo noise.

After the Boundary Pass ULS servicing in October, the hydrophones, mooring, and electronics were all replaced on Frames A and B. Comparing the pre-servicing and post-servicing sound level data suggested that sound levels above 10 kHz were elevated due to higher levels of electronic tonal noise. Thus, sound levels deltas during the November slowdown period are considered to be unreliable above 10 kHz.

The apparent reduction in current velocity at Lime Kiln due to instrument biofouling will have led to more data being included in CDF analyses than if the current meter was functioning fully within specifications. This could have led to higher SPL in broadband and the first two decade bands (10–100 and 100–1000 Hz) being included in analyses. Since this lower current meter sensitivity occurred in October (Figure 9), it should have affected the Slowdown (Jul-Oct) results; however, we see no evidence of this in the CDF results (Figures 26–32).

## 4.2. Evaluation of 2021 Slowdown

The 2021 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 during the Slowdown (Jul-Oct) period decreased by 3.7 dB in Haro Strait and 3.2 dB in Boundary Pass, relative to the Baseline period, after filtering for confounding factors. Generally, there was a greater reduction in sound levels at lower frequencies at the Boundary Pass than at the Lime Kiln hydrophones. 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 (Jul-Oct) 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 2021) in Haro Strait (Table 9) and Boundary Pass (Table 12), respectively. Sound levels were reduced for a greater proportion of the actual Slowdown period because times 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 (~70 m from the coastline) and several kilometres from the international shipping lanes. Small (mostly recreational) vessels (with and without AIS) frequently transited close to shore, which required filtering (using both AIS criteria and the small boat acoustic detector) out more of the acoustic data for quantifying the Slowdown effect on sound levels. In Boundary Pass, the hydrophone was approximately 2 km from shore and positioned between the international shipping lanes. Nevertheless, there were more small boat detections in Boundary Pass than in Haro Strait. This is a result of the properties of the small boat detection algorithms between the two sites. Different thresholds and sensitivities were used, and Boundary Pass had a longer range.

The duration of quiet time (i.e., the times when broadband sound levels were below 102.8 and 110 dB re 1 µPa) changed very little between Baseline and Slowdown (Jul-Oct) periods (Tables 15 and 16). The total quiet time and median quiet time duration in Boundary Pass were longer than in Haro Strait. This was likely driven by differences in use of these areas by recreational boats.

During the 2021 Slowdowns (Jul-Oct) and (Nov), there were 41 SRKW PAM events recorded at Lime Kiln and 14 SRKW PAM events recorded in Boundary Pass. This is in line with historical sightings of SRKW in the Salish Sea. 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 6 transient killer whale events recorded at Lime Kiln and 21 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.

## 4.3. November Results

The CDF results for Slowdown (Nov) at Lime Kiln and Boundary Pass are inconsistent with Slowdown (Jul-Oct), especially in the top two decade bands (1–10 and 10–100 kHz; see Figures 26–32 and Figures 37–43). While there was a small reduction in participation during the November Slowdown, the discrepancies in this month were more likely due to environmental factors. First, small boat traffic decreased at both sites in November due to weather. Second, several storms occurred from the end of October and to end of November, and there were high sustained windspeeds throughout (see Appendix A for Lime Kiln; see Figures 34–36 for Boundary Pass). This resulted in higher noise levels, especially in the top two decade bands (1–10 and 10–100 kHz), as is emphasized in the CDF plots for decade bands 3 and 4 (see Figures 28 and 29 for Lime Kiln, Figures 40 and 41 for Boundary Pass).

In addition, CTD casts indicate that the November sound speed profile was more homogenous due to greater mixing of the water column (Figure 16). It is difficult to determine if this contributed to the Slowdown (Nov) anomalies, and further detailed investigation would be required. This could include comparing the Slowdown (Nov) period to a time period outside of the Slowdown with more similar winter conditions (e.g., December).

After the equipment servicing in October 2021, the new hydrophones were noted to have a different noise floor and also contained some higher frequency tones. The change in measured noise characteristics produced an apparent effect on the noise levels. To mitigate this issue, two hydrophones with lower noise floors were used to minimize this effect to improve the ability to assess real noise differences produced by the Slowdown.

## 4.4. Comparison with Previous Years' Measurements

Overall sound levels during the Baseline period were generally consistent with measurements made at Lime Kiln and in Boundary Pass in previous years. Sound level reductions during Slowdown (Jul-Oct) 2021 were the same or slightly greater than during the 2019 and 2020 Slowdown periods. This is consistent with relatively consistent pilot-reported participation rates (82% in 2019 and 91% in 2020). The acoustic differences between years were relatively small and could be related to minor inter-year differences in vessel populations (e.g., due to changes in proportions of different vessel types) or environmental conditions (e.g., due to changes in sound speed profiles). The reductions observed in 2021 are considered robust and show consistent decreases in SPL during the Slowdown (Jul-Oct) period relative to the Baseline SPL.

# 5. Conclusion

- Median broadband (10–100,000 Hz) sound levels ($L_{50}$) measured at Lime Kiln in Haro Strait decreased by 3.7 dB during the Slowdown (Jul-Oct) period relative to the Baseline period, when filtered for confounding factors.
- Median broadband (10–100,000 Hz) sound levels ($L_{50}$) measured at Lime Kiln in Haro Strait decreased by 2.5 dB during the Slowdown (Nov) period relative to the Baseline period, when filtered for confounding factors.
- Median broadband (10–100,000 Hz) sound levels ($L_{50}$) measured between the international shipping lanes in Boundary Pass decreased by 3.2 dB during the Slowdown (Jul-Oct) relative to the Baseline period, when filtered for confounding factors.
- Median broadband (10–100,000 Hz) sound levels ($L_{50}$) measured between the international shipping lanes in Boundary Pass decreased by 1.0 dB during the Slowdown (Nov) relative to the Baseline period, when filtered for confounding factors.
- The Slowdown (Jul-Oct) period also showed reductions in broadband noise for the mean ($L_{eq}$) and $L_5$ in both locations, with slightly smaller reductions in Boundary Pass ($L_{eq}$ decreased by 3.1 dB) than in Haro Strait ($L_{eq}$ decreased by 3.5 dB).
- The Slowdown (Nov) period also showed reductions in broadband noise for the mean ($L_{eq}$) and $L_5$ in both locations, with slightly smaller reductions in Boundary Pass ($L_{eq}$ decreased by 1.3 dB) than in Haro Strait ($L_{eq}$ decreased by 2.2 dB).
- Median ambient noise reductions for the Slowdown (Jul-Oct) period were largest in the 10–100 Hz decade band in Boundary Pass and Haro Strait.
- Median ambient noise reductions for the Slowdown (Nov) period were the largest in the 10–100 Hz and 1–10 kHz decade band in Boundary Pass and were the largest in the 10–100 Hz decade band 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 (Jul-Oct) (3.9 knots), followed by Car carriers (2.5 knots).
- Large vessel traffic in Boundary Pass and Haro Strait was largely composed of bulk carriers, container ships, general cargo vessels, and tugs.
- 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. Fewer small boats were present in November, possibly due to harsher weather conditions.
- Small boat detections in Haro Strait infrequently dominated sound levels when vessels that were potential Slowdown participants were present. Fewer small boats were presented in November possibly due to harsher weather conditions.
- Filtering out time periods that automatically acoustically detected 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).
- In Boundary Pass, the median duration of quiet time was 6 min for the 102.8 dB threshold during the Baseline and Slowdown periods and was around 9 min for the 110 dB threshold. SPL was below the 102.8 dB threshold approximately 47% 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.

- In Haro Strait, the median duration of quiet time was 3 min for the 102.8 dB threshold during the Baseline and Slowdown periods and was around 5 min for the 110 dB threshold. SPL was below the 102.8 dB threshold approximately 33% of the time and below the 110 dB threshold approximately 60% of the time. There was no significant difference in quiet time between the Baseline and Slowdown periods in Haro Strait.
- The GAMM analysis found statistically significant reductions in SPL from the vessel speed reductions of the Slowdown (Jul-Oct) 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 1.1 dB for Bulk and Containerized vessel types from Baseline to Slowdown (Jul-Oct) periods, respectively.
- SRKW were detected by PAM on 29 separate days at Lime Kiln and 13 separate days at Boundary Pass. At both locations detections peaked in September and were lowest in July.

# Literature Cited


[DFO] Fisheries and Oceans Canada. 2017. *Evaluation of the Scientific Evidence to Inform the Probability of Effectiveness of Mitigation Measures in Reducing Shipping-Related Noise Levels Received by Southern Resident Killer Whales*. Canadian Science Advisory Secretariat Science Advisory Report 2017/041. 21 p. https://waves-vagues.dfo-mpo.gc.ca/Library/40646713.pdf.

Breiman, L. 2001. Random Forests. *Machine Learning* 45(1): 5-32. https://doi.org/10.1023/A:1010933404324.

Dewey, R., T. Dakin, X. Mouy, and I.R. Urazghildiiev. 2015. A regional hydrophone network: Monitor, detect and track. *Underwater Acoustics Conference and Exhibition*. 21-26 Jun 2015, Crete, Greece.

Foreman, M.G.G., W.R. Crawford, J.Y. Cherniawsky, R.F. Henry, and M.R. Tarbottom. 2000. A high-resolution assimilating tidal model for the northeast Pacific Ocean. *Journal of Geophysical Research* 105(C12): 28629-28651. https://doi.org/10.1029/1999JC000122.

Frankel, A.S. and C.M. Gabriele 2017. Predicting the acoustic exposure of humpback whales from cruise and tour vessel noise in Glacier Bay, Alaska, under different management strategies. *Endangered Species Research* 34: 397-415. https://doi.org/10.3354/esr00857.

Fristrup, K.M. and W.A. Watkins. 1993. *Marine animal sound classification*. Report WHOI-94-13. Woods Hole Oceanographic Institution. 32 p. http://darchive.mblwhoilibrary.org:8080/bitstream/handle/1912/546/WHOI-94-13.pdf?sequence=1.

Gillespie, D., D.K. Mellinger, J. Gordon, D. McLaren, P. Redmond, R. McHugh, P.W. Trinder, X.Y. Deng, and A.M. Thode. 2008. *PAMGUARD: Semiautomated, open source software for real-time acoustic detection and localisation of cetaceans*. *The Institute of Acoustics*. Volume 30(5), 14-15 Oct 2008 Southampton, UK. 5, pp. 54-62.

Heise, K., L.G. Barrett-Lennard, R. Chapman, T. Dakin, C. Erbe, D.E. Hannay, N.D. Merchant, J. Pilkington, S. Thornton, et al. 2017. *Proposed Metrics for the Management of Underwater Noise for Southern Resident Killer Whales*. Coastal Ocean Report Series. Volume 2017/2. Report for the Coastal Ocean Research Institute. © Ocean Wise 2017, Vancouver, BC, Canada. 31 p. http://wildwhales.org/wp-content/uploads/2017/09/Read-the-Report.pdf.

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

Institute of Ocean Sciences. 2015. WebTide Northeast Pacific Data (v0.7). Bedford Institute of Oceanography. http://www.bio.gc.ca/science/research-recherche/ocean/webtide/nepacific-nepacifique-en.php (Accessed 16 Jan 2019).

JASCO Applied Sciences and SMRU Consulting. 2020. *ECHO Program 2019 Voluntary Vessel Slowdown Hydroacoustic Studies: Final Report*. Document 01994, Version 1.0. Technical report by JASCO Applied Sciences and SMRU Consulting for Vancouver Fraser Port Authority (VFPA).

Mellinger, D.K. and J.W. Bradbury. 2007. Acoustic measurement of marine mammal sounds in noisy environments. *2nd International Conference on Underwater Acoustic Measurements: Technologies and Results*. Heraklion, Greece. pp. 273-280. ftp://ftp.pmel.noaa.gov/newport/mellinger/papers/Mellinger+Bradbury07-BioacousticMeasurementInNoise-UAM,Crete.pdf.

Miller, P.J.O. 2006. Diversity in sound pressure levels and estimated active space of resident killer whale vocalizations. *Journal of Comparative Physiology A* 192: 449-459. https://doi.org/10.1007/s00359-005-0085-2.

Moloney, J., C.A. Hillis, X. Mouy, I.R. Urazghildiiev, and T. Dakin. 2014. Autonomous Multichannel Acoustic Recorders on the VENUS Ocean Observatory. *OCEANS 2014*. 14-19 Sep 2014. IEEE, St. John's, NL, Canada. pp. 1-6. https://doi.org/10.1109/OCEANS.2014.7003201.

Mouy, X., J. Ford, J. Pilkington, K. Kanes, A. Riera, T. Dakin, and P.-A. Mouy. 2015. Automatic Marine Mammal Monitoring off British Columbia, Canada. *7th International DCLDE Workshop*. 13-16 Jul 2015, La Jolla, CA, USA.

Tollit, D.J. and J.D. Wood. 2021. *SRKW sightings at Lime Kiln State Park in summer 2021*. Report by SMRU Consulting for VFPA ECHO program. 6 p.

Veirs, S., V. Veirs, and J.D. Wood. 2016. Ship noise extends to frequencies used for echolocation by endangered killer whales. *PeerJ* 4(e1657). https://doi.org/10.7717/peerj.1657.

Warner, G.A., J.D. Wood, S. Frey, L. McWhinnie, A.O. MacGillivray, Z. Li, and D.J. Tollit. 2019. *Salish Sea Ambient Noise Evaluation 2016–2017: Enhancing Cetacean Habitat and Observation Program*. Document 01756, Version 2.0. Technical report by JASCO Applied Sciences, SMRU Consulting, Coastal and Ocean Resource Analysis Laboratory for Vancouver Fraser Port Authority.

Warner, G.A., J.D. Wood, A.O. MacGillivray, T.S. Dofher, H. Frouin-Mouy, D.J. Tollit, and T.M. Yack. 2021. Chapter 1. Hydroacoustic Monitoring. *In ECHO Program 2020 Voluntary Vessel Slowdown Hydroacoustic Studies: Final Report*. Document 02363, Version 2.0. Technical report by JASCO Applied Sciences and SMRU Consulting for Vancouver Fraser Port Authority (VFPA).

Wood, S.N. 2004. Stable and efficient multiple smoothing parameter estimation for generalized additive models. *Journal of the American Statistical Association* 99(467): 673-686. https://doi.org/10.1198/016214504000000980.

# Appendix A. Time Series of Environmental Data Collected at Lime Kiln

Figures 65–71 present the time series of the current and wind data at Lime Kiln throughout the ECHO-2021 Baseline and Slowdown periods. As the periods are different durations, each plot shows one month of data so that the x axes are of approximately the same length.

Figures 65 and 66 shows the Baseline months; Figures 67, 68, 69, and 70 shows the Slowdown months (July, August, September, October); Figure 71 shows the briefer Slowdown month (November). Sustained higher wind speeds were present at the end of October and throughout November, and complement similar findings shown at Boundary Pass (see Figures 35 and 36).

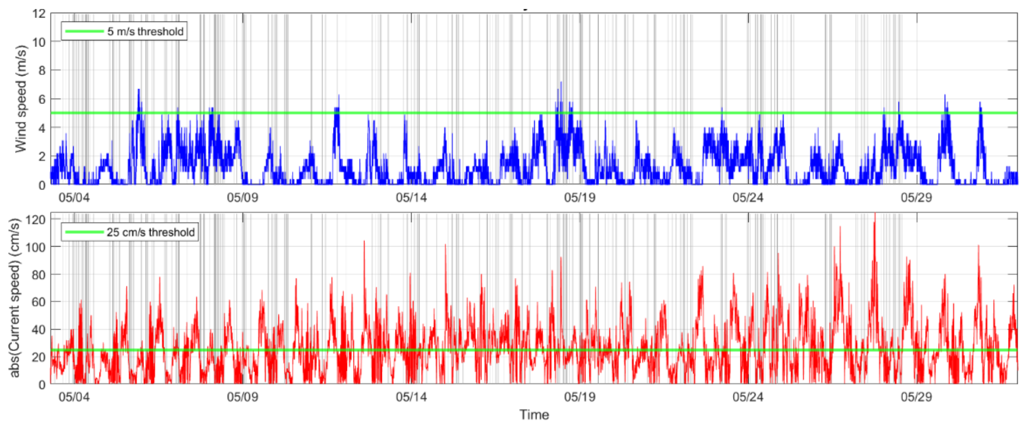



Figure 65. May 2021: Monthly time series of wind and current data (within the Baseline period) at Lime Kiln. The green lines show the wind and current thresholds, beneath which data was included for Cumulative Distribution Function (CDF) analysis. Gray vertical bars show when data passed all criteria (for wind, current, AIS and small boats) and was included in CDF analysis. A gap in AIS data at the end of May accounts for the absence of CDF-available data here.

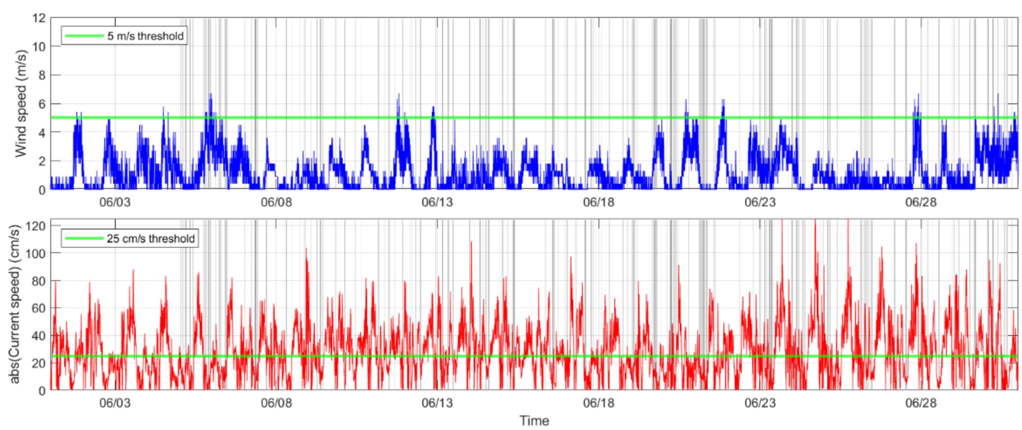



Figure 66. June 2021: Monthly time series of wind and current data (within the Baseline period) at Lime Kiln. The green lines show the wind and current thresholds, beneath which data was included for Cumulative Distribution Function (CDF) analysis. Gray vertical bars show when data passed all criteria (for wind, current, AIS and small boats) and was included in CDF analysis. A gap in AIS data at the start of June accounts for the absence of CDF-available data here.

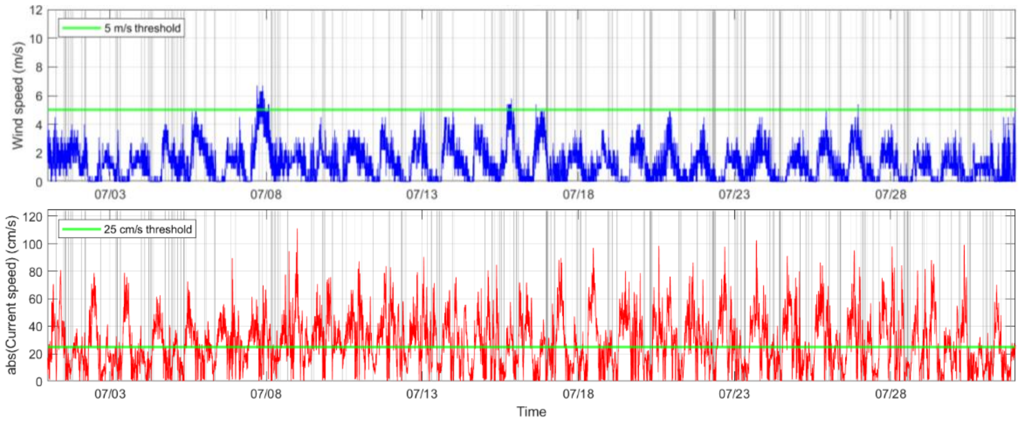



Figure 67. July 2021: Monthly time series of wind and current data (within the Slowdown period) at Lime Kiln. The green lines show the wind and current thresholds, beneath which data was included for Cumulative Distribution Function (CDF) analysis. Gray vertical bars show when data passed all criteria (for wind, current, AIS and small boats) and was included in CDF analysis.

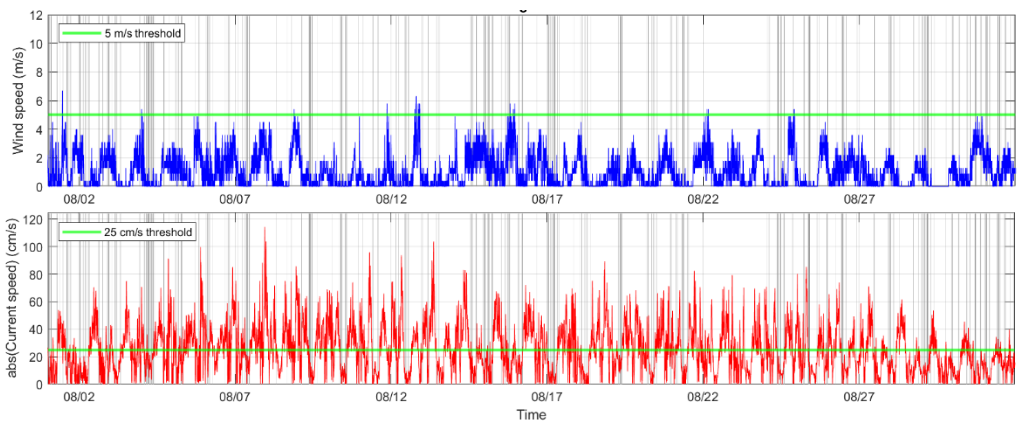



Figure 68. August 2021: Monthly time series of wind and current data (within the Slowdown period) at Lime Kiln. The green lines show the wind and current thresholds, beneath which data was included for Cumulative Distribution Function (CDF) analysis. Gray vertical bars show when data passed all criteria (for wind, current, AIS and small boats) and was included in CDF analysis.

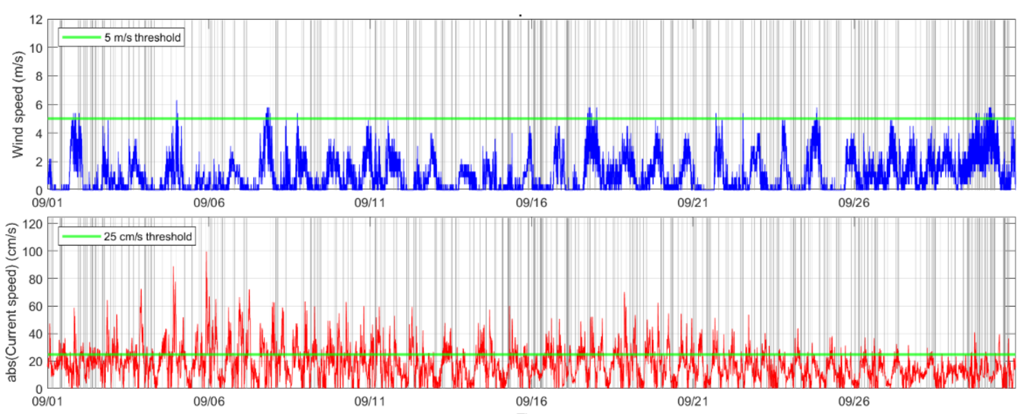



Figure 69. September 2021: Monthly time series of wind and current data (within the Slowdown period) at Lime Kiln. The green lines show the wind and current thresholds, beneath which data was included for Cumulative Distribution Function (CDF) analysis. Gray vertical bars show when data passed all criteria (for wind, current, AIS and small boats) and was included in CDF analysis.

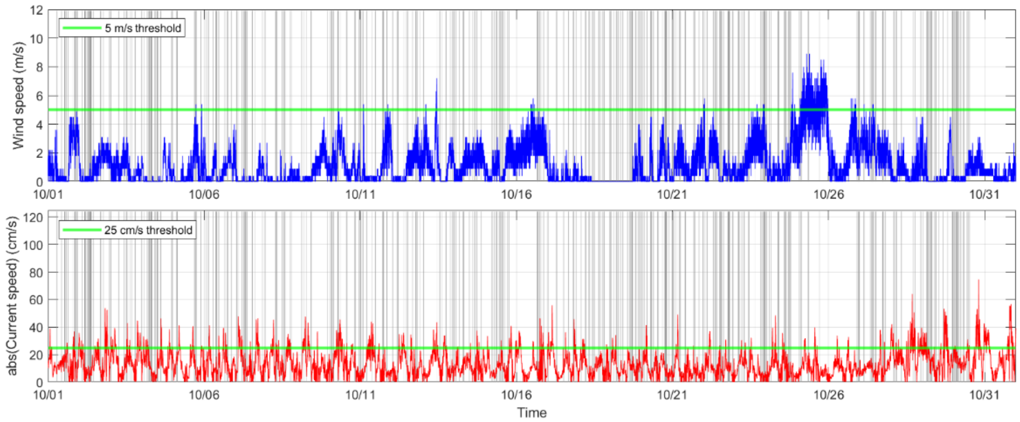



Figure 70. October 2021: Monthly time series of wind and current data (within the Slowdown period) at Lime Kiln. The green lines show the wind and current thresholds, beneath which data was included for Cumulative Distribution Function (CDF) analysis. Gray vertical bars show when data passed all criteria (for wind, current, AIS and small boats) and was included in CDF analysis.

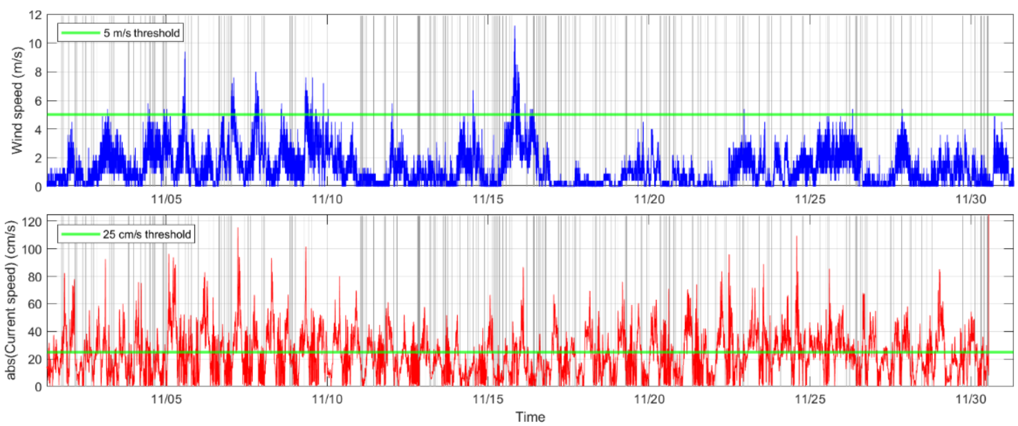



Figure 71. November 2021: Monthly time series of wind and current data (within the extended Slowdown period) at Lime Kiln. The green lines show the wind and current thresholds, beneath which data was included for Cumulative Distribution Function (CDF) analysis. Gray vertical bars show when data passed all criteria (for wind, current, AIS and small boats) and was included in CDF analysis.

**Appendix C.1.**

Haro Strait 2021 SRKW sightings at Lime Kiln State Park

# SRKW sightings at Lime Kiln State Park in summer 2021

Jan 4, 2022

815D Spring St. Unit 1
Friday Harbor, WA 98250
USA

SMRU Consulting North America

604-55 Water Street
Vancouver, BC V6B 1A1
Canada

# SRKW sightings at Lime Kiln State Park in summer 2021

4 January 2022

Prepared by SMRU Consulting NA

Authors:

Dominic Tollit, PhD
Principal Scientist

Jason Wood, PhD
Managing Director

Submitted to ECHO Program, Vancouver Fraser Port Authority

Acknowledgements

Data were collected and kindly provided by Dr. Bob Otis and Jeanne Hyde. We also thank Melanie Knight (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 and fall 2021 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 November 30, 2021. Observations (9:00-17:00, within ½ mile) by Bob Otis were made from June 1 to August 10 and then supplemented more irregularly with observations by Jeanne Hyde (June 1 to November 30) that included observations made earlier and later in the day, but noting daily attendance was irregular and location of sighting was sometimes alternately made from locations near to Lime Kiln or using the video feed at Lime Kiln. Jeanne Hyde also made supplementary observations during July 1 to August 10 outside of the 9:00-17:00 regular observation period. Date, time, direction of travel and pod groupings (where possible) were collected. Consistent timing of transits was not collected this year due to the more irregular schedule in this Covid-19 pandemic year, graphical and tabular comparisons with other years has not been made directly. 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 2021 observations (June 1 – November 30):

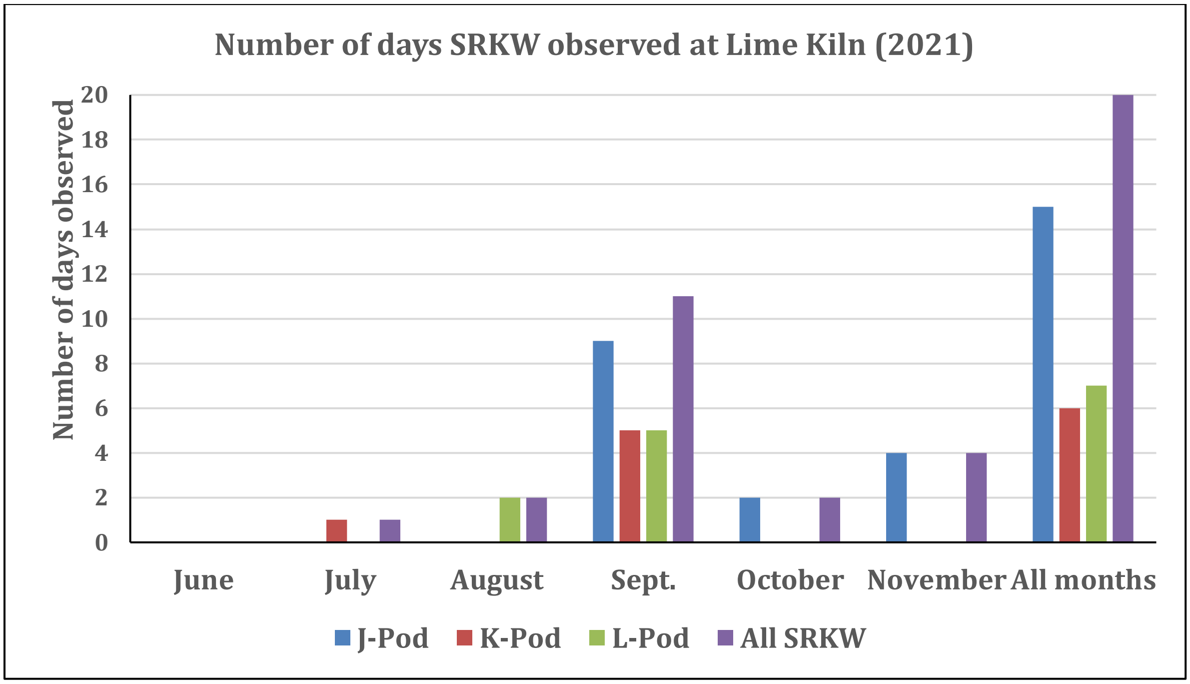
SRKW were visually observed on a minimum of 20 days in total in summer and fall 2021 (June 1 to November 30, 2021) at Lime Kiln. There were a minimum total of 27 confirmed SRKW transits encompassing a total of 37 "individual" pod transits (i.e., when transits by each pod were counted separately, despite 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 15 days (19 pod transits), K-Pod on 6 days (6 pod transits) and L-Pod on 7 days (7 pod transits) (Table 1, Figure 1). On five occasions across two days the particular pod ID was not identified beyond confirmation of the transiting whales being SRKW. Observations were concentrated in September (11 days). No sightings were made in June and less than two in July, August and October 2021. Members of J-Pod alone were observed 13 times, K-pod alone 1 time and L-Pod alone 2 times. All three pods transited together on 4 days in September (Figure 2). This would be counted as 4 SRKW transits and 12 "individual" pod transits. Summary sightings days across each month and overall are presented for 2021 in Figure 1.

Table 1. Summary of Lime Kiln SRKW and individual pod sightings data by individual pod and overall (June 1 to November 30, 2021).

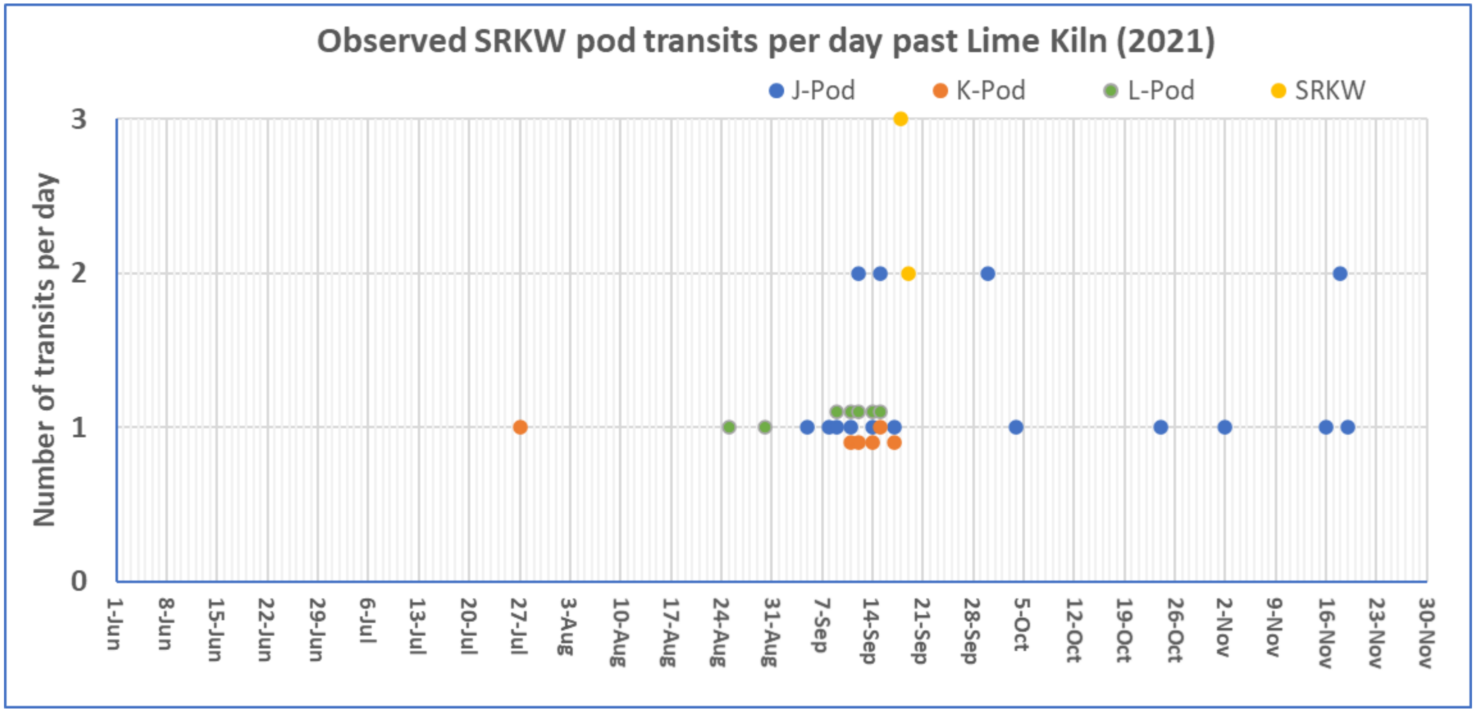
| Metric | J-Pod | K-Pod | L-Pod | Unknown Pod | SRKW |
|---|---|---|---|---|---|
| Detection days | 15 | 6 | 7 | 2 | 20 |
| Number of transits | 19 | 6 | 7 | 5 | 37 |

Figure 1. Number of days SRKW observed at Lime Kiln in summer 2021 (June 1 to November 30, 2021).




Note: Observer attendance was not consistently every day after August 10, 2021.

Figure 2. Observed SRKW pod transits per days past Lime Kiln in summer 2021 (June 1 to November 30, 2021).



## Discussion

Datasets of SRKW sightings made during summer and fall 2021 (June 1 to November 30) at Lime Kiln State Park were kindly provided by two long-term experienced observers, Dr. Bob Otis and Jeanne Hyde. Due to the pandemic observation days and hours and exact observation location from August 11 were more irregular and SRKW were thus sighted on minimum of 20 days, with J-pod sighted on 15 (75%) of those days, similar to that seen in 2020. Sightings were mostly from September, with very low sighting rates in July, August and October and no SRKW sighted in June. No SRKW were sighted between 9am and 5pm by Bob Otis over the period of June 1 to August 10$^{th}$ in 2021 compared to 8 in 2020, but Transient killer whales were sighted on 13 days and humpbacks on 8 days. The lack of sightings in June 2021 mirrored June 2020 and 2019. Despite the extended observations in November, SRKW detection days around Lime Kiln were again considered comparatively low, similar to detection days in both 2020 and 2019. A 2-week period in the middle of September in which all three pods were regularly sighted elevated the overall pod transit count slightly above that seen in 2020 and 2019. Use of the area clearly varies temporally by year and by month, presumably linked to the availability and abundance of salmon.

In addition to the 20 visual observations made by observers at or near to Lime Kiln State Park, Jeanne Hyde 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. Based on this supplementary information, J pod was detected using PAM on a further 7 separate days from June 1 to November 30 (2 days in September, 2 days in October and 3 days in November) and one additional day by other observers and overall for the 2021 ECHO Program slowdown period (July 1 to November 30) there were a minimum of 28 SRKW 'whale days' in Haro Strait (of which 27 were based on data collected at or near to Lime Kiln). Supplemental information provided here are preliminary as data from all data sources, including analysis of PAM data by SMRU Consulting, as well as data from BC Cetacean Sightings Networks and OrcaMaster are not yet fully compiled.

## REFERENCES

SMRU Consulting (2017). SRKW sightings at Lime Kiln State Park in summer 2016 and 2017. Report by D. Tollit and J. Wood for VFPA ECHO program, October 2017, 7 pages.

SMRU Consulting (2018). SRKW sightings at Lime Kiln State Park in summer 2018. Report by D. Tollit and J. Wood for VFPA ECHO program, November 2018, 6 pages.

SMRU Consulting (2019). SRKW sightings at Lime Kiln State Park in summer 2019. Report by D. Tollit and J. Wood for VFPA ECHO program, March 2020, 6 pages.

SMRU Consulting (2020). SRKW sightings at Lime Kiln State Park in summer 2020. Report by D. Tollit and J. Wood for VFPA ECHO program, Jan 2021, 6 pages.

**Appendix C.2.**

Boundary Pass 2021 – Marine mammal observations

# Boundary Pass 2021 Land-based Cetacean Observations

## ECHO Program 2021 Slowdown Evaluation

Submitted to:
Vancouver Fraser Port Authority, ECHO Program

Authors:
Azadeh Gheibi, Kaitlin Baril, Lucy Quayle and Ruth Joy

Final Version
January 7, 2022

Suggested citation:

A, Gheibi., K. Baril, L. Quayle and R. Joy. 2021. *Boundary Pass 2021 Land-based Cetacean Observations*. Technical report prepared by the School of Environmental Science, Simon Fraser University for the Vancouver Fraser Port Authority.

Acknowledgments:

We are grateful for the collaboration and sighting records of the Saturna Sighting Network including Susie Washington-Smyth, Maureen Welton, Martin Wale, Marlene Cummings, Michel Chiasson, Patricia de Joseph, Mairead Boland, Dave Paton, Katie Dentry and others. We are grateful to the Saturna Island Marine Research and Education Society (SIMRES) for their logistic support including access to their head office, loan of field equipment, field logistics and an enormous amount of kindness and support. We thank Parks Canada for providing information on the surrounding area, support and access to the park. We thank Bob Bruce, Scott, Angela and Sarah for providing very comfortable accommodations over the summer. Special thanks to Chris and Caroline, Yane Valdez and family for their enthusiasm and friendship throughout the season.

We acknowledge Jeanne Hyde for her identification and acoustic expertise. We appreciate the careful editorial help from Melanie Knight and Krista Trounce in the preparation of this report. We gratefully acknowledge the financial contributions from the Vancouver Fraser Port Authority led Enhancing Cetacean Habitat and Observation (ECHO) Program towards a MITACS Accelerate grant for SFU graduate student Azadeh Gheibi, and to the financial support of SIMRES through a second MITACS Accelerate grant to support SFU graduate student Kaitlin Baril. These Accelerate scholarship grants provide research support for Azadeh and Kaitlin in the Master of Science program in SFUs School of Environmental Science.

# Contents

# Figures



# Tables

# 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 Southern resident and Transient (Bigg's) ecotypes of killer whales (*Orcinus orca*), humpback whales (*Megaptera novaeangliae*), and harbour porpoises (*Phocoena phocoena*). As little is known about how different 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).

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 (TKW) 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 to the whales.

Beginning in 2017, the Enhancing Cetacean Habitat and Observation (ECHO) Program has coordinated a seasonal large vessel slowdown in Haro Strait and, since 2019, the slowdown also included Boundary Pass. 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. Since 2019, the slowdown has begun once SRKWs are first observed in the area for the season, historically between June and July. Similar to 2019 and 2020 studies, trusted marine mammal observers began monitoring for whale presence in Haro Strait and Boundary Pass on June 1, 2021 in Boundary Pass and Haro Strait. On July 1, 2021, SRKWs were detected and confirmed in Haro Strait triggering the start of the ECHO Program voluntary vessel slowdown in both Haro Strait and Boundary Pass. SRKWs were observed multiple times in the slowdown area throughout the season and throughout the month of October. For this reason, the slowdown was extended to its maximum duration of November 30, 2021 – a total of 153 consecutive days (five months) of the slowdown.

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 August from East Point on Saturna Island. A primary observer was stationed at a viewing platform that overlooked Boundary Pass from 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 infrared cameras, the presence of an observer allows accurate and detailed behavioural information to be collected. Species of interest include killer whales (both Southern Resident and transient ecotypes) and humpback whales.

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 SRKW. Collaborators include the Saturna Island Marine Research & Education Society (SIMRES) and the British Columbia Cetacean Sighting Network (BCCSN).

# 2. Methods

## 2.1. Study Area

This study was based at East Point Regional Park on the eastern side of Saturna Island, overlooking the northern section of Boundary Pass and the Strait of Georgia. The primary observer, Azadeh Gheibi, conducted visual surveys from East Point Regional Park (48.782985 N, 123.045580 W) (Figure 1a and 1b, Site 1) with systematic effort between 9:00 am and 4:00 pm, reported herein as on-effort hours of viewing. Opportunistic observations from the Saturna Sighting Network (SSN), a division of the local citizen scientist group, the Southern Gulf Islands Sighting Network, are also included in this report though they had unreported (unsystematic) levels of ‘effort’. 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 used by the SSN 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)

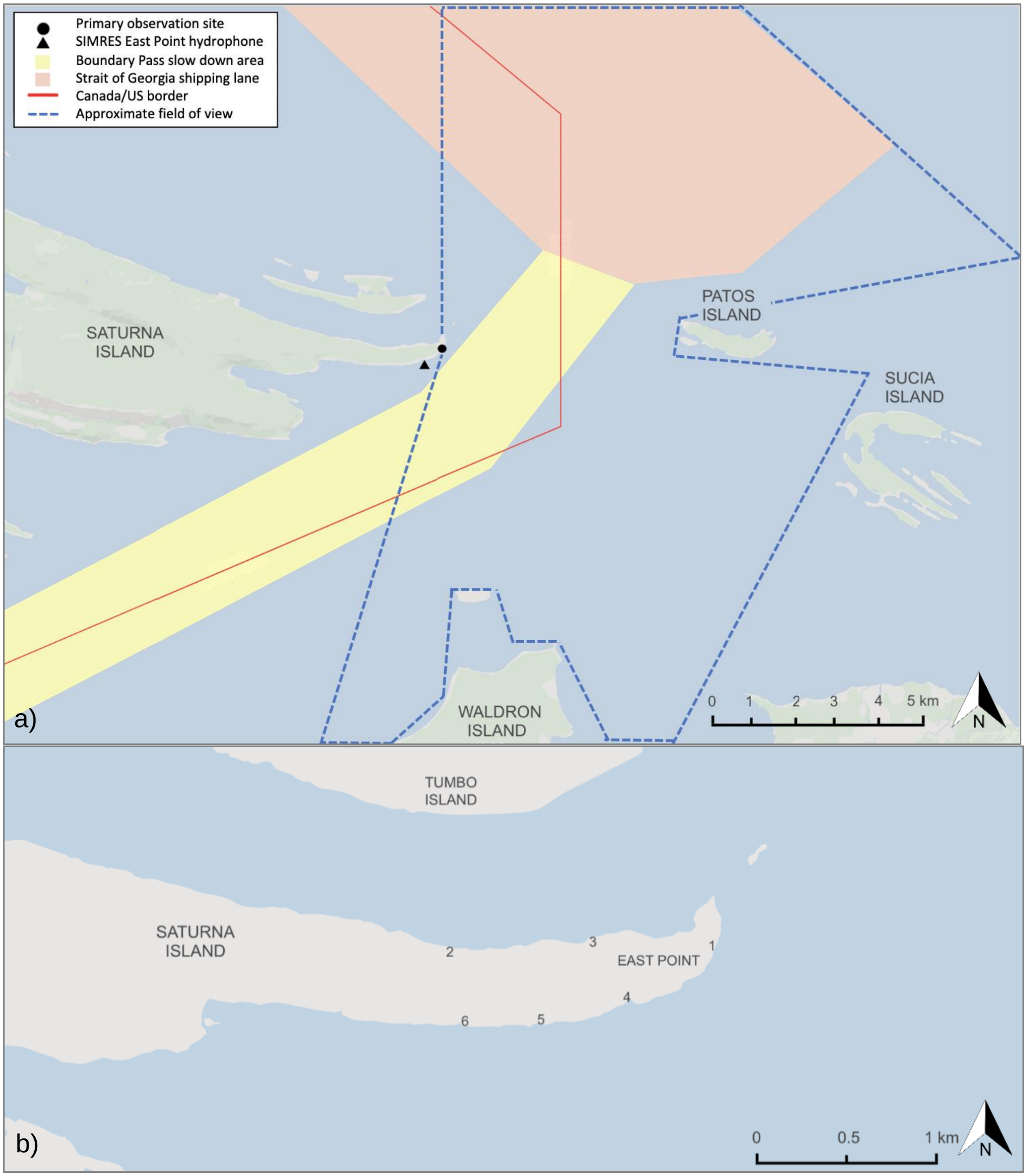



Figure 1. A map of the land-based study area on Saturna Island and Boundary Pass including the location of the shipping lanes, and the Canadian-American international border. Panel a) shows the primary observation site (where the primary observer conducted her marine mammal surveys), SIMRES hydrophone location, shipping lanes and approximate field of view from East Point, Saturna Island. Panel b) shows a subset of Panel a) and includes the 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 1 to August 30, 2021, 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 4:00 pm PT, following the same methods Le Baron et al. (2019) and Quayle and Joy (2021) which follow standardized 'Vantage Point' marine mammal survey methodology (e.g., Lusseau et al. (2009) Di Clemente et al. (2018)). On occasions when reports of incoming whales were received, cetacean observations were recorded outside of the normal survey hours, and this information was noted in our datasheets. Equipment to facilitate visual scans included binoculars (Zeiss 10 x 42), and a DSLR (Sony α7R IV) camera with a telephoto lens (Sony 200-600 mm). A laser range finder (Newcon LRM 3500M-35BT) was used to visually estimating distances from the vantage point, and to note when whales were sighted in the shipping lane.

Although visual scans were performed every 15 minutes across seven hours of on-effort observation hours, 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.

Other methods for improving whale detection included communication with local 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 from the SSN included sightings between 8:30 am to 11:30 pm. In most cases, the SSN reported their observations in the SSN Discord 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 of a snapshot of a sighting event rather than recording the duration and movement of the animal in the region as was collected by the primary observer. For example, only a single time stamp and location was recorded for the species sighting rather than including event duration, travel path, and usage of shipping lane or vessel presence.

When possible, the first detection of a whale (or group) was reported to the BC Cetacean Sightings Network (BCCSN) Whale Report mobile application by the primary observer in real-time. 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 SSN sightings were submitted to the BCCSN by the end of September 2021.

When a target species was visually confirmed, all of the following information was recorded by the primary observer. A subset of the same information was collected by SSN observers, and these fields have been denoted with a '*' below. All observation data collected between June 1, 2021, and September 30, 2021 has been provided in Appendix A.

- Sighting date
- The observer's identity group (primary as 'AG', or Saturna Sighting Network as 'SSN')
- The start and end time of observation event
- Species and ecotype*
- Number of individuals*
- Identified individuals including pods/matrilines where applicable
- Direction of travel *
- Estimated distance from survey position
- Presence within the shipping lane (Boundary Pass or Strait of Georgia – see Figure 1a for boundaries)
- Vessels present (within 1000 m and estimated distance to whale)
- Behaviour (i.e., resting, traveling, foraging, socializing) *
- 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).

The ecotype of killer whale 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 (Ford 2014). Knowledge of recent sightings from local naturalists and researchers within the general area of the Salish Sea also helped to determine ecotype and individuals. Humpback whales were identified by the markings on the underside of the fluke or by the dorsal fin (Happywhale 2020). Wherever possible, sightings of adults were distinguished from those of calves/juveniles. Photographs and videos were taken using the Sony camera during each event 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 (Figure 2c).

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*: Slow, directionless 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 the individual or group traveled was recorded, the general zone of movement including Boundary pass, Strait of Georgia 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. These data are included in Appendix B.


Figure 2. (a) Southern Resident killer whale with ‘open’ saddle patch behind dorsal fin. (b) Transient killer whales with nicks and scratches on dorsal fin and saddle patch. (c) Photo identification of Humpback whale by the underside of the fluke (Identified individual: Cassiopeia) (d) Humpback whale with large body and prominent ‘humpback’ dorsal fin (Mom and calf). Photo Credit: a) Lucy Quayle, b-c-d) Azadeh Gheibi.

# 3. Results

## 3.1. Number of Survey Days and Observation Events

Between June 1 and August 30, 2021, 83 systematic survey days were conducted by the primary observer. This effort included 75 full days (more than six hours) and eight partial days (less than six hours) (Table 1). This constituted over 588 hours of observation effort across the 83 observation days. During this period, whales were observed on 38 of the total 83 survey days (Figure 3) with 54 unique whale events recorded. During the survey period, seven days were non-survey days due to vacation or personal days off. Observations were collected from the SSN between June 1 and September 30 and have been included in Table 1. Combining primary observer observations with SSN observations, whales were detected on 66 of the 122 calendar days between June and September 2021 with a total of 104 unique events, it should be noted that 12 days of 66 whale days happened in September which primary observer was off Island. The SSN contributed 81 days of opportunistic effort that resulted in additional sightings of all three species of cetaceans that were the focus of this report. To avoid recording duplicate whale events, the time, direction, location, number and species of each SSN observation was compared with the primary observer events. Duplicate events were discarded, leaving only unique SSN events to be presented in this report.

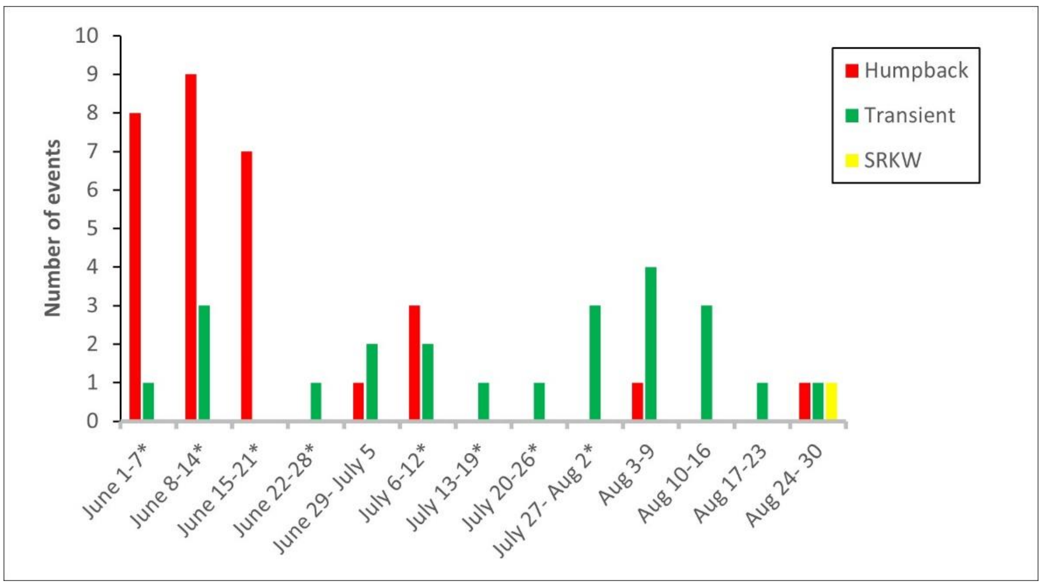



Figure 3. Number of large marine mammal events observed by the primary observer from June 1 to August 30, 2021, broken down by week per species. Weeks with less than seven days of observations are indicated with a '*'. Note: SSN observations are not included in this figure.

Humpback whales were observed most frequently in June (Figure 3) and less frequently for all other months.

TKWs were observed every month throughout the study period, with occupancy in Boundary Pass greatest in July and August (Figure 3).

The primary observer detected one SRKW event in Boundary Pass during the study period. The event occurred on August 30 when SSN observers first detected SRKW, and the primary observer subsequently observed four SRKW in Boundary Pass on the same day. The SRKW were more than 1400 m from the primary observer, and no photos were of sufficient quality to permit individual identification. However, observers from the SSN identified the four individuals as the L54s and L88.

SRKW were not detected in June or July by the primary or the SSN observers. SSN observers had four additional SRKW days in September after the primary observer's systematic effort had finished. SRKW observed by the SSN include members of J pod, L pod and the possibility of some members of the K pod being present for an event on September 9th. Of the SRKW events recorded by the SSN, group size ranged from four individuals to approximately 60 individuals present for one event.

As shown in Table 1, sightings collected by SSN added to the total amount of whale days in Boundary Pass. With the observations from the SSN, there were additional whale days and events recorded for each species throughout the season. Although the SSN whale data collection was opportunistic and done on a volunteer basis, the data remains valuable and beneficial as it contributed additional whale events that were unseen by primary observers. This data helps give a more complete report on whale activity in Boundary Pass. Data collected by the primary observer was systematic and comparable to data collected in previous years (2019 by Nicole le Baron and 2020 by Lucy Quayle).

Table 1. Monthly totals of survey days (and number of observation events) of cetacean presence from June 1 to September 30, 2021. A 'whale day' is a day when at least one whale was sighted in the survey region. A whale 'event' starts by detecting whale(s) in the area and ends when whale(s) exit the survey area or go out of sight due to distance or environmental component.

| | | 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 | | 26 | 27 | 30 | - | - | 83 |
| Number of survey days by primary + SSN opportunistic sighting days | | 30 | 31 | 31 | 30 | 31 | 122 |
| SRKW | Number of whale days by primary observer (Number of events observed by primary) | 0 (0) | 0 (0) | 1 (1) | - | - | 1 (1) |
| | Number of whale days by primary + SSN (Number of events observed by primary + SSN) | 0 (0) | 0 (0) | 1 (1) | 4 (4) | | 5 (5) |
| TKW | Number of whale days by primary observer (Number of events observed by primary) | 5 (5) | 9 (9) | 8 (9) | - | - | 22 (23) |
| | Number of whale days by primary + SSN (Number of events observed by primary + SSN) | 9 (11) | 12 (16) | 11 (13) | 5 (7) | | 37 (47) |
| Humpback | Number of whale days by primary observer (Number of events observed by primary) | 16 (25) | 2 (3) | 2 (2) | - | - | 20 (30) |
| | Number of whale days by primary + SSN (Number of events observed by primary + SSN) | 19 (35) | 6 (8) | 4 (5) | 4 (4) | | 33 (52) |
| All species | Number of whale days by primary observer (Number of events observed by primary) | 17 (30) | 11 (12) | 10 (12) | - | - | 38 (54) |
| | Number of whale days by primary + SSN (Number of events observed by primary + SSN) | 23 (46) | 16 (24) | 15 (19) | 14 (15) | | 68 (104) |

Note: Data collected by primary observer (Azadeh Gheibi) and sightings collected by Saturna Sighting Network (SSN). 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.

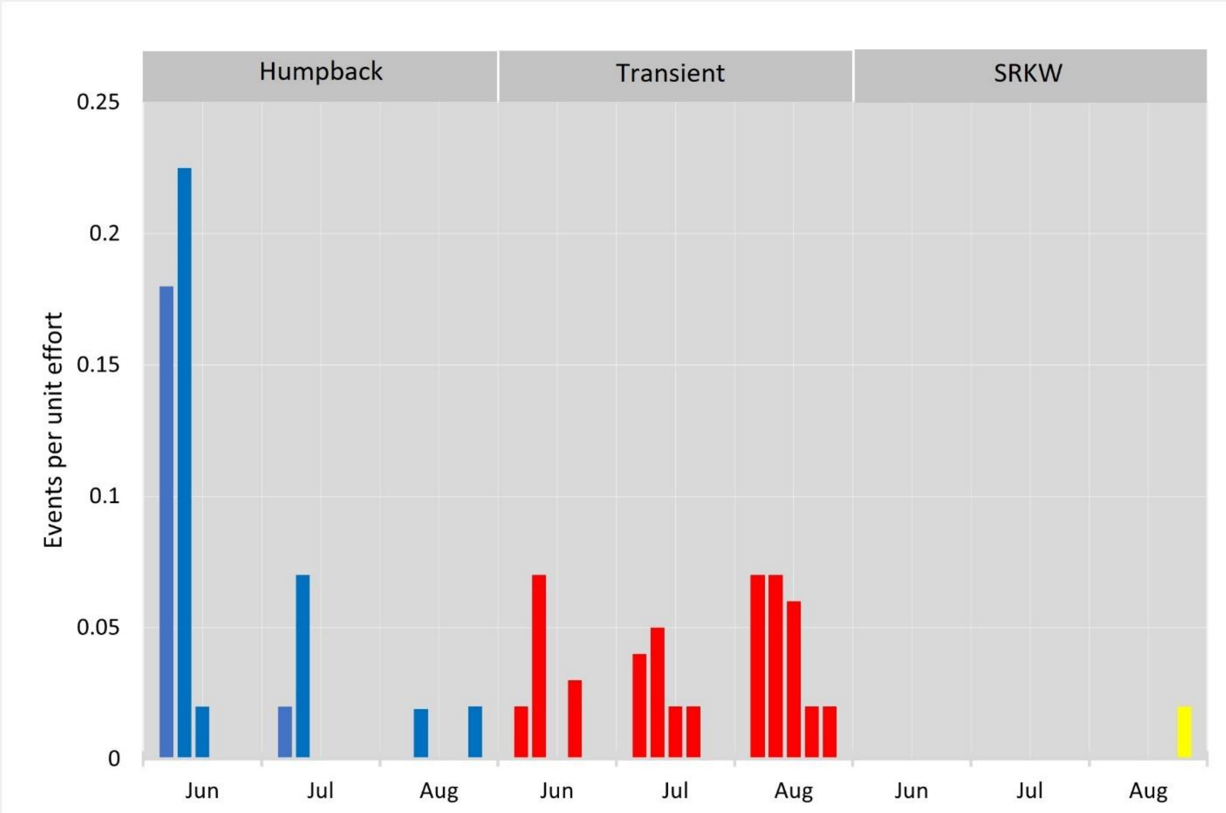



Figure 4. Number of large marine mammal events per species scaled by number of survey hours conducted per week (i.e., whale sightings per unit effort). Data cover the time period from June 1 to August 30, 2021, for observation effort made by the primary observer at Boundary Pass, Saturna Island.

Whale sightings per unit effort of the primary observer is depicted in Figure 4. In this figure, the tallest bar indicates that in the second week of June, the primary observer would expect to see one humpback whale for every 4.5 hours of sampling effort (0.23 events per unit effort). Effort-corrected whale numbers show humpback whales were the most commonly sighted whale per unit of survey effort in June and July, and TKWs were the most common whale sighted per unit effort in August. TKW sightings were consistently seen in Boundary Pass across the survey period starting in mid-June.

The primary observer effort was relatively stable across the months June to August (Figure 5).

The locations of all cetaceans sighted from East Point by the primary observer across the monitoring period are shown in **Error! Reference source not found.**.

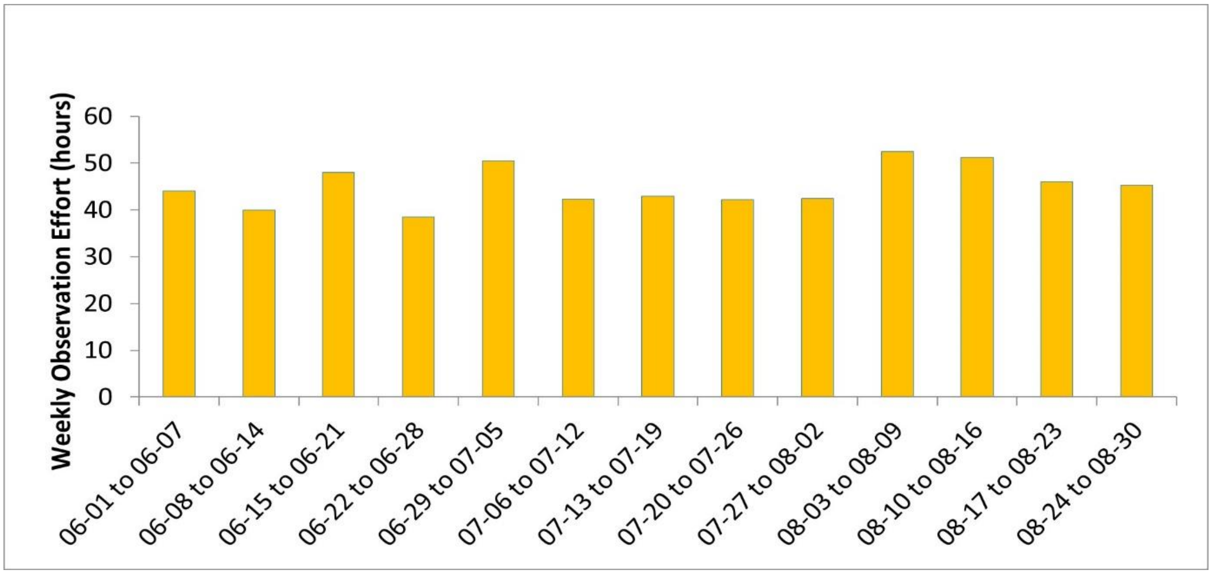



Figure 5. Weekly sum of survey effort by the primary observer from East Point Park, Saturna Island between June 1 and August 30, 2021.

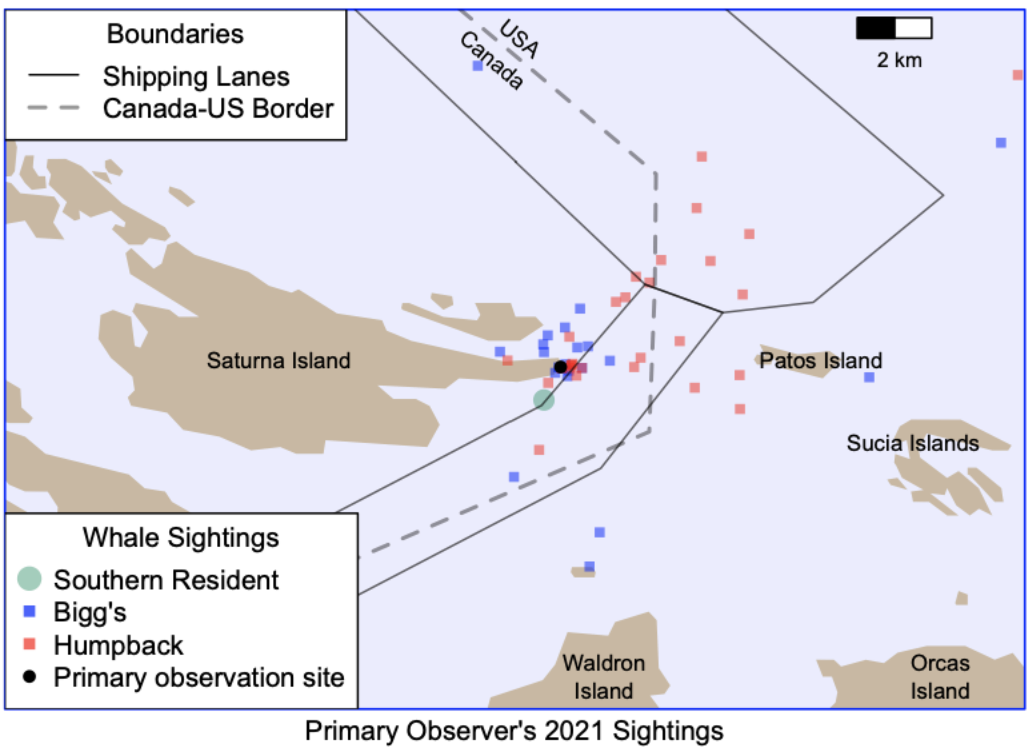



Figure 6. All cetaceans sighted from East Point by the primary observer between June 1 and August 30, 2021. Sightings are shown relative to the international shipping lanes and the Canada-US Border. Note that it is more difficult to detect whales when they are farther way. In this map, sightings are shown without a correction factor to account for loss of detection efficiency with distance.

Though not a part of this project, other marine mammal species of note were observed during the study period include harbour porpoise (*Phocoena phocoena*) and harbour seals (*Phoca vituline*). A small group of harbour porpoise were seen most days throughout the season, traveling in singles or groups of two within 300 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, multiple mother calf pairs were observed and were still present in the area at the end of the survey period on August 30. Harbour seals were also present throughout the season as they have a haul out on nearby Boiling Reef. More than 20 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. Boiling Reef was a hotspot hunting area for TKWs and several hunting and foraging behaviours were observed in that area during the survey period.

## 3.2. Behaviour and Location

Each species utilized unique spatial distributions in Boundary Pass and displayed varying types of behaviour over the study period. Of the total 54 events observed by the primary observer between June 1 and August 30, over 60% took place within the Boundary Pass shipping lane and 20% transited through the Strait of Georgia shipping lane (Table 2).

For the one visually detected SRKW event that travelled past East Point, all four individual whales were observed together in the Boundary Pass and inside the shipping lane. Due to the distance from the observer, the behaviour was uncertain, but most likely a mixture of travelling and socialising.

Most travel for TKWs involved hugging the shoreline, sometimes even touching the shore. Over half of the TKW events (69%) 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). TKWs were recorded in the commercial shipping lanes for 16 of the 23 (69.5 %) whale events. Foraging behaviour was observed in four of 23 (17.4 %) observation events for TKWs and at least two successful harbour seal captures were seen. Socialising behaviour was more common with seven (30.4 %) events including spy hopping, pectoral fin and tail slapping. Event duration for TKWs ranged from four minutes to over 4.5 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. Members of several TKWs were identified throughout the season.

In total, over half of the humpback whale events (16 of 30) involved movement within Boundary Pass and the Strait of Georgia shipping lane (Table 2). Humpback whale events typically had either one to two individuals, with one event occurring where an adult humpback joined a mother and calf pair in Boundary Pass. All events included travel behaviour, with general patterns of three to eight breaths ~ 10 seconds apart followed by a long deep dive. Socialising behaviour (breaching, tail lobbing and pectoral fin slaps) were observed in nine of 30 events. The maximum number of breaches in one event was over 10 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 2-hour event.

Table 2. Movement zones detected during marine mammal observation events 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 | 1 | - | - | 1 |
| TKW | 16 | 5 | 2 | 23 |
| Humpback | 16 | 5 | 9 | 30 |
| **Total** | **33** | **10** | **11** | **54** |

*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.

## 3.3. Vessel Presence During Marine Mammal Events

Vessels were present during 39 of the 54 (72%) marine mammal observations events recorded by primary observer (Table 3). Sixty-five percent (35 of 54) of marine mammal events included small vessels within 1000 m of a whale and 22% (12 of 54) of events had large vessels present. Both large and small vessels were present for 14.8% (8 of 54) of observed marine mammal events. A detailed breakdown of vessel types for both small and large vessels can be found in Appendix B.

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) | | |
| SRKW | 0 (0) | 0 (0) | 0 | 1 (0%) |
| TKW | 103 (18) | 3 (3) | 18 | 23 (74%) |
| Humpback whale | 44 (17) | 13 (9) | 21 | 30 (70%) |
| **All species** | **147 (35)** | **16 (12)** | **39** | **54 (72%)** |

*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 2021 for SRKW in Boundary Pass began on June 1 by the primary observer. On July 1, 2021, SRKWs were detected and confirmed off Lime Kiln State Park in Haro Strait, 30 km away. This SRKW sighting triggered the start of the slowdown in both Haro Strait and Boundary Pass. SRKW were not observed in Boundary Pass on this day by the primary observer nor by the Saturna Sighting Network. No SRKW were observed in Boundary Pass until the last day of dedicated survey effort on August 30, 2021. Five whale days for SRKW (five whale events) were reported by the SSN for Boundary Pass in September 2021. Citizen scientists across the Salish Sea region have reported SRKW on multiple occasions in the region throughout September, October, and November with multiple sightings of SRKW during this fall period in Boundary Pass.

Recent systematic survey effort in summers (between June 1 and August 31) has shown consistently low numbers of SRKW sightings in recent years. Over the past three years of marine mammal studies in Boundary Pass, there were five SRKW whale days in 2019, two in 2020 and one in 2021. It is not understood why this change in summer use of Boundary Pass has occurred, but similar shifts in the spatial and temporal habitat use have been observed in other parts of the historical species range.

Similar to 2020, in 2021 no clear foraging behaviour was observed by SRKW in Boundary Pass. This may in part be because foraging doesn't occur at the surface where it could be observed. Foraging and resting behaviour was reportedly observed in Boundary Pass during summer 2019 (Le Baron et al. 2019). For the one sighting of SRKW in August 2021, the SRKW transited quickly through Boundary Pass while exhibiting some social behaviour (breaching and tail slaps). The five September sightings similarly reported SRKW travelling through the area, with one occasion reporting social behaviours, but no foraging.

In 2021, 23 TKW events were observed on 22 separate survey days by the primary observer, and a further 10 days by SSN observers between June and August, and an additional five days by SSN in September. These numbers are comparable to the 24 whale days reported by the primary observer in 2020, and the 28 whale days in 2019. However, over half of the sightings in 2020 occurred in the month of September, and the busiest months in 2019 was June, and July in 2021. This indicates that Boundary Pass is an area that TKWs are consistently using, but that there is within season, and between year variability. In 2021, TKWs were most often engaged in hunting behaviour in July and August, a period that overlaps with harbour seal pupping and hauling out at Boiling Reef, off East Point. Each family group likely uses this area differently, perhaps depending on prey availability, movement patterns of other family groups and even presence or absence of SRKW.

Humpback whales had the highest number of whale days (and whales per unit effort) out of all cetaceans observed in Boundary Pass. Humpbacks were detected on 20 days by the primary observer and a further 14 by SSN observers. Humpback whale detections were particularly concentrated in June 2021 where whales were seen on 16 of the 26 survey days. Furthermore, 25 of a total 30 humpback events (83%) occurred in June. One unidentified mother humpback was consistently present with her newborn calf throughout the month including spending a significant amount of time in the shipping lanes. The 2021 high prevalence of events in June is consistent with 2020 observations in which the primary observer, similarly, reported a high number of humpback whale events in June (20 whale days, 64 events), many of which were found to be in the shipping lanes (Quayle and Joy 2021). Humpback numbers in September were lower in 2020 (three whale days, three events) compared to four whale days, four events, reported by the SNN in September 2021.

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 (2021), 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.

Limitations of this study included weather conditions that contributed to poor visibility, such as dense fog, forest fire smoke, strong winds, rough sea state, heavy rain and most importantly, the extremely high temperatures in July and August. Increased distance of marine mammals from shore decreased detectability confidence (i.e., the detection function; see Buckland et al. 2004). We made no effort to estimate this function. However, we acknowledge that this results in an under-estimation of the numbers of cetaceans using Boundary Pass from unseen surfacing of whales at distance. Observations in the far channel, east of the shipping lanes were usually detected because ecotourism vessels were present.

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 build on the previous two years of effort of data collection in this area through land-based surveys from June 1 to August 30, 2021. 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 1 and August 30 2021, whales were observed on 38 of the total 83 survey days and during this time, 54 unique whale events were recorded.
- Marine mammal species utilized unique spatial distributions in Boundary Pass and displayed varying types of behaviour over the study period. Over 60% of all whale events viewed by the primary observer included travel within the shipping lanes.
- One observation of SRKW in Boundary Pass occurred during the primary observation period, June 1 to August 30, 2021. Four additional SRKW whale days were observed by SSN in September. Citizen scientists across the Salish Sea region have reported SRKW on multiple occasions beyond the end of the monitoring period of this study period. Throughout October and November, there have been multiple sightings of SRKW in Boundary Pass.
- Of the whale species observed, the greatest number of events were recorded for humpback whales, most frequently detected in June 2021, displaying travelling and socializing behaviour, followed by TKWs 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 70% of the events viewed by the primary observer.
- 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, 2020 and 2021 are consistent or are changing year to year. The COVID-19 pandemic and associated vessel restrictions may have influenced ship traffic movement within the Salish Sea and therefore may have impacted cetacean species movements due to a change or reduction in ecotourism traffic, recreational and commercial vessels.

## Literature Cited


Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. and Thomas, L., 2004. *Advanced distance sampling* (Vol. 2). Oxford: Oxford University Press.

[CWR] Center for Whale Research. 2020. *Recent on the water encounters* (webpage). https://www.whaleresearch.com/encounters.

[DFO] Fisheries and Oceans Canada. 2018. Amended Recovery Strategy for the Northern and Southern Resident Killer Whales (*Orcinus orca*) in Canada. Species at Risk Act Recovery Strategy Series, Fisheries and Oceans Canada, Ottawa, x + 94 pp.

Di Clemente, J., F. Christiansen, E. Pirotta, D. Steckler, M. Wahlberg, and H. Pearson. 2018. Effects of whale watching on the activity budgets of humpback whales, Megaptera novaeangliae (Borowski, 1781), on a feeding ground. *Aquatic Conservation: Marine and Freshwater Ecosystems* DOI 10.1002/aqc.2909.

Hauser, D.D.W., M.G. Logsdon, E.E. Holmes, G.R. VanBlaricom, and R.W. Osborne. 2007. Summer distribution patterns of southern resident killer whales *Orcinus orca*: Core areas and spatial segregation of social groups. *Marine Ecology Progress Series* 351: 301-310. https://doi.org/10.3354/meps07117.

Le Baron, N., L. McWhinnie, and H. Frouin-Mouy. 2019. *Boundary Pass 2019 Land-based Cetacean Observations: ECHO 2019 Slowdown Evaluation*. Document 01906, Version 3.0. Technical report by JASCO Applied Sciences and University of Victoria for Vancouver Fraser Port Authority.

Lusseau, D., D.E. Bain, R. Williams, and J.C. Smith. 2009. Vessel traffic disrupts the foraging behavior of southern resident killer whales *Orcinus orca*. *Endangered Species Research* 6(3): 211-221. https://doi.org/10.3354/esr00154.

Happywhale (2021). Citizen science photoidentification. https://happywhale.com/browse

Nordstrom, C. and C. Birdsall. 2018. Humpback whales are returning to the salish sea. *In Ocean Watch: B.C. Coast Edition*. Coastal Ocean Research Institute. pp 68-75. http://oceanwatch.ca/bccoast/wp-content/uploads/sites/4/2018/10/OceanWatch-BC-Coast-humpback-whale.pdf.

Olson, J. 2018. Final Program Report: SRKW Sighting Compilation 14th Edition. Report by The Whale Museum for the Southern Resident Killer Whale Sighting Compilation 1948-2017 Project. Contract number RA133F-12-CQ-0057.

Olson, J.K., J. Wood, R.W. Osborne, L. Barrett-Lennard, and S. Larson. 2018. Sightings of southern resident killer whales in the Salish Sea 1976–2014: the importance of a long-term opportunistic dataset. *Endangered Species Research* 37: 105-118. https://doi.org/10.3354/esr00918

Quayle, L., and R. Joy. 2021. Boundary Pass 2021 Land-based Cetacean Observations. Technical report prepared by the School of Environmental Science, Simon Fraser University for the Vancouver Fraser Port Authority

## Appendix A. Marine Mammal Observation Event Data

Note: Observations were collected by primary observer Azadeh Gheibi, between June 1 and August 30 2021, indicated by "AG" in Group column. Saturna Sighting Network observations were collected between June 1 and September 30 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 AG 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 | No. of individuals | Travel direction | Closest est. distance (m) | Zone | Behaviour | Vessel present | Notes | Site |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 06-01-21 | AG | 1 | 11:10 | 16:07 | Humpback | 1 | N | 2500 | BP-SoG | Traveling | Yes | | EP 1 |
| 06-02-21 | AG | 1 | 9:15 | 10:45 | Humpback | 1 | NE/N | 1500 | BP-SoG | Traveling | Yes | | EP 1 |
| 06-02-21 | AG | 2 | 12:18 | 12:36 | Transient Killer Whale | 6 | S | 100 | BP | Traveling | No | | EP 1 |
| 06-02-21 | SSN | 3 | 21:40 | ND | Transient Killer Whale | 5 | E | ND | Near zone | Traveling | ND | | TC3 |
| 06-03-21 | AG | 1 | 9:40 | 10:52 | Humpback | 1 | S | 100 | Near zone | Traveling | Yes | | EP 1 |
| 06-03-21 | SSN | 2 | 21:13 | ND | Humpback | 1 | N | ND | ND | Traveling | ND | | Cliff side 4 |
| 06-04-21 | AG | 1 | 9:10 | 10:00 | Humpback | 1 | NE | 300 | BP | Traveling | No | | EP 1 |
| 06-04-21 | AG | 2 | 10:12 | 11:20 | Humpback | 1 | NE | 2500 | BP | Traveling | Yes | | EP 1 |
| 06-04-21 | AG | 3 | 14:02 | 15:48 | Humpback | 1 | SW | 150 | Near zone | Traveling | Yes | | EP 1 |
| 06-04-21 | SSN | 4 | 18:41 | ND | Humpback | 2 | SW | ND | ND | Traveling | ND | | Cliff side 4 |
| 06-05-21 | AG | 1 | 14:37 | 14:46 | Humpback | 2 | NE | 600 | BP | Travel-Social | No | | EP 1 |

| Date | Group | Daily event no. | Start time | End time | Species/ Population | No. of individuals | Travel direction | Closest est. distance (m) | Zone | Behaviour | Vessel present | Notes | Site |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 06-06-21 | AG | | No survey conducted | | | | | | | | | No survey conducted | |
| 06-07-21 | AG | 1 | 13:17 | 14:15 | Humpback | 1 | E | 5500 | SoG | Travel-Social | Yes | | EP 1 |
| 06-07-21 | SSN | 2 | 18:42 | ND | Humpback | 2 | SE | ND | ND | | | | EP |
| 06-07-21 | SSN | 3 | 20:57 | ND | Humpback | 1 | E | ND | ND | | | | EP |
| 06-08-21 | AG | 1 | 9:14 | 10:00 | Humpback | 2 | NE | 100 | BP | Traveling | Yes | | EP 1 |
| 06-08-21 | AG | 2 | 11:02 | 11:31 | Humpback | 1 | N | 800 | BP | Travel-Social | Yes | | EP 1 |
| 06-08-21 | AG | 3 | 13:29 | 15:20 | Transient Killer Whale | 5 | N-NE | 4000 | BP-SoG | Travel-Social-Forage | Yes | | EP 1 |
| 06-09-21 | AG | | No event | | | | | | | | | | |
| 06-09-21 | SSN | 1 | 21:39 | ND | Transient Killer Whale | 5 | N | ND | ND | Traveling | ND | | Cliff side 5 |
| 06-10-21 | AG | 1 | 10:51 | 11:59 | Humpback | 2 | N | 1500 | BP | Traveling | Yes | | EP 1 |
| 06-10-21 | AG | 2 | 12:14 | 12:56 | Humpback | 2 | Various | 6000 | SoG | Travel-Social | Yes | | EP 1 |
| 06-10-21 | AG | 3 | 13:33 | 14:26 | Humpback | 2 | Various | 2000 | BP | Travel-Social | No | | EP 1 |
| 06-10-21 | AG | 4 | 14:52 | 15:20 | Humpback | 2 | E | 8000 | SoG | Travel-Social | Yes | | EP 1 |
| 06-10-21 | AG | 5 | 16:17 | 17:00 | Transient Killer Whale | 4 | S - N | 9000 | BP-SoG | Traveling | Yes | | EP 1 |

| Date | Group | Daily event no. | Start time | End time | Species/ Population | No. of individuals | Travel direction | Closest est. distance (m) | Zone | Behaviour | Vessel present | Notes | Site |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 06-11-21 | AG | 1 | 12:05 | 13:35 | Humpback | 2 | N | 5000 | SoG | Travel-Social | Yes | | EP 1 |
| 06-12-21 | AG | 1 | 8:45 | 9:27 | Humpback | 1 | E | 200 | Near zone | Traveling | No | | EP 1 |
| 06-13-21 | AG | | No survey conducted | | | | | | | | | No survey conducted | |
| 06-13-21 | SSN | 1 | 13:04 | ND | Transient Killer Whale | 4 | W | ND | ND | Traveling | ND | | Cliff side |
| 06-13-21 | SSN | 2 | 16:46 | ND | Transient Killer Whale | 14 | Various | ND | ND | Travel-Forage | ND | | |
| 06-14-21 | AG | 1 | 12:03 | 12:30 | Transient Killer Whale | 1 | N-W | 800 | BP | Travel-Social | Yes | | EP 1 |
| 06-14-21 | AG | 2 | 12:23 | 13:27 | Humpback | 1 | N | 1000 | BP-SoG | Traveling | Yes | | EP 1 |
| 06-14-21 | SSN | 3 | 17:59 | ND | Humpback | 1 | E | | | | | | Cliff side 6 |
| 06-15-21 | AG | 1 | 9:25 | 9:40 | Humpback | 1 | NW | 8000 | SoG | Travel-Social | No | | EP 1 |
| 06-15-21 | AG | 2 | 11:51 | 12:50 | Humpback | 1 | SW | 3000 | Far zone | Traveling | Yes | | EP 1 |
| 06-15-21 | AG | 3 | 12:50 | 13:43 | Humpback | 1 | E | 100 | BP | Traveling | Yes | | EP 1 |
| 06-15-21 | SSN | 4 | 17:11 | ND | Humpback | 1 | Various | ND | ND | Traveling | ND | | TC 3 |
| 06-16-21 | AG | 1 | 14:38 | 15:15 | Humpback | 1 | N | 6000 | SoG | Traveling | No | | EP 1 |
| 06-17-21 | AG | 1 | 10:09 | 10:40 | Humpback | 1 | NW | 4000 | SoG | Travel-Social | Yes | | EP 1 |

| Date | Group | Daily event no. | Start time | End time | Species/ Population | No. of individuals | Travel direction | Closest est. distance (m) | Zone | Behaviour | Vessel present | Notes | Site |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 06-17-21 | AG | 2 | 14:49 | 17:17 | Humpback | 1 | N | 3500 | SoG | Traveling | Yes | | EP 1 |
| 06-17-21 | SSN | 3 | 20:17 | ND | Transient Killer Whale | 7 | E | ND | ND | Traveling | ND | | Cliff side 5 |
| 06-18-21 | AG | 1 | 9:08 | 9:40 | Humpback | 1 | NE | 5500 | SoG | Traveling | No | | EP 1 |
| 06-18-21 | SSN | 2 | 18:00 | ND | Humpback | 1 | W | ND | ND | Traveling | ND | | TC 3 |
| 06-19-21 | AG | | No event | | | | | | | | | | |
| 06-19-21 | SSN | 1 | 17:59 | ND | Humpback | 1 | N | ND | ND | Travel-Social | ND | | TC 3 |
| 06-20-21 | AG | | No survey conducted | | | | | | | | | No survey conducted | |
| 06-21-21 | AG | | No event | | | | | | | | | | |
| 06-21-21 | SSN | 1 | 23:20 | ND | Humpback | 1 | NE | ND | ND | Traveling | ND | | Cliff side 4 |
| 06-22-21 | AG | 1 | 10:29 | 15:02 | Transient Killer Whale | 2 | SW-N-NE | 2500 | BP | Traveling | Yes | | EP 1 |
| 06-23-21 | AG | | No event | | | | | | | | | | |
| 06-23-21 | SSN | 1 | 16:20 | ND | Humpback | 1 | NW | ND | ND | Traveling | ND | | TC |
| 06-24-21 | AG | | No event | | | | | | | | | | |
| 06-25-21 | AG | | No event | | | | | | | | | | |

| Date | Group | Daily event no. | Start time | End time | Species/ Population | No. of individuals | Travel direction | Closest est. distance (m) | Zone | Behaviour | Vessel present | Notes | Site |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 06-26-21 | AG | | No event | | | | | | | | | | |
| 06-27-21 | AG | | No survey conducted | | | | | | | | | No survey conducted | |
| 06-27-21 | SSN | 1 | 18:55 | ND | Transient Killer Whale | 5 | W | ND | ND | Traveling | ND | | Cliff side 4 |
| 06-28-21 | AG | | No event | | | | | | | | | | |
| 06-29-21 | AG | | No event | | | | | | | | | | |
| 06-30-21 | AG | 1 | 12:43 | 13:32 | Humpback | 1 | S | 2500-3000 | BP | Traveling | Yes | | EP 1 |
| 07-01-21 | AG | | No event | | | | | | | | | | |
| 07-02-21 | AG | | No event | | | | | | | | | | |
| 07-03-21 | AG | | No event | | | | | | | | | | |
| 07-03-21 | SSN | 1 | 18:56 | ND | Transient Killer Whale | 2 | S | ND | ND | Traveling | ND | | TC |
| 07-04-21 | AG | 1 | 16:43 | 17:20 | Transient Killer Whale | 4 | W | 2000 | BP | Travel-Social | Yes | | |
| 07-04-21 | SSN | 2 | 21:03 | ND | Transient Killer Whale | 5 to 8 | E | ND | ND | Traveling | ND | | Cliff side 6 |
| 07-05-21 | AG | 1 | 11:03 | 13:20 | Transient Killer Whale | 9 | W-NW-N | 500 | BP | Travel-Social | Yes | | EP 1 |
| 07-05-21 | SSN | 2 | 19:11 | ND | Transient Killer Whale | 5 to 7 | SW | ND | ND | Traveling | ND | | Cliff side 6 |

| Date | Group | Daily event no. | Start time | End time | Species/ Population | No. of individuals | Travel direction | Closest est. distance (m) | Zone | Behaviour | Vessel present | Notes | Site |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 07-05-21 | SSN | 3 | 21:41 | ND | Humpback | 1 | N | ND | ND | Traveling | ND | | TC |
| 07-06-21 | AG | 1 | 13:00 | 13:35 | Transient Killer Whale | 3 | W-S | 500 | BP | Travel-Social | Yes | | EP 1 |
| 07-06-21 | SSN | 2 | 19:41 | ND | Transient Killer Whale | 4 | E | ND | ND | Traveling | ND | | TC |
| 07-08-21 | AG | | No event | | | | | | | | | | |
| 07-08-21 | AG | 1 | 9:56 | 11:20 | Humpback | 2 | N-E | 500 | BP-SoG | Traveling | Yes | | EP 1 |
| 07-08-21 | AG | 2 | 10:40 | 11:20 | Humpback | 2 | E | 4000 | SoG | Traveling | Yes | | EP 1 |
| 07-09-21 | AG | 1 | 11:45 | 12:23 | Transient Killer Whale | 1 | E | 8000 | SoG | Traveling | Yes | | EP 1 |
| 07-10-21 | AG | 1 | 19:24 | 20:35 | Humpback | 1 | E-N | 200 | BP | Traveling | Yes | | EP 1 |
| 07-10-21 | SSN | 2 | 11:41 | ND | Transient Killer Whale | 4 | SW | ND | ND | Traveling | ND | | Cliff side |
| 07-11-21 | AG | | No survey conducted | | | | | | | | | No survey conducted | |
| 07-12-21 | AG | | No event | | | | | | | | | | |
| 07-13-21 | AG | | No event | | | | | | | | | | |
| 07-14-21 | AG | | No event | | | | | | | | | | |
| 07-14-21 | SSN | 1 | 20:18 | ND | Humpback | 2 | E | ND | ND | Traveling | ND | | Cliff side |

| Date | Group | Daily event no. | Start time | End time | Species/ Population | No. of individuals | Travel direction | Closest est. distance (m) | Zone | Behaviour | Vessel present | Notes | Site |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 07-15-21 | AG | | No event | | | | | | | | | | |
| 07-16-21 | AG | 1 | 11:14 | 11:38 | Transient Killer Whale | 5 | N | <100 | BP | Traveling | No | | EP 1 |
| 07-17-21 | AG | | No event | | | | | | | | | | |
| 07-18-21 | AG | | No event | | | | | | | | | | |
| 07-18-21 | SSN | 1 | 11:53 | ND | Humpback | 1 | E | ND | ND | Travel-Social | ND | | TC 3 |
| 07-18-21 | SSN | 2 | 14:14 | ND | Humpback | 1 | NW | ND | ND | Travel-Social | ND | | TC 3 |
| 07-19-21 | AG | | No survey conducted | | | | | | | | | No survey conducted | |
| 07-20-21 | AG | | No event | | | | | | | | | | |
| 07-21-21 | AG | | No event | | | | | | | | | | |
| 07-21-21 | SSN | 1 | 10:05 | ND | Humpback | 1 | N | ND | ND | Travel-Social | ND | | |
| 07-22-21 | AG | | No event | | | | | | | | | | |
| 07-23-21 | AG | | No event | | | | | | | | | | |
| 07-23-21 | SSN | 1 | 17:23 | ND | Transient Killer Whale | 6 | E | ND | ND | Traveling | ND | | TC 3 |
| 07-24-21 | AG | 1 | 12:59 | 14:37 | Transient Killer Whale | 3 | W-N | 2500 | BP | Travel-Social | Yes | | EP 1 |

| Date | Group | Daily event no. | Start time | End time | Species/ Population | No. of individuals | Travel direction | Closest est. distance (m) | Zone | Behaviour | Vessel present | Notes | Site |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 07-24-21 | SSN | 2 | 19:06 | ND | Transient Killer Whale | 4 | E | ND | ND | Travel-Social | ND | | |
| 07-25-21 | AG | | No survey conducted | | | | | | | | | No survey conducted | |
| 07-26-21 | AG | | No event | | | | | | | | | | |
| 07-27-21 | AG | 1 | 11:40 | 12:10 | Transient Killer Whale | 5 | N | 100 | BP | Traveling | No | | EP 1 |
| 07-28-21 | AG | | No event | | | | | | | | | | |
| 07-29-21 | AG | 1 | 11:05 | 11:34 | Transient Killer Whale | 05-Mar | E | 9000 | SoG | Traveling | Yes | | EP 1 |
| 07-30-21 | AG | | No survey conducted | | | | | | | | | Primary observer not on Island | |
| 07-31-21 | AG | 1 | 16:21 | 16:26 | Transient Killer Whale | 3 | E | 100 | BP | Traveling | Yes | | TC |
| 08-01-21 | AG | | No event | | | | | | | | | | |
| 08-01-21 | SSN | 1 | 11:28 | ND | Transient Killer Whale | 3 | E | ND | ND | Travel-Social | ND | | |
| 08-02-21 | AG | | No event | | | | | | | | | | |
| 08-03-21 | AG | | No event | | | | | | | | | | |
| 08-03-21 | SSN | 1 | 14:08 | ND | Humpback | 1 | S | ND | ND | Traveling | ND | | TC 3 |
| 08-04-21 | AG | | No event | | | | | | | | | | |

| Date | Group | Daily event no. | Start time | End time | Species/ Population | No. of individuals | Travel direction | Closest est. distance (m) | Zone | Behaviour | Vessel present | Notes | Site |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 08-04-21 | SSN | 1 | 20:36 | ND | Transient Killer Whale | 3 | NW | ND | ND | Traveling | ND | | Cliff side 4 |
| 08-05-21 | AG | 1 | 10:01 | 10:36 | Transient Killer Whale | 3 or more | W-E | 500 | TC-BP | Travel-Social-Forage | No | | EP 1 |
| 08-06-21 | AG | | No event | | | | | | | | | | |
| 08-07-21 | AG | 1 | 11:59 | 12:06 | Transient Killer Whale | 5 to 6 | N | 100 | BP | Traveling | Yes | | EP 1 |
| 08-08-21 | AG | | No event | | | | | | | | | | |
| 08-09-21 | AG | 1 | 13:31 | 13:51 | Humpback | 1 | N | 400 | BP | Traveling | No | | EP 1 |
| 08-09-21 | AG | 2 | 13:51 | 16:50 | Transient Killer Whale | 3 | E-W | 300 | BP-TC | FOR | Yes | | EP 1 |
| 08-09-21 | AG | 3 | 16:39 | 17:11 | Transient Killer Whale | 4 | N | 200 | BP | Travel-Forage | No | | EP 1 |
| 08-10-21 | AG | | No event | | | | | | | | | | |
| 08-11-21 | AG | 1 | 14:21 | 15:25 | Transient Killer Whale | 3 | E-S | 600 | BP | Traveling | Yes | | EP 1 |
| 08-12-21 | AG | | No event | | | | | | | | | | |
| 08-13-21 | AG | | No event | | | | | | | | | | |
| 08-14-21 | AG | 1 | 14:09 | 14:38 | Transient Killer Whale | 3 | S | 5000 | BP | Traveling | No | | EP 1 |
| 08-15-21 | AG | | No event | | | | | | | | | | |

| Date | Group | Daily event no. | Start time | End time | Species/ Population | No. of individuals | Travel direction | Closest est. distance (m) | Zone | Behaviour | Vessel present | Notes | Site |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 08-16-21 | AG | 1 | 11:37 | 12:13 | Transient Killer Whale | 3 | S-SW | 200 | BP | Traveling | Yes | | EP 1 |
| 08-17-21 | AG | | No event | | | | | | | | | | |
| 08-18-21 | AG | | No event | | | | | | | | | | |
| 08-19-21 | AG | | No event | | | | | | | | | | |
| 08-20-21 | AG | | No event | | | | | | | | | | |
| 08-21-21 | AG | | No event | | | | | | | | | | |
| 08-22-21 | AG | 1 | 12:11 | 13:05 | Transient Killer Whale | 8 | E-S | 700 | BP | Traveling | Yes | | EP 1 |
| 08-22-21 | SSN | 2 | 19:50 | ND | Transient Killer Whale | 2 | W | ND | ND | Traveling | ND | | Cliff side |
| 08-22-21 | SSN | 3 | 20:00 | ND | Humpback | 1 | N | ND | ND | Traveling | ND | | Cliff side |
| 08-23-21 | AG | | No event | | | | | | | | | | |
| 08-23-21 | SSN | 1 | 19:00 | ND | Transient Killer Whale | 3 | NW | ND | ND | Traveling | ND | | TC 3 |
| 08-24-21 | AG | | No event | | | | | | | | | | |
| 08-25-21 | AG | 1 | 15:35 | 16:22 | Transient Killer Whale | 4 | E | 2000 | BP | Traveling | Yes | | EP 1 |
| 08-26-21 | AG | | No event | | | | | | | | | | |

| Date | Group | Daily event no. | Start time | End time | Species/ Population | No. of individuals | Travel direction | Closest est. distance (m) | Zone | Behaviour | Vessel present | Notes | Site |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 08-26-21 | SSN | 1 | 17:00 | ND | Humpback | 1 | SE | ND | ND | Traveling | ND | | Cliff side |
| 08-27-21 | AG | | No event | | | | | | | | | | |
| 08-28-21 | AG | | No event | | | | | | | | | | |
| 08-29-21 | AG | 1 | 20:37 | 21:50 | Humpback | 2 | N | 200 | BP | Traveling | No | | EP 1 |
| 08-30-21 | AG | 1 | 10:18 | 10:38 | SRKW | 4 | SW | 1400 | BP | Traveling | No | | EP 1 |
| 08-31-21 | AG | | No survey conducted | | | | | | | | | Primary observer not on Island | |
| 09-01-21 | SSN | 1 | 20:00 | ND | SRKW | 15 to 25 | SW | ND | ND | Traveling | ND | | Cliff side 4 |
| 09-05-21 | SSN | 1 | 15:20 | ND | SRKW | 10 to 15 | SW | ND | ND | Traveling | ND | | Cliff side |
| 09-06-21 | SSN | 1 | 17:00 | ND | Transient Killer Whale | 4 | E | ND | ND | Traveling | ND | | EP |
| 09-06-21 | SSN | 2 | 17:59 | ND | Humpback | 1 to 2 | W | ND | ND | Traveling | ND | | EP |
| 09-06-21 | SSN | 3 | 20:22 | ND | Transient Killer Whale | 7 | NE | ND | ND | Traveling | ND | | EP |
| 09-09-21 | SSN | 1 | 14:45 | ND | SRKW | 10 | SW | ND | ND | Traveling | ND | | Cliff side |
| 09-14-21 | SSN | 1 | 10:37 | ND | SRKW | 50 | W | ND | ND | Travel-Social | ND | | Cliff side 4 |
| 09-17-21 | SSN | 1 | 17:33 | ND | Humpback | 2 | ND | ND | ND | Traveling | ND | | EP |

| Date | Group | Daily event no. | Start time | End time | Species/ Population | No. of individuals | Travel direction | Closest est. distance (m) | Zone | Behaviour | Vessel present | Notes | Site |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 09-18-21 | SSN | 1 | 12:02 | ND | Transient Killer Whale | 6 to 8 | SW | ND | ND | Travel-Social | ND | | |
| 09-18-21 | SSN | 2 | 13:55 | ND | Transient Killer Whale | 2 | W | ND | ND | Traveling | ND | | |
| 09-19-21 | SSN | 1 | 14:26 | ND | Humpback | 2 | W | ND | ND | Travel-Social | ND | | EP |
| 09-20-21 | SSN | 1 | 14:28 | ND | Transient Killer Whale | 4 | E | ND | ND | Traveling | ND | | |
| 09-22-21 | SSN | 1 | 10:59 | ND | Transient Killer Whale | 4 | E | ND | ND | Traveling | ND | | Cliff side 4 |
| 09-24-21 | SSN | 1 | 13:29 | ND | Transient Killer Whale | 6 to 8 | E | ND | ND | Traveling | ND | | Cliff side 4 |
| 09-26-21 | SSN | 1 | 14:14 | ND | Humpback | 2 | E | ND | ND | Traveling | ND | | Cliff side 4 |

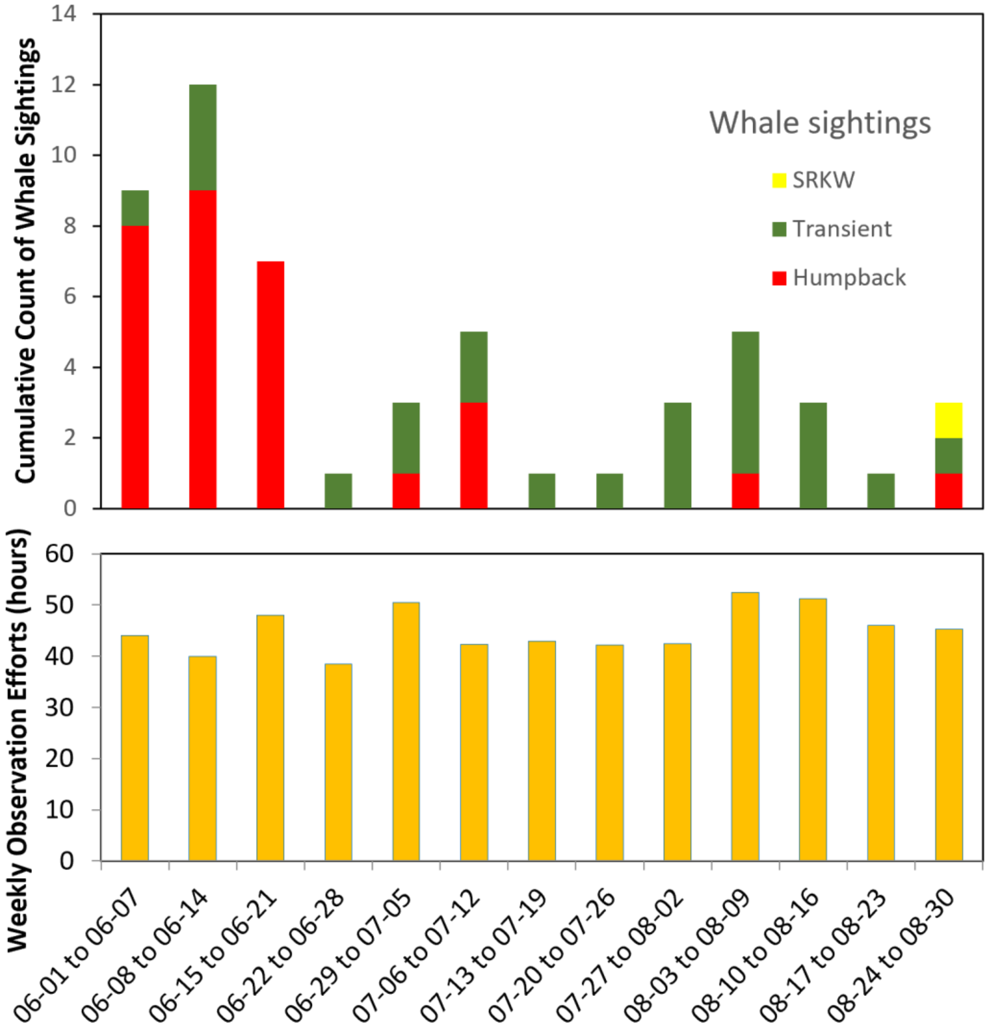
## Appendix B. Vessels Present During Marine Mammal Observations

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). Only events that include vessels within 1000 m of marine mammals are included in this table.

| Date | Daily event no. | Species/ population | Large vessel no. | Small vessel no. | Total vessel count | Notes |
|---|---|---|---|---|---|---|
| 06-01-21 | 1 | Humpback | 1 | 8 | 9 | 1 tug- 7 ecotourism vessels - 1 recreational vessel |
| 06-02-21 | 1 | Humpback | 0 | 2 | 2 | 2 recreational vessels |
| 06-03-21 | 1 | Humpback | 0 | 1 | 1 | 1 recreational vessel |
| 06-04-21 | 2 | Humpback | 1 | 0 | 1 | 1 bulk carrier |
| 06-04-21 | 3 | Humpback | 0 | 3 | 3 | 1 recreational vessel and 2 ecotourism vessels |
| 06-07-21 | 1 | Humpback | 0 | 3 | 3 | 1 recreational vessel and 2 ecotourism vessels |
| 06-08-21 | 1 | Humpback | 0 | 3 | 3 | 2 recreational vessel and 1 ecotourism vessel |
| 06-08-21 | 2 | Humpback | 1 | 0 | 1 | 1 bulk carrier |
| 06-08-21 | 3 | Transient Killer Whale | 0 | 8 | 8 | 3 recreational vessels and 5 ecotourism vessels |
| 06-10-21 | 1 | Humpback | 3 | 1 | 4 | 1 sailboat motoring - 1 commercial vessel- 1 tug- 1 container ship |
| 06-10-21 | 2 | Humpback | 0 | 1 | 1 | 1 ecotourism vessel |
| 06-10-21 | 4 | Humpback | 1 | 1 | 2 | 1 ecotourism vessel- 1 container ship |
| 06-10-21 | 5 | Transient Killer Whale | 0 | 4 | 4 | 3 ecotourism vessels- 1 recreational vessel |
| 06-11-21 | 1 | Humpback | 0 | 3 | 3 | 3 ecotourism vessels |
| 06-14-21 | 1 | Transient Killer Whale | 0 | 1 | 1 | 1 recreational vessel |
| 06-14-21 | 2 | Humpback | 0 | 1 | 1 | 1 ecotourism vessel |
| 06-15-21 | 2 | Humpback | 3 | 3 | 6 | 1 bulk carrier- 1 container ship- 1 commercial vessel- 2 ecotourism- 1 recreational |
| 06-15-21 | 3 | Humpback | 1 | 1 | 2 | 1 sailboat motoring- 1 bulk carrier |
| 06-17-21 | 1 | Humpback | 0 | 2 | 2 | 2 recreational vessels |
| 06-17-21 | 2 | Humpback | 1 | 0 | 1 | 1 bulk carrier |
| 06-22-21 | 1 | Transient Killer Whale | 1 | 7 | 8 | 6 ecotourism vessels- 1 recreational vessel- 1 commercial vessel |
| 06-30-21 | 1 | Humpback | 0 | 9 | 9 | 6 ecotourism vessels- 3 recreational vessels |
| 07-04-21 | 1 | Transient Killer Whale | 0 | 4 | 4 | 4 ecotourism vessels |
| 07-05-21 | 1 | Transient Killer Whale | 1 | 2 | 3 | 1 recreational vessel- 1 DFO boat- 1 commercial vessel |

| Date | Daily event no. | Species/ population | Large vessel no. | Small vessel no. | Total vessel count | Notes |
|---|---|---|---|---|---|---|
| 07-06-21 | 1 | Transient Killer Whale | 0 | 2 | 2 | 1 ecotourism vessel- 1 recreational vessel |
| 07-08-21 | 1 | Humpback | 0 | 1 | 1 | 1 recreational vessel |
| 07-08-21 | 2 | Humpback | 0 | 1 | 1 | 1 recreational vessel |
| 07-09-21 | 1 | Transient Killer Whale | 0 | 7 | 7 | 4 ecotourism vessels- 3 recreational vessel |
| 07-10-21 | 1 | Humpback | 1 | 0 | 1 | 1 container ship |
| 07-24-21 | 1 | Transient Killer Whale | 0 | 22 | 22 | 22 ecotourism vessels |
| 07-29-21 | 1 | Transient Killer Whale | 0 | 4 | 4 | 4 ecotourism vessels |
| 07-31-21 | 1 | Transient Killer Whale | 0 | 2 | 2 | 2 ecotourism vessels |
| 08-07-21 | 1 | Transient Killer Whale | 0 | 1 | 1 | 1 recreational vessel |
| 08-09-21 | 2 | Transient Killer Whale | 0 | 2 | 2 | 2 recreational vessels |
| 08-11-21 | 1 | Transient Killer Whale | 0 | 5 | 5 | 5 ecotourism vessels |
| 08-14-21 | 1 | Transient Killer Whale | 0 | 12 | 12 | 12 ecotourism vessels |
| 08-16-21 | 1 | Transient Killer Whale | 1 | 1 | 2 | 1 Parks Canada boat, 1 commercial vessel |
| 08-22-21 | 1 | Transient Killer Whale | 0 | 5 | 5 | 3 ecotourism vessels- 1 recreational vessel- 1 sailboat motoring |
| 08-25-21 | 1 | Transient Killer Whale | 0 | 14 | 14 | 8 ecotourism vessels- 6 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 1, 2021 and August 30, 2021. Bottom Panel: Weekly sum of the number of hours of effort of the Primary observer.