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Analysis of Southern Resident Killer Whale Management Measures Surrounding Saturna Island

SRKW from J pod breaching on July 4, 2023. Photo taken from shore on Saturna Island by Lauren Laturnus

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By:
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Analysis of Southern Resident Killer Whale Management Measures Surrounding Saturna Island

Final Report

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Executive Summary

Since 2019, Transport Canada has implemented a series of management measures in Southern British Columbia, Canada to limit the effect of vessel disturbance on the endangered Southern Resident killer whales (SRKW). This includes but is not limited to, two Interim Sanctuary Zones (ISZ), located off the southwest coast of Pender Island, BC and the southeast peninsula of Saturna Island, BC, which act as vessel no-go zones from June 1st to November 30th, annually. Following recommendations received through formal engagement processes, which highlight Tumbo Channel as a potential significant foraging area for SRKW and currently lacking sufficient protection from vessel traffic and noise disturbance, Transport Canada is assessing the potential of expanding the existing Saturna ISZ through Tumbo Channel to Boat Passage, BC. The purpose of this report is to assess the potential implementation of the following management measures:

1. Maintaining the status quo (current ISZ)
2. Expanding the ISZ through:
   a) Tumbo Channel to the western tip of Tumbo Island
   b) Tumbo Channel to the western tip of Tumbo Island and continuing 0.5 nm off the Saturna coast to Boat Passage
3. Maintain the current ISZ boundaries but convert to a Speed Restricted Zone (SRZ)
4. Maintain the current ISZ boundaries and convert to a Speed Restricted Zone and expand the Speed Restricted Zone through:
   a) Tumbo Channel to the western tip of Tumbo Island
   b) Tumbo Channel to the western tip of Tumbo Island continuing 0.5 nm off the Saturna coast to Boat Passage

5. Maintain the existing ISZ and add an SRZ through Tumbo Channel to the western tip of Tumbo Island or continue along the coast to Boat Passage

The proposed management measures would apply to most vessels, with some exceptions aligned with the current ISZ.

This report details spatial use of the area of interest (AOI) by both SRKW and small commercial and recreational vessels within the ISZ operational period as well as 12 acoustic propagation simulations to demonstrate relative change in sound pressure level (SPL) between the different management options. The vessel noise acoustic propagation model is used in tandem with a forecast model of SRKW movement to illustrate the potential received SPL by an individual SRKW from small commercial and recreational vessels within the AOI.

The results indicate that the lowest received SPL occurs when vessels travel at 10 knots in the scenarios simulating management measures 1, 2, and 5, where they do not enter the preexisting ISZ. Therefore, creating a quieter environment for SRKW. Moreover, management option 5 of maintaining the current ISZ and limiting vessel speed elsewhere is the recommended option as this provides a reduction in vessel impacts to SRKW and may not significantly disrupt vessel traffic. The majority of AIS-equipped vessels transiting through the area are already moving at speeds of 10 knots or less and this change will not result in rerouting any vessels, which may create more vessel impacts in other areas with moderate to high SRKW use.

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Glossary

1/3-octave-band

Non-overlapping passbands that are one-third of an octave wide (where an octave is a doubling of frequency). Three adjacent 1/3-octave-bands comprise one octave. One-third-octave-bands become wider with increasing frequency.

AOI

Area of interest.

automatic identification system (AIS)

A radio-based tracking system whereby vessels regularly broadcast their identity, location, speed, heading, dimensions, class, and other information to nearby receivers.

BCCSN

British Columbia Cetacean Sightings Network.

broadband sound level

The total sound pressure level measured over a specified frequency range. If the frequency range is unspecified, it refers to the entire measured frequency range.

cetacean

Any animal in the order Cetacea. These are aquatic, mostly marine mammals and include whales, dolphins, and porpoises.

class B vessels

Vessels that are either passenger-type or, that are eight metres or more in length and carry a passenger that must be fitted with a Class B AIS device.

decibel (dB)

One-tenth of a bel. Unit of level when the base of the logarithm is the tenth root of ten, and the quantities concerned are proportional to power.

ECHO

Enhancing Cetacean Habitat Observations

frequency

The rate of oscillation of a periodic function measured in cycles-per-unit-time. The reciprocal of the period. Unit: hertz (Hz). Symbol: f. 1 Hz is equal to 1 cycle per second.

hertz (Hz)

A unit of frequency defined as one cycle per second.

ISZ

Interim sanctuary zone.

KDE

Kernel density estimate.

L95

The lower 95th percentile of a distribution. It represents the point at which 95% of the data fall below, and 5% fall above.

maximum (max) speed

Represented in this report by the L95 speed of the respective vessel class and size.

Mysticetus

A computer software developed by MYSTICETUS LLC that, when connected to a theodolite and calibrated to GPS coordinates of known local landmarks, can determine the geographical location of an object, e.g., vessel or whale.

SFU

Simon Fraser University

source level (SL)

The sound level measured in the far-field and scaled back to a standard reference distance of 1 metre from the acoustic centre of the source. Unit: dBre 1 μPam (pressure level) or dB re 1μPa2·sm(exposure level).

sound speed profile

The speed of sound in the water column as a function of depth below the water surface.

sound pressure level (SPL)

The decibel ratio of the time-mean-square sound pressure, in a stated frequency band, to the square of the reference sound pressure.

speed over ground (SOG)

The speed of a vessel (knots) through water with respect to the ground or any other fixed object.

SRZ

Speed restricted zone.

SRKW

Southern Resident killer whale.

theodolite

A surveying instrument with a rotating telescope for measuring horizontal and vertical angles.

1. Introduction

The Southern Resident killer whale (SRKW) population has experienced a severe decline from 98 individuals in 1995 to 75 individuals as of July 2023, and has been listed by the Species at Risk Act (SARA) in Canada as endangered since 2003. (Center for Whale Research 2023, DFO 2011). SRKW live and travel together in matriarchal social groups called pods; there are three pods: J, K, and L (Ford 1991). Due to their endangered status and small population size, there are concerns about the long-term survival of this population (DFO 2011).

In order to support the survival of this species, the Government of Canada has implemented a number of management measures, including laws, regulations, and voluntary measures, in the waters of southern British Columbia (BC). To address vessel impacts, the establishment of Interim Sanctuary Zones (ISZ) in the Salish Sea commenced in 2019 as a result of the *Interim Order for the Protection of the Killer Whale (Orcinus orca) in the Waters of Southern British Columbia* and continues on an annual basis (Government of Canada 2023 a).[1] Currently, two ISZs exist within the Southern Gulf Islands of BC, west of South Pender Island and southeast of the eastern peninsula of Saturna Island (Government of Canada 2023 a). These interim marine protected areas aim to serve as a refuge for SRKW, with most vessels being prohibited from entering and fishing in the zones from June 1st to November 30th (Government of Canada 2023 a). A number of exceptions apply and include but are not limited to, a vessel avoiding immediate or unforeseen danger, a vessel in distress or assisting another vessel or person in distress, or a vessel being used to fish in accordance with a

[1] For more information on the Interim Order and exemptions please see the Interim Order for the Protection of the Killer Whale (Orcinus orca) in the Waters of Southern British Columbia.

license issued under the *Aboriginal Communal Fishing License Regulations* or for domestic purposes under section 35 of the *Constitution Act*, 1982.[2]

In 2023, Transport Canada received recommendations through their formal engagement and consultation process[3] to expand the existing Saturna Island ISZ to include Tumbo Channel through to Boat Passage (Figure 1, Figure 2). The recommendation was founded on the concern that Tumbo Channel is a key foraging area for marine mammals, including SRKW, and is not adequately protected from vessel traffic and noise disturbance. Vessel disturbance has been recognized as one of the three primary factors hindering the recovery of SRKW in addition to lack of prey availability and environmental contaminants (Holt et al. 2021).

Vessel presence can cause changes in SRKW foraging, resting, socializing, or travelling behaviours that result in increased energy expenditure or decreased time and ability to capture prey (Williams et al. 2009, Lusseau et al. 2009, Holt et al. 2021, Williams et al. 2021). In light of these negative effects vessels impose on SRKW, data show SRKW still highly use areas of heavy vessel traffic (Thornton et al. 2022 b). This underscores the importance of these areas as SRKW still rely on them despite significant acoustic disturbance and highlights the importance for protections of these areas to provide refuge in the most effective locations for the conservation of this endangered population (Thornton et al 2022 b).

1.1. Study Overview

This study analyzes the use of the designated area of interest (AOI) surrounding Saturna Island (Figure 1) by SRKW pods and small commercial and recreational vessels. This study investigates how different noise mitigation measures implemented

[2] For more information on the rights of Indigenous peoples in Canada see section 35 of the Constitution Act, 1982.
[3] For more information on the consultation process see Summary of input provided on management measures to address key threats to Southern Resident killer whales (Government of Canada 2023 b)

to improve whale habitat might change ambient noise levels in this AOI, and noise levels received by SRKW. In particular, this study examines the impact of specific mitigations on noise levels experienced by SRKW in the AOI, considering varying vessel sizes and speeds. The aim is to assess the existing ISZ's effectiveness and to evaluate potential changes to the ISZ that could further mitigate impacts from vessels on the SRKW population.

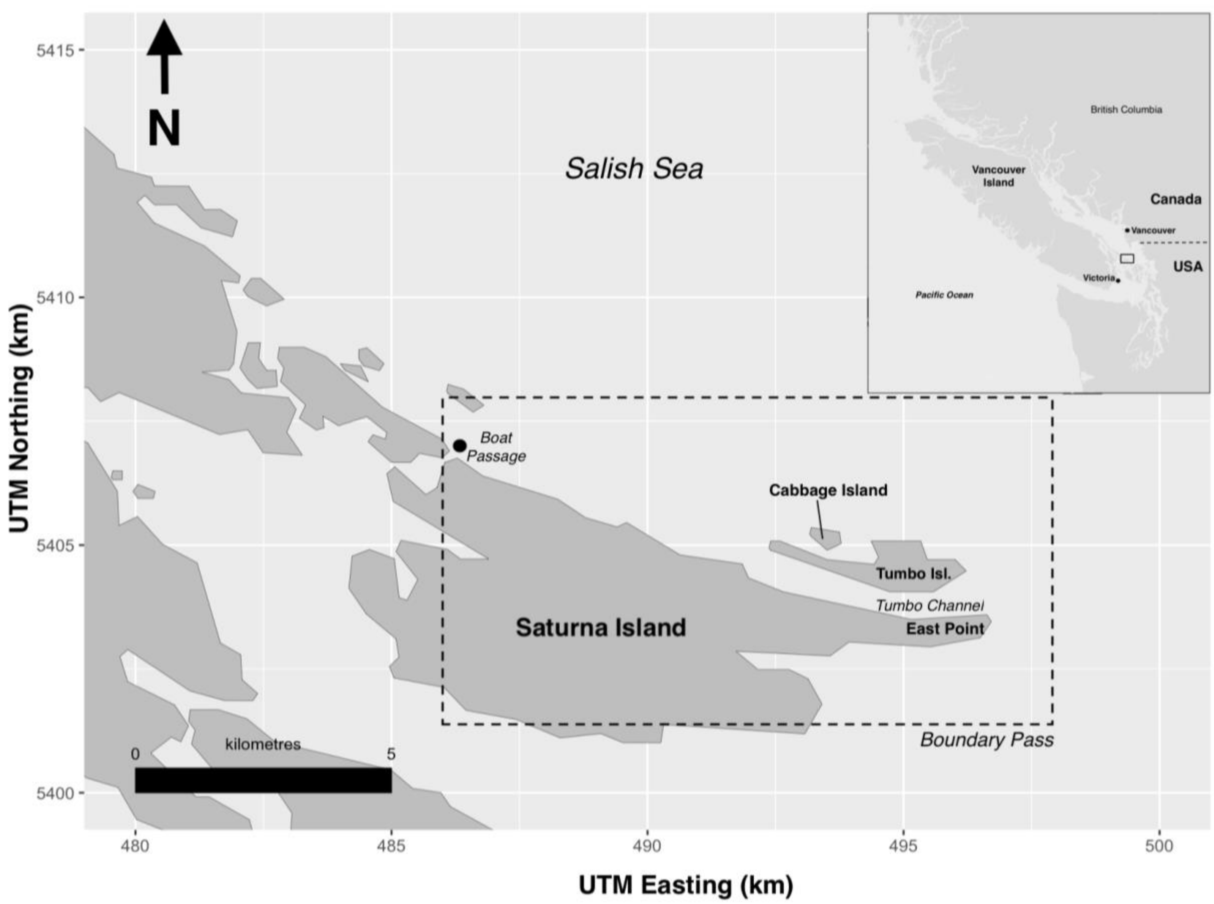

Figure 1. Map displaying the area of interest of the analysis of Southern Resident killer whale management measures surrounding Saturna Island, outlined in a dashed line. Important features within the area of interest include East Point of Saturna Island, Boat Passage, Tumbo Island, Tumbo Channel, and Cabbage Island.

The proposed management options include:

1. Maintaining the status quo (current ISZ)
2. Expanding the ISZ through:
    a. Tumbo Channel to the western tip of Tumbo Island
    b. Tumbo Channel to the western tip of Tumbo Island and continuing 0.5 nm off the Saturna coast to Boat Passage
3. Maintain the current ISZ boundaries but convert to a Speed Restricted Zone (SRZ)
4. Maintain the current ISZ boundaries and convert to a Speed Restricted Zone and expand the Speed Restricted Zone through:
    a. Tumbo Channel to the western tip of Tumbo Island
    b. Tumbo Channel to the western tip of Tumbo Island continuing 0.5 nm off the Saturna coast to Boat Passage
5. Maintain the existing ISZ and add an SRZ through:
    a. Tumbo Channel to the western tip of Tumbo Island
    b. Tumbo Channel to the western tip of Tumbo Island continuing 0.5 nm off the Saturna coast to Boat Passage

An analysis of SRKW use of the AOI utilizes multiple archived datasets of reported SRKW sightings. An analysis of vessel activity in the area of interest utilizes datasets for vessels with an Automatic Identification System (AIS) and datasets for vessels without AIS, herein referred to as non-AIS vessels. A total of 12 acoustic propagation simulations of vessel tracks throughout the AOI demonstrate the relative change in sound pressure level between the listed management options. Collaboratively, a forecast model of SRKW movement and the vessel noise acoustic propagation model are used to illustrate the potential received sound pressure level by an individual SRKW from small commercial and recreational vessels in the area. These analyzes focused on evaluating the impacts of the proposed management measures on underwater noise in the AOI and that received by an individual SRKW travelling through the AOI. A comprehensive high-level literature review supplements the analyzes in the study to provide recommendations for management measures.

2. Literature Review

The Southern Resident killer whale (SRKW) has been on the Endangered list under the Species at Risk Act since 2003 and has experienced a decline from 98 individuals in 1995 to 75 individuals as of July 1, 2023 (Center for Whale Research 2023, DFO 2018). SRKW are a clan of killer whales of the Resident ecotype that also comprises the Northern Resident clan (Barrett-Lennard & Ellis 2001). Northern and Southern Residents are genetically distinct from each other; Northern Residents are found from central Vancouver Island to Alaska, and Southern Residents from Washington state to central Vancouver Island (Barrett-Lennard & Ellis 2001, Krahn et al. 2002).

Resident killer whales live and travel together in matriarchal social groups called pods (Ford 1991). The SRKW clan has three pods, J, K and L (Ford 1991). As of July 1, 2023, K-pod had the smallest population, comprising 16 individuals, followed by J-pod with 25 individuals, and L-pod, which had the highest population at 34 individuals. (Center for Whale Research 2023). Areas frequently used by SRKW in the Salish Sea during the summer have been designated critical habitat for SRKW, including Boundary Pass and the southern portion of the Strait of Georgia which are the surrounding waters of East Point on Saturna Island (DFO 2017).

The Salish Sea is also home to killer whales of the Transient (Bigg's) and Offshore ecotypes, and a plethora of other cetaceans including but not limited to harbour porpoises, Dall's porpoises, humpback whales, Pacific white-sided dolphins, minke whales, and grey whales. SRKW are unique from other whales in the Salish Sea due to their extensive acoustic repertoires made up of whistles, pulsed calls which they use to communicate with members of their pods, and echolocation clicks which they use to locate prey (Ford 1987, Ford 2017, Holt et al. 2021, Erbe 2011). Additionally, SRKW life history traits such as old age of first reproduction and low calving rates lead to low maximum rates of increase and less resiliency to exploitation when compared to other cetacean species (Wade et al. 2012). It is also suggested that killer whales are susceptible to social disruption as they rely on leadership from older individuals to find scarce prey resources, communal nursing, and knowledge transfer can be lost through the removal of older individuals (Wade et al. 2012). It has been shown that specific individuals are more important than others in maintaining the social structure of SRKW (Wade et al. 2012). As SRKW engage in extensive, targeted movements to intercept specific salmon runs, adapting to variable oceanic conditions, knowledge and technique from experienced older individuals likely benefit this population (Wade et al. 2012). Varied matrilines possess distinct cultural knowledge, which may prove more or less beneficial amid changing ocean conditions (Wade et al. 2012).

There are three main identified threats that are impacting SRKW; lack of prey availability, vessel disturbance, and environmental contaminants, or polychlorinated biphenyls (PCBs) (Holt et al. 2021, Lacy et al. 2017, DFO 2021). A literature review focusing on the effect of recreational and small commercial vessels on SRKW was conducted, as this has been identified as the easiest factor to mitigate (Williams et al. 2023, Lacy et al. 2017). While large commercial shipping vessels have been identified as the most ubiquitous source of noise pollution (Viers et al. 2018), it is not a focus of this analysis and literature review.

Cetaceans are considered to be highly sensitive and susceptible to acoustic disturbance as this group of marine mammals require production and perception of acoustic information throughout every stage of their life cycle (Cominelli et al. 2018, Clark et al. 2009, Gabriele et al. 2018). Similar to other odontocetes, or toothed whales, SRKW utilize echolocation for foraging and perception of their surroundings. (Holt et al. 2021). Sound is also used in a variety of complex social interactions including mother calf interactions, interactions among pod and clan members, and vocal learning from generation to generation (Cominelli et al. 2018, Clark et al. 2009). When the frequency of anthropogenic noise pollution overlaps with that of a species' hearing range, acoustic disturbance occurs.

SRKW, and other marine mammals, have been documented to change their behaviour in response to marine vessel disturbance (Gabriele et al. 2018, Holt et al. 2021, Veirs et al. 2018). Marine vessel disturbance includes both direct and indirect disturbance, through physical presence, vessel strikes and noise pollution. (Raverty et al. 2020). Changes in behaviour can occur through changes in foraging, resting, socializing, or methods of travelling that result in increased energy expenditure or decreased time and ability to capture prey (Williams et al. 2009, Lusseau et al. 2009, Holt et al. 2021, Williams et al. 2021).

Noise Disturbance

In the Salish Sea, ambient noise levels have increased significantly due to increasing vessel presence and use. Vessel noise is the dominant source of anthropogenic, or human caused, noise pollution in the ocean, including noise in the frequency range that killer whales use for communication and echolocation (Veirs et al. 2016, Williams et al. 2023, DFO 2021). The effect of increased ambient noise is more acute in Resident killer whales than other marine taxa as they are a highly acoustic species, with an underwater hearing range of 100 to 160,000 Hz, for comparison, human hearing in air ranges from 20 to 17,000 Hz (Branstetter et al. 2017, Purves et al. 2001). In response to increased ambient noise, killer whales increase the amplitude of their calls (Clarke et al. 2009, Holt et al. 2009). Noise pollution that affects the behaviour and/or distribution of a major species can have cascading effects throughout the entire ecosystem (Buxton et al. 2017).

Vessel noise is often in the same frequencies as those used by SRKW and has reduced the majority of SRKW available communication space, translating to habitat loss (Veirs et al. 2016, Williams et al. 2014). This reduction of communication space can span up to 14 km from the source of the boat noise (Foote et al. 2004). The noisiest sections of the Salish Sea cause SRKW to lose up to 97% of their acoustic communication in the band of 1500 to 3500 Hz (Williams et al. 2014). Williams et al. (2014) notes that SRKW living in these noisy environments are losing a substantial amount of the opportunities to communicate. This has resulted in an increase in energy expenditure in order to be heard by other pod members, or themselves when echolocating, this is a phenomenon termed the Lombard effect (Williams et al. 2014, Holt et al. 2009).

This documented increase in communication effort means this endangered population must expend additional energy in order to effectively forage, as this is done using echolocation (Holt et al. 2021, Holt et al. 2009). This is suspected to be one of the main factors contributing to the lack of recovery of SRKW in the Salish Sea (Williams et al. 2021, DFO 2021). Studies have shown that SRKW spend significantly less time foraging and more time travelling when a boat is operating within 400 m of the whale (Lusseau et al. 2009). This could result from a decrease in their echolocation range as the distance between the whale and a motorized vessel decreases (Lusseau et al. 2009). As echolocation is a high frequency acoustic behaviour, it is likely more negatively affected, or masked, by the high frequency noise of an outboard motor following the whale, than low frequency background noise from commercial shipping (Lacy et al. 2017).

SRKW have a high degree of foraging specialization due to their dependance on a single prey species (Ford et al. 2010). These foraging specializations are passed through generations, in addition to pod-specific vocalizations (Ford et al. 2010). Most changes to the soundscape have occurred over the lifetime of an individual, preventing selection and adaptation and leaving few, if any, options for SRKW to successfully communicate and echolocate in areas with high anthropogenic noise disturbance (Clark et al. 2009). Lacy et al. (2017) demonstrated with a Population Viability Analysis that removing acoustic disturbance, while maintaining current Chinook population levels, would allow for SRWK population growth to reach 1.7% annually, coming very close to reaching the 1.9% recovery target. There is no evidence to show that any odontocetes population can increase at a rate greater than 4% per year (Wade et al. 2012)

Whales perform more surface-active behavior (SAB) when in proximity to vessels under motor, compared to stationary vessels, providing further evidence that vessel noise may play a role in SRKW behavior (Noren et al. 2009). SABs include but are not limited to; tail slaps, pectoral fin slaps, breaching, porpoising, spy hopping. It has been suggested that this increase in SABs is caused by SRKW attempting to transfer information to other individuals non-verbally when acoustic communication ability is reduced (Noren et al. 2009). In addition to vessel noise created from propulsion, active echosounder signals (sonar signals used for navigation and fishing) can also cause SRKW to increase prey capture dive times, and/or dive slower, altering foraging behaviour (Holt et al. 2021).

It has been suggested that behaviour changes in SRKW may occur at SPL levels at or above 110 dB. A vessel noise model used to examine the Salish Sea sound field found that SPL levels were above this threshold and noise levels were greatest around Discovery Island, Haro Strait, and Boundary Pass (Vagle et al 2021). These areas contain the shipping lanes, where large commercial ships such as bulk carriers and container ships transit through. The vessel noise additions were greater in the upper 20 metres of the water column and within the frequencies used in echolocation, which could have significant implications for successful foraging (Vagle et al 2021). A restriction of this model is that it was limited to only AIS Class A vessels. Therefore, a large portion of higher frequency vessel noise produced by smaller, recreational vessels is unaccounted for. In an effort to fill the gaps in vessel traffic data, aerial surveys have been conducted to quantify the proportion of vessel traffic without AIS. After 78 surveys across the central portion of the Salish Sea, it was found that 70% of the vessels sighted were not equipped with AIS, and they were predominantly recreational and fishing vessels (Serra-Sogas 2021). It is an ongoing endeavour to better represent these noise sources in noise modelling (Vagle et 2021).

Physical Disturbance

The presence of all vessels in the Salish Sea has been increasing for at least two decades (Seely et al. 2017). Commercial whale watching vessels increased 50% from 1998 to 2015, however Canadian commercial whale-watching vessels viewing SRKW decreased by 90% during the summers of 2018-2020. (Seely et al. 2017, Perkovic & Poirier 2021). The significant decrease in Canadian whale watch vessel presence around SRKW may be attributed to Transport Canada's Sustainable Whale Watch Authorization (SWWA), where commercial whale watch and ecotour operators were given the opportunity to be exempt from the 400-metre distance requirement for Transient (Bigg's) killer whales, on the basis that the naturalists on board are able to distinguish between the two ecotypes of killer whales (Transport Canada 2019). In order for the exemption to be approved, the whale watch vessel must agree to not follow SRKW, thus reducing the risk of both physical and acoustic disturbance to the whales (Transport Canada 2019). While the SWWA resulted in fewer Canadian whale watching vessels present during SRKW events, in 2020 it was observed that the most common vessel type present within 400 metres of SRKW were commercial whale watching operators from the US (Perkovic & Poirier 2021). During the summers of 2018-2020, the top violation of SRKW regulations involved vessels being within 100 metres of SRKW, and these incidents were primarily committed by private motor vessels, demonstrating that non-compliance to minimum distance measures remains a persistent problem (Perkovic & Poirier 2021).

As overall vessel activity continues to rise, this results in more frequent human and wildlife interactions. This increase in vessels in the Salish Sea caused a 6.5-fold increase in vessel incidents and violation of SRKW regulations from 1998-2012 (Seely et al. 2017). This increase in violations was not reflective of commercial whale watching vessels as there was evidence of a significant downward trend of commercial whale watching violations from 1998 to 2015, and private recreational vessels were the most likely to commit an incident between 2006 to 2015 (Seely et al. 2017). The number of private recreational vessels present within 400 metres of SRKW dropped by 71% from the summers of 2018-2020 (Perkovic & Poirier 2021). Recreational vessels such as pleasure crafts, sailboats, fishing vessels, and kayaks opportunistically watch whales, and their presence may increase the probability of whale-vessel disturbance as they may lack the knowledge of how to safely navigate around whales. Following a survey of recreational boaters in the Salish Sea, it was found that 61% were unaware of marine mammal distance regulations (Fraser et al. 2020). It is estimated that 500,000 individuals interact with whales annually through either commercial whale-watching vessels or recreational boats (Fraser et al. 2020). It has however been observed that the number of vessels present within 400 metres of SRKW decreased by 69% from the summer of 2018 to 2020 (Perkovic & Poirier 2021). Commercial whale watching vessels are responsible for 65% of vessels observed by Soundwatch to be within 0.8 kilometres of whales, and since 2002, incidents with kayakers have increased (Seely et al. 2017). It is also important to note that the values reported in the Straitwatch and Soundwatch reports may represent an underestimation of true incident rate as the presence of a marked “authoritative” vessel may act as a deterrent, in addition to their efforts of educating boaters about marine mammal regulations.

This increase in vessels and violation of regulations affects SRKW. It has been documented that SRKW alter diving, movement patterns, and behavioural activity states when in the presence of vessels (Holt et al. 2021, Noren 2009, Williams et al. 2009). In many cetacean species, a reduction in foraging is a common response to vessel disturbance (Senigaglia et al. 2016, Williams et al. 2023, Thornton et al. 2022 a, Lacy et al. 2017). In the presence of vessels, SRKW have been documented to transition from foraging behaviour to travelling behaviour and are less likely to begin foraging at all (Williams et al. 2009, 2021).

SRKW, and other cetaceans, have been documented to increase SABs as vessels approach and vessel counts increase (Williams et al. 2009, Noren 2009). These behaviours are energy intensive, and studies suggest that approximately 50% of the time they are performed, it can be attributed to vessel distance and behaviour (Noren 2009). SRKW have also been documented to change their path of travel with increased presence of vessels and increased proximity (Williams et al. 2009). Evidence suggests that as vessels approach SRKW, their path becomes less direct (Williams et al. 2009). As whales attempt to evade vessels, they alter their swimming paths and potentially increase energy expenditure (Williams et al. 2009). As the number of vessels increase, the path becomes more direct again, suggesting that methods of evading vessels may not be effective when many boats are present (Williams et al. 2009).

SRKW have been documented to increase their dive times as the number of vessels within 400 metres increased (Williams et al. 2009). Changes in dive times affect respiration rates and breathing patterns and this has been observed and recorded by Willaims 2009. There are, however, inconsistent results reported in various studies. This may be explained by observations conducted by Williams et al. (2009) that indicate inter-breath interval increasing when vessels in low numbers (1-6) and decreasing with vessels in high numbers (12 or more).

In addition to causing behavioural changes, vessels have the ability to cause mortality or injury by direct strike (Thornton et al. 2022 a). Direct vessel strikes are a risk to the SRKW population and are dependent upon vessel speed (Thornton et al. 2022 a). Increasing vessel speed increases the chance of whale mortality if struck (Thornton et al. 2022 a). The literature provides conflicting vessel speeds that will result in mortality from a strike, ranging from 11-18 knots (Thornton et al. 2022 a, DFO 2021). Thornton et al. (2022 a) suggests that identifying areas within SRKW critical habitat that have high densities of vessels travelling at elevated speeds will allow for risk assessment of this threat.

Management Measures

Existing management measures implemented in Canada in 2023 to support the recovery of SRKW include: interim sanctuary zones, area-based fishery closures, speed restricted zones, minimum 400 metre vessel avoidance distances from SRKW in Southern BC waters, prohibiting vessels from impeding the path of all killer whales in Southern BC waters and, voluntary large commercial vessel slowdowns and lateral displacement areas within the designated shipping lanes directed by the ECHO program, (Government of Canada 2023 a, Vancouver Fraser Port Authority 2023). There are two interim sanctuary zones first implemented in 2019, one off the coast of Pender Island and the other off the coast of Saturna Island (Government of Canada 2023). These areas were chosen for increased protection from physical and acoustic disturbance as they were deemed key portions of SRKW foraging areas (Government of Canada 2023 a). Vessels are prohibited from transiting or fishing in interim sanctuary zones between June 1 - November 30 with limited exceptions for Indigenous fishing for food, social or ceremonial purposes, vessels involved in emergency response, and human powered vessels transiting through an assigned corridor (Government of Canada 2023 a). In area-based fishery closures, recreational and commercial salmon fishing is prohibited during the specified timeframe, which can vary per area based on SRKW activity (Government of Canada 2023 a). In speed restricted zones, vessels speed is limited to no more than 10 knots from June 1 - November 30 with limited exceptions (Government of Canada 2023 a). The voluntary vessel slowdowns, led by ECHO, are initiated by the first reported sighting of SRKW in the Salish Sea starting June 1 and continue until SRKW are deemed to be no longer present in the Salish Sea for the season or November 30. Once the slowdown is initiated, it is recommended that commercial vessels voluntarily reduce speed to 11 knots or less for bulkers, tankers and government vessels or 14.5 knots or less for container vessels, vehicle carriers and cruise ships (Vancouver Fraser Port Authority 2023).

Numerous studies have evaluated the efficacy of SRKW management measures. Voluntary commercial vessel slowdowns tend to have a higher compliance rate than interim sanctuary zones; however, ISZ infractions by vessels with AIS are predominately committed by Class B non-commercial vessels (Burnham et al. 2021, Burnham & Vagle 2023). Unsuccessful exclusion of vessels in ISZs limits their efficacy in reducing underwater sound levels (Burnham & Vagle 2023). However, compared to a control period, background and median noise was still reduced in the interim sanctuary zones in the SRKW communication and echolocation frequencies (Burnham et al 2021). Noise disturbance is determined by a temporal overlap between the source of the noise and an animal (Veirs et al. 2018). While reducing speed increases the likelihood of a temporal overlap, this is often outweighed by the benefits including a decreased risk of collision (Veirs 2018).

Identifying and protecting areas of significant importance to killer whales is a crucial management measure (DFO 2021). Protected areas aim to limit human disturbances while preserving critical habitats and promoting the overall health of the ecosystem they encompass. However, the area must be large enough to be biologically meaningful for the whales while also being small enough to effectively manage human activities within the boundaries (Ashe 2010). Capron et al (2023) suggest that the Pender and Saturna Island ISZs do not offer the highest impact potential for protecting SRKW foraging grounds in their core summer habitat. This is based on there being little evidence for observed foraging activity within these areas. In addition, the ISZs are not large enough to serve as refuges for foraging, as SRKW typically spread out to up to 10 km^2 and engage in active foraging for up to 2 – 3 hours (Capron et al 2023). As SRKW have been observed to be in this spread-out pattern in Boundary Pass, this supports that the ISZs are not currently large enough (Quayle 2021). However, in scenarios of idealized vessel compliance, the Saturna Island ISZ has the capacity to reduce noise levels within by 2.2 (±1.1) dB when audiogram weighted for SRKW hearing range (Matthews & Grooms 2021). Matthews & Grooms, (2021) also explains how ISZs cause a significant increase in sound around their perimeter due to the displacement of vessels, however noise within the zones is decreased and SRKW likely transit quickly through the area of increased noise, and spend more time within the ISZ, resulting in a net reduction in sound exposure.

It is suggested that areas around the mouth of the Fraser in the Strait of Georgia, and the Strait of Juan de Fuca around East Sooke, Race Rocks, or South of Victoria, should be considered for protected areas as 10% of SRKW sightings have occurred in these locations and foraging is also known to occur (Capron et al. 2023). However, as these areas are also important for many different stakeholders, they may not be suitable as full exclusion zones. A more adaptive approach may include slow-down zones or no-go zones only if SRKW are present. This management option aims to accommodate boating traffic, while also protecting killer whales within their critical habitat (Capron et al. 2023).

With 80% compliance, slow down zones that limit vessels to 12 knots lower monthly-average noise levels, potentially benefiting SRKW (Matthews & Wladichuk 2022). Matthews & Wladichuk (2022) found that in areas of Swiftsure Bank, the greatest improvement of communication space is in the echolocation band, which can be improved up to 4.7dB by reducing vessel speed 7-10 knots. This is a greater improvement than reducing speed to 12 knots, which results in 3.5dB improvement. Comparatively, in the communication band and broadband, noise improvements were 0.5 and 0.7dB respectively. However, even small changes to the broadband and communication bands can greatly improve acoustic environments for SRKW as reducing sound by 0.5dB decreases acoustic intensity by 15% (Matthews & Wladichuk 2022). For many ships, a 1 knot reduction in speed leads to 1 dB reduction in broadband underwater source level (Veirs et al., 2016). These results may be underestimated through an under-representation of non-AIS vessels (Matthews & Wladichuk 2022).

The following paragraph describes findings from Thornton et al. (2022 a) and references therein. These findings are interpreted from models at a spatial scale of the entire critical habitat. The waters surrounding Saturna Island have been identified as critical habitat for SRKW and the ISZ and Tumbo Channel represent areas of 80-90% frequency of SRKW occurrence in the entire critical habitat June through September. This area also represents co-occurrence of all AIS vessels and SRKW intensity. Boat Passage is identified as an area of less than 70% frequency of SRKW occurrence for this period. All of the waters surrounding Saturna Island have been identified as an area where SRKW are likely to travel opposed to forage. These occurrence and behaviour findings are supported by DFO (2021). Models indicate that the Saturna ISZ area represents an area of 0 available SRKW communication space of 10,000 Hz communication range and 50,000 Hz echolocation range in the summer and this impact changed little with depth from 7.5-150m. It is suggested that these results are caused by proximity to the shipping lanes. Tumbo Channel and Boat Passage appear to retain 100% of available communication space in both the communication and echolocation ranges.

Seely et al. (2017) states that in the presence of an enforcement vessel, marine mammal regulation violations show a dramatic decrease. However, presence of Fisheries and Oceans Canada (DFO) enforcement during SRKW events was less than 1% in the summers of 2018-2020 (Perkovic & Poirier 2021). Enforcement efforts in US waters were significantly greater, where vessels from Washington Department of Fish and Wildlife (WDFW) were present in 19% of the SRKW events (Perkovic & Poirier 2021).

Overarching themes in the literature are the need for protected areas that take into consideration the entire system, and to mitigate man-made noise to maintain high quality acoustic habitats (Gabriele et al. 2018, Gaydos et al. 2015). While small, protected areas with reductions in ocean noise provide refuge and benefits for SRKW, they are dependent on a healthy ecosystem (Gaydos et al. 2015). Concurring threats such as lack of prey availability and vessel impacts require comprehensive adaptive management strategies to allow for the best opportunity for SRKW survival. Being a transboundary species with critical habitat extending beyond Canadian waters, SRKW may be left vulnerable without collaborative decision making (Gaydos et al. 2015). Knowledge gaps should not be a barrier to management action (Lacy et al. 2017). There is evidence that odontocete populations lack strong recovery in heavily exploited populations and management of these populations, such as SRKW, should be proactive and precautionary rather than reactive (Wade et al. 2012).

Management of noise in areas of ecological importance fit into two categories identified by Buxton et al. (2017): reducing noise in areas of high pollution and protecting quiet areas. Williams et al. (2014) notes that protecting quiet areas by keeping them quiet may be easier than trying to remove noise from heavily polluted areas and the implementation of management measures that reduce vessel noise will allow SRKW to have an increased proportion of time spent foraging if prey are available (Williams et al. 2023). Minimizing vessel disturbance is important because the acute changes in behaviour caused by vessels can have long-term consequences for SRKW individuals and the population (Lusseau & Bejder 2007). Furthermore, SRKW may be most adversely affected by disturbance because they tend to stay in areas of disturbance due to their prey often being highly aggregated (Gill et al. 2001, Noren et al. 2009). Reducing vessel speeds, moving all boats away from the whales, increasing enforcement of protected areas and marine mammal regulations, and closing some areas to fishing are all essential to the population’s recovery (Williams et al 2021, Perkovic & Poirier 2021).

3. Methods

3.1. Study Area

Saturna Island is located in the Southern Gulf Islands of British Columbia, Canada. The Saturna Island Interim Sanctuary Zone (ISZ) is off the southern coast of the eastern end of Saturna Island (Figure 2), in Boundary Pass. The area of interest for this study (Figure 1) encompasses the Saturna Island ISZ (Figure 2) and coastal waters to the north of Saturna Island from Tumbo Channel up to Boat Passage. Boundary Pass is an international shipping route for vessels travelling to and from the Port of Vancouver. This analysis is focused on small commercial and recreational vessels transiting through the area of interest and omits noise or physical disturbance caused by large commercial vessels.

3.2 Management Measures

This study provides analyses to evaluate the following potential management measures to support the recovery of Southern Resident killer whales (SRKW) around Saturna Island:

1. Maintaining the status quo (current ISZ)
2. Expanding the ISZ through:
    a. Tumbo Channel to the western tip of Tumbo Island
    b. Tumbo Channel to the western tip of Tumbo Island and continuing 0.5 nm off the Saturna coast to Boat Passage
3. Maintain the current ISZ boundaries but convert to a Speed Restricted Zone (SRZ)
4. Maintain the current ISZ boundaries and convert to a Speed Restricted Zone and expand the Speed Restricted Zone through:
    a. Tumbo Channel to the western tip of Tumbo Island

   b. Tumbo Channel to the western tip of Tumbo Island continuing 0.5 nm off the Saturna coast to Boat Passage
5. Maintain the existing ISZ and add an SRZ through:
   a. Tumbo Channel to the western tip of Tumbo Island
   b. Tumbo Channel to the western tip of Tumbo Island continuing 0.5 nm off the Saturna coast to Boat Passage

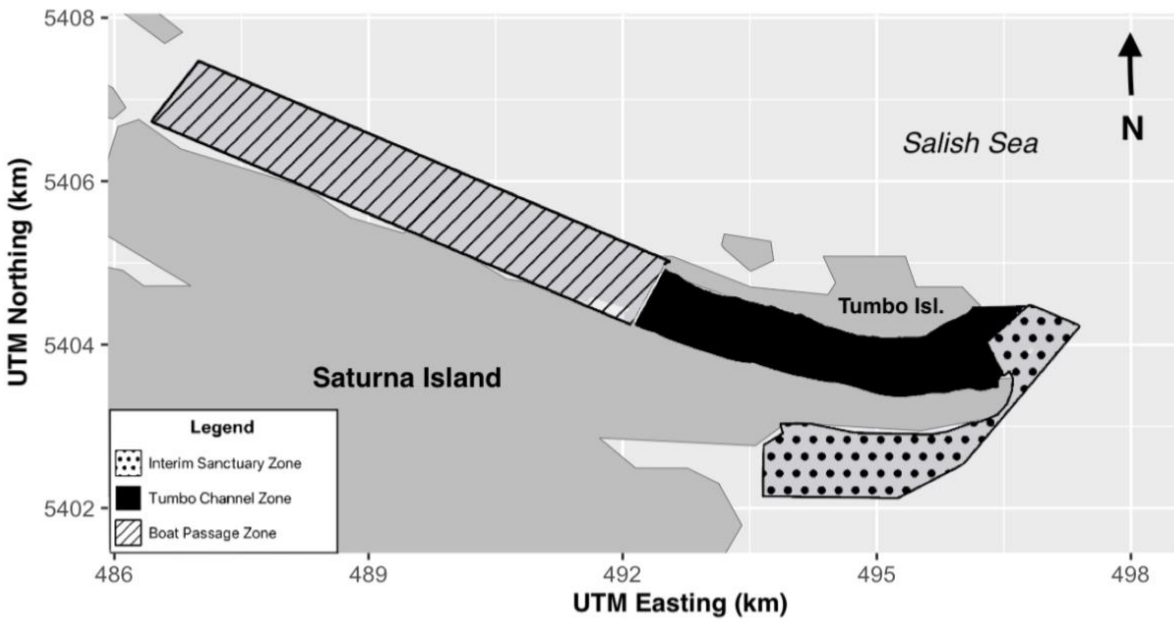

Figure 2. Map of the area of interest for the analysis of SRKW management measures surrounding Saturna Island. This map depicts the existing Interim Sanctuary Zone and two zones proposed for new or extended management measures, Tumbo Channel Zone, and Boat Passage Zone.

To assess these management measures, three geographic zones have been designated for analysis. These include the established Saturna Island ISZ, and two zones identified for this report: the Tumbo Channel Zone and the Boat Passage Zone (Figure 2). The Tumbo Channel Zone spans the entirety of Tumbo Channel, the easternmost point located between Saturna and Tumbo Islands at the westernmost edge of the current ISZ and extending west through Tumbo Channel to its westernmost point at the western entrance to Tumbo Channel. This is the easternmost edge of the Boat Passage Zone, which extends 0.5 nautical miles off the coast of Saturna Island from the western end of Tumbo Island northwest to Boat Passage. SRKW sighting density and vessel activity were assessed individually in each of these zones.

3.3. Analysis – Use of Area of Interest by SRKW

3.3.1. General Trends in SRKW Use

To analyze how SRKW use varies in the AOI, and to decipher monthly and annual trends, SRKW sightings data reported during the ISZ active period of June 1 to November 30 from both the Orca Master 2012-2022 and BCCSN 2002-2022 sightings datasets were combined. These datasets can include multiple reported sightings of the same whale event. Sightings data were synthesized into “whale days” in the AOI for each pod to prevent over-estimation of SRKW use of the AOI due to the multiple sightings reported for unique events. “Whale days” were calculated by summing the number of days each pod was reported in the AOI each week through the period of 2002-2022. Weeks began on Sunday and ended on Saturday. If multiple sightings of the same pod were reported on the same day, these were only considered as one whale day. If multiple pods were seen on the same day, they were considered one whale day each for each pod, but only contributed to a single whale day overall. The proportion of each pod's presence in the AOI during all whale days in the dataset was determined by dividing the pod specific whale days by the overall whale days, including unknown pod reports. The proportions of each pod’s whale days added together does not equal 1 as on some occasions, multiple pods were seen on the same day. Monthly and annual whale days during the ISZ active period is presented to illustrate trends in sightings in the AOI per month and per year over two decades.

Sightings with no pod identification, but were identified as SRKW, were also reported and included in our analysis. Whale days with unidentified pod sightings were only included as such if there were no pod identified sightings on the same day. Additionally, if there were pod identified sightings on the same day as sightings with no pod identification, the pod identified sightings took precedence and the unknown pod sightings were not counted for those days.

3.3.2. Kernel Density Estimate

To assess SRKW habitat use of the AOI, Kernel Density Estimation (KDE) was used. This is a well-established method of assessing a species' habitat use (Worton 1989). Datasets used in the KDE analysis included sightings reported during the months of June through November from the BCCSN from 2002-2022 and Orca Master from 2012-2022. Some sightings reported within these datasets are derived from the same source. Therefore, duplicates of sighting reports were removed so that only one of each sighting report remained for analysis. The months of June through November were analyzed as this represents the period in which the current ISZ is operational. A non-parametric two-dimensional KDE was computed using the kde2d function from the MASS package in R software (Venables & Ripley 2002).

To maintain smoothness while allowing for a multimodal distribution with multiple whale sighting hotspots, a bandwidth of 2000 metres was used. To prevent edge blending effects at the perimeter of our analysis, data from a larger area than the AOI was utilized, and the final KDE figure was cropped to the extent of the AOI. The larger region contained a total of 562 SRKW sightings, and 454 of these SRKW sightings were matched to the region of our AOI.

3.3.3. Movement Modelling

To demonstrate SRKW movement through the AOI, this study utilizes a novel stochastic animal movement model described in greater detail in Lin (2023). This model is guided by a historical database of SRKW sighting records from the Whale Museum Orca Master dataset from 2012 - 2022. Archived (historical) trajectories were compiled and spatially indexed to provide information about direction and velocity across SRKW habitats in the Salish Sea. Given the initial location and swimming velocity, probable trajectories of SRKW can be simulated. Specifically, it makes use of a continuous-time velocity-based Ornstein-Uhlenbeck (O-U) process to simulate SRKW trajectories. The velocity-based O-U process uses a random variable corresponding to animal velocity and models the instantaneous change in velocity. To ensure whale trajectories reflect typical movement pathways, the model utilizes a direction blending scheme that incorporates historical directional pathways by blending this information with the O-U velocity process to create more probable pathways consistent with observed SRKW movement patterns. Since velocity is the prognostic variable, the whale positions along a track are obtained by integrating the velocity process (Patterson et al. 2017).

154 sighting points in the AOI were used as the initial locations of simulated trajectories as these represent known whale locations. These initial locations were all located within the three zones in the area of interest that represents each proposed management measure; the current ISZ, a proposed ISZ extension or speed restricted zone through Tumbo Channel (Tumbo Channel Zone), and a proposed ISZ extension or speed restricted zone through to Boat Passage 0.5 nm offshore (Boat Passage Zone) (Figure 2). Direction of travel was assigned to each initial location based on what was associated with the reported sighting in the dataset, if there was no reported direction of travel, it was assigned a direction towards either the ISZ, Tumbo Channel Zone or Boat Passage Zone. For one realization or trajectory, one location was randomly sampled from the 154 initial locations, and the movement of SRKW was modelled forward in time in 3-minute time increments or “steps”.

1,500 trajectories of possible SRKW movement were simulated through the AOI, each for a 60-minute duration. These 1,500 trajectories were utilized in Section 3.4.3 to assess the relative impact of each management measure along these SRKW trajectories. For a visual map of the simulated whale trajectories see Appendix A. Figure A1.

3.4. Analysis – Use of Area of Interest by Small Commercial and Recreational Vessels

3.4.1. Vessel Activity Analysis

Vessel activity in the AOI was analyzed using data from Automatic Identification System (AIS) equipped vessels and using direct observations of vessels without AIS transponders in the AOI by authors of this report (henceforth referred to in this report as non-AIS vessels). AIS is an onboard navigation safety device that transmits the location and characteristics of the vessel to maritime authorities and other vessels, for the purpose of collision avoidance and safety. In Canada, vessels that are certified to carry more than 12 passengers or that are eight metres or more in length and carry a passenger must be fitted with either a Class A or B AIS device. Due to the prohibitive cost, and installation requirements for AIS class A devices, recreational and smaller vessels generally use AIS Class B, and are herein referred to as Class B vessels (Navigation Safety Regulations 2020 Sec. 118 (2)). Commercial shipping or Class A vessels are not included in this analysis.

Class B AIS vessel data from June through November for 2021 and 2022 was acquired from the United States Coast Guard through AccessAIS with assistance from Quayle Consulting. Non-AIS vessel data was collected systematically through land-based observations using a DT200 TOPCON theodolite from September and October 2022 and June through August 2023. During these periods, an SFU primary observer (and coauthor of this report) was stationed at East Point on Saturna Island and used the theodolite to track non-AIS vessel position in both the ISZ and the immediate area surrounding the ISZ boundary (Appendix, Figure. B1). This specific area was chosen by SFU researchers when collecting data of vessels in and around the ISZ to gain a greater sense of non-ais vessels who purposefully avoid entering the ISZ.

A vessel was identified as non-AIS if they did not appear in real time on the Marine Traffic Application (MarineTraffic 2023). When a non-AIS vessel entered the compliance zone or the ISZ, the vessel class was recorded, and between one and three coordinates of the vessel's location were obtained, while it was transiting the observation area, using the theodolite connected to a computer with Mysticetus software. The theodolite and Mysticetus use calibrated angles between local landmarks with known GPS points to measure the geographical position of targeted vessels.

Class B AIS vessel data was acquired from the same dates, times, and observation area as the non-AIS vessel surveys done by SFU researchers during September and October of 2022 and June through August of 2023. Each unique AIS vessel and each unique non-AIS vessel were counted once per day in the observation area to contribute to the total vessel count, regardless of how many times they entered the observation area that day (for counts see Appendix B, Table B1). These counts were used to determine the proportion of Class B AIS and non-AIS vessels in the monitored area using the following calculations (referred to as Step 1 for later reference):

Step 1:

$$N = n\,(\text{non-AIS}) + n\,(\text{AIS})$$

$$\text{Proportion of AIS Vessels} = n\,(\text{AIS}) \div N$$

$$\text{Proportion of non-AIS Vessels} = n\,(\text{non-AIS}) \div N$$

Where N is the total vessel count, n (non-AIS) is the count of non-AIS vessels, and n (AIS) is the count of AIS vessels.

As non-AIS vessel counts were not available for the entire AOI, the calculated proportion of AIS to non-AIS vessels in the SFU observation area was extrapolated to the entire AOI to calculate total estimated vessel counts for June through November of 2021 and 2022 (for total estimated counts see Appendix B, Table B2). This proportion was extrapolated under the assumptions that the ratio in the entire AOI would be similar to the SFU observation area, and that it would not vary significantly between years. This extrapolation was performed given the relatively small area of the AOI and the observation that AIS equipped vessels similarly to vessels of the same class within the entire AOI, as demonstrated in Figure 13 of the results. It is assumed that all vessels of the same class behave similarly whether equipped with AIS or not. Like the counts used to calculate the proportion, each unique vessel in the Class B AIS dataset for June through November of 2021 and 2022 were counted once per day in the observation area to contribute to the total vessel count, regardless of how many times they entered the observation area that day. Total vessel counts and non-AIS vessel count for June through November of 2021 and 2022 were estimated using the following calculations (referred to as Step 2 for later reference):

Step 2:

$$\approx N = n\,(\text{AIS}) \div \text{Proportion of AIS Vessels}$$

$$\approx n\,(\text{non-AIS}) = \approx N \times \text{Proportion of non-AIS vessels}$$

Where ≈N is the estimated total vessel count, n (AIS) is the actual count of AIS vessels, and ≈n (non-AIS) is the estimated count of AIS vessels. The proportions of AIS vessels and non-AIS vessels are calculated in Step 1.

The following vessel classes were considered in the vessel activity analysis: Pleasure Craft (PL), Passenger Vessel (PA), Sailing (SA), Fishing (FI), Enforcement (EN), and Other (OT). For AIS type codes included in each class see Appendix B. Table B3 and Appendix B. Table B4 for the enforcement vessels that were included in the non-AIS observations by SFU researchers. A passenger vessel is defined as a vessel that carries more than 12 passengers and is required to be fitted with an AIS device (Navigation Safety Regulations 2020 Sec. 118 (2)). The Class B AIS vessels in the passenger vessel class are mostly composed of ecotourism or whale-watching vessels.

The Fishing vessel class only includes commercial fishing vessels and does not include pleasure craft vessels taking part in recreational fishing. There were zero passenger, fishing, or other type vessel classes counted that did not have AIS during the SFU non-AIS vessel survey. Since the composition of the vessel classes for non-AIS vessels is different than that of AIS vessels, the proportion of each type of vessel within the non-AIS data is calculated (see Appendix B, Table B2 for non-AIS count by vessel class).The following equation was used to calculate the proportion of each vessel class in the non-AIS vessel survey (referred to as Step 3 for later reference):

Step 3:

$$\text{Proportion of VC} = n\ (\text{non-AIS VC}) \div n\ (\text{non-AIS vessels})$$

Where Proportion of VC is the proportion of a vessel class, n (non-AIS VC) is the count of the non-AIS vessels in that vessel class from the SFU non-AIS vessel survey data, and n (non-AIS vessels) is the count of all non-AIS vessels in the SFU non-AIS vessel survey data.

The proportion of each non-AIS vessel class is then used to calculate the estimated total count of each vessel class in June through November of 2021 and 2022 using the following equations (referred to as Step 4):

Step 4:

$$\approx n\ (\text{non-AIS VC}) = \approx n\ (\text{non-AIS}) \times \text{Proportion of VC}$$

$$\approx n\ (\text{VC}) = n\ (\text{AIS VC}) + \approx n\ (\text{non-AIS VC})$$

Where ≈n (non-AIS VC) is the estimated count of non-AIS vessels in a vessel class, ≈n (non-AIS) is the estimated total count of non-AIS vessels as calculated in Step 2, the proportion of VC is the proportion of the vessel class as calculated in Step 3, ≈n (VC) is the estimated total count of vessels of that class, and n (AIS VC) is the actual count of AIS vessels of that class.

The estimations and calculations in Step 2 and Step 4 were done separately for monthly and yearly counts in order to analyze both monthly and annual variation. The monthly analysis of vessel use was also looked at for each proposed management measure zone individually.

The Class B AIS data includes additional details such as speed over ground (SOG) and vessel length. This information is valuable as the speed of a vessel and its length play an important role in determining the noise level it generates. Violin plots were used to portray the density estimation of the measured SOG in knots of each vessel class travelling within the AOI. This method of analysis was applied to provide a more comprehensive representation of the speed data distribution, as it combines the elements of a boxplot and a kernel density plot. The boxplot displays the median and the spread of the data, and the width of the 'violin' shows the density of the data, where a wider section represents higher density. Vessel lengths were broken up into different categories, as outlined in MacGillivray et al., 2014. These categories include Over 25 m, 10 to 25 m, 5 to 9 m, under 5 m, and unknown length. The SOG and lengths of each vessel type were examined for the entire AOI, the ISZ, as well as the Tumbo Channel and Boat Passage Zones.

Class B AIS vessels have transceivers that automatically broadcast information regarding their position at regular intervals. To enhance understanding of vessel movement within the AOI, the Class B AIS data was separated by vessel class and track lines were created using R software by connecting consecutive vessel positions provided at each timestamp.

3.4.2. Noise Modelling

To demonstrate how each potential management measure (Current ISZ, Tumbo Channel Zone, Boat Passage Zone) impacts received levels of sound by whales produced by small commercial and recreation vessels, an acoustic propagation model was used to propagate sound from an estimated source level along simulated whale trajectories. This vessel-generated noise was calculated along three hypothetical vessel tracks and propagated into the AOI. The first vessel track extends from inside the Westernmost point of the current ISZ, travels through the ISZ, through the Tumbo Channel Zone, and through Boat Passage Zone, herein referred to as “Inside” (Figure 3a). The second vessel track extends from outside the Westernmost point of the current ISZ, travels around the ISZ, enters Tumbo Channel and, travels through the Tumbo Channel Zone and through Boat Passage Zone, herein referred to as “Status Quo” (Figure 3b). The third and final vessel track extends from outside the Westernmost point of the current ISZ, travels around the ISZ, and travels North of Tumbo Island outside of the Tumbo Channel Zone, and remains on course outside of the Boat Passage Zone, herein referred to as “Outside” (Figure 3c).

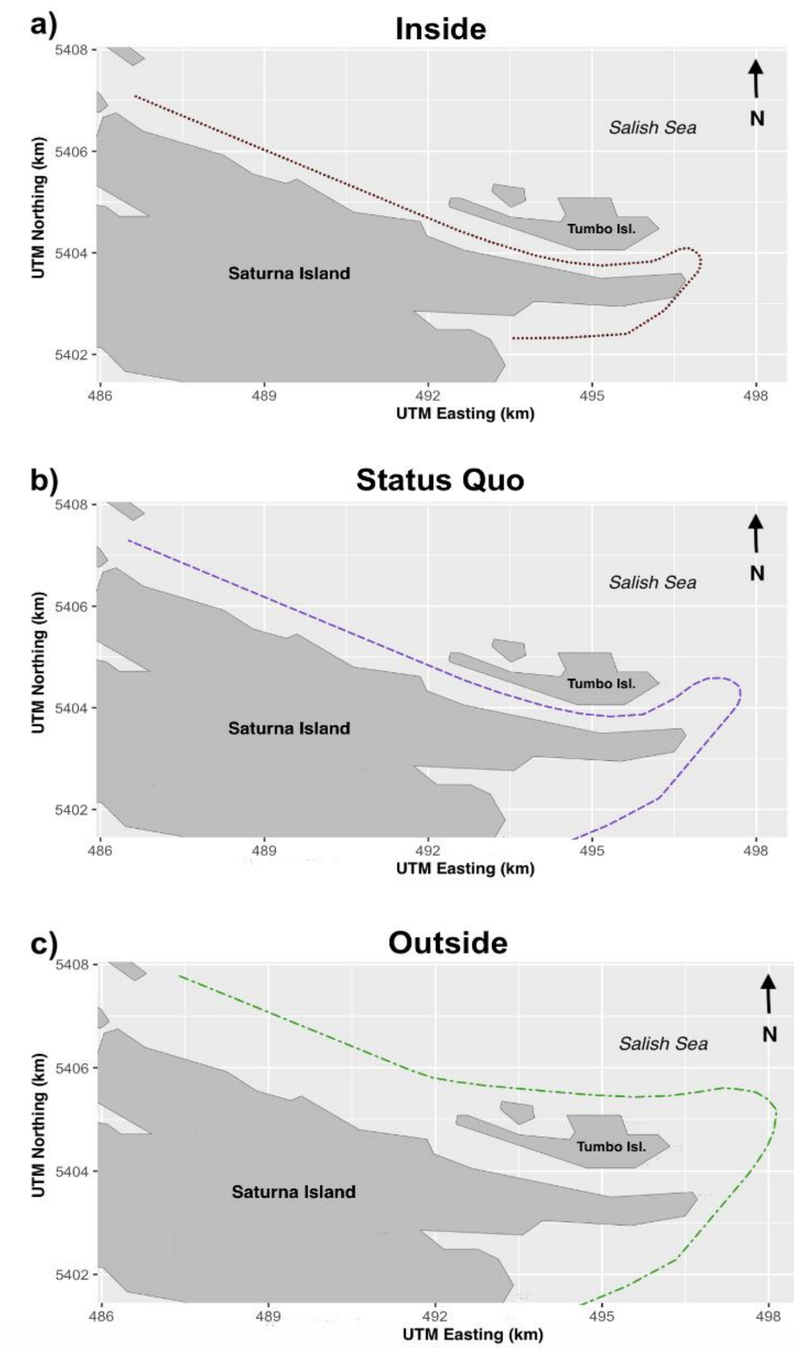

Figure 3. The three track lines used in the acoustic propagation model to calculate vessel generated noise. a) Inside, b) Status Quo, and c) Outside.

A total of 12 acoustic propagation simulations were executed, incorporating two vessel categories, at two speeds along the three hypothetical tracks (Figure 3). Vessels were categorized by vessel type and length due to differences in their L95 speed travelled through the AOI and source levels of vessel noise emitted varying by vessel length. Sailing vessels were omitted from this analysis as it was unknown when these vessels were under sail or motor and these methods of transit would represent different noise disturbances. The two vessel categories selected were 10-25 metre length passenger vessels and 5-9 metre length pleasure craft vessels. These categories represent the highest noise transmitted for pleasure craft and passenger vessels. Source levels were derived from MacGillivray et al. (2014), in which source levels are shown at a reference speed of 10 knots. To obtain source levels at maximum speeds, methods followed Joy et al. (2019) and the Ross's Power Law was used according to the formula (Ross 1976):

$$SL - SL_{ref} = CV \times 10\log_{10} (v \div v_{ref})$$

Where SL is source level, v is speed, v_{ref} is reference speed, SL_{ref} is source level at reference speed, and CV is a best-fit coefficient that is representative of the vessel size. A CV for small commercial and recreational vessels of 2.5 was obtained from Wladichuk et al. (2018). The speeds used were the L95 speed derived from Class B AIS data in our AOI between June through November in 2021 and 2022 for each vessel category and a reduced speed of 10 knots. L95 represents maximum vessel speed, and 10 knots represents the suggested speed for a speed restricted zone, herein. The maximum speeds used in the analyzes are 23.1 knots for pleasure craft vessels and 32.2 knots for passenger vessels. Source level from each speed is represented as ⅓ - octave band source level dB re 1µPa @ 1m.

A speed of 10 knots was selected to represent a speed restricted zone based on evidence that limiting vessel speed to 12 knots or less lowers monthly average vessel noise levels, and limiting to 10 knots or less increased noise savings in the SRKW echolocation band significantly when compared to 12 knots (Matthews & Wladichuk 2022). A speed limit of 10 knots additionally aligns with the mandatory speed limit of the two Speed Restricted Zones around Swiftsure Bank, as specified in Transport Canada's *Interim Order for the Protection of the Killer Whale (Orcinus Orca) in the Waters of British Columbia, 2023* (Transport Canada, 2023).

Each combination of vessel track and speed simulates one of the proposed management measures for each vessel class:

- Vessels transiting the Inside track (Figure 3a) at their maximum speed simulate a scenario where none of the management measures are in effect and vessels can transit through all zones at any speed.
- Vessels transiting the Inside track (Figure 3a) at 10 knots simulate a scenario where all zones are SRZs.
- Vessels transiting the Status Quo track (Figure 3b) at their maximum speed simulate a scenario where the current ISZ is in effect and speed is not restricted in the other zones.
- Vessels transiting the Status Quo track (Figure 3b) at 10 knots simulate a scenario where the current ISZ is in effect and the other zones are converted to SRZs.
- Vessels transiting the Outside track (Figure 3c) at maximum speed and 10 knots simulate scenarios where all three zones are ISZs.

The acoustic propagation model interpolates equally spaced positions of a single vessel along each hypothetical vessel track, representing several points along a single vessel trajectory. This method of analyzing acoustic propagation from a single track was chosen as it is an established method for modeling vessel disturbance on marine mammals (Halliday et al. 2021). To allow for high granularity while maintaining relatively low computational costs due to the time constraints of this project, 80 equally spaced positions of a single vessel were used for each track. The resolution of the model was set at 45 metres for horizontal grid cells, over a bathymetry grid with horizontal cells spaced at 90 metres, while the depth resolution was segmented into 10-metre depth steps. Modelling was done over 36 radials, equating to every 10-degree bearing from the source. A Bellhop model was used for the simulations, using the Bellhop implementation outlined in Pisha et al. (2023). This model was chosen as it is an established method to model sound propagation in complex oceanic environments (Wang et al. 2014), and for its computational and relative efficiency.

The frequency range for acoustic propagation modelling spanned from 10 to 32,000 Hz. This range was chosen as it captures the majority of vessel noise in the lower frequencies (MacGillivray et al. 2014) and the most sensitive range of SRKW hearing (Branstetter et al. 2017), while maintaining low computational processing costs. The transmitter depth was set to two metres below the surface, as referenced by MacGillivray et al. (2014) to be appropriate for vessels less than 100 metres in length. The propagation loss was calculated for each 1/3 octave band, covering the full frequency range 10 to 32,000 Hz, keeping the computational costs manageable. For the acoustic properties of the seafloor substrate, values were obtained from MacGillivray et al. (2014). Two seafloor compositions were considered: first, a clayey silt with a sound speed of 1552 m/s, a density of 1.54 g/cm3, and an attenuation of 0.8 dB/λ p for the Strait of Georgia (Tumbo Channel Zone and Boat Passage Zone) and second, a sand-silt-clay bottom with a sound speed of 1566 m/s, a density of 1.8 g/cm 3, and an attenuation of 0.72 dB/λ p for Boundary Pass (Saturna ISZ). The respective data for these compositions are detailed in Tables 25 and 26 of MacGillivray et al. (2014). Furthermore, sound speed profiles for these regions were extracted from the same report, MacGillivray et al. (2014), from Figure 6 and Figure 7, respectively therein. The modelled sound pressure levels (SPL) for each frequency were then transformed linearly, summed across all frequencies and converted back to decibels to generate a broadband SPL for each vessel class and speed. These simulations can help in understanding the noise's influence on sanctuary zones and formulating potential mitigation strategies for noise pollution. Baseline ambient noise levels are currently not available for Tumbo Channel and Boat Passage Zones and therefore could not be incorporated into the model. As such there was no scenario with no vessel movement in the AOI. The difference in SPLs represent relative change in SPL across the various scenarios and are not representative of actual SPL values as those would include the baseline ambient noise levels.

3.5. Analysis – Received Vessel Noise by SRKW

To calculate the SPLs of vessel noise received by a whale travelling through the AOI under each potential management measure, the trajectories outlined in section 3.3.3 and the acoustic propagation noise model outlined in 3.4.2 were combined. In the SRKW movement model, 1,500 trajectories of possible SRKW movement through the AOI were simulated (see Appendix A. Figure A1). The 1,500 trajectories were replicated for each of the 12 simulated vessel transit scenarios in the noise model. For each simulated trajectory, there were N ($N \geq 1$) steps in one of the management measure zones. The trajectory had to have at least one step in one of the management measure zones to be utilized in this analysis. At each of these N points, for each trajectory, the received SPL (dB re 1 µPa) was calculated based off of the modelled SPL from the vessel noise propagation model. SPL was only calculated for the points when SRKW were within either the current ISZ or the proposed extension through Tumbo Channel and Boat Passage. For each trajectory, L95 was calculated as the 95th quartile of the N SPLs received by a whale. Extending to all simulated trajectories, 1,500 L95 values were calculated, and the distributions of L95 were constructed as boxplots. Management measures targeted underwater noise levels as received broadband SPL within the AOI by SRKW. All scenarios analyzed included vessel noise, and there were no scenarios with no vessel noise.

4. Results

4.1. Use of Area of Interest by SRKW

4.1.1. General Trends in SRKW Use

Data were analyzed from 454 SRKW sightings in the AOI from June 1st through November 30th, 2002 - 2022. SRKW were present in the AOI on 265 days. The total number of reported sightings per season varies annually and ranges from zero to 110. To overcome duplicate sightings from the same event being reported, sightings data were synthesized into whale days in the AOI for each pod.

All three distinct SRKW pods, J, K and L were observed in the AOI, and their presence was varied. Over the entire study period, J-pod was most prevalent, sighted in the AOI on 159 days (60% of whale days), followed by K-pod at 79 days (30% of whale days), and L-pod at 76 days (29% of whale days) (Figure 4). There were 70 whale days (26%) with no associated pod identification (Figure 4). Commonly, members of different pods were seen travelling together, and on some occasions, all members of all three pods were sighted together in a "super-pod" event. Shields (2023) reports in the entire Salish Sea, J-pod was present during 91% of the whale days, K-pod on 29% of the whale days, and L-pod on 26% of the whale days in 2018-2022.

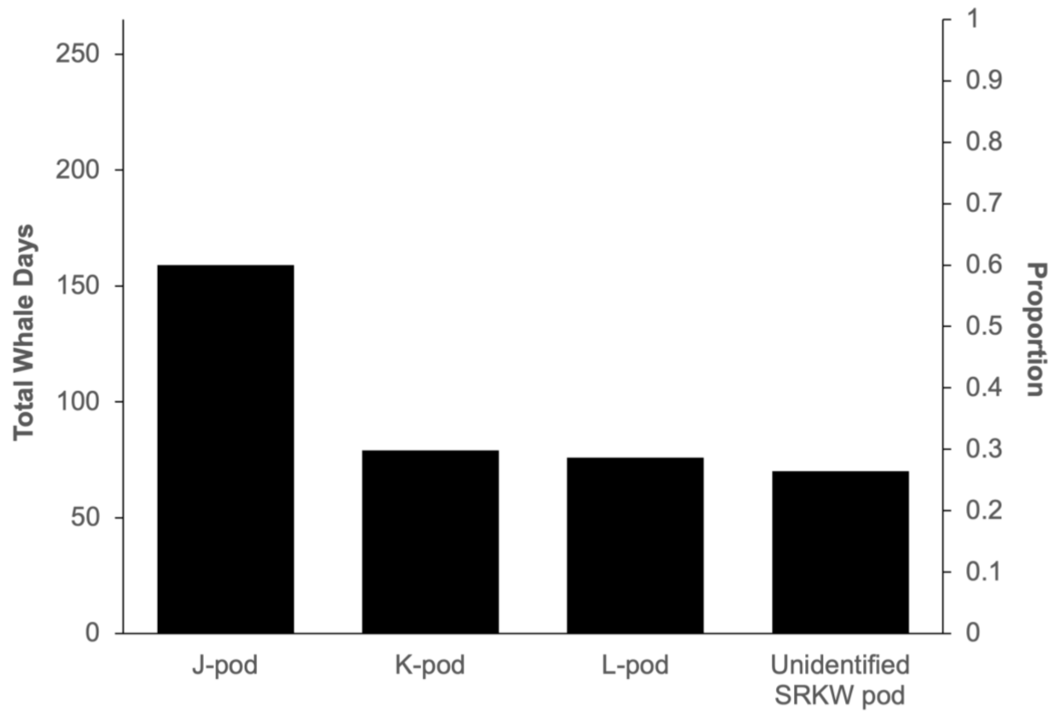

Figure 4. Total whale days and proportion of Southern Resident killer whale pod identifications of 265 total days that Southern Resident killer whales were sighted in the area of interest June through November 2002-2022.

SRKW presence in the AOI varies monthly and annually. During the months in which the ISZ is active, June through November, SRKW were present in the AOI most often in July. On average, there are 3.9 days in July in which SRKW were present in the AOI (Figure 5). SRKW were least present in October, averaging 0.4 days (Figure 5).

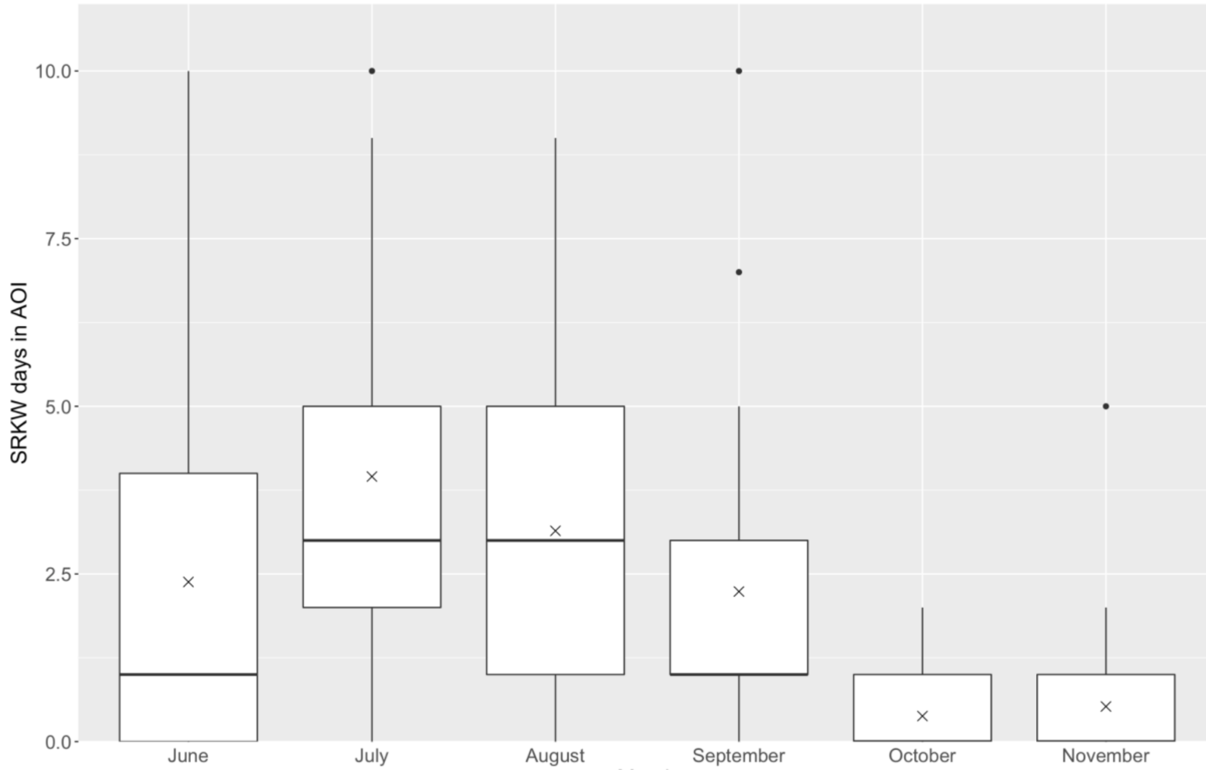

Figure 5. Number of days Southern Resident killer whales were sighted in the area of interest per month June through November 2002 - 2022. These box plots represent the central 50th quartile, whiskers represent the range, horizontal lines within indicate the median, and 'X' represent the mean.

The highest presence of SRKW in a month was 10 days, occurring three separate times, in July 2012, September 2013, and June 2015. SRKW were not sighted in the AOI most often in October and November. However, the outlier in Figure 5 in the month of November represents an increased number of SRKW days in the AOI in the year of 2022. Overall, SRKW presence was highest in both 2002 and 2012 with 26 days detected in the AOI (Figure 6). SRKW were not detected at all in 2017 (Figure 6). Other instances of low SRKW use in the AOI include 2019 and 2020, as reflected in Quayle (2021).

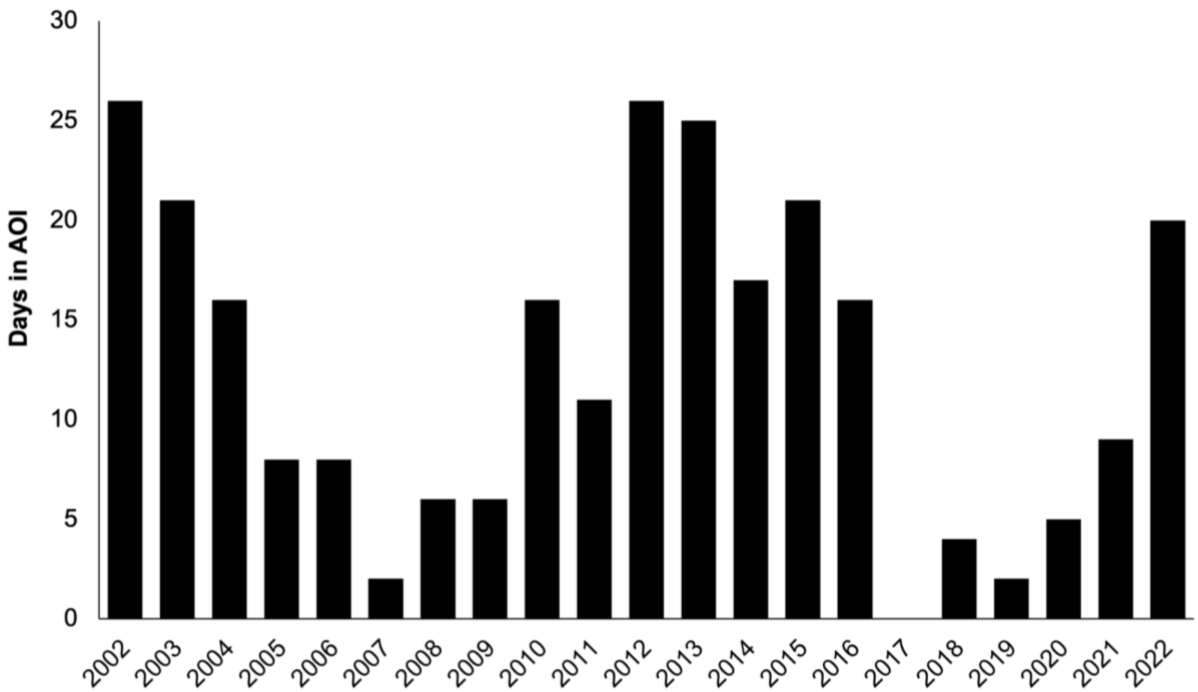

Figure 6. Total number of days that Southern Resident killer whales were sighted in the area of interest per year during June through November of 2002 - 2022.

4.1.2 Kernel Density Analysis

The 454 SRKW sightings from June through November 2002-2022 are not evenly distributed throughout the area of interest. Within our area of interest three sections of interest have been highlighted, the current ISZ, a proposed ISZ extension or speed restricted zone through Tumbo Channel (Tumbo Channel Zone), and a proposed ISZ extension or speed restricted zone through to Boat Passage 0.5 nm offshore (Boat Passage Zone). In Figure 7, it can be observed that the highest density of sightings is clustered to the north, south, and east of East Point, in and around the eastern half of the current Interim Sanctuary Zone. Within Tumbo Channel, there is a moderate to high density of sightings. These sightings are mainly located at both the eastern and western entrances of the channel. The sightings are moderate throughout the Boat passage zone. Other areas of moderate to high density sightings include the region north-northeast of the ISZ and Tumbo Island.

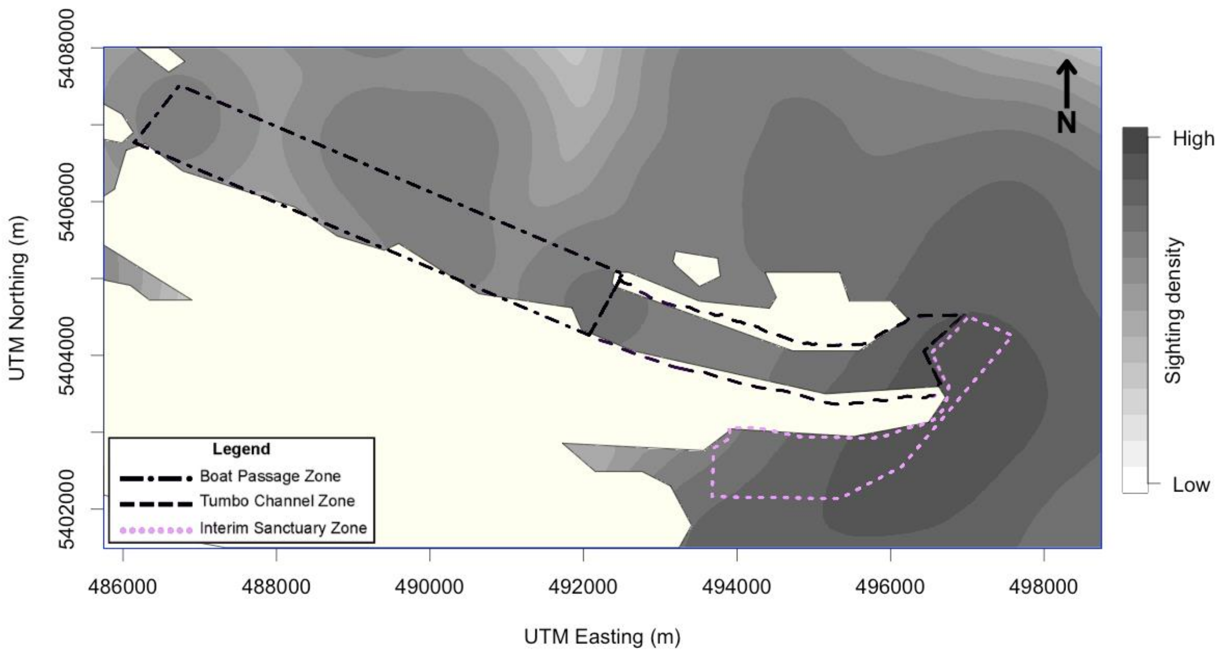

Figure 7. Kernel density estimate of Southern Resident killer whale sightings in the entire area of interest during June through November of 2002 - 2022. The current Saturna Island Interim Sanctuary Zone and the proposed Tumbo Channel and Boat Passage management zones are depicted.

4.2. Use of Area of Interest by Small Commercial and Recreational Vessels

4.2.1. Vessel Activity Analysis

During the ISZ operational period in 2022, the number of AIS vessels counted in the area of interest was double that of 2021 (Figure 8a). The composition of vessel classes within the AIS data exhibited minimal variation between the two years, with classes undergoing changes of no more than 2% in their composition.

The determined ratio of AIS to non-AIS vessels in the SFU observation area (see Appendix B. Figure B1) is 77% non-AIS vessels to 23% AIS vessels. This result aligns with the findings of O'Hara et al. (2023), who reported a similar ratio of 72% non-AIS vessels to 28% AIS vessels adjacent to the area of interest in Boundary Pass. Similarly, Warner et al. (2019) used a land-based camera at East Point, Saturna Island to monitor AIS and non-AIS traffic in Boundary Pass and found that 72% of recreational vessels were not equipped with AIS. Among the non-AIS vessels documented by SFU researchers, the distribution of vessel classes was as follows: 70% pleasure craft vessels, 19% sailing vessels, 11% enforcement vessels, and 0% passenger, fishing, or other vessels (Figure 8b). Vessel type codes included in each vessel class are defined in Appendix B. Table B3.

Pleasure craft vessels were the most recorded vessel type in both the AIS and non-AIS data for all studied years and zones, constituting 64% of the overall vessel count (Figure 8c). Within the AIS data alone, passenger vessels rank as the second most common vessel type in the area (Figure 8a). However, when integrating the actual AIS counts with the estimated non-AIS counts, the number of sailing vessels exceeds that of passenger vessels by a factor of 3.6. Consequently, the difference between pleasure craft and passenger vessels increases from a factor of 1.9 to 11.7 (Figure 8c). Enforcement vessels represent 8.8% of the total vessel count, while fishing and other vessel classes were the least frequently recorded, representing only 1% and 1.2% of the total, respectively (Figure 8c).

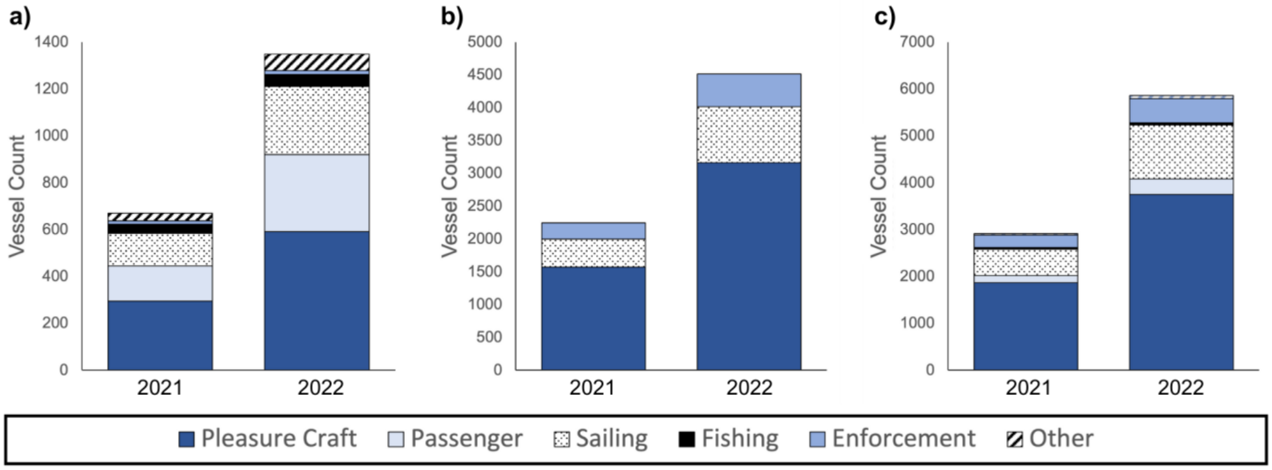

Figure 8. Total count of each vessel class in June through November of 2021 and 2022 in the area of interest for a) AIS vessels, b) estimated non-AIS vessels, and c) AIS and estimated non-AIS vessels combined.

August recorded the highest vessel count across all months and zones, (Figure 9 and Figure 10), with the exception of Tumbo Channel Zone in 2021 where July had the highest count of vessels (Figure 10b). Conversely, November consistently exhibited the lowest monthly vessel count across all zones (Figure 9 and Figure 10).

The monthly distribution of vessel classes within each zone showed minimal variation. Pleasure crafts consistently constituted the highest percentage of monthly vessel class composition in all zones (Figure 9 and Figure 10). Sailing vessels consistently ranked as the second-highest percentage in the monthly vessel class composition for all zones (Figure 9 and Figure 10).

Enforcement or passenger vessels held the next-highest monthly percentage, depending on the specific zone. In the ISZ and the Tumbo Channel Zone, the percentage of enforcement vessels consistently outnumbered the percentage of passenger vessels (Figure 10a and Figure 10b). In the Boat Passage Zone, enforcement vessels outnumbered passenger vessels in all months except for in October of 2021 and June of 2022, where passenger vessels outnumbered enforcement by 3% and 2% respectively (Figure 10c). When looking at the entire AOI, enforcement vessels again outnumbered passenger vessels in all months except for in October of 2021 where they were equal at 9% each, and June of 2022 where passenger vessels outnumbered enforcement vessels by 3%. (Figure 10). The fishing and other vessel classes were consistently the lowest, ranging from 0-4% and 0-2% of the total vessel count per month respectively (Figure 9 and Figure 10).

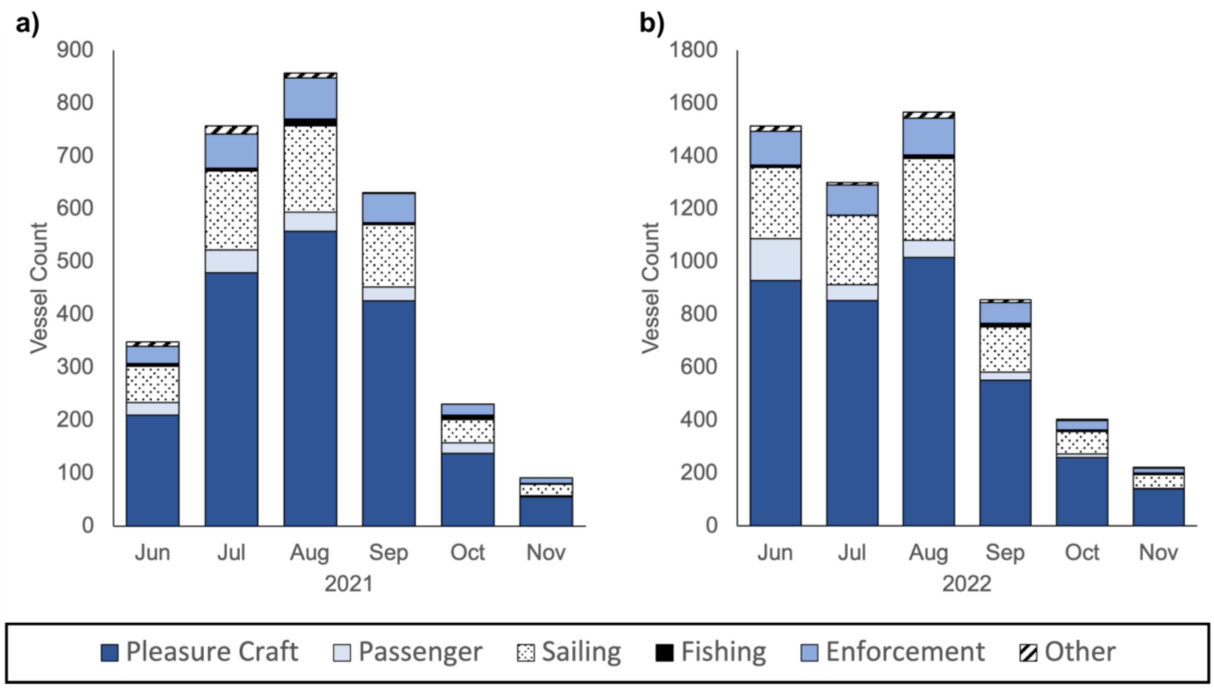

Figure 9. Total monthly count of each vessel class in the area of interest during June through November of a) 2021 and b) 2022. These counts include both actual AIS vessel counts and estimated non-AIS vessel counts.

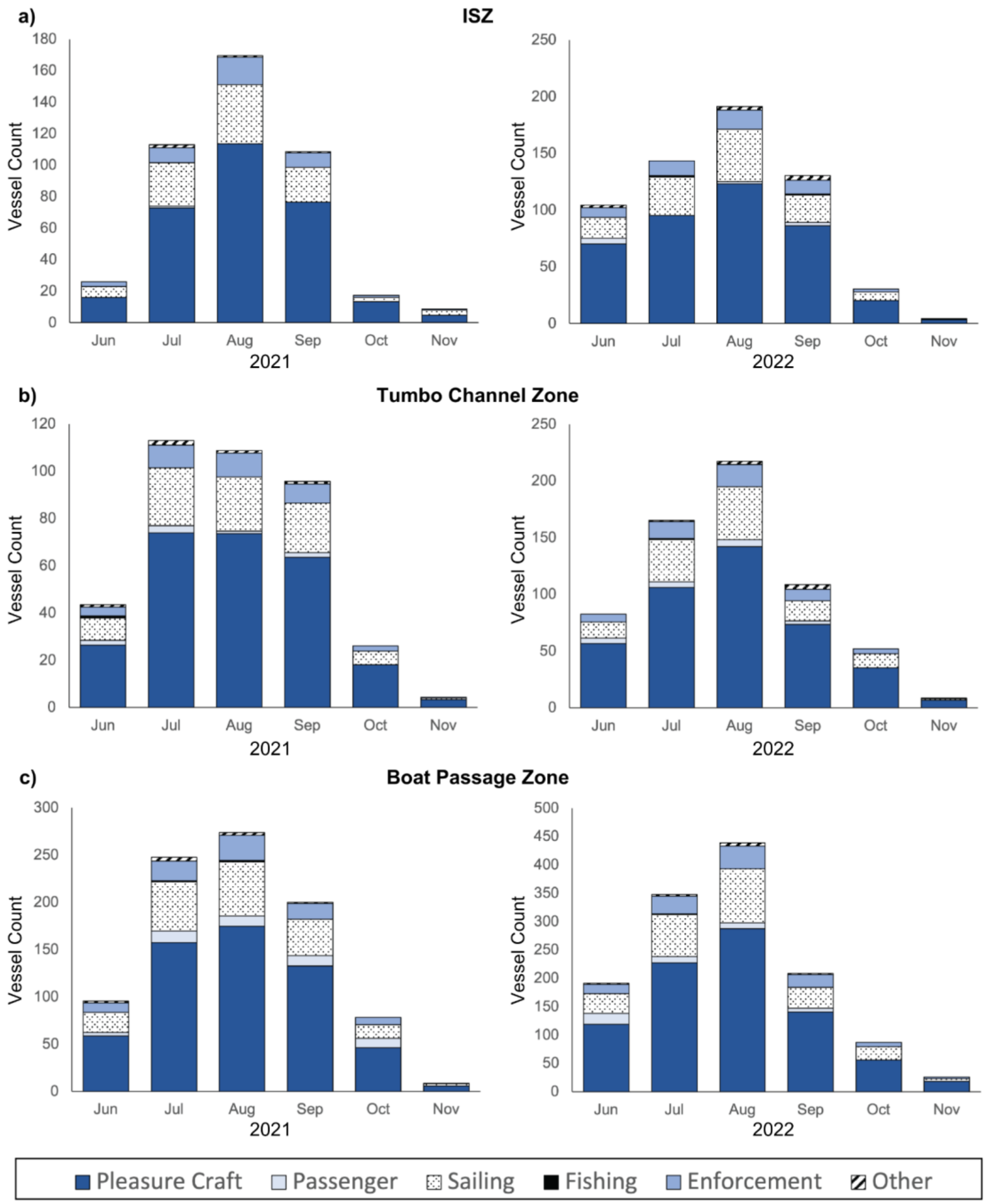

Figure 10. Monthly count of vessels by vessel class during June through November of 2021 and 2022 in the management measure zones of the area of interest a) the current Interim Sanctuary Zone, b) Tumbo Channel Zone, and c) Boat Passage Zone. These counts include both actual AIS vessel counts and estimated non-AIS vessel counts.

Violin plots portraying the density estimation of the SOG in knots of each vessel type travelling within the AOI are visualized in Figure 11a. The fastest categories travelling within the entire AOI were enforcement and passenger vessels. The associated boxplot for enforcement vessels indicates that the third quartile, or 75% of the SOG data, is under 30 knots. The corresponding boxplot for passenger vessels indicates that 75% of the SOG data falls under 25 knots. For all other vessel categories, the third quartile is under 10 knots, aligning with the designated slow-down speed considered in this analysis. It is important to note that outliers exist in this dataset, with some vessels travelling at significantly higher speeds. This is especially apparent within the pleasure craft category, as some vessels were travelling almost as fast as 50 knots. However, these outliers represent a much smaller proportion of the dataset.

These results can also be seen when breaking down the data into the three different zones of interest: ISZ, Tumbo Channel Zone, and Boat Passage Zone (Figure 11b, Figure 11c, and Figure 11d). The enforcement vessel type is consistently travelling at the greatest speeds within each zone. For every other vessel category, the median of the SOG data falls under 10 knots, in each zone. Sailing vessels were the only category which do not have any values which deviate significantly from the overall pattern and these vessels rarely go above 10 knots within each zone.

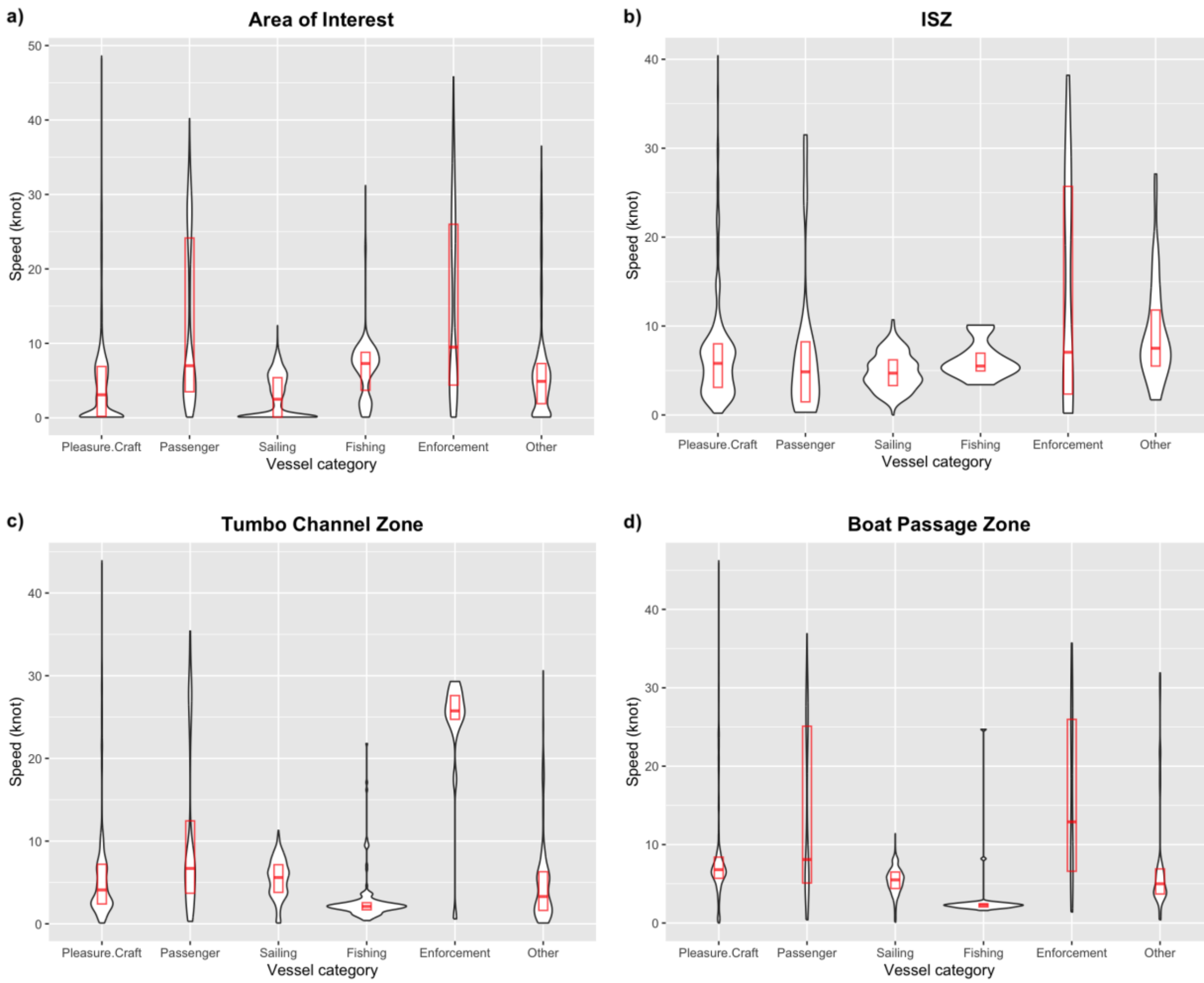

Figure 11. Measured speed over ground (knots) of AIS vessels detected in the area of interest June through November 2021 and 2022 in the following zones: a) entire area of interest, b) the current Interim Sanctuary Zone, c) Tumbo Channel management measure zone, and d) Boat Passage management measure zone.

The lengths of each vessel type within the AOI are portrayed in Figure 12a. The majority of recreational vessels within the AOI measure between 10-25 metres, accounting for 67% across all vessel types. The second largest category is vessels with unknown lengths, comprising 21% of the total. Lastly, 9.5% of vessels measure between five to nine metres within the AOI, with the under-five metre and over 25 metre categories accounting for the remaining 2.5%. Similar distributions can also be seen when looking at the ISZ as well as the Tumbo Channel and Boat Passage management measure zones (Figure 12b, Figure 12c, and Figure 12d). Though, no vessels under five metres or over 25 metres were observed within these three zones.

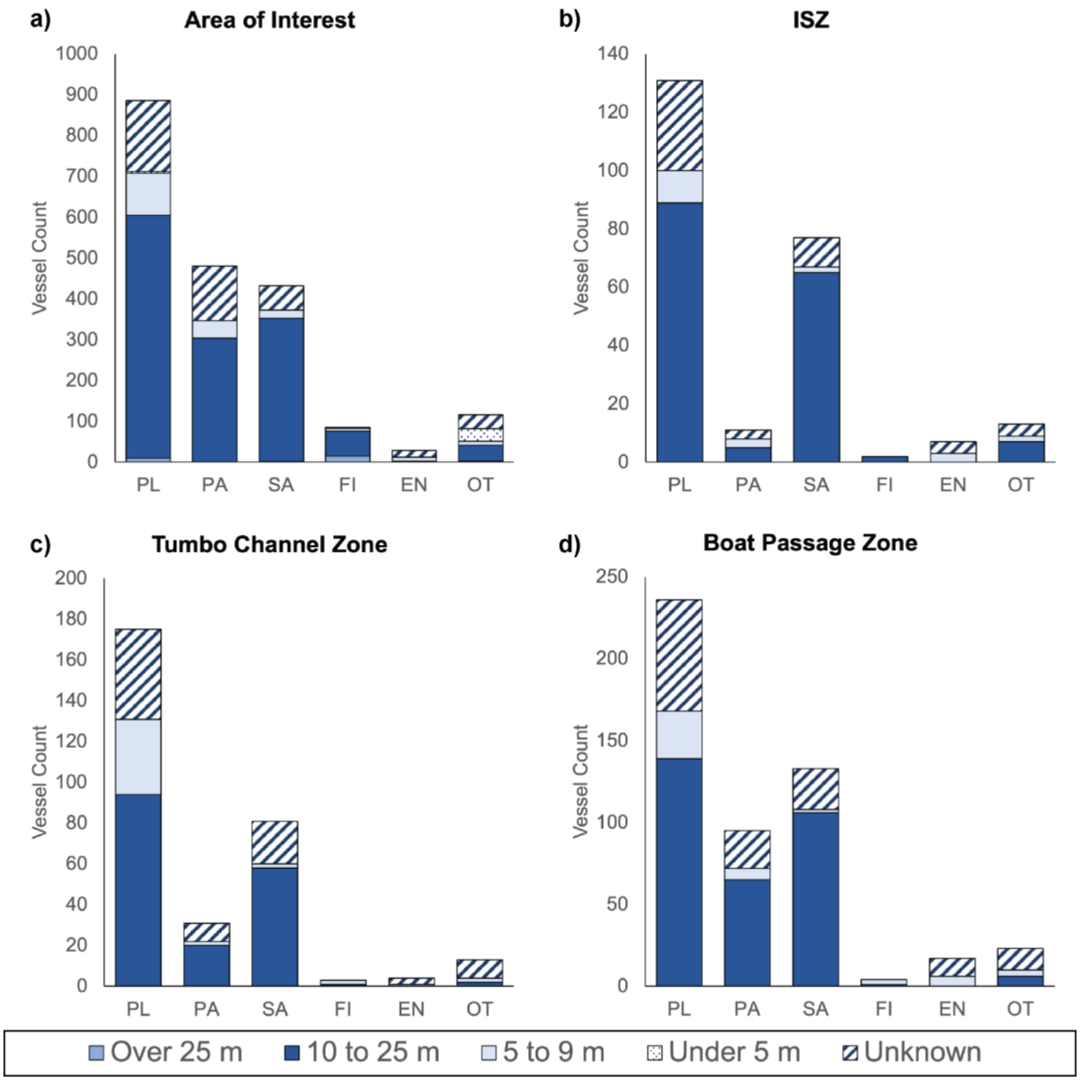

Figure 12. Length of AIS vessels detected in the area of interest June through November 2021 and 2022 in the following zones: a) entire area of interest, b) the current Interim Sanctuary Zone, c) Tumbo Channel management measure zone, and d) Boat Passage management measure zone. AIS vessels are separated by their designated vessel classes and include pleasure craft (PL), passenger (PA), sailing (SA), fishing (FI), enforcement (EN), and other (OT).

The track lines for each vessel category traversing within the AOI can be seen in Figure 13.

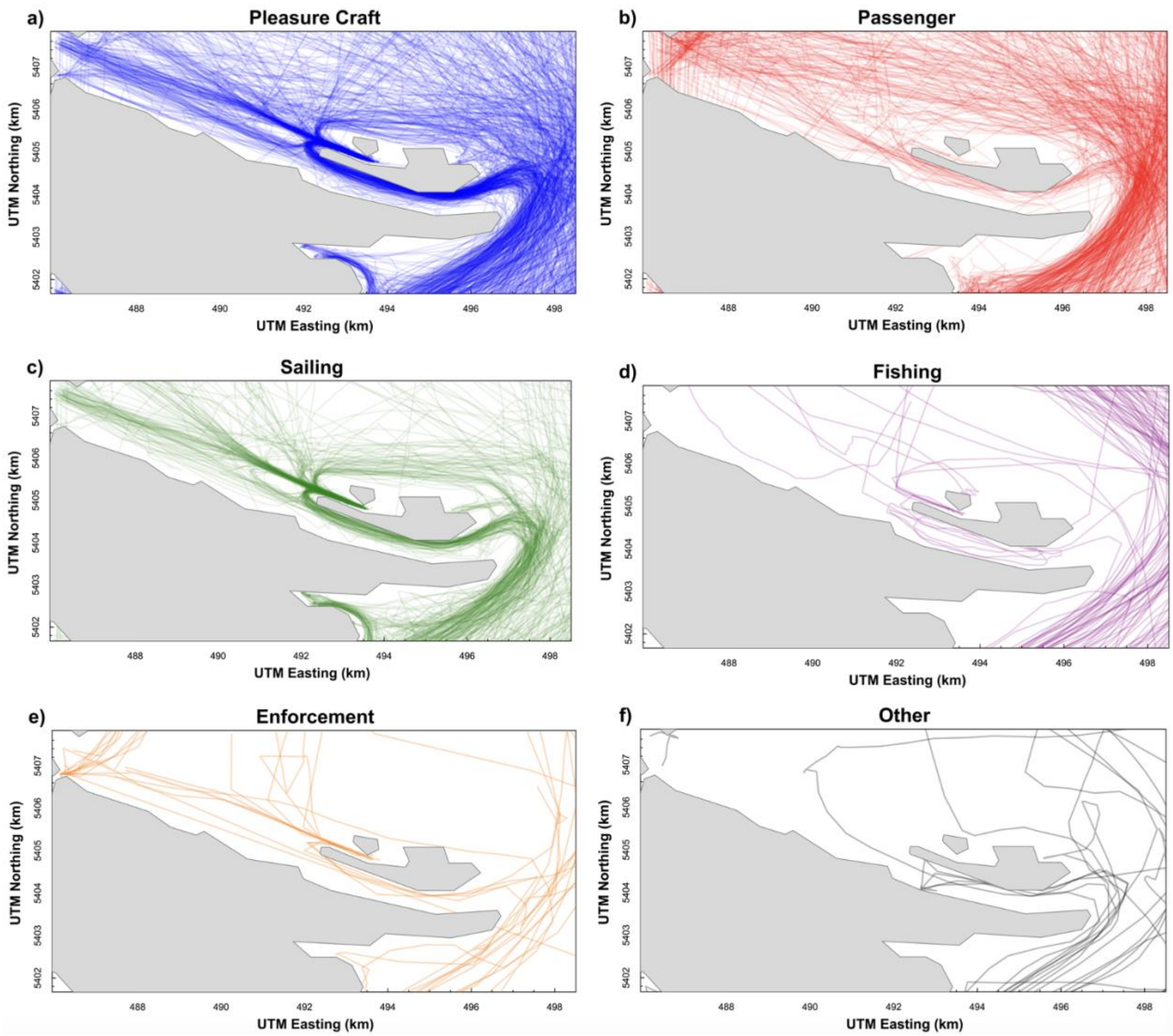

Figure 13. AIS tracks of vessels detected in the area of interest during June through November of 2021 and 2022 for vessel classes a) Pleasure Craft, b) Passenger, c) Sailing, d) Fishing, e) Enforcement, and f) Other.

Pleasure crafts and sailing vessels show similar movement patterns within the AOI. They also were the two vessel categories which have the highest concentration of tracks within the Tumbo Channel zone. Passenger vessels exhibited less dense tracks within the Tumbo Channel and Boat Passage zones and were more concentrated within Boundary Pass and the Strait of Georgia. Enforcement, fishing, and 'other' vessel categories do not reveal significant travel patterns. While they can be seen within the ISZ, and the Tumbo Channel and Boat Passage zones, it is much less frequent than the pleasure craft, sailing, and passenger vessel categories.

4.2.2. Noise Modelling

Acoustic propagation modelling was divided into three hypothetical vessel tracks (Figure 3). Results indicate that increasing the speed of pleasure craft or passenger vessels increases the transmitted SPL under any of the transit scenarios simulated by the model. In the model, passenger vessels output more noise than pleasure craft at both the slowdown speed of 10 knots and their respective maximum speed in all simulated scenarios.

Results of the acoustic model for two scenarios where vessels travel the Inside track are demonstrated in Figure 14. Scenario 1 reflects the management measure where the existing ISZ, Tumbo Channel Zone, and Boat Passage Zone are all converted to an SRZ. Scenario 2 reflects removing all management measures where vessels can transit through all zones at their maximum speed. These scenarios reflect the highest amount of noise pollution in all management measure zones (ISZ, Tumbo Channel Zone, Boat Passage Zone) when compared to other scenarios with their respective speed.

Results of the acoustic model for two scenarios where vessels travel the Status Quo track are demonstrated in Figure 15. Scenario 3 reflects the management measure where the current ISZ is maintained, and Tumbo Channel Zone and Boat Passage Zone are converted to an SRZ. Scenario 4 reflects the Status Quo management measure where the current ISZ is maintained, and vessels can transit through Tumbo Channel Zone and Boat Passage Zone at their maximum speed. Both scenarios reflect a decrease in noise pollution in the ISZ compared to scenarios of vessels travelling the Inside track at the same speeds. Transmitted noise pollution in the Tumbo Channel Zone and Boat Passage Zone for the Status Quo track were the same as Inside track for scenarios with the same vessel type at speed.

Results of the acoustic model for two scenarios where vessels travel the Outside track are demonstrated in Figure 16. These scenarios both reflect the management measure where the current ISZ, Tumbo Channel Zone, and Boat Passage Zone, are all an ISZ. Scenario 5 demonstrates vessels travelling outside of all zones at 10 knots, and scenario 6 demonstrates vessels travelling outside of all zones at their respective maximum speeds. These scenarios reflect the least amount of noise pollution in Tumbo Channel Zone and Boat Passage Zone when compared to scenarios of the same speed condition and is the same for the current ISZ as Status Quo track. This track also highlights an area within the Tumbo Channel Zone that is a refuge from transmitted noise and is substantially quieter than other management measure zones and the waters surrounding the vessel track.

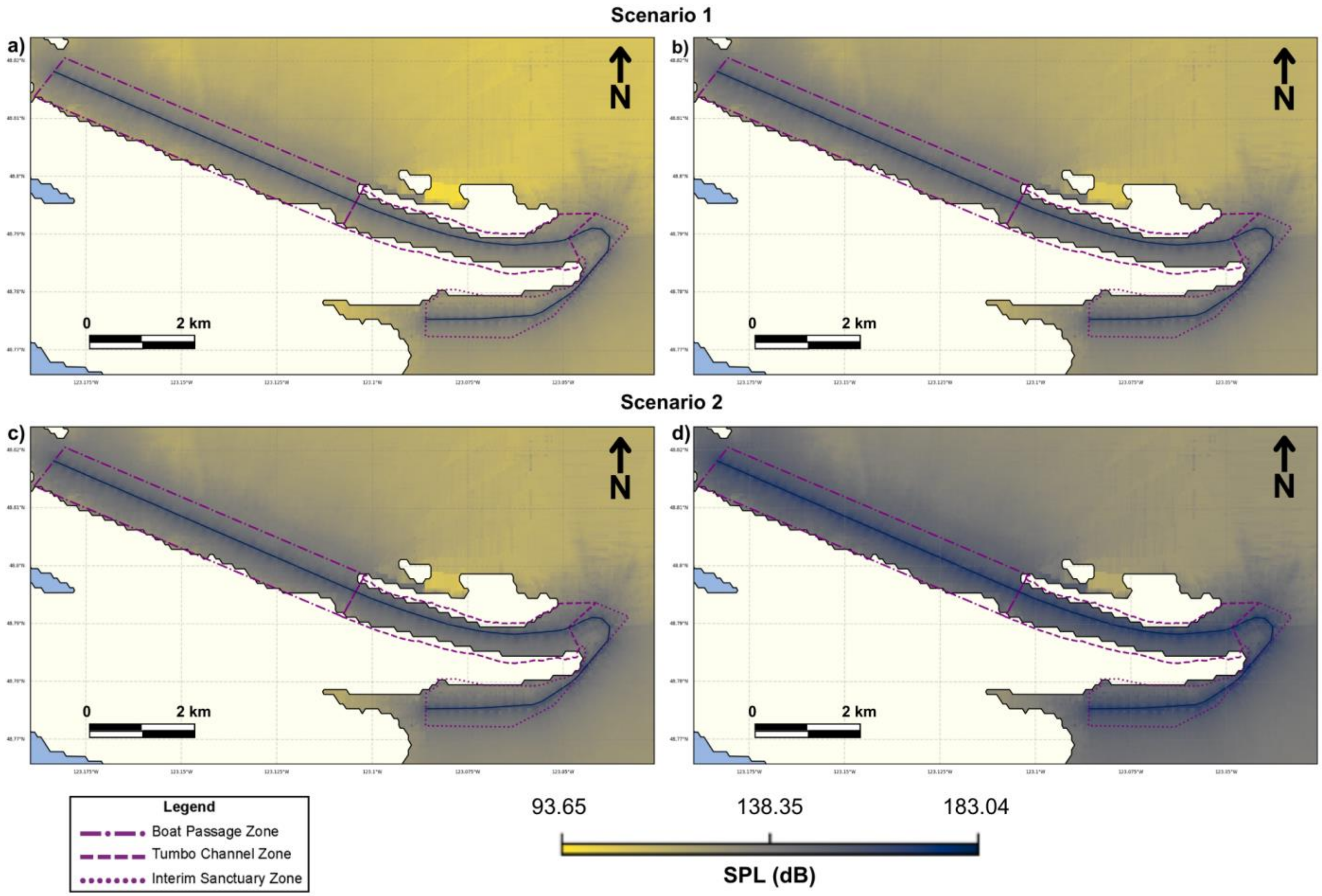

Figure 14. Acoustic propagation model of vessel noise demonstrating two different scenarios in which the current Saturna Island Interim Sanctuary Zone is not in effect. In Scenario 1, all zones are converted to Speed Restricted Zones, displaying a) pleasure crafts and b) passenger vessels transiting at 10 kn. In Scenario 2, all management options are removed, displaying c) pleasure crafts and d) passenger vessels transiting at their L95 speed, representing maximum speeds.

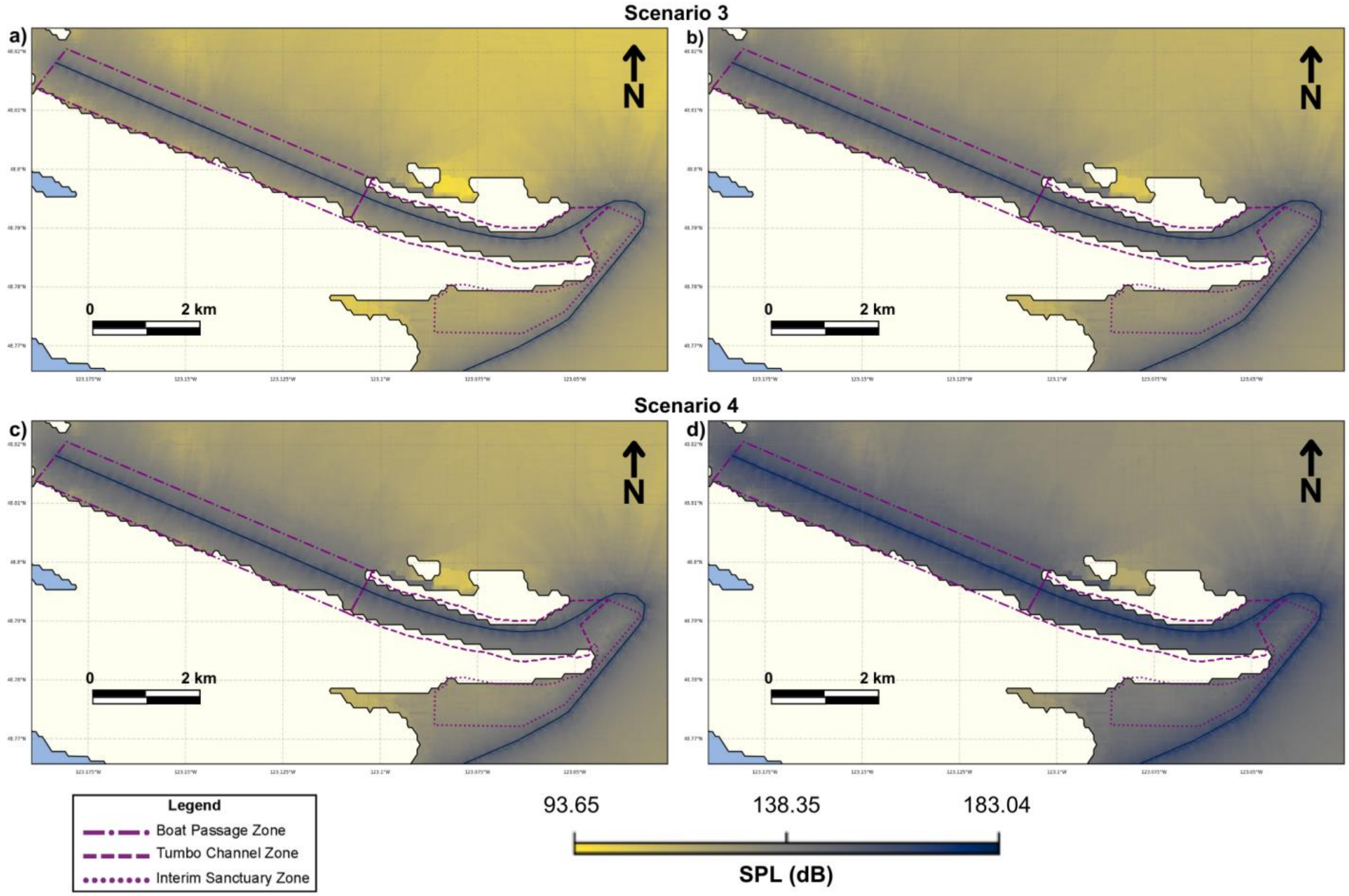

Figure 15. Acoustic propagation model of vessel noise demonstrating two scenarios where the current Saturna Island Interim Sanctuary Zone is in effect. Scenario 3 demonstrates converting Tumbo Channel and Boat Passage Zones to speed restricted zones, displaying a) pleasure crafts and b) passenger vessels transiting at 10 kn. In scenario 4, speed is not restricted, displaying c) pleasure crafts and d) passenger vessels transiting at their L95 speed, representing maximum speeds.

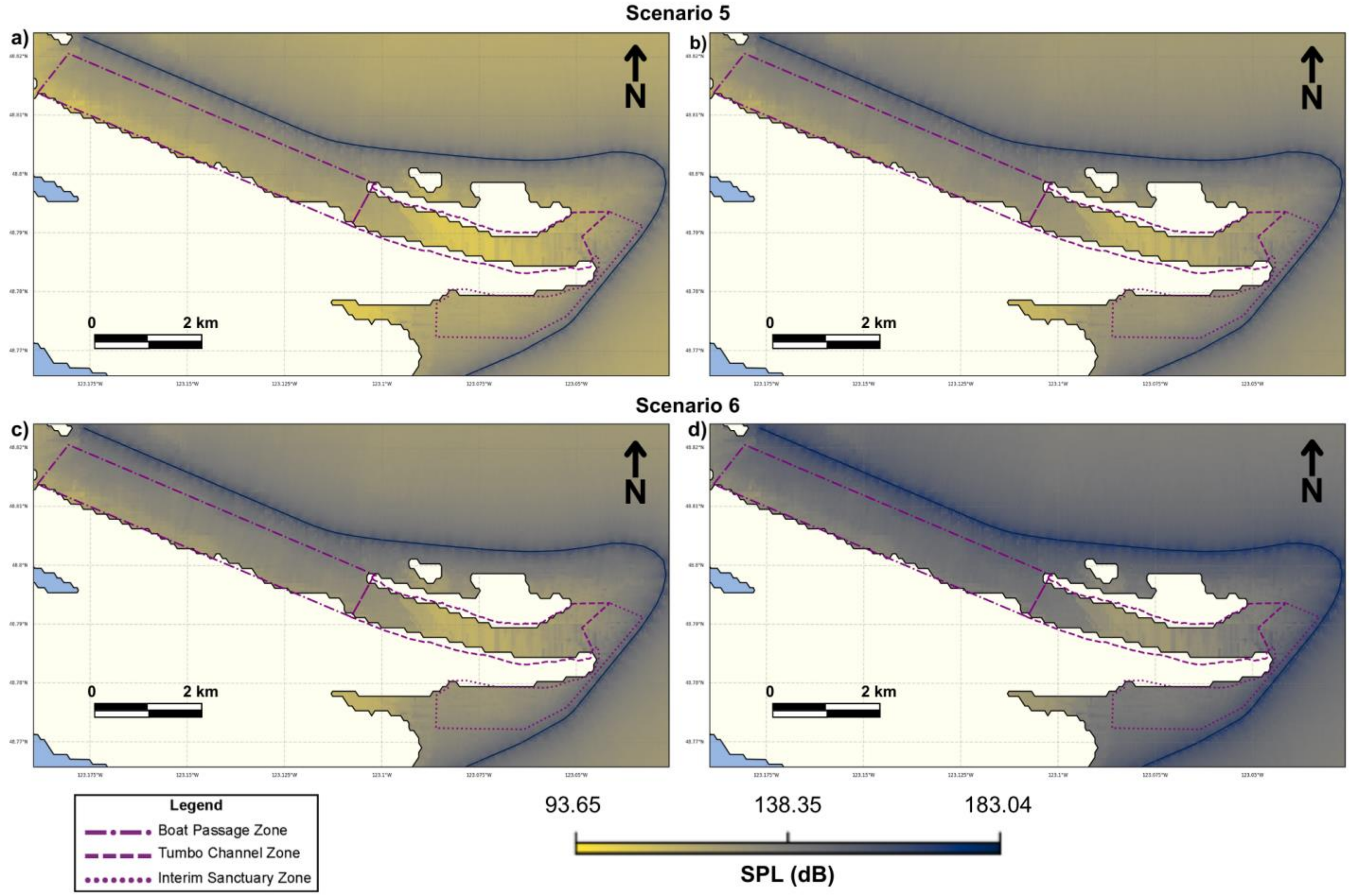

Figure 16. Acoustic propagation model of vessel noise demonstrating scenarios where all proposed management measure zones are converted into interim sanctuary zones. Scenario 5 simulates a) pleasure crafts and b) passenger vessels transiting outside all interim sanctuary zones at 10 kn. Scenario 6 simulates c) pleasure crafts and d) passenger vessels transiting outside all interim sanctuary zones at their L95 speed, representing maximum speeds.

4.3. Received Vessel Noise by SRKW

As the baseline ambient noise levels could not be included in the model, these results demonstrate the relative change in received SPL by SRKW under the different simulated scenarios in the noise model and do not represent actual SPLs potentially received by SRKW. When comparing the median of the L95 SPLs from vessel noise received by a whale, as depicted in Figure 17, it becomes evident that the lowest median SPLs occur when pleasure craft or passenger vessels travel at 10 knots in scenarios where they do not enter the ISZ. The highest median SPLs were observed when vessels travel at their maximum speed along the Inside track which goes through all three management measure zones.

Travelling outside all three management measure zones resulted in the lowest median L95 SPLs for each vessel class at each speed. However, in the comparison of the median for vessels of the same class and speed, those following the Status Quo track were not notably different from those following the Outside track. A notable distinction between these two scenarios is the quantity of outliers. The Status Quo scenarios exhibit a noticeably higher number of outliers that exceed 1.5 times the interquartile range. This is a result of the higher sighting density in the ISZ, leading to fewer simulated trajectories of the SRKW movement model going through Tumbo Channel or Boat Passage zones where there were relatively higher SPLs in comparison to the ISZ. Therefore, the outliers come from high SPLs received by SRKW in Tumbo Channel and Boat Passage Zones.

SPLs received by SRKWs when vessels were at their maximum speed consistently exceeded those when the same vessels were simulated at 10 knots along the same track. The difference between pleasure crafts and passenger vessels is not substantial in the scenario where vessels transit the Inside track. The contrast between pleasure craft and passenger vessels becomes more apparent when they transit the Status Quo and Outside tracks, especially at a speed of 10 knots.

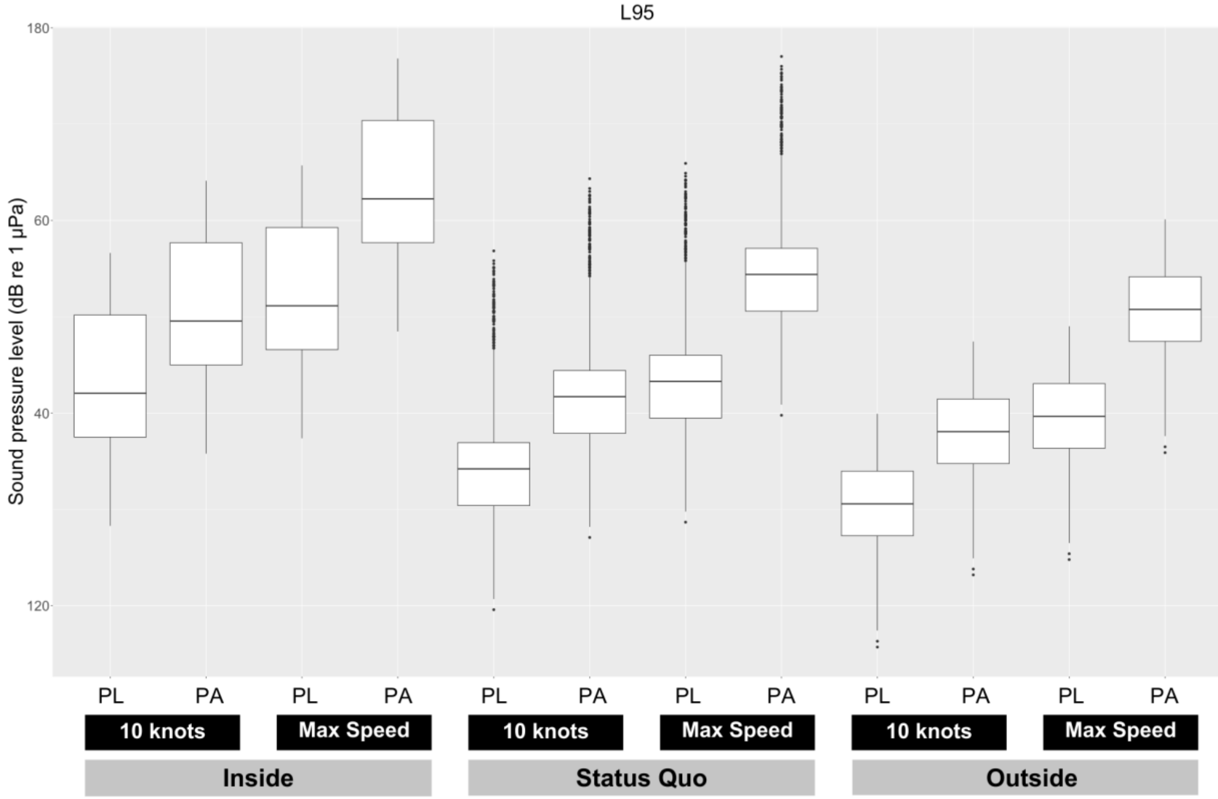

Figure 17: Boxplots representing the L95 received sound pressure level (dB re 1 µPa) by a Southern Resident killer whale during movement model simulations using modelled acoustic propagation of vessel noise. In each scenario, pleasure craft (PL) and passenger (PA) vessels are simulated at a 10 kn slowdown speed and their respective L95 speed, representing maximum (max) speeds. Three scenarios were simulated: Inside - vessels travel within the existing Saturna Island interim sanctuary zone (ISZ) and the proposed Tumbo Channel and Boat Passage management measure zones; Status Quo - the vessels transit outside of the ISZ but inside the proposed management measure zones; Outside - vessels transit outside both the current ISZ and proposed management measure zones.

5. Discussion

5.1 SRKW Activity in the Area of Interest

The general vicinity of the AOI is known to be an area of relatively high SRKW occurrence, specifically, Boundary Pass along the southeastern shore of Saturna Island (Thornton et al. 2022 b). The relative monthly trends in whale days within this study show that the most whale days occur in the AOI in June, July, and August. This pattern is more in line with the trends of 1998-2002, in which whale days for the Salish Sea peak in May, June, and July, as described in Shields (2023). This contrasts with the patterns of 2018-2022, in which whale days for the Salish Sea peak in September and November (Shields 2023). Shields (2023) notes that SRKW have recently been spending more time in the Puget Sound area later in the year, foraging on the fall and winter runs of Chum salmon. Recent evidence also indicates SRKW may be spending more time in other areas of the Salish Sea as well. In 2022, there were 5 whale days in the AOI of this report in November, which is a nearly 10-fold increase from the mean (of 0.52 days) of the previous 19 years. Additionally, in 2023, this late in the year temporal pattern of SRKW presence was observed within the AOI and broader Salish Sea resulting in the longest running ECHO slowdown since its implementation (ECHO Program 2023).

The mean monthly and annual whale day counts reported by this analysis are reduced from that in the literature (Shields 2023; Olson et al 2018), however, the respective scales of the study areas used are not comparable as the AOI used for this analysis covers a much smaller study area than the entire Salish Sea. The prevalence of each pod within the AOI is reflective of that of the entire Salish Sea (Shields, 2023). Historically, J pod typically spends more time in the Salish Sea than K and L pods (Shields 2023) which is aligned with our findings.

Spatial Trends in SRKW Activity

Results of the Kernel Density Analysis provide evidence that the current Saturna ISZ is a commonly utilized area of SRKW habitat. The KDE displays evidence that SRKW use Tumbo Channel a moderate amount compared to the rest of the AOI and should there be evidence that Tumbo Channel is currently an important feeding territory, this refuge could be critical to aid in the recovery of the SRKW population by increasing their opportunities to locate, pursue, and catch prey. In 2022, land-based researchers from SFU on Saturna Island anecdotally observed that when SRKW travel through Tumbo Channel, they travel much slower than when travelling through the current ISZ (Olivia Murphy, personal communication, October 30, 2023)[4]. This could suggest that they were foraging in this area and as such, were covering less area per unit time. While there is evidence that frequent foraging behaviour occurs in Boundary Pass (Thornton et al. 2022 b), the frequency of foraging occurring in Tumbo Channel and throughout the AOI is unknown as it is not recorded in the sightings datasets available for this analysis. This is highlighted in Section 6 of this report as an area of recommended future research. As previously mentioned, the Saturna ISZ is in close proximity to international shipping lanes and the ISZ does not provide refuge from this vessel noise. Tumbo Channel may be an important refuge as it is protected from Boundary Pass where the shipping lanes are located. This area of noise refuge in Tumbo Channel is visible in Figure 16, specifically, when vessels travel on the outside of Tumbo Island, some of the noise is blocked from reaching the inner channel. Figure 16 does not include commercial shipping noise from outside the AOI.

It is important to highlight that due to the set-up of the Whale Report App, a primary contributor to the BCCSN and Orca Master datasets, the KDE represents single point sightings of a whale event and does not represent the duration of the event and the complete movement pattern of the animal in the AOI. For this reason, annual and

[4] Olivia Murphy, MSc., Primary Observer, Simon Fraser University "Saturna Island Cetacean Monitoring"

monthly SRKW use of the entire AOI was analyzed, but not each individual proposed management measure zone, as it would not accurately reflect the use of each area individually.

Lack of sightings data does not necessarily show SRKW absence, it simply indicates no sightings were reported at that location. Data used in the KDE were not effort corrected as this was unachievable due to the time constraints of this project. For this reason, sightings may be biased to the East Point ISZ area as this is a public Gulf Islands National Park Reserve, whereas the majority of the rest of the coast of Saturna Island, including Tumbo Channel, is private property. Specifically, higher reported sightings at both entrances to Tumbo Channel likely reflect that SRKW travel through the Channel, but they are only reported at the time of the first sighting, which occurs at either end of the channel and is more likely to occur at East Point due to the location of the National Parks Reserve. This does not necessarily reflect that SRKW are first seen at East Point because they are travelling west, but individuals are more likely to report seeing them there even if they travel east through Tumbo Channel because this is where individuals are more likely to be observing them from.

Additionally, the relatively lower density of SRKW sightings in the Boat Passage zone does not necessarily indicate that SRKW do not use that area. There are fewer oceanfront residences along this stretch of Saturna Island coastline than along Tumbo Channel or the Saturna ISZ, therefore it may be the case that the sighting effort here is lower than the rest of the AOI, instead of a low use area by SRKW. Applying an effort correction to the sightings data would be a solution to this and is recommended in Section 6 of this report.

5.2 Vessel Activity in the Area of Interest

When looking at the AIS tracks in Figure 13, it is evident that pleasure crafts (Figure 13a) and sailing vessels (Figure 13c) demonstrate similar movement patterns within the AOI. The highest concentration of their tracks is observed from the southern end of Saturna Island, extending northeast to East Point, then turning west along the southern coast of Tumbo Channel. From there, they proceed around the western coast of Tumbo Island, ultimately reaching Cabbage Island (Figure 13a and 13c). These travel patterns likely represent the most common routes taken by vessels in the area as pleasure crafts and sailing vessels represented the majority of vessels counted in the area (Figure 9). Cabbage Island is a popular summer spot in the Gulf Islands National Park Reserve that is only accessible by boat (Parks Canada 2023). If Tumbo Channel were to be designated as an interim sanctuary zone, recreational boaters would still have access to Cabbage Island by navigating north of Tumbo Island instead of passing through Tumbo Channel. If it were instead to be converted to an SRZ, there would be little impact on their ability to access Cabbage Island, as many pleasure crafts and sailing vessels already transit through Tumbo Channel at the suggested restricted speed of 10 knots or less (Figure 11c).

Between all three proposed management measure zones, the Boat Passage zone contained the highest percentage of vessels from the total that transited through the AOI. Vessel tracks do not appear as dense in this zone (Figure 13), however, this is likely due to the zone being larger and having fewer physical barriers influencing travel patterns.

Passenger vessels display a distinct navigation pattern that differs from pleasure craft and sailing vessels. Their routes exhibit the highest concentration from the southern tip of Saturna Island, extending northeast towards East Point, and further north towards the Strait of Georgia. Their tracks are less dense in the Tumbo Channel and the Boat Passage zones. This observation suggests that the potential impact on passenger vessels would be less significant if the Tumbo Channel and/or Boat Passage zones were designated as an ISZ or SRZ, compared to the impact on pleasure crafts or sailing vessels.

Enforcement vessels represent 8.8% of total vessels across all years and zones. It is important to acknowledge that 84% of the vessels included in this class are appointed by the Canadian government and can be exempt from the regulations of ISZs and SRZs. Of the remaining enforcement vessels, 15% are Indigenous marine protection and monitoring organizations and 1% are other independent stewardship monitoring programs (for all vessels included in the enforcement class see Appendix B. Table B4). Indigenous-operated vessels can be exempt from regulations of ISZs but under different circumstances than the government appointed vessels under Section 35 of the *Constitution Act*, 1982.[5] As a result, when evaluating the potential reduction of noise and physical disturbance by reducing vessel traffic in the area, Canadian government and Indigenous operated vessels should not be considered. If the other independent stewardship monitoring vessels in the enforcement vessel class are not appointed by the Government of Canada and have no Indigenous affiliation, they do not have exemptions from ISZ or SRZ regulations as enforcement or under Section 35 of the *Constitution Act*, 1982.[6]

As a result of the limited number of AIS tracks for vessels in the fishing and 'other' classes, it is difficult to determine their most frequently travelled routes in Figure 13 (d and f). However, when in the area, both tend to use Tumbo Channel and the surrounding area of the ISZ. Their activity in the ISZ and Boat Passage Zone appears to be less frequent.

As evident in Figure 11, enforcement and passenger vessels are the fastest categories traversing the entire AOI and these outcomes may be supported through the conduct exhibited by these specific vessel types. The enforcement vessel category includes vessels with the AIS type code for 'Search and Rescue', which are designed to operate at high speeds as they are primarily responding to emergencies. Similarly, the passenger vessel category is mostly composed of ecotourism or whale-watching vessels, which might travel at increased speeds to maximize the distance travelled per

[5] For more information on the rights of Indigenous peoples in Canada see section 35 of the Constitution Act, 1982.
[6] For more information on exemptions please see the Interim Order for the Protection of the Killer Whale (Orcinus orca) in the Waters of Southern British Columbia.

excursion as they search for wildlife. However, passenger vessels exhibit lower speeds within the Tumbo Channel and ISZ zones and this can potentially be attributed to wildlife viewing activities in these areas. The AIS tracks reveal that passenger vessels also spend less time in these zones compared to Boundary Pass and the Strait of Georgia. Therefore, the motivation to travel through Tumbo Channel at a reduced speed may be associated with wildlife observation.

It is evident that, apart from enforcement and passenger vessels, AIS-equipped vessels generally do not travel at high speeds within the AOI. The slowest travelling vessel category in each zone is sailing, and this aligns with expectations as these boats often use wind energy to sustain travel. It is important to note that as the SOG analyzes rely exclusively on AIS data, this does not represent a comprehensive overview of all vessel speeds within the AOI without the inclusion of non-AIS vessel speeds.

In Canada, Class B vessels that are either passenger-type or that are eight metres or more in length and carry a passenger must be fitted with AIS (Navigation Safety Regulations 2020 Sec. 118 (2)). Therefore, as the vessel length analysis relies solely on AIS data, this accounts for the high occurrence of vessels between 10 to 25 metres in length. In addition, it can perhaps be inferred that the high proportion of non-AIS vessels present within the AOI are smaller than eight metres. Vessel length plays an important role in noise propagation and larger vessels generally travel at slower speeds. As stated above in section 3.4.2, the 5 to 9 metres vessel category was chosen to represent the worst-case scenario as they travelled at faster speeds and thus generated a louder sound source level. As vessel length within the AOI is only known for AIS vessels, the addition of many smaller vessels which travel at faster speeds may have a significant impact on the underwater soundscape.

ISZ Compliance

Based on the AIS data, it appears that among the most common types of vessels in the AOI, passenger vessels have demonstrated a comparatively lower likelihood of violating the non-entry restrictions of the ISZ, in contrast to pleasure craft and sailing vessels. In 2021, approximately 15.9% of pleasure crafts, 17.7% of sailing vessels, and only 0.7% of passenger vessels that traversed the AOI entered the ISZ. In the following year, the percentage decreased for pleasure craft and sailing vessels to 10.6% and 11.4% respectively, while there was an increase for passenger vessels to 3.0%.

Non-AIS vessel infractions are most often reported by citizen scientist volunteers and local researchers. As a result, these infractions may be under-reported due to the nature of opportunistic reporting by citizen scientists and dedicated researcher observation hours amounting to less surveillance than the 24/7 nature of the AIS system. If an SRZ is implemented, it would be increasingly difficult for a citizen scientist or researcher to be able to report infractions as they would need a device that can track speed such as a radar speed gun. These devices are sensitive and difficult to operate and small errors of 10° in the angle at which the gun is pointed at the vessel can easily result in a speed error of 10-15 km/h (Erbe 2002). Therefore, enforcement of an SRZ for non-AIS vessels may be more reliant on an increase in government enforcement. It should be noted that as the majority of non-AIS vessels are pleasure craft vessels, one can assume that their transit patterns are similar to pleasure craft vessels with AIS. Specifically, they do not tend to transit through the AOI at speeds faster than the recommended slowdown speed of 10 knots (Figure 11). As smaller pleasure craft vessels (5-9m) have a higher maximum speed in the AOI, and since smaller pleasure craft vessels are less likely to have AIS than larger ones, it could be possible that there are more pleasure craft vessels that do not have AIS, that are small, and tend to transit faster. For AIS outfitted vessels, speed is automatically recorded, and an automatic reporting system could be implemented, with vessels being reported if their speed is higher than the slowdown speed while their location is picked up within the SRZ.

Limitations

Non-AIS vessel data was not available for much of the AOI, including in the Tumbo Channel and Boat Passage zones. Estimates were made based on data from a smaller portion of the AOI (see Appendix B, Figure B1). A dedicated vessel survey to determine the ratio of AIS to non-AIS vessels in these zones is recommended in Section 6 of this report.

5.3 Interaction Between SRKW and Vessels

This study utilized a Bellhop model for vessel acoustic propagation as it is an established method to model sound propagation in complex oceanic environments (Wang et al. 2014). This model was also chosen for its low computational processing time relative to parabolic equation (PE) based models, or a combination of the two, due to the time constraints of this project. Parabolic equation-based models tend to offer better accuracy for frequencies under 200 Hz. However, they are computationally intensive and impractical for higher frequencies. Given these considerations, the Bellhop model, which is based on the assumption that sound travels in rays, was chosen for its relative efficiency, as discussed in Wang et al. (2014).

When the results of the KDE are compared with the acoustic propagation model and L95 SPLs received by SRKW, a more complete picture of how SRKW and vessels may interact under a variety of management measures is revealed. When interpreting the results of the acoustic propagation and received vessel noise models, the relative change should be considered, and not absolute values, as a sound propagation model was used and not an ambient noise analysis approach. Additionally, it is important to recall that vessels in these models were chosen based on a worst-case scenario of source level noise and are used to represent passenger and pleasure craft vessels, but do not necessarily indicate actual values of noise transmitted from all vessels of these classes.

The Inside track of the acoustic model is intended to demonstrate a scenario with no management measures, or a slowdown zone being implemented in all three management measure zones: ISZ, Tumbo Channel Zone, and Boat Passage Zone. Given that SRKW sightings had the highest density within the ISZ, and this acoustic propagation scenario resulted in the highest acoustic disturbance, this is not favourable to SRKW. When coupled with the results of the L95 SPLs received by SRKW, this becomes increasingly obvious. Increasing acoustic disturbance and vessel traffic in the area of high sightings is likely to cause an increase in vessel disturbance to SRKW, leading to decreased opportunities to forage, and increased energy expenditure (Williams et al. 2009, Lusseau et al. 2009, Holt et al. 2021, Williams et al. 2021).

The Status Quo track of the acoustic model is intended to demonstrate a scenario of maintaining the current management measure of the Saturna ISZ and the Tumbo Channel and Boat Passage zones remaining with no management measure or becoming slow down zones. In this scenario, the highest aggregation of SRKW sightings remain with some protection against vessel presence disturbance. Vessels have been documented to cause physical disturbance from 400m and the outer edge of the ISZ is only approximately 150m from shore in some sections, so it does not negate all vessel disturbance (Williams et al. 2009). Maintaining the Status Quo scenario does result in an area of high-moderate SRKW sightings to remain susceptible to physical and acoustic vessel disturbance in the Tumbo Channel Zone. However, when the received vessel noise to SRKW is analyzed, the median L95 SPL is not notably different compared to vessels transiting outside of this area.

This scenario also had the highest number of outliers for received SPL, the majority of which exceed the threshold of 1.5 times the interquartile range. Most of these outliers resulted from SPLs received by SRKW in either Tumbo Channel or Boat Passage zones. This indicates vessels transiting the Status Quo track rather than the Inside track can decrease SPLs in the ISZ where SRKWs have a high probability to be found, based on the KDE, and simulated trajectories. However, once whales leave the ISZ and go into Tumbo Channel and Boat Passage Zones, or if their simulated trajectory started in those zones, the potential noise impact rises. When vessels transit the Outside track, most of these outliers are removed as the noise level in Tumbo Channel and Boat Passage zones decreases and are more like those in the ISZ.

The Outside track of the acoustic model is intended to demonstrate a scenario of all three management measure zones (ISZ, Tumbo Channel Zone, and Boat Passage Zone) being vessel exclusion zones. This scenario resulted in the lowest median L95 SPL received by SRKW however, it is like that of the Status Quo. A noteworthy difference in median L95 SPL received by SRKW is observed when comparing vessels of the same class transiting at their representative maximum speed following the Outside track and at a reduced speed of 10 knots following the Status Quo track. The median L95 SPL received by SRKW is lower if vessels transit through Tumbo Channel and Boat Passage Zones at 10 knots than if they travel with no speed restriction outside of these zones. This indicates SRKW travelling through the three zones could be exposed to relatively higher noise disturbance when vessels transit outside of all zones at their representative maximum speed than when they transit at 10 knots following the Status Quo track. Outside track is only different from the Status Quo by not entering the Tumbo Channel or Boat Passage Zones, and as previously mentioned, there are substantially less outliers of the L95 SPL received by SRKW.

6. Recommendations

Management Measure Recommendations

Based on the findings of this report, the authors recommend the following SRKW protection management measures surrounding Saturna Island:
Maintain the current Saturna Island Interim Sanctuary Zone and implement a maximum 10 knot speed restriction in Tumbo Channel Zone.

These recommendations are founded on information from the literature and results of this report's modelling and analyses.

These recommendations are based primarily on the following highlighted results:

- The lowest median L95 SPLs of vessel noise received by SRKW occurs when vessels travel at 10 knots and do not enter the preexisting ISZ. Otherwise, median L95 SPLs do not distinctly vary.
- The median L95 SPL of vessel noise received by SRKW is lower when vessels travel 10 knots through Tumbo Channel and Boat Passage Zones, compared to when they travel at representative maximum speed outside these zones.
- The highest density of SRKW sightings based on point location is around East Point, in and around the eastern half of the current Interim Sanctuary Zone. Within Tumbo Channel there are a moderate-high number of sightings indicating that these areas are both important areas of protection within our AOI. We acknowledge that there may be an effort bias for whale observations from East Point Park, and caution overinterpretation of this result (i.e., the KDE surface does not include an effort correction component).
- Generally, vessels transiting in the AOI transit inside of Tumbo Channel or north around Tumbo Island. Implementing a full ISZ in Tumbo Channel would reroute

and increase vessel traffic travelling outside of Tumbo Island, which is also an area of moderate-high density SRKW use as per the KDE (Figure 7).

- Transitioning Tumbo Channel to a speed restricted zone should come with minimal safety and navigation corrections as the majority of vessels transiting in this area are already travelling at speeds of 10 knots or less and this change will not result in the implementation of any rerouting of vessels.

- As identified in the literature review, compliance rates for slowdown management measures were found to be higher than those for interim sanctuary zones (Burnham et al. 2021). However, this specific finding may be attributed to the specificity of the slowdown measures, particularly targeting commercial vessels whose captains are likely informed through the Port of Vancouver or their employers.

- The Tumbo Channel Zone and the existing Saturna Island Interim Sanctuary Zone each had at least quadruple the number of SRKW sightings compared to the Boat Passage Zone. It is unclear if this is due to lack of individuals who report sightings with a view of the Boat Passage Zone as discussed in Section 5.1 or if it is due to reduced SRKW presence in that area. As a result, the authors cannot justify recommending a management measure in this zone based on the available data. However, this does not imply that there is no potential merit for the implementation of a management measure in this area and it is included as a recommendation for future research.

Future Research Recommendations

Two main gaps in literature were identified through our literature review that would be meaningful to investigate. Firstly, the utilization of the ebb current flowing through Tumbo channel from the Fraser River by Chinook Salmon. This information could provide significant insight into the status of Tumbo Channel as foraging grounds for SRKW. The literature review did not yield sources for Chinook salmon distribution in the Salish Sea and specifically the AOI and this information would be important when considering future protected SRKW foraging areas. It is noted that one of the reasons Swiftsure Bank is a productive foraging area for SRKW is due to its location in the path of constant tidal currents that forces biomass onto the relatively shallow Swiftsure Bank itself (Thornton et al. 2022 b). Chinook salmon in particular tend to aggregate along the axes of tidal currents (Thornton et al. 2022 b). A similar phenomenon could be occurring on a smaller scale in Tumbo Channel as this area is also relatively shallow with a strong ebb current running through it (Thornton et al. 2022 a, Daber 2018). Second, there is insufficient information on ambient noise levels in Tumbo Channel. This information input into a noise propagation model could provide a more accurate representation of potential sound pressure level received by SRKW.

The following analyses are achievable with additional data, but they were beyond the scope of the timeframe for this report, and it is recommended they are included in future research.

- Effort correction of cetacean sightings from BCCSN, OrcaMaster, and SFU datasets. Effort correction will allow for standardization to ensure that observed patterns are not the result of differences in observation effort. This will also allow for an accurate representation of temporal and spatial trends including seasonal variation. Effort correction will ensure the integrity of the data and allow for robust statistical analyses.
- Analysis of cetacean sightings data from outside the active period of the current Saturna Island Interim Sanctuary Zone. SRKW are in the Salish Sea and specifically around Saturna Island throughout the entire year (Shields 2023). Foraging grounds may vary temporally and this area may be important in the winter or spring, in addition to or instead of the summer and fall.

- Similarly, analyzing vessel use of the area of interest for the entire year will give insights to the cumulative exposure that SRKW are faced with. These findings may help to inform management measures that have not been considered in the temporal scale of this project.
- A dedicated vessel survey in Tumbo Channel and Boat Passage zones for a more accurate representation of the ratio of AIS to non-AIS vessels may prove beneficial for future assessments of vessel traffic and impacts in the area.
- Similarly, a dedicated cetacean survey in Boat Passage Zone would provide insight into whether or not the low reported sightings in this zone are due to low usage of this area by SRKW or is simply a result of low reported sightings. This could additionally provide insight into how all cetaceans utilize this habitat.
- International shipping lanes are in close spatial proximity to the existing ISZ, approximately a few hundred metres away. It is undeniable that commercial shipping vessel traffic contributes to cumulative sound exposure and noise pollution in the area of interest (Matthews et al. 2018). Including this in future research will give a more comprehensive value of sound exposure in this area. Additionally, SRKW and other whale species in the AOI are commonly sighted in the shipping lanes (Quayle 2021). Future research assessing physical interactions between SRKW and vessels in the shipping lane would increase the accuracy of the received level of noise at SRKW individuals when shipping vessels are in close proximity.
- This analysis investigated sound exposure from one vessel transiting through the AOI. At any given time, it is probable and likely that there will be more than one vessel in the AOI, in addition to background noise from outside of the AOI. It is suggested that multiple vessel cumulative sound exposure (cSEL) be considered in the future. Additionally, vessel source levels were obtained from preexisting

literature, and it is recommended that empirical data for vessel source levels from different vessel classes are utilized.

- As mentioned in Section 5., another parameter of future research is the foraging activity level of SRKW in Tumbo Channel compared to other areas in the AOI. The length of time that SRKW spend in the area as well as any evidence of foraging behaviour could indicate this area remains an important foraging territory for SRKW. There is currently anecdotal evidence that may indicate that SRKW are foraging in Tumbo Channel based on travel patterns.

- The significance of Tumbo Channel and Boat Passage Zones to all marine mammals including other cetaceans and pinnipeds and, fish including both forage and predatory fish species. Humpback whales, Transient (Bigg's) killer whales, harbour porpoises, grey whales, harbour seals, California sea lions and Steller sea lions have all been documented in Tumbo Channel. The determination of habitat use of the AOI could be achieved for all aforementioned cetaceans with the SFU, BCCSN, and Orca Master datasets but was out of the scope of this report. A more rigorous observation and reporting effort would be required to include all marine mammals.

- When analyzing Class B AIS and non-AIS vessel data, it became clear that there is a high presence of vessels in the Saturna Island ISZ during the active period of June through November. This can be seen in Figure 13 of AIS vessel tracks through the area of interest and Figure 10a of vessels counted in the ISZ. Increased enforcement and education of the ISZ are likely required to achieve future increased compliance.

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Appendix A. SRKW Movement Model

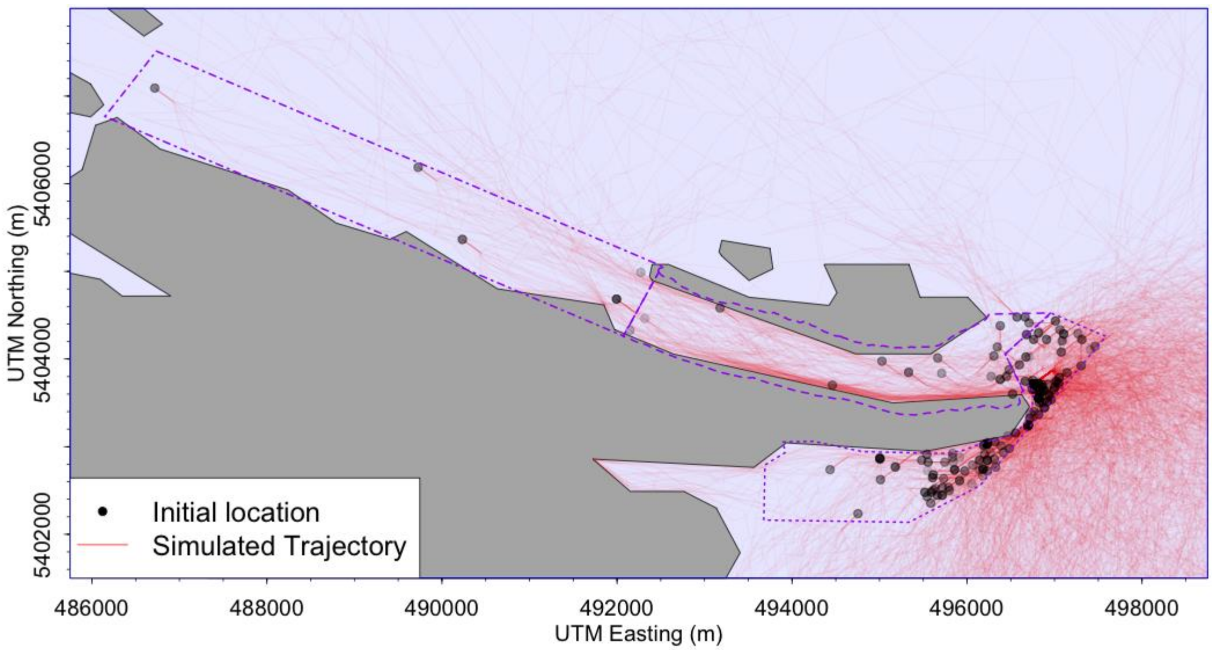

Figure A1: Visual representation of Southern Resident killer whale simulated trajectories (red lines) with sightings of whales between 2012-2022 (black points) within the area of interest. Black points were used as initial locations for the movement model simulated trajectories. Received level of noise from the different noise propagation scenarios were evaluated along the trajectory lines and summarized in Figure 16.

Appendix B. Dedicated non-AIS vessel survey.

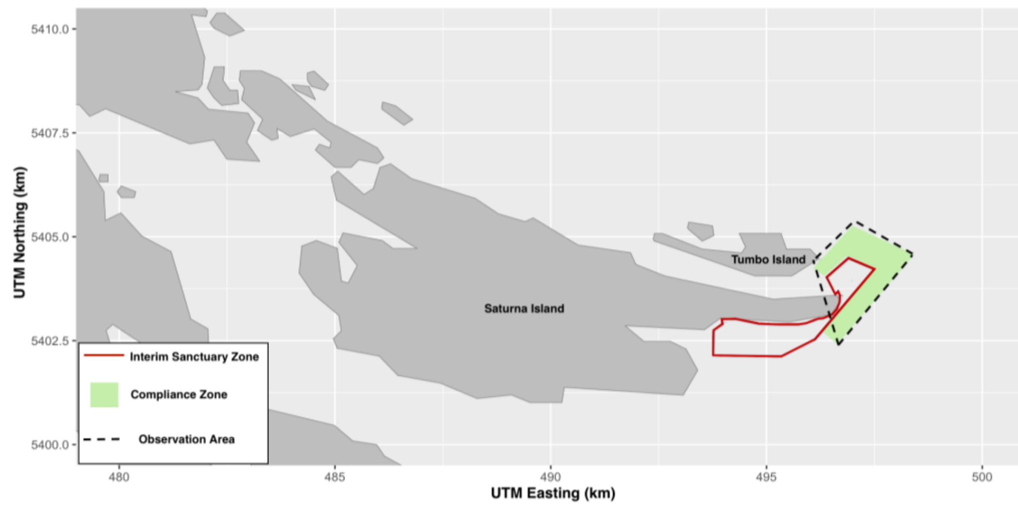

Figure B1. Map of the observation area in the area of interest where non-AIS vessel presence was recorded by researchers from Simon Fraser University in both the Saturna Island Interim Sanctuary Zone and the immediate area surrounding the ISZ boundary, referred to in this depiction as the "Compliance Zone" as vessels transiting this area are in compliance of the ISZ.

Table B1. Number of observation days (OD) and total AIS and non-AIS vessels in SFU observation area (Figure B1) per month.

		OD	AIS	Non-AIS	Total
2021	Sep	9	14	53	67
	Oct	11	16	25	41
2022	Jun	14	41	133	174
	Jul	15	80	202	282
	Aug	19	86	353	439
Total		**68**	**237**	**766**	**1003**

Table B2. Total non-AIS vessels of each vessel class (Table B3) in the SFU Observation Area. Vessel classes with 0 non-AIS vessels observed are omitted from this table.

		PL	SA	EN	Total
2021	Sep	40	9	4	53
	Oct	14	5	6	25
2022	Jun	101	23	9	133
	Jul	126	42	34	202
	Aug	278	75	0	353
Total		**559**	**154**	**53**	**766**

Table B3. Assignment of vessel type codes from the AIS dataset of the area of interest corresponding to the vessel class used for all vessel analyses.

Vessel Class	AIS Type Code
Pleasure Craft (PL)	37 – Pleasure Craft
Sailing (SA)	36 – Sailing
Passenger (PA)	60 – Passenger, all ships of this type 67 – Passenger, reserved for future use
Fishing (FI)	30 – Fishing
Enforcement (EN)	35 – Military Ops 51 – Search and Rescue Vessel 55 – Law Enforcement
Other (OT)	31 – Towing 33 – Dredging or underwater ops 50 – Pilot vessel 90 – Other type, all ships of this type

Table B4. Organizations of vessels recorded by SFU researchers that are included in the enforcement count of non-AIS vessels.

Sector	Organization
Government	Border Patrol Parks Canada RCMP Department of Fisheries and Oceans Canada
Indigenous Marine Protection and Stewardship	W̱SÁNEĆ Marine Guardians Pauquachin Marine Officers
Other Stewardship Monitoring Programs	CETUS Straitwatch

Appendix C. Glossary Sources

Specialized terms defined in the glossary of this report are sourced from:

Matthews MR, Alavizadeh Z, Hannay DE, Horwich L, Frouin-Mouy H (2018) Assessment of Vessel Noise within the Southern Resident Killer Whale Critical Habitat. Document number 01618, Version 2.1. Technical report by JASCO Applied Sciences for Transportation Development Centre of Transport Canada.

Matthews MR, Grooms C (2021) Assessment of Vessel Noise within the Southern Resident Killer Whale Interim Sanctuary Zones. Document number 01979, Version 2.0. Technical report by JASCO Applied Sciences for Transportation Development Centre of Transport Canada.