Does boat presence affect the behavior of Sounders in inland waters? A study on gray whales (*Eschrichtius robustus*) in North Puget Sound.

by

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A Thesis
Submitted in partial fulfillment
Of the requirements for the degree
Master of Environmental Studies
The Evergreen State College
{September} {2022}

This Thesis for the Master of Environmental Studies Degree

by

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has been approved for

The Evergreen State College

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ABSTRACT

Does boat presence affect the behavior of Sounders in inland waters? A study on gray whales (*Eschrichtius robustus*) in North Puget Sound.

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Keywords: Gray Whales, Anthropogenic Effects, Behaviors

Understanding the impacts of vessel presence on whale behavior is a crucial aspect of cetacean conservation. "The Sounders" are a small group of gray whales that stop to feed in North Puget Sound during their annual migration. This leg of their journey exposes them to whale-watching boat-based operations, recreational, and commercial vessel traffic. Research on other cetacean species has indicated that boat presence may have adverse effects, such as disrupted foraging and avoidance of heavily-trafficked areas. There are limited studies on gray whales regarding the behavioral impacts of boats presence. To address this gap, land-based research was conducted from Hat Island, Washington, using a theodolite to record the locations and movements of gray whales. The presence or absence of vessels within one km were also tracked. These observations began on March 14 and ended on May 14, 2021. Whales were tracked for 51 days for a total of 78 hours. 39% of all whale observations occurred while boats were within 1000 m. Results indicated that whale's speed, inter-breath intervals, deviation, and direction indices differed when boats were within 1000 m of the whale. The Sounders' prolonged periods of foraging close to shore provided an ideal opportunity to study the impacts of boats on gray whales, the results of which may better inform the conservation and regulation of the species

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Acknowledgments

In the field, things did not always go to plan. There were advances and setbacks, but I appreciate all the help I received. There truly are countless people who helped make this project happen. I will try to recognize them all below properly, but I apologize in advance for anyone I missed.

There were many people I talked about the idea of this project with or listened to my ramblings about gray whales, including Dr. Pauline yu, Don Chalmers, Dyanna Lambourn, Joe Jauquet, Jeff Harris, Dr. Tony Orr, and the staff and interns of Cascadia Research Collective.

I want to thank the research assistants of Irissa Danke and Quinn Wilson. These folks were outside, rain or shine, with me recording data and helping build the project.

I want to recognize the volunteers who helped with the fieldwork in 2020, including Lynn Pavlinovic, Joe Jauquet, Elsa Toskey, Mackenzie Davidson, Steve Dilley, Dan Lowe, Norm Rathvon, Maggie Santangelo, Kathleen and Bruce C. Thompson Phillip Meade, Katie Wold, Elizabeth and Harry Fuchs.

Regarding theodolite advice, help, and troubleshooting, I want to thank Marena Salerno Collins, Florence Sullivan, and Lisa Hildebrand. They all answered countless questions and responded to many emails.

Also, related to theodolites, I want to thank David Anderson. He helped me troubleshoot the theodolite many times. His thesis was also an excellent reference and sometimes a framework for writing my own.

I want to thank Lori Christopher for all her help. Lori not only got me onto Hat Island, which is private, she also toured me around the island. During this tour, we located and gained access to use all of the observation posts. Lori helped secure a vehicle and rental for the team on the island. She also continually made us aware of a gray whale cited near Hat Island. She was instrumental in the success of the project.

I also want to give a big thank you to the Hat Island community. Not only did they welcome my many helpers and me into their community, they also let us use their property to observe the whales and even fed us from time to time. For landowners, I want to thank Kevin and Jody Meyers, Karen and Stanley Van Spanje, and the owners of K26, W18, and M27. Shawn Potter ferried us countless times to and from the mainland. I also want to thank Kelly and Kerry Dukes, Larry and Linda Bender, Laurie Gray, Kyle Opstead, and Darla and David Younce.

Without the financial support from the Washington Chapter of the WIldife Society and the Master's in Environmental Studies program, this project wouldn't have been possible.

Bill Vogel contributed countless hours to help me. He proofed papers and grant applications. He was always available to bounce ideas off. He helped secure volunteers and funding. From the beginning to the end of the project, Bill supported and helped with this project.

Lynn Pavlinovic, my mother, helped a lot. She proofed papers and helped secure funding. While in the field, Lynn watched my dog, Rosie. She constantly provided moral support and made an excellent field assistant.

I want to thank Kiirsten Flynn and John Calambokidis for their support. They reviewed papers and presentations. Both helped secure equipment and supported me throughout the thesis project. Before this project started, I bounced countless ideas about possible master's projects. After picking one, he provided expertise and guidance.

Dr. John Kirkpatrick was another critical piece of this project. It all started with him agreeing to help me apply for grants. Little did he know that we would end up applying to 12 of them. Next, it continued with him helping me prepare for my fieldwork and supporting me while I was on Hat Island. Most recently, he has reviewed many drafts of my thesis. He trusted me to do the work but was there to support me if it didn't. By the end of this thesis, we will have exchanged hundreds of emails and spent just as many hours on zoom or phone. While we didn't always agree on things, I feel lucky to have had him as my reader.

I want to thank my partner, Elsa Toskey. They spent countless hours helping me figure out statistical issues. Elsa proofed papers and presentations for me; they were excellent field assistant. Elsa provided emotional and moral support, always loving, and putting up with me throughout this long process.

1. Introduction

The Sounders or North Puget Sound (NPS) gray whales (*Eschrichtius robustus*) have been documented detouring into Puget Sound to feed on ghost shrimp every year since the 1990s. Since the original two whales appeared to have discovered this feeding area, the group has grown to approximately 15 individuals as of 2021 (Table 2-1). While there, they interact with commercial, recreational, and boat-based whale-watching operations. With little known about how these interactions may affect the Sounders or gray whales in general, this project aimed to evaluate the presence of boats on the behaviors of the Sounders. With little known about the influence of anthropogenic activities on gray whales, this project focused on the Sounders, and provided an excellent opportunity to assess these impacts.

With few studies about gray whales and whether boat's presence impacts them, we have been forced to rely on studies, primarily on other cetacean species. Usually, boats have adverse effects on whale's behaviors (Senigaglia et al., 2016). Documented results included disrupted foraging, erratic movements, and energy expenditure (Senigaglia et al., 2016), which caused them to avoid and abandon high-disruption areas (Lusseau & Bejder, 2007) and altered gray whale's communication (Burnham & Duffus, 2019). Effects on whale behavior depended on different factors (Senigaglia et al., 2016) and appeared to vary by species (Weinrich & Corbelli, 2009).

Using the methods from Williams et al. 2002, the hypothesis was boats presence impacted whale behavior, specifically speed, direction (DI), and deviation (DEV) indices, dives, blows, and Inter Breath Intervals (IBI). The question posed was, when boats were present within 1000 m or less of a whale, would their presence impact the whale's behaviors? To answer this query, whale behaviors were recorded and divided into two categories. First, when a boat was present within 1000 m or less of the whale being tracked. Second, when no boat was present within 1000 m or less of the whale being tracked. To separate the two groups, when boats were within 1000 m of the whale, their presence and details were recorded. This data was gathered using a theodolite to track the whales and boats and a laptop to record the data. After comparing the two datasets, there were noteworthy results.

This project focused on an understudied species and attempted to answer an unanswered question. Little research has been done on boat's impacts on gray whales and none on the Sounders. Because the Sounders feed around Hat Island, Washington, for several months of the year, it was an ideal place to answer this question. These results are applicable broadly across the geographic home range of gray whales (Figure 2-2) and could be used to manage the species better.

2. Literature Review

2.1 Species Description

Figure 2-1: This image shows a gray whale (NMFS, 2020a).

Gray or grey whales are a unique and common cetacean species found in the North Pacific Ocean (Swartz & Jones, 2016). Typically, they are seen traveling or foraging near shore (Swartz & Jones, 2016). Gray whales are the only remaining member of the Eschrichtiidae Family, but they have a close phylogenetic relationship with the Balaenopteridae Family made up of rorquals (Swartz & Jones, 2016).

As their name indicates, gray whales generally are a gray hue (Figure 2-1). Their backs have whiteish spots (Figure 2-1). Because they travel slowly, they have extensive amounts of barnacles and cyamids (whale lice) on their backs (Osborne et al., 1988). Unlike most Mysticetis, gray whales do not have a dorsal fin but a dorsal ridge of six-twelve knuckles (Osborne et al., 1988). Like other Mysticetis, these whales have two blow holes and use baleen to consume their prey. Gray whales have large pectoral fins and flukes (NMFS, 2020a). Their maximum length is 15 m, and they have a maximum weight of 35 tons (Sumich, 2014). They are also sexually dimorphic, with females slightly larger than males (Sumich, 2014).

2.2 Life History

Gray whales are estimated to live for several decades, with mothers birthing claves every other year (NMFS, 2020a). After a 12-13 month gestation period, a gray whale calf is born (NMFS, 2020a). After spending seven to eight months with its mother migrating and nursing, the calf is weaned (Swartz & Jones, 2016). If the calf survives, it will become sexually mature between the ages of six and twelve, with the average of eight years old being the same for both sexes (Swartz & Jones, 2016). After becoming sexually active, males attempt copulation at every opportunity, while females typically enter estrus every two years (Swartz & Jones, 2016). This latter situation allows the females to regain some of their critical fat stores, which are depleted while nursing the calves (Swartz & Jones, 2016). While the average lifespan of a gray whale is unknown, one deceased female was estimated to be between 75 and 80 years old (NMFS, 2020a).

2.3 Feeding

Gray whales are flexible foragers utilizing many species to flourish. Their primary way of foraging uses suction feeding, but they have been known to employ gulp and skim feeding (Swartz & Jones, 2016). Their primary and preferred food source comprises benthic organisms, including a minimum of 60 benthic amphipod species and 80 to 90 other benthic invertebrate species (Swartz & Jones, 2016). They will also consume swarming species, including krill, mysids, shrimp, sardines, anchovies, and other species (Swartz & Jones, 2016).

With their feeding only taking place during the roughly five months spent in the feeding grounds, these whales must fast and rely on their fat reserves for the rest of the year (Swartz & Jones, 2016). To build these reserves, gray whales have been known to forage 24 hours a day (Swartz & Jones, 2016).

2.4 Distribution & Abundance

Figure 2-2: This image shows the approximate home range of gray whales (NMFS, 2020a).

Historically, gray whales were found throughout the Atlantic and Pacific Oceans (Duffield, 2009). Presently, gray whales are found only in the north Pacific Ocean. Gray whales of the Eastern North Pacific (ENP) stock have been recorded making an annual round trip migration of 15,000-25,000 km, making their species the longest migrating Mysticetis (Swartz & Jones, 2016).

According to NMFS, there are two remaining stocks of gray whales. First is the ENP stock, which breeds in lagoons in Baja, Mexico, and primarily feeds in the Chukchi Sea and Bering Straits (Figure 2-2) (NMFS, 2020a). As of 2015, before the Unusual Mortality Event (UME), this group contained approximately 27,000 whales (NMFS, 2021a). Second, there is the Western North Pacific (WNP) stock, comprised of less than 300 individuals, which feeds in the same area and is thought to breed somewhere off Korea (Figure 2-2) (NMFS, 2020a). Until recently, these two stocks were thought to be mostly isolated from each other (NMFS, 2020a). However, a recent project demonstrated that some WNP gray whales traveled to the calving Lagoons in Baja, Mexico (NMFS, 2020a).

2.5 Unusual Mortality Event

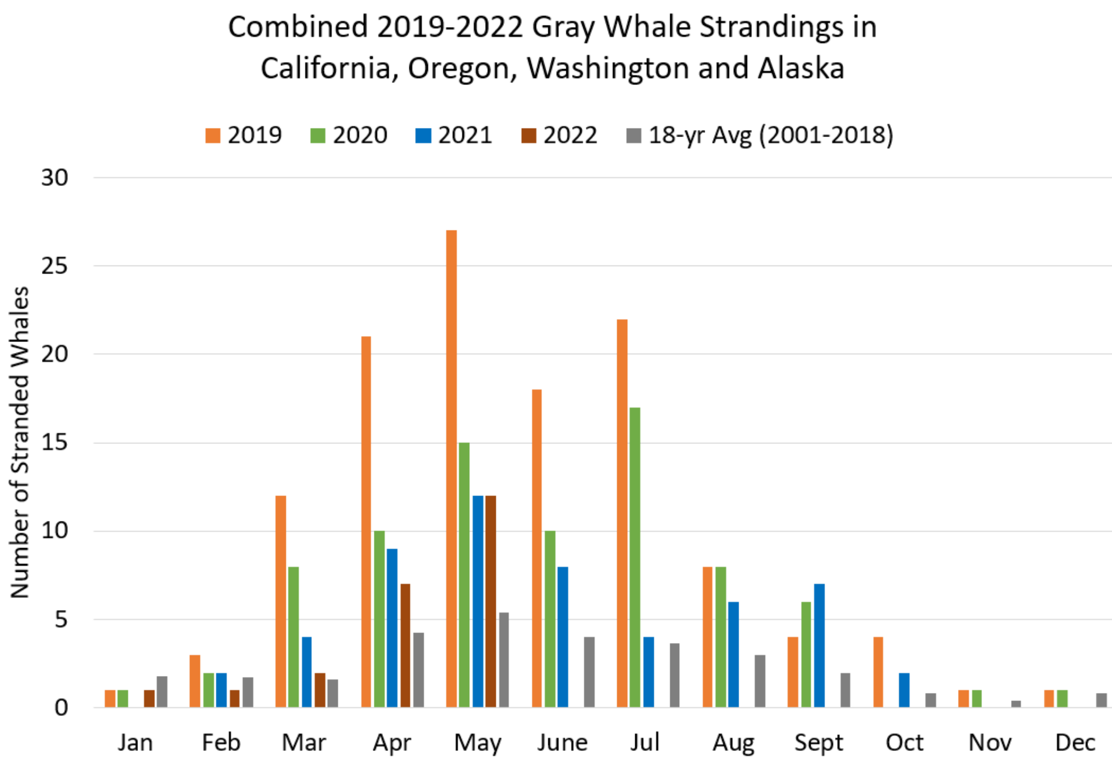


Figure 2-3: This box plot shows the strandings of gray whales between Alaska, Washington, Oregon, and California (NMFS, 2022).

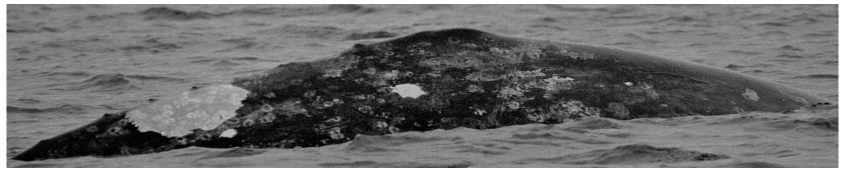
From 2019 to August 2022, 578 gray whales have stranded and died on the west coasts of the United States, Canada, and Mexico (Figure 2-3). These whales are considered part of the ENP (NMFS, 2022). Because of the deaths in 2019 and 2020, this event was declared a UME, which continues into the present year of 2022. To add perspective, these strandings were estimated to be only 14% of the estimated mortality of 4700 whales (CRC, 2022). For perspective, the normal mortality for the Eastern North Pacific population of gray whales is 29 whales stranded yearly (NMFS, 2021b).

2.6 Pacific Coast Feeding Group

Unlike the majority of the ENP, the Pacific Coast Feeding Group (PCFG) is a group of 232 whales that don't make migration to Alaska (Calambokidis et al., 2019). In 2017, this group of 232 whales made up less than 1% of the approximately 27,000 whales of the ENP stock. These animals feed from Northern California, USA, to Vancouver Island, Canada (Calambokidis et al., 2019). While there, they part in risky feeding behaviors in shallow waters off the coasts of these countries. Two studies comparing the PCFG and ENP whales genetically found significant mtDNA haplotype frequency differences (Calambokidis et al., 2019). This development provides the strongest evidence so far that the PCFG whales may be significantly isolated enough from the ENP stock to allow for maternally inherited mtDNA (Calambokidis et al., 2019).

2.7 Sounders/ North Puget Sound Feeding Group

N Puget Sound gray whale (Sounders) histories for whales seen more than 2 years



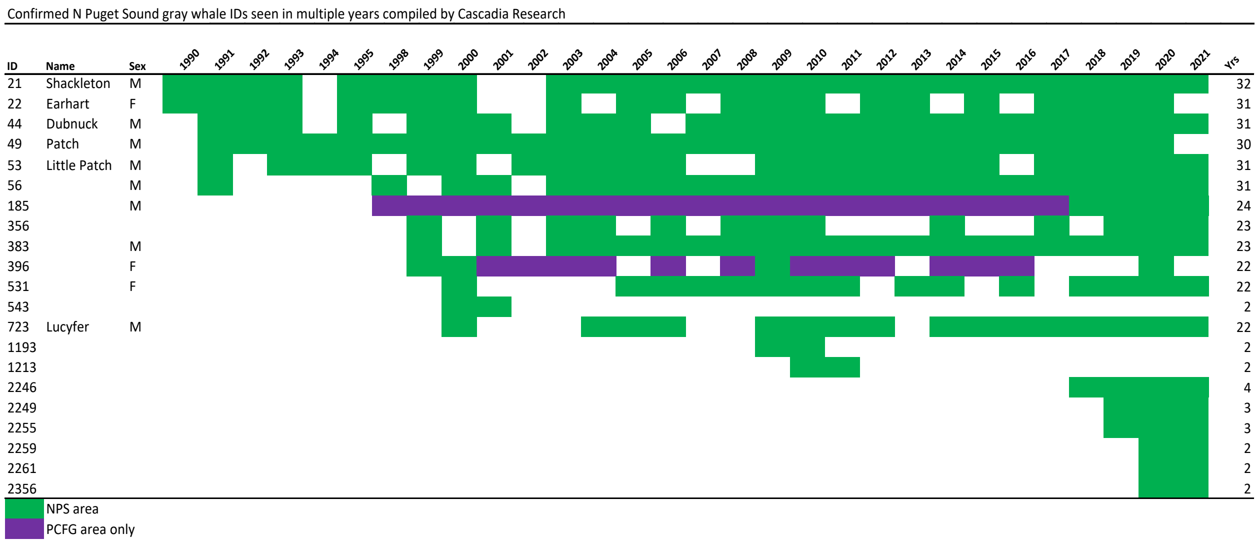


Table 2-1: This table shows the North Puget Sound gray whales recorded in the Puget Sound and/or Pacific Coast Feeding Group areas. It also shows which years they were present in these areas (CRC, 2022).

In 1990, the first members of the North Puget Sound (NPS) feeding group, known as the Sounders, were recorded in the North Puget Sound. These individuals detour into Washington waters for approximately three months before following the other members of the ENP stock to forage in Alaskan waters. The founding group was made up of CRC ID 21 (Shackleton) and 22 (Earhart) (Table 2-1). To be a Sounder, the whale must have shown up for more than two years. Since then, the group has increased. Between 1999 and 2000, the group grew to 11 individuals (Table 2-1). Between 2019 and 2021, the group again increased to approximately 15 individuals (Table 2-1).

Interestingly, some of the PCFG whales have transitioned to being Sounders (Table 2-1). During all three-time segments, UMEs were impacting the ENP. So, it could be speculated that these events pushed the gray whales to explore new areas to survive the difficult events.

To improve their conditions, the Sounders take part in risky behavior in shallow waters to suction feed on ghost shrimp, also known as sand shrimp (Figure 2-4) (Pruitt & Donoghue, 2016). In the wake of these efforts, the gray whales leave feeding pits (approximately 3 x 2 m in size) (Pruitt & Donoghue, 2016).

This strategy of feeding on the shrimp has been beneficial for the Sounders. Between 2020 and 2022, while many other whales in the ENP stock were in poor condition, the Sounders and other whales recorded in Puget Sound improved their condition (Fearnbach & Durban, 2022). While these changes may have happened during different years, there were no drone studies to measure the whale's body conditions until 2020.

Figure 2-4: This image shows three ghost shrimp taken in a sample from the Puget Sound (Pruitt & Donoghue, 2016).

2.8 Whale-Watching Regulations

Whale-watching regulations for commercial trips and the public on the West Coast of the United States break into two categories of killer whales and other cetacean species. For killer whales, their protection ranges from a minimum distance between the boats and whales of 200 to 400 y/m (NMFS, 2020b). Other cetaceans, including gray whales, have a minimum distance between the boats and whales of 100 y/m or .1 km (NMFS, 2020b).

2.9 Anthropogenic Effects

Few studies have investigated anthropogenic effects on gray whales. Therefore, we mainly rely on similar studies on other cetaceans. Whether documented effects on whale's behaviors are present depends on various factors (Senigaglia et al., 2016). In most studies, researchers concluded that the presence of boats adversely affects whales, but this was not consistent across all species and regions (Senigaglia et al., 2016). Some of these disturbances resulted in fasting and increased erratic movement, which combined to cause calorie deficits (Senigaglia et al., 2016). Regarding acoustics, boats have been known to alter gray whale's (Burnham & Duffus, 2019) and humpback whale's communications (Fournet et al., 2018). For Northern Resident killer whales, both males and females showed avoidance tactics during the periods when boats approached them (Williams et al., 2002). In Iceland, minke whales responded to the presence of boats by decreasing their IBI and increasing their sinuous movements (Christiansen et al., 2013). From a study on WNP stock of gray whale's responses to seismic surveys, the researchers found that some of the whales sped up and traveled in a more linear path away from the sounds when present, but these impacts were not found across all individuals studied (Gailey et al., 2016). Cumulatively, these disturbances can cause whales to avoid and abandon high-disruption areas (Lusseau & Bejder, 2007).

Sullivan and Torres produced the most similar paper to this thesis in 2018, which attempted to assess the impacts of vessel disturbance on gray whales off Oregon. This paper had robust methods of using a theodolite and laptop running the software Pythagoras to record the locations of boats and whales and then compare the distances between the two. I disagreed with the way they performed their data-analysis. Specifically, I disagreed with their use of the residence in space and time concept, which divided observations of gray whales into three behaviors of search, travel, and forage, which was an oversimplification of the gray whale's behaviors. Also, they chose to exclude resting from the behaviors, which I disagreed with. I felt that they needed to also measure other response variables of speed, DEV, DI, and IBI. Partially, because of this research, I wanted to perform a similar research project to assess the impacts of vessel disturbance on gray whales.

2.10 Shore-Based Observations

For cetacean research, shore-based observation methods have been used for decades (Piwetz et al., 2018). These noninvasive methods allow researchers to record information about nearshore marine mammals' habitats, behaviors, and movements without affecting the studied individuals (Piwetz et al., 2018). For studying anthropogenic effects on marine mammals, this tool allows researchers to study these impacts without affecting the animals themselves.

2.10.1 Theodolite Observations

The theodolite was built for surveying and construction, but marine mammal scientists have used it for research (Piwetz et al., 2018). In the 1970s, Roger Payne and colleagues repurposed it to study marine mammals (Piwetz et al., 2018). Since then, technology has come a long way. Originally, the angles and other information provided by a theodolite were written down, which would later be used to calculate the observational data (Piwetz et al., 2018). Now, theodolites can be connected to a laptop running software, which organizes and calculates the data from the observations almost immediately (Piwetz et al., 2018). For computer software, Pythagoras can be used, which calculates the locations and records the behaviors of the marine mammals being studied (Gailey et al., 2016).

3. Methods

3.1 Study Area

The Pacific Northwest's Hat Island (Figure 3-1), also known as Gedney Island, is in the North Puget Sound of Washington State (Figure 3-2). It provided an ideal location for observations of gray whale interactions with boats because gray whales forage around this island every year from March to May (Calambokidis et al., 2002)

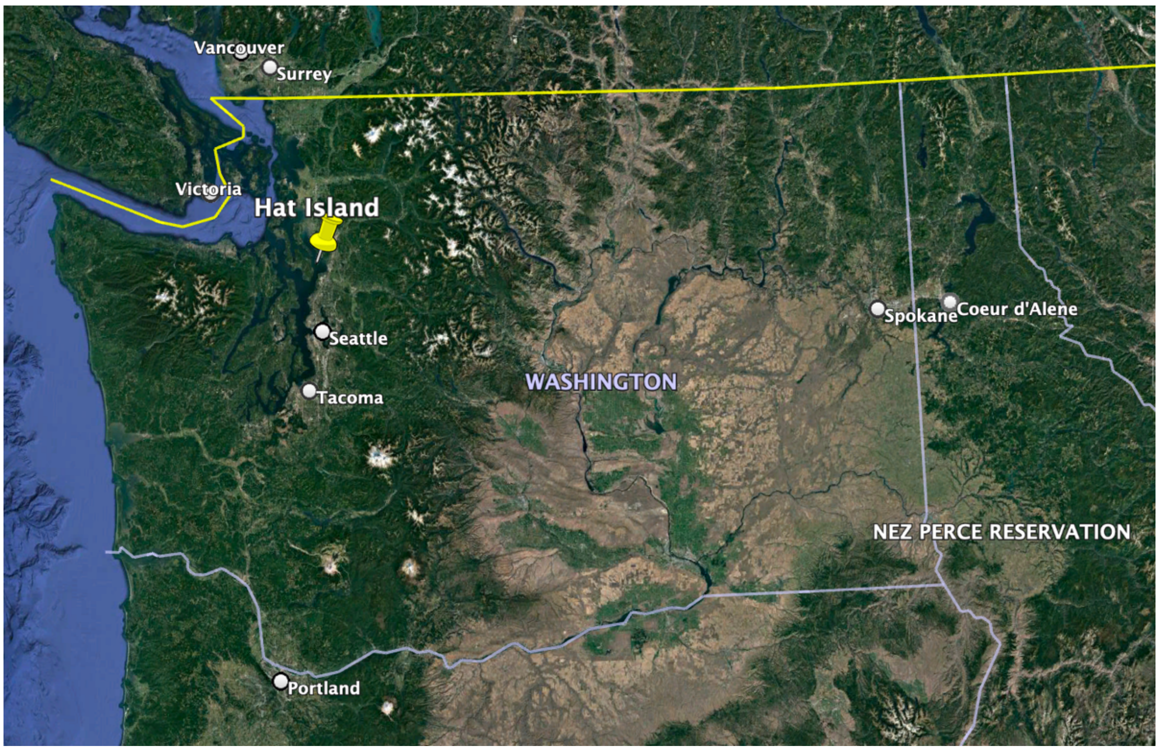


Figure 3-1: This image taken from Google Earth shows Hat Island's location relative to the Pacific Northwest (Google Earth, 2020a).

Figure 3-2: This image shows Hat Island relative to the Snohomish River Delta (Google Earth, 2020b).

3.1.1 Observation Posts

Three observation posts (OPs) were utilized for this project to observe boats, whales, and their interactions. In 2019, a team visited the island to scout the island for the upcoming field season. Because Hat Island was a private island, permission was required to ride the ferry to the island and gain access to private property. From this trip, five OPs were initially selected. After the first week of the project in 2020, the number of OPs was reduced to three.

From this point forward, the OPs will be referred to by a letter followed by a number (e.g., F15) used on the island (historically, the island was divided into approximately 21 different areas of houses, with each area assigned a specific letter). For each OP, the GPS location and heights were entered into the laptop, and reference azimuth points (e.g., tops of flag poles) were selected. Additionally, known points (at sea level) (e.g., boat navigation piling) were chosen to check the accuracy of the theodolite after it was set up.

The most used OP to observe the whales from was F15 (48°00'57" N, 122°19'06" W, 53 m elevation). This location provided the best vantage point, with almost 180 degrees of view. Also, it offered an excellent view of the Snohomish River Delta, where the gray whales fed almost daily. When observing from this OP, the lowest tide was -.18 m, and the highest was 3.1 m, with a mean height of 1.65 m.

The next most used OP was W18 (48°00'17" N, 122°18'21" W, 38 m elevation). From this post, the whales could be observed South and West of Hat Island. From this area, the whales were often seen traveling more than foraging. When observing from this OP, the lowest tide was -.83 m, and the highest was 3.31 m with a mean height of 1.07 m.

The least used post was M27 (48°1'14" N, 122°19'44" W, 78 m elevation). This OP provided a view north of the island, including Camano Head and East Tulalip Bay. From this site, the whales were seen traveling more often than foraging. When observing from this OP, the lowest tide was -.16 m, and the highest was 3.33 m with a mean height of 1.49 m.

3.1.2 Hydrographic Map Around Hat Island

Using the map below, we can see that Puget Sound's floor is quite variable in its depths around Hat Island (USGS, 1993). While some places near the island are shallower than -10 m, the majority of depths are greater (USGS, 1993). In contrast to this shallowness, a deep area northwest of the island is greater than -166 m.

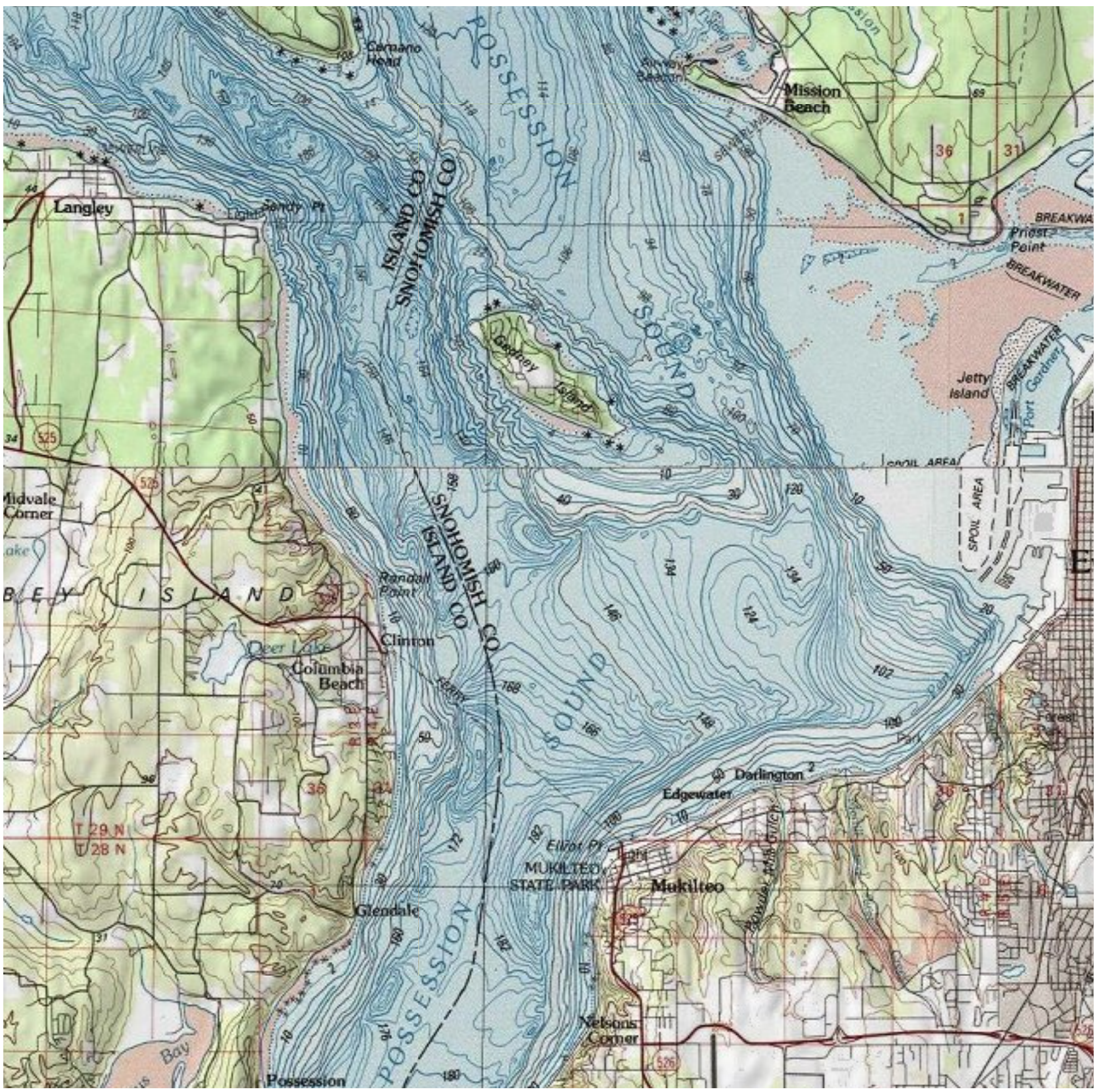


Figure 3-3: This image shows hydrographic information about the Puget Sound around Hat Island (USGS, 1993) in the metric system (m depth).

3.2 Theodolite & Visual Observations

From March 15 to May 14, 2021, theodolite and visual observations were used to record locational data on boats and whales and behavioral data on whales. From the locational data, the proximity of the vessels to the whales was recorded. These observations were limited by the visibility rated on a zero to five scale, usually a four or five. A zero value represented the observers' inability to see six feet in front of them. The Beaufort Sea state also limited the team, usually a two when tracking. One day, the group attempted to observe with the Beaufort scale at a five. After a time, these efforts ceased, because of an inability to follow the whales, due to the height of the waves. All observations took place during daylight hours.

For fieldwork, there was a team ranging from two to four individuals (Figure 3-4). For recording locational data on boats and whales, a Sokkia DT5A theodolite was used with a 5 s level of precision and a 30-power monocular magnification (Gailey et al., 2016). This theodolite was connected to a Toughbook computer running the software Pythagoras (v1.2), which calculated the precise locations of whales and boats. This act was completed using a cord attached to the RS232 output point on the theodolite and a USB port on the laptop. This software also allowed us to record IBIs on the computer. Additional observations were made with binoculars or a spotting scope.

Figure 3-4: This image shows the team set up for tracking whales. The theodolite operator would be using the device on the yellow stand. The computer operator in the red chair would be recording the data. The spotter utilizing the spotting scope would be communicating data to the computer operator.

3.2.1 Tracking Whales

Tracking or conducting focal follows of a specific whale can be broken into five distinct steps.

1. First, the whale or whales had to be located, which was done by using Facebook whale-watching groups and receiving tips from Hat Island Residents. If those options were not producing whales to observe, the team would rotate through the different OPs and scan the surrounding area with binoculars.

2. Once a whale was located, the timing of its breaths was recorded each time it surfaced. These efforts are all under the title of Inter-breath Intervals (IBIs), which include blows, dives, and missed blows and dives, as defined below.

Surfacings: This is an all-inclusive term, including missed dives, missed blows, IBIs, dives, and blows.

Missed dives & blows: When the observers or operators miss the timing of a "blow or dive" but know that it occurred. The recording of these behaviors results in the IBI durations were not calculated.

IBI: The time between whales blows for any duration, including blows dives.

Dive: When the whale blows after being under for 60 seconds or more.

Blow: When the whale blows after being under for less than 60 seconds.

If the timing of the dive duration being recorded were incorrect, then a note would be recorded to remove it later. For example, if the residue of the blow was visible, but the actual blow was not seen. For data accuracy, the exact moment when the whale first blew was recorded. If this was even a second late, a missed dive or blow would be recorded instead.

After leveling the theodolite, the visibility, Beaufort Sea state, and tide heights were recorded into Pythagoras. These numbers were updated and recorded on the laptop at least every thirty minutes. Then, the check accuracy point was used. If the theodolite and laptop provided us with the correct latitude and longitude, then tracking would begin. If not, then the theodolite was releveled. Also, if the theodolite was bumped, we would check the accuracy of the theodolite. Due to the height of observation posts, which increased the accuracy of the theodolite (Würsig et al., 1991), tracking was conducted out to 7600 m. Beyond this distance, visibility became an issue. So, there were no efforts to track whales or boats beyond 8000 m.

Next, whale locations were recorded using a theodolite. Each recorded data point had a fixed type, time, day, latitude, and longitude.

If an inaccurate fix was recorded, either the delete last fix option was selected in Pythagoras, or a note would be taken to remove it from the data set later.

Theodolite accuracy was checked on one occasion. On March 30, 2021, the first session to check the accuracy of the theodolite took place from stations M27 and W18. This test was completed with the help of a Cascadia Research Collective vessel. An individual on the ship recorded a GPS point; then, it would be compared to the land-based crew's data. For a theodolite, the further the distance between the theodolite and the boat or whale being tracked, the less accurate the theodolite is.

Test 1

On March 30, 2021, the accuracy of the theodolite was tested from M27 and W18. The maximum distance between the boat and the land-based team was 2307 m.

After comparing the data sets, the difference in accuracy between the boat and land-based teams' data was 0-22.2 m, except for P9 and P5b. The average difference for latitudinal values was 0.00009375 (much less than 11.1 m) and for longitudinal values was 0.0000875 (much less than 11.1 m). For P9, the theodolite was bumped, which caused the difference between the land-based and boat-based observations to increase to 22-33 m for the longitude and latitude values. For P5b, the locations did not match up because of a communication issue between the land and boat-based teams about when to record the point.

This tracking session gave us confidence in the equipment used for this research. The slight difference between the data recorded by the boat versus the land-based team could be attributed to the groups fixing the points at slightly different times. This situation likely happened because the two teams had identical values during some fixes.

3. When a whale displayed a singular behavior, the team recorded it (see definitions below). If false behaviors were recorded, the computer operator would put a note in to remove it later.

Pectoral Fin showing: When the pectoral fin breaks the surface of the water in any way, i.e., half showing or fully exposed, usually when the whale was on its side assumed to be feeding.

Peduncle showing: When the area where the tail fluke connects to the body was visible after a blow/surface right before a dive.

Spy-hopping: When the whale surfaces vertically so that only its head was seen.

Fluke Up: When after a surface, a whale lifted its fluke completely to clear the surface of the water in preparation for a dive.

Side Fluke: When a whale was seen on its side, and the fluke broke the surface in a vertical position, often seen during foraging bouts.

Breaching: When all or most of a whale's body broke the surface of the water.

4. When possible, the gray whale being tracked was identified. Each gray whale that has visited Puget Sound has been given a corresponding CRC identification number (Table 2-1). Unfortunately, due to the distance at which the whales were tracked, this situation happened approximately 1 in 25 times. When it happened, the team utilized a Nikon DSLR with a 400mm telephoto lens.
5. When operated properly, all these steps listed above became a streamlined process. The whale would first be identified and selected, and the station would be set up. If a boat or boats were within 1 km, it would be mentioned in the notes. First, the breath would be recorded on the laptop. Next, a fix for the whale would be taken. These two actions would take about two sections and involve using two different windows in Pythagoras. If the whale produced any singular behaviors, those would be recorded. While the whale was subsurface, a fix of the boat or boats would be taken. After this, the computer operator got ready to record the breathtaking place, which would quickly be followed by the fix.

3.2.2 Tracking Boats

Anytime a boat was within 1000 m of the whale, this vessel was recorded either by putting it in the notes or getting a fixed point of the ship. These boats were broken into distinct categories based on types and whether they were participating in whale-watching activities. **Recreational/ non-whale-watching boats were this if…**

- They were not actively pursuing the whale.
    - No change in speed or direction to match the path of the whale.
- They were significantly distanced from the whale >1000m.
- They were traveling with no delineation in speed or direction in response to a whale's presence.

While Whale-watching boats were whale-watching if…

- They were actively pursuing a whale with obvious changes in boat speed and directionality to match the whale's path.
- They were within a close range of the whale, <1000m, with signs of using cameras or binoculars.
- They were known as commercial whale-watching boats on active tours.
- Their initial speed and direction changed their orientation towards the whale in response to a whale's blow/surface.

Additionally, vessels were divided into categories based on their hull design and purpose (Wladichuk et al*.,* 2018), including ridged-hull inflatable boats (RHIBs), monohulls, catamarans, landing craft, and sailboats. These same vessels were also divided between being used for recreational, commercial, or research purposes.

3.2.3 Calculating & Cleaning Variables

After removing eccentric and individual (singular) data points, IBIs, speeds, direction (DI), and deviation indices (DEV) were calculated. For IBIs, if the notes said that the dive or blow was missed or the resulting duration was longer than 10 minutes, then that IBI duration was removed. For the movement metrics, if the whale's speed exceeded 15.5 KM/hour, then the corresponding data point would be removed.

From the timing of breaths, IBIs were calculated as the time between two breaths (Christiansen et al., 2013). If a missed dive or blow occurred, then IBI was not calculated for that period (Christiansen et al., 2013). Because of the shallowness of the study area, any dives ≥ 10 minutes were excluded.

From the GPS points and time, speed, direction (DI), and deviation indices (DEV) were calculated for the whales. These metrics were only calculated to get the best analyses if there were a minimum of two surfacings before the specific data point (Christiansen et al., 2013). For each of these groups of three, the three metrics were calculated. This situation allowed us to get the most out of the data. Speed was calculated by dividing the distance traveled between two surfacings by the time taken to complete this action. After reviewing the literature, the highest speed at which a gray whale was recorded traveling was 15.5 KM/hour (Sumich, 1983). So, any speeds recorded greater than that were thrown out.

DEV and DI show the linearity and path predictability of a whale's path (Williams et al., 2002). DEVs ranged from 0°-180°, with 0° being a straight path and 180° being a change in the whale's path to the opposite direction (Figure 3-5).

The values for DI range from 0-1, with 1 showing the whale traveled in a straight line and 0 indicating that the whale traveled in the opposite direction. For equations to calculate DI and DEV, please see the description of Figure 3-5 (Christiansen et al., 2013).

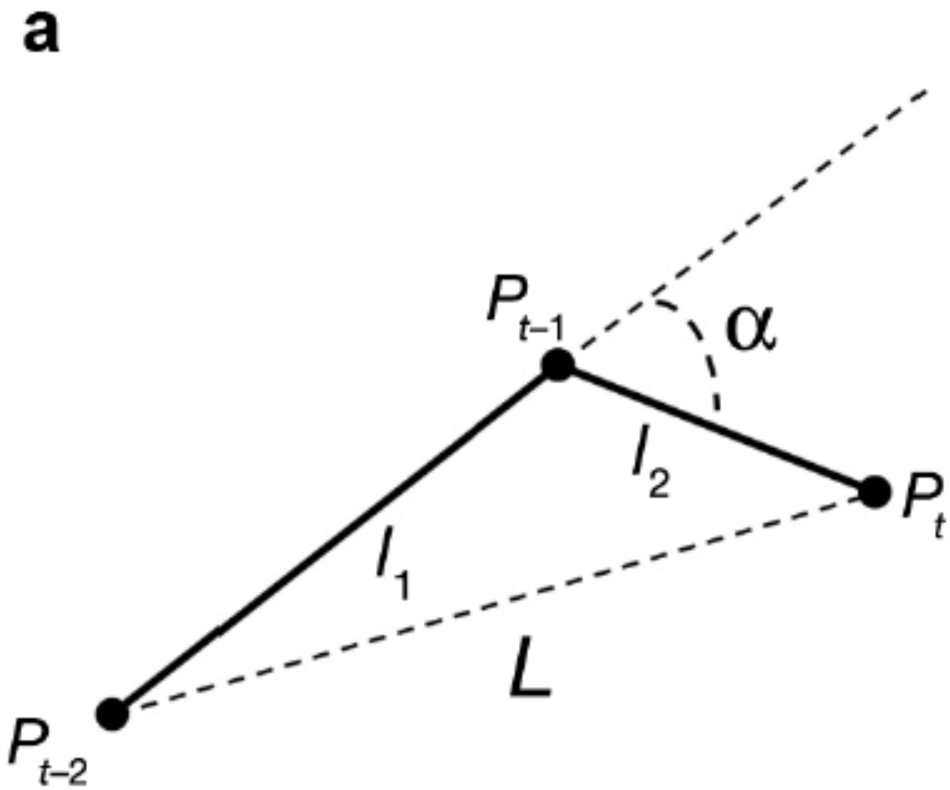


Figure 3-5: This image and description show how DEV, DI, and IBI were calculated, "Example of a movement track of a minke whale with 3 surfacings (Pt, Pt−1 and Pt−2) and 2 inter-breath intervals (IBI) (l1 and l2); Pt is the present position, Pt−1 the previous position, etc. and L is the net distance traveled between Pt and Pt−2. The deviation index for l2 is α. The directness index (DI) for l2 is calculated by DI = 100 · [L/(l1 + l2)]" .

3.2.4 Focal Follow Types

The data recorded about the whales were divided into two distinct categories (boat & no boat). **Boats were believed to be present within 1000 m of the whale (boat) if…**

- Boats were fixed within 1000 m of the whale.
- Notes mention boats present within 1000 m of the whale.

No boats were believed to be present within 1000 m of the whale (no boat) if…

- Boats were not fixed within 1000 m of the whale or were fixed beyond 1000 m of the whale.
- Notes contain no mention of boats present within 1000 m of the whale.

For blows and dives, they were divided into boat or no boat categories. If a boat was present within 1000 m of the whale for most of the blow or dive duration, it was put in the boat category. If a boat was present within 1000 m of the whale for less than half of the blow or dive duration, it was put in the no boat category.

The movement metrics were divided into different focal follows. If a whale was tracked for the first 10 minutes without a boat present, it would be in the no-boat category. However, if a boat appears on the scene at the 11-minute mark, it is broken into a new focal follow in the boat category. For example, if fixes one through twenty are of the same whale, one through ten are with no boat present within 1000 m, and eleven through twenty are with a boat present within 1000 m, then these fixes are separated into two separate focal follows for analysis.

3.2.5 Measuring Anthropogenic Effects & Data Analysis

Speed, DI, and DEV data were recorded about whales to measure possible anthropogenic impacts. The datasets were broken into two distinct categories of when there were and were not boats within 1000 m of a whale. The two categories of boats present versus no boats present had two subcategories. Movement metrics (speed, DEV, DI) were analyzed as one subcategory. The second subcategory was Inter-Breath Indices (IBI). To properly analyze the data points, these two groups had to be separated due to differences in their data structures.

For the movement metrics, the differences between the two groups were tested using multivariate statistics. After the movement metrics were cleaned, organized, and calculated, these three-movement metrics were graphically assessed using violin plots between the two groups (boat versus no boat). Second, all three-movement metrics were tested for normality using the Shapiro-Wilk normality test. Next, we used a multivariate Hotelling's T^2 test to determine the possible impacts of ships on all three-movement metrics together. This test allowed us to account for correlation between behaviors, increase the test's power, and preserve the type I (experiment-wise) error rate.

To assess the difference between individual movement metrics, both Welch's two-sample t-test and Mann-Whitney U-tests tests were used. First, to assess the difference between individual movement metrics parametric, two-sample t-tests were used. Even though the distributions of the movement metrics were non-normal, because of the Central Limit Theorem, these tests were suitable for the datasets. According to this theorem, if the datasets contain a large enough sample size, which movement metrics (956 boat, 1843 no boat) had, then the lack of normality in the data is not problematic, and the t-test was suitable (Lumley et al., 2002). For this test, Welch's t-tests were chosen over Student's because of an unequal variance between the two groups. Additionally, to compare the results of the t-test to a nonparametric test, our three metrics were analyzed using Mann-Whitney U-tests. This test does not require the datasets to be normally distributed.

To account for any correlation structure among the movement metrics and to calculate the effect of each movement metric in separating the two groups of whales with and without boats present, standardized discriminant function coefficients were analyzed.

To standardize the data, each movement metrics distribution was converted to a mean of 0 and a standard deviation of 1. Doing this allows for a direct comparison of the contribution of the movement metrics to the difference between the groups (boat versus no boat).

To assess whether boat presence impacted IBIs, Welch's univariate t-test and Mann-Whitney U-tests were used. After the IBIs were cleaned and organized and IBIs were calculated, this data was divided into three categories of all IBIs, dives, and blows. The three dive duration metrics were graphically assessed between the two groups (boat versus no boat). All three categories were tested for normality using the Shapiro-Wilk normality test. Then, the parametric Welch's two-sample t-tests were used to determine the difference between the boat versus no boat data for IBIs, dives, and blows. Even though the distributions of the IBIs were non-normal, because of the Central Limit Theorem, these tests were suitable for the datasets. According to this theorem, if the datasets contain a large enough sample size, which IBIs (1523 boat, 2549 no boat), dives (555 boat, 725 no boat), and blows (978 boat, 1864 no boat) had, then the lack of normality in the data did not matter, and the t-tests were suitable (Lumley et al., 2002). For the univariate t-tests, Welch's t-tests were chosen over Student's because of an unequal variance between the two groups. To compare the results of the t-test to a nonparametric test, our three metrics were analyzed using Mann-Whitney U-tests. This test does not require the datasets to be normally distributed.

To account for the limited number of focal follows (movement metrics = 98, IBIs =116) and three observation posts (F15, W18, M27) used to observe the whales, Generalized Least Squares (GLS) models were used. To create the best fit models for our variables (speed, DEV, DI, IBI), many different models were compared using AIC and BIC scores. The final models were selected by using these scores. GLS was not utilized for blows or dives. These comparisons included accounting for the correlation among focal follows by using them as the autocorrelation structure for models, which made the model fit better. Additionally, boat and OP were used as the variance structures to create a better-fitting model for the movement metrics. This change was not made for IBI because the models fit worse with that variance structure added.

4. Results

Data was recorded from March 15 to May 14, 2021, on Hat Island, Washington. These efforts resulted in 76.5 hours of observational data on whales. To analyze speed indices, direction indices, deviation indices, dive durations, blow durations, and IBI durations, R (R v4.1.3) was used.

This section will first cover the results and analyses for the movement metrics of speed, DEV, and DI. Next, the results and analysis of IBIs, dives, and blows will be presented. Finally, this chapter will end with a summary of the analysis performed for this thesis.

Figure 4-1: This image shows the locations of the observation posts on Hat Island, Washington (Google Earth, 2020c).

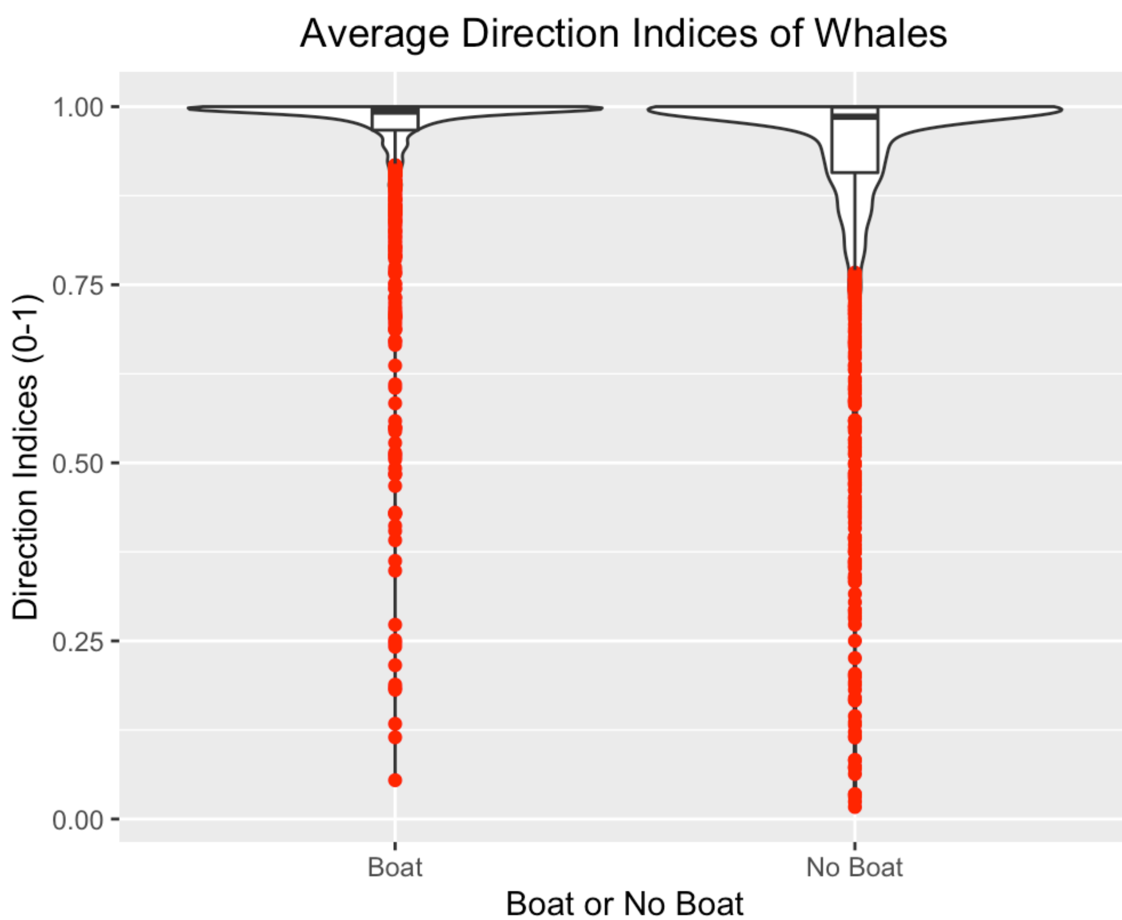
4.1 Direction, Deviation, & Speed Indices

Over 98 focal follows, 4537 fixes of a whale's locations (1297 boat, 3363 no boat), and 1127 fixes of boats were recorded. F15 (Figure 4-1) was the site where we observed the whales from the most, which produced the most fixes totaling 2871. The next most productive OP was W18 (Figure 4-1), with 909 fixes. The least used OP was M27 (Figure 4-1), totaling 757 fixes. After removing the fixes used to check the accuracy of the theodolite, removing the incorrect fixes, and the fixes which could not be used to calculate movement metrics, 3187 fixes remained. The distance between the theodolite at the observation post and the whale or boat being tracked ranged from 256 to 7601 m, with the average distance being 3264 m. From this data, 2799 estimates (956 boat, 1843 no boat) of DEV, DI, and Speed were calculated. These estimates were broken into 98 focal follows ranging from 19 seconds to 2 hours and 9 minutes.

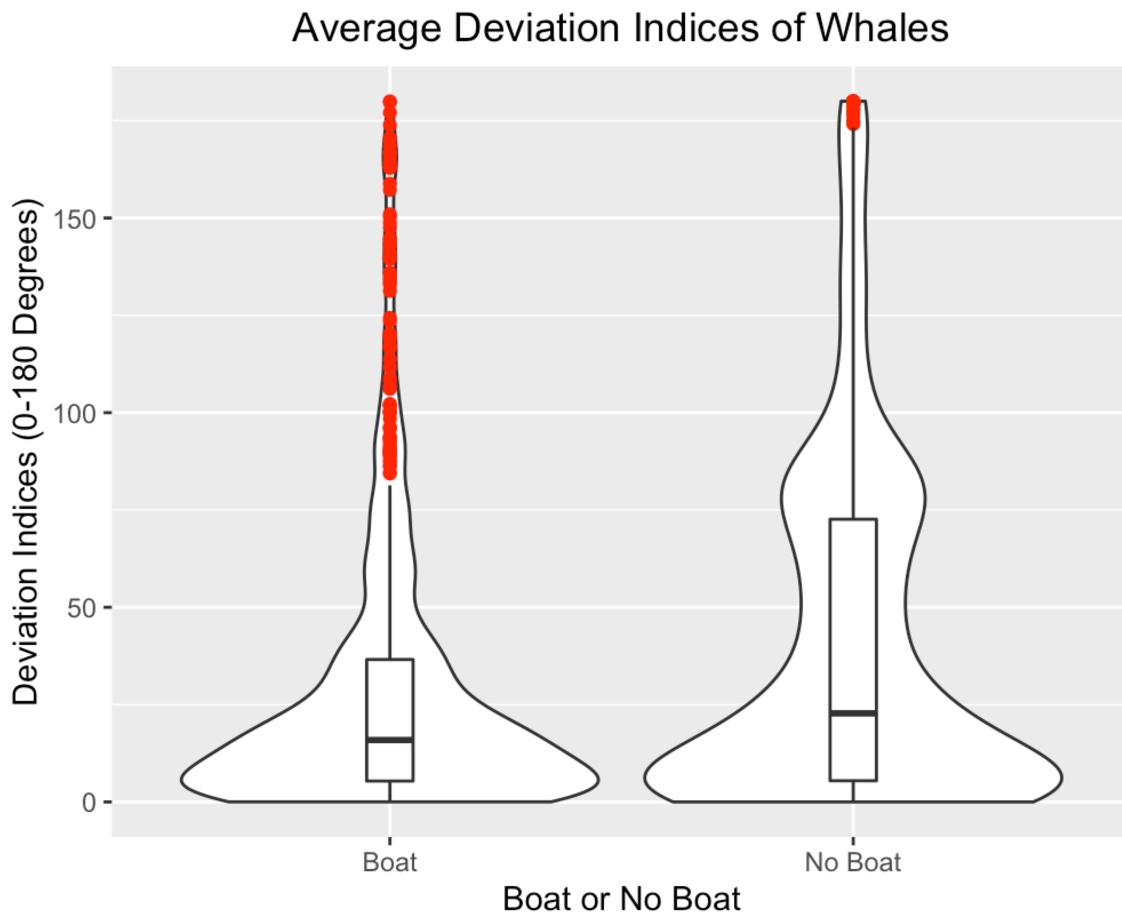
Description	Boat/ No Boat	Mean	SD +/-	Min	Max	N
IBI (S)	**Boat**	66.71	65.18424	2	478	1523
	No Boat	53.09	49.42066	2	448	2549
Dives (S)	**Boat**	130	71.19985	60	478	555
	No Boat	84	60.66844	60	448	725
Blows (S)	**Boat**	30.5	12.9423	2	59	978
	No Boat	30.71	13.91502	2	59	1864
Speed (km/h)	**Boat**	3.5361	1.905158	0.0155	15.1265	956
	No Boat	2.92	1.954908	0	15.346	1843
DEV	**Boat**	28.8345	35.6329	0.0205	179.9494	956
	No Boat	41.844	45.2577	0	179.997	1843
DI	**Boat**	0.94689	0.1276795	0.05444	1	956
	No Boat	0.91527	0.1633662	0.01684	1	1843

Table 4-1: This table shows the data distribution for all the response variables, the presence (boat) or absence (no boat) of vessels within a km of the whale being tracked after the data had been cleaned.
s = seconds, km/h = kilom traveled per hour, IBI =inter-breath interval, DEV = deviation indices, DI = direction indices, SD = standard deviation, and n = number of observations used.

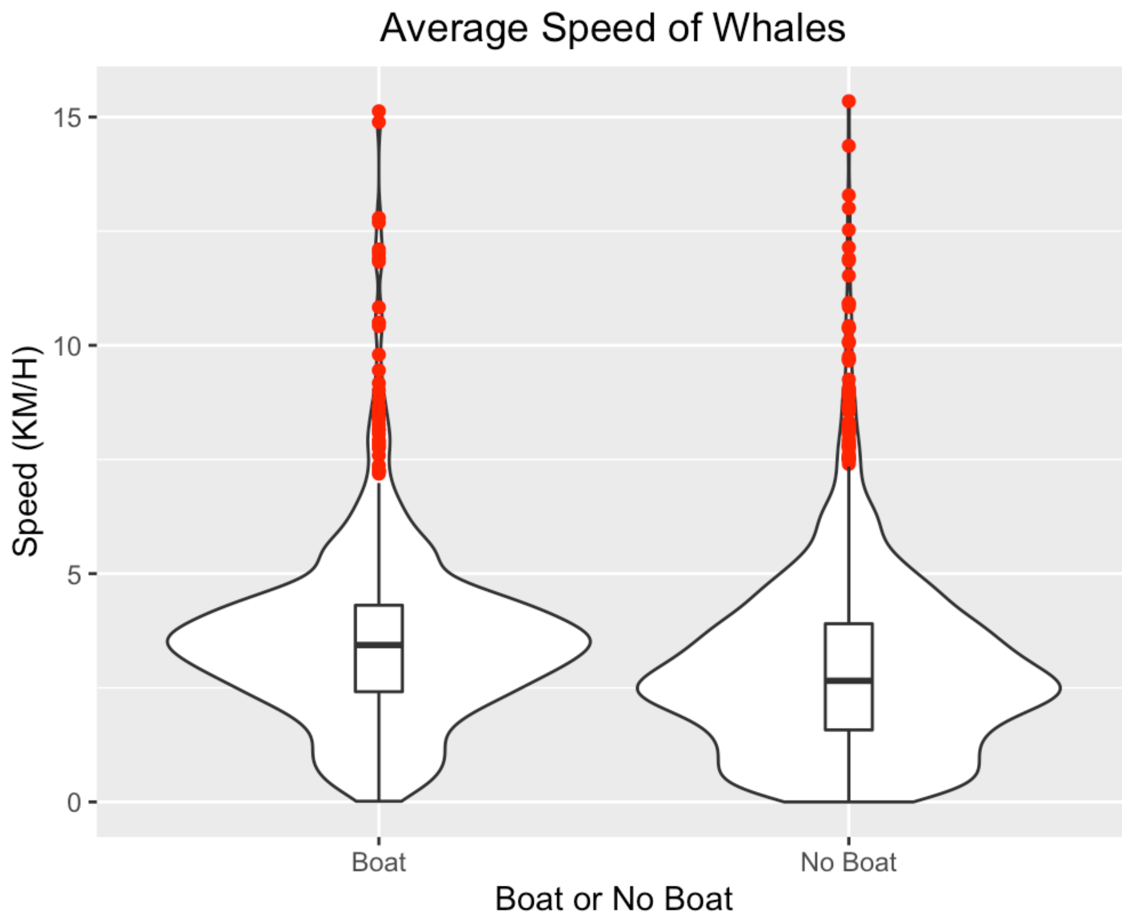
First, all the variables were plotted using violin plots (Figures 4-2) to show their distribution by the presence of boat(s) using the package 'ggplot2'. The mean directness index of whale movement with boats was 0.95 and without boats was 0.92. The mean deviation index of whale movement with boats was 28.8 and without boats was 41.8. The mean speed index of whale movement with boats was 3.54 km per hour and without boats was 2.92 km per hour. The violin plot with the greatest apparent difference between boat and no boat was for the deviation indices with a larger spread and median for no boat than boat.



a.


Average Deviation Indices of Whales
Deviation Indices (0-180 Degrees)
150
100
50
0
Boat
No Boat
Boat or No Boat

b.



c.

Figures 4-2 (a-c): These three violin plots show the distribution of the movement metrics (a) direction, (b) deviation, and (c) speed.

Second, all the movement metrics were tested for normality using the Shapiro-Wilk normality test in base R. For speed, $p < 2.2 \times 10^{-16}$, which was less than 0.05, the null hypothesis was rejected. For DEV, $p < 2.2 \times 10^{-16}$, which was less than 0.05, the null hypothesis was rejected. For DI, $p < 2.2 \times 10^{-16}$, which was less than 0.05, the null hypothesis was rejected. All three-movement metrics were not normally distributed.

Third, based on the multivariate Hotelling's T^2 test in the 'ICSNP' package in R, the null hypothesis was rejected. This test allowed us to determine the possible impacts of ships on all three-movement metrics together and account for the correlation between behaviors. These results showed whale's movement metrics between the whales in the presence of boats and whales, not in the presence of boats, were not equal ($p = 2.2 \times 10^{-16}$, $a = 0.05$, $T^2 = 40.441$, df1 = 3, df2 = -2795). While considering the movement metrics of a gray whale, there was a significant difference between when boats were present within a km of a whale or not.

Fourth, parametric univariate Welch's T-test in base R was used to assess the difference between individual movement metrics. Each movement metrics of speed, direction, and deviation were significantly different when boats were present within a km of a whale versus not. For speed, $p = 1.6 \times 10^{-15}$, which was less than 0.05, the null hypothesis was rejected. This evidence suggests that whale's swimming speeds significantly differed when boats were present versus not (t = 8.038, df = 1977.3). For deviation, $p < 2.2 \times 10^{-16}$, which was less than 0.05, the null hypothesis was rejected at the 5% level. The evidence suggests that the whale's deviation indices significantly differed when boats were present versus not (t = -8.33, df = 2363.8). For direction, $p = 2.0 \times 10^{-08}$, which was less than 0.05, the null hypothesis was rejected at the 5% cutoff level. This test suggested that whale's direction indices significantly differed when boats were present versus not (t = 5.63, df = 2377).

Fifth, nonparametric Mann-Whitney U-tests were used to assess the difference between individual movement metrics in base R. The metrics speed, direction, and deviation were significantly different when boats were present within a km of a whale versus not. For speed, $p < 2.2 \times 10^{-16}$, which was very small, the null hypothesis was rejected. This evidence suggests that whale's swimming speeds significantly differed when boats were present versus not (w = 1080535). For deviation, $p = 3.084 \times 10^{-08}$ was very small, and the null hypothesis was rejected. The evidence suggested that the whale's deviation indices significantly differed when boats were present versus not (W = 768694). For direction, $p = 2.704 \times 10^{-05}$, which was very small, the null hypothesis was rejected. This test suggested that whale's direction indices significantly differed when boats were present versus not (W = 966048).

Sixth, to account for any correlation structure among the movement metrics and to calculate the effect of each movement metric in separating the two groups in the Hotelling's T^2 test, standardized discriminant coefficient function analysis was used in the 'MASS' package in R. DEV appeared to have the most significant impact on separating the two groups (boat versus no boat) with a linear discriminant coefficient value of 0.905. The next most significant variable was speed, with a linear discriminant coefficient value of -0.695. Last and least was DI, with a linear discriminant coefficient of 0.266.

Last, based on generalized least squares models analysis using the 'nlme' package in R, boats presence still impacted the whale's movement metrics, even after accounting for the correlation among focal follows by adding focal follows as the autocorrelation structure. Additionally, by adding Boat x OP as the variance structure, a better-fitting model was established for the movement metrics. For speed, $p < 1 \times 10^{-04}$, which was less than 0.05, and thus the null hypothesis was rejected. Evidence suggested that the whale's speed indices significantly differed when boats were present versus not (t = -5.66040, df = 2795). For observation posts, when observing whales from OPW18 ($p < 1 \times 10^{-04}$, t = -8.40020, df = 2795), but not OPM27 (p = .8124, t = 0.23730, df = 2795), evidence led us to believe that this significantly affected speed indices. Using the AIC and BIC scores as guidance to select the best-fitting model, the final model for speed had an AIC score of 11032 and a BIC score of 11098 (Table 4-2).

Variables	Fixed Effects	Correlation Structure	Variance Structure	AIC	BIC	P_{boat}	P_{M27}	P_{W18}
IBI	Boat* OP	corAR1(form = ~ 1|Focal_Follow)		44053	44135	< .001	0.539	< .035
Speed	Boat* OP	corAR1(form = ~ 1|Focal_Follow)	Boat * OP	11032	11098	< .001	0.8124	< .001
DEV	Boat* OP	corAR1(form = ~ 1|Focal_Follow)	Boat * OP	28258	28323	< .001	< .001	< .001
DI	Boat* OP	corAR1(form = ~ 1|Focal_Follow)	Boat * OP	-2797	-2762	< .003	< .001	< .001

Table 4-2: This table shows the configurations of the final and best fit generalized least squares models for each of our variables. The table format came from (Christiansen et al., 2013). IBI =inter-breath interval, DEV = deviation indices, DI = direction indices, Boat = boat or boats present within a km of the whale, OP = observation post from which the observations were taking place, focal follow = tracking session number, AR= auto-regression, AIC = Akaike's information criterion, BIC = Bayesian information criterion.

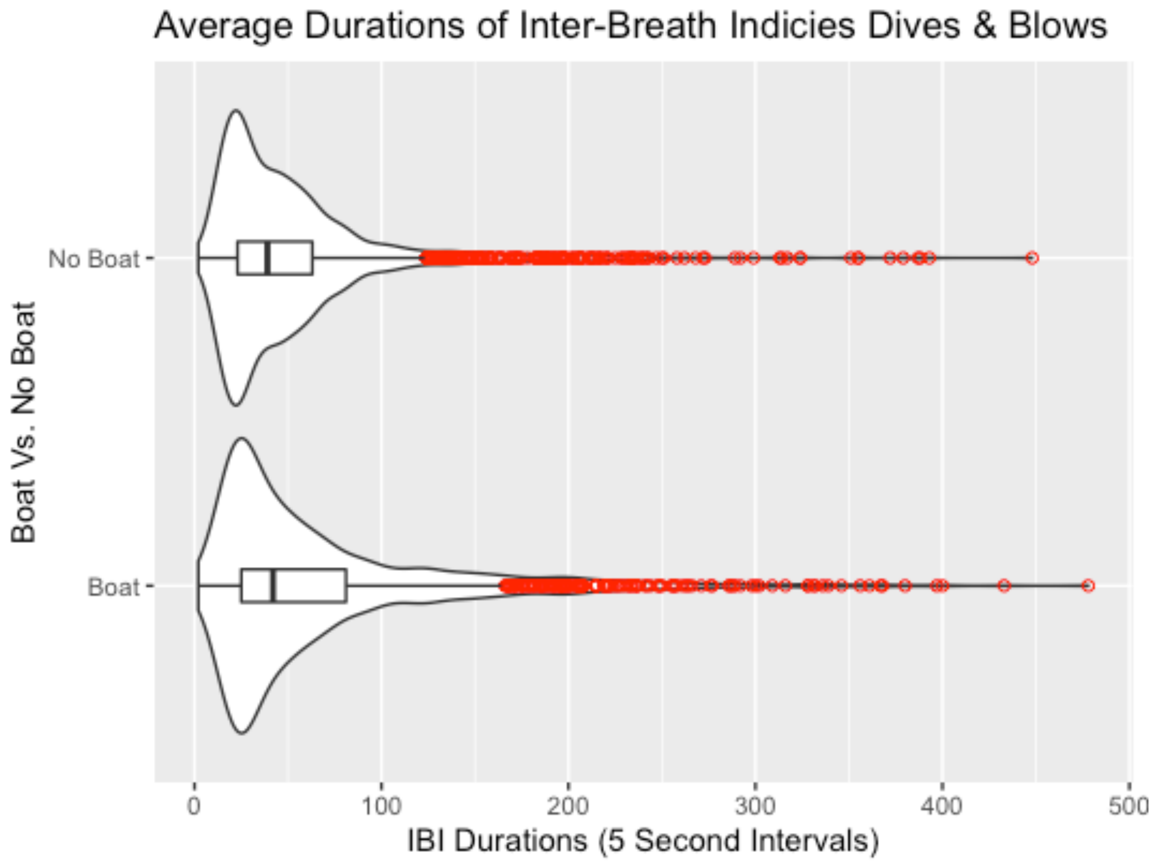
For DEV, $p = 1 \times 10^{-04}$ was less than 0.05, and the null hypothesis was rejected. The evidence suggests that the whale's deviation indices significantly differed when boats were present versus not ($t = 2.017075$, $df = 2795$). For OPs, when observing whales from OPW18 ($p < 1 \times 10^{-04}$, $t = 2.408271$, $df = 2795$) and OPM27 ($p < 1 \times 10^{-04}$, $t = 2.714495$, $df = 2795$) evidence led us to believe that this significantly affected deviation indices. Using the AIC and BIC scores as guidance to select the best-fitting model, the final DEV model had an AIC score of 28258 and a BIC score of 28323 (Table 4-2).

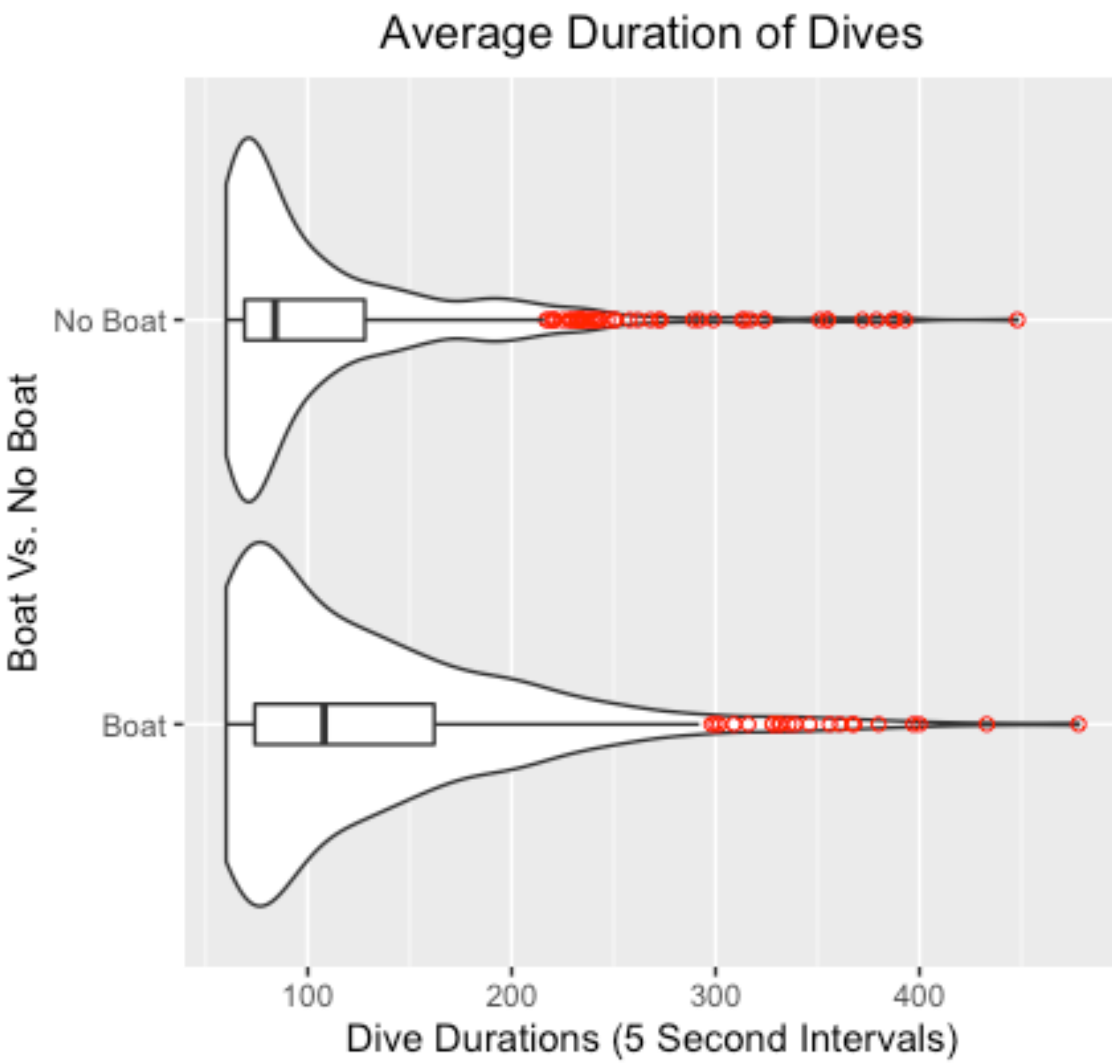
For DI, $p = 3.4 \times 10^{-03}$ was less than 0.05, and the null hypothesis was rejected. The evidence suggests that the whale's deviation indices significantly differed when boats were present versus not ($t = -2.93583$, $df = 2795$). For OPs, when observing whales from OPW18 ($p < 1 \times 10^{-04}$, $t = 4.90659$, $df = 2795$) and fOPM27 ($p < 1 \times 10^{-04}$, $t = 4.84677$, $df = 2795$) evidence led us to believe that this significantly affected direction indices. Using the AIC and BIC scores as guidance to select the best-fitting model, the final model for DI had an AIC score of -2797 and a BIC score of -2762 (Table 4-2).

4.2 Whale Inter-breath intervals (IBIs)

From the initial fieldwork, 6222 focal behaviors were recorded. From this dataset, 4355 surfacings or missed surfacings (1816 boat, no boat 2539) were recorded over 116 focal follows. These focal follows ranged in duration from 40 seconds to 2 hours and 42 minutes. F15 (Figure 4-1) provided the most surfacings with 3033. The next most productive OP was W18 (Figure 4-1), with 793 surfacings. The least used OP was M27 (Figure 4-1), with 529 surfacings. After excluding the missed dives and blows and cleaning the data, 4072 IBIs (1523 boat, 2549 no boat) were calculated. The range for IBI was 2 to 478 seconds. IBIs were divided into dives (555 boat, 725 no boat) and blows (978 boat, 1864 no boat). The range for dives was 60 to 478 seconds, and blows were 2 to 59 seconds.

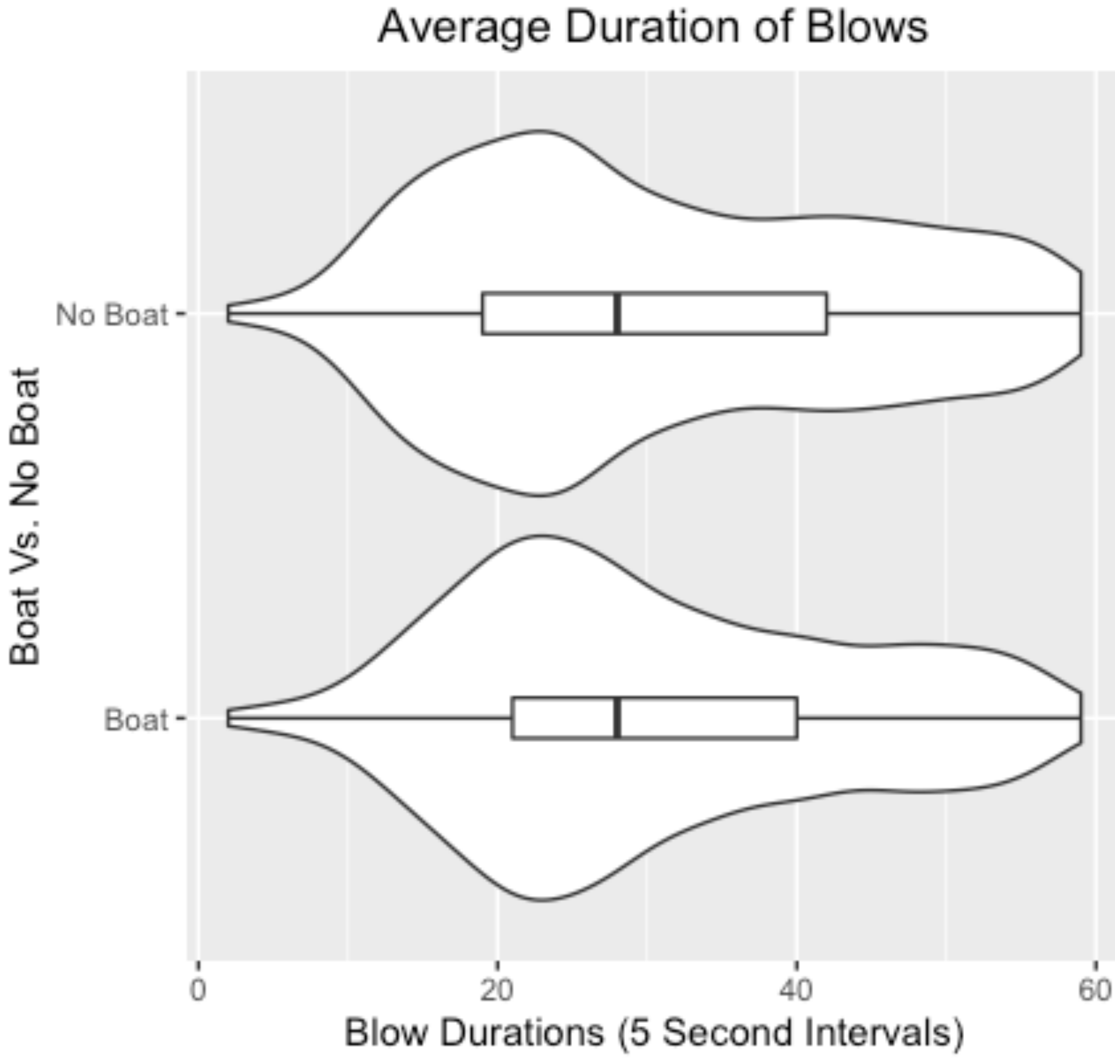
First, IBIs, dives, and blows were plotted using violin plots (Figures 4-3) to show their distribution by the presence of boats using the package ‘ggplot2’. The mean whale IBI durations were 67 seconds with boats and 53 seconds without boats. The mean whale dive durations with boats were 130 seconds and without boats was 84 seconds. The mean whale blow durations with boats were 30.5 seconds and without boats was 30.71 seconds. Visually, the violin plot with the most difference between boat and no boat was for dive durations with a larger spread and median for boat than no boat.


Average Durations of Inter-Breath Indicies Dives & Blows
Boat Vs. No Boat
No Boat
Boat
0
100
200
300
400
500
IBI Durations (5 Second Intervals)
a.


Average Duration of Dives
No Boat
Boat
Boat Vs. No Boat
100
200
300
400
Dive Durations (5 Second Intervals)

b.

c.



Figures 4-3(a-c): These three violin plots show the distribution of the durations for (a) IBIs, (b) dives, and (c) blows.

Second, IBIs, dives, and blows were tested for normality using the Shapiro-Wilk normality test in base R. For IBIs, $p < 2.2 \times 10^{-16}$, which was less than 0.05, the null hypothesis was rejected. For dives, $p < 2.2 \times 10^{-16}$, which was less than 0.05, the null hypothesis was rejected. For blows, $p < 2.2 \times 10^{-16}$, which was less than 0.05, the null hypothesis was rejected. All three of the breathing metrics datasets were not normally distributed.

Third, to assess the difference between the two categories of IBIs, dives, and blows, parametric univariate Welch's T-tests in base R were used. IBIs and dives were significantly different when boats were present within a km of a whale versus not, but blows were not. For IBIs, $p = 2.526 \times 10^{-12}$, which was less than 0.05, the null hypothesis was rejected. This evidence suggests that whale's IBI durations significantly differed when boats were present versus not ($t = 7.0361$, $df = 2566.2$). For dives, $p = 5.062 \times 10^{-08}$, which was less than 0.05, the null hypothesis was rejected at the 5% level. The evidence suggests that the whale's dive durations significantly differed when boats were present versus not ($t = 5.4879$, $df = 1084.6$). For blows, $p = 0.6841$, which was not less than 0.05, the null hypothesis was not rejected at the 5% level. This test proved that whale's blow durations were not significantly different when boats were present versus not ($t = 5.63$, $df = 2377$).

Fourth, nonparametric Mann-Whitney U-tests were also used to assess the difference between individual movement metrics in base R. IBIs and dives were significantly different when boats were present within a km of a whale versus not, but blows were not. For IBIs, $p = 6.074 \times 10^{-08}$, which was very small, the null hypothesis was rejected. This evidence suggests that whale's IBI durations significantly differed when boats were present versus not ($W = 2137666$). For dives, $p = 4.362 \times 10^{-10}$ was very small, and thus the null hypothesis was rejected. The evidence suggests that the whale's dive durations significantly differed when boats were present versus not ($W = 242084$). For blows, $p = 0.8573$, which was greater than 0.05, the null hypothesis was not rejected. This test proved that whale's blow durations did not appear significantly different when boats were present versus not ($W = 915232$).

Last, based on generalized least squares models analysis using the 'nlme' package in R, boats presence still impacted the whale's IBI durations, even after accounting for the correlation among focal follows by adding focal follows as the autocorrelation structure. For IBI, $p < 1 \times 10^{-04}$, which was less than 0.05, the null hypothesis was rejected. The evidence suggested that the whale's IBI durations significantly differed when boats were present versus not ($t = -6.789453$, $df = 4067$). For OPs, when observing whales from OPW18 ($p < 1 \times 10^{-04}$, $t = -2.113918$, $df = 4067$), but not OPM27 ($p = 0.5388$, $t = 0.614735$, $df = 4067$), evidence led us to believe that this significantly affected IBIs. Using the AIC and BIC scores as guidance to select the best-fitting model, the final model for IBI had an AIC score of 44053 and a BIC score of 44135.

4.3 Summary

In this section, the results of the data and analyses were presented. For the movement metrics, the analysis began with visual comparisons between the boat and no boat categories. As the analysis proceeded, increasingly more complex analyses were applied to the movement metrics. The final analysis was generalized least squares (Table 4-2), which accounted for the correlation among focal follows by adding focal follows as the autocorrelation structure. Similar analyses were applied to inter breath-intervals, excluding multivariate statistics and discriminant function coefficient analysis. Across many different analyses, excluding the variable blow, significant differences were found when comparing gray whale's speeds, DEVs, DIs, IBIs, and dives when boats were present within 1 km of the whale versus when there were no boats present within that distance.

5. Discussions

5.1 Interpreting the Data Analysis

Initially, the question was whether the presence of boats would impact whale's behaviors of speeds, DIs, DEVs, IBIs, dives, and blows. It was hypothesized that boat presence would impact the whale's behaviors listed above. However, at what distance would boat's presence impact whale's behaviors? To answer this query, three distance intervals of 100 m or less, 101-400 m, and 401-1000 m were planned to be used. In trying to answer those original three questions, only a combined version of all three were answered. When boats were within 1000 m or less of a whale, most gray whale's speeds, DIs, DEVs, IBIs, and dives were impacted by the presence of boats, but not blows. Intending to record 200 hours and having recorded 76 hours of observations, it was decided not to subdivide the dataset further into the three categories of the distance between the whale and boat of 100 m or less, 101-400 m, and 401-1000 m.

For the movement metrics of speed, DEV, and DI, whale's behaviors were significantly different between when boats were and were not within 1000 m of the whale being studied using multivariate tests. To analyze the impacts of boat's presence on the three-movement metrics together, a multivariate Hotelling's T^2 test was used. With $p = 2.2 \times 10^{-16}$ at the 5% level, this number tells us that the difference in the whale's movement metrics were significantly different in the presence of boats versus not. To calculate the effect of each movement metric in separating the two groups in Hotelling's T^2 test, standardized discriminant coefficient function analysis was used, resulting in the linear discriminant coefficient values of DEV = 0.905, speed = -0.695, and DI = 0.266. These values tell us that DEV had the most significant impact on separating the two groups (boat versus no boat), then speed, and the least was DI. While analyzing the movement metrics as a group, whale's speeds, DIs, and DEVs recorded when boats were present within 1000 m were significantly different than when boats were absent within that distance.

To assess the differences in the boat versus no boat categories for the individual movement metrics, parametric Welch's T-tests and nonparametric Mann-Whitney U-tests were employed. From the Welch's T-tests, speed $p = 1.6 \times 10^{-15}$, deviation $p < 2.2 \times 10^{-16}$ and direction $p = 2.0 \times 10^{-08}$, at the 5% level, the two categories of each of the movement metrics differed significantly. Using the nonparametric Mann-Whitney U-tests, speed $p < 2.2 \times 10^{-16}$, DEV $p = 3.084 \times 10^{-08}$, DI $p = 2.704 \times 10^{-05}$, all very small values, there were significant differences in the two categories of whale movement metrics when boats were within 1000 m versus not. Both these tests seemed to support the idea that there was a significant difference between the boat versus no boat categories for DI (Figure 4-2a.), DEV (Figure 4-2b.), and Speed (Figure 4-2c.). Still, since not all observations were fully randomized – for example, a single focal follow of an individual may have generated multiple measurements – autocorrelation needed to be considered.

Using generalized least squares models, boat's presence was assessed to still impact the whale's movement metrics of speed, $p < 1 \times 10^{-04}$, DEV $p = 1 \times 10^{-04}$, and DI $p = 3.4 \times 10^{-04}$, all tested at the 5% level. This test allowed lumping all the individual fixes into their corresponding focal follows (movement metrics = 98), using focal follows as an autocorrelation structure. Also, the variables Boat X OP were added as the variance structure to create a better-fitting model. Despite making both additions, whale metrics recorded when boats were present were still significantly different from when boats were absent. This test gave a high level of confidence that the boat's presence affected the whale's movement metrics because of the ability to treat all the fixes in a focal follow as correlated.

Using generalized least squares model analyses, the impacts of recording the movement metrics from different locations or OPs were investigated. For speed, when observing whales from OPW18 $p < 1 \times 10^{-04}$, but not OPM27 $p = .8124$, evidence showed that this significantly affected speed indices. For DI, when observing whales from OPW18 $p < 1 \times 10^{-04}$ and fOPM27 $p < 1 \times 10^{-04}$, evidence showed that this affected direction indices considerably. For DEV, when watching whales from OPW18 $p < 1 \times 10^{-04}$ and OPM27 $p < 1 \times 10^{-04}$, evidence indicated that this affected the deviation index considerably. These results are not surprising because the whales performed different behaviors in front of different OPs. For example, the whales were more likely to forage in front of F15 and travel in front of W18. Since all observations were combined for a complete analysis, including sites with different behaviors, the fact that the generalized least squares model still yielded significant results underscores the robustness of the observed differences in whale behavior.

For IBIs, dives, and blows, both parametric Welch's T-tests and nonparametric Mann-Whitney U-tests were used to assess the differences in the boat versus no boat categories. From the Welch's T-tests, IBIs $p = 2.526 \times 10^{-12}$, dives $p = 5.062 \times 10^{-08}$, and blows $p = 0.6841$, at the 5% level, the whale metrics of IBIs and dives were significantly different between when boats were and were not within 1000 m of the whale being studied, but not blows. Using the nonparametric Mann-Whitney U-tests, IBIs $p = 6.074 \times 10^{-08}$, dives $p = 4.362 \times 10^{-10}$, and blows $p = 0.8573$, IBI and dive values were very small values, but not the blow values. So, the whale metrics of IBIs and dives significantly differed between when boats were and were not within 1000 m of the whale being studied, but not blows. Both tests found that the boat versus no boat categories differed significantly for IBIs (Figure 4-3a.) and dives (Figure 4-3b.), but not blows (Figure 4-3c.).

Using generalized least squares models, the whale's IBIs recorded when boats were present were significantly different than when boats were absent $p < 1 \times 10^{-04}$, which was less than 0.05, even after adding focal follows as an autocorrelation structure. This analysis was not completed for dive or blow durations. Even after lumping all the individual IBIs into their corresponding focal follows (dive durations =116), using focal follows as an autocorrelation, boat's presence still impacted whale's movement metrics. This test gave a high level of confidence that the boat's presence affected the whale's IBIs because of the ability to treat all the fixes in a focal follow as correlated.

Using generalized least squares model analyses, the impacts of recording the IBIs from different OPs were investigated. When observing whales from OPW18 $p < 1 \times 10^{-04}$, but not OPM27 $p = 0.5388$, evidence led us to believe that this significantly affected IBIs. These results were not surprising because whales performed different behaviors in front of other OPs. When whales foraged, they had a more variable IBI pattern than when traveling.

To be cautious, only variables analyzed with generalized least squares models were used. To properly analyze these datasets, the IBI durations and fixes were not analyzed individually. Instead, they were analyzed with all data points in their corresponding focal follows (movement metrics = 98, dive durations =116), completed using generalized least squares models.

After running the statistical tests, there was a high level of confidence that whale metrics of speed, DI, DEV, and IBI recorded when boats were present within 1000 m significantly differed from when boats were absent. Over 76.5 hours of observations and countless other hours either observing whales or spent in the field, these efforts resulted in 98 movement metrics, and 116 IBI durations focal follows, made up of 2799 estimates of movement metrics and 4072 estimates of IBI durations. For speed, whale metrics recorded when boats were within a km of the whale had a mean speed of 3.54 km versus 2.92 km per hour when boats were absent (Figure 4-2c.). So, gray whales probably sped up in the presence of vessels. For DI, on a 0-1 scale, with 1 being a perfectly straight path between points and 0 signifying a 180-degree turn, whale metrics recorded when boats were within a km of the whale had a mean value of 0.95 versus 0.92 and had a more extensive spread (Figure 4-2a.). For DEV, on a scale of 0-180, with 0 being a perfectly straight path between points and 180 signifying a 180-degree turn, whale metrics recorded when boats were within a km of the whale had a mean value of 28.8 versus a mean value of 41.8 when boats were absent (Figure 4-2b.). Therefore, gray whales likely traveled a more linear path in the presence of boats. Whether or not these paths were toward, away from, or tangential to boat traffic was not resolved in this data set. However, it is consistent with the observed increase in speed mentioned above. For IBIs, whale metrics recorded when boats were within a km of the whale had a mean value of 67 seconds versus a mean value of 53 seconds when boats were absent (Figure 4-3a.). So, whales probably had longer IBI durations in the presence of vessels.

The assumption was that causality works one way—that boat presence impacted whale behavior, not that whale behavior influenced the presence/absence of boats. Even after including all the potential confounding variables, time of day, a small group of whales, varying depths of the water below the whales, number, and activity of vessels, the previous statement is true. Boat size and activity (for example, noise level or engine condition) could have large differences— for example, a full-throttle motorboat versus a small sailing vessel. Also, given that there were less than 15 Sounders and around 100 focal follows, the same whales must have been tracked multiple times. For seafloor depths, if a whale was tracked while it was in shallower water, it may have reacted differently than if the whale was in deeper water. Observations were from 10:00-18:00 hours, and whales could have acted differently at different times. However, the fact that observations were significant only meant the impact of confounding appears to be relatively small. Still, this would be a valuable area for future research, with potential policy implications. Given this, our analysis of the waters surrounding Hat Island shows that certain gray whale's behaviors appear to have been altered by the occurrence of boats within 1000 m.

5.2 Research Implications

While these gray whales were in Puget Sound, they interacted with several boat-based whale-watching operations and large numbers of recreational and commercial vessels. The results showed that boat's presence likely impacted gray whales. With the Sounders and the number of gray whales utilizing the Puget Sound increasing and individual whales staying longer, this feeding area is becoming more critical to the

Eastern North Pacific Stock of gray whales (CRC, 2022). In the future, this area may need to be protected.

The most recent unusually high mortality event for the Eastern North Pacific population of gray whales started in 2019 (NMFS, 2022). Since that year and continuing into this year, during that time frame, it is estimated that 25% of the approximately 20,000 whales died (CRC, 2022). To put this into perspective, the average mortality for the 18 years before this UME for the Eastern North Pacific population of gray whales was 29 whales stranded yearly (NMFS, 2021). As this population was already under pressure, limiting the stress put on this population may be critical for preventing further losses.

This research fits in well with previous research on the impacts of boats on cetaceans and can be applied to other research on studying anthropogenic effects (Christiansen et al., 2013; Senigaglia et al., 2016; Williams et al., 2002). Using methods based on Williams et al. (2002), speed, inter-breath intervals, direction, and deviation indices were measured when boats were and were not present within 1000 m of the whales. Like their research on killer whales, the presence of vessels correlated with changes in the gray whale's behaviors. These similar reactions have also been with minke whales (Christiansen et al., 2013) and many other cetacean species (Senigaglia et al., 2016).

Interestingly, Gailey et al. (2016) found that individual gray whales reacted to seismic surveys by speeding up and traveling in a more linear path away from the source of the sounds, but this did not happen with every whale. This fact is notable because this reaction was the same as observed in this study, albeit with recreational vessels. Also, while the Sounders foraged in shallow water, they were much more prone to being disturbed by boats (CRC, 2022). Future research on the Sounders population may be able to address what individual differences exist in their reactions to the presence of human activities.

The issue seems to be not if the whales were disturbed by the presence of boats but how they would be disturbed. In Senigaglia et al. (2016), the impacts fell under the categories of DEV, DI, IBI, speed, and activity budget, with the effects dependent on the species, location, and methods. This research showed boats impacted gray whales in four of the five categories listed in Senigaglia et al. (2016), a meta-analysis studying the impacts of boat's presence on whales. It fits in well with the scientific literature. Like most previous papers published on assessing the anthropogenic effects of boats on cetaceans, this research can be used to help guide similar projects in the future.

5.3 Management Implications

At the time of the research, the required separation distance between boats and gray whales was 100 m/y (NMFS, 2020), but the cutoff used in this study was much further, at 1,000 m. Even at this distance, changes were observed. Among other marine mammals, killer whales had special and increased protection from boaters of at least 200 m and up to 400 m of distance (NMFS, 2020), but even this distance between the boats and whales was relatively near. With gray whales found throughout the North Pacific Ocean, this research could be used to better inform managers of the best ways to protect this species.

It has been noted that the Sounders were more sensitive to boats presence when foraging (CRC, 2022). If a boat approached a foraging whale, it would likely stop foraging (CRC, 2022). With a short window of high tide for the whales to forage, interruptions of this critical time could cause large changes in whales caloric intake and, thus, overall health. This information suggested that a "one distance fits all" approach may not be as valuable as protection put into place for the whales in some of these areas. Future research comparing different locations, such as the different observation posts used in this study, could shed light on optimal management strategies.

5.4 Project & Analysis Limitations

Like all research projects, this one had limitations. Initially, the goal of this project was to gather more observational data. Also, the plan was to have two years of field seasons. Due to COVID canceling the pilot project in 2019, this work only took place in 2020. Also, in 2020, the ENP stock, which the Sounders are part of, faced a UME (NMFS, 2022). So, arguably, the whale's behaviors could have been different in these years.

Because there were roughly 15 Sounders, individuals would have been recorded multiple times. The whales were tracked at great distances between the whale and theodolite, and often beyond 2000 m. Photo identification pictures could not be taken of most of the whales tracked. Due to an often inability to identify the individual whale and the possibility that different whales responded differently to the presence of boats, there was no way to determine if the different whales reacted differently to the presence of boats. For example, an older whale that has come into Puget Sound for 20+ years may be more used to avoiding and dealing with boats than a younger whale. To solve this issue in future projects, identification pictures of the whales being tracked would need to be taken.

Observations were only from Hat Island. This situation could have caused a bias, due to geographic limitations. The furthest a whale was tracked from Hat Island was approximately 8000 m, which was not a small distance. Because of this, whales could only be tracked within the greater Hat Island area. If whales behaved differently in other parts of Puget Sound, this data would not be present in this study. Also, with the Puget Sound surrounding Hat Island having varying depths, this variable could have affected the whale's behaviors. The influence of bathymetry as a confounding variable remains unknown.

Using a theodolite for this research added a possible variable to this research. This tool was used to record fixes and later used to calculate the response variables of speed, DEV, and DI. The distance between the theodolite at the observation post and the whale or boat being tracked ranged from 256 to 7601 m. Before a whale or boat was tracked, a known point was used to check the accuracy of the theodolite. If the theodolite was inaccurate, it would be reset. This check revealed several times that the theodolite had not been set up correctly, and this data was removed from the analysis. Also, there was a session used to check the accuracy of the theodolite, which produced an average difference for the latitudinal and longitudinal values of 5.588×10^{-5} (less than 11.1 m). This slight difference between the data recorded by the boat versus the land-based team could be attributed to the groups fixing the points at slightly different times, which likely happened because the two teams had identical values during some fixes. These processes gave us confidence in the equipment used for this research.

There were variables focused on boats that could have impacted the data, specifically, the number, size, type, and type and number of engines on the boats. To simplify matters, the analysis compared the datasets of when there were boats within 1000 m of the whales versus not. If there were multiple boats within that distance, a note was made, and fixes on all the boats within 1000 m of the whales were attempted. When boats were fixed, they were divided into categories based on their hull design and purpose (Wladichuk et al., 2018), including ridged-hull inflatable boats (RHIBs), monohulls, catamarans, landing craft, and sailboats. These same vessels were also divided between being used for recreational, commercial, or research purposes. Also, if possible, information about the boat's engines was recorded, particularly size, number, and horsepower. This information was not included in the analysis presented here because this data was not available for every interaction with boats within 1000 m. However, if more boats with larger engines were near the whale being tracked, it is possible that the impact on the whales would have increased.

Field efforts were limited to daylight hours with good visibility. If it was raining too hard, the whales could not be tracked. The whales could not be observed if the Beaufort scale was too high. Therefore, this dataset primarily shows the whale's behaviors on clear and low-wind days. The observations usually occurred between 10:00 – 18:00 hours. It is possible that whales may have acted differently at other times of the day or night or during other weather events.

Initial methodologies for this project planned to divide the data about whale's when boats were within 1000 m of the whales into three categories of 100 m or less, 101-400 m, and 401-1000 m distance between ships and whales. The project's original goal for this analysis was to record 200 hours of observational data about the whales. By the end of the field season, 76.5 hours of observational data were recorded. Because of the amount of data collected, it was decided not to create the three subcategories and not to dilute the significance of our datasets. Nonetheless, there was still high confidence in the data.

5.5 Future Research

The research question has been answered; whale's behaviors recorded when boats were present within 1000 m or less between them significantly differed from when boats were absent. For future research, it would be valuable to have more data to perform more granular analyses. It would be interesting to compare the impacts on the whales when boats were between 1000-401 m, 101-400 m, and 100 m or less. It could be speculated that the closer the distance between the whales and boats, the more significant the impact. This sort of "dose-response" impact would not only validate the cause-effect relationship but could also be highly valuable for crafting future policy.

It would also be fascinating to look at changed behaviors and see if changes caused the gray whales to burn extra calories. While the difference in swimming speed, for example, was shown to be statistically significant, the practical significance cannot be assessed by this study. It could have a large or a small caloric impact, but that remained unknown. Measuring these impacts on whale's diet, caloric intake, physiological stress, and other factors would be extremely valuable in future work.

5.6 Final Thoughts

By now, as the reader, I hope you have learned something. If not, I hope this has provided you with the perfect document to put you to sleep!

Back to the science, even while knowing the limitations and weaknesses of this study, I am confident in the results of this study. In 2020, gray whales in the North Puget

Sound speed, inter-breath intervals, direction, and deviation indices were different when boats were present within 1000 m or less of the whale to when there were no boats present within 1000 m of the whale. While there are many unanswered questions, as noted above, the data showed a significant trend. With my coauthors' help, we hope to publish a version of this thesis in a scientific journal.

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