Assessing Vessel Related Threats on Whales in Boundary Pass

by

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Abstract

Globally, vessel noise and physical disturbance have been identified as threats to whales. This thesis describes the results of land-based surveys of whales and vessel traffic between June and October 2020 in the busy waters of Boundary Pass, British Columbia. Whale distribution varied per species across the five months monitored, and varied interannually between 2019 and 2020. Whale travel overlapped with the shipping lanes in 74% of sightings, and were observed within 1000 m of vessels in 65% of sightings. Whales were observed within the Interim Sanctuary Zone in 44% of sightings suggesting whales used the zone. However, vessel compliance in the zone was low and the zone's suitability as whale habitat could be improved through better boundary enforcement. As whale distribution is changing in the Salish Sea and vessel numbers are on the rise, it is critical to manage vessel noise and traffic proximity to whales to ensure disturbance and strike risks are mitigated.

Keywords: Boundary Pass; humpback and killer whales; Vessel noise and disturbance; Salish Sea; Interim Sanctuary Zone efficacy.

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List of Acronyms

AIS	Automatic Identification System
BCCSN	British Columbia Cetacean Sighting Network
BCIT	British Columbia Institute of Technology
DFO	Department of Fisheries and Oceans
ECHO	Enhancing Cetacean Habitat and Observation
ISZ	Interim Sanctuary Zone
LBCO	Land based cetacean observation
PSD	Power spectral density
SFU	Simon Fraser University
SRKW	Southern Resident Killer Whale
SSN	Saturna Sighting Network
TOL	Third octave level

Introduction

In British Columbia's (BC) Salish Sea, Boundary Pass is an important transit route and foraging area for cetaceans (includes whales, dolphins and porpoises; hereafter referred to as whales). Connecting the Strait of Georgia to the Pacific Ocean, this area forms part of an international shipping lane and is a popular route and destination for ecotourism and small recreational vessels. Vessel noise and physical disturbance from vessels have been identified as a key threat to whales (Fleming & Jackson 2011; Harwood et al. 2016; Di Clemente et al. 2018; Fisheries and Oceans Canada 2018). Vessel disturbance can increase whale transit time (Williams et al. 2002; Sprogis et al. 2020) and causes them to adopt energy intensive strategies to avoid vessels (Williams et al. 2009; Currie et al. 2021). Noise pollution causes disruptions to whale communication (Holt et al. 2009; Fournet et al. 2018), foraging (Lusseau et al. 2009; Christiansen et al. 2013; Holt et al. 2021) and social cohesion (Visser et al. 2016). Globally, shipping numbers have risen by a factor of 3.5 since the 1950s (Frisk 2012) contributing to an increase in ocean noise levels (Andrew et al. 2002; Hildebrand 2009). Locally, the number of vessels and vessel time on water has increased in the Salish Sea over recent decades (Gillespie 2016; Seely et al. 2017; McWhinnie et al. 2021). Along with the increase in vessel numbers, changes are also occurring in the seasonal distributions of humpback whales (*Megaptera novaeangliae*) and two killer whale (*Orcinus orca*) ecotypes (Southern Resident and Bigg's/Transient). Both humpback whales and Bigg's killer whales are displaying a natural reintroduction into the Salish Sea (Shields et al. 2018; Miller 2020). Not only are numbers increasing, but whales are also staying in the area for longer periods of time (Calambokidis et al. 2018; Towers et al. 2019). In contrast, Southern Resident Killer Whales (SRKW), who used to be common visitors to the Salish Sea during the summer months, are altering their summer distribution (Olson et al. 2018). Given these distributional changes, the predicted increase in vessels (Kaplan & Solomon 2016) and the known threats of vessels to whales, it is critical to monitor whale movements and their overlap with vessels, particularly in areas of high traffic (Williams & O'Hara 2010).

Humpback whales were once considered rare in the Salish Sea as the result of extensive commercial whaling in the early 1900s (Fleming & Jackson 2013; Keple 2002). Since the early 2000s, humpback whales have been recolonizing the Salish Sea

(Calambokidis et al. 2018; Miller 2020). Humpback whales can now be seen throughout the year in the Salish Sea, though are most commonly observed in May to October during their feeding season (Baird 2003; Miller 2020). In the winter months, they are known to migrate south to their breeding grounds in Hawaii or Mexico (Urban et al. 2016). Although population numbers are increasing in some parts of the world (Andriolo et al. 2010; Calambokidis et al. 2018; Noad et al. 2019), noise pollution, vessel strikes and entanglement with fishing gear remain a global threat to population numbers (Fleming & Jackson 2011).

The Bigg's and SRKW populations are two genetically distinct ecotypes of killer whales that commonly occur in the Salish Sea (Barrett-Lennard & Ellis 2001; Riesch & Deecke 2011). Bigg's killer whales are primarily marine mammal eaters and the SRKW specialise on fish, predominantly salmonids (Ford et al. 1998). Each population generally avoids the other (Shields et al. 2018). Key threats for killer whales include vessel disturbance and noise pollution (Lusseau et al. 2009; Williams et al. 2009), oil spills and the bioaccumulation of contaminants (Fisheries and Oceans Canada 2007, 2018). Bigg's killer whales are currently listed as 'Threatened' under the *Species at Risk Act 2003* (Fisheries and Oceans Canada 2007), however their presence in the Salish Sea is increasing (Towers et al. 2019). Factors contributing to this include an increase in population size (Towers et al. 2019) and immigration of new family groups into the Salish Sea (Houghton, Baird, et al. 2015; Shields et al. 2018). Bigg's killer whales are seen year-round in the Salish Sea but peak presence occurs in August to September, coinciding with the pupping season of one of their main prey, the harbour seal (*Phoca vituline*) (Baird & Dill 1995; DFO 2013). A secondary peak has been identified in recent years in April-May (Houghton, Baird, et al. 2015).

As of March 2021, the SRKW population, was estimated at 75 individuals (Center for Whale Research 2021). This population was the target of the live-capture fishery for aquaria in 1962-1973, resulting in the removal of over 48 individuals (mostly juveniles) from the SRKW population in the Salish Sea (Bigg & Wolman 1975; Olesiuk et al. 2005). The population has not fully recovered and as the result of low population size, the SRKW was classified as 'Endangered' under the Canadian *Species at Risk Act 2003* (Fisheries and Oceans Canada 2016) and under the *Endangered Species Act 2005* in the United States of America (NOAA Fisheries 2021). A leading cause for the SRKW continued decline may be the reduced availability of their principal prey, chinook salmon

(*Oncorhynchus tshawytscha)* (Fisheries and Oceans Canada 2016). Historically, Boundary Pass and the surrounding waters of the Salish Sea were important foraging areas for the SRKW and pods were observed frequently throughout the summer (Hauser et al. 2007; Olson et al. 2018). These factors led to the area being included in the designated Species-at-Risk Critical Habitat in 2009 by the federal Fisheries and Oceans Department (Fisheries and Oceans Canada 2018). In recent years, however, SRKW movement through Boundary Pass and other core areas of the Salish Sea has decreased dramatically and occurrences have become less reliable (Ford et al. 2017; Shields et al. 2018). It is not currently known how the distribution changes of humpback and killer whales will affect the underwater ecosystem of the Salish Sea or how the populations will adapt to the increase in vessel presence.

Given the associated risks of vessel strike and disturbance, it is critical to understand how often vessels are within close proximity to whales, both intentionally and by chance. Globally, commercial shipping (e.g. cargo, tankers and bulk carriers) numbers have risen by a factor of 3.5 since the 1950s (Frisk 2012). This growth has contributed to the increase in ocean noise at low frequencies, reported as high as 3 dB/decade, which is equivalent to a doubling of noise intensity every 10 years (Andrew et al. 2002; Hildebrand 2009; Chapman & Price 2011). Active commercial ecotourism vessels, and the number of small recreational vessels and their time spent on water is also increasing in the Salish Sea (McWhinnie et al. 2021). With this increase in small vessels, the number of vessels violating the minimum approach distance to whales and other non-compliance to guidelines and regulations are on the rise (Seely et al. 2017). Most vessels above 150 gross tonnage or carrying more than 12 passengers are mandated to have an Automatic Information System (AIS) installed (SOLAS 2012). AIS transmits vessel information and location via VHF to other vessels and shore-based stations. AIS data can be used as a tool for investigating spatio-temporal changes in vessel activity, illegal fishing (Le Tixerant et al. 2018). As many small recreational vessels do not fit into these categories, many do not have AIS transceivers and their numbers are likely to be underestimated (Kline et al. 2020; McWhinnie et al. 2021).

Tourism was significantly reduced in 2020 because of the coronavirus disease (COVID-19) pandemic and associated travel restrictions (Gössling et al. 2021). As of August 2020, there was an estimated 83% reduction in international visitors to BC for 2020 compared to 2019 (Destination British Columbia 2020). Changes to passenger safety requirements and lower tourist numbers led to a delay in the start of the ecotourism season (Transport Canada 2020a) and reduced the number of boats on the water throughout the season. The closure of the Canada/United States border further restricted both recreational and ecotourism vessels from entering Canadian waters. Large commercial vessels were also impacted by COVID-19 restrictions. An Interim Order banned cruise ship operations in Canadian waters in 2020 and was extended into 2021 (Transport Canada 2021). Though cargo ships, bulker carriers and tankers were still present in 2020, by February 2020 shipping traffic had reduced by an average of 13.3% (Port of Vancouver 2020) and a reduction in underwater noise was detected by bottom mounted observations stations leading into the Port of Vancouver (Thomson & Barclay 2020). This reduction in vessel presence gives an unprecedented opportunity to collect vessel and noise data against which past and future data can be compared. The potential decrease in sound levels in the underwater soundscape during COVID-19 restrictions, or the 'Anthropause', would benefit marine life particularly species that depend on sound for foraging, communication and navigation (Tyack 2008; Joy et al. 2019).

Current vessel management methods to reduce noise and disturbance in whale habitat include seasonal commercial vessel slowdowns, Interim Sanctuary Zones (ISZ) and education initiatives on safe boat practices around whales. A voluntary commercial vessel slowdown has been in place since 2019, organized by the Enhancing Cetacean Habitat and Observation (ECHO) Program of the Port of Vancouver. This program aims to reduce underwater noise levels and risk of fatal vessel strikes by reducing the speed of commercial vessels through Boundary Pass and Haro Strait. Although voluntary, the cumulative self-reported participation rate for speed reduction was 91% between July and October 2020 and has reduced the lost foraging time by >20% for SRKW under normal traffic conditions (Gryba et al. 2021). Whilst reducing vessel speed is an effective method for reducing sound levels (Houghton et al. 2015; Joy et al. 2019; MacGillivray et al. 2019) and reduces the risk of lethal vessel strike (Vanderlaan & Taggart 2007; Leaper 2019), vessels traveling at 10 knots can still cause fatality and injury in whales (Kelley et al. 2021).

To create areas with reduced vessel noise and lower risk of physical disturbance, in June 2019, Transport Canada, supported by DFO, created three ISZs (enacted under the *Canada Shipping Act,* 2001). In these three spatial polygons of ocean habitat, fishing and boating would be prohibited between the months of June and November (Transport Canada 2020b). The 2020 season was the second year that the ISZ was in effect on the east coast of Saturna Island adjacent to Boundary Pass. Efficacy of this area for marine mammal usage and small vessel compliance is not well established. Long-term success of vessel no-go zone initiatives likely requires monitoring, enforcement and active management strategies rather than passive methods (Howes et al. 2012).

This study seeks to address knowledge gaps on what species currently use Boundary Pass and how they use the area both spatially and temporally. Whale monitoring for this study was enhanced through collaboration with the Saturna Sighting Network, the local citizen science group on Saturna Island. Monitoring whale usage of the waters of the Boundary Pass shipping lane and the ISZ can give an indication of how often whales overlap or interact with vessels in both areas. This study aims to aid decision makers and researchers to make informed decisions on methods to mitigate future disturbances caused by the overlap of whales and marine vessels.

Research Questions

1. What species are present in Boundary Pass and how do sightings vary over time?
2. How often does whale travel overlap with potential high-risk areas (Boundary Pass shipping lane) or potential low-risk areas (Interim Sanctuary Zone)? Do vessels comply with the Saturna Island Interim Sanctuary Zone regulations, creating a lower risk area of vessel strike?
3. How often are large commercial vessels or small vessels in close proximity to whales in this area of the Boundary Pass and the inshore waters around East Point, Saturna Island?
4. Was there a seasonal or interannual difference between 2019 (pre COVID-19) and 2020 (during COVID-19) noise levels in Boundary Pass?

Methods

Study Area

Land-based visual surveys were conducted at East Point Park (N48°46.9791', W123°2.7348', Fig. 1A), Saturna Island in the Southern Gulf Island chain of British Columbia, Canada. This position was chosen to maximise visibility of both the Interim Sanctuary Zone (ISZ) and the Boundary Pass shipping lane. This location is also within close proximity to the location of the 2019 Cetacean Observation Study (N48°46.78752', W123°3.48636') conducted by Le Baron et al. facilitating a comparison of sightings between years.

Land Based Cetacean Observation Survey

From 4 June to 6 October 2020, daily land-based cetacean (LBCO) surveys were conducted from Site 1 at East Point Park, Saturna Island (Fig. 1A & 1B). To detect whales, visual scans were conducted every 15 minutes between 09:00 and 17:00 PT, following similar methods to Lusseau et al. (2009), Di Clemente et al. (2018) and Le Baron et al. (2019). On occasion, due to reports of incoming whales, observations were recorded outside of normal survey hours between 07:00 and 20:00 PT. The focus area of this study extended 5 km from East Point, however, when whales were detected outside of this boundary, they were still recorded. An event began as soon as a whale was detected within the survey area and was terminated when the whale travelled out of view or was undetected for more than 20 minutes. When multiple individuals were observed, and if they were sighted within 10 body lengths of each other during the observation, they were classified as a single event (Lusseau et al. 2009).

Surveys were conducted using binoculars (Zeiss 10x42) and a DSLR camera (Sony α7R IV) with a telephoto lens (Sony 200-600 mm). A laser range finder (Newcon LRM 3500M-35BT) was used to measure the distances of vessels from survey site and as a method of standardising distance estimates. Near constant aural monitoring was conducted during survey hours as it was common that events were first detected following the large exhale or splash sound during whale transit or surface-active behaviour.

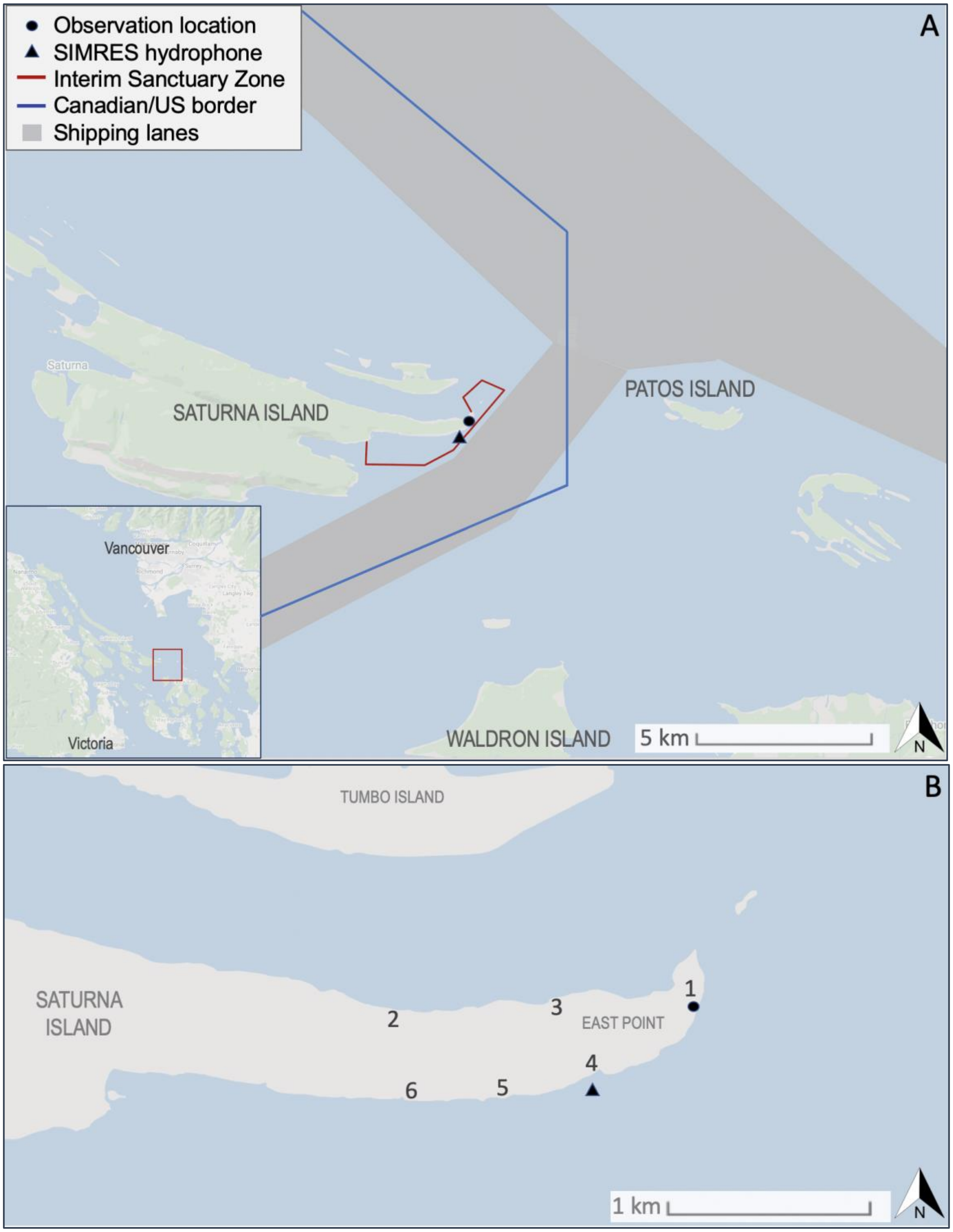

Figure 1. A) Main observation location at East Point in relation to the Saturna Island Interim Sanctuary Zone (2020), the Boundary Pass and Strait of Georgia shipping lanes and the approximate field of view. B) Main observation site (1), and additional Saturna Sighting Network observation locations (2-6) on Saturna Island.

Once a whale was located, it was identified to species and classified as either adult or calf/juvenile when possible. Unique individual humpback whales were identified by the markings on the underside of the fluke or by the dorsal fin. Ecotype was recorded for killer whales and was determined by examining the dorsal-fin saddle patch and the shape of the dorsal fin. These distinguishing features were also used to identify individuals, as each individual has a unique combination of saddle patch colouration, nicks and scratches. Knowledge of recent sightings within the general area of the Salish Sea also helped to determine ecotype and individuals. When possible, verification of SRKW presence through acoustic recordings collected from SIMRES' East Point Hydrophone network was conducted by local whale expert, Jeanne Hyde. No individual identifications were made for minke whales because of infrequent sightings in the area. To increase the chance of individual identification and improve data collection, photographs and videos were taken during each event and were processed after the field data collection. The identification process often required multiple photographs from different angles of an individual to enable a positive identification.

Individuals or groups of animals were monitored constantly during each event. To understand how each species uses the area, route and travel direction were estimated for each event. Presence inside shipping lanes and the ISZ was recorded. If whales entered the ISZ, total time within the zone was recorded and processed into temporal categories (0-14, 15-29, 30-59, 60+ minutes).

Behaviour classification can be used to determine whales' use of the marine habitat. Behaviour categories were adapted from those outlined in Lusseau et al (2009) and Di Clemente et al. (2018) and include rest, travel, forage and surface active behaviour. Behaviour was classified as rest when there was little or no clear movement by an individual. Travel was characterised by forward linear movement of an individual. Foraging was recorded when back and forth movement was observed, including jumping on, or surging/charging in a specific area. Surface active behaviour was classified as any socialising behaviour such as breaching, tail slapping, spy hopping, or other aerial displays. For humpback whales, the forage category was not used in this study as in this region of the Salish Sea, most foraging behaviour occurs out of view beneath the ocean surface.

To understand the frequency of potential whale/vessel interactions, vessels within the survey area were monitored constantly during whale events. When vessels were within

1 km of whales, information on vessels was collected including vessel activity (whale watching/wildlife viewing, fishing, traveling), type and an estimate of distance from animals. The definition of a whale watching vessel was not restricted to commercial ecotourism companies and included recreation vessels engaged in whale watching activities. Vessel activity was monitored for negative vessel behaviours such as corralling and violating maximum non-active approach distances. Vessels that were not actively whale watching were also recorded as they would still pose a risk to vessel strike and noise pollution. Vessel type was classified as a large commercial vessel (e.g. cargo, tankers and bulk carriers) or small vessel (recreational vessel of sailboat under power, sailing vessel, ecotourism vessel or government/research vessel).

When possible, whale sightings were reported when first detected to the BC Cetacean Sightings Network (BCCSN) WhaleReport App provided by Ocean Wise®. Reports were sometimes delayed as data collection was the primary object or because of a lack of cell coverage. All sightings were submitted to the BCCSN by the end of November 2020. Other methods to improve whale detection included communication with citizen scientists and researchers, real-time hydrophone broadcasts from Orcasound Lab and the presence of ecotourism vessels or groupings of recreational vessels.

Citizen Science Collaboration

The Saturna Sighting Network (SSN) is a local citizen scientist group that was formed by Saturna Island residents in early 2020 in collaboration with SIMRES. SSN observers started recording opportunistic whale sightings in April 2020. Observations from this group were based out of two general areas: Tumbo Channel Road with a north/northeast outlook (Fig. 1B, Site 2 & 3) and Cliffside Road in a southerly direction (Fig. 1B, Site 4-6). All sightings from this group were ad-hoc and with no consistent survey schedule established, and as such there is no exact estimate of effort related to these sightings. As a result of the COVID-19 pandemic travel restrictions, observers were on Saturna Island almost constantly throughout the survey period and were actively opportunistically making daily observations. This group also had a strong communication network, reporting wildlife sightings in real-time within the group thereby increasing both reporting accuracy and coverage.

The SSN used a similar data collection protocol to the Land Based Cetacean Observation (LBCO) survey, collecting information on species/ecotype (including confidence rating of uncertain, possible, probable, certain), number of individuals (approximate, exact or range), travel direction, behaviour location of individuals (latitude and longitude), name of observer and description of observer location and an estimate of wind speed and sea state. When possible, photographs from sightings were uploaded to a shared drive for confirmation of species and identification of individuals. In contrast to the LBCO survey, most reports were of a single snapshot of a whale event including a single time, location and information known at the time of report. Some reports included additional comments such as vessel presence, travel route or distinction between male, female or juvenile, although this information was not consistent through all reports.

SSN observers submitted all sightings to the BCCSN WhaleReport App. Sightings were accessible in real-time and as archived sightings through the SIMRES BCCSN Sightings Portal. Archived sightings were downloaded on 26 November 2020 and were assessed for accuracy. In particular, the species/ecotype identification and time of sighting were cross checked with photographs and oral and written reports. Once confirmed, sightings were compared to events collected during the LBCO survey. When multiple sighting reports occurred on a single day, time, location, species and comments were evaluated to determine if sightings were unique or duplicates. Once determined unique, the sightings were given unique identification codes. Only data collected during the study period between June and October 2020 were used in this study, however this group is active year-round since it formed in 2020.

Interim Sanctuary Zone Vessel Survey

The Interim Sanctuary Zone (ISZ) was implemented by the Government of Canada as a seasonal vessel no-go zone to reduce vessel noise and physical disturbance by restricting vessel transit and fishing activity throughout summer months. To determine efficacy of the ISZ, two methods were used to collect vessel data. Method one used visual monitoring techniques concurrently with the LBCO survey. The second method used AIS data for a source of vessel positions collected by shore based AIS receivers as provided by AISHub. As both methods recorded vessel name, time of sighting and other basic vessel information the resulting datasets could be compared. Recordings of the same vessel in both methods provided the opportunity to validate the visual estimation method.

The visual method focused on the northern section of the Saturna Island ISZ (Fig. 2) and required near constant visual monitoring to record all vessel transit within the area. For small vessels, compliance was defined as when a vessel actively transited around the zone without crossing the border (see green compliance area, Fig. 2). This compliance polygon was chosen to maximise the representation of vessels purposively avoiding entering the ISZ while minimising vessel transits that did not interact with the ISZ. Exempt vessels (RCMP, Fisheries Patrol, Border Security and vessels conducting research or First Nations food fishing) were not recorded in this study.

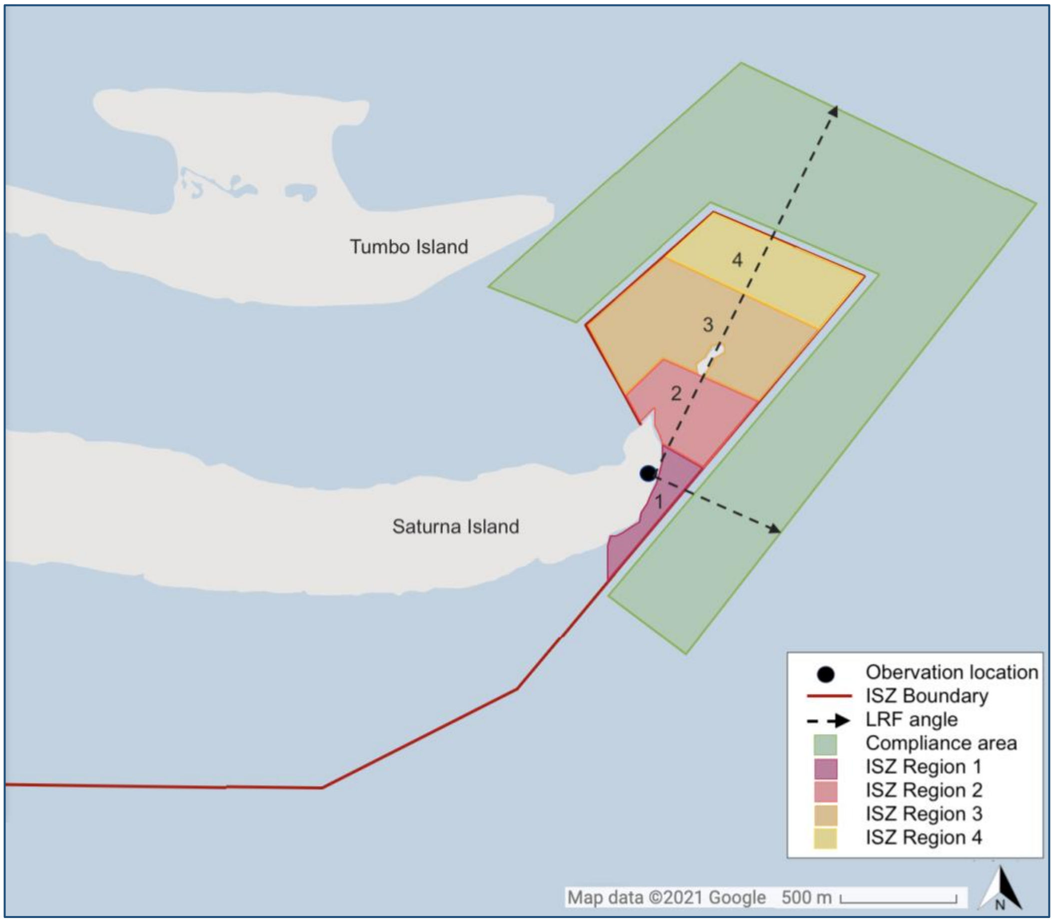

Figure 2. **Northern section of the Saturna Island Interim Sanctuary Zone within the red border broken into regions (ISZ1, ISZ2, ISZ3, ISZ4) to document different usage of the Interim Sanctuary Zone. The designated 'compliance zone' is represented in green. The south-western section (blue colour within red boundary) was not observed in this study.**

To facilitate the assessment of ISZ usage by vessels (and whales), the ISZ area was broken into four regions (Fig. 2). Non-compliance was defined as when a vessel entered any of the four regions within the ISZ. Entering ISZ Region 2 was considered the worst infraction as this region includes a narrow channel between Boiling Reef and the tip of East Point. It often has a strong flowing current, submersed rocks and is a popular route for Bigg's killer whales, harbour seals and Steller sea lions. ISZ Region 3 included vessel travel within close proximity to Boiling Reef (seal haul-out), as well as vessels 'cutting the corners' of the zone. ISZ Region 4 was the region of least confidence because of its distance from shore. Non-compliance designations in this region were conservative and may have resulted in false negative categorisations of non-compliance. As no physical markers delineate the zone boundary, a laser range finder (Newcon LRM 3500M-35BT) was used to confirm vessel passage through the ISZ when required. For confirmation, measurements were taken in two directions (north-east and south-east) from the observation location at East Point (Fig. 2). In the north-east direction, measurements were taken looking through Boiling Reef (located 700 m from observation location, within ISZ region 3). Vessels within 950-1200 m were labelled as 'ISZ region 4' and vessels within 700-949 m were labelled as 'ISZ region 3'. In the south-east direction, measurements were taken looking perpendicular to the shoreline towards Boundary Pass. Vessels measured within 135 m in the south-easterly direction were deemed within ISZ. Vessels inside ISZ Region 2 were easily visually confirmed due to proximity to Boiling Reef and East Point. Once a vessel was classified as non-compliant, a photograph was taken and information was recorded including regions used, activity (transit, fishing or wildlife viewing) and the estimated time within the ISZ, processed into categories (0-14, 15-29, 30-59 and 60+ minutes).

For the second method of measuring the vessel usage of the ISZ, continuous 24-hour coverage of positions from vessels equipped with AIS transponders were collected between 1 July and 31 October 2020. Time stamped geographic positions were recorded along with unique vessel MMSI (Maritime Mobile Service Identifier), name, type, speed and distance from East Point.

Hydrophone data

Acoustic data was collected from an Ocean Sonics icListen HF hydrophone operated by SIMRES and located approximately 25 m from the Saturna Island shoreline (N48°46.82922', W123°3.0924', Fig. 1B) at a depth of 18 m. The focus of this study was on four time periods that covered two lunar cycles in 2019 (pre-COVID-19: 19 April to 18 May and 15 August to 13 September) and two lunar cycles in 2020 (during COVID-19: 7 April to 7 May and 3 August to 1 September). Lunar cycles were chosen to include the full range of tide heights and minimise the effects of variability due to current flow patterns.

For both 2019 and 2020, two time periods were chosen to capture information during expected off-peak small vessel occurrence (April/May) and peak small vessel occurrence (August/September) (McWhinnie et al. 2021). The lunar month starting 7 April 2020 occurred during the BC Public Health Emergency and BC lockdown at the start of the COVID-19 pandemic (CBC 2020).

Data Analysis

Whale Analysis

Whale event analysis was conducted in the R statistical environment using R Studio Version 1.3.1056 (RStudio Team 2020). All whale event data were grouped into weeks, starting from 1 June for both 2019 and 2020 data (see Appendix A, Table A1). To calculate effort for the LBCO, the number of sightings per week was divided by the number of hours spent conducting visual surveys in that week.

ISZ Vessel Analysis

AIS data for the 2020 ISZ analysis was obtained through AISHub.The data was first filtered by date (to match ISZ visual survey dates) and by distance from East Point (< 6000 m). The resulting dataset was then filtered by type to remove large commercial vessels and known exempt vessels (government, law enforcement, anti-pollution equipment, search and rescue vessel and research vessels). Data was then run through the in.out() function in the library package “mgcv” to locate vessel positions within the compliance area and the ISZ. Vessel positions that were recorded inside the ISZ polygon were considered non-compliant unless positions were recorded directly on the border. For the remaining vessels in the dataset, vessels with positions inside the compliance polygon were deemed compliant.

Soundscape Analysis

Underwater sound levels vary continuously in space and time due to different inputs from biological (biophonic), human-made (anthrophonic) and abiotic (geophonic) sound sources (Krause 2008). Each of these sources contribute to three frequency bands of low (10 to 500 Hz), medium (500 Hz to 25 kHz) and high (>25 kHz) (Hildebrand 2009). Marine mammal species not only vocalise at different frequencies, but also have different hearing ranges and sensitivities (Ketten 1994). Although there are uncertainties around species-specific hearing frequency ranges and respective sensitivities, behavioural hearing studies and models have sought to provide estimates (Thompson et al. 1986; Tyack 2009; Erbe 2012). Baleen whales, including humpback and minke whales vocalize at low to medium frequencies (i.e. 40 Hz to 4 kHz) (Thompson et al. 1986). Baleen hearing likely encompasses these frequencies but may extend as high as 24 kHz for humpbacks (Au et al. 2006; Tubelli et al. 2018) and 33 kHz for minke whales (Tubelli et al. 2012). In contrast, killer whales communicate at higher frequencies, producing three types of signals. Whistles are centred around 5 to 15 kHz, pulsed calls between 500 Hz and 15 kHz and echolocation clicks in the 15 kHz to 120 kHz range (Erbe 2011). Killer whale hearing is also more sensitive at high frequencies, estimated between 100 Hz-100 kHz (Erbe 2011).

Anthropogenic sound sources overlap with the frequency bands used for whale hearing and communication. To assess the noise levels in Boundary Pass and investigate the potential overlap, both power spectral density (PSD) and third octave level (TOL) sound analyses were conducted using Python and Jupyter Notebook. PSD was chosen as it is widely used to compare soundscapes across different time periods and interprets the physical attributes of sound as pressure fluctuations. TOL on the other hand, characterizes ambient noise levels in a way that matches how the mammalian ear perceives sound.

PSD was calculated using the Welch method with a sensitivity of -175.8 dB, a 15.652 Hz resolution and averaged over one minute. Window length was of 8192 samples with overlap of 4096 samples (i.e. a hamming smoothing window). Percentile levels (1, 5, 50, 95, 99) were plotted against the frequency spectrum (10 Hz to 100 kHz) to investigate the underwater soundscape. The analysis focussed on the 50th percentile, or median value, and the root-mean-square (RMS) of the average of the square of the pressure of the sound signal over time. In most cases the peaks in the 1st and 5th percentile would be related to occasional short duration, high intensity events such as a small vessel passing close by the East Point hydrophone (Heise et al. 2017).

TOL plots were produced using a Hamming window of 16384 and overlap of 8192 with a sensitivity of -175.8 dB, a 7.8 Hz resolution and averaged over one minute. The 63 and 125 Hz third octave bands were highlighted in this analysis as they are used to represent shipping (Tasker et al. 2010). These bands contain a high concentration of sound produced by large vessels and have a low input from natural sources (Garrett et al. 2016; Heise et al. 2017). Recreational vessels contribute noise to both the 125 Hz and above the 1 kHz TOL bands (Kipple & Gabriele 2004; Hermannsen et al. 2019). For reference, the EU Marine Strategy Framework Directive recommends that ambient noise levels should be kept below 100 dB re 1µPa for the third octave bands 63Hz and 125 Hz, averaged annually (Tasker et al. 2010).

Vessel Transit Analysis

Vessel transits through Boundary Pass were used to estimate the anthropogenic inputs in the underwater soundscape. Vessel transits were determined using vessel positions collected through AIS and were supplied by three means: SIMRES, JASCO Applied Science and AIShub.

AIS data for the 2019 lunar months was collected via VHF receiver by SIMRES. AIS data was manipulated using PyCharm CE 2020.3, using Python programming language with free open-source libraries (Pandas, pyAIS, Shapely and GeoPy). Raw data (NMEA messages) were decoded, incomplete messages were removed and position reports and voyage data (class 1, 2, 3, 18 and 19) were isolated. Data was then downsampled to one position every 60 seconds to reduce resolution and file size and match the following datasets.

For 2020, decoded and downsampled AIS data for spring was provided by JASCO Applied Sciences and for summer, obtained through AISHub. Both of these data sets were combined with 2019 data. No data was obtained for 28 or 29 April 2019 (~70 hours lost) or for small vessels in Group 6 for the spring lunar month in 2020. Data was filtered to include only unique vessel transits that included recorded positional points in line of site of the hydrophone near Site 4, within a 5 km polygon (Fig. 1B). Vessels were removed if speed was equal to 0 knots (i.e. stationary). Vessel 'type' was sorted into groups based on general function and size as recommended by McWhinnie et al. (2021) (see Appendix A, Table A2). Once each lunar month was sufficiently filtered, number of unique vessels and unique vessel transits per group were calculated and then plotted in the R statistical environment using R Studio Version 1.3.1056 (RStudio Team 2020)..

Results

Land Based Cetacean Observation (LBCO) Survey

Between 1 June and 4 October 2020, 104 LBCO surveys were conducted, including 100 full days (more than six hours) and four half days (less than six hours). This totalled over 830 hours of observation effort across the 104 observation days (Fig. 3). Whales were observed on 54 of the total 104 survey days, with 115 unique whale events recorded (Fig. 4). During the survey period, 22 days were non-survey days and eight days were partially obstructed resulting in a modified survey protocol.

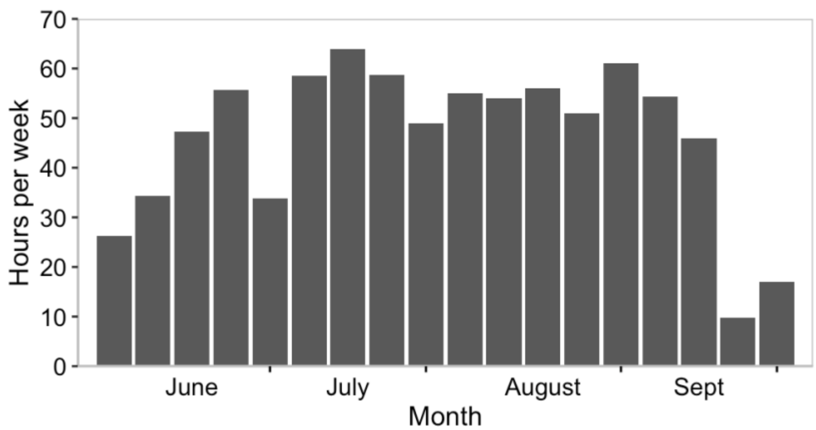

Figure 3. Number of hours per week conducting the Land Based Cetacean Observation survey between 1 June and 4 October 2020.

Saturna Sightings Network (SSN) and LBCO survey

SSN observations contributed to presence-only data rather than present/not detected data. Combining SSN observations with LBCO survey data increases the number of observed events from 115 to a total of 168 event (Fig. 4). Twenty-eight, or over half of these additional SSN events, were recorded outside of the normal survey hours of 09:00-17:00 expanding potential coverage to 06:50-20:30 PT. Twenty-two events occurred on non-survey days which represented 11 extra days covered over the survey period.

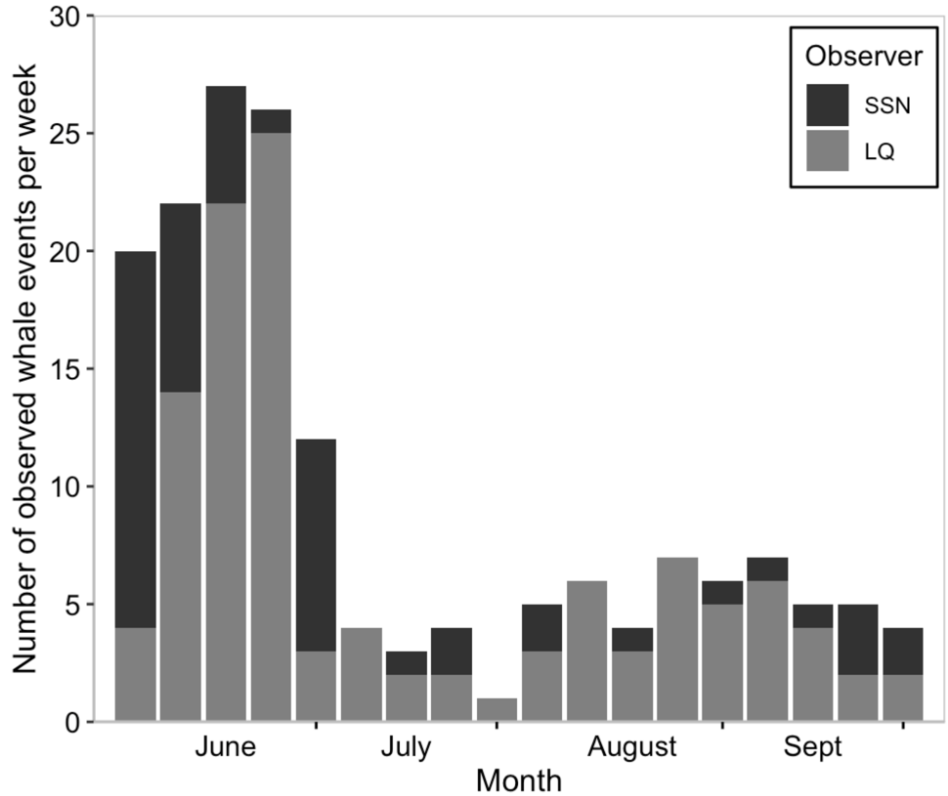

Figure 4. **Number of whale events per week from 1 June to 4 October 2020. Lighter grey bars represent the number of events observed in this study and darker grey bars represent the number of events recorded by Saturna Sighting Network (SSN).**

Breaking down the SSN events per species, the SSN contributed an additional 38 humpback whale, 11 Bigg's killer whale, two minke whale and two SRKW events. Due to the low number of recorded events in the LBCO survey for SRKW (three events) and minke whales (two events) the additional SSN observations not only substantially increased the number of sightings but also expanded the time horizon across months that whales would otherwise not have been documented for this project (Fig. 5). Over 38 events were recorded in the LBCO survey and by the SSN observers. Communication regarding whale detection with SSN observers during the survey period likely increased detections for both the LBCO and the SSN.

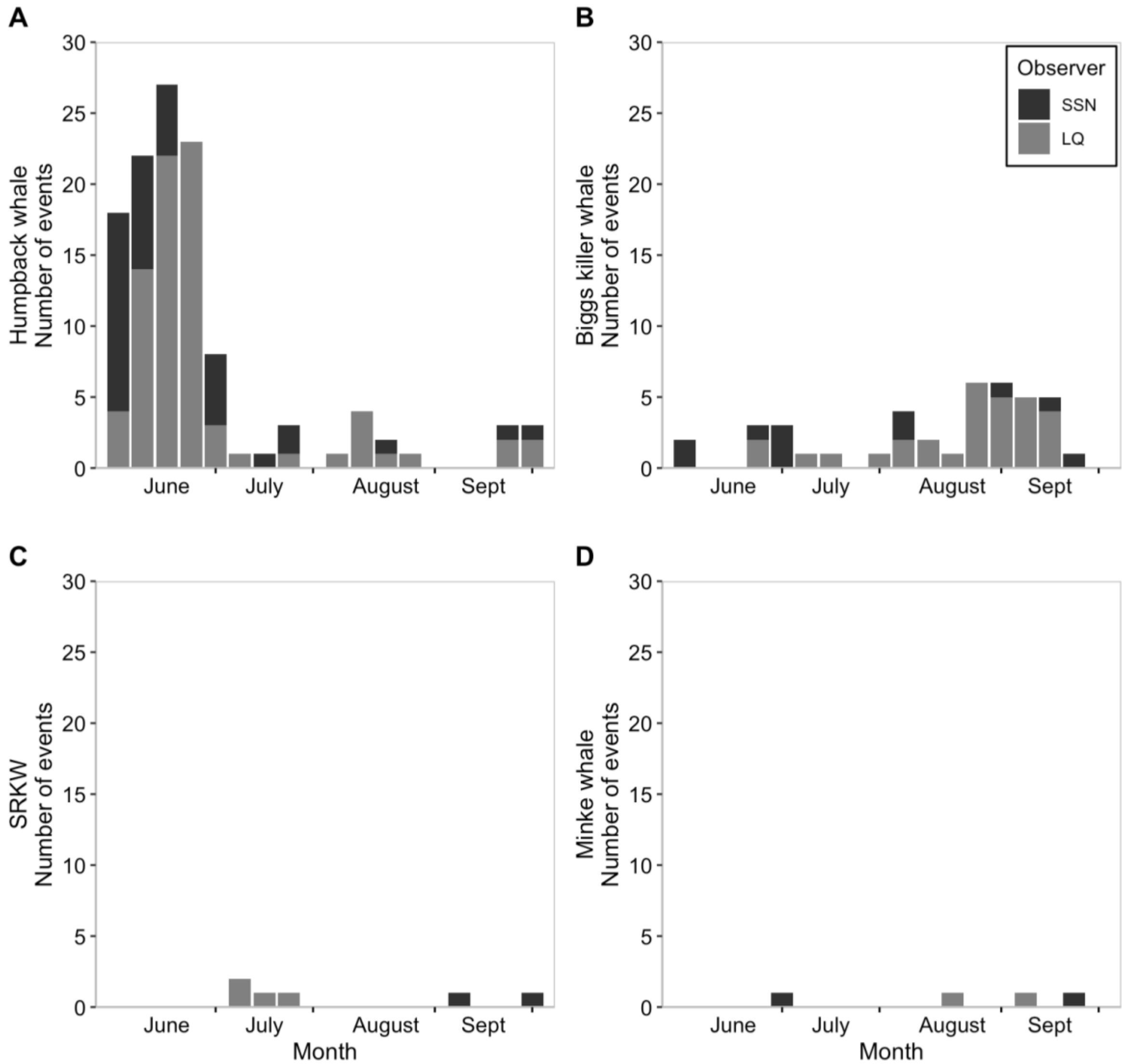

Figure 5. **Number of whale events per week for each species from 1 June to 4 October 2020. Lighter grey bars represent the number of events observed in this study and darker grey bars represent the number of events recorded by Saturna Sighting Network (SSN). Note: The SRKW observation in early September was only detected from hydrophone recordings provided by SIMRES' East Point Hydrophone.**

The humpback whale was the most observed species in Boundary Pass. The peak occurrence for this species was highest in June but with additional events observed in all months (Fig. 5). Ten individuals were positively identified during the survey period and five of these individuals were observed on three or more days. Two individuals, a mother and calf pair identified as Heather (BCY0160) and her 2020 calf Neowise (no id # at time of writing), dominated observations during June 2020, constituting 27 of the total 77 recorded humpback whale events. In this study, the first detection of this pair was on 5 June and the pair were last seen on 28 June, however reports from SSN observers indicate they were present from at least at the end of May until 4 July 2020. Twenty-four events included individuals that were not identified either due to large distance from observer and/or a lack of unique, identifiable features.

Bigg's killer whales were the second most commonly observed whale, with presence greatest in August and September (Fig. 5). At least 13 different groups were identified and at least 10 foraging events were observed during the LBCO surveys. Some family groups were seen multiple times; for example, the T018s/T019s were seen in at least six different events. Other family groups such as the T099s were only observed on one occasion. Only three events included family groups that were not identified.

SRKWs were only observed travelling through Boundary Pass on three occasions during the LBCO survey. One additional sighting was recorded by SSN observers in late September on a day when a LBCO survey was not conducted (Fig. 5). The maximum number of individuals seen during any one SRKW event was ~22 when J pod was observed on 12 July 2020. Members from K and L pod were identified during the 24 July 2020 event. An additional SRKW event was detected through acoustic methods using recordings from the SIMRES East Point hydrophone and confirmed by Jeanne Hyde. This event occurred outside of survey hours at 02:00 PT on 12 September and was discovered after members of J and K pod had been reported travelling northbound in Haro Strait the night before.

Minke whales were observed twice (August, September) during the LBCO surveys and were recorded on two other occasions by SSN observers in July and September (Fig. 5). This species is not as common in this area as other species and is much harder to detect due to body size and cryptic behaviour.

LBCO Survey Observations 2019 and 2020

Le Baron et al. (2019) conducted a whale observation survey in 2019 following the same methods, however her vantage point (Fig. 1B, Site 5) was based approximately 1000 m from the East Point observation location of LBCO study. With a similar view of Boundary Pass and equivalent methods and observation effort, the weekly events per unit effort for each species observed can be compared (Fig. 6).

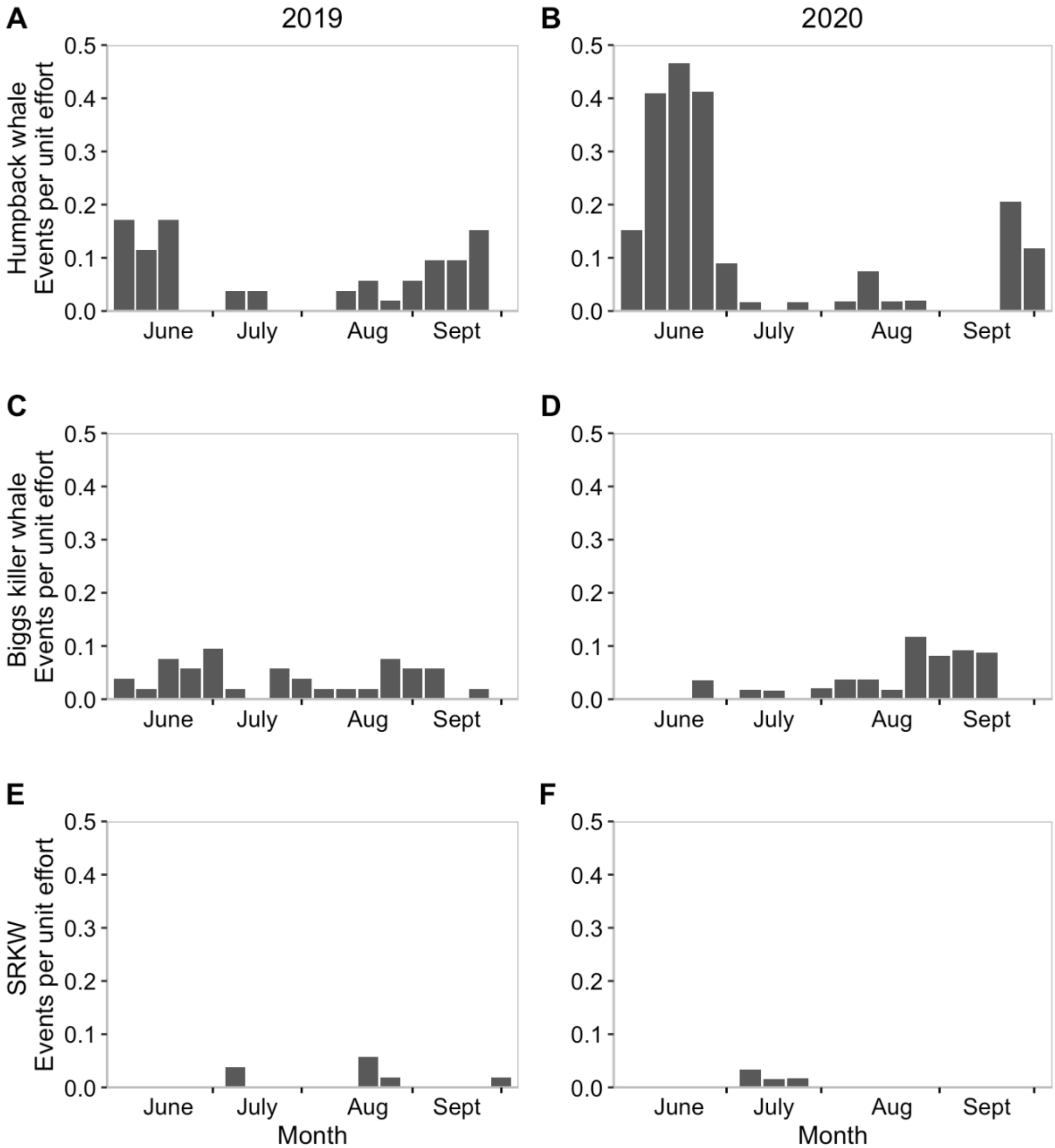

Figure 6. **Number of whale events per week per unit (hour) effort for humpback whales (A, B) Bigg's killer whales (C, D) and Southern Resident Killer Whales (E, F) for both 2019 (left) and 2020 (right). Data for 2019 was adapted from Le Baron et al. (2019).**

Humpback whales were the most observed species in both years with peak observation periods in June and towards the end of the survey period in September. The effort-corrected sightings peaked in June in both 2019 and 2020, with higher sightings rates in 2020 compared to 2019. This was likely due to the repeated presence of the mother/calf pair during this time. Bigg's killer whales were observed in similar numbers in both years, though 2019 sightings data showed a bimodal distribution with peaks in June and September, and 2020 was characterised by one distinctive mode in August and September. Counts of SRKW sightings were low for both years. All sightings of SRKW were collected in 2020 in the month of July, however, as previously mentioned, two other sightings were also reported by the SNN in September and October. Minke whale events have not been included in Figure 6 as they were either not observed in 2019 or not recorded.

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

Location and Behaviour of Whales

Each species utilized unique spatial distributions in Boundary Pass (Table 1; Appendix B, Figure B1) and displayed varying types of behaviour over the study period. As the SSN did not include the same level of detail on location and behaviour, their observations are not included in this section. Seventy-four percent of all whale events included travel within the shipping lanes (Table 1). In total, over 76% of the humpback whale events involved movement within shipping lanes (Table 1) and 36% within the ISZ.

Table 1. Whale travel through shipping lanes and Saturna Island Interim Sanctuary Zone (ISZ).

Population	Total number of whale events	Whale Travel in Shipping lane	Whale Travel in ISZ
Humpback	77	59	28
Bigg's	32	21	21
SRKW	4	3	2
Minke	2	2	0
All populations	**115**	**85**	**51**

As previously mentioned, almost half of humpback whale events observed included Heather and Neowise. This mother/calf pair displayed different movement patterns in Boundary Pass compared to the other individuals observed. While other individuals tended to travel within the shipping lane either north towards Strait of Georgia or south towards Haro Strait, Heather and Neowise travelled closer to shore, often within the Interim Sanctuary Zone. Heather and Neowise account for 17 of the total 28 humpback whale events that included travel within the ISZ. All humpback whale events included travel behaviour, with general respiration patterns of 3-5 breaths approximately 10 seconds apart followed by a long dive. Socialising behaviour (breaching, tail lobbing and pectoral fin slaps) were observed in 18 of 77 events. The maximum number of breaches in one event was recorded with over 60 breaches by the calf Neowise. For humpbacks, feeding behaviour was more challenging to identify as this region of the Salish Sea is dominated by underwater (and out of view) foraging behaviours. As such, foraging behaviour was not recorded for humpbacks. Total time of observation events ranged from the detection of a single blow to events lasting over 3.5 hours.

Bigg's killer whales travelled in small family groups of 3-8 individuals, though on occasion smaller groups would join together to make bigger groups. Most travel for Bigg's killer whales involved hugging the shoreline, sometimes within 2 m of the shore. For 65% of observation events, Bigg's killer whales included travel within the ISZ. Over half of the Bigg's killer whale events (65%) used Boundary Pass either transiting between Saturna Island and Waldron Island or Patos Island, or less frequently, for linear travel within Boundary Pass shipping lane (Table 1). Foraging behaviour was observed in 10 of 32 observation events for Bigg's killer whales and at least four successful harbour seal captures were seen. Successful seal capture was determined when a seal was seen in a killer whale's mouth and/or there were repetitive interactions with a seal. Socialising behaviour was less commonly seen in Bigg's killer, whale with only one breaching event observed when multiple family groups combined. Event duration for Bigg's killer whales ranged from three minutes (observation time limited by heavy smoke) to over 5.5 hours. Long events were usually associated with travel far from shore, for example heading along the US side of Boundary Pass close to Orcas Island.

In contrast to the Bigg's killer whales, the SRKWs used Boundary Pass as a transit route between the Strait of Georgia and Haro Strait. For the three visually detected SRKW events recorded off East Point (two on 12 July and one on 24 July), all pods were observed spread out across Boundary Pass, either in small groups or as singles. Some members of J pod travelled within the ISZ boundaries, estimated as close as 20 m from the shoreline during the events on 12 July, whereas K and L pod were estimated further out at 200 m on 24 July. Members from all three pods also used the Boundary Pass shipping lane, and it took between one and two hours for all individuals to pass East Point. All three pods displayed both travel and social behaviour (both breaching and tail slapping). The spread-out movement pattern observed in Boundary Pass is consistent with foraging behaviour (Ford 1989), however no specific prey capture was observed. The fourth SRKW event did not take place in Boundary Pass, instead, the whales travelled from Strait of Georgia near Point Roberts towards Rosario Strait. Due to the distance from East Point, no behaviour information was collected for this event.

During both minke whale events, only fast travelling behaviour was observed. In both events, travel was observed through the shipping lanes (Table 1). Minke whale respiration pattern (breath followed by one-minute dive) differed from the humpback whale respiration pattern (~ 3-5 breaths every 10 seconds followed by 10-minute dive). Due to detection difficulty associated with this species' small profile and short breath cycles, events were short (from 5 minutes to just over 30 minutes) in duration.

Vessel Presence During Whale Events

Vessels were present within 1000 m of whales in 75 of 115 (65%) recorded events (Table 2). Sixty events (52%) included small vessels within 1000 m of a whale and 37 of these events included active whale watching by ecotourism vessels or recreational vessels (Appendix C, Table C1). Twenty nine percent of events had large vessels present, and both large and small vessels were present for 16% of observed whale events. Three of four SRKW events had vessels present, however only one recreational vessel was determined to be actively watching SRKW during this time within Canadian waters.

Table 2. Vessel presence during whale events observed between 1 June and 4 October, 2020 from East Point, Saturna Island.

Population	Total number of whale events	Total number of whale events with vessels present	Number of events		Total Count of vessels	
			Small vessels present	Large vessels present	Small vessels	Large vessel
Humpback	77	47	35	26	84	43
Bigg's	32	24	22	6	154	8
SRKW	4	3	2	1	8	1
Minke	2	1	1	0	1	0
All populations	**115**	**75**	**60**	**33**	**247**	**52**

As the distance between two objects gets harder to measure or estimate the further away they are, no close encounters (closer than 400 m) between vessels and whales were recorded within the shipping lane or further than 1000 m from shore. Three events, however, were recorded in or on the border of the ISZ that included close encounters (likely within 400 m) between small vessels and whales. Two events included Bigg's killer whales and one event occurred with the mother/calf pair. All three events did not appear to be deliberate interactions (i.e. due to whale watching).

Vessel Compliance in ISZ

To determine efficacy of the ISZ, two methods were used to collect vessel data inside the vessel no-go zone. The ISZ visual survey was the first method and was conducted from Site 1 (Fig. 1B), East Point, Saturna Island at the same time as the LBCO survey. Between 18 June and 11 September 2020, vessel compliance was observed 7.5 hours per day for a total of 69 days. During the survey period, a total of 613 small vessels were observed inside and surrounding the ISZ (Fig. 2), with 391 vessels deemed as non-compliant and 222 recorded as compliant. Between June and September, the number of vessels fluctuated, peaking mid-August (Fig. 7).

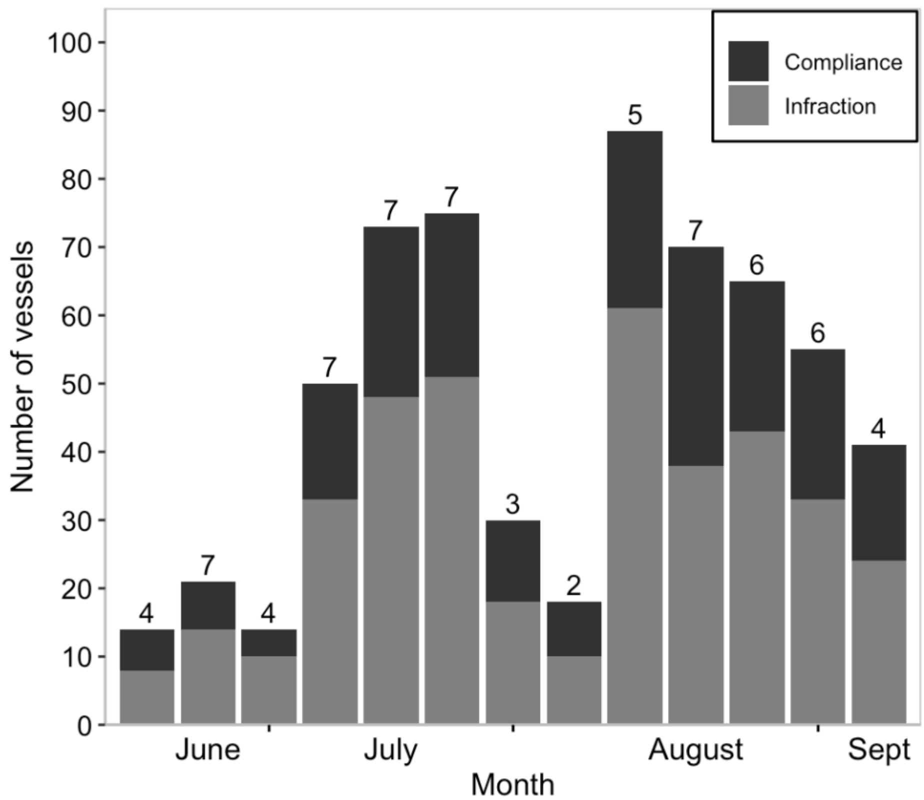

Figure 7. Total number of small vessels recorded per week represented by total bar height during Interim Sanctuary Zone survey from East Point between 18 June to 11 September, 2020. Lighter grey bars represent the number of recorded compliant vessels and darker grey bars represent the number of vessels that entered the northern section of ISZ. Number above bar represents the number of days surveyed per week.

Between June and September, the number of vessels fluctuated, peaking mid-August (Fig. 7). High vessel numbers (more than 15) were observed most often on either Saturday or Sunday. The maximum number of infractions occurred on 16 August with 23 recorded non-compliant vessel transits. Vessel compliance in the ISZ was on average less than 40%. The number of violations increased in the peak of summer (August/September), but the relative compliance rate remained relatively constant (i.e., between 25% and 40%; Fig. 8). Total compliance (100%) occurred on five separate days with an average of 2 compliant vessels per day. Six days had total non-compliance (0%), with an average of 3 non-compliant vessel transits. Only one day occurred when no small vessels were recorded.

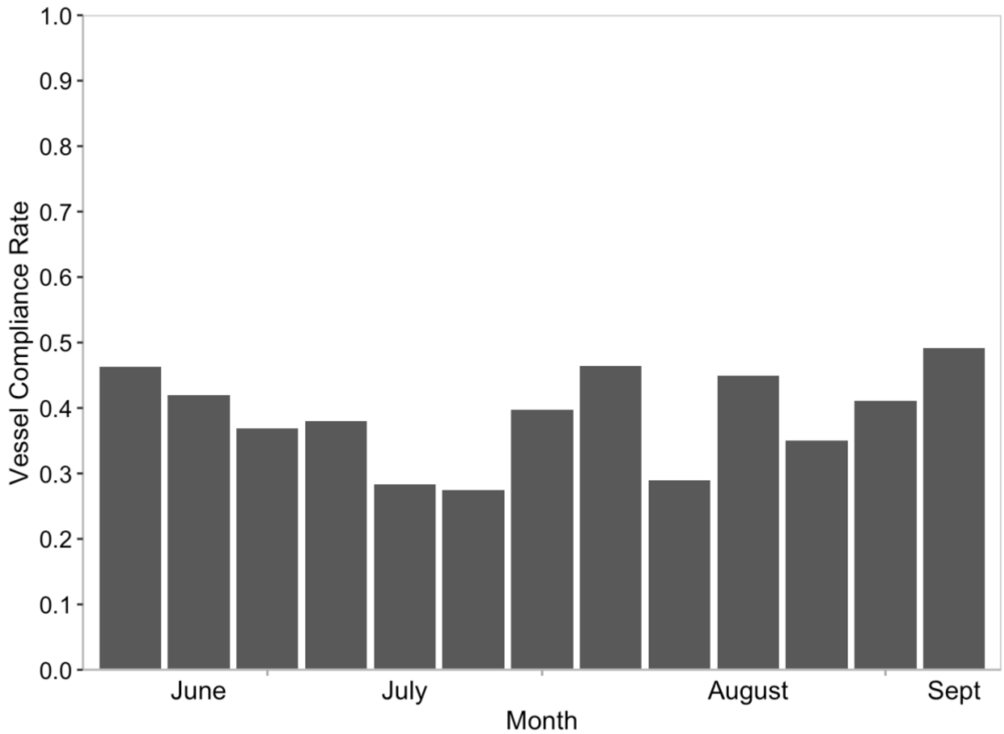

Figure 8. **Mean vessel compliance rate per week, recorded during Interim Sanctuary Zone survey from East Point between 18 June to 11 September, 2020.**

Twenty-four percent (94 vessels) of non-compliant vessels observed from East Point included travel in ISZ Region 2. As previously mentioned, ISZ Region 2 was considered the 'worst' type of infraction as it includes the narrow channel between Boiling Reef and the tip of East Point, which is a common area for wildlife and is a considerable blind spot for both whales and boat skippers (Fig. 2).

Over 97.6% of vessels observed within the ISZ were transiting through the area at speed (estimated >5 knots), and 93% of vessels spent less than 15 minutes within the zone boundaries. Twenty-five vessels were observed fishing within the zone or observed continuously drifting in and out of the zone. Eight vessels spent 15 to 30 minutes in the zone and two vessels spent over 30 minutes within the zone, most of which were engaged in fishing activity. Four vessels were engaged in wildlife or sightseeing activities inside the ISZ, in close proximity to Boiling Reef, the location of a seal haulout. No violations observed were directly caused by obvious whale watching activities. On over a dozen occasions, vessels inside the ISZ were approached by government vessels (Fisheries Patrol, RCMP and Parks Canada) and were educated on the regulations of the area before being escorted out of the zone.

For the second method, vessel positions were recorded using Automatic Identification System (AIS) data collected between 1 July and 11 September 2020 (Fig. 9).

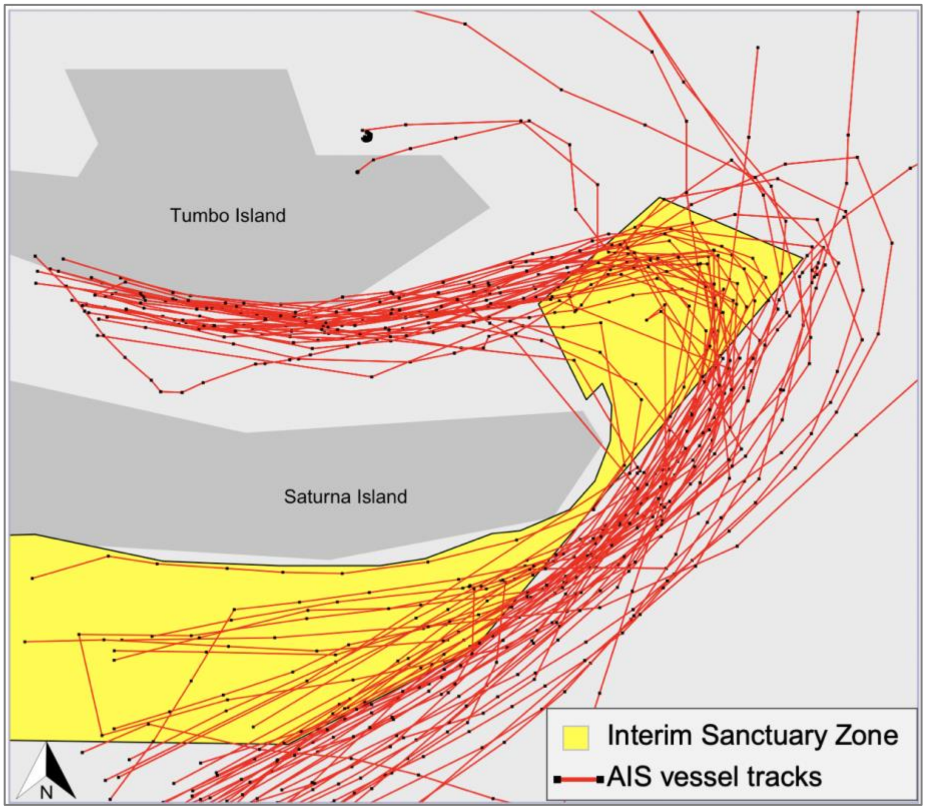

Figure 9. AIS vessel positions (black dots) and paths (red lines) inside the Interim Sanctuary Zone (yellow polygon). Each line represents a unique vessel transit with one or more recorded vessel positions inside the Interim Sanctuary Zone. Vessels with recorded positions on the border are not included in this map.

During the 71 days of AIS monitoring, a total of 49 unique vessel transits were recorded with positions within the ISZ (Fig. 10). Due to a malfunction, no AIS data was recorded on Monday 20 July or 21 Tuesday July so there may be an underestimation of AIS vessels in that week. Of 49 infractions, less than half (22 vessels) were also recorded in the visual survey. The remaining vessels were either tracked outside of survey hours (8 vessels), on non-survey days (7 vessels), not visible from location of visual survey (8 vessels) or deemed compliant due to conservative estimates (4 vessels). Only two vessels were detected with positions in the ISZ Region 2 (Fig. 2) using AIS monitoring. In comparison, during the same 71 days, 384 vessels were recorded in the visual survey, 94 of which, travelled through ISZ Region 2.

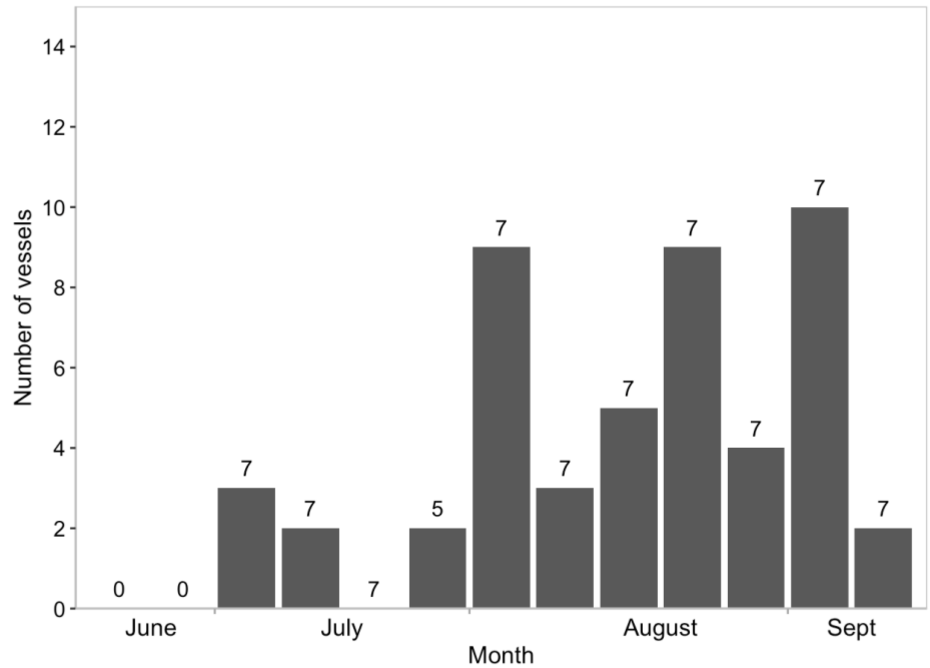

Figure 10. Number of non-compliant small vessels recorded per week using AIS monitoring method between 1 July to 11 September, 2020. Numbers above the bars represent the number of days that AIS data was collected. Note the change of scale when comparing to Figure 7, highlighting the difference between the two methods in estimating vessel infractions.

Acoustic analysis

To understand how the underwater soundscape varied within and between years, acoustic data was analysed using broadband and TOL frequencies. For an estimate of anthropogenic inputs to sound levels, AIS vessel position data were analysed (except no data available recreational and ecotourism vessels for the April/May 2020 lunar month). For potential biophonic contributions, whale presence information during daylight hours was investigated. Whale data was only available for summer lunar months, therefore seasonal variations could not be measured for whale presence. Environmental data such as wind, rain, sea temperature and salinity were not collected, therefore there was no measure of the contribution of abiotic sound to the ambient noise levels.

Seasonal Soundscape Analysis

Noise levels varied between seasons in both 2019 and 2020 (Fig. 11). Peaks occurred around the 63 Hz frequency in the 50^{th}, 95^{th} and 99^{th} percentiles in spring 2019 and 2020 (Fig. 11A & 9C) indicating that energy levels were elevated at this frequency between 50-99% of the time. Larger peaks in all percentiles occurred in the summer for both years (Fig. 11B & 9D). Secondary peaks occurred around 125 and 200 Hz, particularly in the summer (Fig. 11B & 9D). Small sharp peaks, particularly above the 10^3 Hz frequency, associated with small vessel transit, were more pronounced in the summer but still present in spring.

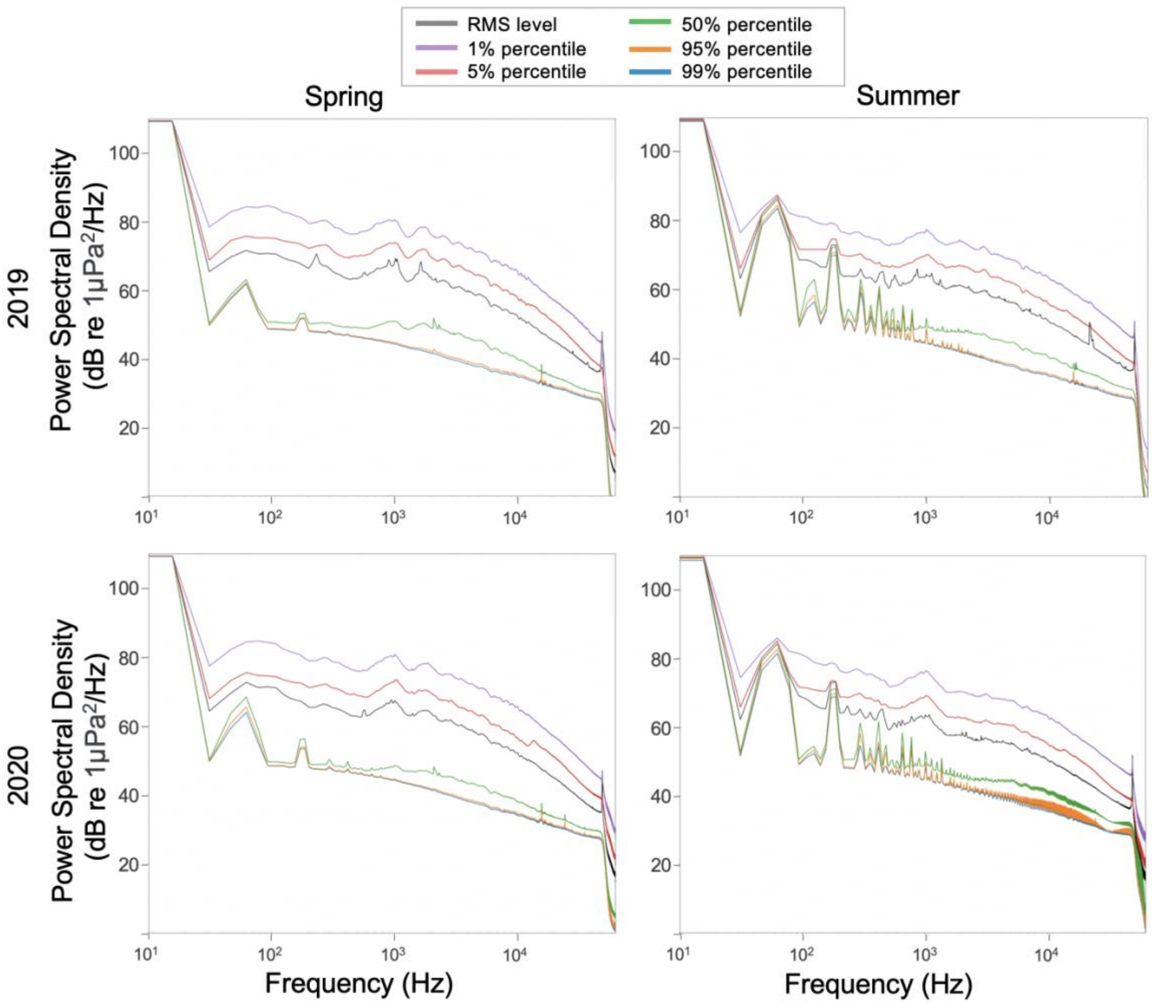

Figure 11. Monthly power spectral densities (PSD) for 10 Hz to 100 kHz showing percentiles (1, 5, 50, 95, 99 and RMS root-mean-square) calculated for two lunar cycles in 2019 pre COVID-19 (A, B) and two lunar cycles in 2020 during COVID-19 (C, D). Spring lunar cycle collected during May/April is shown on left and summer lunar cycle (August/September) is shown on right. Acoustic data collected from SIMRES Hydrophone, East Point Saturna Island.

The general trend in the TOL plots show a linear increase in noise levels with increasing frequency until 1-2 kHz where it levels off before decreasing (Fig. 12 & 13). Comparing third octave band frequencies in Figure 12 and 13, the same general seasonal pattern found in the PSD plot (Fig. 11) is evident.

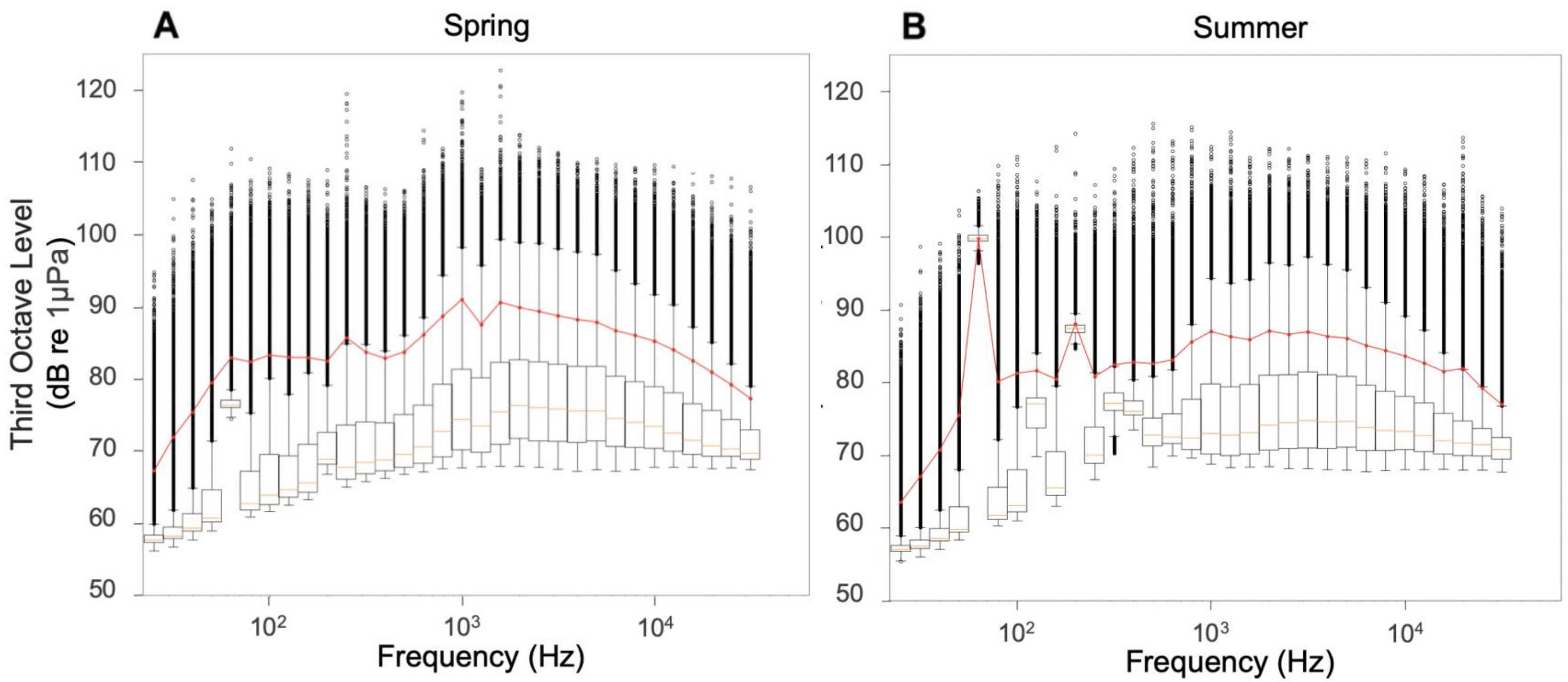

Figure 12. **Underwater noise levels averaged into third octave bands for two lunar cycles in 2019, pre COVID-19. Acoustic data for spring (A) lunar month was collected during May/April and for summer (B) lunar months was collected during August/September. The boxplots represent the quantiles between the 25th to 75th percentiles. The orange line within the box represents the median where 50% of the noise is below this line, and 50% is above. The black dots at the top of each box represents the outliers of unusually loud sound signals. The red line represents the mean of each third octave band. Acoustic data collected from SIMRES Hydrophone, East Point Saturna Island.**

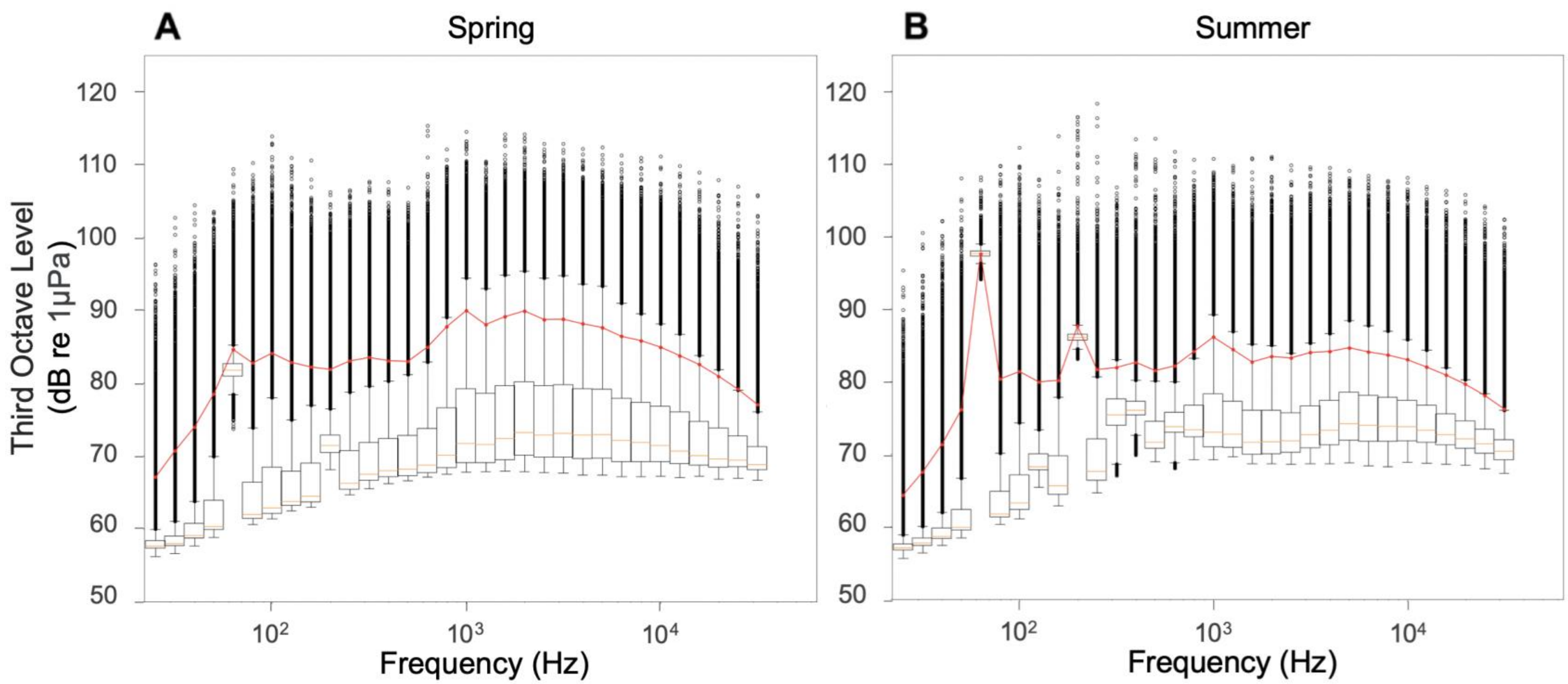

Figure 13. **Underwater noise levels averaged into third octave bands for two lunar cycles in 2020, during COVID-19 related restrictions. Acoustic data for spring (A) lunar month was collected during May/April and for summer (B) lunar months was collected during August/September. The boxplots represent the quantiles between the 25th to 75th percentiles. The orange line within the box represents the median where 50 % of the noise is below this line, and 50% is above. The black dots at the top of each box represents the outliers of unusually loud sound signals. The red line represents the mean of each third octave band. Acoustic data collected from SIMRES Hydrophone, East Point Saturna Island.**

The most marked differences between seasons occur at the TOL bands centered around 63, 125, 200, 315 and 400 Hz. These bands were lowest in spring (Fig. 12A & 13A). lunar months compared to the early summer levels (Fig. 12B & 13B) in both 2019 and 2020.

For the purpose of this study, a difference between two means was considered important when above 3 dB, as this represents a doubling of sound intensity. The key seasonal differences in means between summer 2019 and spring 2019 occurred in the 63, 200, 125, 315 and 400 Hz TOL frequency bands with differences of 22.07, 15.61, 8.61, 6.44 and 5.53 dB respectively (see Appendix D, Table D1). The values of the seasonal differences between means in 2020 were lower than that of 2019 in each of these key frequencies, with the exception of the 630 Hz third octave band. For 2020 summer and spring, maximum differences in TOL means occurred in the 63, 200, 400, 315 and 630 Hz frequency bands with a drop by 15.44, 12.96, 5.77, 5.67 and 3.16 dB respectively.

Interannual Soundscape Analysis

The differences in sound levels between years for the same season was less evident than the seasonal variation (Fig. 11, 12 & 13). The general shapes of the PSD plots between years are similar apart from a few key features. Spring 2020 percentile peaks in Figure 11 are higher in the 63 Hz frequency compared to the peak in spring 2019. This trend is not apparent in summer lunar months between years. For summer 2020, the 50^{th} percentile peak in the 125 Hz frequency is lower than the summer 2019 peak. This is consistent with the TOL frequency bands in Figure 12 & 13. Almost all TOL frequency bands had similar means (± 2 dB) when comparing years for both spring and summer months (see Appendix D, Table D1). The 2020 spring lunar month had lower means in each TOL frequency band except for one exception. The spring 2020 63 Hz TOL frequency band was higher than the 2019 spring month, with a difference in means of 4.53 dB. For the difference in summer month means, the only frequency band with a difference greater than 3 dB was the 125 Hz with a difference of 6.40 dB. For the summer lunar months, most TOL frequency bands had similar means within ± 2 dB. The biggest difference between summer month means (6.40 dB) occurred in the 125 Hz frequency band.

Anthrophonic sound sources

To estimate potential anthropogenic input into the soundscape, AIS data was analysed for the four lunar months (Fig. 14). The seasonal variation in AIS vessel transits in 2019 (Fig. 14) is consistent with the seasonal variation in sound levels provided in Figure 11, 12 and 13. Spring 2019 had a total of 732 unique vessel transits, summer 2019 had 922 and summer 2020 had 787. Spring 2020 had 657 unique vessel transits however data was not available for vessels in Group 6 (recreational and ecotourism vessels) so no direct comparison of total transits can be made between all four months.

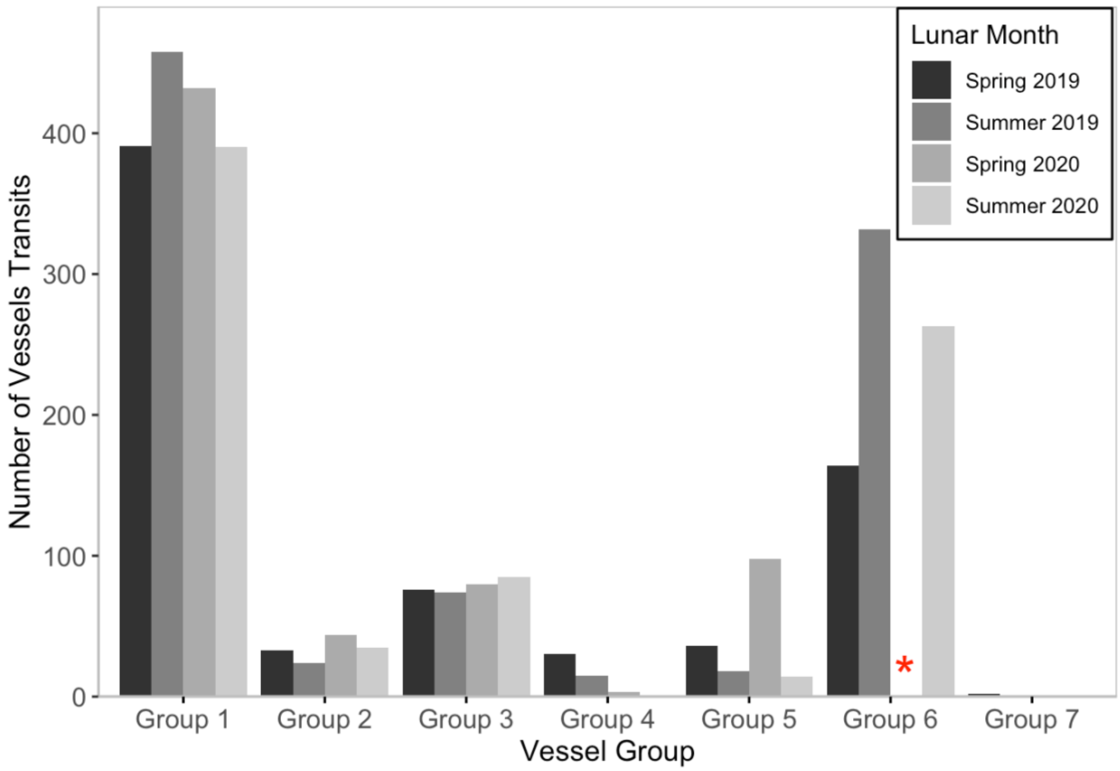

Figure 14. AIS vessel transit counts for lunar months in April/May (spring) 2019, August/September (summer) 2019, April/May 2020 and August/September 2020. Vessel are categorized by type and size (see Appendix C, Table C1). * No data was available for Group 6 in spring 2020.

The total number of AIS vessel transits that occurred in summer 2019 was higher than in spring 2019. The biggest difference in number of transits occurred in Group 6 (recreational and ecotourism vessels) where summer 2019 had 332 vessel transits compared to 164 in spring 2019. Group 1 (bulk carriers, cargo and container ships) 2019 vessel transits was also higher in summer compared to spring 2019 with 458 and 391 transits respectively. In contrast to 2019, Group 1 in 2020 had a decrease of vessel transits in summer compared to spring. There was also a large difference in vessel transits in Group 5 (Government, known research and Naval vessels). The large number of vessel transits in this Group for spring 2020 was linked a high number of Naval vessel activity in Boundary Pass during this time. As no data was available for Group 6 in spring 2020, a seasonal comparison could not be made in 2020 for this group. Vessel transit numbers for both Group 2 (tankers, LNG and chemical carriers) and Group 3 (tugs, fishing and dredging vessels) were relatively consistent between the four months analysed.

Assessing between-year patterns in vessel transits for the spring months shows an increase in all recorded groups except for Group 4 (cruise ships and passenger vessels > 50 m). This matches the detected increase in sound levels captured in Figure 11, 12 and 13. No data was collected for Group 6 (recreational and ecotourism) vessels so no comparisons for this group could be made between years for spring. For the two summer months, the unique AIS vessel transits decreased in summer 2020 compared to summer 2019 (Fig. 14). This follows the same trend in Figure 11, 12 and 13 where noise levels were lower in summer 2020 compared to summer 2019. The biggest differences occurred in Group 1 (cargo, container and bulkers) and Group 6 (recreational and ecotourism) with 68 and 69 more vessel transits in 2019, respectively.

Biophonic sound sources

To provide an estimate of potential biophonic sound inputs, whale sightings data were used from the LBCO survey and the Le Baron et al (2019) study during the summer lunar months. For summer 2019, 15 humpback whales, 12 Bigg's killer whales and four SKRW events were recorded. During the summer month in 2020, 14 humpback whales, six Bigg's killer whales and zero SKRW events were recorded. While not all whale sightings will result in a contribution of sound levels recorded in Boundary Pass, the sightings can be used to validate the acoustic data. Two survey days were missed during the period of the 2020 summer lunar month and no data was available for spring months for 2019 or 2020.

Discussion

Whale Presence in Boundary Pass

In recent years, the spatial and temporal distributions of humpback whales, Bigg's killer whales and SRKW have undergone significant changes in the Salish Sea (Calambokidis et al. 2018; Shields et al. 2018; Towers et al. 2019). To understand when whales are using the waters of Boundary Pass, this study provides a snapshot of daily whale presence through land-based surveys for the summer of 2020. As expected, sighting numbers did vary for humpbacks, Bigg's and SRKW between June and October 2020. Comparing these sightings with the previous year, species presence also varied between 2019 and 2020 (Le Baron et al. 2019). The variation between species is likely associated with fluctuations in prey availability, pod-specific habitat usage and interactions within and between other species and/or populations (Payne et al. 1990; Baird & Dill 1995; Miller 2020).

Both humpback whales and Bigg's killer whales are rebounding from lower presence in the Salish Sea and the number of sightings is still on the rise (Ford et al. 2009; Shields et al. 2018; Miller 2020). Many humpback whale individuals identified in this study, including the mother humpback BCY0160, have been documented in this region of the Salish Sea over multiple years (Happywhale 2021). Humpback whales are known to exhibit site fidelity to their feeding grounds, often returning to the waters that they were brought to as a calf (Clapham & Mayo 1987; Baker et al. 2013). Considering this, this study is consistent with the rise in humpback whale sightings in the Salish Sea over the last few decades (Keple 2002; Calambokidis et al. 2018; Miller 2020). The recent increase in humpback whale sightings is likely to have an impact on the other species in the marine ecosystem. Due to their large body size and their relative low position on the food chain (consumers of zooplankton including krill, and herring, sardines and other schooling fish), humpback whales must consume high densities of prey to meet their metabolic needs (Ford et al. 2009; Witteveen 2011). This means that they compete for the same forage fish that commercially important fish species (salmon) and other marine mammals also consume (Wedekin et al. 2017; Nordstrom et al. 2018). It is therefore important to continue monitoring humpback whales during this period of change to detect potential impacts of such a large consumer in the marine food web and the Boundary Pass ecosystem (Wedekin et al. 2017).

In comparison to the humpback whale, the Bigg's killer whale is an apex predator feeding on prey at higher trophic levels, such as marine mammals (Fisheries and Oceans Canada 2007). Although Bigg's killer whales are considered the same species as the SRKW, they are not considered direct competitors (Barrett-Lennard & Ellis 2001). Bigg's killer whales may even have a positive impact on controlling SRKW competitors including salmonid-eating harbour seal populations (Shields et al. 2018). Peak Bigg's killer whale presence in 2020 coincided with the pupping/weaning/post-weaning season of their prey, the harbour seal. This is consistent with previous studies where Bigg's killer whales target areas to maximise their overlap with the timing harbour seal pupping (Baird & Dill 1995; DFO 2013; Shields et al. 2018). Interestingly, the temporal presence of Bigg's killer whales in Boundary Pass in 2020 was not consistent with the timings of the 2019 observations in Le Baron et al. (2019). In 2019, the highest numbers of Bigg's were seen in June and July whereas these months had the lowest numbers of sightings in 2020. One potential cause for this may be due to the location of observers between years. This study had a direct line of sight of Boiling Reef where the killer whales often foraged, whereas the 2019 study did not. It may also indicate that Bigg's killer whale movement is dynamic throughout the summer and from year to year. Many Bigg's killer whale family groups exhibit site fidelity, usually remaining in a region for short periods of time (DFO 2013). Given the variation between years, Bigg's killer whales likely use the marine habitat differently, perhaps depending on prey life stages, movement patterns of other family groups and even presence of SRKW (Baird & Dill 1995).

For SRKWs, the low number of sightings in 2020 is not consistent with their historical spatial habitat use, although it is comparable with the number of sightings for these waters in 2019. This study aligns with recent findings of SRKW shifting from their historical core summer habitat in the Salish Sea (Olson et al. 2018). During the summer months in 2020, SRKW were detected in other areas such as Haro Strait and Swiftsure Bank, indicating that prey abundance may have been higher in other areas compared to the study area (Ford et al. 1998). Small vessel numbers are higher in summer compared to winter in the inner waters of the Salish Sea, peaking around August September (Veirs & Veirs 2015; McWhinnie et al. 2021). As vessel noise overlaps with the frequency bands used for SRKW communication and echolocation, vessel presence can mask or disrupt SRKW communication and foraging (Veirs et al. 2016; Cominelli et al. 2018). A final theory for the apparent change in summer distribution includes the change of leadership within the population due to the death of the matriarch J2 in 2016. All three of these factors combined with potential unknowns likely contribute to the summer suitability of Boundary Pass.

While the SSN observations are largely opportunistic and do not adhere to a strict survey protocol, they are invaluable in providing a more complete coverage of whale presence. They contributed an additional 53 whale sightings, increasing the number of detections outside of survey hours and expanding the coverage by 11 whale days within the LBCO survey period. The SSN have operated year-round since their formation in early 2020 and their protocols are expanding to include other Islands. Currently, due to the lack of absence or 'presence not detected' data and the limited detail of information that SSN collect, their data could not be included in all sections of analysis of this study. There is, however, an opportunity to train individuals to provide highly specific data collection in these regions. Developing and implementing a measurement of effort for this group would allow for more accurate comparisons with other datasets. This study further confirms the importance of collaborating with citizen scientist groups and how they can contribute to scientific research (Nordstrom et al. 2018).

Land-based or vantage-point surveys have a number of limitations including being limited to day light hours, and are very time intensive. Visibility was affected on some days by fog, heavy rain and/or smoke though surveys were not completely obstructed. Whale detectability confidence likely decreased with an increased distance of whales from shore (i.e., the detection function; see Buckland et al. 2004) and with an increase of sea state (i.e., wind and wave action). Other methods of whale detection include acoustic, photographic and infrared imaging methods (Guazzo et al. 2019; Zitterbart et al. 2020) though many of these require substantial budget input, equipment and maintenance. Whale detection methods generally perform better when a combination of multiple methods is employed and an increase in collaboration with other research groups (Smith et al. 2020).

Whale Overlap with Boundary Pass Shipping lane and Commercial Vessels

As vessel noise and physical disturbance are known threats to whales, it is critical to know how often whales overlap with high traffic areas (Lusseau et al. 2009; Williams et al. 2009; Harwood et al. 2016; Di Clemente et al. 2018). Boundary Pass forms part of the international shipping lane connecting the Pacific Ocean with the Strait of Georgia. This study provides data on how often whales were in close to proximity to commercial vessels and overlapped with the busy shipping channel. Whales were observed within 1000 m of large commercial vessels in 28.5% of sighting events; however, the proportion of all species sightings that intersected shipping lanes during this study was substantial (approximately 74%).

Compared to other whale species, humpback whales are often more at risk of vessel disturbance and collisions due to lack of echolocation and often erratic surface patterns (Calambokidis et al. 2019). Globally, humpbacks are recolonizing the areas where they were historically depleted, exhibiting positive population growths (Wedekin et al. 2017; Noad et al. 2019). Vessel strikes are an increasing threat to humpback whales, likely due to this increase in presence of humpbacks in coastal waters, as well as the increase in vessel traffic density and vessel strike reporting (Noad et al. 2019). A higher proportion of humpback whale calves and juveniles are casualties of vessel strike compared to adults (Capella et al. 2001; Lammers et al. 2013). Many collisions go unreported, particularly in large vessels where vessel strikes often go unnoticed (Lammers et al. 2013). With over 420 commercial vessel transits every month (over 14 transits per day), knowing when whales species (particularly humpback whales and calves) are most often observed in Boundary Pass can help focus mitigation strategies.

This study focussed on daytime observations and therefore there was no estimation of whale presence and vessel interactions during the night. The risk of vessel strike is higher at night (and during inclement weather) due to shipmasters' reduced visibility. Some whale species also have diurnal diving patterns, spending more time closer to the surface and diving shallower during the night (Calambokidis et al. 2019). Considering the increased risk of vessel strike at night, and that this study focusses on day time presence only, the estimation of vessel threats to whales over the 24-hour period is likely higher.

Small vessel interactions with whales and compliance of the ISZ

Small vessel noise, harassment and strike are potential threats to all marine mammals in the Salish Sea (Lusseau et al. 2009; Williams et al. 2009; Harwood et al. 2016; Di Clemente et al. 2018). The Southern Gulf Islands are a popular location for recreational vessels, particularly in the summer months (Veirs & Veirs 2015; McWhinnie et al. 2021). In this study, 60 events (52%) included small vessels within 1000 m of whales. In total, 247 small vessels were recorded during these 60 whale events. Many of these whale and vessel interactions appeared to be unintentional by the boater or some appeared to be unaware of whales in close proximity.

Active whale watching was likely reduced in 2020 with the delay in the start of ecotourism season and the closure of the Canada/US border due the COVID-19 restrictions (Transport Canada 2020a). When whales were detected in Canadian waters, many US ecotourism vessels were observed following the border. For SRKW, the count of vessels within close proximity to whale individuals was lower in 2020 (eight vessels during three events) compared to 2019 (58 vessels in six events) (Le Baron et al. 2019). This reduction was likely due to new regulations for Canadian whale watching companies to shift focus of tours from SRKW to other species, as well as the reduction in tourism and recreational vessels due to COVID-19 restrictions.

As mentioned previously, compared to other species, humpback whales are more commonly hit by vessels due to their size and behaviour (Laist et al. 2001; Calambokidis et al. 2019). Collisions that occur between these large whales and small vessels not only injure the whale but can also pose a significant risk to the vessel, crew and passengers (Noad et al. 2019). Peak collision rates have been found to increase with peaks in whale presence (Lammers et al. 2013). In the Salish Sea in recent years, ecotourism vessels were less likely to violate the maximum non-active approach distance to whales than recreational vessels (Fraser et al. 2020). Ecotourism vessel operators are likely to be more familiar with whale watching regulations and in some cases ecotourism vessels are seen as the stewards of the sea.

Specific rules and regulations related to vessel safety around whales vary per species (Be Whale Wise 2020). In Canada, stricter regulations exist for vessels near SRKW, due to their Endangered status. For example, vessels should not approach SRKW within 400 m within critical habitat (with some exceptions), whereas the distance is 200 m for Bigg’s killer whales or whales at rest/with calf, and 100 m for all other marine mammals. Regulations are different in US waters, and along with the Canadian regulations, are updated every few years. Given that the Salish Sea encompasses both Canadian and US waters, a standardised regulation approach between countries would ease understanding and compliance (Fraser et al. 2020).

Adaptability in management approaches takes into account dynamic conditions but it does make it difficult for the general public to keep up to date. Boater awareness is a critical component of management to reduce risk of vessel collisions. Education initiatives such as the “See a Blow – Go Slow” campaign led by the Marine Education & Research Society are crucial for providing access to Marine Mammal Regulations and promoting stewardship. As humpback whales continue to recolonize the inner waters of the Salish Sea, management strategies and boaters will have to adapt (Calambokidis et al. 2018; Miller 2020). Incorporating Marine Mammal Regulations in boating certification processes would be a positive step towards an awareness of whales, particularly in coastal waters.

To reduce small vessel noise and risk of vessel strike, ISZs were implemented in three locations within SRKW critical habitat. The purpose of the ISZs are to provide a safer area for the SRKW to forage and travel though. However, the distribution of SRKW has changed over recent years and they do not use Boundary Pass and the Saturna Island ISZ as frequently as historical records describe (Hauser et al. 2007; Olson et al. 2018). Although the SRKW may not currently use the ISZ, other species do use the area and are likely to benefit from the zone. Whale travel through the ISZ occurred in 44% of all sightings. Bigg’s killer whale pods were observed often in the ISZ, foraging at Boiling Reef and close along the shoreline of East Point. The humpback whale mother-calf pair also used the waters close to the East Point shoreline. Having the no-go zone likely reduced the risk of vessel strike for both the Bigg’s killer whale and humpback whales in this area in 2020. However due to the high number of violations, the relative quality of the ‘sanctuary’ could be improved.

A higher number of vessels were observed on weekends, although anecdotally weather appeared to be an important factor. Vessels counts were low when wind speed was higher (> 20 knots) near East Point. High wind speed near East Point combined with the local currents creates dangerous conditions for small boat travel. Boaters may choose to use more inland routes or avoid boating altogether in these conditions. From personal observations and discussions with DFO Fishery Patrol personnel, most vessel violations of the ISZ appeared to stem from a lack of knowledge of regulations rather than a deliberate entry of the no-go zone. Due to the COVID-19 pandemic, many education opportunities (e.g. boat shows, dock talks and local outreach) were delayed or cancelled completely, resulting in a general lack of awareness of regulations related to the ISZ.

Modifications were implemented in 2020 after public consultation, including the alteration of zone boundaries, the extension of ISZ duration by one month, and the introduction of a 20 m transit corridor along the shoreline for human powered vessels. These changes resulted in the reprinting and redistribution of education materials by Transport Canada, which again were delayed until after the zone came into effect.

Along with whale reports, the SSN also documented and reported many ISZ infractions, particularly in the southern part of the zone. In October 2020, the Canadian Coast Guard established a “Marine Mammal Desk” to support SRKW and other whales in the Salish Sea (Canadian Coast Guard 2021). Whale and vessel movement will be monitored through the use of multiple techniques including radar, AIS and real-time movement information from on the water (including SSN and BCCSN reports). All information will be shared with on-water personnel to increase enforcement (and disciplinary action) of marine mammal regulations and the ISZ.

Visual survey methods of compliance in ISZs are time intensive and constant visual monitoring of the area is required. Due to the size and location of the Saturna Island ISZ, multiple observers are also required to have full coverage of the zone. In comparison, the AIS method requires little effort and has full coverage of the ISZ and constant coverage day and night. However, as AIS transponders are not required on small recreational vessels, the number of violations by vessels recorded based on AIS data was expected to be less than through visual methods. The comparison between visual and AIS monitoring further confirmed that small vessels are largely underestimated in the Salish Sea (Hermannsen et al. 2019; Kline et al. 2020; McWhinnie et al. 2021). Due to the general underrepresentation of small vessels using AIS, this type of monitoring is not sufficient in determining vessel compliance in areas like the ISZ (Fournier et al. 2018; Kline et al. 2020). Lessons learned from other implementations of sanctuary zones indicate that these areas also need to be actively enforced rather than relying only on passive strategies (Howes et al. 2012).

Based on this study, it is recommended that multiple methods of monitoring be used to estimate compliance in vessel no-go zones. Small vessels should be monitored through a combination of methods including AIS monitoring and visual observations, as well as photographic and acoustic surveys. As visual monitoring is more time intensive, conducting multiple week-long intensive surveys during the ISZ active months would balance time efficiency with accurate coverage. AIS monitoring can be effective in some remote areas as it has the benefit of constant coverage, though it is limited to certain size/type of vessel (Rowlands et al. 2019; Depellegrin et al. 2020; McWhinnie et al. 2021). With community buy-in, groups like SIMRES (who reported many infractions to Transport Canada), and initiatives like the Marine Mammal desk can contribute to an active management strategy involving an increase in patrolling and enforcement of regulations. If constrained by budget or time, targeting weekends, public holidays and on fair weather days particularly in July through September would be most productive.

Noise levels in Boundary Pass

The COVID-19 pandemic had global impacts, significantly altering trade, tourism and human mobility (Depellegrin et al. 2020; Thomson & Barclay 2020). Reductions in vessel activity occurred globally (Depellegrin et al. 2020; Millefiori et al. 2021) and travel restrictions and national lockdowns reduced both international and local tourism. To investigate seasonal variations in noise and if any of these factors translated to a change in the underwater soundscape, acoustic analysis was conducted. Four lunar months covering two years (2019 and 2020) and two seasons (spring and summer) were chosen. Lower noise levels for spring lunar months were detected in both the PSD and TOL analyses compared to the summer lunar months in both years. These results indicate that there was a seasonal difference in the soundscape in the waters at East Point, Saturna Island in 2019 and 2020. Sharp spikes in the frequencies above 1 kHz in the PSD plots indicated the increase in presence of small vessel traffic. In general, the seasonal variation is consistent with the summer increase in AIS vessel transit data, as has been documented by other studies conducted in the Salish Sea (Veirs & Veirs 2015).

Comparing spring 2019 and 2020 acoustic data, the expected drop in noise levels as a result of COVID19 restrictions was not detected. The mean noise level in the 63 Hz TOL frequency band was 4.53 dB louder in spring 2020 as compared to 2019. This was consistent with the vessel transit data which showed an increase in spring 2020 in most of the commercial vessel groups. This was not consistent with the study by Thomson & Barclay (2020) that found a median weekly noise level reduction in the shipping band frequencies in the Strait of Georgia in the first quarter of 2020 compared to 2019. This difference may be due to different time periods (first quarter vs spring lunar month) or the location (Strait of Georgia vs Boundary Pass).

Comparing summer in 2019 and 2020, there was a difference in noise levels, in particular, a decrease in the 125 Hz PSD and TOL frequency. This is consistent with the AIS vessel transit data that showed a large decrease in both commercial, cruise ships and recreational vessel transits. Low frequency noise levels (10 to 500 Hz), have important ecosystem consequences (Hildebrand 2009). For example, humpback and minke whales are reliant on acoustic cues to evade predators such as Biggs killer whales. If the ambient noise levels are too high, this can make these large whales vulnerable to their predators as any noise from potential predators would be masked by high ambient noise levels. In addition to shipping noise masking important sounds from predators and conspecifics, shipping noise can also mask the sound of small vessels. When commercial vessels dominate the ambient noise spectrum with amplitude at low and moderate frequency bands, it can lead to the masking of small vessel noise and increase strike risk from small vessels on whales. It can lead to the reduction of small boat contributions to the ambient noise metrics.

Sound propagation properties should be kept in mind when interpreting seasonal differences in noise levels. Changes in sea surface temperature, which likely occur seasonally in this area, affect the sound speed profile. An increase in temperature can lead to an increase in both the speed and influence of the noise in the soundscape (Abdelrahman 1998; Urick 1979). No analysis was conducted comparing acoustic data and environmental variables. Natural sources can affect the TOL bands that are normally used to characterise vessel noise (Garrett et al. 2016; Warren et al. 2021). Further attention could be given to correlations between sound levels and environmental factors (e.g. sea state, wind, tidal activity, currents and rain).

While whales were only observed in close proximity (<1000 m) in 28.5% of observed events, the number of events where whales were impacted by noise produced by large commercial vessels is likely much higher. The potential decrease in sound levels during the ‘Anthropause’ would benefit marine life, particularly species that depend on sound for foraging, communication and navigation (Tyack 2008; Joy et al. 2019). Killer whales use higher frequency bands for echolocation and communication and are likely more impacted by the higher frequency noise produced by small vessels. Humpbacks use the same frequency bands for communication as the bands that shipping noise contributes to. As humpback whales generally migrate to lower latitudes in the winter, vessel noise reduction measures, such as the ECHO vessel slowdown can target specific periods of the year with peak whale presence. Although the ECHO vessel slowdown strategy was set up to benefit the SRKW and the start date is only initiated by the presence of SRKW, the program could be extended to encompass other species. If there is a seasonal peak in humpback presence (for example in June in this study), the slowdown could be shifted to cover this period of time, thereby reducing noise levels and risk of ship strike.

Globally, countries are beginning to set annual noise level threshold recommendations (i.e. the EU Marine Strategy Framework Directive) specifically in third octave bands 63 and 125 Hz frequencies, that shipping traffic contributes the most to (Tasker et al. 2010). The long-term effect of vessel noise is not fully understood for marine species, however the culmination of chronic noise and the stress associated from vessel disturbance may affect social dynamics and reproductive success, potentially leading to population level effects (Christiansen et al. 2013; Harwood et al. 2016).

Conclusion

This study indicates that each population has unique spatial and temporal usage of Boundary Pass and the waters around East Point, Saturna Island. For each species, movement through the Salish Sea is likely associated with prey abundance, pod-specific habitat usage and/or interactions between and within species (Payne et al. 1990; Baird & Dill 1995; Miller 2020). In 2020, this region was not only a corridor for whales but also an important habitat for humpback whale mother/calf pairs and Bigg's killer whale foraging. Although SRKW were only observed a few times between June and October 2020 in Boundary Pass, it is unknown how SRKW will use this area in the future and the historical significance of the area should not be overlooked.

All observed populations were documented using the shipping lanes, the higher risk area for large commercial vessel interactions. Although whales were seen in close proximity to large commercial vessels in less than a third of all events, the number of events where they were impacted by sound from vessels was likely much higher. Seasonal variations are evident in the underwater soundscape between spring and late summer. No clear difference was detected between sound levels in April/May between 2019 and 2020. A reduction in noise levels may have been detected in summer 2020 due to a reduction in large commercial and recreational vessels. Another factor to consider with the noise level reduction between years is the higher compliance rate during the ECHO programs vessel slowdown initiative.

Vessel compliance in Saturna Island ISZ was low in 2020. Visual survey methods were more accurate at estimating non-compliance in the ISZ and could be done in real-time, though this method was more time intensive than the AIS data analysis method. Targeting weekends, public holidays and fair-weather days would be the most time-effective periods for monitoring and enforcement. With the predicted increase in both commercial and recreational vessels in the future, it is important to continue ongoing vessel slowdown and vessel no-go zone initiatives to mitigate the overlap between whales and vessels.

Sanctuary zones may be beneficial at providing small scale refuges for marine species, however, they depend on compliance by vessel operators. Education campaigns and citizen scientist collaborations can help improve the spread of knowledge of vessel regulation and marine mammal guidelines. Increased education and awareness of these initiatives is crucial as their effectiveness can only be improved if regulations and guidelines are known by the users of the area.

Due to the related threats from vessel noise and disturbance on the species in this underwater ecosystem, restoring the habitat quality would require complete removal of vessels and shipping from the Boundary Pass. As this is not feasible for multiple reasons (global trade, human mobility, recreation), reducing vessel impacts is a realistic option. As noise levels and risk of vessel disturbance can be reduced by slowing down vessels this is an option for improving the habitat. Information gathered from whale distribution research such as in this work, can improve knowledge to predict whale presence in the future. This knowledge can inform management strategies, such as the seasonal commercial vessel slowdown, so that they can target periods of the year where whales are most at risk of vessel related threats.

Boundary Pass is a dynamic area which suggests that mitigation methods should be kept flexible to adapt to both current and future conditions paired with strong educational outreach and citizen scientist collaboration programs. While complete restoration of this ecosystem is not achievable, recommendations based from this study can help target current mitigation strategies and improve potential efficacy of the whale Sanctuaries.

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Appendix A. Supplementary Method Tables

Table A1. Breakdown dates for each survey weeks for both 2019 and 2020.

Week	Start Date	End Date
1	1 June	7 June
2	8 June	14 June
3	15 June	21 June
4	22 June	28 June
5	29 June	5 July
6	6 July	12 July
7	13 July	19 July
8	20 July	26 July
9	27 July	2 Aug
10	3 Aug	9 Aug
11	10 Aug	16 Aug
12	17 Aug	23 Aug
13	24 Aug	30 Aug
14	31 Aug	6 Sept
15	7 Sept	13 Sept
16	14 Sept	20 Sept
17	21 Sept	27 Sept
18	28 Sept	4 October

Table A2 Vessel classifications for AIS data analysis.

Vessel Groups	Vessels types	Spring 2019		Summer 2019		Summer 2020	
		Count transits	Count vessels	Count transits	Count vessels	Count transits	Count vessels
Number of missed days		3	3	0	0	0	0
Group 1	Cargo Container Bulk carrier	391	252	458	270	390	233
Group 2	Tanker Chemical carrier LNG carrier	33	22	24	15	35	24
Group 3	Fishing Dredger Reefer Tug	76	37	74	37	85	42
Group 4	Ferry Passenger - (>50 m)	30	22	15	9	0	0
Group 5	Government Research Naval Vessels	36	13	18	14	14	6
Group 6	Recreational Whale watching	164	84	332	220	263	160
Group 7	Other Misc.	2	2	1	1	0	0

Appendix B. Maps

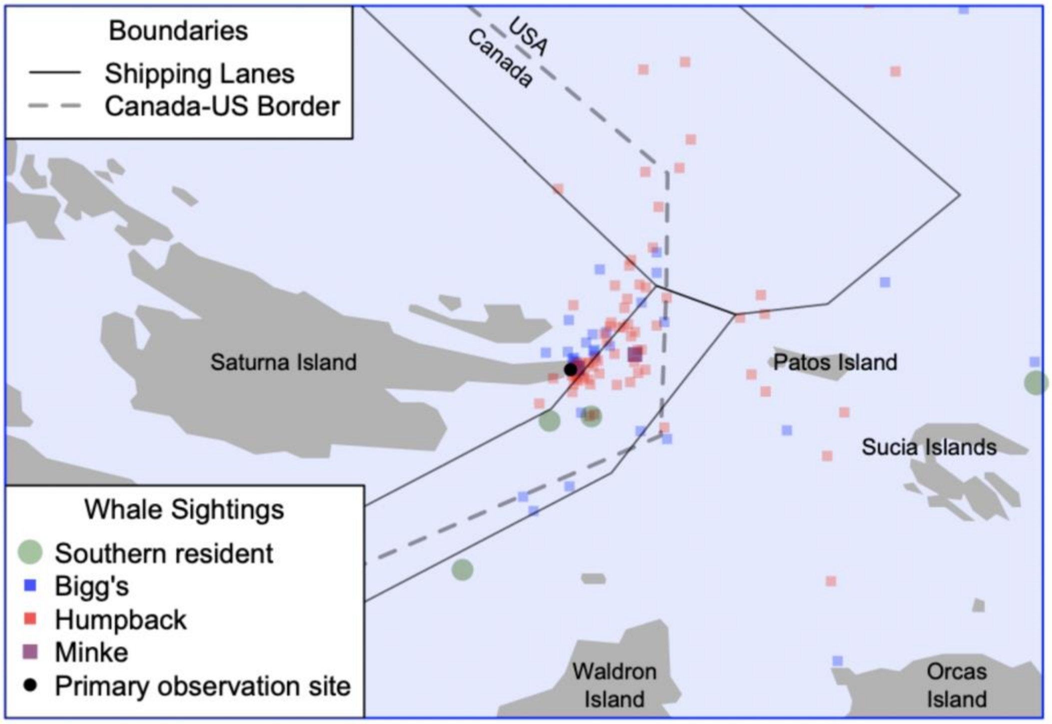

Figure B1 **Snapshot of whale positions as observed during LBCO survey between 1 June and 4 October 2020.**

Appendix C. Vessel and Whale Interactions

Table C1 Total count of vessels within 1000 m of whales during LBCO survey events, broken down into small vessels (ecotourism, recreational, sailboat motoring, government, research boats) and large vessels (container ship, bulk carrier, tanker, tug and Navy vessels).

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

Date	Daily event no.	Species/ population	Large vessel count	Small vessel count	Total vessel count	Vessel types
06-22-20	2	Humpback	1	2	3	1 container ship, 2 recreational vessels
06-22-20	3	Humpback	1	3	4	1 bulk carrier, 1 ecotourism vessel, 2 recreational vessels
06-22-20	4	Humpback	1	1	2	1 container ship, 1 ecotourism vessel
06-23-20	1	Humpback	1	0	1	1 bulk carrier
06-23-20	4	Humpback	1	0	1	1 tug towing
06-23-20	5	Humpback	0	1	1	1 ecotourism vessel
06-24-20	1	Bigg's	0	5	5	1 Parks vessel, 3 ecotourism vessels, 1 recreational vessel
06-24-20	2	Humpback	0	2	2	2 recreational vessels
06-24-20	4	Humpback	0	3	3	1 Straitwatch, 1 sailboat motoring, 1 recreational vessel
06-24-20	5	Humpback	0	1	1	1 RCMP
06-25-20	1	Humpback	3	1	4	1 container ship, 2 bulk carriers, 1 sailboat motoring
06-25-20	2	Humpback	3	7	10	1 container ship, 1 tanker with tug escort, 4 ecotourism vessels, 2 recreational vessels, 1 sailboat motoring
06-27-20	1	Humpback	2	13	15	1 container ship, 1 tanker, 6 ecotourism vessels, 2 recreational vessels, 3 Government vessels, 2 sailboats motoring
06-27-20	2	Humpback	1	0	1	1 bulk carrier
06-28-20	1	Humpback	0	2	2	2 recreational vessels
06-28-20	2	Humpback	1	2	3	1 bulk carrier, 1 recreational vessel, 1 sailboat motoring
06-29-20	1	Humpback	0	1	1	1 recreational vessel
07-02-20	1	Humpback	1	0	1	1 container ship
07-06-20	2	Bigg's	0	16	16	14 ecotourism vessels, 2 recreational vessels
07-12-20	2	SRKW	1	0	1	1 bulk carrier
07-12-20	3	Humpback	0	2	2	2 recreational vessels
07-13-20	1	SRKW	0	5	5	5 ecotourism vessels (in US waters)
07-17-20	2	Bigg's	2	11	13	1 tanker with tug escort, 9 ecotourism vessels, 1 fishery patrol, 1 recreational vessel
07-24-20	1	SRKW	0	3	3	1 fishery patrol, sailboat motoring, 1 ecotourism vessel

Date	Daily event no.	Species/ population	Large vessel count	Small vessel count	Total vessel count	Vessel types
07-24-20	2	Humpback	5	0	5	1 bulk carrier, 1 container ship, 3 Navy ships
08-01-20	1	Bigg's	0	13	13	9 ecotourism vessels, 4 recreational vessels
08-05-20	2	Bigg's	0	2	2	2 ecotourism vessels
08-05-20	3	Bigg's	0	13	13	11 ecotourism vessels, 2 recreational vessels
08-12-20	1	Bigg's	0	3	3	2 ecotourism vessels, 1 recreational vessel
08-13-20	1	Bigg's	0	5	5	4 ecotourism vessels, 1 recreational vessel
08-13-20	2	Bigg's	1	17	18	1 bulk carrier, 1 Straitwatch,1 Soundwatch, 8 ecotourism vessels, 7 recreational vessels
08-13-20	3	Bigg's	0	3	3	3 ecotourism vessels
08-16-20	1	Humpback	0	1	1	1 recreational vessel
08-17-20	1	Humpback	0	5	5	4 ecotourism vessels, 1 sailboat motoring
08-22-20	1	Bigg's	0	10	10	Many ecotourism vessels (est. due to distance)
08-24-20	1	Bigg's	0	10	10	Many ecotourism vessels (est. due to distance)
08-25-20	1	Bigg's	0	3	3	2 Parks vessels, 1 RCMP
08-25-20	2	Bigg's	0	4	4	2 ecotourism vessels, 1 RCMP, 1 Border Patrol
08-25-20	3	Bigg's	0	10	10	Many ecotourism vessels (only estimate due to distance)
08-26-20	1	Humpback	0	2	2	1 Parks vessel, 1 recreational vessel
08-26-20	2	Bigg's	1	3	4	3 recreational vessels, 1 container ship
08-28-20	1	Bigg's	0	5	5	4 ecotourism vessels, 1 Parks vessel
09-04-20	1	Bigg's	0	4	4	3 recreational vessels, 1 sailboat motoring
09-05-20	2	Bigg's	1	0	1	1 bulk carrier
09-06-20	1	Bigg's	0	12	12	1 Soundwatch/Straitwatch, 4 ecotourism vessels, 6 recreational vessels, 1 sailboat motoring
09-07-20	1	Bigg's	0	1	1	1 sailboat motoring
09-10-20	2	Minke	0	1	1	1 recreational vessel
09-17-20	1	Bigg's	0	1	1	1 ecotourism vessel

Date	Daily event no.	Species/ population	Large vessel count	Small vessel count	Total vessel count	Vessel types
09-19-20	1	Bigg’s	2	0	2	1 container ship, 1 bulk carrier
09-19-20	2	Bigg’s	1	3	4	1 Navy, 1 recreational vessel, 2 ecotourism vessels
09-27-20	1	Humpback	0	1	1	1 recreational vessel
10-04-20	2	Humpback	0	1	1	1 recreational vessel

Appendix D. Acoustic Data

Table D1 Mean sound level (dB) for third octave level frequencies bands.

TOL Frequency Band (Hz)	2019		2020	
	Spring (dB)	Summer (dB)	Spring (dB)	Summer (dB)
10	56.04	55.31	55.88	55.26
12.5	55.47	54.80	55.44	54.83
16	55.34	54.71	55.55	54.69
20	57.94	57.10	57.80	57.24
25	59.35	58.42	59.27	58.52
31.5	60.28	59.19	59.94	59.36
40	61.90	60.70	61.49	60.78
50	64.51	63.15	63.96	63.13
63	77.59	99.67	82.13	97.56
80	66.65	65.32	66.10	65.24
100	67.92	66.77	67.15	66.69
125	68.39	76.99	67.61	70.59
160	69.30	68.85	68.26	68.64
200	71.93	87.54	73.37	86.33
250	71.34	72.56	69.96	70.57
315	71.86	78.30	71.06	76.73
400	71.97	77.50	71.44	77.21
500	72.81	74.47	71.71	73.86
630	73.73	74.83	72.33	75.49
800	75.63	75.37	74.01	75.84
1000	77.09	76.07	75.59	75.95
1250	76.20	75.72	75.24	75.40
1600	77.78	75.92	75.90	74.18
2000	78.32	76.80	76.49	74.29
2500	78.05	76.86	76.07	74.31
3150	77.79	77.10	76.11	75.06
4000	77.56	76.85	75.78	75.56
5000	77.56	76.83	75.74	76.29
6300	76.59	76.04	74.93	76.02
8000	76.11	75.59	74.60	75.83
10000	75.66	75.35	74.25	75.66
12500	74.97	74.82	73.72	75.25
16000	74.05	74.07	73.07	74.54
20000	73.31	73.49	72.39	73.78