Changes in sound field levels of the Salish Sea resulting from trials of vessel slowdown, lateral displacement and exclusion from Interim Sanctuary Zones in 2021

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CHANGES IN SOUND FIELD LEVELS OF THE SALISH SEA RESULTING FROM TRIALS OF VESSEL SLOWDOWN, LATERAL DISPLACEMENT AND EXCLUSION FROM INTERIM SANCTUARY ZONES IN 2021

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ABSTRACT

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The reduction of commercial vessel speeds at Swiftsure Bank and Haro Strait-Boundary Pass were successfully reduced median sound levels in mid- to high-frequencies used for southern resident killer whale (SRKW) communication by 0.8-1.3 decibels (dB). However, increases in the echolocation range (0.5-0.7 dB in median sound levels) and broadband underwater sound levels were seen (1.1-7.3 dB in median sound levels). Notable increases in the low-frequencies could result from elevated fishing vessel presence especially on Swiftsure Bank, and a reduced range between transiting vessels and the mooring, despite the high participation in the slowdown trial. Increases in the higher frequencies could result from greater non-commercial vessel presence, known to occur during the summer months and following fisheries openings.
A displacement of 2 km of tugs from SRKW foraging areas in Juan de Fuca Strait resulted in sound levels being consistently reduced by 10 dB in relevant frequencies, and up to a maximum of 20 dB per transit. However, reductions in sound levels were limited for Interim Sanctuary Zones (ISZ) that exclude vessels due to low compliance, especially from recreational traffic.

RÉSUMÉ

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La réduction de la vitesse des navires commerciaux à Swiftsure Bank et Haro Strait-Boundary Pass a permis de réduire de 0,8 à 1,3 décibel (dB) les niveaux sonores médians dans les moyennes et hautes fréquences utilisées pour la communication des orques résidents du sud (SRKW). Cependant, des augmentations ont été observées dans la gamme d'écholocation (0,5-0,7 dB, niveaux médians) et dans les niveaux sonores sous-marins à large bande (1,1-7,3 dB, niveaux médians). Les augmentations notables de niveau des basses fréquences pourraient résulter d'une présence élevée de navires de pêche, en particulier sur le banc Swiftsure, et d'une distance réduite entre les navires en transit et le mouillage, malgré la forte participation à l'essai de ralentissement. L'augmentation de niveau des fréquences élevées pourrait résulter d'une plus grande présence de navires non commerciaux, qui se produit pendant les mois d'été et après l'ouverture des pêcheries.L'éloignement de 2 km des remorqueurs des zones d'alimentation du SRKW dans le détroit de Juan de Fuca a entraîné une réduction des niveaux sonores de 10 dB dans les fréquences pertinentes et jusqu'à un maximum de 20 dB par transit. Toutefois, les réductions des niveaux sonores ont été limitées dans les Zones Sanctuaires Provisoires (ZSP) qui excluent les navires de faible conformité, en particulier ceux provenant du trafic récréatif.

List of Acronyms

AIS: Automatic Identification System

dB: Decibel

CPA: Closest Point of Approach

DFO: Department of Fisheries and Oceans / Government of Canada

DST: Daylight savings time (UTC-7 hours)

ECHO: Vancouver Fraser Port Authority's Enhancing Cetacean Habitat and Observation Program

Hz: Hertz

ISZ: Interim Sanctuary Zone

IQR: Interquartile range measured from the 25^{th} to the 75^{th} percentile.

kHz: kiloHertz

Leq: Equivalent continuous sound level, also known as the time-average sound level.

m: meter

OPP-MEQ: Ocean Protection Plan-Marine Environmental Quality Program

PSD: Power Spectral Density

rms: Root Mean Square

SL: Source Level

SPL: Sound Pressure Level

SRKW: Southern Resident Killer Whale

TC: Transport Canada / Government of Canada

TSS: Traffic Separation Scheme

1. EXECUTIVE SUMMARY

Management measures such as slowdowns and vessel re-routing or exclusion have been shown to be effective means to reduce underwater noise levels and lessen acoustic disturbance on marine mammal species. However, increases in vessel number, and time spent by whales in the presence of vessels could lessen the effectiveness of these measures. Here we examine the compliance and efficacy of vessel slowdowns at Swiftsure Bank and Haro Strait-Boundary Pass, a lateral displacement of tugs through Juan de Fuca Strait, and vessel exclusions in Interim Sanctuary Zones (ISZs) on Swiftsure Bank, in Swanson Channel and off East Point on Saturna Island during summer 2021. The focus of these measures was to lessen the overall broadband ambient sound levels (10 Hz to 100 kHz) and noise levels in frequencies used by Endangered Southern Resident Killer Whales (SRKW) for communication (500 Hz to 15 kHz) and echolocation (15 to 100 kHz).

The most effective operational method to lessen the acoustic impact on SRKW is to reduce the transit speed of vessels through important areas. However, there was little change seen in the SRKW communication and echolocation frequencies when comparing pre-trial and trial periods. Also, increases were seen in the lower frequencies, most notably at Swiftsure Bank during the slowdown period. This may be caused by an increase in vessel traffic, and time spent with vessels in the immediate vicinity of the mooring. Analysis of vessel tracking data does suggest increased numbers of fishing vessels at Swiftsure Bank during this period. Reducing vessel transit speed also increases the time taken to transit the management zones by each vessel. Also, the range from the mooring and vessels transiting was found to be reduced during the slowdown. It is also possible that site-specific sound propagation characteristics may play a role in defining the overall soundscape in the Swiftsure Bank area.

The least change in vessel presence and behaviour was seen for tugs in the lateral displacement. The majority of vessel transits were already in the area designated as the inshore lateral displacement zone or in the outbound shipping lane. Therefore, vessels were already compliant to this requested shift away from SRKW foraging areas along the Vancouver Island coastline before the trial began. Focus was given to two example tugs with multiple transits through the lateral displacement zone during the trial period. This analysis emphasised previous findings, whereby the sound levels in the SRKW frequencies, and those frequency ranges representing vessel presence, decrease as distance of vessel transits from the coast increases.

Increased vessel presence during the summer, and a lack of compliance to the exclusion of vessels from ISZ lessened the efficacy and potential reductions in sound pressure levels (SPL) in these areas.

2. INTRODUCTION

Anthropogenic noise is increasingly being recognised as a threat to marine life. Underwater noise in the North East Pacific has increased as a result of increased commercial vessel number and capacity (Richardson et al. 1995, Hildebrand 2009). Although the noise is focused around shipping routes, soundscapes of areas near coastal cities and major ports also experience elevated sound levels (Andrew et al. 2002, NRC 2005, McDonald et al. 2006, Chapman and Price 2011, Frisk 2012, Merchant et al. 2014, Pirotta et al. 2019). Increased sound levels could hinder life functions of marine organisms in the area, as they rely on acoustic signalling for navigation, communication and prey location, pursuit and capture.

Acoustic disturbance from vessel noise has been listed as one of four key threats to population recovery and success of Endangered Southern Resident Killer Whales (SRKW). This is in addition to the disturbance of vessel presence and risk of strike, prey depletion, and presence of persistent organic pollutants in key habitat regions (DFO 2017, 2018, 2021, Raverty et al. 2019).

The inland waters around southern Vancouver Island and northern Washington State, collectively known as the Salish Sea, host critical habitat for SRKW. Areas with high bathymetric relief and nearshore shallow reefs adjacent to deep water, and regions of strong tidal currents in this area represent foraging habitat (Groot et al. 1984, Heimlich-Boran 1988, Hauser et al. 2007, Hanson et al. 2010, Olson et al. 2018). Whales are frequently seen on Swiftsure Bank, in the Strait of Juan de Fuca, Haro Strait on the west side of San Juan Island, Boundary Pass, Swanson Channel, and southern portions of the Strait of Georgia especially during summer months (Balcolmb and Bigg 1986, Krahn et al. 2004, DFO 2017, Olson et al., 2018). In addition, this area is also heavily impacted by vessel noise. International shipping lanes traverse this area, with recreational boating also common. Foraging areas for SRKW are near to these shipping lanes and areas frequently used by non-commercial boaters, and so management measures have been trialled over a number of years to lessen the impact of the noise derived from vessel presence (Vagle and Neves 2019, Vagle 2020, Burnham et al. 2021). The changes in sound levels as a result of management actions are described using broadband ambient sound levels (10 Hz to 100 kHz), as well as frequency ranges relevant to SRKW communication (500 Hz to 15 kHz) and echolocation (15-100 kHz, Heise et al. 2017).

Voluntary slowdown measures were first applied in 2017 for a portion of Haro Strait contained in the Compulsory Pilotage Area. Since then, the trial area has been extended to encompass Haro Strait and Boundary Pass completely, a total distance of 29.6 nm. In addition, a slowdown was trialed for a section of the shipping lane crossing Swiftsure Bank for the first time in 2020. The target vessels of the slowdown trials are commercial shipping, with this measure seen to reduce source level noise for container ships, cruise vessels, vehicle carriers, tankers, and bulk carriers (MacGillivray et al. 2019, Joy et al. 2019, Burnham et al. 2021). The slowdown trials request a voluntary reduction of speed of bulkers, tankers, ferries and government vessels transit speed to 11 knots, and vehicle carriers, cruise and container vessels to 14.5 knots. Other vessel types, including naval vessels transiting the specified areas, were also requested to participate, however, these vessels are not the focus of the present soundscape and participation analysis.

Lateral displacement of vessels was trialed to move commercial vessels away from coastal areas where SRKW were frequently seen and presumed to forage (Olson et al. 2018). This measure aimed to reduce both the underwater noise and physical disturbance from vessels by requesting vessels transiting the Canadian inshore area of Juan de Fuca Strait to move their route south, away from these feeding areas and travel in either a designated displacement zone or the outbound traffic lane. Initially the request applied to all commercial outgoing traffic, however acoustic reductions were minimal from the displacement of deep-sea and other commercial vessels due to the limited distance they are able to change their transit and remain in the traffic separation scheme (~600 m south). Therefore, since 2019 the lateral displacement trial has been applied to the transits of tugs and barges in the Strait of Juan de Fuca only. This change in approach came as a result of significant noise reductions that have been observed in acoustic signatures from tug passages being displaced, with notable reductions also seen in SRKW-relevant frequency ranges (Vagle 2020, Burnham et al. 2021).

Interim Sanctuary Zones (ISZs) exclude vessels from areas on Swiftsure Bank, in Swanson Channel, off Pender Bluffs, and around East Point off Saturna Island. These are areas where SRKW have been frequently sighted (Olson et al. 2018), and could also represent foraging areas.

In recent years the measures have been initiated by the confirmed presence of SRKW in the Salish Sea, with monitoring beginning on June 1, and running until a period after October 15 when whales have not been sighted for at least two weeks. In 2021, the slowdown trials were in place at Swiftsure Bank from June 1 to October 31, and in Haro Strait-Boundary Pass from July 1 to November 30, in response to SRKW presence. The lateral displacement request was in action from June 1 to October 31 and ISZs were in force from June 1 to November 30. The impacts of measures were assessed through passive acoustic recordings made from a number of bottom-stationed moorings deployed in trial areas. Recordings made while measures were in place were compared to periods pre- and post-trial measures to assess changes in sound fields. Vessel passage data aided in the assessment of participation or compliance to the measures to form an overall idea of the efficacy of each of the management measures used. Reductions in overall soundscape (10 Hz to 100 kHz) sound levels, as well as the levels in frequencies used by SRKW for communication (500 Hz to 15 kHz) and echolocation (15-100 kHz), were evaluated. The levels of participation in trials were also considered. The results of this analysis add to that of previous trial years (Vagle and Neves 2019, Vagle 2020, Burnham et al. 2021) and other management measures in place during the same period, including fisheries closures.

3. METHODS

3.1 Passive acoustic recordings and mooring locations

Recordings for this assessment were made as part of a wider project under the Government of Canada's Ocean Protection Plan-Marine Environmental Quality Program. Moorings deployed in trial areas were used to assess changes in soundscape. Slowdown measures were assessed using continuous recordings from Swiftsure Bank, Haro Strait, and Boundary Pass (Figure 1, Table 1). These recorders are all positioned under or near the shipping lanes. The lateral displacement trial was assessed using a mooring positioned at Jordan River, which has previously been assessed to best represent these management measures in Juan de Fuca Strait (Vagle and Neves 2019, Vagle 2020). This recorder is located approximately halfway through the trial zone from where tugs and barges are being displaced, and sits approximately 5 km north of the outbound traffic lane (Figure 1, Table 1). Each of the ISZs had a designated mooring to monitor changes in ambient noise (Figure 1, Table 1).

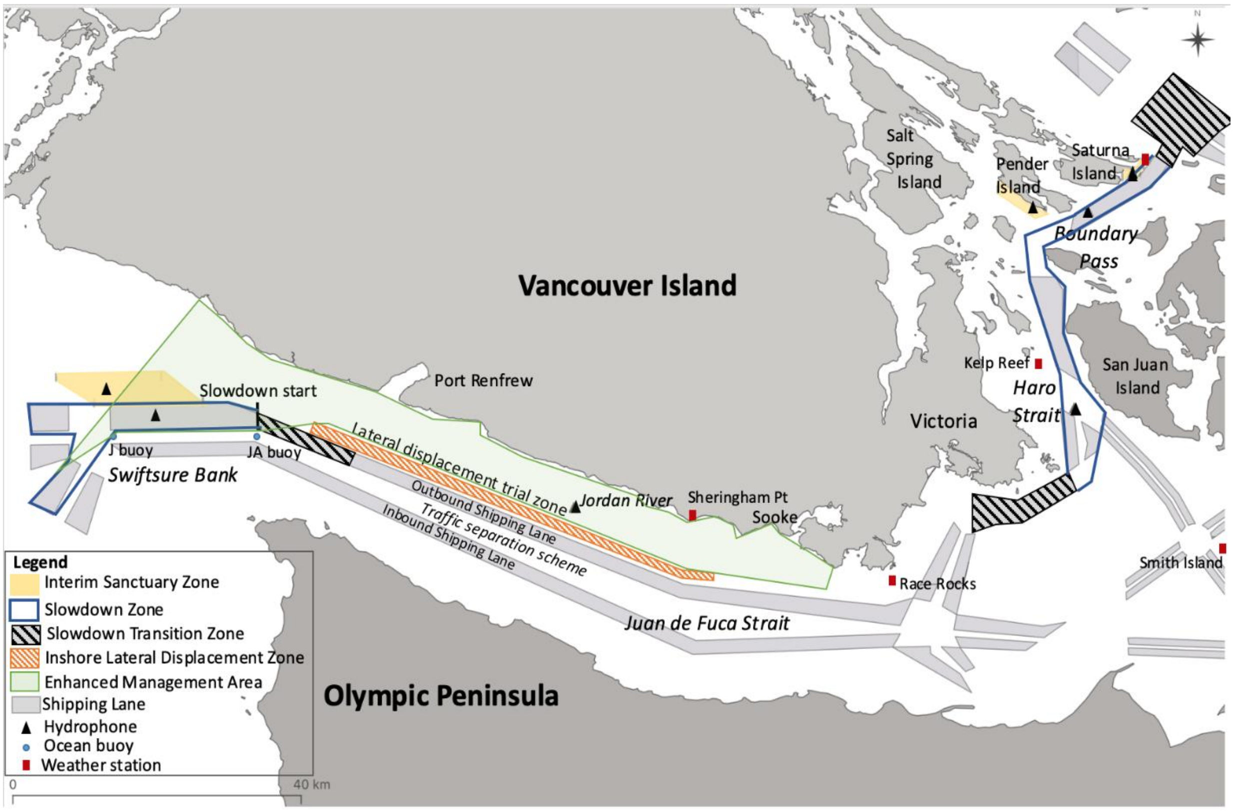

Figure 1: Locations of all management actions undertaken in the Salish Sea during 2021. Commercial shipping lanes are shown for reference (light grey). Hydrophones used for the analysis are indicated by black triangles, while weather stations are indicated with red squares. The interim sanctuary zones (ISZs) are highlighted with yellow.

Table 1: Location and depth of each of the moorings used for the assessment of the 2021 mitigation measures in the Salish Sea. The type of mitigation measures evaluated by a given mooring are also listed.

Mooring	Position	Water depth (m)
Slowdown:		
Swiftsure Bank	48.515N, 124.936W	77
Haro Strait	48. 49583N, 123.192783W	235
Boundary Pass	48. 733567N, 123.145683W	180
Lateral displacement:		
Jordan River	48.397N, 124.134W	120
ISZs:		
Swiftsure Bank	48.552N, 125.0072W	40
Swanson Channel	48.7393N, 123.257W	72
Saturna Island	48.7761N, 123.06927W	86

Continuous passive acoustic recordings were made using Autonomous Multichannel Acoustic Recorders (AMAR G4, JASCO Applied Sciences) equipped with GeoSpectrum Technologies M36-100 hydrophones mounted on a quiet mooring that positioned the hydrophone approximately 2 m above the sea floor. Each system was calibrated from 100 Hz to 250 kHz by the manufacturer, and then again at 250 Hz prior to each deployment. The sample rate was 256-kHz with 24-bit resolution, with data stored on internal SD memory cards as wav files until the mooring was retrieval. The acoustic files were processed using custom Python scripts, modified from those used by Merchant et al. (2015), which computed one-minute power spectra using a 1-second Hanning window, a 50% overlap, and Welch's averaging. From this, sound pressure levels (SPL) measures were calculated. Comparisons of minute-wise, hourly, and monthly median levels of pre-, during, and post-trial recordings were used in this assessment.

3.2 Acoustic analysis

Changes in broadband ambient noise (10 Hz to 100 kHz) were considered during the trial periods. In addition, and to more directly consider the easing of potential acoustic disturbance on SRKW in their mammal-to-mammal communication and their prey detection using echolocation signals, two additional bands (500 Hz to 15 kHz) and (15-100 kHz) were considered (Heise et al. 2017). Examination of these frequency ranges helps assess the potential for acoustic stress on SRKW and masking of critical echolocation or conspecific signalling. The additions of vessel noise to these ranges were further examined by considering frequency ranges that represent vessel metrics (Table 2). The decadal band 100-1000 Hz and 1/3-octave frequency ranges centered around 63-Hz and 125-Hz were used to indicate vessel presence without being influenced by water turbulence in the lower frequencies (Table 2, Merchant et al. 2012, 2015). The 50 kHz frequency range was used to represent the presence of small vessel traffic in the trial areas (Burnham et al. 2021, Vagle et al. 2021).

Table 2: Frequency ranges of interest for analysis, including SRKW communication and echolocation bands, and vessel presence markers.

Frequency range (Hz)	Description
10-100,000	General ambient noise, implications for behavioural change or stress in SRKW
500-15,000	Communication calls (whistles, pulsed tones, etc.) of SRKW (Heise et al. 2017)
15,000-100,000	Echolocation in SRKW (Heise et al. 2017)
10-100	Low frequency vessel noise, water turbulence
100-1000	Vessel presence marker, excluding water turbulence effects (Merchant et al. 2012)
1000-10000	Vessel marker, used in the small vessel detector (Warner et al. 2020)
10000-100000	Vessel marker, used in the small vessel detector (Warner et al. 2020)
49500-50500	Vessel marker, the 50 kHz signal used in depth sounders

Analyses of trials and comparisons between trial and control periods were conducted so as to minimise any confounding variables. Lunar month comparisons were made to lessen the potential of current noise. Restrictions on the data analysed were made to limit abiotic noise additions potentially obscuring the SPL changes resulting from the management measures. Only recordings made during slack tide when current speeds were less than 0.3 ms^{-1}, and when wind speed was less than 5 ms^{-1} were used. Current measures were accessed from Webtide (Hannah et al. 2008), and from in-situ sensors on each of the moorings. Wind speed measures were taken from the La Perouse meteorological buoy for assessment at Swiftsure Bank and Jordan River, Smith Island wave buoy for Haro Strait, and Saturna Island weather station for changes at Boundary Pass (Figure 1).

To assess the changes in commercial vessel speeds more effectively, signals from small vessel were removed. Indications of presence of recreational vessels through the use of Automatic Identification System (AIS) Class B were thought to represent the minimum presence of small vessels, as many more were expected to be present and not be equipped with AIS transponders (Serra-Sogas et al. 2021). A small vessel detection algorithm, based on the approach by Warner et al. (2020), was implemented to identify and remove small vessels both moving slowly and at speed in the acoustic data, while still retaining signals for vessels subject to the trial measures. The detector used hourly median SPL levels in three decadal bands, comparing observed SPL values to threshold SPL values in decibels (dB). Exceedances in SPL at or above the threshold values compared to hourly values were a determinant of small vessels (Warner et al. 2020). The frequency band 100-1000 Hz has previously been used successfully as an indicator of vessel presence (Merchant et al. 2012, 2015, Table 2); for the small vessel detector an increased amplitude in this band by 6 dB, together with SPL elevated by 5 dB in the range 1-10 kHz, and by 23 dB in the 10-100 kHz compared to an hourly median indicated small vessels moving at speed. In addition, this same definition but with SPL in the 100-1000 Hz range exceeding the hourly median by 6 dB, but by no more than 9 dB, represented small vessels moving slowly (Warner et al. 2020). Periods where small vessels were detected using this approach were omitted from the data analysed for slowdown and lateral displacement trials. For the ISZs, times when these criteria were met were examined to determine the changes in the sound field as a result of Class B and small vessel presence. Levels in the 50 kHz range were also considered to assess relative presence of small vessels in trial and control periods.

Acoustic comparison was made by conducting a cumulative distribution function (CDF) SPL analysis. Also, the 25th and 75th percentiles of noise levels and the median (levels of noise 50% of the time) were considered. Minimum, maximum and mean levels were also derived for pre-trial and trial periods. The median exceedance level is used frequently in noise comparisons to represent typical sound levels (e.g., Klinck et al. 2012, Merchant et al. 2012), whereas the other percentile levels help characterize both the background ambient noise level and periods of elevated noise that may mask SRKW acoustic signals or initiate behavioural change in control and trial periods (Clark et al. 2009, Merchant et al. 2015).

3.3 Vessel presence through AIS

Class A and Class B AIS vessel information data were received from the Canadian Coast Guard terrestrial receivers for the control and trial periods. Class A AIS transceivers are mandatory for vessels over 300 tons (excluding fishing vessels) and for passenger vessels over 150 tons carrying more than 12 passengers. Also, towage and escort vessels of any tonnage must carry a Class A transceiver. Therefore, Class A vessels are primarily larger commercial vessels, while the Class B vessels will primarily be pleasure crafts, but also include some fishing vessels and other smaller commercial vessels. The AIS system transmits vessel name, identification number, type, and location every 5-30 seconds. These data were cleaned and binned into 5-minute packages from which the pathway and speed of each vessel was interpolated. Class A vessels were classified into several classes including 1) Bulkers, 2) Container ships, 3) Ferries, 4) Fishing vessels, 5) Government/Research, 6) Naval vessels, 7) Passenger vessels, 8) Recreational vessels, 9) Tankers, 10) Tugs, 11) Vehicle carriers, 12) Registered whale watching vessels, and 13) Others.

The passage rate of vessels by type was determined hourly from the AIS data, and used to assess participation in trials and establish the vessel-derived input to the soundscape for both control and trial periods. The assessment area of vessel presence in slowdown trial areas in Haro Strait and Boundary Pass, and the ISZs on Saturna Island and in Swanson Channel was defined by the geography and constraints of nearby islands or reef landmasses (Figure 1,2). In these cases, the maximum distance for vessel presence analysis was the obstruction or, whenever possible, out to a maximum distance of 8 km (Figure 2). In the more open water areas, vessel presence up to a maximum distance of 8 km was considered to restrict the analysis to vessels within the shipping lanes or waters immediately proximal to the trial zones (Figure 2). This represents the estimated detection range of SRKW communication calls in Juan de Fuca Strait and on Swiftsure Bank, which at its maximum was estimated to be 6.5 km (L_{10}, Swiftsure Bank during the summer; Mouy Pers. Comms.). In the open water areas, the use of the maximum distances restricted the analysis to vessels to the shipping lanes, and waters immediately around the trial zones. The slowdown at Swiftsure Bank only requests that outbound traffic reduce speed, and so analysis was focused on those vessels that indicated outbound travel through examination of the bearing and course over ground of each of the vessel tracks in the AIS data. The analysis was also limited to the analysis to the outbound lane to a maximum of 8 km to ensure this. Similarly, the analysis for the ISZ at Swiftsure was limited to the maximum 8 km distance. Overall soundscape changes resulting from the lateral displacement have been established in previous years and have been shown to be limited (see Vagle and Neves 2019, Vagle 2020, Burnham et al. 2021). Therefore, the focus of the 2021 assessment of the lateral displacement trial was focused on specific vessels.

Participation in the slowdowns and lateral displacement, and compliance to ISZs were assessed through the AIS data. These data were also used to compare the vessel transit rate (hourly and daily) between control and trial periods. The passage of AIS Class A were the focus for slowdown zones, tugs for the lateral displacement, and Class B AIS for the ISZs. Commercial vessel presence was also considered for the ISZs due to their immediate proximity to shipping lanes.

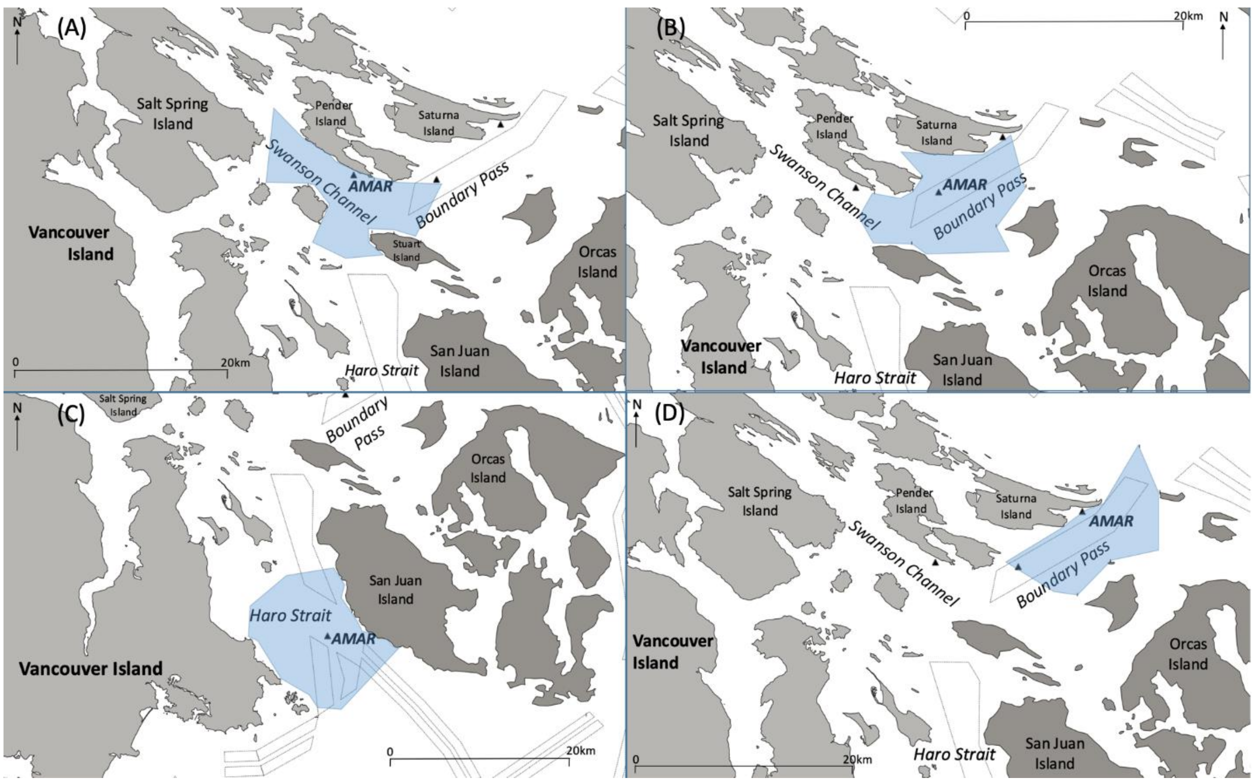

Figure 2: Areas of analysis for the (A) Swanson Channel ISZ, (B) slowdown through Boundary Pass, (C) slowdown in Haro Strait, and (D) Saturna Island ISZ shown with blue shading. Moorings are shown with black triangles, and the mooring used for the highlighted area is labeled 'AMAR'.

3.4 Environmental variables

The influence of abiotic noise was minimised in the analysis by considering the potential noise inputs from water currents and wind. Current was measured at each mooring site through current meters attached to the mooring itself (JFE Advantech Co. Ltd. Infinity-EM electromagnetic current meters). It was assumed, after comparison to Webtide measures (Hannah et al. 2008), that the currents measured at the mooring were representative of surface currents. Wind speed measures were taken from hourly weather and sea state reports from the La Perouse Bank weather buoy

(48.840 N, 126.000 W, Figure 3) for Swiftsure Bank and Jordan River assessments, Smith Island for Haro Strait and East Point on Saturna Island for the IZSs in the Gulf Islands (Figure 4). To limit the influence of abiotic noise on the recordings compared for pre-trial to trial, both data were subject to restrictions whereby recordings for the analysis were those made during slack tide, when current speeds were less than 0.3 ms^{-1}, and when wind speed was less than 5 ms^{-1}.

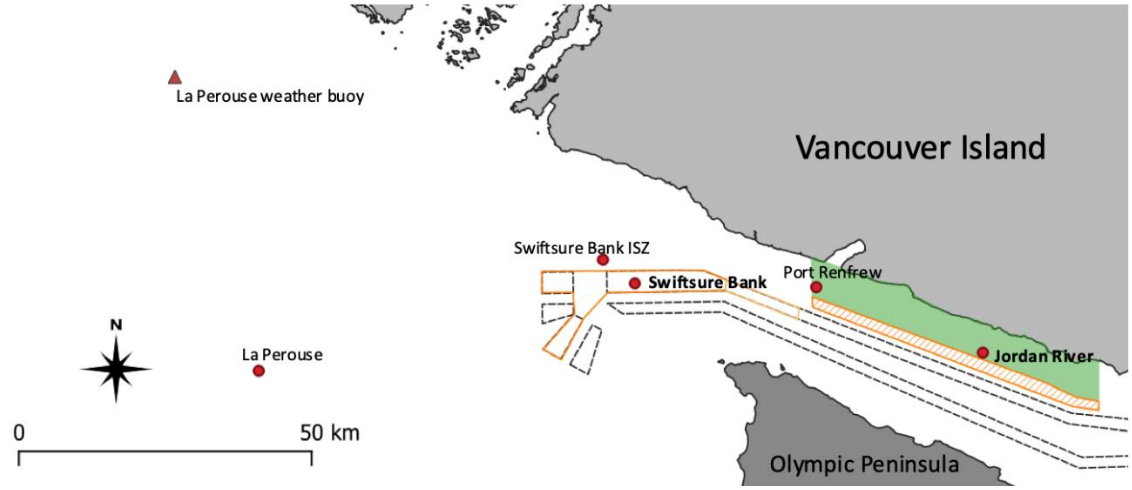

Figure 3: A map of the western Juan de Fuca passive acoustic moorings (red circles). The slowdown area (orange outline) and the transition zone (yellow outline), Management Enhancement area (green shading) and Inshore Lateral displacement area (orange hashed shading) are shown. The La Perouse weather buoy is also indicated (red triangle).

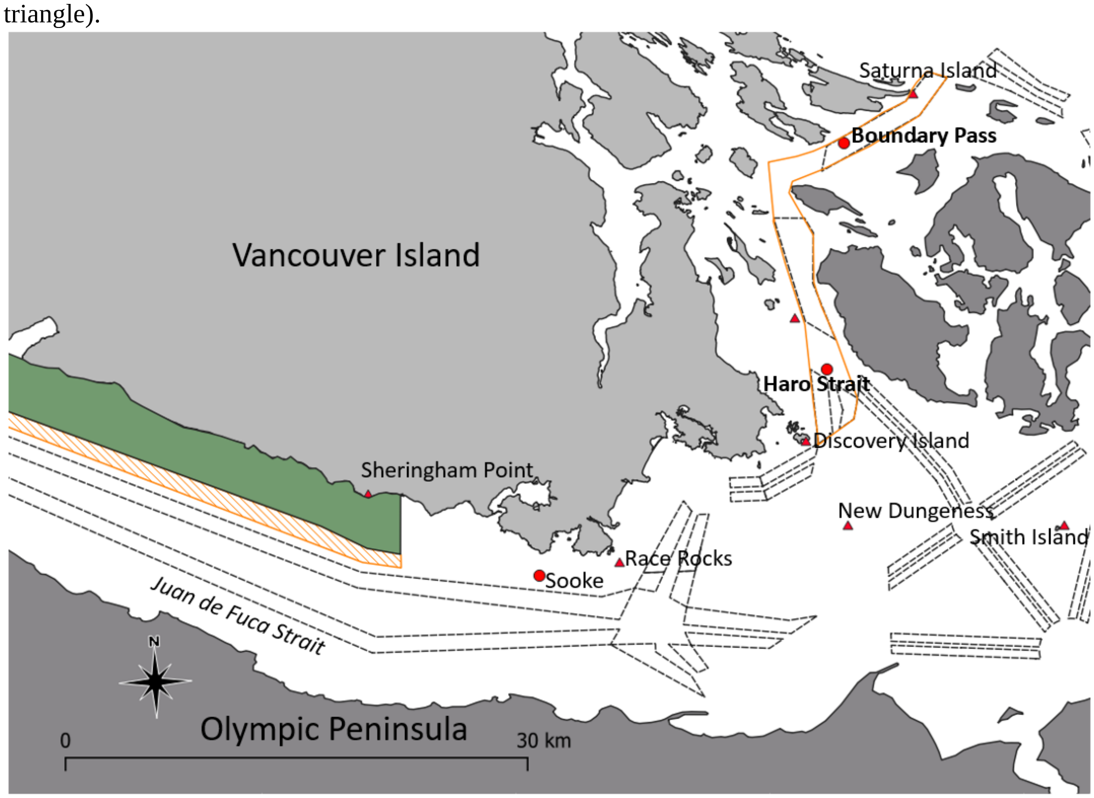

Figure 4: A map of the eastern Juan de Fuca and Gulf Island moorings (red circles). The slowdown area (orange outline),Management Enhancement area (green shading), and Inshore Lateral displacement area (orange hashed shading) are shown, with weather stations marked with red triangles.

3.5 Slowdown assessments

The request for vessels to slow down on Swiftsure Bank applied to outbound traffic transiting a 31-37 km stretch from the start of a transition zone just east of JA buoy to the western to the end of the in- and outbound traffic separation scheme (Figures 1, 5). The slowdown trial zone in Haro Strait and Boundary Pass extended from Discovery Island in the south to East Point of Saturna Island to the north, covering 55 km of Haro Strait and Boundary Pass (Figures 1, 6). The initiation of the slowdown in Haro Strait and Boundary Pass is a confirmed observation (visual or acoustic) of SRKW. Monitoring for the presence of SRKW began at the beginning of June 2021, with the slowdown measures initiated following a confirmed observation of SRKW in the area on July 1. Measures ran until confirmed SRKW absence exceeded two weeks on November 30. The pre-trial control period ran from April 1 to July 1. Participation was assessed through AIS records and self-reporting of pilots or captains. In self-reporting, the captain expresses their intent to transit at the requested speed, and ECHO deemed vessels to be participating if their transit speed was within one knot of the requested speed. The slowdown trial on Swiftsure Bank was from June 1 to October 31, 2021, with participation assessed through the AIS records only. Here the control periods were 2 months prior and a month following the conclusion of the trial. The pre-trial to trial comparison was weighted more heavily in our assessments, as post-trial comparisons could be influenced by known seasonal changes in the soundscapes in areas of the Salish Sea (Burnham et al. 2021).

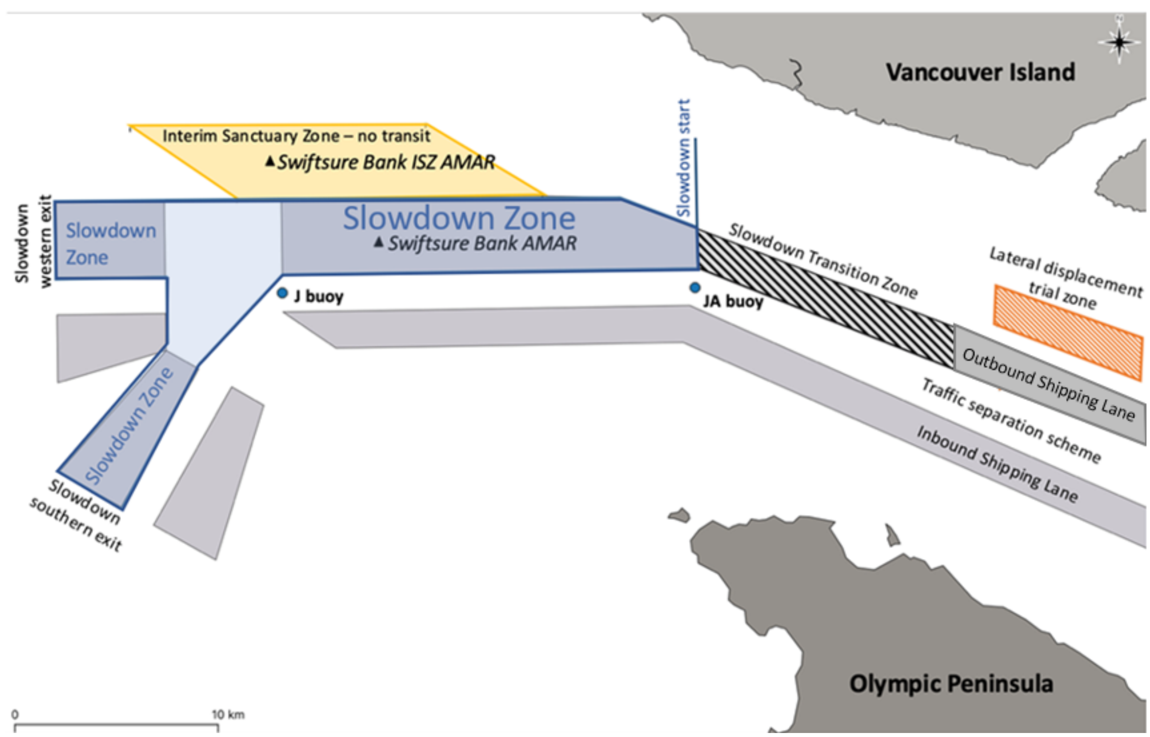

Figure 5: Slowdown measures on Swiftsure Bank for June 1-October 31 2021 (outlined and filled light shading in blue). The transition area is indicated with black cross hatching, and the acoustic moorings shown with black triangles. Orange cross-hatched areas and lines indicate the extents of the lateral displacement trial.

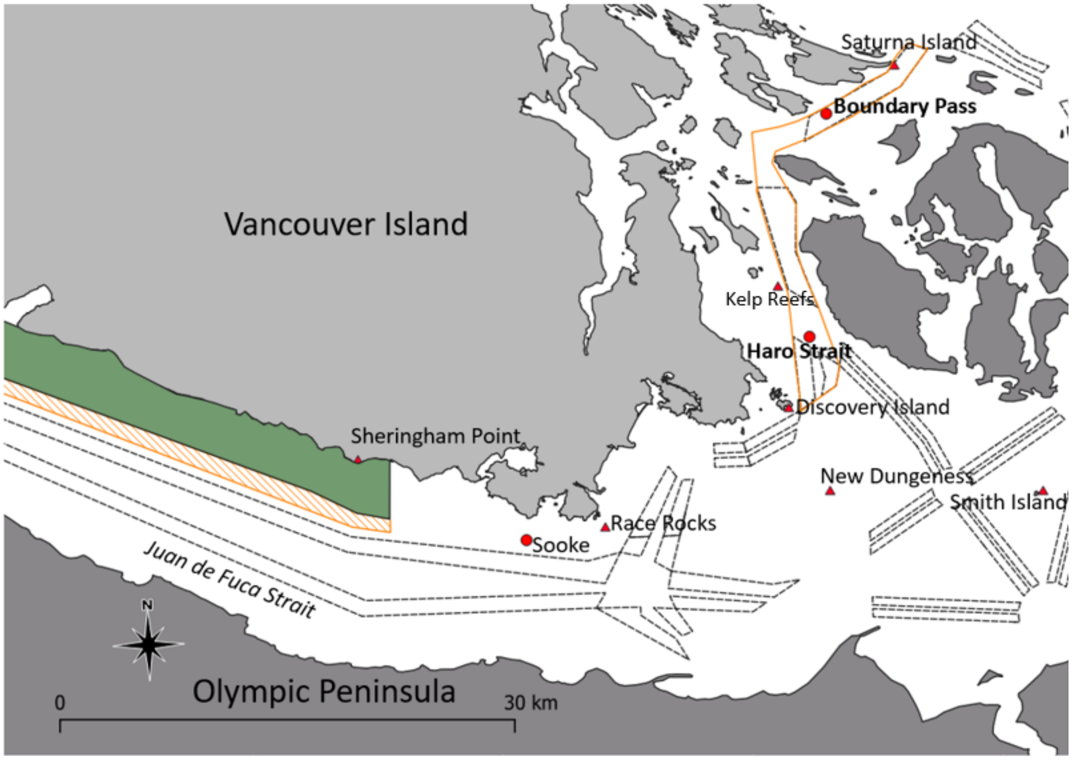

Figure 6: Slowdown measures in Boundary Pass and Haro Strait (outlined and filled light shading in blue) in place for July 1 to November 30, 2021. The transition area is indicated with black cross hatching, and the acoustic moorings shown with black triangles. The ISZs are also shown in yellow.

3.6 Lateral displacement assessments

From June 1 to October 31, 2021, if it was safe and operationally feasible to do so all tugs and barges transiting the inshore waters of Juan de Fuca Strait were requested to change their transits to a more southerly route, away from SRKW foraging areas (Figure 7). Transits were requested to instead be in a designated displacement zone, or in the outbound shipping lane (Figure 7). The displacement zone is a 1500 m wide corridor with a length of approximately 28 nm/ 52 km of the Strait (orange area, Figure 7). Port-to-port transits were exempt from the request.

For 2021, the lateral displacement trial participation was evaluated by considering the change in the closest point of approach (CPA) and transit distance from the Jordan River acoustic mooring during the trial period compared to the months prior for all tug transits. Percentage time spent at distances away from the mooring, and so away from coastal SRKW foraging areas, were used to consider the transit routes taken by tugs for the pre-trial and trial periods. Then focus was given to two representative tugs to better discern the potential reduction in noise from participation in the lateral displacement for each vessel transit. Changes in sound levels for broadband and SRKW-relevant frequency ranges were assessed per transit. The passages during the trial period were compared to those made up to six months prior, with both vessels making multiple transits during both the control and trial periods.

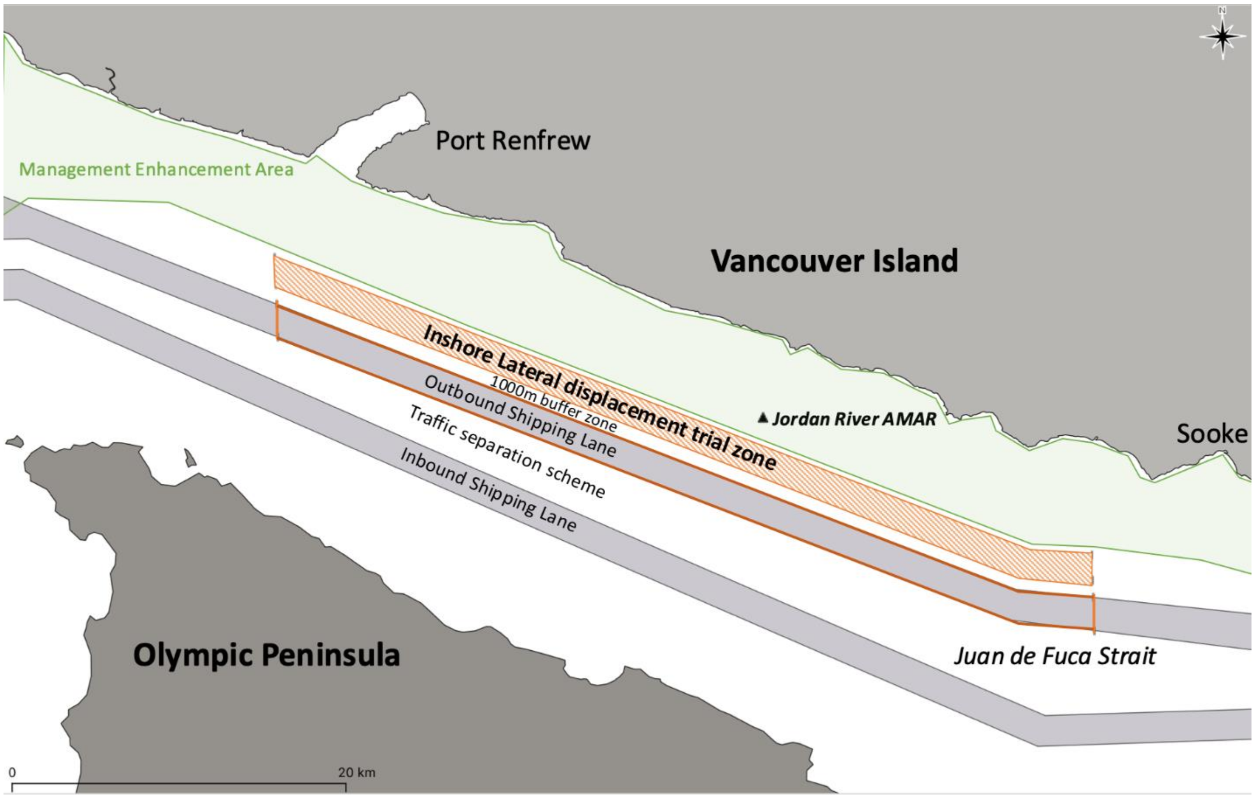

Figure 7: Lateral displacement measures in Juan de Fuca Strait. Tugs are requested to move out of the management enhancement area (indicated in green) into either the inshore lateral displacement trial zone (orange hatched marking) or outbound shipping lane (orange outline).

3.7 Interim Sanctuary Zones (ISZs)

Interim whale Sanctuary Zones (ISZs) on Swiftsure Bank, in Swanson Channel off Pender Island, and around East Point off Saturna Island were implemented between June 1 and November 30, 2021 (Figure 1, Table 3). The presence of vessels and vessel passages were assessed from AIS Class A and Class B data. Full tracks of passages through the ISZ and the surrounding area were examined for any vessel with at least one AIS point within the ISZ polygon. From these tracks the proportion of time of each vessel class spent within the ISZ was also calculated. The comparison control periods were from April 1-May 31, and December 1-31, 2021.

Table 3: Coordinates from Schedule 2 of the Interim Order that outline the Interim Sanctuary Zones at Swiftsure Bank, Swanson Channel, and Saturna Island for 2021.

Interim Sanctuary Zone	
Swiftsure Bank:	
48. 5667N, 125.100W	to
48.5667N,124.093W	to
48.535N, 124.8253W	to
48.535N, 125.030717W	
Swanson Channel	
48.7361N, 123.23167W	to
48.7361N, 123.259167W	to
48.7675N, 123.32527W	to
48.7675N, 123.306383W	
Saturna Island	
48.78583N, 123.04555W	to
48.78945N, 123.048583W to	
48.793616N, 123.041383W	to
48.791217N, 123.032917W	to
48. 775967N, 123.05245W	to
48.772216N, 123.063416W	to
48.7725N, 123.08583W	to
48.77805N, 123.08583W	

Acoustic recordings made during the period the ISZ mandate was in place on Swiftsure Bank were limited due to a loss of equipment. Evaluations of vessel compliance, as much as it is possible to quantify, were made, but comparisons of the sound levels to control periods were not possible.

4. RESULTS

4.1. Vessel slowdown assessments

4.1.1 Swiftsure Bank slowdown trial

The Swiftsure Bank slowdown request was made only for outbound traffic, therefore only vessels indicating outbound travel through bearing and course over ground in the AIS records were analysed. The speed of each commercial vessel transit within 8 km of the mooring was examined to assess participation in the slowdown trail. For vehicle carriers, cruise ships, and container vessels participating travel speed should not exceed 14.5 knots. For bulkers, tankers, and government vessels the travel speed should be no more than 11 knots. Participation rate in the trial was reported by ECHO to be 81%.

Bulkers were the most frequent vessel type to transit Swiftsure Bank for both the pre-trial and trial periods. Vehicle carriers accounted for the least number of passages of the analyzed vessel types (Figure 8). The proportion of time each vessel type was the closest vessel to the mooring, calculated over a 20 km spatial scale for every 5 minutes of the data, were mostly consistent from pre-trial to trial period (Figure 8). The proportional presence of commercial vessel types overall did not change significantly between the control and trial periods (Figure 8). The presence of passenger vessels increased in the summer months (purple, Figure 8). Fishing vessels responded to fisheries opening times, and increased as the summer progressed to fall (green, Figure 8).

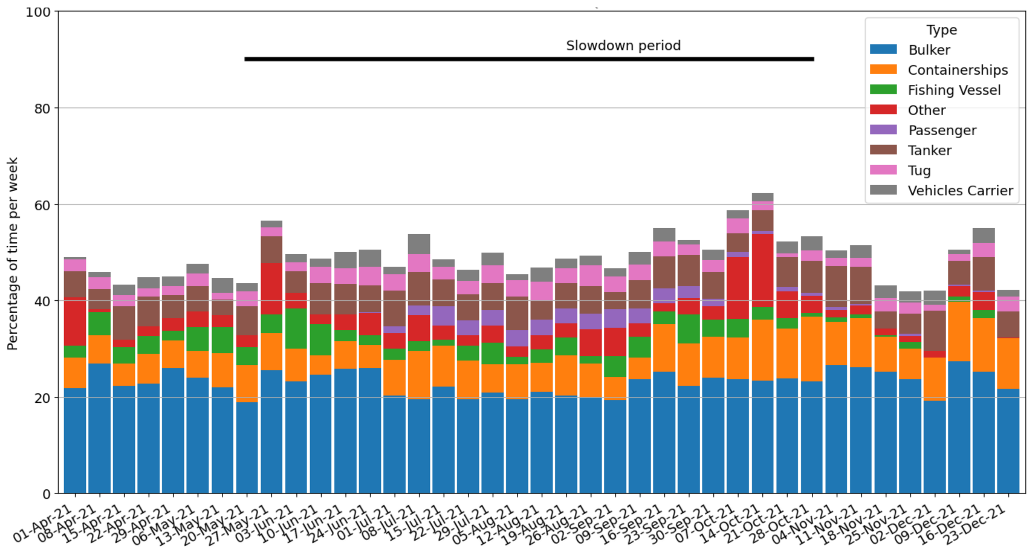

Figure 8: Swiftsure Bank proportional presence of vessel types established weekly using 5-minute data sections for pre-, during and post-trial periods, with the trial starting June 1 and running until October 31, 2021. ‘Other’ category includes recreational, government, naval vessels, and ferries.

The speed of each commercial vessel transit was examined to assess participation in the slowdown trail. Speed over ground (SOG) was calculated directly from the AIS data (Figure 9). The speeds calculated for SOG and speed through water (STW) were not found to be notably different from each other, but speeds between the pre-trial and trial periods showed a marked reduction in both cases (Figure 9). Strong peaks of occurrence for vessel transits at or within 1 knot of the requested speed were seen (Figures 9A,B). The speed of most bulkers was reduced by approximately 2 knots, and tankers approximately 3 knots from pre-trial speed in order to participate in the slowdown (Figure 9). The speed of containerships and vehicle carriers in the pre-trial period showed peaks of occurrence around the requested speed, with little reduction necessary (Figures 9C,D). However, a second peak at around 20 knots for containerships, and 17 and 22 knots for vehicle carriers, suggested that some vessels would have needed to slow almost 10 knots to conform to the 14.5 knot speed limit request. The reduction in speeds from pre-trial to trial periods were most notable for containerships and vehicle carriers (Figure 9C,D). Vehicle carriers especially showed a difference in transit speeds during the trial, with both pre- and post-trial speeds seen to be multi-modal, with a reduction of speed of these peaks in the post-trial compared to the months preceding the trial (Figure 8). The peak seen at approximately 22 knots in the pre-trial period was not seen in December (Figure 8).

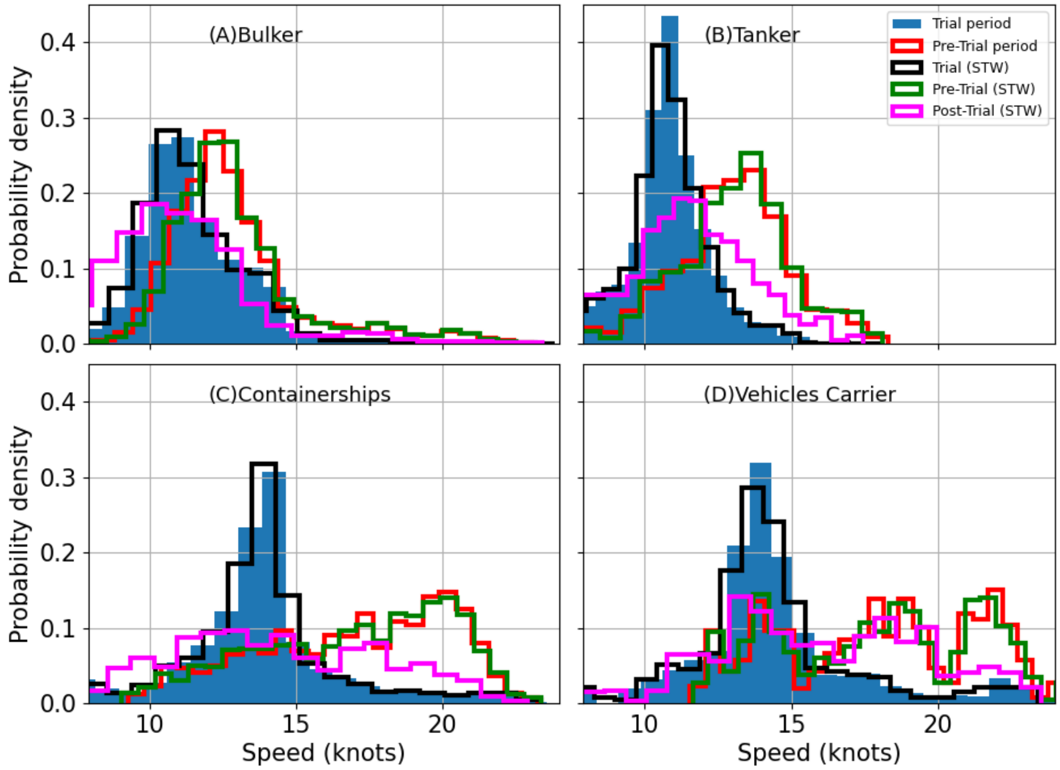

Figure 9: Comparison of the speed over ground (SOG) and speed through water (STW) of bulkers (A), tankers (B), containership (C), and vehicle carriers (D) between pre-trial and trial periods at Swiftsure Bank. The slowdown on Swiftsure Bank was in place from July 1 to November 30, 2021, with a pre-trial control period of April 1 to June 30, 2021. Bulkers and tankers were requested to not travel more than 11 knots, and containerships and vehicle carriers were requested to travel no more than 14 knots.

The greatest range in speed was found for bulkers and the least for containerships (Table 4). On average, bulkers and tankers slowed their passage speed by 1 knot and 1.2 knots respectively from the control and trial periods in both SOG and STW (Table 4). Containership and vehicle carrier speed reduction was 1.6 knots when comparing pre-trial and trial vessel passages, with 75 percent of the vessel speeds measured falling below or within 1 knot of the requested speed during the trial period (Table 4).

Table 4: Speed over ground (SOG) and speed through water (STW) metrics in knots for pre-trial and trial periods at Swiftsure Bank for vessels transiting the slowdown area.

Metric	Bulker	Tanker	Containerships	Vehicle Carrier
Speed over ground (knots)				
- Pre-trial				
Minimum	7.6	0.8	9.3	11.6
Mean	12.9	12.9	16.9	18.0
Median	12.4	13.2	17.3	18.1
75th percentile	13.7	14.2	19.8	21.1
25th percentile	11.5	11.8	14.4	14.8
Maximum	23.1	18.3	23.2	24.3
- Trial				
Minimum	3.7	3.8	3.3	5.4
Mean	11.3	10.7	13.3	14.2
Median	11.1	10.8	13.7	14.0
75th percentile	12.4	11.5	14.5	15.0
25th percentile	10.2	10.1	12.2	13.1
Maximum	23.3	17.9	23.6	24.0
- Post-Trial				
Minimum	2.6	4.1	3.4	5.5
Mean	10.9	11.1	13.1	15.9
Median	10.7	11.3	13.1	15.8
75th percentile	12.2	12.8	16.8	18.9
25th percentile	9.2	9.6	10.0	13.2
Maximum	23.4	16.9	22.7	23.6
Speed through water (knots)				
- Pre-trial				
Minimum	7.3	0.9	9.0	11.6
Mean	13.0	12.9	16.9	18.0
Median	12.5	13.2	17.4	18.2
75th percentile	13.7	14.3	19.8	21.1
25th percentile	11.5	11.8	14.4	14.7
Maximum	23.2	18.1	23.4	24.6
- Trial				
Minimum	3.8	4.1	2.8	5.4
Mean	11.3	10.7	13.2	14.1
Median	11.1	10.7	13.6	13.9
75th percentile	12.3	11.5	14.5	15.0
25th percentile	10.2	10.0	12.1	13.0
Maximum	23.8	18.1	23.4	23.4
- Post-Trial				
Minimum	2.1	4.0	3.0	5.8
Mean	10.8	11.1	13.0	15.9
Median	10.7	11.3	13.1	15.7
75th percentile	12.2	12.8	16.8	18.8
25th percentile	9.2	9.7	9.9	13.3
Maximum	23.4	16.9	22.7	23.6

To clarify the effect of the commercial vessel slowdown, restrictions on environmental conditions were employed and a small vessel detector used to remove any potential confounding noise sources. For the pre-trial period the removal of minute-wise data from periods when current exceeded 0.3 ms^{-1} totaled 3.7 % of the recordings (3274 minutes from a total of 87721 minutes of recording), with a further 46.6% of the data (40872 minutes of 84447 minutes) was removed for when wind speeds exceeded 5 ms^{-1}, and lastly 3.7% (3210 minutes of 43575) removed to exclude small vessel presence. For the trial period, the proportion of data that exceeded our current speed ceiling was much greater than the control period, at 23.9% (20951 minute from a total of 87840). Wind speed was exceeded for less time during the summer, with 35.7% of the remaining data removed to exclude high wind periods (31355 minutes from a total of 66889 minutes) during the trial, and 4.1% removed (3598 minutes of 35534 minutes). For post-trial, more winter like conditions were apparent, which resulted in a 7.0% reduction for periods exceeding the current threshold (6141 minutes from a total of 87232 minutes), a further 69.5% (60595 minutes from 81091 minutes) due to excessive winds, and 1.3% (1135 minutes from 20496 minutes) for the presence of small vessels were removed.

Current velocities differed between control and trial periods (pre-trial average 0.21 ms^{-1}, trial average 0.19ms^{-1}, $t(2729.28803)=38.982$, $p<0.001$), resulting in much greater proportion of the data being removed. Average winds speeds also significantly decreased during the trial (pre-trial average 5.10 ms^{-1}, trial average 3.74 ms^{-1} $t(271852.683)=119.924$, $p<0.001$), which resulted in proportionally more of the trial data being retained for analysis. However, the conditions in December resulted in much more data being removed for the post-trial control. Small vessel presence was proportionally greater during the trial, and the least during the post-trial period.

The SPL levels for the frequency ranges representing SRKW communication, echolocation, and vessel presence were examined before (Figure 10A) and after this data filtering process for pre-, trial, and post-trial periods (Figure 10B). Few obvious differences were seen in the communication and echolocation range between pre- and trial periods; however, levels were elevated in post-trial recordings (Figure 10, Table 5). The lower frequency ranges, especially below 100 Hz, showed greater variation between each of the periods, where SPL levels were elevated from pre-trial to trial, and then again from trial to post-trial (Figure 10).

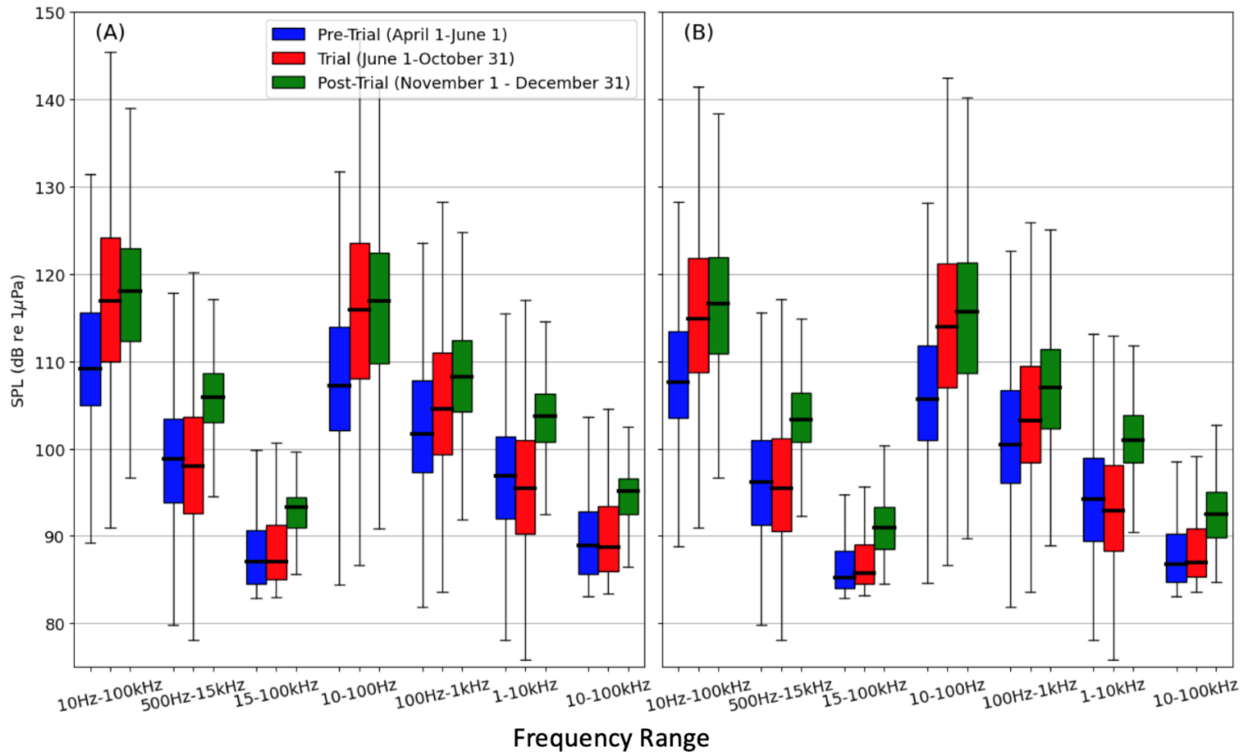

Figure 10: Sound pressure levels of the frequency ranges of interest at Swiftsure Bank as recorded (A) and with the environmental restrictions of current less than 0.3 ms^{-1},wind speed less than 5 ms^{-1}, and small vessel signatures removed (B).

The pre-trial, trial, and post-trial comparison found the median SPL levels of all the frequency ranges of interest to be significantly different in all cases (non-parametric Mann-Whitney U tests, <0.001 level). Despite the levels of participation, the broadband (10 Hz -100 kHz) band and low frequency vessel bands, thought to typically represent commercial vessels (10-100 Hz, 100-1000 Hz), showed increased SPL during the trial period compared to the pre-trial control (Figure 9, Tables 5, 6).

Minimum sound levels were decreased from pre- to trial periods, and again from trial to post-trial in most cases. Average SPL showed less variation, and maximum values between pre-trial and trial periods showed the greatest change and a consistent increase in all frequency ranges of interest (Table 6). The difference between the pre- and post-trial periods showed decreases in minimum, median, and quartile values, suggesting generally decreased ambient sound levels. The maximum values, however, were increased in excess of 4.5 dB in all cases, and up to 21.1 dB increased in the 1-10 kHz range.

Table 5: Sound pressure levels (dB re 1μPa) of the frequency ranges of SRKW relevance and representing vessel presence at Swiftsure Bank with and without the environmental restrictions of current less than 0.3 ms^{-1},wind speed less than 5 ms^{-1}, and small vessels removed.

Metric	10 Hz- 100 kHz	500Hz- 15 kHz	15- 100 kHz	10- 100	100- 1000 Hz	1000- 10000Hz	10000- 100000Hz
Without environmental restrictions							
- Pre-trial							
Minimum	88.5	79.8	82.8	82.4	81.9	78.1	83.1
Mean	129.1	115.1	103.1	128.4	120.4	112.7	105.1
Median	109.2	98.8	87.1	107.2	101.7	96.9	88.9
75^{th} percentile	115.5	103.4	90.6	114.0	107.8	101.4	92.8
25^{th} percentile	104.9	93.8	84.5	102.1	97.3	92.0	85.6
Maximum	162.3	153.7	140.7	162.2	154.9	152.1	143.6
- Trial							
Minimum	91.0	78.1	83.0	86.7	83.6	75.8	83.4
Mean	129.5	112.1	103.8	129.1	118.1	109.0	105.1
Median (P50)	116.9	98.0	87.1	115.9	104.6	95.5	88.7
75^{th} percentile	124.2	103.7	91.3	123.6	111.0	101.0	93.4
25^{th} percentile	109.9	92.6	85.1	108.0	99.4	90.3	85.9
Maximum	162.3	150.2	146.1	162.2	156.6	148.0	146.2
- Post-Trial							
Minimum	96.6	86.5	84.5	84.3	86.5	83.6	84.7
Mean	129.1	114.3	103.8	128.7	118.8	111.7	105.0
Median (P50)	118.1	105.9	93.3	117.0	108.2	103.8	95.2
75^{th} percentile	123.0	108.7	94.4	122.4	112.4	106.3	96.5
25^{th} percentile	112.3	103.0	90.9	109.8	104.2	100.8	92.5
Maximum	162.5	148.3	143.6	162.2	154.9	146.4	143.6
With restrictions: U<0.3 ms^{-1}, WSP <5 ms^{-1}, small vessel filter							
- Pre-trial							
Minimum	88.5	78.9	82.8	82.4	81.9	78.1	83.1
Mean	125.6	114.0	95.4	124.6	118.4	111.9	98.6
Median	107.6	96.2	85.2	105.7	100.4	94.3	86.8
75^{th} percentile	113.4	101.0	88.3	111.8	106.7	98.9	90.3
25^{th} percentile	103.6	91.3	84.0	101.0	96.0	89.5	84.8
Maximum	160.0	153.7	137.7	159.2	154.9	152.1	138.5
- Trial							
Minimum	91.0	78.1	83.2	86.7	83.6	75.8	83.6
Mean	126.0	107.0	94.0	125.7	114.8	103.5	95.6
Median	114.9	95.4	85.8	113.9	103.2	92.9	86.9
75^{th} percentile	121.8	101.2	89.0	121.2	110.1	99.1	91.6
25^{th} percentile	108.7	90.6	84.6	107.0	98.4	88.3	85.3
Maximum	152.3	139.7	123.9	152.3	146.6	129.8	123.9
- Post-Trial							
Minimum	96.6	87.7	84.5	86.5	86.5	84.5	84.8
Mean	126.3	110.0	95.8	120.9	114.9	107.0	97.5
Median	116.7	103.3	91.0	115.7	107.0	100.9	92.5
75^{th} percentile	121.9	106.4	93.3	121.3	111.4	103.8	95.0
25^{th} percentile	110.8	100.8	88.5	108.6	102.3	98.5	89.9
Maximum	155.5	139.4	122.5	155.3	143.2	131.0	122.5

Table 6: The difference in sound pressure levels in decibels (dB re 1μPa) between pre-trial and trial periods of the frequency ranges of SRKW relevance and representing vessel presence at Swiftsure Bank with the environmental restrictions of current less than 0.3 ms^{-1},wind speed less than 5 ms^{-1}, and small vessels removed.

Metric	10 Hz-100 kHz	500Hz-15 kHz	15-100 kHz	10-100	100-1000 Hz	1000-10000Hz	10000-100000Hz
Pre-trial to trial							
Minimum	2.5	-0.9	0.4	4.3	1.7	-2.3	0.5
Mean	0.4	-7.0	-1.4	1.1	-3.6	-8.4	-3.0
Median	7.3	-0.8	0.6	8.2	2.8	-1.4	0.1
75th percentile	8.4	0.2	0.7	9.4	3.4	0.2	1.3
25th percentile	5.1	-0.7	0.6	6.0	2.4	-1.2	0.5
Maximum	-7.7	-14.0	-13.8	-6.9	-8.3	-22.3	-14.6
Trial to post trial							
Minimum	5.6	9.6	1.3	-0.2	2.9	8.7	1.2
Mean	0.3	3.0	1.8	-4.8	0.1	3.5	1.9
Median	1.8	7.9	5.2	1.8	3.8	8.0	5.6
75th percentile	0.1	5.2	4.3	0.1	1.3	4.7	3.4
25th percentile	2.1	10.2	3.9	1.6	3.9	10.7	4.6
Maximum	3.2	-0.3	-1.4	3.0	-3.4	1.2	1.4

Reduction in SPL between the pre-trial and trial periods was not found to be consistent for any of the frequency ranges of interest (Table 6). The greatest changes between the control and trial periods were seen in the low to mid-frequencies. The greatest change was in the 1-10 kHz band, with a 22.3 dB change between maximum values seen in the trial period compared to the months prior.

Monthly median values were considered for both control and trial periods, and showed increases incrementally from April to October in the frequency ranges of 10-100 Hz and 100-1000 Hz (Figure 10). This trend of increasing low frequency noise influenced the overall ambient sound field, which mirrored this increase (10 Hz to 100 kHz, Figure 11).

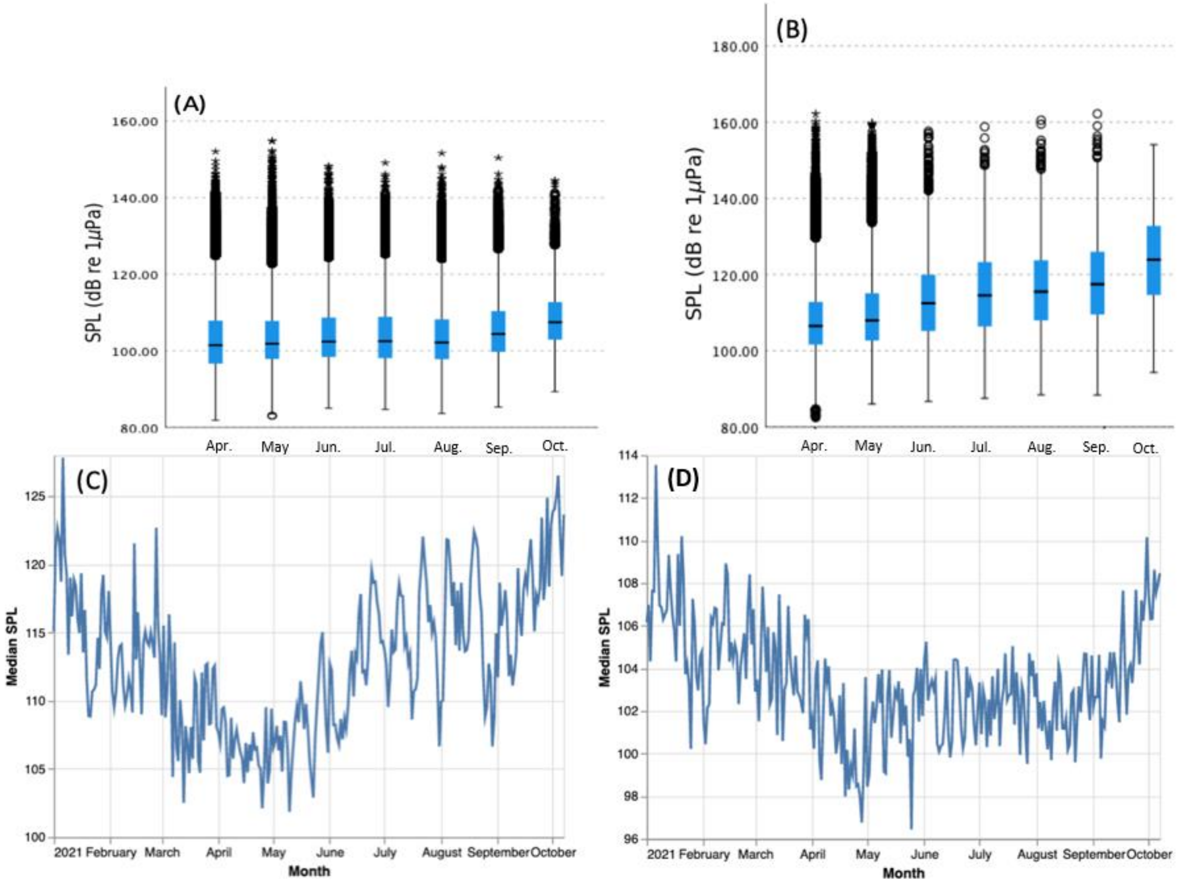

Figure 11: Swiftsure Bank monthly comparison of median, 25th and 75th percentile SPL levels (dB re 1μPa) in the frequency ranges 100-1000 Hz (A) and 10-100 Hz (B) for April to October, 2021, and minute-wise median SPL for 100-1000 Hz (C) and 10-100 Hz (D).

The measures around Swiftsure Bank and through Juan de Fuca are aimed at reducing potential acoustic disturbance for SRKW. Additions seen between control and trial periods were not as evident in the SRKW communication or echolocation bands (Figure 12, Appendix Table 1). The distribution of minute-wise sound level data showed similarities between the control and trial periods for the SRKW-relevant bands (Figure 14). The lowest SPL for 2021 recordings were observed in April and May (Figure 13). A reduction of 0.3 dB was seen in the echolocation range, however increases were seen overall for SRKW communication frequencies. These median SPL sound field changes were found to be significant between periods (Mann-Whitney U test, at the $p<0.001$ level, Figures 12-13, Table 3).

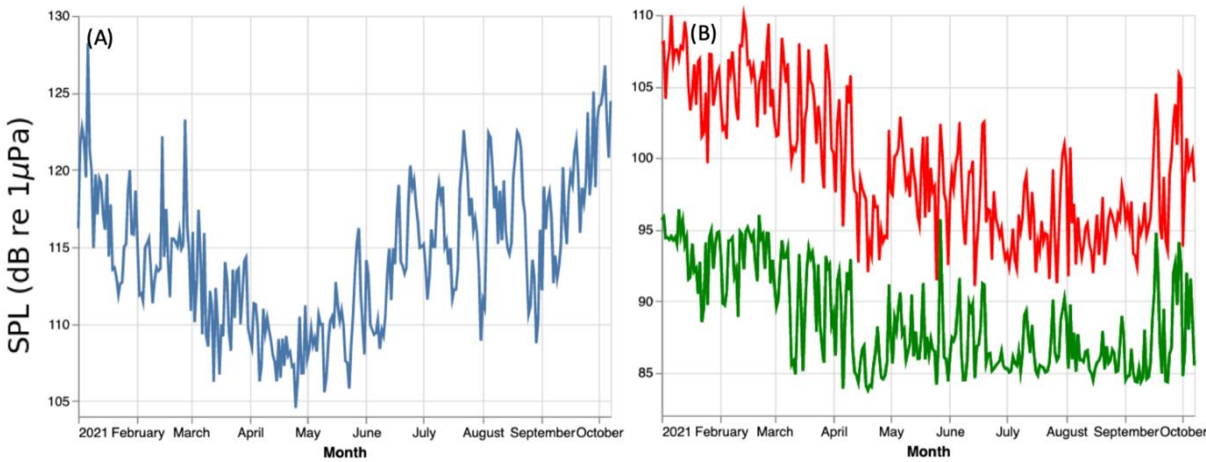

Figure 12: Swiftsure Bank median SPL (dB re 1μPa) from minute-wise data for 10 Hz to 100 kHz (A) SRKW communication (red line (B)) and SRKW echolocation (green line (B)).

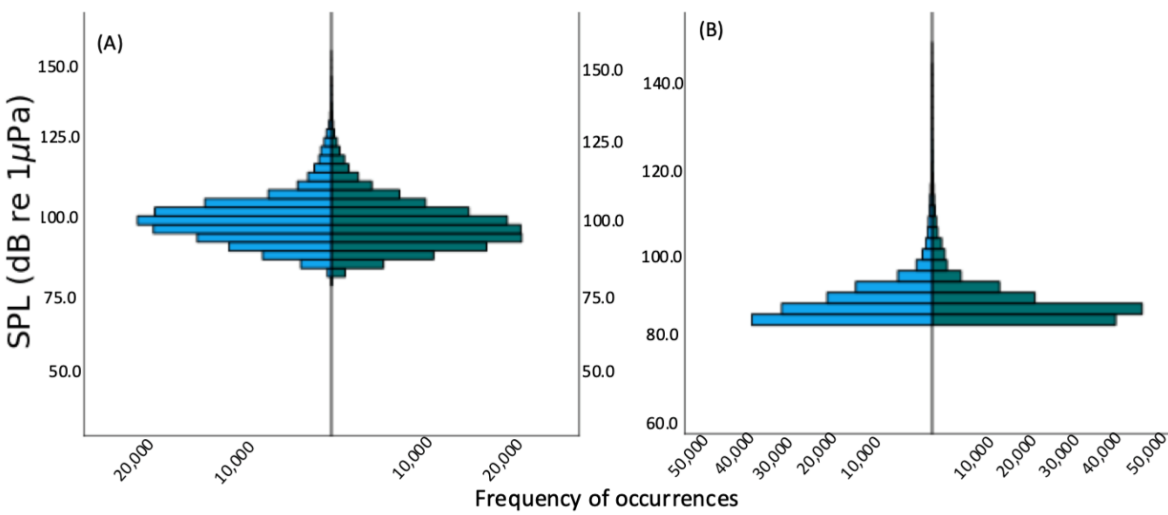

Figure 13: Swiftsure Bank distribution of SPL (dB re 1μPa) in the SRKW communication (A) and echolocation (B) ranges for pre-trial (blue, April 1- June 30, 2021) and trial (green, July 1-October 10, 2021).

The AIS data showed that the number of vessels transiting Swiftsure Bank per hour during the summer trial period was significantly increased compared to the control period (pre-trial mean = 1.61 vessels/hour, trial mean 1.95 vessels/hour; t(37540.782)=-25.844, p<0.001, Figure 14). The overall distance of their passage from the mooring, on average, was increased (pre-trial mean 28962.7m, trial mean 30662.4m; t(636474.296)=-521.916, p<0.001, Figure 14). The increase in the low-frequency noise levels (Figure 10B), and similar relative presence of vessel types across the trial and control period (Figure 8), suggested that the number of commercial vessels may have changed, therefore, passage rate per hour was considered in more detail for bulkers, tankers, containerships and vehicle carriers (Table 5). On average, vessel passage increased for bulkers, tankers and containerships during the trial compared to the control period prior (Figures 14-15). The average number of containership (t(3572.656)=-17.897, p<0.001) and tanker (t(2574.835)=-

4.012, p<0.001) passages were significantly increased during the trial period, with the CPA also generally decreased (Table 5, Figures 14-16). The number of bulkers and vehicle carriers did not show a significant change between the periods. Of the vessel types shown in Figure 14, the category shown as ‘Other’, which includes government/research, naval, recreational vessels, and ferries, increased in number and passage rate during the trial period (Figure 14). Recreational vessel use of Swiftsure Bank increased during the summer in the number of 5-minute observations made in the AIS data (Figure 14).

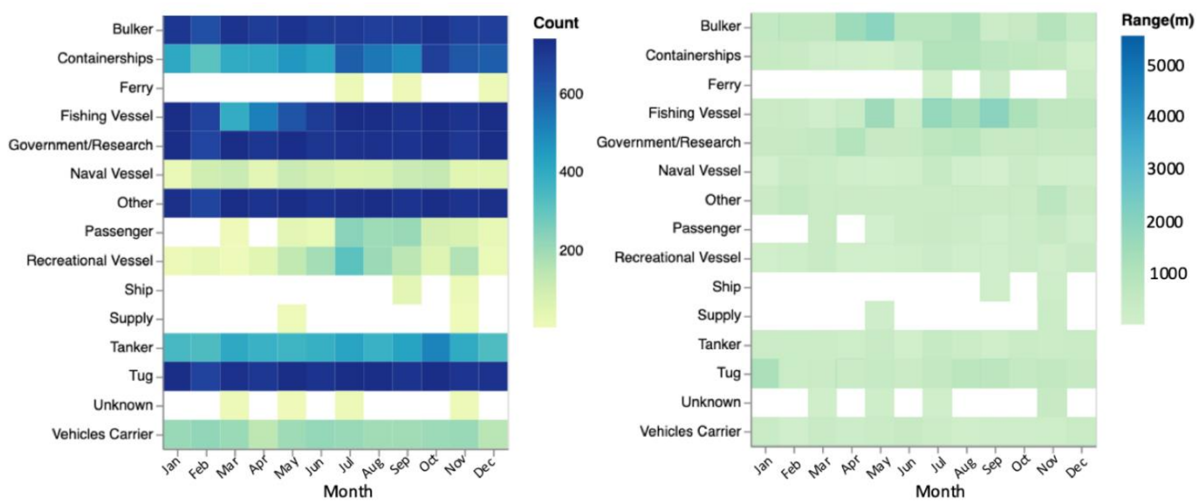

Figure 14: Monthly counts of vessel passages per vessel type (left) and average range between the passage and the Swiftsure Bank mooring in meters (right).

Furthermore, the number of 5-minute AIS records that were within 30 km of the Swiftsure Bank mooring were considered by vessel type (Figure 15, Table 7). This showed an almost linear increase from April, at the beginning of the pre-trial control period, through until the end of the trial period for AIS Class A vessels. The most notable change between periods was the presence of fishing vessels (Figure 15F). The presence of this vessel type increased during the latter part of the trial period, influenced by fisheries openings. The range of closest passage of vessels to the mooring location generally decreased during the trial period, again most notably for fishing vessels (Figure 16, Table 7).

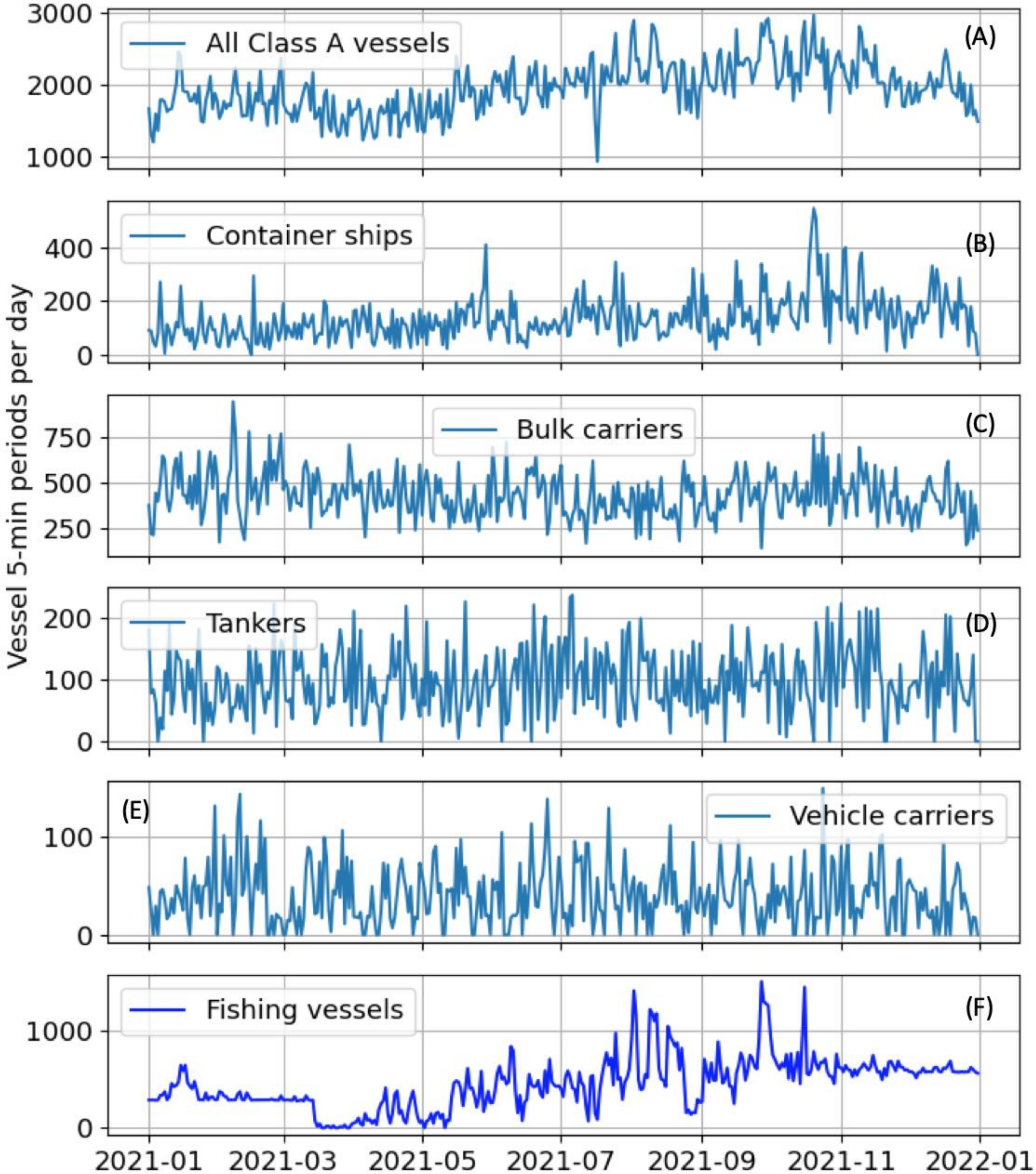

Figure 15: Number of 5-minute AIS data segments that have vessels present within 30 km from the Swiftsure Bank mooring by vessel type.

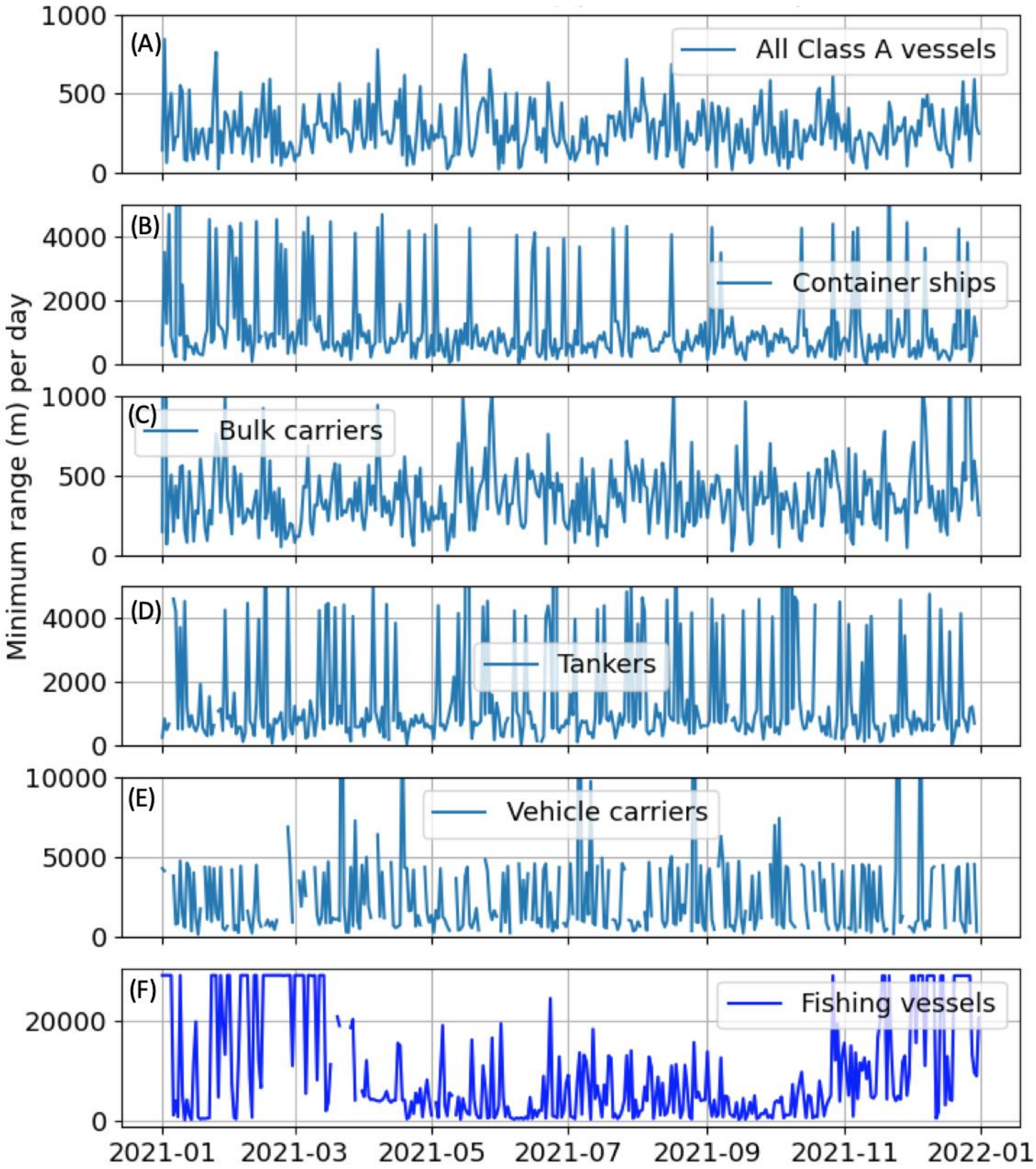

Figure 16: Range of vessels passing the Swiftsure Bank mooring at the closest point of approach for the pre- and trial period. Records shown by vessel type.

Table 7: Passage rate of vessels per hour from the cleaned 5-minute AIS data, and the distance between the vessel track and the mooring (Range, m) for pre-trial and trial periods for Swiftsure Bank slowdown.

Metric	Count	Range (m)
Bulker		
- Pre-trial		
Minimum	0.08	51.3
Mean	2.64	26108.7
Median	2.42	26290.1
Std. deviation	1.50	13969.1
Maximum	11.0	49999.7
- Trial		
Minimum	0.08	19.3
Mean	2.68	25917.6
Median	2.42	26229.0
Std. deviation	1.57	13902.5
Maximum	11.5	49999.9
Tanker		
- Pre-trial		
Minimum	0.08	58.1
Mean	1.08	25791.8
Median	1.00	26001.9
Std. deviation	0.62	13959.5
Maximum	3.92	49998.0
- Trial		
Minimum	0.08	104.9
Mean	1.17	28252.7
Median	1.00	29281.0
Std. deviation	0.70	14820.3
Maximum	4.83	49999.3
Containership		
- Pre-trial		
Minimum	0.08	188.8
Mean	1.19	30621.1
Median	1.00	28984.1
Std. deviation	0.79	11211.0
Maximum	5.00	49999.4
- Trial		
Minimum	0.08	62.2
Mean	0.86	30584.6
Median	1.00	33723.8
Std. deviation	0.29	14054.7
Maximum	1.00	49999.1
Vehicle carrier		
- Pre-trial		
Minimum	0.08	192.7
Mean	0.87	25961.7
Median	1.00	26316.5
Std. deviation	0.49	13872.0
Maximum	3.00	49995.2

- Trial		
Minimum	0.08	68.8
Mean	0.85	25611.9
Median	1.00	25323.1
Std. deviation	0.48	14081.1
Maximum	3.00	49997.1

The frequency range centered around 50 kHz (49.5-50.5 kHz) was used in addition to the AIS data to estimate the relative number of smaller/non-commercial vessels (Figure 17). The AIS data were considered to represent the minimum presence of this vessel type.

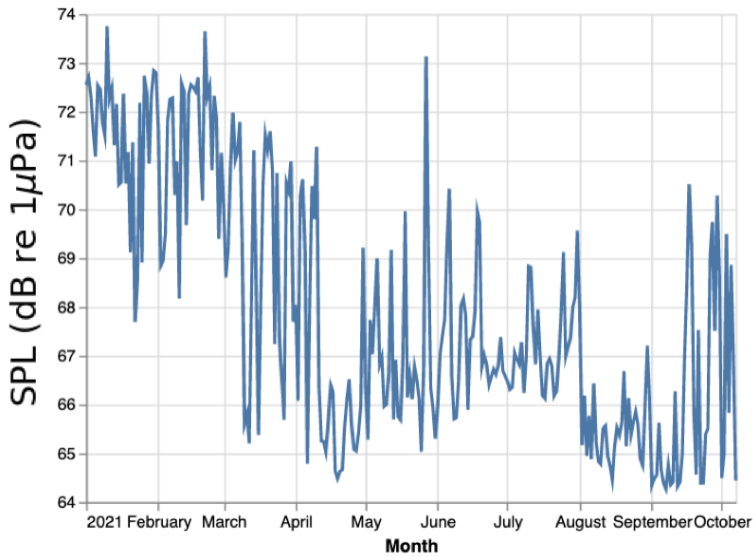

Figure 17: Median SPL (dB re 1μPa) from minute-wise data of the 49.5-50.5 kHz range at Swiftsure Bank.

Seasonal increases in this metric have been noted to represent smaller vessel presence (Burnham et al. 2021). The sound levels increased from April with distinct peaks in late May and into early June. An overall decline in SPL was seen from August onwards, with increases observed later in September and October (Figure 17). High levels prior to and during the pre-trial control period may be indicative of storm events.

The periods when bulkers, tankers, containerships, or vehicle carriers were the vessel of closest approach showed very similar SPL levels in both the control and trial periods between the vessel types (Figure 18, Table 8). The similarities between the changes in the overall sound field (Figure 10) and the acoustic comparison per vessel type (Figure 18, Table 8) suggests that the additions to the soundscape from these commercial vessel types are the predominant influence on sound field levels. The greatest increase of 9.2 dB between pre-trial and trial measures was seen when tankers were the closest vessel to the mooring (Figure 18, Table 8). Reductions in the median SPL levels for SRKW communication and echolocation were only seen when vehicle carriers were the closest vessel (3.2 dB and 0.3 dB respectively). Reductions in the higher frequency vessel metrics (1-10 kHz and 10-100 kHz) were detected for vehicle carriers and bulkers during the slowdown compared to the control period, while lower frequency metrics were elevated (Table 8).

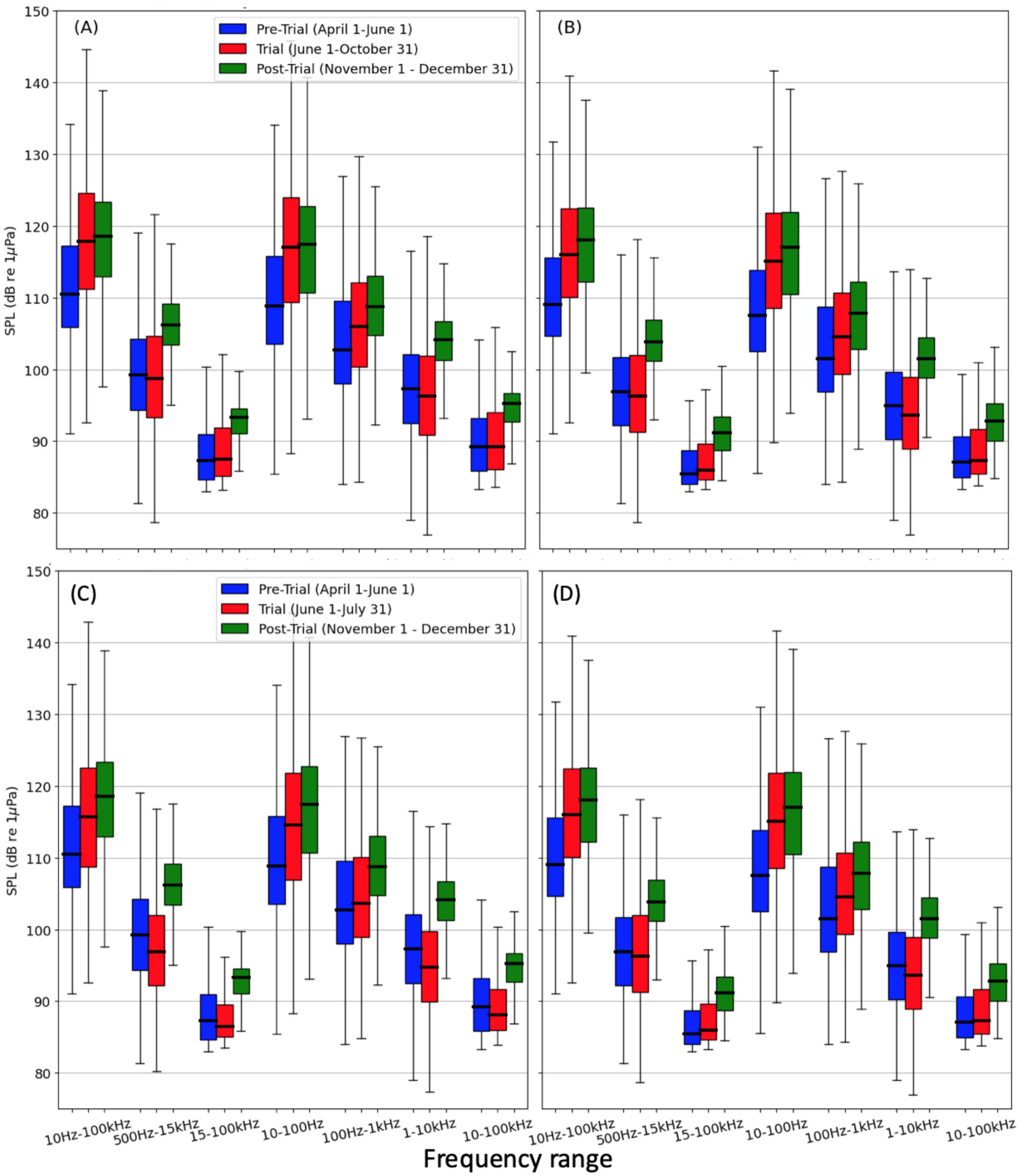

Figure 18: Sound pressure levels (dB re 1µPa) of the frequency ranges of interest at Swiftsure Bank comparing the pre-trial control (blue),trial periods (red), and post-trial (green) for Bulkers (A), Tankers (B), Containerships (C), and Vehicle carriers (D) for the broadband ambient noise (10 Hz to 100 kHz), SRKW communication (500Hz -15 kHz) and echolocation (15-100 kHz) and decadal bands.

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Table 8: Sound pressure levels (dB re 1µPa) of the frequency ranges of SRKW relevance and those representing vessel presence at Swiftsure Bank for periods when only bulkers, tankers, containership and vehicle carrier were present.

Metric	10 Hz-100 kHz	500Hz-15 kHz	15-100 kHz	10-100	100-1000 Hz	1000-10000Hz	10000-100000Hz
Bulker							
- Pre-trial							
Minimum	91.4	80.3	83.0	85.9	86.0	77.4	83.3
Mean	103.3	115.9	105.4	129.5	122.6	113.3	106.8
Median	110.3	97.8	86.5	108.8	101.9	96.1	88.4
75th percentile	118.2	104.5	90.2	116.8	110.4	102.7	92.8
25th percentile	105.4	93.0	84.6	103.3	97.4	91.2	85.7
Maximum	153.8	140.4	133.3	153.8	147.5	138.6	133.3
- Trial							
Minimum	93.5	81.7	83.5	88.8	84.4	79.3	83.8
Mean	130.0	113.9	102.7	129.4	120.8	110.8	104.4
Median	117.1	98.1	86.7	116.3	104.8	95.5	88.3
75th percentile	124.0	105.5	91.5	123.3	111.9	102.5	94.1
25th percentile	110.7	92.2	84.7	109.0	99.1	89.9	85.6
Maximum	155.2	137.4	127.3	155.0	144.8	134.7	129.2
Tanker							
- Pre-trial							
Minimum	93.3 82.7	83.2	85.4	85.4	81.3	83.6	
Mean	127.3	113.4	97.9	125.5	112.7	110.8	100.6
Median	109.5	95.7	85.9	107.7	101.1	94.3	87.4
75th percentile	117.6	103.4	90.5	116.5	109.0	101.4	93.1
25th percentile	104.7	92.2	84.5	102.4	97.0	90.5	85.5
Maximum	150.1	134.4	118.4	146.5	148.0	130.5	120.1
- Trial							
Minimum	98.0 81.0	83.6	95.7	90.0	79.0	83.9	
Mean	128.9	113.8	101.2	128.1	120.9	111.2	103.0
Median	118.7	98.1	86.6	117.6	105.4	95.5	88.3
75th percentile	126.4	105.1	91.3	125.5	113.6	102.7	93.6
25th percentile	111.4	92.3	84.9	109.8	100.0	89.9	85.9
Maximum	148.4	136.0	121.9	145.8	144.7	133.6	123.5
Containership							
- Pre-trial							
Minimum	94.1	83.3	83.1	91.2	87.5	81.5	83.5
Mean	131.5	116.9	104.7	130.7	121.7	114.9	104.2
Median	110.9	96.9	85.9	110.0	103.1	95.0	87.7
75th percentile	120.8	105.3	90.6	119.9	111.8	103.6	93.8
25th percentile	105.8	92.1	84.3	104.0	97.5	90.1	85.3
Maximum	150.7	137.3	128.4	150.3	140.1	136.2	131.5
- Trial							
Minimum	98.7	81.5	83.6	93.7	85.8	79.7	83.9
Mean	129.8	112.8	102.5	129.5	118.7	108.4	103.2
Median	118.3	98.9	86.5	117.7	104.8	96.3	88.3
75th percentile	125.6	105.7	90.9	125.1	111.5	102.8	93.6
25th percentile	112.1	93.6	84.9	110.8	99.8	90.8	85.7
Maximum	147.9	134.8	128.8	147.7	139.7	127.0	128.8

Vehicle carrier							
- Pre-trial							
Minimum	97.8	84.0	83.3	95.5	88.3	82.0	83.9
Mean	129.2	119.6	106.9	127.5	123.8	116.7	108.5
Median	111.4	99.4	86.1	108.3	104.8	97.5	88.0
75th percentile	119.7	107.7	90.4	117.8	113.3	103.9	93.0
25th percentile	106.0	94.3	84.6	103.2	100.6	92.9	85.8
Table 8 continued							
Maximum	150.4	140.7	129.8	148.9	143.9	137.7	131.2
- Trial							
Minimum	100.2	79.9	83.6	95.5	89.3	78.1	84.0
Mean	128.8	111.4	111.5	128.4	118.4	106.9	111.6
Median	117.5	96.2	85.8	117.1	104.2	93.7	87.4
75th percentile	123.8	102.5	92.3	123.4	111.6	99.8	93.7
25th percentile	113.2	90.5	84.5	112.1	99.4	88.8	85.3
Maximum	150.8	132.9	136.0	150.6	137.8	126.4	136.0

Overall increases were seen in broadband levels from trial periods when bulkers, tankers, containerships, and vehicle carriers were passing the mooring (Table 8). The decrease of average levels by 8.2 dB for vehicle carriers in the SRKW communication band (500-15,000 Hz) was the greatest reduction seen from pre-trial to trail period (Table 8).

4.1.2 Haro Strait – Boundary Pass slowdown

The Pacific Pilotage Authority reported 90% participation in the slowdown at Haro Strait and Boundary Pass in 2021. This is comparable to previous years (91% in 2020, 82% in 2019, 87% in 2018, 61% in 2017, Appendix Table 1). Of the vessels that participated, 61% of the transits came within one knot of the target speeds (ECHO 2022). SRKW were observed in the area for approximately 20% of the trial time.

Bulkers were the most frequent vessel type to transit both Haro Strait and Boundary Pass during both pre-trial and trial periods. The passage of tugs was also notable, some likely to be accompanying the bulkers. The least frequently observed were fishing vessels. The proportion of vessels labeled ‘Other’, which may include some recreational vessels, increased during the summer to peak in late June and July (Figures 19-20). The proportion of time commercial vessels were present did not alter notably between the pre-trial and trial periods. The presence of passenger vessels increased in the summer months (purple, Figures 19-20). Fishing vessels responded to fisheries opening times, and were reduced as the summer progressed (green, Figures 19-20). Only after the trial period did the overall number of AIS-tracked vessels decrease (Figures 19-20).

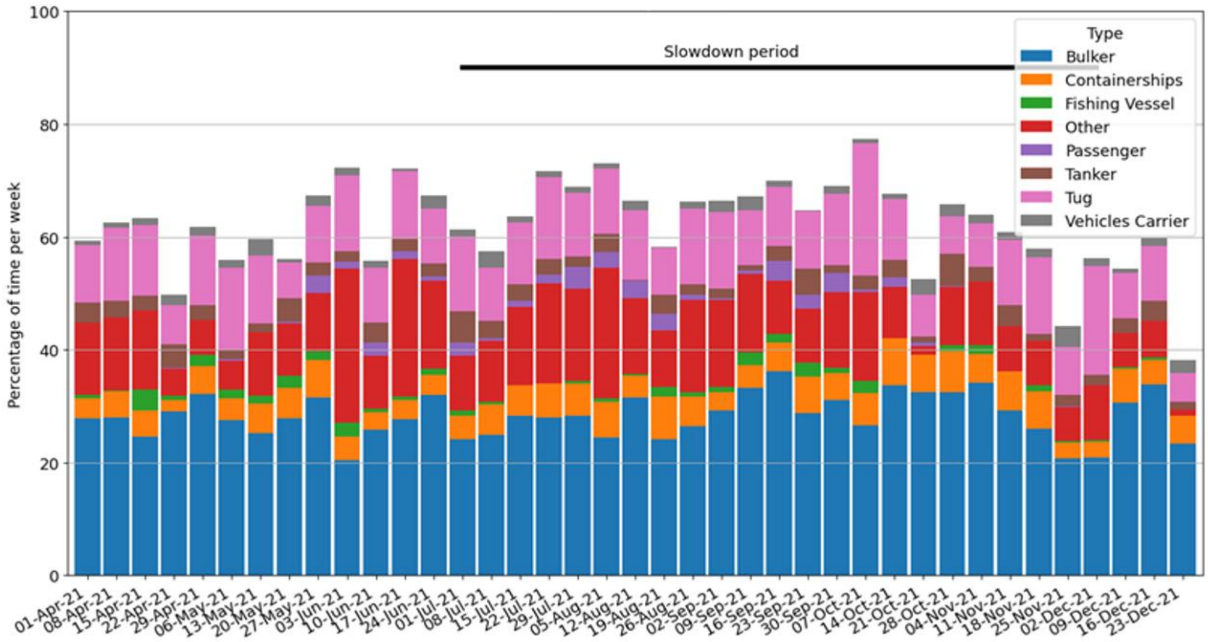

Figure 19: Proportional presence of vessel types established weekly using 5-minute data sections for pre-, during and post-trial periods, with the trial starting July 1 and running until November 30, 2021 in Haro Strait. ‘Other’ category includes recreational, government, naval vessels, and ferries.

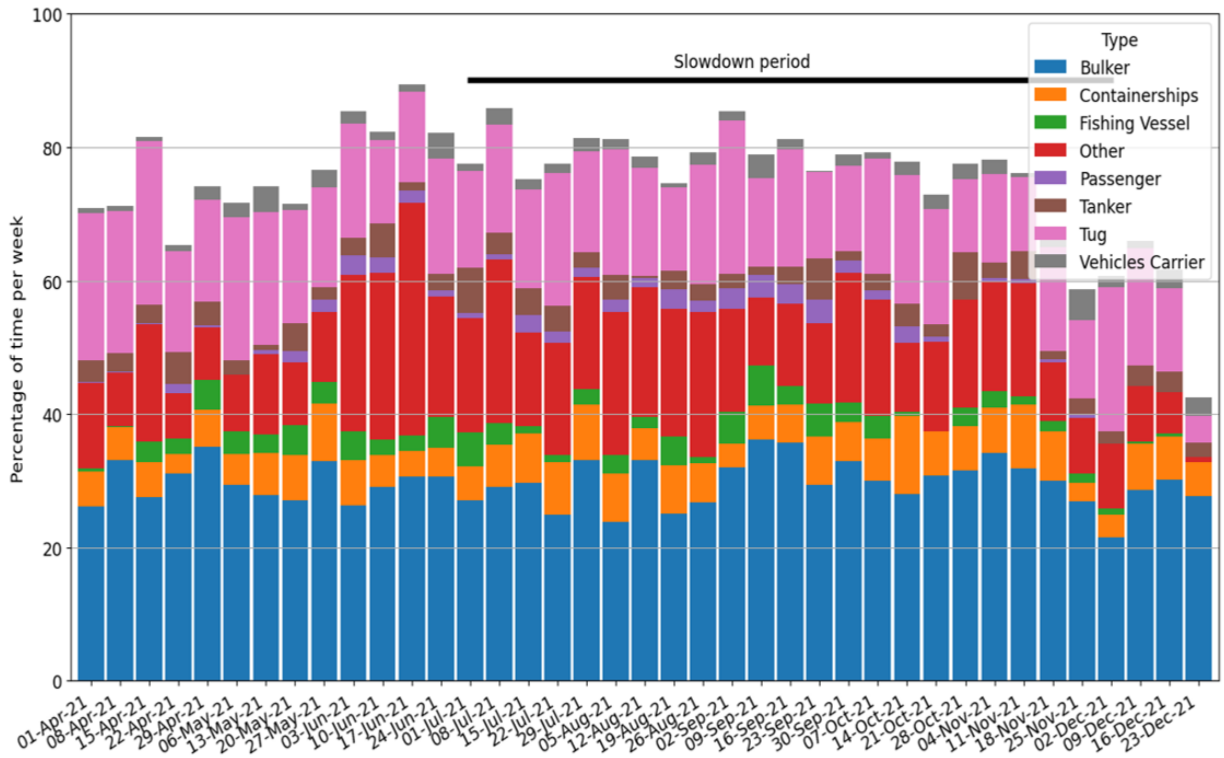

Figure 20: Proportional presence of vessel types established weekly using 5-minute data sections for pre-, during and post-trial periods, with the trial starting July 1 and running until November 30, 2021 in Boundary Pass. ‘Other’ category includes recreational, government, naval vessels, and ferries.

The SOG and STW of commercial vessels transiting both Haro Strait and Boundary Pass were examined. The reduction in speeds from pre-trial to trial periods were most notable for containerships and vehicle carriers (Figures 21-22C,D) compared to bulkers or tankers. The most dramatic change in speed was seen for containerships in both sections of the slowdown, from a peak of approximately 18 knots to the required speed (Figures 21-22). All commercial vessels showed on average at least 1 knot in speed reduction transiting through Haro Strait and Boundary Pass (Figures 19-20, Tables 9-10).

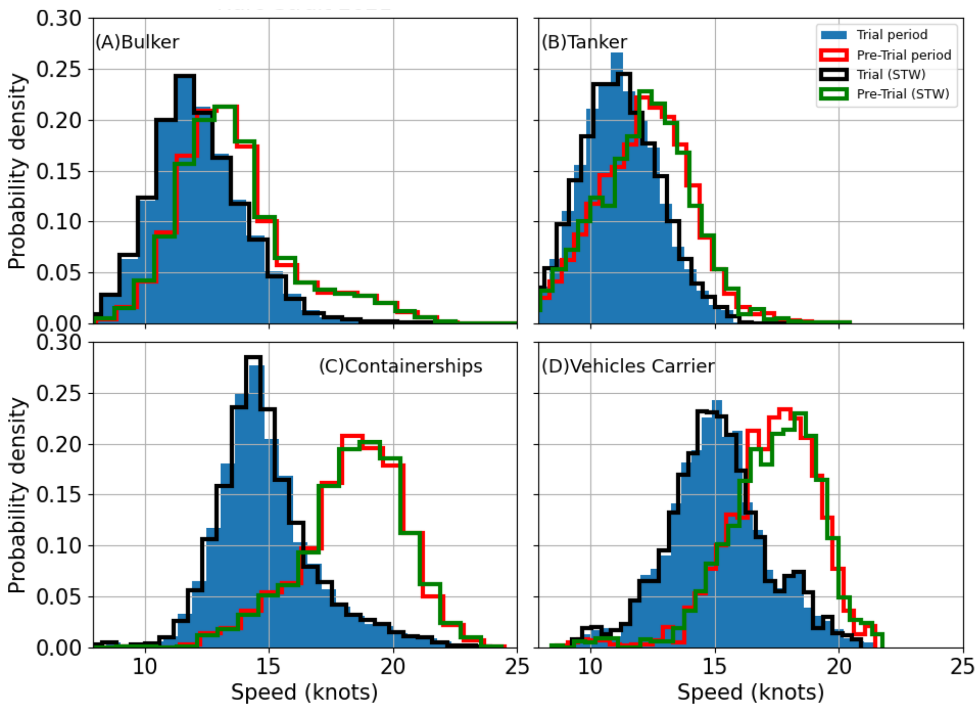

Figure 21: Proportional presence of vessel types established weekly using 5-minute data sections for pre-, during and post-trial periods, with the trial starting July 1 and running until November 30, 2021 in Boundary Pass. ‘Other’ category includes recreational, government, naval vessels, and ferries.

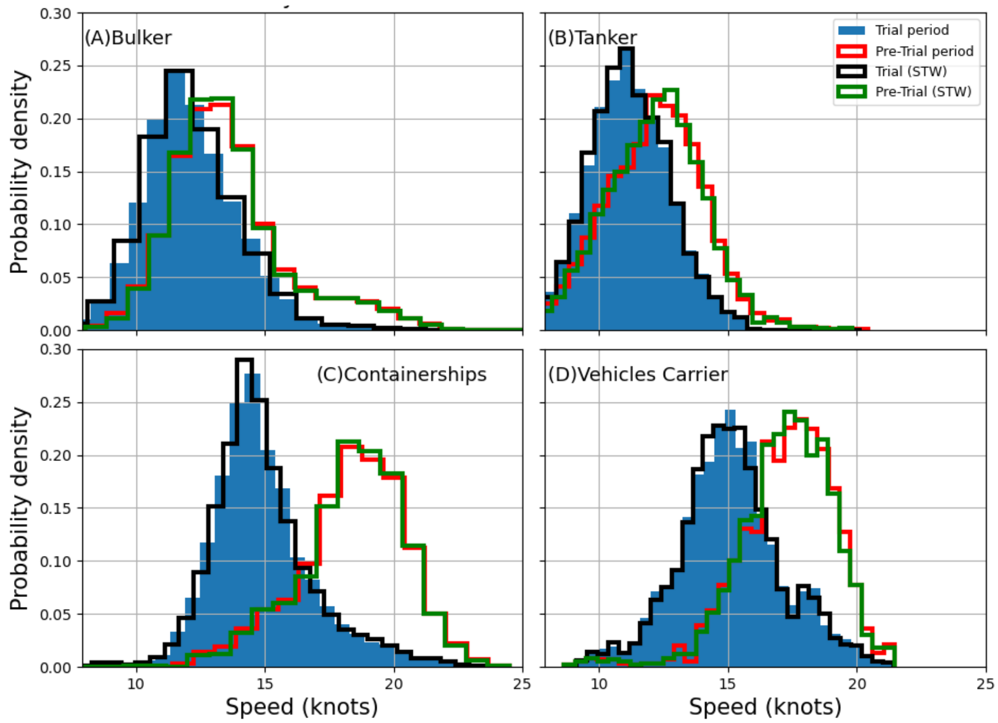

Figure 22: Comparison of the speed over ground (SOG) and speed through water (STW) of bulkers (A), tankers (B), containership (C), and vehicle carriers (D) between pre-trial and trial periods at Boundary Pass. Bulkers and tankers were requested to not travel more than 11 knots, and containerships and vehicle carriers requested to travel no more than 14 knots.

The greatest range in speed was found for containerships (Tables 9-10). On average, bulkers and tankers slowed their passage speed by 1.4 knots and 1 knot, respectively, from the control to trial periods in both SOG and STW, with STW the SOG corrected for by using the current speed and direction as recorded from an in-situ sensor on the mooring (Tables 9-10). Containership and vehicle carrier speed reduction was greater, with a 4-knot reduction on average for containerships to meet the requirement through both Haro Strait and Boundary Pass (Tables 9-10).

Table 9: Speed over ground (SOG) and speed through water (STW) metrics in knots for pre-trial and trial periods for Haro Strait section of the Haro Strait-Boundary Pass slowdown.

Metric	Bulker	Tanker	Containerships	Vehicle Carrier
Speed over ground (knots)				
- Pre-trial				
Minimum	5.6	5.3	0.0	8.6
Mean	13.6	12.2	18.3	17.3
Median	13.2	12.2	18.6	17.5
75th percentile	14.6	13.4	19.9	28.6
25th percentile	12.1	10.8	17.2	16.3
Maximum	24.4	20.4	24.5	21.5
- Trial				
Minimum	0.2	5.4	6.1	9.2
Mean	12.2	11.2	14.9	15.1
Median	12.0	11.1	14.6	15.1
75th percentile	13.3	12.2	15.8	16.3
25th percentile	10.9	10.1	13.7	13.9
Maximum	22.2	20.2	23.5	21.4
Speed through water (knots)				
- Pre-trial				
Minimum	5.5	5.5	0.0	8.4
Mean	13.6	12.2	18.3	17.4
Median	13.2	12.3	18.6	17.6
75th percentile	14.6	13.5	19.8	18.7
25th percentile	12.0	10.9	17.2	16.3
Maximum	24.5	20.5	24.4	21.8
- Trial				
Minimum	0.0	5.2	6.6	9.3
Mean	12.2	11.2	14.9	15.1
Median	12.0	11.1	14.6	15.0
75th percentile	13.3	12.2	15.8	16.2
25th percentile	10.9	10.1	13.7	13.9
Maximum	22.4	19.9	23.9	20.9

Table 10: Speed over ground (SOG) and speed through water (STW) metrics in knots for pre-trial and trial periods for Boundary Pass section of the Haro Strait-Boundary Pass slowdown.

Metric	Bulker	Tanker	Containerships	Vehicle Carrier
Speed over ground (knots)				
- Pre-trial				
Minimum	5.6	5.3	0.0	8.6
Mean	13.6	12.2	18.3	17.3
Median	13.2	12.2	18.6	17.5
75th percentile	14.6	13.4	19.9	18.6
25th percentile	12.1	10.8	17.2	16.3
Maximum	24.4	20.4	24.5	21.5
- Trial				
Minimum	0.2	5.4	6.1	9.2
Mean	12.2	11.2	14.9	15.1
Median	12.0	11.1	14.6	15.1
75th percentile	13.3	12.2	15.8	16.3
25th percentile	10.9	10.1	13.7	13.9
Maximum	22.2	20.2	23.5	21.4
Speed through water (knots)				
- Pre-trial				
Minimum	5.6	5.3	0.0	8.7
Mean	13.6	12.2	18.3	17.3
Median	13.2	12.3	18.6	17.4
75th percentile	14.6	13.4	19.8	18.5
25th percentile	12.1	10.9	17.2	16.3
Maximum	24.3	19.8	24.5	21.5
- Trial				
Minimum	0.1	5.4	6.6	9.1
Mean	12.2	11.2	14.9	15.1
Median	12.0	11.1	14.6	15.0
75th percentile	13.2	12.2	15.8	16.2
25th percentile	10.9	10.1	13.7	13.9
Maximum	30.3	20.2	23.5	21.4

Periods of high winds and currents were removed for the analysis, as were times when the small vessel detector suggested their presence. For Haro Strait during the pre-trial period, 22.1% of the data was removed (28943 minutes of a total 130679 minutes) for periods when current exceeded 0.3 ms^{-1} t. A further 21.4% (28026 minutes of 101736 minutes) were removed for wind speeds exceeding 5 ms^{-1}. Small vessels were indicated 5.2% of the time (6804 of 73710) and so these periods were also removed. During the trial period, 24.8% of one-minute data segments (54491 minutes from a total of 219959) were removed for the current threshold being exceeded, 41.5% of the remaining data was removed (68709 minutes of 165468) for exceeding the low wind threshold, and then 13.6% removed through small vessel presence being indicated (29853 minutes out of the 96759 minutes remaining). The amount of data removed due to high current was similar, yet during the trial period higher wind resulted in almost double the proportion of data being removed. The presence of small vessels in the recordings was also elevated during the summer months of the trial.

The SPL of the frequency ranges of interest, including frequency bands representing SRKW communication, echolocation and vessel presence were examined before (Figure 23A) and after the data filtering process (Figure 23B, Appendix Table 1). Few differences were seen, however, typically sound levels were elevated during the trial period when compared to the pre-trial. The difference between the pre- and trial periods was lessened when data from times with higher wind speeds, current speeds, and small vessel presence were removed (Figure 23, Table 11).

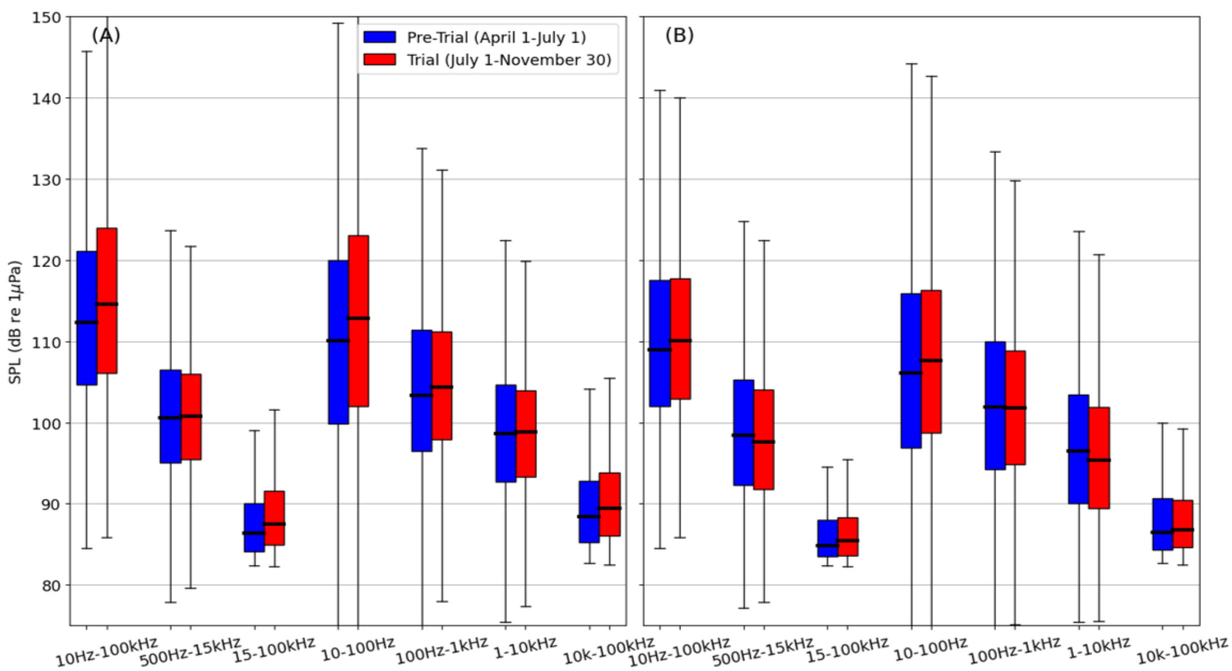

Figure 23: Sound pressure levels (dB re 1μPa) of the frequency ranges of interest at Haro Strait as recorded (A) and with the environmental restrictions of current less than 0.3 ms^{-1}, wind speed less than 5 ms^{-1}, and periods indicating the presence of small vessels removed (B).

Despite the levels of participation, and the rate of occurrence of commercial vessels that reduced their speed during the trial, the ambient noise (10 Hz -100 kHz) and low frequency vessel bands, thought to typically represent these vessels (10-100 Hz, 100-1000 Hz), increased during the trial period compared to the pre-trial control (Figure 23, Tables 11-12).

Table 11: Sound pressure levels (dB re 1μPa) of the frequency ranges of SRKW relevance and representing vessel presence at Haro Strait section of the Haro Strait-Boundary Pass slowdown with and without the environmental restrictions of current less than 0.3 ms^{-1} and wind speed less than 5 ms^{-1}.

Metric	10 Hz-100 kHz	500Hz-15 kHz	15-100 kHz	10-100	100-1000 Hz	1000-10000Hz	10000-100000Hz
Without environmental restrictions							
- Pre-trial							
Minimum	84.6	77.2	82.4	73.0	72.7	75.4	82.7
Mean	125.5	110.0	95.1	124.9	116.1	107.7	97.6
Median	112.3	100.6	86.3	110.1	103.3	98.7	88.4
75th percentile	121.1	106.5	90.1	119.9	111.4	104.6	92.8
25th percentile	104.6	95.0	84.1	99.8	96.5	92.7	85.2
Maximum	152.0	135.9	130.1	152.0	146.4	134.9	130.1
- Trial							
Minimum	85.9	77.8	82.2	74.3	75.1	75.5	82.5
Mean	129.6	108.7	94.1	129.5	114.5	106.0	96.9
Median (P50)	114.5	100.8	87.5	112.8	104.4	98.8	89.4
75th percentile	123.9	105.9	91.6	123.1	111.2	103.9	93.8
25th percentile	106.1	95.4	84.9	102.0	97.9	93.3	86.0
Maximum	154.7	137.9	124.8	154.7	145.1	129.4	137.8
With restrictions: U<0.3 ms^{-1}, WSP <5 ms^{-1}							
- Pre-trial							
Minimum	84.6	77.2	82.4	73.0	72.7	75.4	82.7
Mean	123.5	109.0	92.3	122.8	115.2	106.4	95.2
Median	109.0	98.4	84.9	106.1	101.9	96.4	86.5
75th percentile	117.5	105.3	88.0	115.9	109.9	103.4	90.6
25th percentile	102.0	92.3	83.5	96.9	94.2	90.0	84.4
Maximum	147.8	133.6	118.2	147.8	139.5	128.1	120.1
- Trial							
Minimum	85.9	77.8	82.2	74.3	75.1	75.5	82.5
Mean	122.0	107.4	92.5	121.4	113.5	104.5	94.5
Median	110.1	97.6	85.4	107.6	101.8	95.4	94.5
75th percentile	117.8	104.0	88.3	116.3	108.8	101.9	90.5
25th percentile	102.9	91.8	83.6	98.7	94.8	89.4	84.7
Maximum	152.1	134.2	121.4	152.1	142.6	128.0	121.4

The change in SPL from pre- to trial periods did not consistently show a reduction in sound levels. Reductions between the control and trial were seen in the low and mid-frequency decadal bands (100-1000 Hz, 500-15000 Hz, Table 12). However, increases in SPL were seen overall in the broadband range, in the very lowest frequencies (10-100 Hz) and highest frequencies considered (10-100 kHz, 15-100 kHz, Table 12).

Table 12: The difference in sound pressure levels in decibels (dB re 1μPa) between pre-trial and trial periods of the frequency ranges of SRKW relevance and representing vessel presence at the Haro Strait section of the Haro Strait-Boundary Pass slowdown with the environmental restrictions of current less than 0.3 ms^{-1},wind speed less than 5 ms^{-1}, and small vessels removed.

Metric	10 Hz-100 kHz	500Hz-15 kHz	15-100 kHz	10-100	100-1000 Hz	1000-10000Hz	10000-100000Hz
Minimum	1.3	0.6	-0.2	1.3	2.4	0.1	-0.2
Mean	-1.5	-1.6	0.2	-1.4	-1.7	-1.9	-0.7
Median	1.1	-0.8	0.5	1.5	-0.1	-1.0	8.0
75th percentile	0.3	-1.3	0.3	0.4	-1.1	-1.5	-0.1
25th percentile	0.9	-0.5	0.1	1.8	0.6	-0.6	0.3
Maximum	4.3	0.6	3.2	4.3	3.1	-0.1	1.3

The acoustic data available for analysis at Boundary Pass was substantially reduced by the high current conditions in the area. Of the 87685 minute-long data periods in the pre-trial period, 28637 (32.7%) were removed as current exceeded 0.3 ms^{-1} t. Of this, 10.7% (9363 minutes of 59048) and 6.2% further removed because of the presence of small vessels being indicated (5444 minutes of 49685). During the trial period 30.0% of the data were removed (65890 minutes of 219445 total). From this, 29.8% (45828 minutes of 153555 minutes) were removed for high wind (>5 ms^{-1}) conditions, and finally 5444 minutes (6.2% of the remaining 107727 minutes) were removed due to small vessel presence.

The SPL of the frequency ranges of interest, including representing SRKW communication and echolocation, and vessel presence were examined before (Figure 10A) and after the data filtering process (Figure 24B). Few differences were seen, however typically sound levels were elevated during the trial period compared to the pre-trial. The difference between the pre- and trial period was lessened when data of periods with higher winds and currents, and small vessel presence was removed (Figure 24, Table 13).

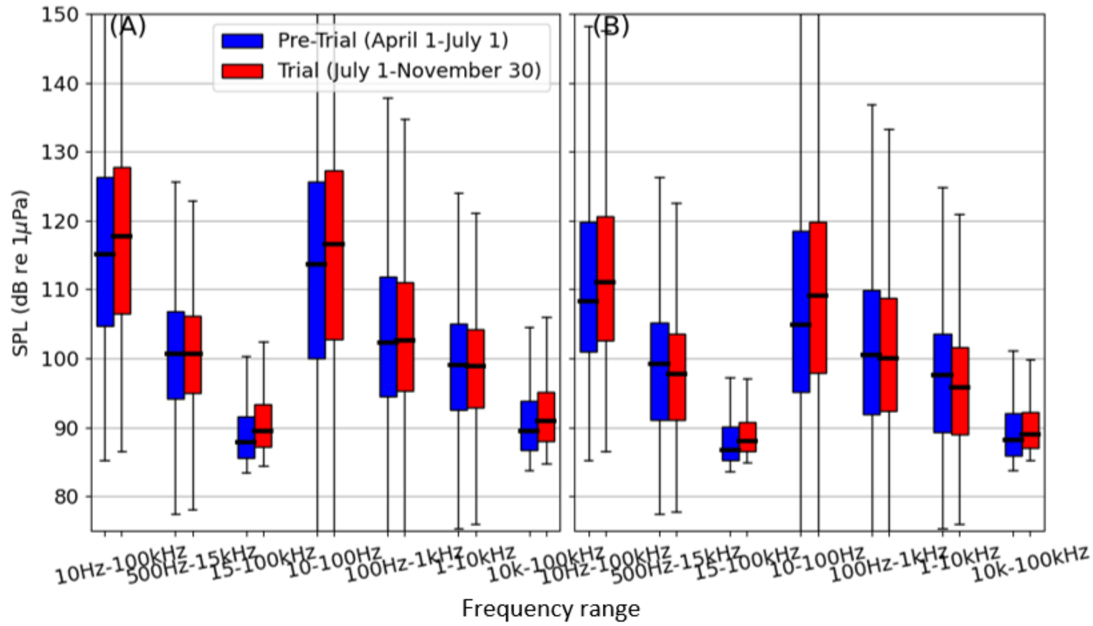

Figure 24: Sound pressure levels (dB re 1μPa) of the frequency ranges of interest at the Boundary Pass section of the Haro Strait-Boundary Pass slowdown as recorded (A) and with the environmental restrictions of current less than 0.3 ms^{-1}, wind speed less than 5 ms^{-1}, and periods indicating the presence of small vessels removed (B).

The SPL recorded in Boundary Pass were similar to those in Haro Strait. The maximum values, however, were greater at Boundary Pass compared to Haro Strait, likely due to the positioning of the recorder directly under the shipping lane.

Despite the levels of participation, and the rate of occurrence of commercial vessels that reduced their speed during the trial, the ambient noise (10 Hz -100 kHz) and low frequency vessel bands, thought to typically represent these vessels (10-100 Hz, 100-1000 Hz), increased during the trial period compared to the pre-trial control (Figure 24, Tables 13-14).

Table 13: Sound pressure levels (dB re 1 μPa) of the frequency ranges of SRKW relevance and representing vessel presence at the Boundary Pass section of the Haro Strait-Boundary Pass slowdown with and without the environmental restrictions of current less than 0.3 ms^{-1}, wind speed less than 5 ms^{-1}, and small vessels removed.

Metric	10 Hz-100 kHz	500Hz-15 kHz	15-100 kHz	10-100	100-1000 Hz	1000-10000Hz	10000-100000Hz
Without environmental restrictions							
- Pre-trial							
Minimum	85.2	77.4	83.4	73.0	72.4	75.4	83.7
Mean	133.7	115.4	102.0	133.5	119.6	112.9	106.4
Median	115.1	100.6	87.8	113.6	102.3	99.0	89.4
75th percentile	126.3	106.8	91.5	125.7	111.8	105.1	93.8
25th percentile	104.7	94.2	85.6	100.0	94.5	92.5	86.6
Maximum	160.8	151.9	134.2	160.4	152.3	150.7	147.1
- Trial							
Minimum	86.6	77.8	84.5	74.2	73.5	76.0	84.8
Mean	134.6	113.3	102.1	134.5	117.7	110.8	103.5
Median (P50)	117.7	100.6	89.5	116.6	103.6	98.8	90.9
75th percentile	127.7	106.1	93.3	127.3	111.0	104.2	95.2
25th percentile	106.5	94.9	87.1	102.8	95.2	92.9	88.0
Maximum	163.2	153.4	145.6	162.0	155.9	150.8	145.6
With restrictions: U<0.3 ms^{-1}, WSP <5 ms^{-1}							
- Pre-trial							
Minimum	85.2	77.4	83.5	73.0	72.4	75.4	83.8
Mean	130.0	112.7	96.0	129.8	117.4	110.0	105.1
Median	108.3	99.1	86.7	104.8	100.5	97.6	88.1
75th percentile	119.8	105.2	90.0	118.5	109.9	103.5	92.0
25th percentile	100.9	91.0	85.2	95.1	91.9	89.3	85.9
Maximum	160.8	148.4	125.8	160.3	150.2	145.4	147.1
- Trial							
Minimum	86.6	77.8	84.9	74.2	73.5	76.0	85.2
Mean	129.6	109.9	95.7	129.4	115.8	107.3	98.1
Median	111.1	97.8	87.9	109.1	100.0	95.8	88.9
75th percentile	120.6	103.6	90.7	119.8	108.8	101.7	92.2
25th percentile	102.7	91.0	86.5	98.0	92.4	88.9	87.1
Maximum	157.4	140.0	124.3	157.4	147.7	135.8	134.8

The change in SPL from pre- to trial periods did not consistently show a reduction in levels. The frequency ranges most frequently showing reductions were again the mid- to high-frequencies. These also showed some of the greatest changes between the control and trial periods (100-1000 Hz, 1-10 kHz, Table 14).

Table 14: The difference in sound pressure levels in decibels (dB re 1 μPa) between pre-trial and trial periods of the frequency ranges of SRKW relevance and representing vessel presence at the Boundary Pass section of the Haro Strait-Boundary Pass slowdown with the environmental restrictions of current less than 0.3 ms^{-1}, wind speed less than 5 ms^{-1}, and small vessels removed.

Metric	10 Hz-100 kHz	500Hz-15 kHz	15-100 kHz	10-100	100-1000 Hz	1000-10000Hz	10000-100000Hz
Minimum	1.4	0.4	1.4	1.2	1.1	0.6	1.4
Mean	-0.4	-2.8	-0.3	-0.4	-1.6	-2.7	-7.0
Median	2.8	-1.3	1.2	4.3	-0.5	-1.8	0.8
75th percentile	0.8	-1.6	0.7	1.3	-1.1	-1.8	0.2
25th percentile	1.8	0.0	1.3	2.9	0.5	-0.4	1.2
Maximum	-3.4	-8.4	-1.5	-2.9	-2.5	-9.6	-12.3

The periods when bulkers, tankers, container ships, or vehicle carriers were the vessel of closest approach showed very similar SPL for both the control and trial periods between the vessel types (Figures 25-26). The similarities between the changes in the overall sound field (Figure 24) and the acoustic comparison per vessel type (Figures 25-26, Tables 15-16) suggests that it is the additions to the soundscape from these commercial vessel types that are the predominant influence on sound field levels. Reductions in Haro Strait were most consistently seen for vehicle carriers, with reductions in excess of 5 dB in some cases (Figure 25, Table 15). Reductions in SPL were not as great for the Boundary Pass recordings (Figure 26, Table 16). At this location the greatest reductions in median levels were during the transit of tankers, whereas the greatest change in the maximum levels were seen for bulkers (Figure 26, Table 16) from pre-trial to trial periods.

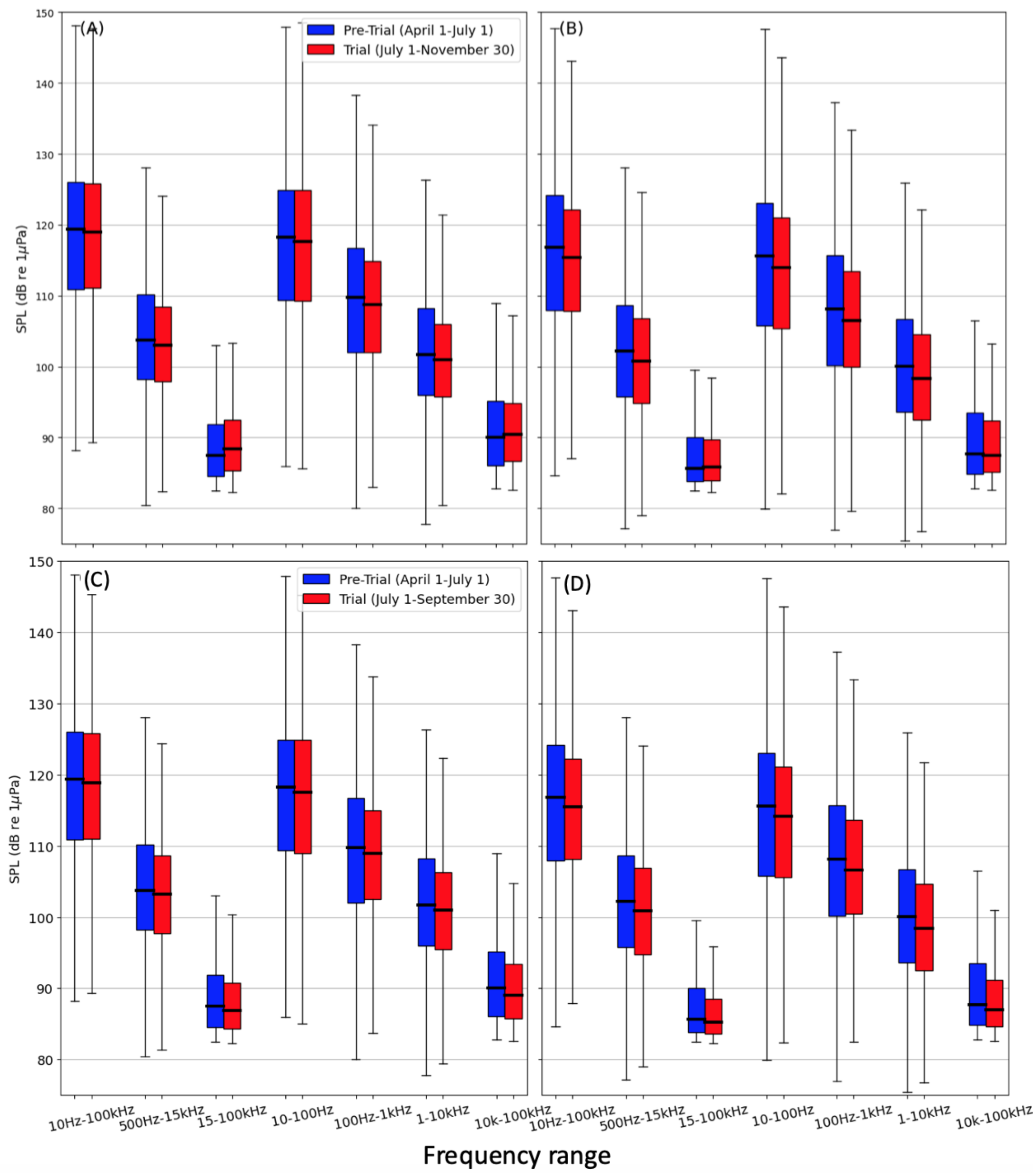

Figure 25: Sound pressure levels (dB re 1 μPa) of the frequency ranges of interest in Haro Strait comparing the pre-trial control (blue) and trial periods (red) for Bulkers (A), Tankers (B), Containerships (C), and Vehicle carriers (D) within the broadband ambient noise (10 Hz to 100 kHz), SRKW communication (500Hz -15 kHz) and echolocation (15-100 kHz), and decadal bands.

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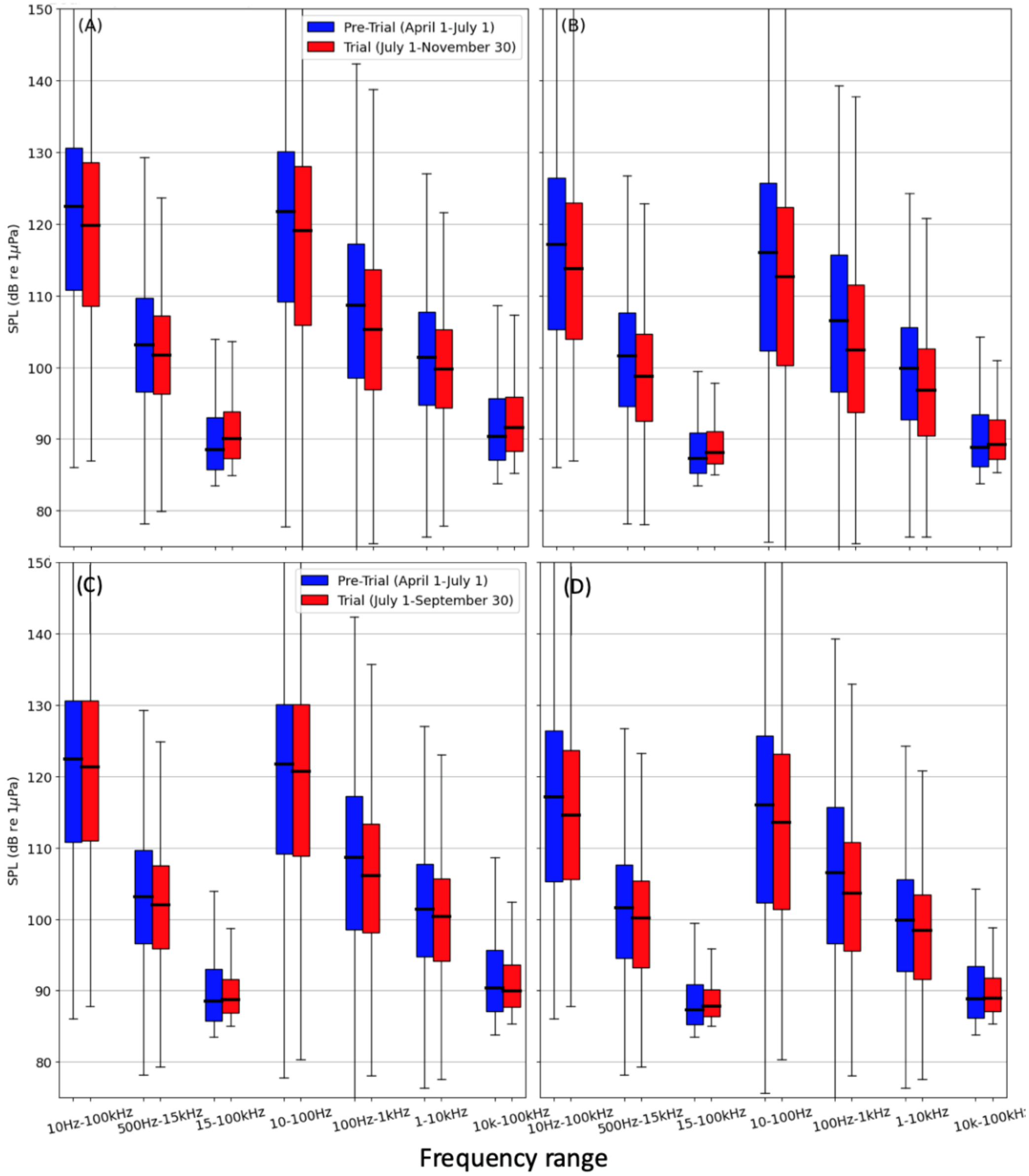

Figure 26: Sound pressure levels (dB re 1 μPa) of the frequency ranges of interest in Boundary Pass comparing the pre-trial control (blue) and trial periods (red) and post-trial (green) for Bulkers (A), Tankers (B), Containerships (C), and Vehicle carriers (D) within the broadband ambient noise (10 Hz to 100 kHz), SRKW communication (500Hz - 15 kHz) and echolocation (15-100 kHz), and decadal bands.

Table 15: Sound pressure levels (dB re 1 μPa) of the frequency ranges of SRKW relevance and representing vessel presence at Haro Strait for periods when bulkers, tankers, containerships, and vehicle carriers are the vessels present.

Metric	10 Hz-100 kHz	500Hz-15 kHz	15-100 kHz	10-100	100-1000 Hz	1000-10000Hz	10000-100000Hz
Bulker							
- Pre-trial							
Minimum	84.6	77.2	82.5	73.0	73.1	75.5	82.8
Mean	126.4	111.1	94.3	125.6	118.4	108.3	97.4
Median	116.9	102.1	85.5	115.8	108.0	99.9	87.5
75th percentile	124.1	108.0	89.6	123.0	115.5	105.9	92.9
25th percentile	108.1	95.6	83.8	105.9	100.3	93.5	84.8
Maximum	147.6	130.6	112.9	147.6	137.2	125.9	116.5
- Trial							
Minimum	87.9	79.3	82.3	80.3	79.0	76.8	82.6
Mean	124.5	109.4	93.7	123.7	116.5	106.1	96.0
Median	115.7	100.5	85.8	114.5	106.4	98.1	87.3
75th percentile	122.3	106.4	89.4	121.3	113.3	104.1	91.9
25th percentile	107.8	94.5	83.9	105.7	99.8	92.4	85.2
Maximum	143.1	129.9	116.1	142.9	142.6	126.2	116.5
Tanker							
- Pre-trial							
Minimum	91.1	80.8	82.5	80.8	84.5	78.0	82.9
Mean	125.8	111.5	93.1	125.0	118.3	107.0	96.1
Median	115.3	100.7	85.2	112.1	107.7	98.5	87.2
75th percentile	122.6	106.6	90.7	120.3	115.9	105.0	93.0
25th percentile	106.5	94.7	83.5	103.5	98.4	92.2	84.4
Maximum	145.5	131.8	106.4	145.5	132.1	120.4	110.4
- Trial							
Minimum	90.0	83.1	82.4	75.7	82.5	80.7	82.7
Mean	124.6	109.3	94.4	124.0	116.4	106.5	96.8
Median	114.5	101.1	86.3	112.3	107.3	98.9	88.3
75th percentile	120.9	106.9	90.3	119.2	113.7	104.7	93.2
25th percentile	107.9	96.2	84.1	103.9	101.2	94.1	85.6
Maximum	143.6	123.8	110.0	143.6	130.1	120.6	112.8
Containership							
- Pre-trial							
Minimum	87.0	80.9	82.6	75.6	74.7	79.5	83.0
Mean	127.0	113.6	96.6	126.3	118.7	111.6	100.0
Median	116.7	103.1	86.0	115.3	107.7	101.2	88.6
75th percentile	125.1	112.8	92.3	123.8	116.4	110.5	96.2
25th percentile	107.7	96.7	83.8	105.5	100.2	94.5	85.2
Maximum	144.3	127.0	113.5	144.1	133.9	125.5	116.2
- Trial							
Minimum	87.1	79.0	82.3	77.5	76.9	77.2	82.6
Mean	124.9	109.4	96.5	124.3	116.2	107.1	98.0
Median	114.9	102.0	86.2	113.2	106.5	100.0	88.1
75th percentile	121.9	108.3	91.1	120.7	114.0	105.7	94.1
25th percentile	107.7	95.4	83.7	104.9	99.4	92.8	85.0
Maximum	142.6	123.2	120.4	142.5	137.1	122.1	120.4

Vehicle carrier							
- Pre-trial							
Minimum	91.9	85.0	82.5	86.0	88.1	83.2	82.9
Mean	128.4	112.2	95.1	127.8	119.5	109.6	97.7
Median	119.4	103.6	86.6	118.2	110.8	101.6	89.2
75th percentile	125.6	111.3	92.3	124.5	117.7	109.3	95.2
25th percentile	109.1	96.4	84.1	108.2	102.1	94.2	85.4
Table 15 continued							
Maximum	141.9	125.7	108.2	141.9	132.3	122.3	110.4
- Trial							
Minimum	90.6	85.4	82.5	82.7	83.4	82.0	82.9
Mean	122.9	107.6	92.8	121.9	116.3	104.8	94.5
Median	114.7	99.7	85.8	113.0	105.3	97.2	87.6
75th percentile	121.0	106.2	88.9	119.9	112.6	103.4	91.5
25th percentile	107.5	94.7	83.6	105.7	98.2	92.0	84.8
Maximum	136.6	119.8	104.4	136.5	130.0	118.2	106.4

Table 16: Sound pressure levels (dB re 1 μPa) of the frequency ranges of SRKW relevance and representing vessel presence at Boundary Pass for periods when bulkers, tankers, containerships, and vehicle carriers are the vessels present.

Metric	10 Hz-100 kHz	500Hz-15 kHz	15-100 kHz	10-100	100-1000 Hz	1000-10000Hz	10000-100000Hz
Bulker							
- Pre-trial							
Minimum	86.1	78.2	83.5	75.6	73.7	76.3	83.3
Mean	132.1	112.1	96.7	131.9	119.4	109.2	99.0
Median	115.7	100.9	87.3	114.8	105.2	99.2	88.8
75th percentile	126.0	106.7	90.8	125.2	114.8	104.7	93.2
25th percentile	104.4	93.6	85.2	101.2	95.6	91.8	86.1
Maximum	154.6	135.9	120.6	154.6	139.3	129.5	122.1
- Trial							
Minimum	87.0	78.1	85.0	74.9	75.4	76.3	85.3
Mean	128.6	109.5	95.8	128.4	116.3	106.8	97.6
Median	111.9	97.7	88.0	110.5	100.4	95.9	88.9
75th percentile	121.7	103.4	90.7	121.1	109.7	101.6	92.1
25th percentile	102.8	91.4	86.5	98.4	92.7	89.3	87.1
Maximum	152.5	135.2	121.6	152.5	139.8	131.6	122.8
Tanker							
- Pre-trial							
Minimum	94.4	81.5	83.6	80.8	84.7	78.9	84.1
Mean	130.4	113.0	97.4	129.8	121.6	109.3	100.0
Median	119.3	103.9	86.6	116.9	112.1	101.4	88.4
75th percentile	126.2	108.1	90.4	124.2	120.2	106.2	93.7
25th percentile	110.8	97.6	85.1	106.9	102.0	96.5	86.1
Maximum	144.1	131.3	115.4	144.2	137.0	125.6	117.9
- Trial							
Minimum	93.1	83.6	85.1	85.4	83.2	82.2	85.4
Mean	129.5	113.4	99.4	128.8	121.3	110.8	101.4
Median	119.5	104.5	88.9	117.9	111.0	101.9	90.5
75th percentile	125.5	110.2	93.1	124.0	117.5	107.8	95.9
25th percentile	113.8	98.5	86.8	111.4	104.8	96.2	87.9

Maximum	148.8	127.2	115.5	148.8	134.5	125.0	117.6
Containership							
- Pre-trial							
Minimum	90.3	78.8	83.7	85.1	79.2	77.0	84.0
Mean	131.2	115.1	99.9	130.8	120.8	113.0	102.8
Median	121.7	105.4	87.3	120.5	112.2	103.2	89.5
75th percentile	128.6	111.8	92.0	127.8	118.0	110.0	96.4
25th percentile	113.8	98.7	85.3	112.6	104.6	96.8	86.5
Maximum	147.0	130.8	118.5	147.0	138.1	127.7	120.5
- Trial							
Minimum	96.2	84.0	85.0	86.1	87.8	80.2	85.3
Mean	132.0	113.6	98.8	131.7	120.6	110.9	100.9
Table 16 continued							
Median	120.9	104.7	89.7	120.1	111.0	102.3	91.4
75th percentile	127.8	110.6	96.0	126.8	117.4	108.2	93.6
25th percentile	114.2	99.8	87.0	113.2	105.3	97.2	88.0
Maximum	150.0	128.2	114.2	150.0	137.5	125.2	115.6
Vehicle carrier							
- Pre-trial							
Minimum	92.9	80.9	83.6	86.3	85.4	79.0	83.9
Mean	132.1	112.8	96.8	131.7	122.4	111.0	99.4
Median	121.3	106.0	87.7	120.2	113.2	104.3	90.5
75th percentile	128.9	111.6	92.1	128.1	118.9	109.6	95.7
25th percentile	111.0	100.2	85.6	108.1	104.5	97.4	86.6
Maximum	145.9	124.0	111.6	145.6	136.9	122.9	113.6
- Trial							
Minimum	97.2	86.4	85.1	84.8	89.3	82.6	85.4
Mean	132.2	113.8	99.5	131.9	120.3	111.4	101.6
Median	122.0	104.1	89.5	121.0	112.1	101.6	90.9
75th percentile	128.2	111.2	94.4	127.5	118.3	107.8	97.3
25th percentile	114.8	98.3	86.9	114.2	105.8	95.9	88.1
Maximum	149.3	128.0	113.2	149.3	133.1	125.4	116.2

4.2. Lateral displacement assessments

4.2.1. Lateral Displacement

The transits of all tug vessels in the trial area during the six months pre-trial control period were compared to those made during the trial. The route taken by tugs was consistent between these two periods, with peaks in transit time observed predominantly south of the Management Enhancement area, at approximately 5000 m and 11000 m from the Jordan River mooring (Figure 27A). The inclusion of bulkers in Figure 27 indicates the presence of the shipping lanes, showing the peaks of tug transits to be in the inbound and outbound shipping lanes, or south of the shipping lanes both during the trial and outside of the trial period. Little change in distance between vessel transits and the mooring at Jordan River was noted during the comparison of the control and trial period (Figure 27A).

The results from 2021 trial data were compared to data from 2019 to examine longer-term trends. The transit distances were similar between the years, although less variation between the pre-trial and trial was seen for 2021, with some vessels in 2019 altering their route by up to 3000 m (Vagle 2020, Appendix Table 1). For both years, the time spent within 5000 m of the Jordan River mooring, and within the Management Enhancement Area, was low (Figure 27B).

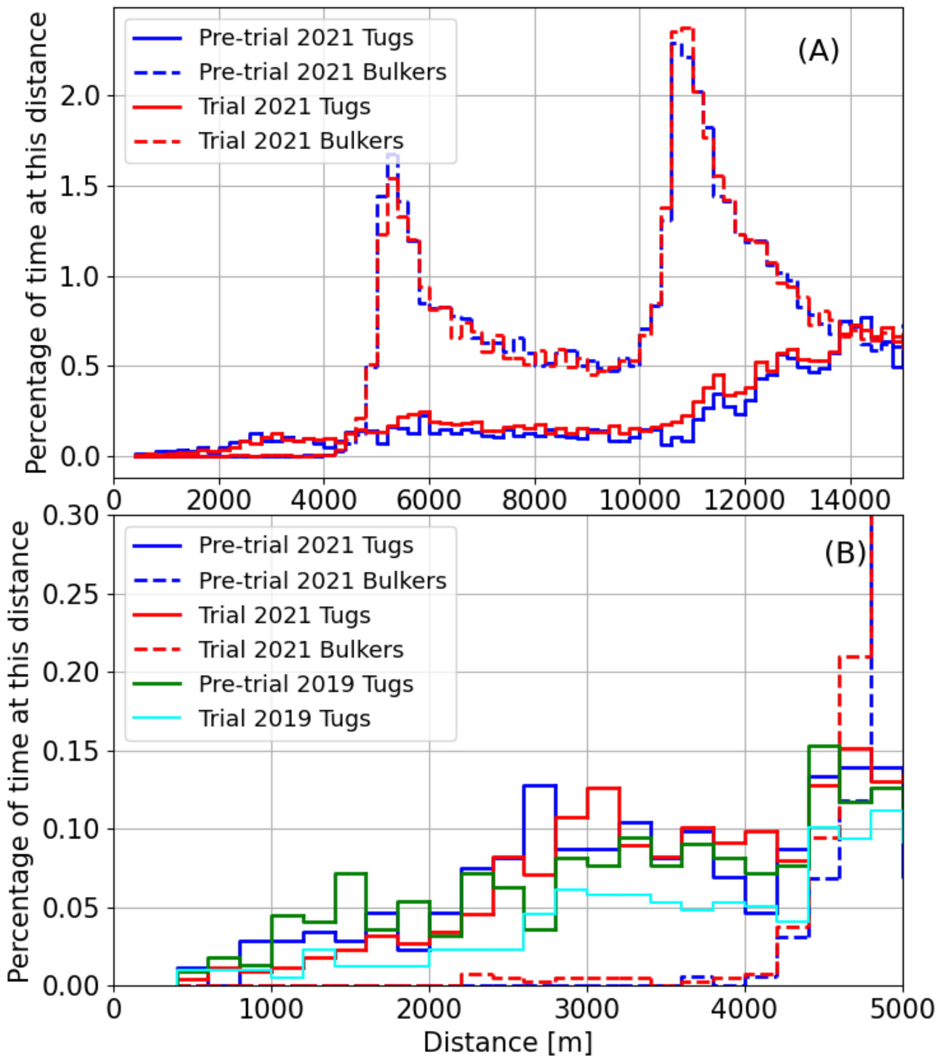

Figure 27: Comparison of pre-trial and trial passage distance for tugs and bulkers (A), and the use of waters within 5000 m of the Jordan River mooring (to the outbound shipping lane) by tugs and bulkers, comparing pre-trial and trial periods and between 2021 and 2019 (B).

The potential reduction in noise per tug transit was considered for two focal vessels *Tug A* and *Tug B*. The two vessels made repeated transits through the trial zone in the pre-trial and trial periods. The distance of transits remained within 4000 m of the Jordan River mooring for both vessels during the trial period (indicated by the black line in Figure 28). *Tug A* had more passages during the trial period than the six months before, with most passages at a distance of 2000 m or more from the mooring. *Tug B* had more passages in the months before June, with passages typically less than 1000 m during the control period, whereas the passages after August were on average double this distance (Figure 28). This offshore movement reduced SPL in the SRKW related frequency ranges. When passages of the tugs were at their closest, SPL in the SRKW communication range (500 Hz to 15 kHz) were highest, reaching nearly 120 dB re 1 μPa. Yet, when the passage distance increased to more than 2000 m, the SPL was reduced to approximately 105 dB re 1 μPa (Figure 29B). A similar pattern was found in the echolocation frequencies, whereby an approximate doubling of distance between the Jordan River mooring and the tug's transit track led to a maximum reduction of nearly 20 dB re 1 μPa. However, this reduction was not consistent and may also be influenced by the use of echosounders by the tugs. Mid-frequency ranges (1-10 kHz) showed a reduction in SPL as the distance from the coast increased (Figure 29E). However, the change in overall ambient sound levels showed a less distinct pattern, with no apparent difference between pre-trial and trial periods (Figure 29D).

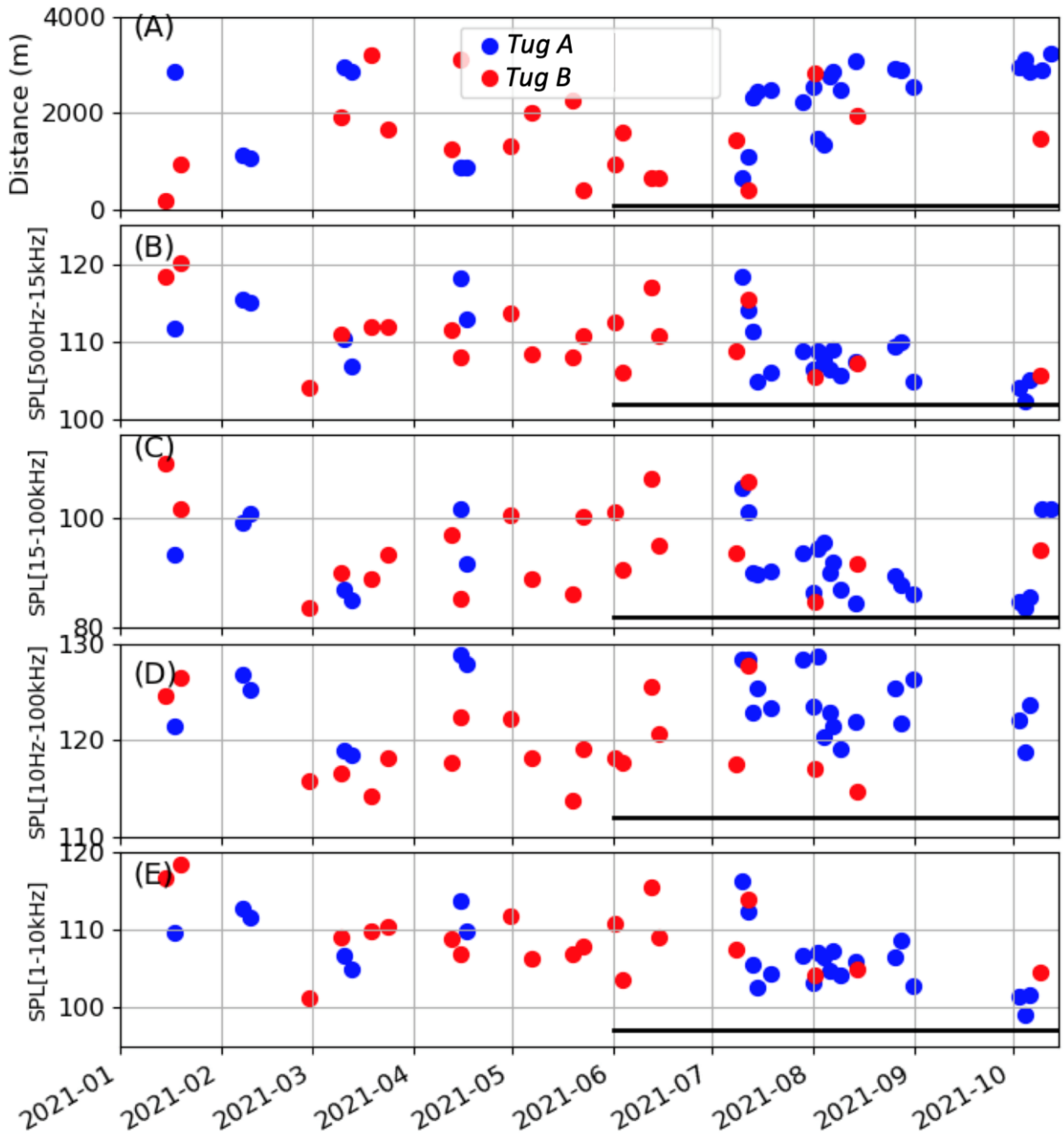

Figure 28: Comparison of the transit distance of the tug vessels *Tug A* (blue) and *Tug B* (red) (A) and the resulting SPL in the Southern Resident Killer Whale (SRKW) communication (B), echolocation frequencies (C), overall ambient noise levels (D), and a vessel metric (E) between pre-trial and trial periods (indicated with a black line after June 1).

To consider the potential changes in SPL with increased distance of the tugs' passages, sound levels were plotted against the distance of the CPA of the vessels to the Jordan River recorder using transits made during both control and trial periods (Figures 29-30). The relationship between the two variables was linear, with many of the frequency ranges of interest showing a strong negative relationship whereby SPL was reduced as distance from the mooring increased (Figures 29-30). First, the SPL of vessel metrics were considered, with the higher frequency ranges of 1-10 kHz and 10-100 kHz showing a steeper reduction in SPL as distances increased up to 3500 m

(Figures 29C, D). At the CPA, both vessels exceeded 115 dB re 1 μPa in the 1-10 kHz range, however, increasing the passage distance by 2500 m and into the designated lateral displacement zone (Figure 29) reduced SPL in this frequency range by at least 12 dB for both vessels (Figure 29C). A more marked reduction was seen for the 10-100 kHz range. Higher frequencies propagate for shorter distances and are more spatially restricted. The observed levels of 108 dB re 1 μPa at distances of 2500 m or more from *Tug A* suggested the use of a shipboard echosounder, adding to the vessel signal. The noise additions from the vessels in the low frequencies were greater in all cases than for the higher frequency ranges considered. Sound levels in both the 10-100 Hz and 100-1000 Hz frequency ranges exceed 125 dB re 1 μPa for both vessels (Figures 29A,B). In the 10-100 Hz range, an increase in distance of 2500 m showed a consistent reduction in SPL of 10 dB or more, with a maximum reduction of 20 dB for *Tug B* when transit route was displaced from ~400m to ~3200 m (Figure 29A). The sound levels received from *Tug B* were typically less than those observed from *Tug A* in the 100-1000 Hz range, although both showed a reduction of approximately 10 dB when comparing their closest and furthest passage distances (Figure 29B).

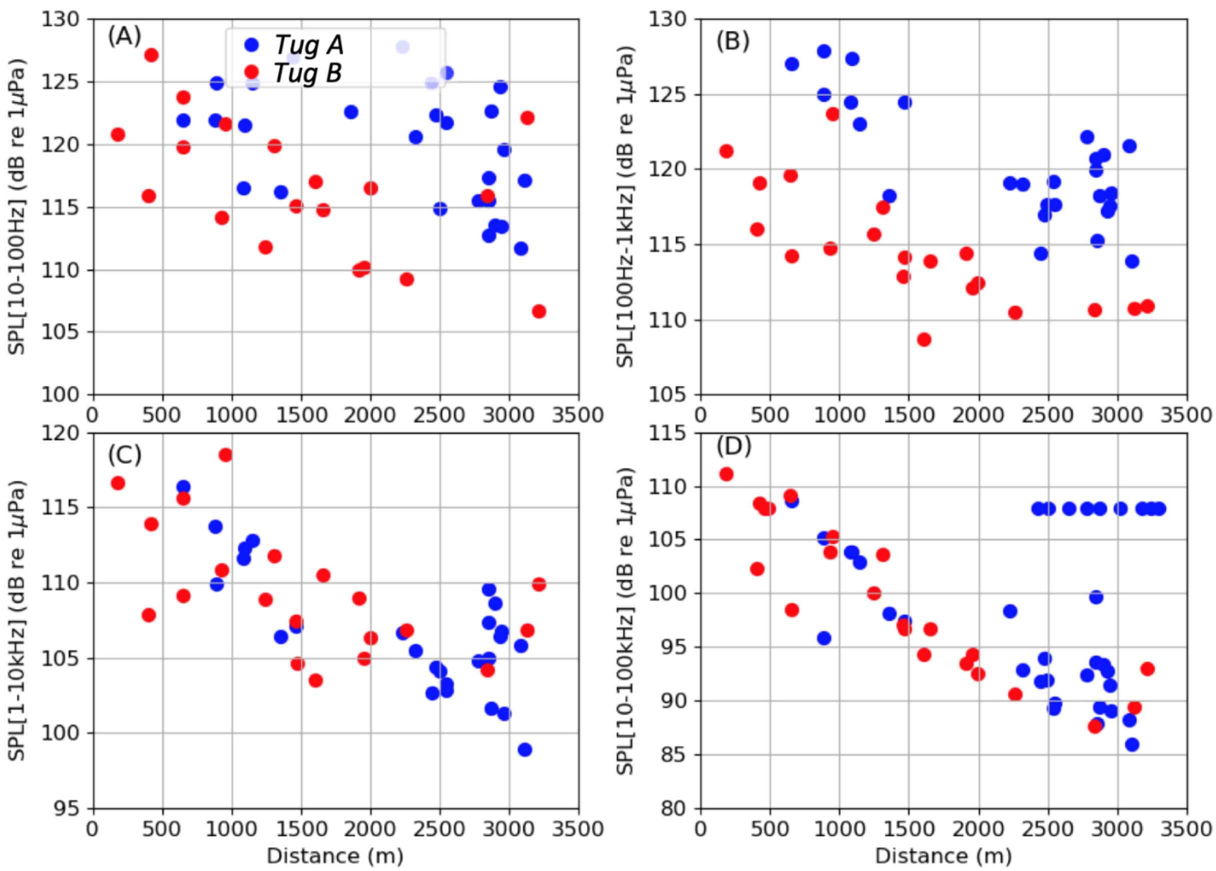

Figure 29: The relationship of SPL and passage distance of the vessels *Tug A* (blue) and *Tug B* (red) in vessel metric frequency ranges.

The potential reductions in SPL with increased distance in frequency ranges relevant to SRKW communication and echolocation were also considered (Figure 30). Again, the most pronounced reductions were seen for mid- to high-frequency ranges (Figures 30A-C). A displacement of 2000-2500 m showed a maximum reduction in SPL of 15 dB in the SRKW communication range (5000 Hz – 15 kHz, Figure 30A). A similar reduction was seen in the 1-10 kHz range (Figure 30C). A SPL reduction of as much as 25 dB was seen from *Tug B* in the echolocation frequency range resulting from a displacement distance of 3000 m (15-100 kHz, Figure 30B). Results in this range for *Tug A* again suggested the use of an echosounder (Figure 30B). The reductions in the overall ambient sound field were less marked with distance, but when considering the levels at the closest (~500m) and furthest (~3000m) a reduction of 10-13 dB was seen (Figure 30D).

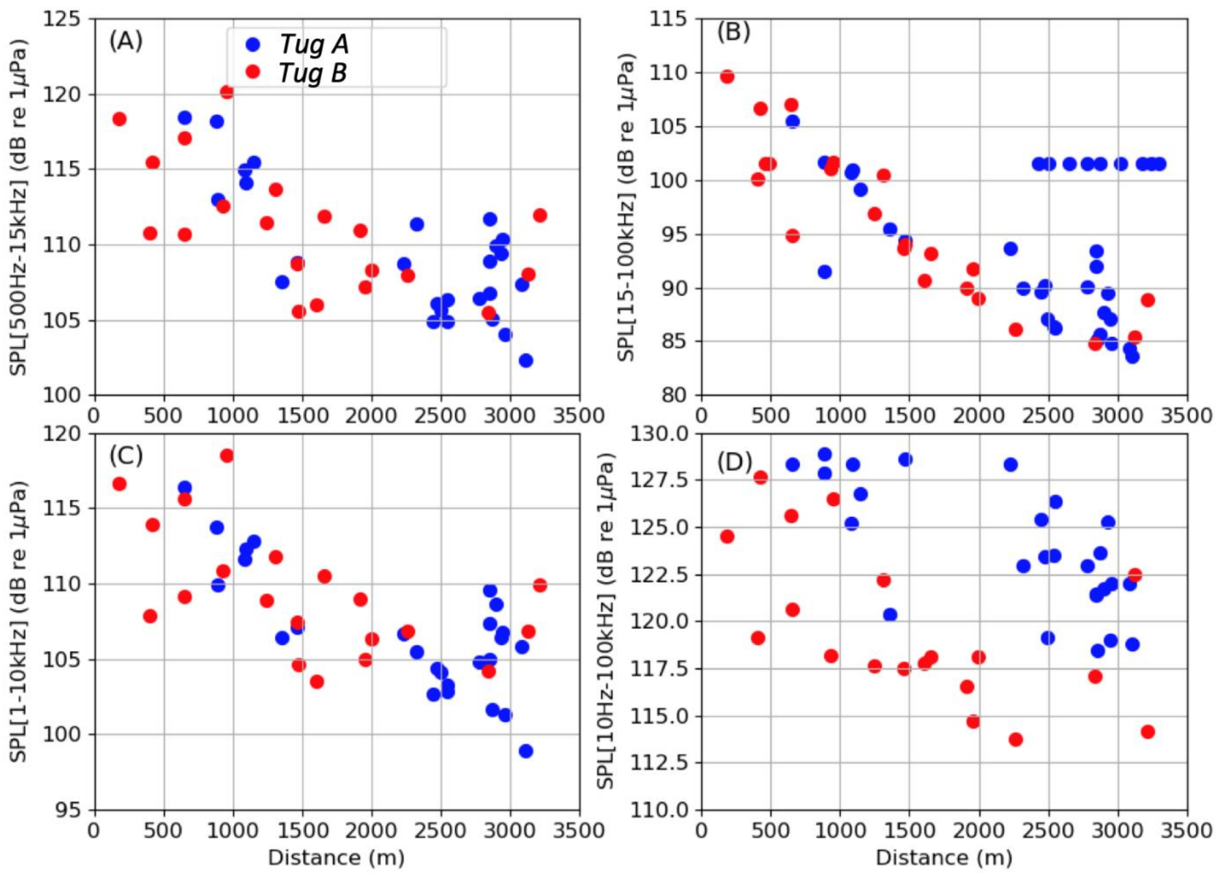

Figure 30: The relationship of SPL levels and passage distance of the vessels *Tug A* (blue) and *Tug B* (red) in the southern resident killer whale (SRKW) communication (A), echolocation frequencies (B), a vessel metric (C), and overall ambient noise levels (D).

4.3. Interim Sanctuary Zones (ISZs)

The success of the ISZs to reduce noise in SRKW foraging areas relies on the compliance of vessels to the exclusion. Previous analysis has shown that recreational vessel number increases in the areas the ISZs are placed during trial periods, and that vessel presence increases despite the measures (Burnham et al. 2021). This was the case again during the 2021 measures (Figures 31-32).

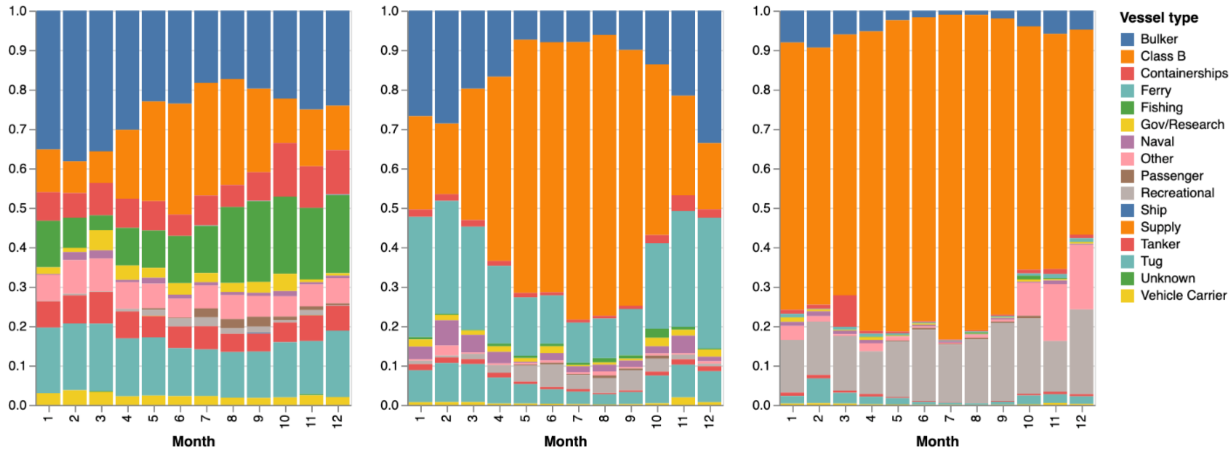

Figure 31: Monthly proportional presence per vessel type within the ISZ using the number of 5-minute AIS points. Swiftsure Bank (left), Swanson Channel (middle) and Saturna Island (right).

Vessel number in the ISZ areas was found to increase during the trial periods, (absolutely and proportionally, Figure 32). This is inline with a general increase in recreational vessel use in the Salish Sea during the summer months. Only after the trial was complete were the number of vessels reduced.

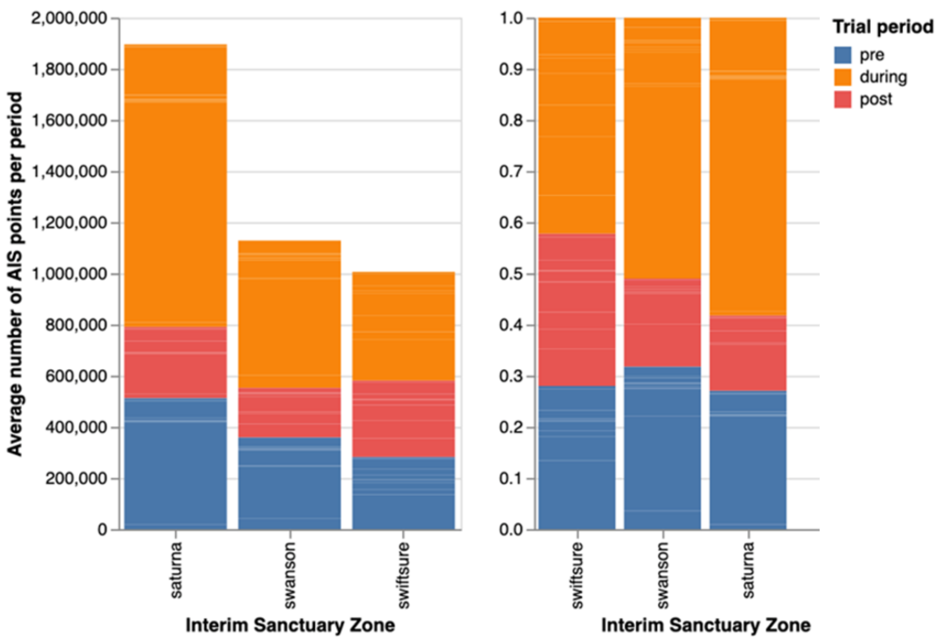

Figure 32: Average number of vessels in each ISZ (left) and expressed proportionally (right).

The dominant vessel types identified by AIS differed between ISZ sites (Figures 31, 33). The Swanson Channel ISZ was most directly influenced by more recreational and passenger vessels, whereas the passage of commercial shipping was noted more for the Swiftsure Bank due to its greater proximity to shipping lanes. A broader range of vessels was noted for Saturna Island including fishing, government, naval, and recreational vessels (Figure 33).

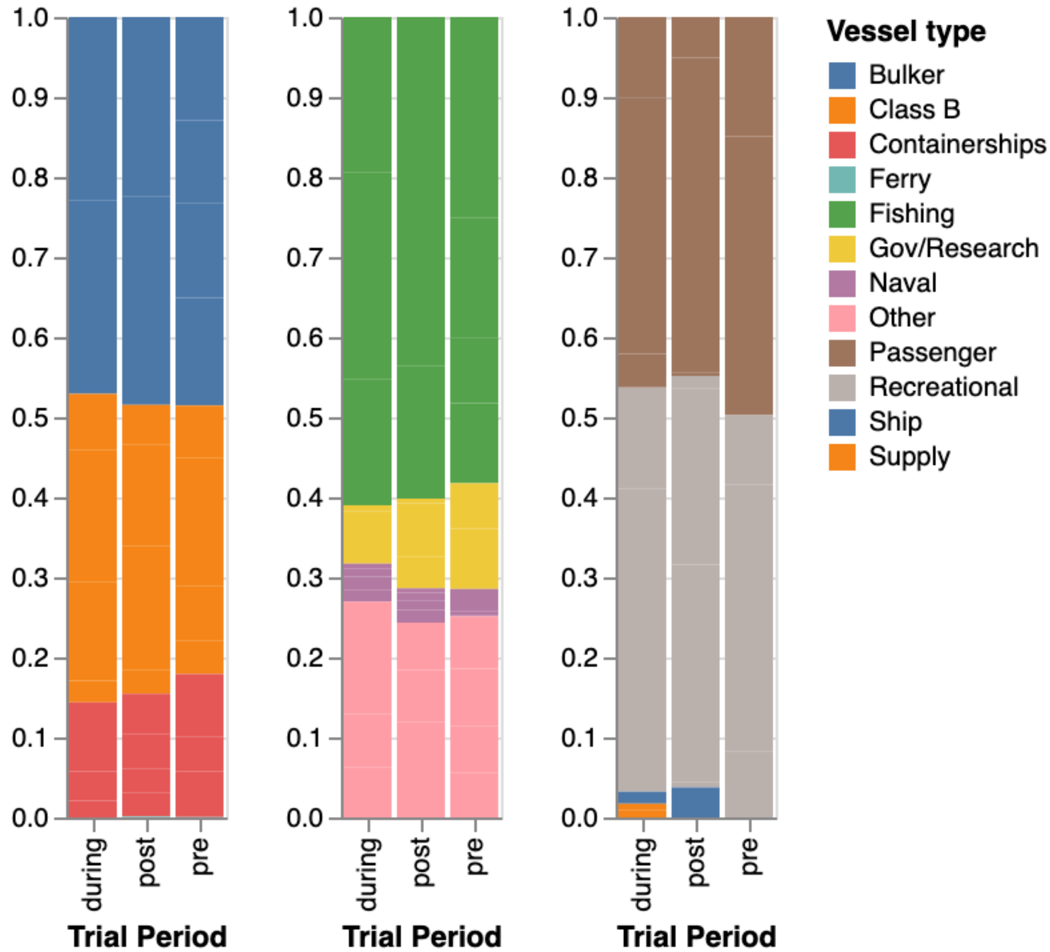

Figure 33: Dominant vessel types at Swiftsure Bank (left), Saturna Island (middle), and Swanson Channel (right).

4.3.1 Swiftsure Bank ISZ

Vessel passages through the Swiftsure Bank ISZ were discerned from AIS data, and the track of any vessel with at least one 5-minute AIS data point in the ISZ examined further (Figure 34). Passages of recreational and Class B vessels were numerous, with the commercial vessels predominantly shown to be within the ISZ entering, exiting or transiting just over the southern extent in the waters closest to the shipping lane (Figure 34).

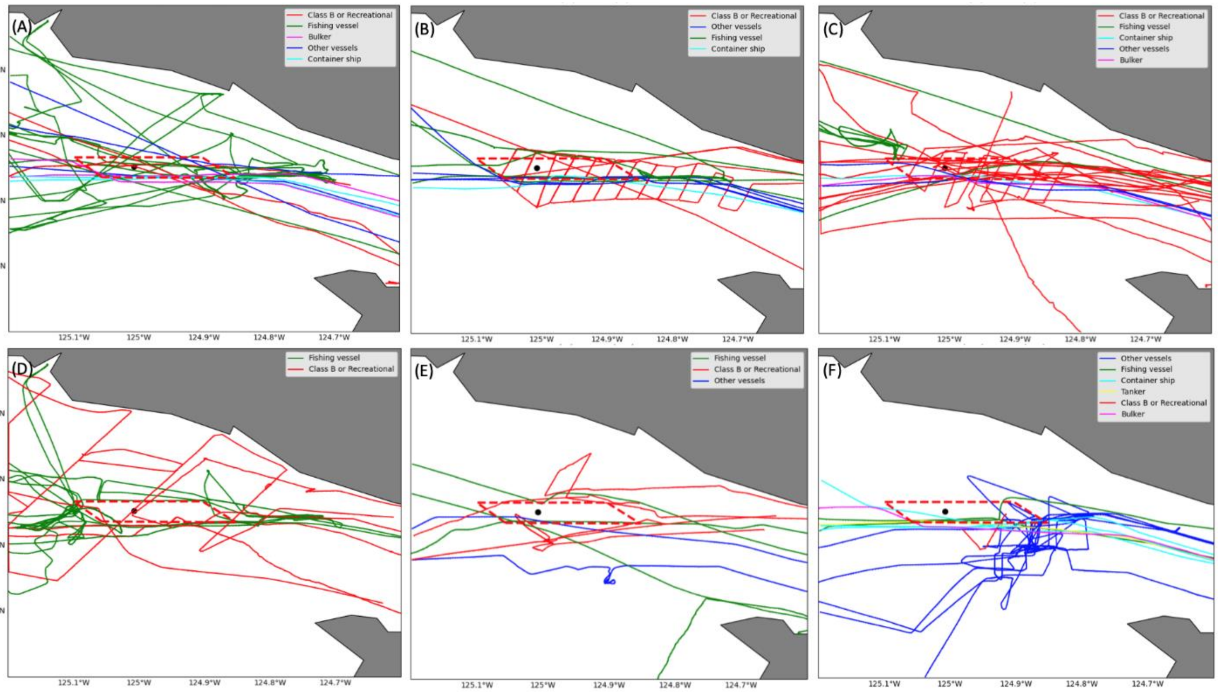

Figure 34: Tracks of vessels passing through the Swiftsure Bank interim sanctuary zone monthly, where (A) is May 1-31, (B) June 1-30, (C) July 1-31, (D) August 1-31, (E) September 1-30, and (F) October 1-31 2021. The mooring location for the Swiftsure Bank ISZ is shown with a black circle.

Vessel presence, and the types of vessels present in the AIS data, represent the proximity of the ISZ to the shipping lane. Deep sea vessels were noted from the AIS data as passing through the ISZ (Figures 34-35). The presence of Class B vessels increased in the early spring and remained consistently high during July, although decreased later in the summer and into the fall. The presence of fishing vessels followed openings (Figure 35). No recreational fishing was allowed from July 16 until October 31, with catch limitations in place until August.

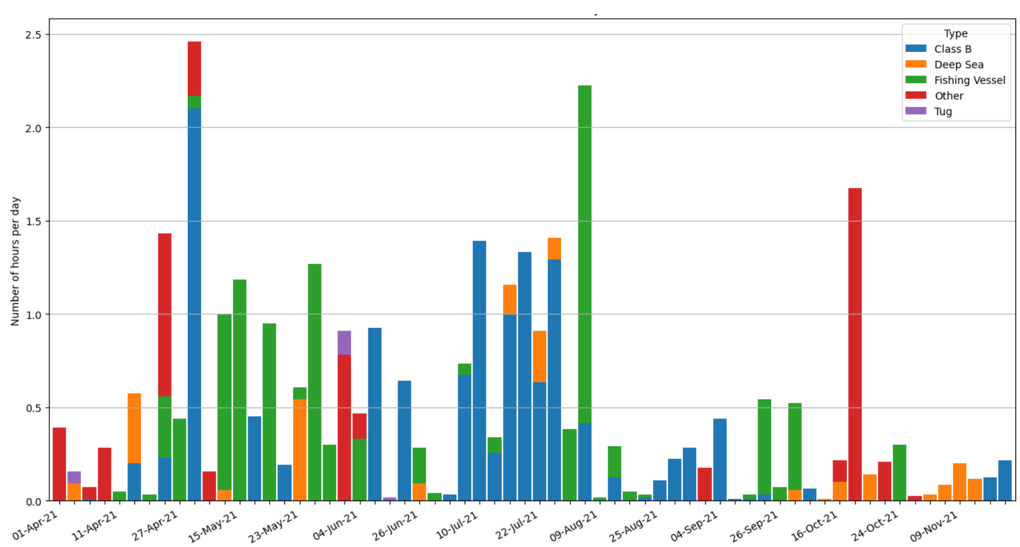

Figure 35: Time spent by different vessel types within the Swiftsure Bank ISZ.

No mooring data were available for comparisons of SPL for the Swiftsure Bank ISZ between trial and control periods due to a loss of equipment. It is expected that the overall trends may be similar to the recordings made for the Swiftsure Bank slowdown (e.g., Figure 10), however smaller, recreational vessels would have a greater impact.

4.3.2. Swanson Channel ISZ

Vessel passages in Swanson Channel increased during the mid-summer months (July-September). The AIS track data did not indicate recreational or Class B vessels avoiding the ISZ (Figure 36). Vessels in the 'Other' category (government, naval vessels, and ferries) did tend to travel around the ISZ, however were frequently seen to cut across the south-western corner in Swanson Channel (Figure 36). Fishing vessels were noted but very infrequently.

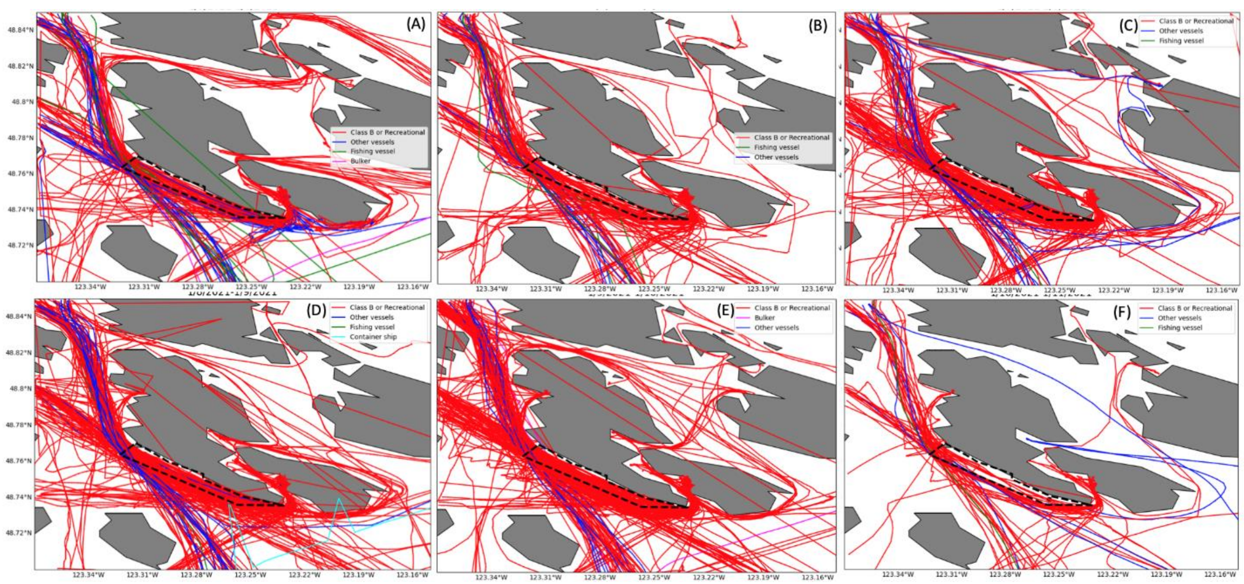

Figure 36: Tracks of vessels passing through the Swanson Channel interim sanctuary zone monthly, where (A) is May 1-31, (B) June 1-30, (C) July 1-31, (D) August 1-31, (E) September 1-30, and (F) October 1-31 2021.

Class B vessels were the dominant type recorded within the ISZ (Figure 37). The time spent by vessels per day in the ISZ was at its greatest during the early part of September, but was elevated throughout the study period (Figure 37). Recreational harvesters were allowed to retain two Chinook a day from September 1 until the end of our study period, although sanctuary measures should have prevented fishers using this area. The tracks and time spent in the ISZ (Figures 36-37) suggest that recreational vessels may be passing through this area and not spending time within it.

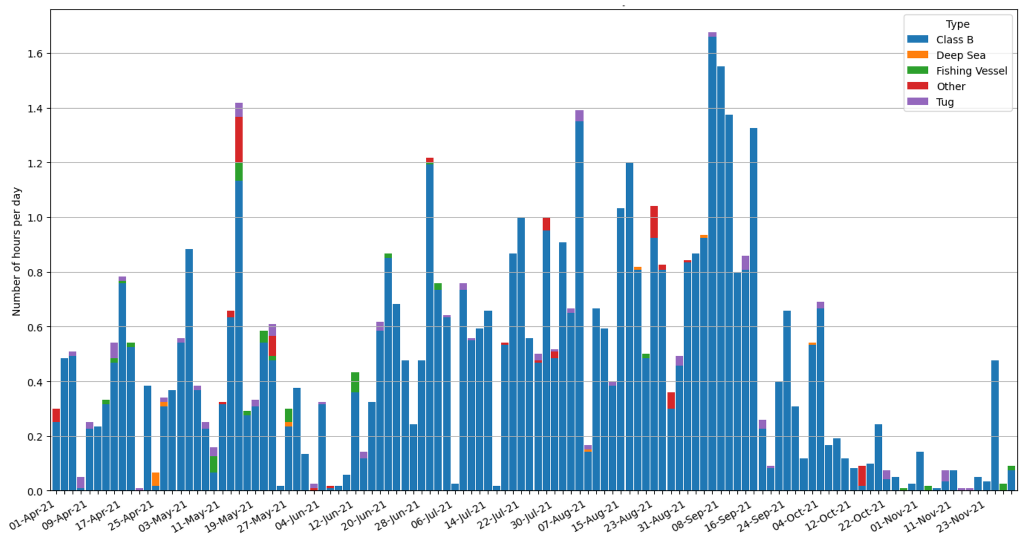

Figure 37: Time spent within the Swanson Channel ISZ by vessel type.

Sound levels were examined as they were recorded, as well as with the environmental restrictions to limit current and wind inputs (Figures 38-39). The SPL were generally similar or increased from pre-trial to trial periods (Figures 38-39). The contributions of commercial vessels and then small vessels only, identified by use of the small vessel detector, allowed us to see the dominant contributions. The change in SPL from pre-trial to trial period was more frequently an increase in sound level than a decrease (Tables 17-18). Some reductions were seen in the higher frequencies, yet it was in these higher frequency ranges that the greatest increase to maximum SPL levels were seen. Reductions were not consistently seen when only considering the smaller vessels, despite the measures targeting the exclusion of smaller recreational vessels from this area.

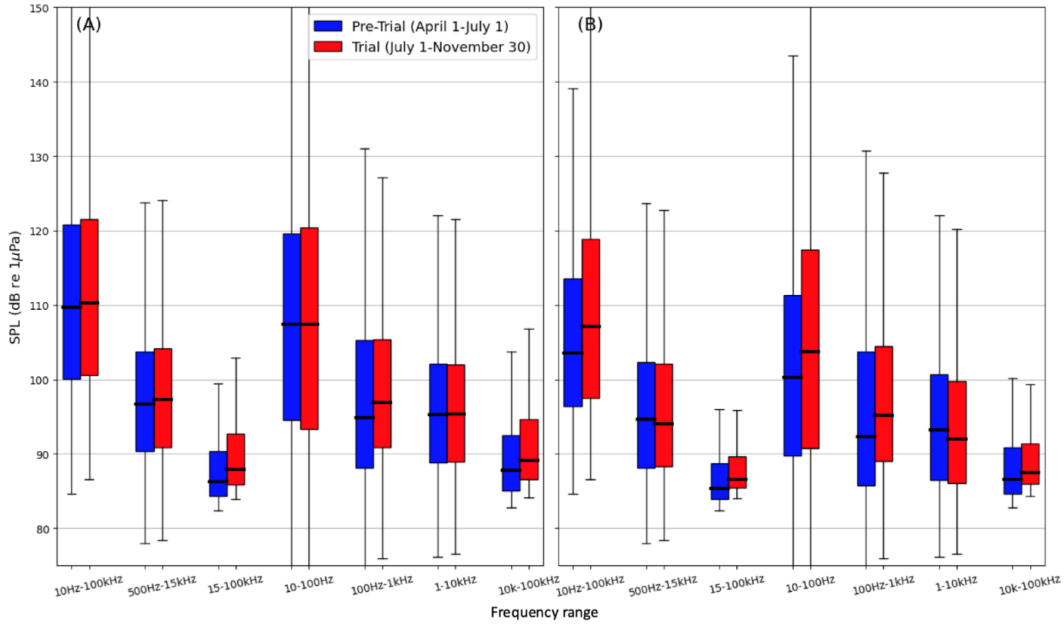

Figure 38: Sound pressure levels (dB re 1 μPa) of the frequency ranges of interest at the Swanson Channel Interim Sanctuary Zone comparing the pre-trial control (blue) and trial periods (red) in the broadband ambient noise (10 Hz to 100 kHz), SRKW communication (500Hz -15 kHz) and echolocation (15-100 kHz), and decadal bands with (A) and without restrictions of current less than 0.3 ms^{-1}, wind speed less than 5 ms^{-1}, and periods indicating the presence of small vessels removed (B).

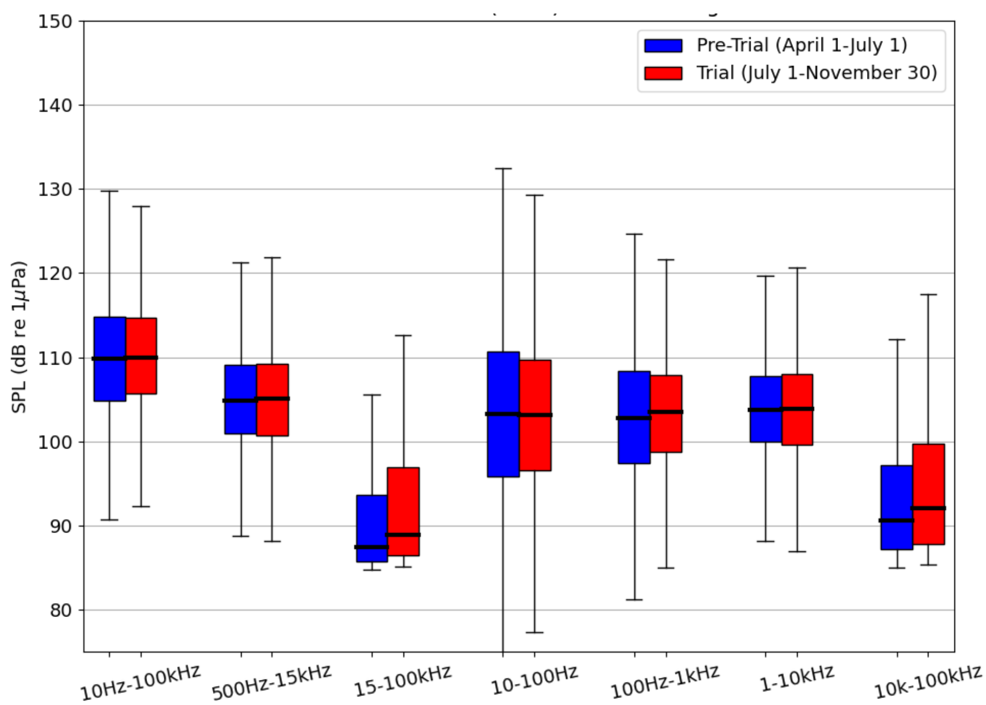

Figure 39: Sound pressure levels (dB re 1 μPa) of the frequency ranges of interest at the Swanson Channel Interim Sanctuary Zone comparing the pre-trial control (blue) and trial periods (red) in the broadband ambient noise (10 Hz to 100 kHz), SRKW communication (500Hz -15 kHz) and echolocation (15-100 kHz), and decadal bands for periods when only small vessels were present. Restrictions of current less than 0.3 ms^{-1} and wind speed less than 5 ms^{-1} were also applied.

Table 17: Sound pressure levels (dB re 1 μPa) of the frequency ranges of SRKW relevance and representing vessel presence at Swanson Channel ISZ with and without the environmental restrictions of current less than 0.3 ms^{-1} and wind speed less than 5 ms^{-1} with small vessel removed, and then with only small vessels present.

Metric	10 Hz-100 kHz	500Hz-15 kHz	15-100 kHz	10-100	100-1000 Hz	1000-10000Hz	10000-100000Hz
Without environmental restrictions							
- Pre-trial							
Minimum	86.1	77.4	84.7	72.8	72.5	75.4	84.9
Mean	120.1	111.1	102.1	118.8	112.7	109.8	103.2
Median	106.3	98.5	86.1	102.0	99.7	96.8	87.4
75th percentile	112.6	103.1	88.9	109.9	105.4	101.5	91.2
25th percentile	100.7	93.0	85.5	94.0	93.8	91.0	86.0
Maximum	158.9	157.2	142.5	156.6	157.7	155.9	142.5
- Trial							
Minimum	86.9	78.5	85.5	73.8	74.8	76.4	85.7
Mean	122.8	109.1	102.9	122.4	109.5	107.8	103.8
Median (P50)	106.8	97.8	86.8	102.0	100.9	96.0	88.0
75th percentile	112.9	102.7	90.1	109.5	105.3	101.1	92.4
25th percentile	101.9	92.1	86.1	95.3	96.1	89.9	86.6
Maximum	148.0	140.7	142.8	148.0	144.3	140.5	142.8
With restrictions: U<0.3 ms^{-1}, WSP <5 ms^{-1}							
- Pre-trial							
Minimum	86.1	77.4	84.7	72.8	72.5	75.4	84.9
Mean	112.7	103.4	91.7	111.2	106.4	101.9	93.4
Median	104.4	96.8	85.8	100.1	98.6	95.1	86.8
75th percentile	110.1	101.3	87.7	107.1	104.3	99.8	89.8
25th percentile	99.1	91.1	85.4	92.4	92.4	89.2	85.8
Maximum	150.9	132.1	119.4	150.7	137.4	130.9	120.7
- Trial							
Minimum	86.9	78.5	85.5	73.8	74.8	76.4	85.7
Mean	118.3	105.5	95.5	117.8	107.5	104.0	97.1
Median	105.6	96.4	86.6	100.6	100.4	94.4	87.6
75th percentile	110.7	101.1	88.7	107.3	104.7	99.4	90.7
25th percentile	100.9	90.8	86.1	94.1	95.6	88.3	86.5
Maximum	146.8	135.9	130.9	146.8	138.2	135.7	130.9
With restrictions: U<0.3 ms^{-1}, WSP <5 ms^{-1} , small vessels only							
- Pre-trial							
Minimum	88.8	83.0	84.8	74.7	78.0	82.5	85.0
Mean	120.6	114.2	110.7	118.2	113.0	112.6	111.2
Median	109.8	104.8	87.4	103.2	102.7	103.7	90.6
75th percentile	114.8	109.1	93.7	110.6	108.3	107.8	97.1
25th percentile	104.8	101.0	85.7	95.9	97.4	99.9	87.1
Maximum	144.1	139.7	140.8	144.1	137.4	138.7	140.8
- Trial							
Minimum	89.6	83.9	85.1	74.1	77.7	82.9	85.4
Mean	122.4	114.6	107.3	120.9	114.2	113.4	108.4
Median	110.0	105.1	88.9	103.1	103.5	103.9	92.0
75th percentile	114.6	109.2	96.9	109.7	107.9	108.0	99.7
25th percentile	105.7	100.7	86.4	96.6	98.7	99.6	87.8
Maximum	145.3	140.3	134.6	145.3	144.3	140.1	134.6

Table 18: The difference in sound pressure levels in decibels (dB re 1 μPa) between pre-trial and trial periods of the frequency ranges of SRKW relevance and representing vessel presence at Swanson Channel with the environmental restrictions of current less than 0.3 ms^{-1} and wind speed less than 5 ms^{-1} with small vessels removed, and small vessels only present.

Metric	10 Hz-100 kHz	500Hz-15 kHz	15-100 kHz	10-100	100-1000 Hz	1000-10000Hz	10000-100000Hz
-Commercial vessels							
Minimum	0.8	1.1	0.8	1.0	2.3	1.0	0.8
Mean	5.6	2.1	3.8	6.6	1.1	2.1	3.7
Median	1.2	-0.4	0.8	0.5	1.8	-0.7	0.8
75th percentile	0.6	-0.2	1.0	0.2	0.4	-0.4	0.9
25th percentile	1.8	-0.3	0.7	1.7	3.2	-0.9	0.7
Maximum	- 4.1	3.8	11.5	-3.9	0.8	4.8	10.2
- Small vessels							
Minimum	0.8	0.9	0.3	-0.6	-0.3	0.4	0.4
Mean	1.8	0.4	-3.4	2.7	1.3	0.8	-2.8
Median	0.2	0.3	1.5	-0.1	0.8	0.2	1.4
75th percentile	-0.2	0.1	3.2	-0.9	-0.4	0.2	2.6
25th percentile	0.9	-0.3	0.7	0.7	1.3	-0.3	0.7
Maximum	1.2	0.6	-6.2	1.2	6.9	1.4	-6.2

4.3.3. Saturna Island

Almost all traffic transiting through the waters in and proximal to the Saturna Island ISZ were recreational Class B vessels, as indicated by the AIS records. The track data did indicate an attempt to avoid the ISZ by recreational vessels, even when transit numbers were at their greatest in the mid-summer (Figure 40).

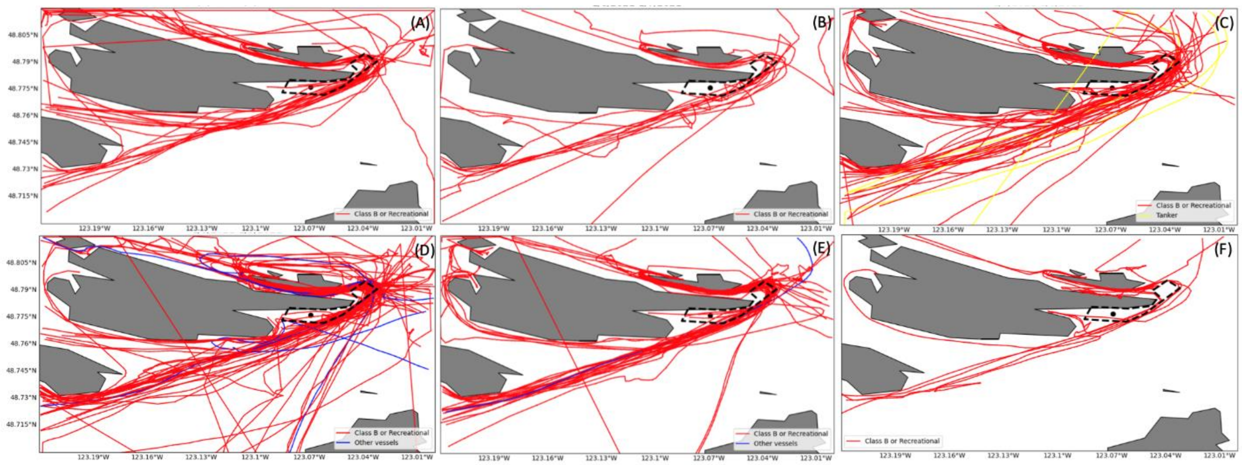

Figure 40: Tracks of vessels passing through the Saturna Island interim sanctuary zone monthly, where (A) is May 1-31, (B) June 1-30, (C) July 1-31, (D) August 1-31, (E) September 1-30, and (F) October 1-31 2021.

The AIS data indicated presence of commercial vessels in the ISZ but this was rare, and likely a result of its proximity to shipping lanes. The data suggests that vessels are transiting the areas and not spending extended time periods in the sanctuary zone (Figures 40-41).

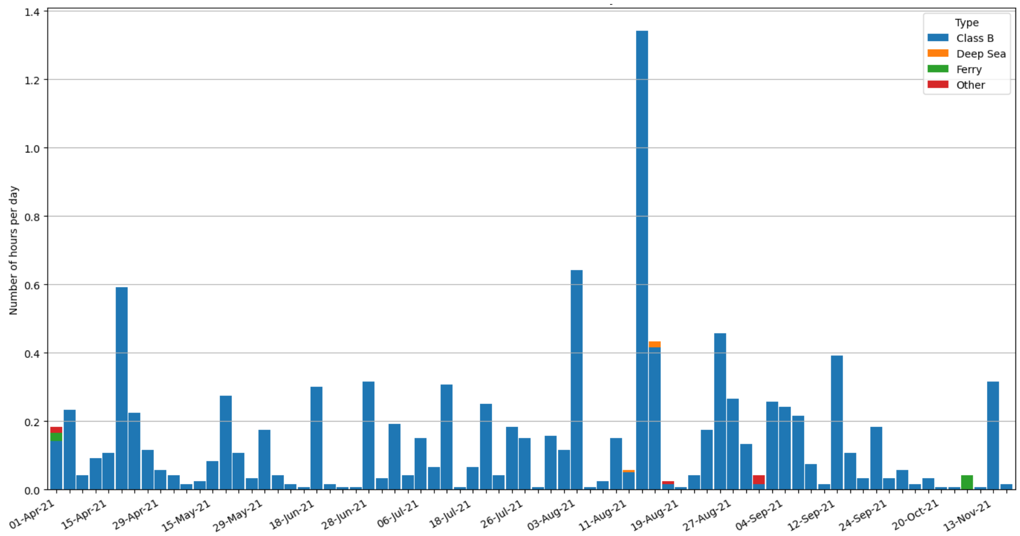

Figure 41: Time spent within the Saturna Island ISZ by vessel type.

The median SPL levels were similar between the pre-trial and trial periods in the frequencies of interest. The environmental restrictions did little to alter the SPL from the un-filtered recordings (Figure 42). Reductions in SPL were most consistently seen in the higher frequencies and when considering the presence of small vessels, as these vessels are the target of the measures and the most frequently recorded present (Figures 41-43, Tables 19-20).

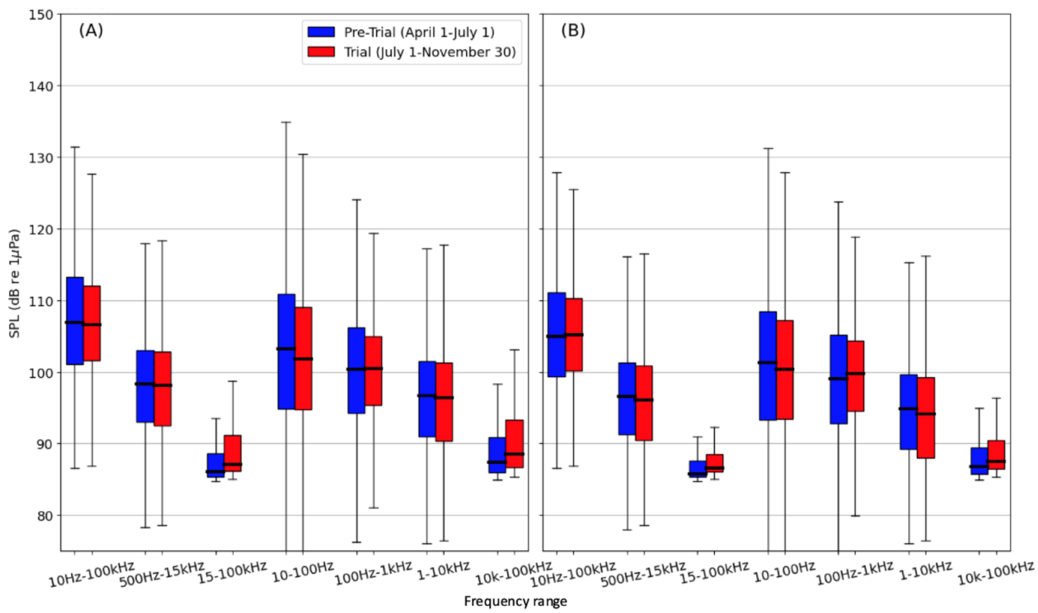

Figure 42: Sound pressure levels (dB re 1 μPa) of the frequency ranges of interest at the Saturna Island Interim Sanctuary Zone comparing the pre-trial control (blue) and trial periods (red) in the broadband ambient noise (10 Hz to 100 kHz), SRKW communication (500Hz -15 kHz) and echolocation (15-100 kHz) and decadal bands as recorded (A) and with restrictions of current less than 0.3 ms^{-1} and wind speed less than 5 ms^{-1}, and periods indicating the presence of small vessels removed (B).

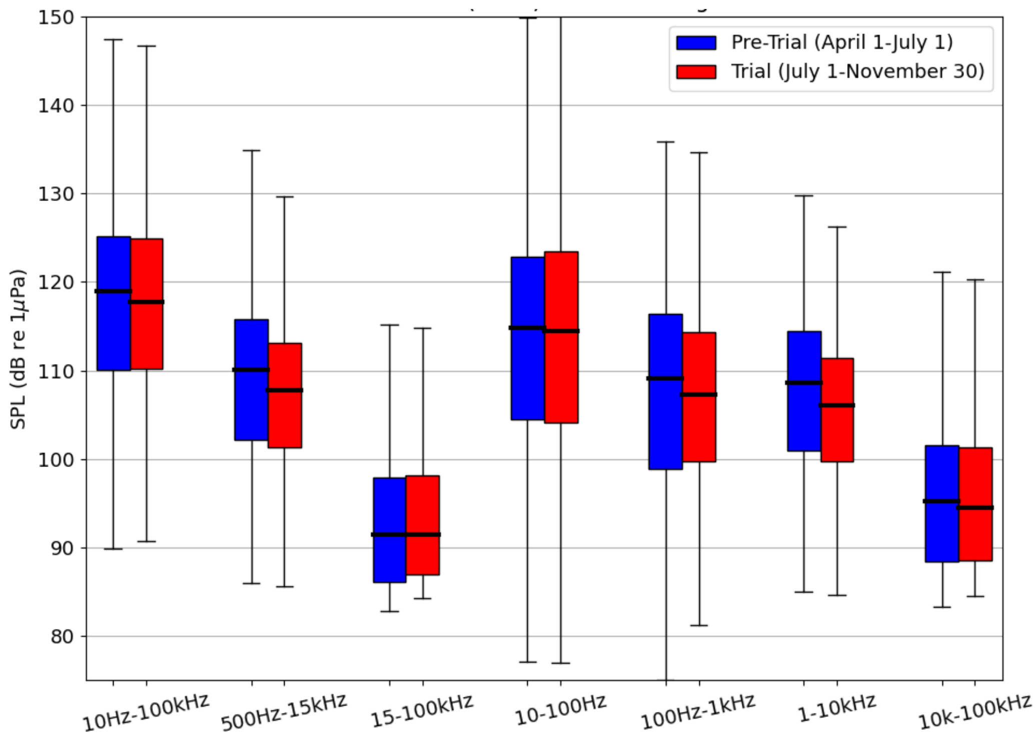

Figure 43: Sound pressure levels (dB re 1 μPa) of the frequency ranges of interest at the Saturna Island Interim Sanctuary Zone comparing the pre-trial control (blue) and trial periods (red) in the broadband ambient noise (10 Hz to 100 kHz), SRKW communication (500Hz -15 kHz) and echolocation (15-100 kHz), and decadal bands for periods when only small vessels were present. Restrictions of current less than 0.3 ms^{-1} and wind speed less than 5 ms^{-1} were also applied.

Table 19: Sound pressure levels (dB re 1 μPa) of the frequency ranges of SRKW relevance and representing vessel presence at Saturna Island ISZ with and without the environmental restrictions of current less than 0.3 ms^{-1} and wind speed less than 5 ms^{-1} with small vessels removed, and small vessels only present.

Metric	10 Hz-100 kHz	500Hz-15 kHz	15-100 kHz	10-100	100-1000 Hz	1000-10000Hz	10000-100000Hz
Without environmental restrictions							
- Pre-trial							
Minimum	84.7	78.0	82.4	72.2	73.1	76.2	82.8
Mean	126.9	111.5	95.5	126.6	114.1	110.0	99.1
Median	109.6	96.6	86.3	107.4	94.9	95.2	87.8
75th percentile	120.8	103.8	90.4	119.6	105.3	102.1	92.5
25th percentile	100.1	90.4	84.3	94.6	88.1	88.9	85.1
Maximum	156.6	155.4	138.0	155.9	151.7	155.1	139.7
- Trial							
Minimum	86.5	78.4	83.9	72.8	75.9	76.5	84.1
Mean	129.0	110.6	96.5	128.8	113.0	109.1	98.6
Median (P50)	110.3	97.3	87.9	107.4	96.9	95.4	89.2
75th percentile	127.7	106.1	93.3	127.3	111.0	104.2	95.2
25th percentile	100.6	90.9	85.9	93.3	90.8	88.9	86.5
Maximum	159.2	157.6	135.7	158.1	151.6	157.3	138.0
With restrictions: U<0.3 ms^{-1}, WSP <5 ms^{-1} , small vessels removed							
- Pre-trial							
Minimum	84.7	78.0	82.4	72.2	73.1	76.2	82.8
Mean	124.4	111.8	93.3	123.9	114.2	110.6	96.8
Median	103.5	94.7	85.4	100.3	92.3	93.2	86.6
75th percentile	113.5	102.3	88.7	111.3	103.7	100.7	90.8
25th percentile	96.4	88.1	83.9	89.9	85.7	86.5	84.6
Maximum	156.6	155.4	125.0	154.9	151.7	155.1	132.8
- Trial							
Minimum	86.5	78.4	84.0	72.8	75.9	76.5	84.3
Mean	128.1	106.9	94.4	128.0	111.7	104.1	96.1
Median	107.1	94.1	86.6	103.7	95.1	91.9	87.5
75th percentile	118.9	102.1	89.6	117.4	104.5	99.7	91.3
25th percentile	97.5	88.4	85.4	90.8	89.0	86.1	86.0
Maximum	152.3	134.9	125.9	152.3	145.2	131.3	125.9
With restrictions: U<0.3 ms^{-1}, WSP <5 ms^{-1} , small vessels only							
- Pre-trial							
Minimum	89.9	86.0	82.8	72.8	75.0	85.0	83.2
Mean	128.9	116.8	101.5	128.4	117.5	114.8	104.5
Median	119.0	110.0	91.5	114.9	109.1	108.6	95.2
75th percentile	125.2	115.8	97.9	122.8	116.4	114.4	101.6
25th percentile	110.0	102.2	86.1	104.4	98.9	100.9	88.3
Maximum	149.8	134.9	120.0	149.8	135.9	129.8	121.2
- Trial							
Minimum	90.7	85.5	84.2	76.9	81.3	84.6	84.5
Mean	131.2	114.2	102.5	131.0	115.1	112.1	104.5
Median	117.8	107.8	91.5	114.5	107.3	106.1	94.5
75th percentile	124.9	113.1	98.2	123.5	114.4	111.4	101.3
25th percentile	110.1	101.2	86.9	104.1	99.8	99.7	88.5
Maximum	151.7	134.3	126.9	151.7	134.7	130.5	127.8

Table 20: The difference in sound pressure levels in decibels (dB re 1 μPa) between pre-trial and trial periods of the frequency ranges of SRKW relevance and representing vessel presence at Saturna Island with the environmental restrictions of current less than 0.3 ms^{-1} and wind speed less than 5 ms^{-1} with small vessels removed, and small vessels only present.

Metric	10 Hz-100 kHz	500Hz-15 kHz	15-100 kHz	10-100	100-1000 Hz	1000-10000Hz	10000-100000Hz
-Commercial vessels							
Minimum	1.8	0.4	1.6	0.6	2.8	0.3	1.5
Mean	3.7	-4.9	1.1	4.1	-2.5	-6.5	-0.7
Median	3.6	-0.6	1.2	3.4	2.8	-1.3	0.9
75th percentile	5.4	-0.2	0.9	6.1	0.8	-1.0	0.5
25th percentile	1.1	0.3	1.5	0.9	3.3	-0.4	1.4
Maximum	-4.3	-20.5	0.9	-2.6	-6.5	-23.8	-6.9
- Small vessels							
Minimum	0.8	-0.5	1.4	4.1	6.3	-0.4	1.3
Mean	2.3	-2.6	1.0	2.6	-2.4	-2.7	0.0
Median	-1.2	-2.2	0.0	-0.4	-1.8	-2.5	-0.7
75th percentile	-0.3	-2.7	0.3	0.7	-2.0	-3.0	-0.3
25th percentile	0.1	-1.0	0.8	-0.3	0.9	-1.2	0.2
Maximum	1.9	-0.6	6.9	1.9	-1.2	0.7	6.6

5. DISCUSSION AND CONCLUSIONS

Vessel presence and vessel-derived acoustic disturbance are listed as factors that are limiting SRKW population recovery and success (Weilgart 2007, Lacy et al. 2017, DFO 2018, 2021). The intention of the management measures assessed was to reduce soundscape levels, focussed on reducing SPL in communication calling and echolocation frequency ranges. In addition, the lateral displacement moves vessel transits away from foraging areas for SRKW, and so lessening the potential for response to the physical presence of the vessels and the risk of vessel strike.

5.1 Slowdowns

Significant overall reductions in the SRKW communication and echolocation frequencies were seen as a result of the vessel slowdown request at Swiftsure Bank (Figure 10). Peak SPL fell below 100 dB in both the 500 Hz to 15 kHz communication and 15 to100 kHz echolocation range (Heise et al. 2017) during the trial period (Figure 12, 13). However, reductions were not seen when commercial vessels were in proximity to the mooring. Reductions in higher-frequency vessel ranges during the slowdown were seen for bulkers and vehicle carriers. The rate of transit of these vessel types did not change significantly between periods. The average distance of vessel passage between the Swiftsure Bank mooring, however, was reduced during the trial, and so significant increases in low-frequency vessel noise were still observed. The presence of smaller, non-commercial vessels, as indicated by the 50 kHz frequency range, indicated a seasonal increase. Peaks in SPL in late May, September, and October are coincident with sailboat race weekends or fishing derbies. Also, the AIS data indicated that there was an increase in fishing vessel presence, particularly in the latter part of the trial period, matching the timing of fisheries openings. These events could account for some of the lower- and mid-frequency increases in the soundscape recorded at Swiftsure Bank. The presence of small vessels and those classified as 'Other' also followed the fisheries opening times at Swiftsure Bank, whereas they showed a more seasonal increase as the summer progressed at Haro Strait and Boundary Pass. The additional vessel traffic and a reduction in relative distance from the Swiftsure Bank mooring increased SPL in the low-frequency vessel metric bands of 10-100 Hz and 100-1000 Hz. The pre-trial to trial comparison of vessel transit number found the average hourly passage rate of tankers and containerships increased significantly during the trial period, with the range from the Swiftsure Bank mooring to each of the transiting vessel, at their CPA, also typically reduced.

Containerships have the highest source levels of the vessels considered in this analysis, with each transit potentially elevating noise levels in the 125 Hz to 20 kHz range up to 20 dB (Viers et al. 2016). Although compliance in the slowdown request was high, and the majority of operators reduced vessel speed as requested, the increases in the low frequencies also elevated the overall ambient sound field levels. Containerships and vehicle carriers typically have faster transit speeds and showed the most change in speed, especially in maximum speed, to comply with the requested slowdown limits for both the Swiftsure Bank and Haro Strait-Boundary Pass trial zones. This reduction in speed was more marked at Swiftsure Bank, although the change at Haro Strait and Boundary Pass was still in excess of 4 knots to meet the request. When considering the time these vessels types were present and closest to the mooring, the greatest reductions in SPL were observed for the Haro Strait and Boundary Pass slowdown zone.

Increases were generally noted during the slowdown trial periods in the lower frequencies compared to the control periods. A similar trend was seen for each of the slowdown zones, although not as noteworthy at Haro Strait and Boundary Pass as was seen at Swiftsure Bank. This increase in SPL was seen both from pre-trial to trial period, and again from trial to post-trial periods in the acoustic data from Swiftsure Bank. In addition, soundscape measures at Swiftsure Bank showed month-on-month increases in the 10-100 Hz frequency range. At Haro Strait, when considering the sound fields under the environmental restrictions and with small vessel presence removed, elevated sound levels were also apparent in the higher frequencies during the trial period.

The trial periods in 2021 ended later than in previous years, which meant the latter part of the trial periods and any post trial comparisons, like at Swiftsure Bank, were into more winter conditions. This impacted the amount of data that was retained for analysis when removing high winds and high current conditions Comparisons between sites showed that current is most likely to influence recordings at Boundary Pass, whereas wind had the greatest addition at Swiftsure Bank. The greatest change in the proportional presence of small vessels was seen at Haro Strait, showing an increased removal of data by 8.4% to from pre-trial to trial periods to eliminate their potential influence on the analysis. The proportion of data removed at Boundary Pass, on the other hand, remained constant between periods. Additions from seismic testing, conducted in June and July 2021 at Swiftsure Bank, was not apparent in the data.

The areas covered by Swiftsure Bank and Haro Strait-Boundary Pass slowdowns are foraging areas for SRKW and so increased soundscape levels could have implications for feeding success as well as navigation and maintaining contact between conspecifics. Although additions were not significant in the frequency ranges used for communication and echolocation, the increases in ambient underwater sound levels in the broadband range (10 Hz to 100 kHz), and even those noted in the lower frequencies, could have implications for physiological stress response and behavioural use of the area.

5.2 Lateral displacement

Tugs represent approximately 10% of the total commercial vessel traffic through Juan de Fuca (Vagle and Neves 2019, Vagle 2020, Burnham et al. 2021). The majority of tug transits were in the shipping lanes, or south of the shipping lanes in US waters both during and outside of the trial period. Therefore, little change was observed in the distance between the transiting tugs and the Jordan River mooring from the control to trial period (Figure 27). These results build on previous years. The comparison to 2019, in Figure 27, shows tugs increasingly using a more southward transit route even outside of the trial periods. Indeed, the pre-trial period in 2020 showed a peak of vessels travelling at approximately 1000 m from the Jordan River mooring that was not evident in 2021 (Figure 27).

The efficacy of moving tug transits to a more southerly route to reduce the vessel noise additions has been assessed per vessel transit in recent years (Vagle 2020, Burnham et al. 2021). In this analysis, focus was given to two example tugs. These vessels made multiple transits of Juan de Fuca Strait in both the pre-trial and trial periods. The acoustic analysis showed the potential for a 10 dB reduction in lower frequencies if tug transits were moved up to 3000 m southward. A maximum of 20 dB per transit SPL reduction was observed in the lowest frequencies (10-100 Hz) for *Tug B* when passage route was displaced nearly 2800 m, moving from approximately 400 m to 3200 m. However, typically reductions of SPL related to increased distance from the Jordan River mooring were most marked in the higher frequency ranges. The reductions in the SRKW-relevant frequencies suggest that if these vessels were to travel at a distance of 3000 m or more from the coastline, the sound field levels could be reduced in excess of 15 dB. Passage at distances of 3000-3500 m would allow ambient sound field levels (10 Hz to 100 kHz) to fall below the 120 dB continuous noise threshold generally considered to cause behavioural change and harassment in marine mammals (Southall et al. 2007, 2019, NOAA 2013). These findings suggest that a movement of these example vessels from the Management Enhancement Area and into the outbound shipping lane could result in a reduction of overall ambient noise to levels below the 110 dB, which is suggested to initiate behavioural modifications in SRKW (Hemmera Environchem Inc. 2014).

5.3 Interim Sanctuary Zones

The compliance to the Interim Order detailed vessel exclusion mandate for the Interim Sanctuary Zones (ISZ) was low. Indeed, the number of vessels and time spent with vessels in the area increased as the summer progressed. The soundscape reflected this increase in vessels with an increase in sound levels, including in the higher frequency ranges such as those used by SRKW for echolocation. The AIS track data did suggest that vessels were attempting to avoid the area, but with these measures aimed at smaller, non-commercial vessel traffic, we are cognisant that the results presented from the AIS data represents the minimum presence of this vessel type.

5.4 Summary

Overall, slowdowns and lateral displacement has been shown to be a successful means to reduce sound levels, especially in frequencies pertinent to SRKW. However, an increase in vessel presence and reduced distance from the mooring appeared to mitigate any gains that might have been made by the vessel reduction, especially at Swiftsure Bank (Appendix Table 1). Although the reduction in maximum speed of containerships and vehicle carriers, the greatest noise emitters, was the most substantial to meet the slowdown request, average speeds changed little, with that also limiting the reductions possible as a result of reduced speed. The unsuccessful exclusion of vessels from the ISZ, and nearby passages of vessels in adjacent waters, limits the efficacy of these measures to reduce underwater sound levels.

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APPENDIX

Table 1: Previous year measures, and resulting changes in sound levels.

Year	Measure	Trial length (days)	Area covered	Participation rate	Ambient noise change
2017	Slow-down: all vessels reduce speed to 11 knots or less	61	16.6 nm	61% (951 transits)	-1.1 dB at Lime Kiln, mostly in the low frequencies
2018	Slow-down: 12.5 knots for bulkers, tankers, ferries and government vessels; 15 knots for vehicle carriers, cruise and container vessels Lateral displacement: Deep-sea vessels in outbound and tugs in inbound move southward	Slow-down: 111 Lateral displacement: 72	Slow-down: 16.6 nm Lateral displacement: 34 nm	Slow-down: 87 % (1678) Lateral displacement: 57% of Deep-seas and 80% (76 transits) of tugs spent more the half of transit time in trial zone	Slow-down: At Jordan River; 1.5 dB Lime Kiln Lateral displacement: Deep-seas < -1.0 dB; tugs -4.3-5.8 dB in Juan de Fuca
2019	Slow-down: 11.5 knots for bulkers, tankers, ferries and government vessels; 14.5 knots for vehicle carriers, cruise and container vessels Lateral displacement: Tugs and barge transit shifted southward Interim sanctuary zones: Vessel exclusion from areas of Swiftsure Bank and Swanson Channel	Slow-down: 103 Lateral displacement: 125 ISZ: 153	Slow-down: 29.6 nm Lateral displacement: 28 nm	Slow-down: 82% (1551 transits) Lateral displacement: 76% of Tugs spent more the half of transit time in trial zone. Average move of 0.9 nm (122 transits) Interim sanctuary zones: low compliance	Jordan River: median broadband: -3.6 dB Lateral displacement: ~7 dB in broadband ambient noise; 11.5 dB in higher frequencies per tug transit ISZ: low compliance
2020	Slow-down: 11.5 knots for bulkers, tankers, ferries and government vessels; 14.5 knots for vehicle carriers, cruise and container vessels for	Slow-down: Haro-Strait, Boundary Pass: 103	Slow-down: Haro-Strait, Boundary Pass: 29.6 nm Swiftsure Bank:	Haro-Strait, Boundary Pass: 91% Swiftsure Bank 82%	Haro-Strait, Boundary Pass: Haro Strait, Median change in 10-100000 Hz: -1.6 dB;

	Haro Strait-Boundary Pass and Swiftsure Bank	Swiftsure Bank: 153	17-20 nm		500-15000 Hz: 0.2 dB; 15-100 kHz: 1.3 dB Boundary Pass Median change in 10-100000 Hz: -2.3 dB; 500-15000 Hz: 0.8 dB; 15-100 kHz: 0.7 dB Swiftsure Bank Median change in 10-100000 Hz: -2.0 dB; 500-15000 Hz: -2.0 dB; 15-100 kHz: -4.3 dB
	Lateral displacement: Tugs and barge transit shifted southward Interim sanctuary zones: Vessel exclusion from areas of Swiftsure Bank and Swanson Channel	Lateral displacement: 133 ISZ: 153	Lateral displacement: 28 nm	Lateral displacement: 82% ISZ: Low compliance	Lateral displacement: Median change in 10-100000 Hz: -1.4 dB; 500-15000 Hz: -1.9 dB; 15-100 kHz: -3.3 dB per transit ISZ: Swiftsure Bank: 1.8 dB; Saturna Island: 2.2 dB, Swanson Channel: -1.0 dB
2021	Slow-down: 11.5 knots for bulkers, tankers, ferries and government vessels; 14.5 knots for vehicle carriers, cruise and container vessels	Slow-down: Haro-Strait, Boundary Pass: 153 Swiftsure Bank: 183	Slow-down: Haro-Strait, Boundary Pass: 29.6 nm Swiftsure Bank 17-20 nm	Haro-Strait, Boundary Pass: 90% Swiftsure Bank 81%	Haro-Strait, Boundary Pass: Haro Strait, Median change in 10-100000 Hz: 1.1 dB; 500-15000 Hz: -0.8 dB; 15-100 kHz: 0.5 dB Boundary Pass

					Median change in 10-100000 Hz: 2.8 dB; 500-15000 Hz: -1.3 dB; 15-100 kHz: 0.7 dB Swiftsure Bank Median change in 10-100000 Hz: 7.3 dB; 500-15000 Hz: -0.8 dB; 15-100 kHz: 0.6 dB
	Lateral displacement: Tugs and barge transit shifted southward	Lateral displacement: 183	Lateral displacement: 28 nm	Lateral displacement: Strong participation	Lateral displacement: Measured per tug, with 2 focal vessels
	Interim sanctuary zones: Vessel exclusion from areas of Swiftsure Bank and Swanson Channel	ISZ: 183		ISZ: Low compliance	ISZ: Saturna Island: 3.6 dB, Swanson Channel: 1.2 dB