Drivers of Humpback Whale Movement in Boundary Pass, British Columbia

by

Azadeh Gheibi

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Declaration of Committee

Name:	**Azadeh Gheibi**
Degree:	**Master of Science**
Title:	Drivers of Humpback Whale Movement in Boundary Pass, British Columbia
Examining Committee:	**Chair:** Ruth Joy Supervisor Faculty, SFU **Douglas Ransome** Committee Member Faculty, BCIT

Abstract

The Salish Sea is critical habitat for several whale species including the humpback whale (*Megaptera novaeangliae*). Boundary Pass is part of the Salish Sea and connects the Pacific Ocean to several commercial shipping ports in the Pacific Northwest Region of North America. Since 1997, the number of Humpback whales continues to increase in this area, meanwhile the number of vessels is also increasing such that Boundary Pass is among the busiest shipping routes in the region. This high vessel traffic in the area leads to acoustic disturbances that degrades whale foraging opportunities for humpback whales. Commercial vessels transporting goods through whale habitat causes an increased risk of vessel collisions with humpback whales. Humpback-whale movements in Boundary Pass was recorded through systematic scan surveys conduction from a vantage point between June and August. Whale occupancy was compared to oceanographic variables and vessel presence. We found humpback whales were most likely to be present during ebb tides of speeds of -2 m/s under the influence of low tides and also whales were active in areas overlap with shipping lane in the area. Based on our founding in the area about humpback whale connection with biophysical properties of region I hypothesized that whale distribution in area and it relation to low tide and ebb current is most probably under the influence of food abundance in those periods of time. This study concludes with policy recommendations for improving humpback whale foraging grounds by reducing acoustic harassment and risk of ship strikes in the Boundary Pass.

Keywords: Humpback whale; movements; oceanographic variables; Boundary pass; Salish sea; Vessel strike; tide; currents; SST; salinity.

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List of Acronyms

AIC	Akaike Information Criterion
BCCSN	British Columbia Cetacean Sighting Network
BCIT	British Columbia Institute of Technology
CTD	Conductivity, Temperature, Depth
ENGO	environmental non-governmental organization
LBCO	Land Based Cetacean Observation
SFU	Simon Fraser University
SGIWSN	Southern Gulf Islands Whale Sighting Network
SSN	Saturna Sighting Network
SST	Sea Surface Salinity
VoIP	Voice over Internet Protocol

Introduction

To provide an effective management plan for the restoration or conservation of any species, it is important to study their ecology, behaviour, and relationships with their surrounding environment. Oceanographic variables such as tides, currents, and water temperature can affect marine-mammal behaviour, including their hunting patterns and migrations (Meynecke et al. 2021). In turn, movement related to these behaviours will affect their energy-consumption rates which will affect life-history parameters, like survival and birth rates. Therefore, a better understanding of their movements as they relate to their environment can improve conservation management outcomes.

Humpback whales (*Megaptera novaeangliae*) are long-distance migratory animals with flexible feeding behaviour that is adaptive to prey availability, density and prey type (Fleming et al. 2016). Almost all humpback whale populations migrate seasonally (Bettridge et al. 2015) from high latitude feeding areas in summer to low latitude breeding areas in cold seasons (Cypriano-Souza et al. 2018).

Humpback whales were once considered rare in the Salish Sea due to extensive commercial whaling in the early 1900s (Fleming and Jackson 2011; Keple 2002). More broadly, since the end of whaling on the BC Coast in the early 20th century (Reeves and Smith 2010), humpbacks have experienced positive population growths and are beginning to recolonize areas where they were historically depleted (Wedekin et al. 2017; Noad et al. 2019). No humpbacks had returned to the waters of the Salish Sea since the early 1900's (Calambokidis et al. 2017).

In 1997, this changed when a humpback whale called 'Big Moma' was spotted for the first time in the Salish Sea. Ever since, humpback whale numbers have continued to increase in the Salish Sea (Calambokidis et al. 2018; Miller 2020). Humpback whales can now be seen regularly throughout the late spring until fall in the Salish Sea. In Boundary Pass, humpbacks are most regularly seen in June, and are now the most common whale seen in Boundary Pass (Quayle and Joy 2021).

Boundary Pass is part of the Salish Sea that experiences significant commercial vessel traffic due to its location connecting the Pacific Ocean to multiple shipping ports in Georgia Strait and Puget Sound. This maritime traffic may affect the life and activities of marine mammals in the area. Other than acoustic disturbance, constant presence of vessels in the region can cause physical disturbance that, in other regions, has been documented to have negative effects on humpback whales (Frankel and Gabrielle 2017). These negative effects can be behavioural or physiological and if persistent could result in the decline of an population survival rate (Schuler et al. 2019). Although there are some studies that suggest humpback whales seem to be tolerant of marine traffic (Borggaard et al. 1999), other studies have indicated that humpback whales that remain in highly trafficked areas despite high exposure to vessel presence and associated stressors may do so because they rely on the bioenergetic resources from that area. Foraging whales, particularly during their spring migration north, may have no higher priority than feeding and may no longer avoid the warning from the presence of vessels (Blair et al. 2016; Schuler et al. 2019). This occurs simply because they can't afford to lose those sources of energy. Another explanation as to why humpbacks may appear to not respond to ship proximity is that observers may have difficulty detecting behavioural responses as these often occur beneath the ocean surface and out of sight. For example, a decrease in feeding ability due to disturbance would be difficult to document if not engaged in surface feeding (Blair et al. 2016). Humpback whales are also known for often erratic surface patterns that are not associated with disturbance (Calambokidis et al. 2019) making them a complex animal to try to understand their behaviour.

The risk of ship strikes is another important danger threatening these whales. In the past three years, there have been two known humpback-whale collisions in the Salish Sea. One juvenile male was hit by a Washington State ferry and may have died, and another juvenile humpback's spine was badly damaged in by a propeller in Georgia Strait. Compared to other whale species, humpback whales are more at risk of vessel disturbance and collisions in the Salish Sea due to a lack of response to vessel proximity and also because they lack echolocation (Calambokidis et al. 2019). Humpback-whale calves and juveniles are particularly vulnerable to strike risk (Alzueta et al. 2001; Lammers et al. 2013). With an increasing population trend for humpback in the Salish Sea, vessel strikes are an increasing threat to them in our waters. Increasing risk is a combination of an increase in presence of humpbacks in coastal waters, as well as an increase in vessel traffic, and vessel strike reporting (Noad et al. 2019).

Knowledge of when humpback whales might surface or travel in Boundary Pass and particularly when humpback whales are in spatial areas that overlap with shipping lanes of Boundary Pass could help focus mitigation strategies. Whale behaviour and distribution data can be key to conservation and restoration management strategies for reducing ship strikes.

Tides and currents are among the most important environmental drivers in humpback-whale distribution and habitat use (Chenoweth et al. 2011). Biological oceanography is influenced by daily tidal cycles while the combination of tidal currents, bathymetry and seasonal changes have a significant control over nutrient flux – the primary driver of primary productivity in the ocean's trophic system (Barlow et al. 2019).

Boundary Pass has a mixed tidal system. This mixed tidal system includes semi-diurnal tides, i.e., each day experiences two high tides and two low tides. Tidal currents driven by the twice daily exchange of tides in the area cause high inflows 3 hours before high tide and strong outflow 3 hours before low tide. These currents can be very strong in narrow passages. Boundary Pass is one of two 'sills' in the Salish Sea, separating the Georgia Strait basin from the Haro Strait basin (Daverne and Masson 2001), creating a restriction through which water flows at speed over the sill. The surface tidal currents of Boundary Pass are further affected by wind and Fraser River run off (Davenna and Masson 2001).

The purpose of this research is to identify important biophysical features of humpback whales' habitat and to study the preference for occupancy in Boundary Pass as it relates to tides, currents, sea surface temperatures and salinity. Investigating links between movements of humpback whales and commercial vessel traffic in and adjacent to the shipping lane can be used for habitat restoration decisions and better management strategies for these whales. Additional results concerning abundance and number of humpbacks whales in the area during their summer migration can be used for conservation purposes and further restoration studies.

The primary food of humpback whales is either small schooling fish such as pollock, herring and capelin, or macro-zooplankton like krill (*Euphausiacea*) (Chenoweth et al. 2011, Curtice et al. 2015). In the southern hemisphere, Antarctic krill is the predominant food of humpback whales and in the northern hemisphere, schooling fish species are their main sources of food (Meynecke et al. 2021). In the Southern Pacific's trophic web, krill is the main food for humpback whales and in the Northern Pacific, krill still play an important role as the major source of nutrient for the schooling fish (Murphy et al. 2006) that are the important prey for humpback whales in my area of study. Krill abundance in an area is influenced by the mesozooplankton productivity of the region, as mesozooplankton are the primary trophic link between phytoplankton and carnivorous zooplankton (Strand et al. 2020).

The migratory nature of humpback whales makes the Salish sea a favorable destination for a population that summers in our region. The Salish sea is not only very productive for resident humpback whales but also as a migratory pathway to other feeding grounds for migrating whales (Gregr et al. 2000; Ware and Thomson 2005).

Humpback whales show regional fidelity to their feeding and breeding grounds (Dransfield et al. 2014). The evidence shows humpbacks come back to areas that they once traveled with their mother (Rambeau 2008). This suggested that persistent regions of anthropogenic disturbance can affect multiple generations of humpback whales.

Intense commercial whaling during the 19^{th} and 20^{th} century depleted this species regionally and put it at the verge of extinction. Consequently, humpback whales were listed under COSEWIC. The population of North Pacific humpback whales remain a species of special concern under COSEWIC. Recent evidence indicated that their populations are starting to increase (Cypriano- Souza et al. 2018), the threats like vessel strike, underwater noise, entanglement in fishing gear and other human activities still remain. Some of these threats are increasing in frequent and severity on humpback whales.

Research Questions

1. What type of dynamic oceanographic variables (tidal heights, tidal currents, temperature, salinity) can influence humpback-whale movements in Boundary

Pass? Is there any tidal preference for predicting whale occupancy in Boundary pass shipping lanes?

2. Can physical and biological oceanographic model outputs be used to understand humpback whales in Boundary Pass?

Methods

Study Area

Data were collected at a land-based observational location at East Point Park (48.78299, -123.0456) on Saturna Island (Figure 1), one of the southern Gulf Islands of British Columbia, Canada. This location has a wide visual angle overlooking Boundary Pass (Figure 2) and is the exact location of a previous study conducted in 2020 by Quayle and Joy (2021), enabling a doubling of effort in the understanding of this area, and a comparison between years. The sighting point is located on the tip of a cliff at East Point Park that is at a higher vantage point than its surroundings with an almost 180-degree view over Boundary Pass.

Land Based Observation Survey

From June 1st to August 30th, 2021, data were collected following the same methods used to visually monitor whales in 2020 (Quayle and Joy 2021). As the primary observer, I used land-based observational-scans from East Point Park, Saturna Island (Quayle 2021). The survey was done daily from 9 am to 4 pm with 5 minutes of survey effort every 15 minutes following whale-observation protocols used by a number of other authors in the Salish Sea including Lusseau et al. (2009), Di Clemente et al. (2018) and Le Baron et al. (2019). The primary observer performs a standardized survey at a constant (static) vantage point, and for each object (whale or boat) detected, the observer records the distance from the point to the object. If the object was a whale, this indicated the start of a ‘whale event’.

During each whale event (the start of a whale sighting), the location of the whale, distance between survey position and the whale, start and end time, species, direction of travel, activity (like traveling, foraging, any surface activity behaviour), vessel presence during the event, number of animals and time between surfacing were collected. In addition, any information that might have affected survey data quality such as visibility, weather conditions, sea state or any significant variability was recorded (Appendix A).

During each scan survey, binoculars (Zeiss 10x42) and a DSLR camera (Sony α7R IV) with a telephoto lens (Sony 200-600 mm) were used. A laser range finder (Newcon LRM 3500M-35BT) was used to determine distance from the observer to the whale. The laser range finder was also used to determine distance between boats and whales.

Another way of detecting whales was auditory monitoring where the primary observer listened for any exhale or splash sound which might indicate nearby whale presence.

Social media like Facebook pages, websites or other communication apps of local citizen scientists were other ways of detecting whales in the area. Presence of ecotourism vessels in the area was another good indicator of whale presence in the region.

As soon as a whale was detected the whale event began and start time was recorded. When the individual was no longer detected for more than 20 minutes, for any reason, the event ended and the end time documented as the last time that whale was observed. The moment a whale was detected the photographic recording began, and these photos were used to track each surface and the time between them. The photographs were also used for identification purposes. Photo documentation was used to differentiate among adult, juvenile, and calf. Identification of individual humpback whales is through their unique marking on the underside of their fluke and also by any distinctive markings on their dorsal fin. The ENGO 'Happywhale' is a global citizen science consortium that collects photo identification of humpback whales from around the world as well as basic life parameters like age, sex, and previous sighting locations (happywhale.com). Happywhale uses image processing algorithms to match whale photos with scientific collections. In 2021, student L. Quayle was the first to report the birth of a young humpback whale (newly named `Neowise') to the database.

During each whale event the monitoring of a humpback's movement was continuous to accurately track whales and document surface locations and whale behaviour. The time and location of each surfacing and of each dive were recorded in real-time on an iPad. Although observers attempted to be precise about the whale locations, no theodolite was used, and locations were estimated from the land-based observational survey using only a range-finder.

Categories for behaviour of whales included “traveling”, characterized by a constant linear movement of animal; “foraging”, characterized by back-and-forth movement in the area; “resting”, identified when there was no obvious movement of the whale; and “surface activity behaviour” when there were behaviours like breaching and fluke or flipper slapping.

All the whale events were reported and submitted to the Whale Report Alert System (WRAS) App, managed by the BC Cetacean Sightings Network (BCCSN). Sometimes lack of internet connection resulted in a delay in reporting the whale sighting but all reports were submitted as soon as a reliable internet connection was available. In all cases, the delay in reporting was no longer than a couple of hours.

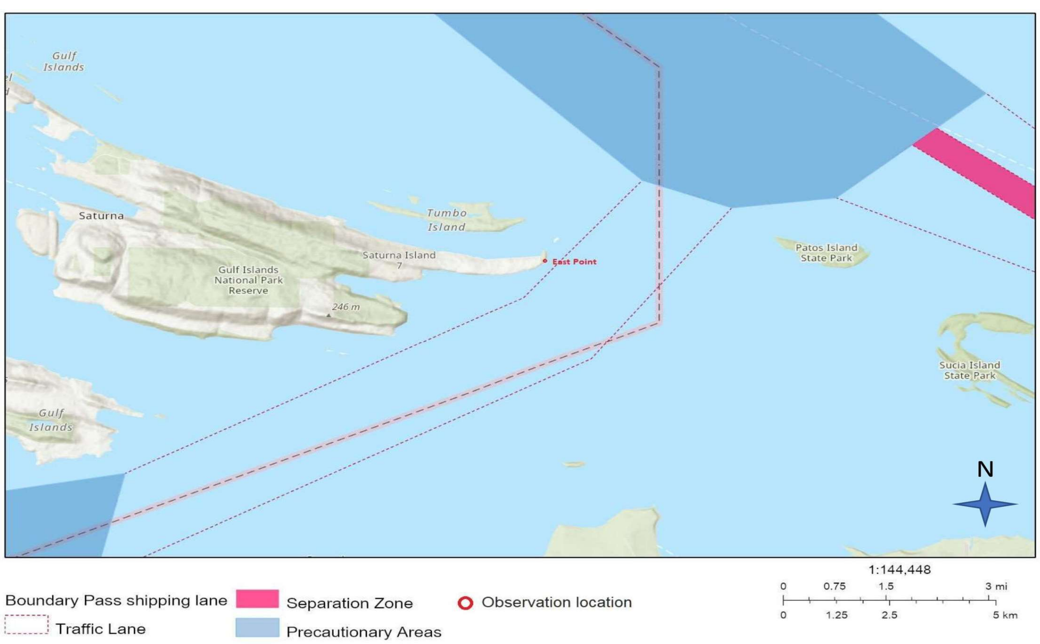

Figure 1. Location of the land-based vantage point where the primary observer conducted the systematic scan surveys from at East Point, Saturna Island and the shipping lane (traffic lane) through Boundary Pass.

Figure 2. An overview map of observation location in Saturna Island in Salish sea.

Citizen Science Collaboration

The recent increase in citizen science proved to be a very useful approach to gathering data, it is especially beneficial when monitoring vast temporal and spatial scales (Tiago et al. 2017). Citizen science datasets are rapidly being used as inputs to explain trends across a broad variety of environmental problems, partly because they are less expensive than professional surveys, and partially because these data can be gathered in areas that are very difficult to access for researchers (Johnston et al. 2020; Araujo et al. 2020).

Citizen science is a way in which the general public can get involve in data collection and contribute to environmental monitoring. These datasets have been used to assist the public on local, provincial, national or even global scales of environmental management decisions (Dickinson et al. 2010). Species like humpback whale with easy identification characteristic due to their body size and surface activities are ideal targets for public science contributions (Araujo et al. 2020).

The Southern Gulf Islands Whale Sighting Network (SGIWSN) previously known as Saturna Sighting Network (SSN), is a citizen scientist group of up to 50 whale sighters that operate in collaboration with SIMRES (Saturna Island Marine Research and Education Society). The SGIWSN provides up to 50 sets of eyes along the coast of three southern Gulf Islands including Saturna, Mayne, North and South Pender islands. The presence and data coverage of these volunteers is admirable and inspirational, it can be challenging to measure the 'time on-effort' to reconstruct whale sightings per unit of effort, as is done with the primary observer engaged in systematic scan surveys at East Point Park.

Typically, citizen scientist collect data without following any systematic data collection structures. This opportunistically collected data can lead to biased evaluation in data gathering (Johnston et al. 2020). However, the SGIWSN volunteers were trained in data collection to maximize the usefulness of the data. Volunteers used a similar data collection protocol to the land-based cetacean observation (LBCO) surveys.

During the summer of 2020 and 2021, the SGIWSN reported opportunistic whale sightings in real-time through the Discord communication app. Discord is a VoIP, instant messaging and digital distribution platform that enabled a network of up to 50 sighters to communicate whale movement in real-time. This additional sighting effort from the SGIWSN resulted in increased accuracy and observations of whales in Boundary Pass as well as some additional real-time reports to WRAS, and an archive submission to the BC Cetacean Sighting Network (BCCSN). I downloaded the archive of these humpback whale sightings in October 2021 and cross checked the SGIWSN sightings with those from the primary observer. This decreased the possibility of pseudo-replication in the primary observer's report. Sightings from this group were not included in data analysis.

Data Analysis: Distance Sampling and Generalised Linear Mixed Models

Distance sampling is a widely used method for estimating relationships between animal locations or density to the environmental (oceanographic) variability in a survey region (Thomas et al. 2010). The key to distance sampling is to fit a detection function, which describes the relationship between distance and the probability of visually detecting the target object. In my study this was humpback whales. The assumption behind this method is that objects become harder to detect with increasing distance from the observer. I used the distance at which detection probability started to fall as the truncation distance at which we excluded sightings. This was to reduce effects of observer bias that might be related to covariates that were confounded with the whale occupancy in Boundary Pass.

There are a number of challenges with analyzing this kind of data. For example, I used a generalized linear model that linked the response to the independent covariates through a logit link function under the assumption of a binomially distributed response variable (humpback whale present/absent during scan event). The relationships between the response and covariate data are sometimes non-linear, and I modeled non-linear smooth functions to these covariate relations. And finally, multiple successive scan surveys on a single day can be temporally correlated, and therefore I corrected for this potential pseudo-replication through a random effect term and an autocorrelation function that decayed across a period of a day. This assumes that whales seen within the same day are not independent, but whales on adjacent days are independent. The statistical model that allows for all of these data features is the Generalized Additive Mixed Model, or GAMM.

I fit a GAMM to examine which environmental (oceanographic) covariates influenced occupancy of humpback whales in Boundary Pass using only the 2021 systematic survey data. GAMM chooses between linear and non-linear combinations of the independent variables to best explain the response variable. I fit presence/absence (1/0) during a scan survey as the response variable, with a binomial family specification with a logit link function to relate the probability of whale occupancy to the environmental covariates. The model's pseudo-code had the following structure:

Model: GAMM (humpback whale (0/1) = tidal currents + tide height + SST (Sea Surface Temperature) + month, random effect = day, covariance = autoregressive order 1)

When selecting between models, we fit the GAMM models sequentially by including main effect covariate terms one by one (using forward selection) and removed from the model if we saw no reduction in the Aikaike Information Criteria (AIC). The AIC is statistical metric that provides a model fit (Spiegelhalter et al. 2002).

Environmental (Oceanographic) Data: Sea surface temperature, salinity and biological covariates

Ocean floor temperature, sea surface temperature data (SST), ocean floor salinity and sea surface salinity in Boundary Pass were kindly sent to us from researchers managing the Live Ocean dataset in Washington University (Dr Parker MacCready, pers. comm.). Live Ocean is a computer model that simulates ocean water properties creating both real-time, and 3-day forecasts of currents, water temperature and salinity. These model outputs are archived and made available upon request to the Live Ocean UW Coastal Modeling Group. We matched the time and location of whales with the closest measure of ocean temperature and salinity provided as output from the Live Ocean output raster and explored the data.

Additionally, we looked at snapshots of mesozooplankton for the Boundary Pass region in June to identify regions of consistent nutrient upwelling that might be an indication of humpback foraging areas. These spatial-temporal indicators of mesozooplankton and diatoms were downloaded from the open-access ERDDAP server that the UBC Salish Sea Cast NEMO model shares its ocean model products on (Soontiens et al. 2016).

Whale Track Map

A map of whale's movement in the area were made by R Studio Version 4.1.2. All the location recorded on site were recorded in latitude, longitude but were converted to UTM coordinates for analysis. All data are plotted in longitude and latitude. All sightings information for humpback whales in Boundary Pass in 2021 is included in Appendix 2.

This map was used only as a visual confirmation of the model results and statistical findings.

All data analysis were conducted using RStudio version 2021.9.2.382 RStudio team 2022 "Ghost Orchid".

Results

Land Based Cetacean Observation (LBCO) Survey

Land-based observational data collection was done in 83 days, from June 1 to August 30, 2021, totaling over 588 h of effort (Figure 3). Multiple reasons including bad weather, observer sickness and vacation days resulted in 9 non-survey days. During the 83 days of survey, whales were observed on 20 days with total of 30 whale events. This compares to 63 days in the summer of 2020 (Quayle 2021).

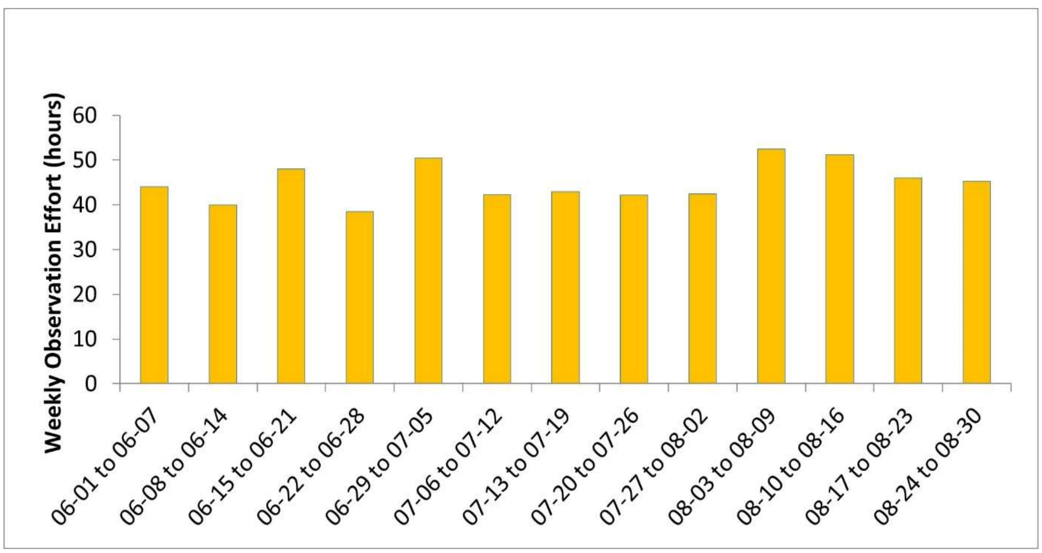

Figure 3. Number of hours per week conducting systematic Land Based Cetacean scan surveys.

LBCO Survey Observations 2020 and 2021

A comparison of humpback sighting data from 2020 and 2021 showed a similar distribution pattern across both years. Comparing the number of observations during 2020 and 2021 indicated a decrease in humpback whale's population that visited the area during the summer of 2021. Similar to 2020, the highest number of humpback whale sightings in 2021 was in June (Figure 4). The number of whale events in June 2021 was 25 but the same period in June 2020, corresponded to 64 whale events. In 2020, a mother-calf pair used Boundary Pass consistently setting up residency here for the month of June, while this did not occur in 2021.

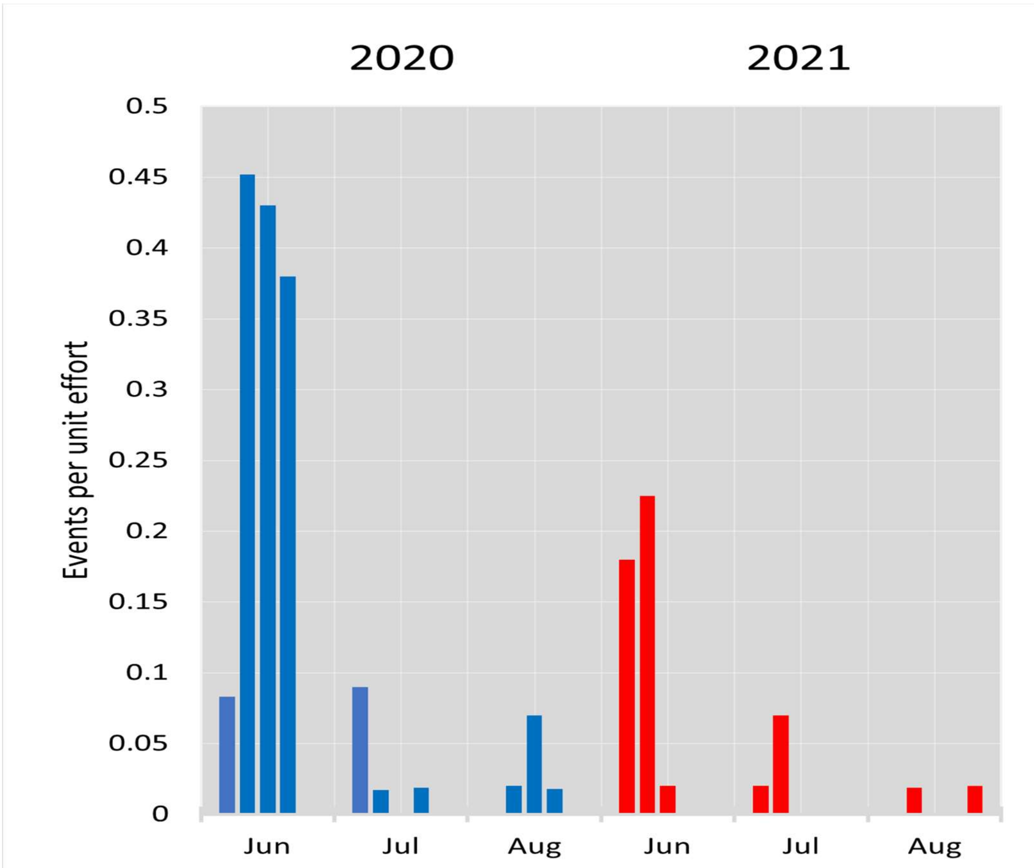

Figure 4. Comparing sighting data from 2020 and 2021 per unit effort.

Weekly observation effort in hours compared to cumulative count of whale sighting in 2020 (Figure 5) demonstrated more whale events through the 2020 observation period compared to 2021 (Figure 6).

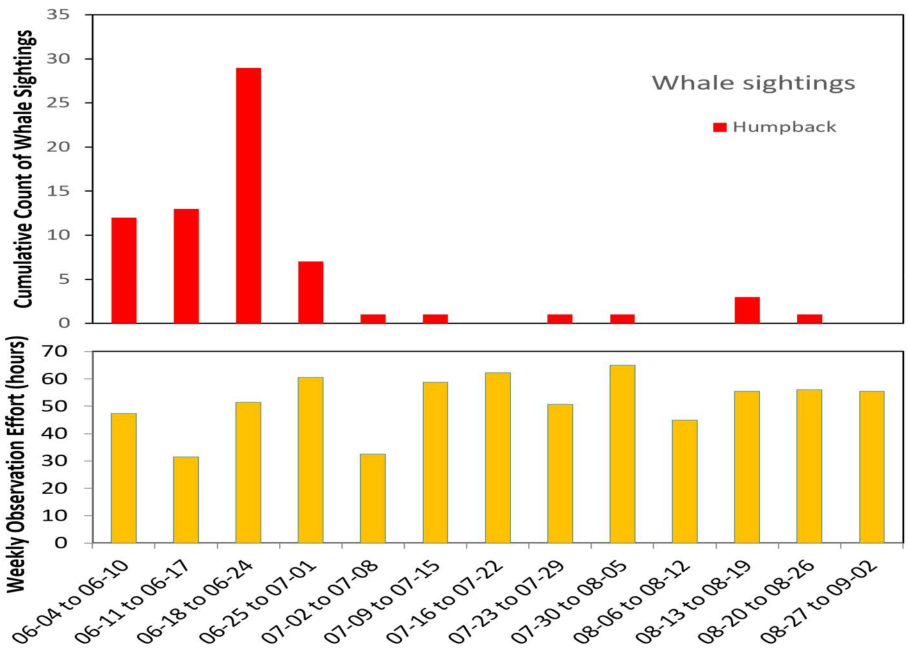

Figure 5. Weekly observation efforts per hours compared to cumulative weekly count of whale sighting in 2020

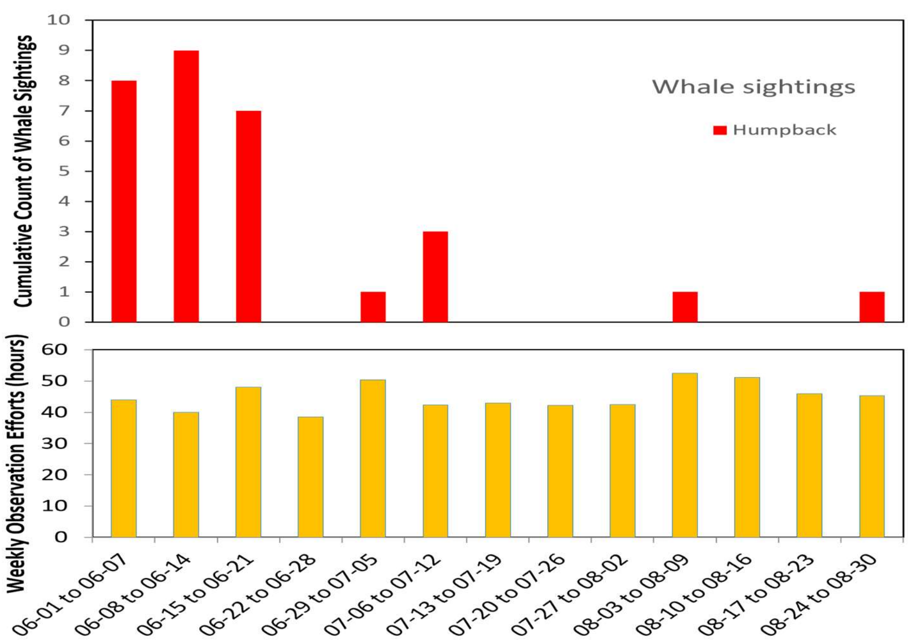

Figure 6. Weekly observation efforts per hours compared to cumulative weekly count of whale sighting in 2021.

Citizen Science Contributions

We benefited from the shared sightings of the SGIWSN (Table 1). This collaboration provided whale sightings and opportunistic effort beyond that included by the primary observer. This SGIWSN citizen science contribution resulted in a higher number of whale observations compare to data collected only by the primary observer. In 2021, up to 50 volunteers were trained and participated in data collection in and around the waters of Boundary Pass, and beyond. Volunteers used a similar data collection protocol to the LBCO survey.

Table 1. Monthly totals of survey days (and number of observation events) of cetacean presence from June 1 to September 30, 2021. A 'whale day' is a day when at least one whale was sighted in the survey region. A whale 'event' starts by detecting whale(s) in the area and ends when whale(s) exit the survey area or go out of sight due to distance or environmental component.

		June	July	Aug	Sept	Oct	Total
Number of calendar days		30	31	31	30	31	153
Number of survey days by primary observer		26	27	30	-	-	83
Number of survey days by primary + SGIWSN opportunistic sighting days		30	31	31	30	31	122
Humpback whales	Number of whale days by primary observer (Number of events observed by primary observer)	16 (25)	2 (3)	2 (2)	-	-	20 (30)
	Number of whale days by primary + SGIWSN (Number of events observed by primary + SGIWSN)	19 (35)	6 (8)	4 (5)	4 (4)		33 (52)

Whale Detection Function

We fit two functional shapes to describe the visual detection function of whale sightability as a function of distance. We found a better fit to the hazard rate (lower AIC metric) over the half normal function (Figure 7). As humpback whales are large, active and noisy whales (i.e., the loud sound of their exhale), they are very detectable whales, and the observation data accuracy is excellent up to 5 km. At distances greater than 5 km, probability of whale detection was <1.0 indicating that the ability to see and record whales was below the expected number. To reduce the effect of this loss of efficiency in observation and to remove visual biases, all the data beyond 5 km were excluded from the GAMM data analysis. All whale sightings that happened in the areas closer than 5000 m from the observation point were included in the data analysis (Figure 8).

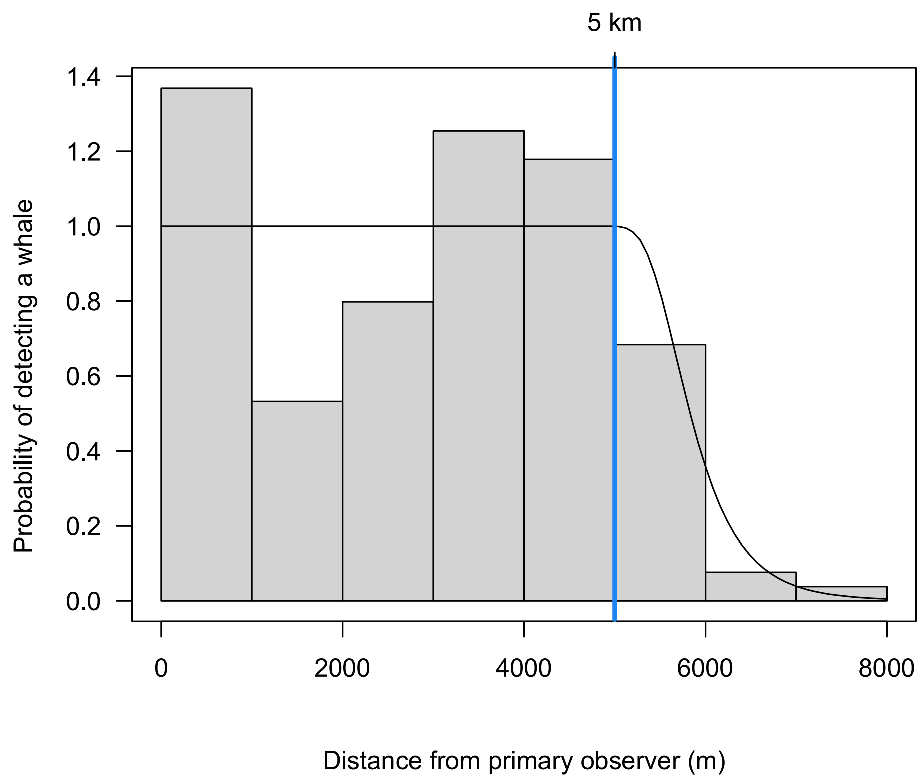

Figure 7. Detection function fit to data observed by the primary observer from East Point Observer Point. The histogram is the observed number divided by the expected number of humpback whales detected during a systematic survey within 1000 m distance bins. The curved lines represent the detection function fit to the observed binned distance data for whale detection. We truncated all sightings beyond r 5 km when visibility of whales started to drop as a function of distance.

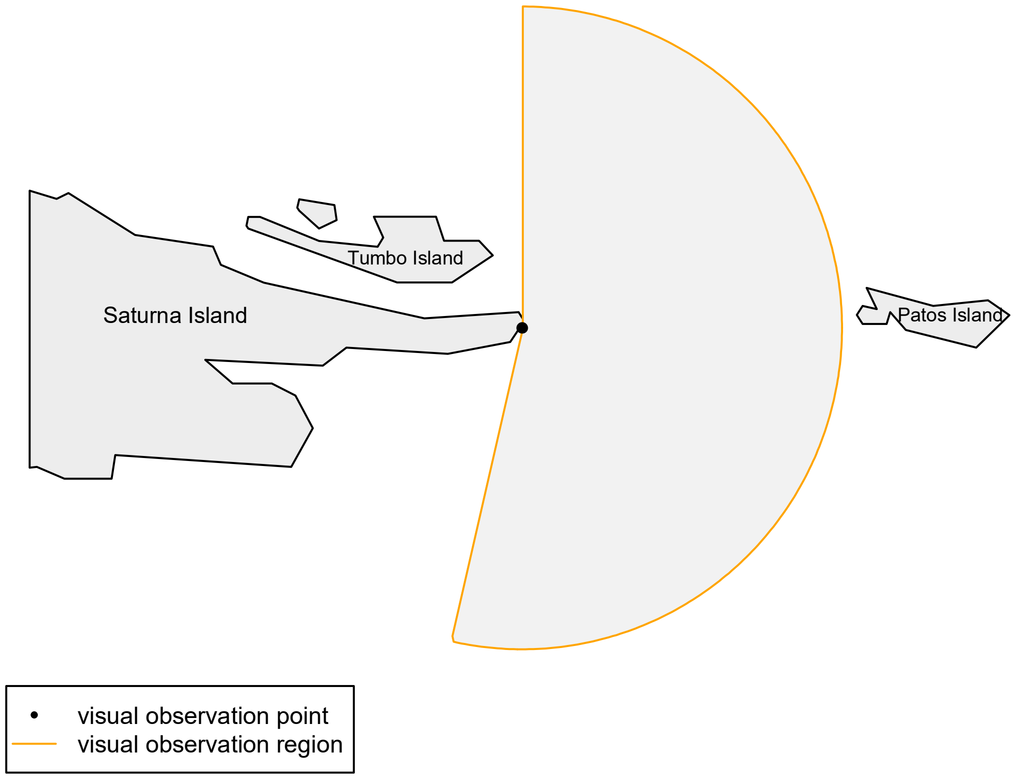

Figure 8. Visual observation region is truncated at 5 km from primary observer as indicated by the detection function (Figure 7). This excludes sightings that occurred outside of the detection region where detection probability was < 1.0. This meant that sightings outside of this visual observation region were not included in the analysis (to remove visual bias).

Tidal Height, Ocean Currents, Sea surface temperature and Salinity

Prior to including variable as possible covariates in our GAMM modeling efforts, we visually examined the relationships between covariates when whales were present vs absent in Boundary Pass. Visual inspection suggested that whales shown a preference of whale activity during low tides and ebb currents (Figures 9 & 10).

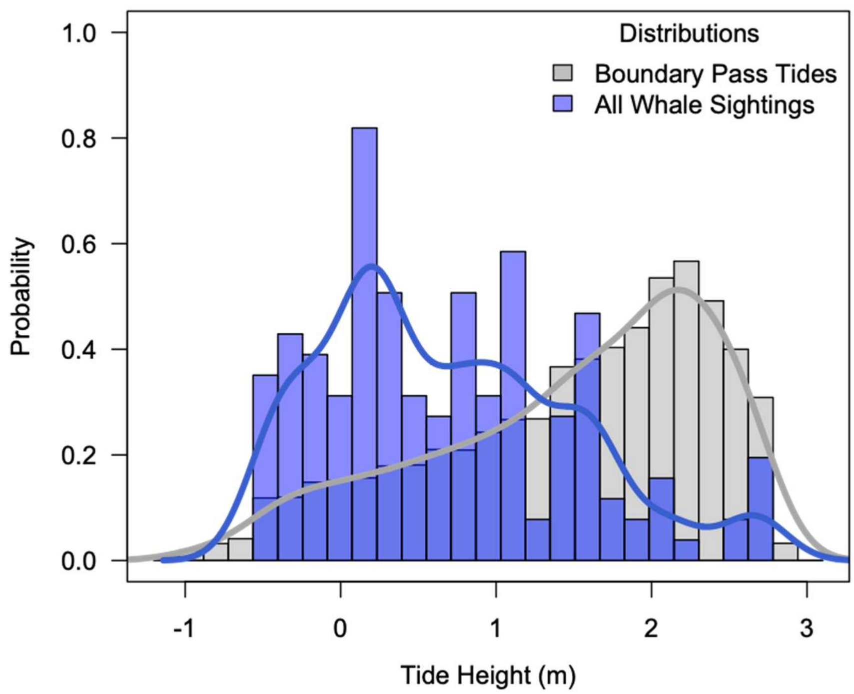

Figure 9. Probability of whale activity relative to tide height in Boundary Pass

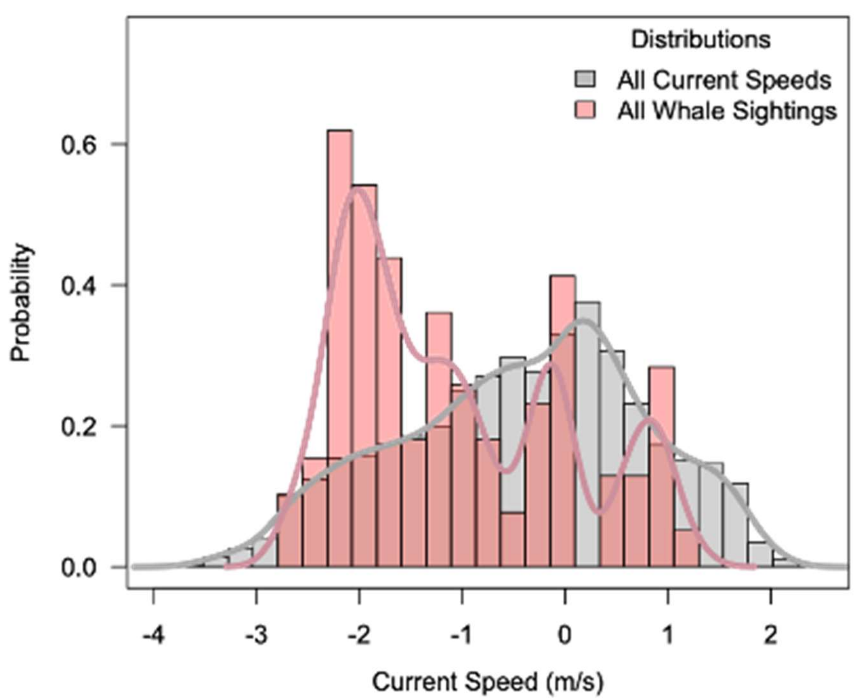

Figure 10. Probability of whale activity relative to current speed in Boundary Pass. Whales are selecting periods with higher ebb currents (Pvalue < 0.001 by fitting randomizations of Kolmogorov-Smirnov tests while controlling for pseudo replication by only randomly selecting one track location, simulations were run 1000 times).

Ocean Salinity and Temperature

Sea surface and bottom temperatures and water salinity at the surface and ocean bottom of the study area were provided to us by the University of Washington's Ocean Live model. To understand if there was a change in water temperature and water salinity in the Boundary Pass during the summer of 2021, data for these two variables were analysed both at the surface and at depth. Data analysis for salinity suggested that there was higher salinity in June 2021 compared to July and August of 2021 (Figure 11) while the ocean floor salinity was consistent across time. Sea surface salinity was over 30 PSU (Practical Salinity Unit, or PSU, is a unitless measure of salinity based on the conductivity of sea water) and is highly variable and consistently lower than salinity at depth. Salinity is higher at depth across all months in 2021, taking a value greater than 30 PSU.

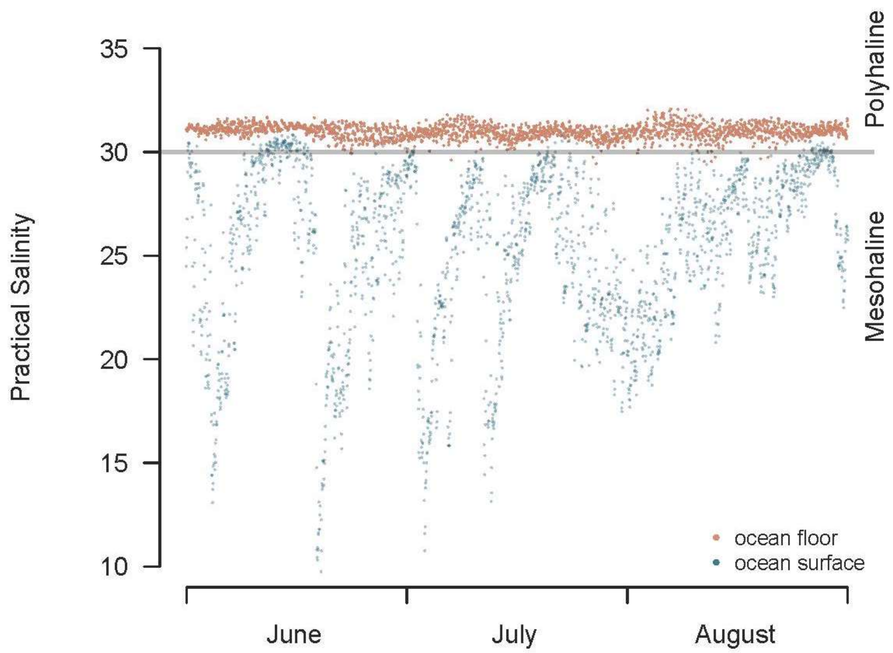

Figure 11.Summer salinity in Boundary Pass at the ocean surface and ocean floor

Data exploration of sea surface temperature showed higher SST in July and August compared to June 2021 (Figure 12). There weren't any considerable changes in Ocean floor temperature.

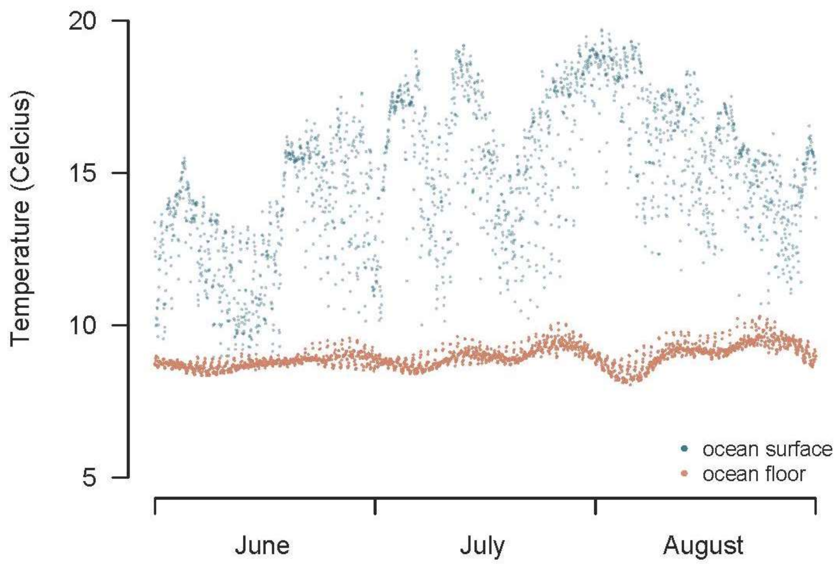

Figure 12. Summer Sea surface temperature and ocean floor temperature in Boundary Pass

As sea surface temperature and salinity are highly variable across time and space, and the process model that would link humpback whale foraging to these variables is unknown, I didn't include these two variables in further analysis. With better forecasting of more coherent surface physics, and a better resolved understanding of how humpbacks might adjust their movement to the perception of these first order oceanographic processes (and how these could relate to the shipping lanes), this would become possible.

Relative Zooplankton and Diatom Density

I plotted the spatial distribution of relative zooplankton (Figure 13) and diatoms (Figure 14) density at 130 m depth, averaged across the days of observed whales in Boundary Pass. This depth was selected as it was the depth that humpback whales with CTD tags were documented to be foraging on herring, capelin and walleye pollock in Juan de Fuca Strait, a body of water separated by 40 km (Rhonda Reidy personal communication).

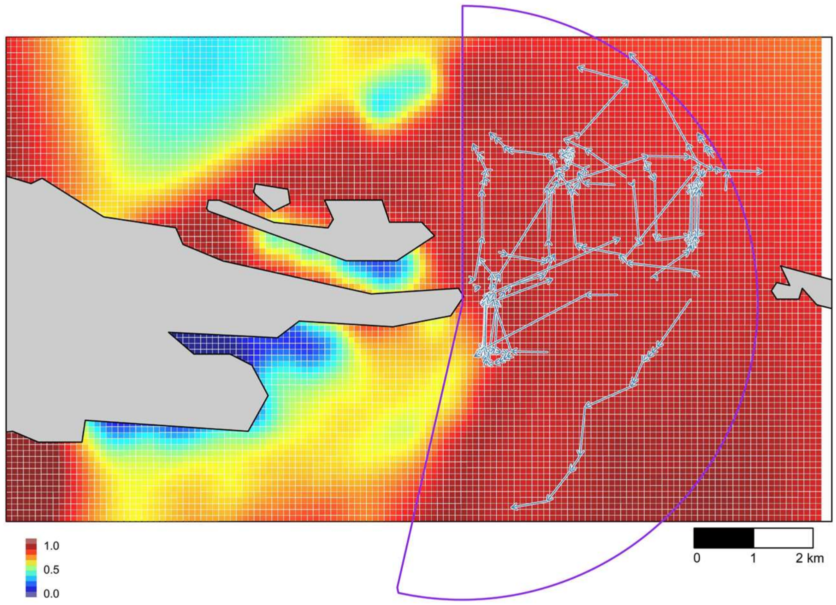

Figure 13 Spatial distribution of zooplankton in Boundary Pass on days when humpback whales were present, the grey lines are indicators of whale movements in the area.

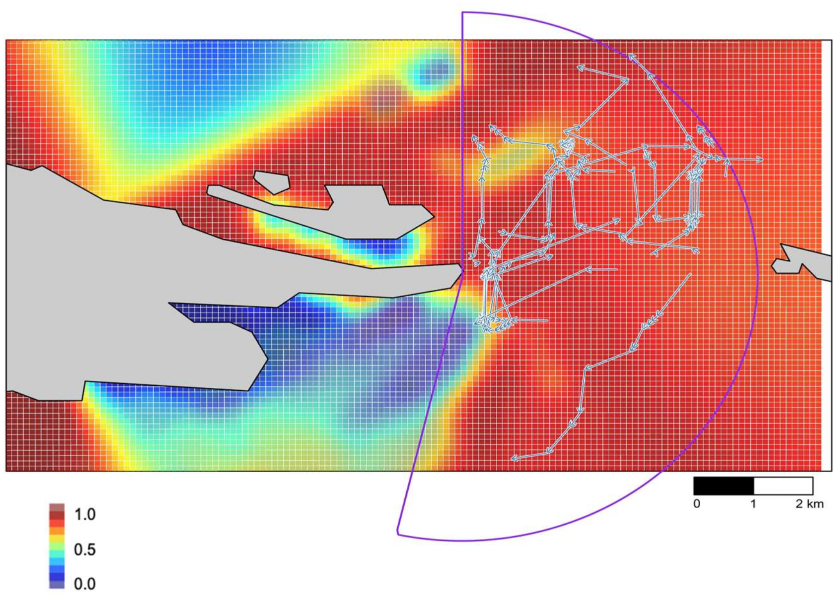

Figure 14 Spatial distribution of diatoms in Boundary Pass on days when humpback whales were present.

I found that in region with coverage from the vantage point location on East Point, the distribution of both mesozooplankton and diatoms was uniformly high, without any spatial variability. Therefore, neither biophysical variable was included in further modeling of humpback whale occupancy.

Generalized Additive Mixed Models

Several generalized additive mixed models (GAMM) were fit using current speed, tidal height, time of day, month of the year as main effect covariates in the model. We found the model with the best fit (smallest AIC) was a model with only current speed included. To account for pseudo-replication, we assumed observations on separate days were independent, but fit an autocorrelation matrix for within day whale events. This covariate weight matrix was included to account for repeated measurements that may be correlated if captured on the same day. We fit both linear and non-linear splines to relate the current speed to the response variable. A non-linear splines model best explained the relationship between humpback occupancy and ocean surface currents (based on AIC GAMM optimisation criteria). This relationship between current speed and the probability of sighting a whale (probability of a whale event) is plotted in Figure 15 below.

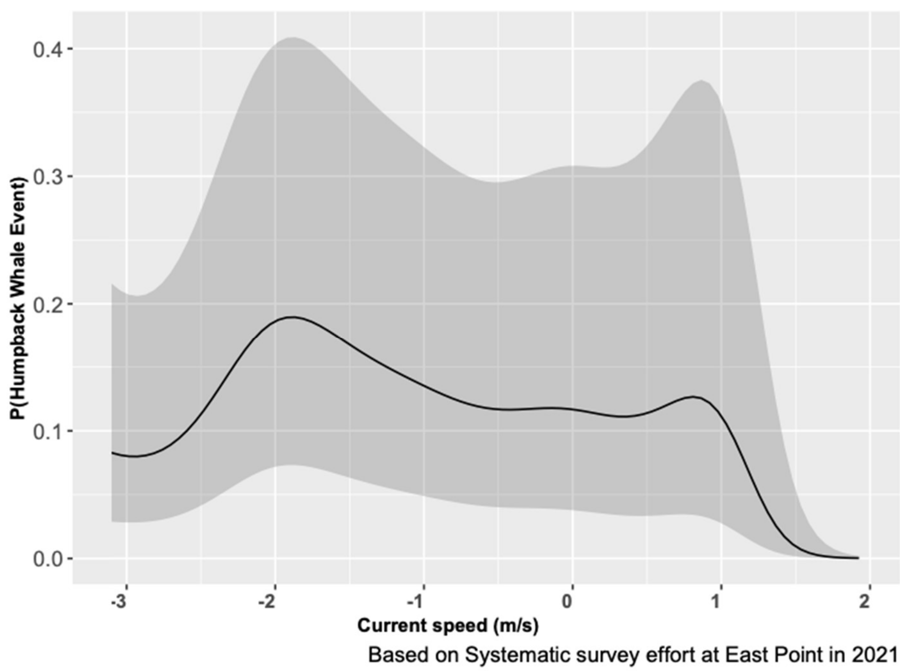

Figure 15. The probability of observing a humpback whale in Boundary Pass is highest at ebb tides of -2 m/s as indicated from fitting a Generalized Additive Mixed Models (GAMM) to systematic survey data from East Point.

Whale Track Map

Over half of all humpback whale events in Boundary Pass in 2021 (16/30) were observed in the shipping lanes (Table 2). In 17 of 30 of these events there were small recreational boats with the whales, and in 9 of 30 events there were commercial vessels present. Overall, there was at least one vessel present with the humpback whale in Boundary Pass on 70% of all whale events in 2021 (Table 3). Compared to 2020 data, in total of 77 humpback whales events occurred in this year 59 of them were detected within the shipping lanes (Table 2), and in 47 of 77 event which include 61% of the events at least one type of vessels where present (Table 3).

Table 2. Movement zones detected during marine mammal observation events in relation to shipping lanes observed by primary observer.

Species	**In shipping lanes**	**Outside shipping lanes**		**Total count of observation events**
		Only near shore*	Only far channel^	
Humpback 2020	59	13	5	77
Humpback 2021	16	5	9	30

*Movement within "only near shore" refers to movement between Saturna Island and the shipping lanes (i.e., within 300 m of shore, west of the shipping lanes).

^Movement within 'only far channel' refers to movement east of the shipping lanes, in US waters.

It is known that the presence of vessels during the whale activity not only increase the risk of ship strike but also adds other stressors like noise disturbance or chemical pollution to their habitat. In addition, the growth of the shipping industry will add to potential impact of shipping route whale habitat overlap. Results from 2020 and 2021 represent this extending overlap. Vessels were present in 61% of whale events in 2020, while this number rose to 70% in 2021 (Table 3).

Table 3. Number of whale observation events that had vessels within 1000 m of the whale observed by the primary observer.

Species	**Vessel presence**		**Total number of whale events with vessels present ****	**Total number of observation events (percentage of events vessels were present)**
	Count of small vessels* (no. of events with small vessels)	Count of large vessels^ (no. of events with large vessels)		
Humpback whale 2020	84 (35)	43 (26)	47	77 (61%)
Humpback whale 2021	44 (17)	13 (9)	21	30 (70%)

*Small vessels include ecotourism, recreational, sailboat motoring, government and research boats

^Large vessels include container ship, bulk carrier, tanker, tug and Navy vessels.

**Multiple events had both small and large vessels present

We plotted tracks of humpback whales as they moved through Boundary Pass during the months of June, July and August. Whales were consistently found foraging and traveling within the commercial shipping lanes during this summer survey period (Table 2, Figure 16). As 53% of whale events were tracked inside the shipping lanes, and whales prefer strong ebb currents, there is strong overlap with humpback whales in commercial shipping lanes (Figure 17), particularly in June (Figure 4).

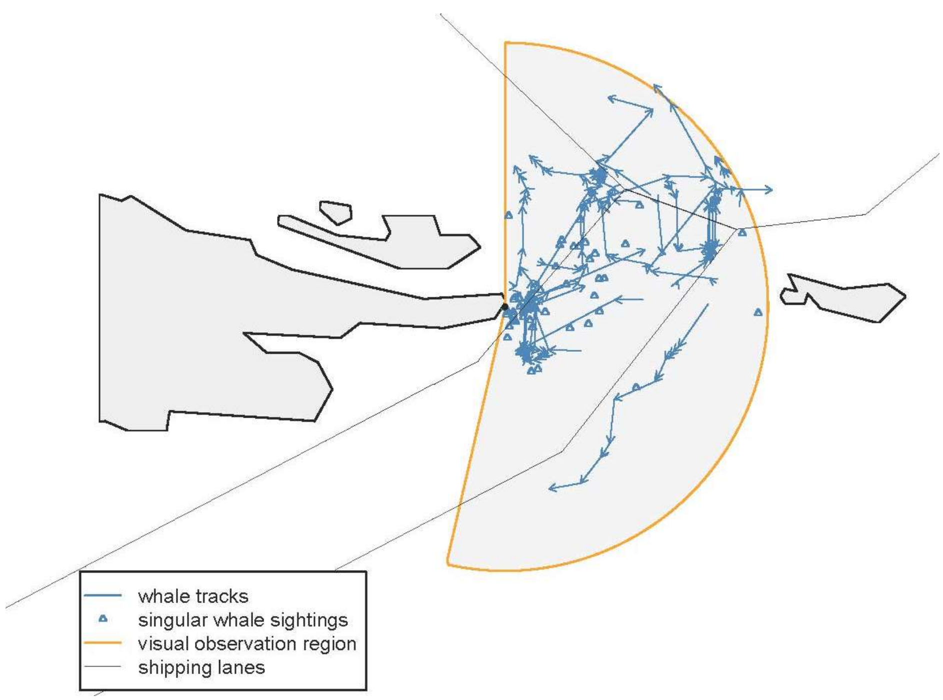

Figure 16. Sightings of singular whales, whale tracks and shipping lanes relative to the vantage point survey location at East Point.

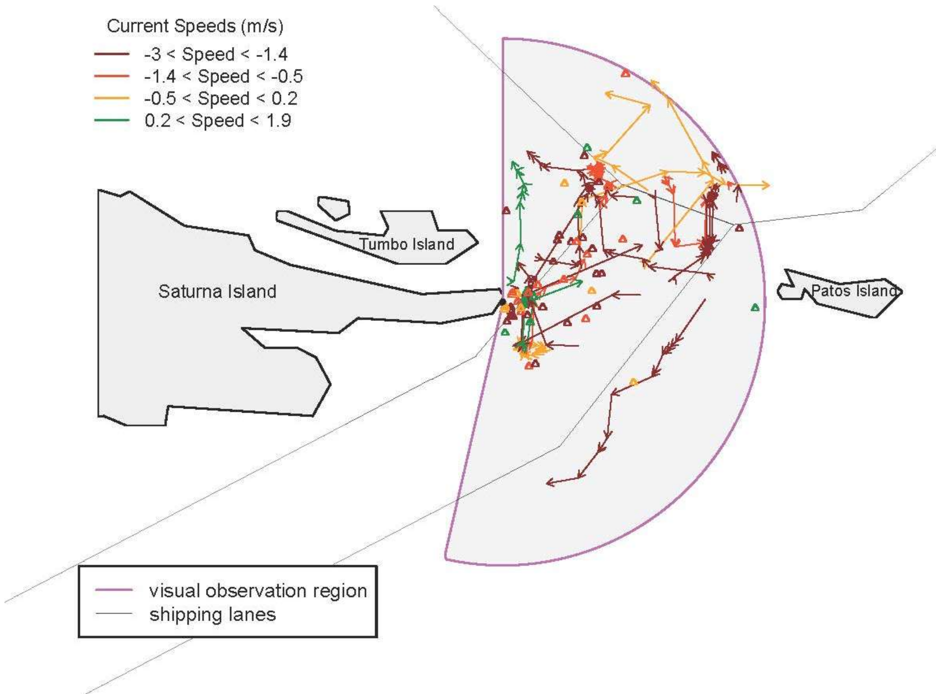

Figure 17. Humpback whale tracks recorded in 2020 and 2021, cross referenced by currents speed data. Represented are the tracks of humpback whales in 2021, and 2020 data is indicated as triangles. (coloured by surface current speed)

Discussion

Whale Presence in Boundary Pass

Humpback whales' distribution and habitat use in Salish sea has changed significantly over the past 25 years. Although in the summer of 2021, occupancy of humpbacks in Boundary Pass was lower than in 2020, across both years there is consistent presence of humpback whales in the Boundary Pass area. This is consistent with increasing numbers of humpback whales throughout the Salish Sea (Miller 2020).

To determine the distribution and habitat use of humpback whales related to oceanographic and environmental factors in Boundary Pass, I examined a suite of possible covariates. I was unable to find a relationship between ocean temperatures, salinity or lower food chain biophysical components (mesozooplankton and diatom density). More work is required in this area, particularly if a link can be found between the prey of humpback (herring, pollock, capelin) and these lower trophic food web constituents.

Despite rising numbers of whales each year in the Salish Sea, this year had lower numbers of whale sighting compared to previous years, which may be attributed to less numbers or density of prey in the area. Humpback whales in the Salish Sea feed on schooling fish which are the food target of many other species (Wedekin et al. 2017). It is possible that in 2021 there wasn't enough food, or the food wasn't in a form that was available to humpback whales. This can have an impact on the distribution of whale populations in the area. Better data on forage fish distribution across time and space and whether prey is available (in aggregated schools for entrapment feeding) to humpbacks should be included in further analyses of humpback whale distributions in Boundary Pass.

Humpback whales also must make decisions about predator avoidance. In 2020, a mother humpback and her young calf were resident in Boundary Pass. It is unclear whether Boundary Pass was a refugia from Bigg's killer whales (their only predator in the Salish Sea), or if the productivity of the area as a foraging ground was a defining characteristic. A third suggestion is the numbers of commercial ships and the associated disturbance they incur may have kept the humpback whales from this area. More years of surveys are recommended to see if the fewer numbers in 2021 was an anomaly or just part of regional interannual dynamics, or if there are some biophysical reason why fewer humpback whale events occurred in 2021 over 2020.

Environmental Conditions.

The rapid change of environmental conditions around the globe and consequently its effect on long distance migratory animals makes it very important to understand the effect of oceanographic variables on the migration cycle of the humpback whales and their appearance in the area. As we can see in this study, the number of whales that appear in this region over the study period, peaks in June and declines across July and August.

Higher temperatures at the end of June as a result of the heat wave may have had effects not only on sea surface temperature (SST), but also on the snowmelt, spring freshet and volume of fresh water flowing out from the mouth of the Fraser River into Georgia Strait. As salt water is more dense than fresh water, this sweet water from the Fraser creates a lower surface salinity when the Fraser River is running high. Because humpback whales are opportunistic feeders that arrive in the Salish Sea hungry after a long migration from their southerly breeding range, arrival in the feeding grounds is linked to the timing and distribution of their prey in the area; temperature is one of the most important influencers of prey abundance in the ocean (Ramp et al. 2015). Even in some cases it’s been observed that humpback whales changed their diet from krill to schooling fish due to rising of SST (Fleming et al. 2016). Studies conducted in the Salish Sea by Calambokidis et al. (2004) and Dransfield et al. (2014) showed the higher number of humpback whales in upwelling areas with cooler water and areas with water temperatures between 12 and 14°C. As it is evident in the SST data analysed in this study, June has relatively lower SST than July and August.

The higher salinity in feeding areas also can be an indicator of prey abundance. The logic behind this idea is these regions are upwelling areas which brings the cold, saline and productive waters to the top (Gregr and Trites. 2001; Tynan et al. 2005; Keiper et al. 2005; Dalla Rosa et al. 2012 ; Dransfield et al. 2014).

I found humpback whales were more likely to be observed under strong ebb currents under low tide conditions. Ebb currents are products of low tides and water moving away from shore (Figure 18).

Associations of topography, wind and tidal currents can result in forming biological aggregations (Wolanski and Hamner 1988). Tides and tidal currents are among oceanographic features that are relatively predictable (Wolanski and Hamner 1988), and this characteristic often use by marine animals to choose their foraging areas (Chenoweth et al. 2011). Ebb and flood currents are among oceanographic drivers that can influence foraging opportunities of marine animals including humpback whales (Chenoweth et al. 2011; Pineda et al. 2015). Therefore, we hypothesis that the abundance of humpback whales in the Boundary Pass during the low tide and strong ebb currents is likely linked to better foraging opportunities.

Figure 18. Correlation between spatial and temporal component of tides, as high tide results in water move toward the shore (flood current), low tides consequently cause water to move back from the shore (ebb current). (Animation by NOAA)

Whale Overlap with Boundary Pass Shipping Lane

Boundary Pass is one of the busiest passages in the area, with a busy commercial shipping lane used by vessel traffic visiting multiple ports inside the Salish Sea. Other than noise disturbance which is made by constant movement of ships and boats in transit in the region, the risk of ship strike is the highest danger for humpback whales. This elevated risk level in humpbacks compared to killer whales is caused by absence of echolocation ability and the sensitivity of the species to lower frequency noise bands (Calambokidis et al. 2019). The rising number of humpbacks and the continued expansion of the shipping industry won’t help the matter.

In this study, I focused on data collection during the daytime, however, whales spend most of their nighttime close to surface which make them more vulnerable to vessel collision (Calambokidis et al. 2019). Commercial ships run through the region both day and night. Also, the number of ship strike are most definitely higher than it's been reported which is result of low accurate documentation and reports, and the low number of carcasses that are recovered relative to those that sink. The sad reality is that lots of whale-ship collisions go unnoticed as their carcass sinks before arriving on-shore (William et al. 2011., Rockwood et al. 2017). According to the findings of this study the range of humpback whale movement in the area from June to August of 2020 and 2021 coincides with strong ebb currents and low tide conditions. These oceanic states are likely a result of higher productivity and food abundance. But as it was suggested in several different studies, ebb and flood currents can have different influences in various location with different topographic and oceanographic characteristics (Alldredge et al. 1980; Wolanski et al. 1988; Chenoweth et al. 2011; Pineda et al. 2015). Further study in this area is needed to better understand the dynamics of these current systems in the Boundary Pass. But meanwhile management of shipping travel in the area could be adjusted to avoid these twice daily periods of the tidal cycle that humpbacks are more likely to collide with marine traffic.

Although ship strike is the most known and increasing lethal anthropogenic disturbance for the humpback whales, it is not the only impact of maritime traffic on humpback whales in the area. Sound plays a very important role in the life of marine mammals. Although humpback whales don't echolocate to find food, they use sound as an important way of communication, males sing during their breeding season, and intermittently through their migration and in their feeding ground (Risch et al 2012). Under water noise pollution caused by marine transportation can mask the singing sound of humpback whales which can results stress, avoidance of the polluted area, alteration in song production or changing in foraging behaviour (Risch et al 2012; Blair et al 2016). Humpback whales produce and use low frequency sound which overlap with noise frequency of commercial vessels (Erbe et al 2019). These noises are produced by propeller cavitation creating bubble clouds behind the propeller. Higher speed, larger size and loads on ships can cause more cavitation noise, therefore continuing to engage the shipping industry in reducing vessel speed will help to decrease these noises (Ross 1976).

Conclusion

The largest concentration of humpback whale movements was observed in the middle of the Boundary Pass and within the shipping lanes, and these results agree with the distribution patterns recorded in the same area in 2020 (Quayle 2021). We found that strong ebb currents and low tides were associated with higher likelihoods of whales being found in Boundary Pass. The results of this research can be used for proposing mitigation strategies and may be particularly relevant during the summer foraging period when humpback whales are resident in the Salish Sea, and in Boundary Pass mostly during particular tidal periods in June.

Although not part of this study, Laist et al (2001) found that most mortality caused by vessel collision happens when the ships travelled at 14 knots or faster speeds. Strikes happening with vessels speeds below 10 knots however collision at this speed usually are not lethal nor will they cause severe injuries (Laist et al 2001). At operating speeds greater than 14 knots, even if ships could detect a whale, it requires a very long distance to change their course or slow their speed to avoid the collision (Silber et al 2009). Therefore a 10 knots restriction or, if possible, modifications to ship routes in the areas of whale movement hotspot that align with their preferred tidal active time periods. This would help to reduce or avoid ship strike in Boundary Pass.

Right now, there are two conservation strategies implemented in the area. DFO is targeting the endangered ecotype, the Southern Resident killer whale. One of these two conservation initiatives is being led by the Enhancing Cetacean Habitat and Observation (ECHO) program and implemented by the Vancouver Fraser Port Authority of Vancouver. and ISZs (Interim Sanctuary Zones) executed by Transport Canada and DFO. ECHO program is a voluntary program that aims to reduce underwater noise degree and risk of lethal vessel strikes by reducing the speed of commercial vessels through Boundary Pass and Haro Strait. This program started since 2014, coordinating the first volunteer commercial vessel slowdown in 2017. Every year since, the ECHO program has initiated the same or expanded the noise reduction measures (vessel slowdowns) in the Salish Sea area. Every year, the commercial ship industry times the start of the speed reduction. activated by detecting the entrance of Southern resident killer whales to Salish sea and will be active till the end of the summer, although in 2021 the program continued till October. The recommended speed for this program is 14.5 knot for container ships and vehicle carriers and 11 knots for other commercial vessels. More research is required to determine the optimal speed for maximum benefit for killer whales, although for now, following the precautionary principle will ensure both whales and ships are safe.

Although the targeted species of ECHO conservation initiatives are Southern Resident killer whales, other species like humpback whale also benefits from their implementation. The problem is these restrictions might not be going far enough not even sufficient for southern resident killer whales. ECHO program is voluntary, and the speed limitation is not adequate to prevent ship collision for humpback whales. So it is clear that more interventions and new ideas about how to reduce anthropogenic stressors should focus on how best to benefit humpback whales.

It might not be feasible to implemented year around restrictions on vessel speeds as this has operational and financial consequences for the shipping industry, but it may be considered an effective strategy throughout the summer non-breeding cycle. Since 1997 when the humpback whale first documented returning to the Salish Sea, there has been a yearly comeback. Despite some research that suggests vessel collision can have population impact on humpback whales (Rockwood et al. 2017; Redfern et al. 2020; Schoeman et al.2020; Laist et al. 2001) there might be an argument that ship strike might not impact population level consequences on humpback whales at present time (Neilson, et al.2012), but the optics of commercial vessels killing whales has a long memory with local conservationist, and I advocate for the precautionary principle to ensure the survival of SRKW in Boundary Pass and in non-protected regions farther afield.

There are several additional facts that should be considered in a restoration plan for this species in Boundary Pass. While the population of humpback whales are still recovering from the commercial whaling, their environment is changing too. For example, climate change that affects ocean circulation, sea surface temperature, and salinity not only can alter biophysical characteristics of whale habitat, but it can also have an impact on prey availability across the species range.

As the population of whales continues to grow, maritime industry is expected to also continue expanding and this is likely to result in more vessel collisions, a danger for both whale and humans. Also, the fact that humpback whales suffer as the second most numerous species of ship strike victims around the globe. This highlights another reason why the protection of whales from ship strike as an extreme threat to whale population recovery. Moreover, the impact of ship strike is not just mortality, the results of ship collisions can have long-term effects on survivors' behaviours. Stress and possible negative psychological effect of strike can cause behaviour alternation (Schoeman et al. 2021). It should be mentioned that vessel presence in the hotspot areas of whale habitat also has some indirect impacts caused by noise disturbances, and chemical pollutions that can result in compound sources of stress in this whale population potentially eliciting changes in feeding behaviour, alternation in communication and other behavioural consequences (Erbe et al. 2019; Pirotta et al. 2019).

Although the result of this study is limited to the duration and size of the study area, and even though humpback whales are among opportunistic feeders which can relocate in response to environmental circumstances and prey availability (Garcia-Morales et al. 2017), long-distance migrating humpback whales may face difficulties as ocean temperatures continue to rise and the anthropogenic stressors continue to put pressure on the oceans shared with whales. Pressure to adapt to this rising temperature might affect population dynamics as has happened before for other species (Ramp et al. 2015). Shift through the seasonal migration time to adopt with altering time of prey availability can cause overlap with other competing species and can result increase in competition between baleen species that chase the same prey resources (Ramp et al. 2015).

Throughout this study the first temporally and spatially dynamic maps of humpback whales in Boundary Pass have been created, Continuous monitoring of humpback whales in the area can create a systematic dataset to assist further assessment and restoration strategies in the area.

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Appendix 1.

Date	Start data collection	End data collection	Species	No. of individuals	Travel direction	Closest Est. distance (m)	Furthest Est. distance (m)	Survey Zone	Shipping lane	Activity	Vessel present	Large Vessel	Small vessel	Closest. distance to vessel
06-01-21	11:10	16:07	Humpback	1	N	2500 m	4000 m	BP-SoG	Yes	Traveling	Yes	1	8	100
06-02-21	09:15	10:45	Humpback	1	NE/N	1500 m	2500 m	BP-SoG	Yes	Traveling	Yes	0	2	100
06-03-21	09:40	10:52	Humpback	1	S	100 m	900 m	Near zone	No	Traveling	Yes	0	1	200 m
06-04-21	09:10	10:00	Humpback	1	NE	300 m	2000 m	BP	Yes	Traveling	No	0	0	
06-04-21	10:12	11:20	Humpback	1	NE	2500 m	4500 m	BP	Yes	Traveling	Yes	1	0	200 m
06-04-21	14:02	15:48	Humpback	1	SW	150 m	1500 m	Near zone	No	Traveling	Yes	0	3	200 m
06-05-21	14:37	14:46	Humpback	2	NE	600 m	1800 m	BP	No	Travel-Social	No	0	0	
06-07-21	13:17	14:15	Humpback	1	E	5500 m	6000 m	SoG	Yes	Travel-Social	Yes	0	3	less than 200 m
06-08-21	09:14	10:00	Humpback	2	NE	100 m	3000 m	BP	No	Traveling	Yes	0	3	200
06-08-21	11:02	11:31	Humpback	1	N	800 m	1000 m	BP	Yes	Travel-Social	Yes	1	0	500
06-10-21	10:51	11:59	Humpback	2	N	1500 m	2000 m	BP	Yes	Traveling	Yes	3	1	500 m
06-10-21	12:14	12:56	Humpback	2	various	6000 m	more than10000 m	SoG	No	Travel-Social	Yes	0	1	100 m
06-10-21	13:33	14:26	Humpback	2	various	2000 m	2500 m	BP	Yes	Travel-Social	No	0	0	-
06-10-21	14:52	15:20	Humpback	2	E	8000 m	90000 m	SoG	No	Travel-Social	Yes	1	1	100 m

06-11-21	12:05	13:35	Humpback	2	N	5000 m	5000 m	SoG	No	Travel-Social	Yes	0	3	200 m
06-12-21	08:45	09:27	Humpback	1	E	200 m	500 m	Near zone	NO	Traveling	No	0	0	N/A
06-14-21	12:23	13:27	Humpback	1	N	1000 m	1500 m	BP-SoG	Yes	Traveling	Yes	0	1	500 m
06-15-21	09:25	09:40	Humpback	1	NW	8000 m	9000 m	SoG	NO	Travel-Social	No	0	0	N/A
06-15-21	11:51	12:50	Humpback	1	SW	3000 m	6000 m	Far zone	Yes	Traveling	Yes	3	3	200 m
06-15-21	12:50	13:43	Humpback	1	E	100 m	1500	BP	NO	Traveling	Yes	1	1	300 m
06-16-21	14:38	15:15	Humpback	1	N	6000 m	8000 m	SoG	NO	Traveling	No	0	0	N/A
06-17-21	10:09	10:40	Humpback	1	NW	4000 m	4500 m	SoG	Yes	Travel-Social	Yes	0	2	500 m
06-17-21	14:49	17:17	Humpback	1	N	3500 m	6000 m	SoG	Yes	Traveling	Yes	1	0	200 m
06-18-21	09:08	09:40	Humpback	1	NE	5500 m	5500 m	SoG	NO	Traveling	No	0	0	N/A
06-30-21	12:43	13:32	Humpback	1	S	2500 m~3000 m	8000 m	BP	Yes	Traveling	Yes	0	9	100 m
07-08-21	09:56	11:20	Humpback	2	N-E	500 m	5000 m	BP-SoG	NO	Traveling	Yes	0	1	<100 m
07-08-21	10:40	11:20	Humpback	2	E	4000 m	5000 m	SoG	NO	Traveling	Yes	0	1	<200 m
07-10-21	19:24	20:35	Humpback	1	E-N	200 m	4000 m	BP	NO	Traveling	Yes	1	0	<1000 m
08-09-21	13:31	13:51	Humpback	1	N	400 m	400 m	BP	Yes	Traveling	No	0	0	N/A
08-29-21	20:37	21:50	Humpback	2	N	200 m	700 m	BP	No	Traveling	No	0	0	N/A

Appendix 2.

	Cetacean.ID	Date	event.number	Steps	No..of. individuals	Large.Vessel	Small.vessel	rownum	StartLat	StartLong	StartTime	EndLat	EndLong	EndTime
1	CET210001	6/1/2021	210601	25	1	1	8	1	48.80433	123.0027	11:07	48.80453	123.003	11:07
2	CET210001	6/1/2021	210601	25	1	1	8	1	48.80318	123.0021	11:11	48.80301	123.0019	11:12
3	CET210001	6/1/2021	210601	25	1	1	8	1	48.80179	123.0009	11:21	48.80154	123.0007	11:22
4	CET210001	6/1/2021	210601	25	1	1	8	1	48.79269	123.0004	11:27	48.79258	123.0004	11:29
5	CET210001	6/1/2021	210601	25	1	1	8	1	48.79323	122.9927	11:33	48.79333	122.9927	11:33
6	CET210001	6/1/2021	210601	25	1	1	8	1	48.80052	122.9924	11:38	48.80063	122.9923	11:40
7	CET210001	6/1/2021	210601	25	1	1	8	1	48.80035	122.9921	12:04	48.80028	122.9921	12:04
8	CET210001	6/1/2021	210601	25	1	1	8	1	48.80003	122.9922	12:11	48.80001	122.9922	12:12
9	CET210001	6/1/2021	210601	25	1	1	8	1	48.79304	122.9922	12:18	48.79302	122.9922	12:19
10	CET210001	6/1/2021	210601	25	1	1	8	1	48.79251	122.9923	12:27	48.79243	122.9923	12:27
11	CET210001	6/1/2021	210601	25	1	1	8	1	48.79219	122.9923	12:58	48.7921	122.9923	12:59
12	CET210001	6/1/2021	210601	25	1	1	8	1	48.7918	122.9927	13:05	48.79177	122.9927	13:05
13	CET210001	6/1/2021	210601	25	1	1	8	1	48.79209	122.9918	13:10	48.79216	122.9918	13:12
14	CET210001	6/1/2021	210601	25	1	1	8	1	48.79253	122.9915	13:24	48.79262	122.9915	13:25
15	CET210001	6/1/2021	210601	25	1	1	8	1	48.79314	122.9913	13:36	48.79328	122.9912	13:37
16	CET210001	6/1/2021	210601	25	1	1	8	1	48.79277	122.9914	13:42	48.79269	122.9914	13:42
17	CET210001	6/1/2021	210601	25	1	1	8	1	48.79332	122.9914	13:48	48.80006	122.9914	13:48
18	CET210001	6/1/2021	210601	25	1	1	8	1	48.80077	122.9907	14:09	48.80067	122.9908	14:09
19	CET210001	6/1/2021	210601	25	1	1	8	1	48.80194	122.9908	14:53	48.8022	122.9908	14:53
20	CET210001	6/1/2021	210601	25	1	1	8	1	48.80309	122.9897	15:01	48.80332	122.9896	15:02
21	CET210001	6/1/2021	210601	25	1	1	8	1	48.80222	122.99	15:07	NA	NA	15:07
22	CET210001	6/1/2021	210601	25	1	1	8	1	48.80165	122.9902	15:10	48.80072	122.9953	15:10
23	CET210001	6/1/2021	210601	25	1	1	8	1	48.80056	122.9905	15:14	48.80043	122.9905	15:04
24	CET210001	6/1/2021	210601	25	1	1	8	1	48.79333	122.9909	16:05	48.79331	122.9909	16:05
25	CET210001	6/1/2021	210601	25	1	1	8	1	48.80025	122.9905	16:07	NA	NA	16:07
26	CET210002	6/2/2021	210602	3	1	0	2	2	48.78983	123.0079	9:13	48.79002	123.0075	9:13

27	CET210002	6/2/2021	210602	3	1	0	2	2	48.80393	122.9905	9:19	48.80721	122.9933	9:19
28	CET210002	6/2/2021	210602	3	1	0	2	2	48.81773	123.0022	10:28	48.82094	123.0065	10:28
29	CET210004	6/3/2021	210603	10	1	0	1	3	48.77604	123.0386	9:41	48.77581	123.0372	9:42
30	CET210004	6/3/2021	210603	10	1	0	1	3	48.77566	123.036	9:45	48.77539	123.0346	9:46
31	CET210004	6/3/2021	210603	10	1	0	1	3	48.77522	123.034	9:49	48.77487	123.0348	9:50
32	CET210004	6/3/2021	210603	10	1	0	1	3	48.77453	123.0356	9:52	48.77415	123.0366	9:53
33	CET210004	6/3/2021	210603	10	1	0	1	3	48.77402	123.0377	9:57	48.77383	123.0394	10:01
34	CET210004	6/3/2021	210603	10	1	0	1	3	48.77445	123.0395	10:03	48.77506	123.0398	10:04
35	CET210004	6/3/2021	210603	10	1	0	1	3	48.77551	123.04	10:07	48.77623	123.0397	10:09
36	CET210004	6/3/2021	210603	10	1	0	1	3	48.77595	123.0402	10:13	48.77582	123.0406	10:13
37	CET210004	6/3/2021	210603	10	1	0	1	3	48.77562	123.0408	10:18	48.77546	123.0412	10:19
38	CET210004	6/3/2021	210603	10	1	0	1	3	48.77524	123.0416	10:24	48.77499	123.0423	10:25
39	CET210005	6/4/2021	210604	4	1	0	0	4	48.77522	123.0392	9:11	48.77563	123.0387	9:11
40	CET210005	6/4/2021	210604	4	1	0	0	4	48.77624	123.0375	9:15	48.78345	123.0369	9:15
41	CET210005	6/4/2021	210604	4	1	0	0	4	48.78487	123.0352	9:20	48.78571	123.0338	9:21
42	CET210005	6/4/2021	210604	4	1	0	0	4	48.7873	123.0261	9:22	48.79043	123.0238	9:24
43	CET210006	6/4/2021	210605	4	1	1	0	5	48.79285	123.025	10:12	48.80061	123.0244	10:13
44	CET210006	6/4/2021	210605	4	1	1	0	5	48.80537	123.0023	10:25	48.80523	122.9926	10:26
45	CET210006	6/4/2021	210605	4	1	1	0	5	48.80321	122.9873	10:31	48.80302	122.976	10:32
46	CET210006	6/4/2021	210605	4	1	1	0	5	48.79203	122.9758	10:51	48.79195	122.9726	10:51
47	CET210007	6/4/2021	210606	4	1	0	3	6	48.78366	123.0394	15:48	48.78392	123.0392	15:49
48	CET210007	6/4/2021	210606	4	1	0	3	6	48.78367	123.039	15:52	48.78353	123.0392	15:53
49	CET210007	6/4/2021	210606	4	1	0	3	6	48.77633	NA	15:58	48.77621	123.0404	15:58
50	CET210007	6/4/2021	210606	4	1	0	3	6	48.77597	123.0405	16:02	48.7759	123.0407	16:02
51	CET210008	6/5/2021	210607	2	2	0	0	7	48.77559	123.0391	14:37	48.77574	123.0388	14:37
52	CET210008	6/5/2021	210607	2	2	0	0	7	48.78356	123.0371	14:43	48.78669	123.0244	14:46
53	CET210009	6/7/2021	210608	7	1	0	3	8	48.82611	122.9923	13:17	48.82549	122.9913	13:23
54	CET210009	6/7/2021	210608	7	1	0	3	8	48.823	122.989	13:29	48.82207	122.9881	13:29
55	CET210009	6/7/2021	210608	7	1	0	3	8	48.81949	122.9866	13:33	48.81886	122.986	13:33
56	CET210009	6/7/2021	210608	7	1	0	3	8	48.81706	122.9841	13:41	48.80961	122.9766	13:41

57	CET210009	6/7/2021	210608	7	1	0	3	8	48.80712	122.9755	13:46	48.80649	122.9743	13:46
58	CET210009	6/7/2021	210608	7	1	0	3	8	48.80416	122.9727	13:49	48.80323	122.9724	13:49
59	CET210009	6/7/2021	210608	7	1	0	3	8	48.80042	122.9697	13:53	48.79282	122.969	13:54
60	CET210010	6/8/2021	210609	5	2	0	3	9	48.77624	123.0401	9:14	48.77645	123.0399	9:16
61	CET210010	6/8/2021	210609	5	2	0	3	9	48.78386	123.0393	9:20	48.78396	123.0392	9:20
62	CET210010	6/8/2021	210609	5	2	0	3	9	48.78584	123.0376	9:24	48.78611	123.0373	9:24
63	CET210010	6/8/2021	210609	5	2	0	3	9	48.78729	123.0366	9:35	48.78754	123.0364	9:37
64	CET210010	6/8/2021	210609	5	2	0	3	9	48.80161	123.023	9:43	48.80269	123.0217	9:43
65	CET210011	6/8/2021	210610	2	1	1	0	10	48.77566	123.0255	11:02	48.77577	123.0338	11:02
66	CET210011	6/8/2021	210610	2	1	1	0	10	48.78343	123.038	11:08	48.78369	123.0379	11:09
67	CET210013	6/10/2021	210611	4	2	3	1	11	48.79084	123.0366	10:52	48.79035	123.0347	10:53
68	CET210013	6/10/2021	210611	4	2	3	1	11	48.78932	123.0255	11:01	48.79024	123.025	11:02
69	CET210013	6/10/2021	210611	4	2	3	1	11	48.79267	123.0253	11:09	48.80064	123.0256	11:10
70	CET210013	6/10/2021	210611	4	2	3	1	11	48.80351	123.0226	11:31	48.80355	123.0206	11:32
71	CET210014	6/10/2021	210612	2	2	0	1	12	48.80019	122.9845	12:12	48.80305	122.984	12:15
72	CET210014	6/10/2021	210612	2	2	0	1	12	48.79239	122.9724	12:18	48.78965	122.9717	12:20
73	CET210015	6/10/2021	210613	3	2	0	0	13	48.80219	123.0074	13:33	48.80642	123.0167	13:37
74	CET210015	6/10/2021	210613	3	2	0	0	13	48.80791	123.0216	13:46	48.80869	123.0178	13:50
75	CET210015	6/10/2021	210613	3	2	0	0	13	48.81674	123.0069	13:55	48.8188	123.0184	14:05
76	CET210016	6/10/2021	210614	2	2	1	1	14	48.85204	122.8728	14:51	48.85101	122.87	14:53
77	CET210016	6/10/2021	210614	2	2	1	1	14	48.84116	122.8587	14:56	48.84021	122.8564	14:57
78	CET210018	6/11/2021	210615	3	2	0	3	15	48.78697	123.0007	12:06	48.78751	123.0004	12:08
79	CET210018	6/11/2021	210615	3	2	0	3	15	48.79098	122.9928	12:11	48.79185	122.9924	12:12
80	CET210018	6/11/2021	210615	3	2	0	3	15	NA	NA	12:36	NA	NA	12:36
81	CET210019	6/12/2021	210616	1	1	0	0	16	48.78415	123.0588	8:47	48.78409	123.058	8:47
82	CET210019	6/12/2021	210616	1	1	0	0	16	48.78537	123.0421	8:50	48.78553	123.041	8:50
83	CET210021	6/14/2021	210617	11	1	0	1	17	48.77041	122.974	12:23	48.77163	122.9736	12:23
84	CET210021	6/14/2021	210617	11	1	0	1	17	48.77414	122.9733	12:29	48.77563	122.973	12:29
85	CET210021	6/14/2021	210617	11	1	0	1	17	48.78366	122.9742	12:34	48.78598	122.984	12:36
86	CET210021	6/14/2021	210617	11	1	0	1	17	48.7872	122.9906	12:40	48.78798	122.9921	12:40

87	CET210021	6/14/2021	210617	11	1	0	1	17	48.7892	123.0072	12:45	48.7905	123.0088	12:46
88	CET210021	6/14/2021	210617	11	1	0	1	17	48.79163	123.0178	12:49	48.792	123.0189	12:49
89	CET210021	6/14/2021	210617	11	1	0	1	17	48.80052	123.0201	12:54	48.80133	123.0211	12:55
90	CET210021	6/14/2021	210617	11	1	0	1	17	48.80287	123.023	12:58	48.80334	123.0237	12:58
91	CET210021	6/14/2021	210617	11	1	0	1	17	48.80513	123.0242	13:03	48.80559	123.0258	13:03
92	CET210021	6/14/2021	210617	11	1	0	1	17	48.80628	123.0346	13:05	48.80692	123.0355	13:05
93	CET210021	6/14/2021	210617	11	1	0	1	17	48.80819	123.0376	13:09	48.80883	123.0387	13:09
94	CET210022	6/15/2021	210618	2	1	0	0	18	48.80041	122.9735	9:25	48.80123	122.9749	9:26
95	CET210022	6/15/2021	210618	2	1	0	0	18	48.80297	122.9859	9:36	48.80366	122.9867	9:37
96	CET210023	6/15/2021	210619	7	1	3	3	19	48.78361	122.9925	11:51	48.77638	123.0002	11:51
97	CET210023	6/15/2021	210619	7	1	3	3	19	48.7755	123.0015	11:56	48.77483	123.0024	11:58
98	CET210023	6/15/2021	210619	7	1	3	3	19	48.77429	123.0035	12:01	48.77418	123.0036	12:01
99	CET210023	6/15/2021	210619	7	1	3	3	19	48.77088	123.0058	12:16	48.77037	123.0064	12:17
100	CET210023	6/15/2021	210619	7	1	3	3	19	48.76734	123.0168	12:25	48.7599	123.018	12:27
101	CET210023	6/15/2021	210619	7	1	3	3	19	48.75771	123.0201	12:35	48.7575	123.0203	12:35
102	CET210023	6/15/2021	210619	7	1	3	3	19	48.75308	123.0255	12:46	48.75212	123.0337	12:49
103	CET210024	6/15/2021	210620	6	1	1	1	20	48.78434	123.0094	13:07	48.78432	123.0167	13:07
104	CET210024	6/15/2021	210620	6	1	1	1	20	48.77611	123.0403	13:13	48.77616	123.0402	13:14
105	CET210024	6/15/2021	210620	6	1	1	1	20	48.7836	123.0398	13:15	48.78369	123.0398	13:15
106	CET210024	6/15/2021	210620	6	1	1	1	20	48.78473	123.0385	13:19	48.78484	123.0385	13:19
107	CET210024	6/15/2021	210620	6	1	1	1	20	48.78749	123.0382	13:21	48.78756	123.0384	13:21
108	CET210024	6/15/2021	210620	6	1	1	1	20	48.78981	123.0412	13:23	48.78993	123.0413	13:23
109	CET210025	6/16/2021	210621	3	1	0	0	21	48.80521	122.9873	14:38	48.80643	122.9885	14:38
110	CET210025	6/16/2021	210621	3	1	0	0	21	48.80676	122.9889	14:42	48.80704	122.9891	14:42
111	CET210025	6/16/2021	210621	3	1	0	0	21	48.80838	122.9905	14:47	48.80879	122.9909	14:49
112	CET210026	6/17/2021	210622	2	1	0	2	22	48.8197	122.9903	10:09	48.8198	122.9905	10:09
113	CET210026	6/17/2021	210622	2	1	0	2	22	48.82066	122.9919	10:10	48.82076	122.9921	10:12
114	CET210027	6/17/2021	210623	18	1	1	0	23	48.80002	123.0194	14:55	48.80019	123.0195	14:56
115	CET210027	6/17/2021	210623	18	1	1	0	23	48.80137	123.0183	15:11	48.80154	123.0182	15:12
116	CET210027	6/17/2021	210623	18	1	1	0	23	48.80343	123.0168	15:18	48.80348	123.0172	15:19

117	CET210027	6/17/2021	210623	18	1	1	0	23	48.80467	123.0212	15:22	48.80474	123.0214	15:23
118	CET210027	6/17/2021	210623	18	1	1	0	23	48.80494	123.0199	15:25	48.805	123.0198	15:26
119	CET210027	6/17/2021	210623	18	1	1	0	23	48.80538	123.0207	15:36	48.80541	123.0208	15:37
120	CET210027	6/17/2021	210623	18	1	1	0	23	48.80549	123.0213	15:52	48.80551	123.0214	15:53
121	CET210027	6/17/2021	210623	18	1	1	0	23	48.8056	123.0219	16:01	48.80562	123.022	16:03
122	CET210027	6/17/2021	210623	18	1	1	0	23	48.80583	123.0215	16:07	48.80584	123.0213	16:08
123	CET210027	6/17/2021	210623	18	1	1	0	23	48.80594	123.021	16:11	48.80596	123.0208	16:12
124	CET210027	6/17/2021	210623	18	1	1	0	23	48.80573	123.0206	16:15	48.80567	123.0206	16:16
125	CET210027	6/17/2021	210623	18	1	1	0	23	48.80568	123.0209	16:19	48.80563	123.021	16:20
126	CET210027	6/17/2021	210623	18	1	1	0	23	48.80586	123.0204	16:24	48.80593	123.0203	16:25
127	CET210027	6/17/2021	210623	18	1	1	0	23	48.80606	123.0206	16:25	48.80607	123.0207	16:28
128	CET210027	6/17/2021	210623	18	1	1	0	23	48.80606	123.0211	16:32	48.80606	123.0212	16:33
129	CET210027	6/17/2021	210623	18	1	1	0	23	48.80603	123.0214	16:38	48.80602	123.0214	16:40
130	CET210027	6/17/2021	210623	18	1	1	0	23	48.80548	123.0216	16:49	48.80548	123.0216	16:50
131	CET210027	6/17/2021	210623	18	1	1	0	23	48.80548	123.0221	17:00	48.80548	123.0221	17:01
241	CET210028	6/18/2021	210624	1	1	0	0	24	48.83558	122.9733	9:08	48.83616	122.9745	9:09
132	CET210030	6/30/2021	210625	5	1	0	9	25	48.77534	122.9742	12:43	48.77531	122.9741	12:43
210	CET210030	6/30/2021	210625	5	1	0	9	25	48.77457	122.9738	12:51	48.77446	122.9738	12:52
310	CET210030	6/30/2021	210625	5	1	0	9	25	48.77339	122.9733	12:58	48.77335	122.9733	12:58
410	CET210030	6/30/2021	210625	5	1	0	9	25	48.77291	122.9732	13:00	NA	NA	13:00
510	CET210030	6/30/2021	210625	5	1	0	9	25	48.77255	122.9731	13:04	48.77239	122.9731	13:05
133	CET210034	7/8/2021	210726	5	2	0	1	26	48.77584	123.0405	9:56	48.77592	123.0404	9:57
211	CET210034	7/8/2021	210726	5	2	0	1	26	48.7764	123.0401	10:15	48.77647	123.04	10:15
311	CET210034	7/8/2021	210726	5	2	0	1	26	48.78345	123.0396	10:17	48.78351	123.0396	10:18
411	CET210034	7/8/2021	210726	5	2	0	1	26	48.78375	123.0394	10:19	48.78381	123.0394	10:20
511	CET210034	7/8/2021	210726	5	2	0	1	26	48.78459	123.0377	10:22	48.78479	123.0375	10:23
610	CET210034	7/8/2021	210726	5	2	0	1	26	48.79287	123.0089	10:41	NA	NA	10:41
134	CET210035	7/8/2021	210727	5	2	0	1	27	48.801	123.01	10:40	48.80131	123.0172	10:41
212	CET210035	7/8/2021	210727	5	2	0	1	27	48.80283	123.0184	10:42	NA	NA	10:42
312	CET210035	7/8/2021	210727	5	2	0	1	27	48.80121	123.0059	10:44	48.80079	123.0056	10:46

412	CET210035	7/8/2021	210727	5	2	0	1	27	48.79222	123.0043	10:51	48.79212	123.0036	10:53
512	CET210035	7/8/2021	210727	5	2	0	1	27	NA	NA	10:57	NA	NA	10:57
135	CET210037	7/10/2021	210728	7	1	1	0	28	48.78625	123.0676	19:24	48.78618	123.0583	19:25
213	CET210037	7/10/2021	210728	7	1	1	0	28	48.78666	123.0431	19:36	48.78668	123.0422	19:36
313	CET210037	7/10/2021	210728	7	1	1	0	28	48.79311	123.0404	19:59	48.80016	123.0406	20:01
413	CET210037	7/10/2021	210728	7	1	1	0	28	48.80188	123.0399	20:04	48.80215	123.0401	20:04
513	CET210037	7/10/2021	210728	7	1	1	0	28	48.80321	123.0394	20:06	48.80332	123.0396	20:06
611	CET210037	7/10/2021	210728	7	1	1	0	28	48.80559	123.0413	20:11	48.80562	123.0416	20:11
710	CET210037	7/10/2021	210728	7	1	1	0	28	48.80714	123.0425	20:15	NA	NA	20:15
291	CET210045	8/9/2021	210829	1	1	0	0	29	48.7757	123.04	13:13	48.77591	123.0398	13:13
136	CET210053	8/29/2021	210830	5	2	0	0	30	48.77611	123.04	20:37	48.77617	123.0399	20:37
214	CET210053	8/29/2021	210830	5	2	0	0	30	48.77653	123.0398	20:40	48.7766	123.0397	20:40
314	CET210053	8/29/2021	210830	5	2	0	0	30	48.78348	123.0396	20:42	48.78353	123.0396	20:42
414	CET210053	8/29/2021	210830	5	2	0	0	30	48.78384	123.0394	20:46	48.78388	123.0394	20:46
514	CET210053	8/29/2021	210830	5	2	0	0	30	48.78422	123.0393	20:50	48.78426	123.0393	20:50