Implications of Fisheries Closures on the Soundscape in areas used by Southern Resident Killer Whales (SRKW)

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2023

Canadian Technical Report of Fisheries and Aquatic Sciences 3535

Fisheries and Oceans Canada   Pêches et Océans Canada

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

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Cat. No. Fs97-6/3535E-PDF ISBN 978-0-660-48117-3 ISSN 1488-5379

Correct citation for this publication:

Burnham, R., Moore K. 2023. Implications of Fisheries Closures on the Soundscape in areas used by Southern Resident Killer Whales (SRKW). Can. Tech. Rep. Fish. Aquat. Sci. 3535: v + 69 p.

ABSTRACT

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Fisheries management measures aim to increase fish stocks; here the potential for an additional acoustic benefit to the Endangered Southern Resident Killer Whale (SRKW, *Orcinus orca*) by lessening disturbance was assessed. Reductions in ambient broadband noise (10 Hz to 100 kHz) were seen generally during fisheries management actions. Recordings made by moorings in western Juan de Fuca Strait showed the greatest decreases in sound levels. For all sites the changes in the SRKW communication band (500 Hz to 15 kHz) seemed to follow seasonal patterns of wind speed, whereas the echolocation frequency range SRKW (15-100 kHz) and higher frequency sound ranges showed an increasing trend from pre- to during to post-measure periods concurrent to increased recreational vessel presence. Reductions seen in Haro Strait and Boundary Pass (~0.5 dB in median sound levels) may be attributable to the voluntary vessel slowdown in place through the summer.

RÉSUMÉ

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Les mesures de gestion de la pêche visent à accroître les stocks de poissons. Dans cette étude, nous avons évalué le potentiel d'amélioration du niveau sonore ambient pour l'orque résident du Sud (SRKW, *Orcinus orca*), une espèce en voie de disparition, en réduisant les perturbations. Des réductions du bruit ambiant à large bande (10 Hz à 100 kHz) ont généralement été observées lors des actions de gestion de la pêche. Les enregistrements effectués par les mouillages dans l'ouest du détroit de Juan de Fuca ont montré les plus fortes diminutions des niveaux sonores. Pour tous les sites, les changements dans la bande de communication SRKW (500 Hz à 15 kHz) semblent suivre les schémas saisonniers de la vitesse du vent, tandis que la gamme de fréquences d'écholocation SRKW (15-100 kHz) et les gammes de sons de plus haute fréquence ont montré une tendance à l'augmentation entre les périodes avant, pendant et après les mesures, parallèlement à l'augmentation de la présence des navires de plaisance. Les réductions observées dans le détroit de Haro et Boundary Pass (~0,5 dB dans les niveaux sonores médians) peuvent être attribuées au ralentissement volontaire des navires pendant l'été.

List of Acronyms and Terms

1/3 octave band – a frequency band that is 1/3 of an octave wide, centered around a frequency of interest

Automatic Identification System (AIS) – used by vessels to project identity, location and planned route to the Port Authority and other vessels

Ambient noise – the level of background noise of an area, where single noise sources are not discerned

Cavitation – the formation of vapour bubbles within a liquid in regions of low-pressure following the liquid being accelerated to high velocities. Cavitation occurs as a result of the spinning of vessel propellers and is the main form of vessel-derived underwater noise.

Critical habitat (CH) - habitat vital to the recovery or survival of a species, and may include a breeding site, nursery area, or feeding ground.

Exceedance levels – used to represent quartiles or percentiles for a proportion of time where a given ambient noise level has been reached.

Knudsen curves – empirical models that parameterize ambient noise as a function of frequency based on abiotic conditions

L_5, L_{95} – The upper and lower 5% of the ambient noise values respectively in the frequency range of interest

L_{50} – used to express the median value, or 50% of the time when recordings surpass a value

L_{25}, L_{75} – used to represent the upper and lower quartiles, representing the value exceed 25% of the time and the value exceed 75% of time (or not exceeded 25% of the time) respectively.

Masking – the threshold of detection and interpretation of a sound or call is raised by the presence of another sound

Noise – an unwanted addition to a frequency band of interest. With regards to masking, noise is used to describe the masking sound

Passive acoustic monitoring (PAM) – an unobtrusive means to listen, describe and characterize the underwater sound field and vocalizing marine mammals within it

Sound Pressure Level (SPL) – the received pressure of a given sound, expressed in decibels (dB) relative to a reference pressure of 1μPa.

Source level (SL) – the amount of sound radiated by a source, defined as the intensity of the radiated sound at a distance of 1 m from the source.

PREFACE

The Southern Resident Killer Whale (SRKW, *Orcinus orca*) population is listed as Endangered under Canada's Species at Risk Act (SARA, COSEWIC 2001) and is in decline; at last count 73 individuals remained (Center of Whale Research 2021). A Recovery Strategy was developed and identified key threats to the population's recovery and survival, physical and acoustic disturbance, principally from vessels, vessel strike, decreased prey availability, and habitat contamination (DFO 2017, Raverty et al. 2020).

Following the publication of a spatiotemporal analysis of the sound field in SRKW critical habitat using two years of recordings from the Salish Sea (Burnham et al. 2021a), an additional comparison of sound levels during fisheries closures was requested by the Marine Mammal Unit (MMU). The potential benefit to SRKW was assessed by considering the change in sound levels in ambient broadband sound levels, vessel noise metrics and frequencies used for communication calls and echolocation by SRKW. The broadband frequency (10 Hz to 100 kHz) range is used to represent the full sound field, with it also thought that changes in this range could result in behavioural changes or physiological stress in SRKW (Heise et al. 2017). Frequency ranges representing vessel noise were considered to establish the potential reduction in the anthropogenic noise during periods of catch limitation or fisheries closure, presuming reduced vessel traffic. The ranges of SRKW communication and echolocation allowed a more direct impact on SRKW, and changes in the efficacy of their acoustics' use to be assessed.

A comparison of the sound fields during the closures to one-month prior to-, and post-closure periods was used to examine whether the closures have a benefit to SRKW by reducing acoustical disturbance. These periods were considered to represent a control period with similar baseline sound fields for the comparisons. In instances where measures were in place year round, or the level of catch or fish size restriction differed, as it did for Chinook salmon (*Oncorhynchus tshawytscha*) measures, comparisons to the different restrictions enacted and periods without measures were also made. Periods of catch limitation and complete fisheries closure in management Areas 18, 19, 20 and 121 on west-coast Vancouver Island were considered.

1. INTRODUCTION

Killer whales (*Orcinus orca*) are year-round inhabitants of coastal waters of the northeast Pacific. In the nearshore waters of British Columbia (BC) three sympatric, yet genetically distinct ecotypes are known; resident, Bigg's (formerly transient) and offshore (Ford et al. 2000). The resident type is distinguished into northern and southern groups. The northern resident (NRKW) population are currently designated as 'Threatened', with an estimated 302 individuals with a mean annual population growth rate of 2.2% (DFO 2019). However, the southern resident (SRKW) population is currently listed as 'Endangered' with 73 individuals at the most recent count (Center of Whale Research 2021). Poor fecundity and survival resulted in a population decline of 17% (2.9% annual decrease) between 1996 and 2001; since then, the number of individuals has fluctuated between 72 and 89 individuals, with no signs of population recovery (Taylor and Plater 2001, Krahn et al. 2002, 2004). Indeed, population models suggest that under current conditions it is likely that the population will be extinct in 100-300 years or less (Taylor and Plater 2001, Krahn et al. 2002, 2004, Velez-Espino et al. 2014, Lacy et al. 2017). These models predict that prey limitation has the greatest impact on population growth, but that an increased level of acoustic stress or habitat degradation from contamination could also result in population decline (Lacy et al. 2017).

SRKW principally depend on Chinook salmon (*Oncorhynchus tshawytscha)* for prey, however, Chum (*O. kisutch*) are preyed on in the late summer and fall (Ford et al. 1998, Hanson et al. 2010). The distribution and seasonal movements of SRKW are strongly influenced by the presence of their salmonid prey (Nichol and Shackleton 1996, Baird et al. 2005). Their presence in inland waters around southern Vancouver Island, the Strait of Juan de Fuca, Gulf Islands, and southern Strait of Georgia in Canada, and the San Juan Islands and Puget Sound in northern Washington State in American waters, collectively known as the Salish Sea, is associated with prey abundance (Nichol and Shackleton 1996, Baird et al. 2005), or traveling between foraging and wintering habitats (Balcomb and Bigg 1986, Krahn et al. 2004). Critical habitat was amended in 2018 to include the southwest coast of Vancouver Island, including Swiftsure and La Perouse Banks for SRKW and NRKW (Ford 2006, DFO 2017, 2018, Ford et al. 2017). Observations of SRKW in these areas are more frequent in the summer (Olson et al. 2018) as they follow the in-migration of Chinook salmon (*Oncorhynchus tshawytscha)*, which typically occurs from April to September (Waples et al. 2004). Chinook from the Fraser River comprises up to 90% of their diet in the Salish Sea, however variable abundance, survival rates, and stock depletion (Ruff et al. 2017, Nelson et al. 2019) have seen SRKW entering these inland waters increasingly later in the summer with reduced residency time (Shields et al. 2018, Hanson et al. 2021). Sightings data shows SRKW to frequently use areas on Swiftsure Bank and in Juan de Fuca Strait, Haro Strait, Boundary Pass, and around the southern Gulf Islands (Olson et al. 2018, DFO 2021). In particular they frequent nearshore areas with shallow reefs adjacent to deep water with strong tidal currents that aggregate prey (Groot et al. 1984, Heimlich-Boran 1988, Baird et al. 2005, Hauser et al. 2007, Hanson et al. 2010, Hanson and Walker 2014).

The Salish Sea is an area of heavy vessel traffic, with deep-sea commercial vessels transiting through international shipping lanes. The productive waters of the area also stimulate fishing traffic from commercial operators, recreational users and First Nations fisheries. Salmon fishery closures are one of several management actions in place to support increasing SRKW habitat quality and prey availability. Closures are put in place to address prey limitation and prey competition with salmon fishers within SRKW foraging areas, and may reduce the presence of fishing vessels more broadly in key foraging areas. While these closures remove salmon fishing from these closed areas, thereby also reducing physical and acoustic disturbance from fishing vessel presence, the measures are not primarily attempting to mitigate vessel noise. Area-based fishing closures for commercial and recreational salmon are in place in portions of Swiftsure Bank and Juan de Fuca Strait and inner Salish Sea, predominantly between June and October (Table 1, Appendix). The impact of fisheries closures were considered for areas where measures were directly implicated, as well as areas adjacent to these regions. The fisheries areas where fisheries measures were in place from 2018 to 2021 are 18- Mayne Island-Saanich, 20- Sooke- Bonilla Point lighthouse, 121-Open water southwest of Pachena Point, and 123-Open water southwest of Ucluelet. Much of these overlap with critical habitat for SRKW (Table 1, Appendix). Area 19-Saanich-William Head was included in the assessment to consider the potential acoustic relief that might be seen in areas adjacent to those with management measures implemented.

Killer whales use their acoustic senses as the principal means to send and receive information. It is key for navigation and foraging, as well as maintaining contact between conspecifics. The return signals of echolocation help navigation and foraging, while conspecific calling is often used to maintain communication within and between groups (Ford 1987, 1991, Ford and Ellis 1999). Communication calls include continuous narrow-band tones or frequency-modulated tones that form whistles (Janik and Slater 1998, Herzing 2000) and broadband rapidly repeating burst pulses (Ford 1987, 1989, 1991, Riesch et al. 2006) focused in the frequency range of 500 Hz to 15 kHz (Heise et al. 2017). Echolocation ‘clicks’ are higher in frequency (15-100 kHz, Heise et al. 2017) and can be bimodal in nature with a center frequency of approximately 50 kHz (Au et al. 2004). Noise additions into these frequency ranges could result in acoustic masking of signals being both sent and received by SRKW, and a reduction of the ‘bio-acoustic space’ that the whales use for acoustic cues (Clark et al. 2009). This could result in reduced foraging opportunities or success, or hinder conspecific communication that allows group cohesion, cooperative hunting, and prey sharing. Reduced effectiveness of acoustic use could reduce the success and survival of SRKW on an individual and population level. In addition, energetic budgets may be stressed to maintain group contact in the presence of noise through call modification, including calling louder, longer, or in altered frequencies (Foote et al. 2004, Holt et al. 2009, 2015, Noren et al. 2017). The acoustic response adds to the behavioural and physiological changes that have been observed in the presence of vessels, which include the cessation of foraging and lost prey capture opportunities (Bain et al. 2006, Lusseau et al. 2009, Williams et al. 2014, Holt et al. 2021).

The acoustic signatures of larger commercial vessels predominantly impact the lower frequencies (<500 Hz, Richardson et al. 1995, Veirs et al. 2016), although cavitation noise can radiate into frequencies up to 100 kHz (Ross 1976, Averson and Vedittis 2000, Hildebrand 2009, Hermannsen et al. 2019). Commercial fishing vessels add to these lower frequencies, however echosounders or fish-finders also create high frequency signals (Burnham et al. 2021a, Vagle et al. 2021). Recreational and First Nations fisheries rely on smaller vessels. These are more likely to add to higher frequencies in the sound field (Richardson et al. 1995, Wladichuk et al. 2019). Smaller vessels are frequently under-represented in vessel-presence analyses as many are not AIS equipped (Hermannsen et al. 2019, Serra-Sogas et al. 2021), with acoustic metrics giving clues to their prevalence and spatial use.

Previous analyses that describe the spatiotemporal patterns of the soundscape within the Salish Sea (Burnham et al. 2021a) found the sound fields to be influenced by both natural and anthropogenic noise. A composite of natural non-biological, biological, and human-derived noise were found for each mooring, with changes in the influence of these inputs over space and time (Figure 1). The soundscape of Swiftsure Bank was influenced by offshore wind, which is then funneled down Juan de Fuca Strait towards Port Renfrew. The influence was greatest in the winter with offshore wind impacting the sound field as far east as Jordan River. Port Renfrew and Jordan River mooring locations had similar soundscapes (Figure 1). However, the similarity was not seen for the recordings made at Sooke, where localised increases in wind in the summer increased mid-frequency sound levels (Figure 1). A west-east or outer and inner Salish Sea divide was also seen in the sound field, whereby those moorings in the more protected waters of inlets and around the Gulf Islands exhibited reduced sound levels (Burnham et al. 2021a). Recordings made in Haro Strait and Boundary Pass showed strong similarities, with both being relatively quiet, but with increased intense noise levels for short periods of each vessel transit (Figure 1, Burnham et al. 2021a). The description of natural and human-derived changes that form patterns in the soundscape of the Salish Sea form a baseline from which to compare the efficacy of management measures, and context to changes.

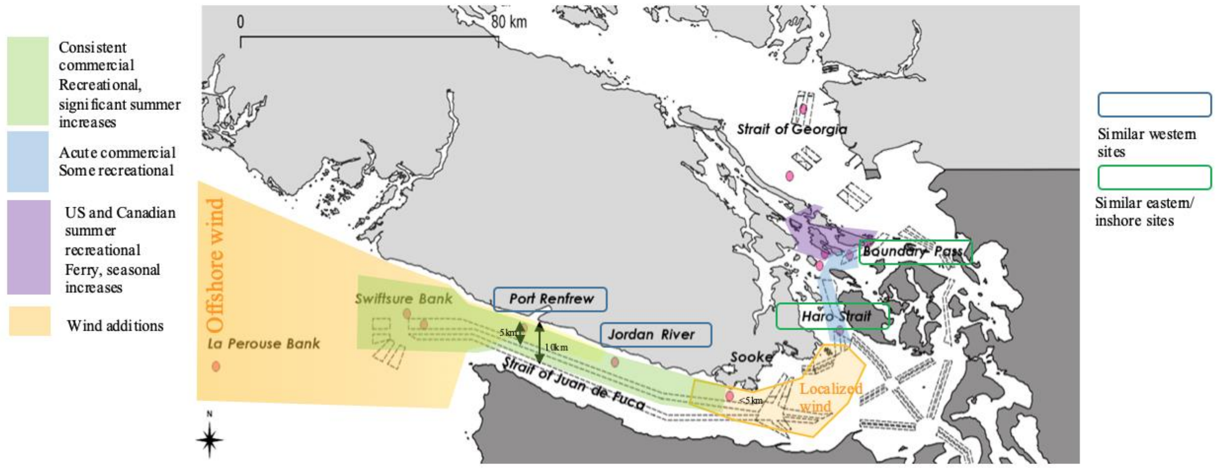


Figure 1: Summary of soundscape patterns found in the Salish Sea, with dominant influences to the sound fields indicated by coloured shading. The mooring locations are shown with pink circles and location labels.

This report presents the results of a comparison of acoustic recordings made during periods where fisheries conservation measures were in place with those recorded one-month prior to or following the implementation of these management actions. Changes in ambient broadband noise, vessel noise metrics, and noise in frequencies pertinent to SRKW will be considered as a means to assess the potential acoustic benefits of fisheries closures in management areas in the Salish Sea. The measures included closures of all fisheries in Juan de Fuca Strait and on the west coast of Vancouver Island, and all commercial and recreational fisheries (food, social and ceremonial fishing is permitted) in Interim Sanctuary Zones (ISZ) that prohibit vessels and fishing. Also comparisons between periods with differing restrictions on catch number and/or fish size implemented as Chinook and Steelhead conservation measures were made (see Appendix, Table 1). Measures applied to management Areas 18, 20 and 121 were considered, as these areas are core summer SRKW habitat. Area 19 was considered in the assessment as adjacent waters to the east and west were subject to management measures. The acoustic analysis used recordings from an existing network of acoustic moorings deployed within these management areas.

2. METHODS

ACOUSTIC RECORDINGS AND ANALYSIS

The underwater recordings were made using Multichannel Acoustic Recorders (AMAR G4, JASCO Applied Sciences) equipped with calibrated omnidirectional GeoSpectrum Technologies M36-100 hydrophones. The passive acoustic equipment was mounted on a custom designed quiet mooring that positioned the hydrophone approximately 2 meters off the sea floor. Mooring locations were on Swiftsure Bank and throughout the Salish Sea (Figures 2) in areas of SRKW critical habitat. Their positions were based on SRKW habitat use data and matched areas where whales are frequently observed (Cominelli et al. 2018, Olson et al. 2018). Broadband recordings were made (256-kHz sample rate, 24-bit resolution) and stored on internal SD memory cards until retrieval. A regular mooring maintenance schedule allowed for continuous recordings throughout the period of interest. The full recording range for analysis was 10 Hz to 100 kHz. On retrieval, the acoustic wav files were processed using custom Python scripts, modified from those used by Merchant et al. (2015). One-minute power spectra were calculated using a 1-s Hanning window, 50% overlap and Welch's averaging. This minute-wise data was then averaged to hourly sound pressure levels (SPL) for further analysis.

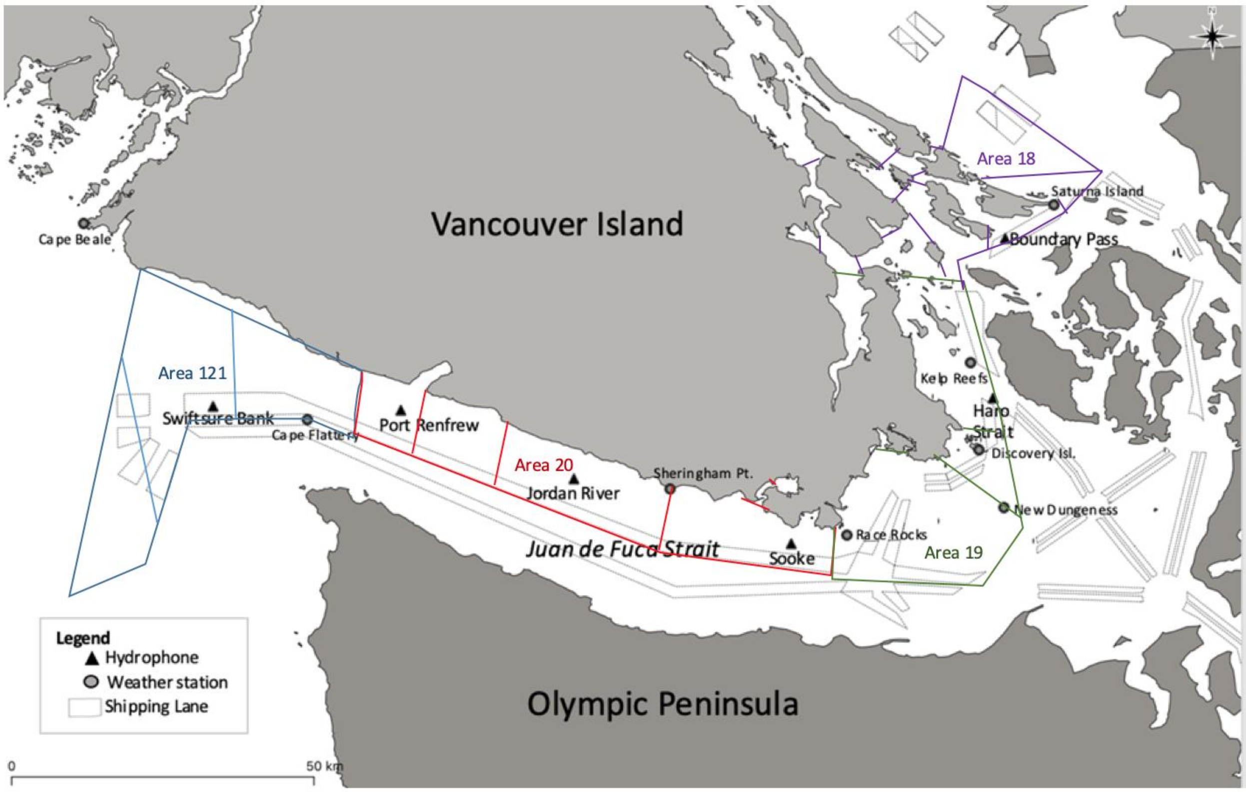


Figure 2: The Salish Sea with hydrophone and weather station locations marked. Fishing management areas and sub-areas are also indicated.

The acoustic moorings were first deployed by DFO in spring 2018 at Swiftsure Bank, Port Renfrew, Jordan River, Sooke, Haro Strait, and Boundary Pass (Table 1, Figure 2). The Swiftsure Bank recorder was well positioned to evaluate changes in Area 121, those recorders in the Strait of Juan de Fuca were considered for Area 20, the Haro Strait recorder for Area 19 and Boundary Pass, and the recorders in the Gulf Islands for used in the evaluation of Area 18 (Table 1, Figure 2). Assessment using the Swanson Channel and Saturna Island recorders are more limited, with recordings only available in 2020 and 2021 (Table 1).

Table 1: Location and timing of deployments of moorings in the Salish Sea. Periods where recordings were not possible (particularly during COVID) are also indicated. The analysis is based on data collected up until March 2022.

Hydrophone Location	Management Area	Deployed	Data Gaps (MMYY-MM-YY)
Swiftsure Bank (MEQ)	Area 121	Apr. 2018	Jul. 29 – Aug. 16, 2018 Mar. 18-Jun. 22, 2020
Port Renfrew	Area 20	Feb. 2018	Jun. 20-Aug. 29, 2018 Feb. 28-Mar. 4, 2019 Mar. 4- Jun. 22, 2020
Jordan River	Area 20	Feb. 2018	Mar. 19-May 14, 2020
Sooke	Area 20	Feb. 2018	Feb. 6 – Mar. 6 2018 Feb. 27- Mar. 5, 2019 May 18-31, 2019 Aug. 9-17, 2019 Nov. 3-25, 2019 Feb. 11-May 14, 2020
Haro Strait	Area 19	Feb. 2018	Feb. 28- Mar. 6, 2019 Mar. 21- Jul. 16, 2020
Boundary Pass	Area 18	Feb. 2018	Feb. 23 – Mar. 6, 2019 Jul. 2 – Aug. 18, 2019 Nov. 3-24, 2019 Fab. 9- May 12, 2020
Swanson Channel	Area 18	Aug. 2019	Jun. 17-22, 2020
Saturna Island	Area 18	May 2020	Mar. 20-May 12, 2020

Comparisons of noise levels were made over several frequency ranges. Broadband ambient noise levels in the 10 Hz to 100 kHz range were evaluated for change between pre-, during, and post-closure recordings, and recordings when various levels of restrictions were in place (Table 2, Table 1 Appendix). Acoustic additions in this range have also been noted for their potential to cause physiological stress or alter behaviour of SRKW (Heise et al. 2017). Vessel-presence signals were considered by the use of three metrics; the 100-1000 Hz decadal band and two metrics applied by the EU Marine Strategy Framework Directive, the 1/3 octave bands centered on 63-Hz and 125-Hz. The use of these metrics is consistent with previous studies in the Salish Sea (Burnham et al. 2021a), and represents vessel noise without potential inclusion of water turbulence noise

(Merchant et al. 2012, 2015, Table 2). They represent the acoustic additions from commercial vessels being focused in the lower frequencies. A 1-kHz frequency band centered around 50 kHz was considered as a representative metric for small vessel presence. It is also the most frequent echosounder frequency used in this area (ECHO 2019, Burnham et al. 2021a). Sound levels in frequencies relevant to SRKW were also examined, using the 500 Hz to 15 kHz range to represent changes in the frequencies used for conspecific-communication calls, and 15-100 kHz for echolocation (Heise et al. 2017, Table 2). These SRKW-relevant metrics provide insight into the potential species response to increased disturbance from anthropogenic noise. Abiotic influence was also considered, with a 1-kHz band centered around 8 kHz used to estimate additions from wind (Vagle et al. 1990, Table 2).

Table 2: Frequency ranges of acoustic metrics used in this analysis to describe changes and additions in the soundscape.

Frequency range (Hz)	Metric	Description
10-100,000	SRKW	General ambient noise metric, range where behavioural change in SRKW may be observed if noise additions are present (Heise et al. 2017)
500-15,000	SRKW	Range for SRKW communication calls (Heise et al. 2017)
15,000-100,000	SRKW	Echolocation range for SRKW (Heise et al. 2017)
100-1,000	Vessel	Vessel presence marker, excluding water turbulence (Merchant et al. 2012). Most indicative of commercial vessels
57-71	Vessel	63 1/3 octave band (Merchant et al. 2012, 2015). European Standard, most indicative of commercial vessels.
113-141	Vessel	125 1/3 octave band (Merchant et al. 2012, 2015). European Standard, most indicative of commercial vessels
49,500-50,500	Vessel	Representative of the 50 kHz signal used in depth/echosounders and fishfinders, and smaller, recreational vessels
7,500-8,500	Wind	Known relationship between wind speed and 8 kHz noise additions (Vagle et al.1990)

Changes in noise levels in these frequency ranges were examined using sound pressure levels (SPL). The L_5, L_{50}, and L_{95} exceedance levels were obtained for the pre-, during and post-closure periods. The L_{95} or 5th percentile, represents the baseline ambient noise level at the mooring 95% of the time, and the L_5, or 95th percentile, represents the upper level of noise additions, in 5% of the recordings. Together these exceedance levels described the range of sound levels present in the frequency ranges of interest. The L_{50} represents median levels of noise, and is frequently used in noise level comparisons (e.g., Klinck et al. 2012, Merchant et al. 2012). Significance between periods (control and closure periods, or periods when different levels of measures were in place) were assessed using non-parametric Kruskall-Wallis tests, with student t-tests used to assess changes in mean acoustic and vessel presence levels. Correlations between sound pressure levels (SPL) on minute-wise, hourly or daily scales, and measures of wind speed and vessel presence, specifically considering fishing vessels and data on AIS Class B Automatic Information System

(AIS) vessels, for periods pre-, during and post-measures were also used to determine the influence of each on the sound levels.

Recorders within or proximal to the area impacted by the closures were the focus of this study. The SPLs in this analysis were unweighted, and not adjusted to reflect the hearing range or capabilities of SRKW.

VESSEL PRESENCE

Data from the vessel AIS were used to examine changes in vessel presence for pre-, during and post-closure periods, or between different measures being enacted in the same region. These data were collected by Canadian Coast Guard terrestrial receivers that list vessel name and unique identification number, type, and location every 5-30 seconds. AIS transceivers are a requirement for any vessel exceeding 150 gross tonnage (GT) and carrying 12 passengers. In addition, international vessels exceeding 300 GT and non-international vessels exceeding 500 GT are subject to this requirement in Canada. The AIS data were cleaned and aggregated into 5 minute bins. From this, the number of passages per hour in the closure areas and in proximity to the moorings (≤5 km) and in a more broad-scale (≤ 10 km) were examined. Focus was given to vessels identified as fishing. For the moorings in Juan de Fuca Strait 5 km is the approximate distance to the outbound shipping lane, and 10 km is the approximate distance to the inbound lane. This 10 km maximum is also the estimated distance over which high frequency noise from shipping vessels will propagate (Erbe and Farmer 2000).

Commercial vessels have a consistent passage rate and distance from the moorings through Juan de Fuca Strait (Burnham et al. 2021 a,b). Sound additions are most acute when the vessels are overhead or in close proximity to the moorings, with vessel noise from cavitation and propulsion emitted predominantly in the low frequencies (< 500 Hz). During the summer months (July to October) voluntary vessel speed reductions, applicable to bulkers, tankers, container ships, ferries, vehicle carriers, cruise ships, and government and research vessels, are put in place in Haro Strait (since 2017), Boundary Pass (since 2019) and Swiftsure Bank (since 2020). This request comes from the Enhancing Cetacean Habitat and Observations (ECHO) Program through the Port of Vancouver as a means to reduce vessel noise as speed decreases (see Veirs et al. 2016). Also, through Juan de Fuca Strait tugs and barges are requested to move their transits away from the Canadian coastline and travel on a more southerly route as part of a lateral displacement trial. This shift aims to move vessel transits that are not limited to shipping lanes further from SRKW foraging areas. These measures were not assessed here (see Burnham et al. 2021b) but are considered in the context of any changes seen.

In Canadian waters, fishing vessels, smaller commercial, or pleasure craft are exempt from carrying an AIS transceiver. However, vessel operators may still choose to carry a transceiver, often the Class B AIS transceiver, rather than the Class A units used on commercial vessels. Class B systems transmit the same information as the Class A systems, but report less frequently and with a lower priority at receivers and have lesser transmission power. Data received from Class B receivers were used to represent recreational vessel presence in this analysis. However, the AIS data used to quantify vessel presence is considered an underestimate, especially for recreational vessels (Serra-Sogos et al. 2021) and so represents the minimum impact of Class B and non-AIS vessels.

This analysis did not assess the compliance level with management measures, or trace changes in vessel presence or movements in detail. Vessel presence, determined from AIS data, was considered on a coarse scale to give context to the acoustic recordings. Also, the vessel behaviour in terms of residency time, transit speeds, and area use were not discernible from the AIS data in the form used in this analysis. Although vessel presence during periods of fisheries closures compared to control periods was evaluated, this was done in the context of the potential of acoustic disturbance only, and did not consider the potential behavioural disturbances that might result from the physical presence of the vessel (Williams et al. 2006, 2009, 2014, Lusseau et al. 2009, Holt et al. 2021).

ANALYSIS OF MANAGEMENT MEASURES

The acoustic and vessel data were separated into control and trial periods, where the control periods are for one month intervals prior to the initiation of the fisheries management (i.e., closure or restrictive) measure(s) being implemented and for one month following release of the management measure(s) (Table 1 Appendix). These dates varied for each year considered. One month intervals were chosen for the control periods to ensure similar sound field conditions for comparison to closure periods. Closures were differentiated based on their conservation target (i.e., SRKW, Chinook or Steelhead), with measures for conservation targets aggregated over time to represent an overall pre-implementation period, periods when any measure was in place and a post-release period. The control-closure comparison was done for each measure implement (catch or size restrictions per conservation target) in each fishing area, as well as a more overall comparison where a period of a month prior to and following any measures being in place were considered. For Chinook measures, which differed in the restriction on catch number and size of fish retained, Chinook restrictions included in the analysis were for periods when there was no retention, one fish maximum, two-fish maximum, and size limitation on a two-fish maximum were in place. Comparisons between each of these restrictions were made, as well as a pre- and post- measures (Table 1 in Appendix). Measures for management regions, and sub-management regions relevant to each mooring were considered (Figure 2, Table 1). However, the impact of measures in areas where measures were not directly applied were also considered. Changes in sound levels for Area 19 was considered using the pre-, during, and post-management measures periods of Areas 18 and 20. Additionally, the reciprocal effects of management measures in Areas 121 and 20 were considered by examining any changes in SPL based on Area 121 closures for Port Renfrew recordings and Swiftsure Bank sound levels based on Area 20 closure dates (Table 1in Appendix). Changes in SRKW communication and echolocation bands (Table 2) were considered to better understand if the management measures reduced the potential for acoustic disturbance for the animals more directly. However, this analysis did not consider if measures taken changed prey levels, nor any actions taken to reduce other disturbance factors that might have been in place other than a brief discussion of the implementation of the ECHO Program slowdown and ISZ exclusion zones.

The data from 2018 to 2021 were first considered together, with comparisons made between the pre-, during, and post-measures periods. However, differences between years were considered for both acoustic recordings and vessel presence. For areas with Chinook measures in place, comparisons were made between each of the Chinook restriction levels to each other and the pre- and post-measures control periods. Although temporal comparisons focused on periods with and without management measures, differences on daily, weekly and monthly scales were also considered. Diurnal patterns were examined for using nautical sunrise and sunset times. Lunar months were used to minimize tidal influences in the recordings. Wind speed data from weather buoys and light house stations in proximity to moorings (Figure 2) were correlated with sound levels in the frequencies of interest (Table 2) to determine the acoustic input.

3. RESULTS

The soundscape in the Salish Sea showed a strong seasonal pattern. Wind speed has a relationship with noise additions around 8 kHz (Vagle et al. 1990, Burnham et al. 2021a, Table 2 in Appendix). In the winter increased wind, wave and precipitation noise from storm events add substantially to the soundscape (Burnham et al. 2021a, Figure 1, Table 2 in Appendix). Recordings made in exposed areas such as Swiftsure Bank and the western extent of Juan de Fuca showed this influence the most. Localised wind speed increases were observed at the eastern extent of Juan de Fuca Strait during the summer (Burnham et al. 2021a, Table 2 and Figure 1 in Appendix). This elevated both the broadband and mid-frequency sound levels.

The results of the non-parametric correlations between sound levels at each mooring highlighted the influence of wind and sea state on the soundscape. This effect can be seen directly in the 8 kHz frequency range (Table 2-3 in Appendix). However, altered wind, and therefore sea state, may indirectly influence vessel presence.

Vessel numbers increased during the summer months (Figure 2 in Appendix), especially the number of smaller recreational vessels, however, the passage of commercial traffic in these areas was similar between seasons (Burnham et al 2021a). More significant correlations were seen between the number of vessels present and sound levels for periods where management measures or fisheries closures were in place, perhaps due to a reduced addition from abiotic (wind/wave) noise and increased vessels (Table 2 in Appendix).

Generally, sound levels were greatest for Boundary Pass in all years considered (Table 3). Recordings were impacted by transits of commercial vessels in close proximity to the mooring, resulting in elevated broadband soundscape levels. Frequency ranges representing vessel presence were also elevated compared to other moorings (Table 4, Tables 2-3 in Appendix). Previous analyses have shown that this location and Haro Strait have periods of relative quiet punctuated by acute vessel noise additions when a commercial vessel is directly transiting the area, elevating average noise levels dependent on shipping timetables (Table 4, Tables 2-3 in Appendix, Burnham et al. 2021a).

The lowest sound field levels were recorded by the ISZ moorings in Swanson Channel and Saturna Island (Table 3). These moorings were positioned in more sheltered inner-water ways in the Gulf Islands, although they are still in proximity to shipping lanes and experience high rates of recreational traffic especially in the summer (Burnham et al. 2021 a,b). Sound field levels were typically greatest for recordings made in 2018, except for ISZ moorings which recorded increasing noise levels each year of their deployment time (Table 3, Tables 2-3 in Appendix).

Overall comparison of broadband noise (Table 3) and vessel metrics (Table 4) was made between the sites, and the changes in broadband ambient noise between years to give context the any changes seen possibly as a result of the fisheries management actions.

Table 3: Broadband (10Hz-100 kHz) ambient sound levels (SPL (dB re 1µPa)) for each site with the overall background L95 and median of all years (Median) and each year of recording shown

Location	Broadband (10Hz-100 kHz) SPL (dB re 1µPa)					
	L95	Median	2018	2019	2020	2021
Swiftsure Bank	106.8	120.5	122.7	119.0	119.5	121.5
Port Renfrew	105.5	115.5	116.1	116.0	116.5	115.0
Jordan River	105.4	117.8	119.9	117.1	115.8	118.2
Sooke	111.7	122.4	122.7	122.3	120.9	124.0
Haro Strait	101.5	119.8	121.2	119.1	118.8	119.8
Boundary Pass	102.9	125.4	126.6	125.5	124.2	124.9
Swanson Channel	99.03	110.1		109.1	110.0	110.7
Saturna Island	98.45	117.2			115.9	118.2

Table 4: Sound levels (SPL (dB re 1µPa)) for each site for the vessel frequency ranges of 100-1000 Hz, 125 1/3 octave band (125 Hz 1/3 Oct.), 63 1/3 octave band (63 Hz 1/3 Oct.), and a 1 kHz band around 50 kHz (49.5-50.5 kHz)

Location	Median SPL (dB re 1µPa) in vessel metrics			
	100-1000 Hz	125 Hz 1/3 Oct.	63 Hz 1/3 Oct.	49.5-50.5 kHz
Swifsure Bank	112.6	105.1	109.4	70.9
Port Renfrew	107.8	100.3	103.4	66.1
Jordan River	107.7	100.7	106.5	65.9
Sooke	100.7	104.4	112.0	68.3
Haro Strait	111.1	103.8	109.2	67.7
Boundary Pass	113.7	106.8	115.3	72.1
Swanson Channel	104.3	96.4	97.6	67.8
Saturna Island	106.5	98.5	103.0	68.0

Table 5: Median sound levels (SPL (dB re 1µPa)) for each site in the SRKW communication (500 Hz to 15 kHz) and echolocation (15-100 kHz) frequency ranges in pre-, during and post-measures periods all years combined

Location	Median SPL (dB re 1µPa)					
	Communication (500 Hz-15 kHz)			Echolocation (15-100 kHz)		
	Pre-	Measures	Post	Pre-	Measures	Post
Swiftsure Bank	113.2	112.2	114.5	100.0	100.5	101.5
Port Renfrew	104.2	104.5	104.5	89.2	91.6	93.1
Jordan River	105.2	104.6	104.2	89.3	90.6	92.3
Sooke	109.3	109.2	108.8	92.3	94.3	94.5
Haro Strait	109.9	110.5	118.9	94.6	94.2	95.9
Boundary Pass	113.7	113.5	113.2	101.4	101.6	101.9
Swanson Channel	105.1	106.2	104.2	92.6	96.9	92.4
Saturna Island	108.7	108.8	109.7	92.9	94.4	94.4

The change in sound pressures levels from the control period prior to the period when measures were in place, and then again for the period where measures were in place to when they were lifted was considered for each site and each year of measures as an overall change (Table 6). The changes seen at each mooring were then considered in more detail, comparing each type of measure in place.

Table 6: Change in sound levels (dB re 1µPa) for each site for broadband ambient (0.01-100 kHz) the SRKW communication (0.5-15) and echolocation ranges (15-100) vessel frequency ranges of 100-1000 Hz (0.1-1), 125 1/3 octave band (0.125.), 63 1/3 octave band (0.63), and a 1 kHz band around 50 kHz (49.5-50.5) and 8 kHz for wind (7.5-8.5)

		Delta SPL (dB re 1µPa)							
kHz:		0.01-100	0.5-15	15-100	0.1-1	0.125	0.63	49.5-50.5	7.5-8.5
Swiftsure Bank - All measures									
2018	Pre	1.6	3.4	2.8	1.4	-0.4	2.0	2.9	3.8
	Post	-3.6	-0.1	-1.5	-0.2	-0.9	-0.6	-0.2	-1.0
2019	Pre	-2.3	0.9	2.9	0.7	0.1	0.4	4.0	1.6
	Post								
2020	Pre	-3.3	0.1	-2.2	-1.6	2.0	-10.0	-6.3	-0.4
	Post	5.0	2.6	4.7	2.8	-1.1	11.43	8.31	3.3
2021	Pre	-0.3	-3.4	-1.1	-1.5	-1.7	-3.2	0.8	-3.8
	Post	2.0	3.3	2.3	0.9	0.4	2.8	-0.5	2.7
Port Renfrew									
2018	Pre	0.5	1.2	0.6	0.8	0.5	0.5	1.0	1.1
	Post	1.7	-1.6	0.3	-0.6	-0.4	1.5	0.9	-1.8
2019	Pre	-3.1	0.6	-1.2	1.2	1.2	-2.0	-1.0	0.8
	Post*	2.1	1.3	5.9	0.2	-0.3	0.4	3.3	3.5
2020	Pre	6.1	-0.4	2.4	0.7	1.5	3.5	6.8	-0.6
	Post	-1.9	0.5	1.8	-0.2	-0.7	-2.0	-2.9	1.6
2021	Pre	1.7	-1.0	0.4	-1.0	-1.2	26.8	4.3	-0.8
	Post	8.0	0.1	-0.1	1.2	0.2	3.3	-5.3	0.8
Jordan River									
2018	Pre	-2.2	-0.1	1.3	-1.0	-1.6	-1.5	2.6	-0.1
	Post	-1.8	-2.1	-3.0	-0.2	-0.1	-1.7	-6.2	-1.1
2019	Pre	-1.2	-0.6	2.1	0.2	0.1	-0.8	1.3	1.0
	Post								
2020	Pre	-8.7	-0.1	1.6	-2.3	-0.9	-1.4	3.9	0.1
	Post	2.9	0.2	3.3	0	-0.2	0.3	-2.1	-8.8
2021	Pre	1.1	-1.4	0.1	-1.5	-1.5	-1.1	3.6	-0.7
	Post	-1.5	0.4	0.6	0.2	0.7	-0.8	-2.8	0.8
Sooke									
2018	Pre	2.4	-0.8	1.9	-1.1	-0.3	3.0	7.0	0.2
	Post	-4.2	0.5	1.2	1.2	-0.3	-0.3	2.9	-0.4
2019	Pre	1.6	1.4	3.3	-1.1	-0.1	-5.0	2.0	2.2
	Post								
2020	Pre								
	Post	1.0	-0.6	-0.7	-0.6	-0.5	0.1	-3.7	-2.0
2021	Pre	8.7	0.2	2.9	1.3	0.7	1.6	6.4	1.0
	Post	-8.4	-1.4	-0.9	-2.8	-2.8	-4.5	-4.0	-1.9

		0.01-100	0.5-15	15-100	0.1-1	0.125	0.63	49.5-50.5	7.5-8.5
Haro Strait									
2018	Pre	0.6	1.1	0.0	0.9	0.2	0.6	4.3	-0.1
	Post	1.6	7.6	1.4	2.5	-0.1	2.1	-4.7	-8.8
Boundary Pass									
2018	Pre	2.7	-0.3	0.3	1.3	0.9	4.8	2.4	-0.1
	Post	-0.5	19.5	-0.8	-1.5	-1.6	-1.8	-2.7	-0.7
2019	Pre	-2.4	-0.7	0.9	-0.8	-1.5	-4.3	2.8	-0.2
	Post								
2020	Pre								
	Post	-0.6	0.7	0.2	0.0	0.6	0.7	0.3	0.2
2021	Pre	3.5	-0.4	-0.9	-1.6	-1.9	-1.9	0.1	-0.5
	Post	-2.6	-0.2	2.5	0.6	1.2	0.8	-1.8	-0.1
Swanson Channel									
2019	Pre								
	Post								
2020	Pre	0.3	0.8	4.5	0.8	0.1	-1.3	6.7	2.4
	Post	-2.6	-2.2	-5.1	-2.2	-1.7	0.1	-10.9	-4.2
2021	Pre	4.2	1.7	4.9	1.3	0.5	-1.7	8.5	2.7
	Post	-4.6	-3.0	-6.2	-1.4	0.7	1.3	-13.7	-4.6
Saturna Island									
2020	Pre								
	Post	5.3	5.1	0.2	3.3	-1.0	1.5	0.8	0.5
2021	Pre	4.6	-0.7	1.6	-1.3	-1.7	-1.5	1.4	-0.1
	Post	-1.6	1.4	-0.4	0.9	0.7	1.5	-1.3	0.9

AREA 121

Swiftsure Bank

The soundscape at Swiftsure Bank was most heavily influenced by commercial traffic, with deep sea vessel passages the most frequent from the AIS data. The AIS recorded fishing vessel passages in the vicinity of the mooring (≤ 5km) averaged 0.5 per hour in the summer and 0.01 passages/hr in the winter. Median broadband ambient noise levels were lowest when any form of fisheries measure was in place compared to control periods (Figure 3, Table 6, Tables 3-4 in Appendix).

Soundscape levels increased during the post-measures control period and exceeded those of pre-measure (Figure 3, Tables 3-4 in Appendix). A comparison between control periods showed that the changes in broadband sound levels were driven by increases in all frequency ranges of interest especially in the higher ranges. For vessel noise frequency ranges, the 95th percentile levels were highest when fisheries management measures were in place, suggesting that vessel presence is greater during this period despite the measures (Figure 2 in Appendix). The changes in higher frequencies suggest that this increase was principally driven by recreational vessels, further substantiated by examination of the Class A AIS data which showed the commercial and deep-sea passage rate to be consistent in comparisons. Decreased wind, in both speed and acoustic metrics may make this area more accessible for recreational fishing and boating in the summer. Indeed, wind speed, and gusting wind speeds showed a negative correlation with vessel metrics and with the frequency range centered around 50 kHz. This suggests that as the winds speeds were reduced the use of this area by vessels, particularly smaller, recreational vessels, increased (Figures 4-5, Figure 1 and Table 2 in Appendix).

A comparison of the sound levels when Chinook conservation measures were in place showed increases when compared to both the pre-measures control period and periods when retention of one or two fish was allowed (Table 4b in Appendix). Further increases were seen when measures were lifted. The presence of vessels in the AIS data was also increased (Figure 1 in Appendix). The presence of fishing vessels up to a distance of 10 km from the mooring also increased during closures compared to control periods, with this same trend seen for closures in the adjoining Area 20 (Figure 2 in Appendix).

Periods when vessels were excluded from the ISZ also showed notable reductions in the frequency ranges of interest. However, compliance with the ISZs, interpreted from AIS data, was lacking (Table 4a in Appendix, Burnham et al. 2021b).

During the period that SRKW fisheries measures were in place, mid- to high-frequency noise was substantially reduced in the SRKW communication frequency range (Table 5, Figure 4). This appeared to follow the pattern of wind speeds and acoustic wind additions (Figure 1, Table 2 in Appendix). However, increases were seen in both SRKW relevant ranges following this closure and an increased presence of vessels within 10 km from the mooring (Figure 2 Appendix). The echolocation frequency showed substantial increases from pre-management measure periods to those when Chinook fishing limitations were increased (Table 5), with the increases in this and the 50 kHz band seen as the summer progressed.

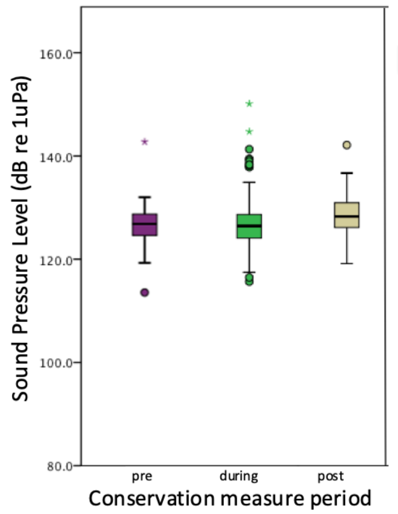


Figure 3: Comparison of broadband (10 Hz to 100 kHz) ambient sound levels for recordings made pre-, during, and post-management measures being in place at Swiftsure Bank. Representing fisheries management area 121.

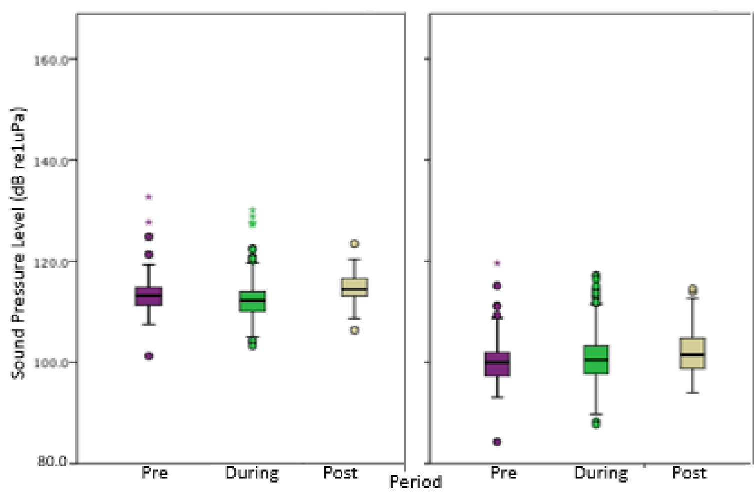


Figure 4: Comparison of SRKW communication (500 Hz to 15 kHz, left) and echolocation (15-100 kHz, right) sound levels for recordings made pre-, during, and post-management measures being in place at Swiftsure Bank. Representing fisheries management area 121.

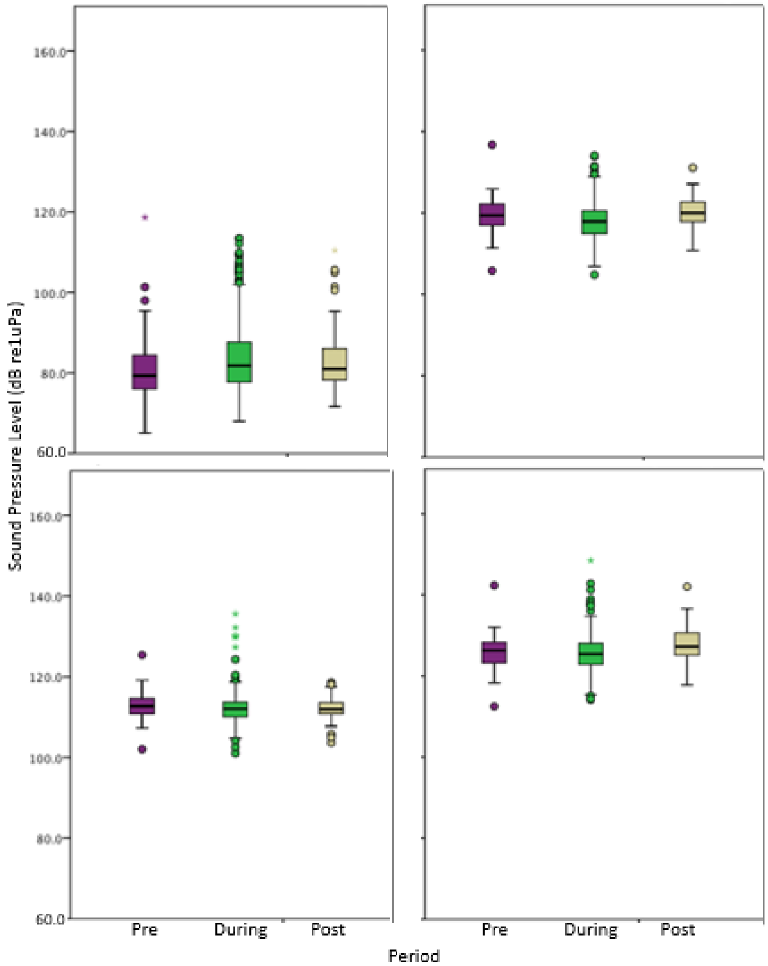


Figure 5: Comparison of vessel metrics (50 kHz, top left; 63 Hz 1/3 octave, top right; 125 Hz 1/3 octave, bottom left; 100-1000 Hz, bottom left) sound levels for recordings made pre-, during, and post-management measures being in place at Swiftsure Bank. Representing fisheries management area 121.

Similar patterns were seen for each year in the data (Table 6, Tables 3-4 in Appendix). Comparison between years showed an overall reduction in sound levels in 2019 compared to other years (Table 3), especially in the higher frequencies of the 50 kHz and SRKW echolocation band. However, Swiftsure Bank still recorded one of the highest levels of noise in these bands during the pre-management measure period of 2019 (Table 3 in Appendix). Previous analysis has found that commercial vessel traffic levels were reduced during the summer of 2019 compared to previous years (Vagle and Neves 2020). It is possible that slowdown measures introduced in 2020 for outbound traffic from the JA/Cape Flattery buoy resulted in overall reductions of noise in vessel frequency bands, except in the 50 kHz band, which represents the noise from smaller vessels.

Overall, for the period that fisheries measures were in place, soundscape noise levels were generally reduced; however, reductions in frequencies representative of SRKW social calls used for communication were likely reduced by lower wind and gusting wind speeds. Voluntary slowdown measures likely reduced commercial vessel noise; however, elevated levels at 50 kHz and its increase as the summer progressed suggests that the presence of recreational vessels increased during closure and post-closure periods with this having implications, and so matching increases, for sound levels in the SRKW echolocation frequency range.

AREA 20

Similar trends to Swiftsure Bank were seen for this area, with reduced wind decreasing noise levels in the mid- to high-frequency ranges (Figure 1, Table 2 in Appendix). This included the SRKW communication frequency range which seemed most sensitive to wind during fisheries closures (Table 2 in Appendix). This correlation is considered independently of vessel presence, but the additions from wind, and therefore soundscape variation tied to wind speed, may become heightened comparatively due to the decreased anthropogenic noise resulting from the closures. Increases in higher frequencies during closure periods, including in the SRKW echolocation band likely resulting from increased recreational vessel presence (Table 5-6).

Port Renfrew

The soundscape levels were at their lowest during the pre-measures period (Tables 3-4 in Appendix). A rise in broadband levels was driven by substantial increases in higher frequency sound. The presence of fishing vessels up to 10 km distance from the mooring was also notably increased during the period measures were implemented (Figure 1 in Appendix). The difference between periods where fisheries measures were in place to the month following again showed a median broadband sound level increase of approximately 4.5 dB (Table 6, Figure 6).

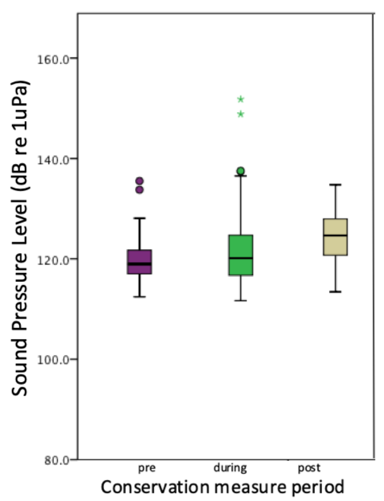


Figure 6: Comparison of broadband (10 Hz to 100 kHz) ambient sound levels for recordings made pre-, during, and post-management measures being in place at Port Renfrew, fisheries Area 20.

The increases in the higher frequencies, including the higher frequency vessel metric and contributions to SRKW echolocation range, as the summer progressed suggested that recreational vessel presence increased as wind speeds and wave conditions were reduced (Figures 7-8). This was confirmed by the AIS data, which showed an increase in Class B vessels using the waters around the coast and the outbound shipping lane around Port Renfrew through the summer and especially between pre- and post control periods. Increases in the 50 kHz band were consistently observed as restrictions in allowable Chinook catch were reduced, for example no retention to one fish, and from one fish to two. In the latter case AIS-tracked vessel presence was increased around the mooring (Figure 2, Table 4b in Appendix), with Class B vessel presence notably elevated within the 10 km range.

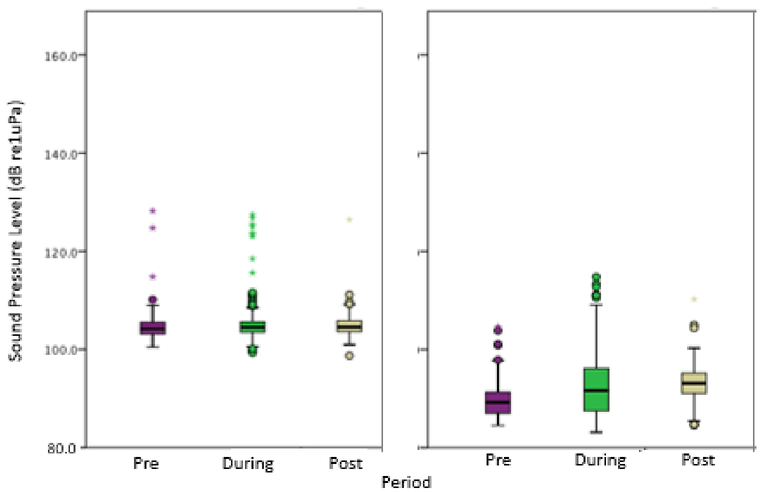


Figure 7: Comparison of SRKW communication (500 Hz to 15 kHz, left) and echolocation (15-100 kHz, right) sound levels for recordings made pre-, during, and post-management measures being in place at Port Renfrew, fisheries Area 20.

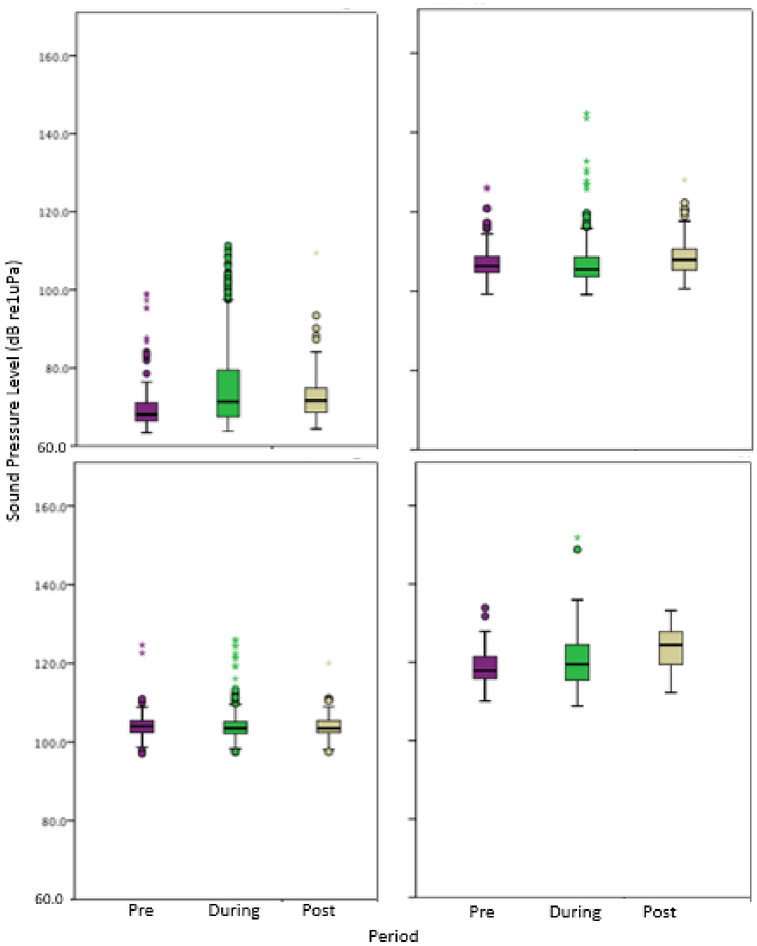


Figure 8: Comparison of vessel metrics (50 kHz, top left; 63 Hz 1/3 octave, top right; 125 Hz 1/3 octave, bottom left; 100-1000 Hz, bottom left) sound levels for recordings made pre-, during, and post-management measures being in place at Port Renfrew, fisheries Area 20.

Between years, the lower-frequency metrics representing large vessel presence were consistent. A general decrease in sound levels in the summer months of 2019 has previously been attributed to reduced vessel presence (Vagle and Neves 2020), with significant increases seen in both the highest (50 kHz: $t(466)=-2.056$, $p=0.040$) and lowest (67 Hz $t(334.477)=-5.444$, <0.001) vessel metrics between 2019 and 2020. The increase in broadband ambient noise in the post-measures period were driven principally by wind particularly in the later years of this analysis. A general annual increased in vessels was noted throughout the multi-year study period (Tables 3-4, Figure 2 in Appendix).

The timing of measures in neighbouring Area 121 were similar, and did not alter the patterns of changes seen in the acoustic record between fisheries closures and pre- and post control periods at this location.

Jordan River

A decrease in broadband ambient noise levels was recorded at Jordan River when fisheries management measures were in place (Table 5, Table 3 in Appendix). The median reduction in sound levels was between 1-1.5 dB from control periods (Table 6). Decreases in the vessel metrics were countered with increases in the 50 kHz frequency range. Commercial, AIS-tracked vessel presence was similar for pre- and post-measures control periods (Figure 2 in Appendix), so reductions in ambient noise levels between these periods likely resulted from reduced wind additions (Figure 9, Figure 1 and Table 2 in Appendix).

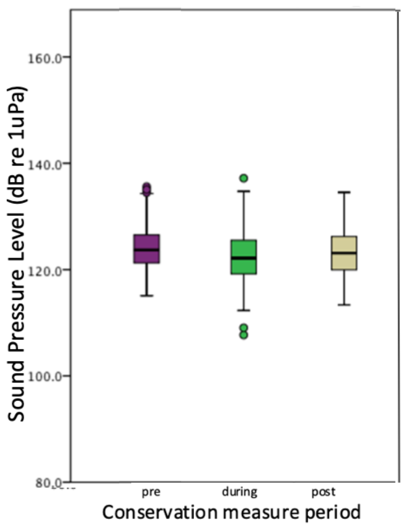


Figure 9: Comparison of broadband (10 Hz to 100 kHz) ambient sound levels for recordings made pre-, during, and post-management measures being in place at Jordan River, fisheries Area 20.

Areas where management measures were in place showed the presence of fishing and Class B vessel transits within 10 km of the mooring to be greatest during month prior to the measures being implemented. However this change was not reflected in increases in sound levels in the vessel metrics. As with the other western Juan de Fuca locations, increases were seen in the 50 kHz range from as the summer progressed, despite fisheries measures being in place. However, decreases were seen in the post-closure period, with this possibly related to the increase in wind speeds seen during this month.

A comparison of the control periods showed an increase in the frequencies used for SRKW echolocation from pre-to post closure months (Table 5), despite the reductions in high frequency noise levels from periods when fisheries measures were in place to the month following (Figure 10, Table 1 in Appendix). However, during periods of SRKW conservation and fisheries measures, decreased wind and AIS-tracked vessel passage (Figures 1-2 in Appendix) reduced the potential for masking in this band. The increases seen in the 50 kHz band, from prior-to to during closure, and with the increase in allowable take during Chinook closures, corresponded to increases of noise in the SRKW echolocation frequency range (Figure 11, Table 4b in Appendix). Increased fish retention from one to two fish for Chinook showed an increase in all frequency ranges of interest except the wind metric (Table 4b in Appendix), and an increase in general vessel presence in a 5 km area around the mooring, up to the outbound shipping lane, and Class B more broadly out to a 10 km distance. Soundscape and high-frequency ranges increased despite a restriction in Chinook size later in the summer.

Measures in place to reduce acoustic disturbance showed similar results to fisheries closures. An increase in high-frequency noise from prior-to to during closure periods were evident, while decreases in broadband and vessel metrics were seen for this same comparison (Tables 4-6). A decrease in the 50 kHz range was seen during the post-closure period compared to periods of management action (Figure 11). A comparison between years showed similarities in the ambient noise (Tables 3-4 in Appendix). Vessel presence showed a general but non-significant increase (Figure 2 in Appendix). Fishing vessel presence increased proximal to the mooring, with the coastal nature of Class B vessels reflected in a decline in vessel transits at a distance of 10 km.

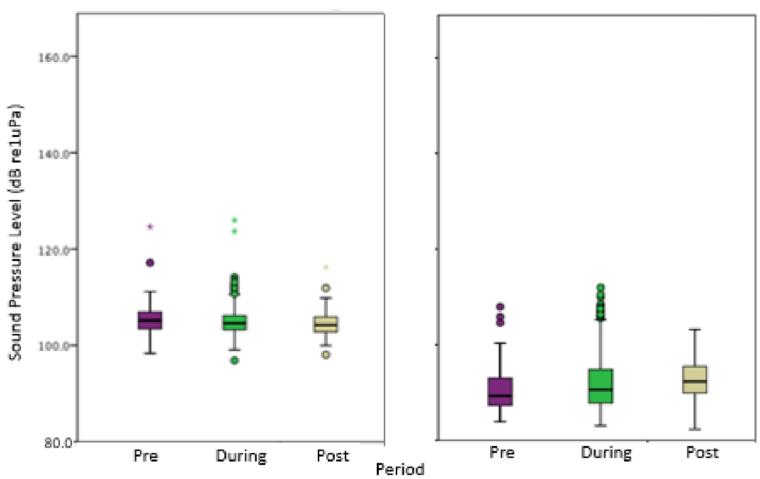


Figure 10: Comparison of SRKW communication (500 Hz to 15 kHz, left) and echolocation (15-100 kHz, right) sound levels for recordings made pre-, during, and post-management measures being in place at Jordan River, fisheries Area 20.

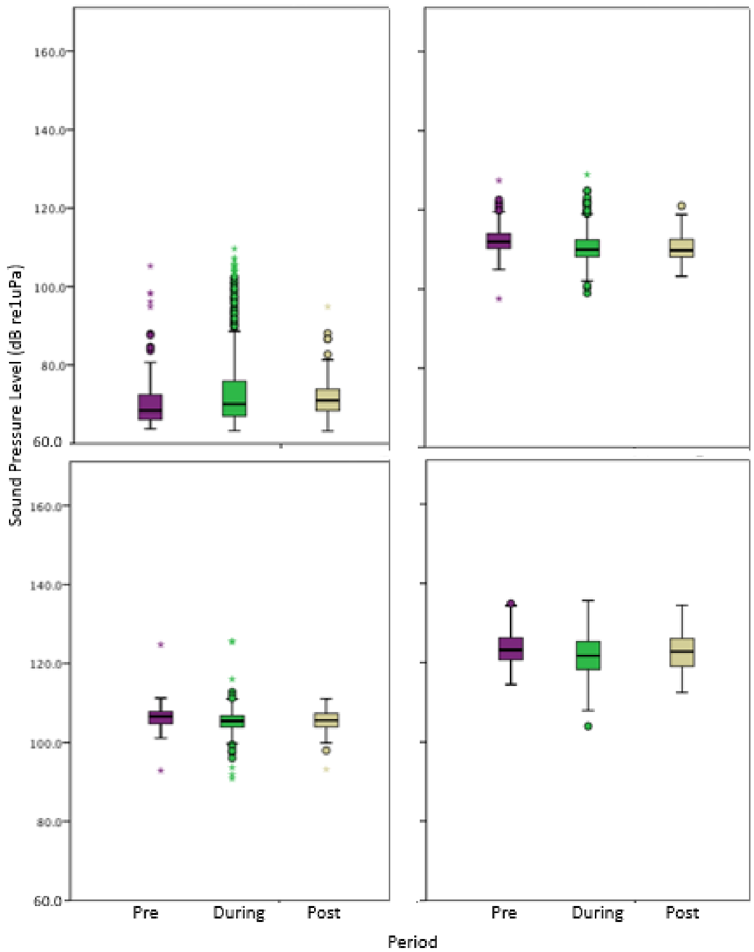


Figure 11: Comparison of vessel metrics (50 kHz, top left; 63 Hz 1/3 octave, top right; 125 Hz 1/3 octave, bottom left; 100-1000 Hz, bottom left) sound levels for recordings made pre-, during, and post-management measures being in place at Jordan River, fisheries Area 20.

Sooke

The soundscape at Sooke through the summer months was heavily influenced by seasonal and locally increased wind (Burnham et al. 2021a, Figure 1 in Appendix). Median sound levels in the wind metric were consistently elevated throughout the summer, with the 8 kHz frequency range showing a significant increase in the mid-summer during fisheries closures (Kruskall-Wallis Test, $p<0.001$, Table 4 in Appendix). This was likely the underlying cause for the approximately 0.5 dB increase in median broadband noise levels seen from pre-measure control to management periods (Figure 12, Table 6). Conversely, wind easing in the late summer-fall could also underlie the decreases seen in the post-management measures control period (Figure 12).

All frequencies of interest showed significant changes in their median sound levels before, during, and after management measures were in place (Figures 13-14, Kruskall-Wallis, $p<0.001$);

however, the difference was less marked for 2018 compared to other years (Tables 3-4 in Appendix). The sound levels in the frequencies considered where greatest during 2018, with notable reductions in all except the highest frequency ranges (49.5-50.5 kHz and 15-100 kHz, Figures 13-14) in later years. Broadband ambient noise level changes (Table 3) between years appeared to be driven by changes in the 10-100 Hz range, and in 2020 and 2021, an increase in vessel metrics was matched by increases in vessel passage rate (Figure 14, Figure 2 in Appendix).

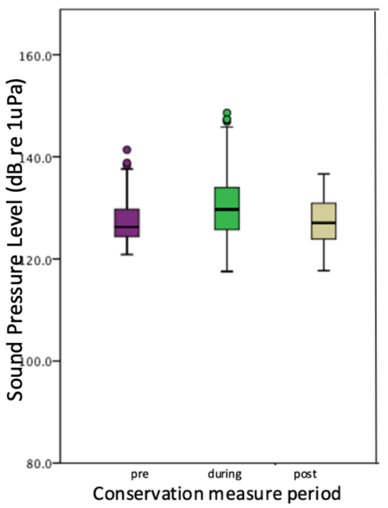


Figure 12: Comparison of broadband (10 Hz to 100 kHz) ambient sound levels for recordings made pre-, during, and post-management measures being in place at Sooke, fisheries Area 20.

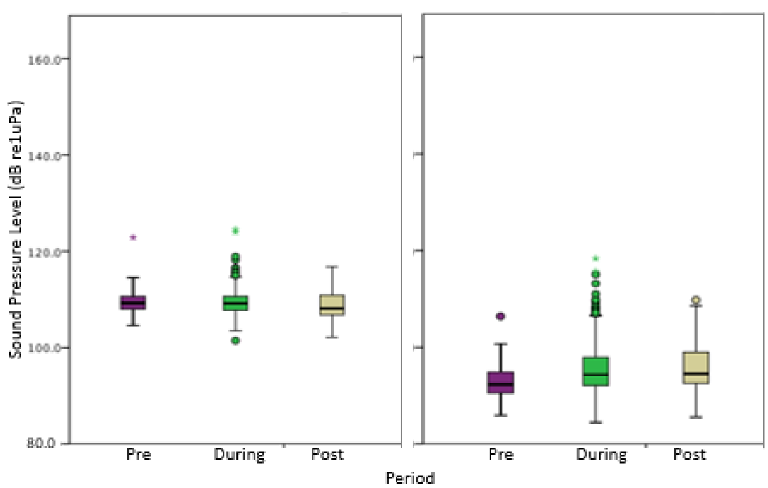


Figure 13: Comparison of SRKW communication (500 Hz to 15 kHz, left) and echolocation (15-100 kHz, right) sound levels for recordings made pre-, during, and post-management measures being in place at Sooke, fisheries Area 20.

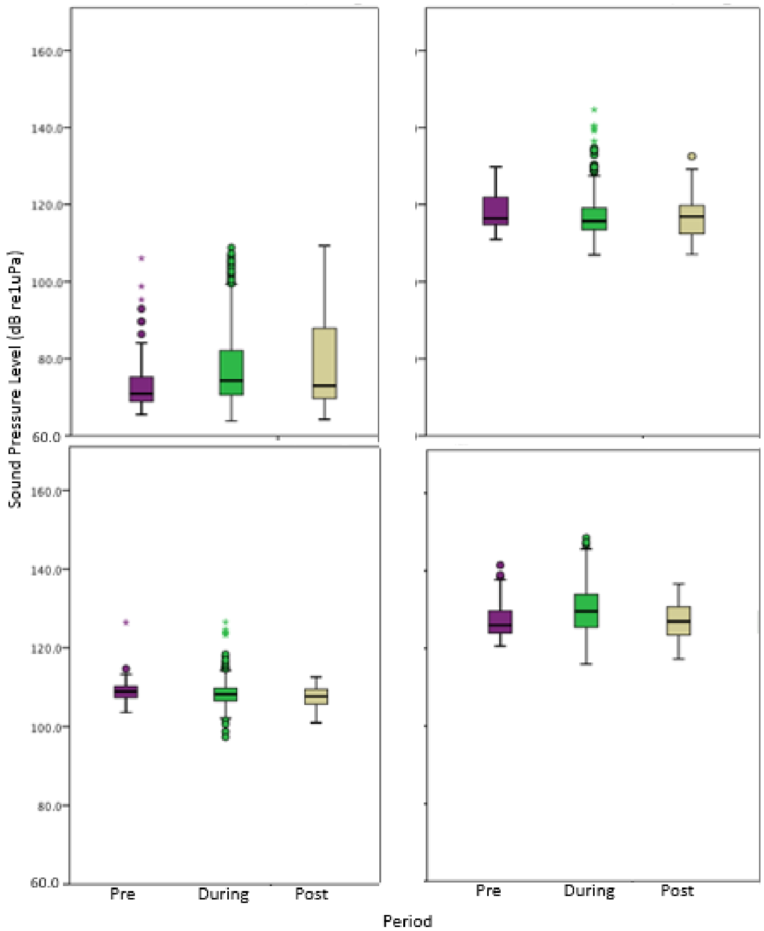


Figure 14: Comparison of vessel metrics (50 kHz, top left; 63 Hz 1/3 octave, top right; 125 Hz 1/3 octave, bottom left; 100-1000 Hz, bottom left) sound levels for recordings made pre-, during, and post-management measures being in place at Sooke, fisheries Area 20.

High-frequency noise levels were again highest during fishery closure periods (Tables 4-5, Tables 3-4 in Appendix), although the greatest average number of passages per day from fishing and Class B vessels were seen in the post-closure period. It could be that the increase in vessel presence was not captured as effectively by AIS data as it is for other regions or that vessels in this area have a greater use of echosounders, for example, but this is speculative. The comparison of Chinook measures again showed an increase in the 50kHz band as the allowable catch increased (Table 4b in Appendix). The greatest change was seen between periods of non-retention and the two fish limit, where increases in high frequency noise and presence of Class B vessels were seen in coastal areas within 5 km of the mooring. The added condition of Chinook size restrictions reduced all sound levels in all frequency ranges of interest except the very highest frequencies (Table 4b in Appendix). Additions to the SRKW communication range followed wind speed patterns taken from the New Dungeness weather buoy (Figure 2, Figure 1 in Appendix), and similar patterns were seen in the 8 kHz wind metric.

When considering the potential influence of the neighbouring Area 19 measures, all frequency ranges of interest showed a notable increase during closures compared to pre-management measures periods. Increases were retained in the 50 kHz range and SRKW echolocation range when moving from periods of fisheries closures to the post-closures control periods. A general decrease in vessel metrics were seen after measures concluded compared to during measures, however the only significant change was a reduction in the average broadband ambient noise level (t(176)=3.530, p=0.001).

AREA 19

Haro Strait

The analysis for this area is limited. The data presented presents changes in the recordings made at Haro Strait that might indicate changes from Chinook closures implemented for Area 19 during 2018 only. The Steelhead measures in 2020 and 2021 were not considered due to limited to the time of analysis (Table 1, Table 1 in Appendix). Median sound levels in broadband ambient noise, all vessel metrics and SRKW relevant frequencies differed between the pre-, during, and post-fisheries closure periods (Tables 4-6, Tables 3-4 in Appendix) except for the 125 Hz 1/3 octave band vessel metric (Figures 15-17). The sound levels were more alike for the pre- and during closure periods, than those recording in the post-closure control periods, which saw an approximate increase of 4.5 dB in median broadband levels (Figure 15, Tables 3-6). This trend was mirrored in the vessel metric ranges (100-1000 Hz, 125 and 63 Hz 1/3 octave band); however a notable decrease was seen in noise levels around 50 kHz in the post measure period (Figure 17). This decrease followed an increase during the closure period, similar to the changes in high frequency noise seen in recordings made in Area 20 (Tables 306, Tables 3-4 in Appendix).

Applying measures from the adjoining Area 18 showed a similar result when comparing pre-closure control to recordings made during fisheries closures.

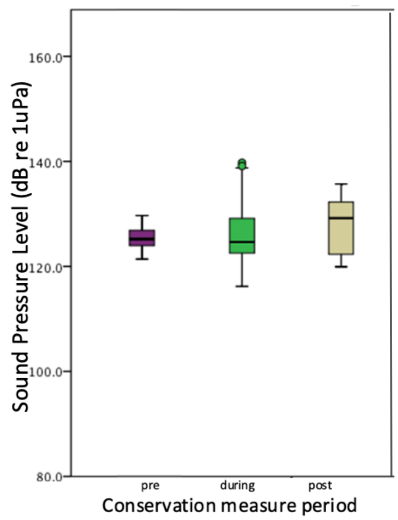


Figure 15: Comparison of broadband (10 Hz to 100 kHz) ambient sound levels for recordings made pre-, during, and post-management measures being in place at Haro Strait. Representative mooring for fisheries management Area 19.

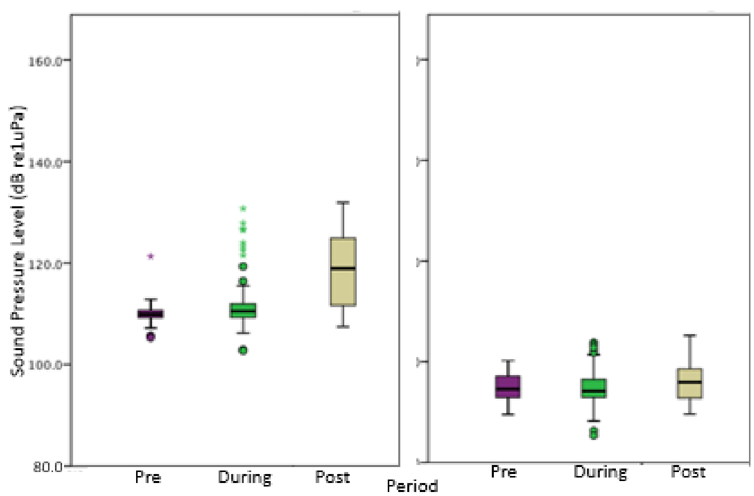


Figure 16: Comparison of SRKW communication (500 Hz to 15 kHz, left) and echolocation (15-100 kHz, right) sound levels for recordings made pre-, during, and post-management measures being in place at Haro Strait. Representative mooring for fisheries management Area 19.

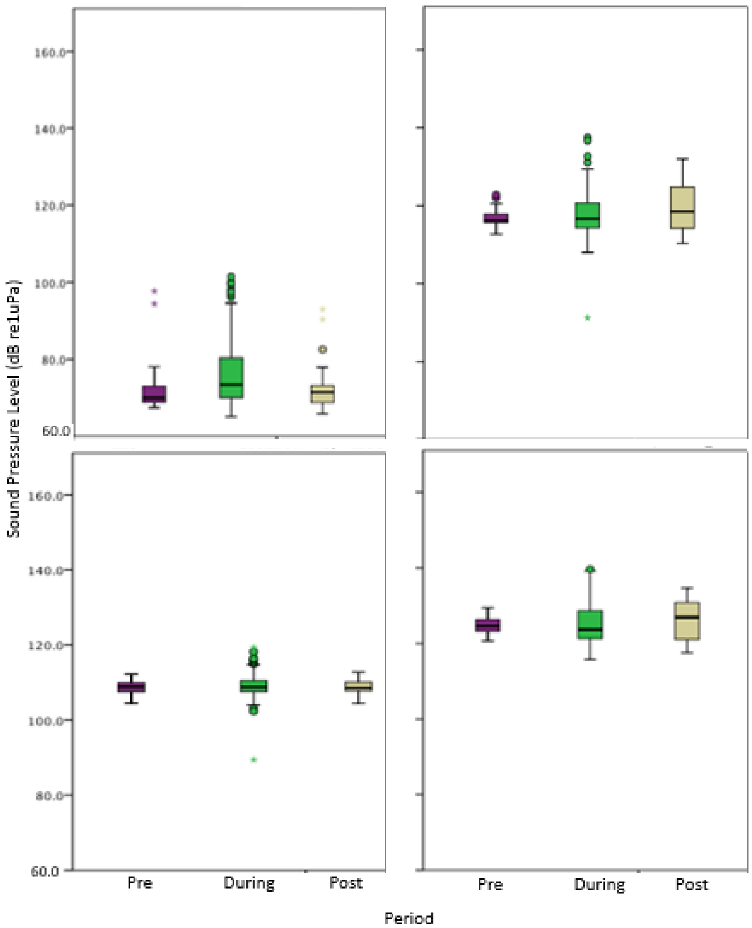


Figure 17: Comparison of vessel metrics (50 kHz, top left; 63 Hz 1/3 octave, top right; 125 Hz 1/3 octave, bottom left; 100-1000 Hz, bottom left) sound levels for recordings made pre-, during, and post-management measures being in place at Haro Strait. Representative mooring for fisheries management Area 19.

Generally, vessel numbers for fishing and Class B vessels were reduced when measures were in place, however, the commercial vessel passage rate was consistent (Figure 2 in Appendix).

AREA 18

Smaller changes in soundscape levels were seen for moorings in Area 18. The impact of recreational vessel presence was substantial, with high-frequency noise elevations evident during the summer months, even during periods where conservations and SRKW protective measures were in place (Tables 3-6, Tables 3-4 in Appendix).

Sub-region 18-6 in the waters by Sidney BC had different allowable catch limits for certain periods, but these slight differences in timing were not considered for the soundscape analysis of moorings in Area 18.

Boundary Pass

Although a Kruskall-Wallis test showed significant difference between pre-, during, and post-measures periods in the median sound level and distribution of noise levels over time, the difference overall between periods was no greater than 0.5 dB (Figure 18, Tables 3-6, Tables 3-4 in Appendix). An increase in broadband noise was seen when comparing the closure period to the pre-measures control. Pre- and post-closure sound levels were similar.

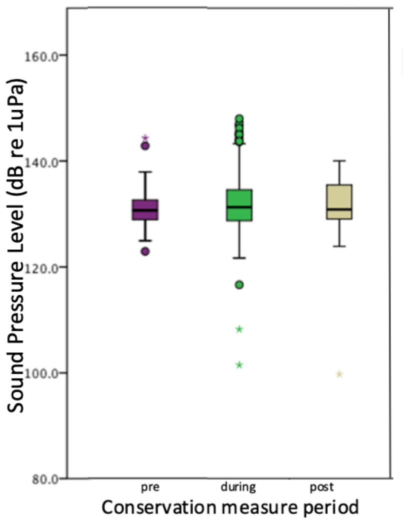


Figure 18: Comparison of broadband (10 Hz to 100 kHz) ambient sound levels for recordings made pre-, during, and post-management measures being in place at Boundary Pass, fisheries Area 18.

There were no significant changes in median sound levels in the high frequencies, including the 50 kHz band used to track small vessels (Figures 19-20, Tables 3-6, Tables 3-4 in Appendix). Unlike the other moorings considered in the Salish Sea, the 50 kHz band sound levels decreased from periods prior-to to during fisheries management measures, and again from the period during measures to the month following. The average number of vessel passages was greatest for the period when fisheries restriction had been lifted, including for the Class B AIS tracked smaller vessels (Figure 2 in Appendix).

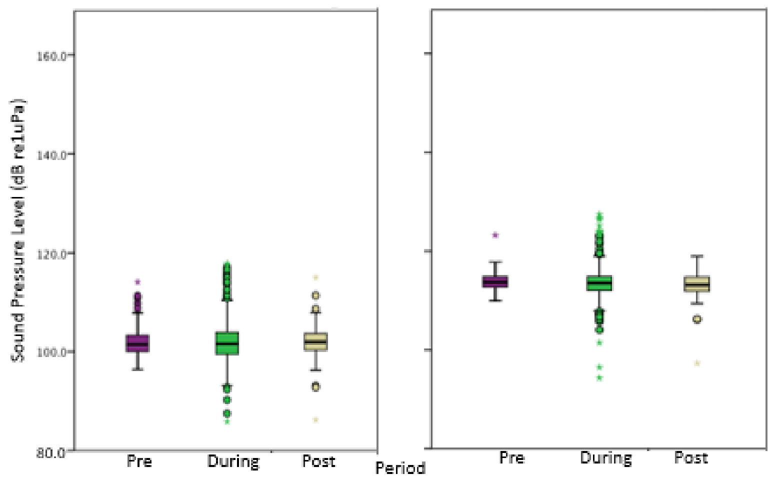


Figure 19: Comparison of SRKW communication (500 Hz to 15 kHz, left) and echolocation (15-100 kHz, right) sound levels for recordings made pre-, during, and post-management measures being in place at Boundary Pass, fisheries Area 18.

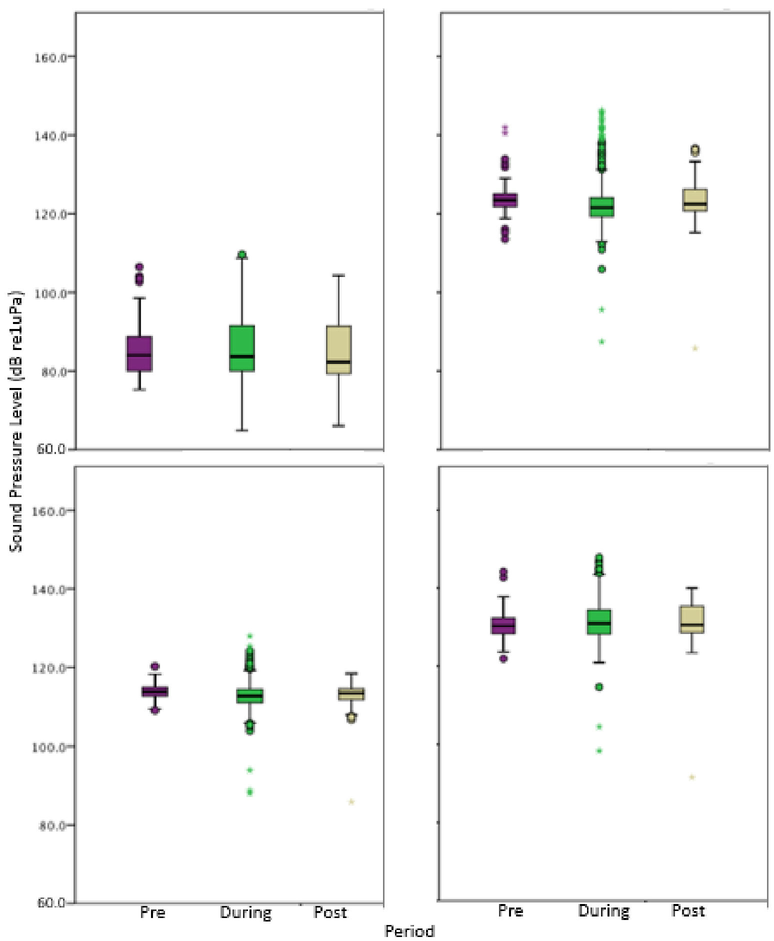


Figure 20: Comparison of vessel metrics (50 kHz, top left; 63 Hz 1/3 octave, top right; 125 Hz 1/3 octave, bottom left; 100-1000 Hz, bottom left) sound levels for recordings made pre-, during, and post-management measures being in place at Boundary Pass, fisheries Area 18.

For the Chinook conservation measures, periods allowing the retention of one fish showed increases in all bands compared to the pre-closure period, with reduced wind conditions (Table 4b in Appendix). Vessel bands showed increases when retention was again increased to two fish. The added restriction of fish size decreased vessel noise compared to pre-measure periods; however, no difference was seen in the high frequency bands (Table 4b in Appendix). Allowing fish retention from closure (one from none) increased the noise level in 50 kHz band (t(252.690)=-3.598), although AIS indicated that fishing vessel passages to the 10 km distance and Class B vessels transits to 5 km were reduced. Again, this might be representative of AIS not capturing the true extent of vessels present. A two fish maximum again showed increases in broadband and all vessel frequency bands compared to no retention. Yet, during the period when size limits were imposed, the sound levels were reduced for commercial vessel noise bands (Tables 3-4 in Appendix).

Commercial and deep-sea passages through this area have a large impact on the sound field. Voluntary slow down measures were in place through Boundary Pass for 2019 onwards aimed at reducing the acoustic disturbance of SRKW. Reductions in the lowest frequency vessel metric (mean levels of 67 Hz 1/3 octave band t(142.296)=4.155, <0.001) despite an increase in vessel passage rate could be attributed to this management action. The sound levels in 2018 were consistently greater than later years. Broadband noise levels and sound levels in vessel metrics were much reduced for 2019 compared to 2018 (broadband: t(222.616)=5.350, p<0.001; 100-1000 Hz: t(229.257)=3.875, p<0.001; 67Hz: t(223.267)=6.434, p<0.001; 125Hz: t(220.163)=3.249=0.001), with the slowdown imposed in this region in 2019.

Swanson Channel

The first year of recording in Swanson Channel was 2019 (Table 1). Increases in noise levels were recorded for all frequencies of interest, significantly so for all except for the 1/3 octave centered around 125 Hz when comparing sound levels during conservation measures to the control periods (Tables 3-6, Tables 3-4 in Appendix). Increases of vessels were also seen from pre- to closure periods with winds significantly reduced (East Point, Saturna Island t(150.783)=4.722, <0.001, Figure 1 in Appendix). Post-closure decreases were found in broadband (Figure 21) and mid-frequencies, including for the SRKW communication ranges, compared to those while measures were in place (Figure 22, Tables 3-6, Tables 3-4 in Appendix). A reduction in the 50 kHz band and wind noise would contribute to these, as vessel presence generally was increased (Figure 23). Post closure periods were typically quieter than those before measures were in place, especially seen in the mid-frequencies and overall sound level (Figure 21-23, Tables 3-6).

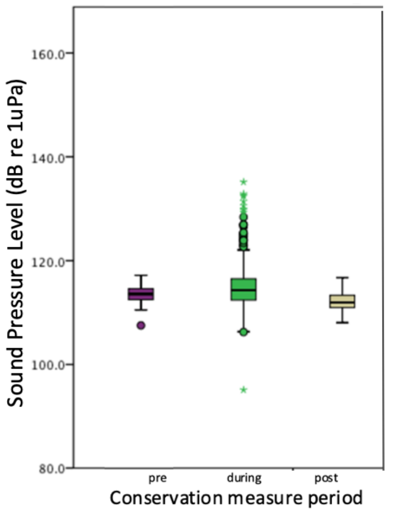


Figure 21: Comparison of broadband (10 Hz to 100 kHz) ambient sound levels for recordings made pre-, during, and post-management measures being in place at Swanson Channel, fisheries Area 18. The mooring was positioned within the Interim Sanctuary Zone.

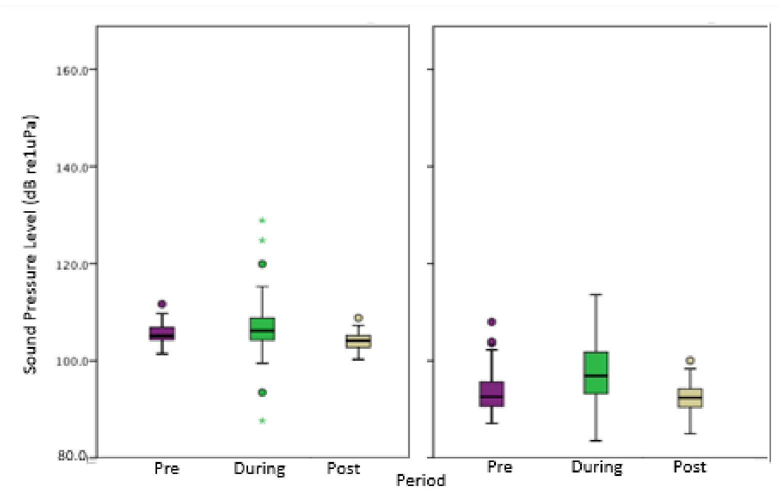


Figure 22: Comparison of SRKW communication (500 Hz to 15 kHz, left) and echolocation (15-100 kHz, right) sound levels for recordings made pre-, during, and post-management measures being in place at Swanson Channel, fisheries Area 18.

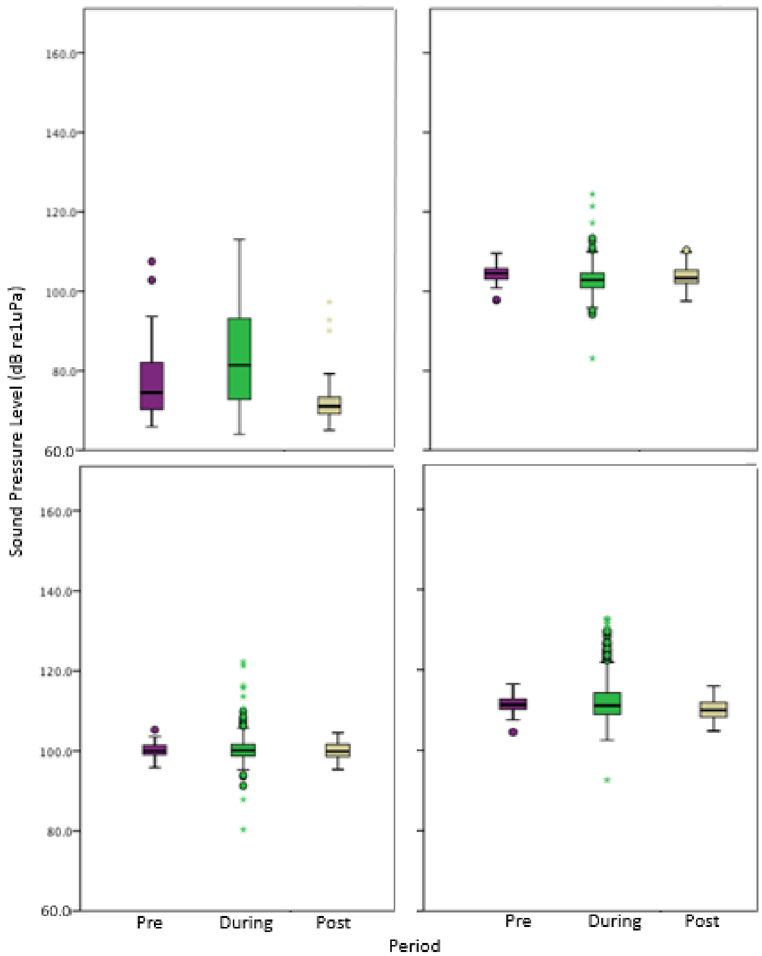


Figure 23: Comparison of vessel metrics (50 kHz, top left; 63 Hz 1/3 octave, top right; 125 Hz 1/3 octave, bottom left; 100-1000 Hz, bottom left) sound levels for recordings made pre-, during, and post-management measures being in place at Swanson Channel, fisheries Area 18.

Sound levels differed between periods of management action taken for Chinook at the $p<0.001$ level for all frequencies (Table 4b in Appendix). Allowing fish retention from closure (one from none) increased the noise level in all frequency bands of interest. Increases were again seen when the allowable Chinook limit was increased, with the average number of Class B vessel transits increased significantly, as were fishing vessels passing within 5 km of the mooring ($t(626)=-2.844$, $p=0.005$).

<u>Saturna Island</u>

Recordings made in 2020 from East Point, Saturna Island seemed least impacted by fisheries measures compared to other moorings in management Area 18. Broadband and vessel noise in the low frequencies were consistent (Figure 24), but those extending into higher frequencies, perhaps more indicative of smaller and recreational traffic differed significantly (125 Hz p=0.002, 50 kHz p=0.021, Figure 25-26). All frequencies of interest differed in 2021 between management measure periods for Chinook (Tables 3-6, Tables 3-4 in Appendix).

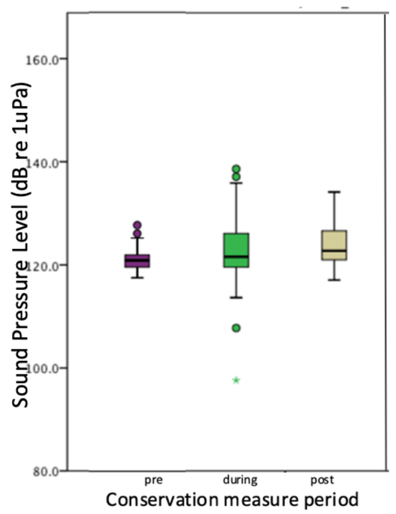


Figure 24: Comparison of broadband (10 Hz to 100 kHz) ambient sound levels for recordings made pre-, during, and post-management measures being in place at East Point on Saturna Island, fisheries Area 18. The mooring was positioned within the ISZ.

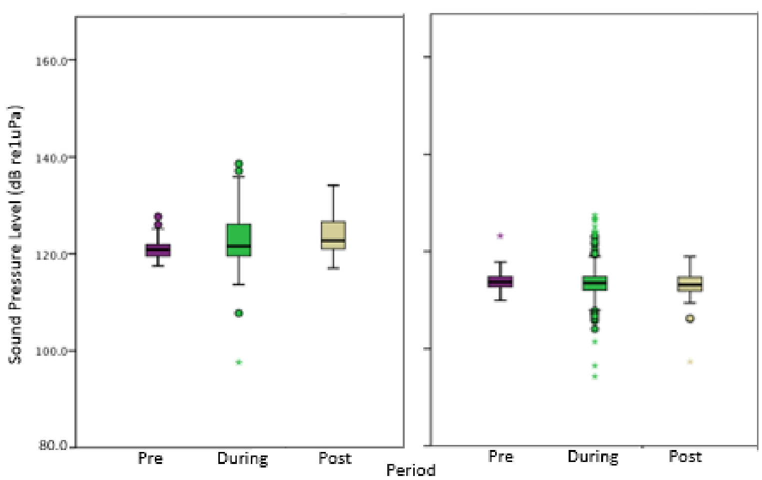


Figure 25: Comparison of SRKW communication (500 Hz to 15 kHz, left) and echolocation (15-100 kHz, right) sound levels for recordings made pre-, during, and post-management measures being in place at Saturna Island, fisheries Area 18. The mooring was positioned within the ISZ.

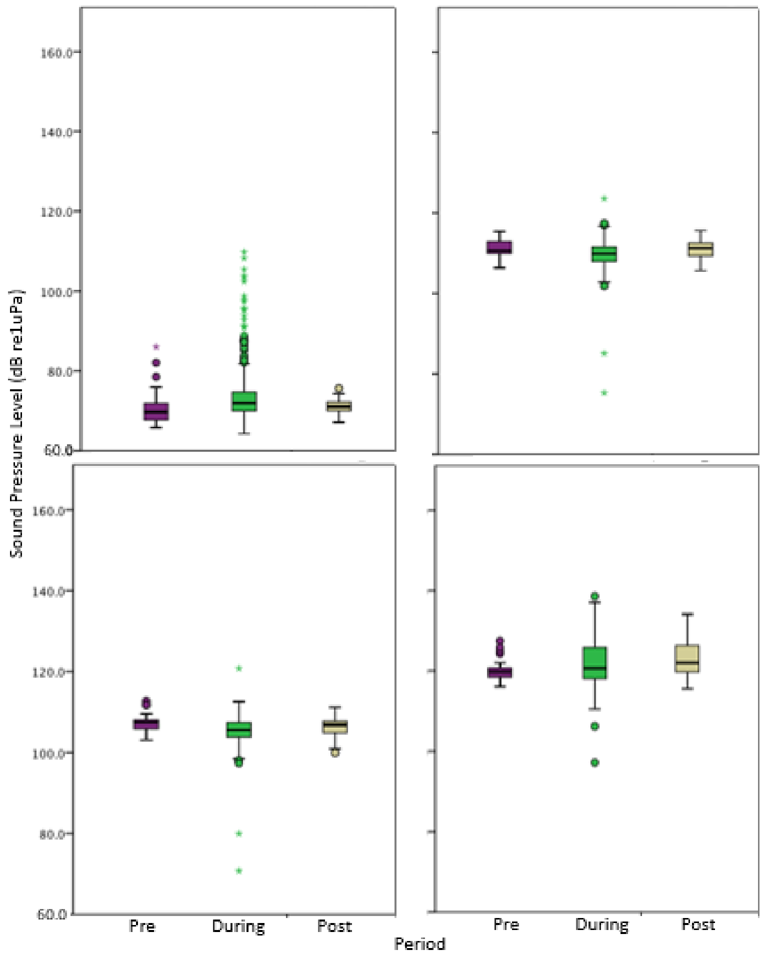


Figure 26: Comparison of vessel metrics (50 kHz, top left; 63 Hz 1/3 octave, top right; 125 Hz 1/3 octave, bottom left; 100-1000 Hz, bottom left) sound levels for recordings made pre-, during, and post-management measures being in place at Saturna Island, fisheries Area 18. The mooring was positioned within the ISZ.

All years considered together showed reductions in commercial vessel noise (Figure 26), perhaps as a result of the slowdown in place, and typically lower wind speeds. Increases in the full broadband range (Figure 24) and SRKW echolocation range (25) were present in the post period when compared to the pre-measures control (Tables 3-6).

When Chinook limits increased, high-frequency noise levels increased, with elevated levels in the SRKW echolocation band also seen. Broadband and SRKW echolocation frequencies were increased in the periods after restrictions were lifted compared to those before they were in place. This increase may also be representative of the salmon closures implemented as SRKW conservation measures ending, as well as restricted use of the waters in the ISZ being lifted (Tables 3-4 in Appendix). It is hard to tease apart the influence of each from the acoustic data alone.

The exclusion of the ISZ measures for the waters around the mooring altered the presence of vessels while it was in place. This, and likely the slowdown in place in Boundary Pass, significantly impacted noise in the frequencies of interest except in the 113-141 Hz band (p=0.719). However, compliance of recreational vessels to the ISZ measures is difficult to accurately determine from the data currently available (also see Burnham et al. 2021b), and vessel presence is indicated in the acoustic records throughout the ISZ measures.

IMPLICATIONS FOR SRKW

The greatest reductions in SRKW communication frequencies were seen in areas most influenced by wind in the control periods; Haro Strait showed up to an 8 dB change in median sound levels while fisheries measures were in place, compared to the month following (Figures 27-29, Tables 3-6).

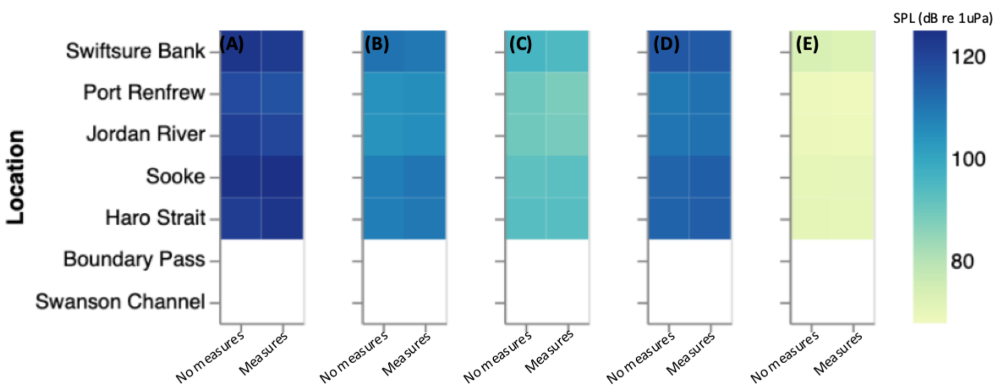


Figure 27: Changes in overall ambient noise (10 Hz to 100 kHz, A), SRKW communication (B), echolocation (C) a vessel metric (100-1000 Hz, D) and 50kHz range (E) when any measures were in place, or not measures are in place, including pre- and post-closure controls

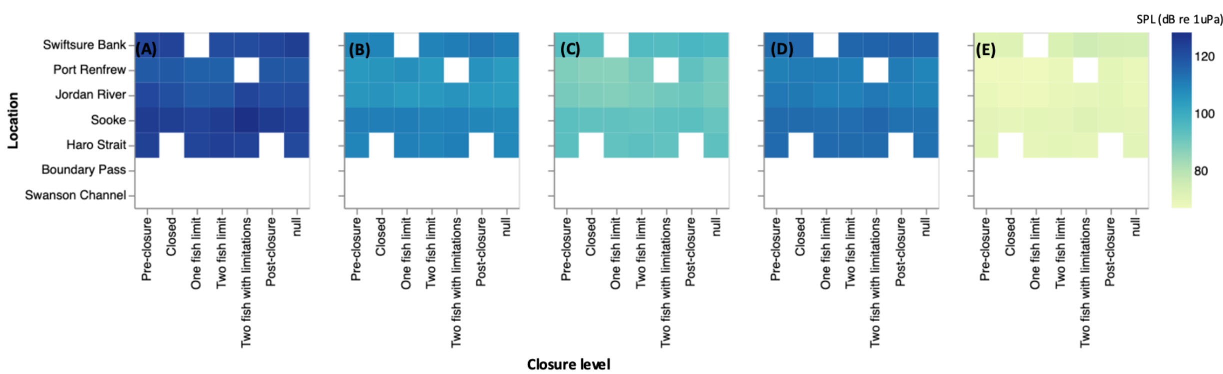


Figure 28: Changes in overall ambient noise (10 Hz to 100 kHz, A), SRKW communication (B), echolocation (C) a vessel metric (100-1000 Hz, D) and 50kHz range (E) when differing levels of Chinook measures were in place

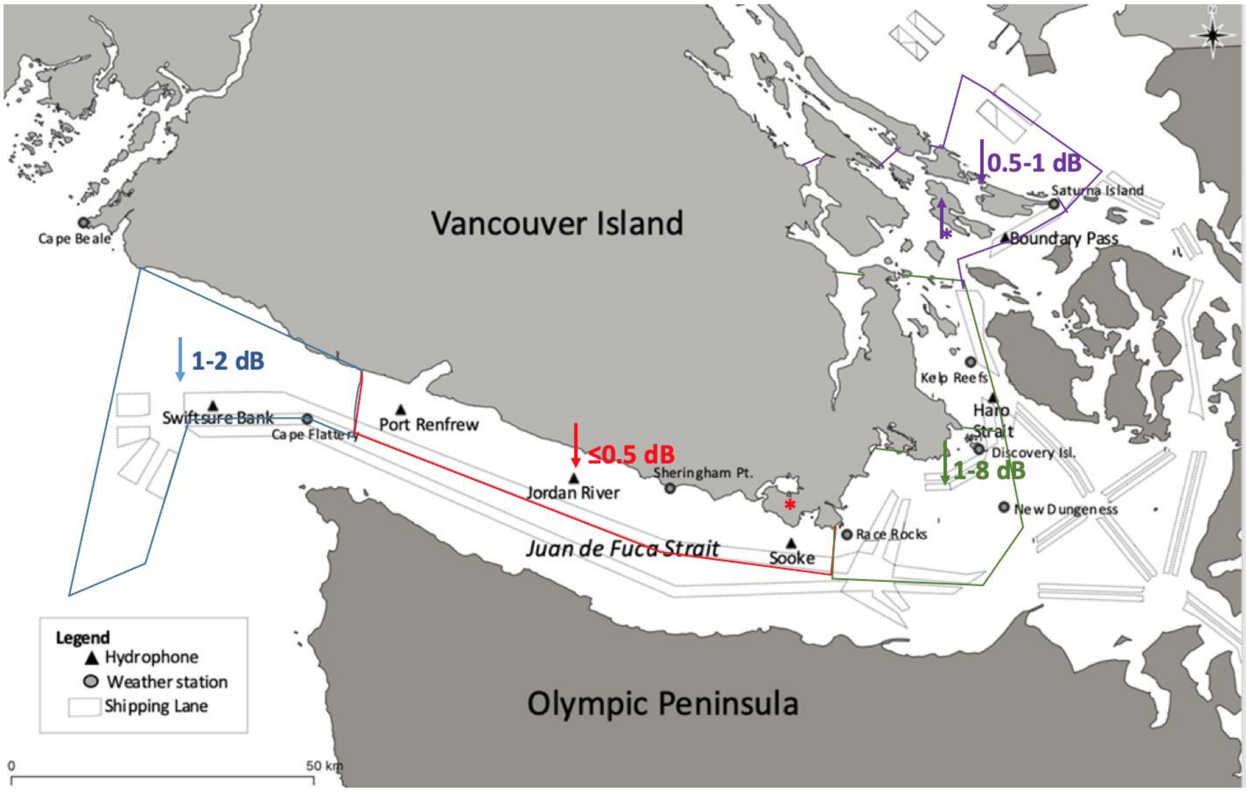


Figure 29: Approximate change in median sound levels for each fisheries management area in the SRKW communication frequencies (500 Hz to 15 kHz) when measures were in place compared to pre- and post-measures control periods.

These reductions contrasted to the additions see at Sooke, where the summer soundscape is heavily impacted by localised increases in wind speed. Overall changes in sound levels for moorings in Area 20 were 0.5 dB or less, with the closure periods likely influenced by seasonal reductions in wind speed (Figure 1 and Table 2 in Appendix). For the moorings in Juan de Fuca Strait and west to Swiftsure Bank the correlation between wind and SRKW communication frequencies was significant (Figures 27-29, Table 2 in Appendix). In more the more sheltered waters of Area 18 the decrease in median values seen in Boundary Pass and at Saturna Island were not seen at Swanson Channel during periods of fisheries measures, but reductions in the SRKW communication band have been seen during the implementation of ISZs (Burnham et al. 2021b, Tables 5-6).

Echolocation is the principal means by which SRKW can use received acoustic information to form a mental image of their surroundings. A broad comparison of the periods with fisheries measures to pre- and post-measure control periods showed an increase in high-frequency (15-100 kHz) noise in the SRKW echolocation ranges for all sites in Areas 121 and 20 (Figure 27,28,30, Tables 5-6). For these areas there was an increasing trend from pre- to during and then to post-measure periods, whereby sound levels were greater when fisheries conservation measures were in place compared to the month prior, and were again higher in the month following the cessation of measures (Tables 5-6, Tables 3-4 in Appendix).

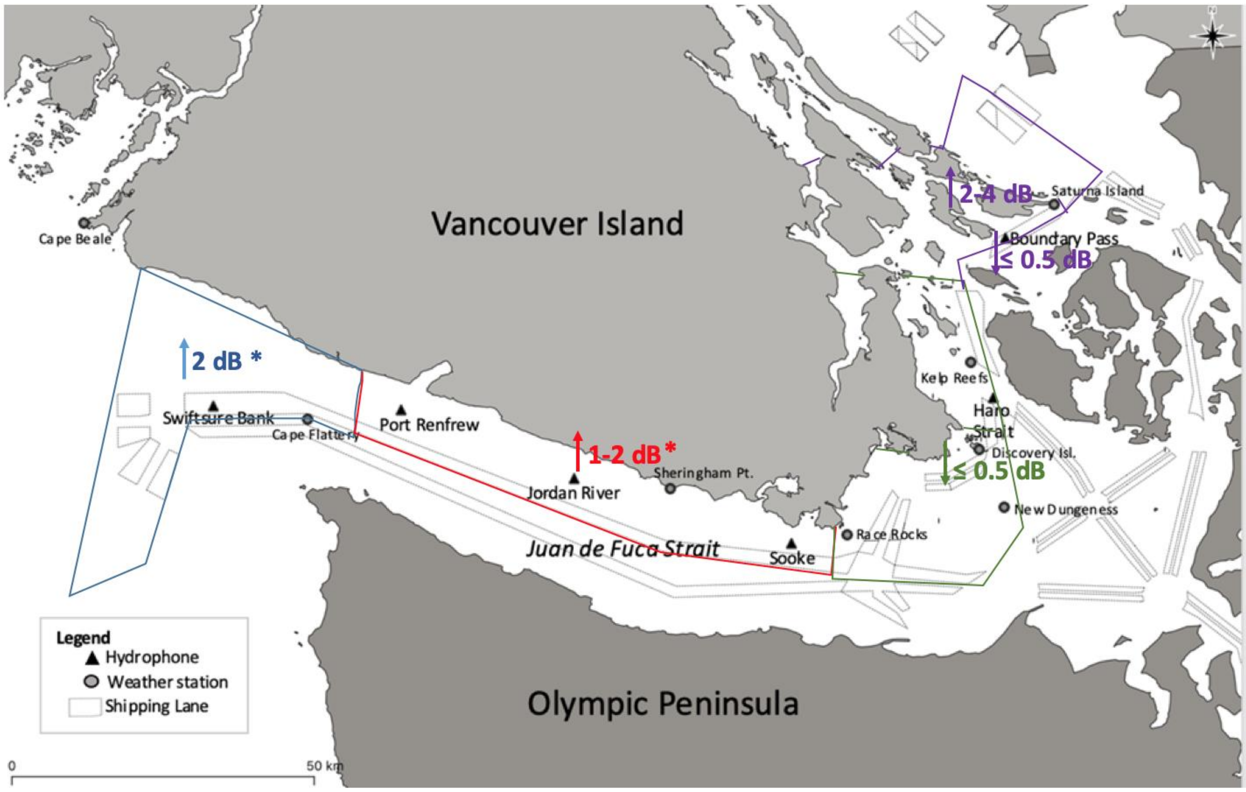


Figure 30: Approximate change in median sound levels for each fisheries management area in the SRKW echolocation frequencies (15-100 kHz) when measures were in place compared to pre- and post-measures control periods considering all years.

Broad-scale changes in median sound levels during periods of salmon conservation measures compared to pre- and post- control periods were not more than a 0.5 dB reduction for Haro Strait and Boundary Pass. The change in SRKW echolocation range was frequently matched by a similar change in the frequency range centered around 50 kHz (Tables 5-6, Tables 3-4 in Appendix).

A coarse consideration of vessel presence around the moorings, highlighted the difference in use of areas within the Salish Sea. Indeed it was typical for AIS-tracked vessel greater hourly vessel passage rates at times when measures were in place (Figure 31, Figure 2 in Appendix) or when catch was limited (Figure 32).

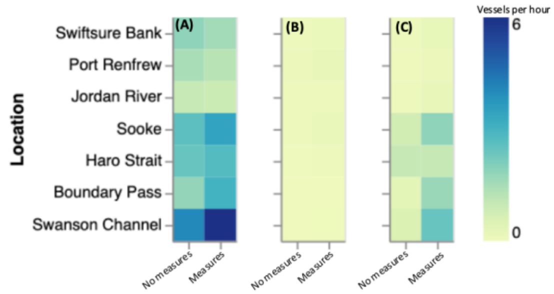


Figure 31: Changes in hourly vessel transit number within 10 km of the mooring when measures are in place or not for all AIS-tracked vessels (A), fishing vessels (B) and Class B recreational vessels (C).

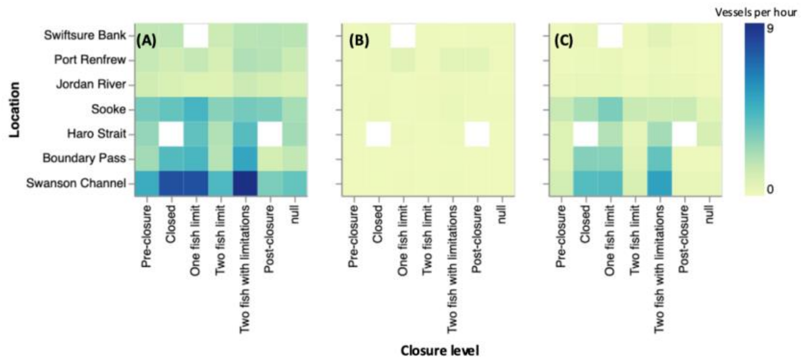


Figure 32: Changes in hourly vessel transit number within 10 km of the mooring when differing levels of Chinook measures were in place for all AIS-tracked vessels (A), fishing vessels (B) and Class B recreational vessels (C).

4. DISCUSSION

Generally, during periods when fisheries measures were in place, reductions were recorded ambient broadband noise (10 Hz to 100 kHz, Table 6) were seen generally during fisheries management actions. Recordings made by moorings on Swiftsure Bank and in western Juan de Fuca Strait demonstrated the greatest decreases in sound levels, and those in the Gulf Islands the least.

Reductions in the frequency range used to describe SRKW communicative calls were also seen (Figure 29, Table 5-6, Tables 3-4 in Appendix). For all sites the changes in the communication band seemed to follow patterns of wind speed, and changes in the wind additions, described through a known relationship with an acoustic metric centered around 8 kHz (Figure 1 in Appendix, Vagle et al. 1990). Communication calls are in the mid- to high-frequencies (500 Hz to 15 kHz) and are important for retaining conspecific contact, used for group interactions, cooperative hunting, and prey sharing. Seasonal patterns seen in the data agreed with previous analyses of the soundscape of the Salish Sea (Burnham et al. 2021a). Wind speeds are typically reduced, except for the localised increase around Sooke, the eastern extent of Juan de Fuca Strait and the southern entrance to Haro Strait.

Changes in the mid- to high frequency range differed to the pattern of acoustic inputs into the highest frequencies, specifically the general increase in SRKW echolocation frequencies (Figure 28, Tables 5-6). Similarities between the SRKW echolocation and 50 kHz band were seen, with this range previously been used as a metric for the high-frequency noise additions that are typical of smaller, recreational vessels, and is also the most common echosounder frequency used in the area (ECHO 2019). The 50 kHz range has been found to correlate well with the increase in smaller or Class B vessels (Burnham et al. 2021a). Soundscape analysis showed seasonal increases in these areas during summer in this frequency range, which were further elevated during the day to night, and over weekends and statutory holidays compared to week days (Burnham et al. 2021a). Increased noise in the SRKW echolocation frequencies heightens the potential for acoustic disturbance, with the interference or masking of acoustic signals reducing the efficacy of whales to discern the echo of the signal, possibly reducing their ability to navigate and find food, and shortening the range over which they can send and receive information about their surroundings.

During the summer months, typically the presence of smaller, recreational vessels increases. Seasonally reduced wind speeds and sea states and in-migrations of salmon encourages the use of these areas by recreational fishers and pleasure vessels. The Class B transmissions in the AIS data indicated the increased presence of these vessels during the summer, and those coincident to fisheries management measures (Figures 31-32). However, these data are an under representation of the true use of recreational boaters in this area (Serra-Sogas et al. 2021). Aerial surveys over the Salish Sea have estimated that more than 70% of smaller vessels present do not carry either Class A or Class B AIS transceivers, and of these in excess of 74% of the vessels are recreational vessels (Serra-Sogas et al. 2021). These vessels are not specifically requested to reduce their speed in slowdown zones, although all vessels are encouraged to do so. Furthermore, enforcement of slowdowns or to the ISZ exclusion zones is difficult without a means to track vessels other than having an on-the water presence to confirm compliance. Swiftsure Bank and recordings made in the western extent of Juan de Fuca Strait show increases in this vessel metric range most strongly (Tables 4-6, Tables 3-4 in Appendix), with perhaps the reduced sea state making these areas more accessible and attractive to recreational boaters during the summer. The spatial scope of impact of these higher frequency increases are more limited than low-frequency additions, with the variation in higher-frequency vessel metric contrasting to the consistent presence of commercial deep-sea vessel presence, which exert a chronic acoustic effect on sound fields in Juan de Fuca Strait.

Spatial sound field patterns, described previously by Burnham et al. (2021a), were also seen in this analysis. Previous analyses have shown an west to east distinction in the soundscapes in the Salish Sea, whereby protected locations like Boundary Pass and Haro Strait have periods of relative quiet punctuated by acute vessel noise additions, elevating average noise levels (Table 3 in Appendix, Burnham et al. 2021a). This contrasts to recordings from Swiftsure Bank and the western extent of Juan de Fuca Strait (Port Renfrew, Jordan River) which have more consistent vessel noise

(Figure 1). Similarity in area usages, exposure, soundscape composition and fisheries measures meant consistencies were seen in the changes in sound fields for moorings in Area 20 as was seen in Area 121. Area 19, Haro Strait, and Boundary Pass in Area 18 showed similar soundscape responses to the fisheries closures, with an approximate 0.5 dB reduction in median sound levels. These sites have very similar sound fields and are subject to similar vessel loads (Tables 3-6, Tables 3-4 in Appendix). The passage of commercial vessels, at a rate of approximately one deep-sea vessel an hour (Veirs et al. 2016), is a dominant influence on the soundscape for both these sites. The least impact of measures were seen in waters around the Gulf Islands, where sound levels were significantly increased compared to control periods.

Fisheries closures along the southern BC coast are one of several management measures in place aimed at protecting SRKW. All fisheries management areas were subject to other noise mitigations actions and so it is difficult to determine the direct contribution of the fisheries actions to overall noise reductions. The trials of the vessel-operations based measures to reduce noise typically run from early summer through to the fall, when most of the fisheries closures are also in place. It is possible, for example, that slowdown measures introduced in 2020 for outbound traffic passing over Swiftsure Bank from the JA/Cape Flattery buoy resulted in overall reductions of noise in vessel frequency bands, except in the 50 kHz band, which represents the noise from smaller vessels. Commercial vessel slowdowns, trialed since 2017 in Haro Strait and Boundary Pass, may have also influenced the sound levels recorded. In Haro Strait, for example, reductions were observed in excess of 3 dB for sound levels in the SRKW communication range, and in the SRKW echolocation range a reduction of up to 4.3 dB at median levels for were seen while the voluntary slowdown of commercial vessels was in place w in 2020 (Burnham et al. 2021b). The level of impact of these voluntary actions were seen was found to be somewhat dependent on the recording location, whereby measures made in Boundary Pass further east than the DFO mooring in this area typically showing decreases more in the ~1-1.5 dB of median levels of the echolocation range (JASCO ULS mooring, ECHO 2020, 2021).

The ECHO Program slowdown measure is a voluntary request made only of commercial vessels in the area. It has, however, shown high compliance rates and success in reducing noise levels in broadband and SRKW pertinent frequency ranges (Burnham et al. 2021b), despite general increases in commercial AIS-tracked vessel numbers from 2018 to 2021 (Figure 2 in Appendix), especially for Class B vessels. The similarity in the sound fields during fisheries closures and in the post-closure period may then speak to both the level of vessel traffic and compliance to the slowdown measures imposed. Class B vessel passages reported by AIS increased through the study period, perhaps representing an increase in vessels, and uptake in the use of AIS transceivers, or both.

In Juan de Fuca Strait, recordings from Jordan River mooring have previously been used to assess the efficacy of lateral displacement trials, with it located at approximately the mid-point of the trial zone (Vagle and Neves 2019, Vagle 2020, Burnham et al. 2021b). The voluntary change in transit route in tugs and barges created little change in the overall sound levels; however, a significant decrease in noise inputs was seen when purely considering the noise directly from tugs. Indeed, for the evaluation of effect per tug a considerable reduction was seen in the mid- to high-frequencies, including those frequency ranges pertinent to SRKW for transits that were displaced away from the coast and into the designated zone or the outbound shipping lane (see Vagle and Neves 2019, Vagle 2020, Burnham et al. 2021b).

In the Gulf Islands and on Swiftsure Bank mandatory vessel exclusions zones, or whale Interim Santuary Zones, have be implemented during the summer months. There was no indication in the AIS records that the commercial vessels changed their transiting patterns in waters around the mooring for those that were deployed in an ISZ. Compliance to the ISZ, determined from the AIS and acoustic record (Burnham et al. 2021b) was low. However, compliance of recreational vessels to the ISZ measures is difficult to accurately determine from the data currently available (also see Burnham et al. 2021b), although vessel presence is indicated in the acoustic records throughout. The mandate of this exclusion zone did not significantly impact vessel noise or frequencies that related to SRKW in 2019, although some reductions in noise level were seen in 2020 (Burnham et al. 2021b, Table 4a in Appendix). The ISZs were in place through until the end of October, after which recreational boating is typically reduced. This was indicated in the data by a reduction in the 50 kHz band in the post closure control period at Swanson Channel. Increased vessel presence was been noted in 2020 and 2021 in the waters around the Gulf Islands, despite reductions of ferry transits and restrictions in US border crossing during the COVID-19 pandemic. The changes in vessel presence and acoustic implications of restrictions due to COVID-19 during 2020 measures have not been given extra consideration during this analysis. Ongoing analyses have shown a reduction in vessel presence in the earlier part of the year, with vessel transits increasing as the year progressed for all vessel types except cruise ships (Thomson and Barclay 2020, DFO Ocean Acoustics unpublished data). The vessel presence evaluations as part of this work did not suggest that fishing or recreational vessels were significantly altered, although cross-border traffic would have been absent.

The analysis presented here compared changes over fairly coarse temporal and spatial scales, and did not consider the timing of SRKW presence. The discussion assumes that any decrease in sound levels would be beneficial to SRKW. The analysis was purely an examination of sound levels during fisheries management measures; the potential interplay and cumulative benefit of other management measures was not considered and measures such as slowdowns and ISZs are only discussed to provide a broader context of the results and findings from the recordings. The examination of changes in the communication and echolocation frequency ranges allowed a more species-specific consideration of acoustic impact, but the sound levels in the broadband range (10 Hz to 100 kHz) also have the potential to alter swimming and diving behaviours and elevate physiological stress levels for SRKW (Heise et al. 2017). It has also been shown that the acoustic energy in calls can be focused in frequencies as low as 100 Hz (Ford 1987), which is captured in both this broadband range and the vessel metrics. To test whether the measures are effective in reducing acoustic disturbance for SRKW using these areas, a finer scale soundscape analysis should be performed incorporating data on the known presence of SRKW through the period of interest. It may be, for example, that although, on a broad scale, acoustic increases are found, for the time and location that SRKW are present the measures do reduce noise or perhaps increasing the length of time that SRKW are able to forage without the influence of vessels when considered at a finer resolution. Although research has been initiated to outline the responses to vessel presence, we still do not know the threshold of noise or vessel presence that would instigate avoidance behaviours in SRKW to foraging in the Salish Sea.

The analysis showed that there are potential acoustic benefits of fisheries closures. A finer scale analysis in both time and space may find even greater reprieve for SRKW through presumed reduced vessel presence and noise associated with fishing activities. The changes seen in this analysis in the SRKW communication band likely resulted from a season reduction of wind speeds, and the increases in SRKW echolocation reflecting the greater presence of smaller, recreation vessel traffic during the summer months. The potential for acoustic disturbance is of particular interest for Swiftsure Bank and Haro Strait where on-the-water surveys have determined high use by SRKW, and observations of whales have been made of SRKW using these areas for foraging (DFO 2021). The interference or masking of acoustic signals in these areas could reduce the efficacy of calls, and reduce the area over which whales are able to retain group contact or search for prey (Burnham et al. in review). The reduced ability to recognise an acoustic stimulus through masking, or reduced listening space over which acoustic cues are received, could also mean a reduced capacity to detect approaching threats, to locate or capture prey, or to find a mate. In these areas, where SRKW have longer residency times, the increases especially in the echolocation range could chronically hinder the sending and receiving of acoustic signals. Previous analysis of recordings made in Haro Strait have suggested that median noise levels present could reduce the ability of SRKWs to communicate with conspecifics at a range exceeding 8 km by 62%, with this rising to 97% at periods of heavy vessel traffic. Furthermore, a recent population viability analysis suggested that the foraging efficiency of SRKW could be reduced by approximately 20% in the presence of constant vessel noise (Lacy et al. 2017).

5. CONCLUSIONS

Declines in prey has been listed as one of the key threats to SRKW success and survival. Another concern, however, is that the disturbance from fishing and other vessels may still make these prey less accessible to SRKW by either avoidance behaviours and/or foraging cessation with the physical presence of vessels (Tennesen et al. 2019, Holt et al. 2021). Fisheries management measures are aimed to increase the availability of Chinook and other salmonid species in foraging areas in the Strait of Juan de Fuca and Gulf Islands within the designated critical habitat. However, in this study the potential acoustic benefits of fisheries closures for SRKW were considered, in the frequency ranges of SRKW communication calls and echolocation signals. However, for most moorings considered these measures were one of several aimed at reducing disturbance of SRKW. Only the mooring at Sooke was subject solely to fisheries measures for the periods of this assessment, with it being difficult to determine the individual impacts of several measures applied simultaneously, and accounting for their individual contribution on the changes in the soundscape seen.

The impact of vessel noise adds to several factors degrading habitat quality for SRKW (DFO 2017 a,b, 2018, Lacy et al. 2017, Raverty et al. 2020, Murray et al. 2021). The wide frequency range determined for the calling and listening capacity of killer whales (Miller 2006, Branstetter et al. 2017, Ferrara et al. 2017), underscores their acoustic sensitivity, and therefore their heightened potential for disturbance. Reductions in ambient broadband noise were seen generally during fisheries management actions. Recordings made by moorings in western Juan de Fuca Strait and Swiftsure Bank showed the greatest decreases in sound levels. However, in establishing the efficacy of these measures to reduce acoustic disturbance the existing variability and changes in wind noise and human-derived acoustic additions were considered. Seasonally reduced wind speeds through most of the study area resulted in reduced noise levels in the frequency ranges used by SRKW for conspecific communication. Higher-frequency noise, which overlaps with the frequency range used for SRKW echolocation, typically increased during periods with management measures and could have resulted from the seasonal increase of recreational vessels in the area. Adaptations in calling behaviours (see Noren et al. 2009, Holt et al. 2009, 2011) to overcome masking effects may energetically tax an already nutritionally stressed population.

The results from this analysis emphasises that smaller non-commercial vessels are an important, consideration, and at times a significant, contributor to the soundscape in the Salish Sea. Although the fisheries conservation measures can limit their behaviours or disincentivize their presence on the water, they do not regulate recreational use of the study area or the number of vessels that can be in the vicinity of SRKW.

6. ACKNOWLEDGEMENTS

Thanks go to Sara Jossul, Rangyn Lim, Johanna Withers and Svein Vagle who provided useful comments for the first draft of this report.

7. REFERENCES

Au, W.W.L., Ford, J.K.B., Horne, J.K., Allman K.A.N. 2004. Echolocation signals of free-ranging killer whales (*Orcinus orca*) and modeling of foraging for chinook salmon (*Oncorhynchus tshawytscha*). Journal of the Acoustical Society of America 115(2), 901–909.

Arveson, P.T. and Vendittis, D.J. 2000. Radiated noise characteristics of a modern cargo ship, Journal of the Acoustical Society of America 107: 118

Bain, D. E., R. Williams, J. C. Smith, and D. Lusseau. 2006. Effects of vessels on behavior of Southern Resident killer whales (Orcinus spp.) 2003–2005. NMFS Contract AB133F05SE3965. (Available from D. E. Bain, Friday Harbor Laboratories, Univ. Washington, 620 University Road, Friday Harbor, WA 98250.)

Baird, R.W., Hanson, M.B., Dill, L.M. 2005. Factors influencing the diving behaviour of fish eating killer whales: sex differences and diel and interannual variation in diving rates. Canadian Journal of Zoology 83(2): 257–267

Balcomb, K.C., and Bigg, M.A. 1986. Population biology of three resident killer whale pods in Puget Sound and off southern Vancouver Island. In: Behavioural biology of killer whales, ed. B.C. Kirkevold, and J.S. Lockard (Alan R. Liss, New York, NY), 85−95.

Branstetter, B., St. Leger, J., Acton, D., Stewart, J., Houser, D., Finneran, J.J., Jenkins, K. 2017. Killer whale (*Orcinus orca*) behavioral audiograms. Journal of the Acoustical Society of America 141: 2387.

Burnham, R.E., Vagle, S., O'Neill, C. 2021a Spatiotemporal patterns in the natural and anthropogenic additions to the soundscape in parts of the Salish Sea, British Columbia, 2018-2020. Marine Pollution Bulletin 170, 112647. DOI: 10.1016/j.marpolbul.2021.112647

Burnham, R.E., Vagle, S., O'Neill, C., Trounce, K. 2021b. The Efficacy of Management Measures to Reduce Vessel Noise in Critical Habitat of Southern Resident Killer Whales in the Salish Sea. Frontiers in Marine Science 8:664691.

Center for Whale Research. 2021. Southern resident orca community demographics, composition of pods, births and deaths since 1998. Unpublished data, accessed from orcanetwork.org, February 2, 2022

Clark, C., Ellison, W., Southall, B., Hatch, L., Van Parijs, S.M., Frankel, A., Ponirakis, D. 2009. Acoustic masking in marine ecosystems: intuitions, analysis, and implication. Marine Ecological Progress Series 395 : 201–222

Cominelli, S., Devillers, R., Yurk, H., MacGillivray, A., McWhinnie, L., Canessa, R. 2018. Noise exposure from commercial shipping for the southern resident killer whale population. Marine Pollution Bulletin 136: 177–200.

COSEWIC 2001. COSEWIC assessment and update status report on the killer whale *Orcinus orca* in Canada. Committee on the status of endangered wildlife in Canada. Ottawa. 47 pp

Department of Fisheries and Oceans Canada, DFO. 2017a. Identification of Habitats of Special Importance to Resident Killer Whales (*Orcinus orca*) off the West Coast of Canada. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2017/011.

Department of Fisheries and Oceans Canada, DFO. 2017b. Evaluation of the scientific evidence to inform the probability of effectiveness of mitigation measures in reducing shipping-related noise levels by southern resident killer whales. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2017/041

Department of Fisheries and Oceans Canada, DFO. 2018. Recovery Strategy for the Northern and Southern Resident Killer Whales (*Orcinus orca*) in Canada. Species at Risk Act Recovery Strategy Series, Fisheries & Oceans Canada, Ottawa, x + 84 pp

Department of Fisheries and Oceans Canada, DFO. 2018. Recovery Strategy for the Northern and Southern Resident Killer Whales (*Orcinus orca*) in Canada. Species at Risk Act Recovery Strategy Series, Fisheries & Oceans Canada, Ottawa, x + 84 pp.

Department of Fisheries and Oceans Canada, DFO. 2019. Cumulative Effects Assessment for Northern and Southern Resident Killer Whale (*Orcinus Orca*) Populations in the Northeast Pacific. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2019/030.

Department of Fisheries and Oceans Canada, DFO. 2021. Identification of areas for mitigation of vessel-related threats to survival and recovery for Southern Resident Killer Whales. DFO Can. Advis. Sec. Sci. Advis. Re. 2021/025.

ECHO 2019. ECHO Program 2018 Voluntary vessel slowdown in Haro Strait Summary Findings

ECHO 2020. ECHO Program 2019 voluntary vessel slowdown trial in Haro Strait and Boundary Pass

ECHO 2021a. 2020 voluntary vessel slowdown in Haro Strait and Boundary Pass

Erbe, C., and D. M. Farmer. 2000. A software model to estimate zones of impact on marine mammals around anthropogenic noise. J. Acoust. Soc. Am. 108:1327–1331.

Ferrara, G. A., T. M. Mongillo, and L. M. Barre. 2017. Reducing Disturbance from Vessels to Southern Resident Killer Whales: Assessing the Effectiveness of the 2011 Federal Regulations in Advancing Recovery Goals. December 2017. NOAA Technical Memorandum NMFS-OPR-58.

Foote A.D, Osborne, R.W., Hoelzel, A.R. 2004 Whale-call response to masking boat noise. Nature 428(6986): 910-910. DOI: [10.1038/428910a](10.1038/428910a)

Ford, J.K.B. 2006. An Assessment of Critical Habitat of Resident Killer Whales in Waters off the Pacific Coast of Canada. Canadian Science Advisory Secretariat Research Document 2006/072

Ford, J.K.B. 1987. A catalogue of underwater calls produced by killer whales (*Orcinus orca*) in British Columbia. Canadian Data Report of Fisheries and Aquatic Science 633: 170.

Ford, J.K.B. 1989. Acoustic behaviour of resident killer whales (*Orcinus orca*) off Vancouver Island, British Columbia. Canadian Journal of Zoology 67: 727–745.

Ford, J.K.B. 1991. Vocal traditions among resident killer whales (*Orcinus orca*) in coastal waters of British Columbia, Canada. Canadian Journal of Zoology 69: 1454–1483

Ford, J.K.B., and Ellis, G.M. 1999. Transients: Mammal-Hunting Killer Whales of British Columbia, Washington, and Southeastern Alaska. UBC Press, Vancouver, British Columbia, p. 96

Ford, J.K.B., Wright, B.M., Ellis, G.M., Candy, J.R. 2010b. Chinook salmon predation by resident killer whales: seasonal and regional selectivity, stock identity of prey, and consumption rates. DFO Can Sci Advis Sec Res Doc 2009/101, https://waves-vagues.dfo-mpo.gc.ca/ Library/339995.pdf

Ford, J.K., Pilkington, J.F., Riera, A., Otsuki, M. Gisborne, B., Abernethy, R.M., Stredulinsky, E.H, Towers, J.R., Ellis, G.M. 2017. Habitats of special importance to Resident killer whales (*Orcinus orca*) off the west coast of Canada. DFO Can Sci. Advis. Sec. Res. Doc. 2017/035

Groot, C., Margolis, L., Bailey, R. 1984 Does the route of sea- ward migration of Fraser River sockeye salmon (*Oncorhynchus nerka*) smolts determine the route of return migration of the adults? In: J.D McCleave, G.P Arnold, J.J. Dodson, W.H. Neill (Eds.) *Mechanisms of migration in fishes.* Plenum Press, New York, NY, p 283−292.

Hanson, M.B., Walker, W.A. 2014 Trans-Pacific consumption of cephalopods by North Pacific killer whales (*Orcinus orca)*. Aquatic Mammals 40: 274−284

Hanson, M.B., Baird, R.W., Ford, J.K.B., Hempelmann-Halos, J., Van Doornik, D.M., Candy, J.R., Emmons, C.K., Schorr, G.S., Gisborne, B., Ayres, K.L., Wasser, S.L., Balcomb, K.C., Balcomb-Bartok, K., Sneva, J.G., Ford, M.J. 2010. Species and stock identification of prey consumed by endangered southern resident killer whales in their summer range. Endangered Species Research 11: 69−82

Hanson, M.B., Emmons, C.K., Ford, M.J., Everett, M., Parsons, K., Park, L.K., Hempelmann, J., Van Doornik, D.M., Schoor, G., Jacobsen, J., Sears, M.F., Sears, M.S., Sneva, J.G., Baird, R.W, Barre, L. 2021 Endangered predators and endangered prey: Seasonal diet of Southern Resident killer whales. PLoS ONE 16(3): e0247031. https://doi.org/10.1371/journal.pone.0247031

Hauser, D.D., Logsdon, M.G., Holmes, E.E., VanBlaricom, G.R., Osborne, R.W. 2007. Summer distribution patterns of southern resident killer whales *Orcinus orca*: core areas and spatial segregation of social groups. Marine Ecological Progress Series 351: 301.

Heimlich-Boran, J.R. 1988 Behavioral ecology of killer whales (*Orcinus orca*) in the Pacific Northwest. Canadian Journal of Zoology 66: 565–578

Heise, K.A., Barrett-Lennard, L.G., Chapman, N.R., Dakin, D.T., Erbe, C., Hannay, D.E., Merchant, N.D., Pilkington, J.S., Thornton, S.J., Tollit, D.J., Vagle, S., Veirs, V.R., Vergara, V., Wood, J.D., Wright, B.M., Yurk, H. 2017. Proposed Metrics for the Management of Underwater Noise for Southern Resident Killer Whales. Coastal Ocean Report Series (2), Ocean Wise, Vancouver, 30pp.

Hermannsen, L., Mikkelsen, L., Tougaard, J., Beedholm, K., Johnson, M., Madsen, P.T. 2019 Recreational vessels without automatic identification system (AIS) dominate anthropogenic noise contributions to a shallow water soundscape. Sci Rep 9:15477. DOI: 10.1038/s41598-019-51222-9

Herzing, D. L. 2000. Acoustics and social behavior of wild dolphins: Implications for a sound society. In W. W. L. Au & R. R. Fay (Eds.) *Hearing in whales and dolphins* New York: NY: Springer pp. 225–272.

Hildebrand, J. 2009. Anthropogenic and natural sources of ambient noise in the Ocean. Marine Ecology Progress Series 395:5-20.

Holt, M.M., Noren, D.P., Veirs, V., Emmons, C.K., Veirs, S. 2009. Speaking up: Killer whales (*Orcinus orca*) increase their call amplitude in response to vessel noise. Journal of the Acoustical Society of America 125, EL27–EL32.

Holt, M.M., Noren, D.P., Emmons, C.K. 2011. Effects of noise levels and call types on the source levels of killer whale calls. Journal of the Acoustical Society of America 130(5), 3100-3106.

Holt, M.M., Noren, D.P., Dunkin, R.C., and Williams, T.M. (2015). Vocal performance affects metabolic rate in dolphins: implications for animals communicating in noisy environments. Journal of Experimental Biology 218, 1647–1654. doi: 10. 1242/%u200Bjeb.122424

Holt, M.M., Tennessen, J.B., Ward, E.J., Hanson, B.E., Emmons, C.K., Giles, D.A., Hogan, J.T. 2021. Effects of vessel distance on sex on the behavior of Endangered killer whales. Frontiers in Marine Science doi.org/10.3389/fmars.2020.582182

Janik, V.M., and Slater, P.J.B 1998. Context-specific use suggests that bottlenose dolphin signature whistles are cohesion calls. Animal Behaviour 56:829–838

Klinck, H., Nieukirk, S.L., Mellinger, D.K., Klinck, K., Matsumoto, H., Dziak, R.P. 2012 Seasonal presence of cetaceans and ambient noise levels in polar waters of the North Atlantic. Journal of the Acoustical Society of America 132, EL176–EL181

Krahn, M.M., Wade, P.R., Kalinowski, S., Dahlheim, M.E., Taylor, B.L., Hanson, B., Ylitalo, G.M., Angliss, R.P., Stein, J., Waples, R. 2002 Status review under the Endangered Species Act: southern resident killer whales (*Orcinus orca*) 2002. NOAA Technical Memorandum NMFS-NWFSC-54, 135 pp.

Krahn, M.M., Ford, M.J., Perrin, W.F., Wade, P.R., Angliss, R.P., Hanson, M.B., Taylor, B.L., Ylitalo, G.M., Dahlheim, M., Stein, J.E., and Waples, R.S. 2004. 2004 Status review of southern resident killer whales (*Orcinus orca*) under the Endangered Species Act. Technical Memo 2004, NMFS-NWFSC-62. U.S. Dept. Commerce, NOAA, Seattle, WA

Lacey, R., Williams, R., Ashe, E., Balcolm III, K.C., Brent, L.J.N., Clark, C.W., Croft, D.P., Giles, D.A., MacDuffee, M., Paquet, P.C. 2017. Evaluating anthropogenic threats to endangered killer whales to inform effective recovery plans. Scientific Reports 7(1): 14119

Lusseau, D., Bain, D.E., Williams, R.,Smith, J.C. 2009. Vessel traffic disrupts the foraging behavior of southern resident killer whales *Orcinus orca*. Endangered Species Research 6, 211–221

Merchant, N.D., Witt. M.J., Blondel, P., Godley, B.J., Smith, G.H. 2012. Assessing sound exposure from shipping in coastal waters using a single hydrophone and Automatic Identification System (AIS) data. Marine Pollution Bulletin 64: 132-1329.

Merchant, N. D., Fristrup, K. M., Johnson, M. P., Tyack, P. L., Witt, M. J., Blondel, P., Parks, S. E. 2015. Measuring acoustic habitats. Methods Ecology and Evolution 6, 257–265

Miller, P.J.O. 2006. Diversity in sound pressure levels and estimated active space of resident killer whale vocalisations. Journal of Comparitive Physiolgy A. 192: 449-459

Murray, C.C., Hannah, L.C., Doniol-Valcroze, T., Wright, B.M., Stredulinky, E.H., Nelson, J.C., Locke, A., Lacy, R.C. 2021. A cumulative effects model for population trajectories of resident killer whales in the Northeast Pacific. Biological Conservation 257: 109124

Nelson, B.W., Shelton, A.O., Anderson, J.H., Ford, M.J., and Ward, E.J. 2019. Ecological implications of changing hatchery practises in Chinook salmon in the Salish Sea. Ecosphere 10(11): e02922

Nichol L.M., Shackleton, D.M. 1996. Seasonal movements and foraging behaviour of northern resident killer whales. Canadian Journal of Zoology 74(6):983-991

Noren, D.P., Johnson, A.H., Rehder, D., Larson, A. 2009. Close approaches by vessels elicit surface active behaviors by southern resident killer whales. Endangered Species Research 8:179– 192.

Noren, D., Holt, M.M., Dunkin, R.C., Williams, T.M. 2017. Echolocation is cheap for some mammals: Dolphins conserve oxygen while producing high-intensity clicks. Journal of Experimental Marine Biology and Ecology 495: doi: 10.1016/j.jembe.2017.07.002

Noren, D. P., Holt, M. M., Dunkin, R. C., Williams, T. M. 2013. The metabolic cost of communicative sound production in bottlenose dolphins (*Tursiops truncatus*). Journal of Experimental Biology 216, 1624–1629. doi: 10.1242/jeb.083212

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

Raverty, S. St. Leger, J., Noren, D.P., Burek Huntington, K., Rotstein D.S., Gulland, F.M.D. Ford, J.K.B., Hanson, B., Lambourn, D.M., Huggins, J., Delaney, M.A., Spaven, L., Rowles, T., Gaydos, J.K. 2020. Pathology findings and correlations with body condition index in stranded killer whales (*Orcinus orca*) in the northeastern Pacific and Hawaii from 2004 to 2013. PLoS ONE 15(12):e0242505.

Riesch, R., Ford, J.K.B., Thomsen, F. 2006. Stability and group specificity of stereotyped whistles in resident killer whales, *Orcinus orca*, off British Columbia. Animal Behaviour 71:79–91. 10.1016/j.anbehav.2005.03.026

Richardson, W.J., Greene Jr., C.R., Malme, C.I., Thomson, D. 1995. Marine Mammals and Noise. San Diego, CA: Academic Press

Ross, D. 1976. Mechanics of Underwater Noise. Pergamon, New York.

Ruff, C.P., Anderson, J.H., Kemp, I.,M., Kendall, N.W., Mchugh, A., Velez-Espino, A.,Green, C.M., Trudel, M., Holt, C.A., Ryding, K.E, Rawson, K. 2017. Salish Sea Chinook salmon exhibit weaker coherence in early marine survival trends than coastal populations. Fisheries Oceanography 00: 1-1310.1111/fog.12222

Serra-Sogas, N., O'Hara, P., Pearce, K., Smallshaw, L., Canessa, C. 2021. Using aerial surveys to fill gaps in AIS vessel traffic data to inform threat assessments, vessel management and planning. Marine Policy. 1333: 104765

Shields, M.W., Lindell, J., Woodruff, J. 2018. Declining spring usage of core habitat by endangered fish-eating killer whales reflects decreased availability of their primary prey. Pacific Conservation Biology 24: 189-193. doi: 10.1071/PC17041.

Taylor, M. and B. Plater. 2001. Population viability analysis for the southern resident population of the killer whale (*Orcinus orca*). Centre for Biological Diversity, Tucson, Arizona. 30 p.

Tennessen, J.B., Holt, M.M., Hansen, M.B., Emmons, C.K., Giles, D.A., Hogan, J.T. 2019. Kinematic signatures of prey capture from archival tags reveal sex differences in killer whale foraging activity Journal of Experimental Biology 222: 1-13.

Thomson, D.J.M, and Barclay, D.R. 2020. Real-time observations of the impact of COVID-19 on underwater noise. Journal of the Acoustical Society of America 147: 3390; doi: 10.1121/10.0001271

Vagle, S. 2020. Evaluation of the efficacy of the Juan de Fuca lateral displacement trial and Swiftsure Bank plus Swanson Channel interim sanctuary zones, 2019. Canadian Technical Report of Hydrography and Ocean Sciences. 332: vi + 60 p

Vagle, S., and Neves, M. 2019. Evaluation of the effects on underwater noise levels from shifting vessel traffic away from Southern Resident Killer Whale foraging areas in the Strait of Juan de Fuca in 2018. Canadian Technical Report of Hydrography and Ocean Sciences. 329 : vi + 64 p.

Vagle, S., Large, W. G., Farmer, D. M. 1990. An Evaluation of the WOTAN Technique of Inferring Oceanic Winds from Underwater Ambient Sound. Journal of Atmospheric and Oceanic Technology 7: 576-595.

Vagle, S., Burnham, R.E., O'Neill, C., Yurk, H. 2021. Variability in anthropogenic underwater noise due to bathymetry and sound speed characteristics. Journal of Marine Science and Engineering. 9: 1047.

Veirs, S., Veirs, V., Wood, J. 2016. Ship noise in an urban estuary extends to frequencies used for echolocation by endangered killer whales. PeerJ PrePrints, 3, e955v3

Vélez-Espino, L.A., Ford, J.K.B., Araujo, H.A., Ellis, G., Parken, C.K., Balcomb, K.C. 2014. Comparative demography and viability of northeastern Pacific resident killer whale populations at risk. Can Tech Rep Fish Aquat Sci 3084: v + 58 p

Waples, R.S., Teel, D.J., Myers, J.M., Marshall, A.R. 2004. Life-history divergence in Chinook Salmon: historic contingency and parallel evolution. Evolution 58:386–403.

Williams, R., Hedley, S.L. and Hammond, P.S. 2006. Modeling distribution and abundance of Antarctic baleen whales using ships of opportunity. Ecology and Society 11, 28.

Williams, R., Bain, D.E., Smith, J.C., Lusseau, D. 2009. Effects of vessels on behavior patterns of individual Southern Resident killer whales *Orcinus orca*. Endang. Species Res. 6: 199–209.

Williams, R., Erbe, C., Ashe, E., Beerman, A., Smith, J. 2014. Severity of killer whale behavioral responses to ship noise: a dose–response study. Marine Pollution Bulletin 79(1–2):254–260.

Wladichuk J.L., Hannay, D.E., MacGillivray, A.O, Li, Z., Thornton, S. 2019. Systematic source level measurements of whale watching vessels and other small boats. Journal of Ocean Technology 14(3): 109-126.

Appendix

Appendix, Table A1:Dates and details of Fisheries measures in the Salish Sea from 2018-2021

Year	SRKW management measures	Chinook conservation measures	Steelhead conservation measures
2021	**Juan de Fuca Strait and WCVI** Jul 16 to Oct 31: **Fishing Closure** – No recreational and commercial salmon fishing (a portion of Subarea 121-1) Aug 1 to Oct 31: **Fishery Closures -** No recreational or commercial salmon fishing (Subareas 20-3 and 20-4) Jun 1 to Nov 30: **Interim Sanctuary Zone -** No fishing or boating (with exceptions) (portions of Subareas 121-1 and 121-2) **Gulf Islands:** June 1 to Nov 30: **Interim Sanctuary Zones** – no fishing or boating (with exceptions) portions of Subareas 18-4, 18-5 and 18-11 July 4 to Oct 31: No recreational or commercial salmon fishing in Subarea 18-9 and portions of 18-2, 18-4, and 18-5	**Strait of Juan de Fuca** and Gulf Islands (Subareas 20-3 to 20-7, Area 18) for recreational harvesters: -April 1 to July 31: No retention of chinook -Aug 1 to Aug 31: 1 Chinook per day, max 80 cm -Sept 1 to Dec 31: 2 Chinook per day **WCVI** (Subareas 20-1, 20-2, Area 121, and seaward of a 1 nm Boundary Line in Areas 123 to 127) for recreational harvesters: -Apr. 1 to Jul. 14: No retention of chinook. -July 15 to July 31: 2 Chinook per day, max 80 cm. -Aug 1 to Dec 31: 2 Chinook per day *For clarity, chinook daily limits remain at 2 per day shoreward of this Boundary Line, and also in Areas 21 to 27.* West Coast of Vancouver Island commercial troll fishery start will be delayed to August 1st.	**Strait of Juan de Fuca and WCVI** Area 19, 20, 21, 121 and 123 closed for commercial troll fisheries. No impact to recreational and FSC fishing -27-day closures start between September 16 and 22nd -42-day closures start between September 9th and 15th
2020	**Juan de Fuca Strait and WCVI** Aug 1 to Oct 31: **Fishery Closures -** No recreational or commercial salmon fishing (Subareas 20-3, 20-4 and a portion of 121-1) Jun 1 to Nov 30: **Interim Sanctuary Zone -** No fishing or boating (with exceptions) (portions of Subareas 121-1 and 121-2) **Gulf Islands:** June 1 to Nov 30: **Interim Sanctuary Zones** – no fishing or	**Strait of Juan de Fuca** and Gulf Islands (Subareas 20-3 to 20-7, Area 18) for recreational harvesters: -April 1 to July 31: No retention of chinook -Aug 1 to Aug 31: 1 Chinook per day, max 80 cm -Sept 1 to Dec 31: 2 Chinook per day **WCVI** (Subareas 20-1, 20-2, Area 121, and seaward of a 1 nm Boundary Line in Areas 123 to 127) for recreational harvesters: -Apr. 1 to Jul. 14: No retention of chinook. -July 15 to July 31: 2 Chinook per	**Strait of Juan de Fuca and WCVI** Area 19, 20, 21, 121 and 123 closed for commercial troll fisheries. No impact to recreational and FSC fishing -27-day closures start between September 16 and 22nd -42-day closures start between September 9th and 15th

<table>
<tr><td></td><td>boating (with exceptions) portions of Subareas 18-4, 18-5 and 18-11

Aug 1 to Oct 31: No recreational or commercial salmon fishing in Subarea 18-9 and portions of 18-2, 18-4, and 18-5</td><td>day, max 80 cm.
-Aug 1 to Dec 31: 2 Chinook per day
For clarity, chinook daily limits remain at 2 per day shoreward of this Boundary Line, and also in Areas 21 to 27.

West Coast of Vancouver Island commercial troll fishery start will be delayed to August 1st.</td><td></td></tr>
<tr><td>2019</td><td><u>Juan de Fuca Strait and WCVI</u>

Aug 1 to Oct 31: Fishery Closures - No recreational or commercial salmon fishing (Subareas 20-3 and 20-4) – after Chinook non-retention expires on July 31

Jun 1 to Oct 31: Interim Sanctuary Zone - No fishing or boating (with exceptions) (portions of Subareas 121-1 and 121-2)

June 1 to Nov 30: Interim Sanctuary Zones – no fishing or boating (with exceptions) portions of Subareas 18-4, 18-5 and 18-11

Aug 1 to Oct 31: No recreational or commercial salmon fishing in Subarea 18-9 and portions of 18-2, 18-4, and 18-5</td><td><u>Juan de Fuca Strait (Subareas 20-3 to 20-7) and Gulf Islands (Area 18)</u>

April 19 – July 31: Chinook non-retention

August 1 – August 29: 1 Chinook per day

August 30 – December 31: 2 Chinook per day

<u>Juan de Fuca Strait (West) Subareas 20-1 and 20-2</u>

April 19 – July 14: Chinook non-retention

July 15 – December 31: 2 Chinook per day

<u>WCVI - Areas 121, 123-127 seaward of 1 nautical mile outside of the surfline</u>

Chinook non-retention from April 19-July 14

<u>West Coast of Vancouver Island AABM commercial troll fishery start will be delayed to August 1st</u></td><td><u>Strait of Juan de Fuca and WCVI</u>

-27-day closures start between September 16 and 22 (commercial troll fisheries)

-42-day closures start between September 9th and 15 (commercial gill net, purse seine, beach seine, and shallow seine fisheries)</td></tr>
<tr><td>2018</td><td><u>Juan de Fuca Strait and Pender Island</u>

June 1 to Sept 30 : Fishery Closures - Finfish closure for recreational fishery and salmon closure for commercial fishery (Subareas 20-3, 20-4 and a portion of Subarea 20-5 west of Otter Point; Subareas 18-2, 18-4, 18-5 and 18-9).

<u>WCVI</u>

WCVI AABM Troll fisheries closed June and July.</td><td><u>Juan de Fuca recreational fishery (Subareas 19-1 to 19-4 and Subareas 20-4 to 20-7)</u>

June 1 to June 28th - 2 per day which may be wild or hatchery marked between 45 and 67 cm fork length or hatchery marked greater than 67 cm in Subareas 19-1 to 19-4 and 20-6 and 20-7 and that portion of Subarea 20-5 that lies east of Otter Point.

June 29 to July 31st - 2 Chinook per day which may be wild or hatchery marked between 45 and 85 cm or</td><td><u>No window closure in Juan de Fuca or WCVI</u>

Steelhead non-retention in recreational and commercial fisheries.</td></tr>
</table>

		hatchery marked greater than 85 cm in Subareas 19-1 to 19-4 and 20-6 and 20-7 and that portion of Subarea 20-5 that lies east of Otter Point. **Gulf Islands (Area 18, managed with southern SOG measures)** May 7 to May 31: 2 Chinook per day, of which only one may be over 67 cm (Subareas 18-1 to 18-6, 18-9, 18-11 and 19-5) June 1 to September 30: 1 Chinook per day with the exception of those portions listed below October 1 to April 18: 2 Chinook per day in Area 18 and Subarea 19-5 Exceptions: May 30 to June 28: 2 Chinook per day, of which only one may be greater than 67 cm in Subareas 18-1, 18-3, 18-6, 18-11, and 19-5. June 29 to July 31: 2 Chinook per day, both of which must be less than 85 cm in Subareas 18-1, 18-3, 18-6, 18-11, and 19-5. Min fork length is 62 cm in Area 18 and 19-5.**No additional measures for WCVI rec** **Area G AABM Troll** No fishing in June or July	

Table A2: Correlation coefficients and p values for correlations between vessel presence and sound pressure levels in frequency ranges of interest for each mooring site. Grey shading indicates a significant result at p=0.05 level

	Pre-measures Control, all years								During measures, all years								Post-measures control, all years							
	Broadband	100-1000	67 Hz	125 Hz	50 kHz	Comm	Echo	Wind	Broadband	100-1000	67 Hz	125 Hz	50 kHz	Comm	Echo	Wind	Broadband	100-1000	67 Hz	125 Hz	50 kHz	Comm	Echo	Wind
Area 121- Swiftsure Bank																								
fishing vessels	0.197, 0.077	0.118, 0.292	0.211, 0.059	0.072, 0.521	0.149, 0.184	0.309, 0.005	0.248,0.026	0.184, 0.100	0.044, 0.258	0.081, 0.037	0.041, 0.299	0.074, 0.058	0.058, 0.139	0.084, 0.032	0.028, 0.471	0.053, 0.179	0.088, 0.496	0.015, 0.910	0.088, 0.496	0.037, 0.777	0.066, 0.610	0.125, 0.334	0.136, 0.293	0.139, 0.280
Class B									0.066, 0.091	0.061, 0.119	0.000, 0.990	0.045, 0.246	0.012, 0.761	-0.096, 0.014	0.073, 0.060	-0.088, 0.024								
All vessels	0.128, 0.256	0.005, 0.963	0.133, 0.237	0.076, 0.499	0.178, 0.112	0.207, 0.064	0.230, 0.039	0.161, 0.152	0.013, 0.736	0.053, 0.173	0.035, 0.370	0.032, 0.414	-0.015, 0.706	0.006,0.873	0.060, 0.123	0.004, 0.911	0.010, 0.941	0.065, 0.614	0.091, 0.483	0.091, 0.483	0.080, 0.534	0.100, 0.439	0.040, 0.755,	0.062, 0.633
wind	0.013,0.931	0.008, 0.954	0.153, 0.288	0.085, 0.559	0.145, 0.314	0.060, 0.678	0.101, 0.483	0.132, 0.360	0.189, <0.001	0.111, 0.017	0.178, <0.001	0.080, 0.086	-0.123, 0.008	0.202, <0.001	0.010, 0.824	0.100, 0.031	0.116, 0.535	0.125, 0.501	0.199, 0.284	0.144, 0.441	0.109, 0.558	0.140, 0.452	0.050, 0.789	0.017, 0.930
Area 20 - Port Renfrew																								
fishing vessels									0.063,0.093	0.037, 0.316	0.094, 0.011	0.004, 0.908	0.008, 0.836	0.39, 0.261	0.056, 0.109	0.050, 0.182	0.170, 0.102	0.032, 0.761	0.149, 0.154	0.110, 0.293	0.067, 0.520	0.034, 0.784	0.105, 0.318	0.025, 0.813
Class B	0.072, 0.445	0.081,0.388	0.132, 0.160	0.132, 0.160	0.045, 0.635	0.112, 0.234	0.015, 0.871	0.079, 0.402	0.089, 0.017	0.006, 0.882	0.035, 0.349	0.003,0.940	0.091, 0.015	0.019, 0.589	0.003, 0.941	0.037, 0.322	0.179, 0.085	0.141, 0.178	0.061, 0.563	0.052, 0.617	0.113, 0.280	0.213, 0.041	0.152, 0.146	0.243, 0.019
All vessels	0.175,0.061	0.021,0.827 (@5l	0.036, 0.702	0.048, 0.611	0.122, 0.195(@5l	0.039, 0.676	0.175, 0.062 (@5	0.055, 0.560 (@5	0.021, 0.564	0.002, 0.965	0.006, 0.872	0.004,0.913	0.002, 0.950	0.016, 0.650	0.030, 0.391	0.005, 0.884	0.127, 0.225	0.053, 0.616	0.080, 0.449	0.076,0.468	0.036, 0.732	0.059, 0.576	0.001, 0.989	0.156, 0.136
wind	0.012, 0.910	0.058, 0.598	0.026, 0.813	0.118,0.287	0.135, 0.221	0.162, 0.142	0.013, 0.909	0.296, 0.006	0.185, <0.001	0.132, 0.002	0.107, 0.014	0.074, 0.092	0.084, 0.054	0.151, 0.001	0.030, 0.498	0.061, 0.164	0.017, 0.898	0.016, 0.901	0.228, 0.075	0.049, 0.704	0.122, 0.346	0.072, 0.578	0.0278, 0.028	0.313, 0.013
Jordan River																								
fishing vessels									0.054, 0.123	0.024, 0.494	0.022, 0.527	0.040, 0.251	0.059, 0.090	0.039, 0.261	0.056, 0.107	0.014, 0.694	0.052, 0.620	0.043, 0.682	0.084, 0.424	-0.224, 0.031	0.145, 0.165	0.122, 0.242	0.145, 0.165	0.186, 0.074
Class B	0.087, 0.360	0.070,0.464	0.098, 0.299	0.061, 0.522	0.119, 0.210	0.049,0.604	0.075,0.428	0.093,0.329	0.039, 0.263	0.045, 0.200	0.016, 0.646	0.061, 0.083	0.010, 0.727	0.019, 0.583	0.000, 0.999	0.008, 0.825	0.118, 0.260	0.077, 0.463	0.032, 0.763	0.057, 0.589	0.075, 0.476	0.097, 0.353	0.068, 0.517	0.018, 0.863
All vessels	0.051, 0.591	0.058,0.543	0.002, 0.985	0.007, 0.943	0.025,0.792	0.110,0.246	0.053, 0.576	0.093,0.328	0.019,0.582	0.008, 0.816	0.036, 0.306	0.011, 0.759	0.038, 0.279	0.016,0.650	0.031, 0.381	0.008, 0.830	0.188,0.071	0.061, 0.562	0.066, 0.529	-0.146, 0.163	0.059, 0.574	0.071, 0.499	0.062, 0.557	0.045, 0.670
wind	-0.282, 0.010	-0.324, 0.003	-0.240, 0.030	-0.238, 0.031	0.073, 0.514	-0.346, 0.001	-0.139, 0.214	0.288, 0.009	0.208, <0.001	0.143, <0.001	0.104, 0.009	0.077, 0.055	-0.108,0.007	0.140, <0.001	0.006, 0.884	0.079, 0.050	0.232, 0.069	0.146, 0.256	-0.503, <0.001	-0.094, 0.467	0.203, 0.114	0.094, 0.467	0.345, 0.006	0.000, 0.999
Sooke																								
fishing vessels									-0.074, 0.044	-0.095, 0.001	-0.073, 0.047	-0.119,0.001	-0.081, 0.026	-0.140, <0.001	0.071, 0.053	-0.139, <0.001	0.024, 0.841	0.142, 0.236	0.056, 0.640	0.043, 0.722	0.005, 0.965	0.207, 0.084	0.016, 0.894	0.137, 0.255
Class B	0.147, 0.175	0.192, 0.074	0.006, 0.955	0.165, 0.127	0.031, 0.779	0.199, 0.065	0.177, 0.101	0.140, 0.194	0.056, 0.124	0.067, 0.068	0.008, 0.819	0.063, 0.085	0.059, 0.106	0.041, 0.267	-0.105, 0.004	-0.072, 0.049	-0.239, 0.045	0.007, 0.955	0.212, 0.076	0.109, 0.364	0.085, 0.479	0.017, 0.888	0.123, 0.307	0.014, 0.910
All vessels	0.038, 0.728	0.003, 0.981	0.180, 0.096	0.052, 0.633	0.090, 0.405	0.004, 0.968	0.003, 0.978	0.048, 0.660	0.053, 0.150	-0.101, 0.006	0.048, 0.189	-0.123, 0.001	0.044, 0.226	0.034, 0.358	0.009, 0.813	0.043, 0.243	0.027, 0.822	0.107, 0.374	0.068, 0.575	0.069, 0.568	0.056, 0.642	0.237, 0.046	0.010, 0.935	0.141, 0.240
wind	0.317, 0.016	0.357, 0.001	0.022, 0.840	0.318, 0.003	0.107, 0.331	0.217, 0.046	0.174, 0.111	0.272,0.012	0.062, 0.260	0.087, 0.113	-0.164, 0.003	0.067, 0.225	0.028, 0.605	0.149, 0.007	0.051, 0.355	0.076, 0.169	0.048, 0.709	0.091, 0.481	0.037, 0.774	0.120, 0.351	0.034, 0.793	0.033, 0.796	0.006, 0.963	0.116, 0.369
Area 19 - Haro Strait																								
fishing vessels	0.191, 0.304	0.088, 0.638	0.220,0.234	0.029, 0.875	0.103, 0.582	0.206, 0.267	0.029,0.875	0.015, 0.938									-0.191,0.304	-0.088,0.638	-0.220, 0.234	0.029, 0.875	0.103, 0.582	-0.206, 0.267	0.029, 0.875	0.015, 0.938
Class B	0.490,0.005	0.412, 0.021	0.402,0.025	0.157, 0.399	0.353, 0.051	0.539, 0.002	0.412, 0.021	0.020, 0.917	0.249, 0.002	0.156, 0.060	0.209, 0.011	0.244, 0.003	0.132, 0.112	0.044, 0.593	0.113, 0.171	0.174, 0.035	-0.490,0.005	-0.412, 0.021	-0.402, 0.025	0.157, 0.399	-0.353, 0.051 (@	-0.539, 0.002	-0.412, 0.021	0.020, 0.917
All vessels	0.084,0.653	0.033, 0.862	0.084,0.653	0.088, 0.638	0.328, 0.072	0.198, 0.285	0.158, 0.396	0.057, 0.762	0.087, 0.293	0.012, 0.886	0.051, 0.536	0.053, 0.526	0.144, 0.081	0.025, 0.764	0.013, 0.872	0.048, 0.564	0.084, 0.653	0.033, 0.862	-0.084, 0.653	0.088,0.638	-0.328, 0.072(@5	0.198, 0.285	0.158, 0.396	0.057, 0.762
wind	0.222, 0.321	0.325,0.140	0.122,0.589	0.008, 0.698	0.335,0.128	0.303, 0.170	0.469, 0.028	0.408, 0.060	0.192, 0.020	0.083, 0.319	0.165, 0.046	0.109,0.190	0.019, 0.822	0.073, 0.382	0.117,0.158	0.082, 0.324	0.222, 0.321	0.325, 0.140	0.122, 0.589	0.088, 0.698	0.0335, 0.128	0.303, 0.170	-0.469, 0.028	0.408, 0.061
Area 18 - Boundary Pass																								
fishing vessels	0.036, 0.747	-0.165, 0.132	-0.117, 0.285		-0.067, 0.544	-0.076, 0.492	0.040, 0.716	-0.022, 0.840	0.015, 0.676	0.015, 0.673	0.009, 0.815	0.014, 0.707	0.008, 0.824	0.026, 0.480	0.064, 0.079	0.004, 0.911						0.031, 0.789	0.059, 0.612	
Class B	-0.101, 0.358	-0.090, 0.412	-0.062, 0.574		0.052, 0.635	0.025, 0.820	0.073, 0.509	0.052, 0.638	0.050, 0.172	0.010, 0.793	0.100, 0.006	0.078,0.032	0.177, 0.001	0.062, 0.091	0.077, 0.035	0.069, 0.058	0.022, 0.849	0.033, 0.775	0.062, 0.589	0.121, 0.294	0.088, 0.446	0.054, 0.642	0.035, 0.761	0.000, 1.000
All vessels	0.163, 0.136	-0.024, 0.829	0.061, 0.576		0.142, 0.192	0.020, 0.854	0.133, 0.224	0.130, 0.235	0.052, 0.153	0.070, 0.056	0.014, 0.710	0.022, 0.554	0.022, 0.556	0.057, 0.177 (@5	0.529, <0.001	0.046, 0.212	0.283, 0.013	0.027, 0.818	0.239, 0.037	0.016, 0.892	0.115, 0.321	0.0693, <0.001	0.903, <0.001	0.045, 0.697
wind	0.060, 0.664	-0.108, 0.436	-0.093, 0.503		-0.078, 0.576	-0.077, 0.589	0.113, 0.417	0.110, 0.430	0.005, 0.910	0.093, 0.025	0.112, 0.007	0.100, 0.016	0.097, 0.019	0.075, 0.072	0.160, <0.001	0.166, <0.001	0.238, 0.063	0.150, 0.243	0.233, 0.068	0.057, 0.661	0.042, 0.743	0.273, 0.032	0.023, 0.861	0.173, 0.178
Swanson Channel																								
fishing vessels	0.173, 0.221	0.154, 0.276	0.191, 0.174	0.154, 0.276	0.219, 0.118	0.126,0.374	0.219,0.118	0.023, 0.870	-0.039, 0.365	0.045, 0.287	0.019, 0.649	0.044, 0.301	0.012,0.770	0.027, 0.523	0.009,0.835	-0.012, 0.770	0.066, 0.609	0.179, 0.165	0.066,0.609	0.158,0.220	0.071, 0.581	0.102, 0.430	0.128, 0.323	0.071, 0.581
Class B	0.304, 0.028	0.162, 0.250	0.340, 0.014	0.118,0.404	0.029,0.840	0.181, 0.198	0.124, 0.381	0.156,0.269	0.001, 0.979	0.018, 0.670	0.044, 0.298	0.032, 0.445	0.041,0.332	0.008, 0.848	0.081, 0.055	0.046, 0.276	0.205, 0.109	0.176,0.171	0.136, 0.293	0.092, 0.478	0.169, 0.190	0.242, 0.058	0.242, 0.058	0.213, 0.097
All vessels	0.156, 0.269	0.195,0.166	0.028, 0.843	0.104,0.461	0.055, 0.699	0.120, 0.396	0.054, 0.706	0.070,0.620	0.065, 0.124	0.089, 0.037	0.002, 0.955	0.053, 0.212	0.069, 0.103	0.086, 0.043	0.033, 0.440	0.077, 0.072	0.072, 0.576	0.101,0.437	0.038,0.768	0.165,0.201	0.309, 0.014	0.058, 0.652	0.279, 0.028	0.126, 0.329
wind	0.232, 0.106	0.002, 0.987	0.047, 0.751	0.037,0.800	0.001, 0.995	0.078, 0.594	0.013, 0.928	0.099, 0.501	0.064, 0.386	0.099, 0.178	0.009, 0.904	0.033, 0.656	0.173, 0.018	0.038, 0.610	0.180, 0.014	0.052, 0.480	0.272, 0.064	0.225, 0.128	0.131, 0.382	0.097, 0.515	0.042, 0.780	0.259, 0.078	0.005, 0.971	0.179, 0.229
Saturna Island																								
fishing vessels																								
Class B																								
All vessels																								
wind	0.032,0.873	0.284, 0.144	0.048, 0.808	0.202, 0.303	0.105,0.597	0.021, 0.914	0.118, 0.551	0.152, 0.441	0.029, 0.747	0.029, 0.747	0.008,0.934	0.024, 0.793	0.074, 0.411	0.059, 0.513	0.011, 0.905	0.015, 0.868	0.291,0.274	0.797, <0.001	0.571,0.021	0.544, 0.029	0.171, 0.528	0.850, <0.001	0.285, 0.284	0.726, 0.001

(grey cell) - significant correlation, at p=0.05 level

Table 3: Sound pressure level measures for each frequency range of interest for pre-, during and post-closure periods. Light grey shading represents greatest SPL between pre-, during, and post-periods, darker grey shading represents the greatest SPL for the frequency band between pre-, during, and post-periods, yellow shading indicates the minimum and maximum SPL values for all years all sites

	Pre-measures Controll								During measures								Post-measures control									
	Broadband	100-1000	67 Hz	125 Hz	50 kHz	Comm	Echo	Wind	Broadband	100-1000	67 Hz	125 Hz	50 kHz	Comm	Echo	Wind	Broadband	100-1000	67 Hz	125 Hz	50 kHz	Comm	Echo	Wind	Max	Min
Sooke																									0	0
2018																									0	0
mean	129.97	115.4	117.91	109.8	75.32	110.71	94.76	91.62	132.43	116.39	120.97	109.51	82.37	110.08	96.68	91.8	128.2	115.55	120.63	109.15	85.31	110.38	97.89	91.31	132.43	75.32
median	128.96	115.5	116	110.25	72.45	110.61	94.11	91.72	131.29	115.76	119.24	108.84	80.25	110.01	96.08	91.63	128.45	114.87	119.72	108.88	79.64	110.37	98.86	91.49	131.29	72.45
95th	141.49	119.39	129.8	114.68	98.75	114.5	100.68	95.2	148.6	132.9	144.64	126.54	106.9	116.51	109.19	98.24	136.03	120.71	132.54	112.61	109.31	116.18	109.74	96.81	148.6	95.2
5th	122.65	111.68	111.69	104.85	65.48	107.47	88.91	88.12	122.04	106.12	108.97	98.74	66.4	101.46	86.59	84.2	122	110.6	107.06	104.38	64.2	105.18	85.53	85.99	122.65	64.2
2019																									0	0
mean	127.35	113.91	122.1	108.22	74.41	108.43	91.65	88.16	128.98	114.33	117.07	108.1	76.47	109.9	94.99	90.42									128.98	74.41
median	126.99	114.36	122.23	108.18	71.29	108.34	90.96	88.44	129.02	114.31	116.32	108.3	73.76	109.99	93.93	90.39									129.02	71.29
95th	132.7	116.73	126.27	111.22	106.03	111	106.37	91.26	144.68	127.97	128.86	123.46	104.61	123.97	109.4	100									144.68	91.26
5th	122.55	111.01	115.14	105.72	66.08	105.19	85.86	84.31	119.6	107.97	107.91	102.26	64.4	103.49	84.43	81.88									122.55	64.4
2020																									0	0
mean									126.73	113.29	113.79	106.98	77.4	108.34	95.03	89.76	127.69	112.66	113.93	106.43	73.63	107.69	94.3	87.74	127.69	73.63
median									126.44	113.09	113.28	106.92	73.35	107.97	94.02	89.55	127.52	112.37	113.32	106.16	70.54	107.13	93.78	87.62	127.52	70.54
95th									142.89	125.23	129.75	114.82	108.8	118.86	118.31	96.03	136.64	119.16	120.68	111.47	102.94	115.32	104.22	91.12	142.89	91.12
5th									117.55	104.38	106.96	97.37	63.8	103.45	87.25	81.58	117.7	107.17	107.94	101	65.23	102.14	88.26	81.75	117.7	63.8
2021																									0	0
mean	125.07	113.94	115.31	108.76	71	108.9	92.11	89.63	133.76	115.32	116.94	109.6	77.4	109.08	95.03	90.63	125.29	112.52	112.43	106.68	73.33	107.68	94.09	88.65	133.76	71
median	124.08	113.62	115.54	108.36	69.77	108.39	91.89	89.74	134.8	114.87	116.37	109.12	73.57	108.82	93.57	90.5	125.72	113.27	112.56	107.38	71.76	107.47	93.29	88.21	134.8	69.77
95th	136.46	129.76	127.65	126.25	83.68	122.86	99.63	98.6	142.5	128.9	129.76	124.66	107.31	124.18	115.03	100.47	128.61	115.06	114.94	109.44	80.11	111.53	100.16	93.47	142.5	80.11
5th	108.99	108.99	110.95	103.58	65.92	104.56	87.09	85.68	122.27	110.75	110.79	105.08	65.58	105.18	87.37	86.38	120.62	107.16	109.61	102.12	68.71	104.59	89.46	87.11	122.27	65.58
Area 19 - Haro Strait																									0	0
2018																									0	0
mean	125.37	115.01	117.02	108.78	72.58	110.18	94.83	91.28	125.99	115.9	117.7	109.03	76.94	111.25	94.83	91.18	127.6	118.43	119.75	108.9	72.24	118.82	96.18	91.55	127.6	72.24
median	125.21	115.32	116.3	108.86	69.89	109.9	94.57	91.2	124.63	115.53	116.63	108.79	73.36	110.5	94.17	91.27	129.19	117.53	118.5	108.55	71.41	118.91	95.94	91.84	129.19	69.89
95th	117.61	117.61	122.79	112.24	97.69	122.19	100.21	102.84	139.72	126.52	137.53	119.35	101.46	130.72	103.81	96.51	135.68	126.73	131.98	112.77	93.01	131.9	105.23	98.6	139.72	93.01
5th	111.14	111.14	112.66	104.44	67.4	105.31	89.54	86.78	116.2	104	91.26	89.41	65.07	102.75	85.38	78.81	119.93	112.53	110.3	104.36	65.85	107.48	89.63	86.34	119.93	65.07
2019																									0	0
mean																									0	0
median																									0	0
95th																									0	0
5th																									0	0
2020																									0	0
mean																									0	0
median																									0	0
95th																									0	0
5th																									0	0
2021																									0	0
mean																									0	0
median																									0	0
95th																									0	0
5th																									0	0

Table 3, continued.

	Pre-measures Controll								During measures								Post-measures control									
	Broadband	100-1000	67 Hz	125 Hz	50 kHz	Comm	Echo	Wind	Broadband	100-1000	67 Hz	125 Hz	50 kHz	Comm	Echo	Wind	Broadband	100-1000	67 Hz	125 Hz	50 kHz	Comm	Echo	Wind	Max	Min
Area 18 - Boundary Pass																									0	0
2018																									0	0
mean	131.1	119.42	122.99	113.5	87.71	114.38	102.92	96.33	133.84	120.79	127.88	114.48	90.16	114.13	103.22	96.26	133.27	119.22	126.08	112.87	87.46	113.62	102.35	95.48	133.84	87.46
median	131.35	119.68	123.17	113.7	86.49	113.98	102.3	96.17	133.25	120.1	125.74	114.05	88.56	114.19	102.8	96.51	134.96	119.96	127.13	113.71	85.01	113.73	102.4	95.65	134.96	85.01
95th	135.61	121.4	128.65	116.8	106.48	123.25	110.85	100.47	147.99	133.86	146.3	127.98	109.62	123.95	116.18	103.72	140.02	124.13	136.62	118.46	104.26	119	86.21	101.27	147.99	86.21
5th	124.89	115.52	116.08	109.08	78.52	109.95	96.4	91.54	101.49	96.62	87.42	88.02	65.82	94.31	85.9	75.5	99.74	95.24	85.73	85.83	66.07	97.32	108.66	83.91	124.89	65.82
2019																									0	0
mean	133.01	120.2	127.06	114.69	85.5	114.09	102.53	95.51	130.62	119.34	122.74	113.15	88.37	113.66	103.46	95.29									133.01	85.5
median	131.75	119.84	124.9	114.6	84.2	114.16	101.58	95.16	130.22	119.26	121.81	113.18	86.53	113.75	102.7	95.47									131.75	84.2
95th	144.23	126.07	141.94	120.27	103.47	117.84	114.04	99.46	144.87	126.86	143.8	121.42	108.75	119.56	117.83	102.08									144.87	99.46
5th	127.99	117.03	121.32	111.4	76.94	111.28	98.4	92.32	122.74	102.13	112.04	93.9	64.87	104.05	87.51	85.14									127.99	64.87
2020																									0	0
mean									131.28	119.22	120.78	112.31	119.22	113.52	100.99	94.45	130.5	118.93	121.5	112.85	83.62	112.75	101.14	94.65	131.28	83.62
median									116.63	118.67	120.98	112.49	118.67	113.03	100.52	94.52	130.21	119	121.68	112.16	80.78	113.04	101.72	95.51	130.21	80.78
95th									145.01	132.11	132.21	120.95	132.11	126.81	114.96	99.92	138.23	123.31	124.78	115.74	102.52	118.74	107.18	98.58	145.01	98.58
5th									124.44	110.6	105.9	103.9	110.6	101.46	93.45	81.76	123.93	112.69	116.91	107.66	70.34	106.16	92.77	87.11	124.44	70.34
2021																									0	0
mean	129.16	119.11	121.97	113.26	83.53	113.39	101.11	95.29	132.66	117.5	120.03	111.33	83.67	112.97	100.19	94.83	130.02	118.1	120.82	112.52	81.82	112.78	102.72	94.72	132.66	81.82
median	129.16	119.17	122.61	113.18	80.55	113.28	101.04	95.25	132.34	117.37	119.99	111.4	81.73	113.11	100.3	94.82	129.34	118.13	121.37	112.32	81.61	112.9	101.76	95.18	132.34	80.55
95th	132.33	122.36	126.12	116.4	97.57	116.25	108.8	99.15	142.81	125.65	130.46	118.27	105.47	127.43	114.07	101.24	135.9	121.41	126.89	116.01	91.3	116.92	114.97	97.58	142.81	91.3
5th	122.87	115.6	113.57	109.46	75.27	110.48	97.08	92.2	122.36	111.76	110.86	105.05	73.23	106.68	92.34	87.93	126.28	113.22	115.18	106.73	77.22	109.41	97.61	90.55	126.28	73.23
Swanson Channel																									0	0
2018																									0	0
mean																									0	0
median																									0	0
95th																									0	0
5th																									0	0
2019																									0	0
mean									112.73	107.79	102.75	99.72	81.49	106.14	95.96	88.52									112.73	81.49
median									112.52	107.36	102.93	99.79	76.41	105.68	94.49	87.37									112.52	76.41
95th									129.95	125.05	113.37	116.3	112.18	124.77	112.64	102.5									129.95	102.5
5th									95.11	89.33	83.1	80.35	64.55	87.67	83.55	70.07									95.11	64.55
2020																									0	0
mean	113.99	107.52	104.22	100.67	75.38	105.41	92.4	86.91	114.29	108.4	102.91	100.84	82.09	106.18	96.96	89.34	111.65	106.2	103.02	99.05	71.16	103.92	91.77	85.14	114.29	71.16
median	114.08	107.91	104.46	100.26	71.14	104.91	91.33	86.29	114.1	108.21	102.83	100.44	78.74	105.93	96.2	89.46	111.46	105.84	103.15	99	70.23	103.6	91.55	85.13	114.1	70.23
95th	117.01	110.84	109.56	105.25	107.5	109.74	108.01	92.81	132.61	128.22	121.38	122.18	107.98	119.92	109.04	98.07	115.9	112.05	106.79	102.43	97.27	108.84	100.06	89.35	132.61	89.35
5th	110.84	105.42	100.84	98.15	65.92	101.4	87.12	83.28	106.33	93.98	94.18	87.88	64.02	93.48	83.77	79	108.73	103.34	99.04	95.4	65.05	101.37	84.97	81.6	110.84	64.02
2021																									0	0
mean	113.26	107.11	104.47	99.74	78.24	105.72	94.3	87.72	117.51	108.5	102.76	100.31	86.82	107.47	99.22	90.48	112.86	107.46	104.04	101.06	73.04	104.47	92.93	85.88	117.51	73.04
median	113.27	107.03	104.76	99.59	75.66	105.3	93.72	87.07	116.17	108.2	102.64	100.11	85.63	107.3	99.42	90.46	112.88	107.69	104.6	101.21	71.86	104.84	93.03	86.33	116.17	71.86
95th	117.19	112.33	109.57	103.57	102.83	111.67	103.96	94.27	135.15	130.64	124.44	121.29	112.99	128.88	113.62	100.96	116.74	110.47	110.35	104.52	92.77	107.28	98.33	88.39	135.15	88.39
5th	107.51	103.95	97.69	95.81	67.7	101.61	87.86	83.15	108.73	102.87	95.22	93.92	67.79	101.87	87.96	82.87	108.04	103.15	97.55	96.22	67.31	100.3	87.83	82.11	108.73	67.31
Saturna Island																									0	0
2018																									0	0
mean																									0	0
median																									0	0
95th																									0	0
5th																									0	0
2019																									0	0
mean																									0	0
median																									0	0
95th																									0	0
5th																									0	0
2020																									0	0
mean									120.46	112.18	109.7	105.29	74.85	108.84	95.06	90.62	125.75	115.47	111.23	104.25	75.64	113.89	95.23	91.15	125.75	74.85
median									120.16	112.32	110.01	105.83	72.62	108.95	94.58	90.77	125.75	115.47	111.23	104.25	75.64	113.89	95.23	91.15	125.75	72.62
95th									133.91	119.26	117	111.27	109.76	117.46	110.29	98.88	125.75	115.47	111.23	104.25	75.64	113.89	95.23	91.15	133.91	75.64
5th									97.61	82.24	75.31	70.75	64.31	84.64	83.78	69.27	125.75	115.47	111.23	104.25	75.64	113.89	95.23	91.15	125.75	64.31
2021																									0	0
mean	121.09	112.96	111.19	107.19	70.98	108.9	92.79	90.08	125.72	111.69	109.73	105.52	72.43	108.21	94.45	90.02	124.11	112.54	111.17	106.23	71.12	109.64	94.02	90.93	125.72	70.98
median	120.85	113.21	110.64	107.43	69.71	108.73	92.86	89.56	125.1	111.64	109.77	105.34	70.94	108.49	94.12	90.19	122.57	113.05	111.15	106.86	71.01	109.68	94.31	90.96	125.1	69.71
95th	127.67	116.69	115.44	112.71	86.02	112.13	95.71	94.15	138.59	126.24	123.61	120.79	105.43	126.81	108.35	98.29	134.12	116.34	115.66	111.17	74.33	114.03	96.61	95.63	138.59	74.33
5th	117.48	110.01	106.37	103.05	65.77	106.51	89.25	87.62	116.5	106.37	101.88	98.49	66.13	101.73	88.32	84.76	117.04	106.68	105.72	99.93	67.13	105.83	90.15	87.92	117.48	65.77
max	144.23	133.67	141.94	126.25	118.63	132.73	119.61	108.85	151.8	145.49	146.3	135.58	132.11	130.72	118.31	104.59	142.12	129.16	136.62	120.07	110.45	131.9	114.97	103.47	151.8	104.47
min	107.51	99.86	97.52	92.87	63.41	98.34	83.9	76.89	95.11	82.24	75.31	70.75	63.24	84.64	83.06	68.67	99.74	95.24	85.73	85.83	63.19	97.32	82.32	75.09	0	0

- greatest SPL between pre-, during, and post-closure periods

- greatest SPL in band for pre-, during, or post-closure period between years for sites

- maximun and minimum values between all years and all sites

Appendix, Table A4a: Median SPL from the six mooring sites comparing sound levels before (pre), during and after (post) management measures. SPL frequency ranges were broadband (0.01-100 kHz), SRKW communication (0.5-15 kHz), echolocation (15-100 kHz) the vessel metrics 0.1-100 kHz, the 125 and 63 Hz 1/3 octave band, and 50 kHz range (49.5-50.5 kHz) and wind metric (7.5-8.5 kHz)

kHz	0.01-100	0.5-15	15-100	0.1-1	125	63	49.5-50.5	7.5-8.5
SRKW Conservation Measures								
Swiftsure Bank								
2018								
Pre	121.12	103.24	88.79	111.01	103.64	109.46	66.19	83.55
During	121.55	106.31	91.32	112.64	105.50	108.99	69.18	86.78
Post	124.04	105.51	91.94	114.17	106.42	114.10	70.85	85.60
2019								
Pre	117.97	107.80	92.30	112.94	105.19	106.84	72.81	88.72
During	118.21	106.14	91.88	112.88	105.74	107.94	69.79	86.61
Post	119.24	108.70	93.10	113.64	106.97	109.55	70.70	87.42
2020								
Pre	118.46	104.04	90.03	111.62	105.01	109.05	69.84	81.31
During	117.70	104.73	91.51	111.39	104.10	106.38	70.19	84.94
Post	124.18	109.72	94.79	115.31	106.83	114.91	72.74	88.36
2021								
Pre	118.55	104.05	91.32	110.47	103.60	108.12	69.65	85.39
During	122.18	102.91	90.10	111.02	103.99	107.61	69.01	83.89
Post								
Port Renfrew								
2018								
Pre	114.78	102.10	84.66	107.63	100.39	102.67	63.43	80.87
During	115.36	103.35	85.32	108.50	101.02	103.16	64.48	82.07
Post	117.07	101.66	85.65	107.75	100.47	104.66	65.36	80.38
Jordan River								
2018								
Pre	121.56	103.44	86.76	109.93	102.72	109.65	65.40	82.08
During	120.55	102.53	86.12	109.14	101.64	108.92	65.47	81.10
Post	119.75	101.20	85.49	108.34	100.55	108.24	64.47	81.27
Sooke								
2018								
Pre	122.55	108.06	91.02	111.84	105.32	111.71	67.80	88.14
During	123.97	107.71	90.65	112.50	105.81	113.22	68.53	88.67
Post	122.42	107.00	89.56	111.47	105.36	112.66	66.84	87.65
Boundary Pass								
2018								
Pre	125.07	109.67	95.41	114.98	107.92	114.40	73.17	91.14
During	126.24	110.32	96.23	115.64	108.64	117.78	74.67	92.33
Post	128.27	108.30	93.81	114.86	107.19	118.80	71.54	89.10
2019								
Pre	125.19	112.07	99.63	116.28	109.04	116.37	79.59	95.18
During	121.63	107.94	94.39	112.99	106.22	111.07	72.67	88.59
Post	126.74	108.64	93.57	115.85	109.85	116.14	71.69	89.66
2020								
Pre	124.72	106.30	92.97	111.29	104.63	114.19	71.41	88.59

Table 4a, cont.

During	123.62	107.19	93.87	112.59	105.69	112.83	72.44	88.07
Post	125.34	107.88	95.76	114.06	107.39	114.92	73.64	89.21
2021 Pre	123.68	107.22	92.54	112.71	105.56	113.06	71.16	89.22
During	125.55	107.73	93.04	111.93	104.71	111.76	70.97	89.33
Post								
Swanson Channel								
2019								
Pre								
During	109.19	101.94	88.70	104.79	96.80	97.06	68.10	84.16
Post	109.14	101.70	86.02	102.84	94.66	96.90	65.73	82.99
2020								
Pre	110.84	100.92	88.32	103.86	95.70	97.12	66.51	83.40
During	110.24	100.65	88.77	104.88	97.55	97.25	67.57	83.33
Post	110.45	101.77	89.43	103.92	96.92	100.19	68.69	84.30
2021								
Pre	110.81	101.63	88.52	104.59	95.95	98.46	67.56	83.45
During	111.35	102.48	90.62	104.87	97.29	97.27	69.73	84.98
Post								
Saturna Island								
2020								
Pre	116.16	105.18	91.42	105.78	97.95	104.31	68.95	87.11
During	114.76	104.26	90.06	106.02	97.72	102.48	68.43	85.63
Post	118.05	105.46	92.11	107.93	100.46	104.88	69.88	86.88
2021								
Pre	118.44	105.75	90.80	107.68	99.88	103.90	67.83	87.50
During	118.41	103.51	90.52	105.28	97.41	101.26	66.43	85.19
Post								
Interim Sanctuary Zones								
Swiftsure Bank								
2019								
Pre	120.73	106.37	89.71	112.29	105.25	108.35	67.07	85.81
During	118.06	106.50	91.79	112.84	105.45	107.77	70.44	87.05
Post	119.24	108.70	93.10	113.64	106.97	109.55	70.70	87.42
2020								
Pre								
During	118.73	106.03	92.40	112.24	104.88	108.24	70.81	85.80
Post	123.87	110.63	95.78	114.75	106.62	113.42	73.28	90.02
2021								
Pre	118.55	104.03	91.31	110.46	103.58	108.11	69.63	85.34
During	122.18	102.91	90.10	111.02	103.99	107.61	69.01	83.89
Post								
Swanson Channel								
2019								
Pre								
During								
Post	109.19	101.94	88.70	104.79	96.80	97.06	68.10	84.16
2020								
Pre	109.14	101.70	86.02	102.84	94.66	96.90	65.73	82.99

Table 4a, cont.

During	109.81	100.27	86.72	104.01	96.04	98.18	65.27	82.10
Post	110.34	100.95	88.84	104.55	97.17	97.61	67.69	83.66
2021								
Pre	110.13	102.00	88.75	103.85	96.36	99.10	68.25	83.74
During	110.82	101.64	88.51	104.59	95.97	98.48	67.56	83.46
Post	111.35	102.48	90.62	104.87	97.29	97.27	69.73	84.98
Saturna Island								
2020								
Pre	116.52	108.30	92.42	109.25	99.09	104.83	69.12	88.95
During	115.48	104.56	90.64	106.19	98.04	103.09	68.72	86.06
Post	118.73	104.40	91.95	106.74	98.32	103.69	69.03	86.49
2021								
Pre	118.44	105.73	90.80	107.67	99.85	103.88	67.83	87.49
During	118.41	103.51	90.52	105.28	97.41	101.26	66.43	85.19
Post								
Steelhead Management Measures								
Swiftsure Bank								
2018								
Pre								
During	122.64	106.96	92.53	113.20	105.52	111.35	70.50	87.07
Post	121.28	110.04	94.58	114.30	105.70	111.29	72.62	88.94
2019								
Pre	120.15	106.98	93.18	112.31	104.92	109.05	71.22	87.08
During	118.34	106.21	92.45	112.98	105.87	108.60	69.80	86.82
Post	119.24	108.68	93.10	113.64	106.97	109.52	70.68	87.40
2020								
Pre	117.08	103.77	90.50	110.58	103.70	105.85	69.56	83.45
During	117.67	104.90	91.66	111.66	104.44	107.43	69.99	84.83
Post	124.19	109.73	94.79	115.32	106.84	114.94	72.74	88.34
2021								
Pre	121.77	101.43	88.61	110.14	102.89	106.24	67.26	82.14
During	125.92	105.20	92.44	112.95	106.35	110.51	69.95	86.16
Post								
Port Renfrew								
2018								
Pre								
During	116.07	102.16	87.38	107.49	100.18	104.75	66.14	81.49
Post	117.78	102.57	88.79	107.66	100.37	108.04	66.75	82.55
2019								
Pre	115.26	102.56	87.18	107.73	100.28	102.76	66.29	82.02
During	112.88	101.37	87.42	107.04	99.93	102.15	66.21	81.18
Post*	114.16	102.60	86.85	108.66	100.96	103.34	65.74	81.04
2020								
Pre	115.79	103.78	86.59	108.38	101.01	104.38	66.15	82.71
During	115.10	101.38	86.60	107.39	100.38	102.86	66.25	80.85
Post	117.40	102.55	88.51	107.94	100.23	103.44	66.79	82.67
2021								
Pre	114.52	103.42	85.04	108.19	100.44	100.20	65.50	82.92
During	115.21	101.82	86.98	108.12	101.23	101.46	66.77	82.30

Table 4a, cont.

Post								
Jordan River								
2018 Pre								
During	119.94	102.22	87.43	108.42	101.01	108.53	66.55	81.53
Post	119.64	102.28	89.06	107.51	100.58	106.96	68.43	82.44
2019								
Pre	116.58	101.82	86.60	107.30	100.45	105.24	65.74	80.63
During	114.31	101.26	85.86	106.33	99.78	104.39	66.22	79.43
Post	116.25	103.41	86.21	108.26	101.21	105.81	66.39	80.83
2020								
Pre	116.13	100.63	84.62	106.83	99.99	103.86	64.51	78.71
During	115.55	100.57	85.61	106.65	100.25	105.01	65.83	79.48
Post	116.41	101.88	86.55	107.33	100.62	105.16	65.53	81.46
2021								
Pre	118.87	100.83	84.93	106.99	100.19	105.99	64.03	79.44
During	121.23	99.87	85.05	107.48	100.89	106.84	64.15	79.53
Post								
Sooke								
2018								
Pre								
During	122.73	106.89	90.48	111.76	105.04	112.70	68.22	87.34
Post	123.94	104.94	89.82	111.38	103.83	114.21	68.09	85.32
2019								
Pre	122.19	106.09	90.49	110.55	103.99	111.10	68.54	87.16
During	122.39	107.14	89.42	111.20	104.58	110.52	68.30	87.15
Post	123.42	107.09	91.11	111.62	104.84	112.12	68.37	87.30
2020								
Pre	120.43	105.77	91.79	110.26	103.83	109.99	70.50	87.53
During	123.30	105.57	91.11	110.68	104.04	111.57	68.44	88.15
Post	120.50	104.88	89.04	108.78	102.30	110.11	68.29	85.99
2021								
Pre	126.55	106.14	89.56	111.44	105.19	111.66	67.16	88.26
During	129.39	107.27	91.64	111.55	105.18	111.54	68.57	89.56
Post								
Haro Strait								
2018 Pre								
During	121.23	107.17	90.96	112.04	104.45	111.32	67.82	87.54
Post	121.45	106.04	90.61	110.80	103.27	110.32	68.02	86.08
2019								
Pre	118.98	105.29	90.28	110.24	103.33	108.11	67.53	86.20
During	116.23	104.63	89.33	109.37	101.75	104.38	66.66	85.20
Post	118.67	105.52	90.45	110.80	103.67	108.67	67.15	86.53
2020								
Pre	118.15	106.00	89.96	110.40	103.09	108.37	68.15	86.96
During	119.13	105.46	90.86	110.58	103.63	108.95	68.83	86.04
Post	119.73	105.87	91.32	110.82	104.24	108.88	67.43	86.81
2021								
Pre	120.31	105.00	89.12	110.76	103.89	107.24	64.62	86.10
During	123.19	104.99	89.76	110.52	103.96	109.02	64.96	85.46
Post								

Table 4a, cont.
Chinook Management Measures

Swiftsure Bank								
2018								
Pre	121.12	103.24	88.79	111.01	103.64	109.46	66.19	83.55
During	122.87	107.53	93.03	113.61	105.80	111.66	71.22	87.59
Post								
2019								
Pre								
During	119.04	107.58	92.76	112.86	105.42	108.66	70.68	87.45
Post								
2020								
Pre								
During	119.53	107.79	93.59	112.82	105.16	109.35	71.56	87.50
Post	124.76	109.86	95.06	112.94	105.70	114.55	72.93	89.45
2021								
Pre	118.58	107.47	93.58	110.29	104.30	109.36	71.52	89.07
During	121.21	103.45	90.31	110.70	103.74	107.48	69.15	84.28
Post								
Port Renfrew								
2018								
Pre	114.78	102.10	84.66	107.63	100.39	102.67	63.43	80.87
During	116.84	102.84	87.27	108.15	100.65	104.76	66.06	82.36
Post								
2019								
Pre								
During	115.06	102.45	86.32	107.92	100.45	103.51	65.54	81.49
Post*								
2020								
Pre								
During	116.46	102.74	87.80	107.83	100.45	103.55	66.60	82.35
Post	119.19	102.80	88.78	107.46	100.05	104.03	66.94	83.19
2021								
Pre	114.01	102.18	88.06	107.13	99.91	103.37	67.16	82.25
During	114.36	102.62	85.27	107.88	100.34	101.22	65.58	81.38
Post								
Jordan River								
2018								
Pre	121.56	103.44	86.76	109.93	102.72	109.65	65.40	82.08
During	120.20	102.34	86.83	108.54	101.04	108.44	65.92	81.88
Post								
2019								
Pre								
During	117.11	102.43	86.30	107.84	100.72	106.74	65.83	80.80
Post								
2020								
Pre								
During	115.79	101.62	86.59	107.14	100.39	104.69	66.05	80.53
Post	116.95	102.23	87.54	107.71	100.85	105.56	66.36	81.77

Table 4a, cont.

2021									
	Pre	118.08	102.16	86.02	107.76	101.03	107.17	64.57	80.22
	During	118.69	101.94	86.15	107.48	100.58	105.88	64.66	80.54
	Post								
Sooke									
2018									
	Pre	122.55	108.06	91.02	111.84	105.32	111.71	67.80	88.14
	During	123.39	107.01	90.49	112.15	105.56	113.22	68.25	87.71
	Post								
2019									
	Pre								
	During	122.28	106.80	89.54	111.29	104.55	113.09	67.37	86.54
	Post								
2020	Pre								
	During	120.87	105.68	90.99	109.83	103.15	110.43	69.40	86.78
	Post	120.34	104.68	91.53	107.82	100.88	108.86	70.36	85.74
2021	Pre	121.90	105.96	88.95	110.05	104.19	112.31	67.41	87.33
	During	124.73	106.76	90.35	111.75	105.40	112.16	67.96	88.13
	Post								
Haro Strait									
2018									
	Pre	120.88	107.32	90.26	112.34	104.13	109.60	67.04	88.00
	During	120.91	107.41	90.69	111.91	104.25	110.64	67.20	87.69
	Post								

Appendix, Table A4b: Median SPL from the six mooring sites comparing sound levels for Chinook measures of differing levels of catch number and fish size were also considered. Periods before (pre), no retention (None), and size restrictions (2, size) were considered for frequency ranges were broadband (0.01-100 kHz), SRKW communication (0.5-15 kHz), echolocation (15-100 kHz) the vessel metrics 0.1-100 kHz, the 125 and 63 Hz 1/3 octave band, and 50 kHz range (49.5-50.5 kHz) and wind metric (7.5-8.5 kHz)

kHz	0.01-100	0.5-15	15-100	0.1-1	125	63	49.5-50.5	7.5-8.5
Swiftsure Bank								
2018								
Pre	121.11	103.23	88.79	110.97	103.61	109.44	66.19	83.52
None	122.77	106.78	91.78	112.51	105.68	109.01	69.22	87.59
1 fish								
2 fish								
2, size								
Post	119.13	106.65	90.20	112.22	104.72	107.98	68.99	86.44
2019								
Pre	119.21	107.73	92.56	111.80	104.66	108.54	69.36	87.52
None	118.78	106.53	90.73	112.34	104.98	108.00	69.58	86.45
1 fish								
2 fish	118.69	107.22	92.87	113.11	105.90	108.69	70.64	87.30
2,size	118.24	108.05	92.42	113.10	105.30	106.41	72.79	88.42
Post	120.50	110.38	94.66	114.81	106.42	111.29	71.95	90.29
2020								
Pre	118.55	106.67	92.88	111.14	104.37	109.12	71.04	87.24
None	117.99	104.32	91.10	111.22	104.64	107.01	69.98	84.38
1 fish								
2 fish	119.81	107.64	93.75	113.03	105.28	109.59	71.91	87.11
2,size	118.89	104.30	91.64	111.06	104.17	105.15	70.64	85.18
Post	124.76	109.86	95.06	112.94	105.70	114.55	72.93	89.45
2021								
Pre	118.47	107.47	93.57	110.23	104.01	109.36	71.52	89.04
None	119.27	103.61	90.54	110.15	103.21	107.04	69.53	84.40
1 fish								
2 fish	123.73	103.28	90.25	111.50	104.34	108.30	68.26	84.15
2, size.	121.11	102.24	89.77	110.70	103.72	106.42	69.58	83.84
Post								
Port Renfrew								
2018								
Pre	114.78	102.12	84.66	107.63	100.41	102.66	63.43	80.87
None								
1 fish								
2 fish	115.04	104.04	85.34	109.09	101.81	103.60	63.79	82.93
2, size								
Post	114.22	103.31	84.52	108.33	100.65	102.35	64.35	81.69
2019								
Pre	117.47	101.97	86.58	106.89	99.49	104.65	66.04	80.42
None	115.56	103.08	84.34	108.60	101.31	103.02	64.70	80.69
1 fish	113.79	104.29	84.32	108.54	100.92	102.00	64.40	82.97
2 fish	113.60	101.92	87.42	107.53	100.11	102.61	65.99	81.42
2, size								

Table 4b, cont.

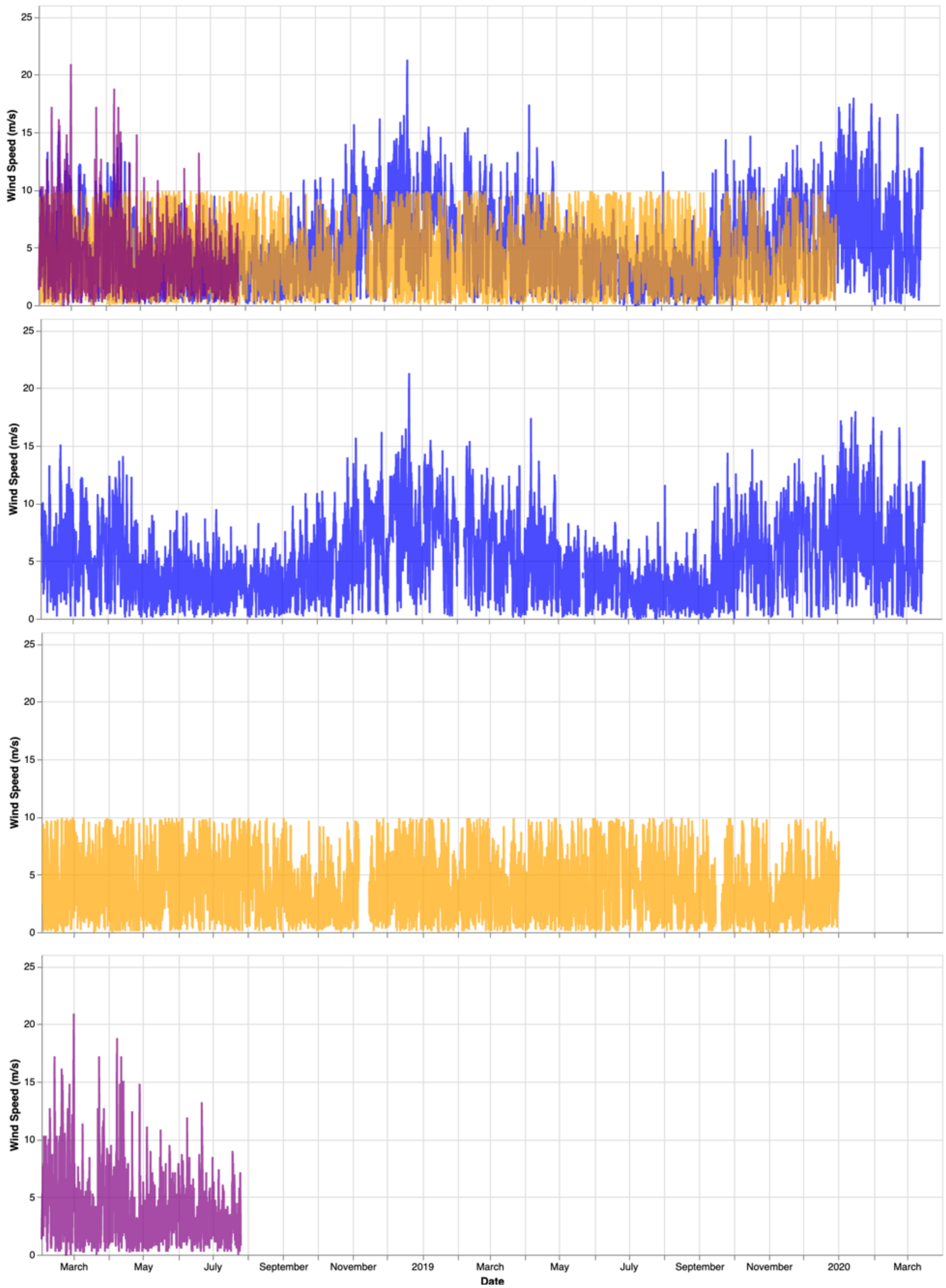
Post	116.45	103.88	91.34	108.33	100.36	103.07	68.28	84.71
2020								
Pre	115.88	102.25	87.52	107.26	99.75	102.58	65.82	81.78
None	118.26	103.16	86.32	108.06	101.53	106.34	66.27	80.57
1 fish								
2 fish	116.54	102.63	87.64	107.79	100.39	103.53	66.57	82.50
2, size	117.78	103.37	86.19	108.58	101.50	105.68	66.14	80.84
Post	119.19	102.80	88.78	107.46	100.05	104.03	66.94	83.19
2021								
Pre	114.01	102.18	88.05	107.13	99.91	103.37	67.16	82.25
None	114.16	102.43	85.03	107.52	99.97	101.87	65.39	80.70
1 fish								
2 fish	114.70	102.62	85.74	108.18	100.75	100.70	65.85	82.46
2,size	113.70	103.94	84.78	108.33	100.30	99.87	65.65	82.10
Post								
Jordan River								
2018								
Pre	121.55	103.44	86.76	109.94	102.74	109.70	65.40	82.11
None								
1 fish								
2 fish	121.73	103.62	85.62	110.08	102.68	110.63	64.99	81.11
2, size	120.32	103.41	87.52	109.21	101.83	109.76	67.06	82.22
Post	120.65	101.69	85.93	108.26	101.04	108.49	65.23	80.89
2019								
Pre	119.63	102.73	85.53	108.17	100.43	108.11	64.63	80.58
None	117.65	103.19	85.58	108.91	101.58	108.25	64.68	81.06
1 fish	115.09	102.00	85.18	107.53	100.88	106.12	65.15	79.98
2 fish	115.26	101.80	86.34	107.11	100.20	105.02	66.51	80.09
2, size								
Post	116.23	102.53	91.74	107.36	100.16	105.22	70.31	83.38
2020								
Pre	116.82	102.21	87.15	107.90	100.75	106.18	67.09	80.85
None	114.39	102.14	85.53	107.02	100.24	103.52	65.11	79.78
1 fish								
2 fish	115.98	101.11	86.23	106.80	100.27	104.67	65.70	80.38
2, size	115.14	101.44	86.00	108.46	101.94	104.25	65.54	80.32
Post	116.95	102.23	87.54	107.71	100.85	105.56	66.36	81.77
2021								
Pre	118.08	102.16	86.01	107.76	101.03	107.17	64.56	80.22
None	118.13	102.92	86.57	107.80	100.74	105.55	64.83	81.02
1 fish								
2 fish	119.52	100.47	85.36	107.23	100.50	106.41	64.26	79.65
2, size	119.22	101.47	86.47	107.11	100.39	105.97	65.06	80.45
Post								
Sooke								
2018								
Pre	122.58	108.09	91.02	111.88	105.40	111.72	67.80	88.15
None								
1 fish								
2 fish	123.64	108.29	90.96	113.19	105.88	113.37	68.04	88.55

Table 4b, cont.

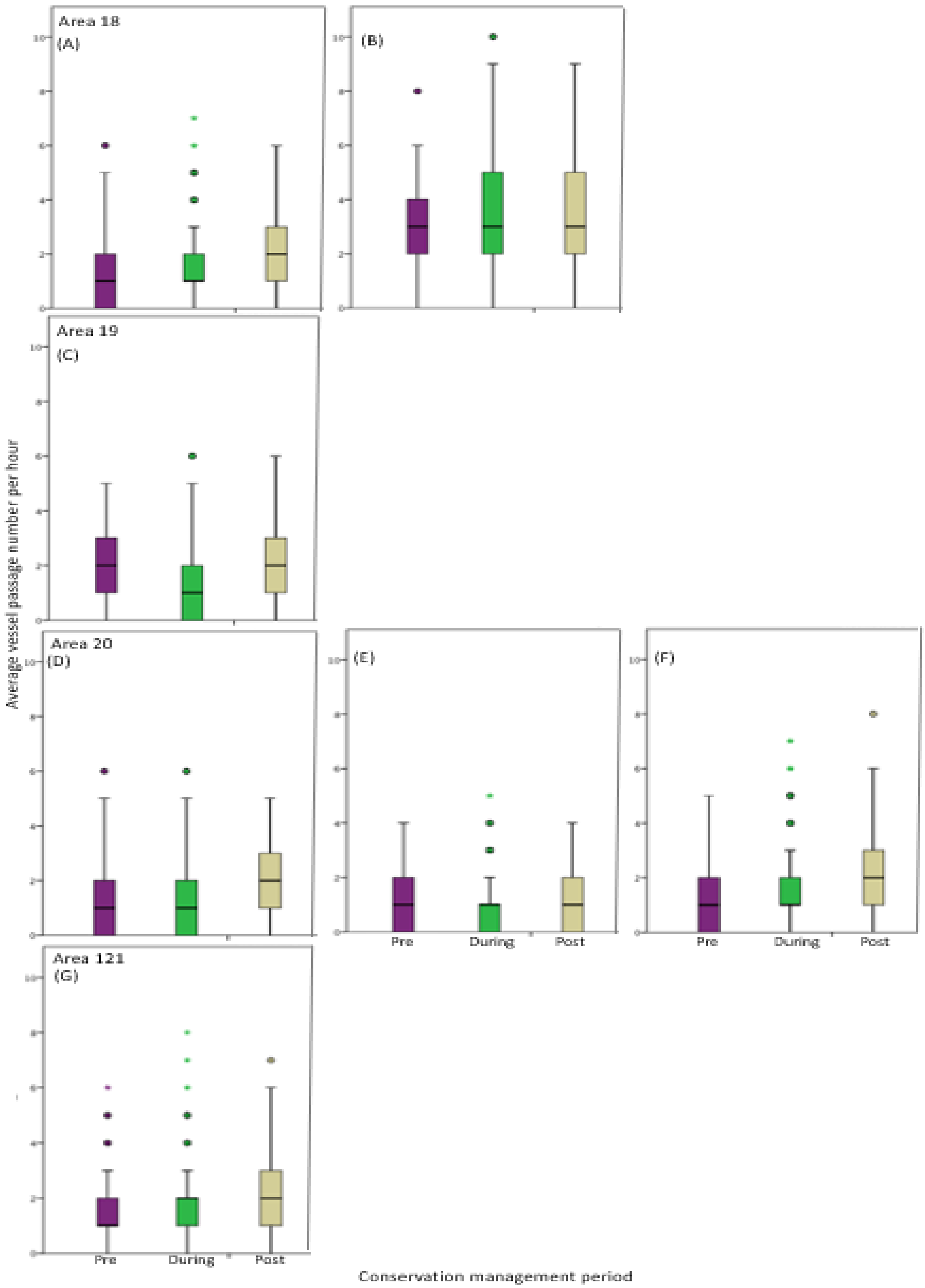
2, size	125.65	107.38	90.71	112.97	106.31	113.83	69.40	88.20
Post	124.05	107.01	90.14	111.84	105.51	112.67	68.17	88.50
2019								
Pre	122.71	106.22	88.18	111.05	104.31	115.24	67.25	85.48
None	121.79	108.02	90.13	111.85	105.28	113.53	67.10	87.62
1 fish	120.61	108.28	90.24	111.45	104.77	110.72	67.69	89.01
2 fish	122.09	106.29	88.92	110.61	103.78	110.65	66.82	85.79
2, size								
Post	120.99	105.71	91.86	109.69	102.39	110.37	68.17	85.80
2020								
Pre								
None	119.86	106.18	90.06	109.82	102.99	110.35	69.20	86.62
1 fish								
2 fish	121.31	105.52	91.18	110.06	103.40	110.51	69.73	87.13
2, size	120.29	105.18	91.65	109.40	102.81	110.48	71.05	87.20
Post	120.34	104.68	91.53	107.82	100.88	108.86	70.36	85.74
2021								
Pre	121.89	105.97	88.95	110.05	104.20	112.31	67.41	87.32
None	122.88	106.72	89.91	111.54	105.27	112.42	67.75	87.71
1 fish								
2 fish	127.65	106.57	90.62	111.55	105.24	111.64	67.97	88.68
2, size	126.71	107.84	91.42	114.85	107.08	113.38	68.68	88.27
Post								
Boundary Pass								
2018								
Pre	125.01	108.10	94.26	114.20	107.40	115.40	72.22	90.18
None								
1 fish	126.24	110.32	96.23	115.64	108.64	117.78	74.67	92.33
2 fish	126.13	108.28	95.70	113.60	105.84	116.93	75.03	89.43
2, size								
Post								
2019								
Pre								
None	126.11	110.53	95.58	115.47	108.46	117.74	73.53	91.59
1 fish	119.37	109.69	95.90	112.63	103.96	109.44	73.89	90.60
2 fish	123.82	107.41	95.39	112.25	105.13	114.27	74.94	88.02
2, size								
Post	122.71	106.23	93.09	111.85	106.44	113.10	70.38	88.20
2020								
Pre								
None	124.66	106.70	93.00	111.55	104.91	114.06	71.30	88.75
1 fish								
2 fish	124.42	107.55	94.51	113.25	106.26	113.74	72.82	88.52
2, size	122.66	106.73	93.24	110.88	104.21	111.63	72.09	87.92
Post	123.91	107.73	96.40	111.49	105.51	113.31	73.82	88.95
2021								
Pre	124.16	106.93	92.80	112.48	105.92	111.85	71.47	88.36
None	124.81	107.75	93.00	112.29	105.27	112.61	71.02	89.59
1 fish								
2 fish	125.21	107.69	93.28	111.68	104.45	110.81	70.72	89.25

Table 4b, cont.

2, size	126.86	106.99	92.33	111.65	104.63	112.67	71.13	88.61
Post								
Swanson Channel								
2019								
Pre								
None								
1 fish	111.91	105.80	94.19	108.10	99.28	98.86	74.30	87.93
2 fish	108.69	101.97	89.82	103.15	94.73	95.97	70.20	83.54
2, size								
Post	107.81	102.00	88.94	102.71	94.34	96.54	67.91	83.23
2020								
Pre	111.08	102.89	86.68	104.50	96.18	98.73	65.97	83.58
None	110.20	100.50	88.00	103.92	95.63	96.83	66.22	82.80
1 fish								
2 fish	110.32	101.37	88.99	104.67	97.58	98.48	68.11	83.82
2, size	109.64	100.47	86.79	104.08	95.58	95.53	66.16	82.38
Post	109.56	102.01	89.00	103.74	96.37	98.10	68.23	82.86
2021								
Pre	110.08	102.75	88.20	104.16	96.17	97.75	67.89	84.07
None	110.99	102.14	88.91	104.49	96.15	98.29	68.04	83.96
1 fish								
2 fish	111.17	102.40	90.99	105.02	97.81	96.68	70.19	85.01
2, size	112.72	102.32	89.80	104.46	96.01	97.50	69.83	83.87
Post								
Saturna Island								
2020								
Pre								
None	116.10	105.75	91.34	106.34	97.86	103.80	68.86	87.33
1 fish								
2 fish	115.79	104.55	90.89	106.70	98.44	103.17	68.78	86.10
2, size	116.66	103.55	89.77	105.55	96.97	103.22	68.43	85.39
Post	118.49	104.91	92.28	107.19	99.48	104.43	69.90	86.80
2021								
Pre	117.88	104.97	90.25	107.36	99.79	103.73	67.23	86.06
None	118.23	104.53	90.32	106.51	98.85	102.90	66.94	86.06
1 fish								
2 fish	117.96	103.26	90.51	105.15	97.27	100.61	66.34	84.94
2, size	120.68	103.50	89.63	105.62	97.60	102.40	66.17	84.39
Post								



Appendix, Figure A1 – Recorded wind speed data for Cape Flattery (blue), New Dungeness (orange) and East Point lighthouse on Saturna Island. Top panel shows an overlay of the data for comparison, and then in separate panels below. Data from Saturna Island was particularly lacking and so New Dungeness was applied in the analysis.



Appendix, Figure A2 – The changes in vessel presence and passage rate per hour for pre- during and post-closure periods for each management area at (A) Boundary Pass (B) Swanson Channel (C) Haro Strait (D) Port Renfrew (E) Jordan River (F) Sooke and (G) Swiftsure Bank up to a 10 km distance from the mooring.