SEABIRD INDICATORS FOR CHERRY POINT AQUATIC RESERVE:

INTEGRATING COMMUNITY SCIENCE DATA INTO MARINE CONSERVATION

by

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ABSTRACT

Seabird Indicators for Cherry Point Aquatic Reserve: integrating community science data into marine conservation

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Seabirds are ecosystem indicators currently used in the Salish Sea to track progress towards management goals and monitor the status of marine habitats. Depending on available data, life history, and regional trends, certain seabird species are better indicators than others. Cherry Point Aquatic Reserve (CPAR), one of eight Aquatic Reserves managed by the Department of Natural Resources Aquatic Reserves Program, encompasses 3,050 acres of nearshore habitats in the eastern Strait of Georgia. Community scientists have collected seabird data at CPAR since April 2013 at three shore-based locations. While this data was collected to inform CPAR management, it had never been reviewed, analyzed, or incorporated into Aquatic Reserves Program frameworks. This thesis thoroughly reviews the CPAR dataset and creates replicable data management, quality control and analysis methods by which the Aquatic Reserves Program can better incorporate other community science efforts. Additionally, this thesis discusses the application of seabird indicators to small management areas and recommends that Surf Scoter, Pelagic Cormorant, and a forage fish specialist like Pacific or Red-throated Loon be the focus of ongoing monitoring and analyses to best track CPAR ecosystem health and resilience. Finally, this thesis outlines recommendations for other agencies and groups that may wish to improve their seabird data collection processes and data quality. Salish Sea conservation and restoration efforts increasingly incorporate community science data to strengthen conservation outcomes. This thesis occupies the space where the objectives of management agencies, academic researchers, and volunteer/community scientists overlap and provides a model for the effective conservation and management of marine habitats.

Key Words: seabirds, indicators, marine conservation, Aquatic Reserves, collaborative management, community science, Salish Sea, Puget Sound

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INTRODUCTION

As the human population has increased and altered local environments, Salish Sea ecosystems and habitats have declined. Marine management and monitoring groups across Puget Sound and the Salish Sea focus on restoration and conservation, but marine ecosystems are interconnected, complex and hard to measure. To track progress towards management goals and assess ecosystem health, scientists have identified measurable variables that function as indicators for the underlying system. Marine bird, or seabird, abundance is one indicator of ecosystem health, biodiversity, and resilience. Long-term datasets on indicators are hard to maintain for many agencies due to funding restrictions or changes in agency direction. Community science can fill these data gaps and seabird data in particular is being incorporated into analyses and literature (Toft et al., 2017).

Marine birds are effective indicators since they are well studied and their abundance and distribution reflect underlying prey availability and habitat health (Gaydos & Pearson, 2011). As top predators in marine systems, seabirds are controlled by bottom-up processes (McLeod et al., 2009; Piatt, Sydeman, et al., 2007). At its most simplified, poor habitat leads to low prey availability which results in fewer birds. Indicators respond to habitat change and perturbation in different ways. Seabirds are non-specific and lagging indicators, meaning that their abundance responds to widespread change and a delay exists between that change and seabird response.

In the Salish Sea, seabird abundance has declined precipitously since the first comprehensive baseline surveys conducted in the late 1970s (Wahl et al., 1981) and have continued to decline since the 1990s (Vilchis et al., 2015). Historical seabird populations were likely even larger as industrialization and colonization of the Salish Sea were well underway by the time of the 1970s baseline surveys (Bower, 2009). Now areas of particularly high seabird density have shifted as continued urbanization impacts prey and habitat resources. Four local seabird species are now listed at the state or federal level: Marbled Murrelet (state endangered, federally threatened), Common Loon (state sensitive), Western Grebe (state candidate) and Tufted Puffin (state endangered). Federal, Tribal, state, and community organizations are a few of the entities collecting data to help track seabirds in the Puget Sound and Salish Sea.

To combat further species and habitat declines, the Puget Sound Partnership was created and tasked with leading the effort to restore and protect Puget Sound. They compile data from community scientists, Tribes, and other state agencies to track "vital signs" or indicators. Seabird abundance is one of these vital signs. Community science efforts like the British Columbia Coastal Waterbird Surveys, Puget Sound Seabird Surveys and Salish Sea Guillemot Network are a few of the many community science networks providing valuable data far beyond any single agency's capability and scientists are increasingly facing the happy challenge of incorporating this kind of data into monitoring and decision-making frameworks. Community science can be particularly valuable for small programs such as Washington State Department of Natural Resources (DNR) Aquatic Reserves Program.

DNR Aquatic Reserve's Program manages eight Aquatic Reserves, each of which was established for their scientific, natural, and cultural importance. One of the reserves is Cherry Point Aquatic Reserve (CPAR). CPAR encompasses 3,050 acres of intertidal and subtidal habitats in the eastern Strait of Georgia along the western coast of Whatcom County in Washington State. This reserve has dedicated community involvement in the form of a Community Stewardship Committee and several self-organized monitoring efforts, one of which is a seabird survey.

The CPAR marine bird surveys were established in 2013 with the intent of providing seabird abundance data specific to the Aquatic Reserve to inform reserve managers. The community scientists conducting these surveys are self-organized and incredibly dedicated. RE Sources, a nonprofit in Bellingham, Washington, is the steward for this data and the community organizer for the Stewardship Committee. The CPAR Birders conduct monthly surveys at three locations along the Cherry Point shoreline. They organize training for new members and implement a consistent methodology developed from the historical Marine Ecosystems Analysis (MESA) surveys conducted in 1978/79 (Bower, 2009). The resulting dataset is now a valuable source of information spanning nine years and including 29 marine bird species.

In this thesis I attempt to answer one main question: How can this small data set, focusing on a specific area, and collected by community scientists, inform conservation and restoration of marine ecosystems? I take the three-pronged approach to citizen science analysis suggested by Toft et al. (2017) incorporating three potential audiences for these analyses: volunteers, managers, and scientists. Each audience has different but overlapping objectives. Volunteers (i.e., community scientist) may be most interested in which species are most often encountered and when. Managers may be interested in which species or groups are the best indicators for this area and warrant continued focus. Scientists, or academic biologists, may be interested in changes to marine bird and/or individual species density over the duration of this survey effort.

Before I could begin analyses, I restructured the database, referenced old scans, and wrangled the data to make it more accessible to data scientists. Data visualization and analysis identified species most often encountered at Cherry Point. I looked at change between and over seasons and months, grouped seabirds by feeding guild (piscivore, herbivore, benthivore, omnivore and planktivore) (Bower, 2009), and looked for shifts in migration timing. The combined efforts of the data collectors and myself establish a status report on CPAR marine birds which can be used as a baseline for future comparison. I identify areas for further analysis and inquiry, suggest methodological alterations to increase the quality of the dataset, and create a system by which the CPAR bird data is accessible to Aquatic Reserve Program staff and managers. In this way, CPAR seabird data can be used to inform adaptive management and track progress towards management goals.

While seabirds can indicate environmental health, biodiversity, habitat condition, and climate change on a large scale (Pearson & Hamel, 2013), using them as indicators for smaller areas like aquatic reserves has limitations. Certain species may be better than others as indicator selection is based on life history, particular ties to the management area and availability of data. Many seabird species are migratory and have mixed life history which means that declines in some species may be due to degradation of the lakes they depend on for breeding grounds (i.e., Common Loon), a decrease in old growth trees required for nesting (i.e., Marbled Murrelet), or negative impacts to other areas of their migratory route.

Despite the concerns around migratory species as indicators, scoters may be a valuable indicator for Cherry Point. The Cherry Point herring stock used to be an unrivaled resource for local seabird populations, but since the 1970s this herring stock has critically declined. Surf Scoter are particularly tied to herring spawn (Boyd et al., 2006, Lok et al., 2012) and during this same time, the population of Surf Scoters foraging at Cherry Point has declined by 90% (WDNR, 2010). The duration of time Surf Scoters spend at CPAR has also decreased with the amount of spawn (Sandell presentation for the Cherry Point Implementation Meeting, Nov. 30, 2021).

At a little more than 12 km^2, Cherry Point Aquatic Reserve is a small part of the entire

18,000 km^2 Salish Sea, but with the extra monitoring and support provided by community scientists, the information available to managers is magnified. This thesis examines the application of seabird indicators to small management areas and provides an example to community and agency scientists alike on how to incorporate community driven data into monitoring and decision-making frameworks. In this way, this thesis contributes to the overall effort to restore and conserve the Salish Sea.

LITERATURE REVIEW

Seabirds are ecosystem indicators used to represent the resilience and function of the underlying marine system. Their abundance can indicate prey availability, habitat suitability, exposure to pollutants and ecosystem stressors such as algal blooms or warm water events. Seabird survival and abundance reflects the structure and function of the marine environment (Pearson & Hamel, 2013). They are a diverse group foraging at different trophic levels and utilizing various habitats. Some seabirds specialize in a specific habitat or prey source which ties them to that resource's availability. Other seabirds are generalists relying on many prey and habitat types. While some seabirds are year-round residents of the Salish Sea, many are migrants that rely on Salish Sea resources for only a portion of their life history.

The first section of this literature review discusses the use of seabirds as indicators and two main applications for their use: focusing on ecosystems and focusing on fisheries. Then it examines the application of seabird indicators to small management areas like Cherry Point Aquatic Reserve (CPAR) and suggests theoretically appropriate seabird indicators for CPAR using information from current ecosystem indicator publications and documented seabird response to herring spawn events.

The second part of this literature review explores seabird trends in the Salish Sea and what these trends may mean for aquatic habitats. Understanding these trends can help contextualize results from this thesis' data exploration and analyses. The Marine Ecosystem Analysis (MESA) seabird surveys are the historical baseline for current seabird abundance studies in the Salish Sea. Those methods have developed into the protocols currently implemented by community scientists at CPAR.

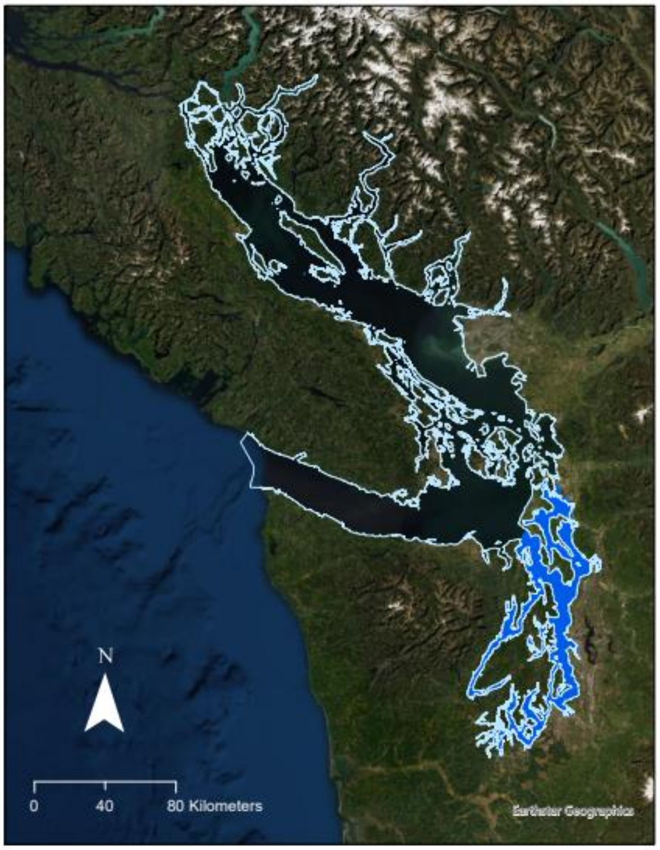
Finally, this review examines literature on the strengths and weaknesses of community science data. The purpose of this thesis is to both evaluate the data and create a framework for the Aquatic Reserve Program by which this kind of community science effort can be better incorporated and used to inform management decisions.

Definitions of the Salish Sea and Puget Sound

The referenced literature refers to two main general locations: the Salish Sea and Puget Sound. These are overlapping areas that encompass the inland waterways of Washington State and British Columbia. Puget Sound is the southern portion of the Salish Sea. It includes Washington's inland waters from the opening of Admiralty Inlet including the Whidbey Basin to the North and East, down to Olympia in the South. The Salish Sea includes Puget Sound as well as the San Juan Islands and Straits of Juan de Fuca and Georgia.

Figure 1

Map of the Salish Sea and Puget Sound



Note. The Salish Sea is outlined in light blue and the dark blue fill denotes Puget Sound. Boundaries were created using definitions from the Encyclopedia of Puget Sound (2015).

What is an indicator?

Indicators serve as quantitative proxies for ecological processes (e.g. energy flow) or ecosystem state (e.g. biodiversity) (Kershner et al., 2011; Tam et al., 2017). Systems are complex, interconnected, and hard to measure. Indicators are easier to measure and reflect the function of the underlying system. Ecosystem managers select a portfolio of indicators specific to their management goal(s) and use those indicators to assess management efficacy and inform adaptive strategies.

Different management goals may require different indicators. Biological indicators are applied to goals like increased biodiversity, habitat resilience and robust food webs. Social indicators are better applied to goals like increased community involvement and participation (Levin et al., 2009). Biological indicators can be diagnostic and track a few key attributes or be nonspecific and track many attributes. They may respond quickly to perturbations and changes and be early-warning indicators, or they may respond slowly and be retrospective.

The Puget Sound Partnership (PSP), the agency tasked with restoring and conserving Puget Sound, is a local example of ecosystem-based management. PSP has identified five Puget Sound Recovery Goals and 13 indicators that that they refer to as vital signs (McManus et al., 2020). These 13 vital signs correspond to five main goals spanning physical, biological, and human processes. The vital signs are a suite of complementary indicators identified by PSP to best track Puget Sound recovery. Birds are just one vital sign used to track progress towards the goal of thriving species and food web (McManus et al., 2020). Suites of complimentary indicators may be the best way to approach complex ecosystems, but that effort is beyond the scope of any single thesis or scientist.

Seabirds as ecosystem indicators

As higher trophic-level species, seabirds are controlled by bottom-up processes (McLeod et al., 2009; Piatt, Sydeman, et al., 2007). Poor habitat leads to low prey availability which results in fewer birds. Seabird biomass, or abundance, can reflect the biomass of lower trophic-level organisms in Puget Sound (Harvey et al., 2012). Seabirds can thus indicate the consequences of ecosystem trends related to climate change and other anthropogenic disturbances (Piatt, Sydeman, et al., 2007). Warming waters, acidification and hypoxic zones affect plankton and forage fish, which propagates up the food chain and is reflected by seabird numbers. Between 2014 and 2016 a marine heat wave known as the ‘Blob’ hit the West Coast of North America. It reduced the biomass of phytoplankton which altered the zooplankton community to be less nutritional for forage fish (Piatt et al., 2020). Forage fish numbers decreased and also became less nutrient rich. The scarcity and nutritional deficiency of forage fish lead to a mass mortality of Common Murre. Between summer 2015 and spring 2016 over 60,000 Common Murre washed up on the beaches of Washington and Oregon in varying states of starvation (Piatt et al., 2020). Thus, seabirds can provide valuable feedback on marine ecosystem trends and anthropogenic activities that impact the environment.

Some seabird species are better indicators than others depending on their feeding behavior, migratory habits, and other aspects of their life history (Harvey et al., 2012). Resident diving birds such as cormorants and alcids; migratory diving birds such as grebes, mergansers, and loons; some local and migratory gull species; and nearshore diving birds such as scoters, goldeneye and bufflehead are all good lagging indicators. The term "lagging" refers to the delay between the initial habitat change and a seabird response. Other species such as bald eagles and dabbling ducks are poor indicators due to their lack of correlation with their prey groups (Harvey et al., 2012). Feeding behavior also influences indicator quality. Aerial and surface feeders (i.e., gulls, terns, dabbling ducks) forage over large areas but rely on prey being available near the surface and are therefore susceptible to vertical changes in prey density. Pursuit divers (i.e., alcids, cormorants, scoters etc.) are more able to cope with vertical changes but are vulnerable if prey spread out over a wider horizontal area (Boyd et al., 2006). Seabirds that expend more energy when foraging are more susceptible to changes in prey abundance, namely large-bodied diving birds (Vilchis et al., 2015).

Seabird indicators used by the Puget Sound Partnership

In Puget Sound, researchers use seabirds as indicators of food web structure and ecosystem resilience. The Puget Sound Partnership (PSP) is a state agency created in 2007 to oversee the regional efforts to restore and conserve Puget Sound. PSP uses indicators to track progress and restoration success. Kershner et al. (2011) focused on one goal of the Partnership which is "healthy and sustaining populations of native species in Puget Sound, including a robust food web" (p. 3). They identified a portfolio of indicators that could provide feedback to managers across different temporal and spatial scales. Kershner et al. (2011) identified seven indicators including non-breeding marine bird population size estimates. They identify seabird abundance as a non-specific, retrospective indicator of ecosystem function.

Pearson et al. (2013) selected specific seabird indicator species for Puget Sound Vital Signs, which is the monitoring component of the PSP. Since Kershner et al. (2011) established that seabird abundance was a food web indicator, Pearson et al. (2013) selected specific seabird species that have established monitoring efforts, are abundant and well distributed, and have significant reliance on Puget Sound resources. 'Significant reliance' means that they consume almost exclusively marine resources and spend most of their time in Puget Sound. This excludes species that use both marine and freshwater ecosystems (i.e., Great Blue Heron, Double-crested Cormorant, and loons). Pearson et al. (2013) recommends three resident species that breed in Puget Sound (Pigeon Guillemot, Rhinoceros Auklet and Marbled Murrelet) and one over-wintering species group (scoters).

For an indicator to be useful there must be a link between the population status and local conditions. Overall, a considerable amount of migrating seabirds' life is spent outside the Salish Sea, therefore outside conditions, as opposed to local environmental conditions, may be driving trends. Despite being migratory, scoter species also have an established link to the Salish Sea. They have site fidelity, returning to the same molting locations year after year (de la Cruz et al., 2009). Molting is energetically taxing, and scoters are particularly reliant on local habitat areas and prey resources for successful primary feather regrowth. Additionally, some juveniles and non-breeding individuals do remain in Puget Sound throughout the year. In this way, Puget Sound has an exacerbated effect on scoter fitness compared to other migratory winter bird species (Crewe et al., 2012). This increased reliance on Puget Sound habitats makes scoters good indicators even though they are not year-round residents.

Limitations and a 'coarse' approach

There are limitations to any single indictor, especially a highly mobile top predator such as seabirds. Abundance estimates can be highly variable, and it may take years of data to detect trends (Boyd et al. 2006, Wahl et al., 1981). Therefore Pearson et al. (2013) selected only species which already had long-term abundance data in Puget Sound. Even then, they refer to their approach as "coarse-grained" (p. 3) with the intent to indicate trends in Puget Sound-dependent bird populations which may reflect a long-term view of Puget Sound health. This 'coarseness' also makes it challenging to identify reasons for change in seabird abundance. A decreasing abundance trend may reflect decreased habitat health but does not provide information on why habitat degradation is occurring. Indicator species that have a foraging preference, will diversify if their preferred prey becomes scarce (Boyd et al. 2006). Seabird abundance is unlikely to respond to anything less than a large-scale change in many different prey options which requires a sweeping impact to the ecosystem. That being said, seabird behavior is highly responsive to ecosystem shifts (Montevecchi, 1993).

Seabirds as fisheries indicators

The idea of seabirds as fisheries indicators has been around since the 1980s (Cairns, 1987; Montevecchi, 1993; Piatt, Harding, et al., 2007; Piatt, Sydeman, et al., 2007). Seabirds consume prey at multiple trophic levels and in areas that are otherwise challenging for fisheries managers to survey. Incorporating seabird data into larger fisheries models allows managers to see how fisheries impact the ecosystem at large. Seabird abundance, behavior and survival are all indices that may reflect prey availability (Sydeman et al., 2017).

For fisheries indicators, the piscivorous (fish-eating) species are most appropriate. Many of these species rely on forage fish, which are the group of small silver fish that form an essential link between primary consumers like plankton and higher trophic-level consumers, such as larger fish, birds, and marine mammals. Specific to herring, a 1999 seabird predation report (Bishop & Green, 2001) created a bioenergetics model for spawn consumption that allowed Alaska Department of Fish and Game to adjust their adult herring spawner biomass estimates. By monitoring Glaucous-winged Gull aggregations, managers could better estimate the amount of spawn consumed by avian predators and incorporate it into their model.

Similar to the application of seabird indicators to ecosystems, seabird indicators for fisheries is a coarse approach and some species may be better suited than others (Sydeman et al., 2017). A challenge that leads to this coarseness is that there are competing forces in play. There may be direct competition between seabirds and fisheries that target forage fish species. Other fisheries may remove competition since they often target higher trophic-level fish species that would otherwise consume the same prey as seabirds. Removing these larger fish can alleviate predation pressure on these prey sources allowing for more availability to seabird predators.

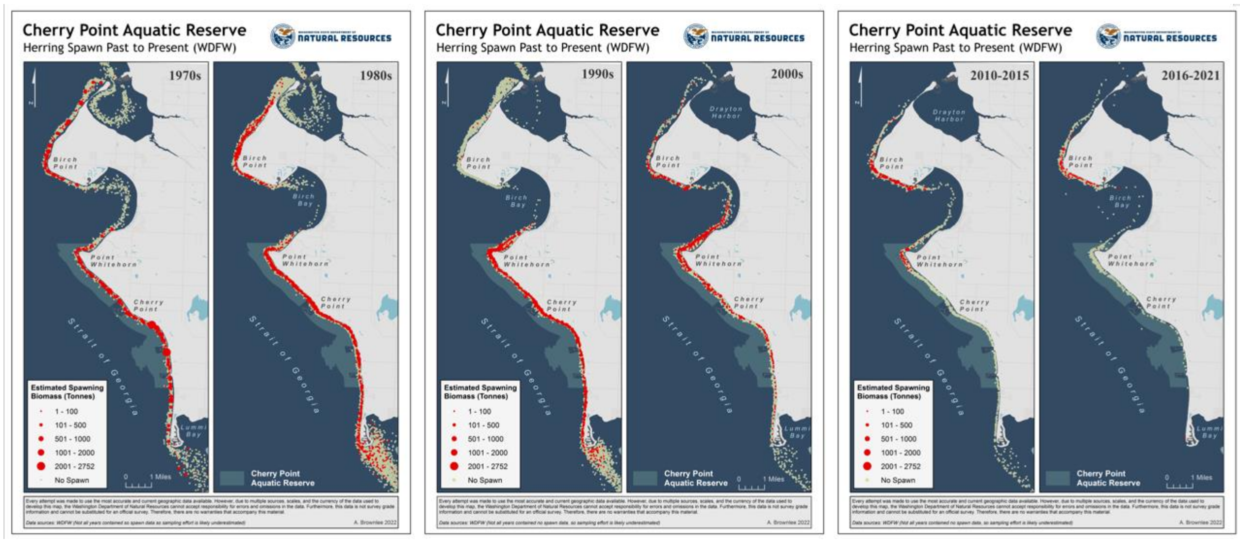
Seabirds and herring

Whether it is an ecosystem or fishery stock, seabird abundance reflects large changes, not small events, or availability of specific prey sources. One exception to this may be Pacific herring (*Clupea pallasii*) spawn. Herring are forage fish that mass reproduce by laying eggs on submerged aquatic vegetation, particularly eelgrass and macroalgae, forming hotspots of potential food for predators such as seabirds. Each spawning event lasts around three to five weeks (Lewis et al., 2007) and, generally, the higher the latitude the later the spawn event (Lok et al., 2012). Herring in Puget Sound spawn from January to June (Sandell et al., 2019).

Washington State Department of Fish and Wildlife (WDFW) customarily monitors the 21 distinct Pacific herring stocks in Puget Sound (Sandell et al., 2019). Each stock returns to the same locality each year to spawn, which means that there is minimal individual movement between localities. Stocks that are depleted receive few recruits from other populations, making recovery more challenging. One struggling stock is the Cherry Point herring stock which is genetically distinct and spawns later (typically late April to mid-June) than any other Pacific herring stocks in Washington State. From 1973 to 2016, the Cherry Point herring stock declined from 13,606 tonnes to 468 tonnes of stock biomass, a 96% decrease (Sandell et al., 2019). Figure 2 illustrates the decline of the Cherry Point herring spawn deposition. Until the 1990s, it was the largest herring stock in Washington State and supported the only commercial roe fishery in Puget Sound. That roe fishery may have caused the initial population plummet (Gustafson et al., 2006). Despite extensive research, the cause for their continued decline is unknown. Climate change, pollution, changes to predator/prey dynamics or disease are all potential culprits (Sandell et al., 2019). In 2003 there was an estimated 1,461 tonnes of Cherry Point herring, which was only half of the population size WDFW estimated was needed for the population to rebound.

Figure 2

Herring Spawn Deposition Maps from 1970 to 2021



Note. Reprinted from "Cherry Point Environmental Aquatic Reserve Management Plan 2022 Update," maps by A. Brownlee, Unpublished, using data from WDFW and prepared for DNR.

Herring spawning events provide ephemeral, high density food pulses that attract many seabird species, especially sea ducks such as scoters (Crewe et al., 2012; Lewis et al., 2007; Wahl et al., 1981). During the winter months, scoters feed primarily on benthic invertebrates like mollusks (clams, snails etc.), marine worms and crustaceans (Lewis et al., 2007). When herring spawn, scoters form massive aggregations at the spawn sites. Of all marine bird species, scoters exhibited the strongest response to herring spawn in Holmes Harbor off Whidbey Island and were observed on the spawning grounds in much higher densities (Cleaver & Frannet, 1946). Wahl et al. (1981) describe a flock of 25,000 scoters off Point Whitehorn at Cherry Point in 1978. Other seabird species have also been documented to exhibit an aggregate response to herring spawn, including gulls (Crewe et al., 2012; Wahl et al., 1981), Pacific Loon (Crewe et al., 2012; Wahl et al., 1981), Harlequin Duck (Crewe et al., 2012; Rodway et al., 2003), and several other species not as commonly seen at Cherry Point such as Common Murre, Marbled

Murrelet, Brandt's Cormorant (Crewe et al., 2012; Wahl et al., 1981), Surfbird, and Black Turnstone (Bishop & Green, 1999).

With the plummet of herring spawn at Cherry Point there has been a correspondingly drastic decrease in scoter abundance. The population of scoters foraging on herring spawn at Cherry Point has declined from 60,000 in the 1970s to 6,000 in the early 2000s (WDNR, 2010; citing unpublished data from Nysewander)[1]. The scoters were likely able to shift their foraging locations or migratory behavior (Lok et al., 2012). Crew et al. (2012) noted an increase in scoter abundance at herring spawn locations in the Canadian portion of the Salish Sea over the last two decades. This is the kind of territory shift that Montevecchi (1993) predicted as an indicator of change in prey abundance. Healthy and persistent herring stocks are key to food web and ecosystem health (Sandell et al., 2019) and their decline is concerning. Wahl et al. (1981) designated Cherry Point as an area of particular importance and vulnerability due to the importance of Cherry Point herring as a prey source for seabirds.

Cherry Point Aquatic Reserve

In 2010, DNR established Cherry Point Aquatic Reserve. It encompasses 3,050 acres of aquatic habitats in the southeastern Strait of Georgia. These habitats include cobble beaches, submerged aquatic vegetation, extensive tidal flats, and a steep subtidal gradient into natural deep-water channels that support local industry. There are three "cut-outs" (as seen in Figure 3) within the reserve boundary to accommodate the piers and shipping activities of the British Petroleum and Phillips 66 refineries, and the Petrogas distribution terminal. The refineries were constructed between 1954 and 1971.The designation of CPAR limits any future uses of the

[1] Vessel traffic increased with the construction of a third refinery in 1971. This is one of many other environmental factors that could have contributed to the decline in Surf Scoters at Cherry Point.

shoreline that might adversely impact habitats and species identified as important by the management plan (WDNR, 2022).

DNR Aquatic Reserves Program

The Aquatic Reserves Program within DNR was established in 2002. DNR manages all state-owned aquatic lands for five main goals, one of which is to ensure environmental protection. Aquatic Reserves are areas of special ecological importance and the Aquatic Reserves Program is responsible for their identification, establishment, and ongoing management (Palazzi & Bloch, 2006). Aquatic Reserve designation does not change public access meaning that fishing, harvesting, and recreation are still allowed within the reserve boundaries. Designation does emphasize the restoration and conservation of natural ecosystems and therefore provides extra protection by limiting future activities that threaten nearshore environments. One way that Aquatic Reserve designation protects aquatic habitats is by removing aquatic land from future leasing limiting the construction of over-water or in-water structures like marinas, docks, or pipelines, within the reserve. Aquatic Reserve designation also creates opportunities for monitoring, research, education, and public engagement which leads to enhanced agency and community driven data sets specific to each Aquatic Reserve.

Currently, there are eight aquatic reserves, of which seven are marine. Figure 3 shows the locations of the eight Aquatic Reserves. Each reserve has a management plan created by DNR managers with input from Tribal managers and local stakeholders, including community members. There are various scientific monitoring activities conducted by DNR staff, interns, and community scientists. An overarching goal for the Aquatic Reserves Program is the conservation of native ecosystems and ecosystem services (Palazzi & Bloch, 2006). The management plans include ecosystem-based conservation goals like those that the Puget Sound Partnership tracks via ecosystem indicators.

Figure 3

Map of all Aquatic Reserves and a Close-up of CPAR

Note. The map of all eight Washington State Department of Natural Resources Aquatic Reserves was provided courtesy of the Aquatic Reserves Program. The close-up of CPAR on the right illustrates the cut-outs for industrial piers.

Applying seabird indicators to CPAR

One major difference between PSP and DNR Aquatic Reserves is spatial scale. DNR Aquatic Reserves are small areas within the larger Puget Sound and Salish Sea ecosystems. Reserve boundaries are drawn based on habitat factors and stakeholder agreement within the context of the larger Salish Sea ecosystems. Marine environments, however, do not tend to have discreet environmental boundaries. Marine habitats and ecosystems are spatially and temporally dynamic (Hooker & Gerber, 2004). When it comes to applying indicators such as seabird abundance to CPAR, the size of the reserve and the overlap of marine environments is an important consideration. Especially for mobile species, abundance may not reflect conditions within the reserve. Nevertheless, protection provided by Aquatic Reserves benefits local species even if that species is highly mobile and the reserve does not cover its entire range (Boyd et al., 2006).

Seabird abundance can still provide valuable feedback to reserve managers, especially if the data is incorporated into a monitoring network. Puget Sound Vital Signs includes a suite of indicators used to track ecosystem function, resilience, and food webs. The Aquatic Reserves Program has many monitoring activities that target some of these same indicators such as seabird distribution and abundance. Trends in overall abundance, specific species and species groups are various approaches to seabird data. One way to group seabirds is by prey source or resource dependency called "foraging guilds" (Anderson et al., 2009, p20). When focusing on the Cherry Point area, there are specific species and guilds that may provide more information than others.

Selecting species that reflect the spatial scale of interest, whether a reserve or a fishery stock, is an important step (Einoder, 2009; Pearson & Hamel, 2013). Due to CPAR's small area within the southern Strait of Georgia and Salish Sea ecosystems, aerial divers that forage across large horizontal spaces (i.e., gulls and terns) are not as appropriate as indicators. Seabirds that roost or nest within the reserve boundaries or species that spend a substantial amount of time within reserve habitats are more tied to the reserve resources and are better selections. This excludes most migratory species apart from scoters that molt in the Strait of Georgia and have historically relied on the Cherry Point herring spawn. CPAR is comprised predominantly of nearshore marine habitats, so species that typically forage in open water or are unlikely to use the nearshore are also less appropriate.

Theoretically, the best potential seabird ecosystem indicators for Cherry Point Aquatic Reserve are Pigeon Guillemot, Pelagic Cormorant and Surf Scoter. Pigeon Guillemot are pursuit divers that forage in the nearshore. While they nest in bluffs on many parts of the Salish Sea shoreline, they have not been observed along the Cherry Point reach (L. Anderson, personal communication, April 16, 2022). Pelagic Cormorants, unlike Double-crested Cormorants, rely solely on marine habitats and they interact heavily with anthropogenic structures. There are currently three refineries at CPAR with piers that extend into cutouts within the Aquatic Reserve boundary. Pelagic Cormorants nest and roost on these structures. They also prey on benthic species and Pacific sand lance (Crewe et al., 2012). Considering the Cherry Point herring population, Surf Scoters are valuable indicators, as are benthivore and piscivore feeding guilds.

Salish Sea seabird trends

MESA historical baseline

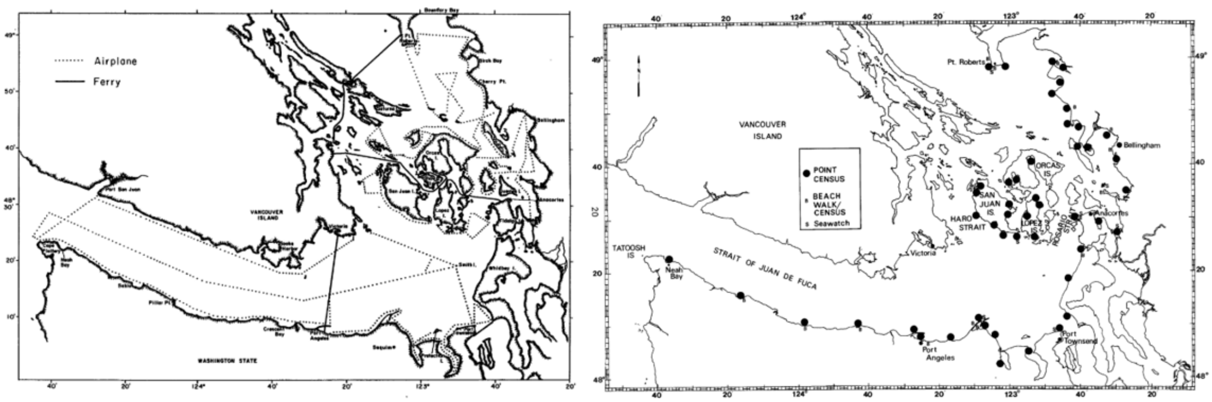
The first comprehensive study of seabirds in the Salish Sea was conducted for the Marine Ecosystem Analysis (MESA) Puget Sound Project in 1978/79. At the time it was the most extensive study of marine bird populations in Washington State and remains the most commonly used baseline for evaluating seabird trends in the southern Salish Sea (Anderson et al., 2009; Wahl et al., 1981). Surveys spanned the Strait of Juan de Fuca, southern Strait of Georgia, and San Juan Islands (Figure 4). MESA surveys included vessel-based, aerial, and shoreline surveys. Shoreline surveys included beach walks, dead bird surveys, and point census counts. It is important to recognize that these surveys are used as a baseline only because there were no widespread and reliable seabird abundance surveys before the 1970s. Based off anecdotal evidence, and the impacts caused to major rivers and waterways through the Salish Sea due to industrialization and colonization, seabird numbers were likely higher before the 1970s (Bower, 2009).

MESA looked at bird density rather than abundance. Wahl et al. (1981) divided each region into subregions and used nautical charts to calculate the subregion area. This helped control for locations that may have similar abundances but vastly different spatial scales. Small, shallow bays and inlets had much higher densities than larger areas of open water. In addition to this spatial variation, there was temporal variation in density as some seabirds roosted in the same area that they foraged within, and others returned to a different nesting location. Therefore, density varied depending on seabird activity at that time of day. Seasonally the highest bird densities were seen in winter as migratory waterfowl arrived in the Salish Sea and in the spring as seabirds aggregated at herring spawn locations, including Cherry Point.

With only two years of data, MESA scientists saw large annual variation and suggested that this is normal. Five to ten years of data at minimum are needed to observe meaningful annual trends (Wahl et al., 1981). In total, MESA surveys documented 116 seabird species. While aerial and vessel-based surveys allowed for greater spatial coverage, point census surveys have the advantage of time. Vessel-based and aerial surveys require quicker scans since the boat or plane is constantly moving forward. Seabirds that are smaller bodied and/or that dive to avoid disturbance are the most likely to be missed. Point census surveys are conducted from a shoreline and record all seabirds visible on the water, at the water's edge, or that fly by during the survey time. There is no time limit, but the survey locations are limited by accessibility and deeper-water species are less likely to be recorded. All surveys underestimated true seabird abundance but point census surveys get the closest to enumerating the true numbers with minimal error.

Figure 4

MESA Vessel-based, Aerial, and Shore-based Survey Locations



Note. Map of MESA vessel-based and aerial surveys on the left and shore-based census survey locations on the right. Reprinted from "Marine bird populations of the Strait of Juan de Fuca, Strait of Georgia and adjacent waters in 1978 and 1979," by T. Wahl, S. Speich, D. Manuwal, K.V. Hirsch and C. Miller, 1981, Report prepared for MESA Puget Sound Project, 19-20. Copyright (1981) by the United States Environmental Protection Agency.

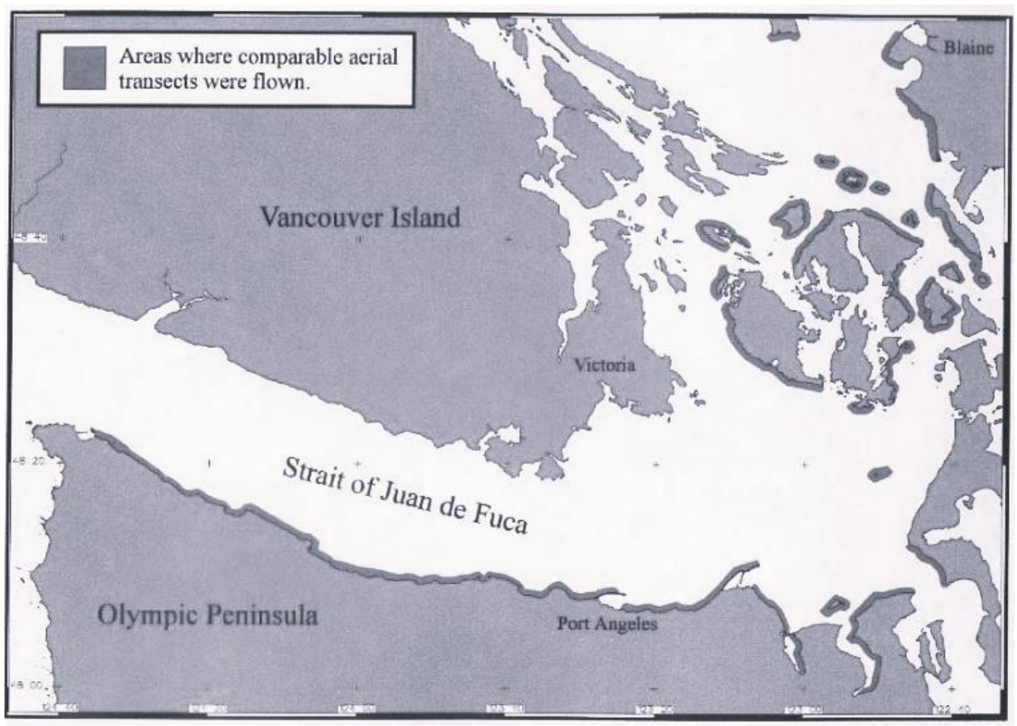
Seabird monitoring efforts have continued in Puget Sound and the larger Salish Sea since the 1970s. State agencies, Tribes, and community groups have pursued different types of seabird survey including aerial, vessel-based, shoreline, and point census methods. The surveys that are easiest to replicate and therefore the most utilized, especially by community scientists, are the point census surveys. Additionally, consistent methodology makes it easier to compare recent data to the MESA baseline.

Recent literature using the MESA baseline

Nysewander et al. (2005) compared Puget Sound Ambient Monitoring Program (PSAMP) aerial survey data from 1992 to 1999 to MESA's aerial surveys from 1978/79. Except for Harlequin Duck, all species with significant changes in density were in decline. Figure 5 illustrates the overlapping survey areas from the two studies. The loud plane utilized by the PSAMP surveys may have scared diving seabirds into submerging which would result in them being missed by the observers and therefore underrepresented in the data. On the other hand, PSAMP surveys were not limited to shorelines and did cover deeper-water habitats.

Figure 5

PSAMP Aerial Surveys that Overlapped with MESA Aerial Surveys

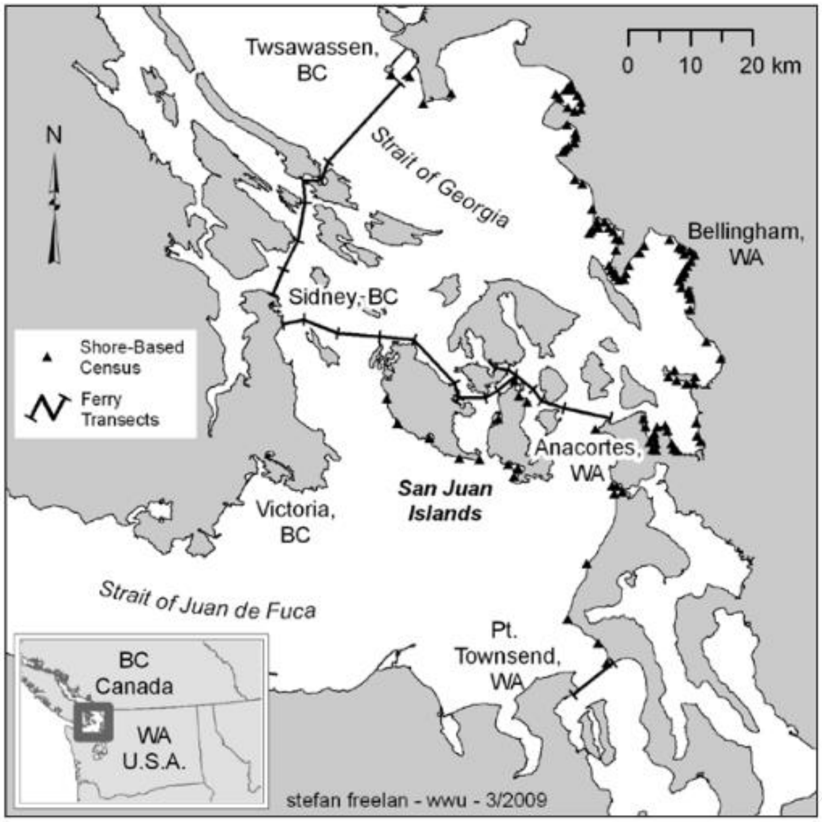


Note. Reprinted from "Report of Marine Bird and Marine Mammal Component, Puget Sound Ambient Monitoring Program," by D. Nysewander, B. Murphie, J. Evenson, and C. Thomas, 2005, report prepared for WDFW, 106. Copyright (2005) by Washington State Department of Fish and Wildlife.

In the early 2000s, Bower (2009) instructed Western Washington University (WWU) students to conduct point census and ferry-based seabird surveys within the southern Strait of Georgia and adjoining inland waters (Figure 6). The WWU student surveys focused on non-breeding seabird abundance and were conducted September through May in 2003, 2004, and 2005. Bower then compared WWU data to the MESA baseline and found a significant decrease of 28.9% in overall seabird abundance. There was no pattern between feeding guilds and no single reason these species are in decline. Bower found that surf scoters declined by 60%. Although this was not a statistically significant finding, it is still notable because the historical gathering at Cherry Point in response to herring spawn was so large, that when the area was removed from the analyses, the magnitude of the decline was halved.

Figure 6

WWU Shoreline Census and Ferry Survey Locations

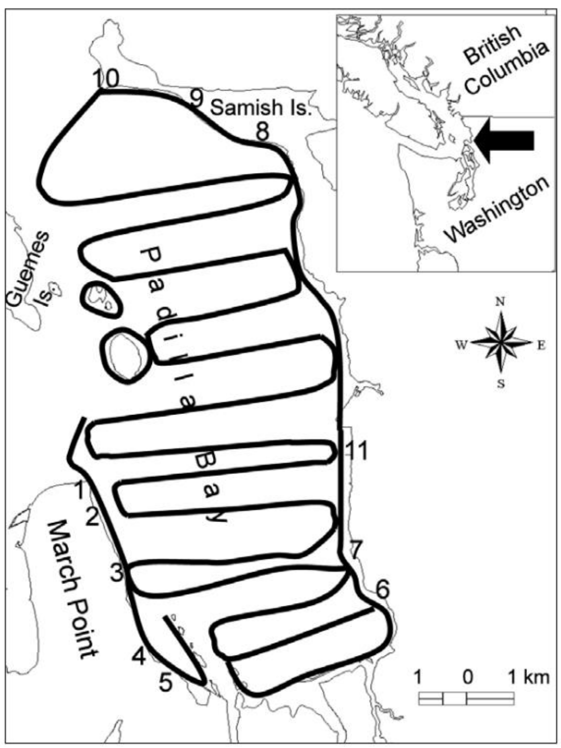


Note. Reprinted from "Changes in Marine Bird Abundance in the Slash Sea: 1957 to 2007," J.L. Bower, 2009, *Marine Ornithology, 37*(1), 11. Copyright (2009) by Marine Ornithology.

Anderson et al. (2009) also used the WWU data but focused on Padilla Bay. Like Cherry Point, Wahl (1981) identified Padilla Bay as an area of importance and vulnerability for marine birds. At Padilla Bay, this recognition is due to extensive eelgrass beds. The authors found a significant decrease in overall seabird density in Padilla Bay of 17% between the 1970s and early 2000s. Padilla Bay does not overlap with CPAR but is an example of how seabird density analyses can be applied to a small management area. The authors documented a significant decline in 13 taxa many of which were species that had formerly been the most abundant such as Brant and Western Grebe. Declines were most prevalent during winter and spring migrations-times when Wahl et al. (1981) had recorded the highest seabird densities across Puget Sound. Many of the Padilla Bay declines were documented across the Salish Sea at large, leading the authors to believe that the cause for species decline may be widespread. They were unable to connect the declines with any habitat change in Padilla Bay; however, further declines or drastic seabird changes could indicate habitat degradation.

Figure 7

Padilla Bay Shoreline Survey Points and Vessel-based Survey Routes



Notes. Reprinted from "Changes in avifaunal abundance in a heavily used wintering and migration site in Puget Sound, Washington, during 1966-2007," by E. Anderson, J. Bower, D. Nysewander, J. Evenson and J. Lovvorn, 2009, *Marine Ornithology, 37*(1), 20. Copyright (2009) by Marine Ornithology.

Community science seabird monitoring efforts

Community science, also referred to as citizen science, refers to natural science data collected by members of the public. Some of the longest running community science programs in the United States are bird programs. The Christmas Bird Count has over 50 years of data spanning terrestrial and marine ecosystems. Community science efforts are often developed to establish baseline monitoring and address conservation questions, but there are limitations inherent to community science data (Ward et al., 2015). Surveys usually have consistent methodology and some form of quality control, but it is challenging to quantify the monitoring effort. Additionally, there tends to be little auxiliary data (i.e., visibility, condition, behavior) and there are often biases based on the location of the survey. Community science efforts are often limited to non-random locations based on accessibility and volunteer availability. As with the ‘coarse’ approach taken by Pearson and Hamel (2013) these limitations mean that the data is suitable for establishing trends, but perhaps not for analysis of specific management activities.

Nonetheless, community science is a growing field that supplies a bounty of data that is increasingly incorporated into scientific models. Sipe (2019) incorporated Ebird data with WDFW survey data to create occupancy models for common loons in Washington State. The models used by Harvey et al. (2012), Pearson and Hamel (2013) and Kershner et al. (2011) for Puget Sound Vital Signs all incorporate community science databases. In addition to comparing WWU to MESA surveys, Bower (2009) compared Christmas Bird Counts from the Strait of Georgia between 1975 and 1984, and 1998 and 2007. The results were mostly consistent with regional changes identified within other literature for these species.

Puget Sound Seabird Surveys are run by the Seattle Audubon Society to monitor winter seabird populations in Puget Sound, Strait of Juan de Fuca and San Juan Islands. Ward et al.

(2015) used Puget Sound Seabird Survey data to map seabird occupancy over space and time to identify seabird hotspots for potential monitoring and conservation efforts. As indicators, shifts in seabird habitat usage can reflect changes in the habitat itself. If areas that were historically seabird hotspots no longer attract those populations, or do so during a different season, that area can be identified for more targeted studies or more intensive monitoring to understand why that shift has occurred. An example of a cooled hotspot is Cherry Point. Community science data is a cost-effective way to identify areas of concern for seabird species on a scale beyond the scope of most single programs.

The Canadian corollary to Puget Sound Seabird Surveys is the British Columbia Coastal Waterbird Surveys (BCCWS). BCCWS is a community scientist effort that is providing seabird information that otherwise would be unattainable to scientists due to cost and effort limitations. This is the only survey focusing on winter non-breeding seabird populations in the Canadian portion of the Salish Sea. Crewe et al. (2012) ran analyses across 12-years of BCCWS data spanning 1999 to 2011. Ethier et al. (2020) continued these analyses using data from 1999 to 2019. Crewe et al. (2012) conducted a power analysis to evaluate data quality and found that the survey is a credible data source capable of detecting annual changes of 3% or less. Both papers saw declines in seabird abundance, especially forage fish dependent species. Many of these species were long-distance migrants and feed at high trophic levels. Additionally, the populations of these species on the outer coast have remained constant (Ethier et al., 2020). Brant, for which Anderson et al. (2009) found a significant decline in Padilla Bay, had been increasing in the Frasier Delta suggesting a territory shift (Crewe et al., 2012).

Interpreting Salish Sea seabird trends

Overall, seabird abundance is on the decline throughout the Salish Sea. Table 1 compiles the results from Nysewander et al. (2005), Bower (2009), Anderson et al. (2009), Vilchis et al. (2015), and Ethier et al. (2020). Temporal, spatial, and methodological variations in seabird survey efforts leads to variability in the results and challenges when comparing data sets. Among the five publications highlighted above, grebe species have consistently declined. However, grebes nest on freshwater and their declines are likely due to degradation of freshwater environments (Bower, 2009; Pearson & Hamel, 2013). This is where specific indicator species suggest more meaningful results. I suggest the use of scoters, Pigeon Guillemot and Pelagic Cormorant as seabird indicators for CPAR.

Scoters have likely been on a regional decline although there may be local redistribution within the Salish Sea (Crewe et al., 2012). Pigeon Guillemot have increased according to shoreline surveys (Bower, 2009; Crewe et al., 2012) although aerial surveys indicated a decline (Nysewander et al., 2005). Shoreline surveys better represent Pigeon Guillemot since they nest in shore-side bluffs and forage in near-shore habitats. The Salish Sea Guillemot Network is a community science program monitoring Pigeon Guillemot breeding colonies throughout Puget Sound with the intent to better understand their population dynamics and their role within nearshore environments. Pelagic Cormorant trends are contradictory. According to Crewe et al. (2012) their breeding population in the Strait of Georgia decreased by 50%, but their nonbreeding presence in the winters appears to be increasing. This suggests that the Strait of Georgia may be an increasingly important winter migratory stop for this species.

While no author can point to specific reasons for the observed population trends, the trends of individual species can suggest areas or resources that may warrant further study.

Vilchis et al. (2015) attempted to characterize seabird trends across the Salish Sea by incorporating WDFW aerial surveys and shoreline BCCWS and Christmas Bird Count (CBC) data (note that the last two are both community science networks). In addition to the results compiled in Table 1, they also looked for life history factors that may explain abundance trends. These life history categories included feeding strategy, main prey source and breeding location (resident vs. migratory). They found that diving species accounted for over 90% of the declines and that diving birds that winter in the Salish Sea like alcids, grebes and loons were 11% more likely to have declined than surface feeders like geese and dabbling ducks. Bird species that feed on forage fish were 8% more likely to decline. On a positive note, species that breed within the Salish Sea were less likely to have declined than non-local breeding species.

Due to the risk factors associated with life history, Vilchis et al. (2015) found that seabird community structure in the Salish Sea shifted from 1990 to 2010. Where previously alcids and sea ducks were common, 2010 saw more non-diving bird species and piscivores with diverse diets (not specializing on forage fish). Overall, pursuit divers that specialize on forage fish and do not breed locally were less likely to overwinter in the Salish Sea in 2010 compared to 1990. Ethier et al. (2020) also found that migratory, forage-fish-specialized, diving birds were the most likely to decline between 1999 and 2019. This is likely due to a shift in prey availability as urbanization has decreased forage fish spawning habitats. Additionally, Ethier et al. (2020) found that benthivores have declined in the Salish Sea while both piscivore and benthivore abundance on the coast have remained stable. These Salish Sea specific decreasing trends reflect how seabirds are choosing to winter elsewhere and indicate specific habitat concerns for nearshore and benthic habitats within the Salish Sea.

Table 1

Percent Change to Seabird Abundance According to Five Relevant Studies for all Seabird Species Currently Surveyed at CPAR

Species	**Nysewander et al. 2005 PSAMP/MESA comparison across the southern Salish Sea 1978-1990s**	**Bower 2009 WWU/MESA comparison across the southern Strait of Georgia 1978 to 2000s**	**Anderson et al. 2009 WWU/MESA comparison in Padilla Bay 1978 to 2000s**	**Vilchis et al. 2015 WDFW, BCCWS and CBC comparison across the Salish Sea 1990-2010**	**Ethier et al. 2020 BCCWS trend analysis in the northern Strait of Georgia 1999-2019**
Double-crested Cormorant *Phalacrocorax auritus*	-61.7	+97.7	Not significant	-7.5 (-10.4 for all cormorant)	Not significant
Pelagic Cormorant *Urile pelagicus*	-53.0 for all cormorant	+87.7	Not significant	Not significant (-10.4 for all cormorant)	Not significant
Red-throated Loon *Gavia stellata*	-79.1 for all *Gavia* spp.	-79.9	-11.7	-3 (-20.9 for all *Gavia* spp.)	Not Significant
Pacific Loon *Gavia pacifica*	-79.1 for all *Gavia* spp.	Not significant	+20.9	-1.5 (-20.9 for all *Gavia* spp.)	-6.01
Common Loon *Gavia immer*	-64.3	+48.8	+9.0	-1.5 (-20.9 for all *Gavia* spp.)	-2.96
Red-necked Grebe *Podiceps grisegena*	-88.8	-45.9	-33.4	-3 and +6 (-23.9 and +6 for all grebe)	Not significant
Horned Grebe *Podiceps auritus*	-82.4	-71.6	-59.1	-1.5 (-23.9 and +6 for all grebe)	Not significant
Western Grebe *Aechmophorus occidentalis*	-95.2	-81.3	-82.6	-19.4 (-23.9 and +6 for all grebe)	-12.72
Red-breasted Merganser *Mergus serrator*	Not significant	Not significant	Not significant	-1.5 and +3 for all *Mergus* spp.	Not significant
Common Murre *Uria aalge*	Not reported	-92.4	Not reported	-22.4	Not significant
Pigeon Guillemot *Cepphus columba*	-55.2	+108.9	Not reported	+4.5	Not significant

Marbled Murrelet *Brachyramphus marmoratus*	-96.3	-71.0	Not reported	-9 and +3	Not significant
Rhinoceros Auklet *Cerorhinca monocerata*	Not reported	Not reported	Not reported	-9	Not reported
Caspian Tern *Hydroprogne caspia*	Not reported	Not reported	Not reported	Not reported	Not reported
Canada Goose *Branta canadensis*	Not reported	+10801.9	+9.9	+3	+4.92
Brant *Branta bernicla*	-66.3	Not significant	-44.8	+6	Not significant
Mallard *Anas platyrhynchos*	Not reported	Not significant	+18.6	+3	Not significant
Scaup *Aythya* spp.	-72.3	-64.8	-93.3	-3	-10.68
Harlequin Duck *Histrionicus histrionicus*	+188.6	Not significant	Not reported	Not significant	Not significant
Long-tailed Duck *Clangula hyemalis*	Not reported	Not significant	Not significant	Not significant	-5.07
Bufflehead *Bucephala albeola*	Not significant	Not significant	-10.9	-1.5	Not significant
Common Goldeneye *Bucephala clangula*	Not significant	-47.8	-10.7 for all goldeneye	Not significant for all goldeneye	Not significant
Barrow's Goldeneye *Bucephala islandica*	Not significant	Not significant	-10.7 for all goldeneye	Not significant for all goldeneye	Not significant
Ruddy Duck *Oxyura jamaicensis*	Not reported	-59.7	-47.6	-6	Not reported
Surf Scoter *Melanitta perspicillata*	-57.0 for all *Melanitta* spp.	Not significant	+14.0 for all *Melanitta* spp.	-9 for all *Melanitta* spp.	-2.27
Black Scoter *Melanitta nigra*	-57.0 for all *Melanitta* spp.	-65.7	+14.0 for all *Melanitta* spp.	-9 for all *Melanitta* spp.	-14.96
White-winged Scoter *Melanitta fusca*	-57.0 for all *Melanitta* spp.	Not significant	+14.0 for all *Melanitta* spp.	-9 for all *Melanitta* spp.	-4.3

Bald Eagle *Haliaeetus leucocephalus*	Not significant	+187.0	Not reported	+1.5	Not significant
Great Blue Heron *Ardea herodias*	Not significant	Not significant	Not reported	Not significant	Not significant

Note. Statistical significance was evaluated with an $\alpha < 0.05$ for all except Vilchis et al. (2015) who used $\alpha < 0.10$. Vilchis et al. (2015) used a depth-based analysis that sometimes resulted in both positive and negative trends depending on the species-depth combination.

CPAR marine bird survey effort

As previously mentioned, it can take years of data for seabird trends to become apparent. The resources required to conduct these long-term monitoring efforts are substantial. The Aquatic Reserves Program is small, and the efforts of community scientists are invaluable. The Cherry Point Aquatic Reserve Citizen Stewardship Committee (CSC) is a group of volunteers who meet monthly to help promote the protection and monitoring of CPAR. RE Sources for Sustainable Communities, a non-profit in Bellingham, WA, coordinates and sponsors the Cherry Point and Fidalgo Bay CSCs. These volunteer teams have several research projects they developed and undertake within the Aquatic Reserves to benefit Aquatic Reserve management. The CSC seabird surveys are one of these efforts. Surveys began at CPAR in spring 2013 and were modeled after the WWU seabird surveys and therefore the MESA point census surveys. Both the WWU and current CPAR surveys are winter surveys designed to capture the influx of migratory species that arrive in the Salish Sea in late fall and depart in the spring. Winter surveys capture non-breeding species and activities. Birds that are not tied to a breeding location are more able to move and follow prey resources which means their presence and abundance may better reflect resource availability (Vilchis et al., 2015).

The CPAR surveys deviate from MESA protocols in two ways: teams of trained observers conduct the surveys instead of a single scientist and CSC members only count individuals of certain species. CPAR surveys started with seven species in 2013 and have increased to 29 species and species groups as volunteers have become more comfortable with the methods and capable of executing them.

With any point census survey, the numbers recorded likely underestimate the true number of seabirds present, but by having unlimited time, the errors are minimized. These surveys are a snapshot of all birds within surveyed species groups at that area at that time. Based off MESA methods, observers record all seabirds on the water, shoreline, or in flight. In a spatially constrained area such as a reserve, birds flying by may not be using the area in question. In fact, as prey options deplete, seabirds may have to travel farther to forage. An area with poorer habitat will see more birds flying by and fewer stopping to use the habitat (Piatt, Harding, et al., 2007). By recording flying birds, this may be artificially increasing the number of seabirds recorded as present within the management area.

In addition to species counts, observers record condition information at each survey site including glare, Beaufort Sea State Code, human disturbance, and visibility. The visibility metric is a value judgment made by volunteers and recorded as poor, fair, good, or excellent. In optimal conditions, seabirds up to about 2000 m are visible. There is currently no way to relate the visibility estimate to a maximum observation distance. BCCWS use a similar methodology with their volunteers but have them record whether the observation as made within 500 m or beyond 500 m. Adding a distance estimate could be an addition to increase the quality of the CSC surveys.

Purpose and value of this thesis

Birds can indicate environmental health, biodiversity, condition of habitats and climate change (Pearson & Hamel, 2013). For the Aquatic Reserves Program, the goal is to promote diverse and resilient ecosystems; seabirds can indicate progress towards this goal. Trends in seabird abundance and distribution can reflect desirability of habitat, prey availability and general ecosystem health. CPAR is a small portion of the larger Salish Sea. Depending on the species, seabirds may not spend much time in the Aquatic Reserve itself and are therefore impacted by things that happen elsewhere in their life history. Therefore, Pigeon Guillemot, Surf Scoter, and Pelagic Cormorant are the three indicator species specifically suggested for CPAR. All three species are documented to spend time on the reserves and are closely tied to a localized marine resource.

Regional seabird abundance studies have varied results depending on methodology and location. The data used in this thesis was collected by community scientists using a methodology adapted from historical MESA surveys and more recent WWU efforts. At the time the CPAR surveys were developed, the intent was to compare to these two baselines. However, these historical datasets are not open-access, and it was meaningful from a management perspective to focus on the status and trends of seabird indicators. I took a similar approach to BCCWS analyses and focused on this dataset alone to identify shifts that occurred within the last decade. Changes to seabird abundance within CPAR may highlight habitats that warrant further monitoring or reflect changes to resource availability like herring spawn.

DNR’s Aquatic Reserves Program manages seven marine Aquatic Reserves. Finding a way to track and assess effectiveness of management decisions is crucial for the program to improve management strategies. Ecosystem indicators, like seabirds, are used in the Salish Sea to track ecosystem-based management efforts and this thesis applies them to a single reserve at Cherry Point. This review and subsequent analyses will evaluate the current methods, create a status update on CPAR seabird density, and provide an example to DNR and other agencies on how to support and incorporate this kind of community science effort. Through this thesis, CPAR community scientists will help DNR better manage and protect our Aquatic Reserve ecosystems.

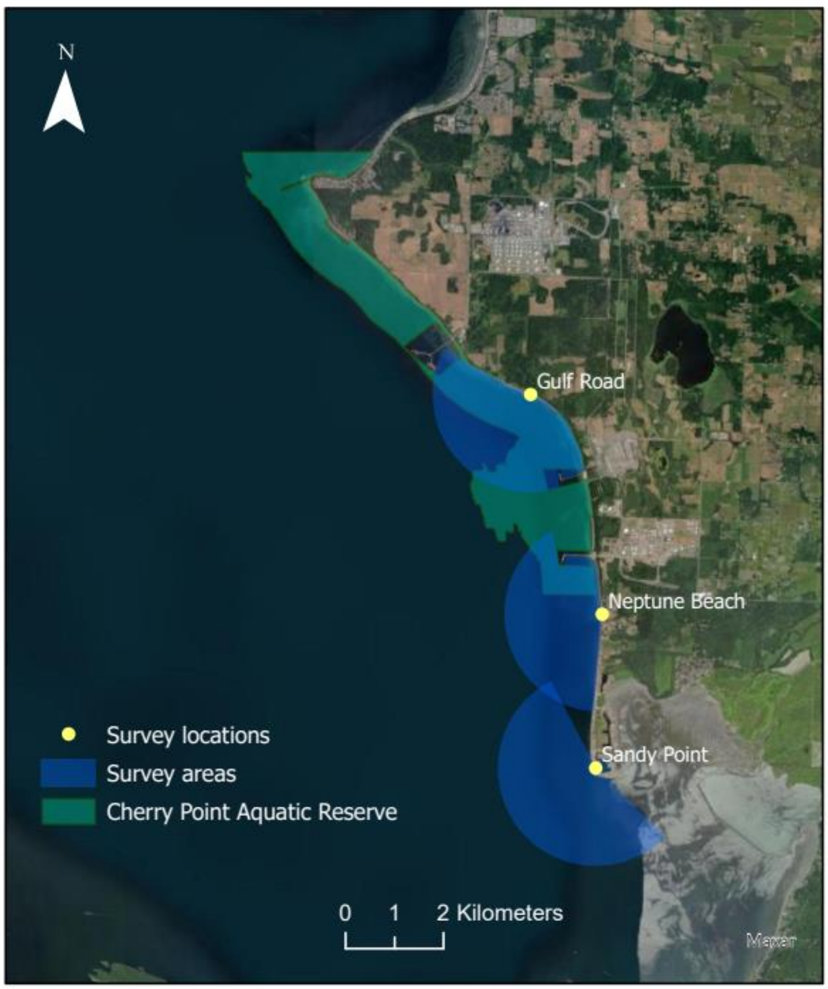
METHODS

Site description and survey methods

Cherry Point Aquatic Reserve covers 3,050 acres of aquatic habitat in the eastern Strait of Georgia. It is bordered to the north by Birch Bay State Park and to the south by Lummi Reservation. Point census seabird surveys are conducted at three shore-based locations along the Cherry Point shoreline. Figure 8 shows the reserve boundary, survey locations and survey areas.

Figure 8

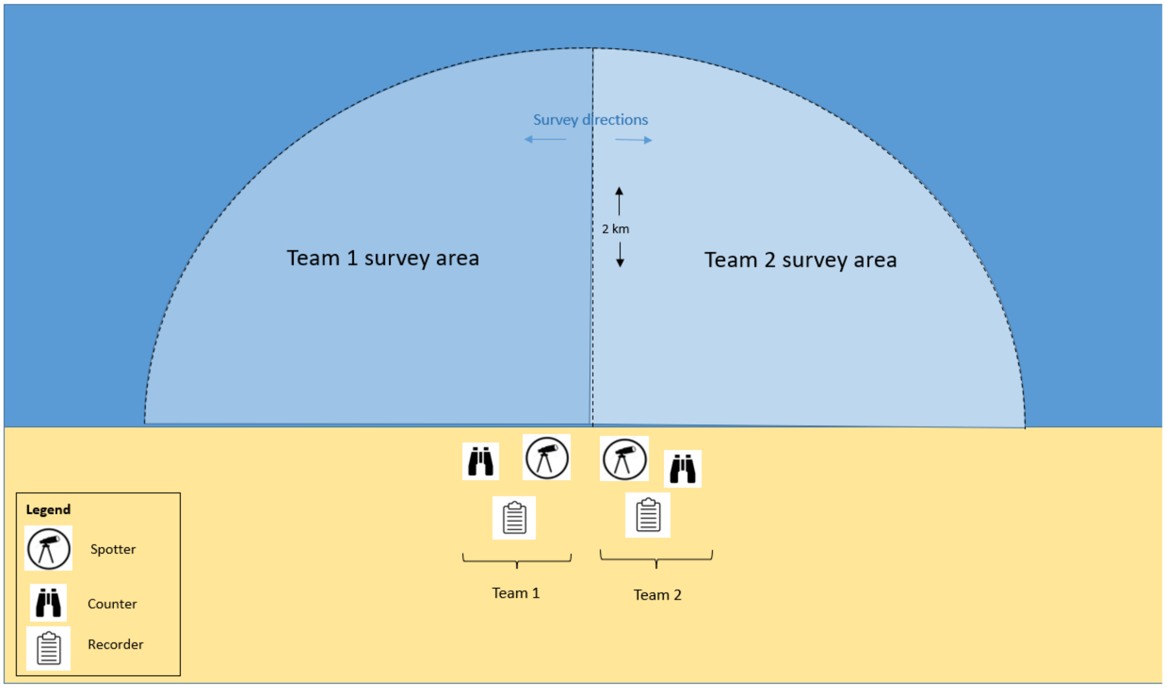
Map of Current CPAR Seabird Survey Locations and Survey Areas



Six or more volunteers conduct each survey forming two teams of three or more. Each team has a spotter who uses a spotting scope to identify distant birds, a counter who used binoculars and identifies nearer birds and a recorder who reports the data on the data sheet. The two teams stand on the same shoreline location, identify a reference point in the middle of the survey area and begin their surveys moving out from that center point with each team covering half of the total area. Figure 9 has an example diagram of the survey design. Binoculars and spotting scopes were approximately equal in quality to Eagle Optics Ranger 10×40 binoculars and 20-40× scopes (Eagle possible Optics, Middleton, WV, USA) which were the equipment strengths used by historical MESA surveys (Bower, 2009; Hines & Jaeren, 2018; Wahl et al., 1981). Surveys continue without time or distance constraint (beside those imposed by the equipment) until all the birds within the targeted species categories have been recorded. Survey times ranged from four to 65 minutes and lasted an average of 19.2 ± 8.3 minutes. All spotters and counters were trained on seabird identification.

Figure 9

Diagram of CPAR Seabird Field Survey Operating Procedure



Point Census Surveys were conducted once a month from September to May starting in April 2013. Rather than identify and count all species present, the surveys target only certain species that are known to be the most numerous and frequently seen in the region. Initially, the targeted species list included seven species. It was expanded to 15 species in March 2015 and type groups were added in September of 2016. Type groups are genus or family level groups meant to capture individuals that could not be identified to species. This means that a mystery loon would be recorded under a loon category, or an unidentifiable duck is recorded as duck rather than being omitted from the data collection as was the previous practice. The final species additions were made in December 2016. Since December 2016, there are 29 species and nine type groups included in the CPAR surveys.

Table 2

All Seabird Species Targeted by the CPAR Survey Effort Including Common Name, Scientific Name, Four-letter Species Code, Feeding Guild, and the Month/Year of Addition to the Targeted Species List.

Type	Common name	Scientific name	Species Code	Guild	Date added
cormorant	Double-crested Cormorant	*Phalacrocorax auritus*	DCCO	Piscivore	Mar 2015
cormorant	Pelagic Cormorant	*Urile pelagicus*	PECO	Piscivore	Mar 2015
cormorant	cormorant species	Phalacrocoracidae	CORM	Piscivore	Sept 2016
dabbling duck	Mallard	*Anus platyrhynchos*	MALL	Herbivore	Dec 2016
diving duck	Greater Scaup	*Aythya marila*	GRSC	Omnivore	Dec 2016
diving duck	Harlequin Duck	*Histrionicus histrionicus*	HARD	Benthivore	Apr 2013
diving duck	Long-tailed Duck	*Clangula hyemalis*	LTDU	Benthivore	Dec 2016
diving duck	Bufflehead	*Bucephala albeola*	BUFF	Benthivore	Dec 2016
diving duck	Ruddy duck	*Oxyura jamaicensis*	RUDU	Benthivore	Dec 2016
diving duck	duck species	NA	DUCK	Other/all	Dec 2016
goose	Canada Goose	*Branta canadensis*	CAGO	Herbivore	Dec 2016
goose	Brant	*Branta bernicla*	BRAN	Herbivore	Apr 2013
goose	Black goose species	*Branta spp.*	GOOS	Herbivore	Dec 2016
goldeneye	Common Goldeneye	*Bucephala clangula*	COGO	Benthivore	Apr 2013
goldeneye	Barrow's Goldeneye	*Bucephala isandica*	BAGO	Benthivore	Mar 2015
goldeneye	goldeneye species	*Bucephala spp.*	GOLD	Benthivore	Sep 2016
grebe	Red-necked Grebe	*Podiceps grisegena*	RNGR	Piscivore	Mar 2015
grebe	Horned Grebe	*Podiceps auritus*	HOGR	Piscivore	Mar 2015
grebe	Western Grebe	*Aechmophorus occidentalis*	WEGR	Piscivore	Apr 2013

grebe	grebe species	Podicipeformes	GREB	Piscivore	Sep 2016
loon	Red-throated Loon	*Gavia stellata*	RTLO	Piscivore	Mar 2015
loon	Pacific Loon	*Gavia pacifica*	PALO	Piscivore	Mar 2015
loon	Common Loon	*Gavia immer*	COLO	Piscivore	Apr 2013
loon	loon species	*Gavia spp.*	LOON	Piscivore	Sep 2016
merganser	Red-breasted Merganser	*Mergus serrator*	RBME	Piscivore	Dec 2016
merganser	merganser species	*Mergus* spp. and *Lophodytes* spp.	MERG	Piscivore	Dec 2016
scoter	Surf Scoter	*Melanitta perspicillata*	SUSC	Benthivore	Apr 2013
scoter	Black Scoter	*Melanitta americana*	BLSC	Benthivore	Dec 2016
scoter	White-winged Scoter	*Melanitta deglandi*	WWSC	Benthivore	Mar 2015
scoter	scoter species	*Melanitta spp.*	SCOT	Benthivore	Sep 2016
alcid	Common Murre	*Uria aalge*	COMU	Piscivore	Dec 2016
alcid	Pigeon Guillemot	*Cepphus columba*	PIGU	Piscivore	Dec 2016
alcid	Marbled Murrelet	*Brachyramphus marmoratus*	MAMU	Piscivore	Dec 2016
alcid	Rhinoceros Auklet	*Cerorhinca monocerata*	RHAU	Piscivore	Dec 2016
alcid	alcid sp.	Alcidae	ALCI	Piscivore	Dec 2016
heron	Great Blue Heron	*Ardea Herodias*	GBHE	Other	Dec 2016
eagle	Bald Eagle	*Haliaeetus leucocephalus*	BAEA	Other	Apr 2013
tern	Caspian Tern	*Hydroprogne caspia*	CATE	Piscivore	Dec 2016

Data management

Since the surveys began in 2013 there has been no comprehensive database review. Previously, both team's data sheets were combined before being entered into a spreadsheet. I went through scans of the data sheets filled out by CPAR community scientist during their surveys. I reworked the database so that raw data is being entered, not compiled data. I then created a pass/fail test to remove data that was low quality or missing values.

Table 3

Criteria for the Pass/Fail Test Used to Assess Data Quality Before Analysis

Pass: Criteria for data to be included in analyses - *Few or no missing values.* Clear scan and no quality concerns. - 90% of the data passed and was included in the analyses
Fail: Criteria used to remove low quality data - *Major errors.* The scans where the species counts were compromised, and the original data sheet could not be found. - *Poor visibility.* Observers stated that all surveys were only conducted when the full survey area was visible, and the poor rating was due to glare or high Beaufort rather than decreased range of vision (personal communication, March 12, 2022). Even though they felt confident that they were able to document all birds in the survey area during poor visibility, the conditions likely led to a greater than normal underestimation of seabirds present, and I opted to exclude this data from analyses. - *Surveys that started after 3 pm*. Seabirds behavior changes based on time of day. For consistency, surveys conducted in the late afternoon/early evening were excluded. - 10% of the data failed the quality test

I also flagged surveys for additional quality assurance/quality control (QA/QC) due to minor errors and missing values that could be extrapolated from the other team. The errors did not impact the seabird count data, and these surveys were included in the analyses, but further review will improve the database.

Some surveys like those conducted in April and May 2020 had only one team of data collectors due to the Covid 19 pandemic. Surveys conducted with reduced numbers were accepted for analysis and their density calculations were altered to account for a single team covering the entire survey area.

Calculating seabird density

To control for the omitted data, I looked at density instead of abundance. Since I am interested in trends across the entire reserve, I did not compare between sites, but combined them to look at trends over the total area. I estimated maximum survey distance to be around 2 km based on personal observation and conversations with the data collectors. The Gulf Road and Neptune Beach locations are on long stretches of beach partially bounded by industrial piers. The survey location at Sandy Point is on a curved promontory and includes a human-made inlet next to the survey location. Views to the south at Sandy Point are bounded by a house and to the north by an additional point of land. To estimate survey area, I mapped the survey locations in ArcGIS Pro and created 2 km buffers. I edited the resulting polygons to account for the visual barriers described above. Estimated survey areas rounded to the nearest tenth of a kilometer are as follows: Gulf Road: 5.5 km^2, Neptune Beach: 5.2 km^2, and Sandy Point: 6.9 km^2. If a single team surveyed, their totals were calculated across the entire survey area.

Data exploration and analyses

To identify species for further analysis, I looked at encounter rate and average density for each of the 29 targeted species. I focused further analyses on the seven species with the highest probability of encounter and average density (Surf Scoter, Common Loon, Horned Grebe, Pelagic Cormorant, Bufflehead, Western Grebe, and Brant). In addition to these seven species, I also looked at total seabird density and feeding guild density. Due to the non-normal distributions of the density data, all analyses that compared between survey seasons and months were conducted using a Kruskal-Wallis rank sums test using the R package *dyplyr* (R Core Team, 2019) and post hoc Dunn's test using the R package *CRAN* (Dinno, 2017) with a Bonferroni p-value correction. The independent variable was either season or month and the dependent was density.

In addition to being non-normal, the data was heavily zero skewed. A negative binomial distribution is best suited to data with many zero-observations (Crewe et al., 2012; O'Hara & Kotze, 2010). I utilized a negative binomial regression model using R packages *foreign* (v0.0-71, R Core Team, 2018) and *MASS* (Venables & Ripley, 2002) to look for change in density as a function of season and month [glm.nb(Density ~ season_num+month)]. In this way I could assess whether density has been increasing or decreasing since 2013 while accounting for the effect of month. Further analyses should focus on model selection within negative binomial regression or Poisson analyses. A pseudo-R squared calculation or log likelihood significance test could be done to assess the strength of the model. Other factors like visibility, tide, time, and human interaction could be incorporated into this model in the future. I also recommend a follow up pair-wise test using the *emmeans* R package (v1.7.3, Lenth, 2022) to identify which seasons and months had different densities and compare these results to the Kruskal-Wallis output. All the data wrangling, visualization and analyses were done in the statistical program R 3.6.0 (R Core Team, 2021). R scripts are retained by the author and DNR Aquatic Reserves Program.

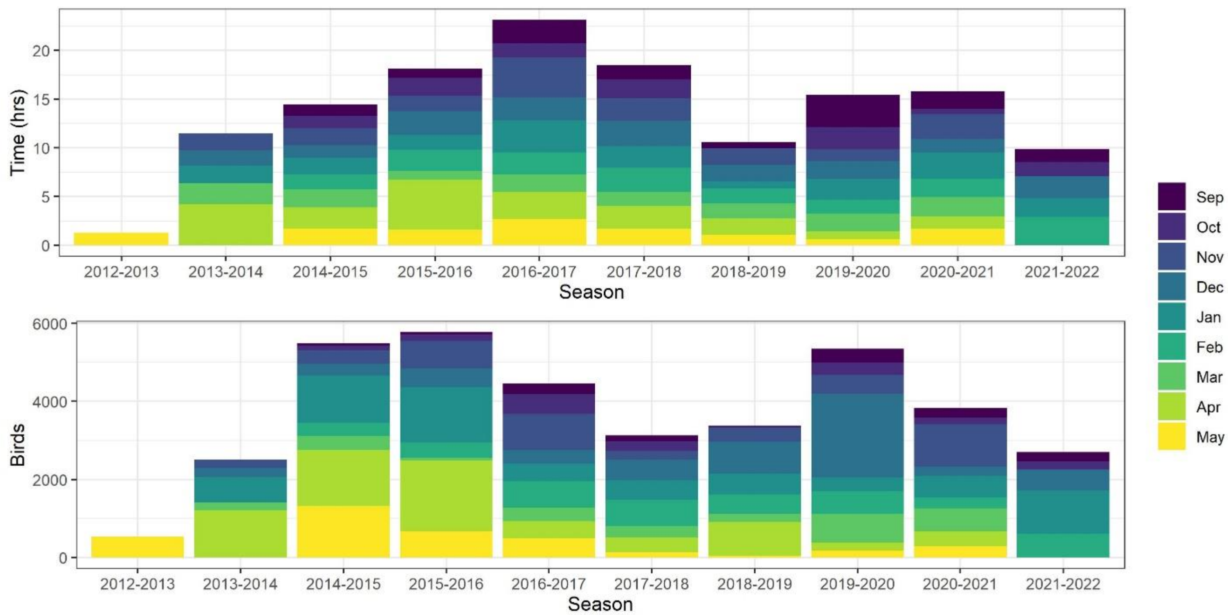
RESULTS AND DISCUSSION

Originally, the Cherry Point seabird data was developed primarily for comparison to an historical dataset. Using the current data as a stand-alone data source required extensive data exploration to identify potential patterns and directions for analysis. I explored both seabird encounter rate and density to identify seven species that have been recorded most often and/or in the largest average densities. I then compared the individual density for each of the seven species between and across seasons and months. Each species has a subsection below with the plots, results of the analyses, and discussion with potential reasons behind the trends. Additionally, I looked at total bird density and density of targeted species grouped by feeding guilds.

This data was collected by community scientists at CPAR. In total, 498 surveys had been conducted constituting over 150 hours of survey time and counting over 37,000 birds. These surveys start April 2013 and are ongoing, although the last data I included was from February 2022. Of the total 498 surveys conducted, 426 passed the QA/QC process outlined in the methods and were included in the analyses and visualizations below. Figure 10 below illustrates the hours of survey time, and the total number of birds counted each season. Each column in the figure corresponds to a single season and each color band within that column represents a month. The taller the color band, the more time was spent, or the more birds were seen depending on the plot. Typically, longer surveys are expected when the number of birds is greater, but the survey length was also influenced by environmental factors like Beaufort Sea State, glare, and precipitation that decrease visibility and make it more challenging to census all targeted bird species. As more species were added to the target list, survey time is expected to increase, however this coincided with the birders becoming more practiced.

Figure 10

Total CPAR Survey Time and Total Seabird Counts Per Season

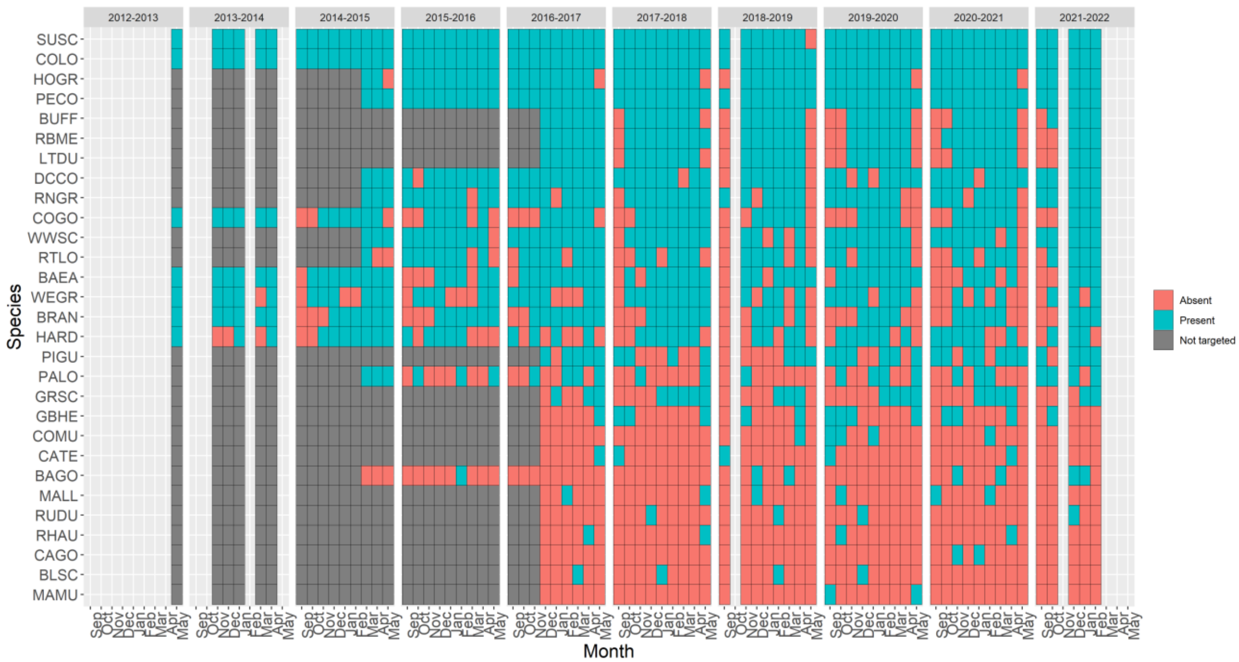


Note. On the top is total survey time per season with the total time per month as fill. On the bottom is the total number of birds recorded per season with the birds per month as fill. Species were added to the target list in March 2015, September 2016, and December 2016. The 2012-2013 season consisted of a single survey and the 2021-2022 season did not include March, April, or May data at the time of analysis.

The number of species targeted by the CPAR surveys has expanded over the total survey effort. During each monthly survey event, all individuals within the targeted species list were counted by trained observers. This was either 73, 61 or 46 months of data depending on when the species was added to the targeted list. Each month, two teams visited three survey sites. Figure 11 illustrates the presence and absence of each targeted species since the surveys first began in May 2013. If the species was marked present it means that it was recorded by at least one survey team at one or more of the three sites on that survey day.

Figure 11

Presence and Absence of All Species Targeted by the CPAR Seabird Surveys



Note. Species encountered most often are at the top and species encountered least often are on the bottom. The figure also illustrates when the survey effort was expanded from 7 to 15 then to 29 species. Type groups were excluded from this plot.

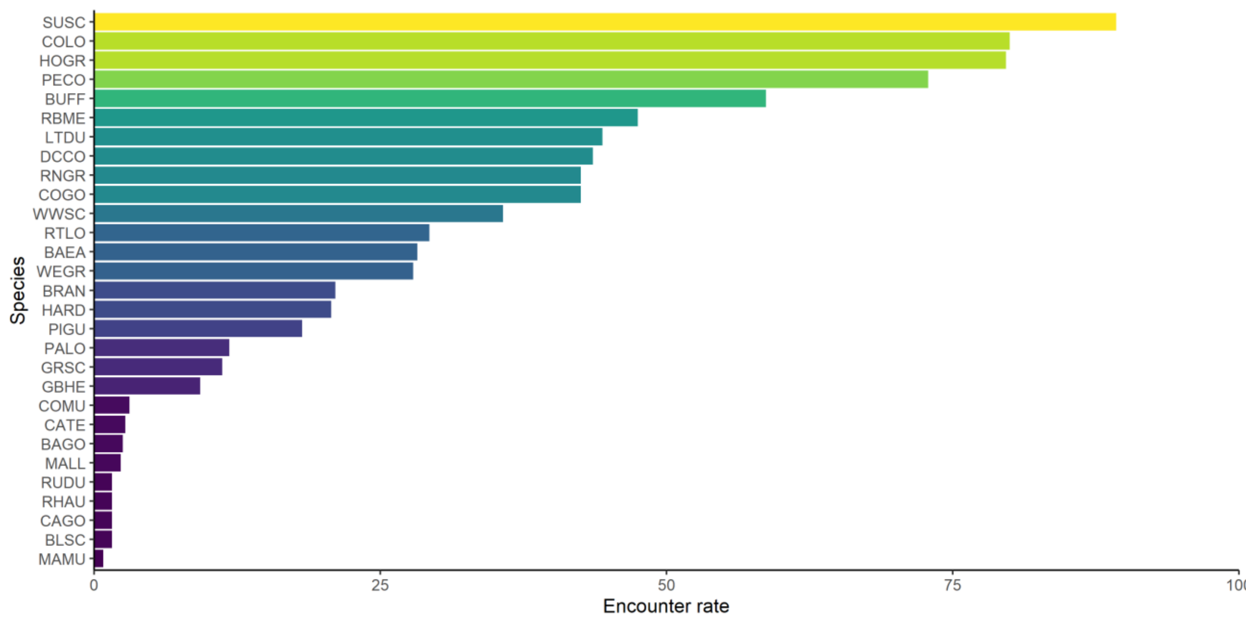
Encounter rate was used to compare how often targeted seabird species were seen at CPAR. To standardize the encounter opportunity across all species, I used only surveys conducted December 2016 or to February 2022 since those were all the surveys in the dataset that were conducted with the most expanded target species list. Encounter rate was calculated by:

$$\frac{\text{sum (\# of surveys with that species)}}{\text{total \# of surveys}}$$

The average probability of encounter across all species was 23 ± 26 percent. Figure 12 plots each species in order of overall encounter probability. I selected the five species with a 50% or higher probability of encounter for further analysis: Surf Scoter, Common Loon, Horned Grebe, Pelagic Cormorant and Bufflehead.

Figure 12

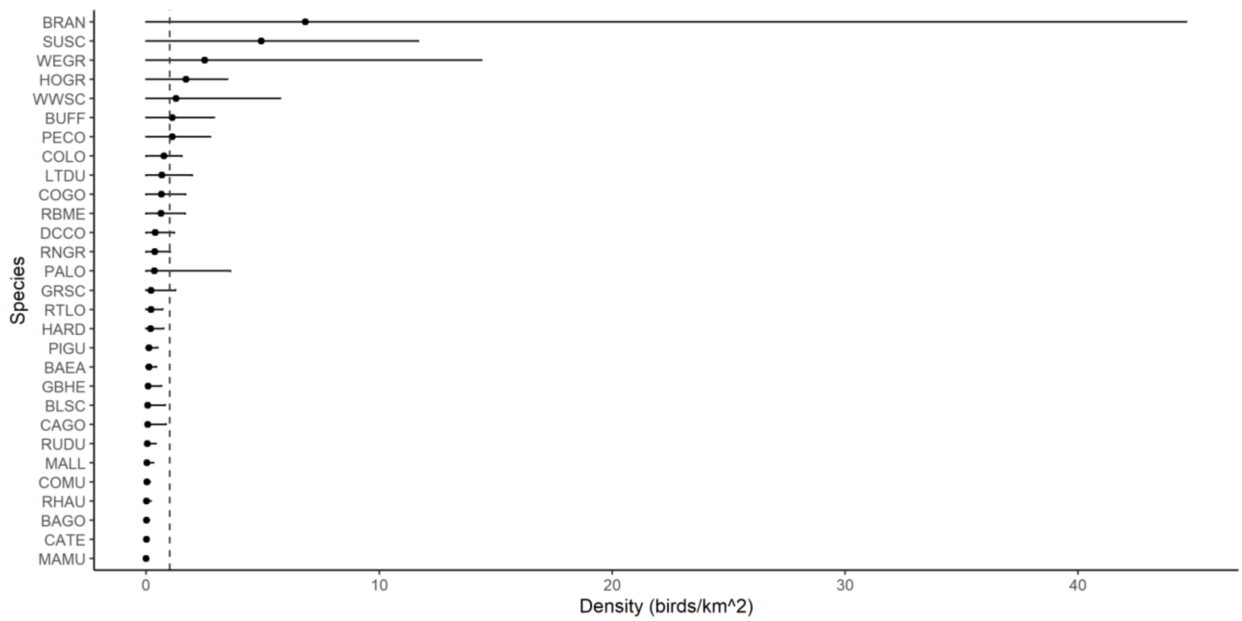
Encounter Rate for All Species Targeted by the CPAR Seabird Surveys



I compared mean density to identify which species were often recorded in groups or flocks (>5 individuals or 1.5 birds/km^2). Unless surveys were excluded in the QA/QC process, each survey event consisted of six density calculations for the two teams at three different sites. I compared density across the four seasons from 2017/2018 to 2020/2021 since these were the most complete seasons with only one survey missed in October 2018. Across all species, mean density was 1bird per km^2 with a standard deviation of 8 (rounded to the nearest bird). Figure 13 shows which species were seen in above average densities. I selected the four species with average densities above 1.5 birds per square kilometer for further analysis: Brant, Surf Scoter, Western Grebe, and Horned Grebe.

Figure 13

Mean Density for All Species Targeted by the CPAR Seabird Surveys



Note. The dashed vertical line represents average density across all surveys (1.02 birds/ square km). Each point is mean density for that species and the error bars represent standard deviation truncated at zero.

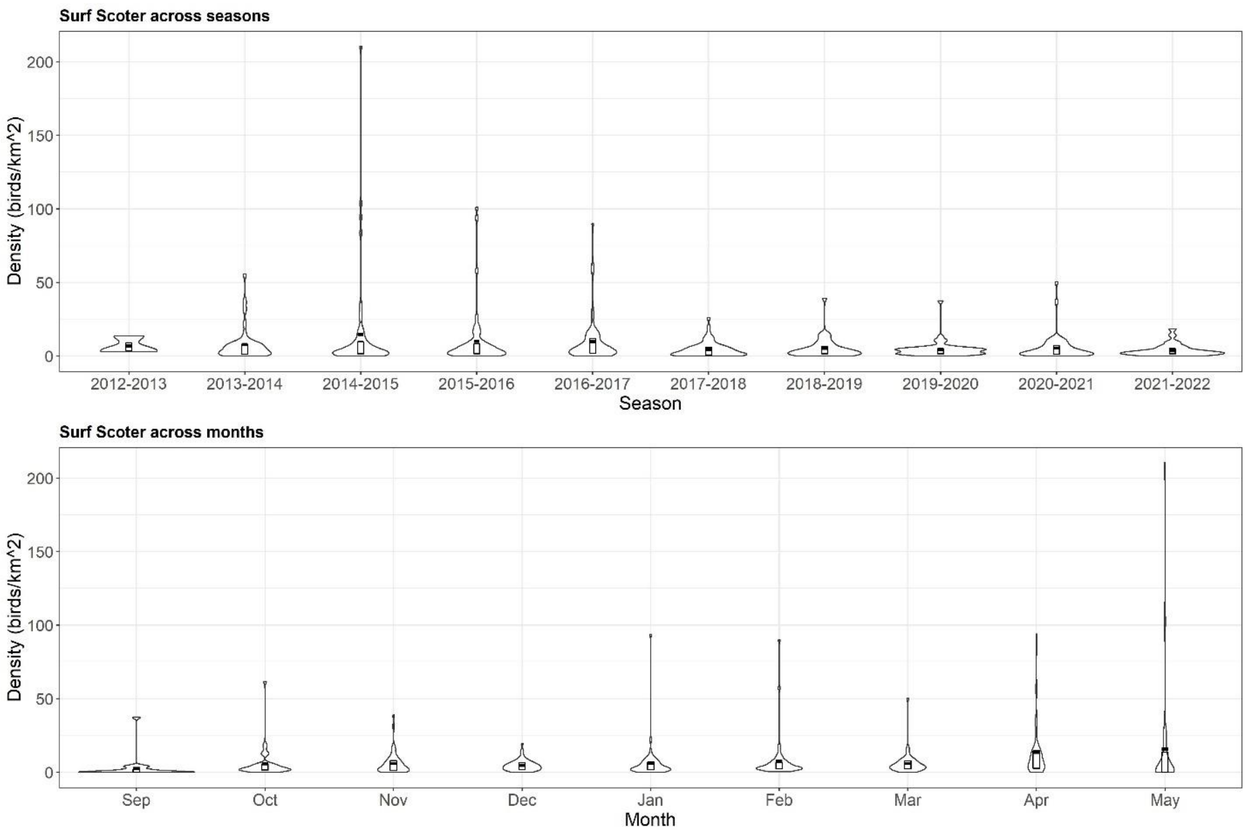
Between encounter rate and average density, I identified seven species that were often in the CPAR area (probability of encounter > 50%) and/or appear in larger numbers when they were present (mean density > 1.5 birds/km^2): Surf Scoter, Common Loon, Horned Grebe, Pelagic Cormorant, Bufflehead, Brant, and Western Grebe. For each of these seven species I looked at change between seasons and survey months. Additionally, I compared total bird density and the density of birds grouped by feeding guild across months and seasons. Through these analyses, I identified times when these seabirds are most present at CPAR. Knowing when seabirds are present is important for management decisions. It can identify times when habitat resources may be more available at CPAR or when certain species may be more susceptible to disturbance. Feeding guilds may indicate the presence of certain prey types (i.e., higher piscivore density may mean there are more fish prey available).

The species-level visualizations are violin plots which reflect the data distribution as well as summary statistics. Each shape represents the density distribution for that month or season. Wider sections of the shape correspond to bird density values that were recorded more often – the wider the shape, the higher the probability that birds will be seen in that density that season/month. Short, wide shapes mean that all the data points were similar in value i.e., density was consistent during that season/month with little variation. Tall, skinny shapes represent more data variation i.e., density was more variable during that time period. Within each violin shape is a box with the mean (dark horizontal line) between the upper and lower quartiles. Multi-species groups had greater levels of variation and, subsequently, are represented with a different plot style. Feeding guild, overall density and type group plots include mean density as a point with standard deviation as error bars truncated at zero.

Surf Scoter

Figure 14

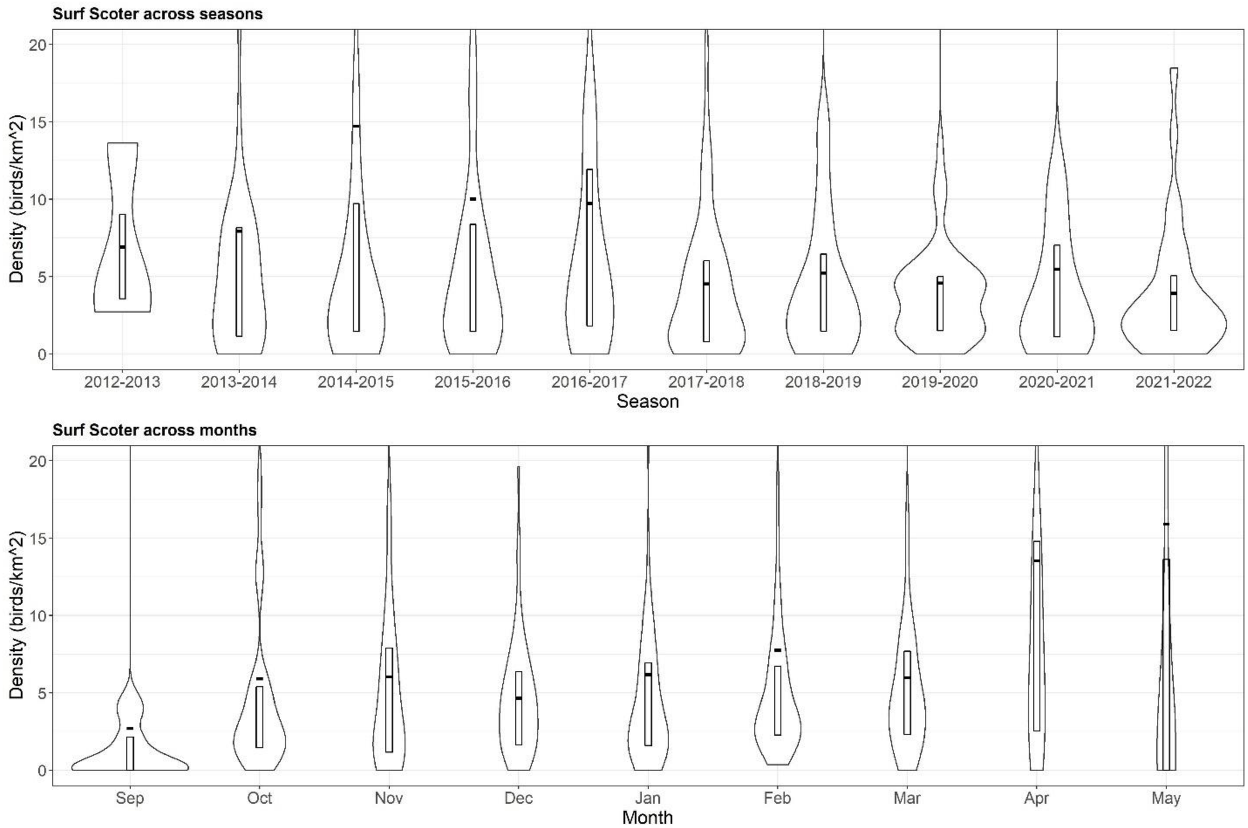
Surf Scoter Density by Season and Month



Note. Surf Scoter density shown by season on top plot and by month in the bottom plot. This plot visualizes data distribution including aggregations, or peaks, in certain seasons or months

Figure 15

Surf Scoter Density by Season and Month Focusing on Summary Statistics



Note. Surf Scoter density by season on the top and month on the bottom with the y-axis bounded at 20 birds/km^2.

There was no significant difference in Surf Scoter density between seasons of observation (Kruskal-Wallis, H_9=8.98, p = 0.44). There were some notable aggregations in the 2014-2015 season that can be seen in Figure 14. While not statistically significant, these instances of high density represented large flocks or aggregations of Surf Scoter and points towards an area of future inquiry. Historically, Surf Scoter formed massive aggregations in response to Cherry Point herring spawn. The 2014-2015 seabird season overlapped with a 2015 peak in Semiahmoo herring spawn deposition (Sandell et al., 2019) which is the herring stock just to the north of the Cherry Point area.

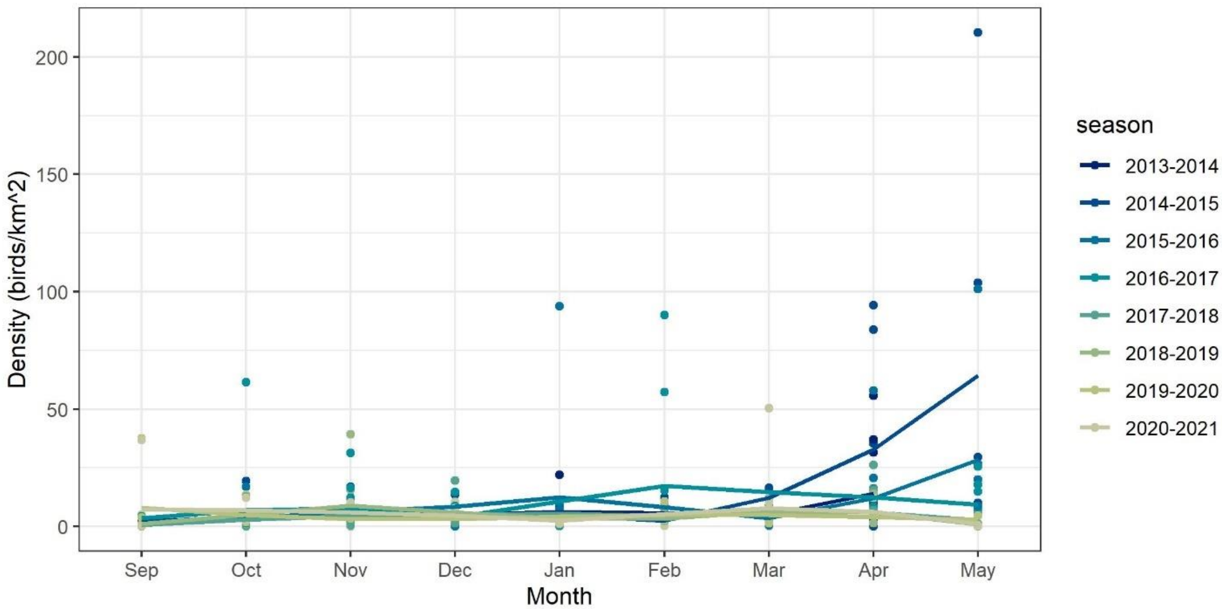
Figure 15 magnifies the summary statistics (means and quartiles) within the violin plots. According to the negative binomial regression model, there has been a significant ($p < 0.01$) decrease in surf scoter density since 2013. The decrease is still significant ($p < 0.01$) even if only data after the peak 2014-2015 season is included in the model.

Across survey months, September had significantly lower density than any other month (Kruskal-Wallis, $H_8 = 60.27$, $p < 0.01$, Dunn's post hoc, $p < 0 .01$ for all pairs except May-Sep $p=.01$). This is likely due to migration timing as Surf Scoter enter the area. Additionally, there is a significant difference between April and May (Dunn's post hoc $p = 0.02$). Analysis shown in Figure 14 shows that there were non-significant density peaks in April and May. This timing is notable because this was when the Cherry Point herring were spawning. Other north Puget Sound herring stocks spawn in February and March (Sandell et al., 2016).

Future applications of this data could include exploring this relationship between Surf Scoter density and local herring spawn deposition. Figure 16 visualizes Surf Scoter density trends across each season and that spring density peak has not been seen since 2017. Whatever resource, whether it be herring spawn or something else, that was keeping Surf Scoter at Cherry Point into the Spring, may no longer be present. Cherry Point herring have been in decline since the 1970s so it will take additional monitoring and research to understand the mechanisms behind this shift in Surf Scoter migration timing.

Figure 16

Surf Scoter Density Across Each Season

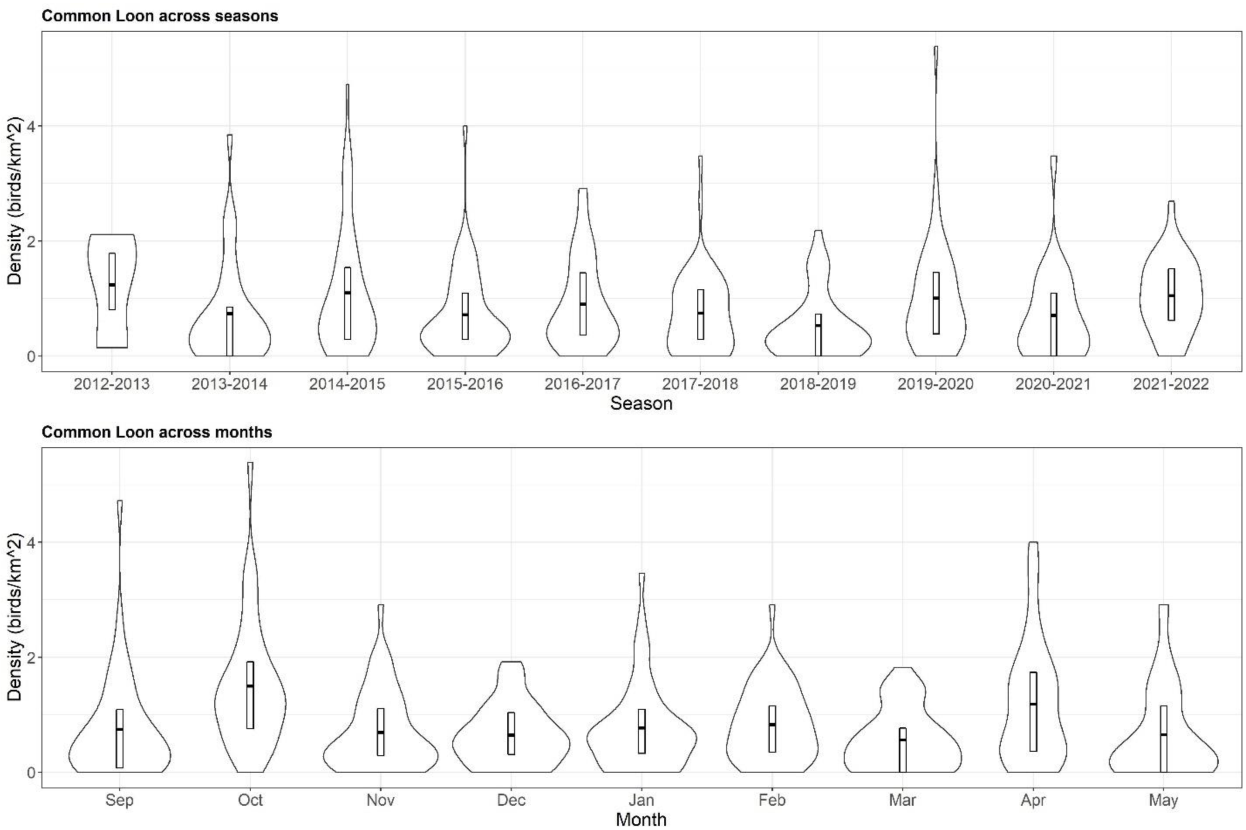


Note. Mean Surf Scoter density each month is represented by a point. The points are connected by best fit line using a loess formula. Each line estimates the density trend for that season.

Common Loon

Figure 17

Common Loon Density by Season and Month



Note. Common Loon density shown by season on top plot and by month in the bottom plot.

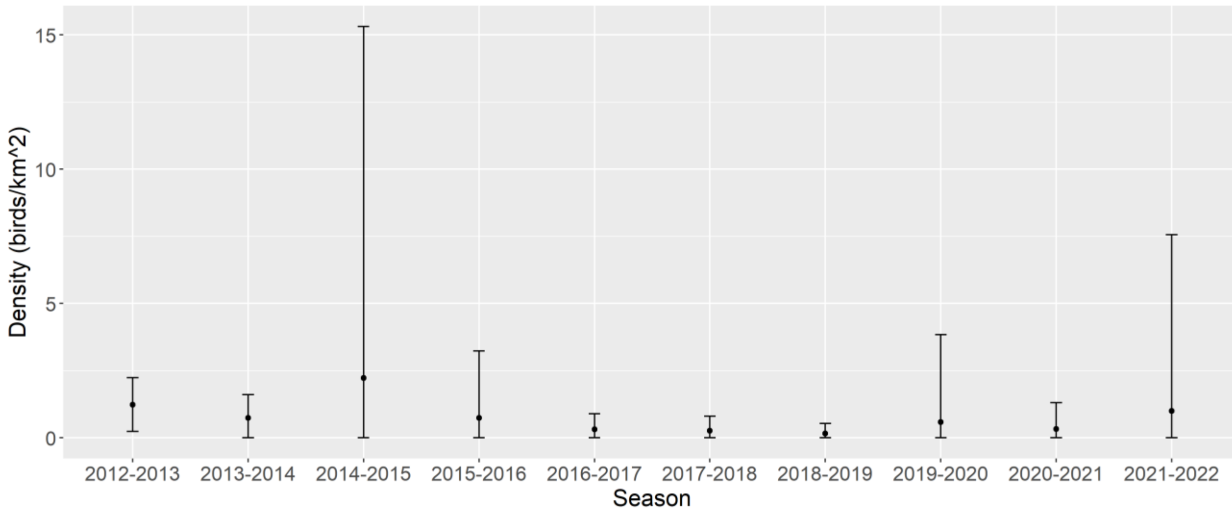
There was a significant difference in Common Loon density between the 2018-2019 and 2021-2022 seasons (Kruskal-Wallis, $H_9 = 22.89$, $p = 0.01$, Dunn's post hoc, $p = 0.02$). However, the 2021-2022 season was incomplete at the time of analysis so this test should be recreated when the full season of data becomes available. Additionally, there was a significant difference in Common Loon density between months (Kruskal-Wallis, $H_8=38.01$, $p < 0.01$). Common Loon density was significantly higher in October than September (Dunn's post hoc $p < 0.01$), November (Dunn's post hoc $p < 0.01$), December (Dunn's post hoc $p < 0.01$), January (Dunn's post hoc $p = 0.01$), March (Dunn's post hoc $p < 0.01$) and May (Dunn's post hoc $p < 0.01$). May densities were also significantly lower than April (Dunn's post hoc $p = 0.04$). Common Loon are winter migrants that breed on freshwater lakes and ponds. Degradation of their lake breeding areas has led to a regional decrease and their listing as a sensitive species in Washington State (Richards et al., 2000). They were seen often and were relatively numerous in the CPAR surveys and there was no change over time in their density (negative binomial regression, $p = 0.72$).

Loons form mixed species aggregations, and it can be challenging to distinguish to species when they are near the edge of the visible survey area. When all loon densities are grouped and analyzed, overall loon density has significantly decreased since 2013 (negative binomial regression, $p < 0.01$). A Kruskal-Wallis rank test ($H_9=95.33$, $p <0.01$) with Dunn's test post hoc found that the 2013-2014 and 2014-2015 seasons had significantly higher loon densities than the 2017-2018 through 2020-2021 seasons ($p < 0.01$) and the 2014-2015 season was also higher than the 2021-2022 season ($p = 0.02$). Additionally, the 2015-2016 season had higher loon densities than 2017-2018 ($p = 0.02$) and 2018-2019 ($p < 0.01$). However, loon density does appear to be increasing again as the 2021-2022 season has higher densities than the 2018-2019 ($p < 0.01$).

Loons are piscivores and Pacific loons have shown an aggregate response to herring. The 2014-2015 season was the same year as the Semiahmoo herring peak. The genus-level loon group was not added until December of 2016. This means that all loon individuals were not recorded prior to that time and there may have been more loons than were recorded in the surveys. This also means there may have been fewer zeros in the data which would artificially increase mean density. If only dates from the 2017-2018 season or later are used, then loon density has a significant increasing trend (negative binomial regression, $p < 0.01$).

Figure 18

Mean Loon Density by Season

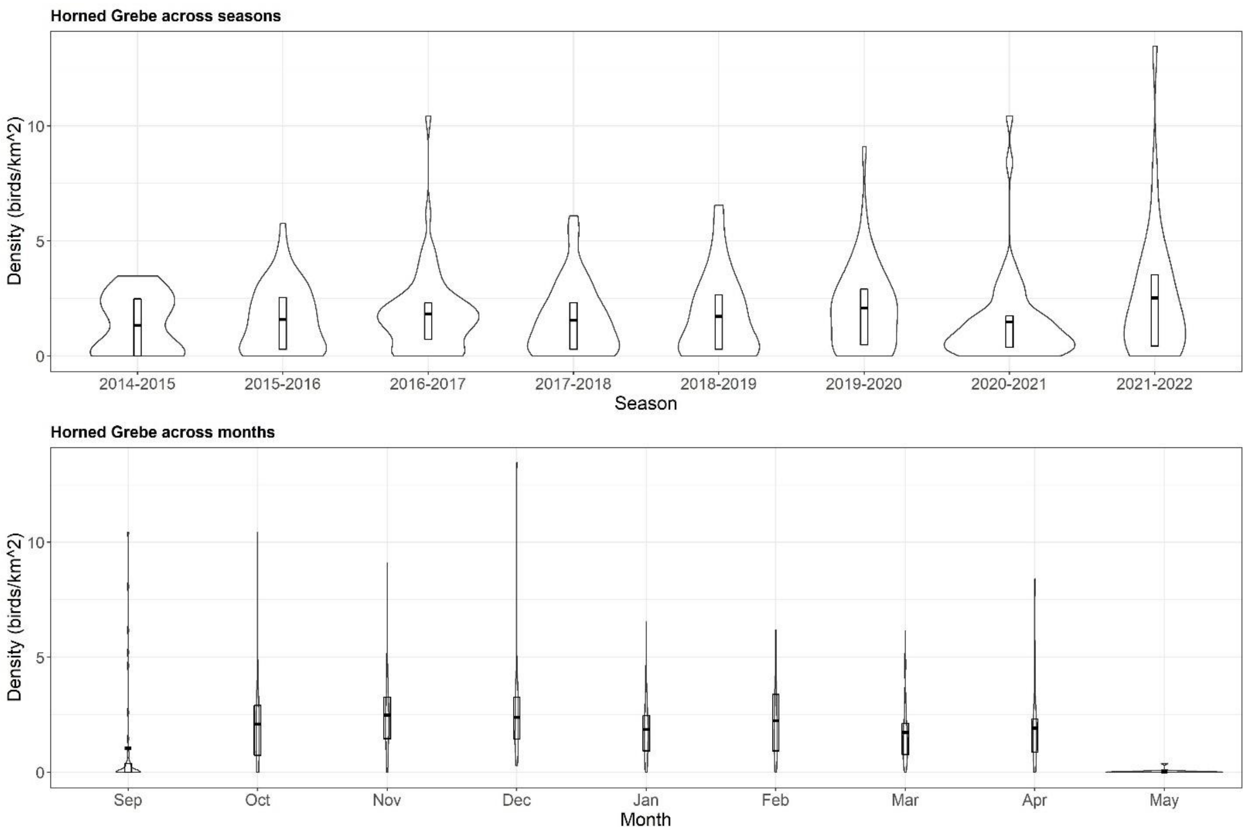


Note. The points represent the mean density for all loon species, and the error bars are standard deviation truncated at zero. The 2017-2018 season is the first complete season where all loon individuals were recorded even if they could not be identified to species.

Horned Grebe

Figure 19

Horned Grebe Density by Season and Month



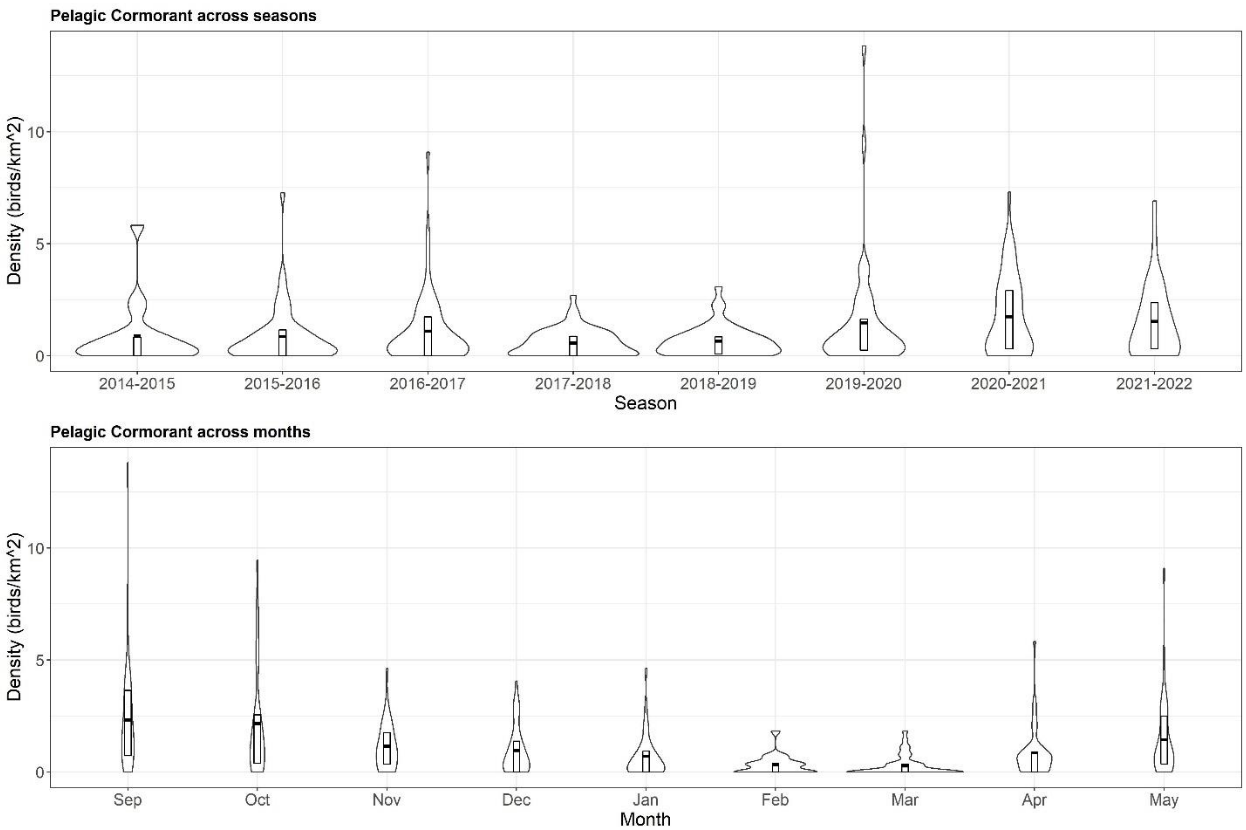
Note. Horned Grebe density shown by season on the top plot and by month on the bottom plot.

There was no significant difference in Horned Grebe density across (negative binomial regression, $p = 0.11$) or between seasons (Kruskal-Wallis, $H_7 = 7.35$, $p = 0.39$). Horned Grebe density is significantly (Kruskal-Wallis, $H_8=122.23$, $p< 0.01$) lower in May (Dunn's post hoc, $p < 0.01$ for all pairwise except September) and September (Dunn's post hoc, $p < 0.01$ for all pairwise except May) and all other months. Horned Grebe are a winter migrant that appear to have consistent times that they arrive and depart the Cherry Point area.

Pelagic Cormorant

Figure 20

Pelagic Cormorant Density by Season and Month



Note. Pelagic Cormorant density shown by season on top plot and by month in the bottom plot.

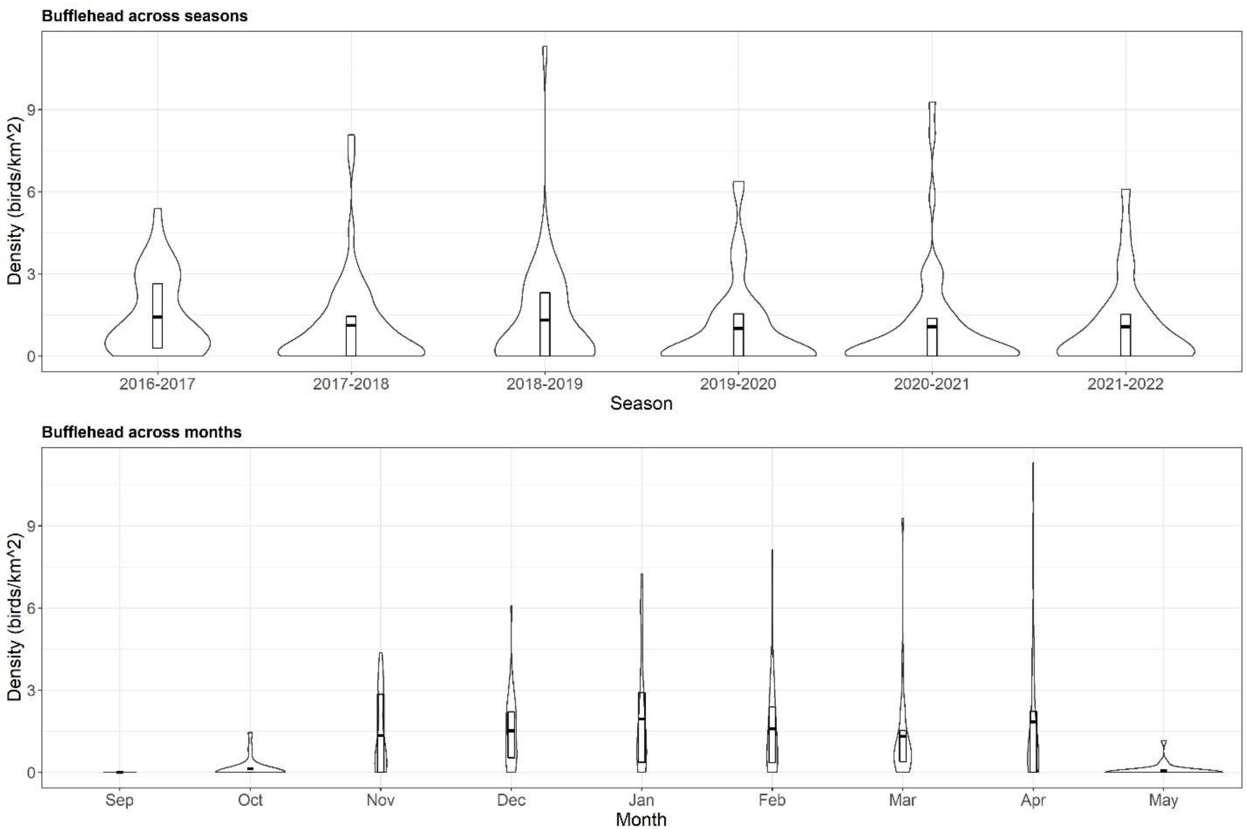
Pelagic Cormorant density was significantly higher in the 2020-2021 season than 2017-2018 (Kruskal-Wallis, H_7=17.33, p = 0.02, Dunn's post hoc, p=0.03). Additionally, there were significant differences between months (Kruskal-Wallis, H_8 = 80.56, $p < 0.01$). Pelagic Cormorant density was higher in September than the months of December (Dunn's post hoc, p = 0.01), January ($p < 0.01$), February ($p < 0.01$), March ($p < 0.01$), and April (p = 0.01). October densities were also significantly higher than February ($p< 0.01$) and March (, $p < 0.01$). February and March both had lower densities than May and November ($p < 0.01$) and March was also significantly lower than April ((Dunn's post hoc, $p = 0.03$) and December (Dunn's post hoc, $p = 0.02$).

Pelagic Cormorant were one of the few resident species that were seen often and in large numbers. They nest on bluffs and anthropogenic structures in the summer which may explain why they were significantly denser in the fall before their numbers appeared to decrease at CPAR over the winter months and into the early spring. This is the opposite pattern to many of the winter migrant species targeted by these surveys. Pelagic Cormorant density did significantly increase over the seasons (negative binomial regression, $p < 0.01$) which is consistent with the findings from Crewe et al. (2012).

Bufflehead

Figure 21

Bufflehead Density by Season and Month



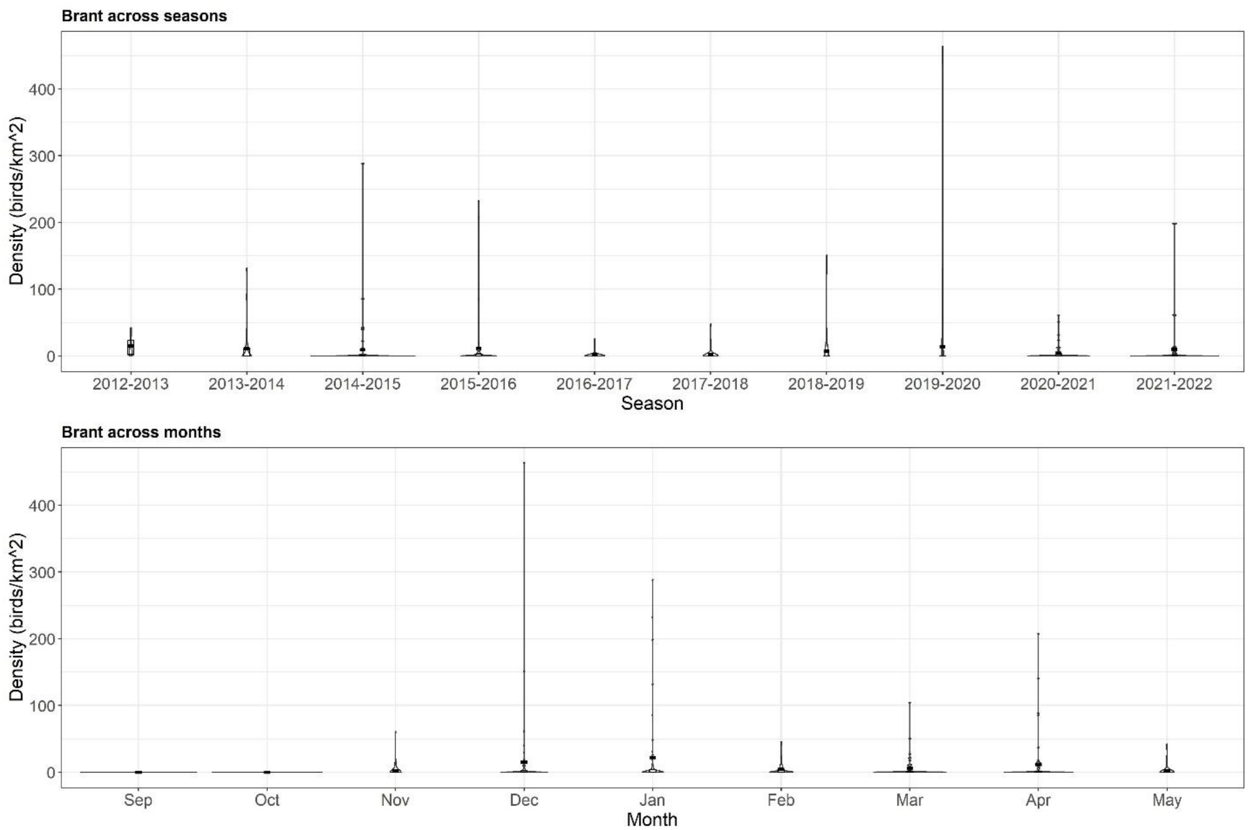
Note. Bufflehead density shown by season on top plot and by month in the bottom plot.

There was no significant difference in Bufflehead density across (negative binomial regression, $p = 0.43$) or between seasons (Kruskal-Wallis, H_5=6.61, $p = 0.25$). Bufflehead are another migratory species. September, October, and May were all significantly lower (Dunn's post hoc $p < .01$ for all pairwise) than November, December, January, February, March, and April. Bufflehead are a winter duck species often seen across Puget Sound and the Salish Sea. The monthly data illustrates their migration timeline as they enter the area in the late fall and leave in the spring.

Brant

Figure 22

Brant Density by Season and Month



Note. Brant density shown by season on top plot and by month in the bottom plot.

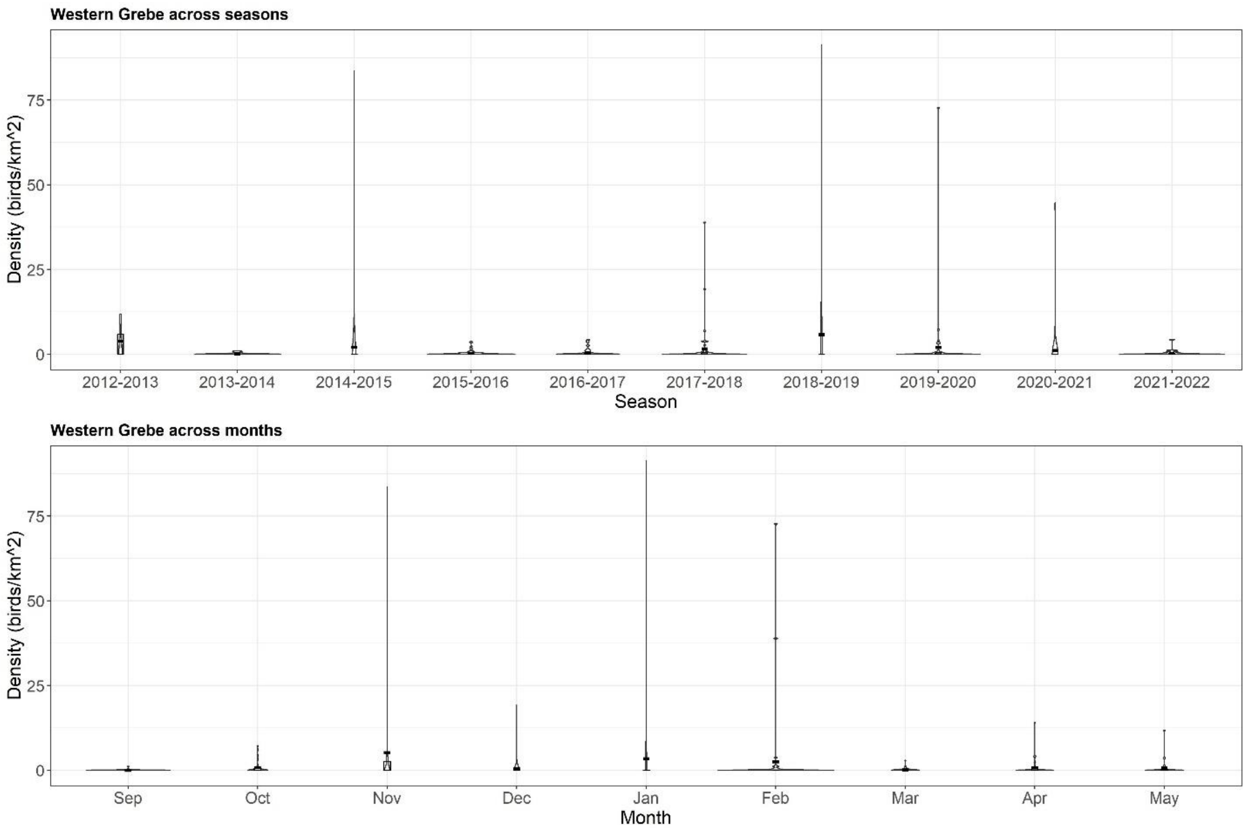
Brant densities have been particularly variable as seen by the narrow plots. There was a significant difference in Brant density between the 2013-2014 and 2018-2019 seasons (Kruskal-Wallis, H_9=23.03, p = 0.01, Dunn's post hoc p = 0.02); however, there was no change across seasons (negative binomial regression, p = 0.95). There was a significant difference (Kruskal-Wallis, H_8=57.58 p< 0.01) in Brant density between September and the months of December (p = 0.02), January (p < 0.01), February (p < 0.01), and April (p < 0.01); and October and the months of January (p< 0.01), February (p = 0.01), and April (p=0.01). January had significantly higher densities than November (p < 0.01) and May (p < 0.01).

Brant form large flocks and the appearance of those flocks likely contributes to the large amount of variability in this data. Brant are herbivores with a preferred diet of seagrass. Like other goose species, they travel in flocks. There are seagrass beds to the north of the survey sites in Birch Bay and to the south near Lummi Bay, but the aggregations were likely due to migratory flocks resting in the CPAR area rather than foraging within it.

Western Grebe

Figure 23

Western Grebe Density by Season and Month



Note. Western Grebe density shown by season on top plot and by month in the bottom plot. Western Grebe have a lower encounter rate as reflected by the diminished size of the violin shapes in the plots.

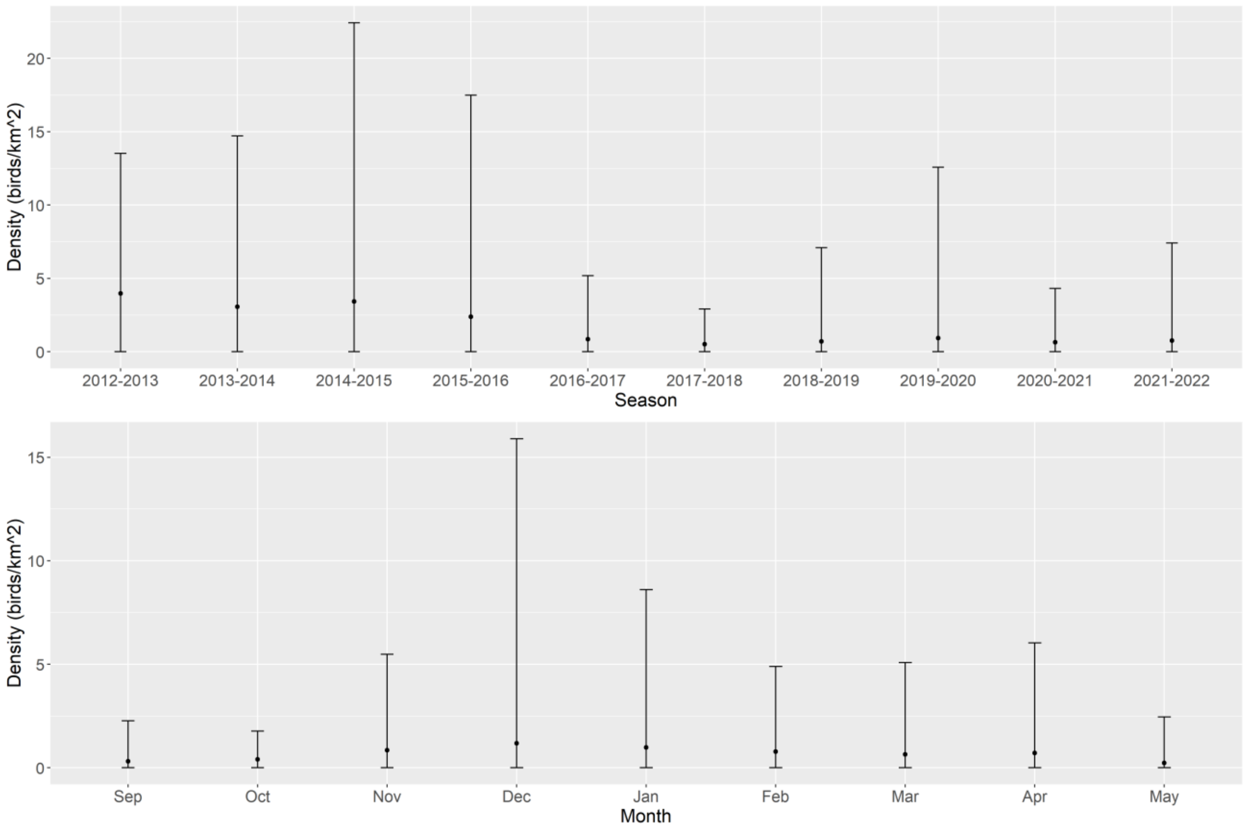
There was no significant difference in Western Grebe density across (negative binomial regression, $p = 0.16$) or between seasons (Kruskal-Wallis, $H_9=6.48$, $p = 0.69$). There was a significant difference (Kruskal-Wallis, H_8=61.55, $p<0.01$) in Western Grebe density between months. November was significantly higher than all other months ($p < .01$) except October. September was significantly lower than October ($p = 0.01$), November ($p <0.01$) and April ($p=0.04$).

Western Grebe have been declining regionally. Bower (2009) and Crewe et al. (2012) conducted analyses showing that Western Grebe have declined over 80% since the MESA baseline and over 16% in the last 12 year. These declines have led to their candidate status in Washington State and their placement on the red list in British Columbia. Due to these conservation concerns, continued monitoring of this species is advised. More than other grebe species, they form large rafts on the water which may account for the records of aggregation at CPAR.

All targeted species

Figure 24

Total Seabird Density by Season and Month



Note. Mean density of all targeted birds shown by season on top plot and by month in the bottom plot. Density by month uses only data collected after December 2016 when the effort expanded to include all 29 species currently being targeted. The points represent the overall mean density, and the error bars are standard deviation truncated at zero.

I looked at all the targeted species including the genus or family level groups (type groups) where the data collectors were unable to identify a bird to species. This analysis included Bald Eagle and Great Blue Heron which are not seabirds but do interact with the marine environment. Prior to December 2016, the few species being targeted included were those that have a higher encounter rate and are seen in higher densities like Surf Scoter, Western Grebe, and Brant. With fewer zeros and more high-density encounters, this artificially biases the data towards high mean densities in those early years. I included those seasons in the density by season plot, but excluded all data collected prior to December 2016 for the density by month plot and analyses. Figure 24 illustrates how density decreases as more species were added in the 2015-2016 and 2016-2017 seasons.

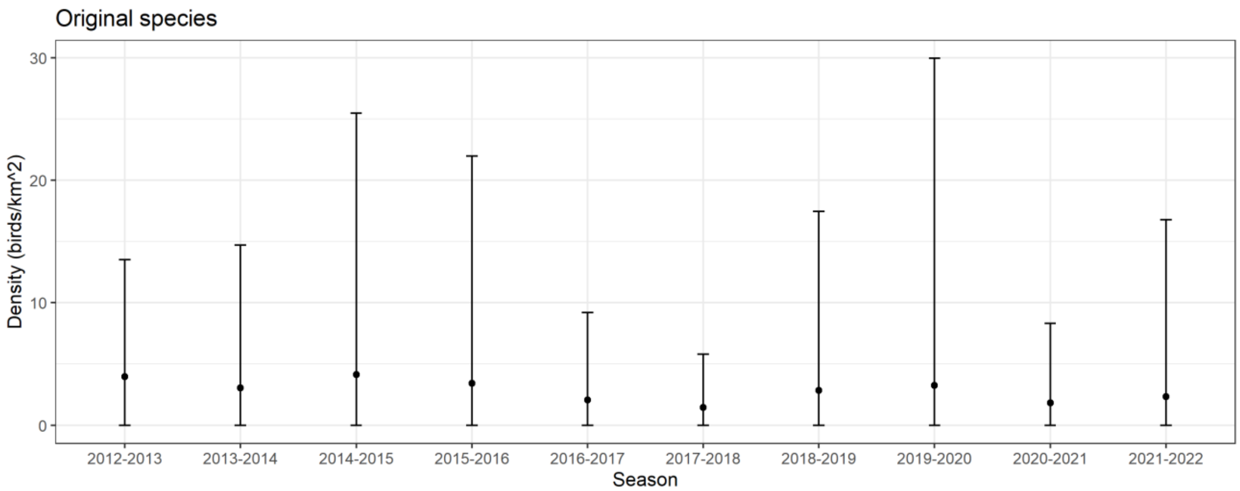
Across all seasons (2012-2013 to 2021-2022) there was a significant decrease in overall seabird density (negative binomial regression, $p < 0.01$). However, if I include only seasons where all 29 species were targeted (2017-2018 to 2021-2022), there was a significant increase in overall seabird density (negative binomial regression, $p < 0.01$). Across the last five seasons, there was a significant difference (Kruskal-Wallis, $H_4=14.69$, $p < 0.01$) in bird density between the 2018-2019 season which had lower bird densities than the 2019-2020 ($p = 0.03$) and 2021-2022 ($p < 0.01$) seasons. These differences and trends will likely change as there are more surveys conducted that target all 29 current species.

There is a significant difference in bird density (Kruskal-Wallis, $H_8=146.82$, $p < 0.01$) between the months. September and May both were significantly lower than all other months (Dunn's post hoc $p< 0.01$ for all pair-wise tests). This mirrors migration timelines which makes sense since over 70% of the targeted species are winter migrants and again include those species that are encountered most often and recorded in the highest density.

If I look at only the seven species originally targeted by the CPAR surveys (Surf Scoter, Western Grebe, Bald Eagle, Common Loon, Common Goldeneye, Brant, and Harlequin Duck), I can compare across all seasons without reservation. Figure 25 illustrates the density of the original seven species. There was a significant decrease in compiled density for these seven species (negative binomial regression, $p = 0.01$). This trend is driven by decreasing Surf Scoter density. If Surf Scoter are removed from the model, then there was no significant change to combined density of the other six species (negative binomial regression, $p = 0.91$). This supports the need for long-term data sets and the importance of continuing this survey effort. Patterns in seabird density may not be visible without five or more seasons of data.

Figure 25

Mean Density of Original Seven Species by Season



Note. Mean density of the original seven species plotted across the seasons. The points represent the overall mean density, and the error bars are standard deviation truncated at zero.

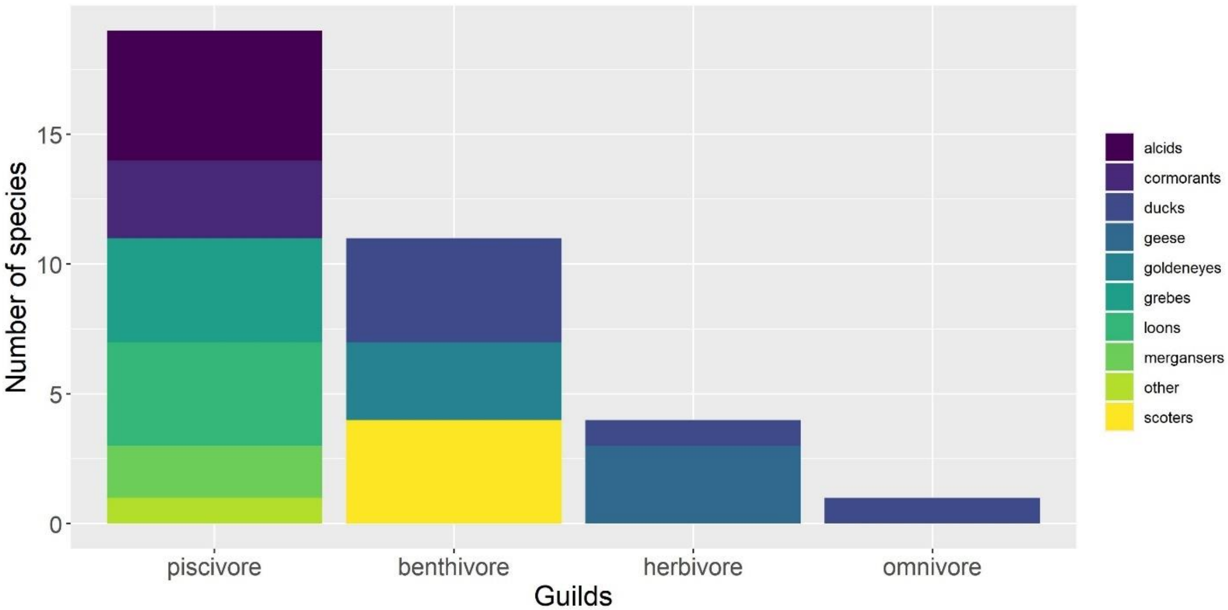
Where individual species may be more specific indicators of a prey source or habitat type, overall seabird density is also an indicator of habitat quality. However, these surveys target only certain species. These results may have statistical significance, but the practical significance is limited because they do not capture the entire seabird population. This limitation is also illustrated by the conflicting negative binomial regression results depending on which species are included in the analysis. Until the CPAR surveys include all bird species present, this combined data presents a partial picture, and this data set may be most rigorous when applied to individual species.

Feeding guilds

Feeding guilds were assigned according to Bower (2009). There were four feeding guilds represented by the CPAR data, but I focused on only two for further analysis. The omnivore (eats everything) feeding guild was represented by a single species (Greater Scaup) and the herbivore (eats vegetation and marine algae) guild was composed of four species groups (Mallard Duck and Brant, Canada, and other geese) which, except for Brant, were rarely recorded at CPAR. In contrast, the benthivore (eats benthic invertebrates) and piscivore (eats fish) guilds had 11 and 19 species groups, respectively. Benthivores include diving ducks like scoters, and piscivores include the loons, alcids, mergansers, cormorants, and grebes.

Figure 26

Species Composition of the Four Feeding Guilds

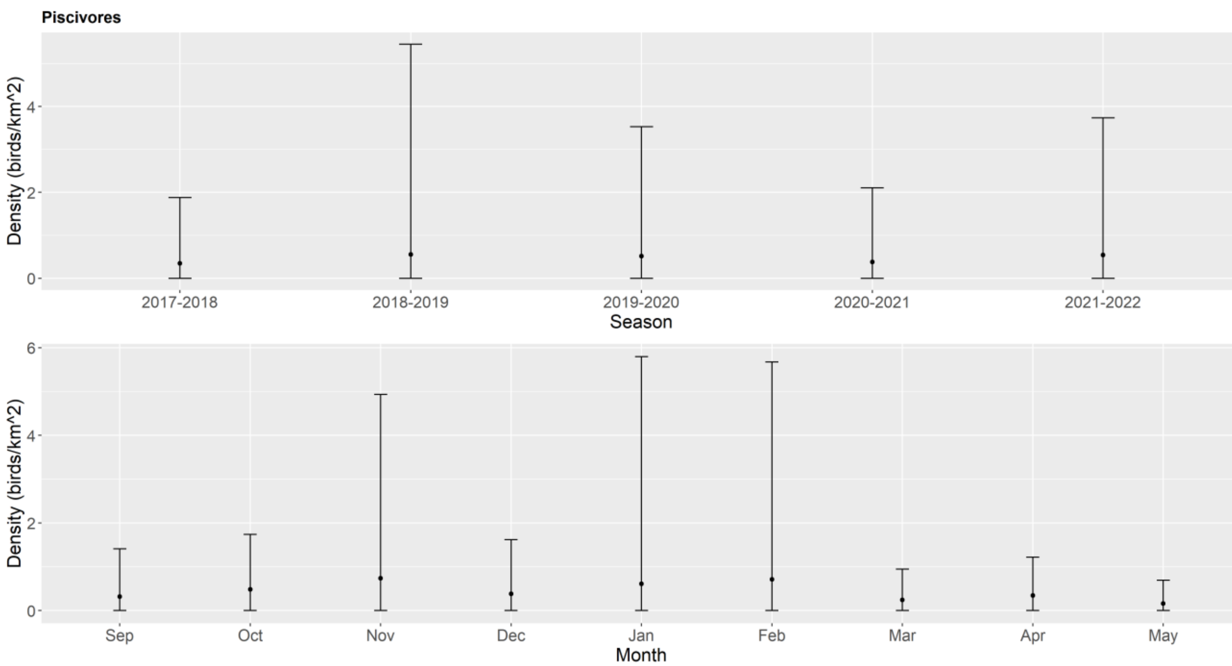


Note. This visualization only includes species currently targeted by the CPAR seabird effort. The species labeled other in the legend is Caspian Tern.

Similar concerns arise when interpreting the data grouped by feeding guild as when looking at overall density. Because the CPAR survey efforts targeted a subset of the species present at CPAR, these guild groupings do not include all potential species that meet the group criteria. For example, there are likely more benthivore seabird species at CPAR than were included in the survey effort. That being said, the surveyed species were targeted because they are known to be the most frequent and abundant seabird visitors in the region and would likely drive any guild related changes even if more species were incorporated into the surveys. I only included data collected December 2016 or later when the survey effort expanded to include the genus and family level groups. I did exclude Bald Eagle and Great Blue Heron since they are not seabirds and therefore do not have an assigned guild.

Figure 27

Mean Piscivore Density by Season and Month

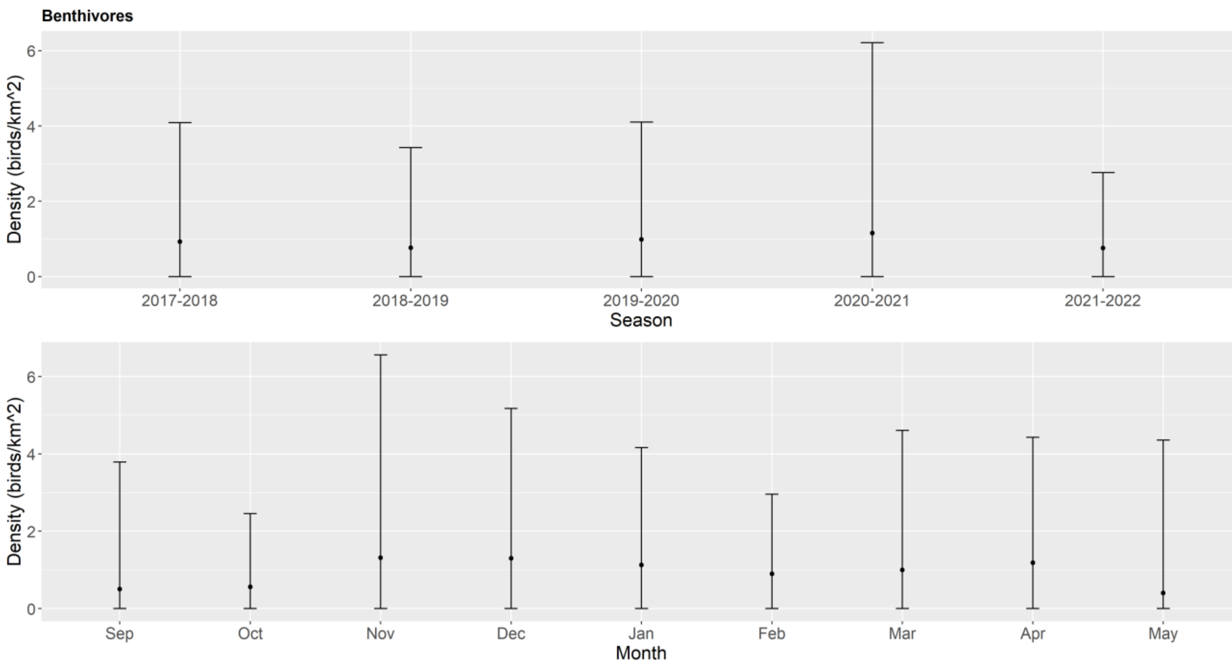


Note. Mean density of all piscivorous seabirds shown by season on top plot and by month in the bottom plot. The points represent the overall mean density, and the error bars are standard deviation truncated at zero.

The only significant difference between seasons was between the 2018-2019 and 2021-2022 season (Kruskal-Wallis, H_4=13.83, $p < 0.01$, Dunn's post hoc $p = 0.02$). There was no significant change in piscivore density across seasons (negative binomial regression, $p = 0.08$). There were significant differences across months (Kruskal-Wallis, H_8=49.54, $p < 0.01$) with May having lower densities than October ($p < 0.01$), November ($p < 0.01$), December ($p < 0.01$), January (p = 0.04), February (p < 0.01), and April (p < 0.01). October had higher densities than September (p = 0.03), and November has higher densities than March (p = 0.01) and September (p < 0.01). This were relatively consistent with migratory patterns although this guild does have the resident species like cormorants and alcids.

Figure 28

Mean Benthivore Density by Season and Month



Note. Mean density of all benthivore seabirds shown by season on top plot and by month in the bottom plot. The points represent the overall mean density, and the error bars are standard deviation truncated at zero.

There was no significant difference in benthivore density between (Kruskal-Wallis, H_4=3.34, p= 0.50) or across (negative binomial regression, p = 0.51) seasons. There were significant differences in benthivore density across months (Kruskal-Wallis, H_8=152.11, p < 0.01). Due to the migratory life histories of most species in this guild, benthivore density was lowest in the fall and spring. May and September both had significantly lower densities (Dunn's post hoc, p < 0.01) than November, December, January, February, March, and April. October was significantly lower than December ($p < 0.01$), January ($p < 0.01$), February ($p < 0.01$) and March ($p = 0.04$). The piscivore and benthivore guilds warrant continued monitoring as they are the two guilds found to be decreasing in the Salish Sea (Bower, 2009; Ethier et al., 2020; Vilchis et al., 2015).

Knowing what months seabirds are most present may be meaningful to answer specific questions or to grant permit applications, but the value of a seabird indicator is most apparent when looking for charge over time. However, shifts to migration timing and duration of stay, like those seen with Surf Scoter, are also indicative of resource availability. Seabirds will choose to visit and stay in areas with healthy habitats and abundant prey. At Cherry Point, and across the Salish Sea, positive progress towards marine conservation should be indicated by increasing seabird numbers.

CONCLUSIONS

The Cherry Point marine bird monitoring project is an ongoing community science effort that is nearing 500 surveys and has documented over 37,000 birds. The CPAR Birders are a largely self-organized group of community members whose passion for birding has produced an incredible data source for Aquatic Reserves managers. The CPAR marine bird monitoring project was originally designed to replicate historical MESA surveys and therefore be compared to the MESA seabird baseline. My approach did not include this historical comparison. Rather than designing a project to answer a specific question, I approached an ongoing project and identified questions it may be able to answer. This required extensive data exploration and visualization. My thesis created a database, quality control process and replicable analyses for the Aquatic Reserves Program that makes the data set available to Washington State scientists.

Of the total 29 marine bird species surveyed, seven species were encountered the most often (> 50% of the time) and/or in higher numbers (> 1.5 birds per km^2 on average): Surf Scoter, Common Loon, Horned Grebe, Pelagic Cormorant, Bufflehead, Western Grebe and Brant. Of these species, all except Pelagic Cormorant are migratory. Four are piscivores, two are benthivores and one is an herbivore. This reflected the overall guild makeup of the targeted species and implied that no single feeding guild dominated the area. Pelagic Cormorant density was found to increase over the seasons while Surf Scoter density decreased. The other five species had non-significant change across the seasons. Guild and overall densities were analyzed across only the five most recent seasons due to the addition of more species in 2015 and 2016. There were no significant changes in piscivore, benthivore or overall seabird density over this time. Monthly fluctuations seemed to be driven predominantly by migratory patterns with the possible exception of Surf Scoter.

I had proposed three specific seabird indicators: scoters, Pelagic Cormorant and Pigeon Guillemot. Pigeon Guillemot, like all the alcids, were seen infrequently and that paucity of data makes them a poor indicator. Scoters and Pelagic Cormorant are viable candidates due to their high number of encounters. Due to the skill of the community scientists, the scoter indicator can be made species specific and become Surf Scoter. Pelagic Cormorant and Surf Scoter use the area differently—Pelagic Cormorant are residents that nest in the area over the summers and Surf Scoter are winter migrants that molt in the area before continuing to nesting grounds farther north. They also forage at different trophic levels and within differing parts of the habitat—Pelagic Cormorant are piscivorous pursuit divers and Surf Scoter are benthivores. Incorporating species that represent different aspects of the habitat is important when selecting an indicator portfolio. Thus, Pelagic Cormorant and Surf Scoter are complementary indicators for CPAR.

It may be too early to tell which species are the most responsive to CPAR habitat shifts, but I recommend that future analyses include Surf Scoter, Pelagic Cormorant and the piscivore and benthivore feeding guilds. I also recommend that a diving seabird that predominantly preys on forage fish be added to a CPAR indicator portfolio. Because alcids are seen so infrequently, a loon species like Red-throated Loon or Pacific Loon—both of which have a documented aggregate response to herring—may be an excellent choice.

Future inquiries and applications

As data collection continues, other directions for future analyses include exploring migration timing, looking for correlations between human impact and changes to seabird density, and further monitoring the relationship between seabirds and Cherry Point herring spawn. Other statistical models may produce more accurate results. As mentioned in methods, assessing other variables may increase the fit of the negative binomial model and, in some cases, a Poisson model may be a better fit. A power analysis like that conducted by Crewe et al. (2012) to assess the rigor of the CSC data set would also be incredibly valuable.

Seabirds may be entering and leaving the CPAR area earlier each year. Shifts to migration timing may be explained by impacts elsewhere on the migratory route but may also reflect habitat resources becoming available earlier in the CPAR region. Additionally, the duration of time seabirds spend at CPAR may reflect the availability of resources provide by the area.

The connection between seabirds and herring spawn is well studied, including several current projects being conducted in the CPAR area (e.g., exclusion studies conducted by WDFW). A better understanding of Surf Scoter, or other species, response to herring spawn in the area may help predict spawning or contribute to herring spawn estimates. In the past two years, herring spawning has been recorded near the industrial piers in the southern part of the reserve. Genetic tests revealed that the spawning fish were not from the Cherry Point stock (Sandell pers. Comm., April 2022), but tracking the response of seabird density to these new spawning locations could provide insight into this relationship.

The value of this data is manifold. It promotes community engagement in Aquatic Reserve monitoring and management efforts. The data provides a baseline for future comparison. If there is a substantial change to human activity or habitat, this data forms a picture of the seabird community prior to that change. If there was a permit application that would impact the reserve habitats, managers could reference this data to see when seabirds are in the area, including species of concern like those listed as threatened or endangered. Within the seven most frequent and numerous species, Western Grebe and Common Loon are listed as candidate and sensitive respectively by the State of Washington.

Recommendations for community science seabird efforts

Through my data management and analyses I identified common errors and suggested protocol updates to address them. I also suggested updates to the data sheet to minimize future errors. Appendix A includes examples of the old and appended data sheets. Table 4 compiles suggestions to improve the pre-analysis data collection and review processes.

Specific to this effort, I recommend that an additional survey location be added at the north end of CPAR. Currently only one of the three survey locations is within CPAR boundaries. Adding a northern location at Point Whitehorn would better represent the overall reserve seabird community, better replicate historical MESA survey locations, and include the area closer to the current Cherry Point herring spawning location off Birch Head.

Table 4

Common errors, recommended solutions and actions taken for the data collection and review processes associated with the CPAR marine bird surveys.

Error	Solution	My action
Confusing/unclear tallies and totals	Before leaving the survey location the recorder should write the total count for each species next to the tally and circle it. Each team should have their own data sheet.	I created a new space on the data sheet for the total count of each species. This space should never be blank as it will either be zero or a total count.
Teams have non-matching information. Some conditions like glare (and therefore visibility) may differ but others like cloud cover should be consistent	Bold or highlight the data sheet fields that should match and have teams double check before leaving the field	I bolded the sections of the data sheet that should match between both teams.
Different start times. Stop times may differ depending on the number of birds encountered but start time should always be the same.	Add to the protocol that teams must start at the same time. Recorders communicate and match start time and end time on the data sheet.	Consistent start times and communication are in the protocol. I brought this error to the attention of the CP birders.
Missing values and incomplete data sheets	Before leaving the field, inspect the data sheet for	This is already in the protocol but was discussed with the birders.

	completeness. No field should be left blank.	
Lack of data review	All data should be entered and scanned within one week of collection. The review will catch any additional errors.	I created a QA/QC script and system for the Aquatic Reserves Program to help review the data in addition to RE Sources staff.
Incomplete or poor-quality scans	All scans should be inspected during data entry, and hard copies retained.	Early hard copies were the main missing items. RE Sources does retain hard copies of the data sheets and will continue to do so or hand them off to DNR staff if they no longer have capacity.

For the future of this project, or for other entities who may wish to establish or refine their own marine bird monitoring efforts, I compiled a list of recommendations in Table 5. These points, while not necessary, will increase the potential applications of the dataset.

Table 5

Recommendations to improve the scale and application of marine bird monitoring efforts including the pros and cons associated with each recommendation.

Include all bird species on the water and shoreline at the time of survey.	
<u>Pros</u> Focusing on only a few key species is a great way to maximize volunteer time and capability but including all species will provide a more complete picture of the marine bird community. Additionally, shorebirds that forage in the intertidal habitat are a valuable a seabird indicator portfolio (Pearson & Hamel, 2013).	<u>Cons</u> Survey effort and time will increase and some species like shorebirds can be challenging to identify which may require additional training.
Include a distance metric within the data either as a cutoff for observations or a minimum distance.	
<u>Pros</u> The farther the bird is from the survey location, the hard it is to see and identify, especially smaller diving birds. There are algorithms that can account for the added challenge of distance and would strengthen the analyses.	<u>Cons</u> We do not want to limit the field of observation, but a good survey to emulate is the British Columbia Coastal Waterbird Surveys which include all individuals but note those within a 500m radius. We can

<table>
<tr><td></td><td>confidently assume that all seabirds within that 500 m radius are seen and counted. This would require a range finder and distance calibration for the surveyors.</td></tr>
<tr><td colspan="2">Quantify visibility (i.e., poor visibility = maximum 500 m, Good = maximum 1000m etc.). This can tie in with the 500 m notation above.</td></tr>
<tr><td><u>Pros</u>
Having visibility directly correlate with a maximum distance of observation will allow flexibility within the analysis of the data. Rather than excluding data with limited visibility, analyses can account for changes to the survey radius when calculating density and still incorporate that data.</td><td><u>Cons</u>
Distance estimations would require a range finder and regular distance estimate calibration for the volunteers.</td></tr>
<tr><td colspan="2">Quantify human disturbance</td></tr>
<tr><td><u>Pros</u>
In addition to noting human activity, quantify the level of disturbance you estimate that activity to cause. This will make it easier to explore the relationship between seabird presence and anthropogenic disturbance.</td><td><u>Cons</u>
There is an initial effort to create a Likert scale and decide what activities qualify as high, medium, or low disturbance. Once the scale has been established, this should require minimal effort to implement.</td></tr>
<tr><td colspan="2">Note: I created a four-point Likert scale for CPAR like below.
0 = no human activity/no disturbance
1 = minimal activity/no to little disturbance
2 = some activity/some disturbance observed
3 = lots of activity/birds seem to be avoiding the area</td></tr>
<tr><td colspan="2">Note bird behavior</td></tr>
<tr><td><u>Pros</u>
Birds in flight may not be interacting with or using the management area. This is especially pertinent to small management areas like an Aquatic Reserve. By noting basic behavior (i.e., flying, foraging, resting, etc.) the analyses can focus on birds actively interacting with the managed habitats.</td><td><u>Cons</u>
For the CPAR surveys, this would require a rework of the current datasheet and may make data collection and entry more time consuming.</td></tr>
<tr><td colspan="2">Survey at a consistent time of day</td></tr>
<tr><td><u>Pros</u>
Birds exhibit different behaviors at different times of day. Survey time consistency will control for any impact that time of day may have on seabird presence and abundance.</td><td><u>Cons</u>
There would be less flexibility around survey timing.</td></tr>
</table>

Final summary

The CPAR seabird data is a valuable resource for the Aquatic Reserves Program and my thesis sets the groundwork for it to be referenced and utilized. This cumulative effort contributes to the literature around regional seabird trends and patterns, explores the application of seabird indicators to small marine management areas, and provides an example of incorporating community-driven science into an agency's decision-making framework. Community science fills data gaps and maintains data continuity, especially for small agencies and programs. Conservation efforts increasingly inhabit the space where resource managers, community scientists and academic researchers overlap. By focusing on this nexus, my thesis promotes collaborative monitoring and management for the purpose of marine conservation.

NOTES

If readers are interested in the Aquatic Reserves Program or have questions about this thesis, please visit https://www.dnr.wa.gov/aquatic-reserves or contact the author at erinstehr@gmail.com

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APPENDICES

Appendix A - Data Sheets

Data Sheet A-1: CPAR marine bird survey data sheets developed by the community scientists and used until May 2022.

Team One Team two				
Site		Sandy Pt.	Neptune Beach	Cherry Pt.
cormorant	double-crested cormorant			
cormorant	pelagic cormorant			
cormorant	cormorant sp.			
dabbling duck	mallard			
diving duck	greater scaup			
diving duck	harlequin duck			
diving duck	long-tailed duck			
diving duck	bufflehead			
diving duck	ruddy duck			
diving duck	duck species			
eagle	bald eagle			
goose	canada goose			
goose	brant			
goose	goose species			
goldeneye	common goldeneye			
goldeneye	barrow's goldeneye			
goldeneye	goldeneye species			
grebe	red-necked grebe			
grebe	horned grebe			
grebe	western grebe			
grebe	grebe species			
loon	red-throated loon			
loon	pacific loon			
loon	common loon			
loon	loon species			
merganser	red-breasted merganser			
merganser	merganser species			
scoter	surf scoter			
scoter	black scoter			
scoter	white-winged scoter			
scoter	scoter species			

Team One Team two

		Sandy Pt.	Neptune Beach	Cherry Pt
tern	caspian tern			
alcid	common murre			
alcid	pigeon guillemot			
alcid	marbled murrelet			
alcid	rhinoceros auklet			
alcid	alcid sp.			
heron	great blue heron			
Site #		Sandy Pt.	Neptune Beach	Cherry Pt
Date				
Counter				
Spotter				
Data Recorder				
Weather conditions				
% Cloud cover				
Wind direction				
Visibility* (P,F,G,E)				
Beaufort Scale**				
Starting Time				
Stop Time				
Glare (yes/no)				
Human/Animal Activity:				
Other Notes:				

* P = Poor (rainy/foggy/windy), F = Fair (drizzling), G = Good (some fog/drizzle, haze/glare), E = Excellent (clear, sunny/well-lit, no glare)

** 0 = calm, 1 = ripples, 2 = crests/no breaks, 3 = scattered whitecaps, 4 = frequent whitecaps, 5 = many whitecaps, some spray

		Date: 9/3/2017		Time
	Tide data from:	Low	0.4	10:10AM
	http://wa.usharbors.com	High	7.1	2:57AM
	Cherry Point	Low	5.3	11:02PM
	48°52'N 122°45'W	High	8.4	5:39PM

Data sheet A-2: Updated data sheets with recommended updates for the CPAR marine bird survey effort.

Date:

Circle one: **Team 1 Team 2**

Bird Counts

Site		Sandy Pt.	Total	Neptune Beach	Total	Cherry Pt.	Total
cormorant	double-crested cormorant						
cormorant	pelagic cormorant						
cormorant	cormorant sp.						
dabbling duck	mallard						
diving duck	greater scaup						
diving duck	harlequin duck						
diving duck	long-tailed duck						
diving duck	bufflehead						
diving duck	ruddy duck						
diving duck	duck species						
eagle	bald eagle						
goose	canada goose						
goose	brant						
goose	goose species						
goldeneye	common goldeneye						
goldeneye	barrow's goldeneye						
goldeneye	goldeneye species						
grebe	red-necked grebe						
grebe	horned grebe						
grebe	western grebe						
grebe	grebe species						
loon	red-throated loon						
loon	pacific loon						
loon	common loon						
loon	loon species						
merganser	red-breasted merganser						
merganser	merganser species						
scoter	surf scoter						
scoter	black scoter						
scoter	white-winged scoter						
scoter	scoter species						
tern	caspian tern						

Date:

Circle one: **Team 1 Team 2**

Bird Counts

Site		Sandy Pt.	Total	Neptune Beach	Total	Cherry Pt	Total
alcid	common murre						
alcid	pigeon guillemot						
alcid	marbled murrelet						
alcid	rhinoceros auklet						
alcid	alcid sp.						
heron	great blue heron						

Site Info		Sandy Pt.	Neptune Beach	Cherry Pt
Observers	Counter			
	Spotter			
	Data Recorder			
- bold items should match between teams-	**Weather conditions***			
	% Cloud cover			
	Wind direction			
	Visibility** (P,F,G,E)			
	Beaufort Scale***			
	Starting Time			
	Stop Time			
	Glare (none, mild, moderate, strong)			
	Human Activity****			
	Other Notes:			

* rainy, overcast, fog, sunny

** E >= 2000m, G = 1000-2000m, F = 500-1000m, P <= 500m (provide etimate in notes)

*** 0 = calm, 1 = ripples, 2 = crests/no breaks, 3 = scattered whitecaps, 4 = frequent whitecaps, 5 = many whitecaps, some spray. Should not be surveying in >4

**** 0 = none, 1 = little activity/no visible disturbance, 2 = moderate activity/likely some disturbance, 3 = high activity/definite disturbance

Tide Data (from usharbors Cherry Point station 48°52'N 122°45'W)							
Time AM	Tide	Time PM	Tide	Time AM	Tide	Time PM	Tide

Copy and paste from http://wa.usharbors.com