DISTRIBUTION, ABUNDANCE, AND SEASONAL VARIABILITY OF MARINE MAMMALS IN THE SOUTHWEST PUGET SOUND

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ABSTRACT

This thesis attempts to address two points of interest regarding marine mammals of the Southwest Puget Sound region using visual ship-based survey techniques and ArcGIS analysis. First, it addresses whether environmental factors (e.g. season, human activity, and temperature) affect marine mammal distribution within the Southwest Puget Sound. Second, it interrogates the abundance of each marine mammal known to inhabit the Southwest Puget Sound.

The species with the greatest population density observed was the harbor seal (*Phoca vitulina richardii*). This research shows seasonal variability in the depth areas preferred by harbor seals in winter when compared with other seasons, as well as the estimated areas of preference for other species, including California sea lions, harbor porpoises, and long-beaked common dolphins.

Maps were generated with ArcGIS to show in-depth species distribution, haul-outs, and environmental factors (e.g. water temperature). This analysis revealed that the strongest predicting variable recorded for harbor seal distribution by season is water depth-class ($P<0.001$) after area occupied by each depth-class was equalized and the count simulated.

Minimum abundance estimates of harbor seals in the survey region were generated from the average count in each survey area divided by the number of times that area was surveyed. This analysis suggests the Southwest Puget Sound as defined by this study is the day-time home to 298 seals in the summer, 332 seals in the fall, and 180 seals in the winter, on average. When comparing results with NOAA haul-out aerial survey estimates and NOAA's correction value of 1.53, the findings of this survey are consistent with existing estimates (Carretta et. al., 2017). These data suggest that close to all in-water and hauled out seals were counted in the region, as the correction value calculated with this survey's results is 1.59, comparable to NOAA's value.

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Chapter 1: Literature Review

Marine mammal populations in the Southwestern Puget Sound are some of the most thoroughly studied and accessible populations in the world. Simultaneously, they highlight notable gaps in scientific knowledge essential to describing the lives of these fascinating animals. Being charismatic megafauna, seals, sea lions, porpoises, dolphins, and whales benefit from a rich interest in their preservation and understanding.

This research encompasses all marine mammals found in the South Puget Sound. However, an overwhelming abundance of harbor seals across the region has led to a special focus on their representation within the literature. When seals and sea lions are being discussed in this paper, the Latin name for their clade, pinnipeds (seals and sea lions), will be used. When whales and dolphins are discussed, the name for their infraorder, cetaceans, will be used.

Several key organizations will be mentioned throughout this paper and will be referred to by their acronyms or shortened versions of their full organization names. The National Oceanic and Atmospheric Administration (hereafter NOAA) is a U.S. scientific agency under the Department of Commerce tasked with the research and management of marine mammals by the Marine Mammal Protection Act of 1972 (hereafter MMPA) (NOAA, 2019). The Washington Department of Fish and Wildlife (hereafter WDFW) is a state agency tasked with the management of Washington's fish and wildlife resources. Other states have similar agencies such as Alaska Department of Fish and Game (hereafter ADFG). Other key research organizations include Cascadia Research Collective (hereafter Cascadia), Seal Sitters, Orca Network, North Atlantic Marine

Mammal Commission (hereafter NAMMCO), and Washington Department of Natural Resources (hereafter DNR).

Though many well-resourced organizations have looked into marine mammal behavior, abundance, distribution, and management with great public interest, surprisingly there are still many unknowns. This is in part due to the inherent difficulty of studying marine mammals, as they live most of their life out of reach and sight of researchers. Many populations are currently classified as unknown, as either an effective methodology has yet to be developed or surveying stopped once a population projection curve could be developed (Carretta et. al., 2017). The unknowns also extend into behavioral knowledge about these animals (Hayward et. al., 2005).

The content of this essay will consider current and past marine mammal survey methodology, review current findings, describe behavior, identify methodological challenges, converge on important considerations in designing such a survey, and proclaim the significance of a data-rich study. The goal of this work is to condense the required and relevant information that guides the methodological considerations for this survey.

Methods

Major efforts to estimate populations of marine mammals in U.S. waters began with the enforcement of the MMPA (NOAA, 2019). As a stipulation to the new protections, NOAA must publish annual reports on marine mammal stocks (NOAA Alaska Fisheries, 2018). Aerial survey methods were rapidly integrated, as they could be done quickly and easily with limited staffing and technology (Laws, 1993). Shore- and sea-based counting came as a secondary option in areas where aerial surveying was difficult for pinnipeds (Bengtson et. al., 2004).

Aerial survey methods for pinnipeds consist of attaching a high-resolution camera to the belly of an aircraft, such as a small plane or helicopter, and flying over the survey area while taking pictures to create a full mosaic of the area (Bengtson et. al., 2004). Researchers then analyze the photographs for animals to varying degrees of success (Bengtson et. al., 2004). Aerial surveys of harbor seals are conducted at the optimal haul-out date and time. Then in-water seals are estimated using a mathematical correction value (Jefferies et. al., 2003). This correction value is regionally and species-specific, usually found using radio tagging surveys (Huber et. al., 2001). The result is an estimate of minimum abundance in the region surveyed, which is then checked against the population curve generated from previous surveys in that area (Thompson et. al., 1990). Altitude can be adjusted in areas that allow for maneuverability to either limit disturbance to the animals or to generate greater detail in images that may reveal previously hidden seals (Bengtson et. al., 2004).

For mathematical abundance corrections to work, researchers must count the hauled out seals of a given region using aerial surveying methods near the optimal haul-out day (Jefferies et. al., 2003). This exact day changes from location to location but generally "...maximal daily haul-outs during pupping season occur during receding tides, approximately midway between high and low tides." (Hayward et. al., 2005); for Washington state, maximal haul-out occurs in the last week of July. (Hayward et. al., 2005). Researchers must also measure local environmental factors to help include in-water seals that would have been missed using "...tide height and current direction..." which "...explained 40% of the variability in hourly census data." (Hayward et. al., 2005). The simplest correction that can be made to adjust final counts is the maximal count correction or "upper bound", which assumes that the researcher has estimated the optimal haul-out date and time using further equations (Hayward, 2005). The minimal count being the actual number of seals seen by surveyors (Jefferies et. al., 2003). The "upper bound" equation is as follows:

"$M(t) = \beta e^{-\gamma(\text{day of year} + t/24 - \delta)^2}$" (Hayward et. al., 2005).

Equation 1: Hayward et. al., 2005 Upper Bound equation.

The correction value used to estimate the total population based on the number of individuals hauled out during maximum haul-out in the Southern Puget Sound by NOAA was determined to be "1.53" (Huber et. al., 2001). This value was derived from radio tagging studies on approximately 20 seals from various locations within the Puget Sound (Carretta et. al., 2017). This small sample used to estimate the behavior of thousands of harbor seals in a variety of local conditions (Carretta et. al., 2017).

The use of small unmanned aircraft (here-after "drones") to survey marine mammals has increased in recent years. In the Puget Sound, harbor seal haul-outs can be accurately counted, and biometrics can be taken, using drone photographs to enrich the data and inform final counts from land- or sea-based researchers (NAMMCO, 2018). Special permitting is required to use drones in marine mammal research; and thus, it is mainly large research organizations like NOAA and Cascadia that conduct such studies (NOAA, 2019).

Other pieces of technology are making waves in the world of marine mammal research. Hydrophones (underwater microphones) can be used in presence surveys where the survey aims to detect which animals are present in a specified area (Laws, 1993). This is most effective for more “talkative” animals hidden by ice or landscape, or that dive for extended periods (Laws, 1993). Radio tagging is used with a wide variety of marine mammals to study an individual’s behavior to learn about the species as a whole (NOAA Alaska Fisheries, 2018). Tagged harbor seals have revealed seasonal variability in their activity and show the extent of a population’s range (NOAA Alaska Fisheries, 2018).

The most cutting-edge modern surveys utilize many pieces of technology in synchrony; however, they are still not able to include in-water seals. First, a predetermined percentage of seals in the survey region are radio-tagged and used to estimate the percentage of in-water seals during the flyover. Second, during max haul-out time and in ideal conditions, the aerial photographs are taken. The photographs are analyzed, alongside radio tag data to generate the final count (Alaska Dept. of Fish and Game, 2019). This technique does not account for transient seals or seals that do not use that particular haul-out but still exist in the region. It does take into account regional seal behavior and time spent in-water, which has been a problem that has plagued many studies:

> “Although the timing and methodology of surveys differ considerably between studies, they all share one problem: common seals spend an unknown proportion

of their time in the water, even as pups and these counts can, therefore, be regarded only as minimum population estimates." (Thompson et. al., 1990).

Research concerning cetacean abundance along the West Coast of the U.S. is done by ship along transects, while inland waters such as the Puget Sound are surveyed using aerial methods (Carretta et. al., 2017). Harbor porpoise abundance estimates are currently reported using this methodology. However, a breakdown of regional abundance is not reported (Carretta et. al., 2017). It is impossible with the published format to say how many porpoises are found in any given region, except on a statewide scale for either the coastal or inland porpoise stock.

Marine mammal surveys are growing with the pace of technology, but some of the best and most widely accepted findings still depend on observers in the field. With the inclusion of new and easily accessible technology, such as drones and geolocators, researchers are gaining a better grasp of marine mammal behavior (NOAA Alaska Fisheries, 2018). A greater understanding of the behavior of marine mammals helps to solve confounding variables and reveal new ones, so that new methods may take them into account (Hayward et. al., 2005). Old surveys with significant pitfalls are still used as the authority on population estimates for many regions of the U.S. allowing for significant growth in the field (Carretta et. al., 2017). Safe and accurate methods to represent spatio-temporal data of all species of marine mammal is essential for their conservation and management (Watson et. al., 2019).

Current Findings

The current numbers of marine mammals living in the Southwest Puget Sound are generally reported as “unknown” (Carretta et. al., 2017). Many of the researchers reporting this are also working to create a current estimate of their particular study species with varying success. It has been acceptable to report the harbor seal population in Southwest Puget Sound as “stable at carrying capacity” or “Optimal Sustainable Population” (Jefferies et al., 2003). Although both listings have prevented adequately intensive and high-detailed studies from being conducted, some broader monitoring projects have been published.

Current fisheries stock reports on pinnipeds rely on aerial survey methods during the pupping season with corrective equations. Harbor seal estimates reported in NOAA’s legally required annual reports are derived from data collected in 1999 by Jefferies et al., which is now considered out of date at 21 years old. Jefferies et.al. also supply widely accepted and detailed population projection methods, possibly contributing to the complacency of current researchers to not pursue a more current count of harbor seals.

Currently, published harbor seal stock reports by NOAA conclude that there is no current estimate for the Puget Sound ecoregion. Despite this, the minimum population estimate for the South Puget Sound, estimated using WDFW reports from 2009 (summing max counts at major haul-outs on Gertrude Island, Woodard Bay, and Eagle Island), is approximately 1,000 seals in all waters south of the Tacoma Narrows (Lambourn et. al., 2009).

Population estimates of harbor seals in inland Washington waters from 20 years ago are generally accepted and supported by the population curve generated in 1999 showing a flattening of growth (Jefferies et. al., 2003). The flattening of population growth indicates that the population has presumably reached carrying capacity and will fluctuate sustainably until significant changes occur (Lambourn et. al., 2009).

Harbor porpoise population is also reported on a statewide scale. NOAA reports that the total for all Washington inland waters is approximately 11,233 individuals derived from aerial surveys in 2015 (Carretta et. al., 2017). The harbor porpoise population curve for Washington State is not officially known, but the total numbers have greatly increased from past estimates (Carretta et. al., 2010).

Across the species currently inhabiting the Southern Puget Sound, populations have increased sharply and significantly since the MMPA began in 1973 (NOAA, 2019). For harbor seals inhabiting Washington inland waters, the increase has been at least three-fold from 337 individuals in 1978 to 1,025 individuals in 1999 (Jefferies et. al.). Harbor porpoises had disappeared from southern regions of the Sound but recently returned as inland stocks increased from 3,298 individuals in 1990 to 11,233 in 2015 (Carretta et. al., 2017). With the return of their prey species (harbor seals and harbor porpoises), it has been hypothesized that orcas may utilize the South Puget Sound (provided the orcas can traverse the noise barriers of Seattle and Tacoma) more often and potentially see a similar increase (Kriete, 2007).

Behavior

To understand a particular species and survey their population, survey designers must take into consideration their behavior. Whether it's haul-out requirements for pinnipeds or typical cruising grounds for cetaceans, having detailed knowledge of a species' needs can make or break methodology. Currently, marine mammals are poorly understood, and counts are biased towards what observers can learn from the shoreline (Hayward et. al., 2005).

Seal behavior, because of their amphibious nature and socialness, can be incredibly complex but accessible to land-based observers. Larger patterns in their lives dictate certain patterns of behavior throughout the year allowing for survey designs to make the best use of these times. These life chapters are as follows: pupping in early to mid-summer, molting in fall, and foraging in late fall to spring (Alaska Dept. of Fish and Game, 2019).

Pupping is the most common time of the year for aerial surveys to be conducted, as the most seals are hauled out during this time (Hayward et. al., 2005). Pups are born around June and are weaned approximately one month after birth (Alaska Dept. of Fish and Game, 2019). Although they can swim immediately after birth, they remain on land as much as possible (Alaska Dept. of Fish and Game, 2019). After August, it is expected to find the surviving pups in the water around or on the haul-out of their birth; this increases the number of individuals counted by approximately 6% for Washington inland waters each breeding season (Cammen et. al., 2019). Harbor seal pup mortality is typically due to starvation, which is expected from harbor seal populations at carrying capacity (Essington et. al., 2019). Historically, predation was a major source of harbor seal pup mortality, most notably from coyotes (Steiger et. al., 1989), but this is no longer the case in South Puget Sound.

Molting, the time when adult harbor seals shed their old fur and new fur grows, is the second most populated time of the year for haul-outs (Alaska Dept. of Fish and Game, 2019). Increased blood flow to the skin to rapidly grow new fur increases the risk of hypothermia if a seal is in the water. As such, seals prefer to be out of the water as much as possible during this critical period (Fontaine, 2007). It is very important to take care when navigating near haul-outs during this time to prevent seals from fleeing into the water and expending immense energy re-heating themselves (NOAA Alaska Fisheries, 2018).

In winter, harbor seals are much more dispersed as they hunt for food and do not rely as much on the availability of haul-outs. Seals spend 80% of their time in the water in winter as opposed to 50% or less at other times of the year (Kinkhart et. al., 2008). In order to survive the more challenging conditions of the season and bear healthy young in the early summer, harbor seals must acquire enough food-stores during this time (Alaska Dept. of Fish and Game, 2019). Molting extends the period of diminished hunting in the warmer months (Kinkhart et. al., 2008).

Other aspects of harbor seal behaviors are important for researchers to note to generate a working methodology. Harbor seals are capable of great physiological feats due to their thick oxygen-saturated blood (Fontaine, 2007). Harbor seals are capable of diving 1,640 feet (Alaska Dept. of Fish and Game, 2019) and can remain underwater for over 30 minutes (Seal Sitters, 2019). Most dives, especially in shallow inland waters, last less than four minutes (Alaska Dept. of Fish and Game, 2019). Harbor seals can swim up to 10.5 knots (12 mph), but like diving for shorter amounts of time, they prefer to move much slower (Alaska Dept. of Fish and Game, 2019).

Distribution of harbor seals in-water is driven by a multitude of environmental factors. Two important factors that predict where seals can be found are proximity to established haul-out platforms and places of abundant prey (Pearson, 2018). Both are affected by human-made infrastructure in the South Puget Sound (Pearson, 2018). Dams, bridges, and other marine structures artificially concentrate prey into a small area that is utilized to great effect by pinnipeds (Pearson, 2018). Major haul-outs in the Southwest Puget Sound are purely human-made structures such as log-floats, swim platforms, marinas, and fishing structures. These structures provide a predator-free but greater human-caused disturbance location for pinnipeds to haul out (Lambourn et. al., 2009).

Small cetaceans, most commonly the harbor porpoise, inhabit the South Puget Sound (Garrett, 2019). Porpoises can be found in the deeper waters, such as around Heron Island in Case Inlet, and the deeper waters of Budd Inlet, but are rarely seen in the shallow inlets (Garrett, 2019). This has not always the case, predatory pressure from orcas in the early 20th century drove harbor porpoises into shallow water areas such as bays and rivers (Scheffer et. al., 1944).

Large cetaceans occasionally visit the South Puget Sound’s deeper waters within Case Inlet. These species include humpback whales, grey whales, minke whales, and orcas (Garrett, 2019). Recently, the numbers of large cetaceans traveling through the Tacoma Narrows into the South Puget Sound ecoregion have diminished, possibly due to increased ship traffic in Seattle and Tacoma (Kriete, 2007), or pollution emanating from the South Puget Sound (Cullon et. al., 2005). Orcas used to regularly hunt these waters in the 1940s when it was common to see them in pursuit of small porpoises and seals (Scheffer et. al., 1944).

Knowing what to expect before getting into the air or water can help with the workflow and thus the outcome of a survey. A well-designed census takes the behavior of the animals studied and optimizes the design around the likelihoods presented by their physiology and observed habits.

Challenges

Despite 50 years of refinement and incremental steps in methodological progress, the surveying of marine mammals faces great challenges (NOAA, 2019). Complex interactions between variables with unknown significances plague even the best survey designs and resource-rich efforts (Hayward et. al., 2005). Mitigation efforts must be instilled to counteract these challenging conditions and more accurately describe the populations being surveyed. To address the challenges of surveying marine mammals, these challenges must be recognized.

Aerial survey methods come with a set of challenges as a result of their very nature. They are limited to large organizations with aircraft equipment to conduct such surveys (NOAA, 2019). While some techniques help to mitigate the errors, they are inherently limited by the technology and may affect marine mammal behavior for the sake of getting a more accurate count (Bengtson et. al., 2004). Aerial survey raw data is always classified as a minimum abundance estimate or is too “fuzzy” to tell whether the correct mathematical corrections are being applied (Hayward et. al., 2005).

Because aerial surveys must account for in-water animals, mathematical processing must take place to generate an accurate estimation of abundance in the region. The number used to multiply the final count is called the “correction value.” The correction value can vary from one site to another and typically falls between 1.3-1.7 (Hayward et. al., 2005). Studies suggest this number may not be accurate because of the complexity of seal haul-out behavior and variability (Patterson et. al., 2008).

Due to the photographic nature of aerial surveys, and that in-water behavior is not considered, these surveys are a snapshot in the life of a seal. A survey method needs to be developed that combines the commanding view offered by aerial surveys and the real-time view of shore-based counts where observers can see seals commuting. Regardless of the date, seals will be in the water and thus current methods designed to count the maximum haul-out time are doomed to be minimal counts and in minimal detail (Jefferies et. al., 2003). Ultimately, seals spend an unknown and significant percentage of their individual lives in the water (Thompson et. al., 1990). While radio tagging surveys allow for a glimpse into this essential medium and allow for an ever-increasing amount of detail, full counts made at sea are rarely considered as a viable survey option even in regions comprised of restrictive shallow inlets like the South Puget Sound (Thompson et. al., 1990).

Sea- and shore-based surveys are typically employed where aerial surveys are difficult or impossible. One must consider a specific set of challenges and mitigation procedures when conducting a non-aerial survey to prevent inaccurate or false data. While some meta-analysis studies find this methodology to be more accurate than aerial surveys when counting seals (Bengtson et. al., 2004), others have the opposite finding (Thompson et. al., 1990). The studies previously referred to only counted hauled-out seals, a greater weak point for shore- or sea-based observers than aerial surveys (Bengtson et. al., 2004).

One of the greatest problems posed to both land- and ship-based seal surveys is the impaired ability to count seals while they are hauled out in large groups and individuals are hidden from view by their neighbors. Seals naturally clump together, as this raises their survivability in the event of a predatory attack on the group, thus it is rare to see seals hauled out on their own (Scheffer et. al., 1944). Few methodological changes can be done to mitigate this issue but acquiring high-powered optics, watching for movement over some time, and having a trained or experienced observer can help in getting an accurate count (Bengtson et. al., 2004).

While the use of drones can eliminate or mitigate problems with counting “clumped” seals (NAMMCO, 2018), drones pose many problems to wildlife. A low flyover of seal haul-outs can cause a stampede, adding unnecessary stress and potential harm to the seals (NOAA, 2019). Seals are much more aware of above-water activity when compared to other marine mammals (Smith et. al., 2019). Viewing guidelines for drone pilots are mentioned in the MMPA as general avoidance (NOAA, 2019), but recent proceedings on drones have shown that they cause behavioral change even at the highest allowed FAA (Federal Aviation Administration) drone altitude limit of 400 feet (Smith et. al., 2019).

Another pressing issue posed to land-based observers that also applies to ship-based observation is the proximity bias wherein marine mammals closer to the observer are counted more often and more accurately than distant ones (Bengtson et. al., 2004). Again, this issue can be mitigated with proper optics if the observer continually scans the limits of the given area for marine mammals as diligently as nearer areas. Further mitigation can be made by limiting the observer's allowed area of view and adding transect lines that do not stretch the visual limits of the observer (Laws, 1993).

Considerable effort must be made to prevent the occurrence of double counting of in-water marine mammals to the point where most surveys do not consider the counting of in-water data points a viable option (Alaska Dept. of Fish and Game, 2019). This is potentially because the methodology of current and past seal surveys employed the use of aircraft to take a snapshot at the optimal time (Hayward et. al., 2005).

Unexplained variables still haunt the researcher's ability to accurately describe harbor seal populations. These variables include environmental stochasticity, demographic stochasticity, error in modeling assumptions, and observational errors (Hayward et. al., 2005). Environmental stochasticity refers to changes in environmental variables that affect the behavior of wildlife. In the case of seals, this includes heat load (solar radiation), wind gusts, changes in food availability, and waves, all of which can change quickly (Hayward et. al., 2005). Demographic stochasticity refers to the natural phenomena of wildlife exhibiting unique behavior from one individual to the next, even among seals of the same haul-out (Hayward et. al., 2005). Observational error refers to variation in the conditions and quality of view between observers or inaccurate counts made by individual researchers (Hayward et. al., 2005). Modeling assumptions may vary easily and be inaccurate or just plain wrong (Hayward et. al., 2005). There are still many other variables that are not accounted for in corrective mathematics (Hayward et. al., 2005).

Designing a respectable survey of marine mammals in any region of the world poses similar, and sometimes much more intense, problems for designers to consider. Many of the challenges presented above are caused by the current reliance on the methodology of aerial photography with corrective mathematics. Radio tagging studies help with this issue by providing information on the behavior of subjects, uncovering the likelihood of the individual to be counted (Huber et. al., 2001). Further research will be required to develop a more perfect marine mammal survey method.

Design

Given limited resources, a survey must be designed using the tools available and executed most optimally. Using information derived from the literature and taking into consideration the specific limitations of the research project's resources, a methodology for surveying marine mammals in a given region over a given time with available resources emerges. The methodology of this study is a ship-based survey where seasonal counts in specific areas will be averaged to gain a minimum count estimation. All that remains is the will to pursue its feasibility, where the MMPA will dictate the researcher's capabilities.

The MMPA lays out very specific guidelines for researchers, observers, and commercial vessels likely to interact with marine mammals (NOAA, 2019). Researchers of many forms must register for the necessary permits depending on methodology from NOAA. However, there are grey areas in the requirements, and researchers that fall into these grey areas are referred to the NOAA permitting office (NOAA, 2019). Typically, so long as no breach in MMPA marine mammal observation guidelines are breached, these grey area researchers may proceed with their research without permitting (NOAA, 2019).

The MMPA viewing guidelines are species-specific and are distributed widely across the Puget Sound in the form of posters (on ferries and docks) and digital information. The distance requirement for pinnipeds is 50 yards (46 meters) at sea, and 100 yards (92 meters) when they are hauled out. The distance requirement for viewing small cetaceans varies from 50 - 100 yards (46-92 meters) depending on local laws. Orcas have a unique requirement of 200 yards (183 meters) in inland Washington waters, while other large cetaceans, including whales, are 100 yards (92 meters) (NOAA, 2019). The MMPA also requires that vessels slow and idle their engines if the marine mammal approaches to prevent collision and minimize disturbance (NOAA, 2019).

Binoculars are required to minimize proximity bias in wide-open waters, such as Case Inlet, or any of the other large inlets (Bengtson et. al., 2004). Another layer to prevent this bias is designing charters that do not require excessively distant observations (Bengtson et. al., 2004) and giving the observer the best vantage point to make observations (Laws, 1993). Presumably, double counting can be prevented by moving the vessel at an average of 5 knots. At this speed, harbor seals diving from zero to ten minutes (encompassing the usual four-minute dive time of harbor seals in shallow water) can be counted and overtaken as the vessel moves from one area to the next, as the seals will stay within visual range (Alaska Dept. of Fish and Game, 2019).

With powerful optics, well thought out nautical transects, and a set average speed, a ship-based survey that encompasses both hauled-out and in-water seals is possible legally and physically. While some areas of the Southwest Puget Sound will be blocked by fishing activities and unfavorable water-depth conditions to the degree that an insufficient data indication must be applied, major haul-outs and foraging areas used by seals, porpoises, and large cetaceans are still viewable from the sea. While challenging and time-consuming, a sea-based study of marine mammal distribution and abundance with seasonal considerations is feasible and may lead to previously unknown patterns in these elusive, complex animals.

Significance

Marine mammals play an important role in the Puget Sound ecoregion and throughout history. It is important to contextualize them in their cultural, commercial, and ecological significance to give purpose and understanding to research into their status and health. Aerial surveys have revealed more information than ever before about the status of marine mammal stocks. However, some meta-analyses have been conducted looking into the effectiveness of this tradition and have found significant flaws (Patterson et. al., 2008).

The cultural significance of marine mammals in Puget Sound cannot be understated. They have provided sustenance, clothing, and tools to the human residents of the Puget Sound for thousands of years (Scheffer et. al., 1944). Pacific coastal indigenous communities continue to rely on marine mammal stocks for their spiritual value and to continue artful traditions from live performance to sculpture (Kriete, 2007). In many places along the west coast of North America, especially in Alaska, harbor seals still play an important role as a natural resource in the lives of native communities (Alaska Dept. of Fish and Game, 2019). Harbor seals draw eco-tourists to bay tours along the coast and drive recreational equipment rentals wherever they are present because of their visibility (Alaska Dept. of Fish and Game, 2019). This is also the case in the Southwest Puget Sound where Olympia-based businesses rent paddling equipment for those that want to visit the inland waterways.

With an impending cull of harbor seals in Puget Sound to protect fish stocks (Pearson, 2018), and with the population facing bioaccumulative toxins increasing in Washington's waterways, especially in the Southern Puget Sound (Calambokidis et. al., 1985), research into their abundance, distribution, and behavior is particularly relevant. Illegal shooting of harbor seals in Puget Sound continues in unknown numbers, most likely by fishermen who falsely believe are partly responsible for diminished fish stocks and that harbor seals are overly abundant (Cammen et. al., 2019).

Recently, NOAA has determined that the Southern Puget Sound population of harbor seals is genetically distinct enough to be considered its own stock (Carretta et. al., 2017) and now we must estimate their status in an effort to better protect them as a resource for genetic diversity. A comprehensive pinniped survey in the Southwest Puget Sound will reveal fine details about the habits of seals in this region. Researching marine mammals can help define the health of the ecoregion (Hindell et. al., 2013). Seals have been used as indicator species for pollution, fish population, and disturbance research (Hindell et. al., 2013).

As with many mesopredators in human conflict, seals experience population patterns of dramatic peaks and troughs (Cummen, 2019). This cycle goes as follows: 1. Depletion from habitat degradation and management techniques (early 20th-century Puget Sound hunting and fishing), 2. Conservation policy to recover the population (MMPA of 1972 passed), 3. Recovery (Jefferies et. al., 1999 verdict that population is at carrying capacity), 4. Policy change (taken off the protected list and culled), 5. Repeat (Cummen, 2019). We are at a unique time in history where we can prevent depletion and reinstate protections (Cummen, 2019).

In the context of the early 2000s, one researcher reflected upon the ecological role harbor seals play in the Puget Sound and condemns the 20th century's management of the population:

> "It was once assumed that commercially important fish make up significant portions of seal diets. As a consequence, prior to the 1970s many seal populations were dramatically reduced by rampant slaughtering. Today, seals and other marine mammals are valued components of marine ecosystems and their numbers are carefully managed." (Hayward et. al., 2005)

Washington State is on the doorstep of a new era of pinniped villainization with higher approval ratings for culling than non-lethal methods (Pearson, 2018). The information to make better population management decisions is out there and we are armed with this knowledge of the past so we can better the future.

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Chapter 2: Manuscript

Abstract

This survey attempts to answer two questions about marine mammals in the Southwest Puget Sound. First, how do environmental factors (e.g. season and human activity) affect marine mammal distribution within the Southwest Puget Sound? Second, what is the abundance of each marine mammal species observed the Southwest Puget Sound?

Harbor seals (*Phoca vitulina richardii*) were observed in abundant numbers across all seasons. This research shows seasonal variability in the depth areas preferred by harbor seals. Additionally, the research shows the distribution for the other species of marine mammals observed, including California sea lions, harbor porpoises, and long-beaked common dolphins.

Maps were generated to show in-depth species distribution, haul-out locations, and environmental factors (e.g. surface water temperature, water depth, ship traffic, shore activity, beach-intrusive properties, docks, and industrial areas). This analysis revealed that the strongest predicting variable recorded for harbor seal distribution by season is water depth-class ($p<0.001$).

Minimum abundance estimates of harbor seals in the region were generated from the average count in each survey area divided by the number of times that area was surveyed. This analysis suggests the Southwest Puget Sound survey area is the day time home to 298 seals in the summer, 332 in the fall, and 180 in the winter on average. The findings of this survey are consistent with current NOAA estimates (Carretta et. al.,

2017). These data suggest that close to all in-water and hauled-out seals were counted in the survey area, as the correction value calculated with this survey's results is 1.59, a difference of only 0.06 from the NOAA value of 1.53.

Introduction

Marine mammal abundance and distribution in the South Puget Sound is poorly described and understood (Pearson, WDFW 2018). Despite the common occurrence of marine mammals in the maze of inlets and channels west of Nisqually Reach (Figure 1), official surveys into the populations ended in 1999 (Jeffries, 2003). To study the effects of environmental factors, seasonality, and disturbance on behavior, in-water marine mammals must be observed in a reproducible method over time.

The Southwest Puget Sound was chosen as the area of research, cutting off where Case Inlet meets Nisqually Reach (Figure 1). This area was chosen for the relative lack of restricted waters and local relevance. In this area of the Puget Sound, four marine mammal species are likely to be detected: harbor seals (very common), California sea lions (uncommon), long-beaked common dolphins (seasonal) (Cascadia, 2011), and harbor porpoises (common) (Carretta et. al., 2017).

Several research groups have evaluated the Puget Sound and mapped haul-out hotspots for pinniped conservation purposes (Carretta et. al., 2017; Jeffries et. al., 2003; Lambourn et.al., 2009), but none have published maps of the Southwest Puget Sound in detail, nor sought to link environmental factors on distribution.

Materials and Methods

Methods and materials used in this survey were based upon availability due to limited financial and equipment resources. The style of data collection was inspired by Antarctic ship-based surveying and adapted for spotting primarily harbor seals in the narrow waters of the Southwest Puget Sound. Esri applications and Microsoft Excel were used in data collection and data analysis.

Areas with a low tide average of 20 feet or deeper were surveyed using the main vessel, a 1977 Newport 28-foot Mk1 sailboat with a 4.5-foot draft, 9.5-foot-wide beam, and 30-foot tall mast. The vessel was retrofitted with a Mercury 9.9 Horsepower 4-stroke Kicker on the transom. The Mercury outboard maintained maximum speeds of 4 knots against the tide and 6 knots with the tide with typical current strengths averaging 5 knots. A volunteer navigated the vessel from the cockpit at the command of the captain-observer on the bow to ensure undivided attention on counting marine mammals.

Shallow water areas that were publicly accessible, such as the ends of inlets, were surveyed by kayak. The kayak used was a 10-foot Pelican Cove 100XP in “electric green”, which was paddled at an average of 2.5 knots. Survey equipment was strapped to the observer, including a thermometer, binoculars, and a mobile collection device. All kayak surveys were conducted in fair weather around high tide.

The survey region was divided into 13 distinct geographic areas (Figure 1), each surveyed three times per season. Results from these “laps” were then averaged to find results and collectively painted a detailed picture of the region. Chi-squared and R-squared values were calculated with Microsoft Excel (Version 16.0.11929).

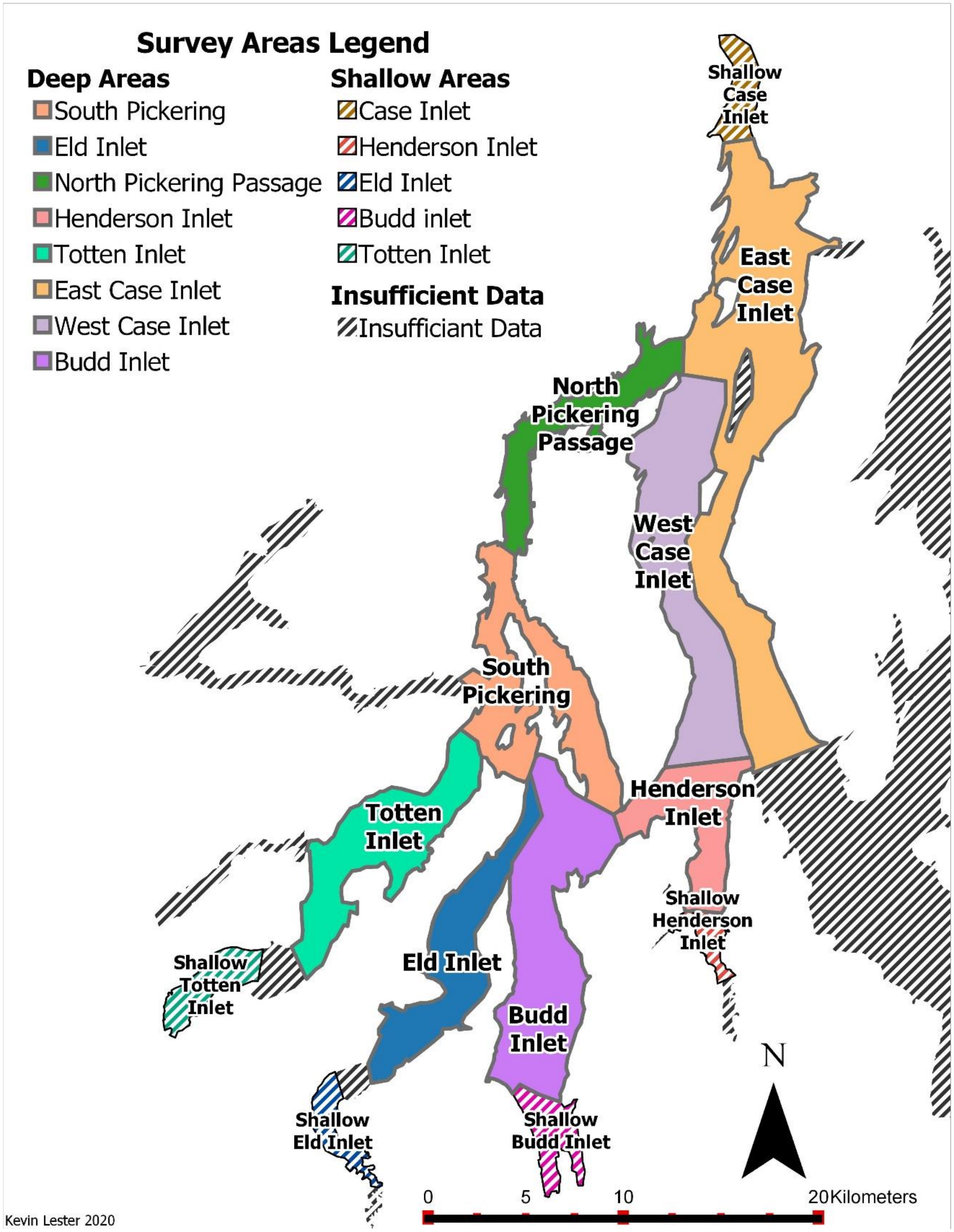

Figure 1: Map of all survey areas. Grey hatched areas indicate locations with insufficient data.

The observer kept in mind the limitations of a continuous visual survey while actively searching for data points and combated double counting using the following guidelines. First, the observer questioned whether the individual had already been counted by considering if it was in a location predictable by past observations that day. Second, the observer was aware of distance sampling bias and spent the same amount of time scanning each area near and far (Bengtson et. al., 2004). Third, the observer surveyed from the same vantage point, preferably a high and visually clear space free of distractions (e.g. the bow superstructure).

Full coverage of the Southwest Puget Sound was attempted, but as the survey progressed, certain areas proved to be too problematic to be surveyed. These areas were categorized as insufficient data areas, with designation on a case-by-case basis (Figure 1). Reasons for their designation included industrial activity, shallow depth, danger, inaccessibility, or were missed due to design flaw. With these areas aside, the majority of the Southwest Puget Sound region was adequately surveyed.

Essential to the methodology of this survey was the implementation of marine mammal viewing guidelines as set forth by NOAA. These guidelines drove the design of visual survey techniques used to include optics and consideration of haul-out safety buffers when drawing survey routes. Thanks to these distance guidelines, marine mammals were not disturbed during the survey.

Results

Observation records were broken down by season and area using time-stamped and spatially-imprinted data points. Results with sufficient sample sizes were tested for normality (or goodness of fit) to evaluate if the distribution of observations across an environmental perimeter was random.

The largest survey area was East Case Inlet with 46.9 km^2 of water area, and the longest survey route of 34.9 km. This route took 3.7 hours on average to complete in the summer, 4 hours in the fall, and 3.3 hours in the winter. The most demanding shallow water survey area was Shallow Budd Inlet which covers 4.6 km^2 and has a 12.6 km survey route. The reason this survey route is so long in comparison with the total area is because of the way downtown Olympia juts into the inlet creating east and west bays. This route took 3.3 hours on average to paddle in the summer, 3 hours in the fall, and 3.3 hours in winter (Table 1-3).

Summer Area Name	**Size (km^2)**	**Route Length (km)**	**Avg Time (hrs.)**	**Total HS Count**	**Avg HS Count (total/3)**	**Avg Water Tmp. (f.)**	**Avg Air Temp (f.)**	**Total Boats**
Totten	17.9	18.9	2	44	14.7	60.4	59.6	14
Eld	15.1	22.3	2	32	10.7	58.6	59	10
Budd	26.8	23.9	1.7	71	23.7	58.8	59	31
Henderson	11	14.4	1	121	40.3	58	60.2	32
West Case	27	16.1	2.3	40	13.3	58	61	18
East Case	46.9	34.9	3.7	66	22.0	59	60.2	54
South Pickering	19.8	21.3	2	166	55.3	56.8	57.2	16
North Pickering	11.3	17.3	1.7	33	11.0	57.8	59	11
Shallow Totten	4.6	7.9	1	1	0.3	68.3	64.6	0
Shallow Eld	3	8.5	1	3	1.0	65.8	65	2
Shallow Budd	4.6	12.6	3.3	251	83.7	62.8	68	96
Shallow Henderson	2	7.4	1	39	13.0	65.6	65.8	4
Shallow Case	3.7	5	1	9	3.0	67.7	66.4	6

Table 1: Survey area statistics for summer. (HS denotes “Harbor Seals”) Average counts are found by dividing the total for the season by the number of laps (3).

Fall Area Name	**Size (km^2)**	**Route Length (km)**	**Avg Time (hrs.)**	**Total HS Count**	**Avg HS Count (total/3)**	**Avg Water Tmp. (f.)**	**Avg Air Temp (f.)**	**Total Boats**
Totten	17.9	18.9	2	27	9.0	65	63.4	8
Eld	15.1	22.3	2	60	20.0	62	63.2	17
Budd	26.8	23.9	2	63	21.0	62	63.2	69
Henderson	11	14.4	1	264	88.0	61	63.7	34
West Case	27	16.1	2	42	14.0	61	63.7	25
East Case	46.9	34.9	4	76	25.3	62	64.6	54
South Pickering	19.8	21.3	2	283	94.3	63	63.4	26
North Pickering	11.3	17.3	1.3	19	6.3	61	64.6	35
Shallow Totten	4.6	7.9	1	0	0.0	63	56.5	1
Shallow Eld	3	8.5	1	3	1.0	60	56.9	4
Shallow Budd	4.6	12.6	3	135	45.0	57	47.4	51
Shallow Henderson	2	7.4	1	9	3.0	57	47.5	1
Shallow Case	3.7	5	1	14	4.7	58	50.8	2

Table 2: Survey area statistics for fall. (HS denotes "Harbor Seals") Average counts are found by dividing the total for the season by the number of laps (3).

Winter Area Name	Size (km^2)	Route Length (km)	Avg Time (hrs.)	Total HS Count	Avg HS Count (total/3)	Avg Water Tmp. (f.)	Avg Air Temp (f.)	Total Boats
Totten	17.9	18.9	1.7	25	8.3	46.8	42.4	1
Eld	15.1	22.3	2	25	8.3	47	41.9	3
Budd	26.8	23.9	2	33	11.0	47.4	41.9	17
Henderson	11	14.4	1	92	30.7	47.2	40	3
West Case	27	16.1	2	105	35.0	47.2	40	3
East Case	46.9	34.9	3.3	82	27.3	47.2	41.9	5
South Pickering	19.8	21.3	2	62	20.7	47.1	42.4	7
North Pickering	11.3	17.3	1.7	56	18.7	47.1	41.9	3
Shallow Totten	4.6	7.9	1	1	0.3	46	40.1	1
Shallow Eld	3	8.5	1	1	0.3	48.4	46.6	0
Shallow Budd	4.6	12.6	3.3	50	16.7	48.1	43.6	11
Shallow Henderson	2	7.4	1	5	1.7	48	45.1	1
Shallow Case	3.7	5	1	2	0.7	48.5	46.3	0

Table 3: Survey area statistics for winter. (HS denotes “Harbor Seals”.) Average counts are found by dividing the total for the season by the number of laps (3)

Harbor Seals

Harbor seals (*Phoca vitulina richardii*) were the most abundant and widely dispersed marine mammal observed in this survey (Figure 2-4). As such, their data is available for deeper analysis of their preferences and distribution patterns as compared to the other species accounted for in this survey. Results concerning harbor seals were sectioned into distribution mapping, data summary by depth-class, haul-out distribution map, abundance estimates, seasonal distribution comparison results, raw data summary by depth-class, and adjusted depth-class distribution summary. Comparisons between harbor seals and environmental variables other than depth are detailed in the discussion.

Harbor seal results from this survey reveal some of the daytime behavioral patterns in the region and estimate abundance by season. For both total counts and simulated counts where the depth-class area is normalized, the data strongly suggests that harbor seals vary their depth-class preference (p-value <0.001) (Table 4-6). In summer and fall, seals prefer depths of 10-50 feet, whereas in winter, they prefer depths of 100+ feet (Table 4-6). The minimum abundance of harbor seals in the Southwest Puget Sound is estimated to be 298 individuals in the summer, 332 individuals in the fall, and 180 individuals in the winter (*Figure 7*). The most populous areas during max haul-out were Henderson Inlet, Carlyon Beach Marina, and the Olympia log booms (Figure 5).

The methodology is validated by near-matching haul-out to total population correction values used by NOAA to estimate the total population for the same region. The survey correction value is calculated to be at 1.59 and the NOAA value at 1.53 (Carretta et. al., 2017). This suggests, as methodology did not change between seasons, that in-water data is comparable in validity to hauled-out count data.

Summer

Depth Class (ft)	Count	%
Hauled	243	27.21%
0-10 (29.82% of Area)	109	12.21%
10-20 (11.71% of Area)	164	18.37%
20-50 (24.52% of Area)	239	26.76%
50-100 (21.06% of Area)	89	9.97%
100-200 (9.8% of Area)	40	4.48%
200-300 (2.89% of Area)	8	0.90%
300+ (0.19% of Area)	1	0.11%
Total	**893**	**100%**
In-water AVG	**92.9**	
ChiSQ	**219.1**	
P-value	<0.001	

Table 4: Harbor seal depth distribution for summer.

Fall

Depth Class (ft)	Count	%
Hauled	625	62.81%
0-10 (29.82% of Area)	85	8.54%
10-20 (11.71% of Area)	78	7.84%
20-50 (24.52% of Area)	138	13.87%
50-100 (21.06% of Area)	50	5.03%
100-200 (9.8% of Area)	16	1.61%
200-300 (2.89% of Area)	3	0.30%
300+ (0.19% of Area)	0	0.00%
Total	**995**	**100%**
In-water AVG	**52.9**	
ChiSQ	**424.4**	
P-value	<0.001	

Table 5: Harbor seal depth distribution for fall.

Winter

Depth Class (ft)	Count	%
Hauled	70	12.99%
0-10 (29.82% of Area)	26	4.82%
10-20 (11.71% of Area)	65	12.06%
20-50 (24.52% of Area)	122	22.63%
50-100 (21.06% of Area)	128	23.75%
100-200 (9.8% of Area)	88	16.33%
200-300 (2.89% of Area)	40	7.42%
300+ (0.19% of Area)	0	0.00%
Total	**539**	**100%**
In-water AVG	**67**	
ChiSQ	**178.4**	
P-value	<0.001	

Table 6: Harbor seal depth distribution for winter.

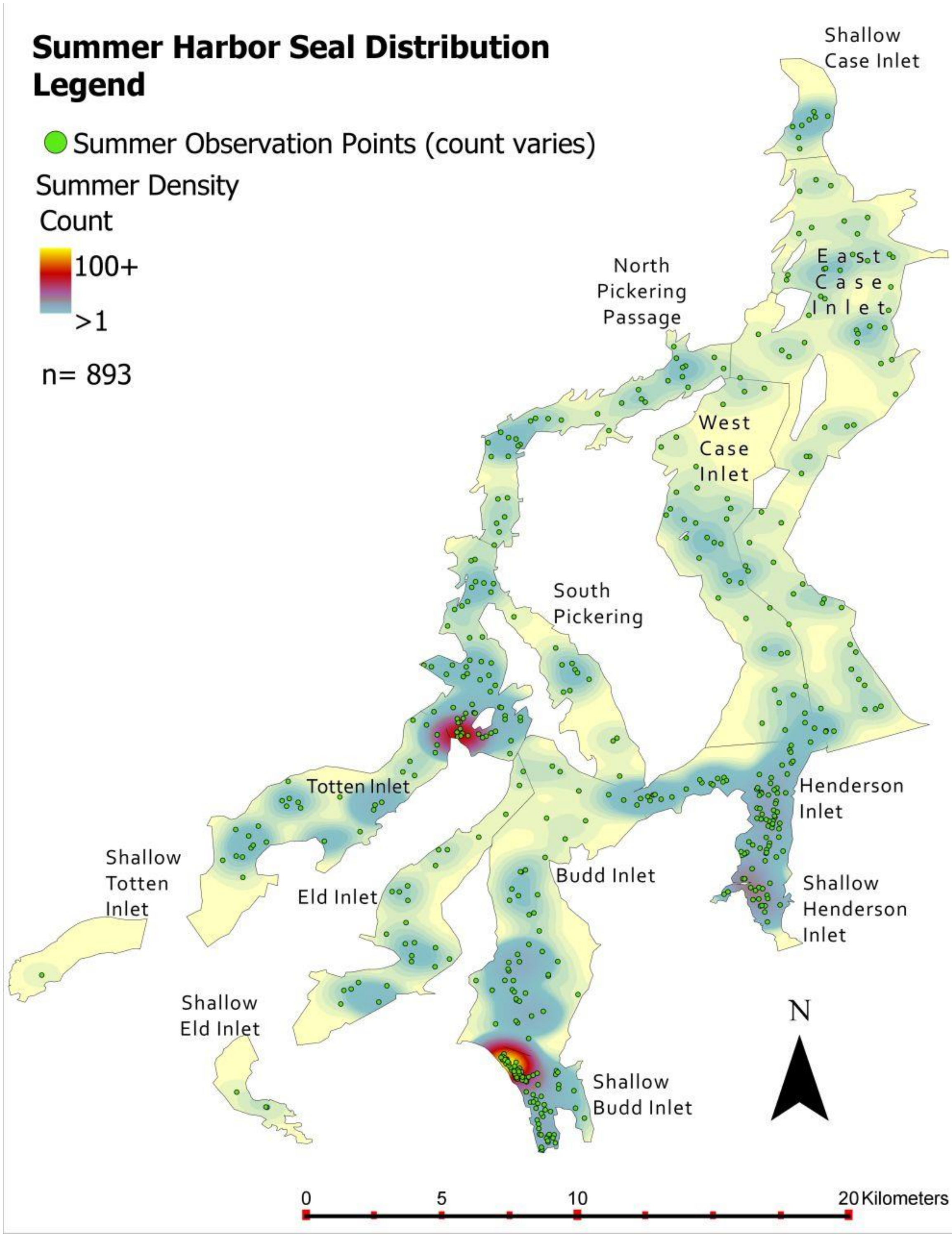

Figure 2: Map of harbor seal distribution for summer using the total count.

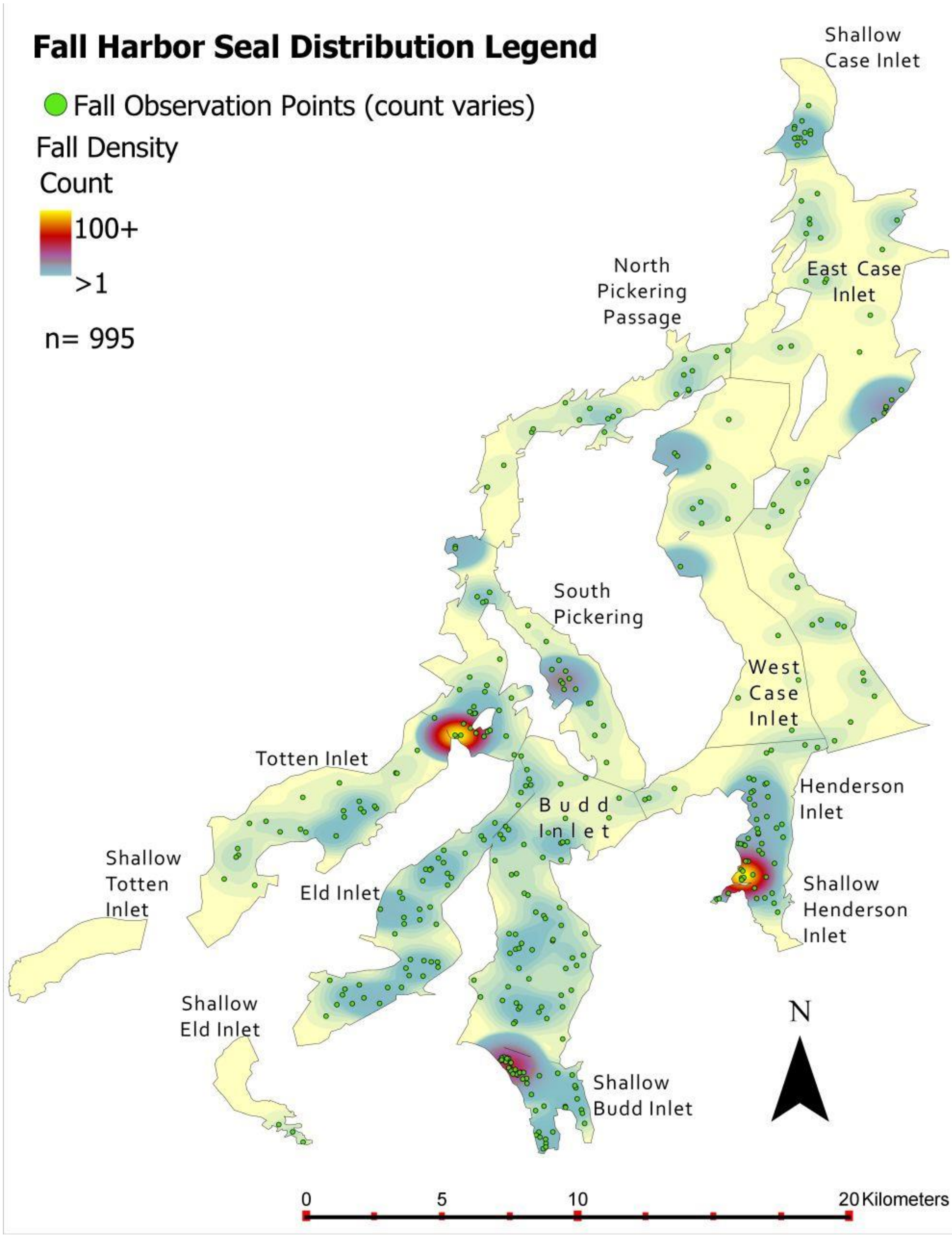

Figure 3: Map of harbor seal distribution for fall using the total count.

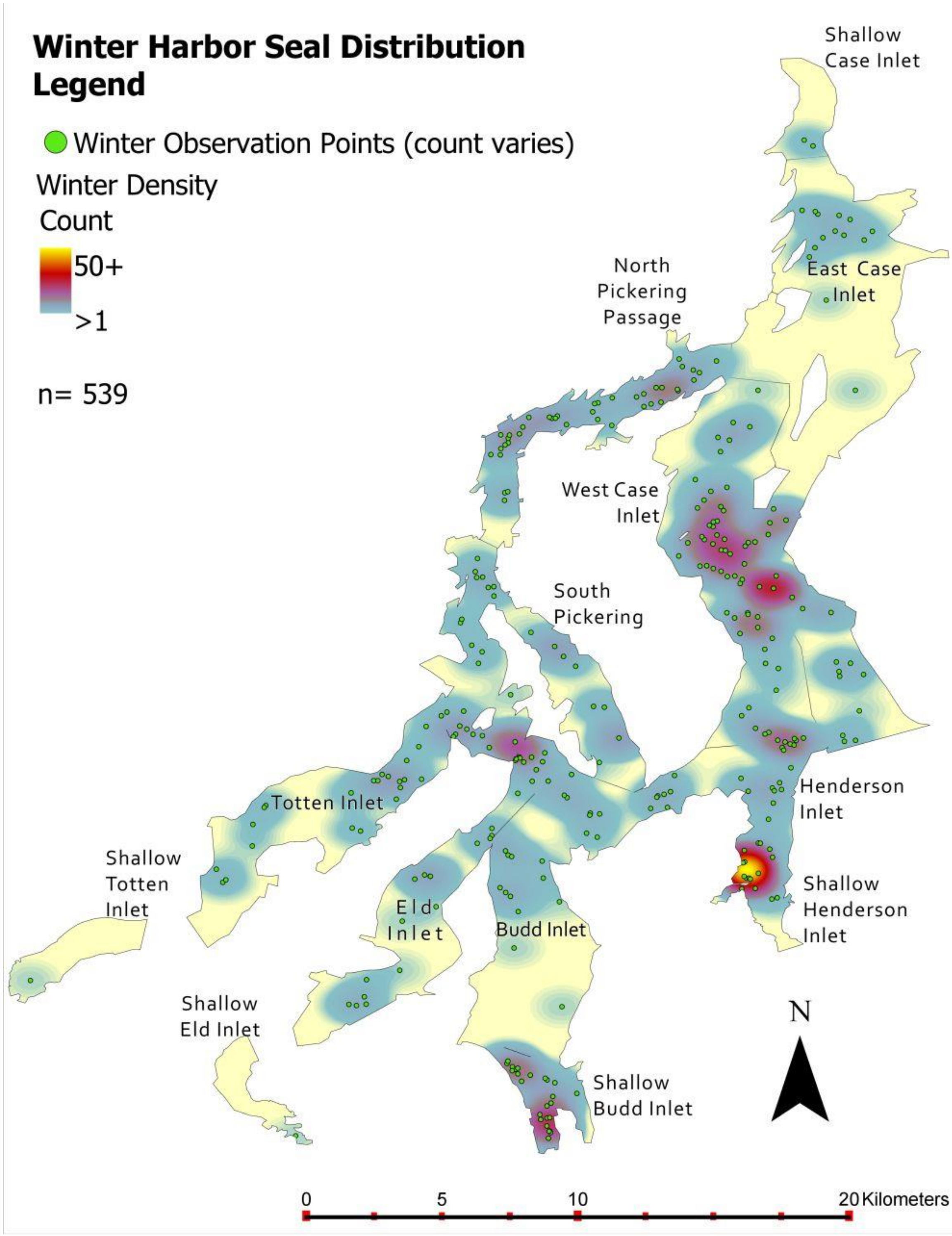

Figure 4: Map of harbor seal distribution for winter using total count.

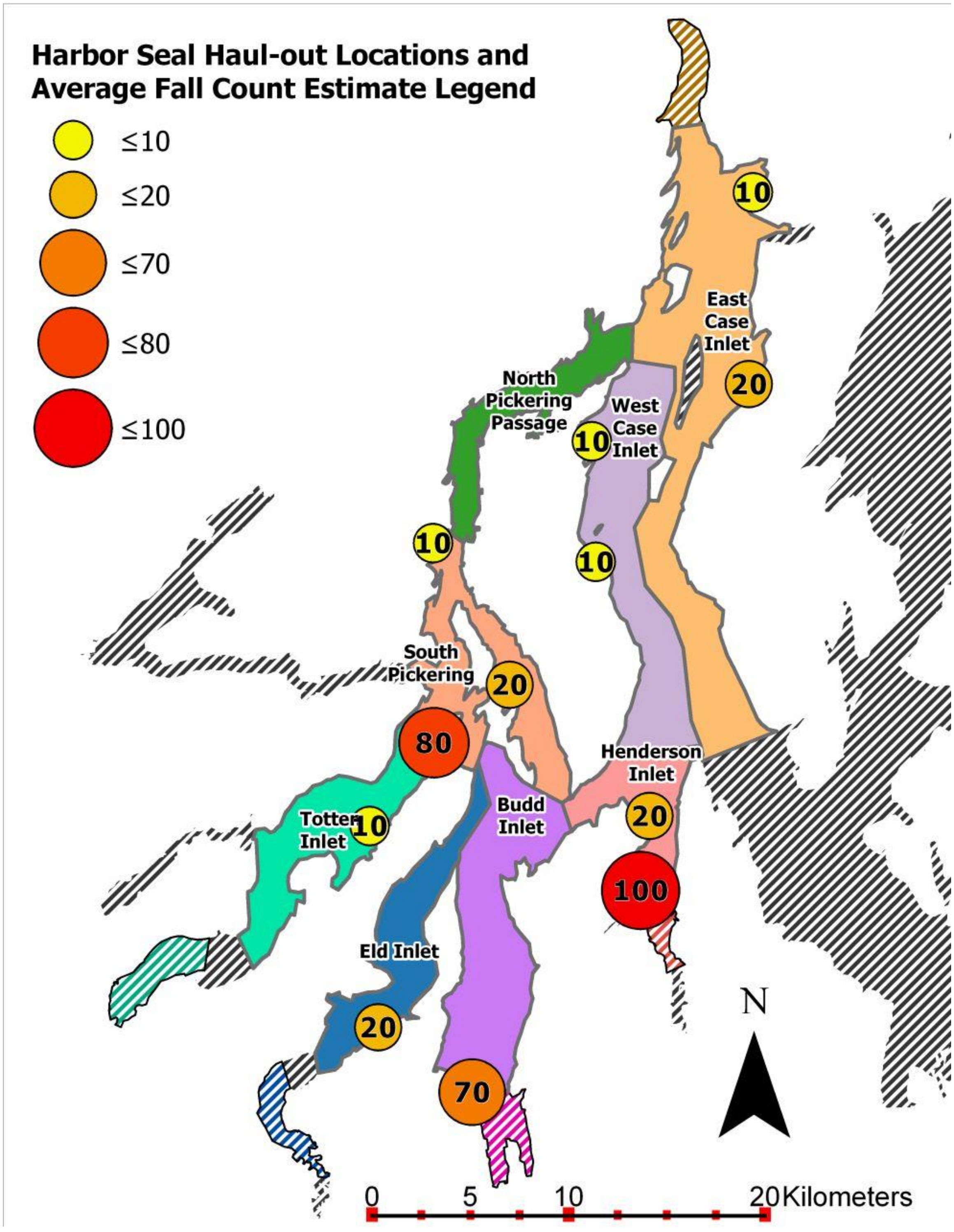

Figure 5: Map of survey region with harbor seal haul-outs and estimated maximum size in fall. The total for the displayed estimates comes to 380 seals which is higher than the average observed number per region lap at 331 seals because these numbers are based on maximum numbers observed at each haul-out rounded to the nearest 10 seals.

Abundance

Minimum harbor seal abundance within the survey region was estimated using the summation of total counts for survey areas divided by the number of laps (as previously defined). The NOAA population estimate derived from the NOAA correction value of 1.53 was generated from radio tagging studies of Washington inland waters used to correct for seals in-water during maximal haul-out (Huber et. al., 2001). This correction value was applied to the average haul-out count for fall, as that is this survey's haul-out maximum. These estimates must be split by season; results for each season and the depth preferences of harbor seals by season suggest movement in and out of the survey region. The annual estimates are a total of the seasons divided by the number of seasons surveyed.

	Minimum Population Estimate	NOAA Population Estimate	Average
Summer	298	NA	298
Fall	332	318	325
Winter	180	NA	180
Average	270	NA	270

Table 7: Table of average population estimates for the survey region by season. Including estimates using NOAA methodology which can only be applied to maximum haul-out.

For future haul-out reliant surveys of harbor seals in the Southern Puget Sound, a table of correction values can be generated. However, because this survey was only conducted during a single year, these values should only be cautiously considered (Table 8).

	In-water Total	Hauled Total	In-water Correction Value
Summer	650	243	3.67
Fall	370	625	1.59
Winter	469	70	7.7

Table 8: Table calculating in-water correction values for each season.

Raster Analysis

Band Collection Statistics tool by Esri was used to compare seasonal harbor seal distribution patterns with each other to test for similarity. This analysis reveals that summer and fall harbor seal distribution show the most similarity with a correlation value of 0.28, and summer and winter are the least similar with a value of 0.02 (*Table 9*). Winter has the strongest independence, suggesting harbor seals spend their time in much different places than they would in either summer or fall.

Harbor seal observations for each season were summarized into maps comprised of 100 square meter squares weighted by seal count called a raster. Using a tool designed to compare these maps, the below results were generated (Table 9). The size of the squares was set at 100 square meter because at that scale, they encompass haul-outs but provide enough detail to note generalized inlets. This resulted in representational raster maps for the program to analyze.

Band Collection Statistics Output for 100m Harbor Seal Raster Comparison

Layer	MIN	MAX	MEAN	STD
Summer	1	87	1.9253	5.2856
Fall	1	91	2.9880	8.9402
Winter	1	23	1.8651	2.4408

COVARIANCE MATRIX

Layer	Summer	Fall	Winter
Summer	0.21739	0.08742	0.00165
Fall	0.08742	0.45496	0.00943
Winter	0.00165	0.00943	0.02941

CORRELATION MATRIX

Layer	Summer	Fall	Winter
Summer	1	0.27796	0.02065
Fall	0.27796	1	0.08153
Winter	0.02065	0.08153	1

Table 9: Output for the Band Collection Statistics ArcGIS Tool comparing 100-meter raster maps from each season. Values range from 0 (no overlap) to 1 (100% overlap).

Harbor Seal Depth Results

To test whether harbor seals vary their distribution by depth, observational data were imprinted with depth values and charted. The data for all seasons suggests that harbor seals do vary their distribution by depth-class area ($p<0.001$).

To correct for the bias of area covered by each depth-class, counts were adjusted to simulate a survey where all in-water depth-classes occupied the same amount of area. This extrapolated the existing trends in the data and normalized curves. Curves for fall and summer distributions became similar after normalization, creating “bells” around the 10-50-foot average low tide depth range (*Figure 7*-8). Winter curves upward with increasing depth, suggesting the bell curve for winter distribution had peaked at 300 feet or had yet to reach its peak distribution (*Figure 9*).

Two depth-classes were not analyzed. The hauled-out class was eliminated because the true area that could be occupied by harbor seals in the survey region is unknown. The other class eliminated from this analysis is the 300+ foot range because the amount of area this depth-class occupied was less than 0.2% of the total survey area. This was deemed not sufficient to create representational counts. It is important to note that the counts displayed in the adjusted tables and plots are not true counts and are only used to test harbor seal distribution patterns (Table 10-12).

Summer

Depth Class (ft)	Count Normalized by Area	%
0-10 (16.16% of Area)	60.9	9%
10-20 (16.16% of Area)	233.4	36%
20-50 (16.16% of Area)	162.4	25%
50-100 (16.16% of Area)	70.4	11%
100-200 (16.16% of Area)	68.0	11%
200-300 (16.16% of Area)	46.1	7%
300+ (0% of Area)	NA	NA
AVG	106.9	
ChiSQ	259.6	
P-value	<0.001	

Table 10: Summer harbor seal counts adjusted for equal depth-class area.

Fall

Depth Class (ft)	Count Normalized by Area	%
0-10 (16.16% of Area)	47.5	14%
10-20 (16.16% of Area)	111.0	33%
20-50 (16.16% of Area)	93.8	28%
50-100 (16.16% of Area)	39.6	12%
100-200 (16.16% of Area)	27.2	8%
200-300 (16.16% of Area)	17.3	5%
300+ (0% of Area)	NA	NA
AVG	56.1	
ChiSQ	127.0	
P-value	<0.001	

Table 11: Fall harbor seal counts adjusted for equal depth-class area.

Winter

Depth Class (ft)	Count Normalized by Area	%
0-10 (16.16% of Area)	14.5	2%
10-20 (16.16% of Area)	92.5	14%
20-50 (16.16% of Area)	82.9	12%
50-100 (16.16% of Area)	101.3	15%
100-200 (16.16% of Area)	149.7	22%
200-300 (16.16% of Area)	230.7	34%
300+ (0% of Area)	NA	NA
AVG	111.9	
ChiSQ	235.5	
P-value	<0.001	

Table 12: Winter harbor seal counts adjusted for equal depth-class area.

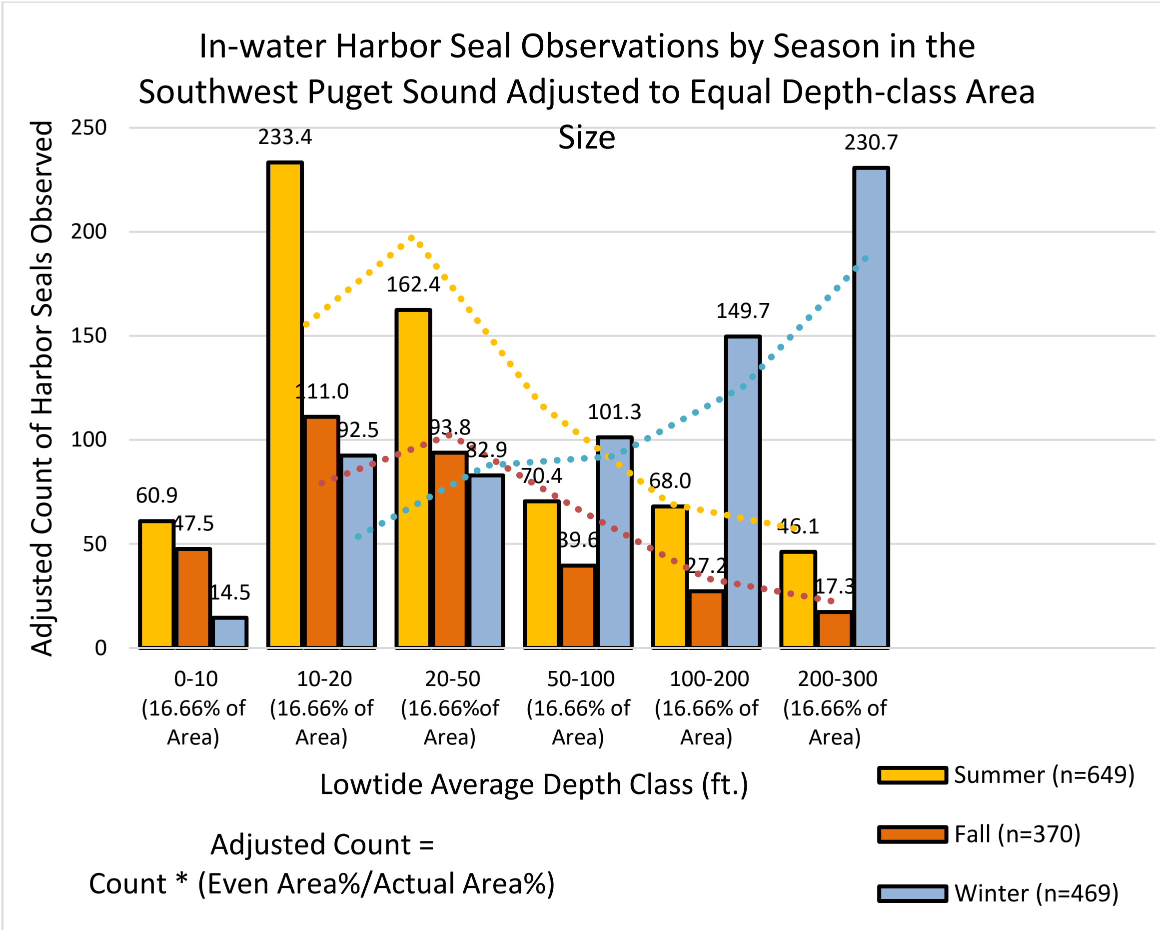

Figure 6: Graph showing the count of in-water harbor seals from each survey season found over different depth-classes and adjusted for the percentage of the area each depth-class covers to simulate equal sizes.

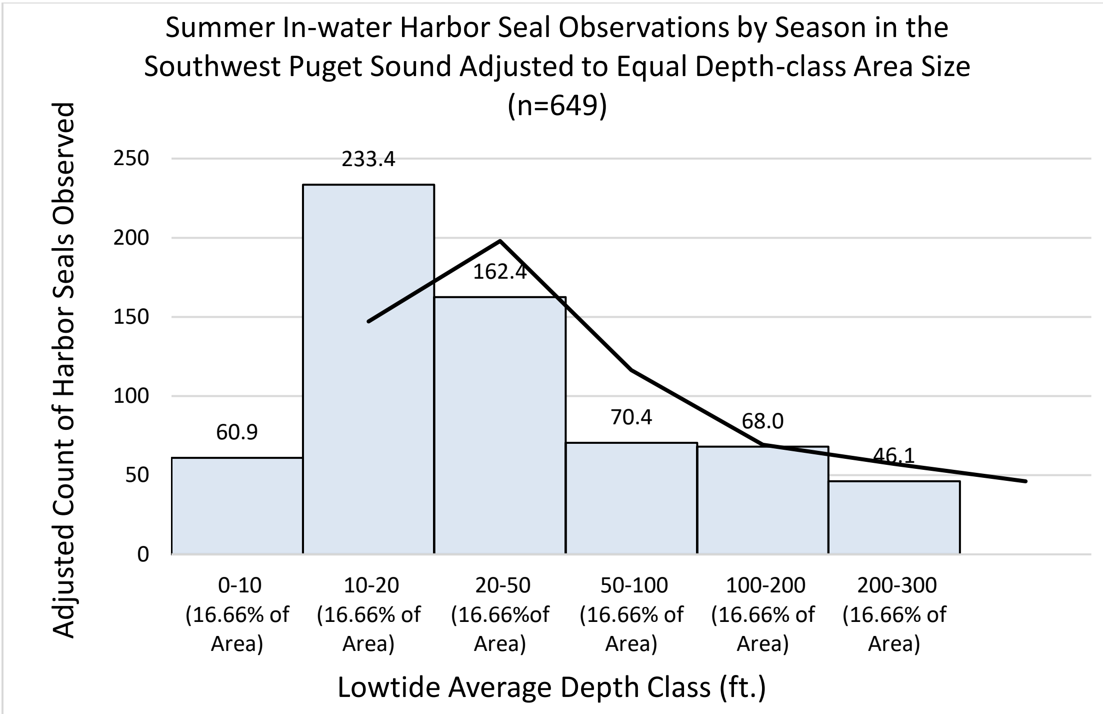

Figure 7: Graph simulating summer harbor seal observations by depth-class if the area each depth-class cover was equal-sized. (Hauled-out and 300+ feet classes removed.)

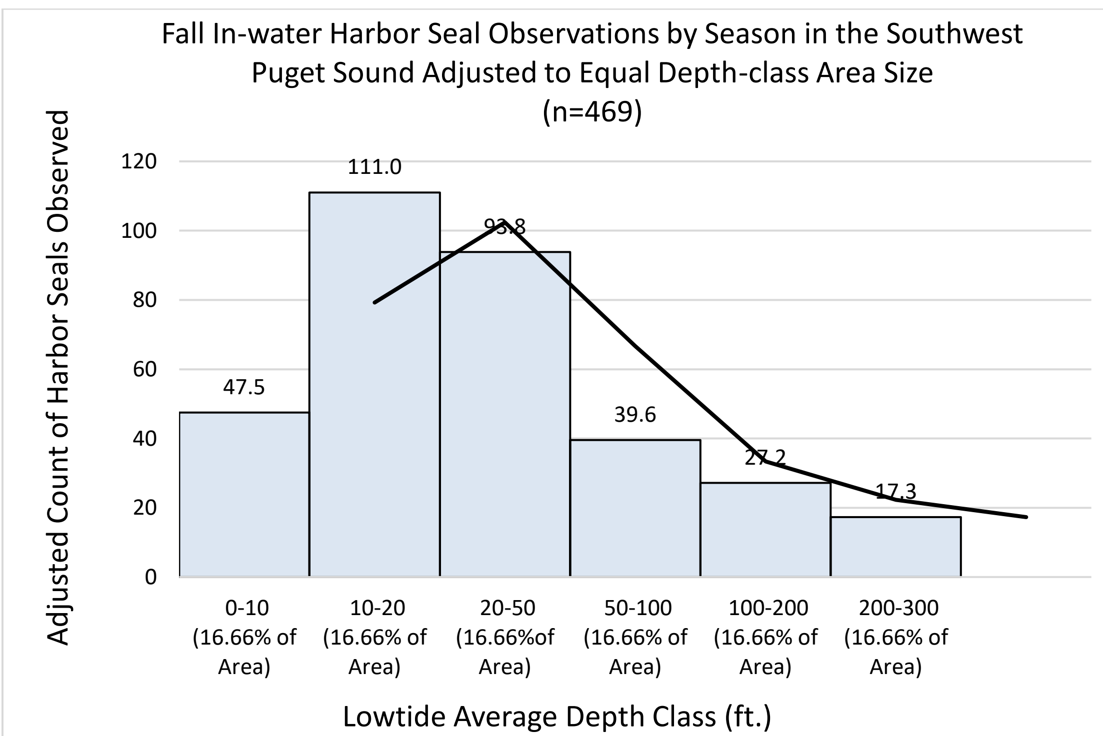

Figure 8: Graph simulating fall harbor seal observations by depth-class if the area each depth-class cover was equal-sized. (Hauled-out and 300+ feet classes removed.)

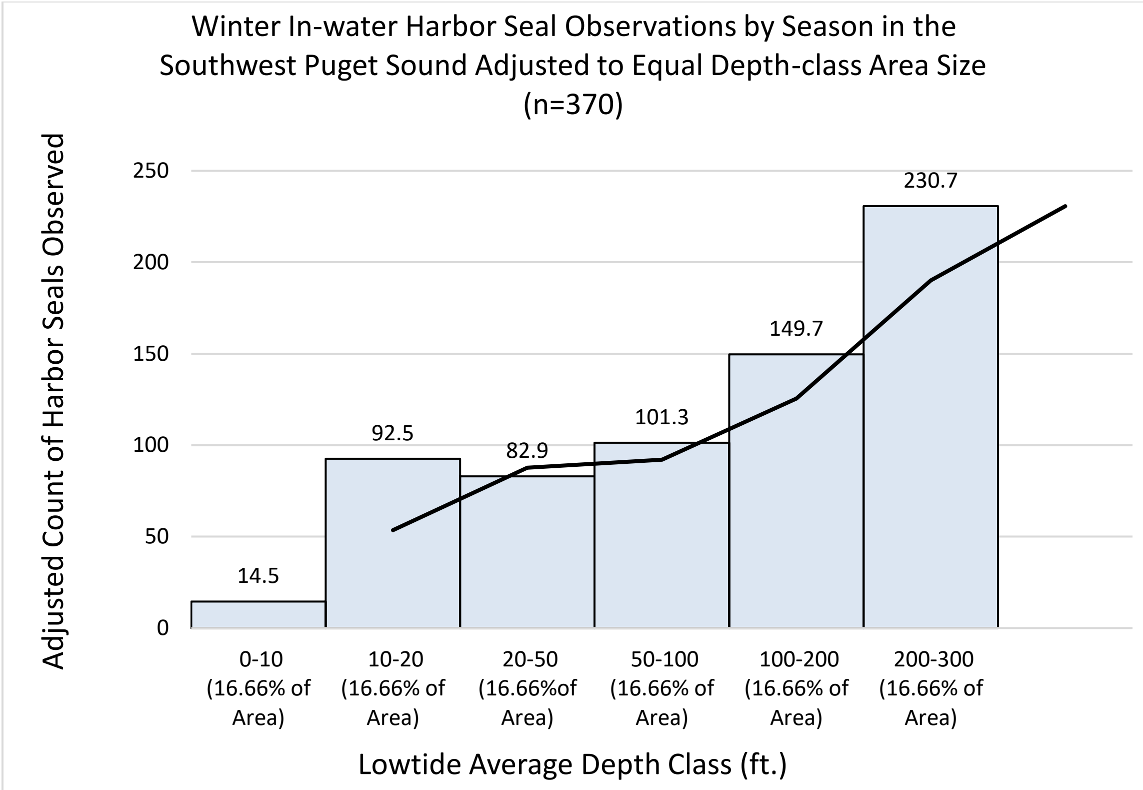

Figure 9: Graph simulating winter harbor seal observations by depth-class if the area each depth-class cover was equal-sized. (Hauled-out and 300+ feet classes removed.)

Harbor Porpoises

Harbor Porpoises (*Phocoena phocoena vomerina*) were observed in all seasons of the survey, typically in deep water areas around Case Inlet and the Dana Passage near Henderson Inlet. Harbor porpoises were observed in small groups of 3-6 individuals. Which could be seen swimming in large circles or traveling through passages. Because of their shy behavior and small infrequent breaches, they were difficult to count.

Harbor porpoises were seen in the greatest abundance during the winter survey with 71 individual observations averaging at 23.7 porpoises per lap (*Table 15*). While distribution changed little between seasons, observations in fall and summer were much less frequent when compared with winter data. During summer, a total of 22 observations were recorded averaging 7.3 porpoises per lap (Table 13). During the fall, a total of 16 observations were recorded averaging 5.3 porpoises per lap (Table 14)

Depth distribution for harbor porpoises varied slightly by season. In fall and summer, observations were mostly within the 50-200-foot depth range, while in winter most observations fell within the 100-300-foot range. These values are not adjusted for depth-class as performing this analysis with the limited data would not be effective. However, it is assumed that depth-class preference for harbor porpoises is that of deeper waters.

Summer

Depth Class (ft)	Count	%
0-10 (29.82% of Area)	0	0.00%
10-20 (11.71% of Area)	0	0.00%
20-50 (24.52% of Area)	1	4.55%
50-100 (21.06% of Area)	8	36.36%
100-200 (9.8% of Area)	9	40.91%
200-300 (2.89% of Area)	4	18.18%
300+ (0.19% of Area)	0	0.00%
Total	**22**	**100%**

Table 13: Harbor porpoise depth distribution for summer.

Fall

Depth Class (ft)	Count	%
0-10 (29.82% of Area)	0	0.00%
10-20 (11.71% of Area)	0	0.00%
20-50 (24.52% of Area)	5	31.25%
50-100 (21.06% of Area)	5	31.25%
100-200 (9.8% of Area)	1	6.25%
200-300 (2.89% of Area)	2	12.50%
300+ (0.19% of Area)	3	18.75%
Total	**16**	**100%**

Table 14: Harbor porpoise depth distribution for fall.

Winter

Depth Class (ft)	Count	%
0-10 (29.82% of Area)	0	0.00%
10-20 (11.71% of Area)	0	0.00%
20-50 (24.52% of Area)	0	0.00%
50-100 (21.06% of Area)	17	23.94%
100-200 (9.8% of Area)	35	49.30%
200-300 (2.89% of Area)	19	26.76%
300+ (0.19% of Area)	0	0.00%
Total	**71**	**100%**

Table 15: Harbor porpoise depth distribution for winter.

California Sea Lions

California sea lions (*Zalophus californianus)* were the only other species of pinniped besides harbor seals observed during the survey, though the presence of Steller's sea lions (*E. jubatus*) was recorded in the survey area just prior to the start of the winter survey (Garrett, 2019). California sea lions were only observed in significant numbers during the winter, with only 1 observation each in summer and fall and 89 observations in winter (*Table 16*-18).

Observations in winter were exclusively within the 100-200-foot depth class and strongly favored the waters southwest of Heron Island in Case Inlet where they could be seen in groups of 20 individuals. These winter congregations also included many harbor porpoises, seals, and sea birds.

Occasionally, individual sea lions were observed in passages around the survey area typically followed by small groups of 3-5 harbor seals. California sea lions were identified by the shape of their heads and distinctive swimming behaviors (e.g. synchronized full breach diving, group porpoising, and logging).

Summer

Depth Class (ft)	Count	%
Hauled	**1**	**100.00%**
0-10 (29.82% of Area)	0	0.00%
10-20 (11.71% of Area)	0	0.00%
20-50 (24.52% of Area)	0	0.00%
50-100 (21.06% of Area)	0	0.00%
100-200 (9.8% of Area)	0	0.00%
200-300 (2.89% of Area)	0	0.00%
300+ (0.19% of Area)	0	0.00%
Total	**1**	**100%**

Table 16: California sea lion depth distribution for summer.

Fall

Depth Class (ft)	Count	%
Hauled	0	0.00%
0-10 (29.82% of Area)	0	0.00%
10-20 (11.71% of Area)	0	0.00%
20-50 (24.52% of Area)	0	0.00%
50-100 (21.06% of Area)	0	0.00%
100-200 (9.8% of Area)	**1**	**100.00%**
200-300 (2.89% of Area)	0	0.00%
300+ (0.19% of Area)	0	0.00%
Total	**1**	**100%**

Table 17: California sea lion depth distribution for fall.

Winter

Depth Class (ft)	Count	%
Hauled	0	0.00%
0-10 (29.82% of Area)	0	0.00%
10-20 (11.71% of Area)	**1**	**1.12%**
20-50 (24.52% of Area)	**1**	**1.12%**
50-100 (21.06% of Area)	**2**	**2.25%**
100-200 (9.8% of Area)	**78**	**87.64%**
200-300 (2.89% of Area)	**7**	**7.87%**
300+ (0.19% of Area)	0	0.00%
Total	**89**	**100%**

Table 18: California sea lion depth distribution for winter.

Long-beaked Common Dolphins

Long-beaked common dolphins (*Delphinus capensis*) are typically found in the tropic waters around Baja California (Carretta et. al., 2017). They were observed only in Case Inlet during the summer survey.

The group of six individuals has been observed and recorded by other research organizations for several years; the reason for their continued presence in the Southwest Puget Sound is unknown (Cascadia, 2011). What is known is that they appear to be in good physical condition and exhibit healthy playful behavior (Cascadia, 2011). It is unknown where this pod goes in the colder months. These dolphins were the largest cetacean observed during the survey and preferred depth-class areas of 50-200 feet (Table 19).

Summer

Depth Class (ft)	**Count**	**%**
0-10 (29.82% of Area)	0	0.00%
10-20 (11.71% of Area)	0	0.00%
20-50 (24.52% of Area)	**3**	**17.65%**
50-100 (21.06% of Area)	**6**	**35.29%**
100-200 (9.8% of Area)	**8**	**47.06%**
200-300 (2.89% of Area)	0	0.00%
300+ (0.19% of Area)	0	0.00%
Total	**17**	**100%**

Table 19: Long-beaked common dolphin depth distribution for summer.

Temperature

A key objective of the study was mapping surface water temperature distribution in the Southwestern Puget Sound to compare marine mammal distribution to the differences in each area.

Summer area averages ranged from 57 degrees Fahrenheit to 68 degrees Fahrenheit. The ends of each inlet were warmest, ranging from 62 degrees Fahrenheit to 68 degrees Fahrenheit. Deeper areas and the Pickering Passage were the coldest, ranging from 57 degrees Fahrenheit to 59 degrees Fahrenheit.

Fall surface water temperature distribution was more variable possibly due to "fall mixing," which is when cold water and warm water are not as stratified in the water column, causing localized areas of temperature variability (Moore et. al., 2012). Fall temperatures ranged from 52 degrees Fahrenheit to 65 degrees Fahrenheit.

Winter temperatures were incredibly consistent across the region ranging from 46 degrees Fahrenheit to 48 degrees Fahrenheit with the larger areas at 47 degrees Fahrenheit on average. All inlet shallow areas were 1 degree warmer (48 degrees Fahrenheit) with the exception of Totten Inlet's shallow area, which was 1 degree Fahrenheit colder at 46 degrees Fahrenheit.

Human Activity

Structures that affected the natural matrix of the tidal coastline, as well as human activities that may impact marine mammals' behavior, were categorically recorded (Table 23). This information is only a fragment of the true activity in the survey areas. The true scale of coastline alteration in the survey region is unknown. It is important to note where these alterations are, as well as the traffic of survey areas, to study the preferences of marine mammals.

Powerboat traffic ranged from 296 observations in the summer to 328 observations in fall to only 55 observations in the winter (Table 20-22). Major traffic areas in the survey region across seasons by total observations included Budd Inlet, Case Inlet, and the Pickering Passage. Beach intrusive infrastructure was most common in the Pickering Passage, East Case Inlet, Shallow Eld Inlet and Shallow Budd Inlet (Table 23).

Summer Area Name	**Total Active Disturbances**	**Powerboats and Barges**	**Paddlers and Swimmers**	**Shore Activity**
Totten	16	14	0	2
Eld	14	10	0	4
Budd	37	32	2	3
Henderson	40	32	4	4
West Case	28	18	3	7
East Case	94	54	18	22
South Pickering	18	17	0	1
North Pickering	15	11	1	3
Shallow Totten	0	0	0	0
Shallow Eld	4	2	1	1
Shallow Budd	134	96	25	13
Shallow Henderson	7	4	3	0
Shallow Case	9	6	2	3

Table 20: Disturbance counts for summer by area.

Fall Area Name	**Total Active Disturbances**	**Powerboats and Barges**	**Paddlers and Swimmers**	**Shore Activity**
Totten	13	8	1	4
Eld	32	17	3	12
Budd	84	69	6	9
Henderson	43	34	3	6
West Case	43	25	5	13
East Case	95	54	13	28
South Pickering	42	26	4	12
North Pickering	51	35	3	13
Shallow Totten	2	1	0	1
Shallow Eld	6	4	0	2
Shallow Budd	74	52	8	14
Shallow Henderson	2	1	1	0
Shallow Case	6	2	2	2

Table 21: Disturbance counts for fall by area.

Winter Area Name	Total Active Disturbances	Powerboats and Barges	Paddlers and Swimmers	Shore Activity
Totten	6	1	1	4
Eld	10	3	3	4
Budd	25	17	1	7
Henderson	8	3	4	1
West Case	6	3	1	2
East Case	15	5	1	9
South Pickering	12	7	1	4
North Pickering	7	3	0	4
Shallow Totten	1	1	0	0
Shallow Eld	4	0	0	4
Shallow Budd	27	11	0	16
Shallow Henderson	1	1	0	0
Shallow Case	3	0	0	3

Table 22: Disturbance counts for winter by area.

Area Name	Total Land Use Points	Industrial and Marinas	Boardwalks and Historical	Residential and Docks
Totten	14	5	1	8
Eld	10	1	0	9
Budd	10	4	1	5
Henderson	12	1	2	8
West Case	6	2	0	4
East Case	27	3	1	23
South Pickering	20	10	2	8
North Pickering	16	4	2	10
Shallow Totten	9	4	2	3
Shallow Eld	18	7	0	11
Shallow Budd	15	7	2	6
Shallow Henderson	7	1	1	5
Shallow Case	9	1	0	8

Table 23: Land use disturbance counts by area.

Discussion

One of the goals of this research project is the comparison between marine mammal distribution and environmental variables. The most significant of these variables was discussed in the results section with comparisons between marine mammal distribution and depth profile. Additional environmental comparisons are detailed in this section.

Harbor Seals and Temperature

Using linear regression of the number of seals counted in each area for a given season against that area's average water temperature the data suggests that there is no relationship between these variables. This disproves the initial hypothesis that water temperature helps drive harbor seal haul-out location and in-water distribution in the South Puget Sound region.

Harbor Seals and Survey Areas

To test the survey design, it is important to know if greater numbers of seals are being found in an area simply due to its size. After comparing the data of area size to the number of seals, there does not appear to be a strong relationship between the two variables in any season. This suggests that, during the day, harbor seals prefer to be in certain inlets, regardless of density.

To better understand which areas in the Southwest Puget Sound are the most important to harbor seal's daytime activities, areas were stacked against each other after standardization and organized by the number of seals present per season. The data show South Pickering, Shallow Budd Inlet, and Henderson Inlet are the most populous areas for harbor seals in the summer and fall (*Figure 10*-11). In the winter, Case Inlet, Henderson Inlet, and the Pickering areas (north and south) were the most populous areas (*Figure 12*). It is important to note that West and East Case Inlet, and the North and South Pickering areas are highly connected, like the shallow counterparts to each inlet.

After the data was condensed into areas summarized by high connectivity, it is revealed that the Pickering Passage, Budd Inlet, and Henderson Inlet are the most highly populated areas for seals in the summer and fall. In the winter, Case Inlet, the Pickering Passage, Henderson Inlet, and Budd Inlet are the most populous areas (Figure 10-12).

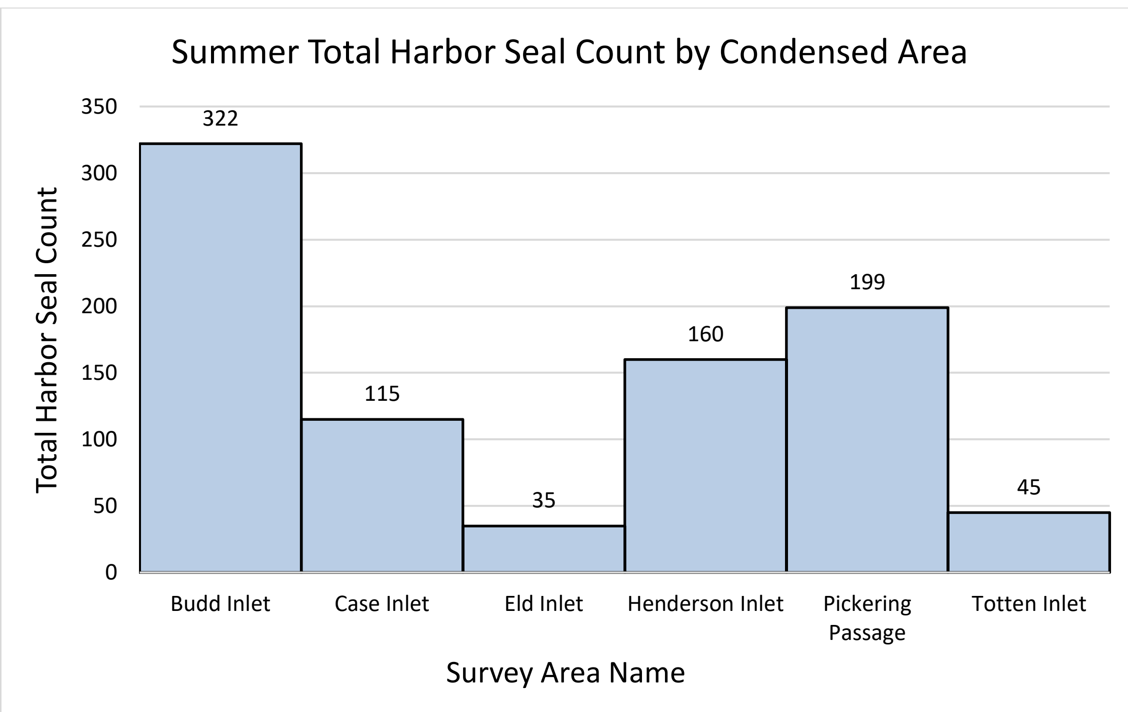

Figure 10: Graph showing summer harbor seal distribution by condensed areas in descending order.

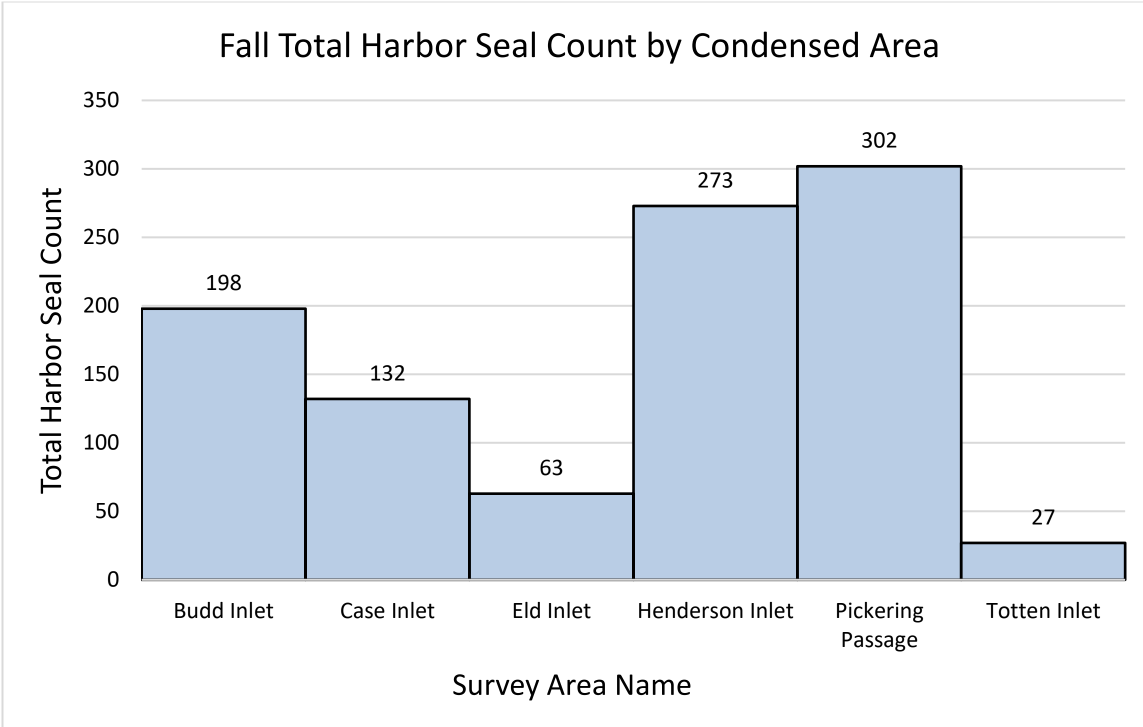

Figure 11: Graph showing fall harbor seal distribution by condensed areas.

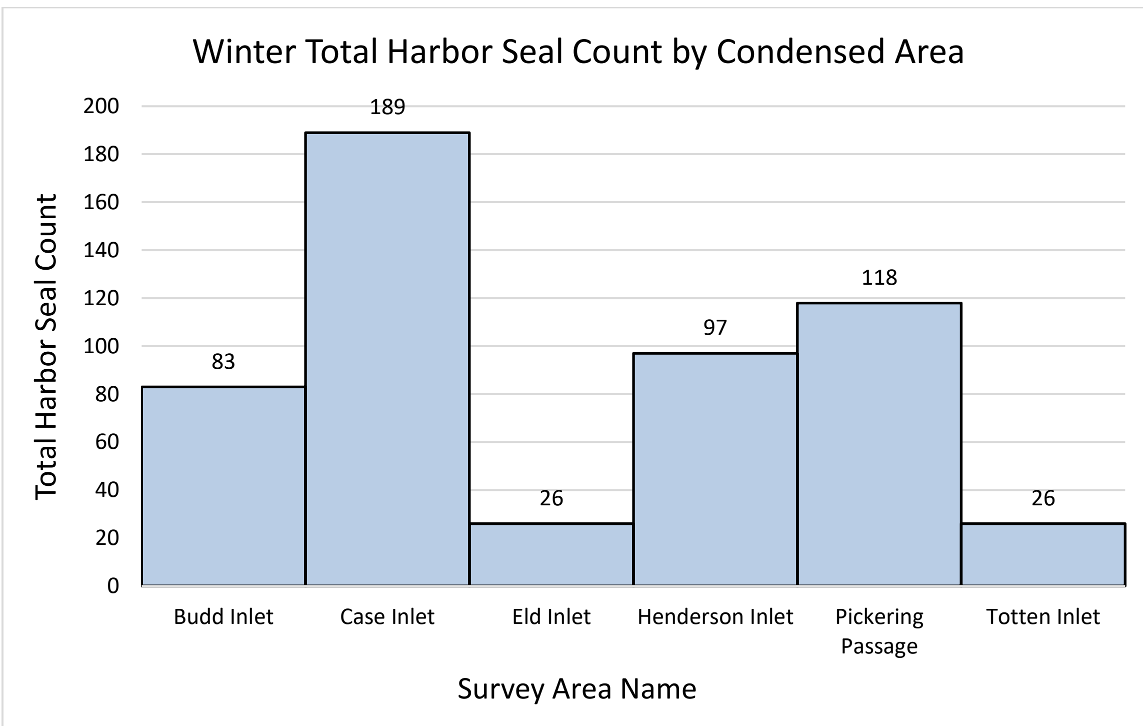

Figure 12: Graph showing winter harbor seal distribution by condensed areas.

Disturbances

Human disturbances to marine mammals have widely been documented as having a negative effect on population health and size (Cammen et. al., 2019). To investigate whether it is likely harbor seals are experiencing interactions with humans and their machinery, the average number of seals for each survey area was compared with the number of powerboats observed in that area. This analysis revealed a practical but insignificant positive relationship between harbor seals and traffic ($R^2 = 0.66$), while in the fall and winter there appears to be no relationship ($R^2 < 0.15$).

Conclusion

After surveying with the methodologies detailed above, several changes could be implemented to improve the survey design. First, a shallow water capable main vessel would have allowed for greater maneuverability in the ends of inlets, eliminating some insufficient data areas and possibly the need for kayak survey routes. Second, a consistent and skilled navigator that could operate independently of instruction would have been helpful to the observer so that undivided attention could be given to counting. Third, Esri Survey123 Connect (as oppose to Esri Survey123 Collector app) allows for greater customization of surveys and would have provided richer data sets. Finally, advanced sampling methods (e.g. transects across deep water areas, multiple vessels, and paired observers) and better technology (e.g. portable weather stations) would have been used to help mitigate biases or provide better localized data. Future surveys will be required to flesh out the entire picture of all marine mammal stocks in the Southern Puget Sound.

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Chapter 3: Broader Relevance to Environmental Studies

Abstract

This thesis attempts to address two points of interest regarding marine mammals of the Southwest Puget Sound region using visual ship-based survey techniques and ArcGIS analysis. First, it addresses whether environmental factors (e.g. season, human activity, and temperature) affect marine mammal distribution within the Southwest Puget Sound. Second, it interrogates the abundance of each marine mammal known to inhabit the Southwest Puget Sound.

The species with the greatest population density observed was the harbor seal (*Phoca vitulina richardii*). This research shows seasonal variability in the depth areas preferred by harbor seals in winter with a similarity value of 0.021 when compared with other seasons, as well as the estimated areas of preference for other species, including California sea lions, harbor porpoises, and long-beaked common dolphins.

Maps were generated with ArcGIS to show in-depth species distribution, haul-outs, and environmental factors (e.g. water temperature). This analysis revealed that the strongest predicting variable recorded for harbor seal distribution by season is water depth-class ($P<0.001$) after the area occupied by each depth-class was equalized and the count simulated (*Figure 34*).

Minimum abundance estimates of harbor seals in the survey region were generated from the average count in each survey area divided by the number of times that area was surveyed. This analysis suggests the Southwest Puget Sound as defined by this study is the day-time home to 298 seals in the summer, 332 seals in the fall, and 180 seals

in the winter, on average. Disparities between seasons may be explainable by the seasonal depth-class preferences of harbor seals or movement of food sources within the larger South Puget Sound region. When comparing results with NOAA haul-out aerial survey estimates and NOAA's correction value of 1.53, the findings of this survey are consistent with existing estimates (Carretta et. al., 2017). These data suggest that close to all in-water and hauled-out seals were counted in the region, as the correction value calculated with this survey's results is 1.59, comparable to NOAA's value (*Table 31: Table calculating in-water correction values for each season.*).

Introduction

Marine mammal abundance and distribution in the South Puget Sound is poorly described and understood (Pearson, WDFW 2018). Despite the common occurrence of marine mammals in the maze of inlets and channels west of Nisqually Reach, official surveys into the populations ended in 1999 (Jeffries, 2003). To study the effects of environmental factors, seasonality, and disturbance on behavior, in-water marine mammals must be observed in a reproducible method over time.

The Southwest Puget Sound was chosen as the area of research, cutting off where Case Inlet meets Nisqually Reach. This area was chosen for the relative lack of restricted waters and local relevance. In this area of the Puget Sound, four marine mammal species are likely to be detected: harbor seals (very common), California sea lions (uncommon), long-beaked common dolphins (seasonal) (Cascadia, 2011), and harbor porpoises (common) (Carretta et. al., 2017).

Several research groups have evaluated the Puget Sound and mapped haul-out hot spots for pinniped conservation purposes, but none have published maps of the Southwest Puget Sound in detail nor sought to link environmental factors on distribution.

Methods and Materials

Methods and materials used in this survey were based upon availability due to limited financial and equipment resources. Both the main vessel and kayak used in this project came into the possession of the main researcher by chance or at a low enough price to utilize in the survey. Alterations and additions were made to the main vessel for it to be used for surveying and to serve as the home of the main researcher for the duration of each two-and-a-half week survey season. The style of data collection was inspired by Antarctic ship-based surveying and adapted for spotting primarily harbor seals in the narrow waters of the Southwest Puget Sound. Esri applications and Microsoft Excel were used in data collection and analysis.

Main Vessel

Areas with a low tide average of 20 feet and deeper were surveyed using the main vessel, Seawolf. Seawolf is a 1977 Newport 28-foot Mk1 sailboat (*Figure 14*) with a 4.5-foot draft, 9.5-foot wide beam, and 30-foot tall mast. The above water section of the hull is painted sea green and the below water hull is black. The unreliable diesel Atomic 4 inboard engine was removed and replaced with a Mercury 9.9 Horsepower 4-stroke Kicker on the transom. The Mercury outboard maintained maximum speeds of 4 knots against and 6 knots with the current, averaging 5 knots. The vessel was refueled before each survey day to ensure consistent time was spent in each survey area. Sails were not used during surveys as operating them would affect course and the researcher's attention. A volunteer navigated the vessel from the cockpit at the command of the captain-observer on the bow to ensure undivided attention on counting marine mammals.

Kayak

Shallow water areas that were publicly accessible, such as the ends of inlets, were surveyed by kayak. The kayak used was a 10-foot Pelican Cove 100XP (*Figure 13*) in "electric green" paddled at an average of 2.5 knots. Survey equipment was strapped to the observer including a thermometer, binoculars, and mobile collection device. The observer also wore a rain shell, life jacket, and hat in all seasons. The kayak used was transported to a public park along the survey path by land vehicle and launched from the beach. All kayak surveys were conducted in fair weather around high tide.

Navionics (Version 14.8)

Mobile app Boating & Lakes by Navionics S.R.L. was used in the navigation on the main vessel for deep water survey routes. Routes and timestamps were saved for later use and analysis. The app was installed on both the main researcher's phone and the boat's tablet device, using the device's global positioning system for navigation. The app was also used to find average speed, estimated fuel consumption, and avoid hazardous or restricted areas. Large solar panels were installed on the bimini of the main research vessel to meet the high energy demands of the navigation tablet.

ArcGIS Pro (Version 2.1.0)

The analysis software used for this research project was ArcGIS Pro by Esri. With a suite of powerful analysis tools and support from The Evergreen State College, this software was found to be the most suitable choice for data analysis. ArcGIS Pro is easily connected with ArcGIS online services, making it able to transfer the Survey123 data (described below) and acquire reference maps through the ArcGIS Portal service.

Survey123 (Versions 3.5.176 – 3.6.158)

Survey123 for ArcGIS mobile application by Esri was used in the collection of data for this research. The mobile device's global positioning system combined with a cellular connection for data point submission made collecting each data point accurate and secure. Data points were uploaded when in areas with good cellular service, although a strong connection was not necessary to continue collecting data, which would then be stored on the device for later uploading. Once data collection was complete, the information was downloaded from ArcGIS online in the form of Microsoft Excel spreadsheets for refinement and analysis.

Excel (Version 16.0.11929)

Microsoft Excel was used to refine and analyze data after collection. Excel files were uploaded to ArcGIS Pro to transfer spatial attributes such as nearest environmental readings, survey areas, and depth-classes to each data line before returning the datasheet to Excel for further analysis. Graphs were generated in Excel and simple mathematical calculations were used to derive averages, adjusted values, and unit conversion. Advanced analytical tools, such as chi-squared and summary statics, were installed and used to derive more information from patterns in the data.

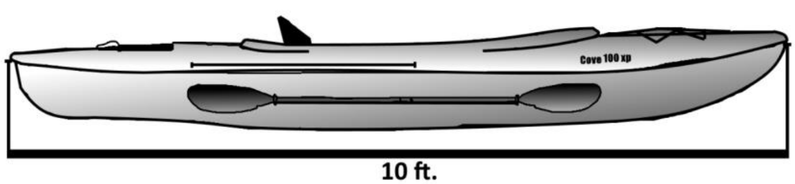

Figure 13 Drawing of the kayak used: Pelican’s 10-foot Cove 100XP.

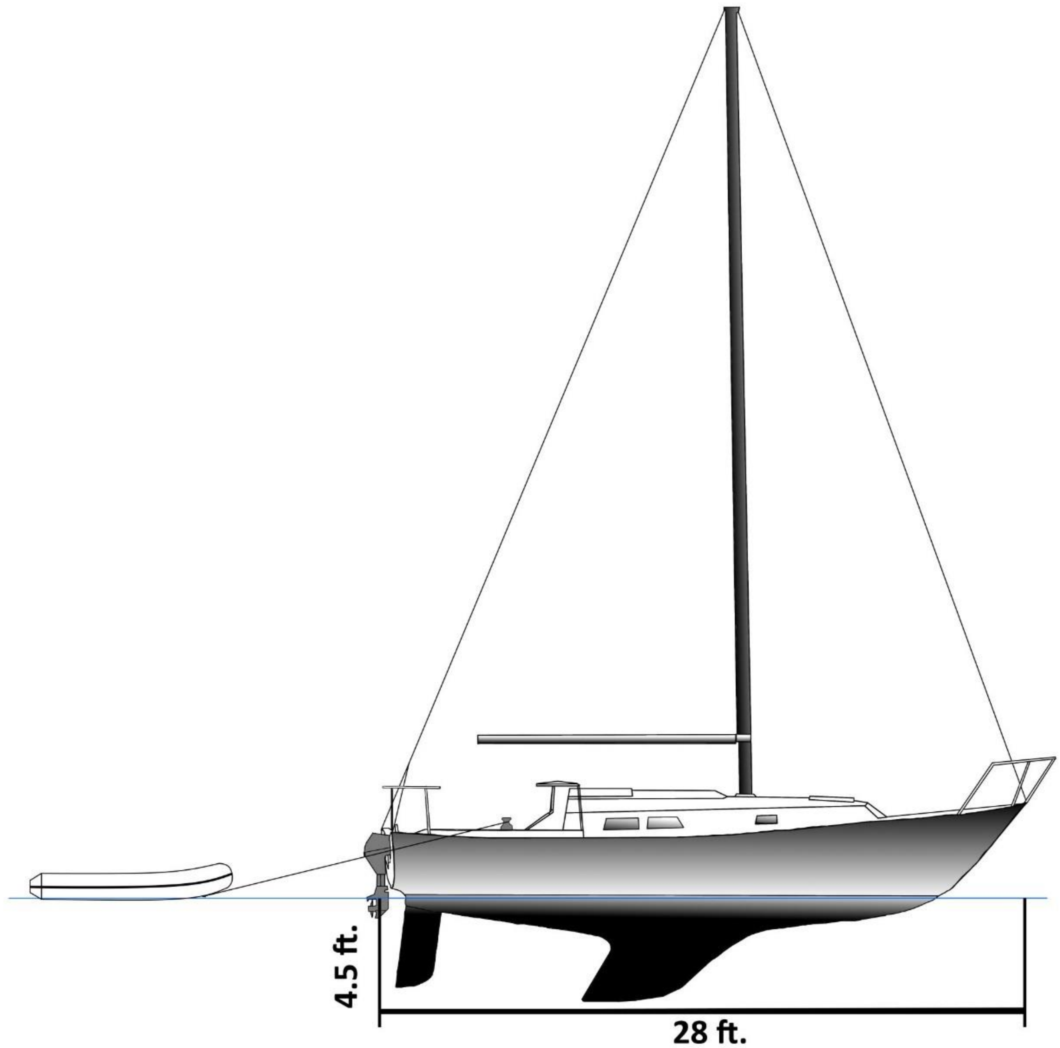

Figure 14: Drawing of the main vessel: 1977 Newport 28’ Mk1 retrofitted with a 2019 Mercury 9.9 4-stroke Kicker outboard motor and dinghy in tow.

Data Collection Methods

All accessible areas of the Southwest Puget Sound were divided into routes easily accomplished in the research timeframe (Figure 15). Boating routes were established and repeated three times per season (Figure 16). Observations were recorded in Survey123 software for efficient transfer into ArcGIS for analysis. The main vessel research (deep water surveys) took place on June 19th - July 3rd, 2019 (summer), August 30th - September 13th, 2019 (fall), and December 21st, 2019 - January 4th, 2020 (winter). Kayak (shallow water surveys) surveys took place July 14th – August 14th, 2019 (summer), September 24th – October 12th, 2019 (fall), December 6th - 12th, 2019 continued January 9th – 28th, 2020 (winter). The weather throughout all these dates was generally fair with an average Beaufort level of 0.9 (ripples) in summer, 1.1 (ripples) in fall, and 1.5 (wavelets) in winter. Rest days were moved to days with the worst weather forecast to help maintain consistent viewing conditions.

In advance of voyages, supplies for as much of the survey season as possible were stored and vessel maintenance was completed. Volunteers confirmed their availability in advance for their scheduled survey days and the main vessel was then moved from its dock in Port Orchard, Washington to Hope Island State Park in the South Pickering survey area. Hope Island State Park was chosen for its protected waters, boat launch to pick up volunteers, park facilities, and central location among many of the survey areas in the region. The three-night restrictions on vessels using buoys was avoided by anchoring occasionally and by moving to Jerrell Cove State Park for Case Inlet surveys.

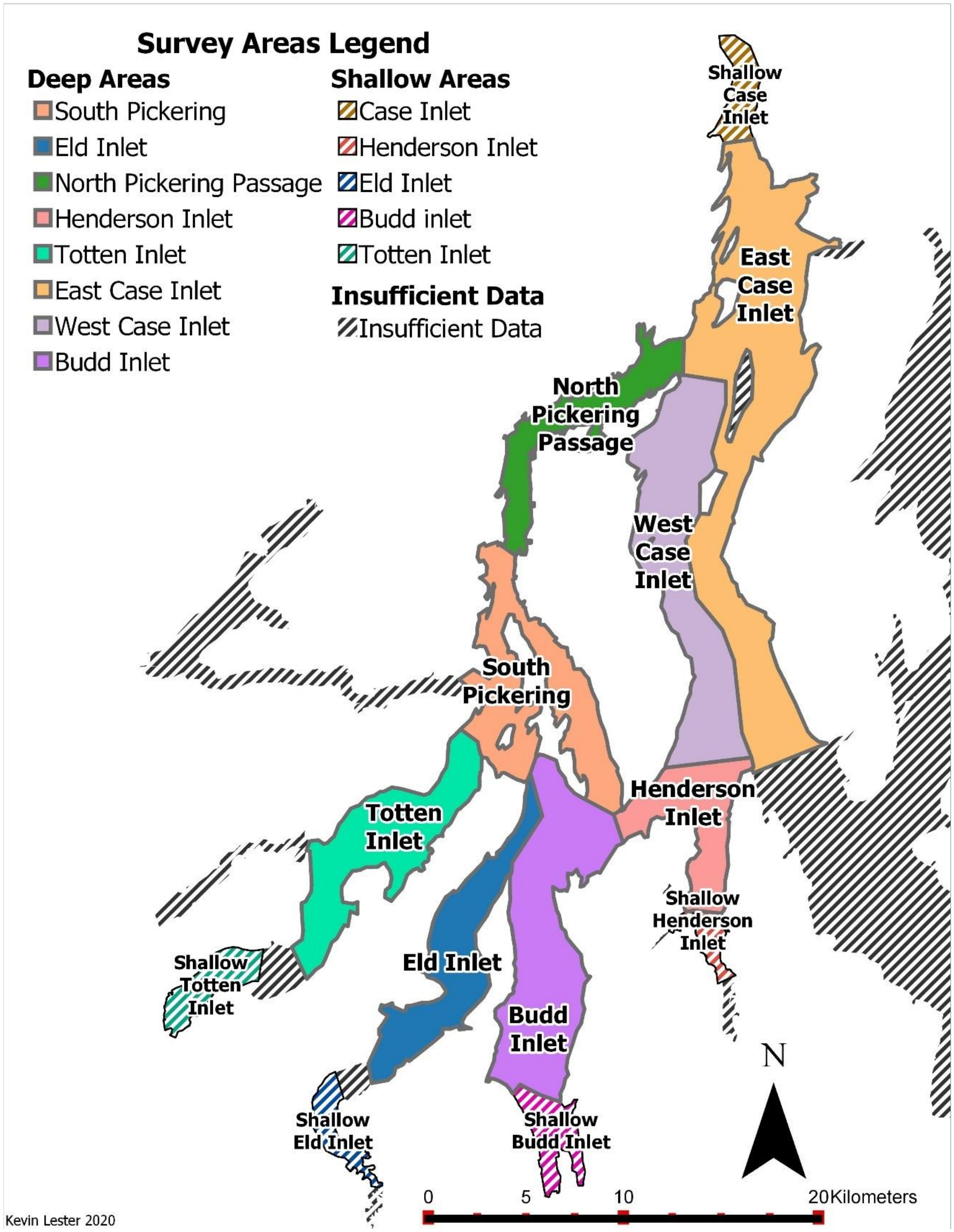

Figure 15: Map of all survey areas. Grey hatched areas indicate locations with insufficient data.

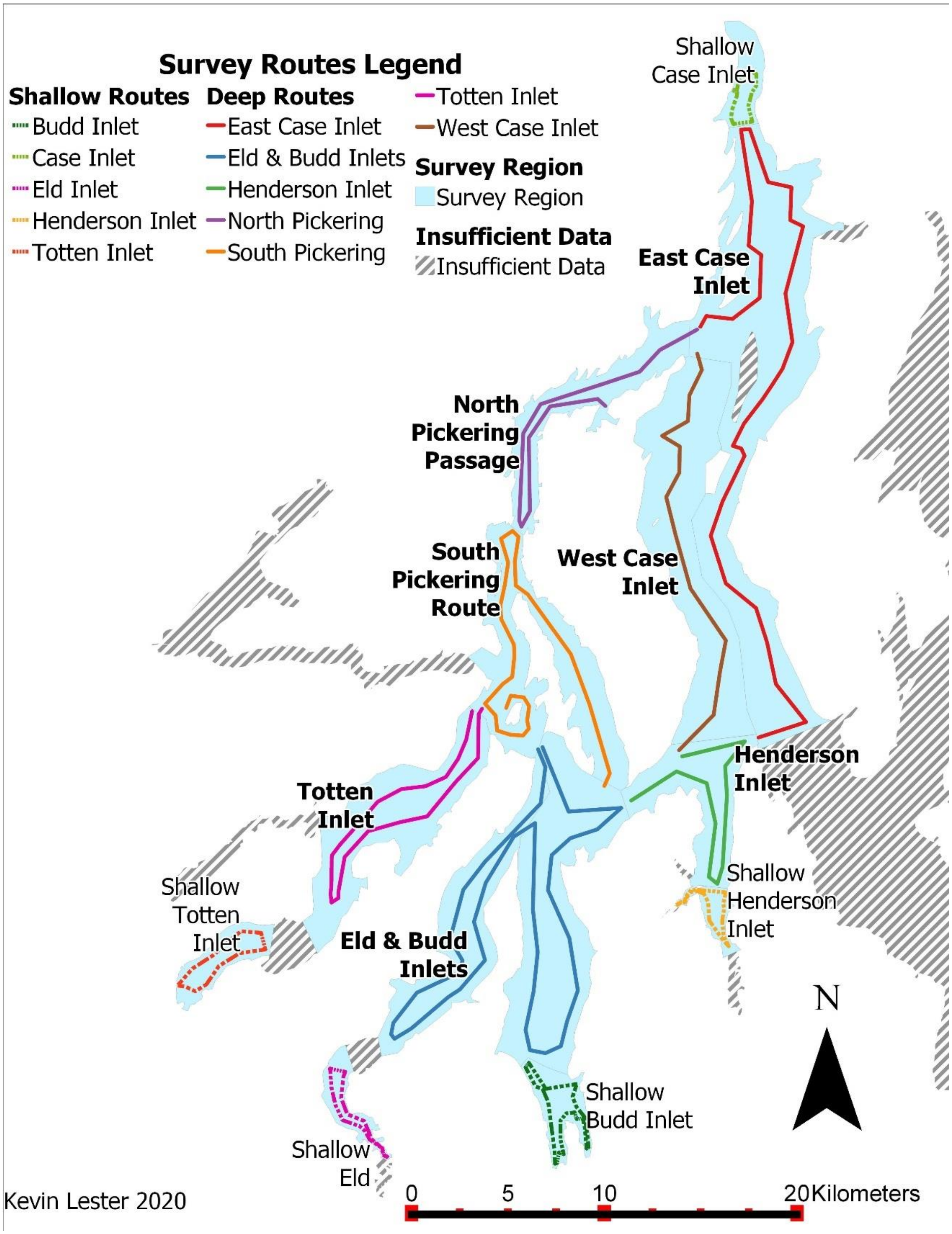

Figure 16 Map of survey routes.

Deep Water Surveys

A typical deep water research day took place as follows: the main survey vessel was moored at the relevant starting area, which was Hope Island State Park or Jerrell Cove State Park depending on the survey day. The prescheduled volunteer arrived at or near the state park. Volunteers were picked up by dinghy and helped in setting up all the necessary equipment once aboard the main vessel. The motor was warmed up and volunteers were briefed on safety and procedure for the day's survey. With the course set on Navionics software, the vessel moved into the survey area.

Once in the area, surface water temperature readings were made using a thermometer at a depth within 1 foot from the surface, marine mammal sightings were recorded using mobile GIS software, and human disturbance variables were recorded with mobile GIS software. During all excursions, the team did not pursue or harass marine mammals in compliance with the Marine Mammal Protection Act viewing guidelines (NOAA Fisheries, 2019).

The main vessel was operated at an average speed of 5 knots and stopped or slowed to allow marine mammals to travel undeterred. Surface water temperature was recorded using the built-in Humminbird PiranhaMAX 4 DI Sonar depth sounder. Upon completion of the region, volunteers were returned to shore and the main researcher completed any further survey work or preparations for the next day.

Shallow Water Surveys

The main vessel used throughout deep water surveys is unsafe or unable to be operated in all areas of the survey region consistently outside of the high tide window. This is due to the limited horsepower of the vessel and 4.5-foot draft. For the remaining areas that are still accessible by land, a kayak was transported to a launch point and used to survey the area. These areas are denoted in figures and tables as "shallow" areas and typically have low tide averages of 0-20 feet.

Area Name	Size (km^2)	Route Length (km)	Summer Time (hrs.)	Fall Time (hrs.)	Winter Time (hrs.)
Totten	17.9	18.9	2	2	1.7
Eld	15.1	22.3	2	2	2
Budd	26.8	23.9	1.7	2	2
Henderson	11	14.4	1	1	1
West Case	27	16.1	2.3	2	2
East Case	46.9	34.9	3.7	4	3.3
South Pickering	19.8	21.3	2	2	2
North Pickering	11.3	17.3	1.7	1.3	1.7
Shallow Totten	4.6	7.9	1	1	1
Shallow Eld	3	8.5	1	1	1
Shallow Budd	4.6	12.6	3.3	3	3.3
Shallow Henderson	2	7.4	1	1	1
Shallow Case	3.7	5	1	1	1

Table 24: Statistics on survey areas and routes with seasonal estimated average completion hours breakdown.

While the vantage point of the observer is greatly reduced in a kayak, so is the size of the area being surveyed. The surface water temperature was recorded using the AcuRite Digital Thermometer which gave consistent temperature readings with the depth sounder used in deep water surveys. Being human-powered, shallow routes were surveyed more slowly at a pace of 2.5 knots. The choice of survey day was more flexible than deep water surveys making them safer and providing improved visibility, however, deep water surveys were able to be completed in fair conditions as well.

As with deep water surveying, marine mammals were not pursued or harassed in compliance with the Marine Mammal Protection Act viewing guidelines (NOAA Fisheries, 2019). Restricted access areas such as preserves, private docks, marinas, industrial areas, etc. were not intruded upon but observed from well within public areas. Seal haul-outs were treated with the utmost caution and given as wide a distance as reasonable to not cause stampeding or changes in behavior. The health and well-being of both surveyors and wildlife were prioritized.

Limited and Insufficient Data Areas

Insufficient data areas were discovered during the survey (Figure 17-22). Commonly, insufficient data areas were created by limitations of access whether for reasons of low tide average depth, industrial activity, or natural area preserves. Often these areas were attempted or approached and confirmed to be too dangerous or otherwise inaccessible.

Deep Case Inlet (Figure 17) is an exception to many of the issues presented in the other insufficient data areas. This area was created post-surveying as a hole in the data.

Upon further investigation, it was found to be quite distant from the survey routes and may have not been surveyed thoroughly. The observer, however, did scan the area with binoculars when passing to the east, though the normal array of data points do not appear there.

The oyster industry in the Southwest Puget Sound has a presence in every inlet's extremity except Budd Inlet. These oyster farms have markers and equipment near or above the surface of the water, making navigating near the farms in a large vessel too dangerous and in a small vessel suspicious. Additionally, large oyster boats are commonly maneuvering in the farm areas during survey times. For these reasons the farms were observed at a safe and respectful distance to the utmost visibility of the observer and left as areas of insufficient data.

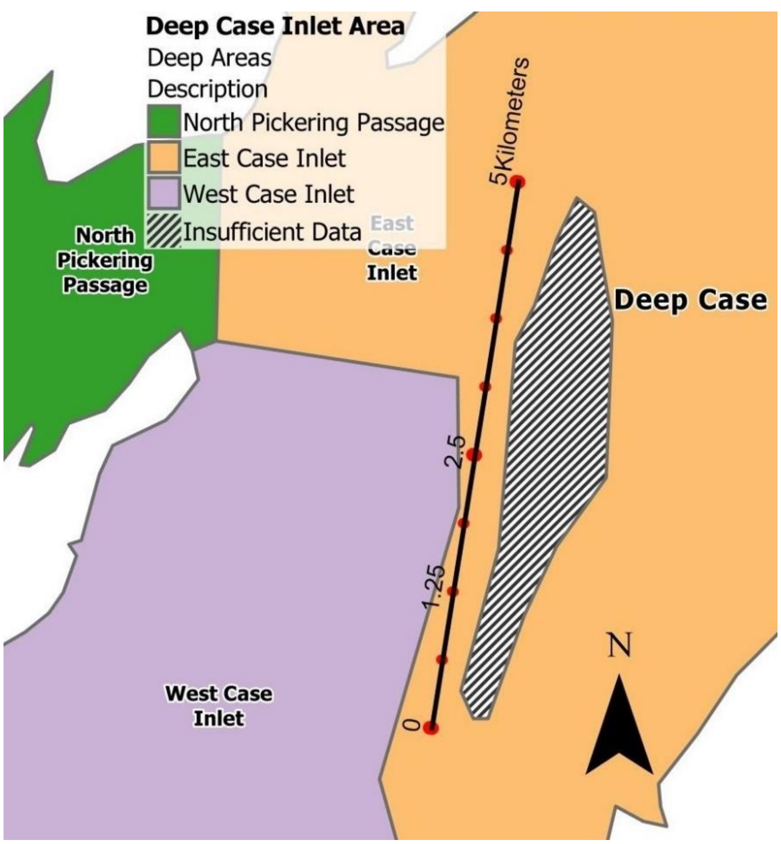

Figure 17:Map for Deep Case Inlet insufficient data region.

Deep Case Inlet is a possible area of insufficient data or a data-hole north by northeast of Heron Island (Figure 17). No survey points were recorded in this area and it was distant from the nearest routes. A zig-zag route pattern could have been used to increase the surveyor's coverage of the area and confidence that nothing was to be found there, however this was not used and it remains an area of low confidence due to its remoteness.

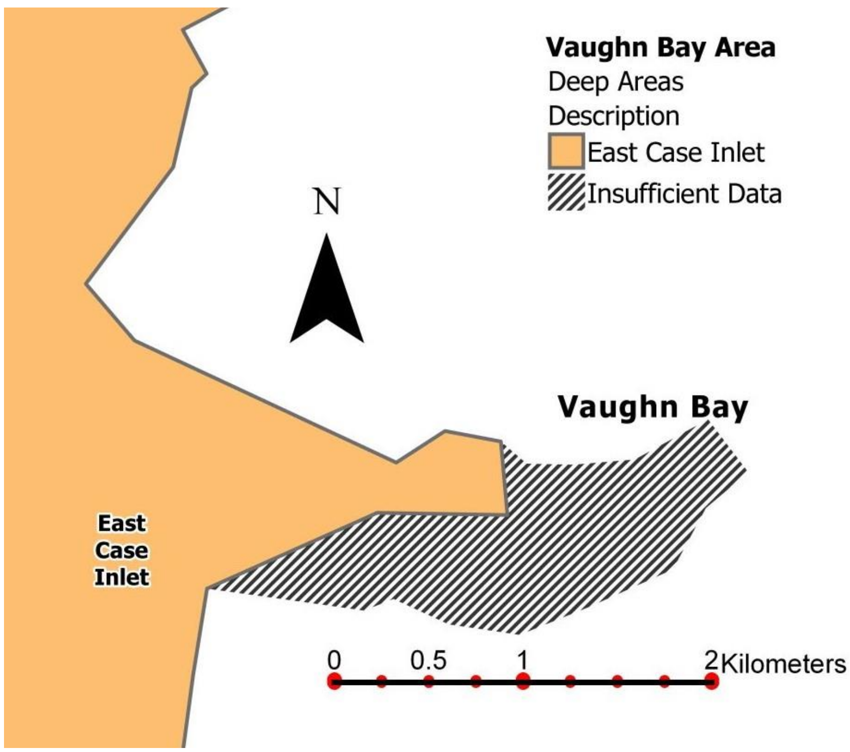

Figure 18: Map for Vaughn Bay insufficient data region.

Vaughn Bay is nestled on the northeastern coast of Case Inlet (Figure 18). A breakwater extends across the entrance of the area and leaves a narrow passage with a low tide average of 1.5 feet to the already shallow narrow bay lined with private docks. This area was not surveyed, as much of the area can be observed from deeper water and the entrance is inconsistently traversable for the main survey vessel.

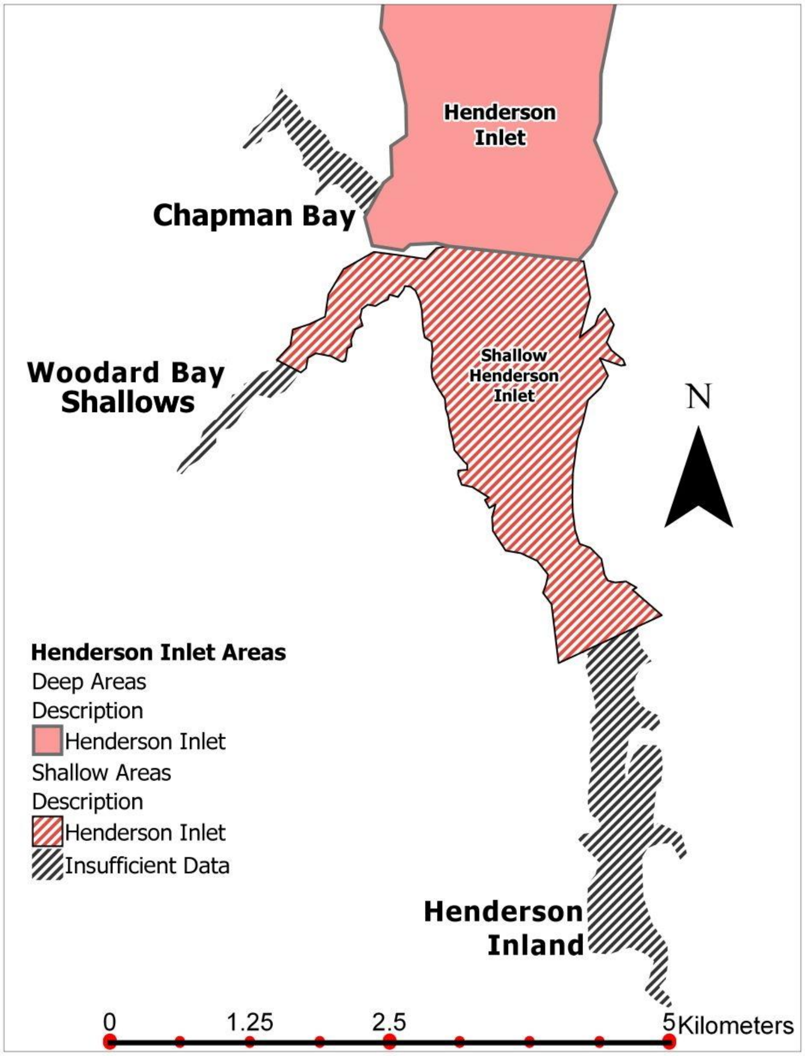

Figure 19: Map for Woodard Bay Shallows and Chapman Bay insufficient data regions.

The Henderson Inlet areas of insufficient data are Chapman Bay, inland Woodard Bay waters past the parking area for the preserve, and the southern extremity of Henderson Inlet (Figure 19). There is no public access to the waters in Chapman Bay itself due to the importance of the harbor seal haul-out at the deep water entrance. The haul-out itself was counted via deep water surveys but both historical structures and seals require observations to be distant and access to be blocked. The Woodard Bay Natural Resources Conservation Area parking lot is next to a small bridge that blocks the western shallows. The southern extremity of Henderson Inlet becomes progressively shallow and is occupied by oyster farms making it inaccessible.

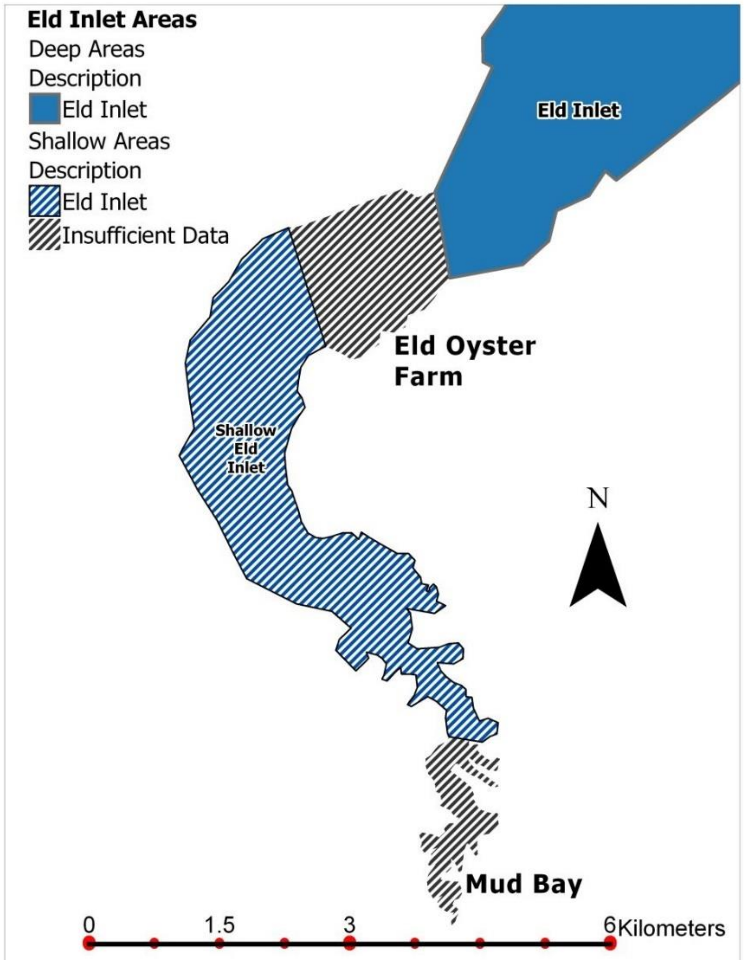

Figure 20: Map for Eld Inlet insufficient data regions.

The Eld Inlet areas of insufficient data are south of the Mud Bay bridge and the oyster farm between the shallow water survey area and deep water survey area (Figure 20). The southern extremity of Eld Inlet becomes progressively shallow with deep mudflats exposed outside of high tide. The oyster farm area was cut so as not to be intrusive to its industry and because the area of the farm becomes too shallow for the deep water vessel.

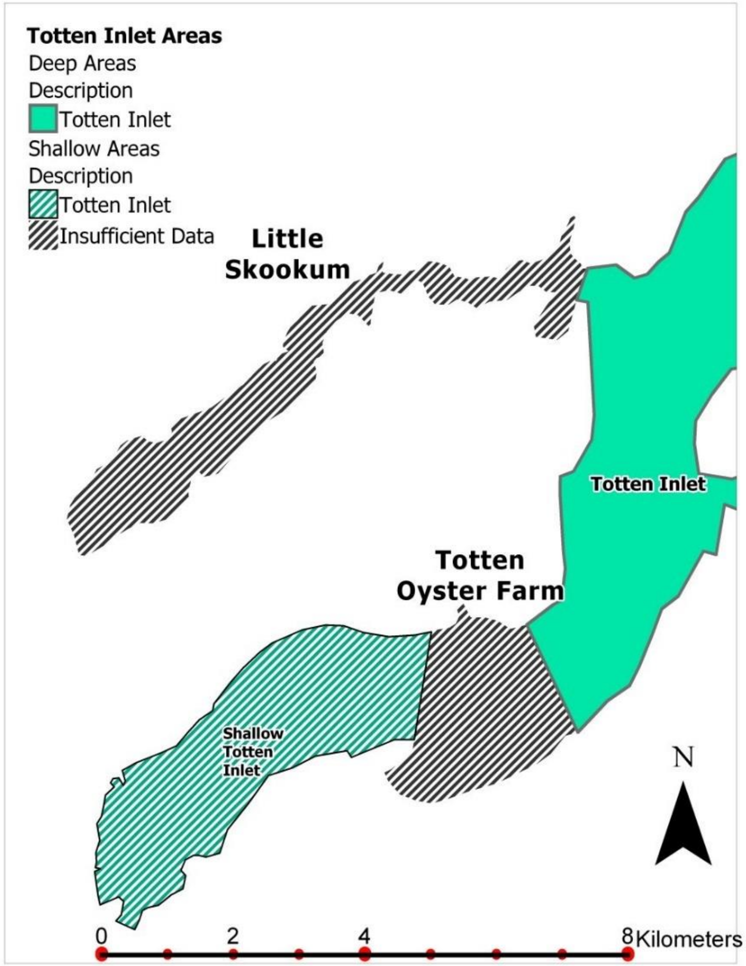

Figure 21: Map for Totten Inlet and Little Skookum Inlet insufficient data regions.

Totten Inlet contains two areas of insufficient data. Similar to Eld Inlet, the oyster farm near Totten's southern extremity was a barrier between the shallow water surveys and deep water surveys (Figure 21). A long array of floating barges and equipment block further access from the deep water side, and the oyster farming activity blocks the shallow water side. Little Skookum is a large and very shallow branch off of Totten Inlet. The waters within drain nearly completely at average low tide, house oyster farms, contain Kennedy Creek Natural Area Preserve, and are full of private waterfront private property.

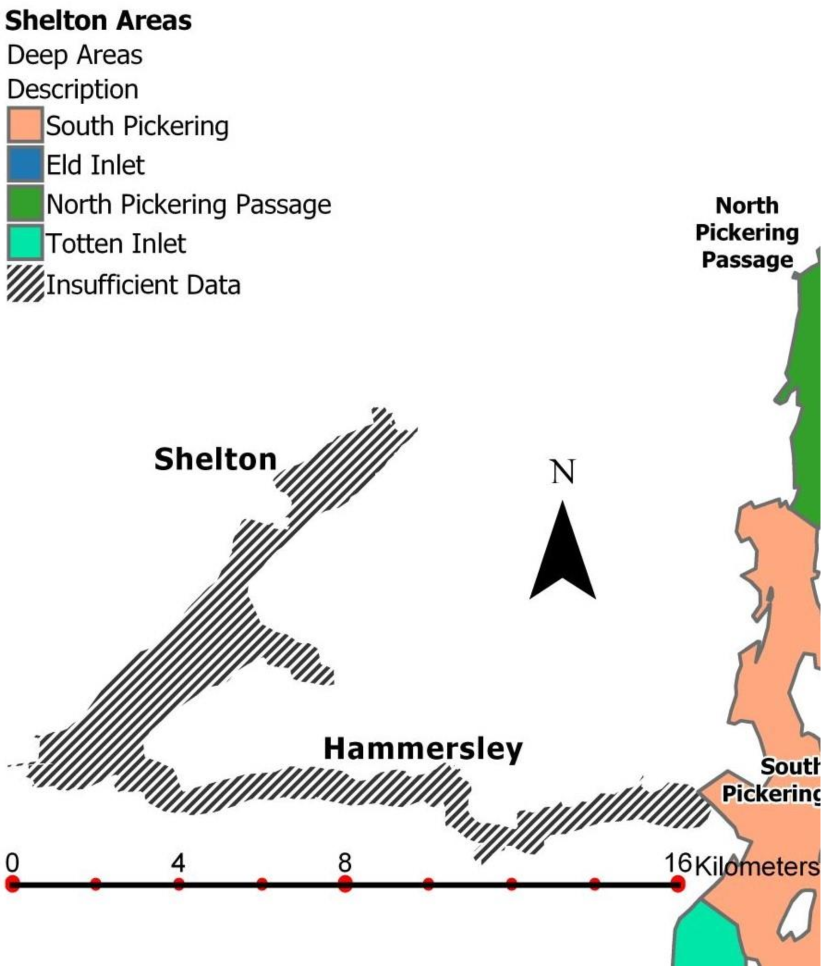

Figure 22: Map for the Shelton area and Hammersley Inlet insufficient data regions.

Originally a survey area, it was quickly discovered that access to Shelton's Oakland Bay via Hammersley Inlet was not consistently possible in the deep water vessel (Figure 22). The passage is dangerously shallow, lined with oyster activity, and the currents are strong. A great number of harbor seals have been recorded in the Shelton area and the attempts to reach Shelton in the deep water vessel did reveal many seals along the way, but further investigation into the area was halted after the vessel was nearly run aground by the strong currents in the narrow passage.

Visual Survey Techniques and Tools

The observer kept in mind the limitations of a continuous visual survey while actively searching for data points and combated double counting using the following guidelines (*Table 25*). First, the observer questioned whether the individual had already been counted by considering if it was in a location predictable by past observations that day. Second, the observer was aware of distance sampling bias and spent the same amount of time scanning each area near and far (Bengtson et. al., 2004). Third, the observer surveyed from the same vantage point, preferably a high and visually clear space free of distractions (e.g. the bow superstructure).

Binoculars were used to extend the visual range of the observer to mitigate distance bias in counts and to ensure accuracy in observations when in more expansive areas. Bushnell BSH134211 H2O Series 10x42 binoculars were used for their ease of use and weather repellent qualities. The use of binoculars extended the range of the observer's ability to record accurate data from 200 meters to 600 meters and ensured haul-outs or cetaceans remained undisturbed.

Occasionally, haul-outs and large congregations of marine mammals were difficult to count due to "stacked" seals or multiple heads and tails in the water. If the continued movement of the vessel did not remedy this, a Canon Mkii digital camera with a 600-millimeter lens was used to take a snapshot and assist with species identification and counts.

Survey routes were designed to allow observers to capture all of the survey area's water and shoreline while avoiding the chance of double counting subjects. Areas in close geographic proximity were typically surveyed on the same day, except for the largest area, Case Inlet, which was completed over two sequential days. Routes were designed with the observer's comfortable visual range in mind and altered only as required due to boat traffic, adverse weather conditions, or passing marine mammals to avoid violating their safety buffers.

Land use and human activity data were also collected during the survey. The collection of these points followed a different set of rules than species observation points. Land use points were only recorded in summer, as it is unlikely for permanent structures to change from season to season. Human activity points were hypothesized to vary by season and were thus counted in summer, fall, and winter. The categories offered in the survey software for activity points were shore activity, paddler, powerboat, swimmer, and other. For land use points, the following options were offered: industrial, marina, residential, dock, boardwalk, historical, and other. Shore activity was only recorded when there was more than one person or when that person had a potentially disruptive animal. Powerboats, barges, sailboats, Jet Skis, and powered dinghies were recorded as powerboats. Paddleboards, rowboats, kayaks, canoes, and paddle boats were categorized as paddlers.

Conclusion

This section covered the methodology used for a ship-based marine mammal survey in the Puget Sound. Much of the difficulty and variability in such a survey comes from the inclusion of in-water data points. While in-water counts are avoided in most pinniped inclusive surveys, the goals of this research need to show the distribution of species outside of their maximal haul-out times.

Full coverage of the Southwest Puget Sound was attempted, but as the survey progressed, certain areas proved to be too problematic to be surveyed. These areas were categorized as insufficient data areas with designation on a case-by case basis. Reasons for their designation included industrial activity, shallow depth, danger, inaccessibility, or were missed due to design flaw. With these areas aside, the majority of the Southwest Puget Sound region was adequately surveyed.

Essential to the methodology of this survey was the implementation of marine mammal viewing guidelines as set forth by NOAA. These guidelines drove the design of visual survey techniques used to include optics and consideration of haul-out safety buffers when drawing survey routes. Thanks to these distance guidelines, marine mammals were not disturbed during the survey.

Design

Ship-based methods to survey marine mammals are often avoided due to the intrusion of many confounding variables (Bengtson et. al., 2004), although sailboat-based survey techniques are still used by some teams counting Antarctic seals (Laws, 1993). Even with bias and error mitigation, the data produced by the chosen methods are arduous to acquire and only a fuzzy picture of real-world conditions at best. However, deviation from the typical survey methods was required to show variations in seasonal distribution. This was especially important for studying harbor seals which are typically surveyed via aerial techniques during one day of the year at maximal haul out. This section will cover considerations that shaped the survey and techniques used to mitigate bias.

Methodological Design

The main vessel's physical limitations and the time constraints to accomplish a seasonal census survey shaped the scope of the survey region and determined which techniques were used. The researcher contacted and met marine mammal conservation expert Dr. Cindy Elliser with Pacific Mammal Research in Anacortes, Washington to design an accomplishable census survey of South Puget Sound regions.

The resulting route and area design (Figure 15-16) were crafted to be completed during two-and-a-half week long intervals for the deep water research. Deep water areas were designed to be completable regardless of season and tide while the research lived on board. Shallow water areas could be completed during fair weather days immediately before or after each season's survey.

A small sailing vessel with a team of two often requires some amount of multitasking, especially with inexperienced navigators. During the times when the observer had to assist with navigation, the navigator assisted in identifying data points to ensure nothing was missed. Volunteer callouts of observation points that may have been missed were most welcome for the observer attempting to input many data points at a time and were carefully curated by the observer so as not to double count.

To reduce distance sampling bias, the observer used optics and spent the majority of the survey on the highest point of the main vessel with the greatest all-around view. Shallow water distance sampling bias is likely more pronounced due to the shorter sightline of the observer and the fact that the observer must paddle.

Though the shallow and deep water surveys are presented as equal areas of data in this survey, the methods were drastically different. The surface water temperature was measured using different instruments at a slightly different depth. However, looking at average temperatures throughout the survey region, the temperatures were remarkably consistent (Table 29). While paddling and motoring were different in other ways, including noise production, marine mammals appeared more concerned with a paddler than a passing motorboat, which is a more common disturbance for wildlife in that region of the Puget Sound (*Table 46*-48).

Legal Considerations

The MMPA lays out detail-specific guidelines for researchers, observers, and commercial vessels likely to interact with marine mammals (NOAA, 2019). Researchers of many forms must register for the necessary permits depending on methodology from NOAA. However, there are grey areas in the requirements, and researchers that fall into these grey areas are referred to the NOAA permitting office. The main researcher called the NOAA permitting office and was told that as long as no breach in MMPA marine mammal observation guidelines were breached, the research could proceed without permitting (NOAA, 2019).

The MMPA viewing guidelines are species-specific and are distributed widely across the Puget Sound in the form of posters and digital information. The distance requirement for pinnipeds is 50 yards (46 meters) at sea, and 100 yards (92 meters) when hauled out. The distance requirement for viewing small cetaceans varies from 50 yards (46 meters) to 100 yards (92 meters) depending on local laws. Orcas have a unique requirement of 200 yards (183 meters) in inland Washington waters, while other large cetaceans, including whales, are 100 yards (92 meters) (NOAA, 2019). The MMPA also requires that vessels slow and idle their engines if a marine mammal approaches to prevent collision and minimize disturbance (NOAA, 2019).

These guidelines were strictly followed. When animals did approach researchers, the animals were not touched or harassed in compliance with MMPA guidelines and the recommendation of conservation experts. Routes were designed and followed to mitigate disturbing marine mammal haul-outs, helping to limit the change in course they may cause in compliance with viewing guidelines.

Biases

Double counting was at the forefront of the observer's mind for the entire survey, and though it is entirely possible some subjects were counted twice, the survey routes were designed to limit this occurrence. Subjects that were suspect were not counted.

The traveling behavior of most marine mammals in this survey was predictable. A seal moving in a certain direction typically did not deviate from its path, except to haul out on a platform or to dive. Seal pups in water were less predictable, as they appeared to interact with each other and attempt to play with debris more than adults. The predictability of behavior was important for the observer to record to prevent double counting subjects.

Vast areas of the Sound may not have been as thoroughly surveyed as the smaller areas due to the nature of those spaces. It is easier to identify the presence of a marine mammal in a small, shallow bay than a deep subsection of a large body of water. This was mitigated with the use of optics, scanning evenly across the field of vision, and route design.

Other important biases that may have impacted the data include surveyor fatigue, surveyor mood, daily difference in the crew, intermittent vessel maintenance, daily traffic variation, variation of time of day, weather variation, and other environmental factors.

The consistency of survey day operations became more mechanical after the first lap of surveying for a given season. The resulting data variation was mitigated using lap averaging.

The use of laps in the survey helped to limit variations and biases in the data. Double counting was mitigated by averaging the number of observations by the number of laps, weather conditions averaged out to be fair, and novel amounts of subjects were diminished.

Bias	Effect	Mitigation
Double Counting	Artificially large counts.	Lap averaging, behavioral awareness, route design, use of optics.
Surveyor Fatigue	Observations diminish in quality and quantity as the survey season progresses.	Lap averaging, break days, short survey days interspersed with long days.
Distance Sampling	Observations are more limited at greater distances and only subjects near the vessel are counted.	Route design, optics, scanning techniques.
Methods Variation	Differences in data between shallow and deep water days.	Separation in analysis, use of optics, general awareness of the differences and limitations.
Multitasking Observer	Data points missed.	Observer practice, lap averaging, volunteer training and callouts.

Table 25: Table detailing the most prominent sampling biases and what was done to mitigate them.

Conclusion

The fashion in which this survey was conducted was designed to make the most of the resources available to the researcher and to mitigate expected biases. This survey is insufficient to account for all marine mammal behavior in the Southwest Puget Sound. Surveys were only conducted during the day, leaving nocturnal behavior and distribution unaccounted for. Fair weather days were made to be survey days, making the foul weather distribution unaccounted for. Animals observed were counted regardless of age, which was often impossible to estimate due to their fleeting presence at the surface of the water. These limitations are important to note and provide direction for future research opportunities.

Analysis

Data collection throughout this survey was performed such that user error was limited and allowed for a plug-and-play analysis using various software. Survey123 by Esri is designed to be easily incorporated into Microsoft Excel and ArcGIS Pro, which were the software systems used in this analysis.

The nature of this survey's data is geospatial, meaning any relationship-based analysis will have to consider the areas in space and time. Data was analyzed by season and by survey area then compared within the given season or across seasons to investigate possible changes through the data's geospatial values. This survey recorded depth, temperature, human disturbance, and species observations. Each variable required a different form of analysis and comparison.

Significant values, should they arise, follow the well-respected rules around the given method. Methods that generated p-values have a <0.05 threshold of significance. Methods that generated R^2 values hold the >0.7 threshold of significance. Methods that generated a more nuanced report, such as visual-spatial patterns, are discussed and occasionally tested for other kinds of significance.

Often because of the spontaneity of ecology studies in the real world, variables and constraints are unequal. If the data were adjusted or represent total counts rather than lap averaging, it will be mentioned and explained. One area of analysis that required adjustments and refining to see the "true" data patterns was depth analysis.

Depth

GIS depth class maps were generated using one of NOAA's National Geophysical Data Center images of the Puget Sound's bathymetry (water-depth profile), then analyzed using the ArcGIS Pro classification wizard tool ("supervised" process) to create a feature class (Figure 23). The feature class allows for those depths to be transferred to the survey data points and shows areas of the survey region by depth class.

The choice of depth class stepping was designed for higher detail in the shallow inlets and broader classifications in the deeper areas, which occupy a much smaller percentage of the survey region. The class stepping was limited to the gradient of colors in the bathymetric map used, which was also more detailed in shallow areas. This made it easier for the program to be trained to differentiate color ranges in shallow regions than deeper ones.

In the Southwest Puget Sound, there are very few areas deeper than 300 feet at low tide average, making up 0.19% of the region (*Figure 24: Graph showing the size of depth class areas across the survey region against each other in square kilometers.*). Areas deeper than 200 feet are also limited to covering 2.89% of the region (*Figure 24: Graph showing the size of depth class areas across the survey region against each other in square kilometers.*). Approximately half of the region's water area is 20-120 feet deep, which is shallow as compared with the rest of the Puget Sound where the average water depth is 450 feet and maximally 930 feet (NOAA, 2019). As a result, the behavior of the genetically distinct southern harbor seal is likely different from their more pelagic northern neighbors (Carretta et. al., 2017).

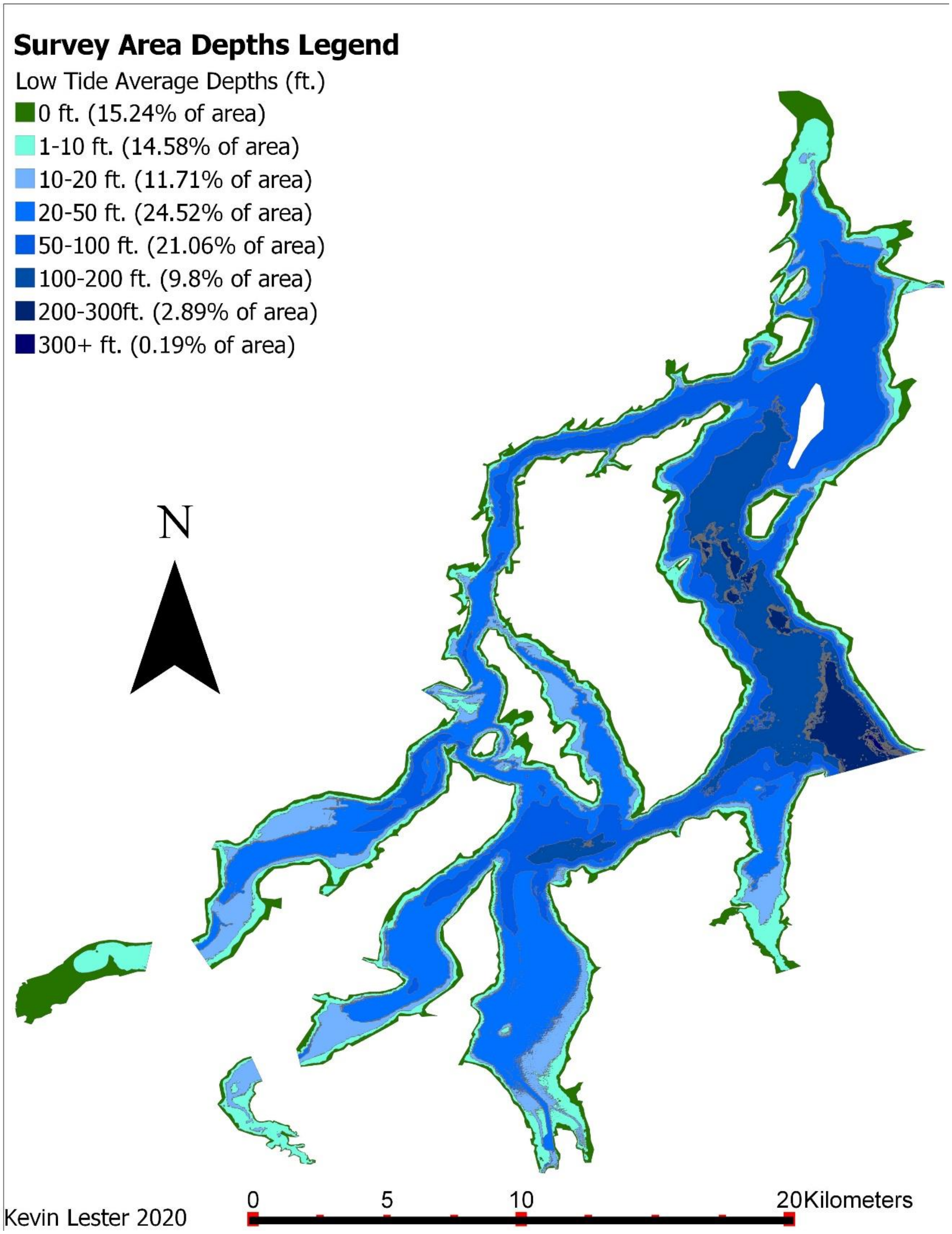

Figure 23: Depth profile of the survey region rendered using reclassified NOAA bathymetric imagery.

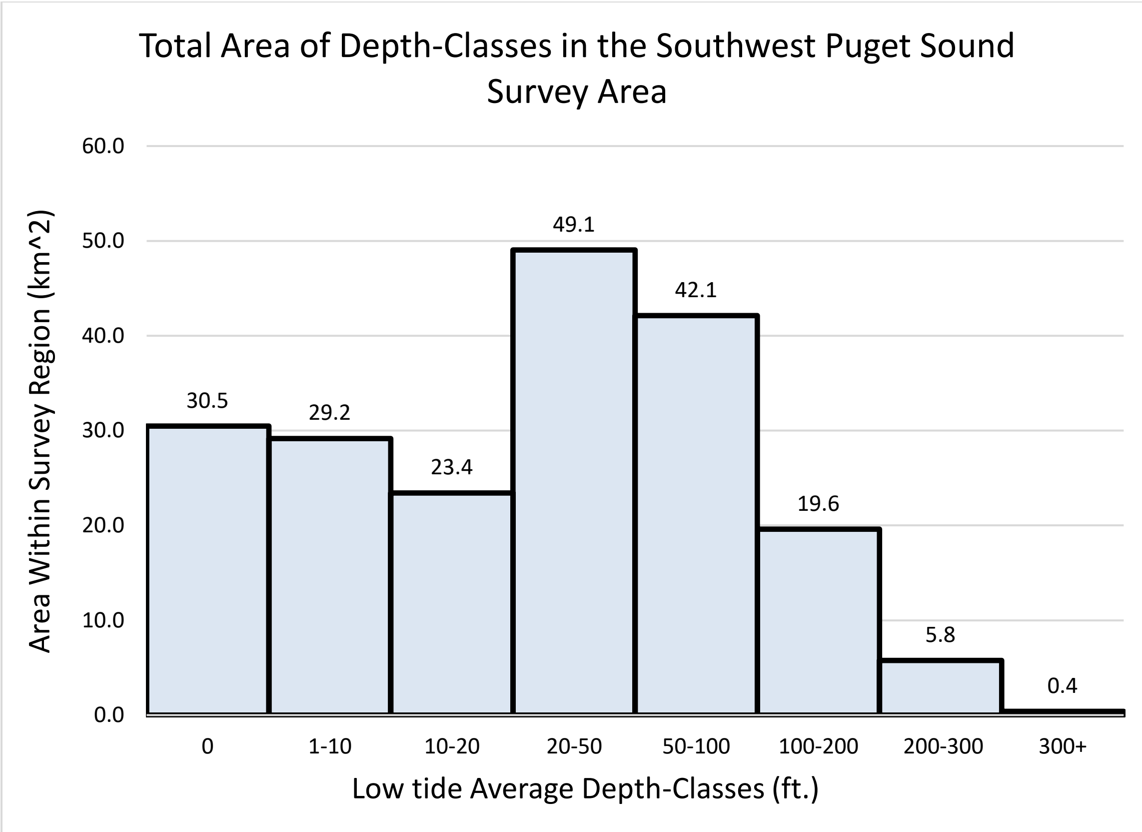

Figure 24: Graph showing the size of depth class areas across the survey region against each other in square kilometers.

Depth throughout the survey region varied in area coverage (Figure 24). Thus, observations in those areas were normalized to simulate a perfectly even seal count by depth coverage. This weighted analysis highlighted the depth area preferences of species by removing the effect of area size on total observation counts.

Temperature

Surface water temperature values were collected in Fahrenheit, then converted to Kelvin for averaging. These values were restored to Fahrenheit for display. This was done to improve the accuracy of the averaging process. Temperature values for all areas were summed and averaged to generate seasonal distribution maps where all areas of the survey could be represented on a scale across the region and tested against observation counts in those regions.

Band Collection Statistics

$$Cov_{ij} = \frac{\sum_{k=1}^{N}(Z_{ik} - \mu_i)(Z_{jk} - \mu_j)}{N - 1}$$

Equation 2: Band Collection Statistics processing equation for raster covariance values.

$$Corr_{ij} = \frac{Cov_{ij}}{S_i S_j}$$

Equation 3: Band Collection Statistics processing equation for raster correlation values.

KEY:

Z	Value of a raster cell.
i, j	Layers of a raster stack.
µ	The mean of a raster layer.
N	The number of cells.
k	Denotes a particular cell.

Table 26: Key for Band Collection Statistics equations

The “Band Collection Statistics” tool in ArcGIS Pro is designed to provide statistics on stacked raster data sets. Covariance measures variability from the mean count and is used in the correlation equation. The correlation equation outputs a number between 1 and -1. A positive number is a positive spatial association between the two rasters. A negative number is a negative spatial association between rasters. As the number approaches 0, the more independent the rasters are from each other. Comparing multiple rasters creates a matrix in which results can be compared to one another. A value between 0.05 and -0.05 is a difference of at least 95% between rasters. (Esri, 2016) Raster cell size does affect the outcome of the test; smaller cells produce more significant independencies and large cells show more correlation. It is important to make the cells large enough to incorporate area patterns, but small enough to provide detail.

Trend Analysis

$$x^2{}_c = \sum \frac{(O_i - E_i)^2}{E_i}$$

Equation 4: Chi-squared equation for goodness of fit.

Chi-squared was used to test the likelihood that harbor seals are evenly dispersed across depth-classes for a given season. The null hypothesis was the mean of the total count tested against both the "raw" observations and the "normalized" observations. The resulting value was compared with the chi-squared test value index for a P-value. This process was used to test if the distribution of seals was random or not.

$$R^2 = 1 - \frac{SS_{Regression}}{SS_{Total}}$$

Equation 5: R-squared equation for linear regression.

A R^2 value is provided for many of the regression lines in figures in the following sections. However, R^2 values may be deceptive, as they can be swayed easily with outlying values in a small data set. These values were generated automatically with the Microsoft Excel plotting tool and are intended to explore possible relationships between two variables, such as area's seal count and an environmental variable. As there are only 13 areas, and thus 13 data points in the graph the values are to be considered with caution. R^2 values greater than 0.7 for positive relationship or less than -0.7 for negative relationship suggest a strong relationship between the two variables being considered.

Results

Observation records were broken down by season and area using timestamped and spatially imprinted data points. Results with sufficient sample sizes were tested for normality (or goodness of fit) to see if the distribution of observations across an environmental parameter was random. Note that not all species were abundant enough in every season to generate a heat map of their distribution. Where applicable, environmental parameters and maps are given.

Areas Overview

For the interest of context, statistics on each survey area and route were collected. These tables are just a summary of data to be discussed in detail later. Comparisons between environmental parameters and counts are discussed in deeper detail in the discussion section of this paper. As with most items in this survey, data is reported by season and area. Area size and route length did not change by season.

The largest survey area was East Case Inlet with 46.9 square kilometers of water area as well as the longest survey route of 34.9 kilometers. This route took 3.7 hours on average to complete in the summer, 4 hours in the fall, and 3.3 hours in the winter. The most demanding shallow water survey area was Shallow Budd Inlet which covers 4.6 square kilometers and has a 12.6-kilometer survey route. The reason this survey route is so lengthy in comparison with the total area is due to the geography of downtown Olympia, which juts into the inlet creating east and west bays. This route took 3.3 hours on average to paddle in the summer, 3 hours in the fall, and 3.3 hours in winter.

Analysis of size and route length was measured post-survey, while times and counts were collected during each season. The air temperature was collected from the Olympia airport climate records and may not be representative of the exact air temperature of the area on the water level (NWS, 2020). The average air temperature was estimated by taking the air temperature readings for each day that area was surveyed and averaged for the season. Harbor seal counts, powerboat counts, and average surface water values are displayed in the following tables (**Error! Reference source not found.**-29).

Summer Area Name	**Size (km^2)**	**Route Length (km)**	**Avg Time (hrs.)**	**Total HS Count**	**Avg HS Count (total/3)**	**Avg Water Tmp. (f.)**	**Avg Air Temp (f.)**	**Total Boats**
Totten	17.9	18.9	2	44	14.7	60.4	59.6	14
Eld	15.1	22.3	2	32	10.7	58.6	59	10
Budd	26.8	23.9	1.7	71	23.7	58.8	59	31
Henderson	11	14.4	1	121	40.3	58	60.2	32
West Case	27	16.1	2.3	40	13.3	58	61	18
East Case	46.9	34.9	3.7	66	22.0	59	60.2	54
South Pickering	19.8	21.3	2	166	55.3	56.8	57.2	16
North Pickering	11.3	17.3	1.7	33	11.0	57.8	59	11
Shallow Totten	4.6	7.9	1	1	0.3	68.3	64.6	0
Shallow Eld	3	8.5	1	3	1.0	65.8	65	2
Shallow Budd	4.6	12.6	3.3	251	83.7	62.8	68	96
Shallow Henderson	2	7.4	1	39	13.0	65.6	65.8	4
Shallow Case	3.7	5	1	9	3.0	67.7	66.4	6

Table 27: Survey area statistics for summer. (HS denotes “Harbor Seals”) Average counts were found by dividing the total for the season by the number of laps (3).

Fall Area Name	**Size (km^2)**	**Route Length (km)**	**Avg Time (hrs.)**	**Total HS Count**	**Avg HS Count (total/3)**	**Avg Water Tmp. (f.)**	**Avg Air Temp (f.)**	**Total Boats**
Totten	17.9	18.9	2	27	9.0	65	63.4	8
Eld	15.1	22.3	2	60	20.0	62	63.2	17
Budd	26.8	23.9	2	63	21.0	62	63.2	69
Henderson	11	14.4	1	264	88.0	61	63.7	34
West Case	27	16.1	2	42	14.0	61	63.7	25
East Case	46.9	34.9	4	76	25.3	62	64.6	54
South Pickering	19.8	21.3	2	283	94.3	63	63.4	26
North Pickering	11.3	17.3	1.3	19	6.3	61	64.6	35
Shallow Totten	4.6	7.9	1	0	0.0	63	56.5	1
Shallow Eld	3	8.5	1	3	1.0	60	56.9	4
Shallow Budd	4.6	12.6	3	135	45.0	57	47.4	51
Shallow Henderson	2	7.4	1	9	3.0	57	47.5	1
Shallow Case	3.7	5	1	14	4.7	58	50.8	2

Table 28: Survey area statistics for fall. (HS denotes "Harbor Seals") Average counts were found by dividing the total for the season by the number of laps (3).

Winter Area Name	Size (km^2)	Route Length (km)	Avg Time (hrs.)	Total HS Count	Avg HS Count (total/3)	Avg Water Tmp. (f.)	Avg Air Temp (f.)	Total Boats
Totten	17.9	18.9	1.7	25	8.3	46.8	42.4	1
Eld	15.1	22.3	2	25	8.3	47	41.9	3
Budd	26.8	23.9	2	33	11.0	47.4	41.9	17
Henderson	11	14.4	1	92	30.7	47.2	40	3
West Case	27	16.1	2	105	35.0	47.2	40	3
East Case	46.9	34.9	3.3	82	27.3	47.2	41.9	5
South Pickering	19.8	21.3	2	62	20.7	47.1	42.4	7
North Pickering	11.3	17.3	1.7	56	18.7	47.1	41.9	3
Shallow Totten	4.6	7.9	1	1	0.3	46	40.1	1
Shallow Eld	3	8.5	1	1	0.3	48.4	46.6	0
Shallow Budd	4.6	12.6	3.3	50	16.7	48.1	43.6	11
Shallow Henderson	2	7.4	1	5	1.7	48	45.1	1
Shallow Case	3.7	5	1	2	0.7	48.5	46.3	0

Table 29: Survey area statistics for winter. (HS denotes “Harbor Seals”) Average counts were found by dividing the total for the season by the number of laps (3).

Harbor Seals

Harbor seals (*Phoca vitulina richardii*) were the most abundant and widely dispersed marine mammal observed in this survey (*Figure 25*-27). As such, their data is available for deeper analysis than the other species observed. Findings for this species are not broadly applicable to other species or even to other species of pinniped.

Harbor seal results from this survey reveal behavioral patterns in the region and estimate abundance by season. For both total counts and simulated counts, the data strongly suggest that harbor seals vary their depth-area preference (p-value <0.001) (Table 10*: Summer harbor seal counts adjusted for equal depth-class area.*). In summer and fall, seals prefer depths of 10-50 feet, while in winter they prefer depths of 100+ feet (*Figure 30*). The minimum abundance in the survey region is estimated to be 298 individuals in the summer, 332 individuals in the fall, and 180 individuals in the winter (*Table 30*). The methodology is validated by near-matching haul-out to total population correction values used by NOAA to estimate the total population of the same region (*Table 31*). The survey correction value is calculated to be at 1.59, and the NOAA value at 1.53 (Carretta et. al., 2017). This suggests that, because methodology did not change between seasons, in-water data is just as valid as hauled-out count data.

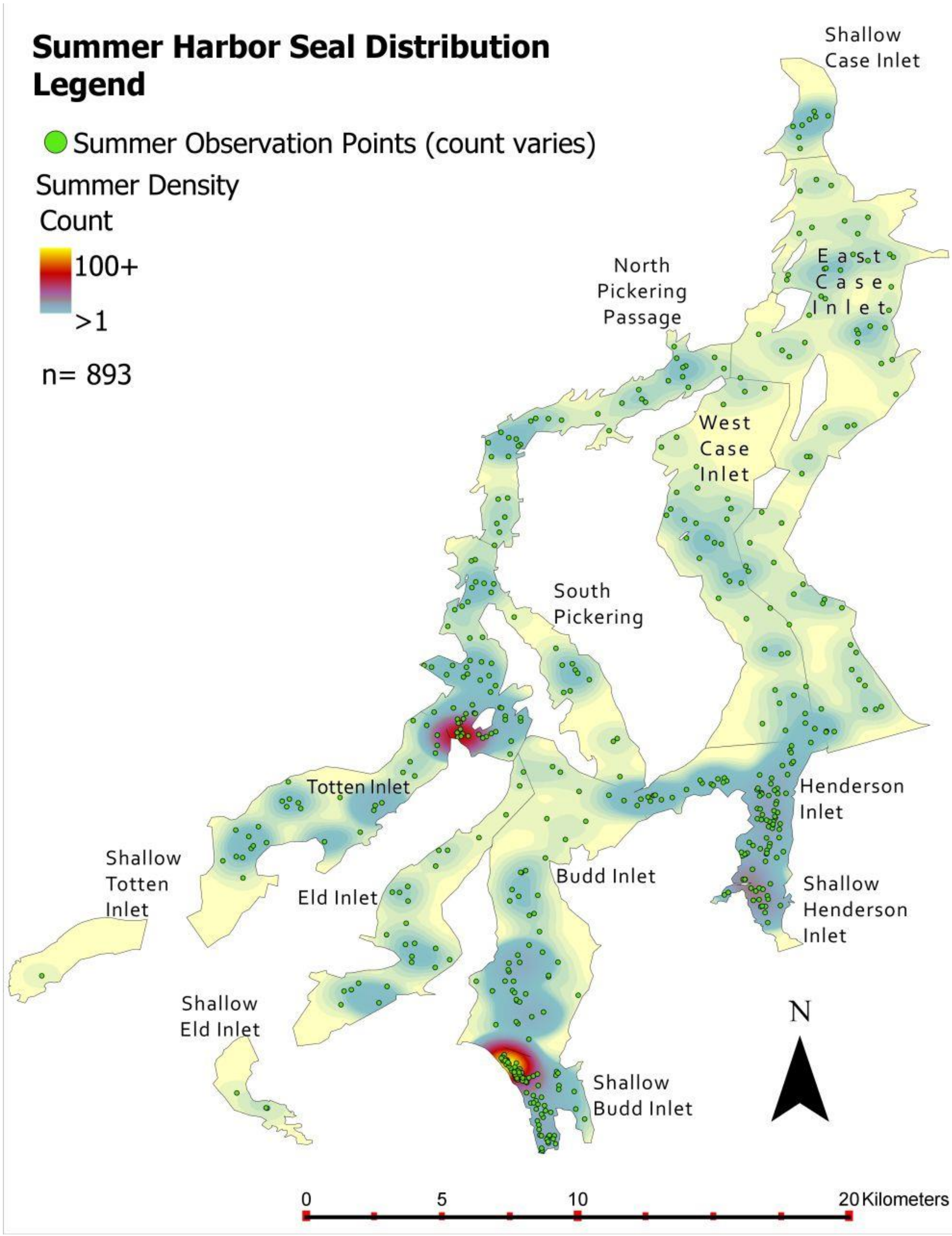

Figure 25: Map of harbor seal distribution for summer using the total count.

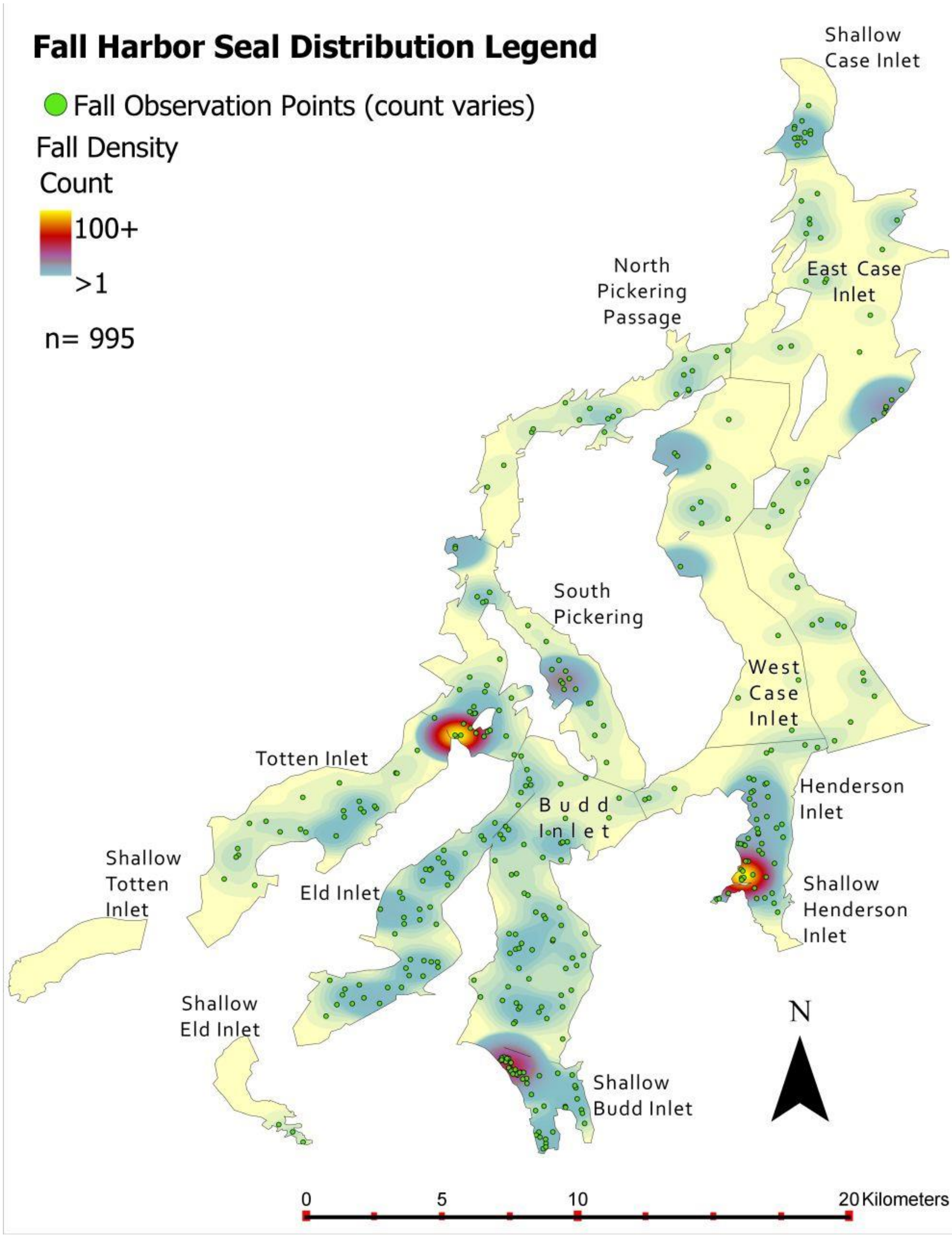

Figure 26: Map of harbor seal distribution for fall using the total count.

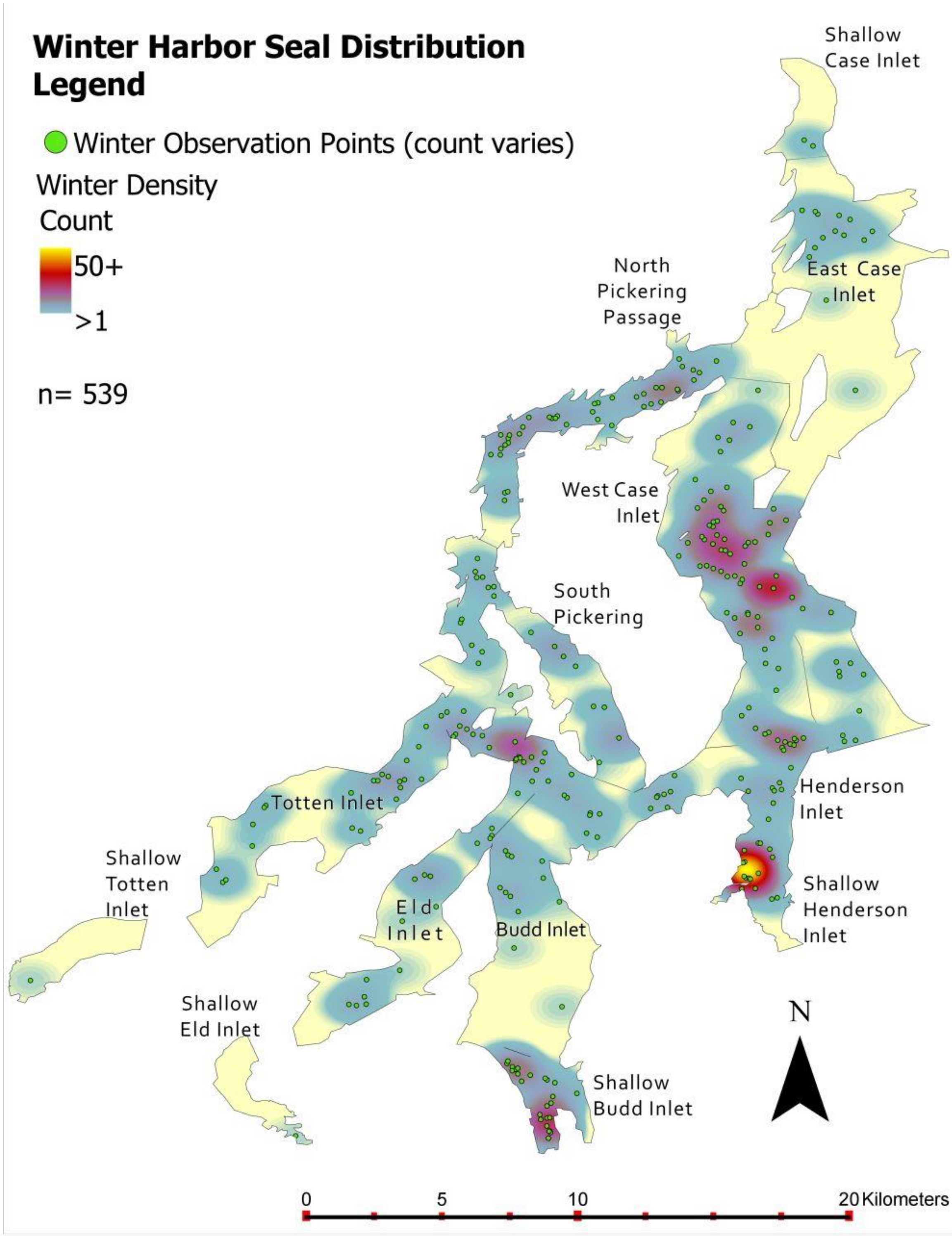

Figure 27: Map of harbor seal distribution for winter using the total count.

Haul-outs

One of the descriptive elements for each harbor seal observation was whether or not the individual was hauled out. Fall had the highest percentage of seals hauled out at 62.8% of observations and a total of 625 individuals. This averages to 208 individuals per lap. To estimate the population of each haul-out, the main platform was identified and served as the point on the map. Seals hauled out on surrounding platforms and in water adjacent to the main haul-out were counted as part of the haul-out population. The total was averaged by the number of survey laps and rounded to the nearest 10. Haul-outs with an average of fewer than 6 individuals were not mapped.

After mapping the haul-out locations and sizes, there appear to be three major haul-outs and nine minor haul-outs in the Southwest Puget Sound (*Figure 28*). The major haul-outs in order of estimated population are Woodard Bay with 100 harbor seals (northern Henderson's minor haul-out of 20 seals may be considered part of the same group but use residential swim platforms rather than the log booms and platforms in the natural area preserve), Carlyon Beach Marina with 80 harbor seals, and Southern Budd Inlet log booms with 70 harbor seals. Despite the survey routes being designed to spot harbor seals hauled-out on the coastline, no seals were seen there.

Harbor seals during other seasons also hauled out, but not in the frequency and quantity seen in fall. Summer had the second most frequent haul-out percentage at 27.2% of observations. Seals were generally seen on the same haul-out locations as fall observations but not in the same numbers. Winter had the least haul-out percentage at

13%, and seals were only observed to be hauled out on one of the major haul-out platforms (*Table 33*-35).

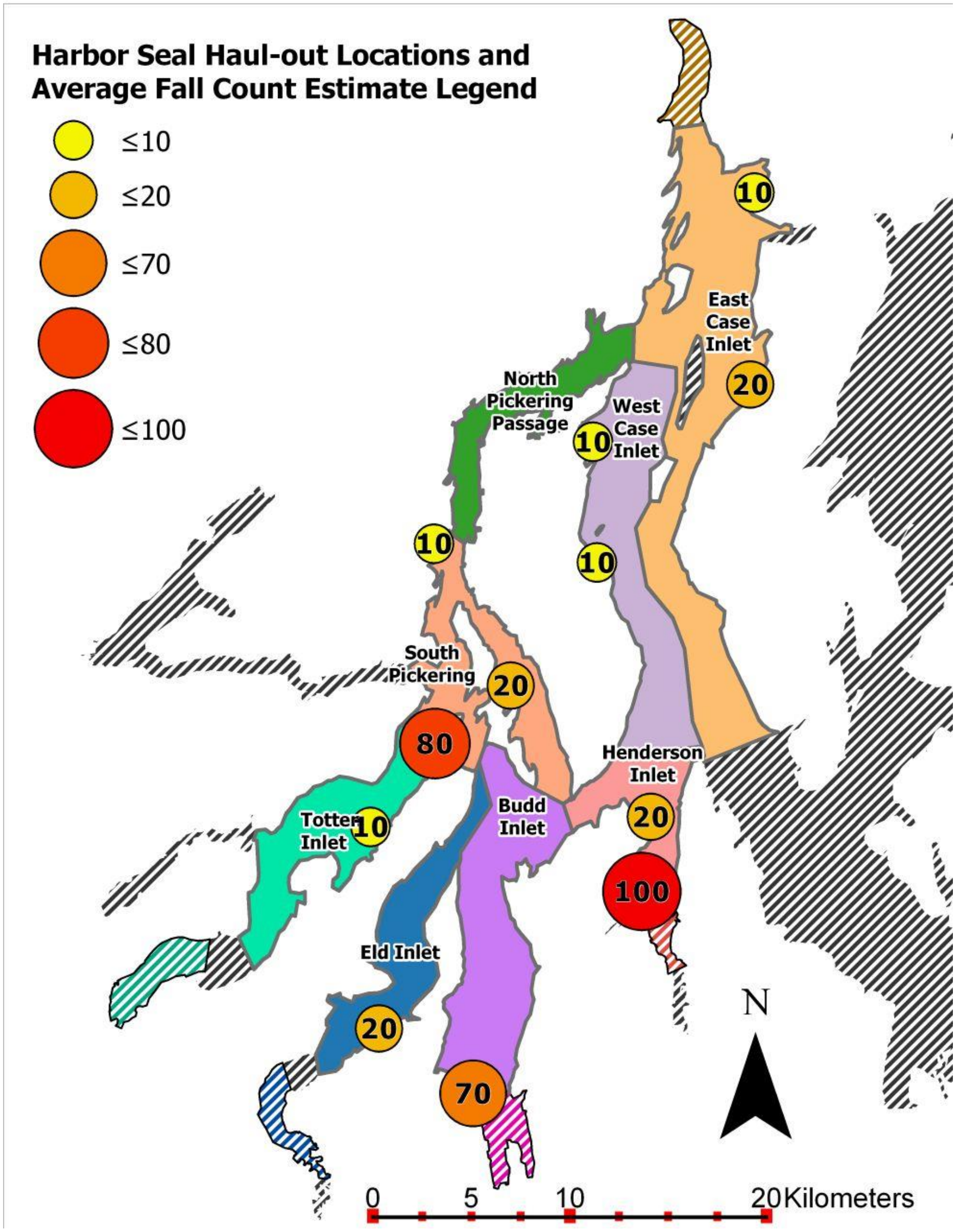

Figure 28: Map of survey region with harbor seal haul-outs and estimated maximum size in fall. The total for the displayed estimates comes to 380 seals which is higher than the average observed number per region lap at 331 seals because these numbers are based on the maximum number of seals in each haul-out area.

Abundance

Minimum harbor seal abundance within the survey region was estimated using a summation of total counts for survey areas divided by the number of laps. The NOAA population estimate derived from the NOAA correction value of 1.53 comes from 2017 stock estimates of Washington inland waters used to correct for seals in water during maximal haul-out (Carretta et. al., 2017). This correction value was applied to the average haul-out count for only fall observations as that is this survey's haul-out maximum. These estimates must be split by season as results for each season and the depth preferences of harbor seals by season, suggest movement into and out of the survey region. The annual estimates are a total of the seasons divided by the number of seasons surveyed.

	Minimum Population Estimate	NOAA Population Estimate	Average
Summer	298	NA	298
Fall	332	318	325
Winter	180	NA	180
Annual	270	NA	268

Table 30: Table of average population estimates for the survey region by season. Including estimates using NOAA methodology which can only be applied to maximum haul-out.

For future haul-out-reliant surveys of harbor seals in the Southern Puget Sound, a table of correction values can be generated from the data in this survey. However, because this survey was only conducted during a single year and results are based on one survey season, each of these values should only be cautiously considered (*Table 31*).

	In-water Total	Hauled Total	In-water Correction Value
Summer	650	243	3.67
Fall	370	625	1.59
Winter	469	70	7.7

Table 31: Table calculating in-water correction values for each season.

The correction value calculated for the survey's maximal haul-out time is very close to the value NOAA uses for the same purpose in the same region, within 0.06 (Carretta et. al., 2017). This result validates the methodology used in the survey regarding the counting of harbor seals and suggests that the observer was able to count all of the seals in the region both in and out of the water or at least in the same ratio as estimated by NOAA. Counting of hauled out seals during the survey was easier, leading to more concrete estimates of hauled out seals than in-water counts. However, the finding that the ratios have remained consistent with the literature suggests that methods for counting in-water seals were sound. As methods remained the same across seasons, the estimates presented in this paper are held as sound.

Raster Analysis

Band Collection Statistics tool by Esri was used to compare seasonal harbor seal distribution patterns with each other to test for similarity (*Table 9*). This analysis reveals that summer and fall are the most similar seasons with a correlation value of 0.28, and that summer and winter are the least similar seasons with a value of 0.02. Winter has the strongest independence from the other two seasons, suggesting that harbor seals spend their time in different places than in the other two seasons.

Harbor seal observations for each season were summarized into maps comprised of 100 square meter squares weighted by seal count called a raster (*Figure 29*). Using a tool designed to compare these maps, the above results were generated. The size of the squares was chosen to be 100 square meters because at that scale they encompass haul-outs but provide enough detail not to generalize inlets. This results in representational raster maps for the program to analyze.

This process was also attempted with raster cells of 1 square kilometer, and 10 square meter. The 1 square kilometer raster analysis gave invalid values over 2 (on a scale of -1 to 1) suggesting over 200% similarity. 10 square meter raster squares returned extremely significant values of <0.0000 suggesting complete independence. This is possibly because at the 10 square meter scale haul-outs become many different points even if they are the same platform.

This tool may not be the most significant way of measuring spatial similarity between maps, but it does generate valid results that are consistent with other patterns in the data, such as depth analysis. When used on the proper scale, this tool can reveal changes in distribution across data sets.

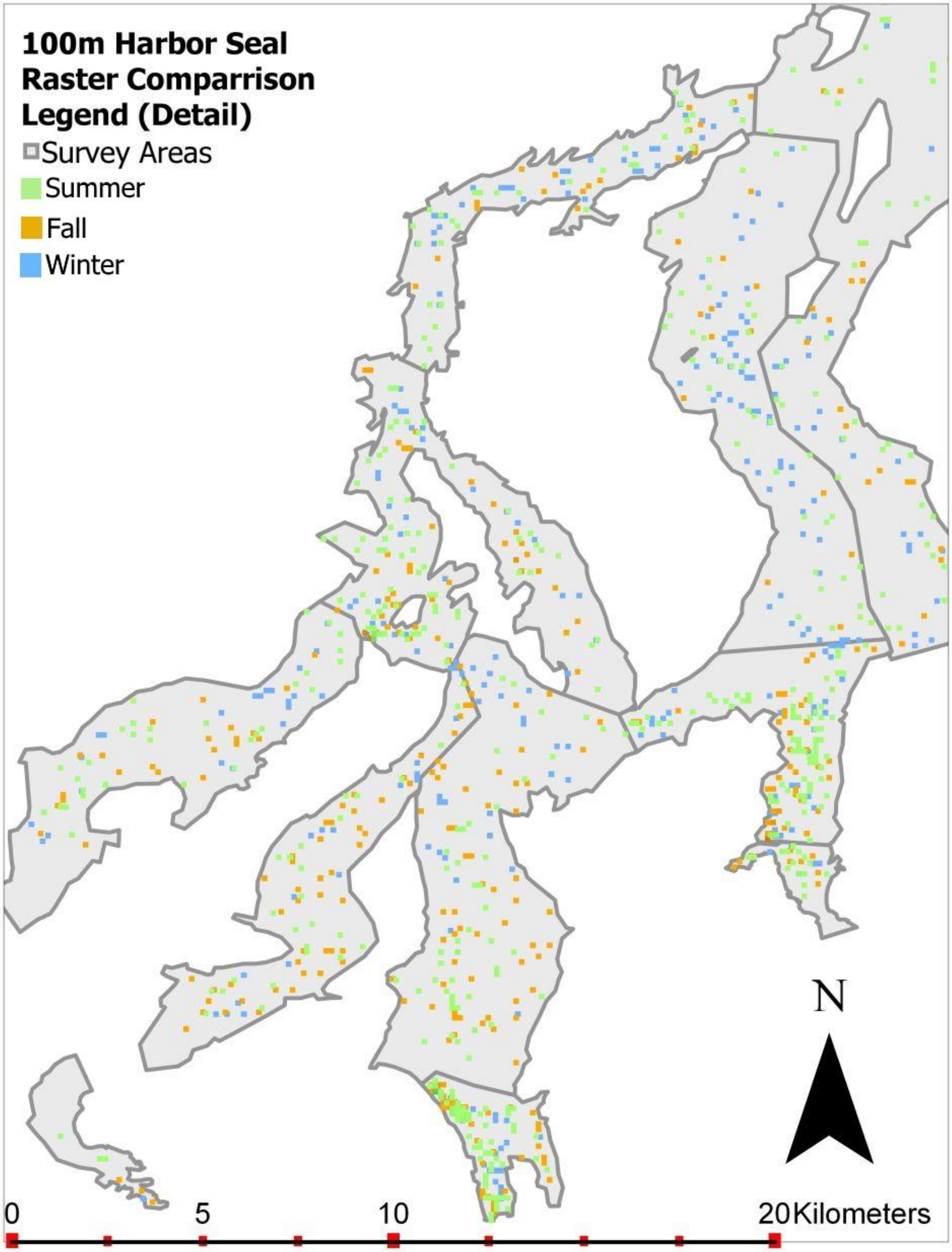

Figure 29: Map detail showing layers for each season weighted by count and summarized as an array of 100-meter squares (100m Raster) for similarity comparison.

Band Collection Statistics Output for 100m Harbor Seal Raster Comparison

Layer	MIN	MAX	MEAN	STD
Summer	1	87	1.9253	5.2856
Fall	1	91	2.9880	8.9402
Winter	1	23	1.8651	2.4408

COVARIANCE MATRIX

Layer	Summer	Fall	Winter
Summer	0.21739	0.08742	0.00165
Fall	0.08742	0.45496	0.00943
Winter	0.00165	0.00943	0.02941

CORRELATION MATRIX

Layer	Summer	Fall	Winter
Summer	1	0.27796	0.02065
Fall	0.27796	1	0.08153
Winter	0.02065	0.08153	1

Table 32: Output for the Band Collection Statistics ArcGIS Tool comparing 100m raster maps from each season. Values range from 0 (no overlap) to 1 (100% overlap).

Harbor Seal Depth Results

To test whether harbor seals vary their distribution by depth, observational data were imprinted with depth values and charted. The patterns of distribution for the raw data were deemed nonrepresentational due to the varying size of each depth-class area’s coverage. Regardless of its accuracy, the chi-squared values for all seasons suggest harbor seals do vary their distribution by depth-class area (p-value <0.001). Raw data patterns suggest harbor seals prefer areas of 10 feet to 50 feet low tide average depth in the summer and fall and 20 feet to 200 feet low tide average depth in the winter (*Table 33*-35).

Summer

Depth Class (ft)	Count	%
Hauled	243	27.21%
0-10 (29.82% of Area)	109	12.21%
10-20 (11.71% of Area)	164	18.37%
20-50 (24.52% of Area)	239	26.76%
50-100 (21.06% of Area)	89	9.97%
100-200 (9.8% of Area)	40	4.48%
200-300 (2.89% of Area)	8	0.90%
300+ (0.19% of Area)	1	0.11%
Total	**893**	**100%**
In-water AVG	**92.9**	
ChiSQ	**219.1**	
P-value	<0.001	

Table 33: Harbor seal depth distribution for summer.

Fall

Depth Class (ft)	Count	%
Hauled	625	62.81%
0-10 (29.82% of Area)	85	8.54%
10-20 (11.71% of Area)	78	7.84%
20-50 (24.52% of Area)	138	13.87%
50-100 (21.06% of Area)	50	5.03%
100-200 (9.8% of Area)	16	1.61%
200-300 (2.89% of Area)	3	0.30%
300+ (0.19% of Area)	0	0.00%
Total	**995**	**100%**
In-water AVG	**52.9**	
ChiSQ	**424.4**	
P-value	<0.001	

Table 34: Harbor seal depth distribution for fall.

Winter

Depth Class (ft)	Count	%
Hauled	70	12.99%
0-10 (29.82% of Area)	26	4.82%
10-20 (11.71% of Area)	65	12.06%
20-50 (24.52% of Area)	122	22.63%
50-100 (21.06% of Area)	128	23.75%
100-200 (9.8% of Area)	88	16.33%
200-300 (2.89% of Area)	40	7.42%
300+ (0.19% of Area)	0	0.00%
Total	**539**	**100%**
In-water AVG	**67**	
ChiSQ	**178.4**	
P-value	<0.001	

Table 35: Harbor seal depth distribution for winter.

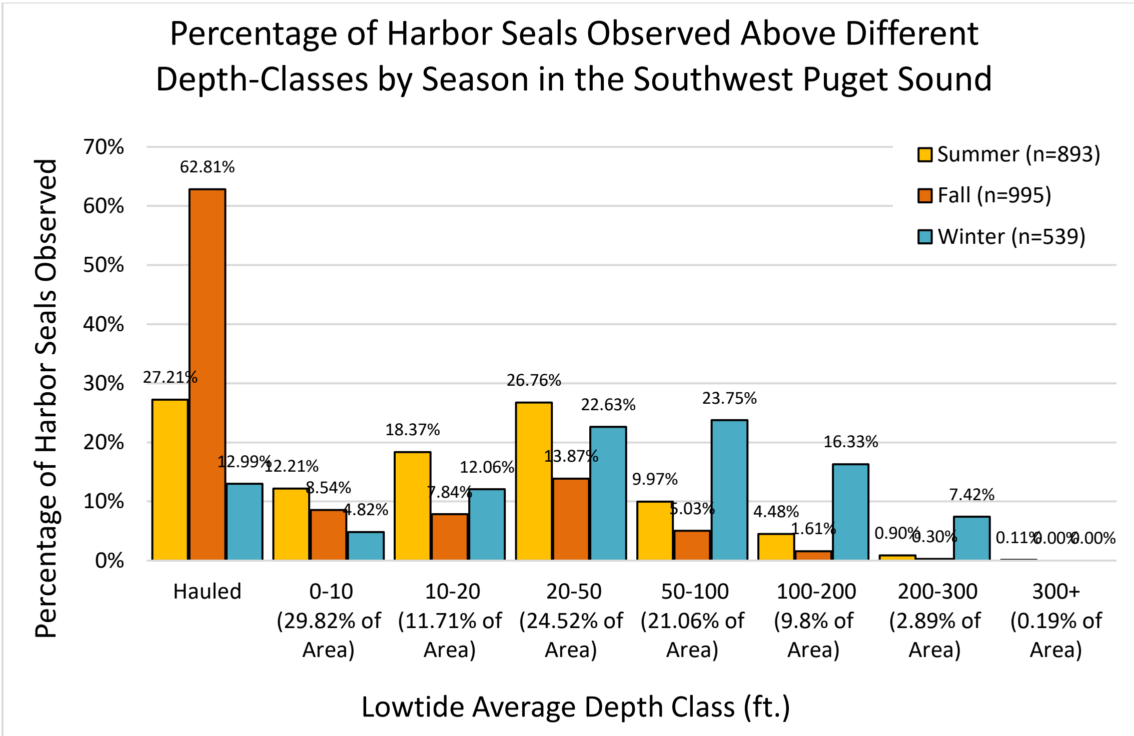

Figure 30: Graph showing the percentage of harbor seals from each survey season found over different depth-classes.

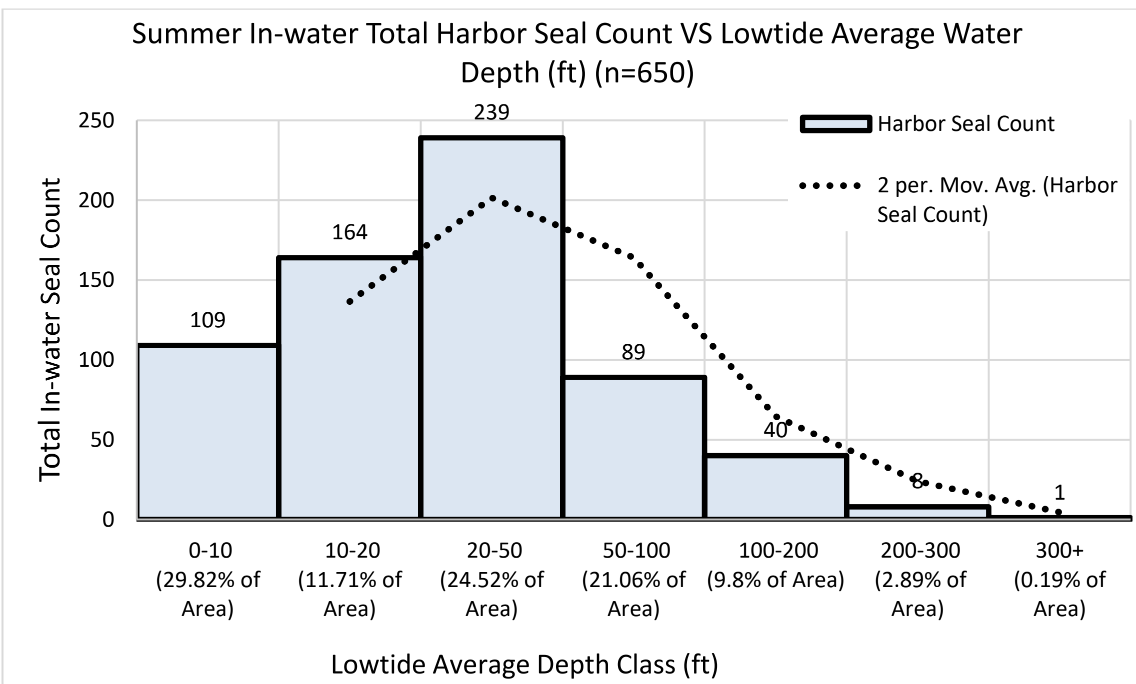

Figure 31: Graph detailing total harbor seals found over different depth-classes in summer.

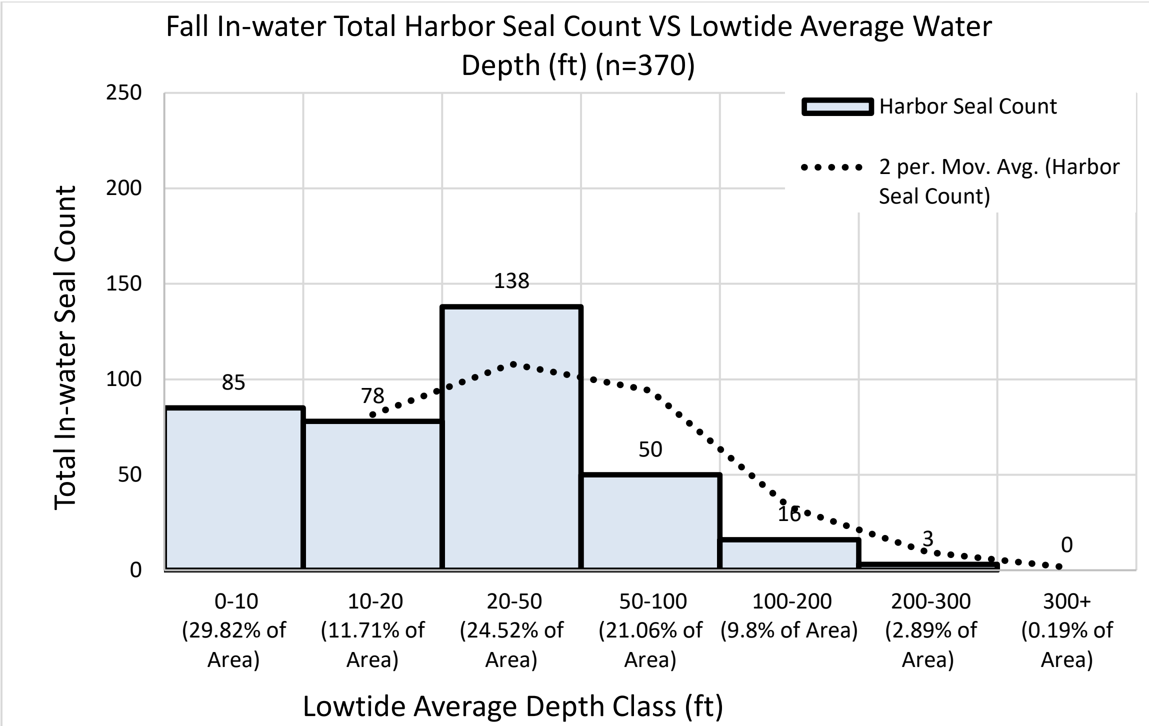

Figure 32: Graph detailing total harbor seals found over different depth-classes in fall.

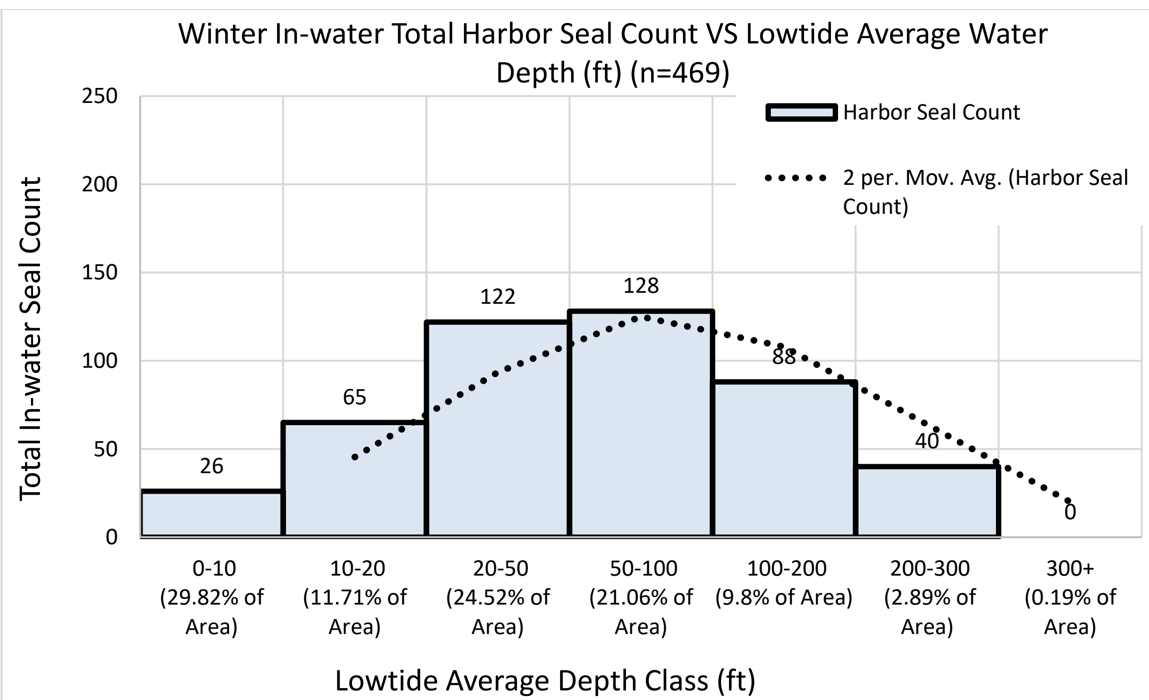

Figure 33: Graph detailing total harbor seals found over different depth-classes in winter.

To correct for the bias of the area covered by each depth class, counts were adjusted to simulate a survey where all in water depth-classes occupied the same amount of area. This extrapolated the existing trends in the data and normalized curves. Even with this normalization, chi-squared values for all seasons suggest harbor seals do vary their distribution by depth-class area with a (p-value <0.001) (*Table 36*-38).

Curves for fall and summer distributions became very similar after normalization, creating bells around the 10 feet to 50 feet average low tide depth range (*Figure 35*-37). Winter curves upward with increasing depth, suggesting the bell curve for winter distribution had peaked at 300 feet or had yet to reach its peak distribution (*Figure 37*). When overlapping all three seasons, the differences between harbor seal depth-class preferences is striking (Figure 34).

Two depth-classes were not analyzed from this analysis. The hauled-out class was analyzed because the true area that could be occupied by harbor seals in the survey region is unknown. The other class not evaluated is the 300+ feet range because the amount of area this depth-class occupies is less than 0.2% of the survey area, which was deemed insufficient to create representational counts. It is important to note that the counts displayed in the adjusted tables and plots are not true counts and are only included to test harbor seal distribution patterns.

Summer

Depth Class (ft)	Count Normalized by Area	%
0-10 (16.16% of Area)	60.9	9%
10-20 (16.16% of Area)	233.4	36%
20-50 (16.16% of Area)	162.4	25%
50-100 (16.16% of Area)	70.4	11%
100-200 (16.16% of Area)	68.0	11%
200-300 (16.16% of Area)	46.1	7%
300+ (0% of Area)	NA	NA
AVG	106.9	
ChiSQ	259.6	
P-value	<0.001	

Table 36: Summer harbor seal counts adjusted for equal depth-class area.

Fall

Depth Class (ft)	Count Normalized by Area	%
0-10 (16.16% of Area)	47.5	14%
10-20 (16.16% of Area)	111.0	33%
20-50 (16.16% of Area)	93.8	28%
50-100 (16.16% of Area)	39.6	12%
100-200 (16.16% of Area)	27.2	8%
200-300 (16.16% of Area)	17.3	5%
300+ (0% of Area)	NA	NA
AVG	56.1	
ChiSQ	127.0	
P-value	<0.001	

Table 37: Fall harbor seal counts adjusted for equal depth-class area.

Winter

Depth Class (ft)	Count Normalized by Area	%
0-10 (16.16% of Area)	14.5	2%
10-20 (16.16% of Area)	92.5	14%
20-50 (16.16% of Area)	82.9	12%
50-100 (16.16% of Area)	101.3	15%
100-200 (16.16% of Area)	149.7	22%
200-300 (16.16% of Area)	230.7	34%
300+ (0% of Area)	NA	NA
AVG	111.9	
ChiSQ	235.5	
P-value	<0.001	

Table 38: Winter harbor seal counts adjusted for equal depth-class area.

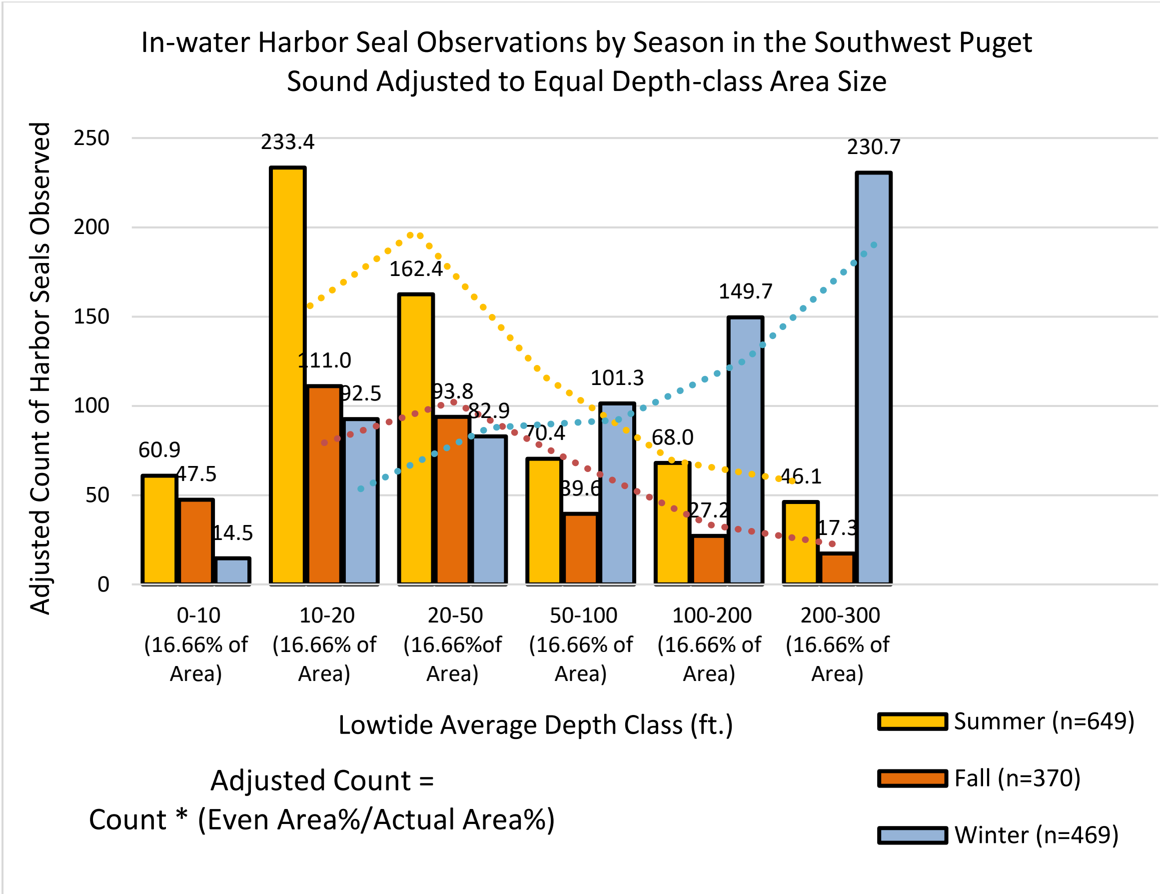

Figure 34: Graph showing the count of in-water harbor seals from each survey season found over different depth-classes and adjusted for the percentage of the area each depth-class covers to simulate equal sizes.

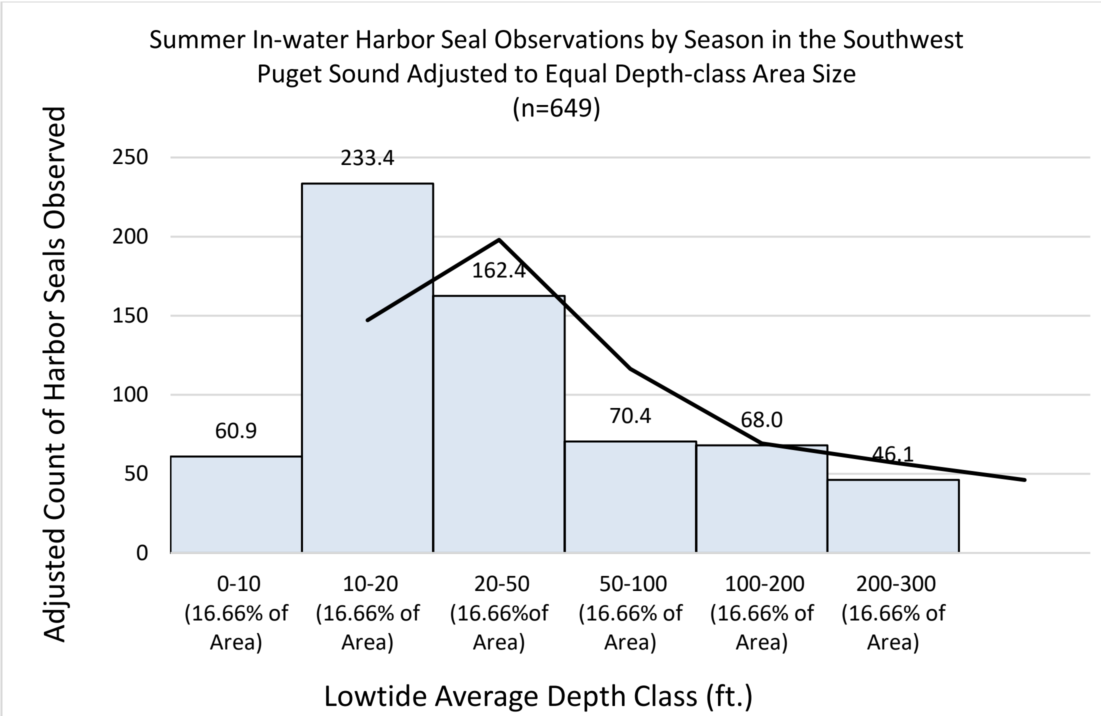

Figure 35: Graph simulating summer harbor seal observations by depth-class if the area each depth-class covers was equal-sized. (Hauled-out and 300+ feet classes removed.)

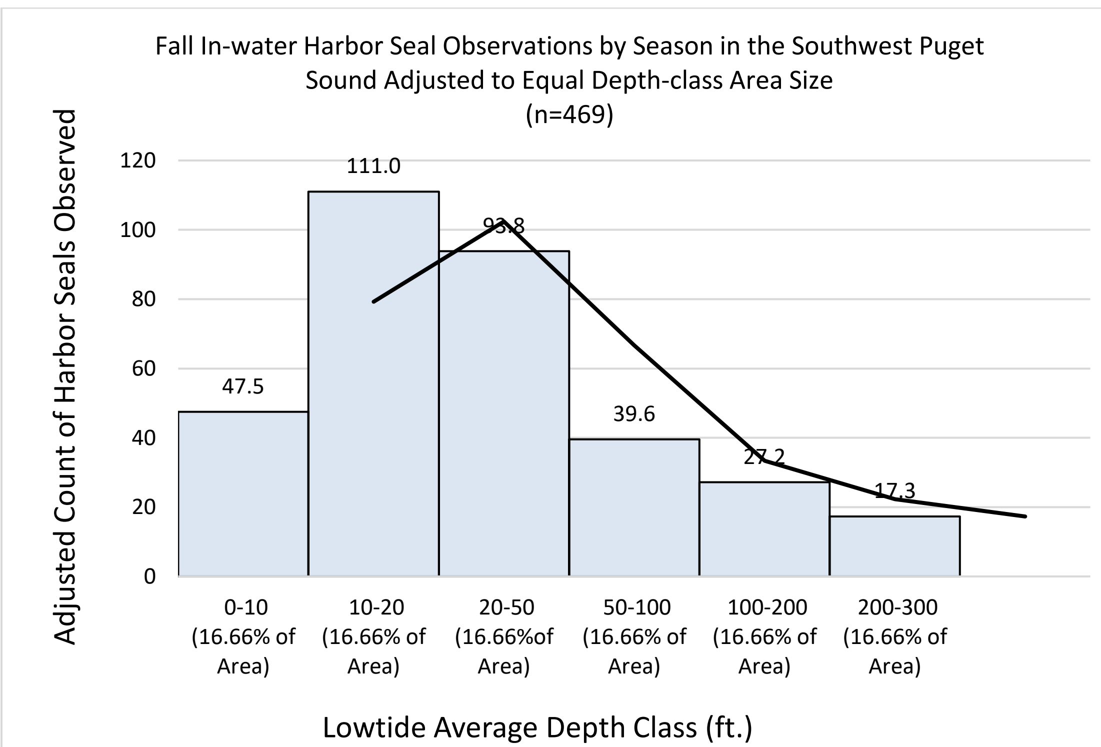

Figure 36: Graph simulating fall harbor seal observations by depth-class if the area each depth-class covers was equal-sized. (Hauled-out and 300+ feet classes removed.)

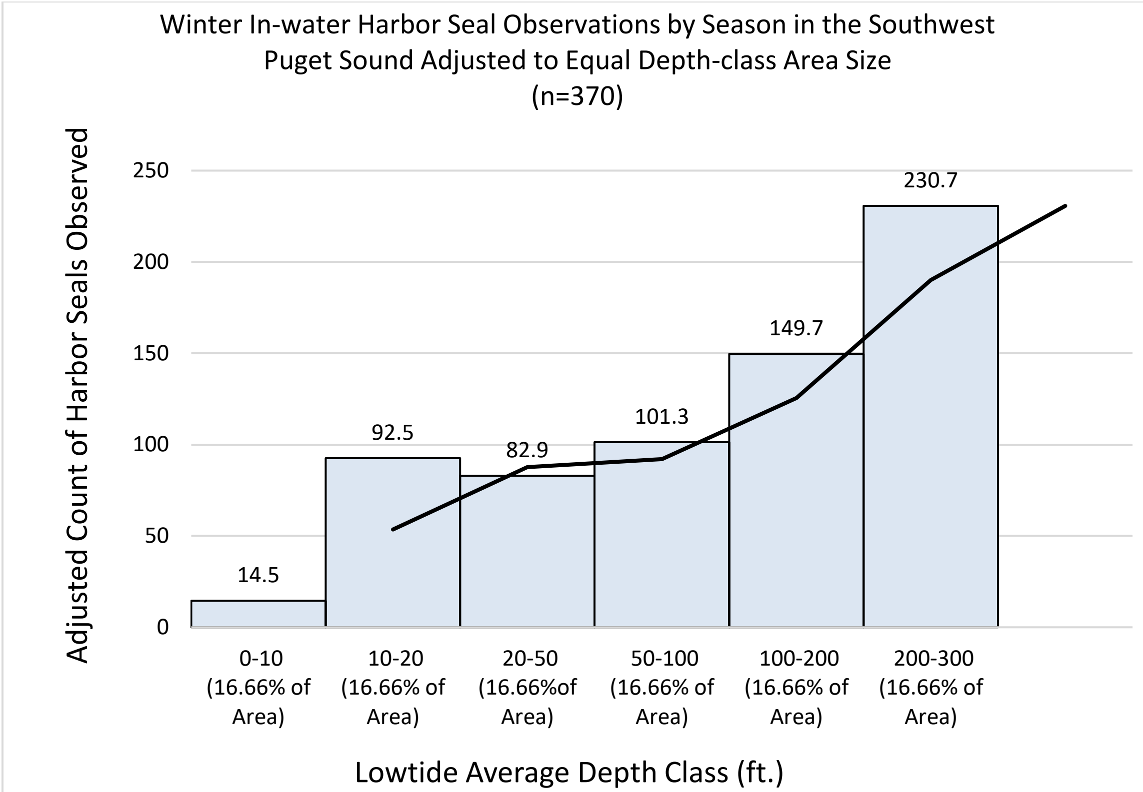

Figure 37: Graph simulating winter harbor seal observations by depth-class if the area each depth-class covers was equal-sized. (Hauled-out and 300+ feet classes removed.)

The methodology of this study has produced results consistent with the literature with the matching correction value for taking maximum haul-out counts and estimating the total population in the Southwest Puget Sound (Table 31). This study has also shown that harbor seals' distribution varies by season (Table 32). The data have also shown that harbor seals are distributed unevenly across depth-classes, indicating a preference based on the season (Figure 34).

Harbor Porpoises

Harbor Porpoises (*Phocoena phocoena vomerina*) were observed in all seasons of the survey, typically in deep water areas around Case Inlet and the Dana Passage near Henderson Inlet (*Figure 38*-40). Harbor porpoises were observed in small groups of 3-6 individuals, which typically could be seen swimming in large circles or traveling through passages.

Harbor porpoises were seen in the largest numbers during the winter survey with 71 individual observations averaging at 23.7 porpoises per lap (*Table 41*). Distribution of harbor porpoises changed little between seasons, observations in fall and summer were fewer when compared with winter data. During the summer survey period, a total of 22 observations were recorded averaging 7.3 porpoises per lap. During the fall survey period, a total of 16 observations were recorded averaging 5.3 porpoises per lap.

Depth distribution for harbor porpoises varied slightly by season. In fall and summer, observations were mostly made in the 50-foot to 200-foot depth range, while in winter most observations fell into the 100-foot to 300-foot range. These values are not adjusted for depth-class area size and doing so with so little data would not provide accurate analytical results. However, it can be assumed that depth-class preference for harbor porpoises is that of deeper waters given these observations.

Summer

Depth Class (ft)	Count	%
0-10 (29.82% of Area)	0	0.00%
10-20 (11.71% of Area)	0	0.00%
20-50 (24.52% of Area)	1	4.55%
50-100 (21.06% of Area)	8	36.36%
100-200 (9.8% of Area)	9	40.91%
200-300 (2.89% of Area)	4	18.18%
300+ (0.19% of Area)	0	0.00%
Total	**22**	**100%**

Table 39: Harbor porpoise depth distribution for summer.

Fall

Depth Class (ft)	Count	%
0-10 (29.82% of Area)	0	0.00%
10-20 (11.71% of Area)	0	0.00%
20-50 (24.52% of Area)	5	31.25%
50-100 (21.06% of Area)	5	31.25%
100-200 (9.8% of Area)	1	6.25%
200-300 (2.89% of Area)	2	12.50%
300+ (0.19% of Area)	3	18.75%
Total	**16**	**100%**

Table 40: Harbor porpoise depth distribution for fall.

Winter

Depth Class (ft)	Count	%
0-10 (29.82% of Area)	0	0.00%
10-20 (11.71% of Area)	0	0.00%
20-50 (24.52% of Area)	0	0.00%
50-100 (21.06% of Area)	17	23.94%
100-200 (9.8% of Area)	35	49.30%
200-300 (2.89% of Area)	19	26.76%
300+ (0.19% of Area)	0	0.00%
Total	**71**	**100%**

Table 41: Harbor porpoise depth distribution for winter.

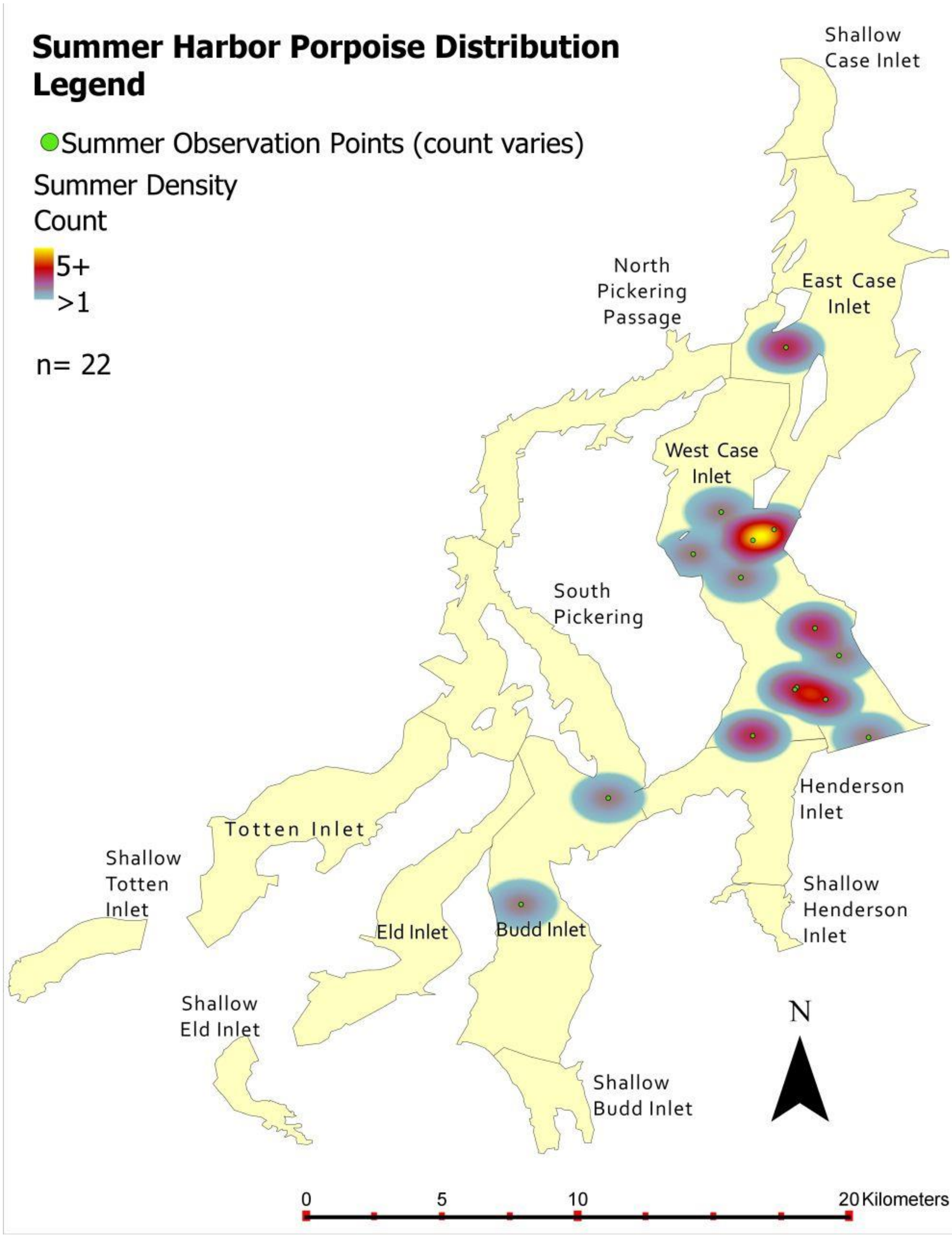

Figure 38: Map of harbor porpoise distribution for summer using the total count.

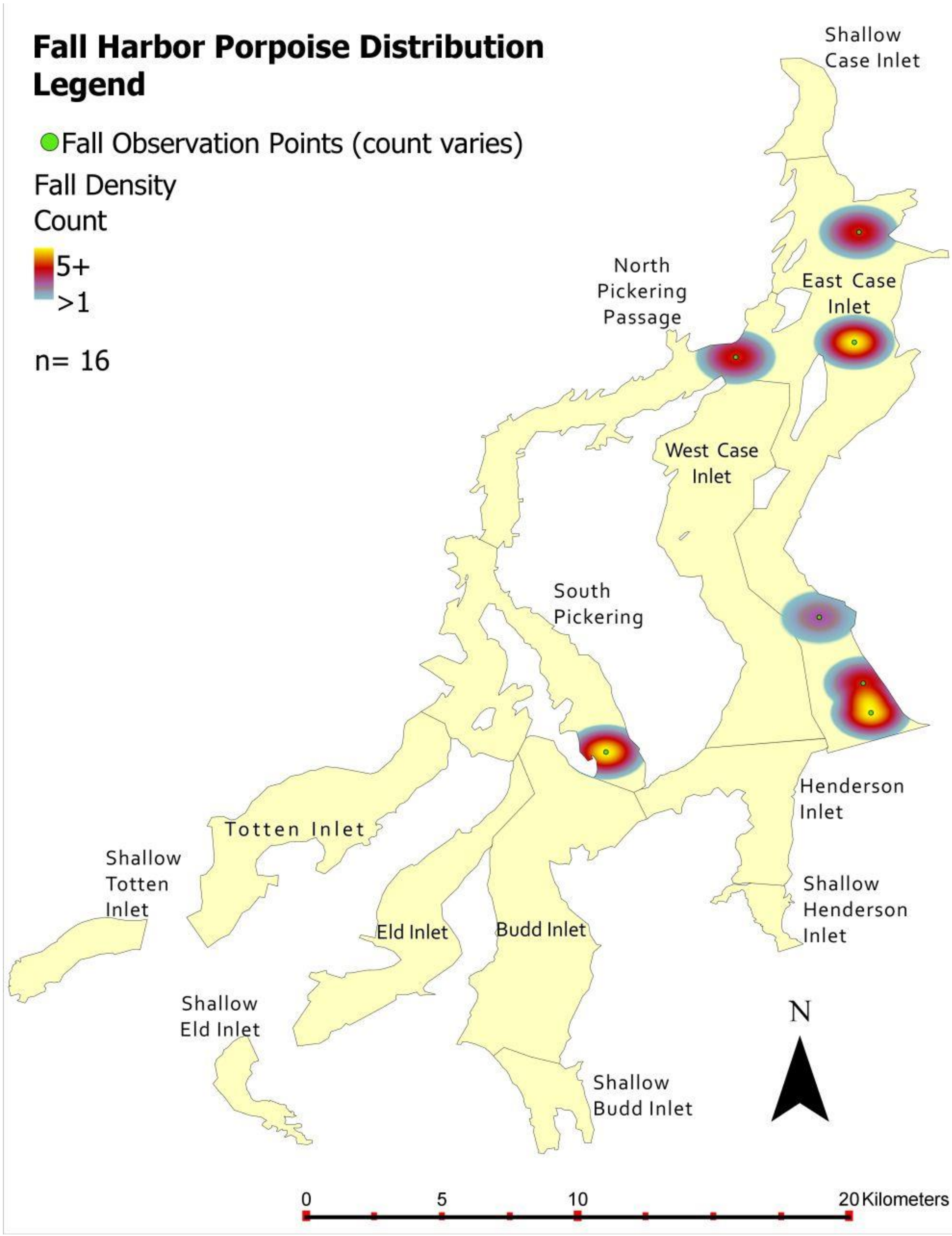

Figure 39: Map of harbor porpoise distribution for fall using the total count.

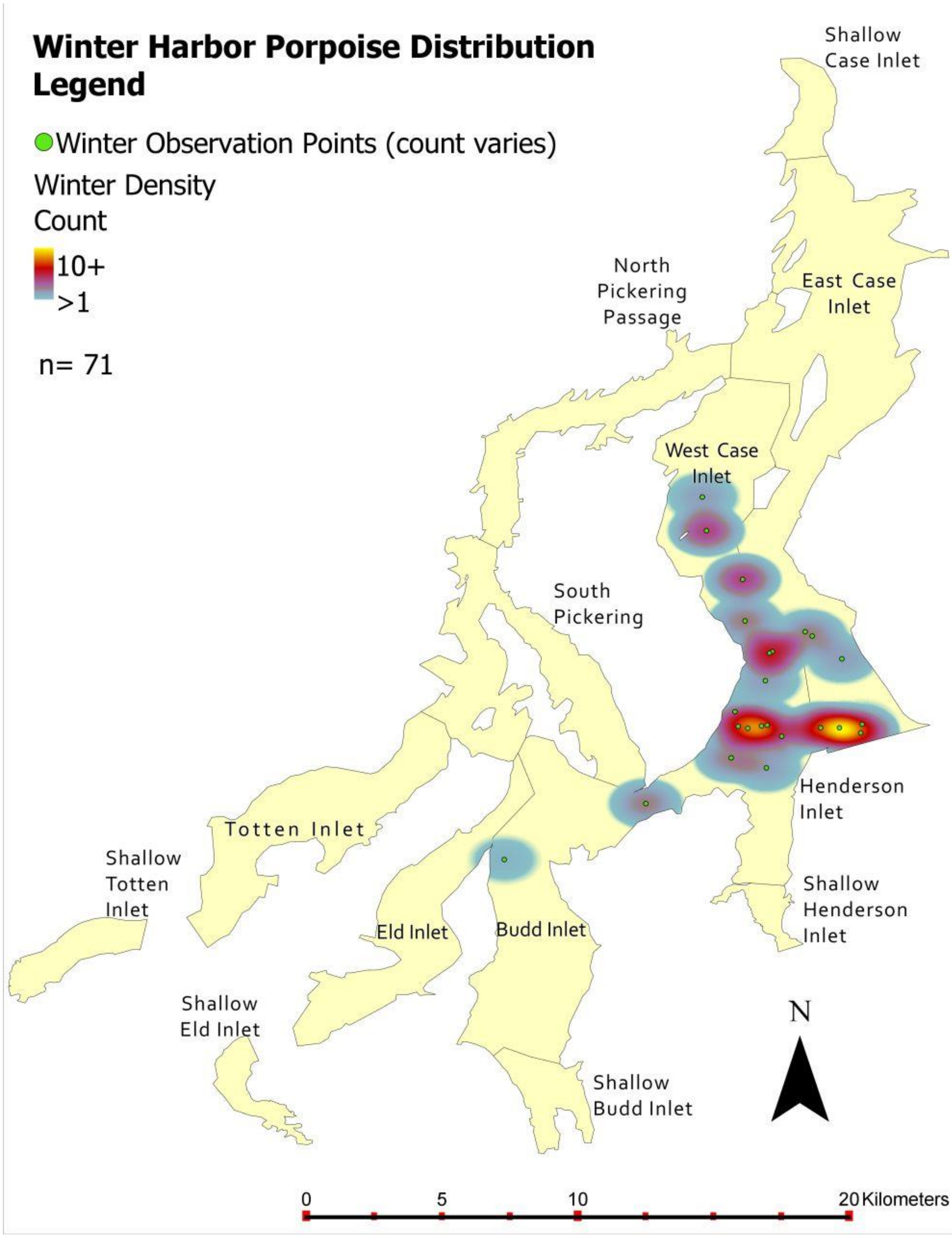

Figure 40: Map of harbor porpoise distribution for winter using the total count.

California Sea Lions

California sea lions (*Zalophus californianus)* were the only other species of pinniped besides harbor seals observed during the survey, though the presence of Steller's sea lions (*E. jubatus*) were recorded in the survey area just prior to the start of the winter survey (Garrett, 2019). California sea lions were only observed in significant numbers during the winter with only 1 observation each in summer and fall and 89 observations in winter (*Table 16*-18).

Observations in winter were exclusively within the 100-foot to 200-foot depth class, and strongly favored the waters southwest of Heron Island in Case Inlet where they could be seen in groups of 20 individuals. These winter congregations also included many harbor porpoises, seals, and sea birds.

Occasionally, individual sea lions were observed in passages around the survey area typically followed by small groups of 3-5 harbor seals. California sea lions were identified by the shape of their heads and distinctive swimming behaviors (e.g. synchronized full breach diving, group porpoising, and logging).

Summer

Depth Class (ft)	Count	%
Hauled	**1**	**100.00%**
0-10 (29.82% of Area)	0	0.00%
10-20 (11.71% of Area)	0	0.00%
20-50 (24.52% of Area)	0	0.00%
50-100 (21.06% of Area)	0	0.00%
100-200 (9.8% of Area)	0	0.00%
200-300 (2.89% of Area)	0	0.00%
300+ (0.19% of Area)	0	0.00%
Total	**1**	**100%**

Table 42: California sea lion depth distribution for summer.

Fall

Depth Class (ft)	Count	%
Hauled	0	0.00%
0-10 (29.82% of Area)	0	0.00%
10-20 (11.71% of Area)	0	0.00%
20-50 (24.52% of Area)	0	0.00%
50-100 (21.06% of Area)	0	0.00%
100-200 (9.8% of Area)	**1**	**100.00%**
200-300 (2.89% of Area)	0	0.00%
300+ (0.19% of Area)	0	0.00%
Total	**1**	**100%**

Table 43: California sea lion depth distribution for fall.

Winter

Depth Class (ft)	Count	%
Hauled	0	0.00%
0-10 (29.82% of Area)	0	0.00%
10-20 (11.71% of Area)	**1**	**1.12%**
20-50 (24.52% of Area)	**1**	**1.12%**
50-100 (21.06% of Area)	**2**	**2.25%**
100-200 (9.8% of Area)	**78**	**87.64%**
200-300 (2.89% of Area)	**7**	**7.87%**
300+ (0.19% of Area)	0	0.00%
Total	**89**	**100%**

Table 44: California sea lion depth distribution for winter.

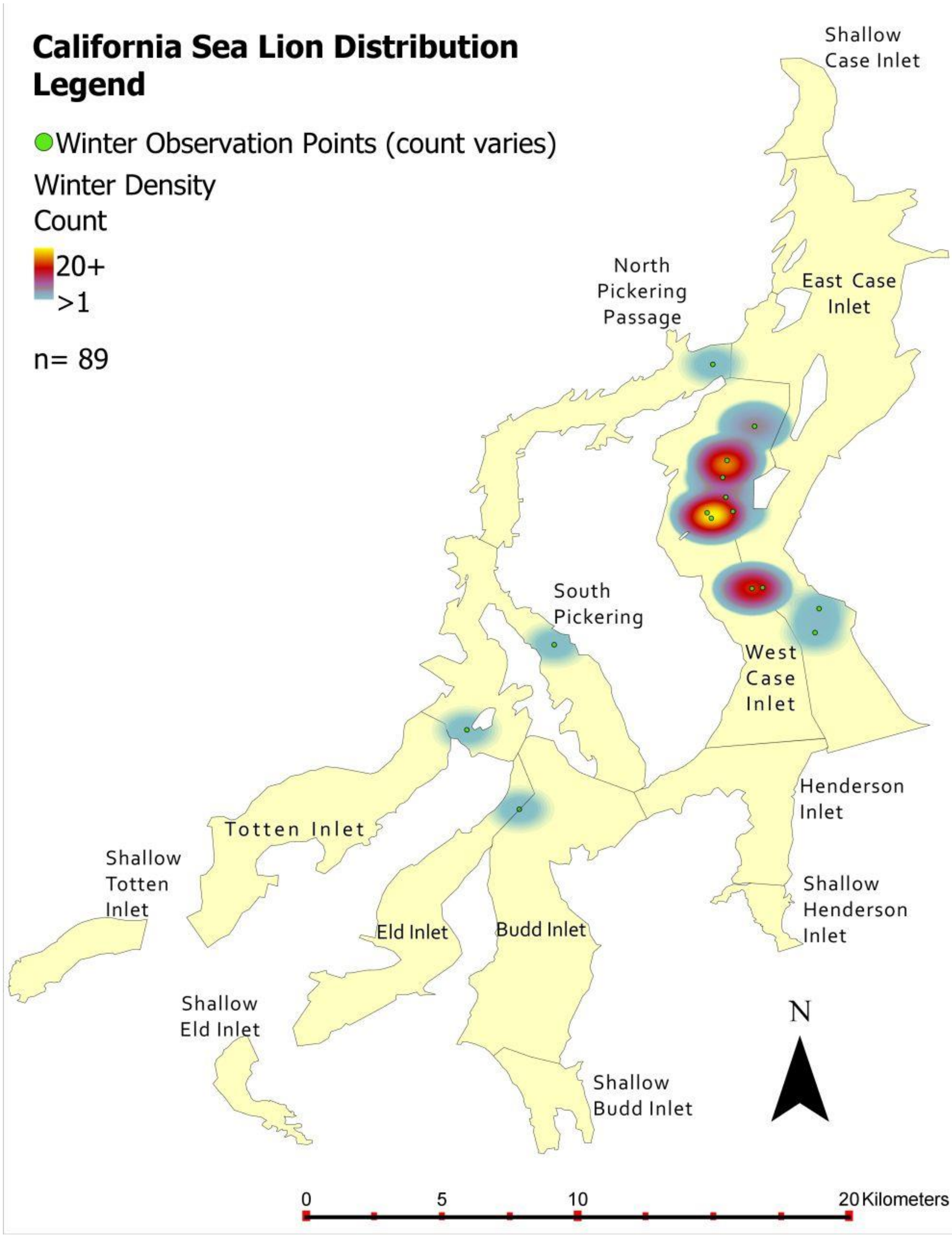

Figure 41: California sea lion distribution for winter using the total count.

Long-beaked Common Dolphins

Long-beaked common dolphins (*Delphinus capensis*) are typically found in the tropic waters around Baja California (Carretta et. al., 2017). They were observed only in Case Inlet during the summer survey.

A group of six individuals has been observed and recorded by other research organizations for several years. The reason for their continued presence in the Southwest Puget Sound is unknown (Cascadia, 2011). What is known is that they appear to be in good physical condition and exhibit healthy playful behavior (Cascadia, 2011). It is unknown where this pod goes in the colder months. These dolphins were the largest cetacean observed during the survey and preferred depth-class areas of 50-200 feet (*Table 45*).

Summer

Depth Class (ft)	Count	%
0-10 (29.82% of Area)	0	0.00%
10-20 (11.71% of Area)	0	0.00%
20-50 (24.52% of Area)	**3**	**17.65%**
50-100 (21.06% of Area)	**6**	**35.29%**
100-200 (9.8% of Area)	**8**	**47.06%**
200-300 (2.89% of Area)	0	0.00%
300+ (0.19% of Area)	0	0.00%
Total	**17**	**100%**

Table 45: Long-beaked common dolphin depth distribution for summer.

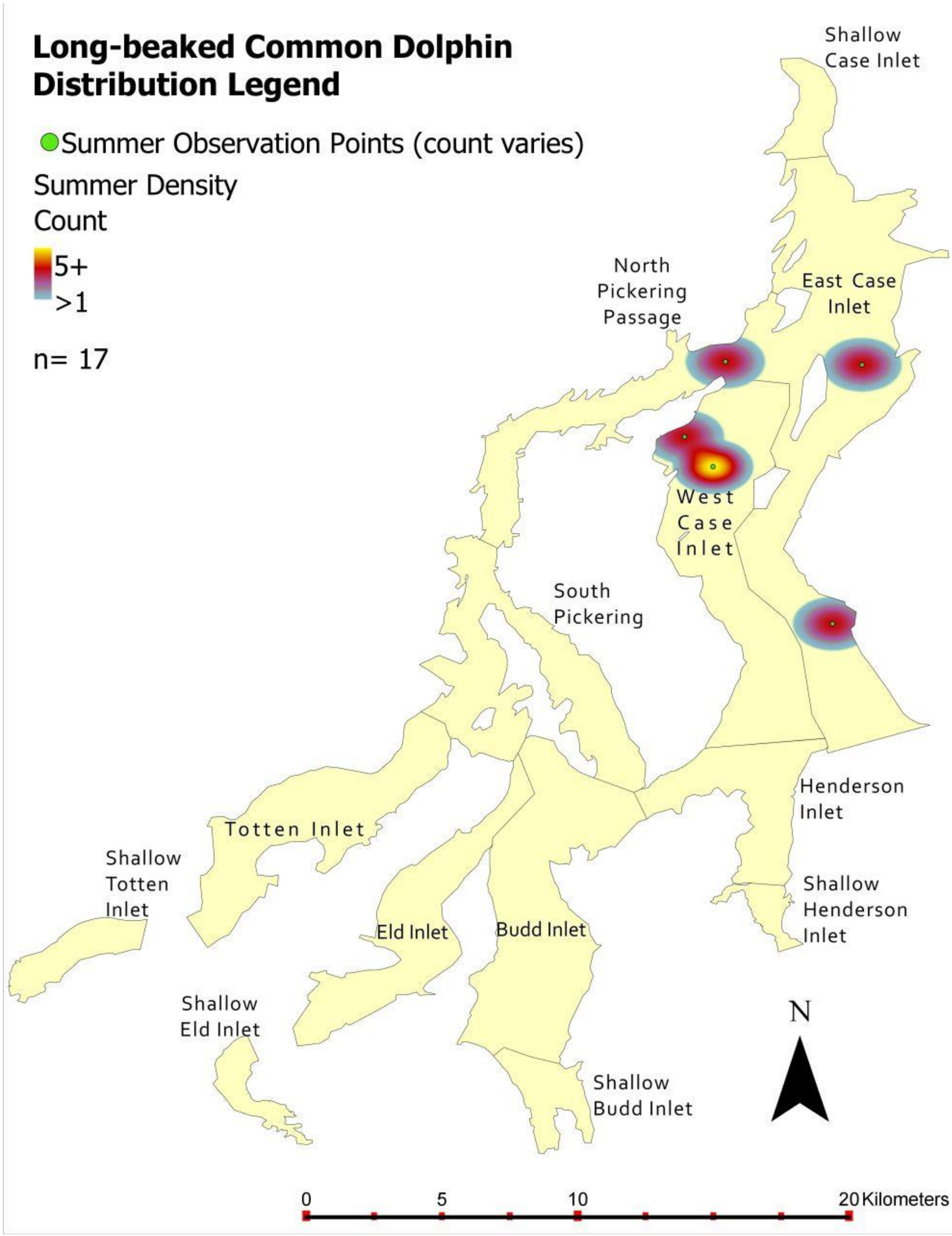

Figure 42: Long-beaked common dolphin distribution for summer using the total count.

Temperature

A key objective of the study was mapping surface water temperature distribution in the Southwestern Puget Sound to compare marine mammal distribution to the differences in each area.

Summer area averages ranged from 57 degrees Fahrenheit to 68 degrees Fahrenheit. The ends of each inlet were warmest, ranging from 62 degrees Fahrenheit to 68 degrees Fahrenheit. Deeper areas and the Pickering Passage were the coldest ranging from 57 degrees Fahrenheit to 59 degrees Fahrenheit (*Figure 43*).

Fall surface water temperature distribution was more variable. Possibly due to "fall mixing," which is when cold water and warm water are not as stratified in the water column, causing localized areas of temperature variability (Moore et. al., 2012). Fall temperatures ranged from 52 degrees Fahrenheit to 65 degrees Fahrenheit (*Figure 44*).

Winter temperatures were incredibly consistent across the region ranging from 46 degrees Fahrenheit to 48 degrees Fahrenheit with the larger areas at 47 degrees Fahrenheit on average. All inlet shallow areas were 1 degree warmer (48 degrees Fahrenheit) with the exception of Totten Inlet's shallow area, which was 1 degree Fahrenheit colder at 46 degrees Fahrenheit (*Figure 45*).

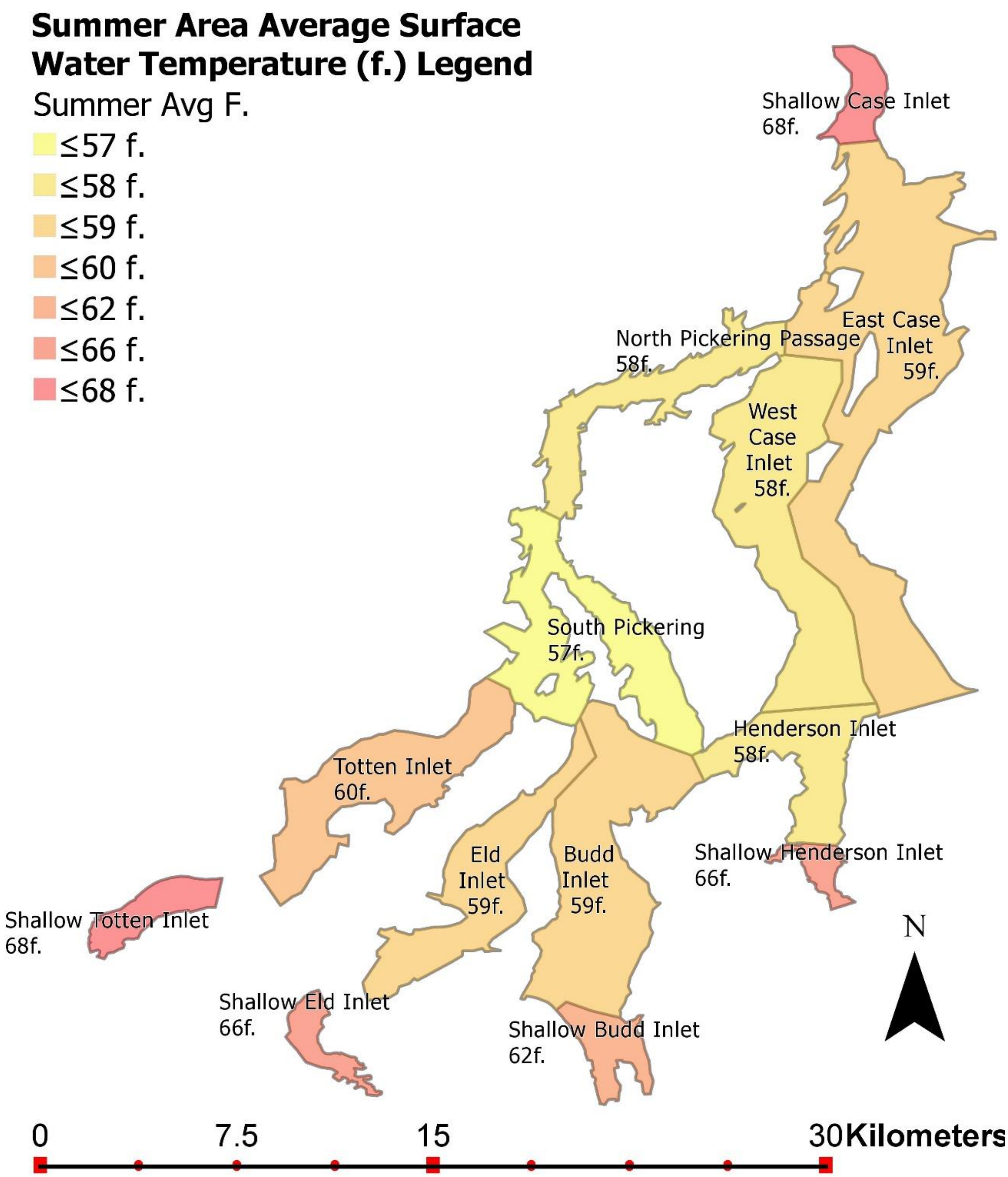

Figure 43: Map showing summer surface water temperature (°F). Note that shallow water areas were measured using different equipment.

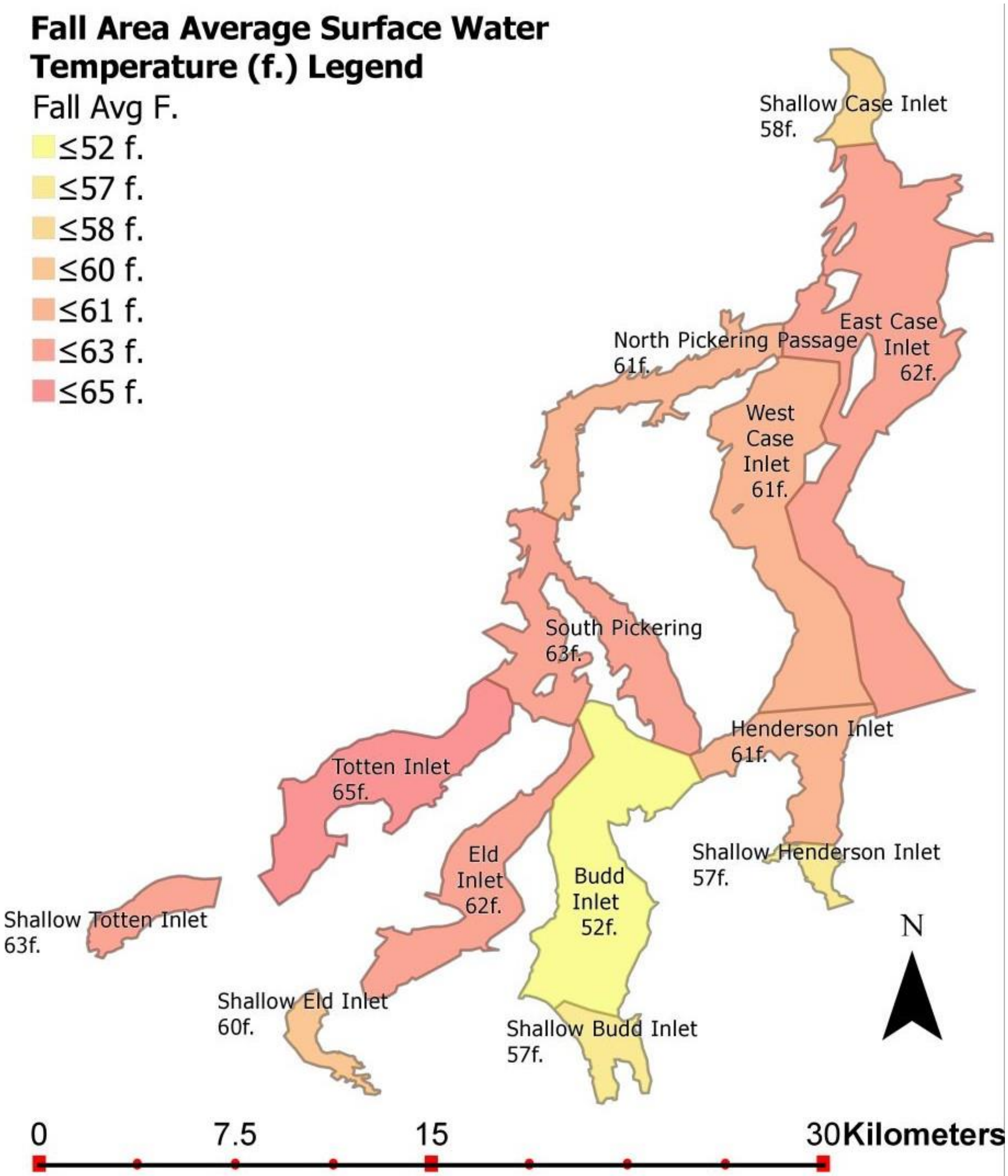

Figure 44:Map showing fall surface water temperature (°F). Note that shallow water areas were measured using different equipment.

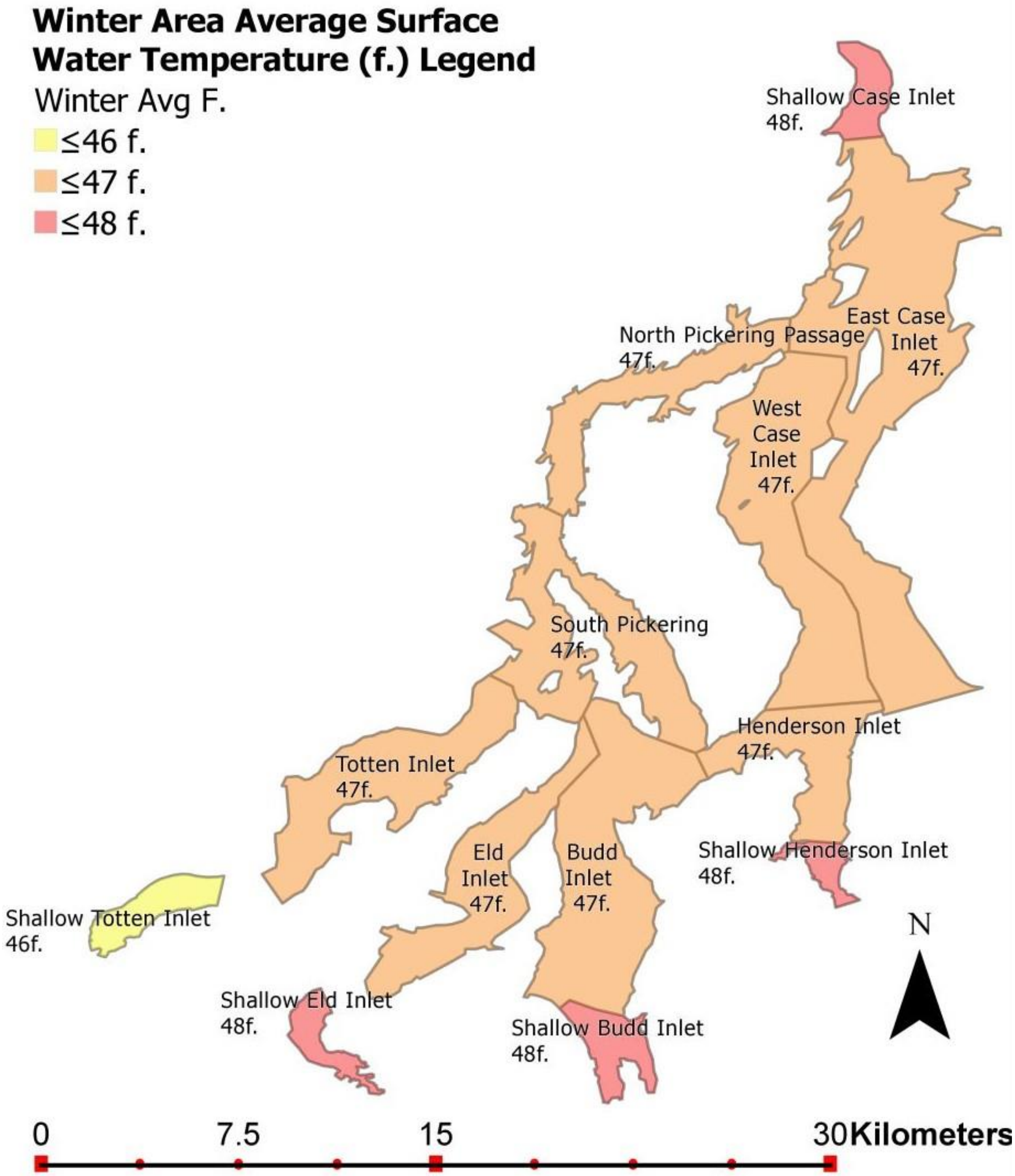

Figure 45:Map showing winter surface water temperature (°F). Note that shallow water areas were measured using different equipment.

Human Activity

Structures that affected the natural matrix of the tidal coastline, as well as human activities that may impact marine mammals' behavior, were categorically recorded. This information is only a snapshot of the true activity in the survey areas, and the true scale of coastline alteration in the survey region is unknown. Marine mammals have been shown to change their behavior with the activities of humans in their habitat (Cammen et. al., 2019). Pinnipeds have been observed to utilize marina docks and swim platforms as haul-outs then flee from passing boats (Cammen et. al., 2019). It is important to note where these disturbances are and to record the traffic of survey areas to study the preferences of marine mammals.

As with other data sets in this survey, results were separated by season. Fall and summer had more activity disturbances than winter. Powerboat traffic increased from 296 observations in the summer to 328 observations in fall then decreased to only 55 observations in the winter (*Table 46*-48). Major traffic areas in the survey region across seasons by total observations included Budd Inlet, Case Inlet, and the Pickering Passage. Beach-intrusive infrastructure was most common in the Pickering Passage, East Case Inlet, Shallow Eld Inlet, and Shallow Budd Inlet. The most common activity observation type was powerboat use (*Figure 46*-48).

Summer Area Name	Total Active Disturbances	Powerboats and Barges	Paddlers and Swimmers	Shore Activity
Totten	16	14	0	2
Eld	14	10	0	4
Budd	37	32	2	3
Henderson	40	32	4	4
West Case	28	18	3	7
East Case	94	54	18	22
South Pickering	18	17	0	1
North Pickering	15	11	1	3
Shallow Totten	0	0	0	0
Shallow Eld	4	2	1	1
Shallow Budd	134	96	25	13
Shallow Henderson	7	4	3	0
Shallow Case	9	6	2	3

Table 46: Disturbance counts for summer by area.

Fall Area Name	Total Active Disturbances	Powerboats and Barges	Paddlers and Swimmers	Shore Activity
Totten	13	8	1	4
Eld	32	17	3	12
Budd	84	69	6	9
Henderson	43	34	3	6
West Case	43	25	5	13
East Case	95	54	13	28
South Pickering	42	26	4	12
North Pickering	51	35	3	13
Shallow Totten	2	1	0	1
Shallow Eld	6	4	0	2
Shallow Budd	74	52	8	14
Shallow Henderson	2	1	1	0
Shallow Case	6	2	2	2

Table 47: Disturbance counts for fall by area.

Winter Area Name	Total Active Disturbances	Powerboats and Barges	Paddlers and Swimmers	Shore Activity
Totten	6	1	1	4
Eld	10	3	3	4
Budd	25	17	1	7
Henderson	8	3	4	1
West Case	6	3	1	2
East Case	15	5	1	9
South Pickering	12	7	1	4
North Pickering	7	3	0	4
Shallow Totten	1	1	0	0
Shallow Eld	4	0	0	4
Shallow Budd	27	11	0	16
Shallow Henderson	1	1	0	0
Shallow Case	3	0	0	3

Table 48: Disturbance counts for winter by area.

Area Name	Total Land Use Points	Industrial and Marinas	Boardwalks and Historical	Residential and Docks
Totten	14	5	1	8
Eld	10	1	0	9
Budd	10	4	1	5
Henderson	12	1	2	8
West Case	6	2	0	4
East Case	27	3	1	23
South Pickering	20	10	2	8
North Pickering	16	4	2	10
Shallow Totten	9	4	2	3
Shallow Eld	18	7	0	11
Shallow Budd	15	7	2	6
Shallow Henderson	7	1	1	5
Shallow Case	9	1	0	8

Table 49: Land use disturbance counts by area (data recorded in summer).

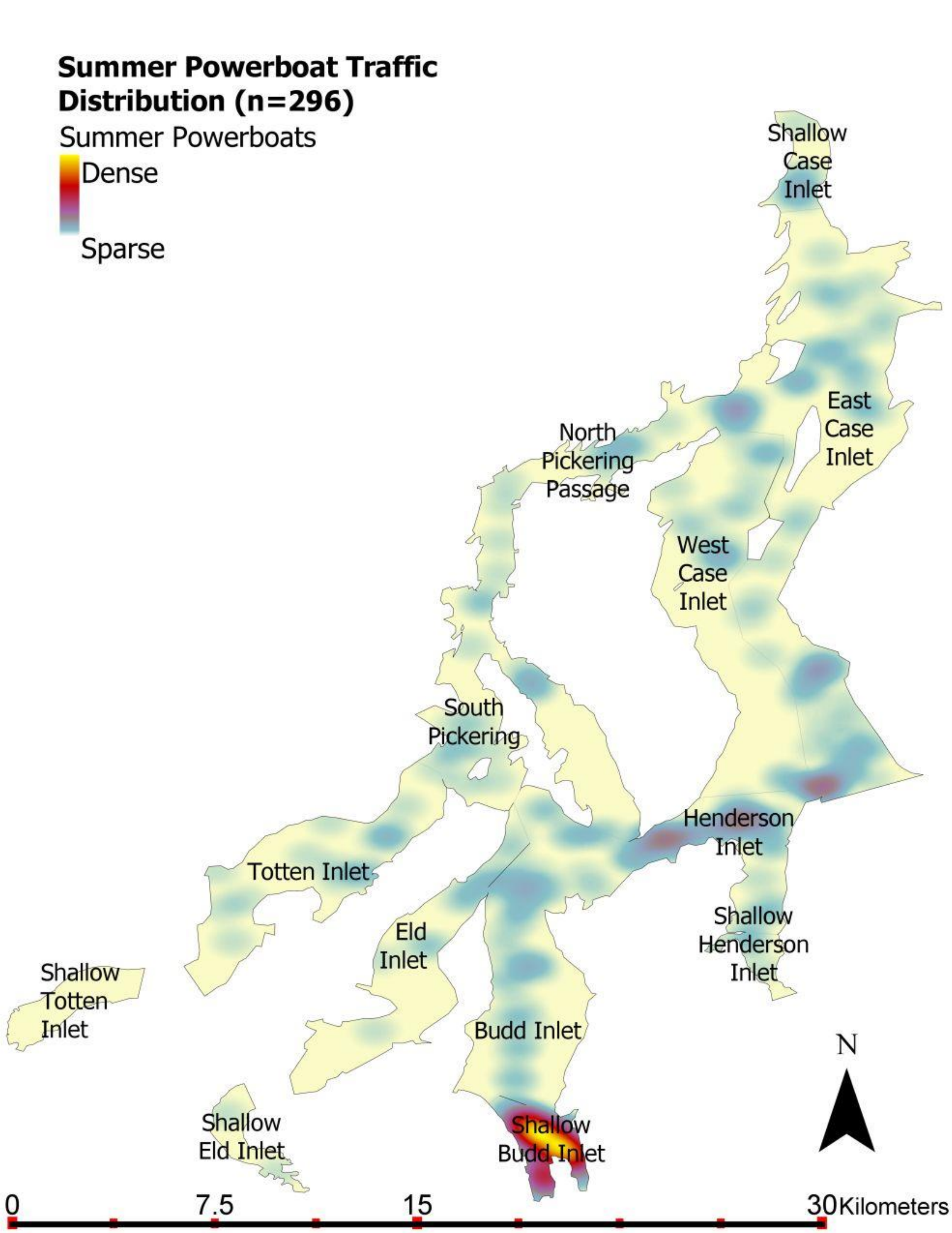

Figure 46: Map of powerboat distribution for summer.

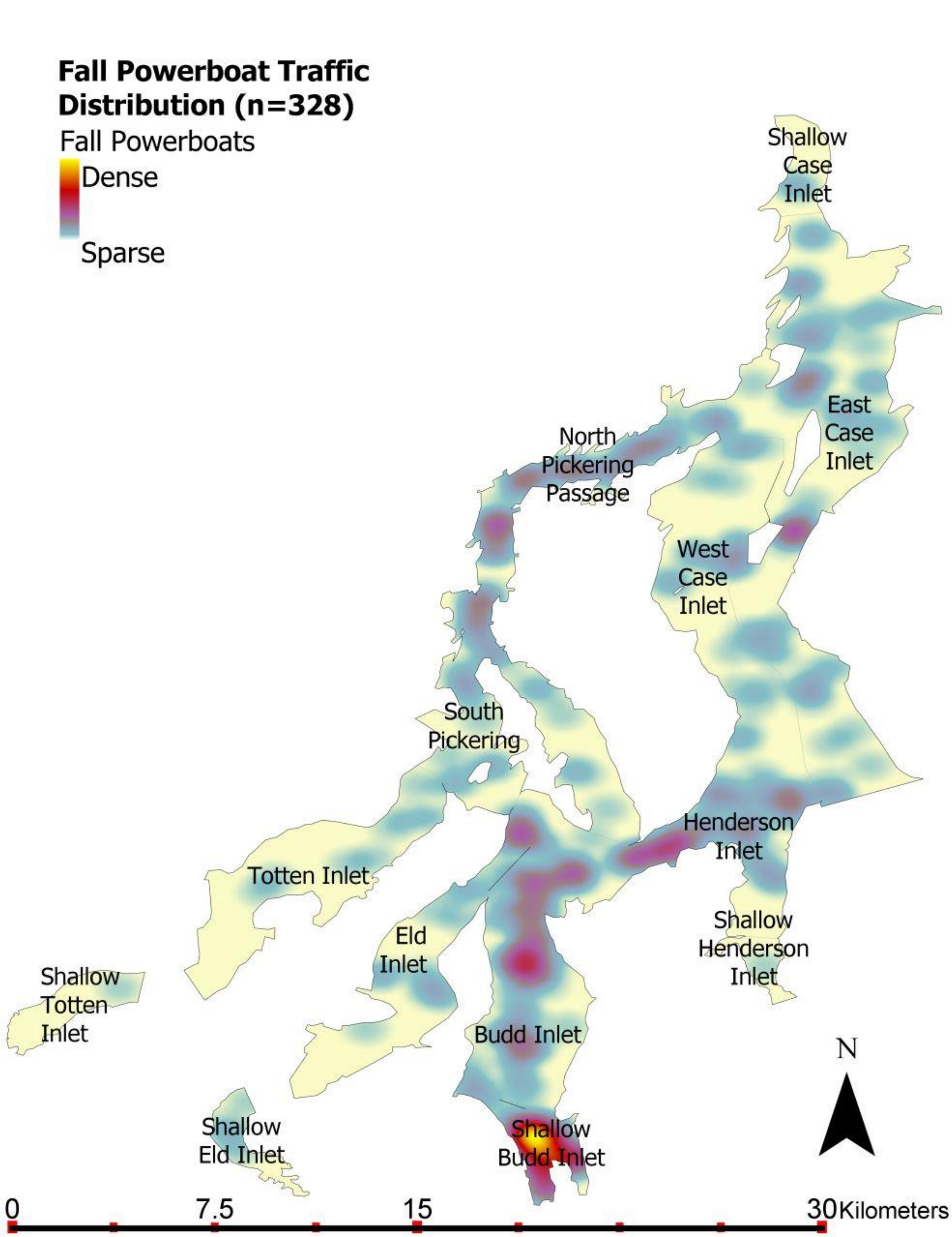

Figure 47: Map of powerboat distribution for fall.

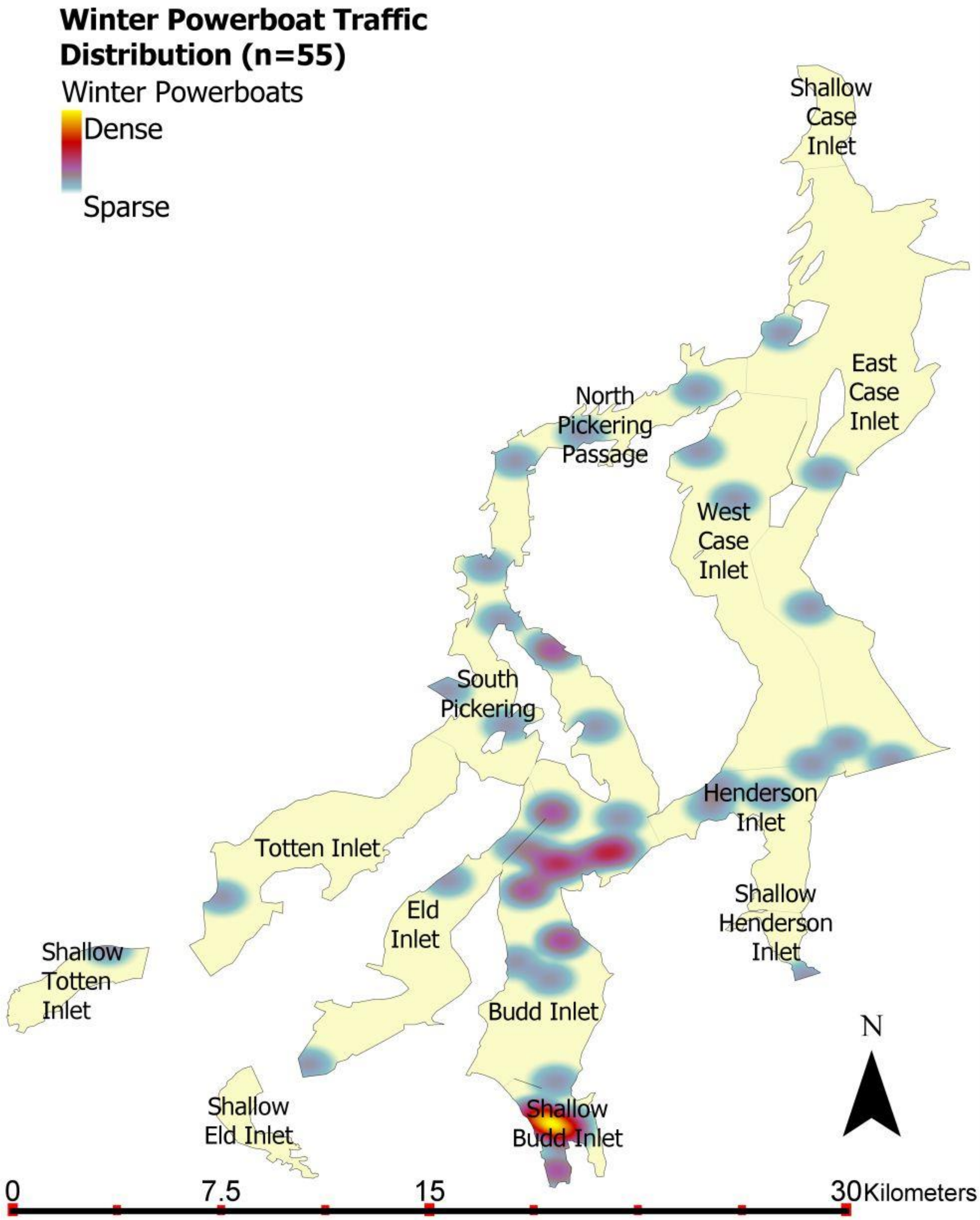

Figure 48: Map of powerboat distribution for winter.

Discussion

This section will discuss the relationship between harbor seals and temperature, human disturbance mapping, and explore the methodology used to project what the ideal survey might entail. The largest part of this section in terms of pages will be detailed maps of survey areas showing harbor seal distribution and the human activities recorded there. Some of these maps were generated at the request of local interests, including the Washington Department of Natural Resources, to better understand the areas around their natural area preserves.

Harbor Seals and Temperature

This survey project was in part designed to study whether seal distribution was related to environmental variables, including surface water temperature in the Southwest Puget Sound. Upon comparing the number of seals counted in each area for a given season against that area's average water temperature, linear regression of the data suggest that there is no relationship between these variables (*Figure 49*-51). It is important to note that in fall and spring, water mixes in a way that can create drastically different temperatures in a small area and that the data collected in this survey on temperature was the only surface water temperature.

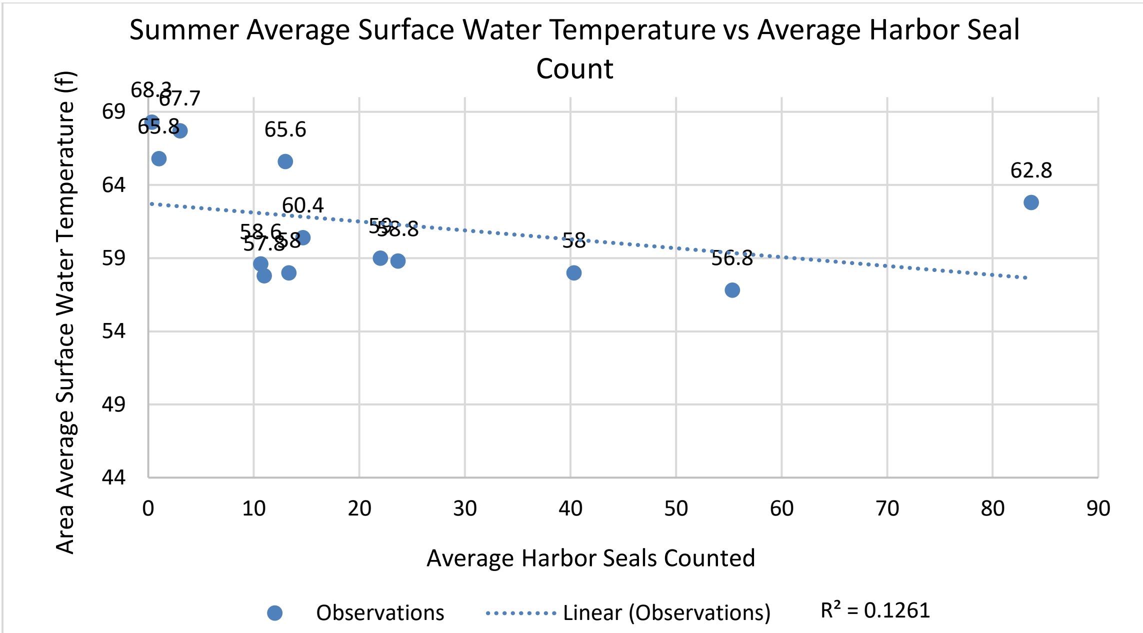

Figure 49: Graph investigating harbor seal distribution and area average surface water temperature (°F) in the summer.

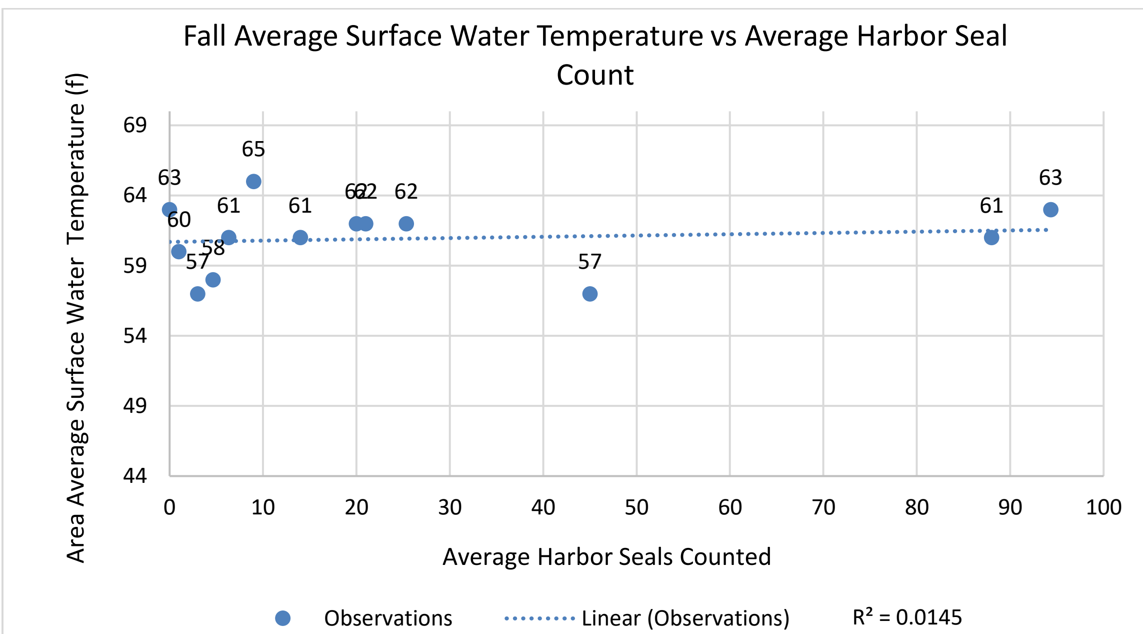

Figure 50: Graph investigating harbor seal distribution and area average surface water temperature (°F) in the fall.

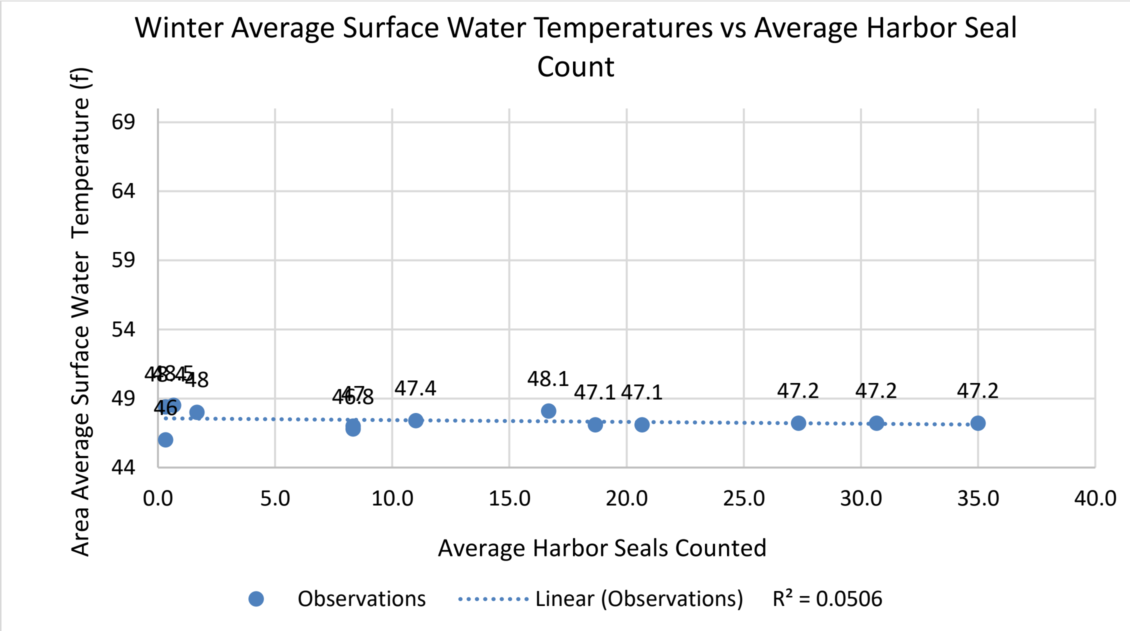

Figure 51: Graph investigating harbor seal distribution and area average surface water temperature (°F) in the winter.

Harbor Seals and Survey Areas

To test survey design, it is important to know if greater numbers of seals are being found in an area simply due to its size. After comparing the data of area size and the number of seals observed, there does not appear to be a strong relationship between the two variables in any season (*Figure 52*-54). This suggests that during the day harbor seals prefer to be in certain inlets, regardless of density.

If an effect was detected between area size and the number of seals, it would have several implications counter to what was found in the results of this survey. The results of this study show that harbor seals are not normally distributed across the available space, but rather prefer some inlets over others.

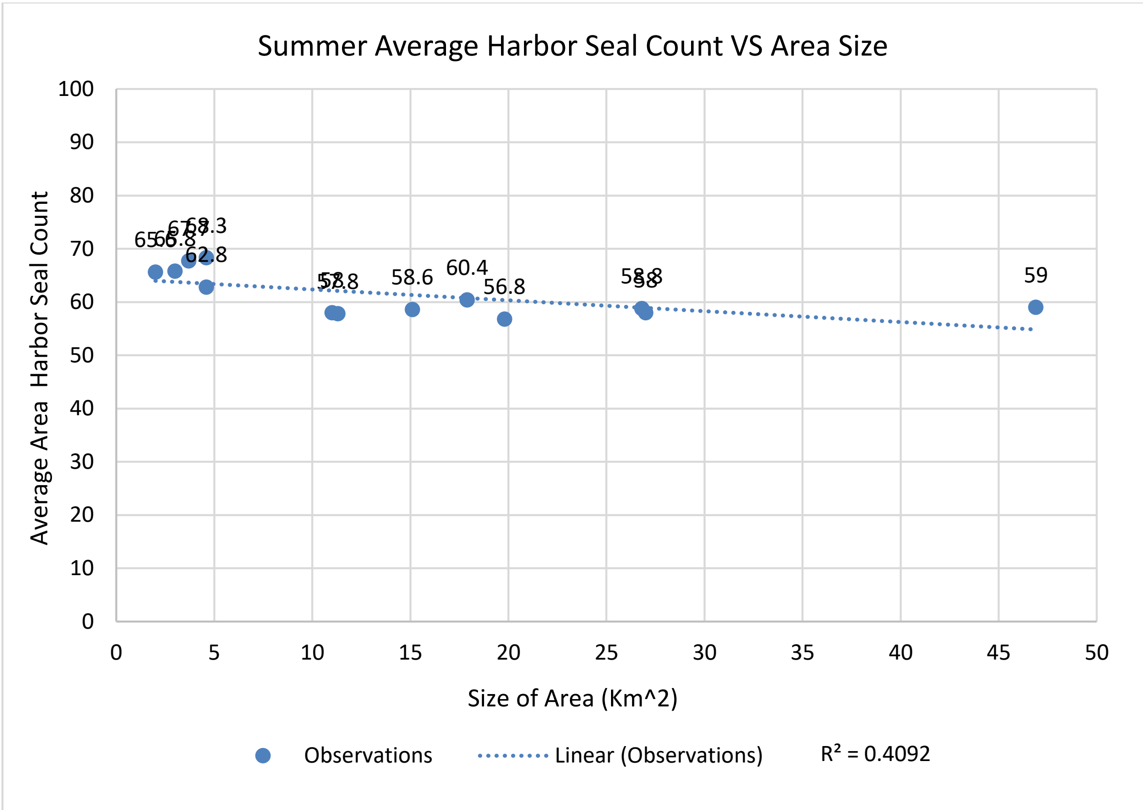

Figure 52: Graph investigating harbor seal distribution and area size in the summer.

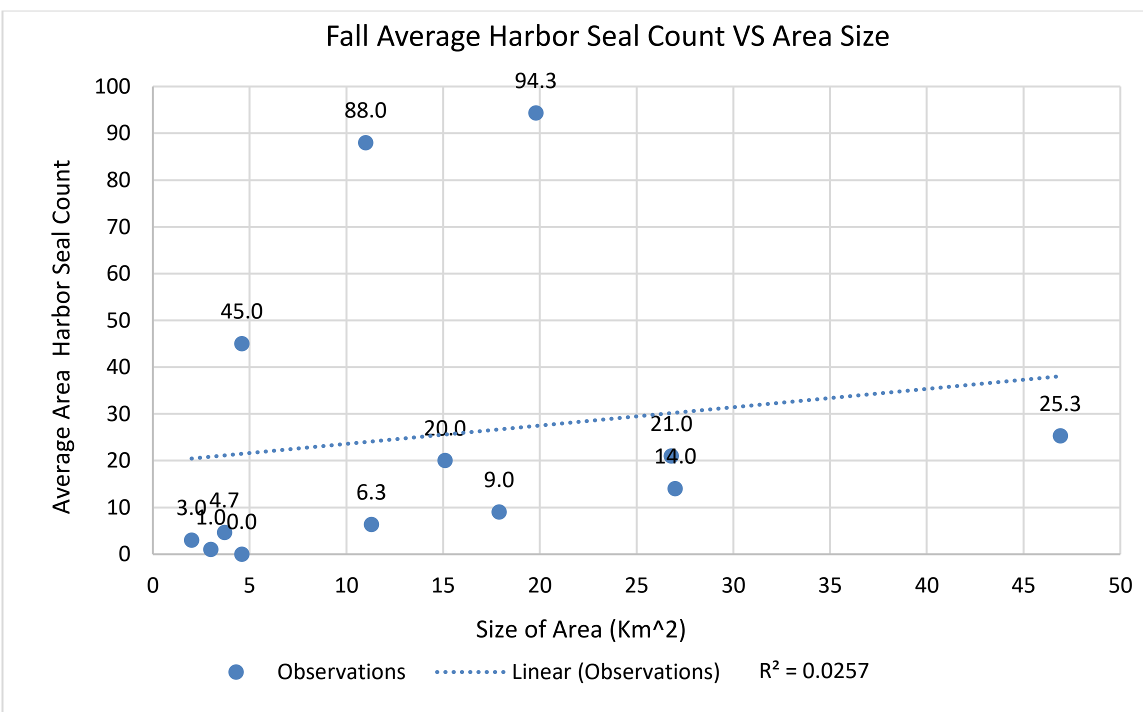

Figure 53: Graph investigating harbor seal distribution and area size in the fall.

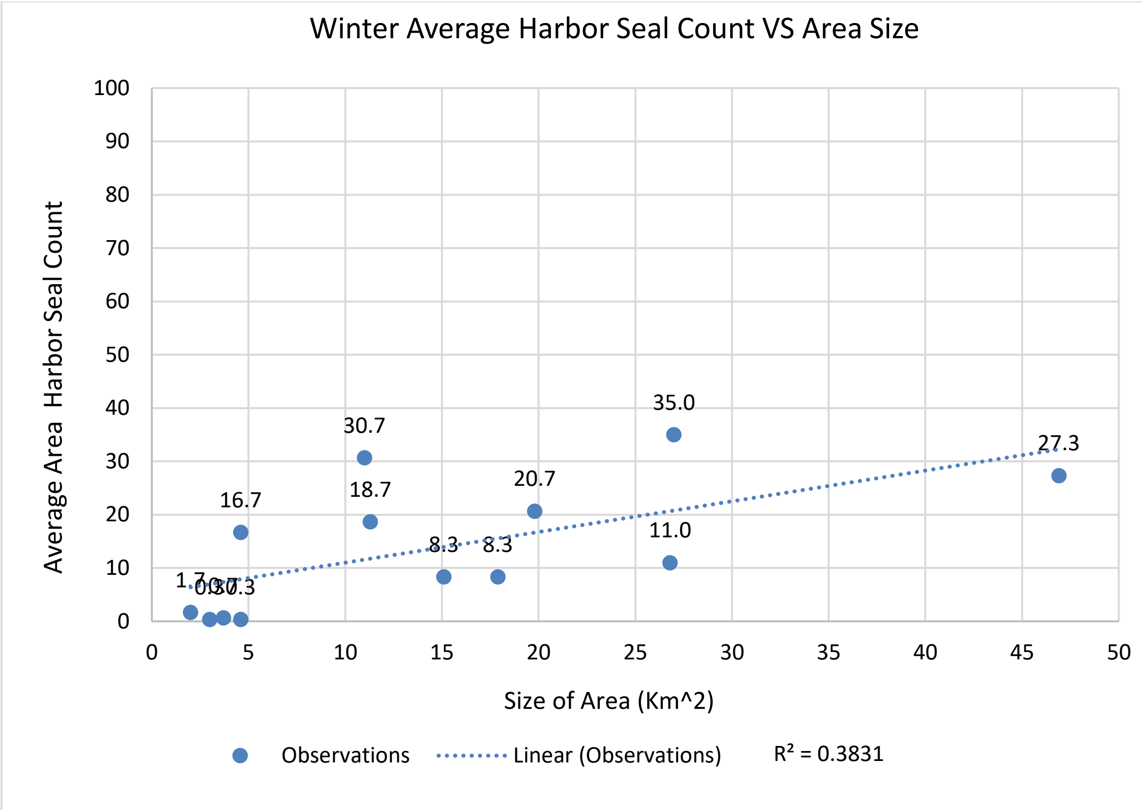

Figure 54: Graph investigating harbor seal distribution and area size in the winter.

To further investigate or further evaluate which areas are the most important to the harbor seal's daytime activities, areas were stacked against each other and organized by the number of seals present for each season. South Pickering, Shallow Budd Inlet, and Henderson Inlet were the most populous areas for harbor seals in the summer and fall (*Figure 58*-60). In the winter, Case Inlet, Henderson Inlet, and the Pickering areas (north and south) were the most populous (*Figure 55*-57).

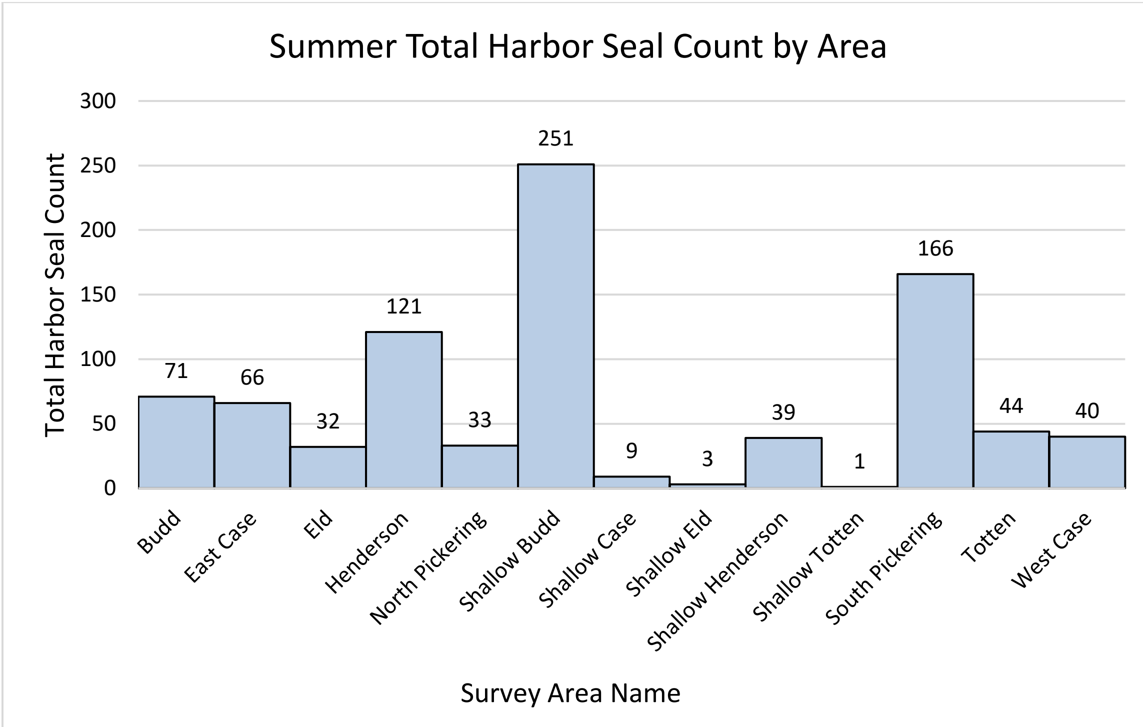

Figure 55: Graph showing summer harbor seal distribution by area.

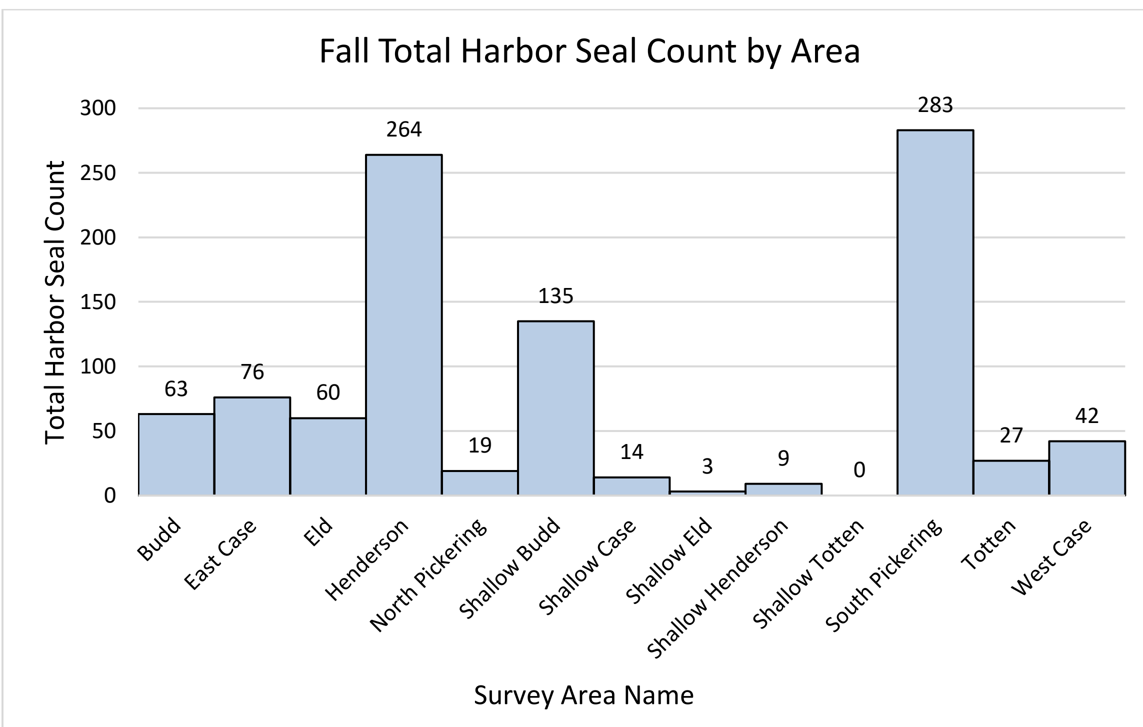

Figure 56: Graph showing fall harbor seal distribution by area.

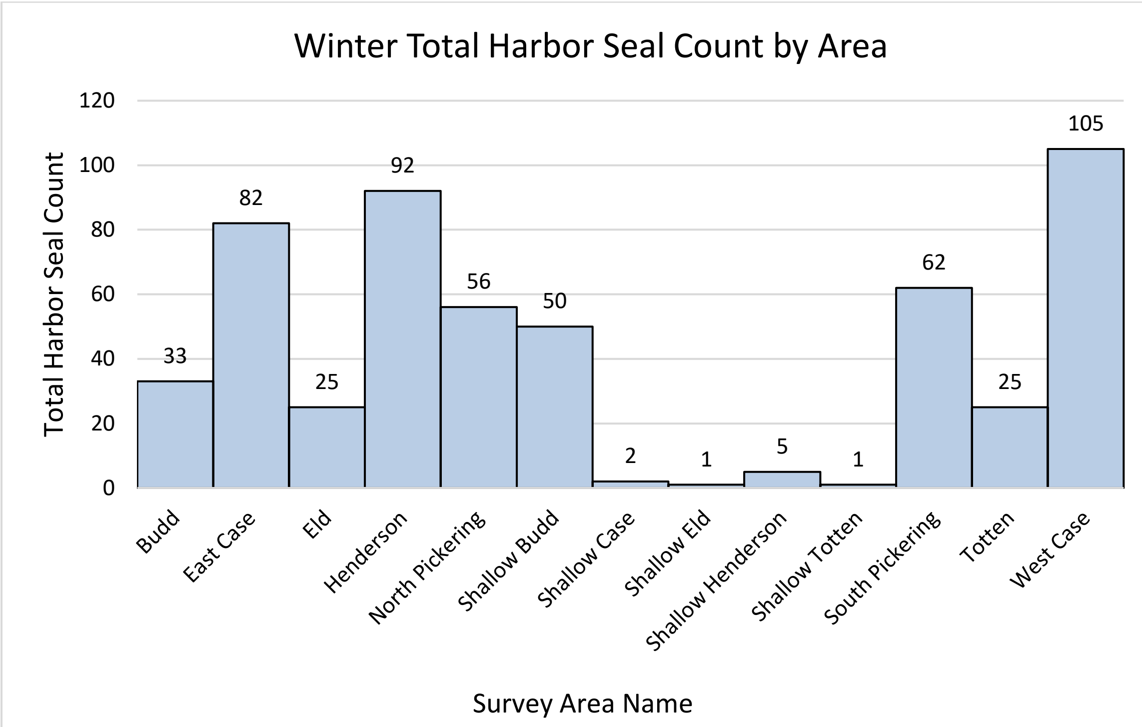

Figure 57: Graph showing winter harbor seal distribution by area.

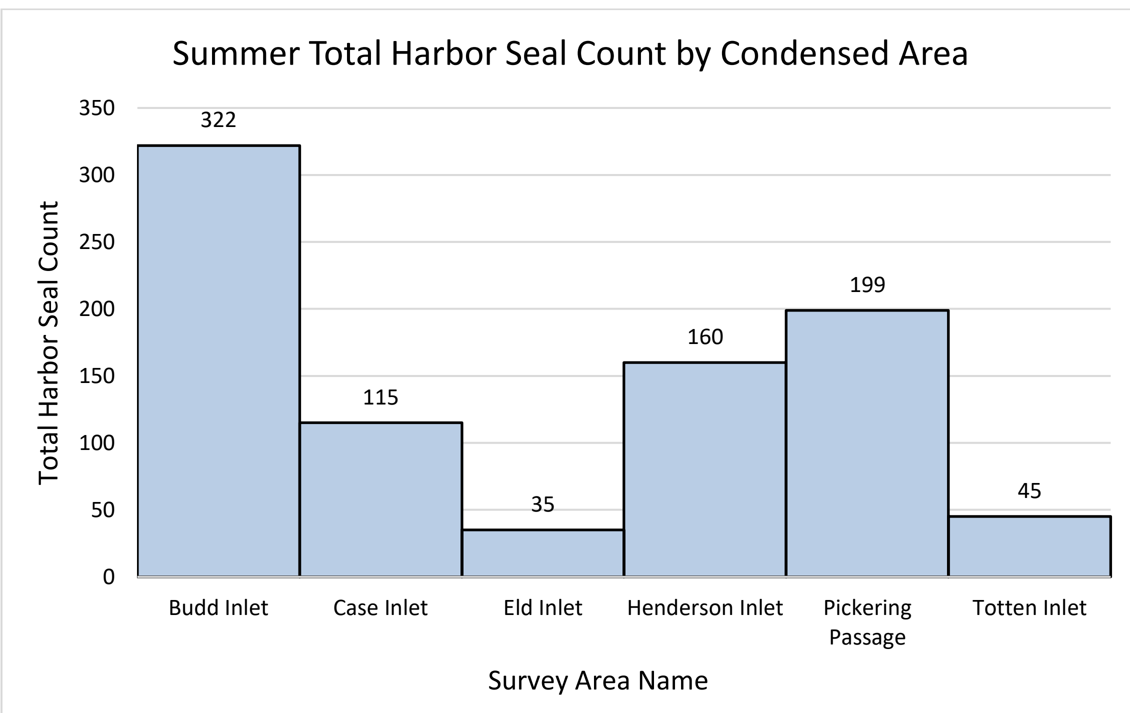

Figure 58: Graph showing summer harbor seal distribution by condensed areas.

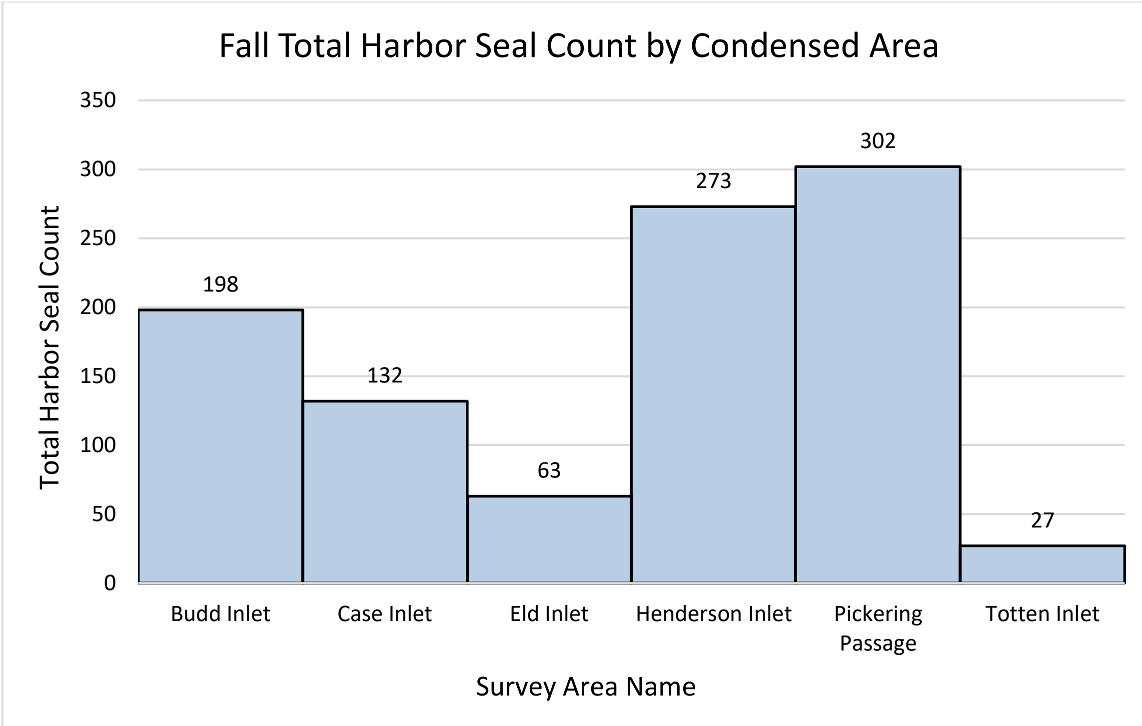

Figure 59: Graph showing fall harbor seal distribution by condensed areas.

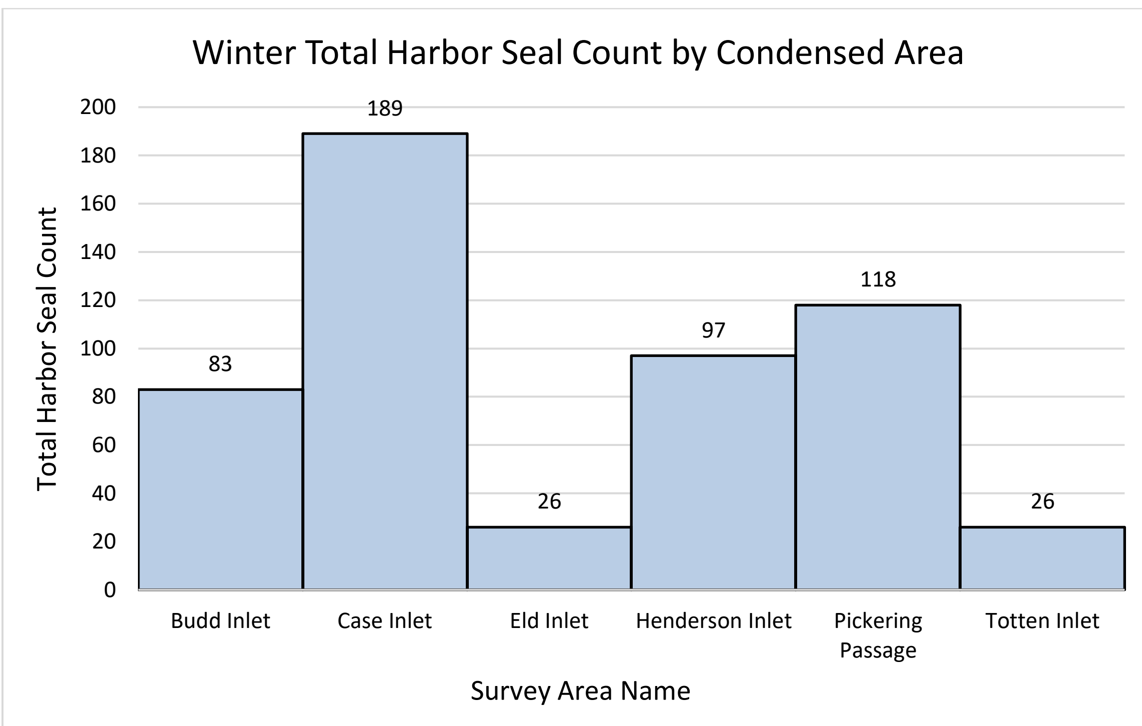

Figure 60: Graph showing winter harbor seal distribution by condensed areas.

After data was condensed into areas of high connectivity, it is revealed that the Pickering Passage, Budd Inlet, and Henderson Inlet are still the most highly populated areas for seals in the summer and fall (Figure 58-59). In the winter, Case Inlet, the Pickering Passage, Henderson Inlet, and Budd Inlet are shown to be the most populous areas (Figure 60). Note that the numbers displayed are from total counts and that the actual minimum population estimate would be that number divided by the number of laps (3). Additionally, note that these are from daytime observations only.

Disturbances

Human disturbances to marine mammals have widely been documented as having a negative effect on population health and size (Cammen et. al., 2019). To investigate whether it is likely harbor seals are experiencing interactions with humans and their machinery, the average number of seals for each survey area was compared with the number of powerboats observed in that area. This was done using Microsoft Excel's linear regression. R^2 values of greater than 0.7 were considered significant. However, because this data is "binned" data, one outlier can drastically impact the analysis. Summer data suggest that there is a practical but nonsignificant positive relationship between the number of powerboats and the number of harbor seals in each area ($R^2 = 0.66$), but it is important to note that this could be for any number of other reasons (Figure 61). Seals in the summer tended to haul out and congregate around haul-outs, which are often docks and marinas, more than in winter. Fall and winter show weak R^2 values in comparison at 0.14 and 0.06, respectively (Figure 62-63).

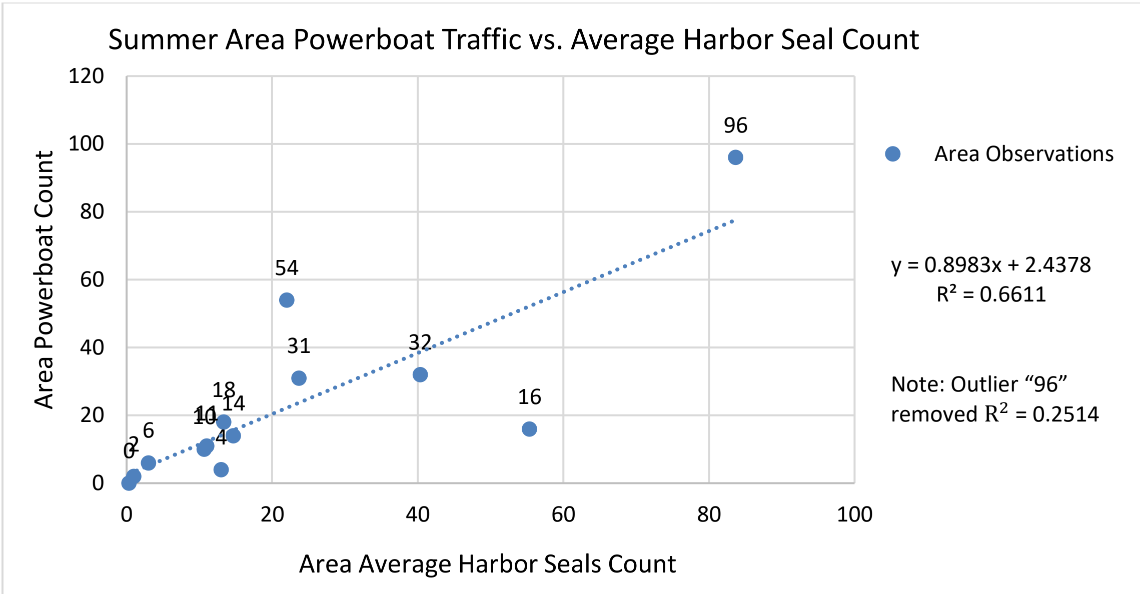

Figure 61: Graph showing summer area powerboat count vs. average harbor seal count for each area.

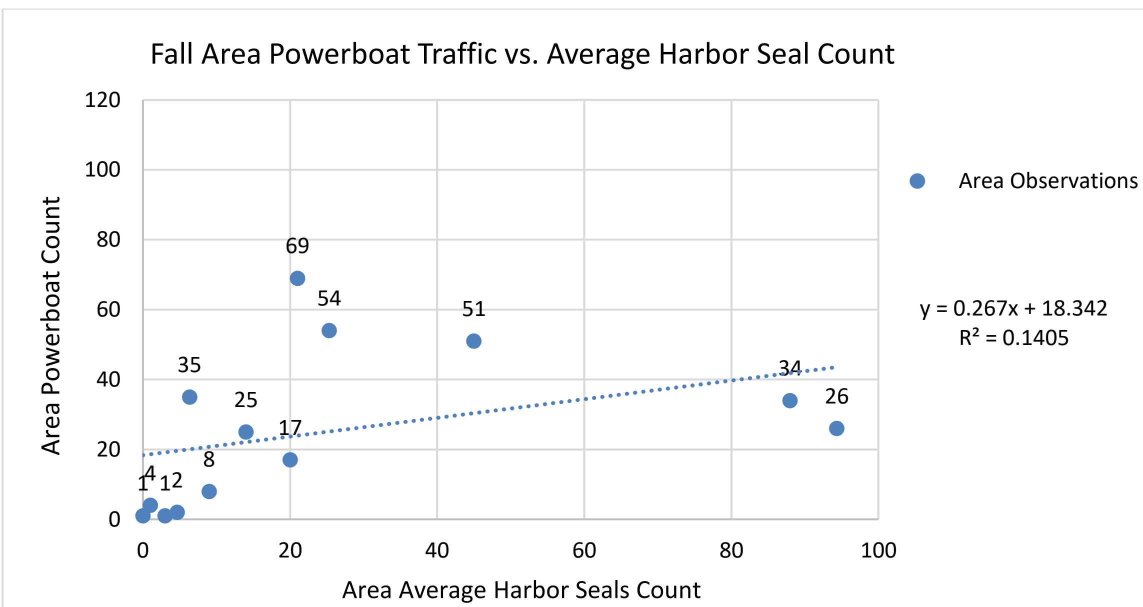

Figure 62: Graph showing fall area powerboat count vs. average harbor seal count for each area.

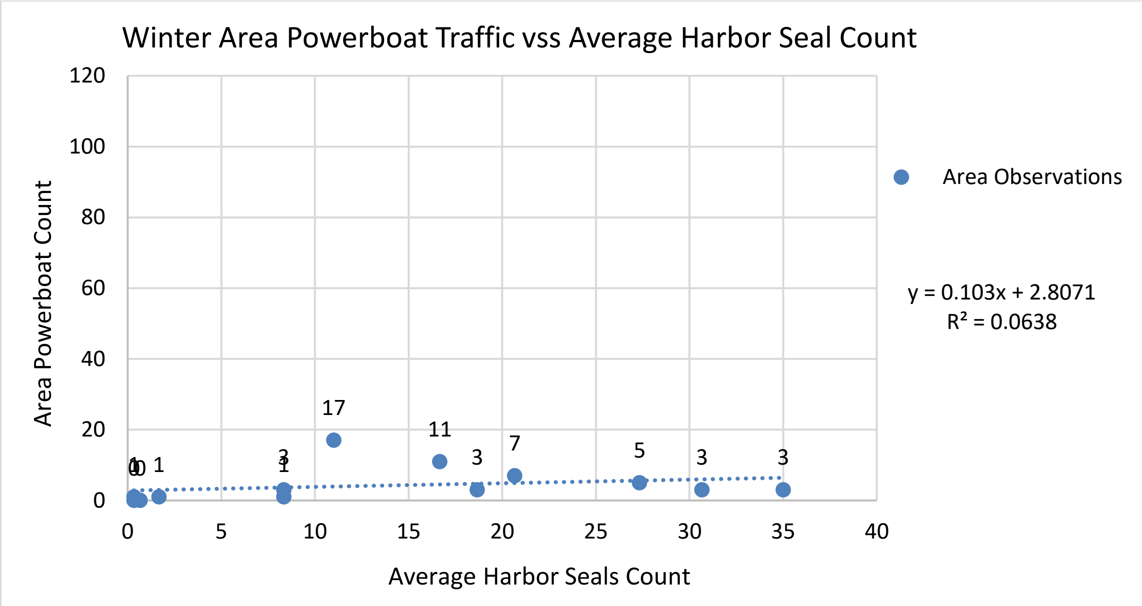

Figure 63: Graph showing winter area powerboat count vs. average harbor seal count for each area.

Area Details

The Southern Puget Sound can be a high boater traffic area, but this varies by season and area. To better understand the relationship between seal distribution and human activity, on beaches or at sea, data was collected during the survey and mapped. The seal distribution is mapped as relative density for each area, and as such is not comparable across maps. Land use data points were only collected if the object intruded upon a beach, preventing seals from hauling out. Human disturbances varied by type from walkers on the beach to kayakers to powerboats.

To contextualize each map, supplemental tables were generated. It is important to note that this data was all collected around noon, so it is not representative of other parts of the day. At noon, people visiting the water were usually on boats or walking on beaches. Therefore, data may represent peak activity. Surveying an area on a weekend may have skewed the data to having more human disturbances, as people go out and enjoy the outdoors more on weekends. However, because three laps were conducted of each area, and every area was visited at least once on a weekend, the effect averages out.

For those with an invested interest in a local area, the focused inlet maps may provide some answers as to the distribution and well-being of seals in their region and the type of human interactions they may be experiencing in each area. It was observed on many occasions, especially in the northwest corner of Shallow Budd Inlet, paddlers and powerboats extremely close to hauled-out seals, sometimes causing stampede behavior.

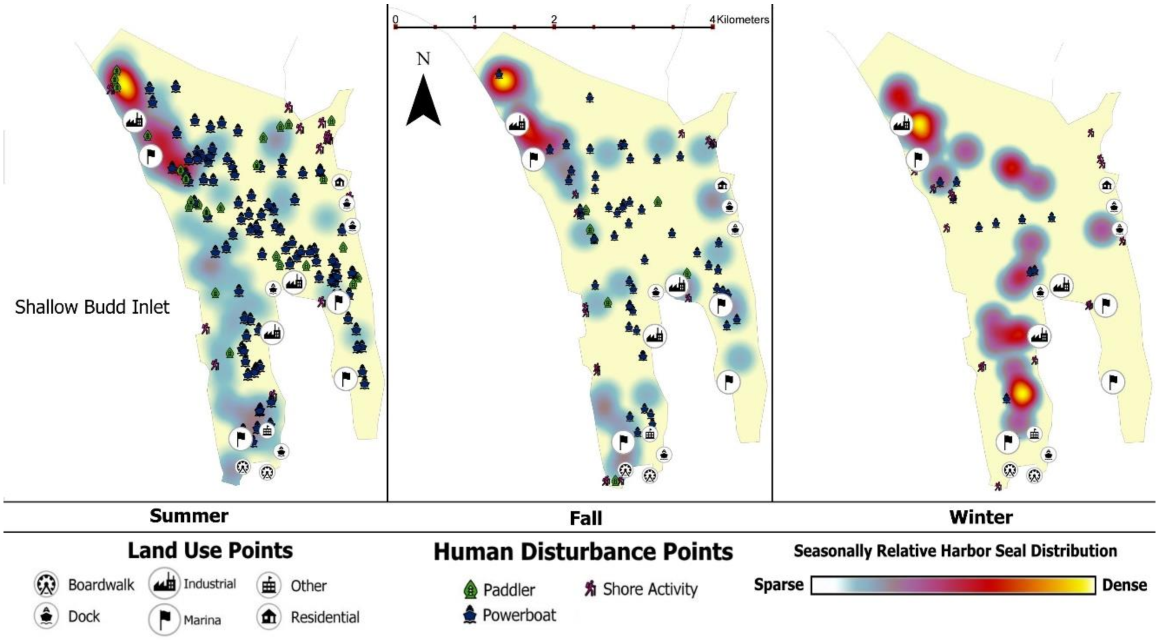

Figure 64: Maps of harbor seal and disturbance data from Shallow Budd Inlet.

Season	Area Size (km^2)	Number of Recorded Land Use Disturbances	Number of Activity Disturbances	Average Number of Harbor Seals	Average Surface Water Temp (F.)
Summer	4.6	15	134	83.7	62.8
Fall	*	*	74	45	57
Winter	*	*	27	16.7	48.1

Table 50: Table of harbor seal and disturbance data from Shallow Budd Inlet.

Shallow Budd Inlet is the heart of downtown Olympia's waterfront (*Figure 64*). Several marinas share this space, and it is home to the third-largest harbor seal haul-out in the survey region. As a result, there is a great deal of activity across the area both in terms of seals and people (*Table 50*). Harbor seals were concentrated on the log-booms in the northwest corner of the area during pupping and molting season, while in winter they were more dispersed.

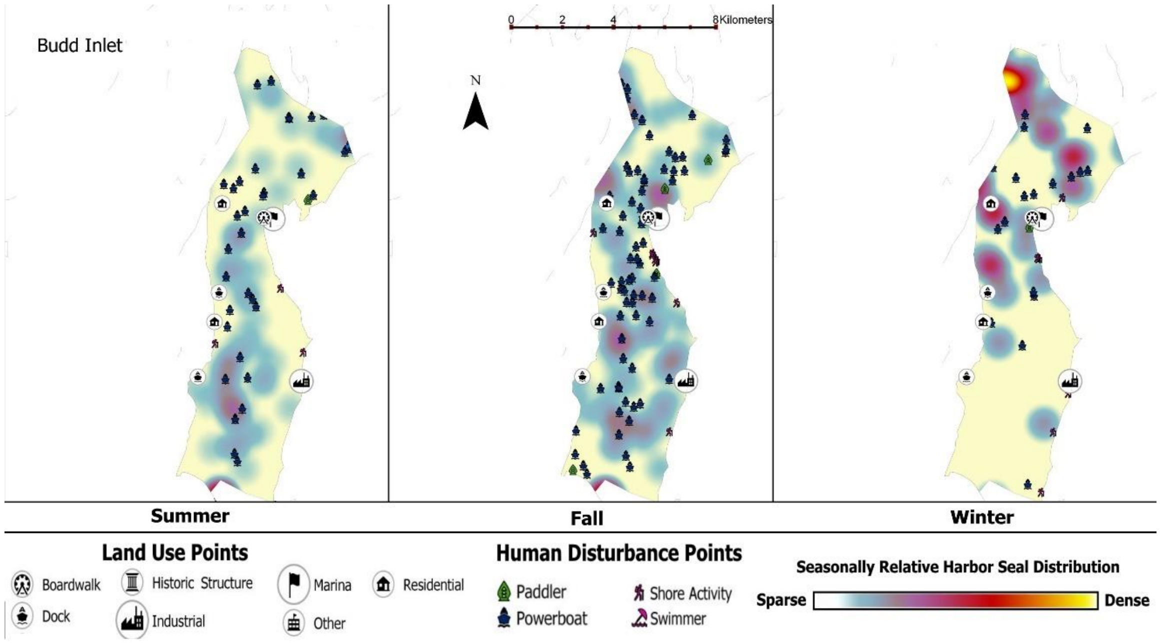

Figure 65: Maps of harbor seal and disturbance data from Budd Inlet.

Season	Area Size (km^2)	Number of Recorded Land Use Disturbances	Number of Activity Disturbances	Average Number of Harbor Seals	Average Surface Water Temp (F.)
Summer	26.8	10	37	23.7	58.8
Fall	*	*	84	21	62
Winter	*	*	25	11	47.4

Table 51: Table of harbor seal and disturbance data from Budd Inlet

Budd Inlet was notable for its high boat traffic during warmer months and a small gathering of harbor seals in the winter (*Figure 65*). Boater activity and the surface water temperature peaked in fall (*Table 51*). The coastline along this area was highly developed, mostly in the form of residential structures.

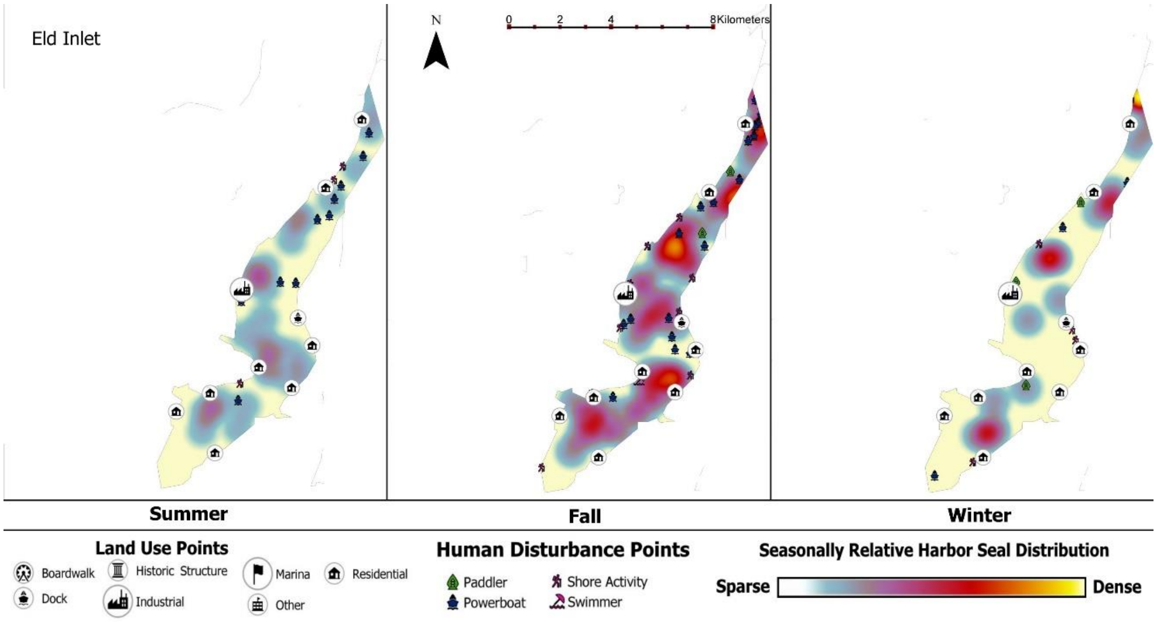

Figure 66: Maps of harbor seal and disturbance data from Eld Inlet.

Season	Area Size (km^2)	Number of Recorded Land Use Disturbances	Number of Activity Disturbances	Average Number of Harbor Seals	Average Surface Water temp (F.)
Summer	15.1	10	14	10.7	58.6
Fall	*	*	32	20	62
Winter	*	*	10	8.3	47

Table 52: Table of harbor seal and disturbance data from Eld Inlet.

Eld inlet was often surveyed on the same day as Budd Inlet and featured similar patterns of residential development (Figure 66). While there were relatively few seals found within the Inlet, the ones that did frequent the area found rest on the multitude of residential floating swim platforms (Table 52). Note that the blowout of the fall distribution map may be due to software error, however, fall did see a doubling in the number of seals.

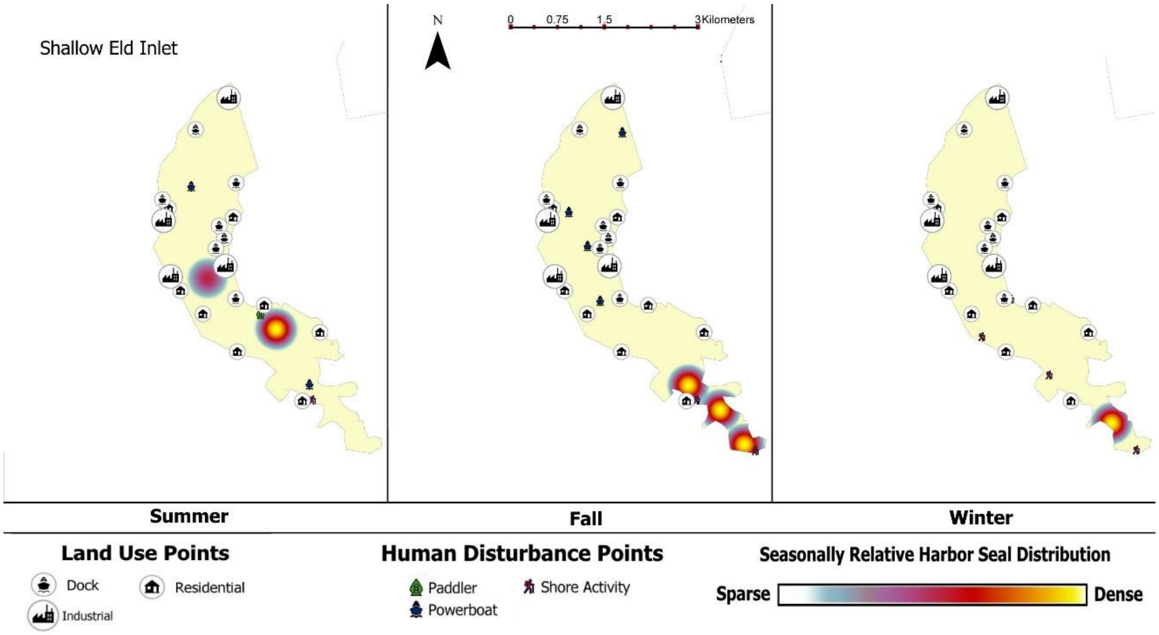

Figure 67: Map of harbor seal and disturbance data from Shallow Eld Inlet.

Season	Area Size (km^2)	Number of Recorded Land Use Disturbances	Number of Activity Disturbances	Average Number of Harbor Seals	Average Surface Water temp (F.)
Summer	3	18	4	1	65.8
Fall	*	*	6	1	60
Winter	*	*	4	0.3	48.4

Table 53: Table of harbor seal and disturbance data from Shallow Eld Inlet.

Shallow Eld Inlet extends from the Mud Bay bridge to the oyster beds near the beginning of the deep water area. Harbor seals were only occasionally observed near the bridge and at the beginning of deeper waters (*Figure 67*). Average number of disturbances and seal count was quite low across all seasons (*Table 53*). This may change during salmon runs, as there are many fishermen and seals near the bridge at that time, which was outside of this survey period.

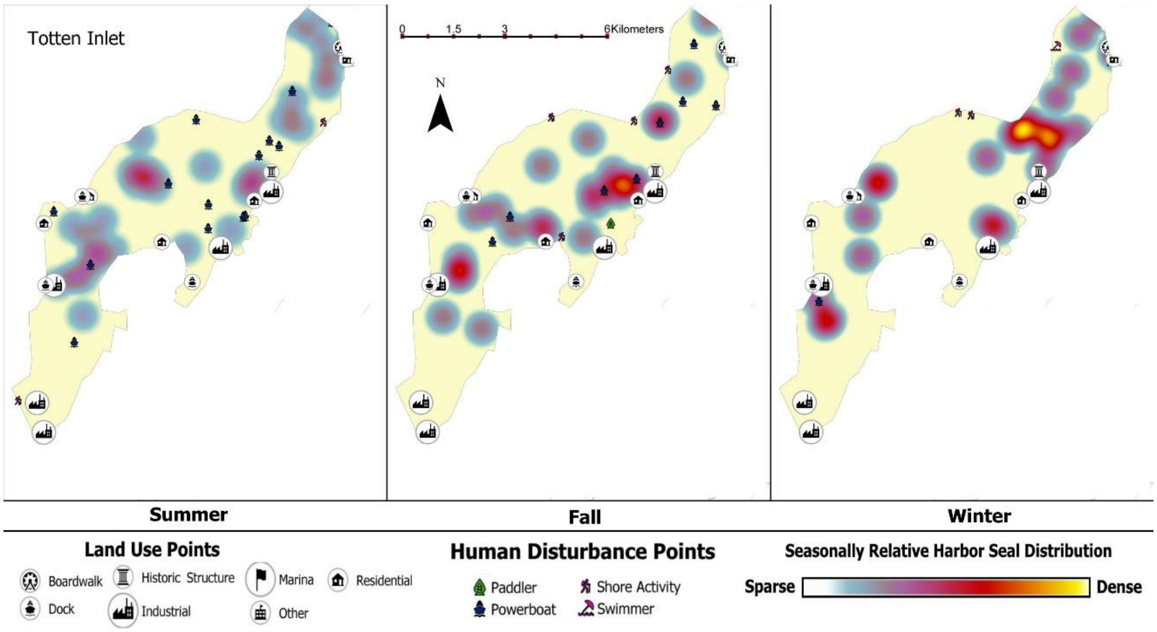

Figure 68: Map of harbor seal and disturbance data from Totten Inlet.

Season	Area Size (km^2)	Number of Recorded Land Use Disturbances	Number of Activity Disturbances	Average Number of Harbor Seals	Average Surface Water temp (F.)
Summer	17.9	14	16	14.7	60.4
Fall	*	*	13	9	65
Winter	*	*	6	8.3	46.8

Table 54: Table of harbor seal and disturbance data from Totten Inlet.

Totten Inlet had a large oyster industry presence throughout the entire length of the Inlet interspersed with residential areas (*Figure 68*). The southern end of the area is a large fish farm that spans the width of the inlet. With all of the industrial barges and swim platforms along the Inlet, seals were commonly seen both in-water and hauled out (*Table 54*).

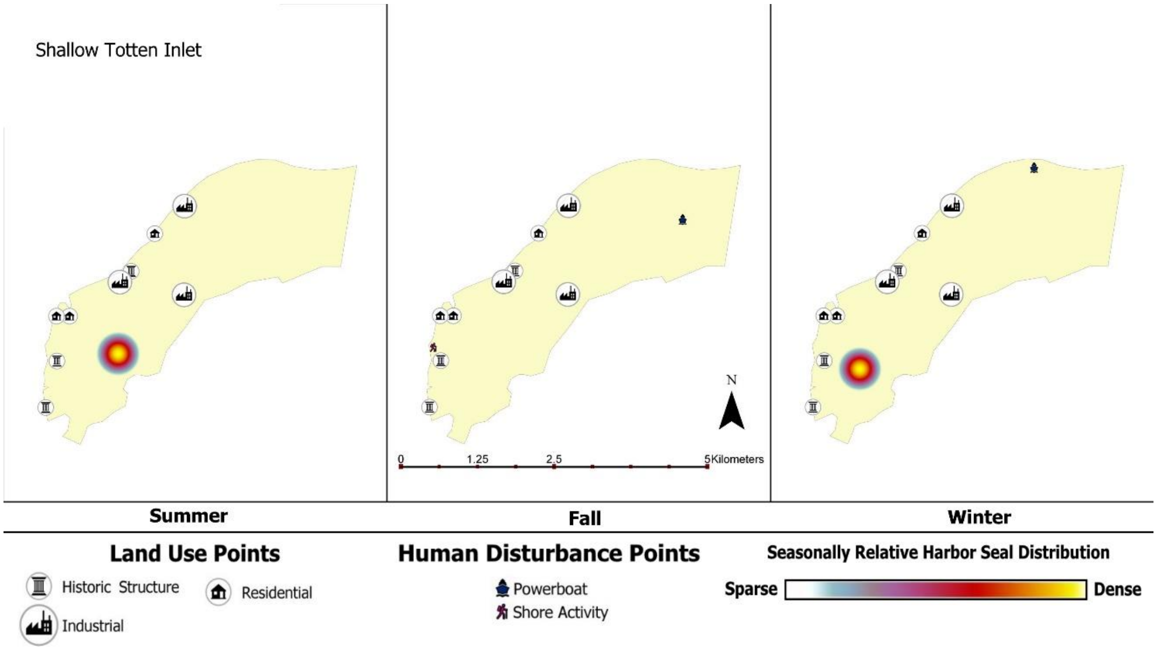

Figure 69: Map of harbor seal and disturbance data from Shallow Totten Inlet.

Season	Area Size (km^2)	Number of Recorded Land Use Disturbances	Number of Activity Disturbances	Average Number of Harbor Seals	Average Surface Water temp (F.)
Summer	4.6	9	0	0.3	68.3
Fall	*	*	2	0	63
Winter	*	*	1	0.3	46

Table 55: Table of harbor seal and disturbance data from Shallow Totten Inlet.

The Shallow Totten Inlet area was sparsely populated and rarely visited by harbor seals (*Table 55: Table of harbor seal and disturbance data from Shallow Totten Inlet.*). Activity disturbances included an occasional oyster boat and people walking near the shore (*Figure 69*).

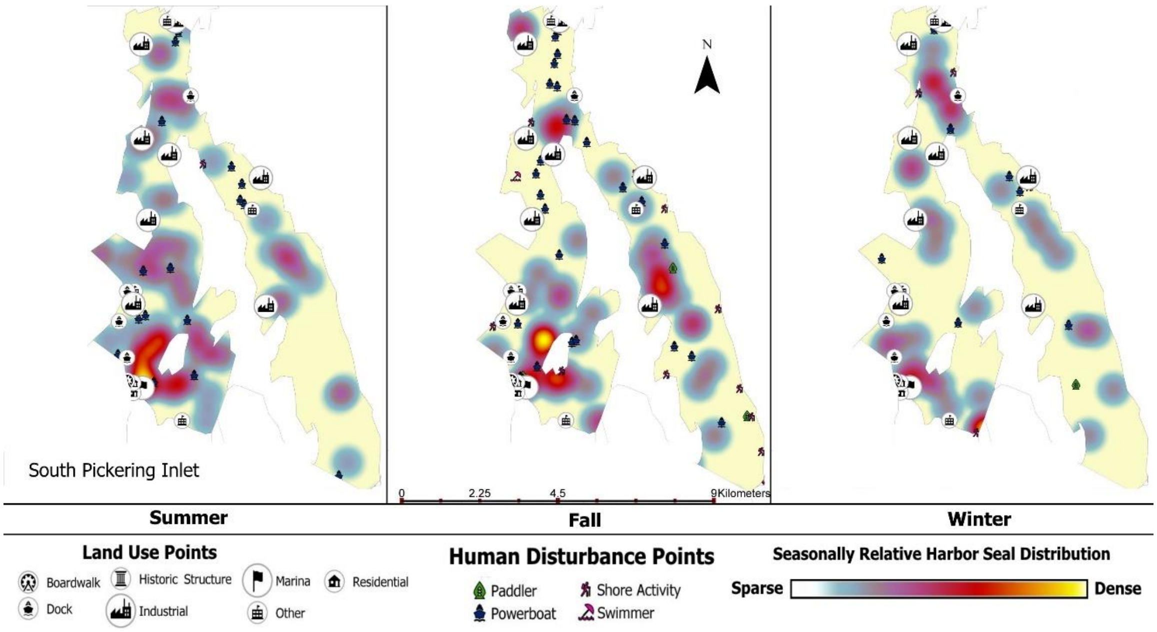

Figure 70: Map of harbor seal and disturbance data from South Pickering.

Season	Area Size (km^2)	Number of Recorded Land Use Disturbances	Number of Activity Disturbances	Average Number of Harbor Seals	Average Surface Water temp (F.)
Summer	19.8	20	18	55.3	56.8
Fall	*	*	42	94.3	63
Winter	*	*	12	20.7	47.1

Table 56: Table of harbor seal and disturbance data from South Pickering.

South Pickering Passage land use was highly variable with remote islands, intensive industrial presence, a marina, and residential areas (*Figure 70*). It was also a high traffic area for powerboats. With the second largest haul-out, harbor seals were found in great abundance (*Table 56*).

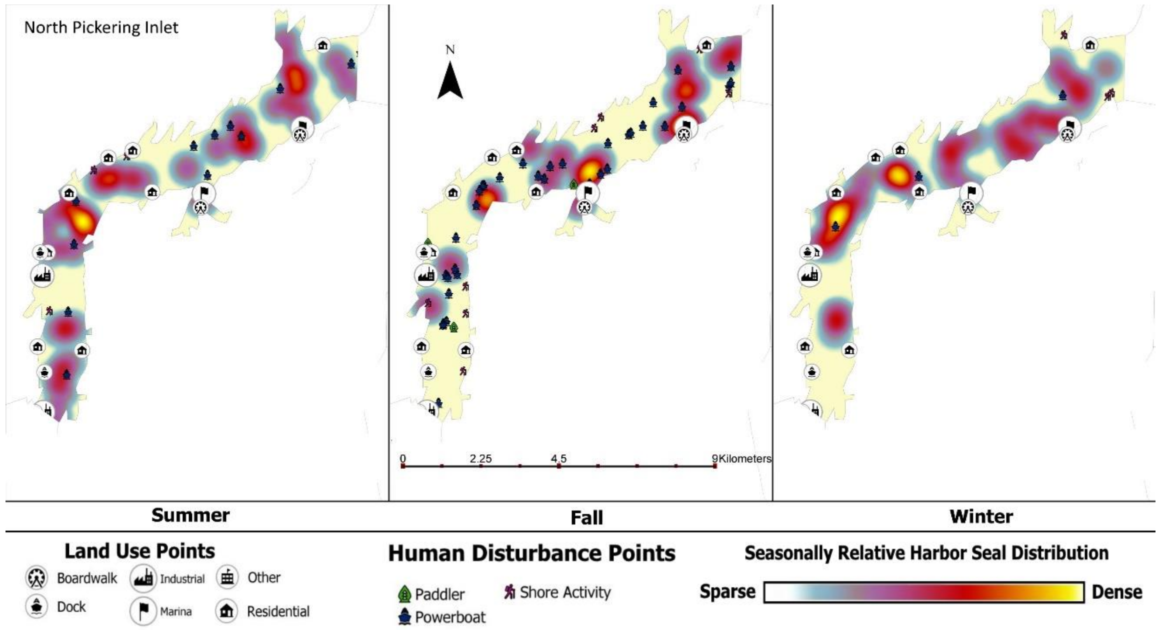

Figure 71: Map of harbor seal and disturbance data from North Pickering.

Season	Area Size (km^2)	Number of Recorded Land Use Disturbances	Number of Activity Disturbances	Average Number of Harbor Seals	Average Surface Water temp (F.)
Summer	11.3	16	15	11	57.8
Fall	*	*	51	6.3	61
Winter	*	*	7	18.7	47.1

Table 57: Table of harbor seal and disturbance data from North Pickering.

North Pickering Passage is a boating highway that connects the northern Case Inlet area with Olympia. As a result, there was a high amount of powerboat traffic (Table 57), and most seals observed in this area were traveling. In winter, harbor seals were regularly observed in the sharp curve in the passage diving in small groups (Figure 71).

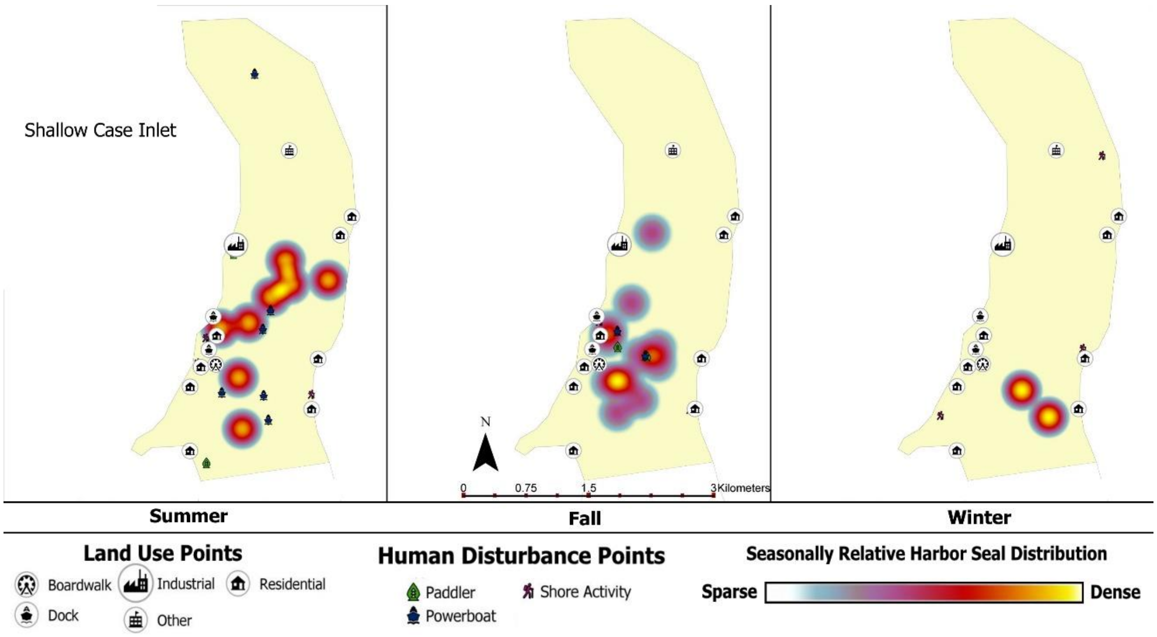

Figure 72: Map of harbor seal and disturbance data from Shallow Case Inlet.

Season	Area Size (km^2)	Number of Recorded Land Use Disturbances	Number of Activity Disturbances	Average Number of Harbor Seals	Average Surface Water temp (F.)
Summer	3.7	9	9	3	67.7
Fall	*	*	6	4.7	58
Winter	*	*	3	0.7	48.5

Table 58: Table of harbor seal and disturbance data from Shallow Case Inlet.

Shallow Case Inlet is primarily the Allyn waterfront and thus experienced a great deal of recreational activity (*Table 58*). Few harbor seals were observed in these shallow waters, but the ones that were seen were located just southeast of the public dock (*Figure 72*).

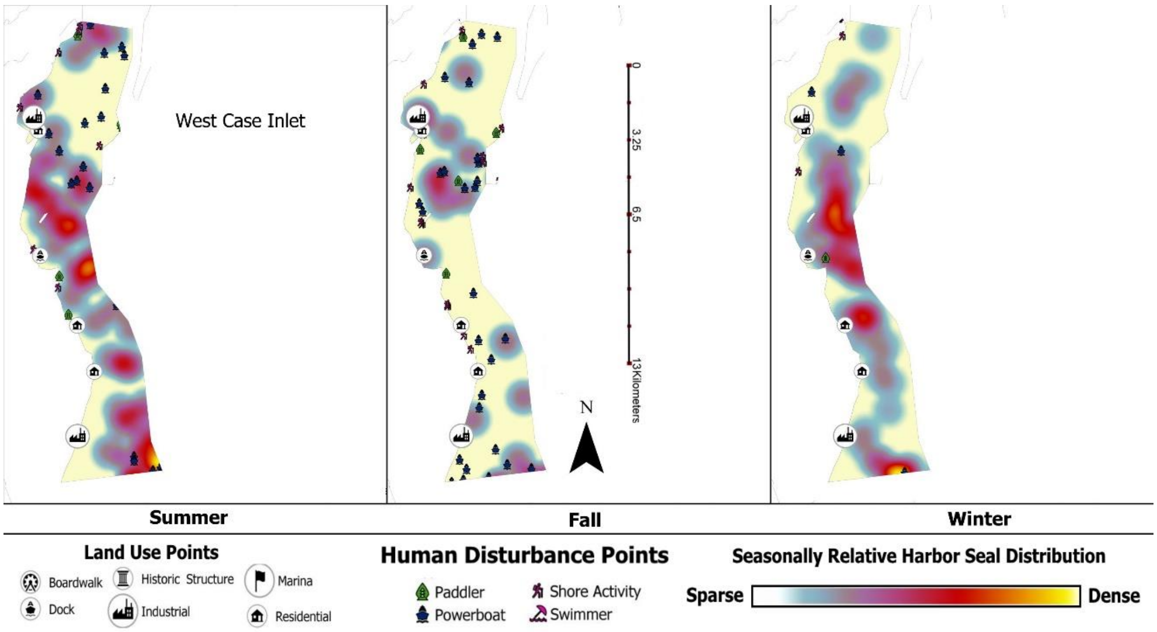

Figure 73: Map of harbor seal and disturbance data from West Case Inlet.

Season	Area Size (km^2)	Number of Recorded Land Use Disturbances	Number of Activity Disturbances	Average Number of Harbor Seals	Average Surface Water temp (F.)
Summer	27	6	28	13.3	58
Fall	*	*	43	14	61
Winter	*	*	6	35	47.2

Table 59: Table of harbor seal and disturbance data from West Case Inlet.

West Case Inlet is the smaller half of Case Inlet being just north of the largest harbor seal haul-out in the Southwest Puget Sound. In summer, long-beaked common dolphins were often found in its northern areas. In the winter, it hosted the largest gathering of marine mammals of the season on every lap (*Figure 73*). The western coast is sparsely populated with residential areas and few industrial docks. The area sees a fair amount of boat traffic (*Table 59*).

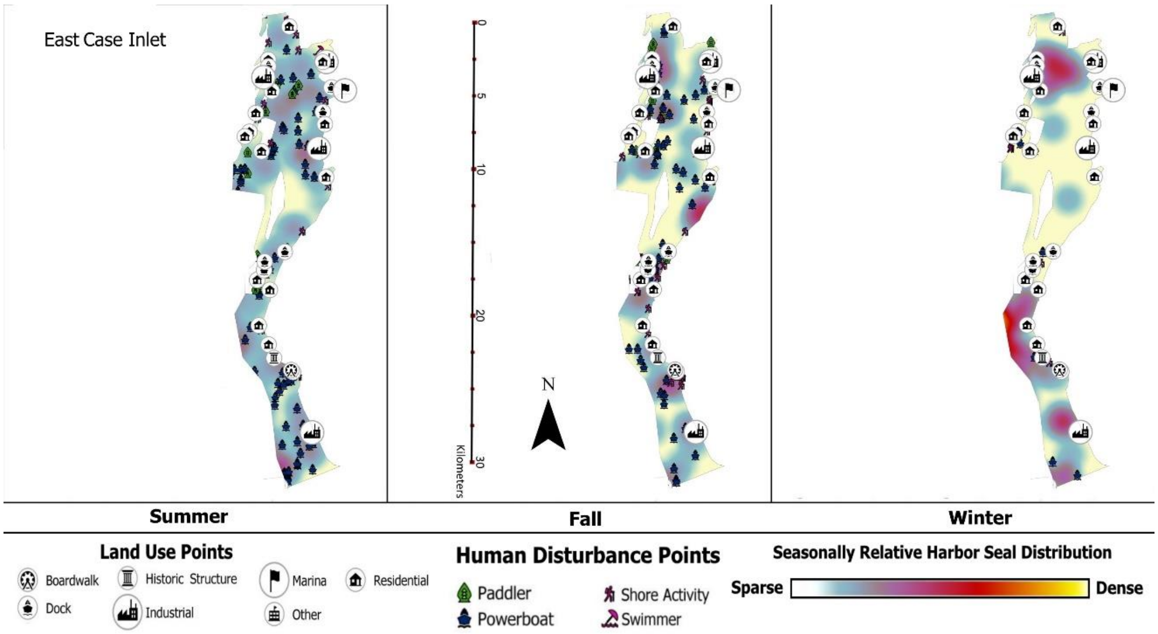

Figure 74: Map of harbor seal and disturbance data from East Case Inlet.

Season	Area Size (km^2)	Number of Recorded Land Use Disturbances	Number of Activity Disturbances	Average Number of Harbor Seals	Average Surface Water temp (F.)
Summer	46.9	27	94	22	59
Fall	*	*	95	25.3	62
Winter	*	*	15	27.3	47.2

Table 60: Table of harbor seal and disturbance data from East Case Inlet.

East Case Inlet was the largest area surveyed. It also contains several densely populated and boat-friendly communities. As a result, many disturbance points were recorded (Table 60). Compared with West Case Inlet, East Case Inlet had few widely distributed marine mammals (Figure 74). During haul-out seasons, residential swim platforms were used by harbor seals to rest but were disturbed frequently by people walking along the beaches and high boat traffic.

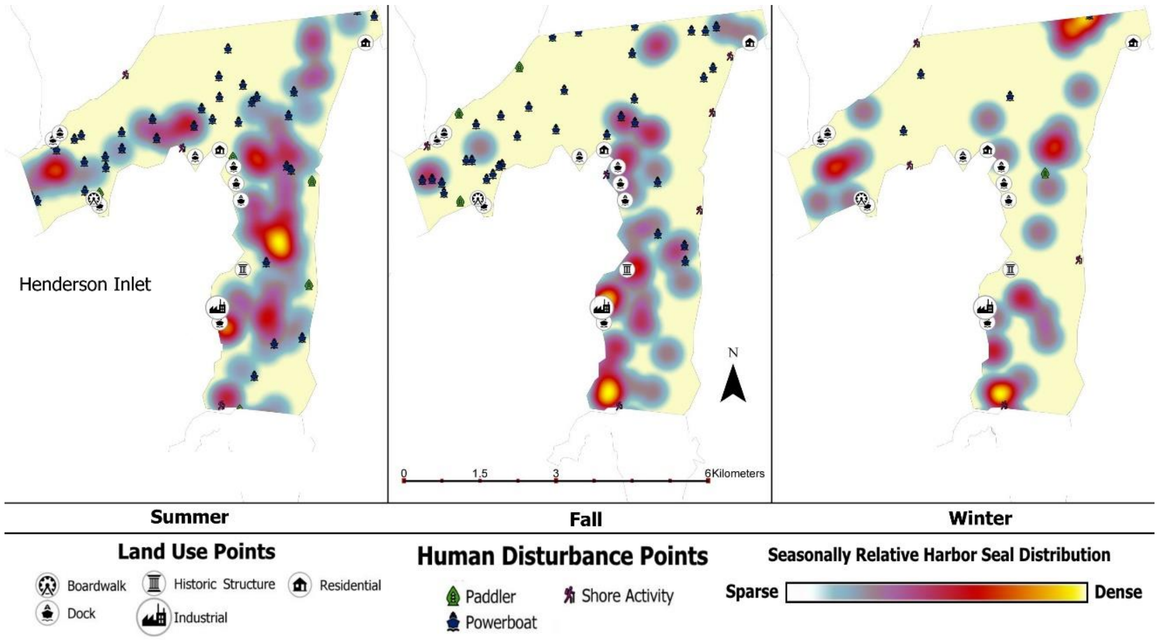

Figure 75: Map of harbor seal and disturbance data from Henderson Inlet.

Season	Area Size (km^2)	Number of Recorded Land Use Disturbances	Number of Activity Disturbances	Average Number of Harbor Seals	Average Surface Water temp (F.)
Summer	11	12	40	40.3	58
Fall	*	*	43	88	61
Winter	*	*	8	30.7	47.2

Table 61: Table of harbor seal and disturbance data from Henderson Inlet.

Henderson Inlet contains the largest harbor seal haul-out in the Southwest Puget Sound, which extends from the nature preserve in the south to the residential swim platforms on the western coast (*Figure 75*). There was also very consistent harbor porpoise presence where the inlet meets Nisqually Reach. Fishing vessels often dropped lines at the northern mouth of the inlet, which accounts for much of the powerboat observations (*Table 61*). The Dana Passage was included in this area.

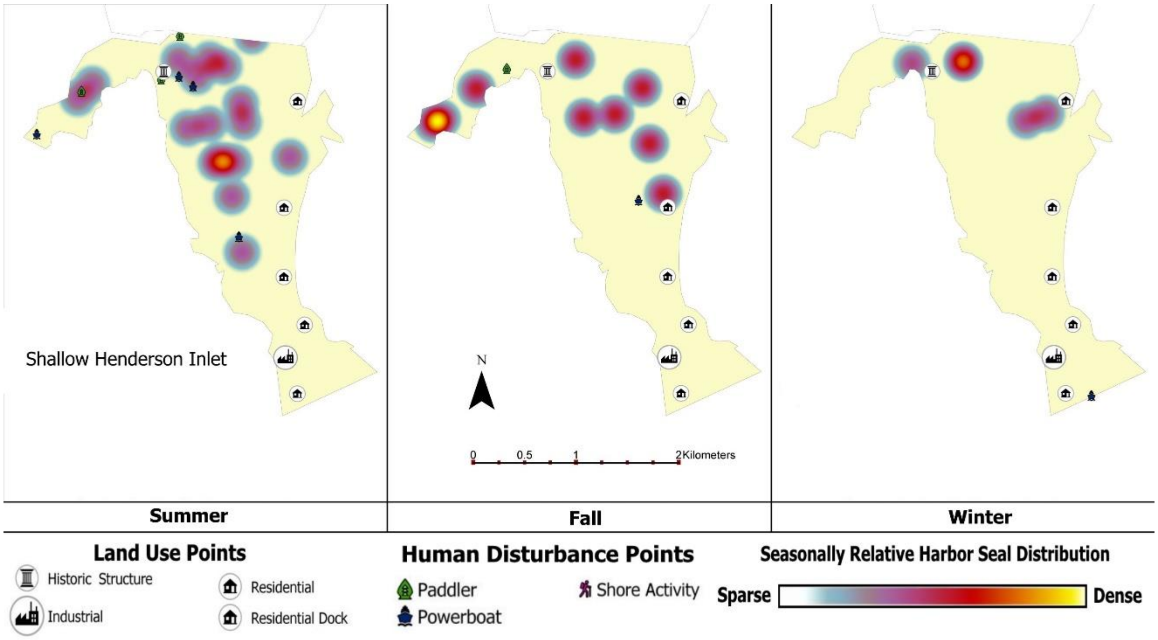

Figure 76: Map of harbor seal and disturbance data from Shallow Henderson Inlet.

Season	Area Size (km^2)	Number of Recorded Land Use Disturbances	Number of Activity Disturbances	Average Number of Harbor Seals	Average Surface Water temp (F.)
Summer	2	7	7	13	65.6
Fall	*	*	2	3	57
Winter	*	*	1	1.7	48

Table 62: Table of harbor seal and disturbance data from Shallow Henderson Inlet.

Shallow Henderson Inlet had a large amount of seals and people during pupping season but was relatively sparse during the other seasons (*Table 62*). At the south end of the area, there was oyster boat activity, and around the coastline was residential development. Harbor seals tended to stay near the large haul-out just north of the area and occasionally found platforms to haul out on near the western coastline (*Figure 76*).

Methods

After surveying using the methodologies outlined, several changes could be implemented. First, a shallow water capable main vessel would have allowed for greater maneuverability in the ends of inlets, eliminating some insufficient data areas and possibly the need for a kayak survey. Second, a consistent and skilled navigator that could operate independently of instruction would have been helpful to the observer so that undivided attention could be given to counting. Third, Esri Survey123 Connect (as opposed to Esri Survey123 Collector app) allows for greater customization of surveys and would have provided richer data sets. Finally, advanced sampling methods (e.g. transects across deep water areas, multiple vessels, and paired observers) and better technology (e.g. portable weather stations) would have bene used to help mitigate biases or provide better localized data.

The Southern Puget Sound is a maze of shallow waterways and bays with fast currents and quickly changing weather. A flat bottom-type vessel and a stronger well maintained engine would have opened some opportunities missed by the keel-type vessel used. Areas like little and big Hammersley Inlet could have been surveyed, and kayak surveys would have been absorbed into the adjacent deep water areas. The only reason this type of vessel was not used was because of resource availability.

Volunteers served as helmsman under the direction of the observer and Navionics software. Volunteers varied greatly in ability, and the operation of the vessel was typically given over to the main observer during tricky passages. Over time, veteran volunteers were able to operate more independently of the observer, allowing the observer to focus more completely on spotting data points. Under ideal circumstances, the survey could have used a highly skilled navigator to assist the observer by operating completely independently. This ideal circumstance was not pursued because of the limited resources of the project to hire such a person and the limited availability of individuals that could meet such requirements.

The survey project was designed by the main researcher early in their geographic information systems training and thus used simpler apps to collect data than an expert would have used. Survey123 Connect varies from the regular Survey123 in that the participant inputs can be richer in detail, question trees are more customizable, and inputs can be coded more easily and freely. Despite the greater flexibility of Survey123 Connect to create complex surveys, the regular survey app worked effectively enough to generate unflawed data sets.

The methods used in this survey project were very simple, and as a result, provided a limited investigation of marine mammals in the Southwest Puget Sound. Given the resources, this survey could include many more variables to compare with marine mammal distribution.

One of these other variables could be the collection of water temperatures at different depths. Different temperatures of water stratify in the water column in a variety of patterns depending on the season. This can contribute to water quality and the preferences of marine mammals’ prey species and therefore the distribution of marine mammals in the region.

Sufficient lab services would have also been valuable to this research. Water samples could have been collected and the levels of different pollutants could be mapped against distribution patterns. This information could be used to identify areas in need of protection and could measure potentially harmful compounds to marine mammals.

Originally, the target survey region included all areas of water on the south side of the Tacoma Narrows, which serves as a barrier to harbor seals and has caused southern seals to become genetically distinct (Carretta et. al., 2017). Results from a survey of all South Sound regions would be much more easily compared with NOAA data as the Southern Puget Sound harbor seals are managed as a separate stock and are thus summarized independently in NOAA reports (Carretta et. al., 2017). The area eventually decided upon was chosen because it would have been extremely taxing on survey resources and time to complete a full stock survey.

Future surveys will be required to flesh out the entire picture of marine mammal stocks in the Southern Puget Sound. In some ways, the limitations became an important guiding factor through the struggle to accomplish the goals set forth by the main researcher. The challenges faced throughout the survey only served to spur on the research team who strived to understand the greater patterns of marine mammals in the Southwestern Puget Sound ecoregion.

Chapter 4: Discussion

This thesis survey was as challenging endeavor as the researcher could have ever hoped to complete in the allotted time. Resources of all types were stretched to their limits to the extent that it was ultimately luck that made the project accomplishable. From the acquisition of a vessel to seasonally fair weather to supportive third-party emergency assistance, it is remarkable in several ways that this survey was completed and yielded significant results.

Results

The results from this survey were separated by season and showed distinct trends that support the validity of its methods, revealing patterns of harbor seal (*Phoca vitulina richardii*) distribution that were not expected. Because harbor seals were overwhelmingly more abundant than any other marine mammal observed, they were the focus of the bulk of the analysis. Results for harbor seals were compared with depth-class, temperature, and human activity, but first, the data had to prove to be non-random in distribution.

Non-random distribution tests included Band Collection Statistics tool in ArcGIS Pro to test for seasonal variability (Table 32) and chi-squared goodness-of-fit analysis of depth-class imprinted seal data (Table 33-35). A relationship between area size and harbor seal count was also explored, as a strong correlation with area size would indicate a normal spread of seals by area (Figure 52-54).

Band Collection Statistics analysis revealed that winter was the most unique season of the three seasons surveyed (Table 32). The tool compares maps with information summarized into cells that are assigned different values, such as seal count, and generates a correlation matrix. The results within the correlation matrix range from -1 to 1, with 0 being completely independent, -1 for a negative relationship, and 1 for a positive relationship. The results are as follows: summer-fall 0.28, summer-winter 0.02, fall-winter 0.08. This shows that summer and winter had the greatest variation in harbor seal distribution while summer and fall had the most distribution. This result begs the question as to why distributions are different.

The most promising relationship guiding variability in the distribution of harbor seals was depth-class. Seal abundance data was imprinted with depth-class values and then analyzed for non-randomness and normality. Chi-squared goodness-of-fit results across all seasons, even after adjustments made to simulate an even distribution of depth-class area, reveal that seals do prefer certain depth-classes over others ($p<0.001$) (Table 10-12). Fall and summer distributions, once plotted, are in normal curves encompassing 10-foot to 50-foot depth-classes (Figure 35-36). Winter was far different, seal depth-class preference continued to the limit of the survey region at the 100-foot to 300-foot depth-classes (Figure 37).

The most significant revelations from this research regarding harbor seals involve the estimates of abundance for the region. The way NOAA has surveyed harbor seals in the Southern Puget Sound has been to fly over haul-out sites and multiply that number by 1.53 to correct for seals missed in water during maximum haul-out (Carretta et. al., 2017). This correction value was derived from a study where a small sample of harbor seals in the Puget Sound was radio tagged from multiple populations and their haul-out behavior analyzed then averaged (Huber et. al., 2001). The results from this survey observed the maximum haul-out to be in fall, when 625 out of the 995 total seals were observed hauled out. This leaves 370 total in-water seal observations, which generates a correction value of 1.59 from the survey data (Table 31). This number is only 0.06 away from the number NOAA uses to estimate the total seals in the Southern Puget Sound region, based purely on haul-out counts.

The implications for the connection between the survey-generated correction value and the one NOAA used was enormous. It indicated that the methodology used produced similar results that NOAA would have estimated while having much richer information on the distribution of seals, regardless of whether they were in-water or hauled out. Because methodology and viewing conditions changed very little between seasons, this supports the accuracy of the survey's results on in-water harbor seals. Additionally, the methodology used did not cause seals to flee into the water, becoming in-water observations, at a higher rate than aerial surveys.

Harbor seal abundance estimates by season with haul-out percentages were as follows: summer had an average of 298 seals per lap with 27% hauled out, fall had an average of 332 seals per lap with 63% hauled out, and winter had an average of 180 seals per lap with 13% hauled out (Table 30).

Results for other species counted were not nearly as abundant as harbor seals and showed high seasonal variability. Harbor porpoises (*Phocoena phocoena vomerina*) were observed a total of 22 times in summer, 16 times in fall, and 71 times in winter, favoring deeper areas and passages in all seasons (Table 39-41). California sea lions (*Zalophus californianus)* were observed a total of 1 time in the summer, 1 time in the fall, and 89 times in the winter (Table 42-44), favoring the deep waters around the southwestern tip of Heron Island (Figure 41). Long-beaked common dolphins (*Delphinus capensis*) were only observed in the summer with a total count of 17 (Table 45). It is important to note that these are total counts across three laps of the survey area, and the true average would be those totals divided by three.

Challenges

As with any resource-limited survey, this project encountered many challenges along its one-year journey from conception to completion. These challenges occurred at regular increments starting with feasibility and with continuation into final data analysis. In this subsection, I will discuss a few challenges that made their mark and suggest ways in which future studies could be improved.

The conception of this project spawned from my passion for polar seal research, which arguably encompasses this survey, as harbor seals are an arctic species. Regardless, because the project started as an expression of passion for the animals being researched, ideas of feasibility and bias towards the conservation of marine mammals were present.

Originally, this project's research included topical discussions on fish conservation techniques by culling seals. Eventually, these discussions were redacted as I tended to side with the preservation of pinnipeds, and the survey's goals did not include fish-related elements. A separation between studying the distribution of marine mammals and engaging in the current fish conservation discussions was made. The question of whether to cull seals or not in the Puget Sound will be a question that haunts this area of research, and I am unable to comment on it as I am not knowledgeable on fish stocks only pinniped information.

The feasibility of this project was the first hurdle to overcome in its long journey to completion. I reached out to the Northwest NOAA permitting office, which informed me of the exact legal restrictions on conducting such a survey without a permit. Essentially, as long as the survey did not breach any normal marine mammal guidelines, it could legally be done. The survey was further refined with a visit to the PACMAM (Pacifica Mammal Research) office in Anacortes, Washington. Together with Dr. Cindy Elliser, a feasible design was drafted.

In April 2019, the Dent family offered me a 1977 Newport 28 sailing vessel, which would become the main research vessel. This vessel needed repair and deep cleaning before it could be used. Between April and June 2019, I worked on the boat until it was capable of having someone living aboard for extended periods, functional, clean, and Coast Guard legal.

In June 2019, summer surveys began and quickly became more about survival than surveying as the motor repeatedly failed. The Newman family generously purchased a new motor for the vessel, and surveys could continue as scheduled. Fall surveys went without incident and were conducted as planned.

Winter surveys were expected to be taxing and did result in some challenges. The dinghy motor and oars broke simultaneously during rough weather. I towed the dinghy with a kayak one mile through some of the roughest weather of the winter survey to exchange the old gas motor with an electric troller. The battery for the troller had a short and gave out several times for the remainder of the survey.

The point to these stories is to drive home the stress of operating old, barely functional equipment, yet nonetheless producing valuable survey results. There were many times at sea that I believed the current situation was the end of the survey. Either through the support of volunteers or family, these challenges were surmounted, and I was made better through struggle.

Once the data had been collected, it was time for the challenge of analysis techniques. These included downloading Survey123 results, complications with certain analysis techniques, and reflection on the survey methods used.

Survey123 functioned well as a data collection app, but the post-collection process was difficult. The most problematic issue was that Survey123 only downloads data with UTC (Coordinated Universal Time) of 0. This was fixed later in Microsoft Excel, but if this mistake had not been caught, results could have been for the wrong days and environmental value allocations could have been applied to the wrong data points, undermining all the Survey123 collected data. Future surveyors should design the program for the Esri Collector app which has options to remedy this issue.

The Band Collection Statistics tool in ArcGIS Pro is designed to provide statistics on stacked raster data sets. Covariance measures variability from the mean count and is used in the correlation equation. The correlation equation outputs a number between 1 and -1. A positive number is a positive spatial association between the two rasters, a negative number is a negative spatial association between rasters, and as the number approaches 0, the more independent from each other the rasters are. Comparing multiple rasters creates a matrix in which to compare results to one another. (Esri, 2016)

Raster cell size does affect the outcome of the test; smaller cells produce more significant independencies and large cells show more correlation, so it is important to make the cells large enough to incorporate area patterns but small enough to provide detail. This process was also attempted with raster cells of 1 square kilometer, and 10 square meters. The 1-square-kilometer raster analysis gave invalid values over 2 (on a scale of -1 – 1) suggesting over 200% similarity. The 10-square-meter raster squares returned extremely significant values of <0.0000 suggesting complete independence. This is possibly because at the 10-square-meter scale haul-outs become many different points even if they are the same platform. The 100-meter-square raster preserved the detailed distribution patterns of harbor seals while summarizing smaller areas (e.g. a swim platform, log boom, or dock) the most effectively when compared to the 10 square meter and 1 square kilometer rasters.

As a result, this tool may not be the most significant way of measuring spatial similarity between maps because results can be engineered to be significant, but it does generate valid results that match other patterns in the data, such as depth analysis. When used on the proper scale, this tool can reveal changes in distribution across data sets.

At times, this project uses R^2 to show relationships between environmental factors and the distribution of seals in an area. The areas make bins, and outlier values tend to affect R^2 results greatly. As a result, findings using this method are presented as areas of a possible relationship and not as significant findings.

Finally, I must address my own inherent biases. I am passionate about seals and I wish them the best, however, something as simple as this position can cause problems in Washington State. There is a push in Washington to save the salmon and other marine mammal populations by culling seals (Hayward et. al., 2005). My position is that it is the industrialized fishing practices of the state that has brought this issue in the first place and that the seals are being blamed because they are an easier target to alleviate political pressure than to tackle a whole industry. It may be that I believe in this position because I have never relied on a steady supply of fish to survive physically, culturally, or economically and thus am biased towards seal preservation.

Another point where my bias may seep into the data of my research is through the executive decisions I must make to prevent double counting. In wishing to produce a significant sample size, I was continually tempted to double count a seal even if they may very well have been the same seal I just saw. Even with all the preventative measures I took, there are still some grey areas when it comes to counting a seal that pops up in the water. I have aired on the side of caution and not counted "double count suspect" seals, regardless of what the volunteers believed or reported and blinded myself to the results of the survey while in that season's voyage.

Future Research

Continuing the legacy of ship-based marine mammal surveying can be quite the task for an individual or small research team. Digging for the methodological lessons learned by sailors who accomplished this effort without knowing a professional maritime historian, can turn up fruitless. In the interest of passing down what was learned during this endeavor to future surveyors, I have compiled a few suggestions regarding feasibility, methodology, and general observations for those new to the field.

The first step in creating a marine mammal survey is to talk to experts and discuss the ideal project that will answer a set of research questions. I began this project with several additional tasks to collect biometric data on marine mammals and collect water samples for pollutant analysis. These "arms" to the research were shown to me by professionals in the field to be difficult to accomplish due to the lack of lab resources and kinds of permitting required. Do not expect a warm welcome by experts in this field to inquiries as their default response is generally to tell you not to do anything marine mammal related. The only way to know for sure if your project is legally possible and to seek any permitting required to carry out a marine mammal survey is to contact your local NOAA permitting office (if in the USA) and truthfully lay out your research plans. This step may take anywhere from a few minutes to a year depending on the study.

Once the survey’s premise is confirmed to be ethical and legal then work on the scope can begin. The amount of time the researcher has, the area the research must cover, and the resources available will dictate the scope of the study. Because this study’s survey region had to be completed within school breaks, the size of the area comfortably surveyable had to be modified from the entire South Puget Sound to the western half of the South Puget Sound (Figure 15) then smaller due to other restrictions. Had this project covered the entire South Puget Sound, numbers and haul-outs could have been comparable with NOAA results, potentially adding to the significance of the study.

Even with such a large area to study in a short amount of time, a surveyor cannot compensate for this with a faster vessel. Moving at a speed of 5 knots, which was the typical speed of the main research vessel, was accidentally discovered to be the ideal speed for observing harbor seals in-water. It was slow enough to catch harbor seals popping up out of the water after a deep dive and fast enough to outpace their typical cruising speed, helping to prevent double counting. To cover a larger area in the same amount of time, it would have been beneficial to have multiple vessels with the same capabilities crewed by individuals with the same capabilities surveying different areas at the same time. However, this enters into the level of resources typically only accomplishable by larger organizations.

If the researcher or survey group has the luxury of choosing the specifications of the vessel used in their survey, there are a few considerations I would recommend. First, obtain a vessel with a shallow draft and a flexible range of speed. This will help the surveyor reach the ends of shallow bays and fight currents in narrow channels. Ensure the vessel is quiet, muted in color, and otherwise not intimidating to marine mammals to preserve their natural behavior. Finally, make sure the vessel is well up for the task before casting off, as technical issues may cause confounding variables in the data.

If the researcher or survey group has the luxury of choosing the crew of the survey vessel, make sure the navigator can operate completely independently of the rest of the team and that they are well in line with bias prevention methods. Second, a dedicated crew member should be present whose job is to solve technical issues should they arise and hand equipment to the navigator or observer. Occasionally, this was the case during this thesis when a volunteer navigator brought a third person aboard and allowed the observer to count without going below for water or different optics. Finally, it would be ideal if the same person with the best eye for spotting and counting was the observer throughout the survey. Not only does this help with consistency in viewing conditions, but every time a new person takes on a new role, there may be a learning curve that causes variability in the data.

On the topic of equipment, there are few changes that would have bettered this study. Environmental sensors that could give readouts of air and water temperature accurately in real time could have aided in the creation of a high-detail local temperature map across the survey region and enriched the data collected. These pieces of high-tech equipment are prohibitively expensive and require even more equipment to operate properly. Radio tagging and drone use would have also greatly added to the complexity and richness of this study. Radio tagging seals could have revealed their nocturnal distribution patterns, whereas the use of high-altitude drone imagery could have led to easier and safer counting of haul-outs. The drone images could also be used to collect biometric data for health analysis at different haul-outs. These methods, however, come with heavy permitting and high prices making them out of reach for unestablished researchers.

Ultimately, this thesis project was a proof of concept for small vessel observations of marine mammals in the region. Ideally, the survey would have used professional equipment, crew, and techniques with the backing of a large organization to accomplish the goal of updating the status of marine mammals in the South Puget Sound for the first time since 1999. There is still much room for improvement across all aspects of this study, and it will take many more years of rigorous surveying ventures to uncover more nuanced techniques. With ongoing management of marine mammals in a region of current unknowns, there is a race against the clock to uncover the true distribution and abundance of marine mammals in the South Sound ecoregion.

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Appendix

CAPTAIN'S LOG (Deep water Surveys)

Summer Survey

6-18-2019 Port Orchard – Hope Island

0730	Cast off smoothly. Volunteer Sarah K. onboard.
0900	Rounded the point by Blake Island heading south. Average of 5.9 knots. No wind, riding the tide out of Sinclair Inlet.
1140	Averaging 3.9 knots against the current, approaching Point Defiance.
1400	Passed under the Tacoma Narrows, now traveling at 6 knots with current.
1700	Arrived at Hope Island. Hooked buoy.

6-19-2019 Hope Island – Hammersley – Hope Island

0900	Underway from Hope Island with Volunteer Hayley B. onboard.
1200	Reached halfway point in Hammersley, ran out of gas fighting the current, water too shallow, and engine repeatedly dies on full throttle. Threw anchor to save the vessel from running aground. Now underway again returning to Hope Island.
1400	Exited Hammersley and continuing the South Pickering survey route.
1600	Windy conditions beginning to make navigation difficult.
1800	Hooked buoy at Hope Island.

6-20-2019 Hope Island – Case Inlet

0900	Underway from Hope Island with Volunteer Hayley B. onboard.
1100	At the northern extent of Case Inlet, motor quit and unable to start. Sails raised and returning to Hope Island.
2100	Currents and wind in Dana Passage have overpowered the vessel and twisted the rigging. Drifted towards the southern shore of the passage and threw anchor to save the vessel from running aground. Waiting for the storm to cease. Too rough to tow with the dinghy.

6-21-2019 Dana Passage – Hope Island

0000	I woke from light sleep to find the vessel had pulled anchor and is now adrift in the passage heading east. Anchor dragging and unable to be pulled up. Rigging still twisted. Motor still unable to start but seas have calmed. 911 called.
0045	Changed out the main motor for the dinghy motor, pulled anchor using a winch. Dinghy motor now pushing the vessel along at 5 knots. Harbor patrol called off.
0300	Arrived at Hope Island.
1247	Harbor patrol stopped by while repairs were underway to check-in.

6-22-2019 Hope Island – Eld – Budd - Hope Island

0830	Cast off from Hope Island and headed down Eld Inlet. Volunteer Noelle L. on-board.
1030	Completed Eld and heading down Budd.
1400	Hooked buoy at Hope Island. No engine trouble today. Many people out sailing in Budd Inlet.

6-23-2019 Hope Island – Totten – Peale Passage - Hope Island

0830	Cast off from Hope Island and heading down Totten Inlet. Volunteer Kaitlynn M. onboard.
1100	Completed Totten and beginning South Pickering route. Harstine bridge confirmed to be too low for the vessel to traverse. The motor stopped briefly but was easily restarted.
1400	Hooked buoy at Hope Island.

6-24-2019 Hope Island – Henderson - Case Inlet – Jerrell Cove

0830	Cast off from Hope Island with volunteer Sally N.
0930	Entered Henderson Inlet
1020	Completed Henderson Inlet, heading up Case Inlet.
1300	Entered Pickering Passage, engine hiccup but restarted.
1430	Completed Picking to bridge and back. Hooked buoy at Jerrell Cove.

6-25-2019 Jerrell Cove - Jerrell Cove

0800	Cast off from Jerrell cove with volunteer Sally N. South into Pickering.
0900	Reached Harstine bridge and turned north.
0945	Engine out and unable to be restarted. Dinghy motor tangled in the line. Began towing vessel with dinghy oars back to Jerrell Cove.
1030	Dinghy motor repaired and the vessel towed back to Jerrell under power. New motor for the main vessel ordered.

6-26-2019 Jerrell Cove – Case Inlet – Henderson – Hope Island

0800	Set off from Jerrell Cove with new motor and volunteer Sally N.
0830	Entered Northeast Case Inlet.
1020	Passed Heron Island.
1145	At Henderson Inlet. New motor working at 6 knots with the tide.
1300	At Dana Passage, water completely still all day.
1330	Hooked buoy at Hope Island.

6-28-2019 Hope Island – Peale Passage – Budd – Eld – Totten - Hope Island

0845	Set off for South Pickering survey with volunteer Hayley B.
1000	Completed the South Pickering area and beginning Budd Inlet.
1345	Completed Budd and Eld Inlets. Visited Hope Island for rest.
1500	Set off again down Totten Inlet.
1800	Completed Totten and hooked buoy at Hope Island.

6-29-2019	Hope Island – Henderson - Case Inlet – Jerrell Cove
0830	Set out from Hope Island with volunteer Sara N.
0915	Entered Henderson Bay. Police vessel traffic observing fishing boats forced research vessel to tack into shallow water just before entering inlet to avoid a collision.
0955	Completed Henderson Bay, continuing north along West Case Inlet.
1148	5 dolphins visited and swam around bow northwest of Heron Island.
1230	Entered Pickering Passage.
1400	Completed Pickering Passage, hooked buoy at Jerrell Cove.

6-30-2019	Jerrell Cove – Case Inlet – Henderson – Hope Island
1030	Cast off from Jerrell Cove into Pickering Passage with volunteer Sara N.
1105	Reached North Case Inlet.
1230	Lunch in East Case Inlet.
1300	Continued south along East Case Inlet.
1500	Entered Henderson Inlet.
1600	Entered Dana Passage.
1630	Hooked buoy at Hope Island.

7-1-2019	Hope Island – Totten - Hope Island
0900	Cast off from Hope Island heading into Totten Inlet with volunteers Sara N. and Sally N. onboard.
1000	Arrived at Little Skookum Inlet, attempting to survey with the dinghy.
1200	Tide went out, remaining water far too shallow for the dinghy. Walked out of Little Skookum dragging dinghy.
1400	Hooked buoy at Hope Island.

7-2-2019	Hope Island – Eld – Budd - Hope Island
0840	Cast off from Hope Island heading into Eld Inlet with volunteer Hayley B.
1000	Completed Eld, entering Budd Inlet.
1200	Cruising by Boston Harbor.
1300	Arrived at East Hope Island. Very low tide.

7-3-2019	Hope Island – Case Inlet – Hope Island
0830	Cast off Hope Island with volunteer Hayley B.
1130	Reached North Bay in Case Inlet to make up for the 6-20-19 survey.
1430	I arrived back at Hope Island.

7-4-2019	Hope Island – Port Orchard
0730	Cast off from Hope Island with volunteer Caelin Lee.
1030	Under Tacoma Narrows.
1230	Rounded corner into Sinclair Inlet. Lots of traffic heading to Seattle.
1400	Arrived at the dock.

Fall Survey

8-29-2019	Port Orchard – Hope Island
0900	Cast off from dock with the tide. Volunteer Hayley B. onboard.
1030	Rounded corner out of Sinclair Inlet to head south.
1400	Crossed under Tacoma Narrows Bridge.
1530	Lighting storm ahead of the vessel, crossing south sound heading north
1815	Hooked last buoy remaining at Hope Island.

8-30-2019	Hope Island – Totten Inlet – Hope Island
0930	Cast off from Hope Island with volunteer Claire O. Beginning South Pickering area.
1050	Completed South Pickering with Peale Passage, entered Totten Inlet.
1355	Hooked buoy at Hope Island.

8-31-2019	Hope Island – Eld – Budd - Hope Island
0930	Cast off from Hope Island with volunteers Sara N., Paul L., and Hayley B. onboard.
1100	Completed Eld, Beginning Budd Inlet.
1400	All buoys taken, anchored to the south of western buoys.
1700	Hooked a buoy that opened.

9-1-2019	Hope Island – Henderson - Case Inlet – Jerrell Cove
0930	Cast off from Hope Island with volunteer Sara N.
1000	Arrived at Henderson Inlet.
1100	Completed Henderson Inlet heading up Case.
1500	Arrived at Jerrell Cove.

9-2-2019	Jerrell Cove – Case Inlet – Hope Island
1100	Cast off from Jerrell Cove with volunteer Sara N. into Pickering.
1300	Completed Pickering Passage, entering Case Inlet.
1600	Completed East Case Inlet.
1700	Arrive at Hope Island.

9-4-2019	Hope-Island – Totten Inlet – Hope Island
1000	Cast off from Hope Island with volunteer Sarah K. onboard.
1200	Completed survey of South Pickering, entering Totten Inlet.
1430	Returned to Hope Island.

9-5-2019	Hope Island – Eld – Budd - Hope Island
0945	Cast off from Hope Island. Volunteer Hayley B. onboard. Heading for Eld.
1200	Completed Eld Inlet.
1300	Completed Budd Inlet
1430	Hooked buoy at Hope Island.

9-6-2019	Hope Island – Henderson Inlet - Case Inlet – Jerrell Cove
1430	Cast off from Hope Island. Volunteer Sally N. onboard.
1530	Arrived at Henderson Inlet.
1630	Completed Henderson, heading into Case Inlet. Very stormy waters.
1845	Arrived at Jerrell Cove.

9-7-2019	Jerrell Cove – Case Inlet – Hope Island
1100	Cast off from Jerrell Cove. Volunteer Sally N. onboard. Beginning Pickering.
1400	Completed Pickering, now in North Bay.
1800	Completed East Case, heading into Dana with bad weather.
1910	Arrived at Hope Island. All buoys taken, anchored northwest of buoys.
1930	Hooked buoy that opened.

9-8-2019	Hope Island – Totten Inlet – Hope Island
0900	Cast off from Hope Island with volunteer Sally N. Beginning South Pickering area.
1100	Entered Totten Inlet
1400	Hooked buoy at Hope Island.

9-10-2019	Hope Island – Eld – Budd - Hope Island
0930	Cast off from Hope Island. Volunteer Claire O. onboard. Heading for Eld.
1000	Completed Eld Inlet.
1200	Completed Budd Inlet
1300	Hooked buoy at Hope Island.

9-11-2019 Hope Island – Henderson Inlet - Case Inlet – Jerrell Cove

1200	Cast off from buoy. Volunteer Hayley B. onboard.
1300	Entered Henderson Inlet.
1400	Completed Henderson, entering Case Inlet.
1630	Arrived at Jerrell Cove.

9-12-2019 Jerrell Cove – Case Inlet – Hope Island

1030	Cast off from Jerrell Cove with volunteer Hayley B. into Pickering.
1130	Completed Pickering Passage, entering Case Inlet.
1400	At Heron Island.
1800	Arrive at Hope Island.

9-13-2019 Hope Island – Port Orchard

0500	Cast off from Hope Island with volunteer Sally N.
0725	Passed McNeil Island Prison. Mainsail up.
0822	Crossed under Tacoma Narrows.
0830	Main and headsails up on the wing.
1100	Rounded corner to Sinclair inlet.
1300	Arrived at the dock.

Winter Survey

12-20-2019 Port Orchard – Hope Island

0400	Preparations to disembark began. Rain and wind constant.
0430	Departed dock smoothly. Volunteer Hayley B. onboard.
0800	Sunrise, heading south, averaging 5-6 knots. Wind and rain constant.
1030	Heavy wind, waves, and rain. Passing McNeil Prison.
1130	Entered Nisqually Reach and approaching Case Inlet. The weather only slightly improved.
1445	Hooked buoy at Hope Island. Everything is soaked. Tarp deployed and heater on to dry the interior.

12-21-2019 Hope Island – Totten Inlet – Hope Island

1100	Cast off from Hope Island. Volunteers Hayley B. and Paul L. onboard.
1330	Completed South Pickering. Heading into Totten with drizzling rain.
1530	Completed Totten Inlet and hooked buoy at Hope Island. Rain stopped. All is dry now.

12-22-2019	Hope Island – Eld – Budd - Hope Island
0930	Cast off from Hope Island. Volunteer Jenifer W. onboard.
1000	Entered Eld inlet.
1200	Completed Eld, entering Budd Inlet.
1400	Completed Budd Inlet.
1430	Hooked buoy at Hope Island.

12-23-2019	Hope Island – Henderson Inlet - Case Inlet – Jerrell Cove
0930	Cast off from Hope Island. Volunteer Sally N. onboard. Overcast and cold, but no rain.
1030	Completed Dana Passage, entering Henderson.
1130	Heading north along West Case Inlet. No other boats but many sea lions, porpoises, and seals southwest of Heron Island.
1300	Arrived at Jerrell Cove just as the sun came out. Very warm and calm now.

12-24-2019	Jerrell Cove – Case Inlet – Hope Island
0930	Cast off from Jerrell Cove with volunteer Sally N. into Pickering.
1045	Reached Harstine bridge, turned north.
1130	Wind and waves in Case Inlet, heading into North Bay.
1230	Reach North Bay turn around. Heading south into Case.
1330	Dinghy motor came loose. Refastened and refueled while in the northeast Case Inlet.
1430	Passed Heron Island.
1530	Entered Budd Inlet.
1630	Hooked buoy at Hope Island.

12-26-2019	Hope Island – Totten Inlet – Hope Island
1000	Cast off from Hope Island with volunteer Hayley B. onboard. Beginning South Pickering area.
1220	Completed Peale Passage.
1300	Entered Totten.
1500	Hooked buoy at Hope Island.

12-27-2019	Hope Island – Eld – Budd - Hope Island
1000	Cast off from Hope Island with volunteer Hayley B. onboard.
1200	Completed Eld, entering Budd Inlet.
1400	Completed Budd Inlet.
1430	Hooked buoy at Hope Island.

12-28-2019	Hope Island – Henderson Inlet - Case Inlet – Jerrell Cove
1000	Cast off from Hope Island with volunteer Angela D. onboard.
1045	Through Dana Passage.
1130	Completed Henderson Inlet, entering Case Inlet.
1400	Arrived at Jerrell Cove.

12-29-2019	Jerrell Cove – Case Inlet – Hope Island
1030	Cast off from Jerrell Cove with volunteer Angela D. onboard.
1100	At Harstine Bridge turnaround.
1300	At North Bay turnaround.
1430	Passed Heron Island.
1540	Case Inlet complete, sails raised for Dana Passage.
1630	Hooked buoy at Hope Island.

12-31-2019	Hope Island
0830	Attempted to pick up volunteer Claire O. dinghy motor unable to start. Attempted to row back to the vessel but oars broke off.
1000	Paddled against current, wind, rain, and waves back to the vessel.
1400	The storm has not let up. Towed dinghy with a kayak through rough water to Acadia boat launch where volunteer Sally N. was waiting to replace the motor with electric troller.
1530	Completed motor swap, heading back to Hope Island.
1500	Motor battery box had short in it. Paddled to the northern shore of Hope Island with a broken oar and walked dinghy with kayak back to vessel.

1-1-2020	Hope Island – Peale – Budd – Eld – Totten – Hope Island
0850	Cast off from Hope Island with volunteer Claire O. onboard.
1050	Completed South Pickering. Now headed south into Budd Inlet. The wind is gale force and large waves coming from the south.
1230	Completed Budd, entering Eld, wind slightly improved.
1430	Completed Eld, gale winds again.
1500	Entered Totten, light rain and gale winds.
1600	Completed Totten.
1630	Hooked buoy at Hope Island.

1-2-2020	Hope Island – Henderson Inlet - Case Inlet – Jerrell Cove
0920	Cast off from Hope Island. Volunteer Sally N. onboard.
1020	Completed Dana Passage, picked up two floating 55-gallon barrels with the dinghy.
1120	Completed Henderson Inlet, heading up Case.
1230	Many sea lions around Heron Island.
1430	Tied to Jerrell Cove dock.

1-3-2020	Jerrell Cove – Case Inlet – Hope Island
0830	Cast off from Jerrell Cove with volunteer Sally N. into Pickering.
0930	Reached Harstine Bridge, heading back north.
1100	Reached North Bay, heading south.
1300	Passed Heron Island.
1530	Hooked buoy at Hope Island.

1-4-2020	Hope Island – Port Orchard
1020	Cast off from Hope Island. Volunteer Jenifer W. onboard.
1115	Sail up by Henderson, though lowered shortly after as wind and waves begin.
1315	Under Tacoma Narrows. Currents and waves causing the vessel to surf through the passage.
1530	At Blake Island, waves intense from deeper Puget Sound.
1630	Through the cut to Sinclair Inlet. Very rough water on both sides of the passage. Sunset.
1800	Tied to dock in Port Orchard.