# HABITAT DISTRIBUTION

# OF NORTH PUGET SOUND GRAY WHALES

# BETWEEN 1990-2019

by

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# ABSTRACT

Habitat distribution of North Puget Sound gray whales between 1990-2019

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A small group of gray whales, known as the Sounders, migrate into North Puget Sound each spring to feast on ghost shrimp. This unique subset of the Eastern North Pacific gray whale population has been observed in the waters surrounding Whidbey Island for the last 29 years. Whale observation and identification data provided by Cascadia Research Collective was analyzed with the intention of identifying potential relationships between the whales, and the various areas they had been observed within Puget Sound. Utilizing ArcGIS to map observations of the 13 whales over 29 years, patterns and varying densities were identified in the different areas identified within North Puget Sound. This analysis was confirmed through the use of a Chi-square test, which indicated there is a relationship between the whales and the parcels. The recorded observations of the gray whales indicated they have preferred areas within Puget Sound that differ by individual whale. However, of all seven areas identified in this study, Possession Sound contained over 67% of the total observations recorded over 29 years. Previous research done in this field point to the abundance of ghost shrimp, their preferred prey, as one explanation for this behavior and high density of sightings within this area.

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# Chapter 1: Introduction

Gray whales are unique among whales; not only are they the only members of the genus *Eschrichtius*, they are coastal benthic filter feeders with the longest recorded migratory route of any mammal (Croll et al., 2017). Once found throughout the northern hemisphere, today gray whales only inhabit the Northern Pacific Ocean (Alter et al., 2012). They migrate over 12,000 miles annually, between the overwintering and calving grounds off the coast of Mexico to the nutrient dense summer feeding grounds in the Bering Sea. However, during the course of this long migration, 12 whales (out of 27,000) detour over 170+ miles from the standard migratory route, to come inland to feed in Puget Sound (Durban et al., 2017). Within the last two decades, scientists have determined that these 'Sounders' (affectionately nicknamed for their continued presence in Puget Sound) are using the intertidal zone in Puget Sound to feast on ghost shrimp after their winter fast (Weitkamp et al., 1992). Current research using drone aerial images to track body condition of the Sounders show noticeably 'fatter' whales leaving Puget Sound than when they enter, indicating that ghost shrimp, and at large Puget Sound, could be playing an important role in the Sounders overall health (Fearnbach, 2020).

Previous research has documented why the whales are using this area, and how their unique feeding strategy has helped them to capitalize on an abundant food source (ghost shrimp). However, a large-scale study examining the habitat distribution of gray whales within the area has never been completed. Using gray whale observational data generously provided by Cascadia Research Collective, this study will fill that gap by primarily using ArcGIS tools to use spatial analysis in order to examine where the whales have been physically observed in Northern Puget Sound.

In recent years, the larger gray whale population has declined due to an Unusual Mortality Event, an event in which there is significant die off of the population for largely unknown reasons (Marine Mammal Commission, 2020). However, the Sounders have not lost a single member of their population during these events, in fact, one researcher remarked that there has been historically small recruitment into this population during mass die-off events such as those that have affected gray whales in 2019/2020 (J. Calambokidis, personal communication, May 14, 2021). A better understanding of the habitat distribution of these unique whales could be the first step to protecting them well into the future; as policy decisions around protecting food sources, as well as high visitation areas of the Sounders are dependent on a in depth understanding of where they are spending their time.

# Chapter 2: Literature Review

## Overview

Throughout this section, I will use relevant academic literature to showcase the unique qualities of the North Puget Sound gray whale population. Each spring, these gray whales return to the area around Whidbey Island to forage for a short time before continuing on their migration route northward. However, the whales' movements while in Puget Sound had never been mapped before. This thesis will explore the observations of the Sounders from 1990 through 2019 with the intent of identifying areas of high-use among the group, as well as exploring the preferences of individual whales. I plan to explore what is known about their life history and biology to provide context as to why this behavior is unique among this sub-population compromising of 13 adults. After reviewing behavior, migratory patterns, and habitat, the focus will shift to prey selection. To understand one of the potential reasons why the whales would deviate from the traditional migratory route, we need to understand more about their preferred prey in Puget Sound: ghost shrimp. Lastly, I will review relevant research to highlight the importance of identifying critical habitat areas when it comes to policies that have the ability to protect and conserve this species.

## Gray Whale Biology

Gray whales (*Eschrichtius robustus*) were once common throughout the entire Northern Hemisphere. However, due to a number of human caused stressors including past whaling practices, pressures from pollutants, climate change, ship strikes, and

entanglement in fishing gear; gray whales are now only found in the North Pacific Ocean (NOAA Fisheries, 2020). The entire North Pacific population forms two genetically distinct groups: East and West (Alter et al., 2007). My research, and the larger scope of this paper, will focus on a smaller subset of the Eastern population, the North Puget Sound (NPS) gray whales.

## Appearance

Gray whales are named after their mottled gray and white markings and colorations. The overall mottled gray coloration set them apart from other baleen whales and aid in their identification (Nerini, 1984)). Averaging 50 feet long, these whales have no dorsal fin, and short broad pectoral fins. Females on average tend to be slightly larger than males, however, like most baleen whales the females and males are not sexually dimorphic—making them hard to sex unless observed in active breeding behavior, or with offspring (Guazzo et al., 2019).

Each gray whale has a unique pattern on their body and flukes, it is this pattern that allows scientists and researchers to positively identify individuals and track their movements over time (Croll et al., 2017). These markings set each individual apart from the group, much like a fingerprint (Johnson et al., 1984). For example, the scientists and interns at Cascadia Research Collective, the lead non-profit monitoring the movement of the North Puget Sound gray whales, have been using photographs of the whales backs and flukes since 1990 to confirm the presence of returning whales, and identify new whales in the area (Calambokidis, 2004). These photographs are kept in a data base that

is routinely updated with the purpose of tracking new scars, markings, etc. on the whale's bodies over time (Figure 1) (Calambokidis, 2016).

*Figure 1 Side profile of CRC 21 & 22*


*Note.* Each gray whale has unique mottling, scars, and other miscellaneous markings that allow researcher to identify individuals using photographs of their backs and flukes. Photo courtesy of Cascadia Research Collective.

## Population genetics

Gray whales have been found all along coastal areas in the North Pacific Ocean, however the eastern stock, which is the main focus of this paper, are found along the west coast of North America (Durbin et al., 2015). The western stock, compromising of less than 300 individuals, are found along the coast of eastern Russia, Korea, Japan and China. According to a 2018 study, "There is evidence of gene flow between the two "stocks", but there is also statistically detectable genetic differentiation between them." (Brüniche-Olsen et al., 2018). This statistically significant genetic differentiation between the two stocks may be one factor to explain why the eastern population has continued to grow in size, while the western population has remained critically endangered (Brüniche-Olsen et al., 2018).

This latest insight into the whale's genetics show that the two populations do interbreed, but not often. Additionally, the two populations of gray whales on average only co-mingle during the summer feeding season, meaning that the winter breeding between the two groups would only be possible if an individual broke away from their standard range to follow the opposite population south to breed (Alter et al., 2007). For example, a whale from California would need to head up to the arctic to feed for the summer, then migrate south, down the coast of Russia, in order to spend the winter (breeding season) with the whales of the western population (Brüniche-Olsen et al., 2018). More research needs to be done in this topic to fully understand how often this type of genetic distribution occurs between the two populations—however based on what is known now, it does not appear that breeding between the two populations happens frequently (Alter at al., 2012).

## Habitat Range

The gray whale annual migration, nutrition needs, and adaptability have allowed them to survive in a wide variety of coastal ecosystems. Due to the seasonal nature of the seas in the northern latitudes, the whales have adopted a migratory strategy in order to ensure their nutritional needs are met, as well as being able to raise their young in a safe environment (Gailey et al., 2020). For example, eastern North Pacific gray whales in the course of one year, will spend time in the near-tropical waters off the coast of Baja, California, only to migrate to the sub-artic seas in the Bering Sea (Buckland et al., 1993). The only constant, is that the whales never venture more than a few miles from the shoreline (Croll et al., 2017).

Gray whales have the longest migration of any mammal on earth (Guazzo et al., 2019). In one season a gray whale is capable of traveling 12,000 miles. In one extreme case, a tracked individual named Varvara, a member of the eastern population, completed a round trip migration totaling 14,000 miles—for perspective that's the equivalent of swimming from New York City to Los Angeles five times (Croll et al., 2017). Now, while this particular distance is considered slightly out of the ordinary—a typical migration is 12,000 miles—it does showcase the impressive distance these animals may travel in a given year to feed, mate, and birth young (Oliver et al., 1985).

The migration route of gray whales follows a predictable annual cycle. The majority of eastern North Pacific gray whales spend the winter in the shallow waters off the coast of Baja, California/Mexico (Moore et al., 2003). These warm waters provide a safe nursery for female whales to raise their young, as there are fewer predators around to threaten their survival. Additionally, these waters provide a safe, albeit nutrient deficient environment, for the whales to wait out the turbulent weather and ice-covered seas of their summer feeding grounds (Moore et al., 2001). In the late winter/early spring (approximately February to May) the whales start their northward migration where they can be seen along the west coast of the United States (Fearnbach, 2020). The majority of the whales, approximately 26,000 individuals, spend May through August in the nutrient rich waters of the Bering and Chukchi Seas. These whales will remain in the shallows of the Bering Sea through the summer into early fall (May to August) before they start their migration southward (September to November) to from their summer feeding grounds, to their wintering and calving areas in Baja (Croll et al., 2017).

During the northward migration two small sub-groups of whales break away from the vast majority headed to the Bering Sea: the North Puget Sound (NPS) gray whales, and the Pacific Coast Feeding Group (PCFG) (Durbin et al., 2017). The NPS group numbering, currently, 13 individuals, head into the waters of the Northern Puget Sound, near Whidbey Island, during the spring. These whales have been observed arriving as early as mid-February and have been observed leaving as late as June (Calambodkidis et al., 2004). Once they have spent the spring gorging themselves in the Puget Sound, they will rejoin the northward migration to the Arctic, and eventually head south again (NOAA Fisheries, 2020). Conversely, the PCFG, which numbers approximately 200-250 individuals, remain on the west coast between northern California and Washington State for the entire summer, only joining the southward migration of whales back to the wintering grounds (Durbin et al. 2017). The fact that 13 whales, out of a larger population numbering roughly 26,000, deviate from their migration each year to spend the spring in the Puget Sound is one of the things that makes the Sounders so unique.

## The Sounders

To be considered a member of the Sounders, a gray whale must venture into Northern Puget Sound during the spring more than once, and most importantly, have mastered the high-risk/high-reward intertidal feeding strategy that allows for them to feast on ghost shrimp (Calambokidis et al., 2004). Perhaps most interestingly, it is not known how other whales learn this behavior, nor is it known how the first whale came to discover the feeding areas within Northern Puget Sound (Weitkamp et al., 1992). In fact, some gray whales do venture into Puget Sound during the time the Sounders are feeding

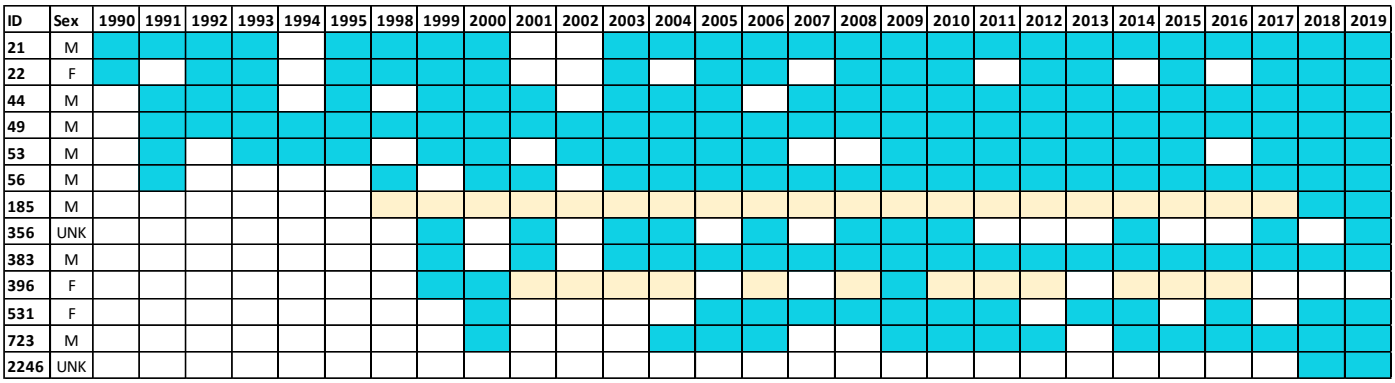
here, however, these whales don't stay long and are often not sighted again (Cascadia Research Collective, 2021). The leading hypothesis is that these whales are not able to learn the Sounders feeding strategy and leave the area shortly after arriving (Fearnbach, 2020).

There are currently 13 individuals that make up the slowly growing North Puget Sound gray whale population (Cascadia Research Collective, 2021). When research began on these whales in the early 1990's, only six whales were routinely observed in this area, additional whales were added to the population starting in the early 2000's, and the population continues to increase today. Of these 13 individuals, 11 have been sexed; this group is comprised of 8 males and 3 females of unknown ages.

The Sounders deviate 170+ miles off the traditional migration route along the Pacific Coast to come inland to the Northern Puget Sound to feed every spring from approximately March through May. However, not all whales are sighted within Puget Sound every year (Figure 2). Scientists have theorized that the gaps in sightings of the female whales correspond to the years they have calves, as no gray whale has ever been sighted in Puget Sound with their offspring (Cascadia Research Collective, 2021). Additionally, the gaps in sightings for the male whales may be attributed to a variety of reasons: for example, the whale(s) could have come into Puget Sound but were not observed and therefore not recorded, or the whale(s) were absent from Puget Sound for unknown reasons. Lastly, two of the whales considered Sounders (185 & 396) are also members of the Pacific Coast Feeding Group and infrequently venture into Puget Sound (Figure 2) (Durban et al., 2017). The tan color used for the two whales included in both

Pacific Coast Feeding Group and Sounders populations indicate that they were observed outside Northern Puget Sound (Cascadia Research Collective, 2021).

*Figure 2: Table showing Sounders sightings from 1990 to 2019*



| ID | Sex | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | M | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 22 | F | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 44 | M | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 49 | M | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 53 | M | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 56 | M | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 185 | M | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 356 | UNK | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 383 | M | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 396 | F | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 531 | F | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 723 | M | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2246 | UNK | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

*Note.* This table contains sightings of gray whales from 1990 through 2019. Individual whales are on the left, blue indicates a whale was observed within Puget Sound, white indicates years whales were not observed in Puget Sound, and tan is indicative of whales that were observed outside of Northern Puget Sound. Figure courtesy of Cascadia Research Collective.

Lastly, several of the Sounders have nicknames in addition to their identification numbers. Shackleton (21) and Earhart (22) were the first whales observed within Puget Sound waters in 1990, and are attributed with pioneering the high-risk/high-reward feeding strategy—hence their pioneer inspired named (Calambokidis et al., 2004). Additionally, Patch (49) is arguable the most well-known Sounder as this male has an easily identified white patch on his right dorsal side that sets him apart from the other whales (Pruitt et al., 2016). Individual 44, also named Dubknuck, is named for the so-called double knuckles behind the dorsal hump and has been consistently spotted in Northern Puget Sound since 1991. The last of the ‘named’ whales includes Little Patch (53) named for the small distinctive white spot on his left dorsal side. This individual has

also been consistently seen since 1991 and is well known for staying in Puget Sound waters longer than many of the other Sounders (Cascadia Research Collective, 2021).

## Feeding

Unlike other baleen whales that feed on prey near the surface of the water, gray whales rely predominantly on bottom, or benthic, feeding (Croll et al., 2017). They consume a large variety of invertebrates in and above the sea floor by rolling on their sides and sucking sediment into their mouths (Fearnbach, 2020). In fact, scientists have observed wear patterns on right and left sides of gray whale jaws—suggesting that they have a preferred feeding side (most appear to be "right-handed"). Water, mud, and other fine sediments are filtered out through the whale's baleen, leaving behind the targeted food source of amphipods, worms, and other invertebrates (Croll et al., 2017).

The areas in the sediment that are disturbed by the whales are called feeding pits, and at low tide they can be seen off the coast of Whidbey Island (Fearnbach, 2020). These feeding pits are notable in that they show just how close to the shore these whales routinely feed; no other baleen whale has been observed feeding in such close proximity to the shore on such a regular basis (Calambokidis et al., 2015). This phenomenon has been documented since the 1990's with two whales, Shackleton and Earhart (named after Earnest Shackleton and Amelia Earhart, respectively), paving the way for the high-risk/high-reward strategy of coming into the intertidal zone to feed on ghost shrimp (Weitkamp et al., 1992).

It may seem at first glance that gray whale feeding is very one-sided, benefitting only the whale, but the truth is gray whales are crucial to redistributing sediment into the

environment (Harrison, 1979). Through disturbing the benthic layers in the intertidal zone, the whales are resuspending particulates that provide much needed nutrients for phytoplankton, zooplankton, polychaeta worms, and other amphipods to feed on (Oliver et al., 1985). These nutrients, if not disturbed, would remain trapped in the sediment. In a 1992 study done by Weitkamp et al. researchers estimated that the ghost shrimp numbers outside a feeding pit were between 2-5 times higher than inside one (Weitkamp et al., 1992). However, after a disturbance the feeding pits are recolonized by scavenging members of the benthic community. Rapid succession of amphipods and other organisms move through to recolonize the pit within hours, and within two months the ghost shrimp populations within the recently disturbed site have recovered (Weitkamp et al., 1992). Interestingly, the areas within the pits contained higher biodiversity than outside the pits—as the pits served as a catch point for decaying organic matter (Oliver et al., 1985). This increase in biodiversity can last months before the area returns to pre-feeding numbers (Weitkamp et al., 1992).

The Sounders gray whales have developed a high-risk/high-reward style of feeding that is unique to them (Fearnbach, 2020). The risk comes from feeding in the intertidal zone, as this area of water is entirely tide dependent; meaning when the tide goes out, it become a mud-flat, or beach, and when the tide is in the depth can vary wildly. Whales have been observed feeding in as shallow as 7 to 9 feet of water, which is quite noteworthy for an animal that grows on average 42-49 feet long and can weigh over 30 tons (Calambokidis et al., 2019). The whales must be aware of tidal levels, time spent in an area, and be intimately familiar with the space they are feeding in order not to become stranded, and potentially die (Sumich, 2014). However, the reward comes from

being able to gorge on ghost shrimp, largely unchallenged by any other predators—save humans (Fearnbach, 2020).

Scientists still do not know what caused this dozen or so whales to break ranks with the larger migrating population to venture into Puget Sound; nor do they fully understand how the whales were able to communicate these findings to others in their population. For example, the high-risk-/high-reward feeding behavior is a learned behavior (Calambokidis et al., 2004). Other whales, outside the group of 13 Sounders, have been observed coming into Puget Sound, but not feeding in the shrimp flats (Cascadia Research Collective, 2021). Unlike their intertidal savvy counterparts that are able to gain weight coming into Puget Sound, the whales that have not learned the necessary feeding strategy leave the area sooner, without any significant weight gain (Fearnbach, 2020).

Only now have researchers started to examine how important ghost shrimp are to The Sounders diet (NOAA Fisheries, 2020). Preliminary body condition photos taken by Cascadia Research Collective scientists (Figure 3), show that the high-risk/high-reward behavior appears to be paying off; body conditions of the Sounders in drone photos, seem to be healthier when compared to vast majority of the larger Eastern population that do NOT venture into Puget Sound (Fearnbach, 2020).

*Figure 3: CRC723 (aka Lucyfer) body condition photograph*


*Note.* This drone photograph taken by researcher Dr. Holly Fearnbach shows an improvement of overall body condition of whale CRC723 of the time spent feeding on ghost shrimp and other invertebrates. The whale becomes noticeably wider with time, indicating an increase in blubber and body mass. Adapted from Cascadia Research Collective.

Now, these drone photos are not definitive proof that the small group of whales that make up the Sounders are healthier than the rest of the migrating whales that bypass the Puget Sound—but it does pose several interesting questions with potential policy implications (Fearnbach, 2020). For example, should this population be given the same protections that other cetaceans, namely killer whales, are given in Puget Sound due to their unique behavior (NOAA Fisheries, 2020)? Should the areas these whales frequent be given protections to ensure the whales thrive? If so, what would that mean to local fisheries that are dependent on harvesting ghost shrimp? Clearly, much more research will be needed to answer these, and many other questions, however the preliminary

findings are certainly interesting and point to the fact that the habitat in Puget Sound is of great benefit to the health of these whales (Calambodkidis et al., 2004).

## Ghost Shrimp

The intertidal zone of Puget Sound off the coast of Everett and Whidbey Island provides excellent habitat for ghost shrimp. This environment, which is hostile to many plants and animals due to its regular exposure to air, is ideal habitat for ghost shrimp and other burrowing invertebrates as they wait out the low tide in relative safety under the sand (Pruitt et al., 2016). Inhabiting burrows up to 4 feet deep, ghost shrimp play an important part in the intertidal ecosystem—serving a role similar to that of terrestrial earthworms (Feldman et al. 2000). They overturn sediments, bring oxygen into their burrows, and feed on various detritus and organic matter that settles on the seafloor (Dumbauld et al., 2003). Ghost shrimp have been known to breed year-round, but females are most commonly found to be carrying eggs in June and July (Moore et al., 2001).

The abundance of ghost shrimp in Puget Sound is the main driving factor for the return of the Sounders annually. For example, a 1990 study focusing on the consumption of ghost shrimp by resident gray whales in Puget Sound estimated that a single whale consumes, on average, 6-13 pounds of shrimp per pit (Weitkamp et al., 1992). A total of 19,000 feeding pits were identified in the summer of 1991 over a stretch of beach 11 miles long. Cascadia Research Collective has identified that there were six North Puget Sound gray whales present in summer of 1991, meaning that in one season an estimated 6

resident gray whales consumed an average of 95 tons of shrimp in that 11-mile strip (Calambokidis et al., 2004).

Ghost shrimp provide gray whales with a high caloric dense prey, providing the "reward" part of their risk/reward feeding strategy. Scientists have estimated that ghost shrimp provide a caloric meal 2-15 times higher than any other reported prey (Weitkamp et al., 1992). Additionally, the density of ghost shrimp in the intertidal zone can be 10 times that which would be found in deeper waters (Moore at al., 2001). This densely packed, high caloric diet, can be observed in the tangible weight gain of the gray whales leaving the North Puget Sound who have perfected the intertidal feeding strategy; and in their return to these nutrient packed feeding grounds annually (Fearnbach, 2020).

## The Nexus Between Critical Habitat and Policy

Once classified as endangered under the federal Endangered Species Act, the eastern Pacific population of gray whales now represents a conservation victory. This victory comes from a combination of prohibition of whaling practices, creation of the Marine Mammal Protection Act, and a better understanding of their behavior (Perrin et al., 2002). Delisted in 1994 the eastern Pacific population has been steadily growing and is estimated, as of a 2016 survey, to be approximately 27,000 individuals (NOAA Fisheries, 2020). However, there are signs that have scientists worried about the future of these animals, namely the 'unusual mortality events', that have taken place as recent as 2019-2020 (NOAA Office of Protected Resources, 2020). Unusual mortality events (UME's) are defined in the Marine Mammal Protection Act as "a stranding that is

unexpected, involves a significant die-off of any marine mammal population; and demands immediate response" (Marine Mammal Commission, 2020).

Resistance to UME's is yet another thing that sets the Sounders apart from the larger overall eastern Pacific gray whale population—in the 30 years of collecting location, photograph, video, and monitoring data, not a single member of the Sounders has died in a UME (Calambokidis et al., 2019). Conversely, scientists have recorded a total of 214 stranding's of gray whales along the west coast of North America in 2019 alone. The table below (Table 1) breaks down the most recent confirmed stranding data as of February 4th, 2021 (NOAA Fisheries, 2020).

*Table 1: West Coast Gray Whale Stranding Data*

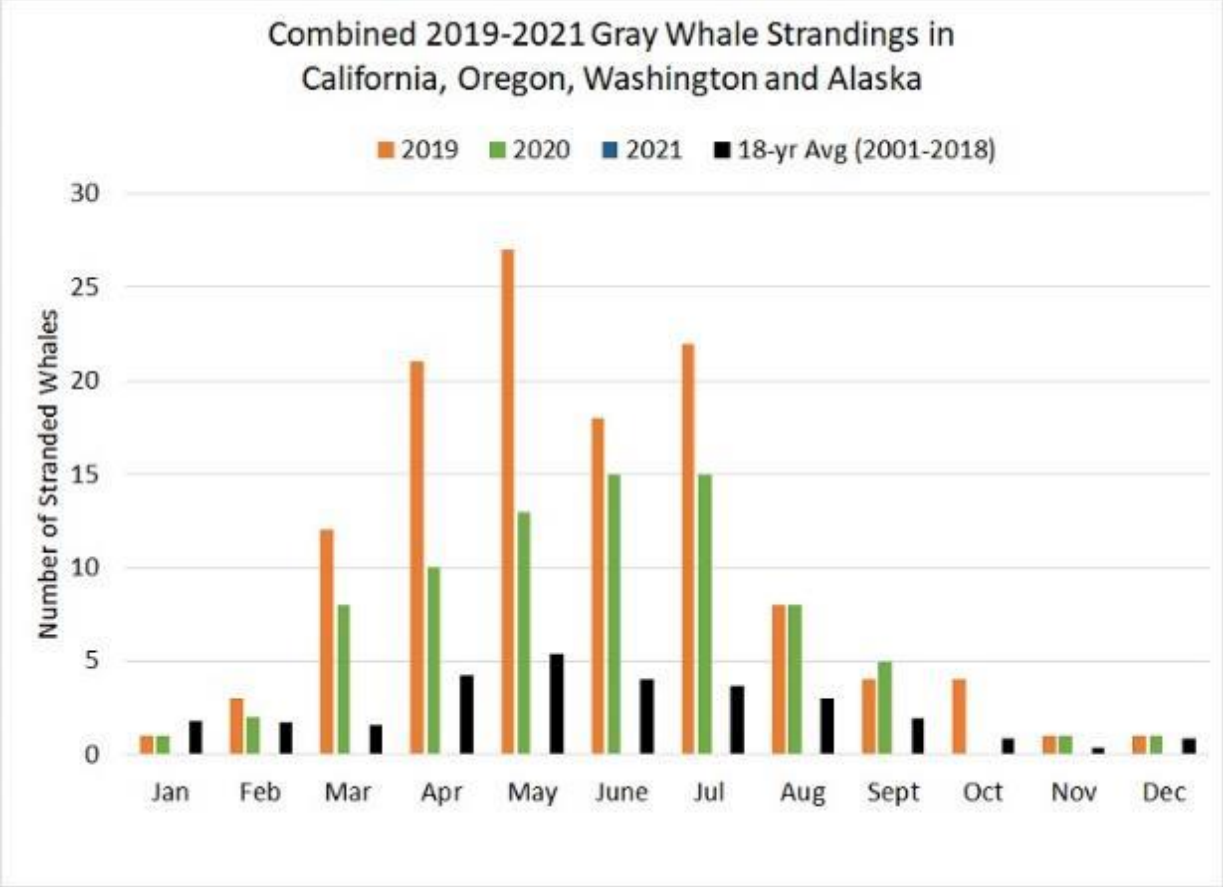
| Country | 2019 | 2020 | 2021 | Total |
|---|---|---|---|---|
| Canada | 11 | 5 | 0 | 16 |
| United States | 122 | 79 | 0 | 201 |
| Mexico | 81 | 90 | 3 | 174 |
| **Total:** | 214 | 174 | 3 | **391** |

*Note.* It has become accepted that 2019 and 2020 were considered 'unusual mortality events' (UME's) in which a disproportionally high number of whales are found ashore dead. While these number may seem low, they are a small fraction of the overall deaths occurring as the majority of whale carcasses sink, never making it to shore.

With the purpose of viewing the stranding data on a finer scale, the chart below combines the data for California, Oregon, Washington, and Alaska highlighting the UME in 2019 and comparing that to the 2020, 2021, and 18-year average stranding data

(NOAA Office of Protected Resources, 2020). The highest mortality month is May 2019 numbering just over 25 whales, compared to the 18-year average during that same year which numbers just over 5 whales. The total number of whales that expired in May 2019, is higher than the 18-year average for all months combined (Figure 4). Furthermore, it is worth noting that researchers collectively agree this mortality rate is a fraction of the total deaths that took place during the UME (World Wildlife Fund, 2020). For example, many whale carcasses are assumed to never to make it to land in the first place, rather they decompose at sea undetected and thus are not captured in this data (Sumich, 2014).

*Figure 4: West Coast Gray Whale Stranding's 2019-2021*




*Note.* The peak time where gray whales are found stranded, March through July, corresponds to the time of year they are migrating to their summer feeding grounds in the arctic. The high rates of stranding's in 2019-2020 align with the known unusual mortality event—this become especially evident when compared to the 18-year average which is much lower.

Necropsy examinations done on a subset of all the stranded whales showed evidence of emaciation—which is attributed as one of the main driving factors behind the UME. These findings were not consistent across all the whales that have been examined, meaning more research will be needed, but the leading hypothesis is that the whales are starving to death (NOAA Office of Protected Resources, 2020). There are many reasons why the whales may not be getting enough food: climatic triggers causing a decline in prey, development in coastal areas, plastic pollution, over harvesting of resources etc. (Sullivan, 2017). However, no matter the cause, the evidence that at least a percentage of

the whales stranded in the 2019 UME event died of starvation makes the habitat the Sounders utilize all the more important.

The Sounders have been using intertidal zone of Northern Puget Sound to fatten up on ghost shrimp for the better part of 30 years. The latest drone photos of their body condition, shows skinny, undernourished whales swimming into Puget Sound in the spring, and much more healthy and robust whales leaving in the early summer (Fearnbach, 2020). This monitoring of body condition is an important step to understanding what an important role this critical habitat is providing them.

Through changes in policy, understanding of gray whale behavior, collaboration with fisherman who rely on ghost shrimp, the Puget Sound could continue to be a refuge for these unique animals. The continued documenting of their migration through the Sound, and identification of the key areas that are providing them with the abundance of nutrients that aid in the rest of their migration are the first steps in ensuring their continued survival, and potential future recruitment into this special population (Pruitt et al., 2016).

## Conclusion

We may never know exactly what brought Shackleton and Earhart (CRC21 and CRC22 respectively) to Northern Puget Sound, but we do know that their risk continues to pay off in that they have returned to the same feeding grounds for nearly 30 years, and always leave Puget Sound healthier than when they entered. Through careful monitoring of this slowly growing gray whale population, and sustainable management of the ghost shrimp industry, this population of whales should continue to thrive for at least another

30 years (Calambokidis et al., 2019). With more research we may begin to understand just what a vital role ghost shrimp play in the overall health and wellbeing of a population that has remained untouched by Unusual Mortality Events (Pruitt et al., 2016). Tracking these whales and identifying critical habitat areas that they may be returning to year over year could be the first step in implementing policies and practices that will protect them for years to come.

# Chapter 3: Methods

## Introduction

The primary purpose of this research was to analyze and map North Puget Sound gray whale sighting data to determine critical areas of habitat, and to gain a better understanding of overall habitat distribution. Whale watching operations, non-profit research teams, and state agencies have been tracking and monitoring this unique population of gray whales for the better part of thirty years—however, a broad (temporal and spatial) distribution analysis has not occurred to date. This research utilized the abundance of reliable gray whale sighting data provided by Cascadia Research Collective within the Puget Sound in order to identify important habitat areas that whales return to annually. This section will describe the methods used to collect whale sighting data, create geospatial habitat distribution maps with ESRI product ArcGIS, as well as conduct the statistical analysis to better understand where each whale was spending the majority of its time in Puget Sound.

## Cascadia Research Collective

Cascadia Research Collective provided the North Puget Sound gray whale sighting data set that compromises the entirety of the data presented in this thesis. This sighting data is a subset of images taken from their larger photo-identification records of gray whales in the Pacific Northwest. Cascadia is a non-profit organization that has been conducting research on marine mammals, bird biology, animal behavior, ecology, and anthropogenic impacts on the environment since 1979 (Cascadia Research Collective,

2021). Cascadia has been conducting photo-identification research on gray and other large whales since its inception and started a concerted research effort on gray whales in the mid 1980's. The majority of Cascadia's work with gray whales has focused on the Pacific Coast Feeding Group of gray whales. After initially documenting the presence of the Sounders gray whales in 1990 in northern Puget Sound, their research and photo-identification efforts have focused on this group. The data provided by Cascadia came from their identification database of the Sounders which spans over 29 years and includes the verified sighting locations of the 13 individual whales that currently make up the Sounders group. In addition to this research, Cascadia promotes education and learning through publications in scientific literature, providing educational programming to diverse audiences, and training the next generation of marine scientists through their robust internship program (Cascadia Research Collective, 2021).

## Data Collection

Cascadia Research Collective provided data that included date, time, and position of each verified identification of the Sounders in northern Puget Sound. The reports were collected in one of three main ways:

1.) Cascadia staff carrying out surveys on one of their small research vessels (6-7 m Rigid Hull Inflatable Boat)
2.) Cascadia interns collected sighting reports while riding aboard commercial whale watching vessels
3.) Reports submitted from other miscellaneous sources—namely local agencies and organizations outside Cascadia staff and interns.

All three approaches to collection are represented within the data set researched here (J. Calambokidis, personal communication, May 14, 2021).

Cascadia's dedicated surveys generally consisted of day-trips operating out of Everett, Washington with the goal of covering all the nearshore waters of Possession Sound, Saratoga Passage, and Port Susan (the primary areas used by the Sounders). Surveys outside of these areas including Skagit Bay, North Saratoga, and Admiralty Inlet were covered less often. The surveys conducted by Cascadia staff included following detailed GPS tracks (search areas), and verifying identifications of whales from photographs. The data that comes from miscellaneous sources (for example: Washington Department of Fish and Wildlife staff) must have a corresponding photo to allow for subsequent verification of the photo-ID by Cascadia staff, as well as the position provided from a GPS, or the location could be estimated from a point calculated from a descriptive location. Once the sighting is submitted to Cascadia, staff review validity of the observation and add the report to the main database if/when it is confirmed.

The North Puget Sound gray whale observation data set, first started in the spring of 1990, has been an ongoing focus for the researchers at Cascadia Research Collective. It should be noted, however, that Cascadia's effort on North Puget Sound gray whales is variable year-to-year due to fluctuation in funding, or competing research efforts. This is also true for the observations from whale watching vessels which have only been contributing to the database since 2004. This has resulted in an uneven distribution of surveys over time. The absence of reports, or low count of reports, especially in earlier years may be less of a reflection of the Sounders, and more to do with lack of funding and effort. Note, for example, that in years 1996-1997 there were zero identifications of

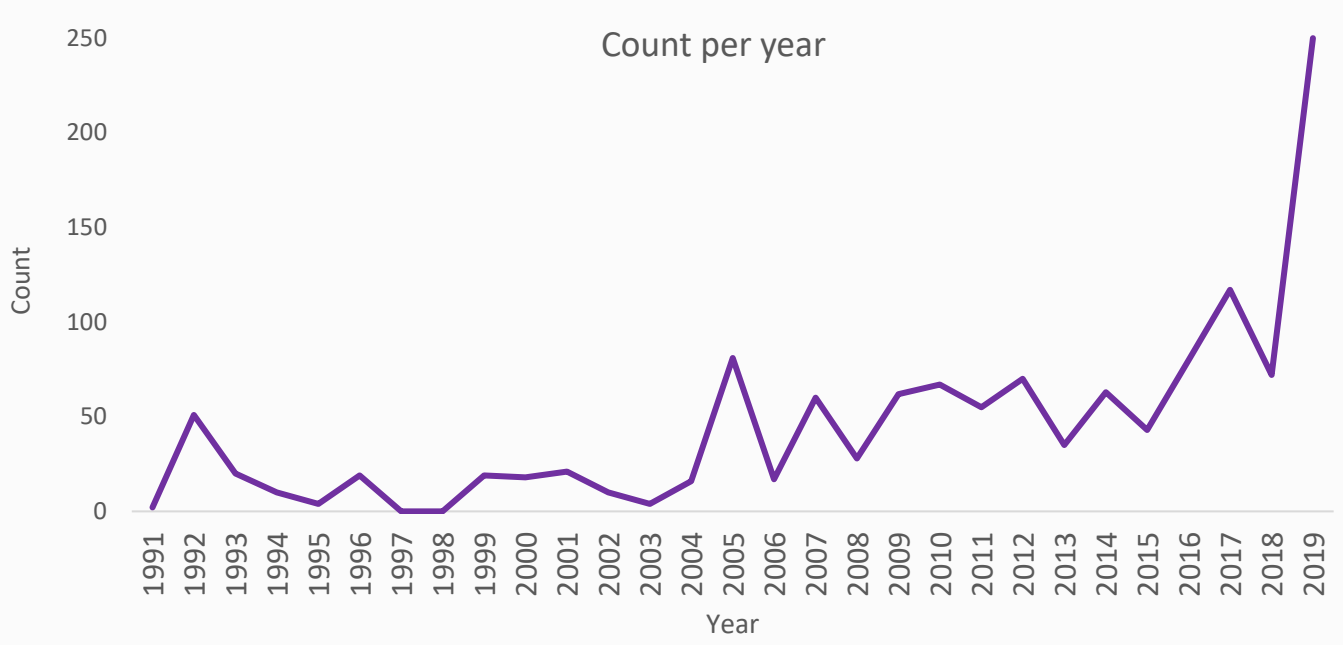
Sounders gray whales within North Puget Sound. This does not mean that no whales were present during this time, rather, this lack of observations reflects a low level of effort by Cascadia, and also the absence of identifications from other sources. For example, whale watching trips that had not yet begun to focus on the Sounders as a part of their business until later.

Conversely, higher count years may be the result of a combination of factors. For example, grant funding may be higher allowing for more field staff time to observe the whales for longer, more resources (boats, miscellaneous equipment, etc.), and more money for maintenance and upkeep (gas, storing a boat in a slip, travel costs, etc.). Lastly, whale watching operations, in addition to other miscellaneous sources, started to contribute their own observations to the database increasing overall observational counts.

One of the challenges that came up when looking at 29 years' worth of data was how to display the information in a cohesive and constructive way. For example, sampling effort throughout the 29 years is not identical, some years there is more of an effort than others. The constant fluctuation in field effort, combined with the fact that not all 13 Sounders return to Northern Puget Sound each year made time comparisons difficult.

For example, after conducting a time focused layer in GIS it became apparent that it would be challenging to compare the data as some years had observations of different whales, other years had no observations, effort may be concentrated in one parcel versus another, and so on. Rather, the data analysis was more valuable when viewed as a whole, as there is more to draw from, rather than comparing chunks of time to one another (Figure 5).

*Figure 5: Counts per year line chart*



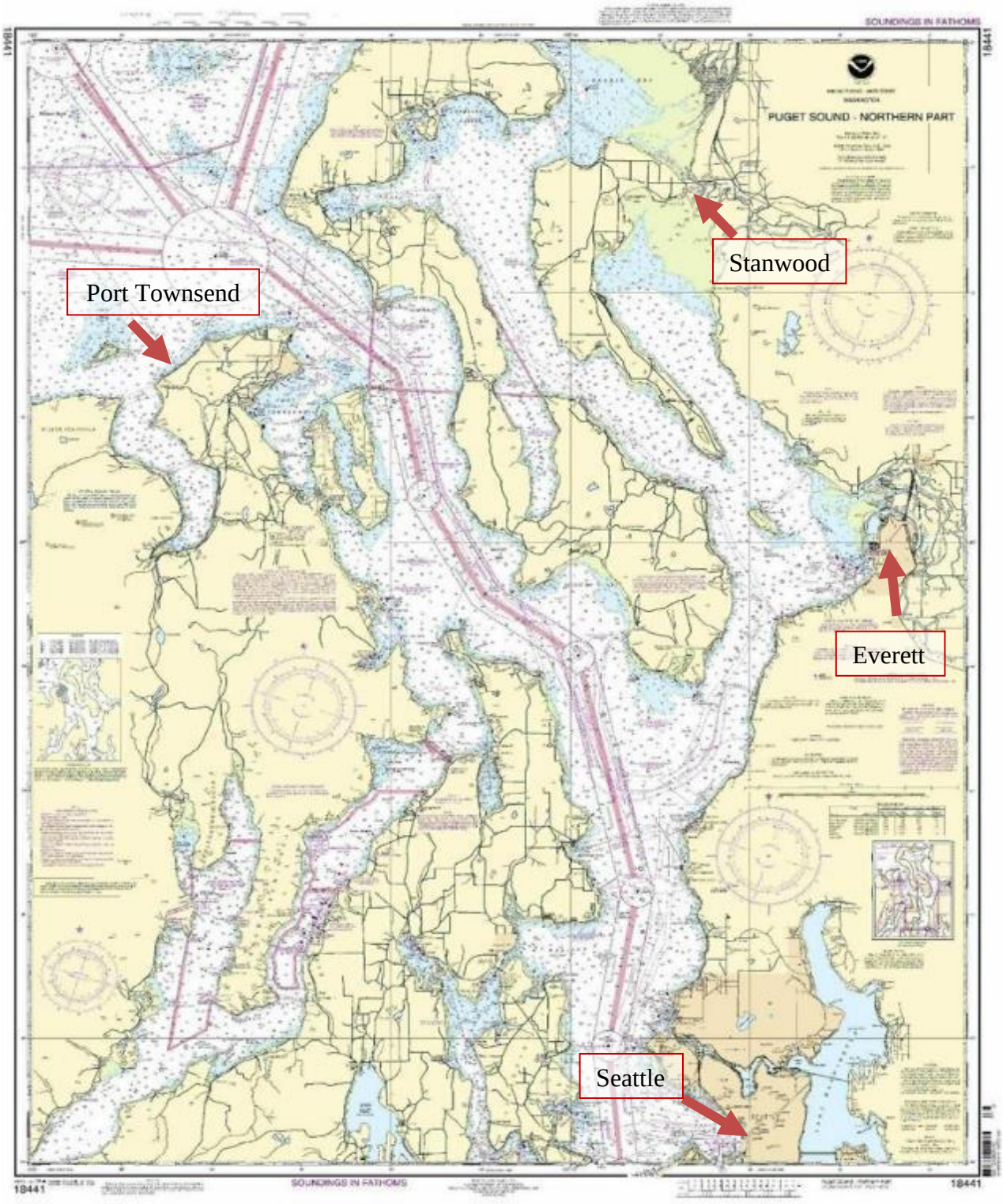

*Note.* Line chart showing total number of confirmed gray whale sightings per year.

## Study Area

For the purposes of this project, only the gray whale sightings that occurred within the area defined as North Puget Sound were utilized. The Sounders use the Strait of Juan de Fuca as their primary route into Puget Sound (NOAA Office of Protected Resources, 2020). However, the straight is not their destination, nor their primary feeding grounds; therefore, any information collected within this area, while interesting, is irrelevant for the purpose of this study.

Lastly, there is some debate about the exact boundary between what designates South Puget Sound from North Puget Sound. In order to secure standard boundaries for the analysis portion of this thesis, the definition provided by the National Oceanic and Atmospheric Administration was used. The map boundary shows Seattle towards the south, and Skagit Bay/Stanwood as the northern border, Everett towards the east, and finally Port Townsend toward the west (Figure 6) (NOAA, 2016).

*Figure 6: Northern Puget Sound, Study Area*

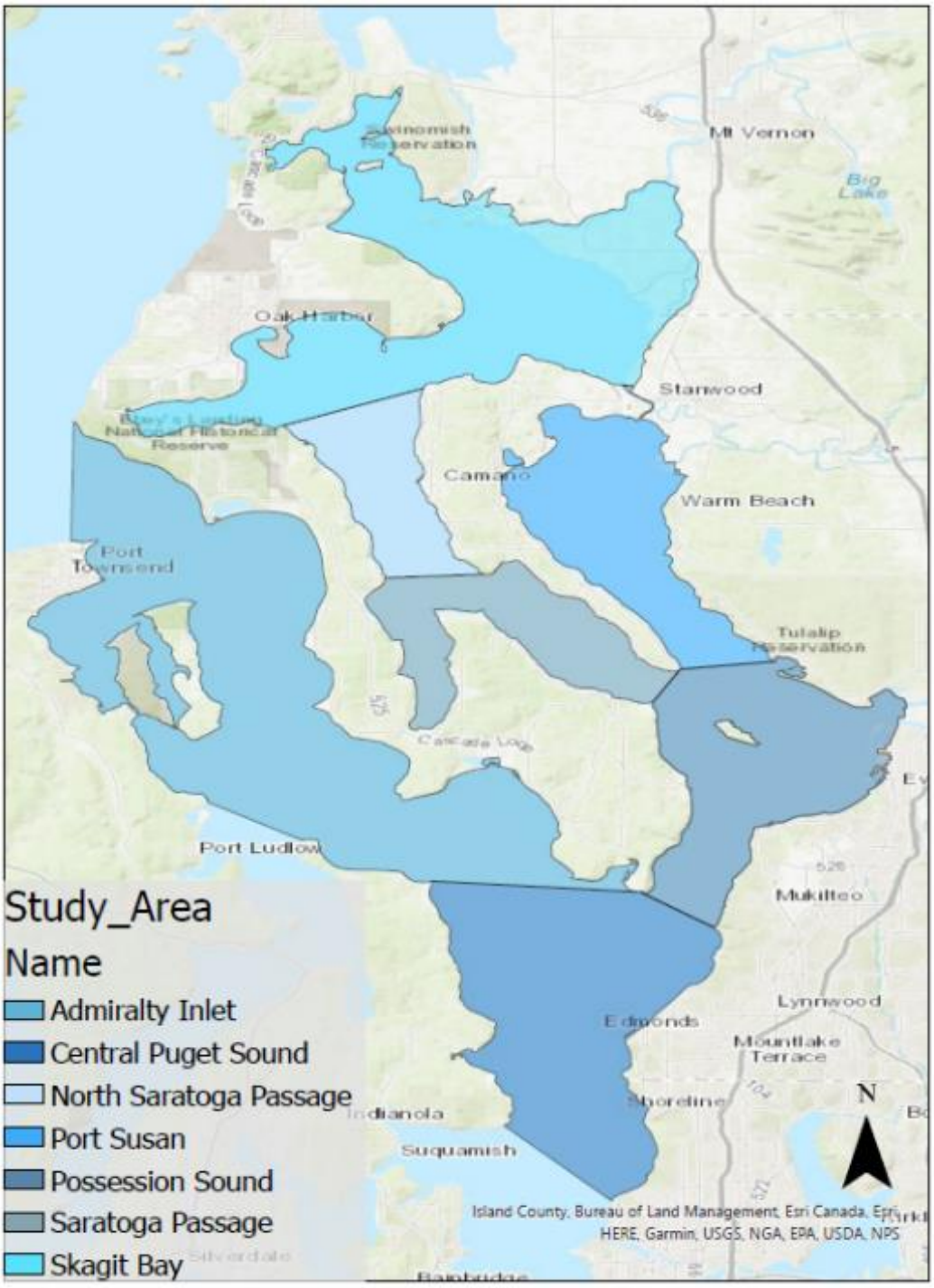



*Note.* Study area for North Puget Sound gray whale habitat distribution analysis using boundaries indicated by NOAA, at the south end Seattle is pictured and the north end is delineated by Skagit Bay. (NOAA, 2016).

The study area included both the spatial distribution of previously recorded gray whale sightings in Northern Puget Sound, as well as the temporal observations collected by Cascadia Research Collective that span almost thirty years. Spatial distribution in this case is defined as the latitude and longitude point recorded by the whale observer, and temporal distribution is defined as the month/day/year in which the sighting took place. For example, it is well documented that the Sounders spend much of their time in the shallow waters off the coast of Whidbey Island, but the specific areas may vary year-to-year based on any number of factors, some known, and many more unknown (Pruitt et al., 2016). Some years the whales may concentrate in one area off the coast of Everett, other years the whales may be spread throughout Admiralty Inlet not staying in any one area for long.

Given that a major objective of this research was to identify which regions of the Northern Puget Sound gray whales were most commonly observed, the study area was divided into seven unique parcels that could be compared to one another. Dividing the Northern Puget Sound into seven smaller sections made for easier, and more meaningful analysis. The boundaries of the seven parcels were drawn by John Calambokidis to better reflect the smaller inlets, bays, and other identifying geographical areas, as well as locations that were frequently visited by Cascadia in order to collect Sounder's location data (J. Calambokidis, personal communication, January, 8 2021). The seven sub-basins are henceforth referred to as: Admiralty Inlet, Central Puget Sound, Port Susan, Possession Sound, Skagit Bay, North Saratoga Passage, and South Saratoga Passage (Figure 7).

*Figure 7: Study Area with Basins*




*Note.* The seven sub-basins of North Puget Sound with labels. Imported from GIS.

## GIS Process: Preparation

In preparation for geospatial analysis, the data were reviewed for consistency, formatted for the appropriate coordinate system, and screened of any unnecessary details. The data were then imported into ArcGIS. The original dataset contained over 1,400 entries; however, after the initial screening which removed any extraneous information—like whale sightings of individuals not belonging to the Sounders population—the remaining observations used in this analysis contained just over 1,200 entries.

## GIS Process: Mapping

After the data had been organized and uploaded into the GIS project, the next step was to create separate categories in which to track individual whales over time. As there are currently 13 individuals that are classified as Sounders, the best way to identify these whales was to label each using a distinct color. This labeling enabled for easier tracking and identification of the robust data set at a quick glance.

One of the many benefits to using ArcGIS, is the ability to view a data set in a multitude of ways. For example, heat maps show areas of density within a space, location points can show range, and individual parcels can aid in managing large quantities of data by breaking the map into smaller areas to track patterns within these locations. The versatility and flexibility that ArcGIS provides was one of the key reasons it was chosen to view the whale observation data set.

## GIS Process: Time Lapse

ArcGIS has a tool that enables the user to display temporal data. This Time tool was used to display the data sequentially from 1990-2019. The Time tool may be used for selective filtering (i.e., 1, 5, 10, etc. year increments). This filtering allows for high-level overview of movement, without having to manually set filters repeatedly to get the same effect. An advantage of this tool is that many years of data can be displayed quickly in the form of an animation.

## Statistical analysis: Set Up

A key question of this research relates to where the whales selectively choose to spend time in the Puget Sound. Statistical analysis was performed using JMP, and Excel. To start the process, a query was set in ArcGIS for the purpose of yielding a total point count for the whales in each of the seven parcels (i.e., the number of times a whale was observed in a given parcel). This query resulted in whale identification number(s), parcel number(s), total number of observations of each whale per parcel, and percentage of whale visits within the parcels. For example, whale CRC-21 was observed in Possession Sound 46% of the time it spent in Northern Puget Sound. After the query was completed, the data was exported into Excel.

Excel was used to quantify and cross reference the information from the spatial analysis completed in ArcGIS. For example, percentages were calculated in Excel to quantify the results that yielded the heat maps in ArcGIS, such as determining what

percentage of time each whale spends in an area, and what the percentage of the sightings each whale comprises per parcel.

## Statistical Analysis: Chi-Squared Test Using JMP

For further analysis of the question—how likely it is to find whales depending on the habitat locations within Puget Sound? —a robust statistical analysis was needed. To attempt to answer this question, a Chi-square test was performed using the statistical software JMP. A Chi-square test compares two variables in a contingency table with the purpose of seeing whether or not they are dependent.

To run a chi-square analysis, the data must contain two categorical variables (in this case, these variables are 1.) the name of the seven parcels, and 2.) the identification number associated with the individual whales). Next, there must be two, or more, categories for each variable. In this case, each of the ten individual whales, and each of the seven parcels satisfied the requirement. Further, the data must result from independent observations. Lastly, a Chi-square test requires a relatively robust sample size. The whale observational data used in this test spans over 30 years and includes over 1,000 points making it an excellent candidate for a Chi-square test. Finally, not all 13 individuals were used for this analysis; rather, whales observed within the Puget Sound for less than a decade were removed from the data set so as not to skew the results for the whales that have been returning to the Sound for the last 30 years (J. Calambokidis, personal communication, May 14, 2021). As such, three whales (185, 396, and 2246) were removed from subsequent analysis.

The analysis was conducted using the JMP software and significance was determined using a p-value < 0.05. A chi-square test was run several times to examine whether the dependecy of whales on a particular parcel waried by different time periods.

## Statistical Analysis: R Cooccurence

The final analysis performed in this study used the cooccur test within R for the purpose of identifying whether certain whales were positively, negatively, or randomly associated (Griffith et al., 2016). First, a correlation matrix was created with whale identification numbers as rows, study areas within Puget Sound as columns, and a 0 or 1 within the body of the table. If a whale was found to be present within an area, that cell was marked with a 1, conversely, if a whale was not observed within a parcel that cell was marked with a 0 (Appendix 7) (R Core Team, 2020). Using the R statistical platform, the matrix was examined in order to measure the strength and direction of the relationship between the individual whales, and the areas they are found to inhabit (Gotelli et al., 2015).

The first test used all 13 Sounders and the observations taken in 2019. The year 2019 was chosen due to the high count of observations and presence of 12 out of the 13 Sounders. This test did not yield useable results. For example, of the 77 total pair combinations analyzed, 67 were randomly associated and 10 were unclassifiable. The results of this test were unable to indicate whether certain individuals were more likely, or less likely, to occur within the same parcel in Puget Sound compared to random chance alone (Griffith et al., 2016).

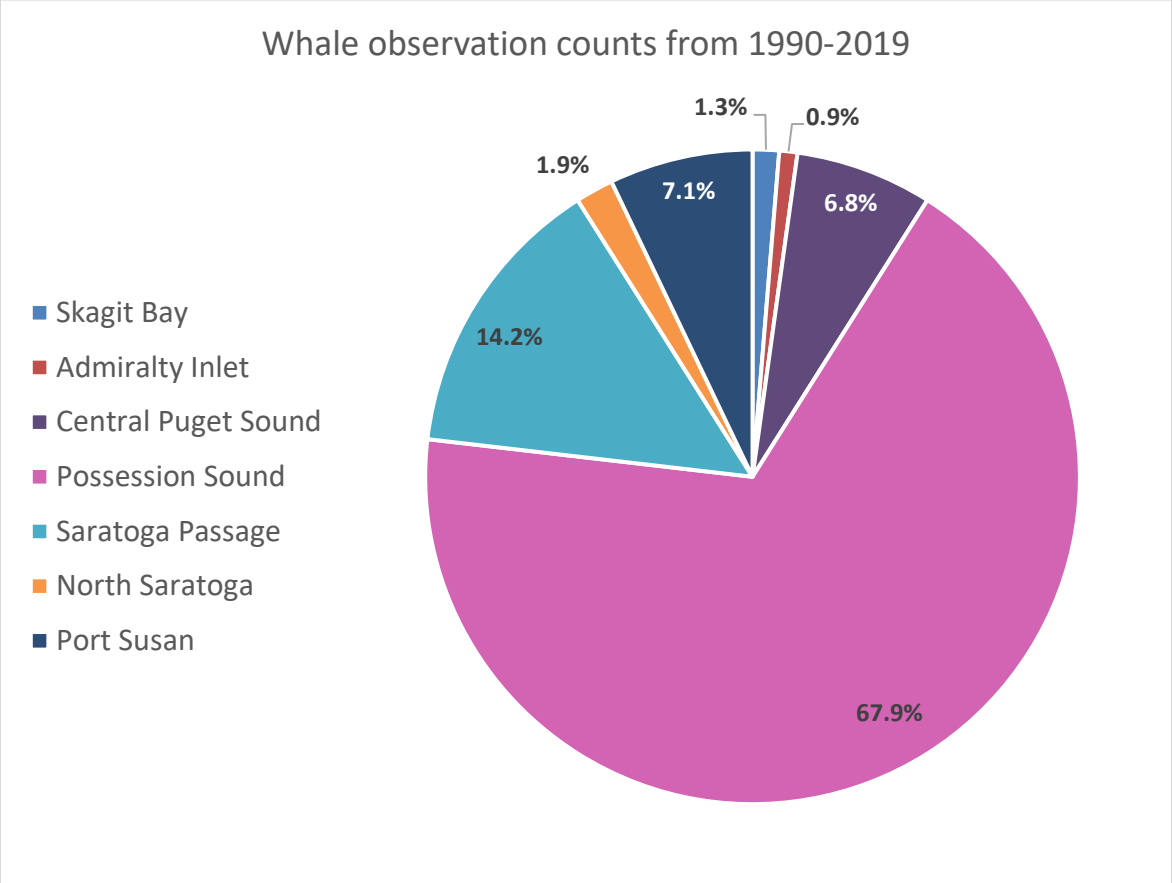
After the initial test using only 2019 observational data yielded insignificant results, another test was completed using observational data collected between 2016 and 2019. These years were chosen as there was a distinctive increase in effort, over 30% of the total observations (spanning 29 years) were recorded within this period. The same table was created, using whale ID as the rows, areas as the columns, and presence in an area was indicated with a 0 for ‘not present’ and a 1 for ‘present. The test was performed again, using all 13 Sounders, and this time yielded significant results.

# Chapter 4: Results

## Observations from 1990-2019

Initial review of whale observation data from 1990-2019 indicated that the majority of whale observations recorded occurred within Possession Sound. For instance, for the 1,226 confirmed observations over 29 years, 832 of those observations were recorded within Possession Sound, accounting the largest percentage of observations by more than half (Figure 9).

*Figure 8: Percentage of whale observations from 1990-2019 found within the 7 parcels of the Northern Puget Sound*




*Note.* The majority of observations were recorded within Possession Sound over the last 29 years, followed by Saratoga Passage, and then by Port Susan.

Next, the number of observations counts per whale, per parcel was calculated in order to allow for more comprehensive understanding of the number of total observations for each whale, as well as the total number of observations of all present whales within each parcel. Note that whale 396 was only observed 4 times over the studied time frame. Conversely, whale 49 was observed 212 times, which represented the maximum observations recorded per whale across the study site.

*Table 2: Number of whale observations between 1990-2019 found within each parcel.*

| | Whale Identification Number | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parcel Name | **21** | **22** | **44** | **49** | **53** | **56** | **185** | **356** | **383** | **396** | **531** | **723** | **2246** | ***Total*** |
| **Skagit Bay** | 3 | 2 | 5 | 0 | 2 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | *16* |
| **Admiralty Inlet** | 0 | 3 | 1 | 0 | 0 | 3 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | *11* |
| **Central Puget Sound** | 9 | 7 | 10 | 6 | 14 | 7 | 1 | 2 | 11 | 0 | 4 | 12 | 0 | *83* |
| **Possession Sound** | 65 | 113 | 32 | 165 | 116 | 47 | 13 | 10 | 102 | 1 | 54 | 106 | 8 | *832* |
| **Saratoga Passage** | 41 | 32 | 8 | 29 | 12 | 9 | 1 | 0 | 14 | 1 | 21 | 6 | 0 | *174* |
| **North Saratoga Passage** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | *23* |
| **Port Susan** | 5 | 2 | 5 | 2 | 1 | 3 | 0 | 0 | 2 | 0 | 2 | 1 | 0 | *87* |
| Total: | *141* | *162* | *86* | *212* | *160* | *76* | *15* | *14* | *132* | *4* | *86* | *129* | *9* | *1226* |

| | Whale Identification Number | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parcel Name | **21** | **22** | **44** | **49** | **53** | **56** | **185** | **356** | **383** | **396** | **531** | **723** | **2246** |
| **Skagit Bay** | 2% | 1% | 6% | 0% | 1% | 1% | 0% | 0% | 0% | 25% | 1% | 1% | 0% |
| **Admiralty Inlet** | 0% | 2% | 1% | 0% | 0% | 4% | 0% | 7% | 1% | 25% | 0% | 1% | 0% |
| **Central Puget Sound** | 6% | 4% | 12% | 3% | 9% | 9% | 7% | 14% | 8% | 0% | 5% | 9% | 0% |
| **Possession Sound** | 46% | 70% | 37% | 78% | 73% | 62% | 87% | 71% | 77% | 25% | 63% | 82% | 89% |
| **Saratoga Passage** | 29% | 20% | 9% | 14% | 8% | 12% | 7% | 0% | 11% | 25% | 24% | 5% | 0% |
| **North Saratoga Passage** | 4% | 1% | 6% | 1% | 1% | 4% | 0% | 0% | 2% | 0% | 2% | 1% | 0% |
| **Port Susan** | 13% | 2% | 29% | 5% | 9% | 8% | 0% | 7% | 2% | 0% | 5% | 2% | 11% |
| Total %: | *100* | *100* | *100* | *100* | *100* | *100* | *100* | *100* | *100* | *100* | *100* | *100* | *100* |

*Note.* The top table represents the total number of observations, whereas the bottom table represents the percentage of times a particular whale has been observed in each parcel. The areas to focus on have been highlighted.

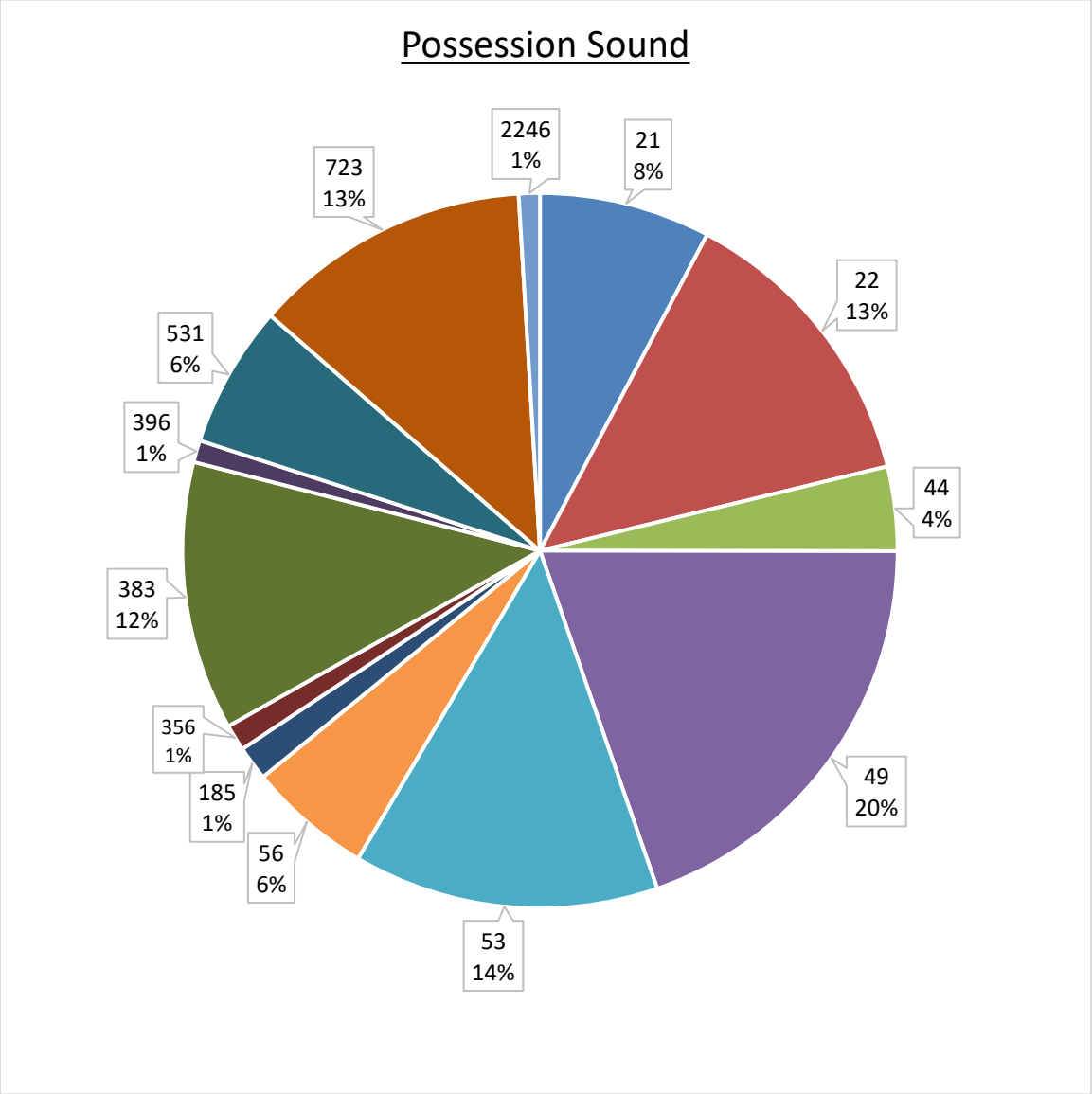
The top table in the figure above is an accumulation of all of the observations across the thirteen Sounders between 1990-2019 broken down by parcel (Table 2). Note, that in this example that Possession Sound contains the highest count of observations (ranging between 1-165 observations for a total of 832 observations) of all the parcels for each individual whale—with the exception of whale 396 who has only been sighted once (and four times overall), and each time has been observed in a different parcel. Next, Saratoga Passage, the area of water adjacent to Possession Sound (between Whidbey Island and Camano Island), contains the second highest number of observations at 174. Additionally, each of the Sounders, except for 356 and 2246 have been recorded in this area at least once. As can be seen from the table, some areas have more individual whales observed within them than others. Using Possession Sound as an example again, each of the 13 Sounders have been observed at least one time within this area. Conversely, Admiralty Inlet contains less individuals within the parcel versus other areas. In Admiralty Inlet only 7 of the 13 Sounders account for the total number of observations in this area of Northern Puget Sound, and as such, only 7 Sounders were used for this calculation. Lastly, Port Susan, the area of water directly North adjacent to Possession Sound contains the third highest number of observations at 87—closely followed by Central Puget Sound at 83 observations. Interestingly, only 4 out of the 13 whales that make up the Sounders have been observed in every parcel at least once: 22, 44, 56, 723 (Table 2).

The bottom table contains the same observational data, but converted into the percentage of time that each whale spends in a given parcel. Meant to be read in columns, the break percentage for each whale totals 100%, and is calculated given the total

observations divided by each section. For consistency, Possession Sound has been highlighted in this second table as well (Table 2).

This result is particularly interesting as it shows that even within Northern Puget Sound the individual whales have preferences. For example, whale 21 has been observed in Possession Sound 46% of the time, followed by Saratoga Passage at 29% of the time. Similarly, whale 44 has been observed in Possession Sound 37% of the time, followed by Port Susan 29% of the time. These observations suggest that whale 44 has a preference for a location that is different than whale 21—outside of Possession Sound. The repeated observations of individual whales in some locations, but not others, is consistent with whales potentially exhibiting preferences for those locations where they are found most frequently.

*Figure 9: The relative importance of each whale (i.e., %) to the total number of observations within Possession Sound*




*Note.* The whale identification number is the number listed above the percentage.

Lastly, Possession Sound accounts for over 800 total observations—over 4 times the number of observations of the second highest area. In addition to the high observation count, every member of the Sounders has been observed in the area at least once. Breaking down the recorded observations of each individual whale yielded the above pie chart (Figure 10). Note that one whale, 49, accounts for 20% of the total recorded

observations within this area over the 29 years. The next highest number of observations within Possession Sound are those of whale 53, 22, 383 with 14%, 13%, and 12% of the total observations, respectively.

## GIS Results: Time Lapse

One of the challenges that came up when looking at 29 years' worth of data was how to display the information in a cohesive and constructive way. For example, sampling effort throughout the 29 years is not identical, some years there is more of an effort than others. The constant fluctuation in field effort, combined with the fact that not all 13 Sounders return to Northern Puget Sound each year made time comparisons difficult.

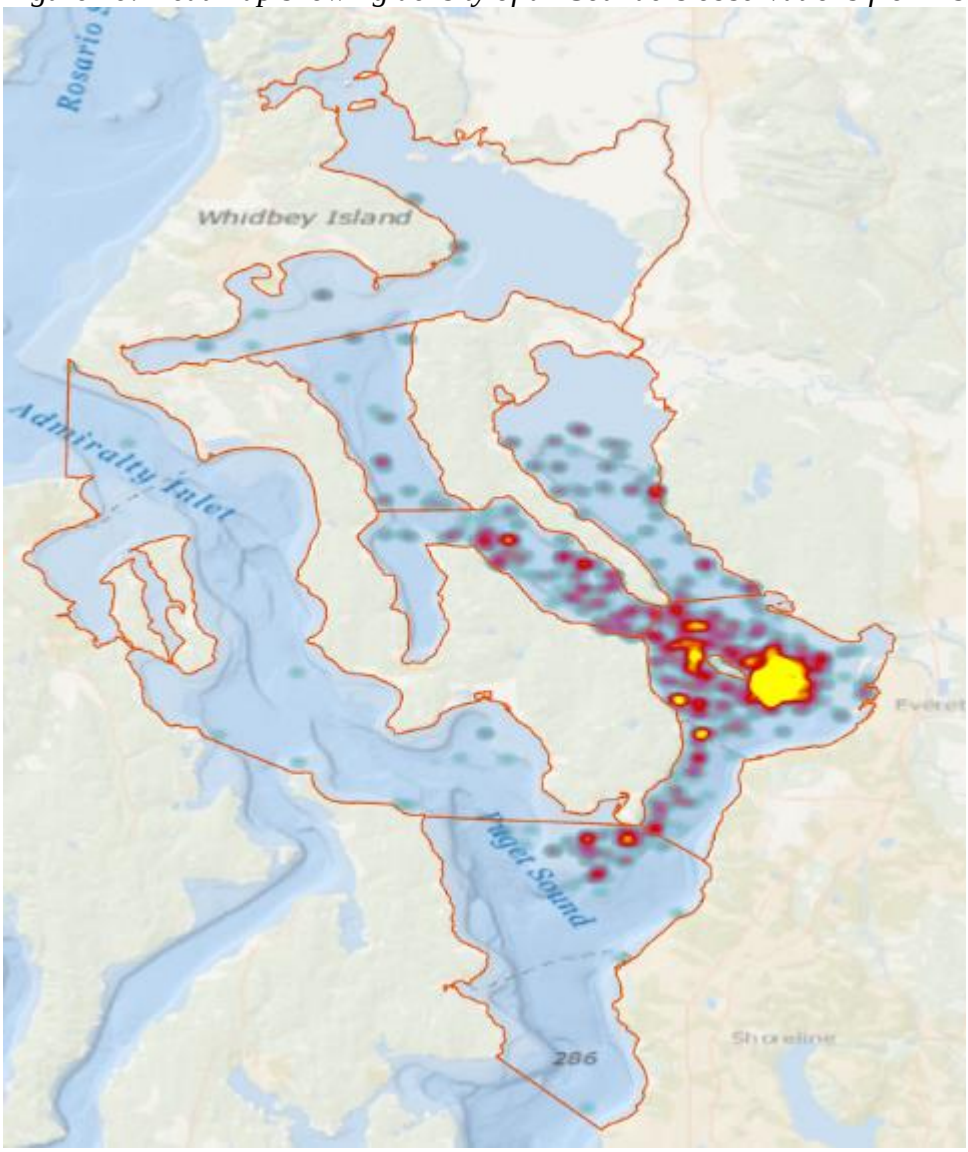
For example, after conducting a time focused layer in GIS it became apparent that it would be challenging to compare the data as some years had observations of different whales, other years had no observations, while simultaneously effort could be concentrated in one parcel versus another, and so on. As such, analyses were conducted on the whole datasets, or subsets of the dataset with similar sampling effort, rather than doing a detailed year-by-year analysis.

## GIS Results: Heat Map

A heat map was generated to show how the density of observations of the Sounders was spread through the Northern Puget Sound. The first map shows a dense cluster of sightings that are indicated as a yellow area just off the coast of Everett,

Washington within the Possession Sound parcel. This heat map is showing the density of all observations from 1990 through 2019 (Figure 11).

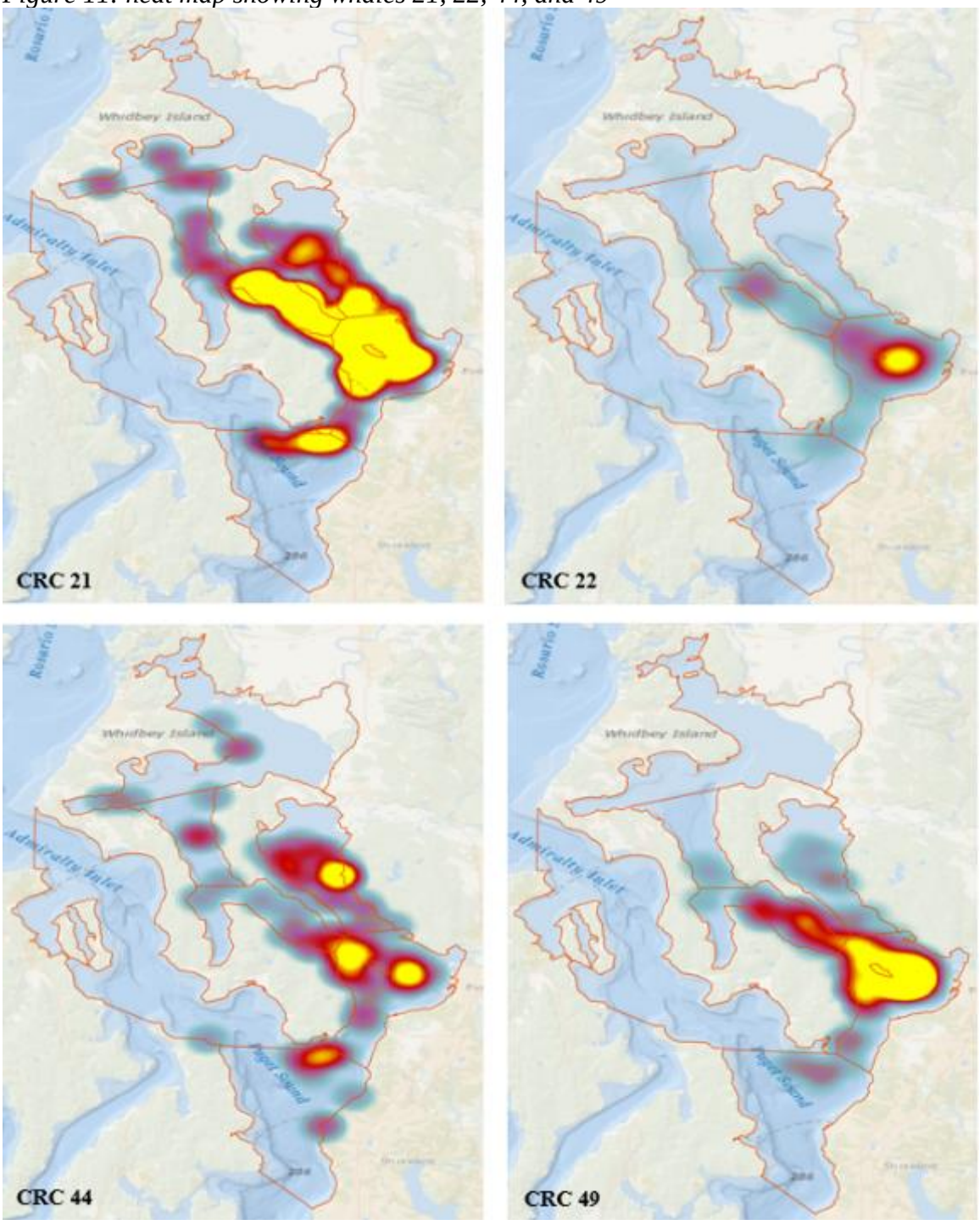
*Figure 10: Heat map showing density of all Sounders observations from 1990-2019*




*Note.* Warmer tones indicate areas of high density, whereas cooler tones are used to indicate lower density. The boundary of the seven areas has been highlighted in orange to provide context and orientation. The highest density of observations over 29 years between all Sounders can be seen here in Possession Sound off the coast of Everett.

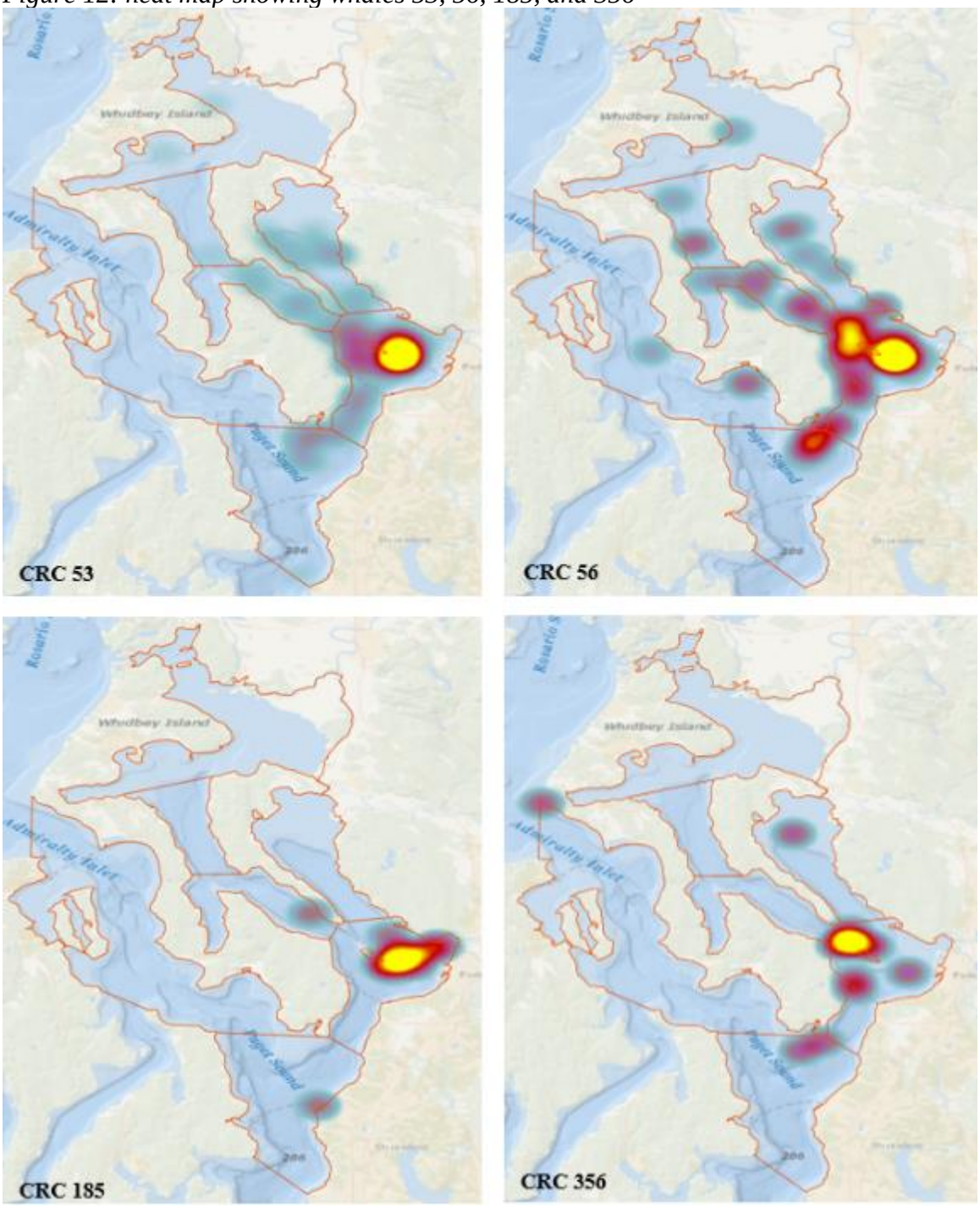
However, the overall density and distribution of the Sounders becomes slightly less localized when we view the observation of each individual whale. However, the number of observations for each whale are not equal. For example, CRC 396 has only been observed four times between 1990-2019, therefore, each observation is a 'high density' point given the low observational count. However, when contrasting CRC 396 with CRC 49—which has the most observations, over 200, of all the Sounders—the heat map indicates the majority of this individuals time is spent in and around Hat Island in Possession Sound based on the density shading (Figure 12 & Figure 13). Lastly, the vast majority of Admiralty Inlet, Skagit Bay, and the Southern portion of Central Puget Sound appear to have the lowest density of observations between all areas. This information is consistent with the tables in the above section of individual observations of whales between 1990-2019.

*Figure 11: heat map showing whales 21, 22, 44, and 49*



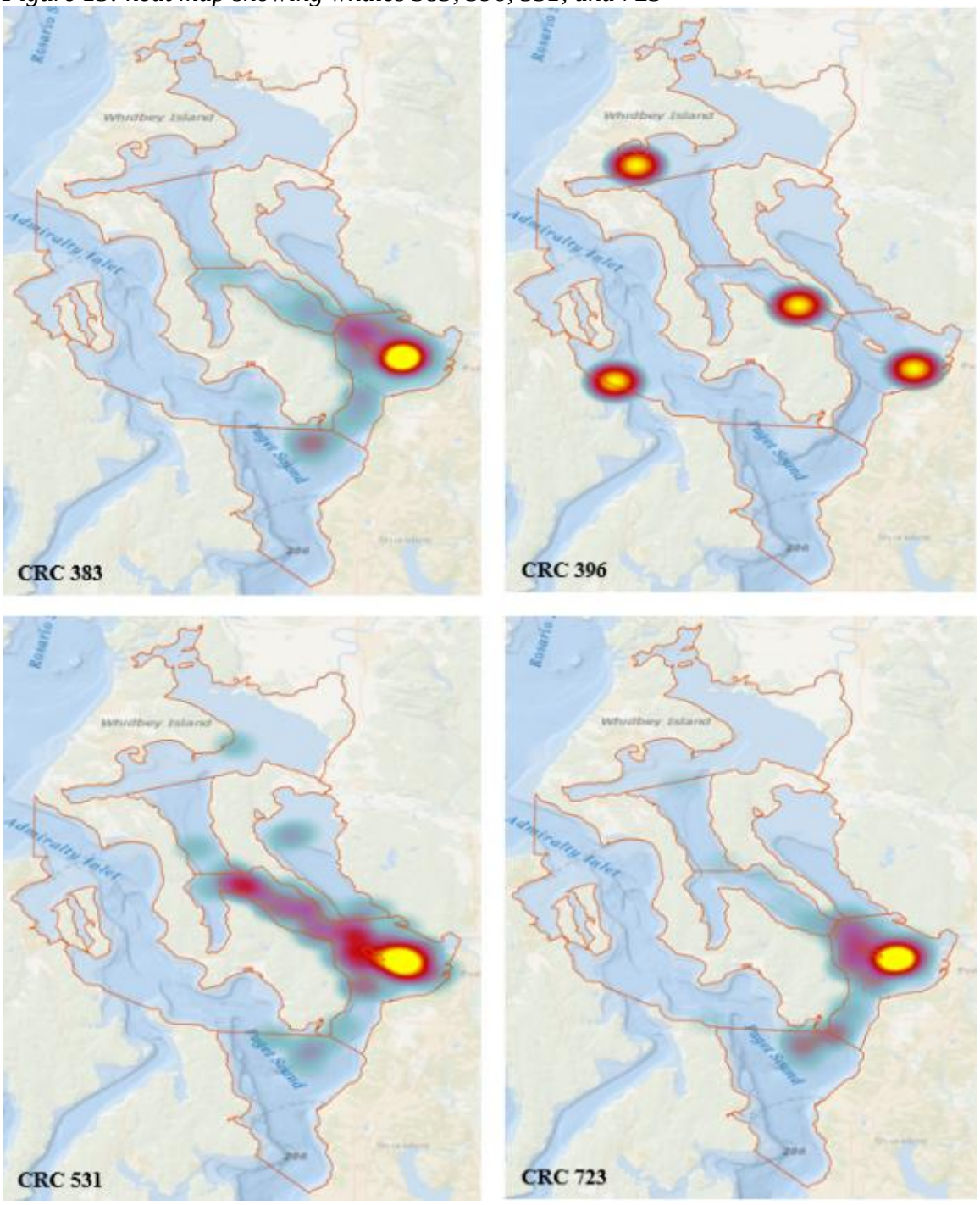

*Note.* This heat map illustrates the different areas of density based on number of observations. For example, whales 21, 22, 44, 49 have been sighted 141, 162, 86, 212, times respectively. However, as the heat map represents the density provided by the total number of points, rather than the individual points themselves, it allows for easier comparison between whales with different observation totals.

*Figure 12: heat map showing whales 53, 56, 185, and 356*



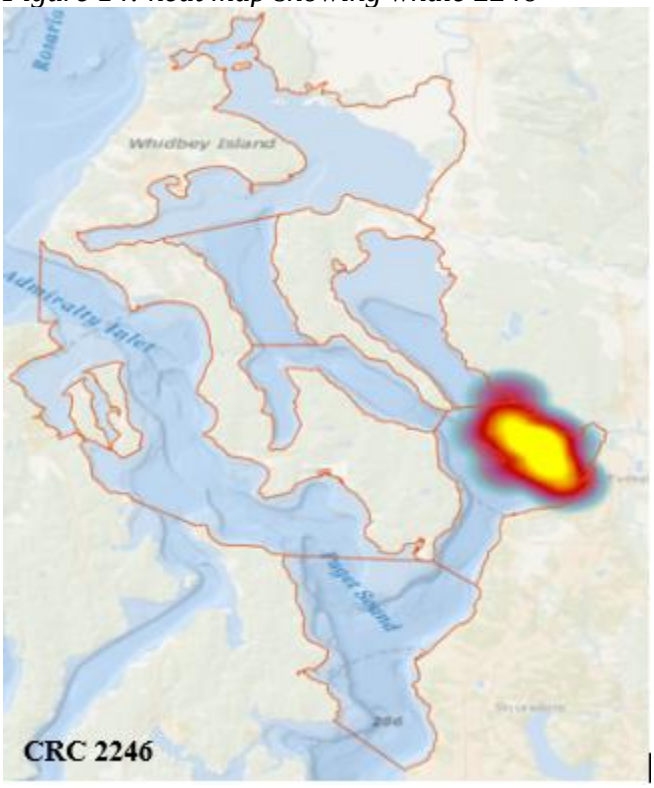

*Note.* This heat map showcases the area of high observations/density for each of the individual whales. The yellow areas indicate a higher density than the blue or purple areas.

*Figure 13: heat map showing whales 383, 396, 531, and 723*




*Note.* This heat map showcases the area of high observations/density for each of the individual whales. The yellow areas indicate a higher density than the blue or purple areas. Whale CRC-396 is a recent addition to the Sounders and only has a total of four observations which is what gives the equal areas of density.

*Figure 14: heat map showing whale 2246*




*Note.* This heat map showcases the area of high observations/density for whale CRC-2246. The yellow areas indicate a higher density than the blue areas.

## JMP Chi-squared results

A chi-square test of independence was conducted to assess whether the likelihood of finding individual whales is dependent upon parcel locations (in other words, are whale preferentially found in certain parcels). In total, six variations of the Chi-squared test were performed. Each test was completed using different whale and parcel combinations. Two of the six test results were successful in meeting the minimum requirements to run the test. For example, to run a successful and accurate Chi-square test, a minimum count of 5 was required for each section (i.e., there must be at least 5 observations of a whale in a given parcel).

The first scenario combined the areas of Skagit Bay, North Saratoga Passage, and Saratoga Passage together as one single area. Additionally, the areas of Admiralty Inlet and Central Puget Sound were also combined with the purpose of meeting the minimum number of observations needed to run the test. Lastly, the areas of Possession Sound and Port Susan were combined. In other words, the seven initial parcels were collapsed into a total of 3 parcels. Lastly, three of the thirteen whales were omitted from the chi-squared test as they all contained less than 5 observations each, or had been observed in Northern Puget Sound for less than 5 years.

The Chi-Square test of independence indicated there is a significant relationship between the number of whale observations per parcel ($x^2 = 82.418$, 18, $P < 0.001$). In other words, individual whale observations are dependent on parcel location. The Chi-Square table breaks it down even further by showing the actual count of observations, expected count of observations (if there was a normal distribution indicating no relationship), and the deviation between the expected and actual counts.

This same test was repeated a second time using a different combination of parcels to examine whether or not the relationship would change if the areas examined were different. In the second test, Skagit Bay, North Saratoga Passage, and Saratoga Passage were combined under number '1'. Admiralty Inlet and Central Puget Sound were combined again, this time under number '2'. Lastly, Possession Sound and Port Susan were not combined and instead were given the numbers '4' and '7', respectively. The same ten whales were used for consistency and the test was performed in JMP again.

The second Chi-Squared test in JMP yielded similar results as the first, again indicating that the number of whale observations is dependent upon parcel location ($x^2 =$

189.283, df=27, p <0.0005). This second test performed provided a closer look into the results of Possession Sound and Port Susan, as these two areas were combined in the first test which revealed the majority of the observations were in these combined parcels. However, in this examination of the relationship, even with the two parcels teased apart there is enough data to further indicate a relationship between the two variables, and further indicates that Possession Sound contains the majority of the observations.

While these tests are not detailed enough to suggest the specific kind of relationship between whales and areas within Northern Puget Sound, it does help to answer the question: does the likelihood of finding the Sounders depend on the physical location (i.e., Possession Sound, Port Susan, etc.) within Northern Puget Sound? Based on the results of the Chi-Squared test, the answer to this question appears to be yes—although this test does not allow for more detail than that. In order to better understand the relationships that are unfolding, further analysis must be completed.

## Species co-occurrence in R

Cooccurrence was assessed using observations collected between 2016-2019. The data set yielded significant results with positive associations between two pairs of whales: 22 & 383, and 53 & 531. This result indicates that these pairs of whales occur together frequently enough such that the associations cannot be explained by chance. There were no negative associations. It is worth highlighting, that while this test indicated a positive association between two pairs of whales, the remaining majority pairings are considered to be randomly associated, or unable to be classified.

# Chapter 5: Discussion

This study has demonstrated that the gray whales, known as the Sounders, have a distinct location preference within Northern Puget Sound. The whales have been observed most often—collectively over 67% of the time—in the area of Northern Puget Sound known as Possession Sound.

## Importance of Northern Puget Sound

Gray whales migrate for two reasons: to mate and give birth, and to feed. There have been no documented accounts of the Sounders exhibiting mating behavior while in Northern Puget Sound (Moore et al., 2003). However, it has been well established in the literature that gray whales migrate to Northern Puget Sound with the purpose of feeding on ghost shrimp (Calambokidis et al., 2004). For example, one ongoing study is examining the body condition of the Sounders upon their arrival to Northern Puget Sound, and again on their departure. The preliminary results have noted healthier looking whales departing Northern Puget Sound than when they first arrive to the area. Healthier, in this instance, is measured through body condition, a rounder body equates to a healthier, well-fed whale (Fearnbach, 2020).

However, knowing why gray whales migrate only provides a small clue as to why the Sounders wander 170+ miles off the traditional migration route to spend spring in Puget Sound. To better understand why the Sounders are spending so much time in Possession Sound, and other areas of Northern Puget Sound, the focus needs to shift to ghost shrimp; the food source that is providing an incentive for this divergence.

Every member of the Sounders, with the exception of the recent addition CRC-396, has been observed most often within Possession Sound. The frequency of observations in Possession Sound (832) is followed by Saratoga Passage at 174 observations, Port Susan at 87 observations, and Central Puget Sound at 83 observations. Which begs the question: why is Possession Sound frequented so often?

The large sand and mud flats that make up the eastern portion of Possession Sound have been formed over time by the sediment deposits of the Snohomish River. The Snohomish River estuary is the second largest estuary habitat within Puget Sound, and provides habitat to salmon fry, shore birds, and ghost shrimp (Rice et al., 2014). The ghost shrimp gorge themselves on the detritus brought into Possession sound by the Snohomish River (Pruitt et al., 2016). The Sounders have been observed frequently in this intertidal zone feeding on ghost shrimp using the high-risk/high-reward strategy in which the whales venture into the intertidal zone during high tide to feed, which puts them at risk of becoming stranded should they not leave before low tide (Weitkamp et al., 1992).

Further evidence of this feeding intensity at which the Sounders focus their efforts can be found in the thousands of feeding pits that pock-mark the Snohomish River delta. Aerial surveys performed in by the Cascadia Research Collective between 2005-2015 identified over 14,000 feeding pits in the Snohomish River delta alone (Calambokidis et al., 2016). Furthermore, the Washington State Department of Natural Resources conducted a study to estimate abundance of ghost shrimp near the areas where gray whales were known to feed in order to determine harvest levels for future years. The findings from this study calculated that the average total biomass consumed by the gray

whales in the Snohomish River delta during 2015 to equate to approximately 286.3 metric tons of ghost shrimp—with a standard error of 30 tons. The overall abundance of ghost shrimp within the Whidbey Island Basin—which includes Possession Sound, was calculated to be 9,377 metric tons with a standard error of 562 tons (Pruitt et al., 2016).

Ultimately, more research is needed to understand the relationship between ghost shrimp and the Sounders. However, it would not be an unreasonable hypothesis to suggest ghost shrimp abundance within Possession Sound is dense enough to incentivize the Sounders to return annually based on what is known about gray whale behavior, and current estimates of ghost shrimp abundance.

## Data Observations

Review of the data lead to some interesting observations among the individual whales, sighting frequency, and areas with the highest observations. Not all of these observations have statistical, or even practical significance, but are worth drawing attention to all the same.

First, of all 13 whales discussed throughout this study there was one that stood out: individual 49. Whale 49, also known as Patch, had 50+ more observations than the second most observed whale (53 at 160 observations). The reasons for this may be twofold, but are impossible to tease apart. For example, Patch has been the whale most consistently observed within Puget Sound showing up 28 out of the 29 years reviewed in this study. Next, Patch is nicknamed for an easily identified large white patch on his right dorsal side (Cascadia Research Collective, 2021). The ease for which he can be identified may be attributing to some observational bias—giving the illusion that he is present in

Puget Sound more often than the other whales. However, there is no way to know for sure whether the observations are reflecting reality, bias of verification due to his unique markings, or a little of both.

Finally, one of the most interesting discoveries of this thesis was the indication that individual whales are exhibiting some preference for the second and third most frequented areas, namely Port Susan and Saratoga Passage. Both of these areas are adjacent to the most frequented parcel, Possession Sound. This close proximity to such a productive feeding site may be an indication of a yet-unknown abundance of ghost shrimp in these areas, or the whales may be drawn to these areas of Puget Sound for other reasons. At this time, we can only speculate as to why the whales are mainly concentrated in the areas in and adjacent to Possession Sound.

## Unusual Mortality Events

Understanding where the Sounders are spending their time is an important step in the process to better protect the species as a whole. For example, location and migration information is especially pertinent given the unusual mortality event (UME) that NOAA declared to be affecting gray whales in 2019/2020, and may well continue into 2021 (NOAA Office of Protected Resources, 2020). An UME is defined by the Marine Mammal Commission as "a stranding that is unexpected, involves a significant die-off of any marine mammal populations; and demands immediate response" (Marine Mammal Commission, 2020).

Completed necropsies of gray whales found stranded during these events have cited malnutrition as the main cause of death for the majority of animals (NOAA Office

of Protected Resource, 2020). It is worth noting that the Sounders have been untouched by this mortality event thus far. There could be many reasons for this, including the small population size, however, some research has indicated the detour into Puget Sound may be beneficial to their overall health (Fearnbach, 2020). However, this connection would need more research to draw definitive conclusions between a detour in migration route, and overall resiliency.

## Policy Implications

As UME's pose a real threat to the survival of Eastern Pacific gray whales, any and all information that can be gathered from healthy sub-populations could be crucial for the longevity of the species. Protections for the areas the Sounders frequent may be an important policy step in ensuring their continued presence and survival in the area. One example of a policy recommendation that may benefit the Sounders would be to impose a moratorium on the ghost shrimp fishery for the duration of the time the whales are in the Sound. Current research indicates that ghost shrimp populations are able to bounce back fairly quickly after harvest; whether that be from humans or gray whales, however allowing ample time for recolonization of a harvested area would ensure the survival of ghost shrimp, and potentially the long-term presence of gray whales within Northern Puget Sound (Fieldman et al., 2000).

Ultimately, it will take much more than a shrimping moratorium in Puget Sound to recover gray whales as a species, especially if the Unusual Mortality Event continues in 2021 and beyond. However, the unique subset of whales that have frequented Northern Puget Sound for decades may provide insight for how to protect them into the future.

Further research done in areas such as primary diet of Pacific Coast Feeding Group Gray Whales, estimates of ghost shrimp abundance within Puget Sound, and how gray whales learn the intertidal feeding strategy of the Sounders may all have implications in regards to the conservation and health of not only the Sounders but all Eastern Pacific gray whales.

## Bias in the data

It is important to acknowledge that the observational data for this thesis will have bias that cannot be eliminated due to the way it is collected. For example, researchers at Cascadia who are recording the observations are conducting their field work in the areas where the whales are known to be. In other words, there is not an evenly distributed effort throughout all of Northern Puget Sound. Although observation reports from third parties (ex. whale watching vessels, other agencies, etc.), once verified, are added to this growing data set, the vast majority of observations are performed by Cascadia staff (over 94%). Due to constraints on time, staff availability, funding, and equipment needs researchers have to concentrate their efforts in specific areas for efficiency. Possession Sound is located just off the coast of Everett, Washington. This close proximity to an established port makes for an easier time planning logistics, ultimately allowing for more time on the water surveying. That said, John Calambodkidis noted in an interview, that the researchers go to where the whales are known to be, so while this observational data set may not completely reflect the location of the Sounders 100% accurately, it does indicate that they are spending a significant amount of time within Possession Sound (J. Calambokidis, personal communication, January 8, 2021). Ultimately, if the whales were elsewhere, the scientists would be elsewhere, too.

Lastly, the results from the co-occur data are interesting, but preliminary. More research is needed into this subject to identify as to whether the positive associations between the two sets of whales are at all significant. For example, after reviewing the original observational dataset provided by Cascadia, there were instances recorded in which these two sets of whales were observed together, as well as part of a larger group. However, there are a few drawbacks from this test, namely, there is no way to indicate whether or not the positive association between the pairs of whales is due to the whale activity; just as there is no way to indicate whether or not the behavior being exhibited is social or feeding behavior is responsible for their positive association. For example, this test is unable to indicate whether the whales are grouping together, rather, it confirms the presence of whales in the same parcel other individual they are associating with. Lastly, while this result is interesting, much more research would need to be conducted to surmise why they are occurring together.

# Chapter 6: Conclusion

North Puget Sound gray whales over the course of 29 years have shown a statistically significant preference for spending spring and early summer in Possession Sound. This finding, combined with the knowledge that Possession Sound is ideal habitat for ghost shrimp, suggests the abundance of ghost shrimp is likely affecting gray whale presence. For example, ghost shrimp may be providing a significant enough nutrient load that makes the detour off the traditional migration route worth the detour. Additionally, this study has indicated that the likelihood of finding an individual whale is related to the specific area being observed. In other words, the individual whales are showing preferences for different areas within Puget Sound.

Finally, more research is needed to identify if certain whales prefer the company of others. Additionally, should positive associations between whales be identified, further investigation would be needed to determine if this behavior is based on social or feeding needs. For example, review of the original observational dataset indicated that many of the animals were observed in the company of others. In a 2016 Cascadia staff mounted cameras on several of the individuals (49, 383, and 723) and 9 hours of footage revealed social behavior, such as rubbing, and swimming together (Calambokidis et al., 2016). While the cooccur test did provide results indicating a positive relationship between two sets of whales that was further supported by the observational data, this is not enough information to draw definitive conclusions.

Lastly, the Sounders are a reminder of how important the nearshore environment of Puget Sound can be for the health and wellbeing of those that depend on it. The Sounders have been utilizing these waters, and the ghost shrimp it provides, for over 30

years. The 170-mile deviation from the traditional migration route has provided them sustenance on their incredible journey, and potentially insulated them from the UME that has been affecting the greater population. Continued research of these animals may provide clues as to how best conserve the remaining populations of gray whales well into the future. While the 13 individuals that find their way into the Puget Sound every spring are a small subset of the eastern North Pacific population, they provide insight into gray whale behavior and activities that can be informative of the whole population. Further, they have become a cultural icon here in the Pacific Northwest, and knowing where their preferred locations within the Puget Sound are located, can help us to continue to protect these regions, ensuring the return of the Sounders each spring.

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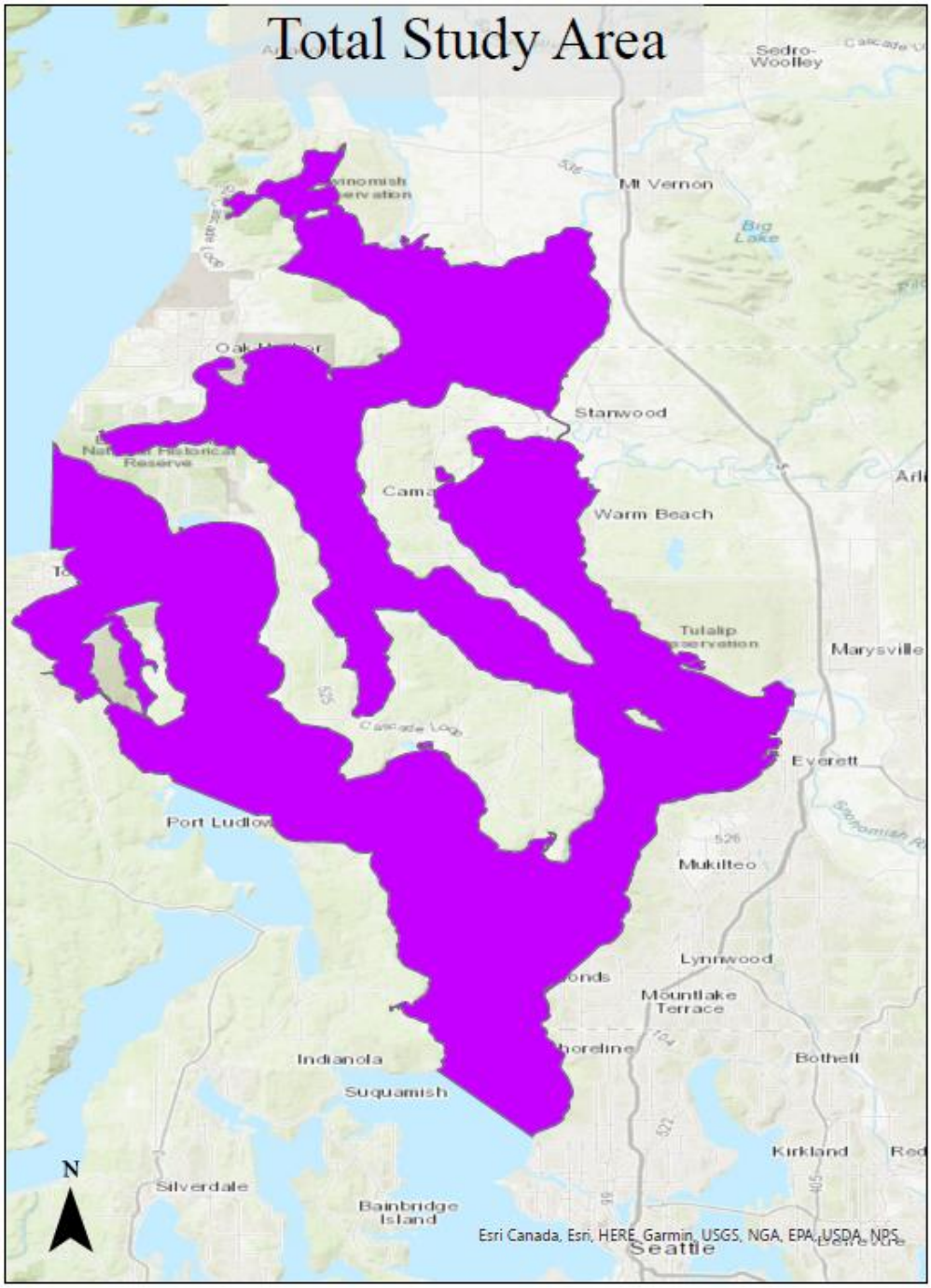
Appendices

**Appendix 1**



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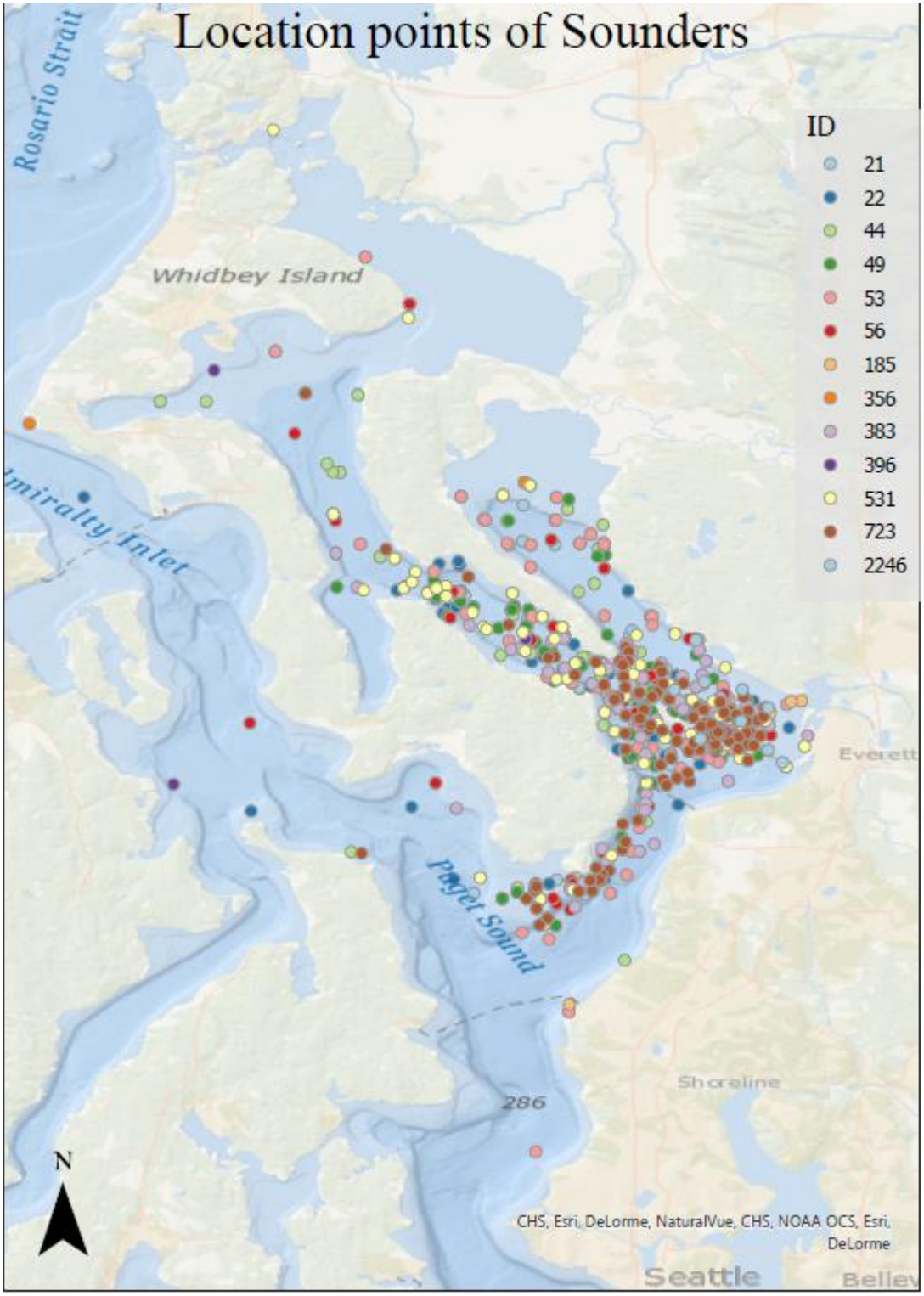
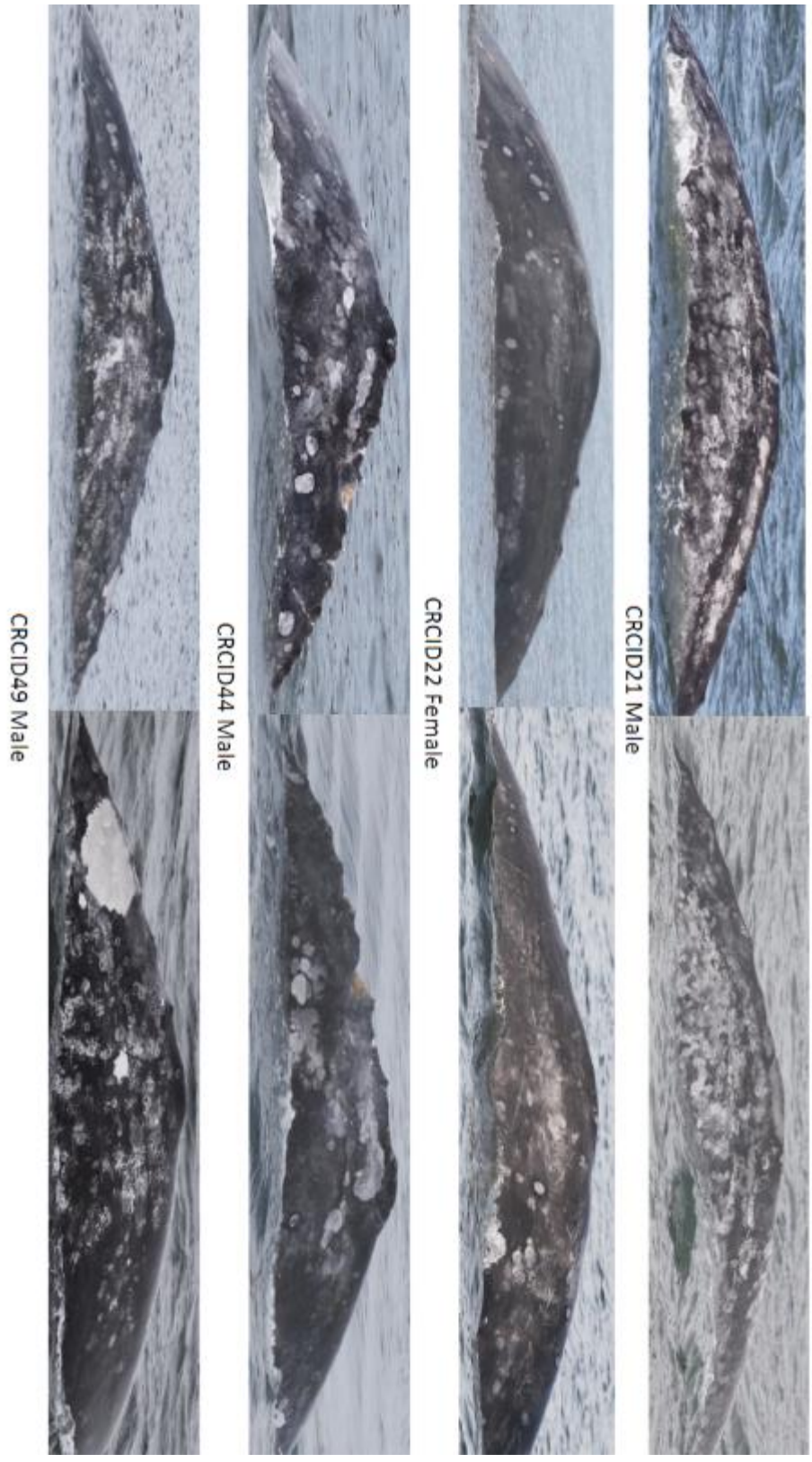

Location points of Sounders
ID
21
22
44
49
53
56
185
356
383
396
531
723
2246
Rosario Strait
Whidbey Island
Admiralty Inlet
Puget Sound
Everett
Shoreline
286
Seattle
N
CHS, Esri, DeLorme, NaturalVue, CHS, NOAA OCS, Esri, DeLorme

## Appendix 3



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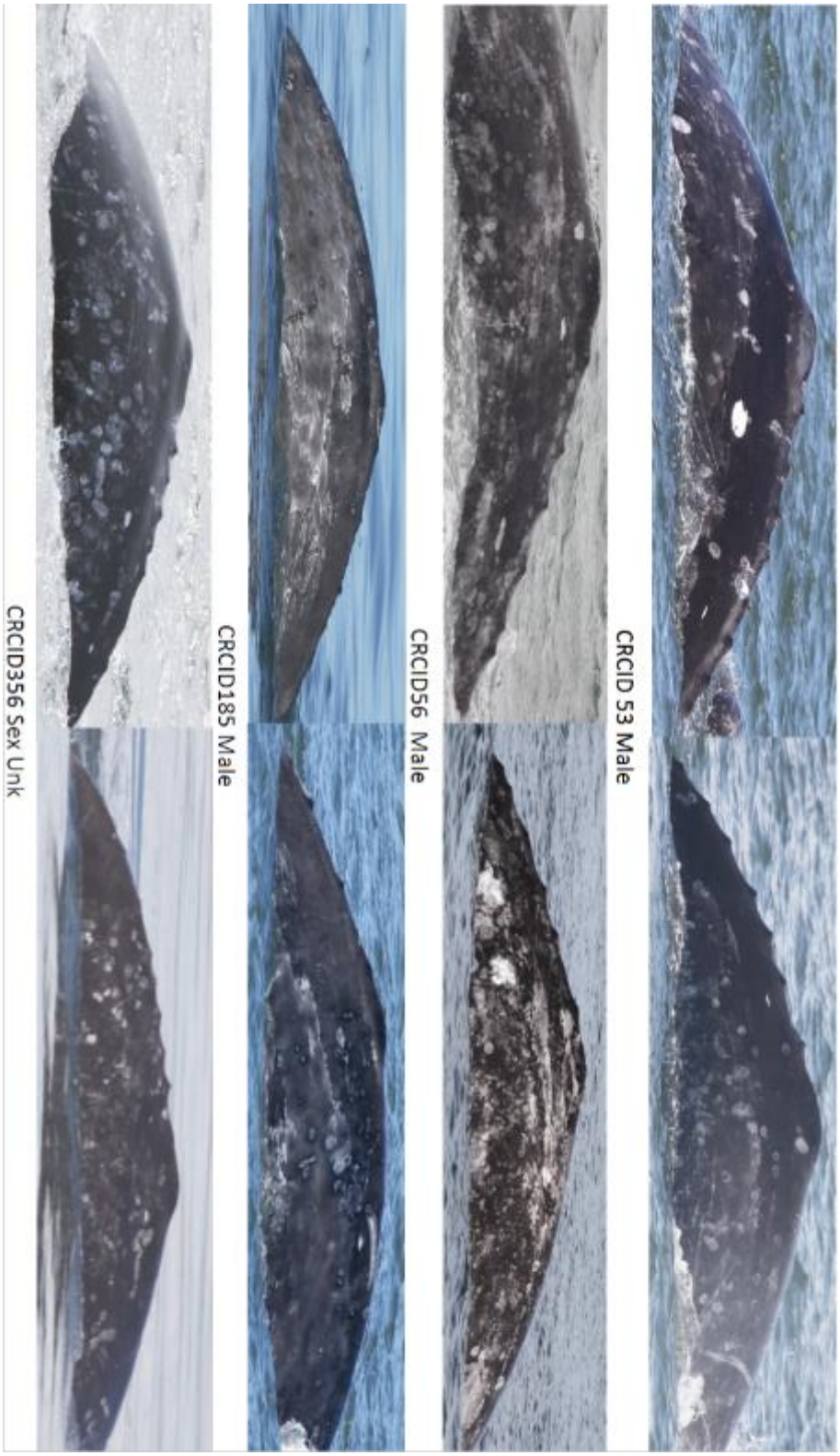

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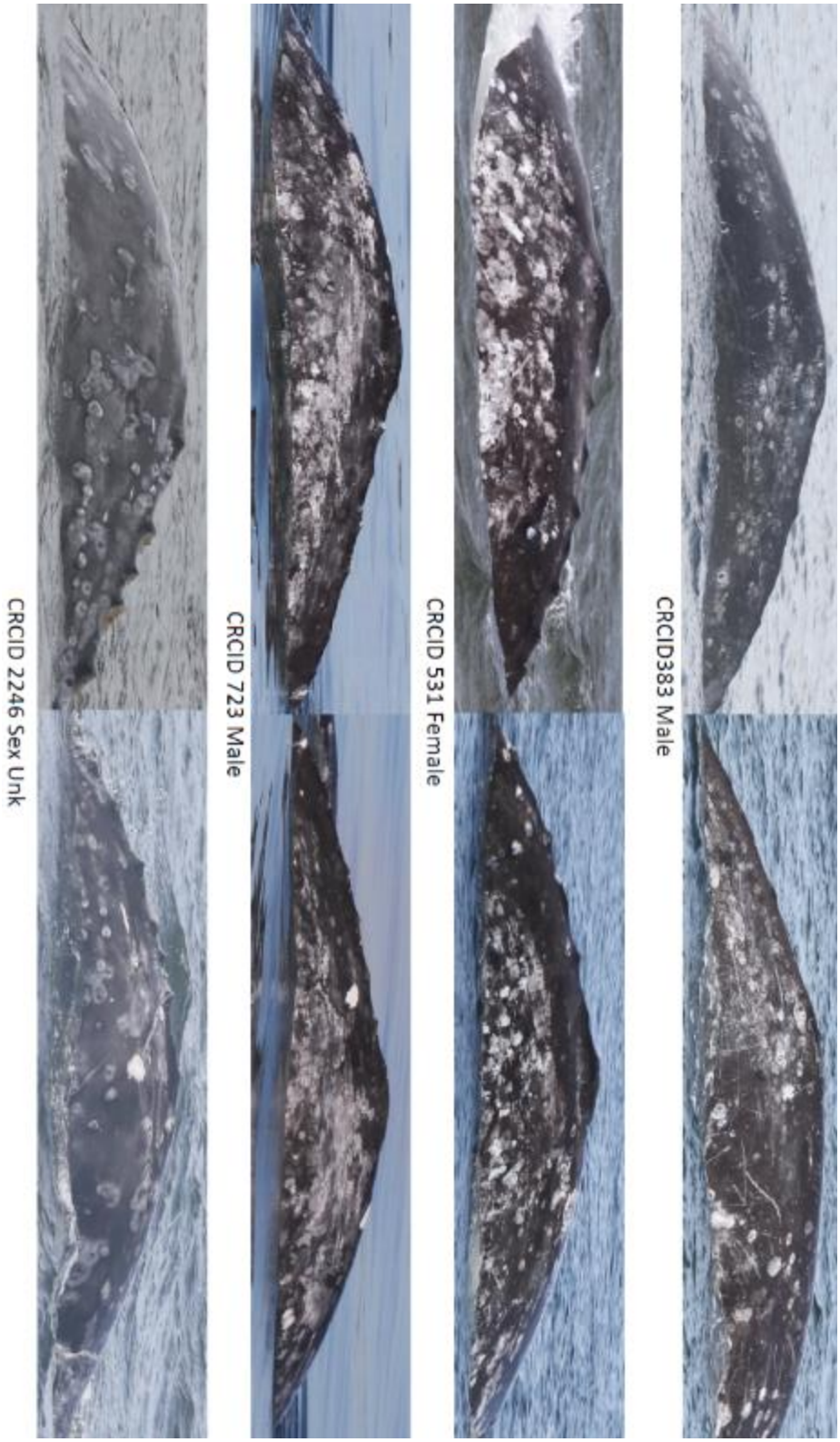
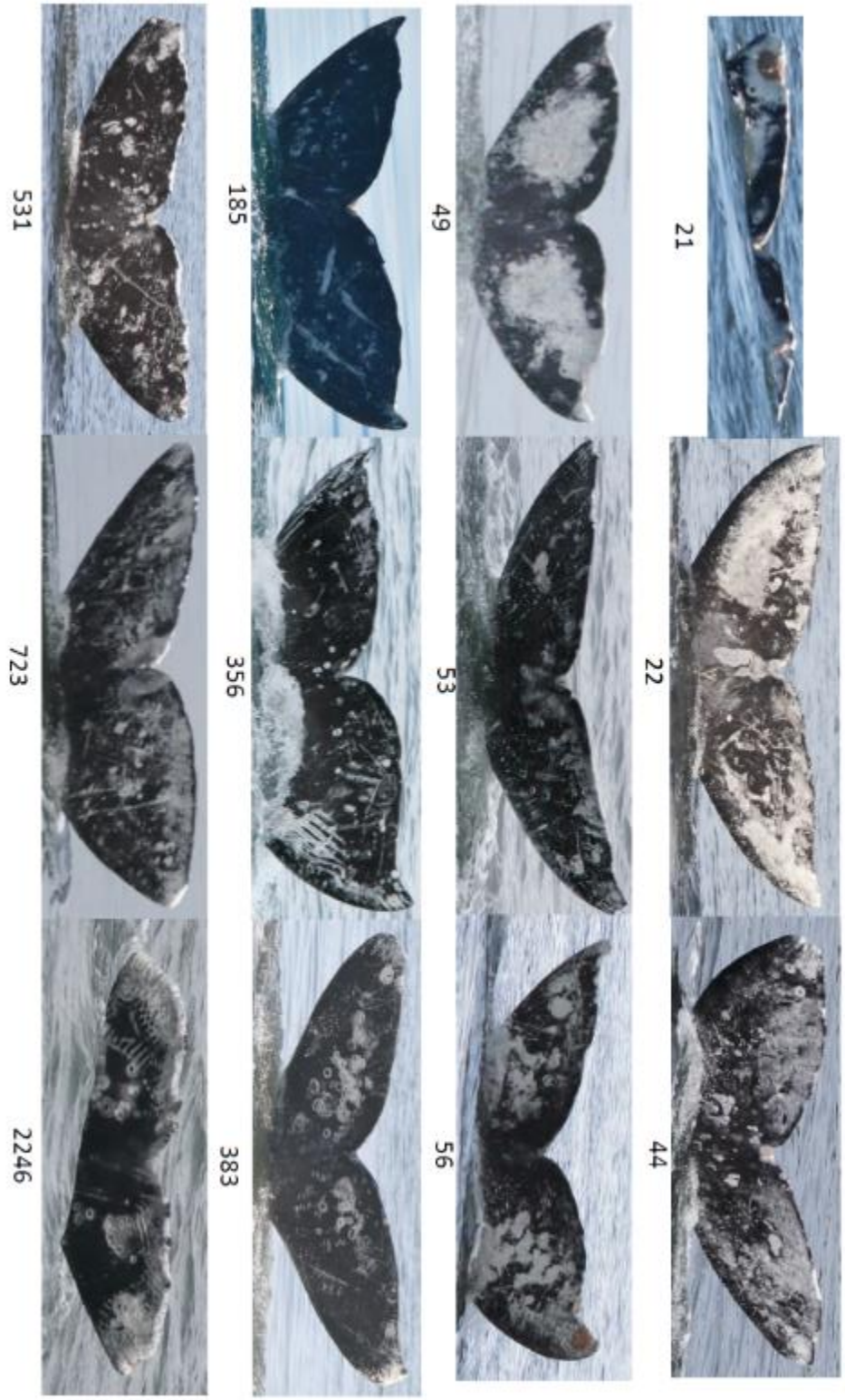

CRCID383 Male
CRCID 531 Female
CRCID 723 Male
CRCID 2246 Sex Unk

## Appendix 6



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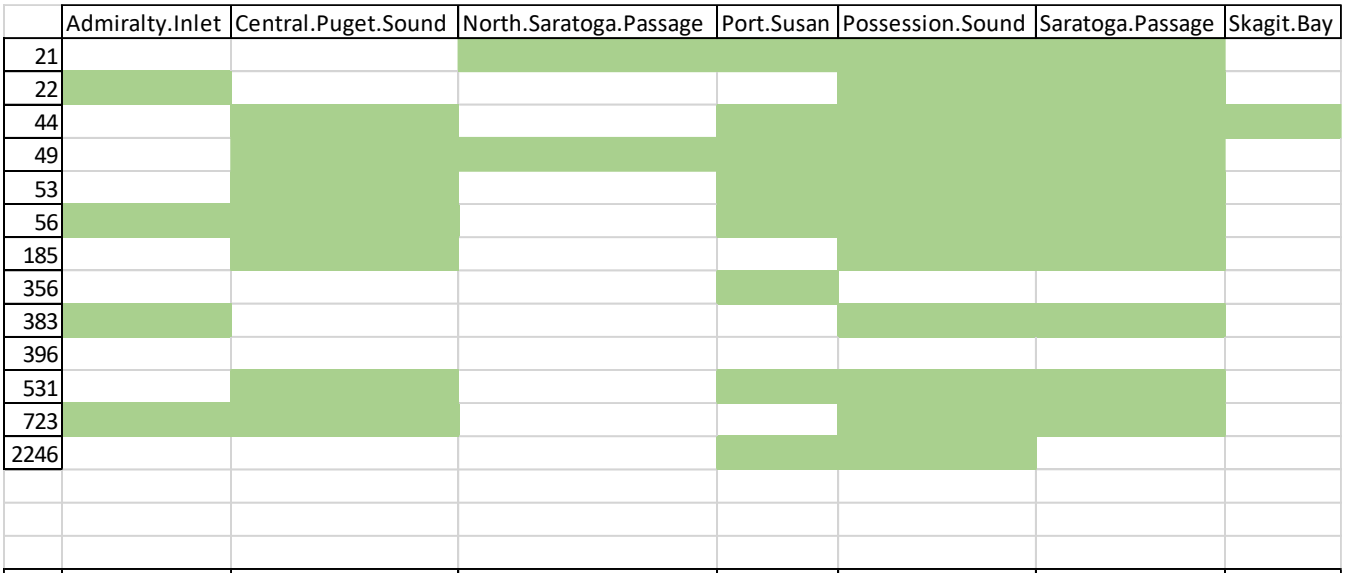

| | Admiralty.Inlet | Central.Puget.Sound | North.Saratoga.Passage | Port.Susan | Possession.Sound | Saratoga.Passage | Skagit.Bay |
|---|---|---|---|---|---|---|---|
| 21 | 0 | 0 | 1 | 1 | 1 | 1 | 0 |
| 22 | 1 | 0 | 0 | 0 | 1 | 1 | 0 |
| 44 | 0 | 1 | 0 | 1 | 1 | 1 | 1 |
| 49 | 0 | 1 | 1 | 1 | 1 | 1 | 0 |
| 53 | 0 | 1 | 0 | 1 | 1 | 1 | 0 |
| 56 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| 185 | 0 | 1 | 0 | 0 | 1 | 1 | 0 |
| 356 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 383 | 1 | 0 | 0 | 0 | 1 | 1 | 0 |
| 396 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
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