Examining the Correlation between Living and Beached Seabird Species in the San Juan Channel and Salish Sea Region.

Chyenne Pomeroy
UW Friday Harbor Laboratory Pelagic Ecosystem Functioning, Autumn 2024
Dr. Rebecca Gunther, Dr. Alex Marquez, Dr. Matt Baker

Table of Contents

Abstract

Alcids are some of the most common seabird species in the Salish Sea region, a sheltered pelagic ecosystem supporting various marine life. Alcids are a family of seabirds that rely solely on the water column for their nutritional needs, unlike gulls, grebes, loons, and other commonly observed marine birds that can migrate between terrestrial and oceanic ecosystems. This unique niche makes alcids a valuable indicator species for ocean health and food web disruption since they cannot exploit a broader range of food resources. This study examined the densities of live birds' densities in the San Juan Channel, obtained from surveys between 2008 and 2023 for Common Murres, Rhinoceros Auklets, and Glaucous-winged Gulls and compared these densities to densities of beached birds. To analyze interannual variations in bird densities and the correlation between seabird population dynamics and sea surface temperature in the Salish Sea region. In most years, there is a positive correlation between the number of living and beached birds for all three species, indicating a consistent mortality rate within the populations. However, the outlier years of 2010, 2012, 2016, and 2017 appear to be related to abnormal oceanic temperatures.

Introduction

The Puget Sound and Strait of Georgia provide ideal habitat for a wide variety of sea and water bird species year-round, alongside a sheltered area for birds migrating along the Pacific Flyway. This region is protected from the harsher conditions of the outer coast of the Western United States; it has a more temperate climate and calmer seas. The region provides a wide variety of aquatic habitats, ranging from the more homogenized waters of the northern Puget Sound to Strait of Georgia.

The Salish Sea ecosystem is a bottom-up food web rich with algae, phytoplankton, and zooplankton, all supporting various species of foraging fish. These forage fishes are the basis for many of the seabird diets in the region, with the exception of most Gull (*Larinae*) species, which will forage in terrestrial and freshwater environments. The family *Alcidae* feeds solely from within the water column, relying on forage fishes and zooplankton to make up the entirety of their diet. This reliance on the ocean as the sole provider of nutrition severely limits the plasticity of Alcids.

Previous PEF studies have examined the interannual densities of various families of seabirds in the region and found that the populations declined in the past (Hamacher, 2018). Of these families, alcids were found to be the most abundant in the channel, with Common Murres being the most observed species in the region (Hamacher, 2018). Examining the patterns of interannual population densities for bird species in the San Juan Channel may provide insight into the patterns of population fluctuation in the Salish Sea region. This allows for insight into environmental patterns that might have triggered these changes.

Alcids are a family of approximately 20 diving seabird species that reside in the Northern Hemisphere, including Common Murres and Rhinoceros Auklets ("Alcids | Center for Coastal Studies," n.d.). These species share a few distinct characteristics, including a stout body, short, narrow wings, thick waterproof plumage, and feet set back on the body for swimming and diving ("Alcids | Center for Coastal Studies," n.d.). These birds are often piscivorous or planktivorous and rely on diving as their primary foraging method when searching for food (Wilson, 1977). The two alcid species in this study represent different alcid feeding niches, with Rhinoceros auklet representing intermediate feeders, while Common Murres are exclusively piscivorous (Mondloch, 2019).

Common Murres are the most frequently observed bird species in the San Juan Channel and, thus, one of the most studied seabird species due to their abundance. These fish-eating diving birds are common across the Pacific and have been thoroughly studied, making most aspects of their behaviors and biology well understood. Common Murres are an upper-trophic level piscivore species with a low reproductive output that is especially sensitive to changes in their ecosystem, making them an excellent sentinel species to monitor changes in ecosystem health (Romano et al., 2020).

Rhinoceros Auklets share some foraging patterns with Cassin's Auklets; both rely on access to zooplankton as a food source. However, Rhinoceros Auklets are adaptable in their foraging behaviors and will rely more heavily on fish as a food source when there is more near-surface abundance (Davoren, 2000). This plasticity might allow for more resilience than Common Murres or Cassin's Auklets during changing conditions in the Pacific Ocean.

Gulls are the second most abundant seabird family in the Salish Sea region, with most individuals identified as Glaucous-winged Gulls. Most species of gulls do not solely rely on foraging directly from the water column as their only food source. This increases the adaptability of the family during periods when the water column is disrupted, and the food web is unbalanced. Glaucous-winged Gulls were chosen as the final species of interest in the study since they are the most abundant beached bird observed by COASST in the Salish Sea region during average condition years. These gulls are also frequently observed during PEF marine bird and mammal surveys throughout the San Juan Channel (Hamacher, 2018). Incorporating this species into the analysis will serve as a benchmark to compare shifts in alcid species populations.

Common Murre die-offs during 2015-2016 were responsible for an estimated 1 million murre deaths in the Pacific Ocean and massive reproductive failures in breeding colonies (Piatt et al., 2020). In the following years, reproductive failures and massive die-offs were observed in Alaska's Bering and Chukchi Seas. Before 2016, these types of reproductive failures were infrequent in these regions of Alaska and have become more common since 2018 (Romano et al., 2020).

These various die-offs have been connected to the extensive marine heatwave in the Pacific Ocean during the same period and other oceanic warming events that have occurred since. Jones et al. found that the body condition of Murres that washed up after the heatwave events decreased, indicating starvation as a probable cause of death for murres at sea (Jones et al., 2017). Warming conditions in the Pacific Ocean prompted the movement of fish to cooler waters, disrupting the food web of these regions of the Pacific Ocean and decreasing access to food for seabirds in the open Pacific Ocean (Jones et al., 2017). These effects were also seen in planktivorous or intermediate feeders, with a die-off of Cassin's Auklet from 2014-2015 due to decreases in the energy content of mesozooplankton in warming waters (Jones et al., 2018).

Beached birds are deceased birds that wash up in coastal areas, usually on the outer coasts of a continent. Currents wash these carcasses onto the beach and deposit them above the surf. Most of these birds die at sea, and these deaths often fluctuate with seasons, weather patterns, and migrations. These carcasses wash up in various conditions, and identifying species can provide valuable insight into migration patterns, conditions at sea, and overall species health in a region. Recording data about bird mortality trends and large die off like those that have occurred within Common Murre die offs can offer insight into a population's health and success in a region.

COASST collected the bird mortality data used in this study. This citizen science program trains interested individuals to correctly identify and log deceased birds that become hauled up or stranded on a beach after their death at sea. The time series offered by this data allows for examining interannual beached bird trends in the Salish Sea region and the San Juan Channel and parallels the time series for live bird density collected at Friday Harbor Labs PEF program since 2008.

This study aims to compare the interannual population changes of three distinct species: Common Murres (*Uria aalge*), Rhinoceros Auklets (*Cerorhinca monocerata*), and Glaucous-winged Gulls (*Larus glaucescens*) to bird mortality data for these species.

Understanding the population dynamics of bird species in the channel and their response to environmental stressors can offer valuable insight into monitoring population health and oceanographic changes.

Methods

For this analysis, data was collected via transect surveys conducted along one consistent transect that runs down the San Juan Channel and is divided into six zones. The surveys were conducted aboard the *R/V Rachel Carson* and *R/V Kittiwake* by four individuals using 8x42 binoculars, two on the vessel's port side and two on the starboard side. The four observers noted observations of seabirds and marine mammals within 200m from each side of the vessel for a total of 400m. They relayed the number of individuals and species identification to two recorders (one for each side of the vessel), who recorded the observations alongside the Zone where the organism was observed and the time of observation. 2024 was the first time walkie-talkies were used to relay information between observers and recorders.

The transect is divided into six zones with similar oceanographic, biogeographic properties and benthic geography (Figure 1). For every MBM cruise aboard the research vessels, the transect is surveyed twice, once North to South and then South to North, with the tide noted for every survey. With mean interannual densities for living and beached birds calculated for each species. Density was calculated for each survey by dividing the number of birds counted during each surveying effort by the total square kilometers surveyed.

CTD drops at North and South oceanographic stations measured average sea surface temperature, with one drop at each station for each cruise date. The measurements for the upper few meters of the water column were averaged for each station, and then North and South were added together and averaged to obtain the yearly mean sea surface temperature for the San Juan Channel.

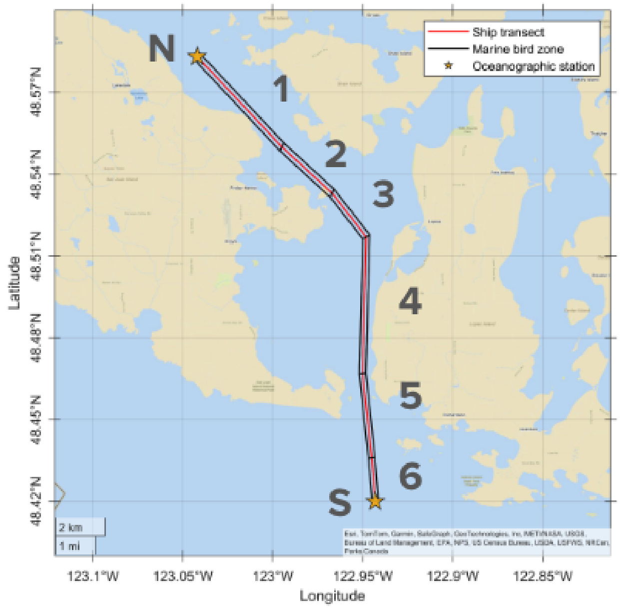

Figure 1. A map of PEF marine bird and mammal cruise transects zones between the North and South oceanographic stations. Credit Tim Iringan, 2024.

This study focuses on the data for Common Murres (*Uria aalge*), Rhinoceros Auklets (*Cerorhinca monocerata*), and Glaucous-wing Gulls (*Larus glaucescens*), broken down by year from 2008 to 2023, to examine changes in species density trends along the San Juan Channel over time. This data is then compared to COASST data, a citizen scientist study designed by Dr. Julia Parrish at the University of Washington.

COASST data is collected by volunteer citizen scientists from Northern California up to Alaska, trained by COASST officials, and provided consistent tools for correctly identifying all found birds. Data is collected monthly at the same beach location, where dead beached birds are photographed and identified, and measurements of feet and beaks are taken and logged before the information is entered into the COASST database. Charlie Wright uses the photograph to verify species identification. Once the birds are logged and identified, they are tagged by the COASST observer to prevent double counting in future surveys.

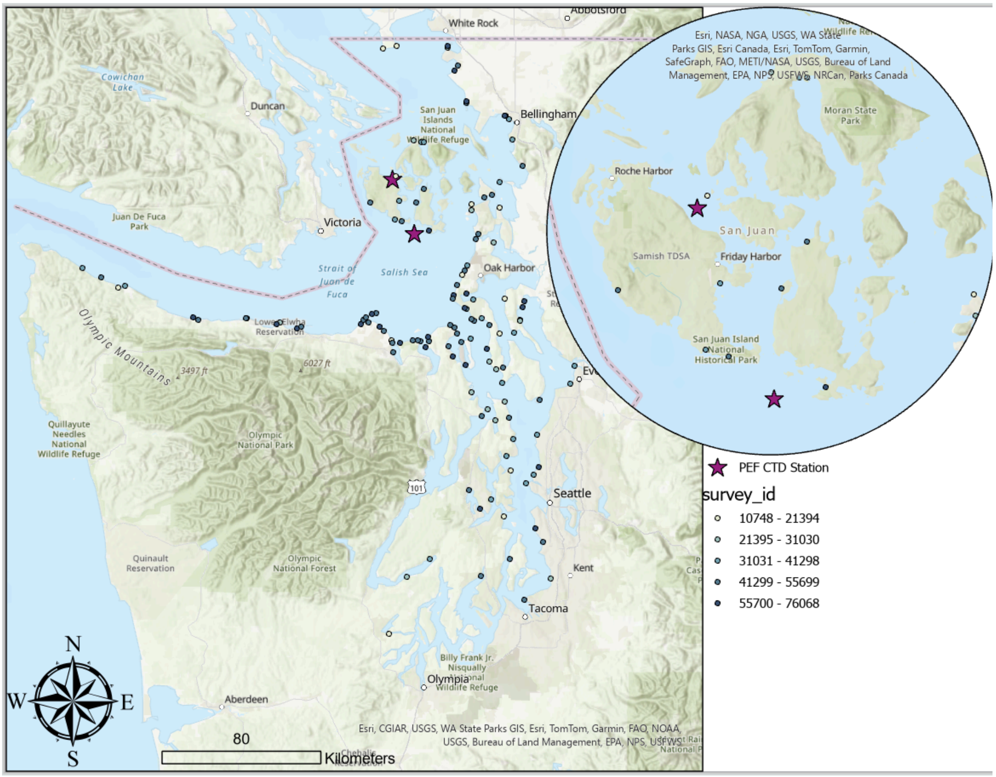

Figure 2. A map created in ArcGIS Pro that has the beach locations of all COASST surveys done from 2008-2023, as well as the locations of North and South Oceanographic stations, which are the end points for the PEF marine bird and mammal surveys.

The data obtained from COASST contained only beached birds identified in the Salish Sea region, including the Strait of Juan da Fuca, Puget Sound, and San Juan Islands (Figure 2). The COASST team was responsible for most of the data manipulation and sent data that had already been verified and complied with the frequency of birds per km of beach calculated for the species of interest. The data also contained information on each spotted beached bird's latitude and longitude.

The data was analyzed in R Studio and Excel, the interannual average densities were plotted into bar plots in Excel with custom standard deviation error bars. The calculated average densities for beached and living birds for each of the three species were then run through a correlation analysis in Excel and plotted against each other by species. The beached bird densities were also plotted against average sea surface temperature, and a correlation analysis was done.

Results

The average number of live birds on the transect varied considerably by species. When the mean densities of all years were averaged together Common Murres were the birds identified the most frequently, with an average density of 23 birds per km^2 (Table 1). Glaucous-winged gulls had the second highest density, with 11.6 birds identified for every km^2 of transect observed (Table 1). Rhinoceros Auklets were the least commonly identified bird species, with a density of 6 birds per km^2 (Table 1).

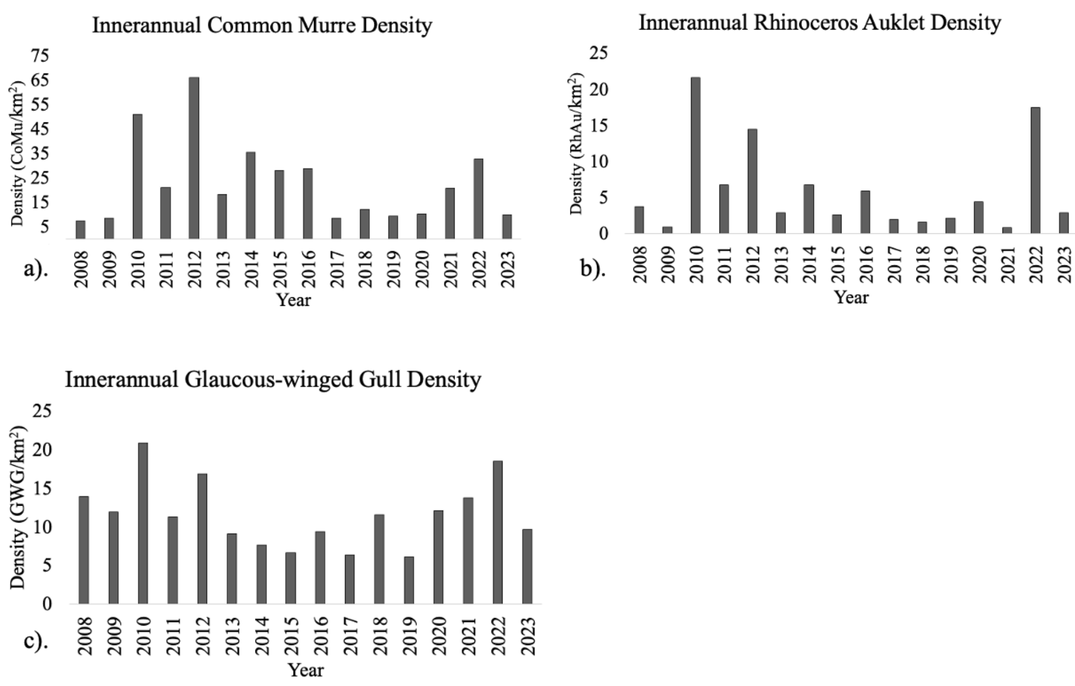

Figure 3. Graphs of interannual averages of live bird density on PEF transects cruises from 2008 to 2023. (a) Interannual Common Murre density. (b) Interannual Rhinoceros Auklet density. (c) Interannual Glaucous-winged Gull density.

The highest densities of bird for all three species were observed in the 2010 and 2012 PEF marine bird and mammal surveys (Figure 3). 2010 was the year where the highest densities of Rhinoceros Auklets and Glaucous-winged Gulls were observed during PEF surveying efforts, with a density of 21.5 birds per km^2 for Rhinoceros Auklets and 20.8 birds per km^2 for Glaucous-winged Gulls (Figure 3b & 3c). During 2010, the second-highest density of Common Murres was 51 birds per km^2 was observed (Figure 3a). Two years later, in 2012, the highest density of Common Murres was observed, with over 65 birds per km^2 (Figure 3a). 2012 also had the second-highest densities of Rhinoceros Auklets and Glaucous-winged Gulls observed during surveys (Figure 3b & 3c).

Years with low bird densities varied by species; Rhinoceros Auklets and Common Murres shared low-density years for living birds in 2008, 2009, 2017, and 2019 (Figure 3a & 3b). Common Murres had the lowest density recorded by PEF in 2008, with only 7.5 birds per km^2 reported on the surveys (Figure 3a & Table 1). While Rhinoceros Auklet had their lowest density in 2021 with 0.8 birds per km^2, 2009 also had a <1 bird per km^2 density (Figure 3b & Table 1). Glaucous-winged Gulls showed a consistent density distribution throughout the surveys, with 2019 being the lowest observed density of 6 birds per km^2 that year (Figure 3c & Table 1).

Table 1. Table of live bird densities for all three species of interest showing the highest and lowest densities recorded on PEF marine bird and mammal surveys during the 2008-2023 time frame and the average live densities. The average live densities are calculated from all average annual densities.

Species	Highest Live Density (birds/km^2)	Lowest Live Density (birds/km^2)	Average Live Density all years (birds/km^2)
Common Murre	65.9	7.5	23.0
Rhinoceros Auklet	21.5	0.8	6.0
Glaucous-wing Gull	20.8	6.0	11.6

Compared to the average annual density for each species, the lowest recorded density of Glaucous-winged Gulls was 48.3% lower than the average density of 11.6 birds per km^2 (Table 1). Rhinoceros Auklets' lowest density year was only 13.3% of the average number of birds observed annually, making it 86.7% lower than the expected density (Table 1). The density of Common Murres during the year with the lowest density of observations was 67.4% lower than the average annual density (Table 1).

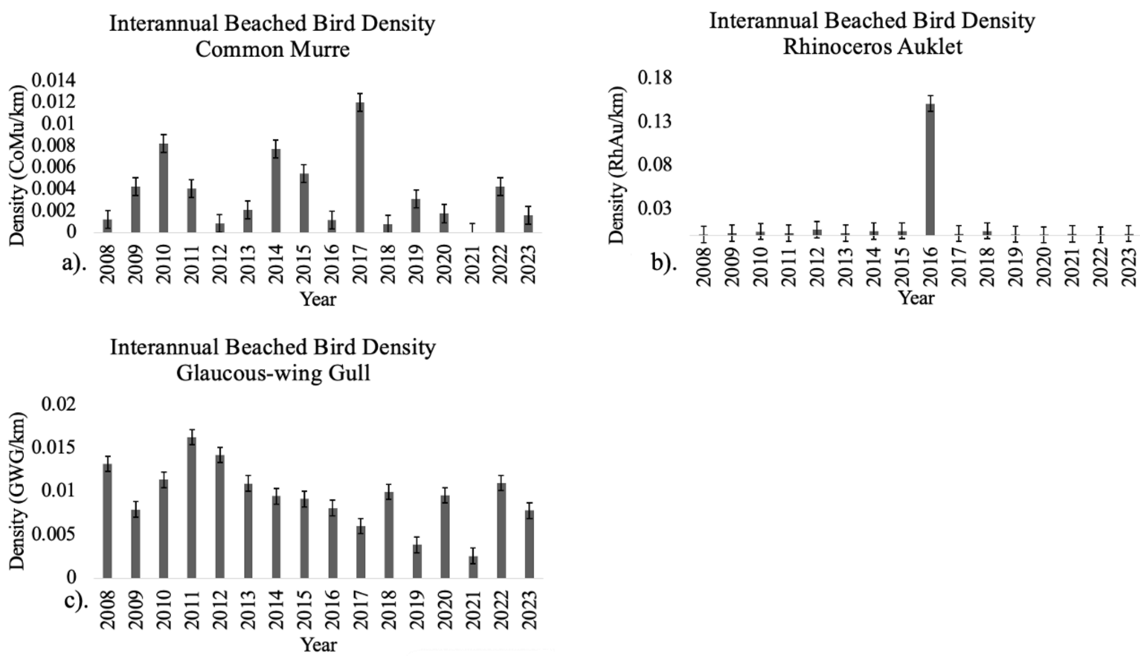

Figure 4. Graphs of interannual average beached bird densities for COASST surveys conducted from 2008 to 2023 in the Salish Sea region. (a) Interannual Beached Common Murre densities. (b) Interannual Beached Rhinoceros Auklet densities. (c) Interannual Beached Glaucous-winged Gull densities.

Table 2. Table of beached bird densities for all three species of interest shows the highest and lowest densities calculated from COASST surveys during the 2008-2023 time frame and the average beached densities calculated from all annual densities.

Species	Highest Beached Density (birds/km)	Lowest Beached Density (birds/km)	Average Beached Density all years (birds/km)
Common Murre	0.012	0.000	0.003

Rhinoceros Auklet	0.151	0.0012	0.012
Glaucous-wing Gull	0.016	0.0025	0.009

Common Murres showed a significant increase in the density of beached birds in the Salish Sea region during 2010, 2014, and 2017, with 2017 having the highest density of deceased birds recorded by COASST (Figure 4a). The average density of beached birds annually is 0.0016 Common Murre per km of beach surveyed (Table 2). In 2017, there was an increase of 76.3% from the average annual beached density of Common Murres (Figure 4a). In 2021, no Common Murres were found in COASST surveys for the region, making it the lowest recorded year (Figure 4a & Table 2).

Rhinoceros Auklets also recorded a significant increase in the number of beached birds in 2016, an increase of over 1000% from the average density of 0.012 beached birds per km (Figure 4b & Table 2). The average density overserved 2017 was 0.15 beached birds per km (Figure 4b & Table 2). In 2012, the second-highest density of beached Rhinoceros Auklets was observed, with 0.0069 birds per km recorded, which was still significantly lower than the die-off of 2016 (Figure 4b).

Glaucous-winged Gulls (GWG) showed a decrease in the density of beached birds observed from 2014 to 2016, showing a trend of decreasing death recording over those years (Figure 4c). The average annual beached bird density for GWG was 0.0094 beached birds per km (Table 2). This contrasts the other two species, which all had higher-than-average beached bird observations, especially in 2016 and 2017 (Figure 4). Glaucous-winged Gulls had the highest beached bird density in 2011 for adult individuals, with 0.016 birds per km2 (Figure 4c & Table 2).

Table 3. Table of correlation coefficients for living and beached bird densities in the Salish Sea region, from 2008 to 2023 for three species: Common Murre, Rhinoceros Auklet, and

Glaucous-winged Gulls. The years 2012 and 2017 were removed from Common Murre, and 2016 was from Rhinoceros Auklets.

Species	Correlation Coefficient Live vs Beached Birds – R^2 (All Years)	Correlation Coefficient Live vs Beached Birds– R^2 (Outlier years removed)
Common Murre	0.086	0.714
Rhinoceros Auklet	0.006	0.248
Glaucous-winged Gull	0.417	--

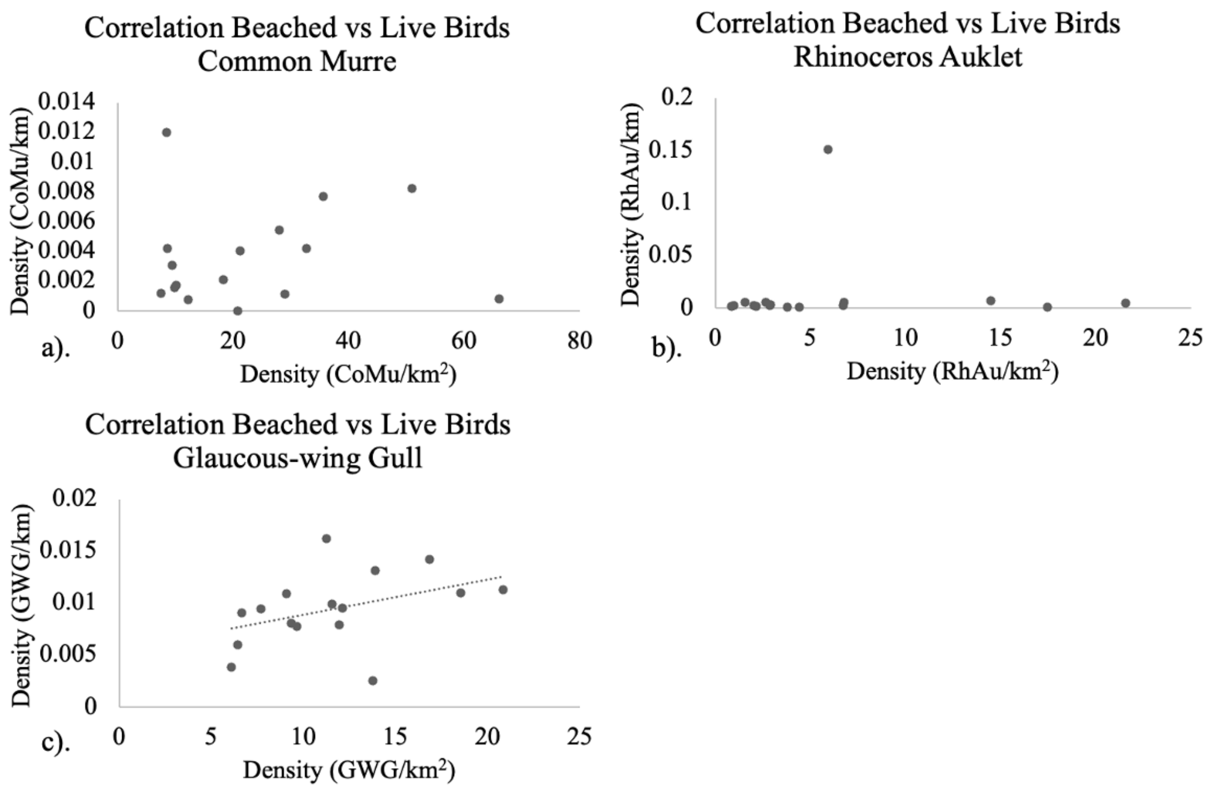

Figure 5. Correlation plots of beached bird densities on the y-axis vs live bird densities on the x-axis. (a) Correlation of beached vs live Common Murres. (b) Correlation of beached vs live Rhinoceros Auklets. (c) Correlation of beached vs. live Glaucous-wing Gulls.

The correlation analysis run on each species showed that interannual densities between beached and living alcid species had little correlation (Figure 5a, 5b, & Table 3). When all 15 years of collected data were included in the correlation analysis, Common Murre and Rhinoceros Auklets had correlation coefficients of <0.1, meaning there was little correlation between living and dead birds (Table 3). When the correlation analysis was rerun on Common Murre density data with the outlier points of 2012 and 2017 removed, the correlation coefficient increased to 0.71 (Table 3). This shows a strong correlation between living and dead birds observed in the Salish Sea region (Figure 5a). Rhinoceros Auklets also showed a large increase in the correlation coefficient when the outlier year of 2016 was removed from the data set, increasing from 0.007 to 0.25 (Table 3). When the correlation analysis was run on GWGs, a correlation coefficient of 0.42 was calculated for adult individuals, and no outlier data had to be removed from the analysis (Figure 5c & Table 3).

The mean annual sea surface temperature (SST) for the San Juan Channel usually remains around 9 to 10 annually, with small amounts of interannual variation (Figure 6). In the past decade, there have been three occurrences of increased SST in the region, the first and most prominent peak from 2014-2015, in conjunction with the larger Pacific Marine Heatwave (Figure 6). Another marine heatwave event occurred from 2021 to 2022, though the temperature did not reach the same levels as the 2014/15 event (Figure 6).

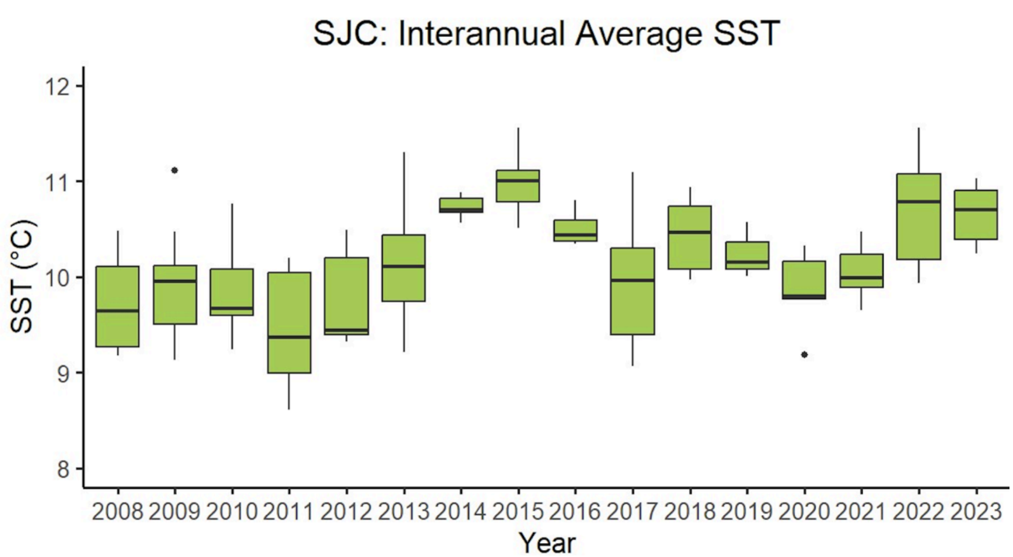

Figure 6. Mean annual sea surface temperature for the years of 2008-2023 for North and South PEF oceanography stations combined. Credit Maria Pagliaro.

When the correlation analysis was run on the data, no significant patterns or correlations between beached birds and average SST were found (Figure 7 & Table 4). Even when the outlier data points were removed from both alcid species, the R2 values remained less than or equal to 0.2 (Table 4). Figure 4 visualizes the trends between SST and beached bird densities, and all three species plots demonstrated random distributions (Figure 7).

Table 4. Table of correlation coefficients for average SST and beached bird densities in the Salish Sea region, from 2008 to 2023 for the three species of interest: Common Murre, Rhinoceros Auklet, and Glaucous-winged Gulls. 2012 and 2017 were removed from Common Murre, and 2016 was from Rhinoceros Auklets.

Species	Correlation Coefficient SST vs Beached Birds – R^2 (All Years)	Correlation Coefficient SST vs Beached Birds– R^2 (Outlier years removed)
Common Murre	0.26	-0.02
Rhinoceros Auklet	0.14	0.18
Glaucous-winged Gull	0.15	--

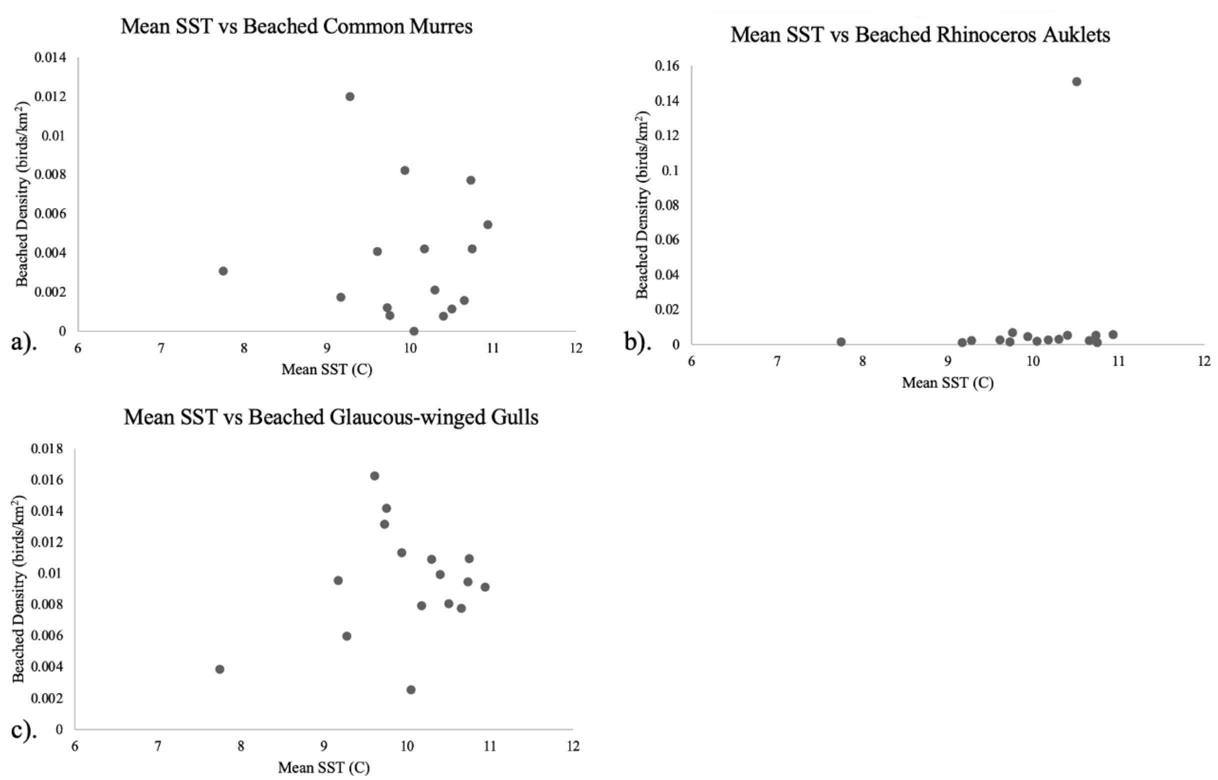

Figure 7. Graphs of plotted correlation between mean sea surface temperature and beached birds for all three species of interest. (a) Mean SST vs beached Common Murres. (b) Mean SST vs beached Rhinoceros Auklets. (c) Mean SST vs beached Glaucous-wing Gulls.

Discussion

The analysis of living and beached bird densities in the Salish Sea region offers insight into the region's interspecies population dynamics and interannual trends. This study examined the patterns of population fluctuation of three distinct seabird species in the Salish Sea region. From 2008 to 2023, there have been significant fluctuations in the densities of living and beached seabirds in the region. The survey findings highlight significant variations in the density and distribution of live and beached bird species in the Salish Sea region. These fluctuations varied by species and year, pointing to possible environmental factors in the region being a leading mechanism for bird migration and increased mortality.

Among the three species analyzed—Common Murres, Rhinoceros Auklets, and Glaucous-winged Gulls—Common Murres consistently exhibited the highest average density of live birds. At the same time, Rhinoceros Auklets displayed the lowest average density. These differences in densities might be due to these alcid species' life history and foraging patterns. A 1982 study of alcid life histories found that Murres make 3 to 8 foraging flights a day, while Rhinoceros Auklets primarily forage at night (Glutz et al., 1982). Differences in foraging ecology for these species might reduce competition for food and increase reproductive success, explaining why fewer Rhinoceros Auklets are seen in areas where Common Murres forage for fish during the day. Glaucous-winged Gulls had a consistent pattern of densities, indicating that gull populations have a relatively stable population dynamic compared to alcid species in the region. These differences in both live and beached bird density trends highlight the increased vulnerability of alcid species to changes within their habitat, making them more susceptible to mass mortality events stemming from external stressors.

The years 2010, 2012, and 2022 all showed higher-than-average live bird densities for all three of the study species, indicating favorable ecological conditions during those years.

Increased densities of all study species during these years may have been due to increases in prey availability, ideal climate conditions, or variations in migration patterns. Cooler average water temperatures in the region during 2010 and 2012 may have influenced the number of birds reported (Lindquist & Edited By: S. Moore, 2017). These cooler conditions may have increased forage fish abundance in the region, leading to more successful breeding efforts on Protection Island for the alcid species and healthier body conditions for adult birds. More GWG than average has also been observed during these years, likely due to increased food availability in the water column, encouraging more individuals to forage in the pelagic ecosystem rather than terrestrially.

Beached bird densities increased dramatically for both alcid species in 2016 and 2017, respectively. During normal conditions, adult annual survival rates of alcids are approximately 87-93% survival (Glutz et al., 1982). With significantly higher beached bird densities than average during those years for both Common Murres and Rhinoceros Auklets. In 2016, Rhinoceros Auklets experienced a highly anomalous breeding season characterized by a large die-off of fledglings (Moore et al., 2017). The reproductive success rates of Rhinoceros Auklets are anywhere from 44-56% annually, with 62.1% of fledging surviving (Johnsgard, 1987). These die-offs are hypothesized to be caused by a decrease in food availability to forage adult birds, leading to starvation of both chicks and mature birds (Moore et al., 2016). Starvation in mature individuals leads to a lack of body condition and suppressed immune systems, making individuals more susceptible to diseases. The 2016 Marine Waters Report for the Salish Sea Region cited increases in bacterial infections in mature Rhinoceros Auklets as a leading cause of mortality for the region's populations.

Similar patterns have been observed in alcid species during marine heat wave events in other regions, including off the outer coast of the Western United States, the Gulf of Alaska, and the Chukchi Sea. In 2018, Common and Thick-billed Murres in the Bering and Chukchi Seas of Alaska experienced severe distress during a warmer-than-average year for the region (Romano et al., 2020). The 2018 breeding season was affected by higher-than-average mortalities in mature Murres, lower-than-average offshore densities, and low reproductive outputs (Romano et al., 2020). The timing of these die-offs and reproductive failures indicates a relationship between marine heatwaves and abnormally warm ocean temperatures and susceptibility to increased mortality. However, the mechanism behind the increase in mortality, whether starvation or higher rates of diseases in the colonies, is still unknown.

Cassin's Auklets experienced a similar trend of die-offs in 2014/2015 off the Western Coast of the United States. Colonies of Auklets had congregated into small nearshore bands of cooler water, where zooplankton abundance was higher (Jones et al., 2018). Wide-scale starvation was the primary mechanism in the Cassin's Auklet die-off due to the changes in food quality available and the decrease in nutritionally necessary zooplankton (Jones et al., 2018). This pattern underscores the importance of environmental factors, such as temperature fluctuations and oceanic currents, in shaping the dietary resources available to these seabirds.

The correlation analysis revealed weak relationships between living and beached bird densities for both alcid species, with correlation coefficients below 0.1 when all years were included. This suggests that factors influencing live bird densities' breeding success and prey availability are distinct from those driving mortality events leading to beached birds, including extreme weather and disease. However, removing outlier years significantly strengthened correlations, particularly for Common Murres ($r = 0.714$) and Rhinoceros Auklets ($r = 0.248$).

This highlights the importance of isolating anomalous years in understanding underlying trends in bird die-offs. For Common Murres, the strong correlation after removing 2012 and 2017 suggests a link between high live densities and subsequent die-offs in most years. This is expected since healthy populations have a consistent mortality rate, leading to the conclusion that the more living individuals there are in a population, the more deceased individuals will be found.

GWGs are an example of a species with a healthy population dynamic that reflects the expected presence of a consistent mortality rate. Healthy bird populations show consistent density patterns, with an annual adult survival rate that shows limited variability, alongside annual average reproductive success rates reflecting the number of chicks that successfully fledge in breeding colonies. In most years, the density of beached birds reflects the density of live gulls, with the number of beached gulls reported increasing as the density of live birds counted and vice versa. This relationship suggests a balanced ecosystem where the mortality rate of the gulls remains relatively constant, indicating that while there may be fluctuations in the overall bird population, these changes do not drastically impact the health and stability of the species. These trends can also be tied to gulls' ability to migrate between terrestrial and pelagic ecosystems, allowing them to travel to more ecosystems with higher food availability. This plasticity can account for changes in observed gull density due to lower mortality rates and location of death.

The observed patterns of bird mortality and live bird densities in the Salish Sea region indicate that oceanography and climate changes in the Pacific Ocean and Salish Sea affect seabird populations. A comparison of living and dead bird densities shows that years with cooler-than-average ocean temperatures positively impact live bird densities. In contrast, years with abnormally high ocean temperatures correspond with alcid die-offs. The strong correlation between live birds and beached bird density when the outlier years of 2012 and 2016 were removed from the analysis further points to environmental factors influencing seabird population dynamics in the region.

Expanding the data set to include a longer time frame could enhance this study, particularly for live bird observations. By incorporating count and density data from the Puget Sound Seabird Survey, we could create a higher-resolution data set for the entire region rather than limiting it to the San Juan Channel. Additionally, the trends observed in these three species could be compared to other common species identified in the PEF Marine Bird Surveys, such as gull species, loons, grebes, and scoters, by broadening the scope of this study to encompass additional species and a wider geographical area, a more developed picture can be created of the ecological dynamics of marine bird populations. A lag analysis would also offer more insight into how differences in beached bird densities affect live bird populations in the years following. This study did not examine how alcid populations changed in response to the 2016/2017 die-offs that occurred in the region. However, there may be correlations between increased beached bird densities and lower live bird densities on transects recorded in the years directly following these events. This more comprehensive approach would facilitate more full comparisons with existing data sets like COASST and contribute to a better understanding of regional biodiversity and the factors influencing bird distribution and abundance. A more comprehensive approach also allows for narrowing down the mechanisms of bird decline in the region. It might offer insight into lower trophic levels, such as forage fishes, that are hard to measure.

Conclusion

This study highlights the complex interactions between the pelagic ecosystem and seabird species in the Salish Sea region, revealing the highly variable interannual trends for alcid species. Peaks in live bird density during cooler-than-average years and beached bird density following abnormal heat events demonstrate increased vulnerability to pelagic ecosystem shifts for key alcid species. Understanding the mechanisms behind these dramatic changes in bird density in the region can increase our understanding of the pelagic ecosystem and help targeted conservation efforts for higher trophic level species. In conclusion, this study emphasizes the need for continued research and conservation initiatives to mitigate the impacts of environmental and climate changes on alcid populations and preserve the pelagic ecosystem in the Salish Sea.

Citations

Alcids | Center for Coastal Studies. (n.d.). Retrieved November 1, 2024, from https://coastalstudies.org/connect-learn/stellwagen-bank-national-marine-sanctuary/sea-birds/alcids/

Davoren, G. K. (2000). Variability in foraging in response to changing prey distributions in rhinoceros auklets. *Marine Ecology Progress Series*, *198*, 283–291. https://doi.org/10.3354/meps198283

Glutz von Blotzheim, U. N., & Bauer, K. M. (1982). *Handbuch der Vögel Mitteleuropas*. Wiesbaden: Akademische Verl.

Jones, T., Parrish, J. K., Peterson, W. T., Bjorkstedt, E. P., Bond, N. A., Ballance, L. T., et al. (2018). Massive Mortality of a Planktivorous Seabird in Response to a Marine Heatwave. *Geophysical Research Letters*, *45*(7), 3193–3202. https://doi.org/10.1002/2017GL076164

Jones, T., Parrish, J. K., Punt, A. E., Trainer, V. L., Kudela, R., Lang, J., et al. (2017). Mass mortality of marine birds in the Northeast Pacific caused by Akashiwo sanguinea. *Marine Ecology Progress Series*, *579*, 111–127. https://doi.org/10.3354/meps12253

Diving Birds of North America by Paul A. Johnsgard (1987) | Papers in the Biological Sciences | University of Nebraska - Lincoln. (n.d.). Retrieved December 8, 2024, from https://digitalcommons.unl.edu/bioscidivingbirds/

Hamacher, E.W. (2018). Exploring Interannual Variations of Distinct Populations within the San

Juan Channel Pelagic Ecosystem. Pelagic Ecosystem Function Apprenticeship.

Lindquist, A., & Edited By: S. Moore, R. W. (n.d.). Puget Sound Marine Waters: 2017 Overview: NOAA Northwest Fisheries Science Center For The Puget Sound Ecosystem Monitoring Program'S (Psemp) Marine Waters Workgroup. Retrieved from https://repository.library.noaa.gov/view/noaa/28038

Mondloch, E. (2019). Investigating the Relationship Between Sea Surface Temperature, Chlorophyll, and Alcid Density in San Juan Channel. Pelagic Ecosystem Function Apprenticeship

Moore, S., Wold, R., Stark, K., Bos, J., Williams, P., Hamel, N., et al. (n.d.). Puget Sound Marine Waters: 2016 Overview. Retrieved from https://repository.library.noaa.gov/view/noaa/46965

Piatt, J. F., Parrish, J. K., Renner, H. M., Schoen, S. K., Jones, T. T., Arimitsu, M. L., et al. (2020). Extreme mortality and reproductive failure of common murres resulting from the northeast Pacific marine heatwave of 2014-2016. *PLOS ONE*, *15*(1), e0226087. https://doi.org/10.1371/journal.pone.0226087

Romano, M. D., Renner, H. M., Kuletz, K. J., Parrish, J. K., Jones, T., Burgess, H. K., et al. (2020). Die–offs, reproductive failure, and changing at–sea abundance of murres in the Bering and Chukchi Seas in 2018. *Deep Sea Research Part II: Topical Studies in Oceanography*, *181–182*, 104877. https://doi.org/10.1016/j.dsr2.2020.104877

Wilson, U.W. (1977) A Study of the Biology of the Rhinoceros Auklet on Protection Island, Washington. University of Washington.

Acknowledgments

Marine Bird & Mammal Peers:
Celeste Jerome
Tim Iringan
Kylie West

Dr. Rebecca Gunther
Dr. Alex Marquez
Dr. Matt Baker
Dr. Jan Newton
Dr. Mike Siegler

PEF Peers