SOUTHERN RESIDENT KILLER WHALE (*ORCINUS ORCA)* BEHAVIORAL RESPONSE TO VESSEL TRENDS IN TRANS-BOUNDARY CRITICAL HABIT

A Senior Thesis Presented to

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by

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Abstract:

Since 1998, the number of active commercial and recreational whale watching activities on-scene with the Southern Resident killer whales (*Orcinus orca*) (SRKWs) has increased exponentially, leaving many to wonder how such an influx of traffic and incidents can further harm the already dangerously endangered population and the Salish Sea habitat. This study focused on the observed behaviors exhibited by the Southern Residents in response to reported incident types, the correlation between the two, and the relationship between vessel traffic and incident cases. Data was collected through continuous monitoring while I was a data intern for the Soundwatch Boater Education Program from June-October, 2020. Soundwatch monitored for seven incident types and recorded observed behavioral responses by the SRKWs that would later be categorized for further specificity. All incidents and SRKW responses were recorded using ODK Collect and later uploaded to ODK Aggregate. With support from past data, we concluded that the Southern Residents respond to harmful vessel trends in close-proximity with short-term behavioral changes. The most alarming consequence of these changes is the reduced time spent foraging and the resulting potential reduction in prey consumption. Although it is unknown if these short-term behavioral changes affect the population dynamics, it is likely that because Southern Residents are exposed to vessels most of the daylight hours they are in inland waters, there may be biologically relevant effects at the population level that will become more obvious as time goes on.

Furthermore, because we are seeing a steady increase in vessel traffic and with it, vessel incidents, it is recommended that this and other supporting data be taken into consideration when drafting new laws and regulations for boaters around the Southern Residents and in the Salish Sea to preserve and nurture their critically endangered populations and this unique, vital habitat. All data was submitted to the Washington Department of Fish and Wildlife (WDFW) and will be used to draft legislation requesting that SRKW critical habitat and feeding grounds be protected under the United States Fish and Wildlife Service and the United States National Oceanic and Atmospheric Administration (NOAA). Data was also included in the 2020 Soundwatch Program Annual Contract Report.

Keywords: *Orcinas orca,* SRKW (Southern Resident Killer Whales), foraging, short-term behavioral changes, vessel trends, chinook salmon (*Oncorhynchus tshawytscha),* boating incidents

Introduction

The Southern Resident Killer Whales (*Orcinus orca)* (SRKW) are an endangered killer-whale ecotype that inhabit the Pacific Northwest Coastline with a range from Monterey to southeastern Alaska (NMFS 2008, Hanson *et al.,* 2013). During the summer months of June through October, the SRKWs are primarily found in the Salish Sea near Washington's San Juan Islands and Victoria, British Columbia (Hauser *et al.,* 2007). The Salish Sea is considered a critical habitat for the SRKWs due to the abundance of Chinook Salmon *(Oncorhynchus tshawytscha),* their primary food source (Ford and Ellis 2006; Hanson et al., 2010; Ford et al., 2016).

The SRKW populations have been closely monitored for several decades. Their population peaked at *97* whales in the 1990s and then declined to 79 whales in 2001 (Center for Whale research). In 2005, the National Marine Fisheries Service (NMFS) listed the SRKWs ecotype as endangered under the Endangered Species Act (ESA). Three primary threats to their survival were identified as (1) prey availability, (2) high level of contaminants in the Salish Sea, and (3) disturbance from vessels and anthropogenic sound (Ferrara *et al.,* 2017). As of December 2020, there were *74* SRKWs (Center for Whale Research). Since their listing, a number of studies have been conducted in order to understand more about the threats facing the SRKWs and their habitat.

It is hypothesized that vessel traffic may have contributed to the population decline, through a variety of different mechanisms, past studies show. Collisions between vessels and killer whales occur occasionally and result in injury or death (Ford et al. 2000, G. M. Ellis pers. comm.).

Unburned fuel and exhaust from vessels may contribute to toxin load, anthropogenic noise from vessels may contribute to stress (Romano et al. 2004) and mask echolocation signals, (Bain & Dahlheim 1994, Erbe 2002), making it harder to forage. Behavioral changes in response to vessels may result in increased energy expenditure, or disrupt feeding activity, which may reduce energy acquisition (Bain 2002, Williams et al. 2006). Energetic mechanisms for impact are of particular concern, since southern resident killer whales may be food limited. These past studies have identified key ways the populations have been impacted through anthropogenic facts by vessels, but there is still a gap of understanding regarding the behavorial adjustments that are being made by the SRKWs themselves to accommodate for these disturbances.

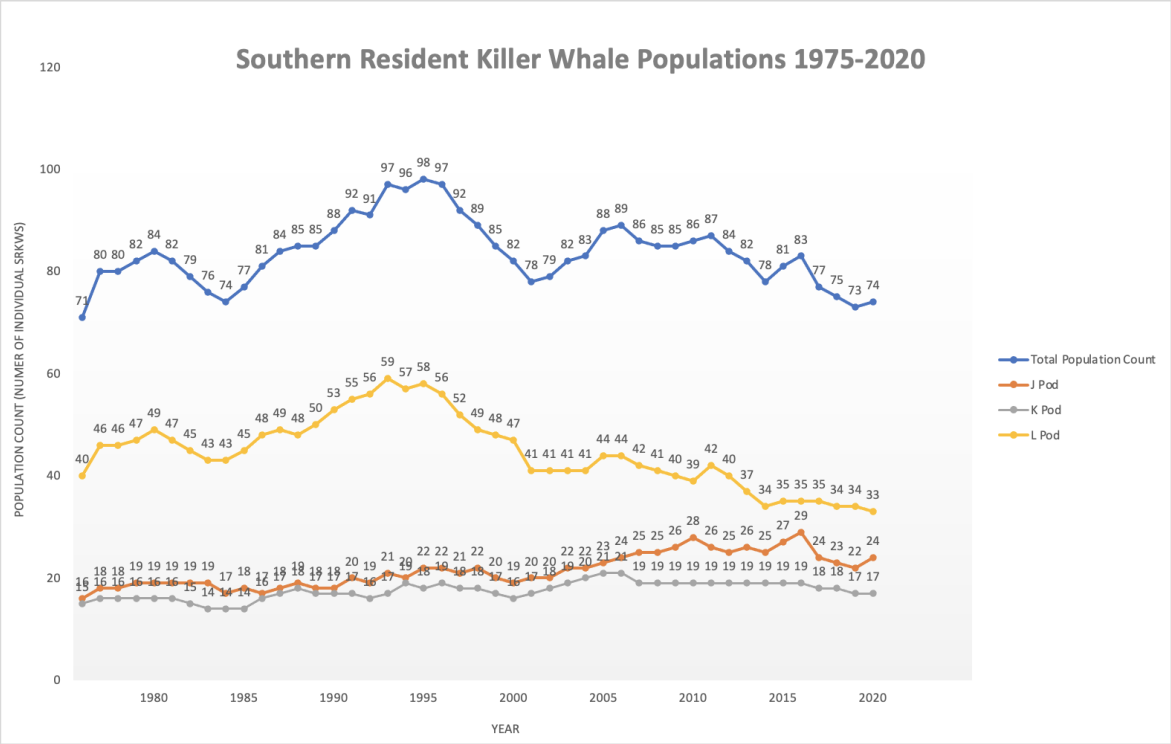

Figure 1: Population size and trend of SRKWs, 1975 to 2020. Data was obtained through photo-identification surveys of three SRKW pods (J, K, and L). Data was provided by the Center for whale research and NMFS .

Since 1998, the number of active commercial and recreational whale-watching vessels on-scene

with the SRKWs has increased exponentially, leading to the question how such an influx of vessel traffic can further harm the already low SRKW population and the Salish Sea habitat. The Soundwatch Boater Education Program was established in 1993 through the Whale Museum, located in Friday Harbor, WA, with the mission to reduce vessel disturbance to whales and to educate boaters on the water about new and existing state and federal regulations while also collecting data on vessel trends and traffic in critical SRKW habitats (Seely *et al.,* 2017). Since its establishment, Soundwatch has used this annual long-term data to evaluate the effectiveness of current regulations and to recommend amendments to existing regulations and new regulations (Seely *et al.,* 2017). The data has also been used to promote conservation efforts and presented in legislation requesting the protection of SRKW critical habitat (Soundwatch, 2020). In 2005, a voluntary no-go zone for motor boats was designated along the western shoreline of San Juan Island (figure 2). These voluntary no motor boat zones were developed by a coalition that included the Whale Watch Operators Association Northwest, the Whale Museum's Soundwatch Boater Education Program, the Canadian Marine Mammal Monitoring Program, the Canadian Department of Fisheries and Oceans and the U.S. National Marine Fisheries Service .

Figure 2: Outline of voluntary no-go zone extending from Mitchell Point until Eagle Point from the shore out to ¼ mile (440 yards). In addition, there is a 2-mile area around Lime Kiln Lighthouse that extends ½ mile (880 yards) from the shore (Soundwatch, The Whale Museum, 2005).

In 2006, critical habitats were identified and established in the Summer Core Area in Haro Strait, the surrounding waters of San Juan Island, Puget Sound, and the strait of Juan de Fuca (71 FR 69054, November 29, 2006). These efforts have been in response to an increase in boating traffic and consequently an increase in boating incidents on-scene with the SRKWs. To try and prevent

these incidents, a project called *Be Whale Wise* was created through the Whale Museum which aims to educate boaters on the guidelines when on-scene with the SRKWs (figure 3).

there is still a lack of understanding surrounding the specific behavioral responses exhibited by the SRKWs to vessel incidents. There are a number of This study's purpose is to intensely analyze short-term behavioral response by SRKWs, to test the correlation between the number of incident cases and observed behavioral responses, and to determine whether or not there is a relationship between the average, maximum, and total number of vessels on-scene with the SRKWs and the resulting number of incidents per year.

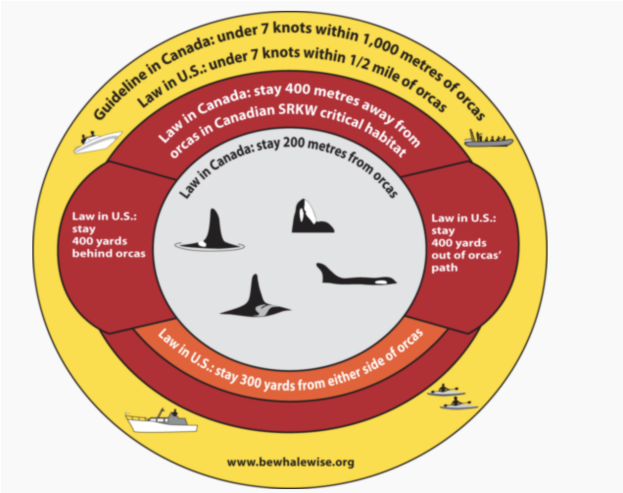

Figure 3: Be Whale Wise Guidlines: 100 metres/yards no approach zone for all other marine mammals in US and Canada; and keeping 200 metres away from whales, dolphins, or porpoises if they are resting or with their calf. Reprinted from *Be Whale Wise* website.

Materials and Methods

The data for this study was collected during the summer whale-watching season lasting from June – October 2020. Soundwatch operated vessel patrols to educate and monitor boaters and collect whale behavior data under National Marine Fisheries Service (NMFS) research issued permit number 21114. 35-40 hours per week were spent on the water with the SRKWs and other cetacean species mainly including humpback whales *(Megaptera novaeangliae)*, minke whales *(Balaenoptera acutorostrata)*, and gray whales *(Eschrichtius robustus)*. This study only contains data collected from the days spent with the SRKWs.

The on-the-water crew operated with a minimum of two and a maximum of four crew members. Soundwatch totaled *146* days of effort, with *118* days on-the-water between June 1 and October 8, 2020, totaling *669* hours of effort on the water traveling *4,658* nautical miles throughout the trans-boundary Salish Sea. Out of the *146* days of effort, *24* total days were spent directly monitoring Southern Residents.

Equipment utilized in 2020 consisted of a *17'* American Eagle rigid hulled vessel, *R/V Raydiance* and a *19'* Safe Boat rigid hulled vessel, *R/V L-98*, operated as a secondary vessel. Funding for this secondary vessel was provided by the National Fish and Wildlife Foundation's Killer Whale Conservation and Research Grant. Both vessels were fully equipped with safety equipment, VHF radios, and chart plotters. The radar unit on *R/V L-98* was utilized for accurate distance calculations of vessels and navigation on poor weather condition days. *R/V Raydiance* was not equipped with a radar, but did have a Raymarine GPS unit.

We located SRKWs with the help of reports by whale-watching vessels, acoustical detection by hydrophones monitored by Jeanne Hyde at Lime Kiln Lighthouse and also through sightings from land, reported mainly by civilians.

All data was collected using a program called ODK collect, an open-source Android app that replaces paper forms used in survey-based data gathering. All data was then uploaded to ODK Aggregate, an open-source Java application that stores, analyzes, and presents Xform survey data

using ODK collect. From here, data was downloaded and imported into Microsoft Excel where the incidents (table 1) and behavioral responses (table 2) were categorized.

Vessel Counts and Types

All vessels within one half-mile of all known whale activity were counted every half-hour using a digital (ODK) Soundwatch Vessel Count/Whale Survey data sheet (Appendix A). Soundwatch staff and volunteer crews recorded vessel data using a set of standardized vessel type and vessel activity definitions agreed upon by U.S. and Canadian cetacean researchers (2004 NOAA SRKW workshop) (Appendix B). Counts were taken by confidence level. An 'A count' was highest confidence and included the Soundwatch vessel in the count and a 'B count' was still reliable enough to count, but with less confidence and did not include the Soundwatch vessel in the count.

Each observed vessel within the count range is categorized according to a vessel type and a specific best-fit vessel activity to describe what the vessel was engaged in (Appendix A). Vessel activity categories include transiting (moving through the area within one half mile); whale oriented (moving or stationary whale watching); fishing (moving or stationary with poles or nets in the water); research (engaged in any type of research, including cetology); enforcement (enforcement vessel in pursuit or engaged with a vessel at the time of the count); acoustic (outside of the count range one half mile, but in acoustic/visual range); or other (which must be described, such as a rescued vessel in tow, etc.).

The area of known whale activity is variable and not limited to a half-mile, but rather represents the core of individual whales or groups of whales in the immediate area that can range up to one mile.

Often the whales are spread greater than one mile. When visibility and conditions were good, a secondary count was made for a group of vessels and whales beyond one mile from the Soundwatch vessel, provided crew could reliably record beyond the primary count.

In total, U.S. EcoTour vessels were observed *72* days and in *475* vessel counts, Recreational (private motor, private sail) *67* days and *494* counts, Canadian EcoTour *29* days and *79* counts, Research *30* and *117* counts, Monitoring/Enforcement (including Soundwatch presence) *71* days and *467* counts, Commercial Fishing *54* days and *136* counts, and kayaks (ecotour and recreational) *17* days and *28* counts.

Monitoring for and Recording Incidents

Vessel incidents, observations of vessels operating contrary to current voluntary guidelines and regulations, are recorded using standard definitions. Descriptions of guidelines and regulations, along with the incident codes used to record incidents of regulation and guideline violations can be found in Appendix C. Incidents were recorded opportunistically as they are observed using a Vessel Incident datasheet (Appendix D). We were conservative in recording incidents.

We focused on monitoring for *7* specific incidental categories (table 1) based on past Soundwatch data that identified the most common incidents reported in past years (Soundwatch Annual Report, 1993-2019). An incident is defined as an act by a boater or vessel that goes against *Be Whale Wise* (figure 3) guidelines and regulations.

A Going over 7 knots within half a mile of SRKWs

B Within 400 yards and in the path of SRKWs*

C	Within 300 yards of SRK
D	Vessel in the San Juan Island NO-GO zone
E	Within 200 yards of SRKWs while under motor power*
F	Within 100 yards of SRKWs while under motor power*
G	Fishing within 200 yards of SRKWs

Table 1: Most commonly observed incidents reported by Soundwatch over the past 26 years of operation. Incidents with an asterix* are listed as federal and state regulations punishable by fine and citation through WDFW (Soundwatch Annual Report, 1993-2019).

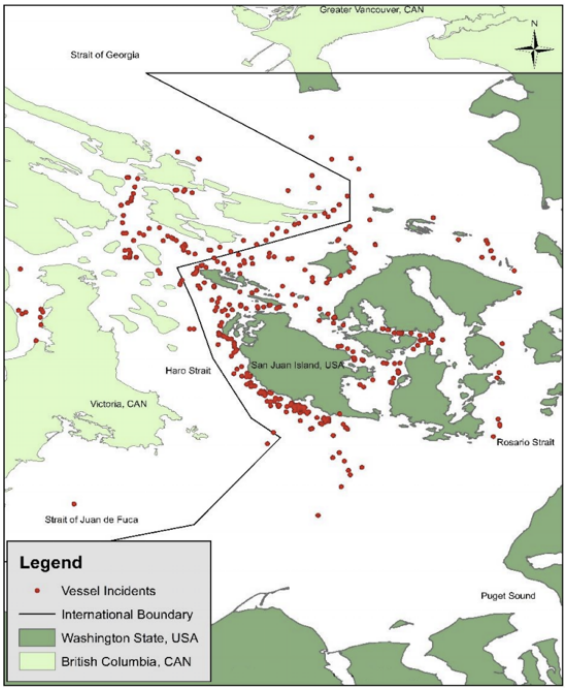

Figure 4: Total vessel incident locations involving SRKWs observed by Soundwatch from June – October 2020. Points can be multiple violations, *N=184*.

When an incident occured, the boat name, registration, and port were recorded and photos were taken of the incident in action. During the 2020 field season, Soundwatch recorded a total of *749* incidents, *184* of which were on-scene with the SRKWs. The locations of these observed incidents in the vicinity of the SRKWs were recorded and plotted (figure 4) to better understand the areas where the most incidents were occurring and investigating why.

Monitoring for Short-Term Behavioral Responses Exhibited by SRKWs to Observed Incidents

Upon arrival to the scene with the SRKWs, similar to vessel counts, an initial whale behavior survey was conducted and then taken in 30-minute increments on the hour and every half-hour using a set of whale attributes agreed upon by U.S. and Canadian cetacean researchers (2004 NOAA SRKW workshop) (Appendix E & F). For this study, my primary focus was on the exhibited responses by the SRKWs when provoked by the recorded boating incidents. Constant monitoring when an incident was observed was required. The whales

were immediately localized and watched for the duration of the incident and an additional five minutes afterwards. Pictures were also taken for later inspection. During this observation period, key behavioral changes were identified and written down in the notes of the incident ODK collect form where it would later be accessed, sorted (table 2), and analyzed.

The most commonly observed changes were used to specify 4 different behavioral categories (table 2) exhibited in response to a recorded incident. The noted key behavioral changes exhibited by a SRKW during an incident were used to sort that case into one of the below categories (table 2) (Williams et al., 2002a, Bain et al., 2006; Williams et al., 2009). A change in behavior is defined as a clear disruption of the natural actions of the SRKWs. All behavioral changes listed are short-term.

A	Changes in foraging behavior (hunting and feeding strategies, and foraging pod structure)
B	Changes in travel behavior (speed and direction)
C	Changes in dive behavior (dive time and dive angles)
D	Changes in social behavior (above-water acoustics, breaching, and spy-hops)

Table 2: The 4 most commonly observed behavioral changes during the 2020 summer whale-watching season.

Due to certain conditions such as inclement weather, lack of visibility, view obstruction, or otherwise, behavioral responses were recorded whenever possible, so there ended up being an abundance of unknown and unusable data.

Statistical Analysis

We tested for the correlation between the number of recorded incidents and the resulting number of SRKW behavioral change cases observed. We also utilized data from past *Soundwatch Annual*

Report Updates (2013-2019) on the total yearly vessel incidents, maximum number of vessels, and average number of vessels on-scene with the SRKWs that year to see if there was any correlation between vessel traffic and the resulting number of incidents. The year 2020 was not included in this correlation due to it being an abnormal traffic season because of the COVID-19 Pandemic.

Results

Vessel Counts and Trends

We calculated that the 2020 annual maximum number of total vessels counted with whales within a half-mile was *39* (figure 6), which is a slight increase from 2019's maximum of *29* total vessels. The daily average of boats with whales was *11* (figure 7 & 8), ending a consistent downward trend since the peak of a daily average of *18* in 2014. We also found that the most common vessel types to be accompanying the SRKWs were commercial, recreational, and kayaks (figure 8). The most common among those three were both commercial and recreational vessels, with an average of *3* vessels each time accompanying the SRKWs (figure 8).

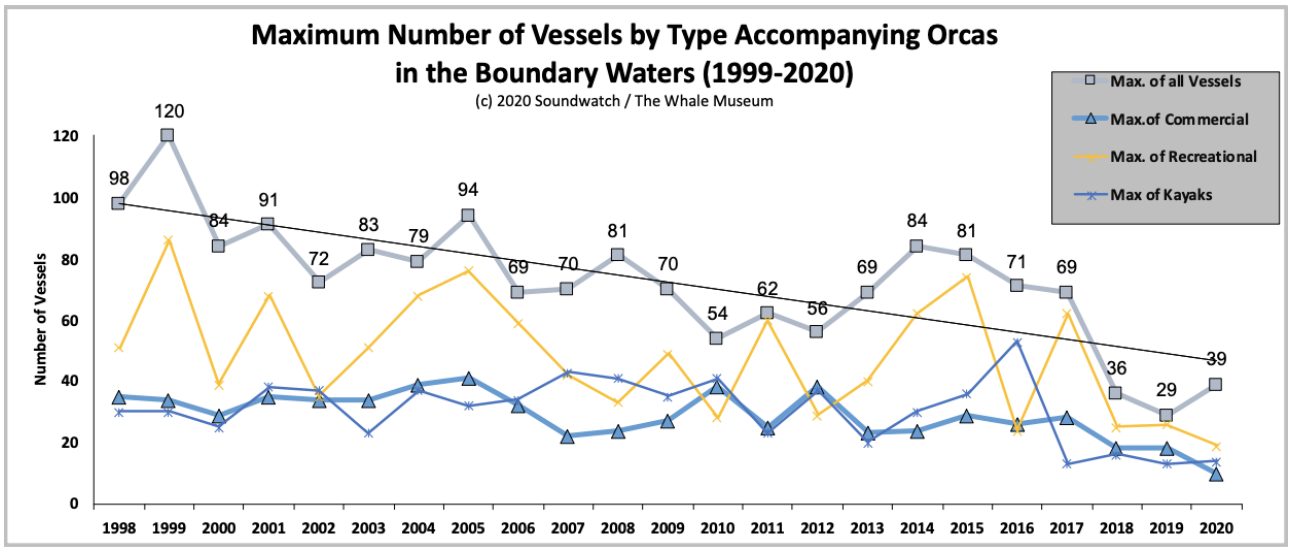

Figure 6: Maximum number of vessels within one half-mile of killer whales in the Salish Sea by vessel category from 1998-2020.

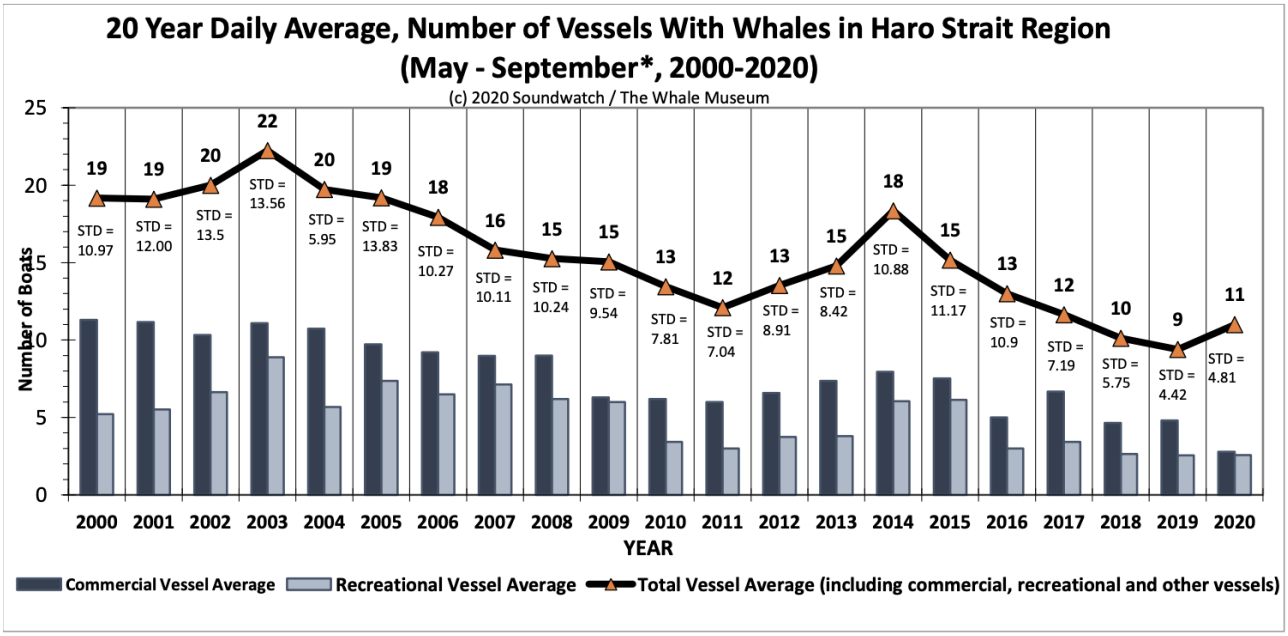

Figure 7: Average number (of recreational, EcoTour (commercial)) and total of all vessels with killer whales in the last twenty years in Haro Strait Region (May-September 1998-2016, 2018-2019 and *June-September 2017 and June-October 2020) (Soundwatch, 2020)

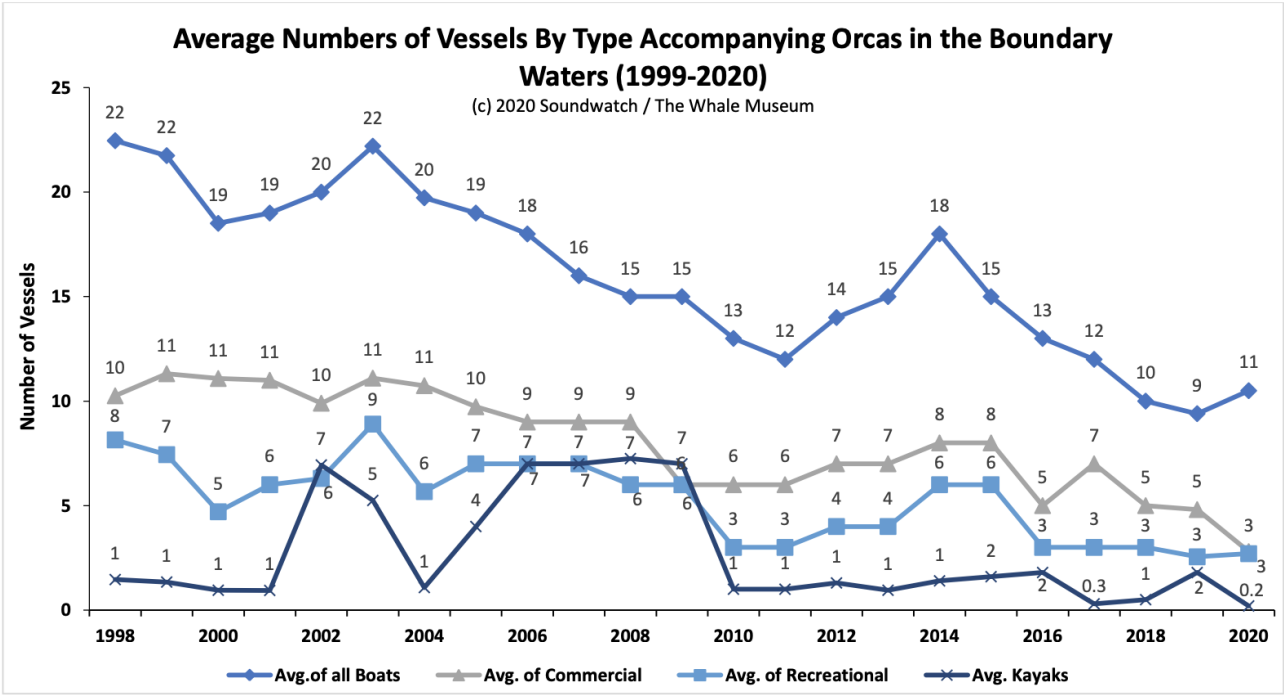

Figure 8: Average number of vessels by vessel category within one half-mile of killer whales from 1998- 2020 in the Salish Sea

Incidents

The most common incident recorded during the summer 2020 season was over 7 knots within a half-mile at *30%* of all occurences, followed by 400 yards in-the-path at *12%,* within 300 yards at *10%*, within 200 yards at *9%*, SJI no-go zone at *7%*, within 100 yards under power at *5%*, and fishing within 200 yards at *4%* (figure 9.1). *72%* of all recorded boating incidents from the summer of 2020 were committed by private motors, followed by ecotours at *10%*, kayaks at *9%,* private sails at *6%,* and commercial fishing at *2%* (figure 9.2)

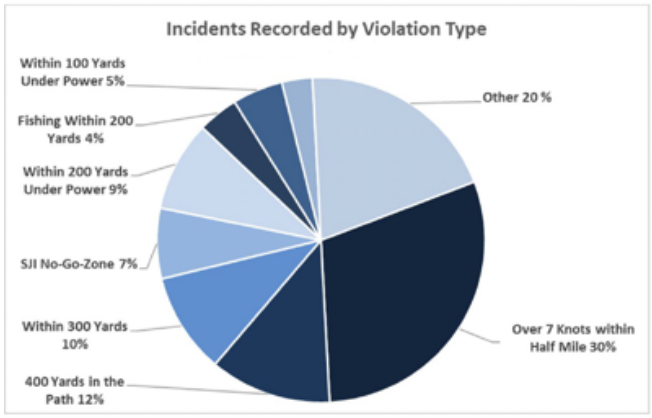

Figure 9.1: Total percentage of incidents recorded and categorized by violation type

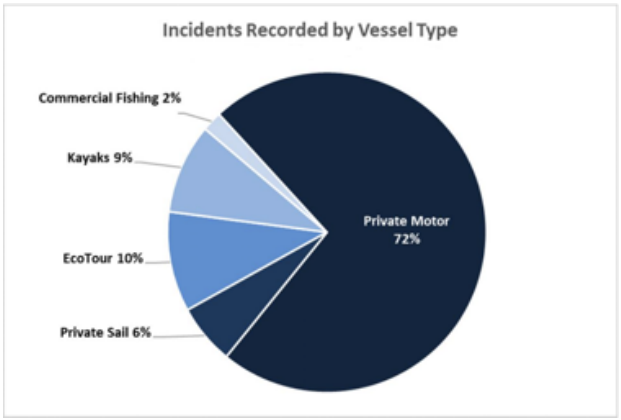

Figure 9.2: Total percentage of incidents recorded and categorized by type of vessel

The most incidents out of the total observed occurred immediately on the West side of San Juan Island out into Haro Strait, a vital habitat for the SRKWs, especially near Lime Kiln Lighthouse due to the prime hunting grounds available to them (figure 10).

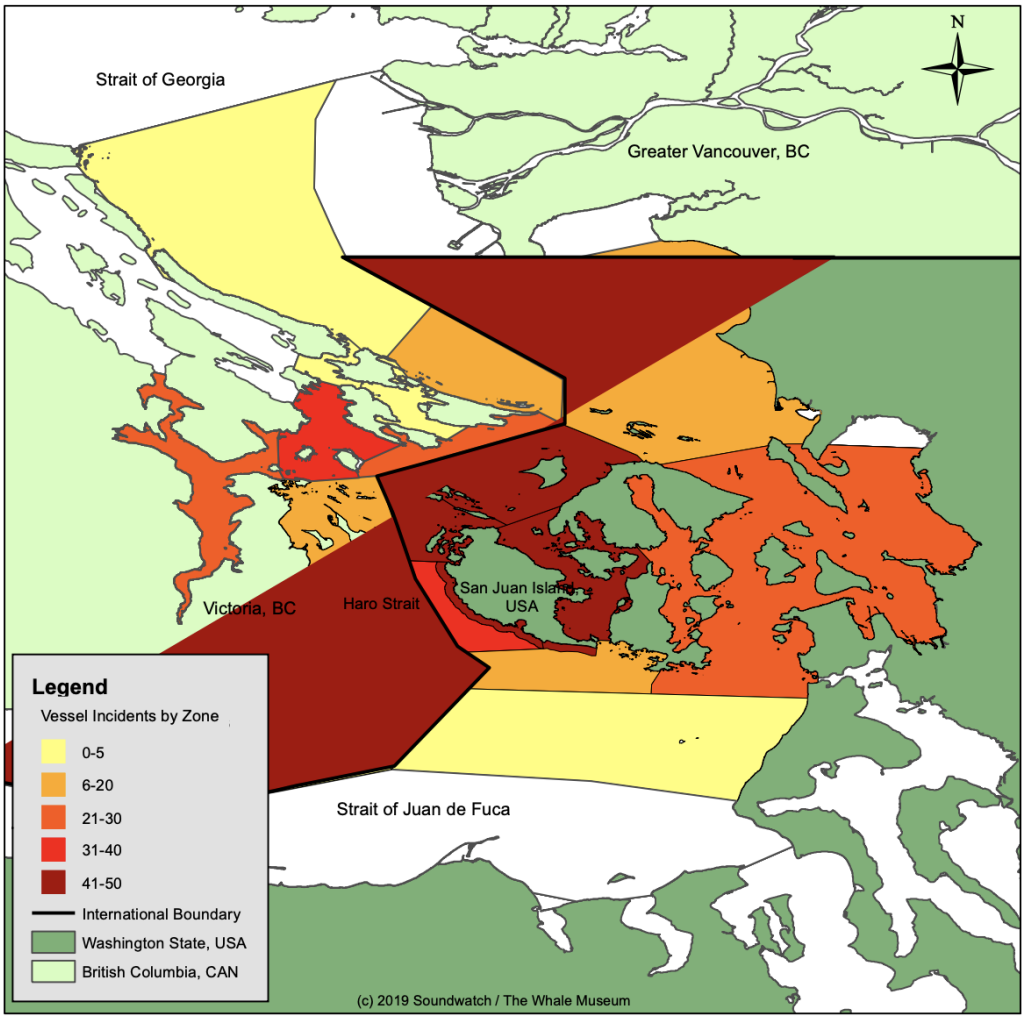

Figure 10: 2020 Vessel incidents involving SRKWs by zones, with lighter colors having fewer total incidents than zones in darker colors. Locations can be multiple violations, N=184 incidents.

There is an apparent trend that as the maximum and average number of vessels on scene with the SRKWs increases, so does the total number of vessel incidents, suggesting that if the influx of vessels in the Salish Sea continues, the more incidents there will be per year (figure 11).

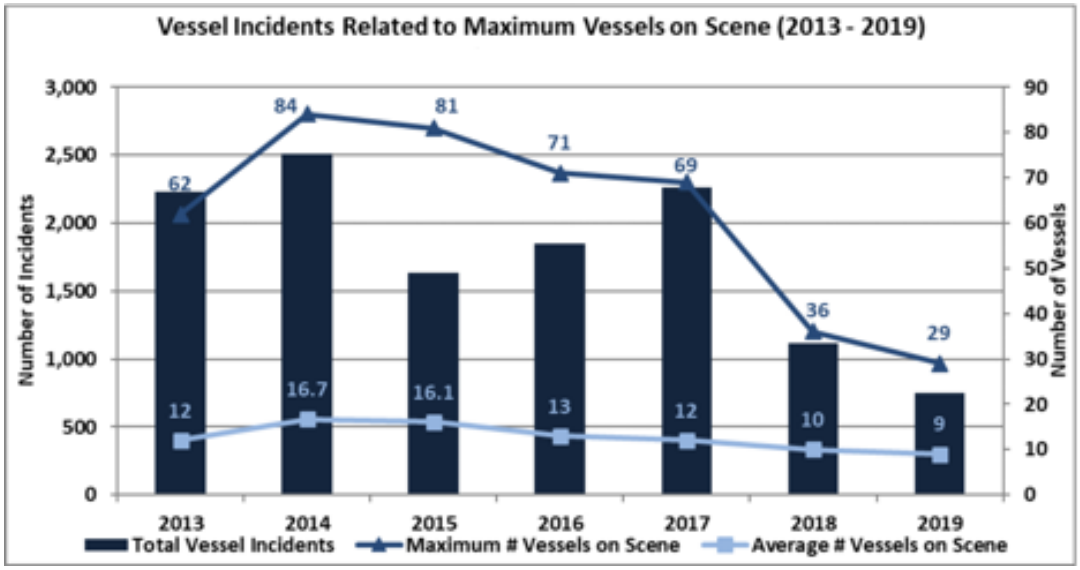

Figure 11: Average, Maximum, and Total number of vessels on scene with killer whales plotted with number of vessel incidents from May-September 2013-2019 observed in the Salish Sea by Soundwatch. Data from 2020 was not included in this plot as it was an abnormal traffic year due to the COVID-19 Pandemic.

SRKW Behavioral Responses

For each vessel incident, it was determined how many of the behavioral response cases resulted in a change in behavior, no change in behavior, or unknown (figure 12). In the majority of cases, it is unknown whether or not there was a behavioral change, as it could not be observed due to extenuating circumstances. Despite this, we can still infer that a behavorial response was observed more often than no response as the number of observed cases in which there was a behavorial change is consistently more than the number of observed cases in which there was not a behavioral change.

For observed incident A: Going over 7 knots within half a mile of SRKWs

60% of behavioral response cases resulted in unknown change, *25.45%* resulted in a change in behavior and *14.54%* resulted in no change in behavior (figure12). Changes in travel behavior was the most observed response, happening in *42.86*% of cases (figure 13).

For observed incident B: Within 400 yards and in the path of SRKWs

46.15% of behavioral response cases resulted in unknown change, *46.15%* resulted in a change in behavior and *7.69%* resulted in no change in behavior (figure 12). Changes in foraging behavior was the most observed response, happening in *44.44%* of cases (figure 13).

For observed incident C: Within 300 yards of SRK

52.78% of behavioral cases resulted in a change in behavior, *38.89%* resulted in unknown change, and *8.33%* resulted in no change in behavior (figure 12). Changes in foraging behavior was the most observed response, happening in *47.36%* of cases (figure 13).

For observed incident D: Vessel in the San Juan Island NO-GO zone

33.33% of behavioral response cases resulted in unknown change, *33.33%* resulted in a change in behavior and *33.33%* resulted in no change in behavior (figure 12). Changes in foraging and social behavior were the most observed responses, each happening in *50.00%* of cases (figure 13).

For observed incident E: Within 200 yards of SRKWs while under motor power

61.11% of behavioral response cases resulted in unknown change, *33.33%* resulted in a change in behavior and *5.56%* resulted in no change in behavior (figure 12). Changes in dive behavior was the most observed response, happening in *50.00%* of cases (figure 13).

For observed incident F: Within 100 yards of SRKWs while under motor power

50.00% of behavioral response cases resulted in unknown change, *37.50%* resulted in a change in behavior and *12.50%* resulted in no change in behavior (figure 12). Changes in foraging behavior was the most observed response happening in *66.67%* of cases (figure 13).

For observed incident G: Fishing within 200 yards of SRKWs

47.62% of behavioral cases resulted in a change in behavior, *42.85%* resulted in unknown change, and *9.52%* resulted in no change in behavior (figure 12). Changes in travel behavior was the most observed response, happening in *34.25%* of cases (figure 13).

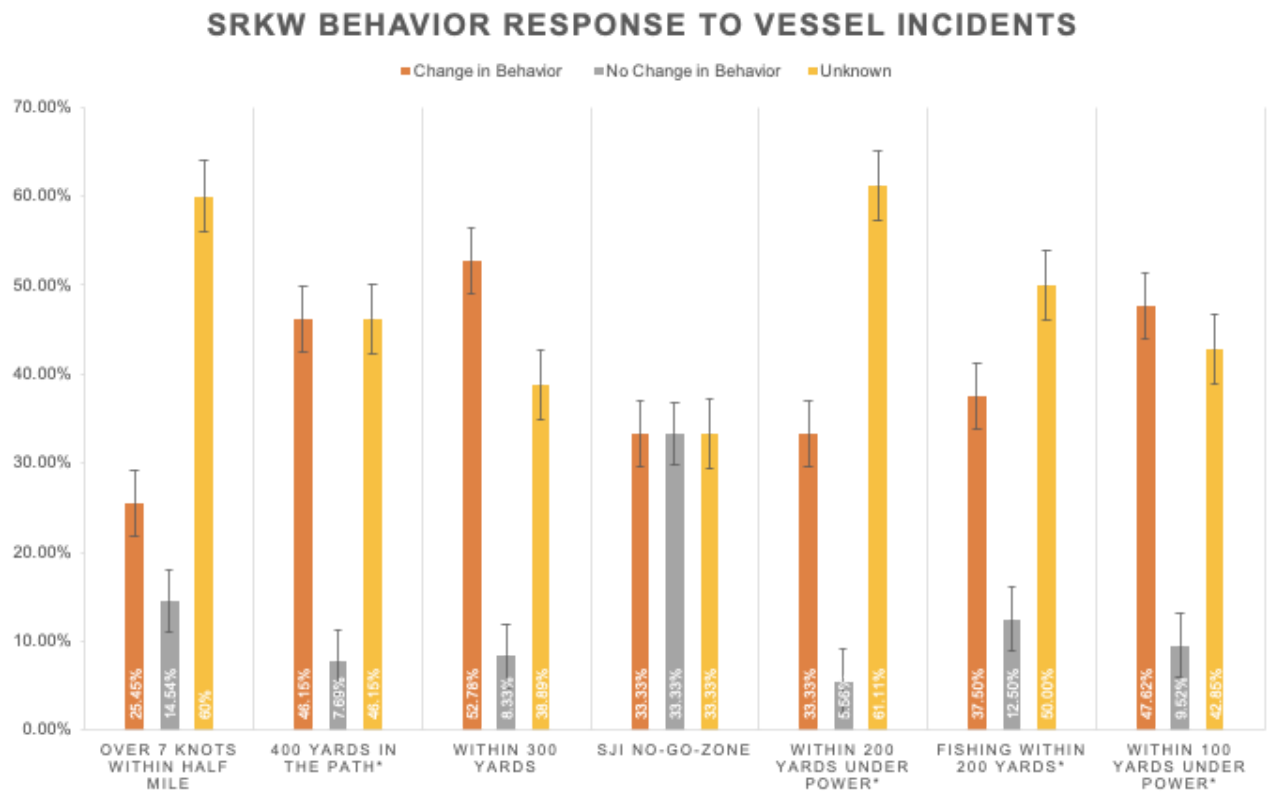

Figure 12: Total percentage of specific incidents resulting in a change in behavior (orange), no change in behavior (grey), and unknown or unobserved change in behavior (yellow).

* Federal/State Vessel Regulations

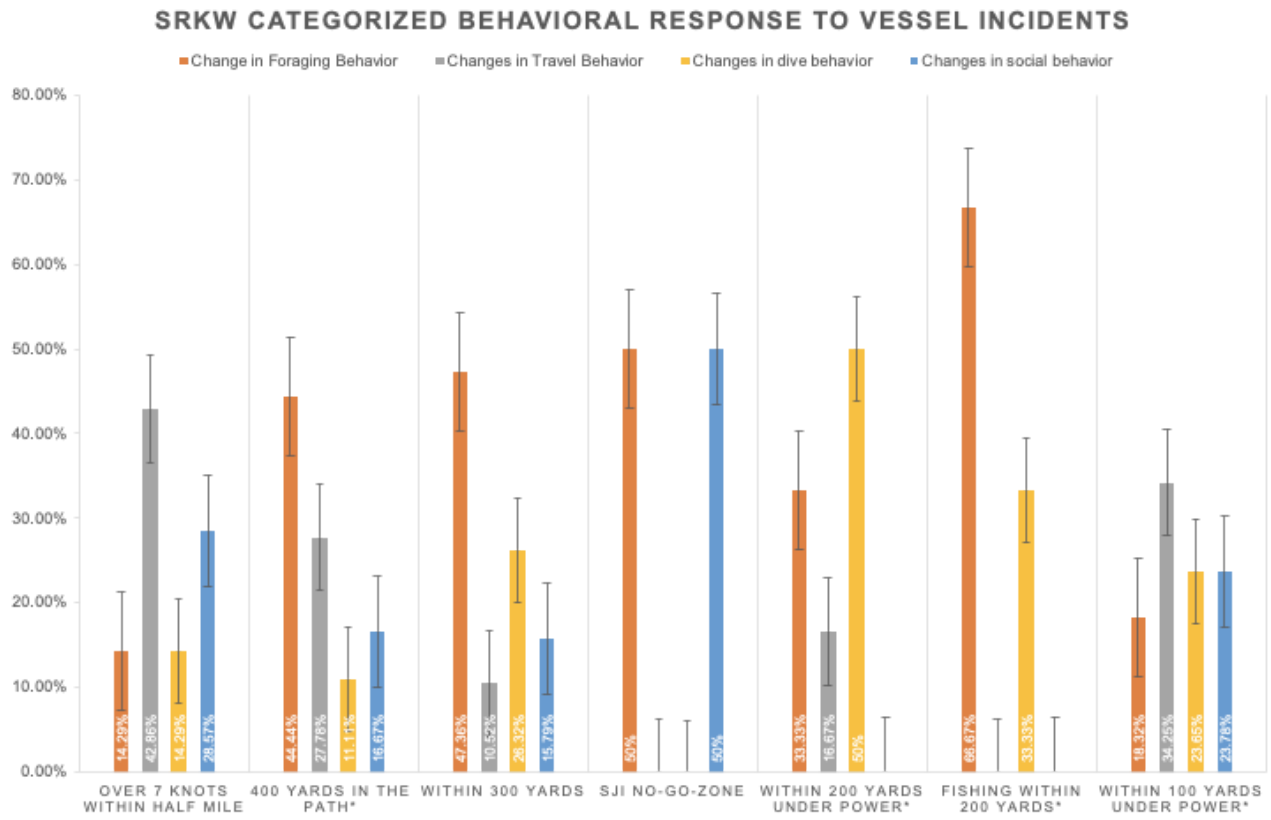

Figure 13: Total percentage of categorized behaviors in response to specific incidents. Behaviors were sorted into four categories: (1) Change in foraging behavior (orange) (2) Changes in travel behavior (grey) (3) Changes in dive behavior (yellow) and (4) Changes in social behavior (blue).

*Federal/State Vessel Regulations

Overall, the most common behavioral change observed in 4 out of the 7 cases was changes in foraging behavior, suggesting that this is one of the most impacted SRKW behaviors by harmful vessel trends (incidents) (table 3).

Incident	% of cases resulting in behavioral change	Most common behavioral change observed
(a) Over 7 knots within half mile	25.45%	Travel
(b) 400 yards in the path	46.15%	Foraging
(c) Within 300 yards	52.78%	Foraging
(d) SJI No-go-zone	33.33%	Foraging and Social
(e) Within 200 yards under power	33.33%	Dive

(f) Fishing within 200 yards	37.50%	Foraging
(g) Within 100 yards under power	47.62%	Travel

Table 3: The reported incident, the percent of incident cases that resulted in a behavioral response, and the most common behavioral change observed in response to each specific incident.

Correlations Between Behavioral Change and Incidents

We found that there was a positive correlation between the number of cases of observed behavioral change in response to the number of recorded incidents. The R^2 value is equal to *0.708*, which means that *70.8%* of the cases of observed behavioral changes can be explained by vessel incidents.

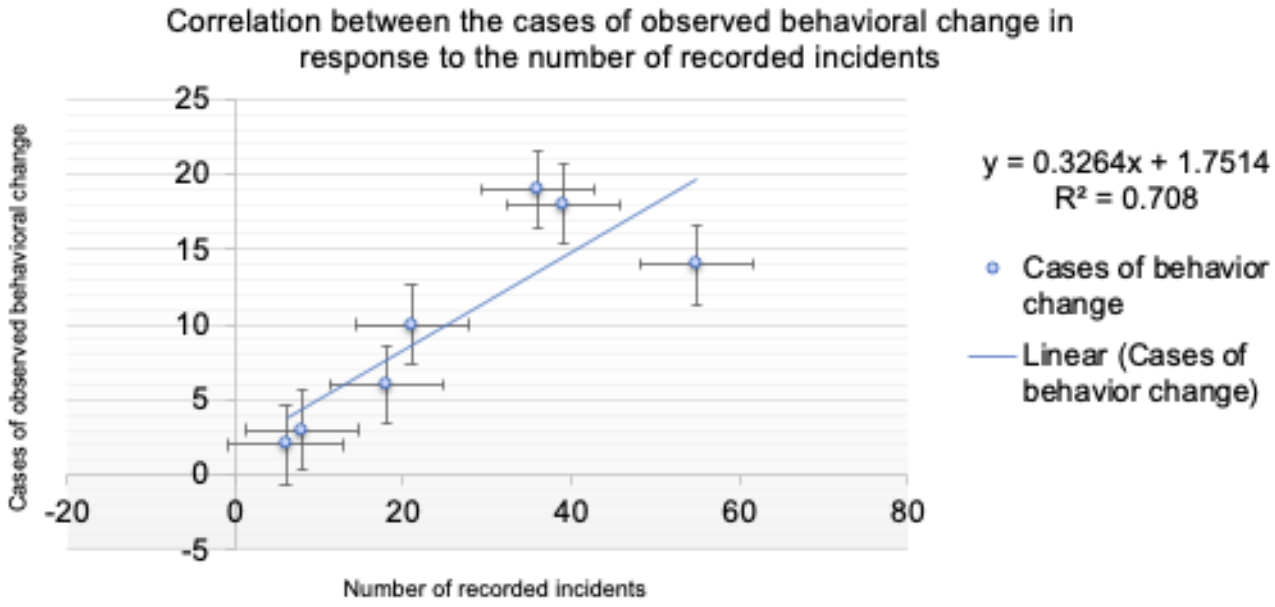

Figure 14: A positive correlation between the number of recorded incidents and the resulting observed behavioral responses. **R^2 = 0.708.**

Discussion

This year's vessel counts showed a slight uptick in the maximum (*39,* figure 6*)* and average (*11,* figure 7*)* number of vessels counted within a half-mile of the Southern Resident Killer Whales, which is likely due to an influx of recreational boaters observed later in the season (figure 6). The average value of *11* contradicts the previous downward trend since the average of *18* in 2014. The observed average increase in total vessel traffic around orcas during the summer of 2020 may be due to increased use of the Salish Sea as a result of boating being permitted as a suitable socially-distanced activity. The increase could also be linked to presence of orcas during events of increased vessel activity, such as the September fishing season. Average number of commercial vessels accompanying orcas specifically continues to trend downward since 2017 while the average number of recreational boaters has remained at around 3. The Pacific Whale Watchers Association (PWWA) does suggest a limit of the maximum number of EcoTour vessels around a single group of orcas. This limit was codified into law by WDFW's Commercial Whale Watch Licensing Program (CWWLP), instated along with other regulations in January 2021. This observed decrease in the average EcoTour vessels with the whales since 2017 could be linked to increased dispersion of SRKW in particular. During the 2020 season, recreational boating was the only category to see a slight increase from 2.6 to 2.7 (Figure 8). Recreational vessels had the greatest presence around whales during the peak season months of July, August, and September. Overall vessel activity around whales saw a sharp increase after the month of June, likely due to the lifting of certain COVID-19 restrictions in the region.

Over 7 knots with a half mile had the highest rate of incidents, occurring *30%* of the time. In the Path incidents had the second highest incident rate of *12%*, followed by 300 yards under power and

shutdown at a rate of *10%* (figure 9.1). The higher incident rate in less than 200 yards of whales incident category may be attributed to operators staying in close proximity to the whales and shutting down their engines versus attempting to remain at a greater distance by engaging their engines. This is important to note since in *52.78%* of incident cases (figure 12) where vessels came within 300 yards of SRKWs, the whale(s) changed its (their) behavior. We noted EcoTour operators announcing over VHF radio they were shutting down their engines when killer whales were less than 200 yards from their vessel in efforts to reduce engine noise, but vessel operators should consider turning off their engine prior to being within 300 yards of the SRKWs to prevent further disturbance to the habitat.

Our data also suggests that private motors are responsible for *72%* of the total reported incidents (fig. 9.2), suggesting that non-commercial boaters are not well-versed in the knowledge of federal laws and regulations surrounding the SRKWs, there is not enough enforcement on-scene with the whales, or a combination of both.

Looking at the categorical data, we can see that a majority of whether there was or was not a behavioral response is unknown. Variations in incident and behavioral response data are likely due to annual variation in whale presence, social cohesion, and awareness. These factors can reduce the number of incidents recorded by Soundwatch. Soundwatch operations are limited by time, resources, weather, and other research or education activities on-the-water. Therefore, incident numbers and observed responses recorded by Soundwatch are not a full representation of the whale watching scene on the water over the course of the season and could be a source of explanation for the high volume of unknown observations. One thing to also take into consideration is the extreme

circumstances of this summer. Due to the COVID-19 pandemic, it was difficult to collect data in a truly natural setting with regular boat traffic and SRKW sightings. Despite the majority unknown, we can still infer that a behavioral response was observed more often than no response (figure 12) as the number of observed response cases is consistently more than the number of no-response cases.

Looking more specifically **(**figure 13), out of the cases where a response was recorded, foraging behavior is the most impacted, followed by travel behavior, dive behavior, and finally social behavior (table. 1)**.** This is concerning for many reasons, but especially because a multitude of past projects have highlighted the increasing difficulty for the SRKWs to hunt and survive in the Salish Sea due to the rapidly decreasing Chinook salmon populations (Ferrara *et al.,* 2017). If foraging is being further impacted by vessel incident traffic, it is imperative that we have measures drafted to protect one of last and most vital hunting grounds (Lusseau *et al.,* 2009) for the SRKWs. More troubling, in *70.80%* of cases, an observed behavioral change can be explained by a boating incident (figure 14) which means that we can assume that if the number of recorded incidents increases with vessel traffic (figure 11), we can expect to see in the coming years more behavioral changes made by the SRKWs and maybe even see them start to avoid the habitat altogether.

Long-term trends show declines in average number of vessels with the whales and some reductions in incidents and incident rates (figure 11), however, ongoing noncompliance demonstrates the continued need for the continuation and expansion of shore and water-based boater education and outreach efforts. Increased efforts and funding for additional enforcement patrols and enforcement action are vital to the success of Southern Resident killer whale protection and recovery.

Sustainable funding for education, monitoring and enforcement may also become a critical issue due to economic impacts of COVID-19 and the availability of this information to the general public.

We can conclude with support from past data that Southern Resident killer whales respond to harmful vessel trends in close-proximity with short-term behavioral changes. The most alarming consequence of these changes is the reduced time spent feeding and the resulting potential reduction in prey consumption. Although it is unknown if these short-term behavioral changes affect the population dynamics, it is likely that because Southern Residents are exposed to vessels most of the daylight hours that they are in inland waters, there may be biologically relevant effects at the population-level that will become more obvious as time goes on. Furthermore, because we are seeing a steady increase in vessel traffic and with it, vessel incidents, it is recommended that this and other supporting data be taken into consideration when drafting new laws and regulations for boaters around the Southern Residents in the Salish Sea in order to preserve and nurture their critically endangered populations and this unique, vital habitat.

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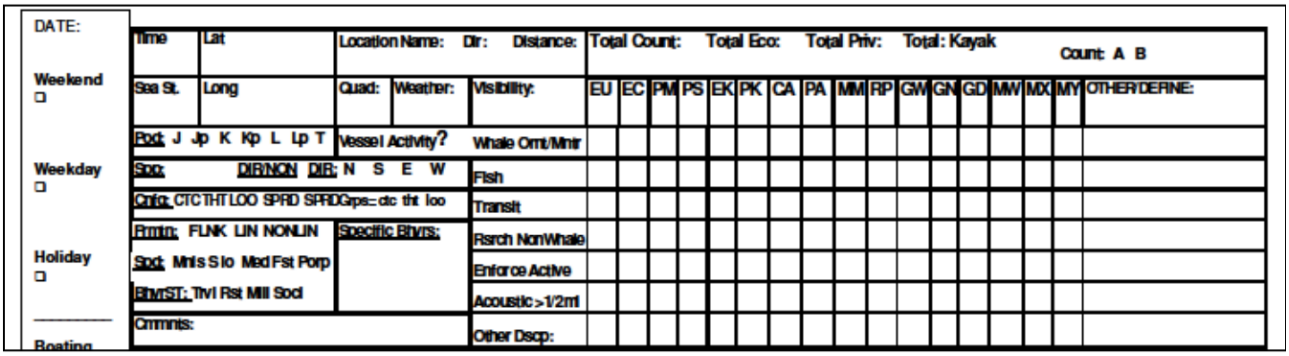
It should also be noted that aspects of this thesis and its data will be published in the *2020 Soundwatch Program Annual Contract Report*, for which I am very grateful to the program for including my research!

Appendices

Appendix A: Soundwatch data Sheet - Vessel Count



DATE:

Weekend ❑

Weekday ❑

Holiday ❑

Boating

Time	Lat	Location Name:	Dir:	Distance:	Total Count:	Total Eco:	Total Priv:	Total: Kayak	Count: A B
Sea St.	Long	Quad:	Weather:	Visibility:	EU EC PM PS EK PK CA PA MM RP GW GN GD MW MX MY	OTHER DERNE:			
Pod: J Jp K Kp L Lp T		Vessel Activity?		Whale Orni/Mmir					
Spp:	DIR/NON DIR: N S E W			Fish					
Cnfg: CTC THT LOO SPRD SPRDGps=: clc tht loo				Transit					
Rmin: FLNK LIN NONLIN	Specific Bhvrs:			Rsrch NonWhale					
Spd: Mnls S lo Med Fst Porp				Enforce Active					
BhvrST: Trvl Rst Mill Socl				Acoustic >1/2mi					
Cmmnts:				Other Dscp:					

Appendix B: Soundwatch Marine Conditions & Vessel Codes for Vessel Counts

Beaufort Scale	Mariner's Description	Wind Speed	Effect of Wind at Sea
0	calm	0-1	like a mirror (flat)
1	light air	1-3	ripples form with the apperance of scales, but w/out foam crests
2	light breeze	4-6	small wavelets, crests appear glassy, no breaking
3	gentle breeze	7-10	larger wavelets begin to break, glassy foam, scattered white caps
4	moderate breeze	11-16	small waves predominant but fairly frequent white caps
5	fresh breeze	17-21	moderate waves, distinctly elongated, many white horses, chance of spray
6	strong breeze	22-27	long waves with extensive white foam breaking crests begin to form, spray likely
7	moderate gale	28-33	sea heaps up, white foam breaking waves start to be blown in streaks, beginning of spindrift
8	fresh gale	34-40	
9	strong gale	41-47	
10	white gale	48-55	
11	storm	56-66	
12	hurricane	above 66	

Vessel Code	Description
CA	Commercial Aircraft
EA	Ecotour aircraft
EC	Ecotour Canadian
EK	Ecotour Kayak
EU	Ecotour US
PA	Private Aircraft
PK	Private Kayak/Paddle
PM	Private Motor
PS	Private Sail
MC	Marine Charter
MF	Marine Fishing
ML	Marine Tug with log barge
MM	Marine Monitoring
MQ	Marine Cruiseship
MW	Marine Tug with tow
MX	Marine Shipping
MY	Marine Ferry
GA	Government aircraft
GB	Government BC Parks
GC	Government Coast Guard
GD	Government DFO
GL	Government military
GN	Government NOAA
GO	Government
GW	Government WDFW
RP	Permitted Research

Visibility
none
poor
fair
good
excel

Weather
sunny
sunny w/ partial clouds
overcast - high
overcast
foggy
rain - light
rain - heavy

Location
Prominent Place Name
Direction:
N, NE, NW, E, S, SE, SW, W
Distance:
1/4 Mi, 1/2 Mi, 1 Mi, 2mi, 2+Mi

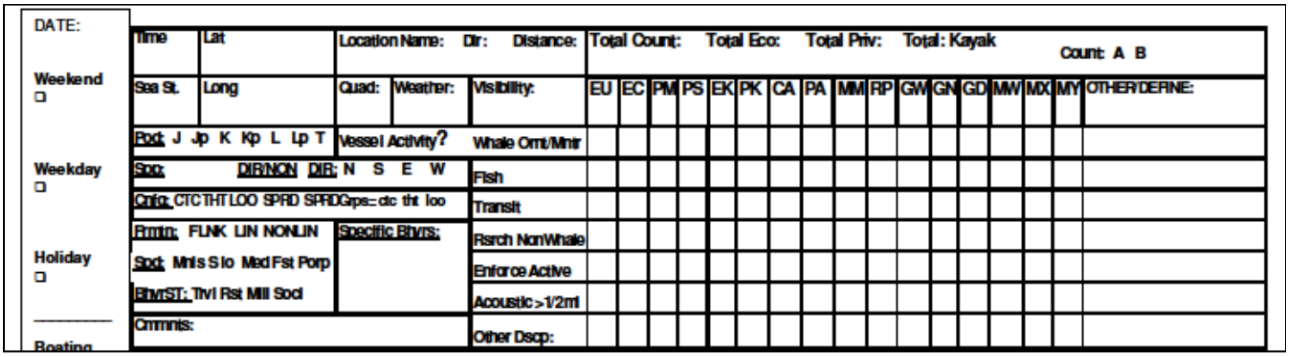
Vessel activity	
W	Whale Oriented
F	Fishing
T	Transiting
R	Research (whale oriented)
E	Enforcement
A	Acoustic Range
O	Other with description

Appendix C: Soundwatch Marine Wildlife Guideline and Law Incident Codes for Vessel Incident Observations

	FAST/SPEED	
2.0	speed	vessel traveling over 7 knots w/in **400y**/366m of whales, fast w/in 1/4 mile (**440y**/402m)
2.1	speed - approaching scene	vessel traveling over 7 knots w/in **400y**/366m of whales, fast w/in 1/4 mile (**440y**/402m)
2.2	speed - departing scene	vessel traveling over 7 knots w/in **400y**/366m of whales, fast w/in 1/4 mile (**440y**/402m)
	IN PATH	**NEW 2011 LAWS**
3.1A	In path 200-400 yds	**w/in 200y**/183m corridor path in front of whales between **200-400y**/183-366m ahead of whales
3.3	In path - cross	crossing path of whales, vessel traveling across expected path **(200-400yds)**whales predictable
	APPROACH	
4.1	approach - head on	vessel approaching a whale/group head on w/in **200-400y**/181-366m when whales are traveling in a relatively predictable pattern
4.2	approach - behind	vessel approaching/traveling behind a whale/group w/in **200-400y/181-366m** when whales are traveling in a relatively predictable pattern
	W/in 100 YARDS/M	
5.1	**100y/91m - stopped**	**vessel stopped w/in 100y/91m of whales**
5.2	**100y/91m - under power**	**vessel under power w/in 100y/91m of whales**
5.4	100y/91m - fishing	vessel fishing w/in **100y/91m** of whales (did not attempt to move out of path of whales)
	W/in 200 YARDS/M	**NEW 2011 LAWS**
6.1	**200y/183m - stopped**	**vessel stopped w/in 200y**/183m **of whales**
6.2	**200y/183m - under power**	**vessel under power w/in 200y**/183m **of whales**
6.4	200y/183m - fishing	vessel fishing w/in **200y**/183m of whales (did not attempt to move out of path of whales)
7.0	**INSHORE**	vessel on the inshore side of whales, when whales are traveling close to shore (within 1/2 mile)
	AREA RESTRICTION	****Placeholder for WDFW Proposed New SLOW ZONE Guideline: NOT IN EFFECT as of June 2011****
40.1	area restriction - SJIVNBZ 1	vessel w/in **1/4mile** (**440y**/402m) of the SJI shoreline in the determined zone with whales present
40.2	area restriction - Lime Kiln	vessel w/in **1/2mile** (**880y**/808m) of shoreline 1mile radius of Lime Kiln Light with whales present
40.3	area restriction - NWR	vessel w/in **200y**/183m of U.S. National Wildlife Refuse (NWR) site
40.4	area restriction - RRER	vessel w/in **100y**/91m of any Race Rocks Ecological Reserve shoreline
40.6	area restriction - SJIVNBZ 2	vessel w/in **1/8mile** (**220y**/201m) of ANY shoreline with whales present
40.7	area restriction -SJI Slow Zone	vessel > 7 knots w/in **1/2mile** (880y/808m)SJIVNBZ with whales present ****WDFW PROPOSED New Guideline****
	AIRCRAFT	
50.1	aircraft - low flying	aircraft flying lower than 1000feet (**333y**/305m)
50.2	aircraft - low circling	aircraft circling lower than 1000 feet (**333y**/305m)

60.1	**kayaks - spread out**	**kayaks not rafted up (spread loosely) when whales are present**
60.2	**kayaks - 100y/91m**	**kayaks paddling w/in 100y/91m of whales**
60.3	kayaks - launching	kayaks launching into area when whales are present
60.4	kayaks - offshore 1/4m	kayaks paddling farther than 1/4 mile (**440y**/402m) offshore when whales are present
60.5	**kayaks- parked on headland**	**kayaks parked on headland with whales present**
60.6	**kayak - 200y/183m**	**kayaks paddling w/in 200y/183m of whales NEW 2011 LAW**
	BOWRIDING	
20.1	bowriding - erratic	vessel operating in erratic fashion while engaged in bowriding
20.2	bowriding - deliberate	vessel deliberately attempting to have animal(s) bow/stem ride i.e. REPEATED CIRCLING
	HAULOUT	
30.0	haulout - speed	vessel over 7 knots w/in **200y**/183m of active haulout
31.2	haulout - no navigation restriction	vessel w/in **100y**/91m of an active haulout - no navigation restriction
32.0	haulout - disturbance	vessel w/in **400y**/366m of active haulout causing disturbance
32.1	haulout - disturb deliberate	any deliberate disturbance of active haulout
32.2	haulout - disturb maintain	disturbance with no attempt to move away from haulout
32.3	haulout - disturb but moved	disturbance but moved away
9.0	INTERACTION	swimming, feeding, touching wildlife DEFINE INTERACTIONS
10	Other: Define	something out of the ordinary or site specific DEFINE OTHER
8.0	TIME LIMIT	vessel is staying longer than 30 minutes w/in 1/4 Mi (**440y**/402m) of whales- record if only a few whales

Appendix D: Soundwatch Data Sheet Vessel Incidents



Appendix E: Soundwatch Whale Survey & Behaviors Codes for Whale Scans (Page 1)

Species code	Species Name	Latin Name
oror (SR)	killer whale - **southern resident**	Orcinus orca
oror (T)	killer whale - **transients**	Orcinus orca
oror (NR)	killer whale - **northern resident**	Orcinus orca
esro	gray whale	Eschrichtius robustus
meno	humpback whale	Megaptera novaeangliae
baac	minke whale	Balaenoptera acutorostrata
bamu	fin whale	Balaenoptera musculus
phph	harbour porpoise	Phocoena phocoena
phda	Dall's porpoise	Phocoena dalli
laob	Pacific white-sided dolphin	Lagenorhyncus obliquidens
phvi	harbour seal	Phoca vitulina richardsi
euju	Stellar's sea lion	Eumatopius jubatus
enlu	sea otter	Enhydra lutris
brma	marbled murrelet	Brachyramphus marmoratus
syan	ancient murrelet	Synthliboramphus antiquus
arhe	Pacific great blue heron	Ardea herodias fannini

Configuration
Contact: physical contact
Tight: 0 to 10m from another animal
Loose: 10 to 100m
Spread: Greater than 100m

Orientation/Formation
Flank: side-to-side-to-side
Linear: head-to-tail
Non-linear: no particular orientation within group

Speed
Motionless: 0 knots, "hanging", "logging"
Slow: less than 2 knots, less smooth or "jerky" surfacing
Medium: 2-6 knots, slow roll, "normal"
Fast: 6-10 knots, fast roll
Porpoising: greater than 10 knots, large portion of body out of water

Common Behaviors		
Spy Hop	Aerial scan	Breach
Half breach	Bellyflop	Pec slap
Pec wave	Inverted pec slap	Tail wave
Tail Slap	Inverted tail slap	Tail lift-headstant
Dorsal fin slap	Cartwheel	Chasing
Lunging/surging	Rolling at surface	High arch dives
Reverse	Push/lift/carry whale	Playing with log / object
Kelping	Fish seen	Vocalization heard
Bubble blowing	Synchronous surfacing	Mating
Penis seen-whale w/another	Penis seen-whale alone	Other-describe

Direction of travel	
N	North
NW	SouthWest
NE	NorthEast
E	East
S	South
SW	SouthWest
SE	SouthEast
W	West

Directionality
Directional: less than or equal to 90deg from previous direction of travel
Non-directional: deviation of greater than 90deg from previous direction of travel

Appendix F: Soundwatch Whale Survey & Behaviors Codes for Whale Scans (Page 2)

Species code	Species Name	Latin Name
oror (SR)	killer whale - southern resident	Orcinus orca
COOSE ALL THAT APPLY: J Jpartial K Kpartial L Lpartial List ID's If possible		
oror (T)	killer whale - transients	Orcinus orca
oror (NR)	killer whale - northern residents	Orcinus orca
esro	gray whale	Eschrichtius robustus
meno	humpback whale	Megaptera novaeangliae
baac	minke whale	Balaenoptera acutorostrata
phvi	harbour seal	Phoca vitulina richardsi

Common Behaviors/Overall Behavior State		
Spy Hop	Aerial scan	Breach
Half breach	Bellyflop	Pec slap
Pec wave	Inverted pec slap	Tail wave
Tail Slap	Inverted tail slap	Tail lift-headstant
Dorsal fin slap	Cartwheel	Chasing
Lunging/surging	Rolling at surface	High arch dives
Reverse	Push/lift/carry whale	Playing with log / object
Kelping	Fish seen	Vocalization heard
Bubble blowing	Synchronous surfacing	Mating
Penis seen-whale w/another	Penis seen-whale alone	Milling
Tail-Lob	Sharking	**Other-describe:**
Fast Non-Directional	Long-dives	
Behavior States: TRAVEL REST MILL SOCIALIZE		

Sea State	Effect of Combined Wind And Currents on Sea State
0	like a mirror (flat)
1	ripples form with the appearance of scales, but w/out foam crests
2	small wavelets, crests appear glassy, no breaking
3	larger wavelets begin to break, glassy foam, scattered white caps
4	small waves predominant but fairly frequent white caps
5	moderate waves, distinctly elongated, many white horses, chance of spray
6	long waves with extensive white foam breaking crests begin to form, spray likely
7	sea heaps up, white foam breaking waves start to be blown in streaks
8+	WHY THE HELL ARE BOATS STILL OUT THERE?

Configuration (Overall Group)
Contact: physical contact
Tight: 0 to 10m from another animal
Loose: 10 to 100m
Spread: Greater than 100m **Spread in Groups:** Distinct sprd groups

Formation (Overall Group)
Flank: side-to-side-to-side
Linear: head-to-tail
Non-linear: no particular orientation within group

Speed
Motionless: 0 knots, "hanging", "logging"
Slow: less than 2 knots, less smooth or "jerky" surfacing
Medium: 2-6 knots, slow roll, "normal"
Fast: 6-10 knots, fast roll
Porpoising: greater than 10 knots, large portion of body out of water

Direction of travel
Directionality
Directional: less than or equal to 90deg from previous direction of travel
Non-directional: deviation of greater than 90deg from previous direction of travel
N, NW, NE, E, S, SW, SE, W

Weather & Abbrv.
sunny **S**
sunny w/ partial clouds **SPC**
overcast - high **OCH**
overcast **OC**
foggy **FOG**
rain - light **RL**
rain - heavy **RH**