The Effects of Vessel Disturbances on Northern Resident Killer Whales in the Robson Bight (Michael Bigg) Ecological Reserve

by

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Declaration of Committee

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Degree:	**Master of Science (Ecological Restoration)**
Title:	**The Effects of Vessel Disturbances on Northern Resident Killer Whales in the Robson Bight (Michael Bigg) Ecological Reserve**
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Abstract

Presence of vessels in the ocean has a significant impact on northern resident killer whales (NRKWs). In this study, we investigated the effects of physical disturbance caused by vessels on NRKWs' beach rubbing behaviour, a cultural behaviour of importance to these whales. We hypothesized that the presence of vessels would deter NRKWs from beach rubbing, but we also investigated the influence of tide height and vessel distance from the rubbing beaches on this behaviour. From July through September in 2020 and 2021, our study was conducted in and adjacent to the Robson Bight (Michael Bigg) Ecological Reserve (RBMBER), a marine reserve in Johnstone Strait, British Columbia (BC) where the rubbing beaches exist. The data were collected from a land-based platform and analysed using GAMM. We found that NRKWs preferred the beaches inside RBMBER, and proximity of vessels to NRKWs at the rubbing beach outside RBMBER affects their decision to rub, as the probability of beach rubbing increases as the distance between NRKWs and vessels increases. Tide height influences beach rubbing only at the beaches inside RBMBER. Given the results, it is evident that vessel presence and their proximity to whales in critical habitats need to be addressed and the existing guidelines need amendments.

Keywords: Northern Resident Killer Whale (NRKW); rubbing beaches; vessel presence; physical disturbance; ecological reserve; marine protected area (MPA)

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List of Acronyms

AIC	Aikaike Information Criteria
BC	British Columbia
coAR1	Class, representing an autocorrelation structure of order 1
DFO	Fisheries and Oceans Canada
GAMM	Generalized Additive Mixed Model
GLM	Generalized Linear Model
MPA	Marine Protected Area
NRKW	Northern Resident Killer Whales
RBMBER	Robson Bight (Michael Bigg) Ecological Reserve
SARA	Species at Risk Act
SRKW	Southern Resident Killer Whales

Glossary

Aikaike Information Criteria (AIC)	AIC is an estimator of prediction error and thereby relative quality of statistical models for a given set of data. AIC provides a means for model selection.
Bathymetry	Refers to the depths and shapes of underwater terrain.
Beach Rubbing	A unique behaviour among cetaceans categorized as the NRKWs come close the smooth pebbled beaches and rub themselves.
Bioenergetics	It is be defined as the study of energy relationships and energy transformations and transductions in living organisms.
Canadian Cordillera	A part of American Cordillera, which is a mountain chain along the western coast of the Americas.
Ecological Reserve	Areas selected to preserve representative and special natural ecosystems, plant, and animal species, features and phenomena.
Ecotype	An ecotype is a population that is adapted to local environmental conditions.
Hydrophone	A hydrophone is an underwater device that detects, and records ocean sounds from all directions.
Insular Mountains	A range of mountains in the Pacific Coast Ranges on the Coast of British Columbia and a part of Canadian Cordillera
Interim Sanctuary Zones	Temporally created in Southern Resident killer whale foraging area in the Salish Sea to reduce noise and physical disturbance from vessels.
Marine Protected Areas (MPAs)	Ocean areas set aside for conservation.
Matriline	A line of descent from a female ancestor to a descendant (of either sex) in which the individuals in all intervening generations are mothers.
Metabolism	The chemical reactions in the body's cells that change food into energy.
Mysticetus	A software to observe marine mammals to mitigate anthropogenic impacts.
Species at Risk Act	It is a Canadian federal law designed to meet one of Canada's key commitments under the International Convention on Biological Diversity. The goal of the Act is to prevent wildlife species in Canada from disappearing by protecting endangered or threatened organisms and their habitats.

Theodolite	An instrument that can measure both horizontal and vertical angles, which allows surveyors to triangulate the position of objects in a specific area.

Photo by Varsha Rani

Chapter 1. Introduction

1.1. Background

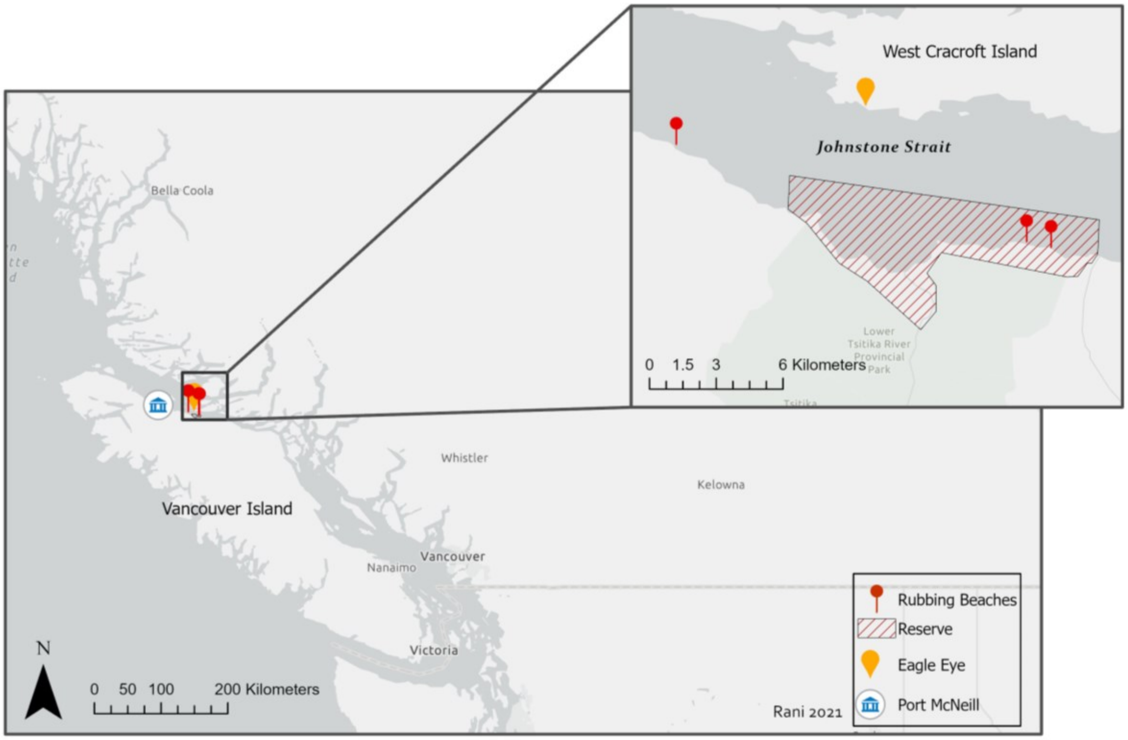

Figure 1: *Location of Robson Bight (Michael Bigg) Ecological Reserve (RBMBER) in the Johnstone Strait shown in red hatched area. The red markers on the map indicate the rubbing beaches, with two being inside RBMBER and one on the outside. The orange marker indicates the location of land-based monitoring platform Eagle Eye - overlooking RBMBER - from where the data were collected in 2020 and 2021. The blue marker is the City of Port McNeill on Vancouver Island.*

Killer whales are apex predators in many marine ecosystems, and they feed on an array of species including fish, invertebrates, and mammals (Ford 2009; Ford et al. 2009). They live in tight-knit matrilineal pods whose members share cultural specialisms or cultures that reinforce within-pod associations. Several matrilines with shared cultures that are known to interbreed are grouped into ecotypes (Barrett-Lennard 2000). Ecotypes are culturally distinct with vocalizations and behaviours differing between the many known ecotypes (Filatova et al. 2015). There are three genetically distinct ecotypes of killer whales found off the coast of British Columbia (BC), Canada: the residents, transients (also known as Biggs), and offshores (Ford et al. 2011). The residents can be further divided into two acoustically distinct populations: southern resident killer whales (SRKWs) and northern resident killer whales (NRKWs) (Olesiuk et al. 2005). While SRKWs are listed as “endangered” under the Canadian Species at Risk Act (SARA; Government of Canada 2002), NRKWs are listed as “threatened” under SARA. Both populations of resident killer whales are red listed under provincial law (BC Conservation Data Centre 2021). One of the major threats that NRKWs are facing in their habitat is physical disturbances caused by vessel traffic (Williams & Ashe 2006), which is the focus of my research.

The federal protections under SARA define a critical habitat as a habitat that is necessary for the survival or recovery of a wildlife species listed in the Act (Government of Canada 2020). In BC, to safeguard these critical habitats, marine protected areas (MPAs) such as ecological reserves are created to preserve representative and unique natural ecosystems, plant and animal species, features, and phenomena (BC Parks n.d.). One such reserve is the Robson Bight (Michael Bigg) Ecological Reserve (50.488010°, -126.505891°), referred to as RBMBER from here on. It is situated on the northeast end of Vancouver Island, BC, Canada, approximately 123 km from the city of Port McNeill (Figure 1). RBMBER is a part of the Insular Mountains of the Canadian Cordillera, the youngest of the four north-south parallel mountain ranges. RBMBER is located on the west end of the Johnstone Strait across West Cracroft Island (Figure 1). Johnstone Strait and the waters around it form the core summer foraging habitat of NRKWs (Briggs 1988). The Lower Tsitika River Provincial Park is south of RBMBER. The RBMBER is bordered to the west by the Tsitika Mountain Ecological Reserve, and to the east by the Mount Derby Ecological Reserve with the aim of providing protection to RBMBER from off-site disturbances from both directions. The Tsitika River flows through the uplands of the Lower Tsitika River Provincial Park forming an estuary where it enters RBMBER and the Johnstone Strait. At the end of this estuary are several smooth pebble beaches where NRKWs engage in a behaviour called beach rubbing. This behaviour is unique amongst killer whales (Figure 1) (Ashe et al. 2010) and is found at geographically distinct pebble beaches inside and adjacent to RBMBER.

RBMBER was established in 1982 as an Ecological Reserve to protect and preserve the rubbing beaches (Ashe et al. 2010). For the NRKWs, this unique ecosystem in Johnstone Strait is further protected federally as critical habitat (Government of Canada

2020) for whales that come to feed, socialize, and use the rubbing beaches. RBMBER has a 12.5 km^2 marine portion and a 5.1 km^2 forested upland portion (BC Parks 2007). Despite its protected status, the marine portion (NRKWs' critical habitat) experiences high amounts of recreational and commercial vessel traffic (Morton & Symonds 2002). This discord exists because while RBMBER was established by BC Parks, Fisheries and Oceans Canada (DFO) has jurisdiction over marine affairs, and the DFO permits fishing and large vessel transiting throughout the Johnstone Strait, including within RBMBER (Williams et al. 2009b). Voluntary no-go status of RBMBER does little in reducing the disturbances created by private and ecotourism vessels (Whitney et al. 2016)

From July to October, Pacific salmon migrate through the inside passage of Johnstone Strait to get to their spawning grounds on the east side of Vancouver Island and mainland BC (Nichol & Shackleton 1996). This migratory channel of salmon attracts NRKWs to RBMBER and while the whales are here, they use the rubbing beaches (Nichol & Shackleton 1996). There are three rubbing beaches found in the area, two in RBMBER, named Main and Strider, and one outside of RBMBER, named Kaizumi (Figure 1). Beach rubbing is a behavior that is not fully understood by researchers (Ford et al. 1998); however, possible motivations could be for hygiene (removing parasites or dead skin) or social (pleasure or sexual) purposes (Dudzinski et al. 2012), or simply because they enjoy the sensation of rubbing against the pebbles (Ford 1989). Regardless of the motivation, this behaviour appears to be traditionally important to NRKWs and has not been observed in any other killer whale ecotypes and is therefore culturally distinct (Ford et al. 2017).

Humans also find sustenance and enjoy recreational activities here. Summers in RBMBER are dry and mild in temperature (Church & Ryder 2010), with August the warmest month (Government of Canada 1981-2020). This creates ideal conditions for marine-related recreational activities such as kayaking, whale watching, and recreational fishing, although these activities are prohibited inside the waters of RBMBER. However, the guidelines are not enforced as compliance is voluntary (Whitney et al. 2016).

Vessels are known to have significant impacts on marine mammals (Culloch et al. 2016) and are known to affect the behaviour of killer whales (Holt et al. 2021). Jelinski et al. (2002) found that whale watching vessels affect the movements of NRKW when vessels deliberately entered RBMBER and actively tracked the whales. Cetus Research & Conservation Society – a non-profit marine conservation organization – has a warden program during the summer months where the wardens patrol the perimeter of the Reserve and ensure no unauthorized vessels enter it and educate recreational users (Cetus Research & Conservation Society n.d.). However, this measure is not sufficient to prevent transgressions, and the effectiveness of such voluntary measures is not well studied (Whitney et al. 2006).

Recreational users put up tents and camp on Kaizumi Beach, just outside of RBMBER. As fishing and transiting by commercial vessels is permitted inside RBMBER, whales have been documented to move away or leave RBMBER entirely upon vessel entry (Trites et al. 2007). Vessel presence was found to have a direct negative effect on the rubbing and feeding activity of the NRKWs in RBMBER, reducing time spent engaged in these two activities (Williams et al. 2006). This suggests that the habitat quality is degraded by vessel presence. Chinook salmon, the primary source of their summer diet (Ford et al. 2010), is in decline (Riddell et al. 2013). In Johnstone Strait, there has not been a commercial fishing opening for Chinook salmon since 2018 (Fisheries and Oceans Canada n.d.). Like all top predators, NRKWs are limited by bioenergetic rules in which a decline in prey abundance affects available energy for survival and reproductive success. Adding physical vessel disturbances can compound stress. Evasive movement by NRKW to avoid vessels can result in longer travel and more tortuous movement pathways. These behavioural consequences may negatively impact daily metabolism and bioenergetics. The energy NRKW spend evading vessels could potentially be budgeted towards foraging, resting, or beach rubbing (Williams & Ashe 2007). More research is needed to reach an in-depth understanding of NRKW behaviour and how behaviour is impacted from interactions with vessels. Understanding changes in NRKW movement and behaviour in response to vessel presence will facilitate better outcomes in restoration of NRKW critical habitat. Moreover, understanding important causal or correlative links between killer whales and boats may provide new insights into other populations of whales, most important of which would be insights that might help protect the endangered SRKW population.

For my research, I pose the following questions about NRKW behaviour and vessel disturbance at rubbing beaches in Johnstone Strait, inside and adjacent to RBMBER:

1. What effect do vessels have on beach rubbing behaviour of NRKWs?

2. What is the NRKW usage frequency of the beaches that are inside versus outside RBMBER?
3. Is there a relationship between vessel presence and rubbing beach preference?

1.2. Goals and Objectives

Goal: Assess the effects of vessel disturbance on NRKW beach rubbing behaviour. If NRKWs are found to be showing preference for one beach over others, determine if there is an observable cause, whether anthropogenic or environmental.

- **Objective 1:** Determine the role of number of vessels and distance of vessels from NRKW have on beach rubbing behaviour.
- **Objective 2:** Determine the role environmental factors such as tide height have on beach rubbing behaviour.
- **Objective 3:** Establish the usage frequency of the beaches both inside and outside RBMBER in the absence and presence of vessels.

Chapter 2. Methodology

2.1. Study Area and Effort

In 2020 and 2021, data about cetaceans in the region were collected by observers at a land-based monitoring platform on West Cracroft Island (Eagle Eye, 50.52453°, -126.5974°, Figure 2). In 2020, data were collected from the 1st of July to the 7th of September. In 2021, similar data were collected from 1st July 2021 to 5th September 2021. Each year, two observers participated in data collection, typically on different days, but occasionally working together. Cetus staff and volunteers were also stationed at Eagle Eye and assisted the observers by tracking whales and assessing their behaviour. In both years, whale sighting effort at Eagle Eye occurred from approximately 0900 to 1630 hours. During times when NRKW were visible from Eagle Eye, sightings of NRKWs, commercial vessels, and recreational boats were collected. Data were collected for 44 days out of 69 days in 2020, and 59 days out of 67 days in 2021.

The Eagle Eye viewing platform overlooks the study area which encompasses the three rubbing beaches. In the west and outside RBMBER is Kaizumi Beach. Kaizumi is a beach that has a land portion where rubbing gravel come out of the water. Towards the east and inside RBMBER is Strider Beach and Main Beach. Both beaches are underwater beaches – meaning the rubbing gravel never comes out of the water (Figure 2).

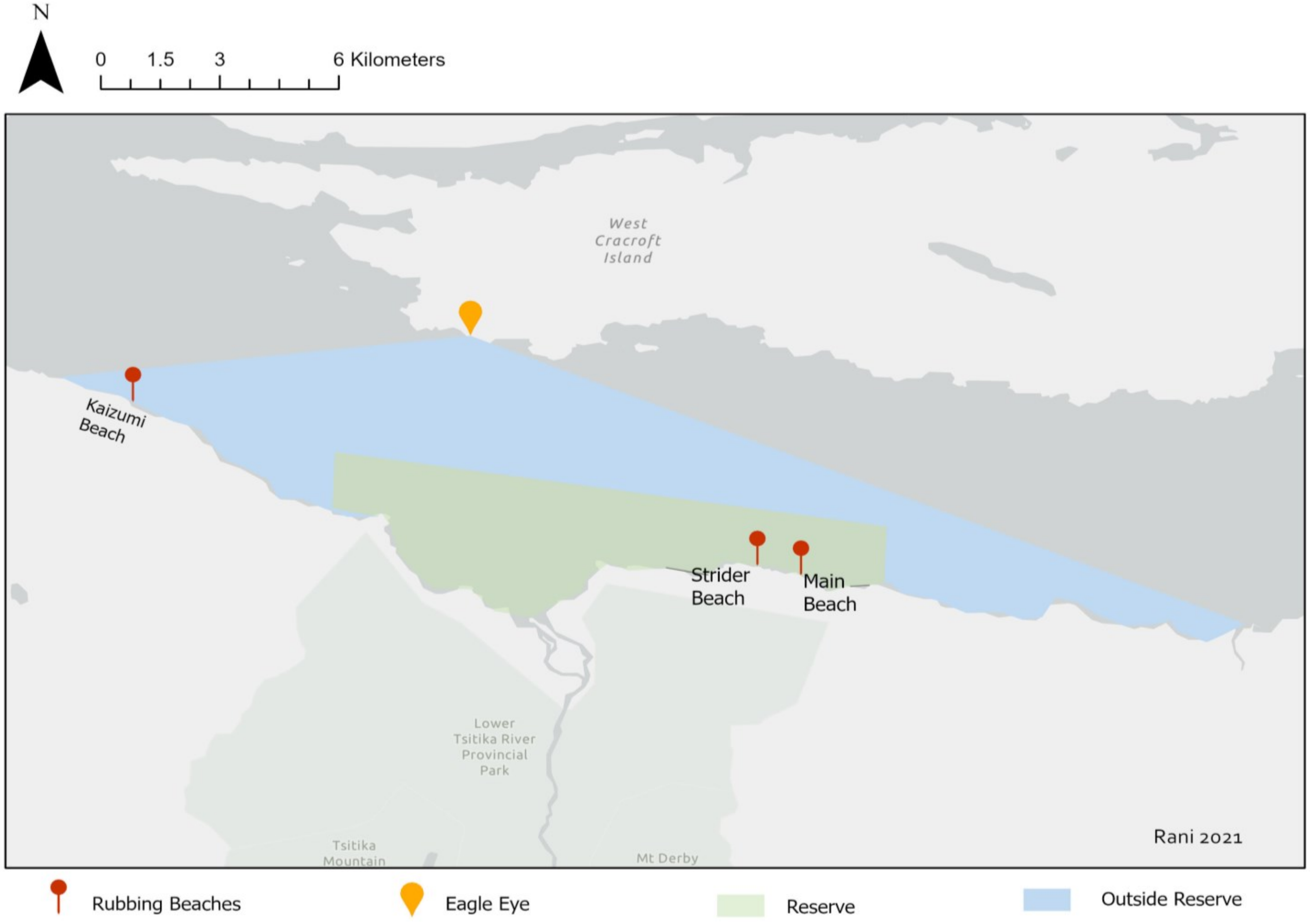

Figure 2: *2020 and 2021 study area in the Johnstone Strait, BC includes Robson Bight (Michael Bigg) Ecological Reserve shown in green and observable area adjacent to RBMBER shown in light blue. The red markers on the map indicate the rubbing beaches. The orange marker indicates the Eagle Eye monitoring platform where data collection took place.*

2.2. Equipment and Environmental Data Collection

The study area was surveyed systematically by visually scanning the study area from east to west following methods in Lusseau et al. (2009), this standardized effort to ensure consistent reporting across each data collection period. The observations were recorded in the Mysticetus software (version 2020.0043. in 2020; version 2021.21 in 2021). NRKWs, commercial vessels, and recreational boats were observed using binoculars, a spotting scope (Zeiss – Model No: Conquest Gravia 85). Whale positions were recorded using a theodolite (TOPCON – Model No: DT-205) and the Mysticetus software.

Prior to starting scan surveys every morning, the theodolite was leveled, and calibrated using the known location of the theodolite, the vertical angle to a vertical reference location with a known position, and a horizontal angle to a horizontal reference location with a known position. This allowed the Mysticetus software to calculate the location of targets (vessels or whales) viewed through the theodolite. The theodolite was placed approximately 50 m above sea level, however this height changed throughout the day depending on the tide height. To record tide height changes and compensate for this fluctuation, an updated vertical angle to the vertical reference location was determined every 15 minutes to ensure locational data were accurate. Two horizontal reference locations were selected: one as far from Eagle Eye as possible and the other closer to Eagle Eye. The closer horizontal reference location was used as back up if the distant one was not visible due to poor weather conditions (e.g., covered by fog or glare).

Environmental conditions (sea state, visibility, precipitation, cloud cover, glare) were recorded at the start of each day and updated when weather conditions changed (Appendix A – Table 8). As Kaizumi Beach is outside RBMBER and therefore accessible and popular for recreational use, we also recorded the presence of people at the beach. Positions of NRKWs and vessels in the study area were recorded using the theodolite at a minimum interval of every 5 minutes in 2020 and of every 15 minutes in 2021. In both years, it sometimes took longer than the specified minimum interval to collect all positions. In addition to environmental conditions as stated above, whale and vessel characteristics were recorded for each scan interval concurrently.

2.3. NRKW Data Collection

Table 1: Definitions used to categorize group spread of NRKW in Johnstone Strait, BC in 2021.

Spread Category	Definition
Alone	Solo whale
Tight	Whales are within one body length of each other
Loose	Whales are within one to five body lengths of each other
Dispersed	Whales are within five to ten body lengths of each other

Table 2: Definitions of the NRKW behaviours observed in 2020 and 2021 in Johnstone Strait, BC, adapted from Williams et al. (2006).

Behaviour	Definition
Resting	Movement at slow speeds. No surface activity. Visible breaths. Tips of the dorsal fins at the surface.
Beach Rubbing	Whale presence near a rubbing beach. Independent surfacing and diving of individuals. Slow swim speeds toward a rubbing beach. Bubbles or splashing could be observed in the vicinity of the rubbing beach.
Travelling	At the same time surfacing within 10 to 20 seconds of each other. Travelling in the same direction. Pattern of short dives followed by long one.
Feeding	Fast and non-directional surfacing, surfacing independently and irregularly. Unpredictable dive sequences.
Socializing	Tight groups, tactile behaviour, and other surface behaviour (spy hopping, tail lobbing, breaching). Irregular and independent dives. Non-directional surfacing and frequent directional changes.

In a scan interval, when an NRKW or a group of NRKWs was sighted it was classified as a whale event. Once spotted, whales were categorized as solo or in a group. For a group of NRKWs, a sighting was taken for the lead whale and follow whales through theodolite. In 2020, the sightings through the theodolite were only taken when they were approximately within 2 km of the Vancouver Island shoreline. Whale behaviour, spread, group size, and configuration were noted opportunistically in comments. In 2021, the sightings through theodolite were taken for the whole study area and behaviour, spread, group size, and configuration were recorded systematically and according to defined values. We recorded group spread as either alone, tight, loose, or dispersed (Table 1). Configuration was classified as linear, non-linear, or flank (if a whale was alone – configuration was noted as null). Definitions of behaviour were adapted from Williams et al. (2006) and include resting, beach-rubbing, travelling, feeding, and socializing (Table 2). Changes in activity and location of NRKWs were recorded every scan.

2.4. Vessel Data Collection

The protocol for vessel data collection was the same for 2020 and 2021. In a scan interval, when a vessel was sighted, it was classified as a vessel event. For each vessel sighting taken through the theodolite, we recorded the type of vessel. Vessel types were grouped according to whether they were private vessels, fishing vessels, large commercial vessels, whale watching vessels, coast guard vessels, or other (Appendix A – Table 9). We recorded size of the vessel: small (<30ft), medium (30-80ft), or large (>80ft), and engine position: inboard, outboard or without engine. A second sighting of vessels was taken after approximately 5 seconds, allowing the Mysticetus software to calculate the approximate speed of the vessels in knots.

2.5. Data Analysis

Data in 2020 and 2021 were collected by different teams of observers. There were some differences and inconsistencies with the protocol and its interpretation related to a slightly modified scan protocol. Therefore, before beginning the data analyses, quality control was done in the form of correction and removal of some scans. Due to limitations in the precision of the data collection process, theodolite sightings sometimes showed up on land, particularly those at greater distance from the theodolite. Those locations were corrected by moving the points to the edge of the water, along the horizontal bearing angle from Eagle Eye of the sighting. As mentioned above, in 2020, behavioural information was noted opportunistically. I used these notes, in addition to concurrent data collected by Cetus, to assign behaviour post-hoc where possible. If I was unable to determine the behaviour, it was assigned as ‘unknown’. Because in 2020 scans were sometimes conducted as frequently as every 5 mins, to make 2020 data comparable to 2021 data, redundant scans were deleted from the 2020 dataset. Scans were considered redundant if the time gap between the start times of the scan preceding it and the scan following it was less than 20 mins. In addition, periods with poor weather conditions (scans with severe glare and fog), and training days at the start of each field season were excluded from the analysis.

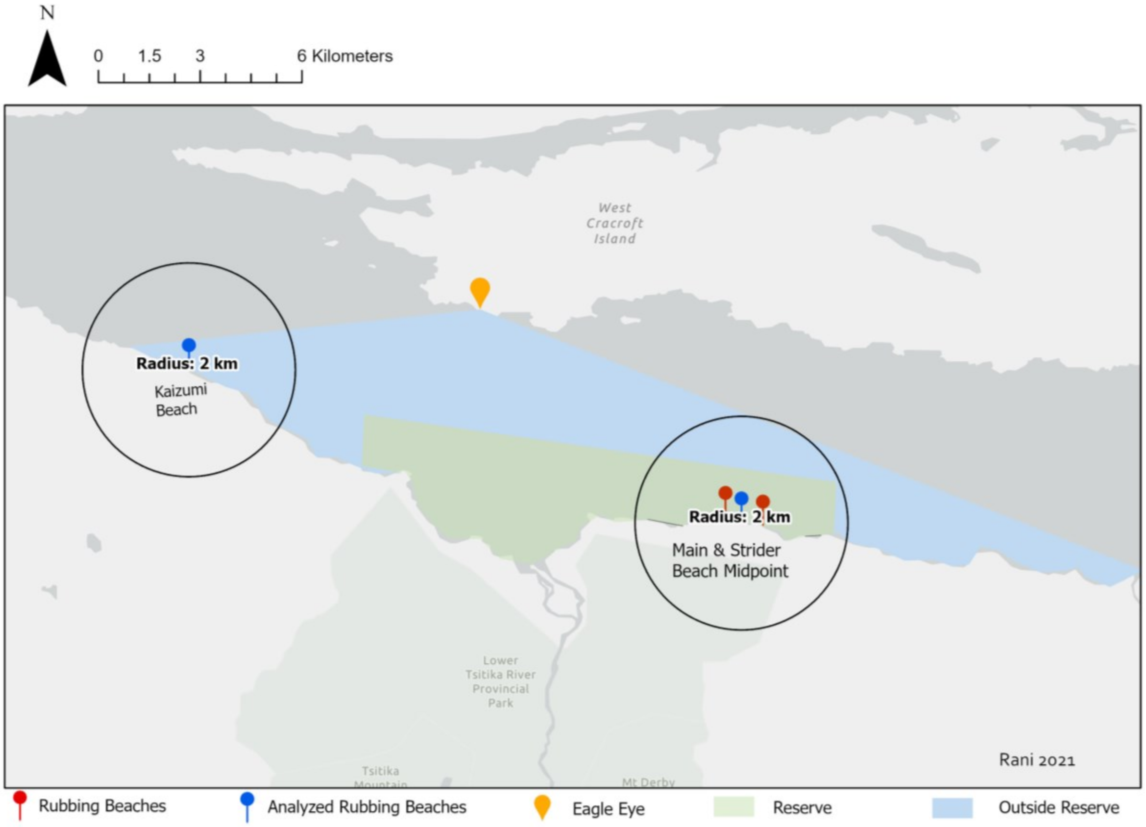

Figure 3: *Study area in the Johnstone Strait, BC includes Robson Bight (Michael Bigg) Ecological Reserve shown in green and observable area adjacent to RBMBER shown in light blue. The blue markers on the map indicate the rubbing beach locations used in analysis. The*

red markers on the map are the actual locations of rubbing beaches: Main Beach (east of midpoint) and Strider Beach (west of midpoint). The 2 km radius around the beaches show the area in which NRKWs were considered for beach rubbing analysis. The orange marker indicates the Eagle Eye monitoring platform where data collection took place in 2020 and 2021.

Data analyses were carried out in RStudio®. For the purposes of analysis, the midpoint between Main and Strider rubbing beach was used to represent their location (inside RBMBER) as they are only 750 m away from each other (Figure 3; Appendix A – Table 7). The midpoint will be referred to as Main/Strider. Because I am interested in beach rubbing behaviour, which can only occur when whales are at the beaches, only the NRKWs within 2 km of beaches were considered in the data analysis (Figure 3). Further, only the vessels within 5 km of NRKWs near beaches were considered when determining the values for the vessel characteristics. Vessels at distances further than 5 km were assumed to not affect beach rubbing behaviour significantly. For a given scan, a visual search of the study area was conducted from east to west, and sightings were recorded of NRKWs and vessels.

Data was collated where each scan was considered one data point. In the transformed dataset, the following variables were chosen for analysis:

- ***Beach rubbing (0 for no / 1 for yes)*** – While NRKWs were present in the scan, did beach rubbing occur. This is the response variable in our statistical models
- ***Location of NRKW (Main & Strider / Kaizumi)*** – This variable was chosen to determine whether there is difference in the beach rubbing behaviour at beaches inside RBMBER versus beach outside RBMBER
- ***Time of day*** – We hypothesized that time of day might influence beach rubbing of behaviour of whale
- ***Total number of vessels in each scan*** – This variable was chosen as we hypothesize the number of vessels present will influence beach rubbing behaviour of NRKWs
- ***Tide height (represented by Eagle Eye altitude, in m)*** – This variable was chosen as we hypothesize the tide height will influence beach rubbing behaviour (Observed range for 2020 and 2021 was from 0.5 m to 4.8 m)
- ***Distance between NRKW and closest vessel (in m)*** – This variable was chosen as we hypothesize the vessel distance from NRKW will influence beach rubbing

behaviour. This was calculated using RStudio®, where distance between every NRKW and every vessel events present in a scan was determined. The distance that was shortest was chosen as representative of a scan

- ***Type of closest vessel*** – We hypothesize that different vessel types may have different effects on NRKWs rubbing behaviour. This was determined from the closest distance variable This variable is not used in the model, it is used for distribution assessments

There are a number of challenges with analysing this kind of data. For example, I used a generalized linear model (GLM) that linked the response to the independent covariates through a logit link function under the assumption of a binomially distributed response variable (beach rubbing yes/no). The relationships between the response and covariate data are sometimes non-linear, and I modeled non-linear smooths functions to these covariate relations. And finally, multiple successive scan surveys on a single day are temporally correlated, and therefore I corrected for this pseudo-replication through random effect terms and an autocorrelation function (within day). The statistical model that allows for all these data features is the Generalised Additive Mixed Model (GAMM).

I fit GAMM a to examine which independent covariates were correlated to beach rubbing behaviour in NRKWs. GAMM chooses between linear and non-linear combinations of the independent variables to best explain the response variable. I fit beach rubbing (0/1) as the response variable, with a binomial family specification with a logit link function to relate the probability of beach rubbing to the environmental covariates. Since the data were collected in 15 minutes scans, to account for temporal correlation in the model, I used an autoregressive (order one) weight matrix (corAR1) to down weight adjacent scan surveys, and I included a random effect to account for differences in days. The models had the following structure:

Model 1: gamm (beach rubbing = vessel event count + distance of closest vessel from NRKW + tide height, at the two beaches)

Model 2: gamm (beach rubbing = vessel event count + distance of closest vessel from NRKW + tide height + time of day, at the two beaches)

Model 1 looks at the effects of variables – vessel event count, distance of closest vessel from NRKW, and tide height – on beach rubbing behaviour at different beaches. In Model 2, time of day was another variable considered; however, it was dropped after no significant effect was observed. The best model was selected based on selecting the model with the smallest Aikaike Information Criteria (AIC). Model 2 had the AIC equal to 1276.929 and model 1 had the AIC equals to 1273.496, thus model 1 was ultimately used in the final analysis.

The expectation of the probability of observing NRKW beach rubbing at each of the two rubbing beaches was determined by using the predict () function in RStudio® for Model 1. We used the fitted model to compare the predicted probability of beach rubbing with vessels absent against a maximum number of vessels present in the study area per scan.

Chapter 3. Results

3.1. NRKW Presence Summary

In 2020, NRKWs were present in the study area 30 days during data collection period and hours, and beach rubbing was observed 18 out of those 30 days during collection hours (Figure 4A). In 2021, NRKWs were present in the study area 29 days during the data collection period and hours, and beach rubbing was observed on 16 out of those 29 days during collection hours (Figure 4B).

Table 3: NRKW behavioural events observed on the 30 days in 2020 and 29 days in 2021 in Johnstone Strait, BC. A behavioural event is when an NRKW or a group of NRKWs was sighted performing one of the below listed behaviour in a scan interval.

Behaviour	Event Count in 2020	Event Count in 2021
Unknown	411	17
Resting	48	50
Socializing	47	83
Beach rubbing	115	122
Foraging	384	161
Travelling	412	861
Total Events Observed	1417 in 319 Scans	1290 in 310 Scans

In 2020, 115 beach rubbing events were observed out of 1417 total comprising 8.12% of all events and in 2021, 122 beach rubbing events were observed out of 1290 total comprising 9.46% of all events (Table 3; Figure 4A & 4B). Resting and socializing were the least observed behavioural events whereas travelling was the most observed.

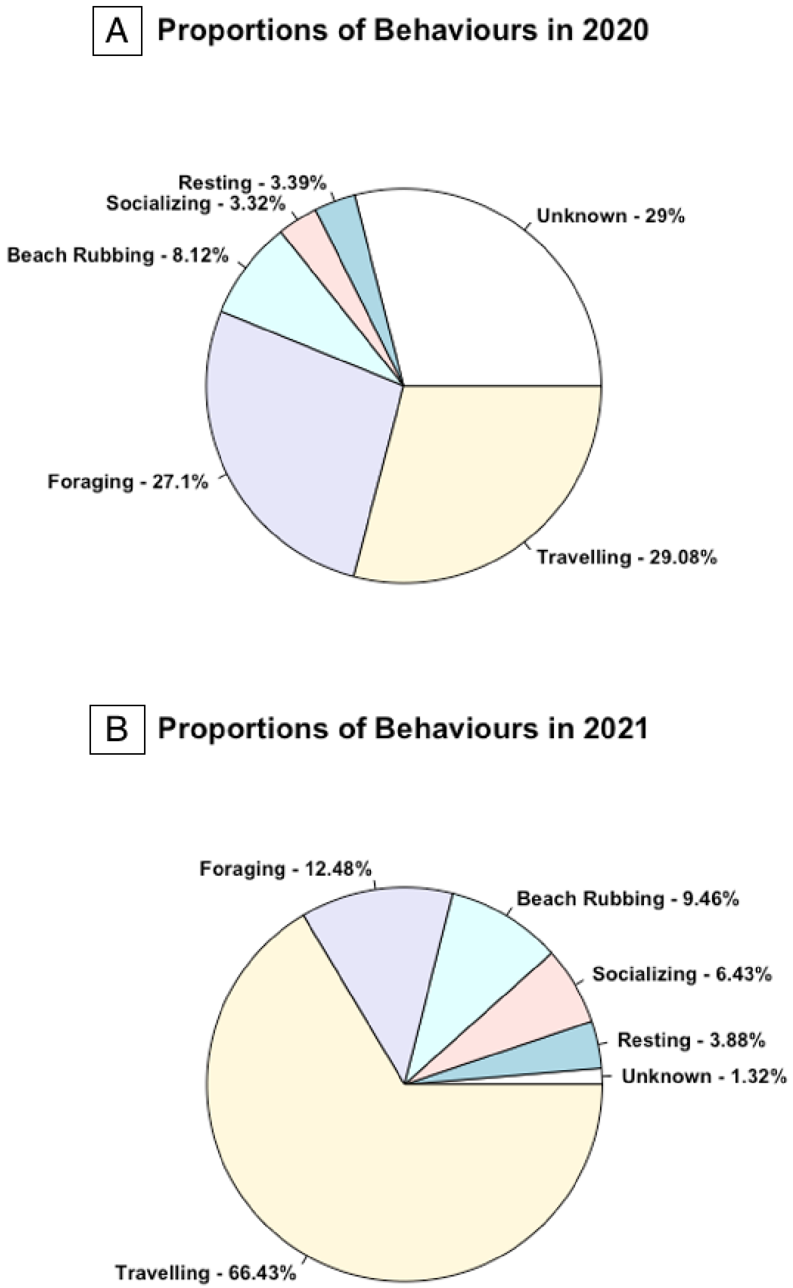

Figure 4: *Proportion of behavioural events (A) in 2020 on the 30 days NRKWs were present and (B) in 2021 on the 29 days NRKWs were present in Johnstone Strait, BC.*

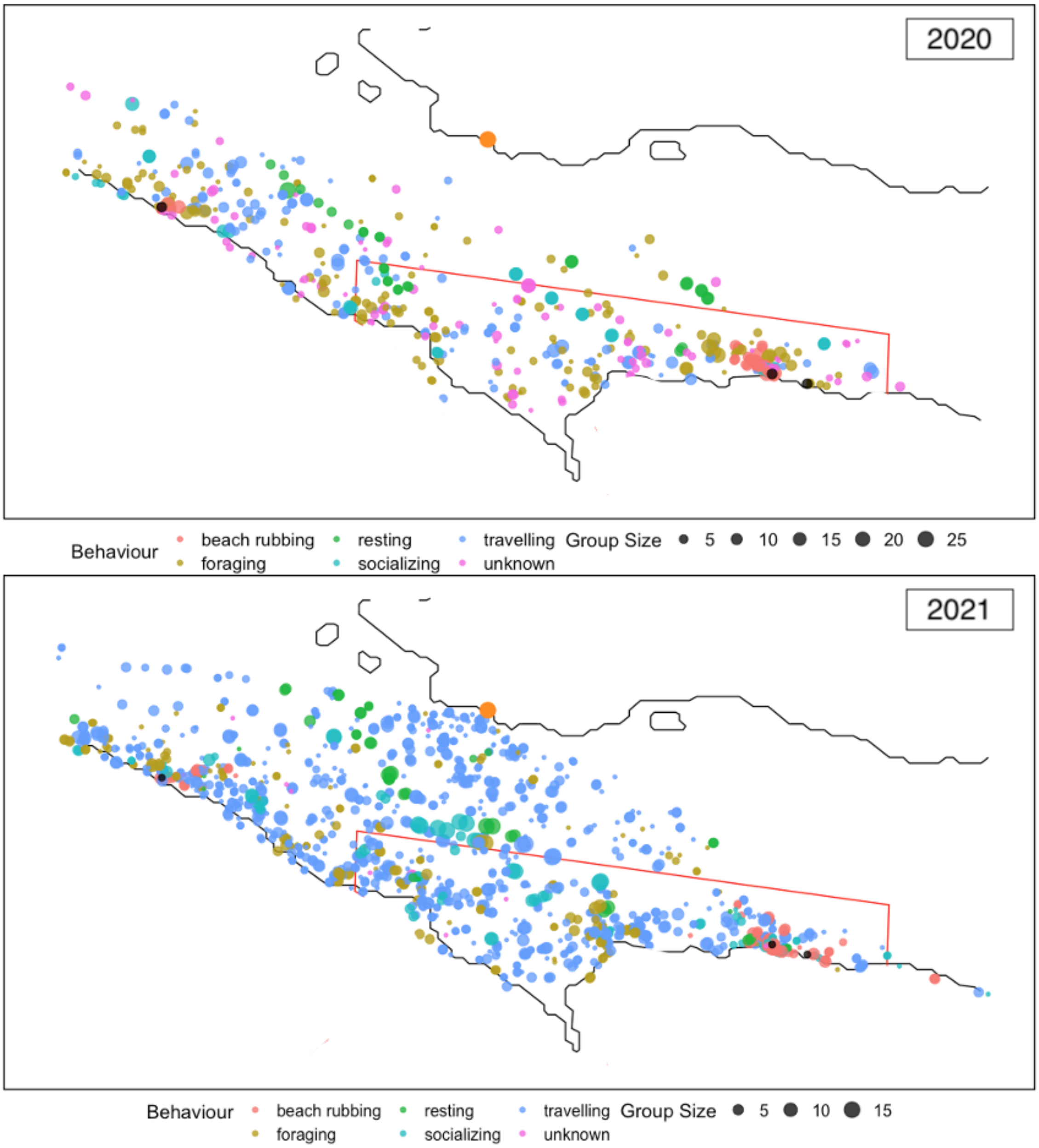

Figure 5: *Whale presence in Johnstone Strait, BC in 2020 and 2021. Colours represent the different behaviours and size of the bubble represents group size of whales observed. Black lines represent the shorelines: top shoreline – West Cracroft Island and orange dot on that shoreline is Eagle Eye, and bottom shoreline – Vancouver Island and black dots here are rubbing beaches. Red line represents RBMBER boundary.*

NRKWs were observed in the whole study area (light blue and green region in Figure 3) for both years generally; however, certain behaviours were only performed in certain areas. Travelling – the most observed behaviour – was noted throughout the study area (Figure 5). Beach rubbing was observed only at the three rubbing beaches (Figure 5). Foraging was mostly observed closer to the shoreline, whereas resting was mostly observed away from the shoreline as noted in Figure 5.

NRKW Characteristics in 2021

Group configuration and group spread of NRKWs are shown in Table 4 and Figure 6. While beach rubbing and foraging, most of the groups were in a non-linear configuration and loose in spread (Figure 6). While resting, most of the groups were in a flank configuration followed by linear, and tight in spread (Figure 6). While socializing, most of the groups were in a non-linear configuration followed by linear and flank, and they were either tight or loose in spread (Figure 6). Lastly, while travelling most of the groups were in a linear configuration followed by flank, and they were tight in spread followed by loose (Figure 6). Travelling and foraging were the two behaviours where a significant proportion of whales were observed alone. For all behaviours, the proportions of configuration and spread noted were similar both near the beaches and the rest of the study area (Figure 18; Appendix B).

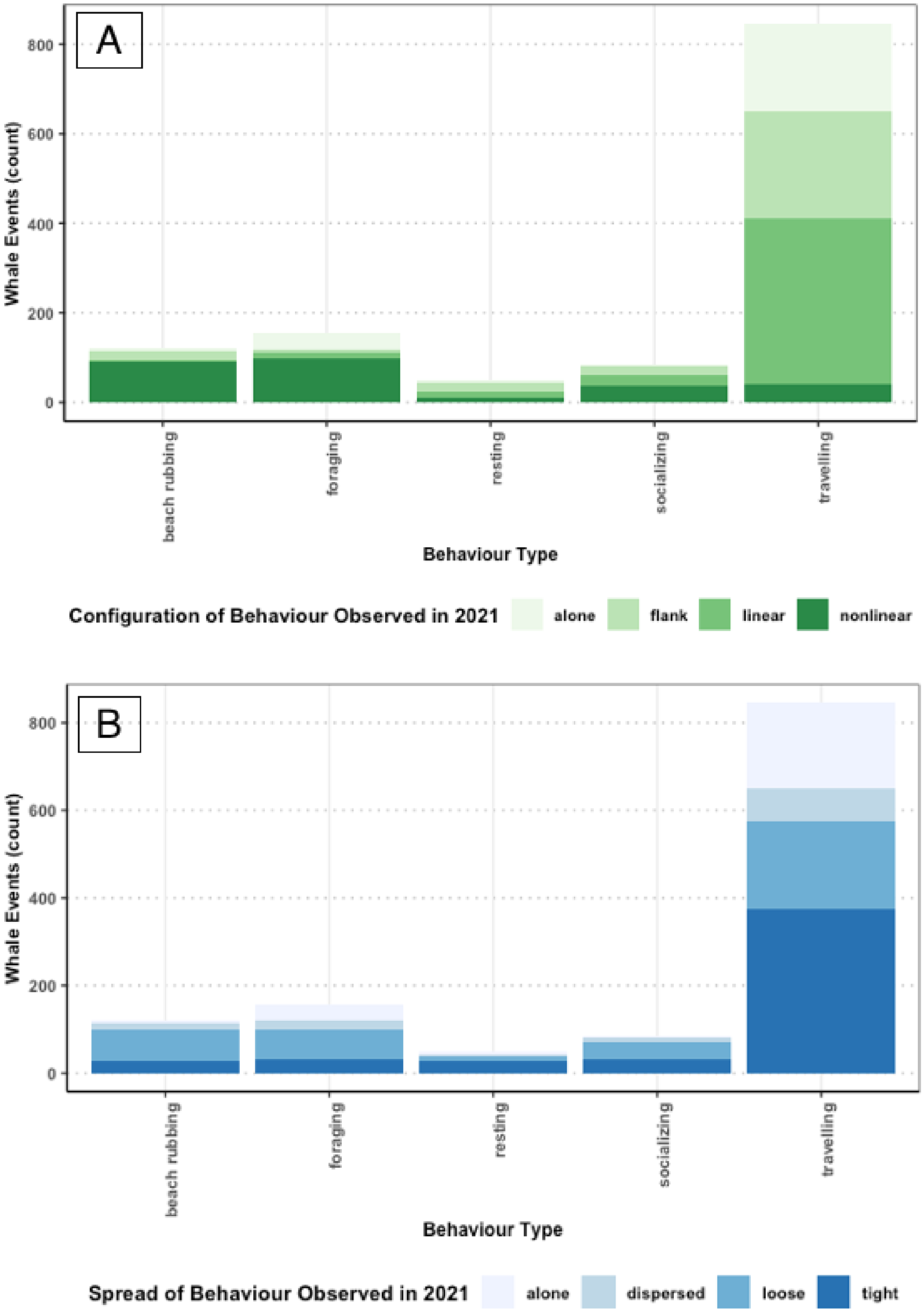

Figure 6: *Group (A) configuration and (B) spread of NRKWs across different behaviours observed by whale event count in Johnstone Strait, BC in 2021.*

3.2. Vessel Presence Summary

The effort of vessel data collection was 44 days in 2020 during collection hours and 59 days in 2021 during collection hours. When the NRKWs were present, the vessel types observed were private vessels, commercial non-fishing vessels, commercial fishing vessels, whale watching vessels, government vessels, and marine monitoring vessel (Figure 7). If a vessel did not match any of the categories listed in Table 8 (in Appendix A), it was categorized as ‘other’ as noted in Figure 8, and if a vessel category was missed during data collection it was categorized as ‘unknown’ as noted in Figure 7. While vessel events with NRKWs being present were mostly noted outside RBMBER, many vessels still ventured inside RBMBER (Figure 7).

In both years, most vessel events in the study area while the NRKWs were present were in the private category and included private motorboats, sailboats (motoring or sailing), and kayaks. The majority of these vessels present in both years were small (under 30 ft) (Figure 8). Whale watching vessel events category was the second highest, which included both motorboats and kayaks, where the vessels were small and medium between 30 ft to 80 ft (Figure 8). Fishing vessel events were third in sighting categories where a significant proportion of these vessels were medium in size (Figure 8).

As the top three vessel present in the study area were private, whale watching, and fishing, their engine positions were as follows. In 2020, for private vessels, 138 were outboard, 55 were inboard, 42 had no engines, and one was unknown (Figure 9A). For whale watching vessels, 98 were outboard, 13 were inboard, and 20 had no engines (Figure 9A). For fishing vessels: two were outboard, 128 were inboard, and one was unknown (Figure 9A). In 2021, for private vessels, 106 were outboard, 130 were inboard, and 67 had no engines (Figure 9B). For whale watching vessels, 88 were outboard, 82 were inboard, and 57 had no engines (Figure 9B). For fishing vessels, one was outboard, and 174 were inboard (Figure 9B).

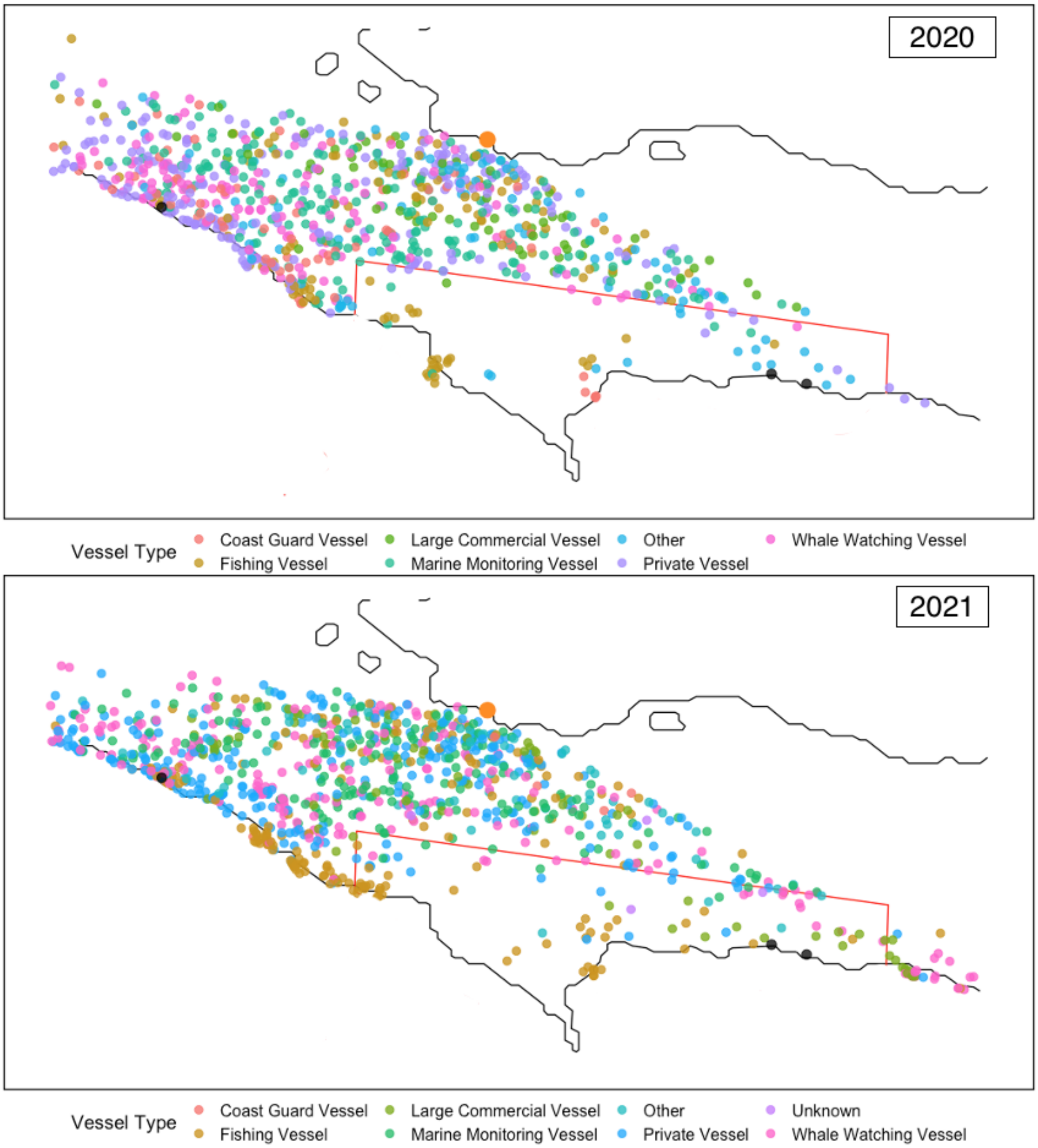

Figure 7: *Vessel presence in the Johnstone Strait, BC in 2020 and 2021 when the NRKWs were present in the study area. Colours represent the vessel type observed. Black lines represent the shorelines: top shoreline – West Cracroft Island and orange on that shoreline is Eagle Eye, and bottom shoreline - Vancouver Island and black dots here are rubbing beaches. Red line represents RBMBER boundary.*

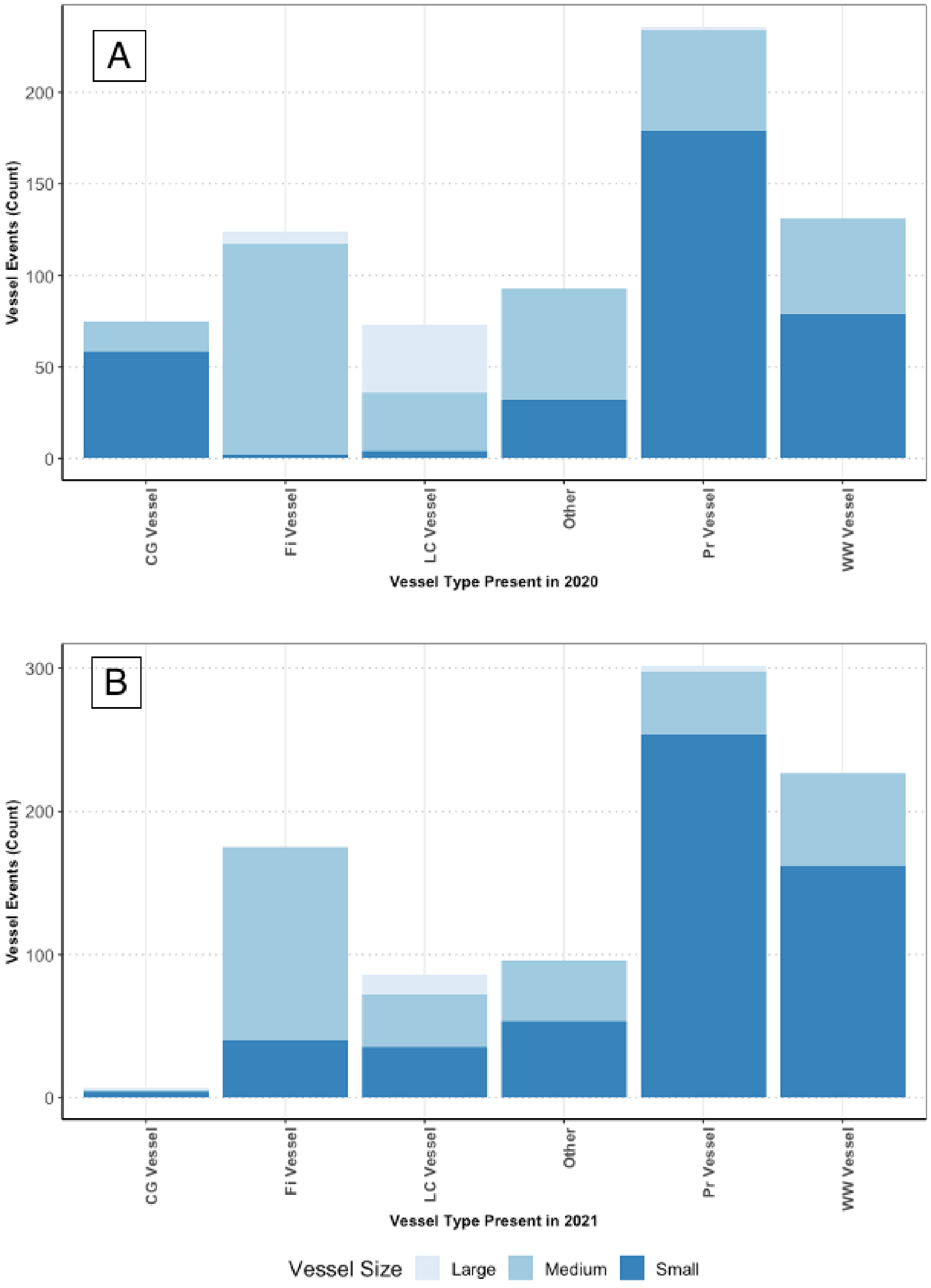

Figure 8: *Number of vessel event count by vessel type observed in year 2020 (A) and 2021 (B) when NRKWs were present in the study area in Johnstone Strait, BC. Colours represent size and organized by the proportion at which they were observed. Codes: CG – Coast Guard, Fi – Fishing, LC – Large Commercial, Pr – Private, WW – Whale Watching.*

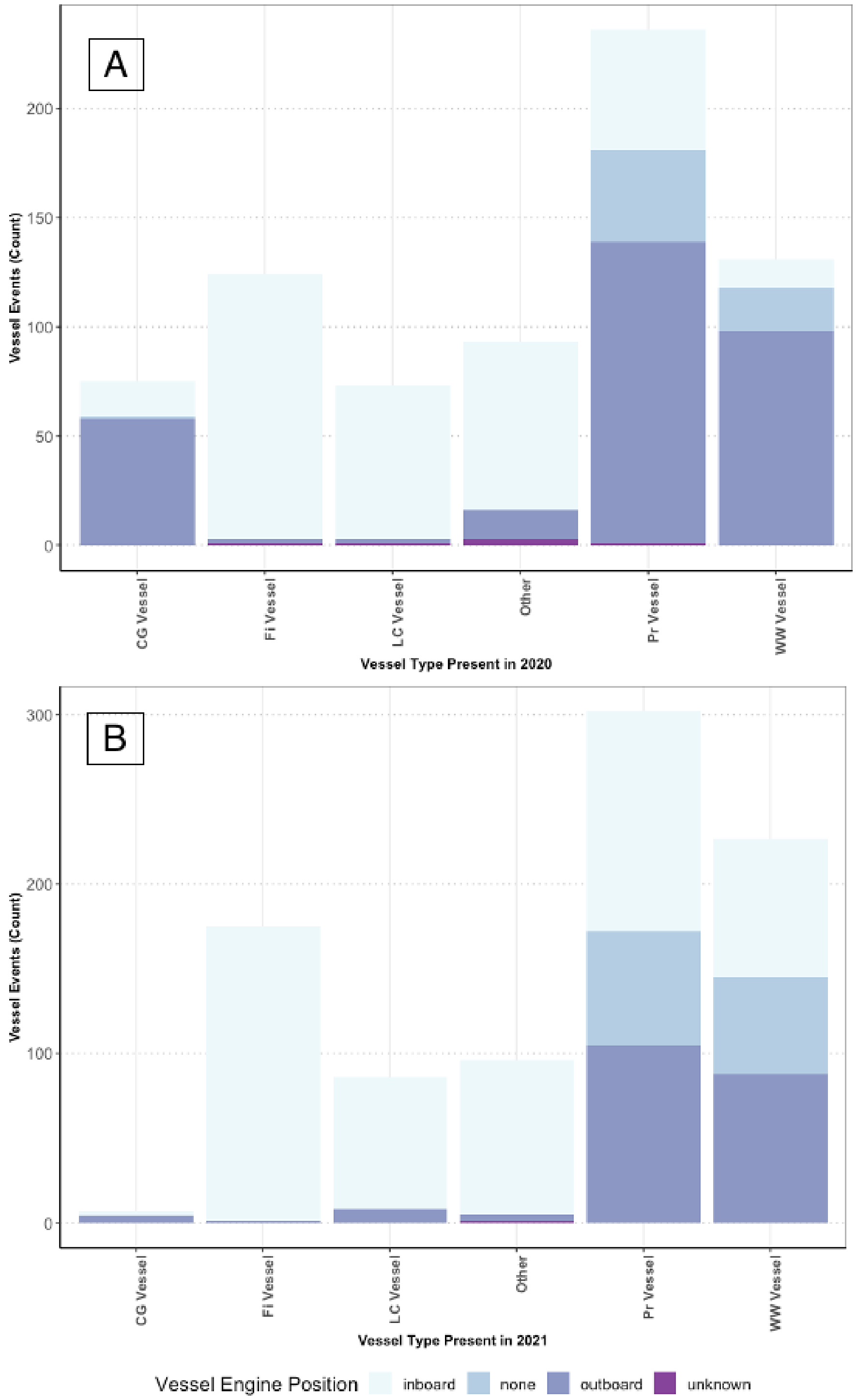

Figure 9: *Number of vessel event count by vessel type observed in years 2020 (A) and 2021 (B) when the NRKWs were present in the study area in Johnstone Strait, BC. Colours represent engine position and organized by the proportion at which they were observed. Codes: CG – Coast Guard, Fi – Fishing, LC – Large Commercial, Pr – Private, WW – Whale Watching.*

3.3. Effects of Vessels on NRKW Beach Rubbing

I fit a GAMM to determine the effects of vessels on beach rubbing. I tested the effects of vessel count, distance of closest vessel from NRKWs, and tide height in a given scan on the NRKW beach rubbing behaviour at both beach rubbing locations – Kaizumi and Main/Strider (midpoint between Main and Strider Beaches).

Table 4 displays the summary statistics generated from the model, where vessel count had no significant effect on the likelihood of observing NRKW beach rubbing behaviour; however, a weak positive relationship was noted between number of vessels present and beach rubbing behaviour at Kaizumi with a p-value of 0.1374 (Appendix B – Figure 19). A significant correlation was found between distance of closest vessel from NRKW and NRKW beach rubbing behaviour (p-value of 0.0186) at Kaizumi (Table 4; Figure 10). A significant correlation was found between tide height and NRKW beach rubbing behaviour (p-value of 0.0213) at Main/Strider (Table 4; Figure 11).

Table 4: GAMM statistics summary, showing the relationships between vessel and environmental variables and NRKW beach rubbing behaviour, based on data collected in 2020 and 2021, in Johnstone Strait, BC. Significant relationships are shown with an asterisk (*) in the p-value column.

Variables (Interaction by beaches)	Effective degrees of freedom	Reference degrees of freedom	F-statistic	p-value
Vessel count: Kaizumi	0.726	9	0.159	0.1374
Vessel count: Main/Strider	0.000	9	0.000	0.4453
Closest vessel from NRKW: Kaizumi	1.010	9	0.521	0.0186*
Closest vessel from NRKW: Main/Strider	0.000	9	0.000	0.4727
Tide height: Kaizumi	0.000	9	0.000	0.7843
Tide height: Main/Strider	0.892	9	0.495	0.0213*

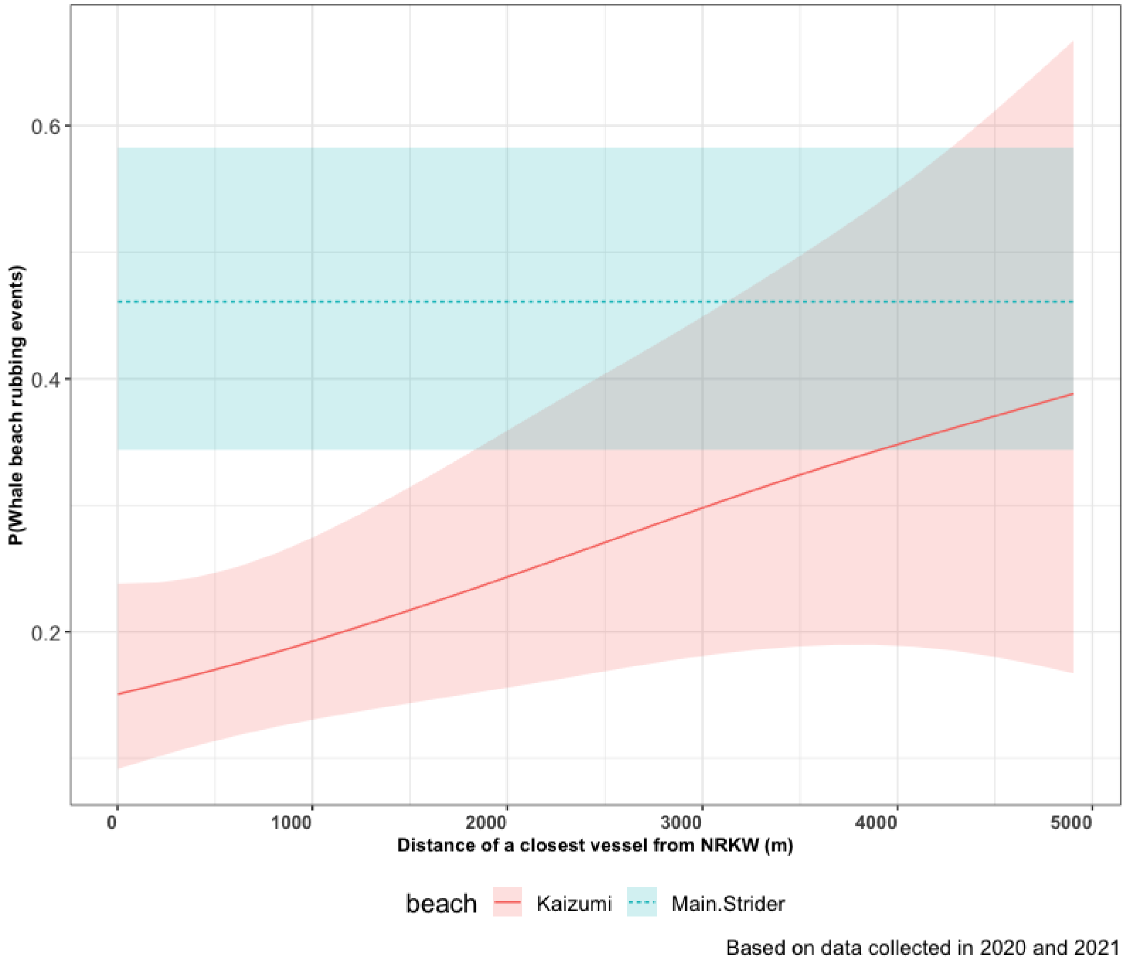

Figure 10: *Probability of NRKW beach rubbing at Kaizumi and Main/Strider with increasing distance of the closest vessel from an NRKW up to 5 km present in the study area, in Johnstone Strait, BC.*

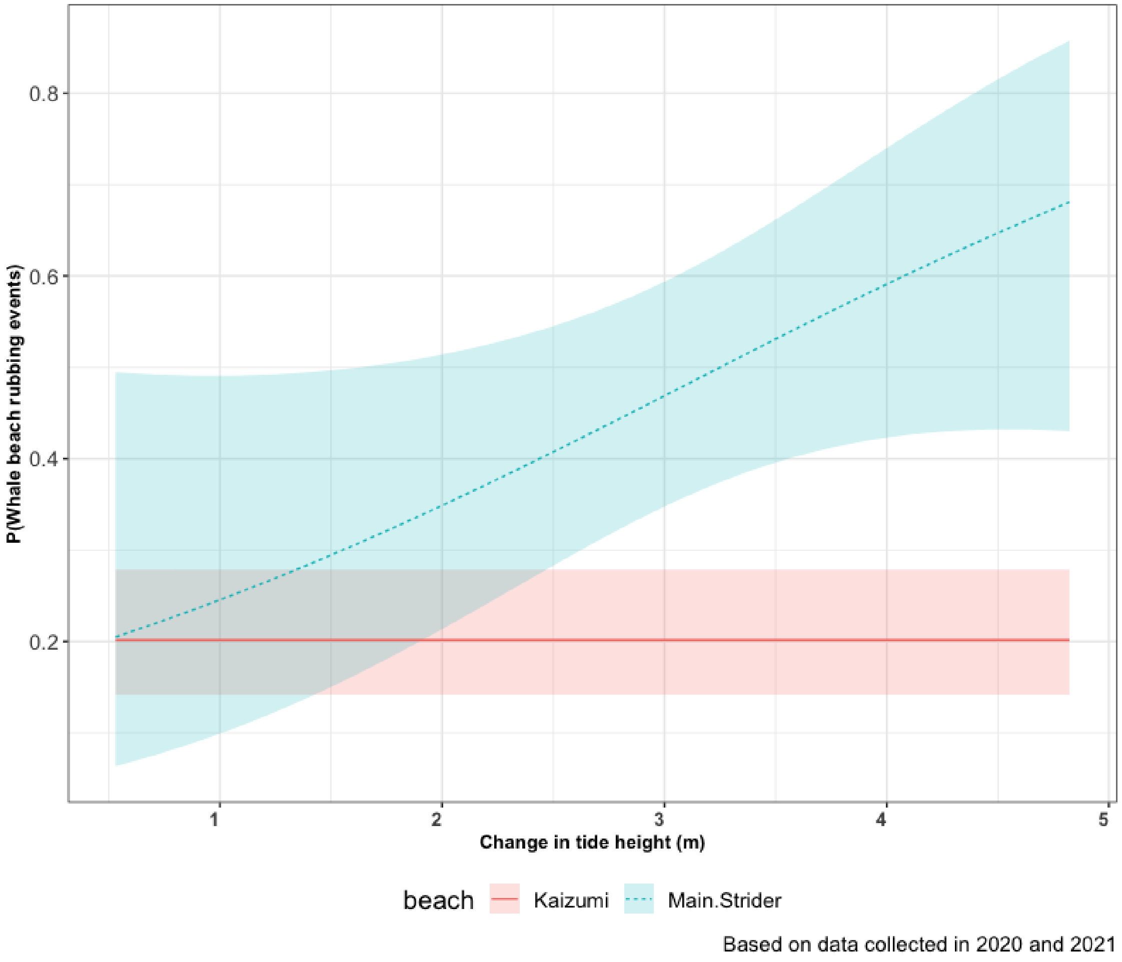

Figure 11: *Probability of NRKW beach rubbing at Kaizumi and Main/Strider beaches with increasing tide height in the study area, in Johnstone Strait, BC.*

3.4. Rubbing beach usage and preference by NRKWs

In 2020 and 2021, beach rubbing was observed at both locations; however, more beach rubbing events were observed inside RBMBER (Main and Strider Beaches) than outside RBMBER (Kaizumi Beach) (Figure 12; Appendix B – Figure 18).

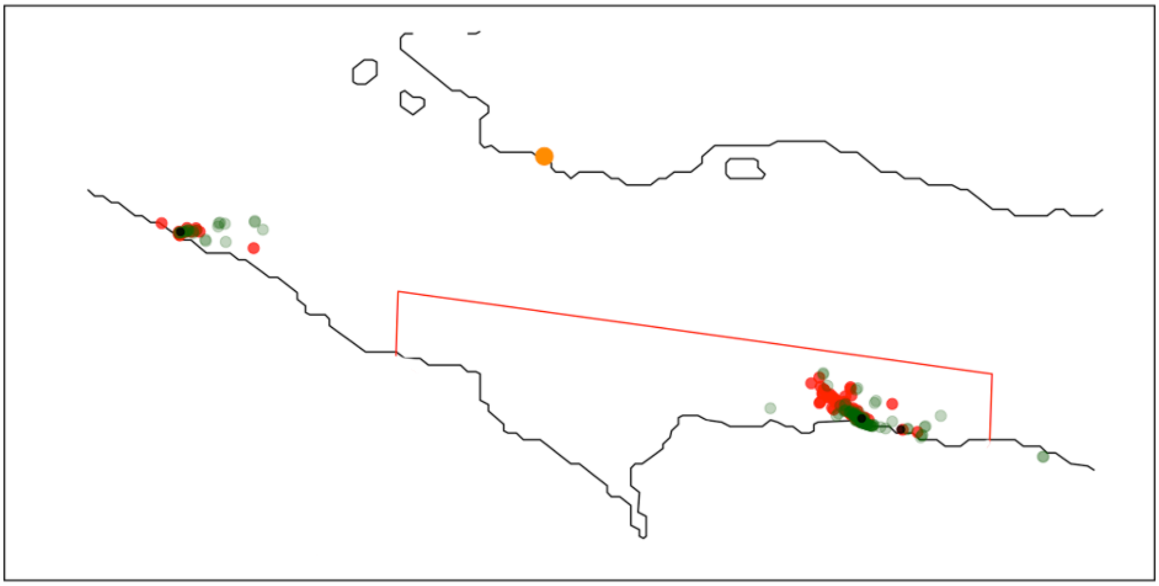

Figure 12: *Beach rubbing observed in Johnstone Strait, BC in 2020 and 2021. Red dots represent beach rubbing in year 2020 and green dots represent beach rubbing in year 2021. Black lines represent the shorelines: top shoreline – West Cracroft Island and orange dot on that shoreline is Eagle Eye, and bottom shoreline – Vancouver Island and black dots here are rubbing beaches. Red line represents RBMBER boundary.*

Even though the probability of beach rubbing increases with tide height at Main/Strider, there's still a higher probability of beach rubbing at Main/Strider at most tidal conditions when there are no vessels present (Figure 13A). Beach rubbing behaviour was assessed across all tidal heights with vessel counts of 19 boats (highest count recorded in a scan) and with vessel proximity of 200 m (current whale approach distance for boats north of Campbell River; Be Whale Wise, 2021). At these suboptimal conditions, at low tides (0 – 1 m), NRKW tend to prefer Kaizumi; however, as the tide gets higher the preference switches over to Main/Strider (Figure 13B). Due to a high degree of uncertainty around our model prediction, this difference between beaches at low tides is not significant (overlapping 95% confidence intervals in Figure 13).

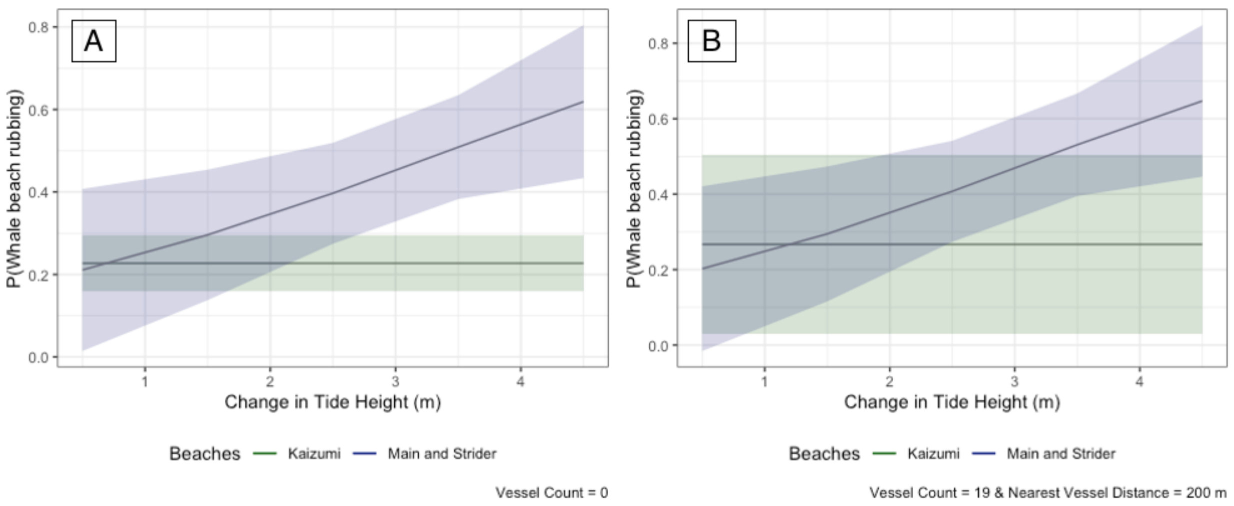

Figure 13: *Predictions of beach preference in Johnstone Strait, BC based on GAMM analysis (A) at vessel count = 0 versus (B) at high vessel count = 19 and short vessel distance from NRKW = 200 m.*

The average number of vessels present in one scan was 5. While keeping the vessel count constant, I compared the probability of beach rubbing when the nearest vessel to whale distance was 200 m, 400 m, 1000 m, and 2000 m. The probability of NRKW beach rubbing at Main/Strider did not change with the increasing distance between NRKW and vessels (Figure 14). The probability of NRKW beach rubbing at Kaizumi did increase with increasing distance between NRKW and vessels, but only at distances of 1000 m and 2000 m (Figure 14C & 14D). When the vessels are 200 m and 400 m away from the NRKWs the probability of beach rubbing remains at 0.17 – 0.18 (Figure 14A & 14B), but at 1000 m – the probability increases to 0.20 and at 2000 m it goes up to 0.24 (Figure 14C & 14D).

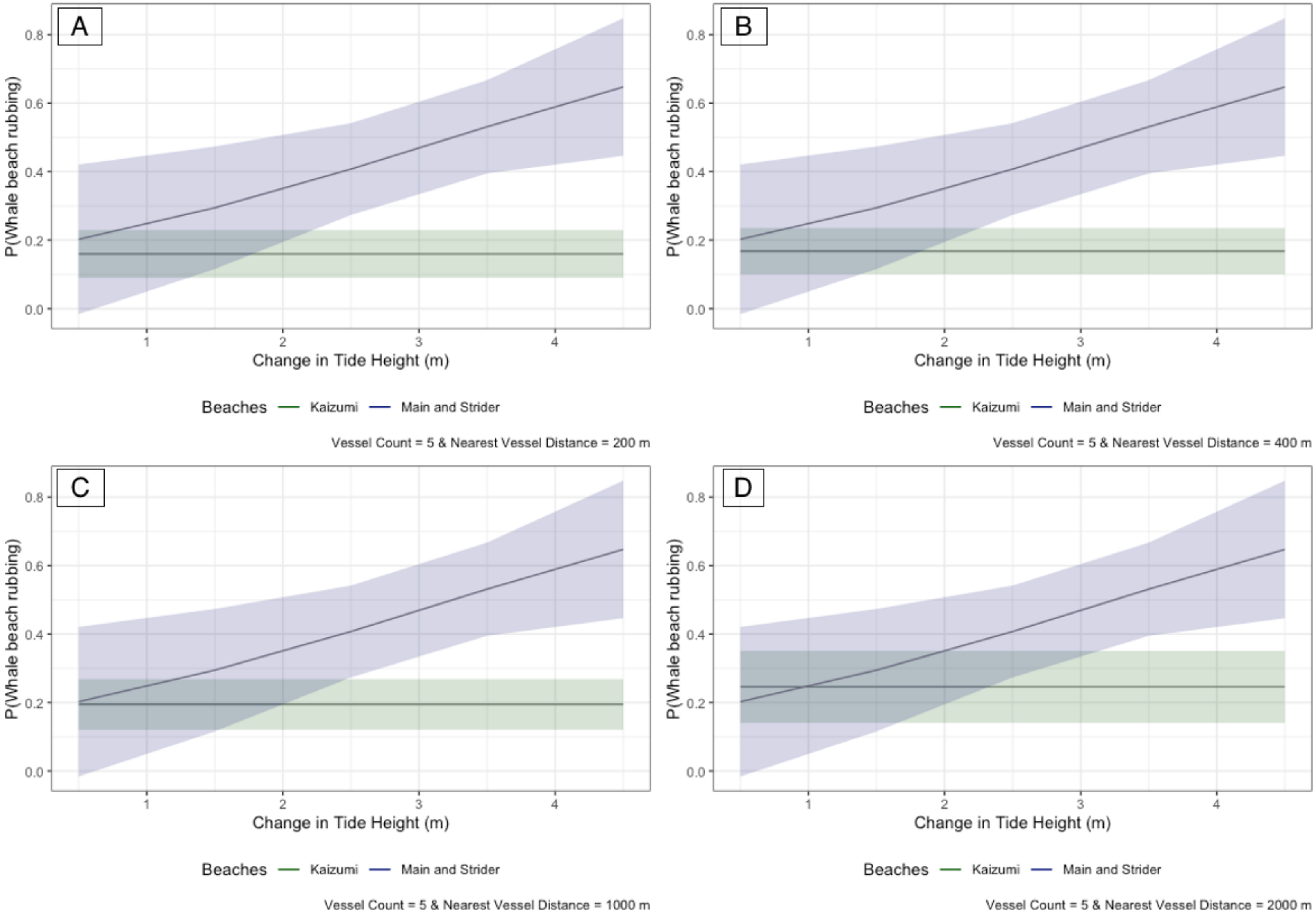

Figure 14: *Predictions of beach preference in Johnstone Strait, BC based on GAMM analysis with the average vessel present in the strait = 5 and increasing distances from closest to furthest (A) 200 m, (B) 400 m, (C) 1000 m, and (D) 2000 m.*

3.5. Anthropogenic Presence

Through Blackfish Sound and into Johnstone Strait where RBMBER lies, NRKWs follow a rigid travel pattern when passing through the area (Johnstone Strait Whale Committee, 1991; Figure 15). As the NRKWs travel towards the RBMBER, they hug the Vancouver Island shoreline (Johnstone Strait Whale Committee, 1991; Figure 15). On that travel path lay several beaches outside RBMBER including Kaizumi, which are accessible to people either via logging roads or through kayaks or private motors (Figure 16). Presence of recreational users were noted at all 5 beaches at one point or another across both years (noted in comments). Only the presence at Kaizumi was systematically recorded (Table 5).

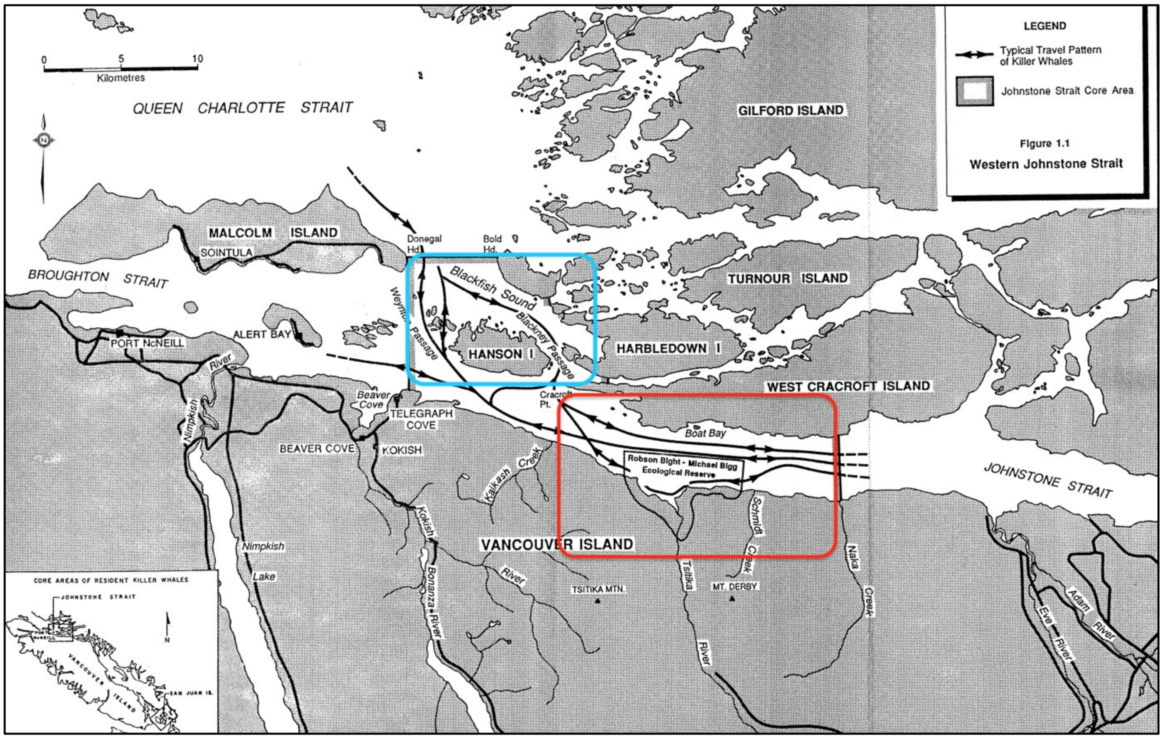

Figure 15: *Travel pattern (in black arrows) of NRKWs noted over the years in Blackfish Sound (blue box) and Johnstone Strait (red box) where RBMBER lies in BC. (Johnstone Strait Whale Committee, 1991).*

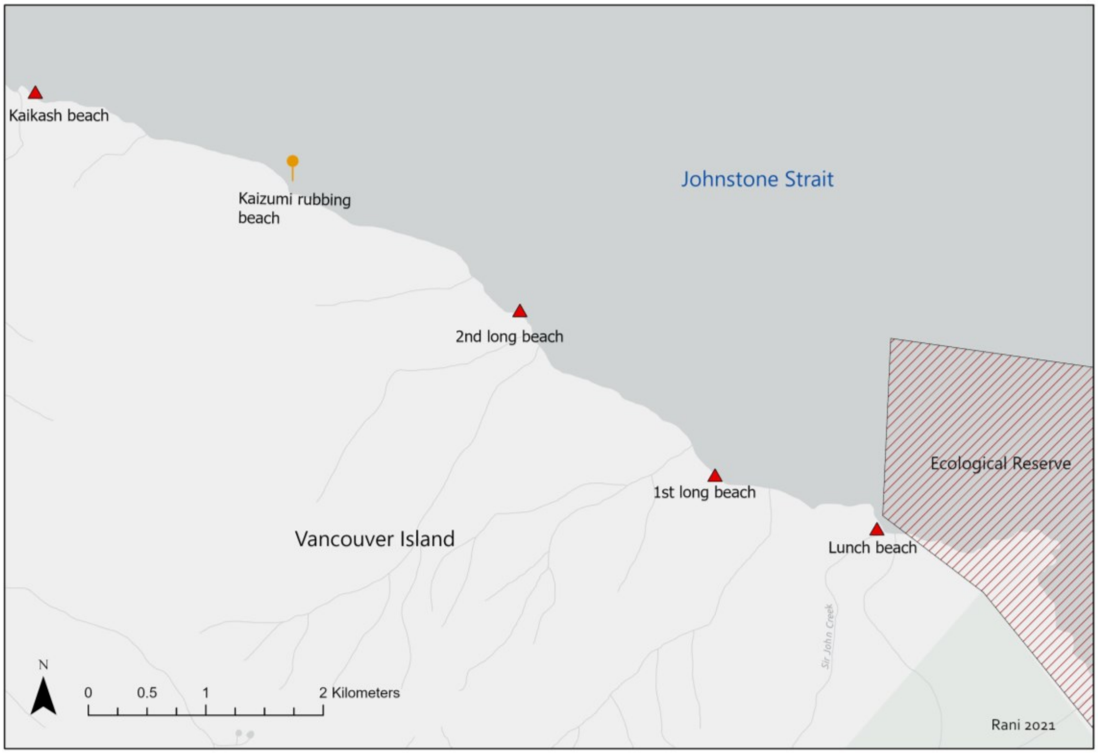

Figure 16*: Map of several non-rubbing beaches as well as Kaizumi rubbing beach along the Vancouver Island shoreline, west of RBMBER in Johnstone Strait BC. At all five beaches, kayakers (private, whale watching and tours) and other small private motors stop by and/or camp.*

Table 5: Number of days with people present at Kaizumi at the same time as NRKWs, in 2020 and 2021.

Data collection months	**2020** People Days	**2020** NRKW Days	**2021** People Days	**2021** NRKW Days
July	3	7	2	7
August	3	11	5	19
September	1	0	1	4

Chapter 4. Discussion

The percentage of days with beach rubbing observed was consistent across both years, 8.12 % in 2020 and 9.46 % in 2021. The beaches inside RBMBER (Main and Strider) were used more than the beach outside RBMBER (Kaizumi). The group spread and group configuration of NRKWs while beach rubbing was loose and non-linear, respectively, which enables them to perform the behaviour freely.

Various types of vessels were present in the Strait and were mostly observed outside RBMBER as people respected the Ecological Reserve boundaries. One important aspect of vessels when considering their impact is their size, a greater proportion of vessels present in the Strait were small and medium in size, with many being recreational vessels. Engine position of the vessels is of importance as well as noise levels produced by outboard vessels have been found to be adverse for NRKWs (Bain et al. 2002). As the greater proportion of vessels present in the Johnstone Strait were small and had an outboard engine position, thus potentially affecting beach rubbing behaviour of NRKW. In 2020 vessels with outboard engines were present in greater numbers whereas in 2021 it was vessels with inboard engines followed by vessels with outboard engines.

4.1. GAMM Analysis Results

Results of the GAMM provide us further insight into the effect of vessels on beach rubbing behaviour at each of the two locations, Main/Strider versus Kaizumi. No relationship was found between the number of vessels and beach rubbing events at Main/Strider (Appendix B – Figure 19) likely indicative of the protection and security provided by RBMBER. At Kaizumi, there was no significant correlation between the number of vessels and beach rubbing events; however, a positive linear relationship was noted implying that the probability of beach rubbing increases as the number of vessels increases (p=0.14; Appendix B – Figure 19). This result is likely an artefact of the data (or lack thereof) because the data collection hours often coincided with hours in which most vessels are present in the Strait. Commercial, recreational, and whale watching vessels took advantage of daylight hours. Moreover, when in Johnstone Strait and adjacent areas nearby, whale watching vessels have constant surveillance of the whale watchers' radio channel. During those hours NRKWs are never left alone and when NRKWs enter the study area, they are accompanied by several whale watching and private vessels who had been following them all along. In this situation, it is the presence of NRKWs that affects the vessel behaviour around them. It is important to note that the number of beach rubbing events observed at Kaizumi were significantly lower in number when compared with Main/Strider (Figure 17). More data is needed to further understand how the number of vessels affects NRKW beach rubbing at Kaizumi.

We looked at the distance of the vessel that was closest to an NRKW or a group of NRKWs on whale behaviour. At Main/Strider, no significant relationship was found between vessel distance and beach rubbing behaviour – likely because vessels may never come close enough as RBMBER boundary provides protection of at least 0.5 nautical miles from the shore. Kaizumi on the other hand does not offer the same protection and this is indicated by the significant relationship (F = 0.521, df = 9, p = 0.0186). At Kaizumi, the probability of beach rubbing increases as the distance between the NRKWs and vessels increase. These results suggest that NRKWs are more likely to rub when the vessels are further away from them at Kaizumi. Within 200 m and 400 m of NRKWs there were more vessels nearby at Kaizumi when compared to Main/Strider; therefore, it stands to reason that the distance between NRKWs and vessels affects whether a NRKW initiates this behaviour or continues to beach rubbing (Figure 17). Most of the vessels that were violating the guidelines and getting close to the NRKWs were private (including motorboats, kayaks, and sailboats) and whale watching vessels (kayaks and motorboats) (Figure 17).

The results of the variables, the number and proximity of vessels are in line with previous studies; they have been found to be two different aspects of vessel traffic that affect killer whales (SRKWs) differently (Williams et al. 2002, Williams & Ashe 2007). While on average there was no response to the number of vessels (Williams & Ashe 2007), the proximity of vessels resulted in more evasive behavioural cues such as variability in respiration, departure from direct path, and variability in swimming speed (Williams et al. 2009a). The lack of a negative response or no response due to number of vessels could be a result of habituation, as different kinds of whales have appeared to habituate to vessel traffic in other parts of the world such as the Gulf of Alaska and North Atlantic Ocean (Teerlink et al. 2018, Watkins 1986). It is plausible that a similar effect might be occurring here as killer whales off the coast of BC have been experiencing increasing vessel traffic.

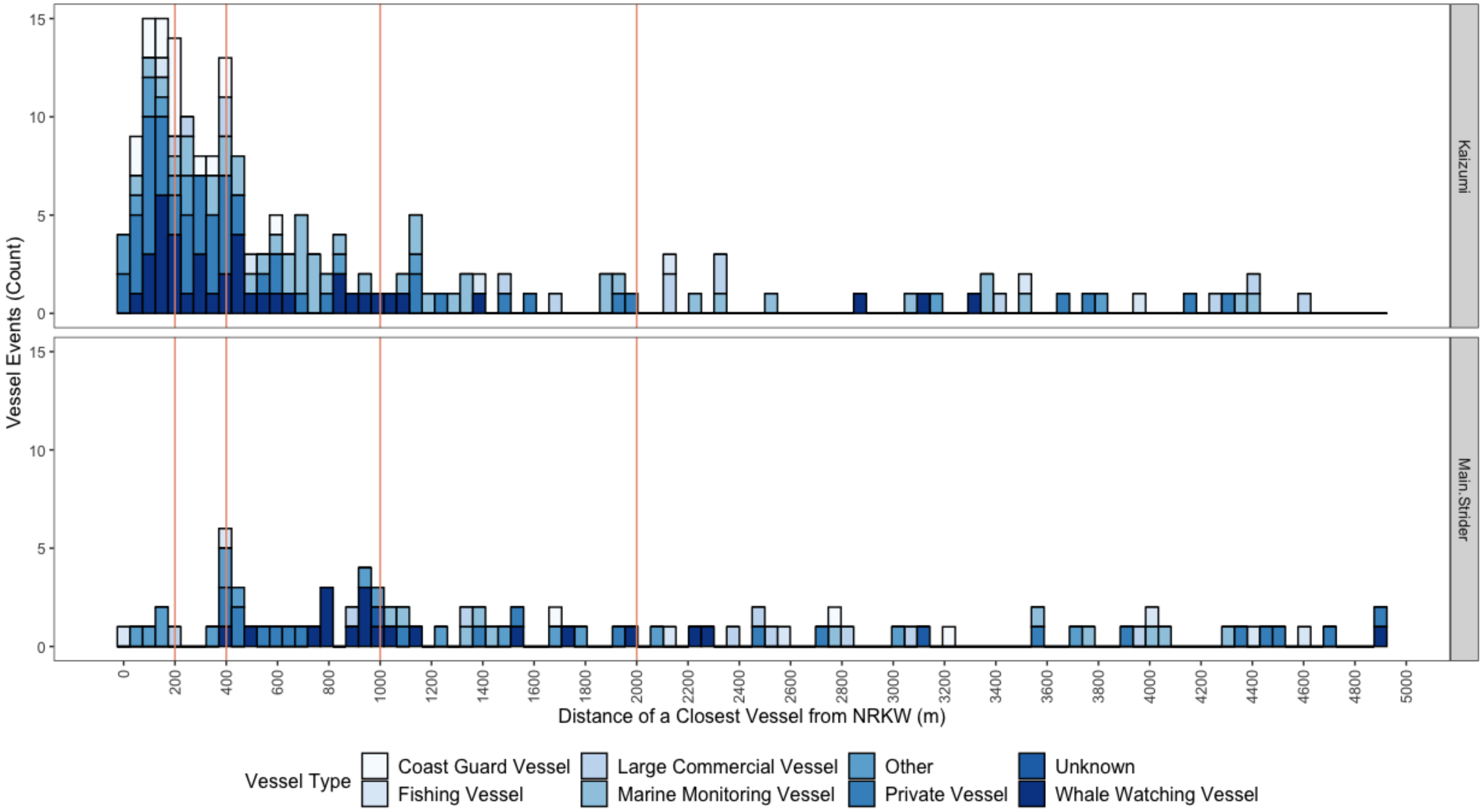

Figure 17: *Distribution of vessels (by type) closest to NRKWs at different distances in 2020 and 2021, at Kaizumi and Main/Strider rubbing beaches in Johnstone Strait, BC. Red lines indicate the distances at which beach preference was analysed. More vessels are present within 400 m of NRKW at Kaizumi compared to Main/Strider.*

The last and only environmental variable that was analysed was the change in tide height; it was found to significantly influence beach rubbing behavior at the beaches inside RBMBER. Now why this we are seeing this trend is unknown, but a couple of speculative reasons can be related to substrate and bathymetry of the beaches. Despite the unknown reasons, it is possible that at low tides both Main beach and Strider beach in RBMBER become unavailable/unsuitable leaving Kaizumi to be the only option available for rubbing. Therefore, in the event of low tides when Kaizumi is the preferable beach available for rubbing, and if at the same time Kaizumi is highly inundated with vessel traffic (e.g., during daytime), then in this scenario all the rubbing beaches are rendered unsuitable for rubbing.

4.2. Beach Preference and Guideline Distances

In ideal conditions, when no vessels are present NRKWs showed a preference for Main/Strider and the preference increased (probability increases 0.20 to 0.65) as the tide height increased (Figure 13). Whereas at Kaizumi when no vessels were present the probability of beach rubbing remained at 0.21 at all tidal conditions (Figure 13). When comparing ideal conditions with the worst conditions observed (i.e., 19 vessels and at least 200 m from NRKWs), the overall probability of beach rubbing at Main/Strider did not change. However, at Kaizumi the probability of beach rubbing increased to 0.27 under these conditions. As stated in section 4.1, these results may reflect the results of distance of vessels from whales, but not of the number of vessels as the NRKWs are never alone during data collection hours. Other methods need to be considered to understand the true relationship between the number of vessels and beach rubbing behaviour of NRKW.

In contrast, when vessels are present, the probability of beach rubbing at Kaizumi dropped. With the average vessel count of 5, the probability of beach rubbing increased from 0.17 to 0.24 at Kaizumi (Figure 14) as the distance between whales and vessels increased from 200 m to 2000 m. At all distances, NRKWs prefered Main/Strider over Kaizumi (Figure 14). They only show more affinity for Kaizumi over Main/Strider when the tides are low, and the vessels present are away from them – distances 1000 m (0.20) and 2000 m (0.24). At distances 200 m and 400 m, the probability of beach rubbing at Kaizumi remains 0.17 which was less than probability Main/Strider all tidal conditions. These distances are of importance as they are the current approach distance guidelines for boaters to killer whales' (all ecotypes). When encountering killer whales in all Canadian

Pacific waters, boaters should stay away from killer whales at least 200 m and from south of Campbell River further down into Salish sea this distance increases to 400 m. In recent years, NRKWs have been seen to venture south of Campbell River, particularly to a rubbing beach in Sechelt in January 2018 and January 2022 (CBC 2018; Coast Reporter 2022). The model predicts that there is no difference in likelihood of beach rubbing behaviour to occur at Kaizumi if the approach distance is increased from 200 m to 400 m for vessels (Figure 14A & 14B), therefore suggesting that the existing guidelines are not conferring the protection they are meant to provide.

4.3. Implications and Future Study Directions

The main findings of this study are that the proximity of vessels and tide height influence the beach rubbing behaviour of NRKWs and protection of their critical habitats (in form of MPAs) is beneficial for NRKWs to facilitate and perform their natural behaviours free from vessel disturbance. The impact of vessels can be even more considerable when combined with other threats NRKWs encounter. One of the major threats is the decline of Chinook salmon in Southern BC which is NRKWs' primary food source (Riddell 2013; Hanson et al. 2010). Given this and considering the rules of bioenergetics, the energy reserves for NRKWs are limited. On the energy expenditure ladder behaviours such as reproduction, resting, socializing, and beach rubbing are placed latter compared with behaviours such as foraging and travelling for food. As the behaviours necessary for survival will always come first, the energy allocated to culturally important behaviours such as beach rubbing, and other social behaviours will be limited. This has been noted in other apex marine predators as well, where limited supply of prey had resulted in more foraging by Weddell Seals and less resting behaviour was noted (Beltran et al. 2017).

Now, in the case of NRKWs, if food availability is combined with physical vessel disturbance – the energy supply issue is exacerbated. To reach rubbing beaches NRKWs must use their already decreased energy levels to evade and dodge vessels using convoluted pathways (2009a). At Kaizumi rubbing beach in the Johnstone Strait, the magnitude of harassment (in the form of vessel proximity to NRKWs) does not even permit them to beach rub as suggested by the results. Williams et al. (2009a) has studied vessel avoidance and has found that having them in the NRKWs' path increases energy expenditure. As NRKWs are evading vessels they are deviating from a direct path and changing swimming speeds resulting in extraneous energy expenditure (Williams et al. 2009a). This will ultimately impact their overall welfare and survival, and therefore vessel presence and their proximity to whales in critical habitats need to be addressed by improving and enforcing guidelines.

The important finding of this study was the protection provided by MPAs as the rubbing beaches in RBMBER were preferred over the rubbing beach outside. RBMBER is protecting a culturally important habitat for NRKWs, but in terms of application of these results to SRKWs, other types of critical habitats for foraging and socializing can be identified and protected in a similar manner. The existing interim sanctuary zones with a few restrictions in the Salish Sea are a start for the protection of the endangered SRKWs (DFO 2021).

This study gives us some insights into the impact of vessels on NRKWs and following these insights, I suggest some future study directions. During non-pandemic years, large vessels such as cruise ships are typically present (Williams & Ashe, 2006) and NRKWs are found to show a behavioural response such as minor to moderate change in respiration, direction, and locomotion to these large vessels (Williams et al. 2014b). In 2020 and 2021 because of COVID-19 restrictions, cruise ships were not present in Johnstone Strait and therefore we were unable to assess this, but this should be a consideration for the future. Biological factors such as age, group size, and sex of NRKWs were not assessed in this study but should also be considered for future studies.

This picture that is presented by the current dataset is incomplete as we are missing other information on the behaviour of NRKWs in RBMBER and in the Johnstone Strait. Studying the acoustic data collected via hydrophone from the beaches at times when visual data cannot be collected (e.g., nighttime) will help us better understand how their behaviour changes with respect to ambient noise indicating vessel presence. As we found in 2020 more vessels had outboard engines, and in 2021 inboard vessels overtook the majority. A comparison study of ambient noise near beaches and its effect on beach rubbing behaviour across years will provide us with a deeper level of understanding. Additionally, the NRKWs have been venturing into the waters of southern BC to access a beach in Sechelt (CBC 2018; Coast Reporter 2022). Monitoring of that area will provide insight on how they are extending from their home range and pursuing new habitats.

4.4. Recommendations

Extend the Boundary of the Ecological Reserve

Based on the study results my first recommendation is to include Kaizumi in RBMBER. This beach is a desirable beach rubbing location, but vessel traffic renders it improbable for NRKWs to do so. The distance between western reserve boundary and Kaizumi rubbing beach is ~3.7 km; therefore, with a buffer zone of 1 – 2 km the boundary should be extended at least up to 5 km from current boundary. Protection at Strider was not only observed in visual data analysis but also in the acoustic analysis where ambient noise levels did not impact the length of beach rubbing bout or their decision to stop rubbing (M. Bouvier, pers. comm, March 3, 2022). Extending RBMBER boundary to Kaizumi will extend the protection and security to this beach as well.

Enforcement of Guidelines and Boundary Rules

Most of the vessels found near the NRKWs were whale watching boats and private vessels. Even though a vast majority respected the guidelines and voluntary no-go status of RBMBER there were some instances where that was not the case. These vessels would go into RBMBER and would even track NRKWs. There were cases where kayakers who stopped by at the beaches along the NRKW path (Figure 15 & 16) would jump into the water with their kayaks to get closer to the whales. For such cases and other instances of harassment, the Robson Bight Marine Warden program (by Cetus) is in place in the summer months where they educate boaters in the area; however, this measure is insufficient. Therefore, my second recommendation is that guidelines and the no-go status of RBMBER should be strictly enforced by the DFO.

Reassessment of Existing Guideline

From this dataset, we only assessed how the distances between NRKWs and vessels affect beach rubbing behavior and it is likely that other behaviours could also be affected by the proximity of vessels. Therefore, the guidelines near the rubbing beaches should be greater than 400 m. Furthermore, we need to understand how the distances affect other behaviours and reassess the existing guidelines based on scientific data.

Chapter 5. Conclusion

Beach rubbing is a culturally important behaviour of NRKWs that is learned from generation to generation. While we may not understand the function of this behaviour, it appears to be inherently valuable to NRKWs. Thus, protecting these beaches, where the rubbing takes place, are of utmost importance. Killer whales, which were once feared, are now held in admiration in the eye of public as people travel to areas such as Johnstone Strait to catch a glimpse of these charismatic species. However, whale watching needs better compliance to current regulations. At Kaizumi, vessel traffic is causing physical disturbances that is not only affecting NRKWs' behaviour but could also have population-level consequences on these whales, impacting their overall welfare and long-term survival. The results of this study suggest that the harassment caused by vessels and their proximity deter NRKWs from beach rubbing at Kaizumi beach (which is situated outside RBMBER). The results also suggest the MPAs are effective in providing protection from vessel harassment, thus Kaizumi beach should be included in RBMBER by extending the western boundary by up to 5 km. Additionally, reassessment of current guidelines needs to be prioritized because the current guideline of 200 m near the rubbing beaches in the Johnstone Strait may not be effective. A better understanding of interactions between vessels and NRKWs in regions of cultural importance for whales can help inform future policies and guidelines in MPAs. Protecting such culturally important habitats will help us understand the behaviour of NRKWs, and by extension may enable us to better understand what management actions will best benefit clans of other ecotypes and cetacean species along the coast of BC.

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Appendix A - Tables

Table 6: GPS Coordinates of relevant locations in Johnstone Strait, BC.

Location	Latitude	Longitude
Theodolite (Eagle Eye)	50.52328° N	-126.5974° W
Main Hydrophone	50.48678° N	-126.5225° W
Strider Hydrophone	50.48825° N	-126.5324° W
Kaizumi Hydrophone	50.51319° N	-126.6738° W
Mid-point of Main and Strider	50.48751° N	-126.5274° W

Table 7: Weather assessment factors and their description used during environmental data collection in Johnstone Strait in years 2020 and 2021.

Weather assessment factor	Description
Visibility	• Unlimited: crystal clear visibility • OK: can generally see across the strait, but some areas are fuzzy/obstructed • Restricted: significant portions of the strait are fuzzy/obscured • Poor <1km visibility
Glare	• Record the severity of the glare o None o Mild (can see through without sunglasses) o Severe (cannot see through without sunglasses) • If any glare, record the compass bearings where the glare begins and ends
Cloud cover	• As a percentage of the sky over the study area (i.e. over water), to the nearest 10%
Sightability	• a subjective index on a scale of 1–5, with 1 = very poor and 5 = very good. • summarizes overall conditions for spotting whales, considering the factors above

Table 8: Vessel codes for the various types of vessels observed in Johnstone Strait, BC in 2020 and 2021.

Vessel Type	Vessel Code
ecotour CDN	EC
ecotour US	EU
ecotour kayak	EK
private motor – not actively fishing	PM nf
private motor – active fishing	PM f
private sail – motoring	PS m
private sail – sailing	PS s
private kayak	PK
maritime cruise ship	MQ
maritime ferry	MY
maritime fishing – not actively fishing, any type	MF nf
maritime fishing – actively fishing, trolling	MF tro
maritime fishing – actively fishing, trawling	MF tra
maritime fishing – actively fishing, seining	MF sei
maritime fishing – actively fishing, shellfish	MF she
maritime fishing – actively fishing, type unknown/other	MF f
maritime charter	MC
maritime cargo/shipping/tug (no tow)	MX
maritime tug with log tow	ML
maritime tug with tow	MW
marine monitoring	MM
government coast guard CDN	GC
government coast guard US	GU
government DFO	GD
government BC Parks	GB

Appendix B – Figures

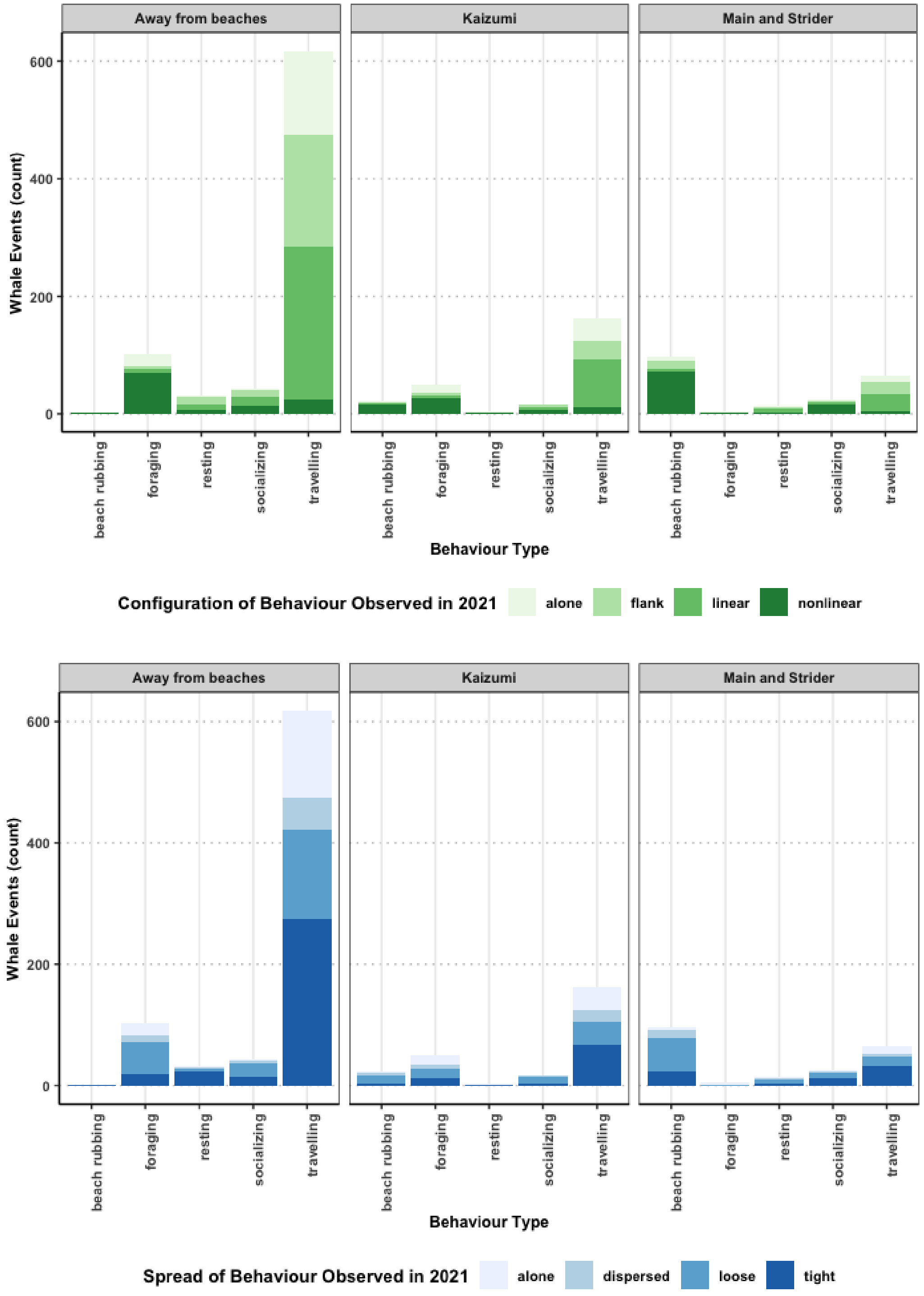

Figure 18: *Characteristics of NRKW behaviour observed within near the beaches and in the Johnstone Strait BC in 2021.*

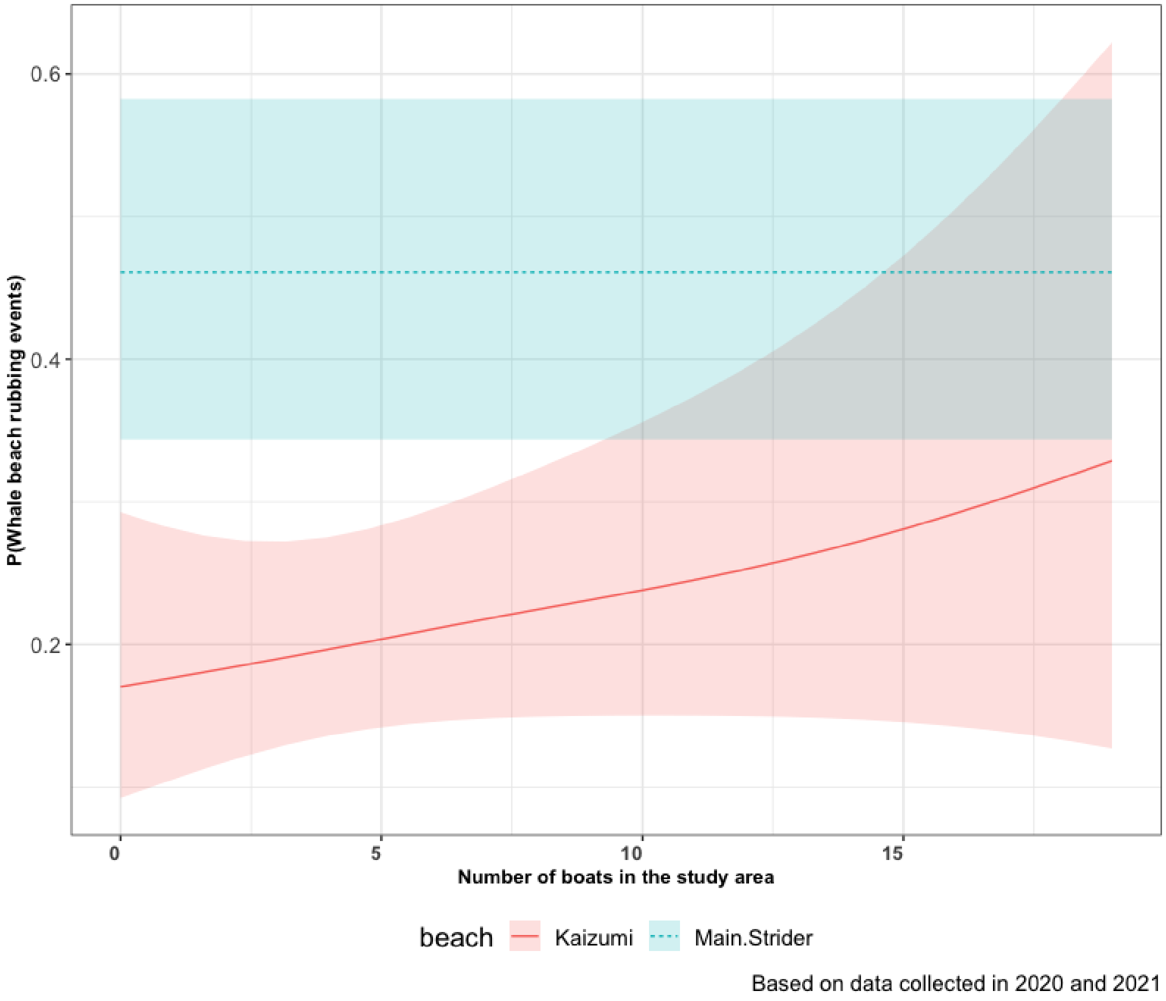

Figure 19: *Probability of NRKW beach rubbing at Kaizumi and Main/Strider with increasing number of vessels present in the study area, in Johnstone Strait, BC.*