PIGEON GUILLEMOT

ABUNDANCE AND PREY COUNTS

IN THE PUGET SOUND

By

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ABSTRACT

Pigeon Guillemot; Abundance and Prey Counts in the Puget Sound

David Alexander Stocks

This thesis research explores the abundance and prey counts of 36 Pigeon Guillemot colonies in the Puget Sound located in two regions, the South Sound Puget Sound and on Whidbey Island. The data utilized were collected from 2015-2020 by two citizen science organizations, the Whidbey Island Audubon Society, and the Nisqually Reach Nature Center. The primary research question was whether prey types observed being given to Pigeon Guillemot chicks, had any correlation with the next year's colony abundance. Individual colony abundance were also correlated with each other (in each region) to assess population synchrony. The results of the analyses performed here did not provide evidence for or against theories discussed within this thesis, primarily the high and low lipid theory and the junk-food hypothesis.

Exploring trends over time in the two regions there was no linear trend to the abundance of South Sound, while Whidbey Island has a slight increase in their abundance. In the two regions gunnel was the most observed prey with South Sound (69%) of observed prey being gunnel, and Whidbey Island (50%). Neither region showed any correlation between abundance counts or prey types. Neither region demonstrated synchronous changes across the colony abundance counts.

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Chapter One: Introduction

The Puget Sound is a dynamic and important marine environment for the Pacific Northwest. Not only does it contain a wide range of biodiversity it also functions as an important hub for travel. The Puget Sound is home to over 3,000 invertebrates and 200 marine fish, including 8 species of salmon (National Wildlife Federation, 2020). There are twenty-six species of kelp alone in the Puget Sound along with seagrass. Over 172 marine birds frequent the Puget Sound with 72 species being highly dependent upon it as a food source and breeding site, including the Pigeon Guillemot (Gaydos & Pearson, 2011). The Pigeon Guillemot is highly dependent on the Puget Sound due to the species' year-round residence, depending entirely on the Puget Sound for both habitat and food.

The study of such a rich region is important for the continued conservation and management of the Puget Sound. Approximately 4.2 million people live along the Puget Sound coastline (Puget Sound Regional Council, 2020). This makes the conservation and management of the Puget Sound important from an economic, environmental, and public health perspective. To accomplish successful management of the region requires studies of a wide range of topics, which is a daunting task requiring not only governmental, scientific, and academic institutions but the utilization of citizen scientists. The work done with the Pigeon Guillemot is a good example of how to utilize the resources of the community to accomplish a wealth of data collection and to coordinate that data with a wide range of organizations. The marine enviornment is a difficult but nevertheless important region of our earth to study for conservation and basic science.

The process of taking yearly surveys over many years is a important to establish a baseline for the abundance of Pigeon Guillemot. Conservation and avoiding future loss of biodiversity requires a baseline to direct conservation in the best direction for the overall health of the environment (Bull et. al., 2014). Thoughtful conservation planning requires data analysis and long-term observation to ensure that actions create the desired effects, and the ability to examine those results over time. By utilizing systemic surveys many species can be evaluated and tracked through citizen-based activity.

One of the primary difficulties when it comes to surveying marine birds is acquiring an accurate count of abundance. A winter survey of Pigeon Guillemot is conducted by airplane during the winter months when they travel to the northern side of the Salish Sea (Gaydos, et. al., 2011), but many colonies are counted by various organizations throughout the Puget Sound during their breeding season (April to September). As a burrow nesting bird, the opportunity to count breeding adults in their burrows can be difficult and like other members of the Auk family, primarily the Black Guillemot and the Atlantic Puffins, it can be difficult to discriminate between breeding pairs and non-breeding adults (Cairns, 1979) as they are monomorphic. Non-breeding adults tend to leave the colony for extended periods throughout the day, usually returning at first light while the breeding pairs can spend much of their time away from the colony also, returning when the tide is high and the opportunity to successfully forage has decreased. Mixing of juveniles can occur between colonies that are in proximity of one another adding to the difficult of successful abundance counts. With the current members of a colony spending much of their time away from the colony the understanding of the tidal impacts along with the forage habits of an individual colony are important factors. To complete those counts, volunteers depend on visual counts as visual count are key to successfully surviving hole-nesting Auks (Cairns, 1979).

Pigeon Guillemots themselves spend a large amount of their time perched near the colony’s nests, limiting their time interacting with the burrows themselves except when feeding, to reduce predation (Bishop, et. al., 2016). They generally have a large percentage of non-breeding adults and juveniles who spend a mixed amount of time both on the water and within the area of the colony itself (Drent, et. al., 1965). Like the Black Guillemot, the Pigeon Guillemot has a morning and evening peak in its colony attendance, which provides a good time of day to perform visual counts. For the Salish Sea this morning peak is typically 8:00 - 9:00 am (Terence Lee, pers. comm.). While one cannot control all the factors to make this the most optimal time for surveying such as inclement weather, disturbances (both manmade and natural), tidal shifts, or predation, weekly counts help to develop an overall abundance estimate. As a six-year survey study suggested (Bishop, et. al., 2016), the highest number of birds seen at any one time can be taken as the maximum for the colony in which they have been counted. Multiple counts are taken throughout an hour-long survey and those surveys generally happen over the Pigeon Guillemot three-month breeding period (Bishop, et. al., 2016). The surveys have been conducted in Puget Sound by citizen scientists for 16 years. Originally the surveys started with the Whidbey Audubon Society, but four other Audubon Society groups and the Nisqually Reach Nature Center now also participate. In 2020, the Washington State Department of Fish and Wildlife (Department of Fish and Wildlife, 1970) joined to curate this survey data, utilizing Geographic Information Systems (GIS) and Survey123 to collect this data. The data from the surveys is also being utilized by University of Washington for studies on the connection between Pigeon Guillemot numbers and tidal to their chicks, tidal heights, and disturbances to the colony.

Chapter Two: Literature Review

Marine Birds as Sentinel species

Marine birds serve as an invaluable indicator of various factors in their environment. Seabird data has provided insights into not only the study of climate change but also changes in the marine ecosystem (Piatt et. al., 2007). The study of one species can provide a look into a much larger range of subjects. A species like the Pigeon Guillemot that focuses upon specific fishing stocks can show a decline or increase in said stocks as their prey choices shift. A Pigeon Guillemot colony that primarily feeds off sculpin (*Cottoidea)* that suddenly shifts to feeding on sand lance *(Ammodytidae)* could reveal a decline in their common foraging area or a general change in their feeding habits. The Pigeon Guillemot is an important sentinel species for the Puget Sound/Salish Sea area as it lives in the region year-round and is sensitive to environmental factors such as water temperature, pollutants, and rising sea levels. By maintaining surveys on a wide range of colonies within the Salish Sea scientists can monitor other far-reaching factors.

The Washington State Department of Fish and Wildlife and the Puget Sound Partnership recommend the expansion of Pigeon Guillemot monitoring to provide more data on their diet and reproduction due to their importance to the Puget Sound ecosystem (WDFW, 2013). By creating an expansive database on the Pigeon Guillemot over multiple years any notable shifts in their abundance could hopefully influence policy made in conservation management in the Puget Sound. The collection of this data will largely rest upon citizen scientists within the communities of the Puget Sound with the support of both academic, governmental, and conservational experts.

One of the main influencers on Pigeon Guillemot abundance is the prey upon which the Pigeon Guillemot sustain themselves and the growth of their chicks from year to year. The choices that an adult makes while feeding their chicks have a large impact on survival and growth rates. Pigeon Guillemot tend to forage in established fishing areas though individuals can forage in more wider ranges, though the success of this shift in tactics is debatable. Another big choice that an adult must make is their prey type. Do they focus on the size of their prey or their high/low lipid content? Not every pair forage the same as earlier mentioned but colonies can easily have a wide range of prey counts in comparison. Yearly shifts in prey types tends to represent some shift in traditional forage locations or newer breeding adults seeking to establish new forage sites.

Table 1 Wet mass energy density values of four common prey types for Pigeon Guillemot in the Puget Sound. Based on Table 1 from Litzow et. al., (2002)

Prey Type	**Scientific Name**	**kJ g-1**
Pacific Sand Land	*Ammodytes hexapterus*	5.25
Prickleback	*Lumpenus spp.*	4.76
Gunnel	*Pholidae*	4.69
Sculpin	*Cottidae*	4.10

The study of fluctuating abundance counts and unexpected collapse in marine birds is a well-documented phenomenon (Stier et. al., 2020). The Pigeon Guillemot has been the subject of research by several scientists since the 1950’s, primarily along the west coast with the focus on the Gulf of Alaska (Litzow, Piatt, Abookire, Speckman, et. al., 2004) and the Farallon Islands in California (Nelson, 1987). While much of this research was conducted outside of the Puget Sound it is important to understand as the breeding habits, risks to Pigeon Guillemot, and results of prior studies. This thesis follows in the footsteps of those studies by examining the possible influence of prey types on the abundance of breeding colonies of Pigeon Guillemot in the Puget Sound.

Natural History of Pigeon Guillemot

The Pigeon Guillemot is a small pigeon-sized seabird that is a member of the Auk family, the Alcidae. They are a monomorphic species; both male, and female adults have entirely black feathers with white wing patches. They also have bright red feet and gape (Drent, 1965). Nonbreeding juveniles have smudgy black and white bodies. They reach sexual maturity at 3-5 years, with an average lifespan of 6- 8 years, although the oldest recorded Pigeon Guillemot was 15 years old (Cornell Lab of Ornithology, n.d). They generally mate for life with the male returning to the same colony earlier than its mate to claim a burrow. The females will arrive a week or two later than the male to join their partner in courtship displays. Their courtship displays consist of circling and bill-touching. Rapid zigzag chases on water near the colony have also been observed (Kenn Kaufman, 2019). The male and female share incubation and feeding tasks to ensure their brood is successful. Pigeon Guillemot colonies tend to be centered around cliffside burrows along the coast though some cases of utilizing downed logs, piers, and other structures have been recorded (Bishop et. al., 2016). In North America, the Pigeon Guillemot has a range along the coastal waters from southern California to Alaska (Ewins, P.J, 2020).

The Pigeon Guillemot native to the Puget Sound winter in the northern Salish Sea, they return to their original colonies during breeding season, from April to September, to attempt to mate. Upwards of 40% of the colony are generally comprised of non-breeding juveniles who have been unsuccessful in acquiring a mate and/or a burrow (Harkness, 2017). The feeding habits of different Pigeon Guillemot colonies can prove to be interesting as some will forage in the same location year after year and others will be broader in their feeding habits. Their dependence on specific benthic fish also reveals otherwise hard to observe shifts in those fish stocks as the Pigeon Guillemot abundance shifts are largely dependent upon prey availability

(Litzow, Piatt, Abookire, & Robards, 2004b), though there are various factors that can impact this abundance in outlier events, such as high-water temperatures and pollution in the water. They also have a relatively large and stable abundance counts which allows dips and variances to be more observable.

Threats to Pigeon Guillemot abundance

Pigeon Guillemots like many marine birds are notoriously susceptible to pollutants. The Pigeon Guillemot is the only marine bird species that is "considered as not recovering from the 1989 Exxon Valdez oil spill (Bixler, 2010). The impacts on Pigeon Guillemot in Alaska could easily be seen in the Puget Sound if it were to suffer a similar environmental pollution event or seen on a smaller scale by localized pollution events. The impacts of pollution can be directly connected to the Pigeon Guillemot as they suffer die-off or indirectly through their prey, forcing shifts from their traditional foraging habits to new, less beneficial foraging sites.

Rising sea levels have two large impacts upon Pigeon Guillemot as a species (Vermeer et. al., 1993). Firstly, Pigeon Guillemot have greater foraging success in lower tides as it provides easier access to their prey and a rising sea level will make their catch success decrease which will mean increased risk of predation as they are forces to make further attempts and a decrease in the success of their chicks to fledge. Adults might be forced to pick less nutritional prey to feed their chicks or decrease their brood numbers which would have far reaching impacts on their abundance over an extended period. As a coastal burrow nesting species rising sea levels can increase the risk of erosion to their traditional nesting sites, forcing them to decrease their breeding pairs, relocate or lose entire colonies. While there is a natural shift of colonies over long periods of time due to natural erosion a much faster rate of erosion could force such transitions to new colony sites more often, much more than Pigeon Guillemot are adapted to. Colony attendance by Pigeon Guillemot is widely dependent on tidal heights. Tidal height impacts foraging behavior and food availability, which in of itself also influences the colony attendance as many birds are absent due to foraging (Vermeer et. al., 1993). Pigeon Guillemot are generally classified as mid-water foragers, meaning that the tide flow did not really cause too much impact on their foraging habitat and those in the mid-range tend to have the most diverse level of foraging strategies (Drew et. al., 2013).

Pigeon Guillemot are threatened by increasing water temperatures both directly and indirectly. Indirectly the impacts on their forage fish while varied by species could still cause some disturbance to those Pigeon Guillemot who focus on specific fish more so than those Pigeon Guillemot who have a wide-ranging foraging style. An increased difficulty in feeding and unseasonal shifts in water temperatures, even the lack of upwelling winds to increasing nutrient availability has been shown to reduce reproduction success as was seen in the Farallon Islands in the mid-1800s which could easily occur in other temperature dependent locations (Lewis, 1974).

Prey base

While Pigeon Guillemot are known to eat a wide variety of prey throughout their large range the focus on Puget Sound means that the prey types discussed will focus on that region. The majority of foraging conducted by Pigeon Guillemot during the breeding season is within 0.2 – 7.0 km from the colony (Vermeer et. al., 1993b), and like many marine birds are central-place foragers during their breeding season (Bolton et. al., 2019), the precise relationship on their colony density will be dependent upon surrounding coastal morphology, which is varied within both regions.

The two main prey types for nesting Pigeon Guillemot in Puget Sound are the Sculpin (*Cottoidea*) and Gunnel (*Pholis laeta*) (Lee & Grant, 2018). Pigeon Guillemot are known to have traditional forage sites where they routinely forage specific fish types. Declines in abundance of Pigeon Guillemot in Alaska have been linked to the loss of forage food availability (Romano, 1997) as they were forced to switch from high-lipid to low-lipid prey. This study also showed that those Pigeon Guillemot who switched to low lipid tended to have lower fledgling success of their chicks. Another factor for chick fledgling success is those Pigeon Guillemot who specialize in selecting prey items for their chicks than those members of their species who have more generalized forage habits (Golet et. al., 2000). This same study pointed to the fact that the size of prey from specialized hunters might have had far more importance than just the high lipid levels of their prey. This also has the benefit of reducing the risk of predation on the chicks, as the feeding trips are reduced. Specialization also did not affect chick growth in the early stages which pointed to a focus on quality over quantity. Golet et. al., (2000) also points to the importance not only of high-lipid prey but low-lipid prey, while high-lipid prey is important for its nutritional impacts those prey types tend to have more movement through the environment while low-lipid prey is more residential in their movements. So low lipid prey can sustain chicks while the high lipid prey can produce increased growth rates. This is likely the reason Pigeon Guillemot do not specialize in specific high-lipid prey to maintain a more generalized foraging habit. Alongside the sculpin and gunnel Pigeon Guillemot are known to eat are recorded to eat a handful of other prey types. Additional prey types for Pigeon Guillemot in the Puget Sound is Pacific Cod (*Gadus macrocephalus*), Sand Lance (*Ammodytes hexapterus)*, Surf Perch (*Embiotocidae*), and Prickleback (*Stichaeidae*).

The Junk Food Hypothesis as explored by Österblom et. al. (2008), is the correlation of predatory fish and mammals eating prey that is low lipid in comparison to their normal prey, which lowers the weight gain of their own weight and most importantly, their chicks. Weight gain is key to the survival of fledgling chicks and juveniles through their first few years. Abundance declines can be seen to occur in correlation with shifts in prey types, for example in sea lions (Österblom et. al., 2008). In the same regions where sea lions saw decline seabirds in the same region also suffered abundance decline. In the research conducted by (Litzow et. al., 2004), predators such as Pigeon Guillemot will trade off high lipid prey for a more consistent abundance of prey, even if it has lower lipid amount.

Pigeon Guillemot abundance can be negatively impacted by a shift in their fish stocks, which has been shown to vary with decadal-scale climate variability (Litzow et. al., 2002). The energy demands of growing chicks is high enough that a shift to low-lipid prey where their energy density is not able to maintain a functioning population. Pigeon Guillemot tend to focus their foraging habits on specific areas, so knowledge of their available fish types is possible.

Pigeon Guillemot must navigate the choice between quantity over quality with regards to their fish type and the energy pay-off. This quality-variability trade-off hypothesis seeks to make a connection between energy density and spatial-temporal variability in the abundance of prey, primarily nearshore fish; with some findings that the Pigeon Guillemot is negatively affected by shifts in the abundance of this prey (Litzow, Piatt, Abookire, Speckman, et. al., 2004). The Pigeon Guillemot in the Puget Sound have a variety of prey to choose from.

Breeding Biology

Unlike most other species of the Auk family species Pigeon Guillemot lay two eggs per clutch. As stated by Emms & Verbeek (1991) this is most likely due to their tendency to feed closer on inshore benthic fishes while the other Alcidae tend to forage on offshore pelagic prey. This reduces the amount of food they can bring to their young. At the same time, inexperienced mating pairs often will lay a single egg per clutch, which can consist of 5-28% of mated pairs

(Emms et. al., 1991). The breeding season is often split by two clutches per season with the second clutch often being a single egg. It has also been noted that food provisioning rates on chicks is dependent on the chicks’ age, paying attention to the deliver rates (number of fish per unit time) and estimating provisioning rates (biomass or energy per unit time (Emms & Verbeek, 1991). Besides factors such as chick age, tidal height, and time of day, the growth rate of the chick can influence provisioning rates. The energy requirements of chicks slow as their growth rate slows. Pigeon Guillemot are unlike other alcids in that their chicks are fast growing and the reduction in provisioning may be due to encouraging their chicks to fledge (Golet, 2000).

Foraging is a high energy cost event with risk of predation so reducing delivery rates is beneficial to the parents. By reducing delivery rates later in the season, the loss to the chicks is minimized. Feeding rates are increased in the morning and evening hours while the colony members forage though high tides will decrease the forage rate. Breeding pairs with a clutch of two eggs will forage at an increase amount. Observed variation among nests in the proportions of different fish types suggest either that individual birds specialize on different prey types or that they foraged in areas that differ in relative abundance of prey types.

Chapter Three: Methods

Citizen Science Organizations

The organizations involved in the Pigeon Guillemot Group are varied in their reach, scope, and goals. They have coordinated together to ensure the passing of information and a uniform way in conducting their surveys. Among the primary organizations involved are Audubon Societies around the Puget Sound; Olympic Peninsula, Vashon-Maury Island, Dungeness River, Kitsap, Washington. The two primary regions this thesis focus on are the Whidbey Island Audubon Society and the Nisqually Reach Nature Center which survey Whidbey Island and the South Sound respectfully. The focus has been on the two organizations due to their long time conducting this survey and are the two primary groups coordinating the format of the survey.

Whidbey Island Audubon Society originally started the survey of the Pigeon Guillemot throughout Whidbey Island. Whidbey Island initiated the surveys in 2002 and since that time have taken a leadership role with the various other organizations as they got involved. The second organization to join in 2011 was the Nisqually Reach Nature Center which coordinated the South Sound survey volunteers. In 2020, the Washington State Department of Fish and Wildlife took over the data storage for the organizations involved and has begun to utilize Geographic Information Systems (GIS) programs to make an interactive survey for the volunteers.

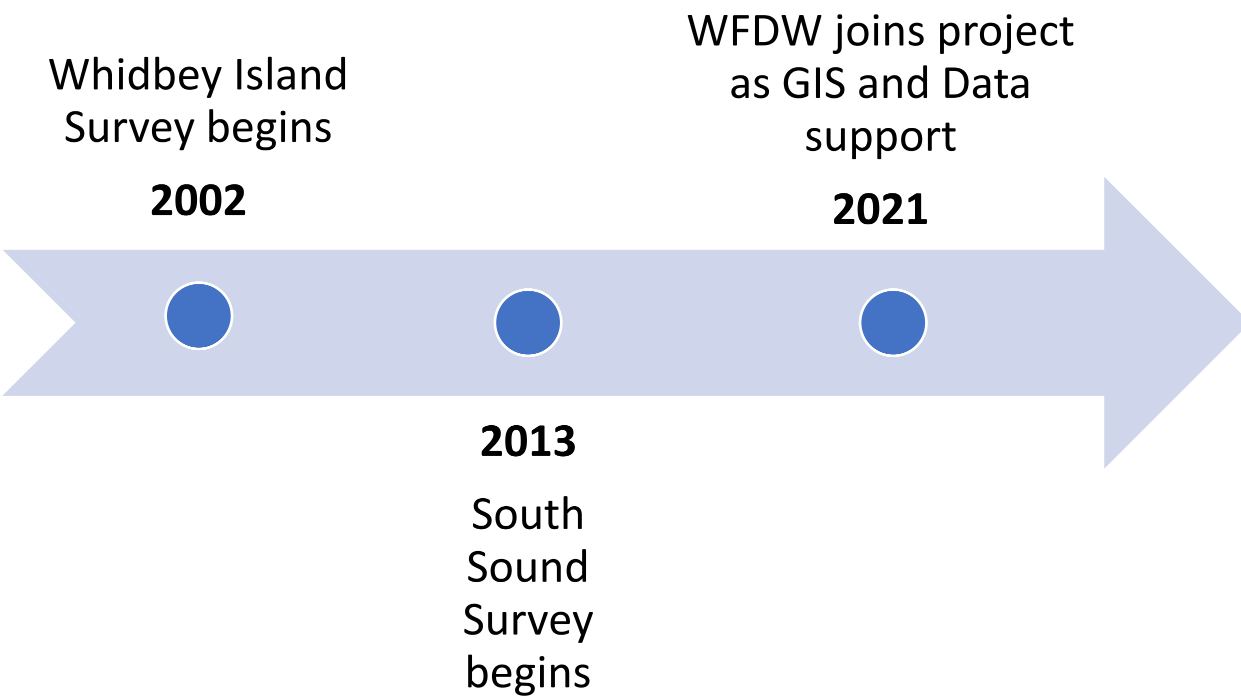
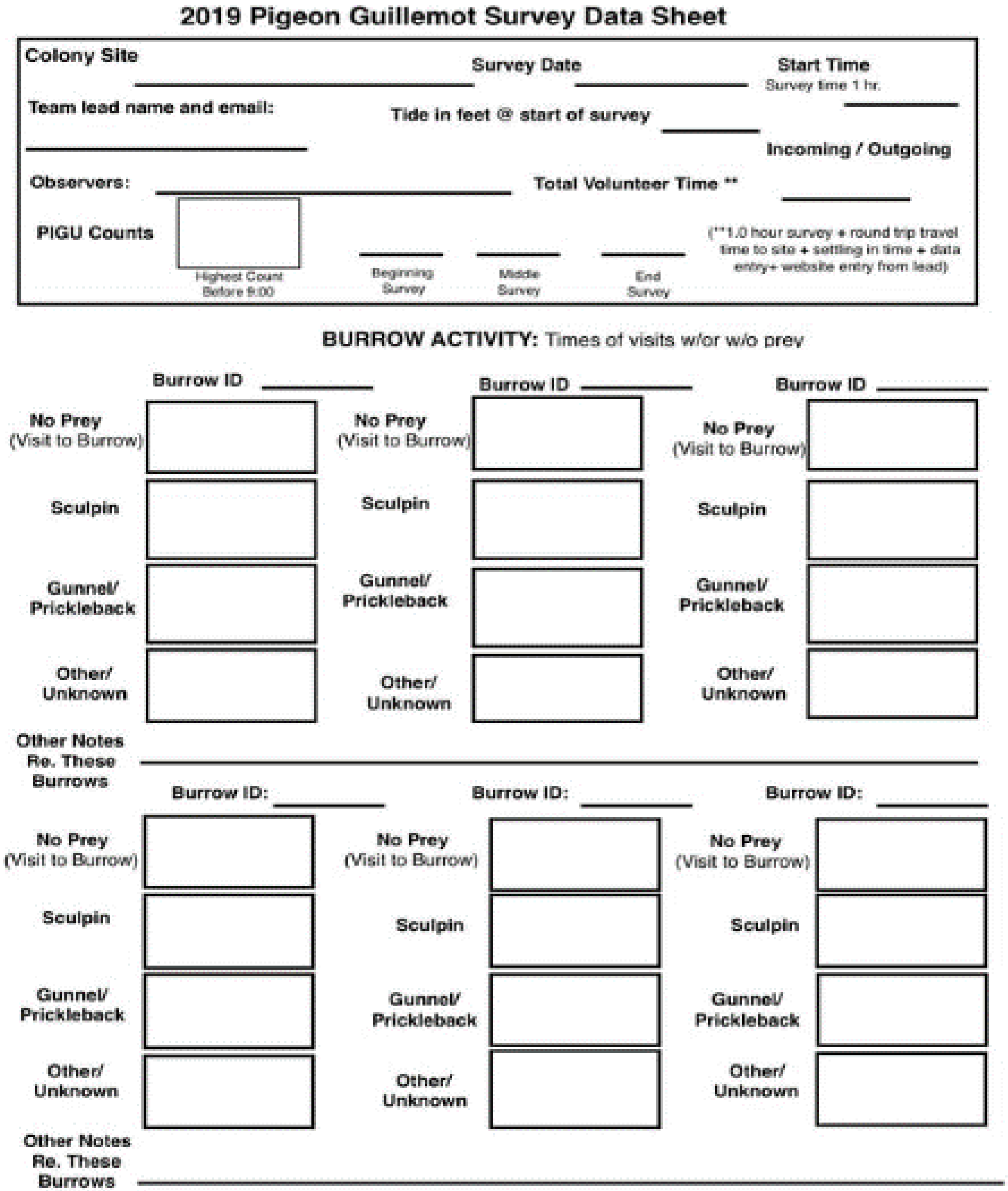


Figure 1: Timeline of organizations joining surveying of Pigeon Guillemot in the Puget Sound.



2019 Pigeon Guillemot Survey Data Sheet

Colony Site ____________________ Survey Date ____________ Start Time
Survey time 1 hr. ________

Team lead name and email: Tide in feet @ start of survey ________

____________________ Incoming / Outgoing

Observers: ____________________ Total Volunteer Time ** ________

PIGU Counts [ ] ________ ________ ________ (**1.0 hour survey + round trip travel time to site + settling in time + data entry+ website entry from lead)
Highest Count Before 9:00 | Beginning Survey | Middle Survey | End Survey

BURROW ACTIVITY: Times of visits w/or w/o prey

Burrow ID ____		Burrow ID ____		Burrow ID ____	
No Prey (Visit to Burrow)		No Prey (Visit to Burrow)		No Prey (Visit to Burrow)	
Sculpin		Sculpin		Sculpin	
Gunnel/ Prickleback		Gunnel/ Prickleback		Gunnel/ Prickleback	
Other/ Unknown		Other/ Unknown		Other/ Unknown	

Other Notes Re. These Burrows ____________________

Burrow ID: ____		Burrow ID: ____		Burrow ID: ____	
No Prey (Visit to Burrow)		No Prey (Visit to Burrow)		No Prey (Visit to Burrow)	
Sculpin		Sculpin		Sculpin	
Gunnel/ Prickleback		Gunnel/ Prickleback		Gunnel/ Prickleback	
Other/ Unknown		Other/ Unknown		Other/ Unknown	

Other Notes Re. These Burrows ____________________

Figure 2: A typical breeding season survey for Pigeon Guillemot. The top section focuses on abundance while the bottom ("Burrow Activity") section focuses on prey county.

Region Descriptions

The sites in this study are split into two regions, South Sound and Whidbey Island, with each further broken down into colonies. With 13 in South Sound (see Fig. 3) and 23 in Whidbey Island (see Fig. 4 & 5), this study included data from 36 colonies. Those colonies that are close to one another, sharing similar names are combined (e.g., Edgewater A, Edgewater B, Edgewater C were combined into "Edgewater"). This is done as many of the colonies have young adults who move about between related colonies (Mills et. al., 2014). Colonies are generally located along coastal cliffs in both regions, while individual burrows can be found in sand, gravel, or soil. Many of such burrows are small cavity in the soil type allowing the Pigeon Guillemot to decrease predation by aerial predators, though the difficulty to reach some burrows can also decrease mammalian predation, such as from raccoons. Some individual burrows can be small crevices, gaps in man-made structures such as pier supports, or rock piles near the other burrows of their colony. The size of each colony can vary greatly as their number of burrows and overall abundance are not uniform. South Sound colonies which are spread along the various peninsulas and islands centered on the Nisqually Reach Nature Center. South Sound colonies have much smaller abundance counts than those in Whidbey Island.

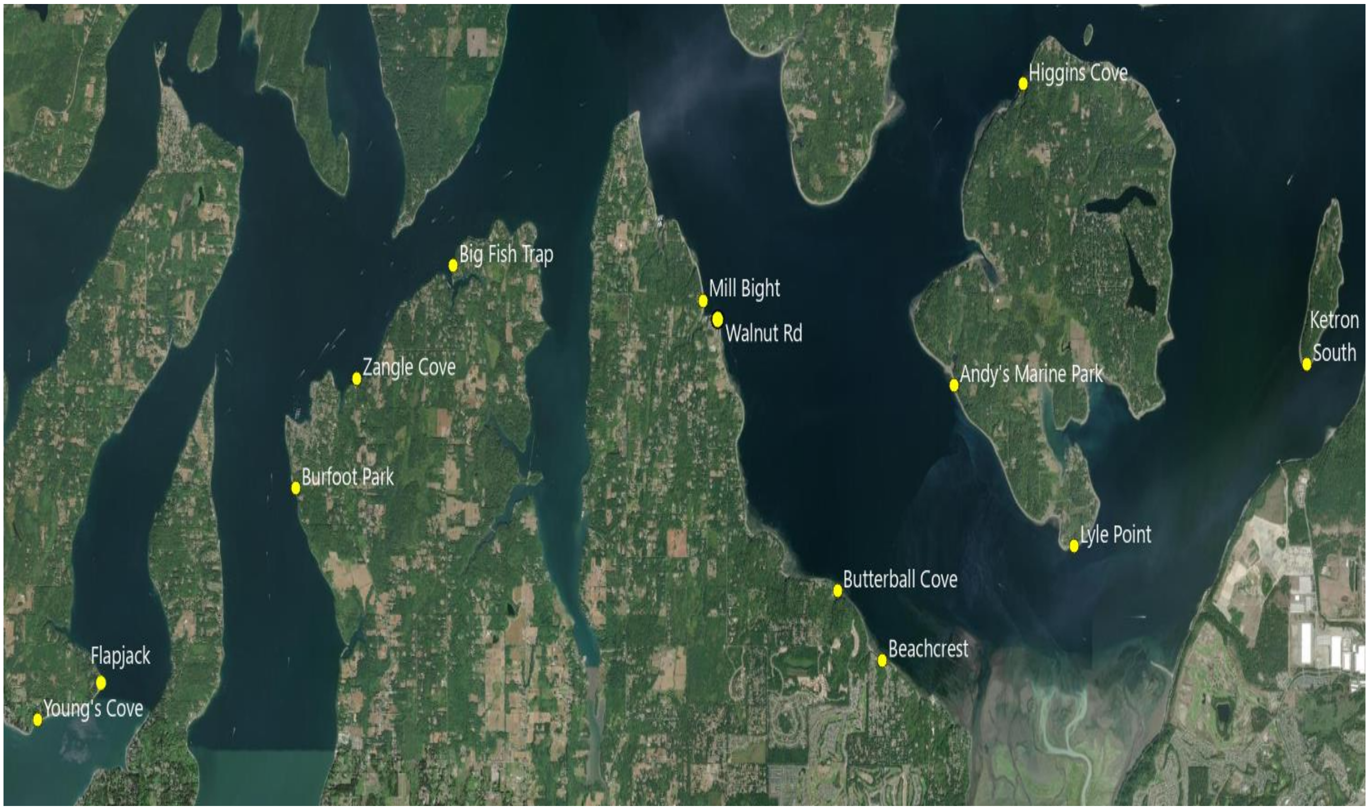


Figure 3: The colonies of South Sound

Figure 4: The northern colonies of Whidbey Island

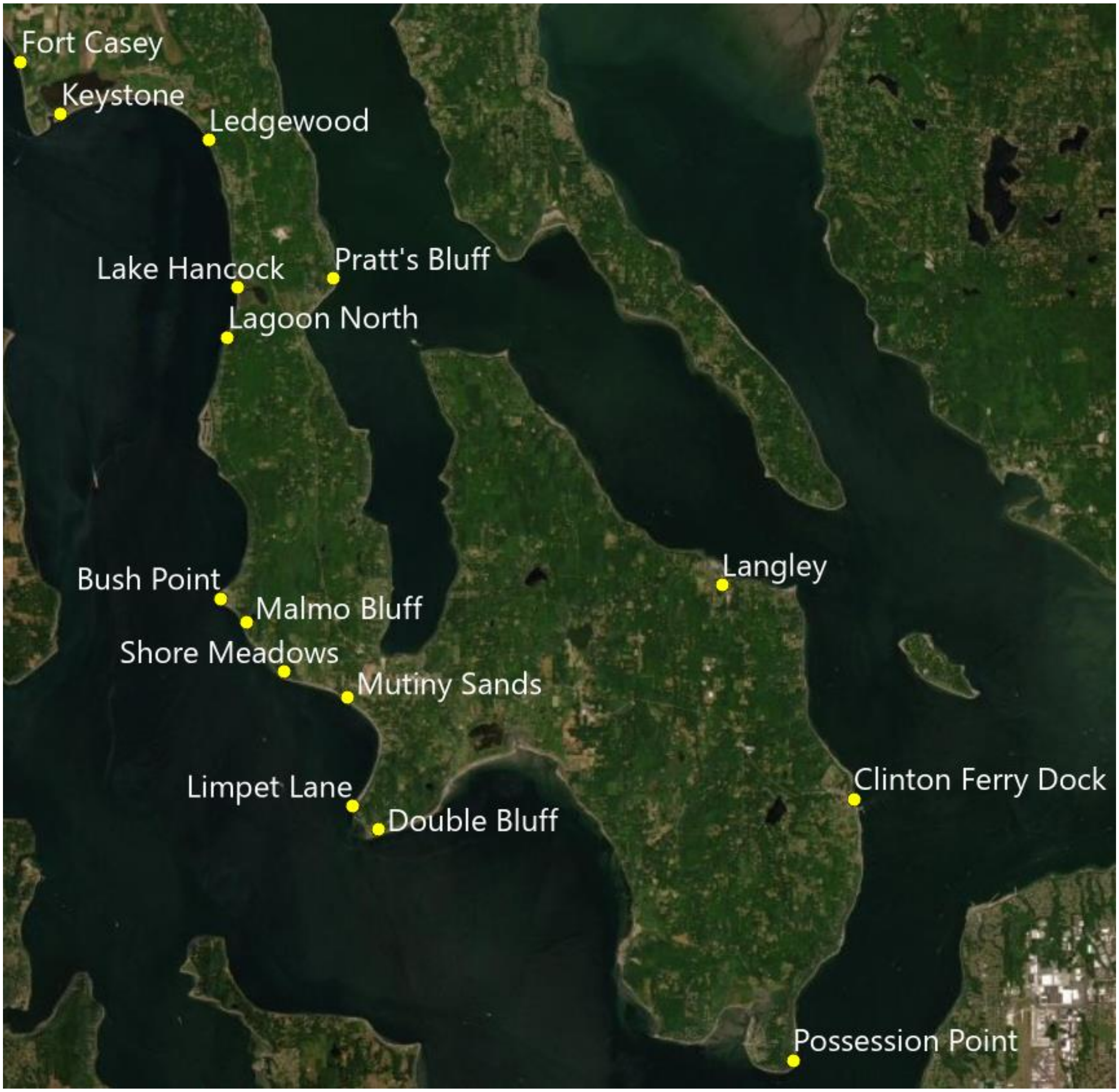


Figure 5: The southern colonies of Whidbey Island

Abundance Counts

As an annual estimate of abundance from each colony, the maximum count records each year was used (abundance data from 2015 to 2020). Any colony that was missing 3 or more years of abundance counts from 2015 to 2020 was not used in the analysis.

Prey Counts

The surveys utilized four main submissions for prey type brought to chicks. Surveyors do this through visual identification of the fish catch, which is not as difficult as it could be due to the Pigeon Guillemots' habit of "dipping" (where the bird dips their fish repeatedly into the water after catching it). The data for the prey types are sculpin, gunnel, and other/unknown (Figure 2). Those fish types were selected as they are the primary forage for the Puget Sound Pigeon Guillemot populations (Lee et. al., 2018).

Data Analysis

Data from the Whidbey Island and South Sound regions were analyzed separately, without examining any direct connection between the two. Some analyses were based on regional data (i.e. data summarized from colonies from either Whidbey Island or South Sound) and others were based on colony-level data within each region. Statistical analyses were performed in R version 4.0.4 (R Core Team, 2021), using packages as specified below.

Regional analysis

Linear regression was used to determine whether abundance counts, specifically the sum of colony abundance within a region, a significant positive or negative trend from 2015-2020. Similarly, the sum of all prey count observations were analyzed using a χ^2 test of association to ask whether the counts of different prey types were proportionally similar throughout the years.

Colony-Level Analyses

Within each region, linear regression was used to determine whether colony abundance had a significant positive or negative trend from 2015-2020. Prey counts from one year (total, gunnel, and sculpin) were correlated with the abundance of the colony in the following year (e.g., prey counts from 2015 with the abundance of 2015), using Kendall's Tau in the R package "Kendall" (Mcleod, 2011). This analysis used data from 2014-2019 for prey types, and 2015-2020 for abundance.

A synchrony analysis was used to ask whether colony abundance, within each region, varied synchronously or asynchronously. The R package "synchrony" (Gouhier, 2014) calculated mean Pearson's, Kendall's W, and Spearman's ranked correlation of colony abundance.

Chapter Four: Results

Abundance Counts

The overall Pigeon Guillemot abundance of the Whidbey Island and South Sound colonies varied somewhat from year to year (Figure 5). South Sound abundance did not show any significant trend over time ($p = 0.22$, adj. $R^2 = 0.18$). Whidbey Island abundance showed a significant linear increase over time ($p = 0.039$, adj. $R^2 = 0.62$).

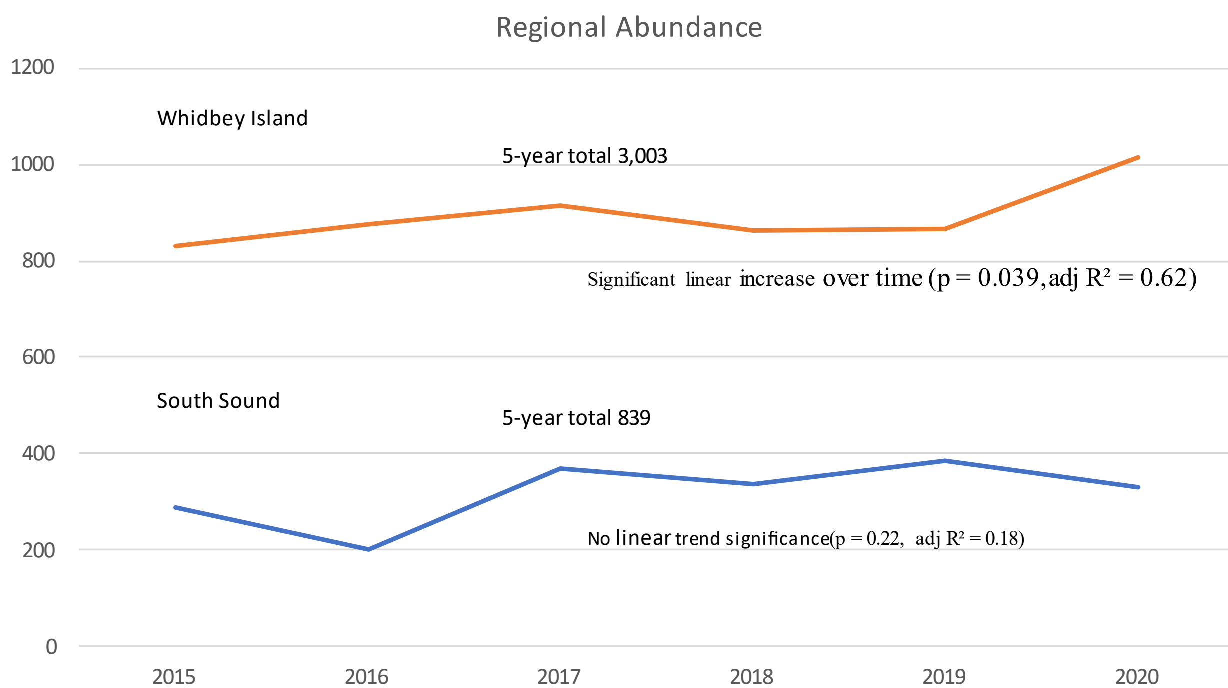


Figure 5: South Sound and Whidbey Island annual abundance. The 5-year total is the sum of the counts in each region for the 5-years (2015-2020) used in this study.

Prey Counts

In South Sound Pigeon Guillemot gunnel were observed more often compared to any other prey, 69% across all the years (Figure 6; see Appendix 1 for counts by year). The proportion of different prey types observed over varied over the years ($\chi^2_{10} = 49$, $p < 0.001$). For example, 2018 showed a larger count of gunnel than one would expect by chance, based on examinations of the χ^2 residuals.

In Whidbey Island Pigeon Guillemot gunnel were observed more often compared to any other prey, 50% of their total prey being gunnel (Figure 7; see Appendix 2 for counts by year). The proportion of different prey types observed varied over the years $\chi^2_{10} = 144$, $p < 0.001$).

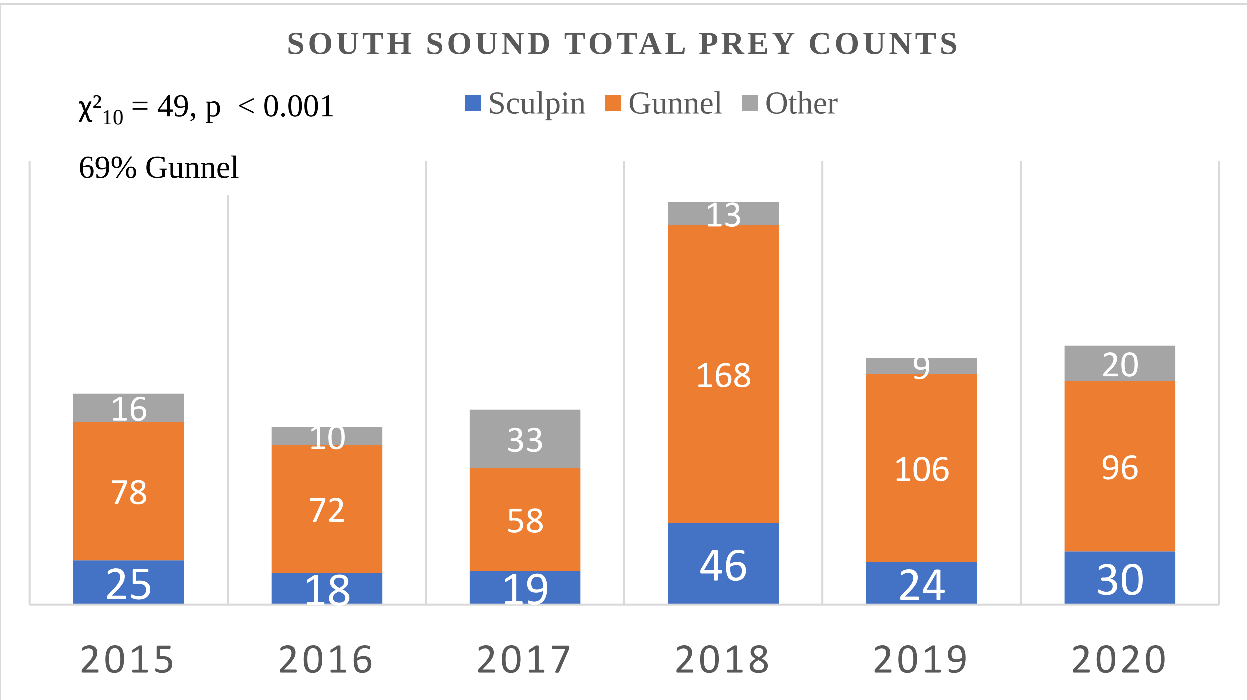


Figure 6: South Sound total prey counts. See appendix 1 for yearly prey diversity breakdowns. 69% of all prey was gunnel. $\chi^2_{10} = 49$, $p < 0.001$ showed the prey type varied significantly from year to year.

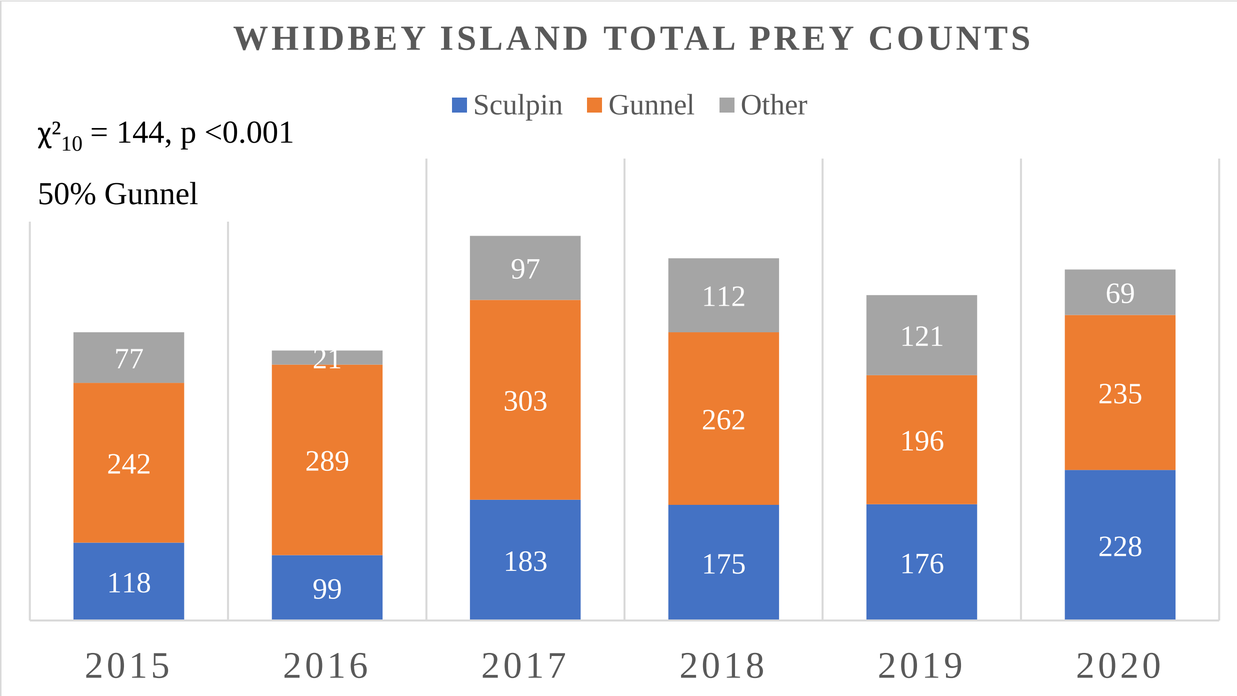


Figure 7: Whidbey Island total prey counts. See appendix 2 for yearly prey diversity breakdowns. 50% of all prey was gunnel. $\chi^2_{10} = 144$, $p < 0.001$ showed the prey type varied significantly from year to year.

In the South Sound region, there was only one weak correlation between abundance and prey types (Table 2). This correlation was for the Young's Cove abundance counts weak correlation with total prey (0.06).

Table 2: South Sound Colony Results. The regression coefficient column is from simple linear regression of colony abundance with you (2015-2020. Correlation columns show Kendall's Tau of colony abundance with prey counts (Total, Sculpin, and Gunnel) from the previous year (2014-2019). Significant correlations are marked in bold with *. In correlation results, n/a represents missing prey count data.

Colony	Regression Coefficient	Correlation w/total prey	Correlation w/sculpin	Correlation w/gunnel
Andy's Marine Park	4.55	n/a	n/a	n/a
Beachcrest	5.22	0.66	0.5	0.66
Big Fish Trap	-0.22	0.75	0.75	0.75
Burfoot Park	0.17	-0.3	-0.3	-0.64
Butterball Cove	3.85	0.4	0.31	-0.2
Flapjack	-0.65	n/a	n/a	n/a
Higgins Cove	-1.14	0.46	0.56	0.46
Ketron South	-4.28	0.1	0.35	-0.1
Lyle Point	13.08	0.35	0.64	0.41

Mill Bight	-2.51	0.35	0.64	0.41
Walnut Road	3.71	0.13	0.59	0.13
Young's Cove	2.91	**0.06***	0.54	-0.57
Zangle Cove	0.77	-0.13	0.14	-0.21

In the Whidbey Island region, there were several colonies that showed positive or negative correlations between abundance and prey types (total prey, sculpin, and gunnel, Table 3). All of the correlations were weak (between -0.10 and 0.10). Cliffside abundance was weakly correlated with the previous year's total prey (-0.07), sculpin (0.08), and gunnel (-0.07). Double Bluff abundance was weakly correlated with previous year's total prey (-0.07) and sculpin (-0.08). Malmo Bluff had one positive correlation with gunnel (0.06). Finally Mutiny Sands also had a positive correlation with total prey (0.06).

Table 3: Whidbey Island Colony Results. Linear Trend represents simple linear regression of colony abundance from 2015 to 2020. Kendall's Tau correlation of colony abundance with prey counts (total, sculpin, and gunnel) from the previous year, 2014 to 2019. Those results with significance are marked in bold with *. Those results in bold show a correlation.

Colony	**Regression Coefficient**	**Correlation w/total prey**	**Correlation w/sculpin**	**Correlation w/gunnel**
Bush Point Dock	0.48	0	0.40	0
Cliffside	1.22	**-0.07***	**0.08***	**-0.07***
Clinton Ferry Dock	-0.30	0.18	0.51	-0.40
Coupeville Wharf	1.34	-0.33	0	0
Double Bluff	5.25	**-0.07***	**-0.08***	-0.23
Forbes Point	-0.9	0.20	-0.52	0.10
Fort Casey North	5.54	0.41	0.55	-0.13
Harrington	**-0.08***	-0.33	0.43	-0.20
Hastie Lake South	-0.17	0.20	0.33	-0.20
Keystone	-3.79	0	-0.10	-0.40
Lagoon North	-8.48	0.41	-0.27	0.73

Colony	Regression Coefficient	Correlation w/total prey	Correlation w/sculpin	Correlation w/gunnel
Lake Hancock	8.94	0.33	0.66	0.66
Langley Marina	-2	0.54	0.40	0.67
Malmo Bluff	-1.22	0.00	0.69	**0.06***
Monroe Landing	2.94	0.20	0.20	0.10
Mutiny Sands	3.48	**0.06***	0.69	-0.46
Possession Point	-1.28	0.33	-0.14	0.13
Pratts Bluff	-0.80	0.27	0.21	0.35
Rolling Hills	-0.62	0.13	0.13	0.00
Shore Meadows	1.05	0.20	-0.13	0.69

Synchrony Analysis

Neither region demonstrated synchronous changes across the colony abundance counts (Table 4). Using the mean Pearson correlation, Kendall's W, or Spearman's ranked correlation did not influence the finding. In South Sound there was no correlation between the abundance counts of the colonies suggesting those abundance counts are not influenced by one another (Figure 5). For Whidbey Island there was no correlation between the abundance counts of the colonies suggesting those abundance counts are not influenced by one another (Figure 6). It is interesting that the abundance of Pigeon Guillemot is asynchronous as this has been found to increase the risk in predation of marine birds, such as the Common Tern (Hernandez-Matias et. al., 2003), but predation does not seem to be a large factor in Pigeon Guillemot abundance counts in the Puget Sound.

Table 4: Synchrony Analysis of Pigeon Guillemot abundance from each colony per region. There are no statistically significant results.

	South Sound	Whidbey Island
Mean Pearson Correlation	-0.03	0.05

Mean Correlation p-value (two-tailed test)	0.54	0.12
Kendalls W (uncorrected for tries)	0.07	0.04
Kendall’s W (corrected for tries)	0.07	0.04
Kendall’s W p-value (one-tailed test)	0.40	0.39
Spearman’s ranked correlation	0.00	0.00

Chapter Five: Discussion

The study of fluctuating abundance counts, and unexpected collapse is a well-documented phenomenon in herring, though this can be possible in many organisms (Stier et. al., 2020). Population dynamics are an important factor to understand when it comes to species in the Puget Sound. To project those counts into the future, we can generate expected abundance in a generation as a direct function of individuals in a previous generation (Heino et. al., 1997). By knowing the population of the Pigeon Guillemot, we can tie it in with both wildlife conservation and economy focused endeavors (Cusack et. al., 2019) as the utilization of statistical analyzes to produce timely adaptive management plans.

Differences in overall abundances from Whidbey Island and the South Sound is a complicated subject. There are many factors which could influence their large difference, South Sound has colony abundance in the tens, Whidbey Island often will go up to the hundreds. Papers such as (Heino et. al., 1997) show that subpopulations of a species can be negatively impacted by traveling long distance, so the fact the Pigeon Guillemot populations in Puget Sound stay year-round, rather than migrate any great distance, this would suggest that the population should be stable, lending more credence to their prey being a much bigger factor to their abundance counts. So future studies into their primary prey (gunnel and sculpin) is important. Other factors that could influence this wide range of colony abundance including traditional sites survival (i.e., natural, and man-made erosion and human interference be it through producing loud noises which Heino (1997) mentioned as a negative factor to a species population or disturbing them directly at their colonies. Other environmental factors no doubt influence the abundance counts of each region and colony individually, as earlier shown (Figures 3, 4, and 5) the colonies of each region are widely dispersed. One major factor for the much larger abundance counts of Whidbey Island is likely due to the island's location closer to the wintering grounds and more foraging opportunities. Perhaps there is a large gunnel population in the area, or their hunting is easier, leading to a greater success rate and the slight increasing trend. The variety of abundance counts of the two regions points to the asynchrony of colony abundances, which is surprising given the colonies' proximity to one another. It is worth nothing that population synchrony could be operating, and potentially detected with many more years of data, but that is beyond the scope of this thesis. In a future study it might be interesting to see if there is any synchrony with abundance counts in a colony in a single year, to see if they perform in similar ways to other seabirds, like the glaucous-winged gull (*Larus glaucescens*) which lay their eggs in synchrony with one another in their colonies (Henson et. al., 2011). An example of abundance synchrony is the study of several grazing birds (Greenland, Svalbard barnacle geese, Greenland white-fronted goose, Greylag goose, and Svalbard pink-footed goose, along with the common crane) in northern Europe which showed variable synchrony in both the short- and long-term abundance counts (Cusack et. al., 2019). This variation was due to differing management goals, and lack of consistent monitoring; all factors which could play a role in Pigeon Guillemot synchrony.

While the proportions of each prey type recorded varied from year to year, gunnel was observed the most often in both regions. Though the amounts taken did vary throughout the years as shown by the χ^2_{10} results. This is not totally unexpected as the data was for only six years and not all the colonies had enough data to analyze, decreasing the pool of data for the study. There are of course many possible reasons for the higher counts of gunnel. As mentioned by Lee (2014) in their surveys they noted a much larger amount of gunnel than sculpin, about three times as much. One suggested reason for this tendency to feed on gunnel is due to the bony nature of sculpin which can make failures more often as digestion is more difficult. It is worth noting here that sculpin only contain 87% of the gunnel's total wet energy mass, which could be another key factor in the foraging of more gunnel than sculpin (Table 1). It is worth gunnel is not the most nutritional prey types available to Pigeon Guillemot which might reinforce the idea that breeding pairs forage specific sites, more study into this is needed.

Nelson (1987) focused on the importance in trying to connect prey and abundance data together while also collecting quantitative data for the attendance of colonies. This was the main motivation for me to examine the data on individual colony abundance and prey counts, potentially to test the junk-food hypothesis. It is interesting that in table 1 there is evidence to show other more energy efficient prey types that Pigeon Guillemot could forage on, but they tend to take gunnel and sculpin, with gunnel being the top prey item for both regions. Their energy needs are presumably influenced by distance, forage habits of the colony, and their needs to fledge their chicks. Pigeon Guillemot are known to feed their chicks varied amounts of prey throughout their growth to pack on weight and encourage chicks to fledge. We do not actually know what the adult Pigeon Guillemot are eating themselves, though high-lipid prey would increase their reproductive performance (Golet, 2000). As they might be feeding themselves a larger variety of prey in comparison to their chicks. They may seek quantity over quality to bulk up their chicks. Golet also found that Pigeon Guillemot who specialized in prey items had a higher reproductive success that those who were more generalized in their approach (2000). To successfully forage like any organism Pigeon Guillemot, need to assess prey distribution and abundance as the energy costs of acquiring prey needs to be maintained at a viable level (Dall & Cuthill, 1997), and by specializing in a specific fishing site(s) they reduce much of the energy costs.

For the future it is important to see how the format of the survey can be improved upon or add additional information to be utilized by the various organizations that are working with the Pigeon Guillemot Group. To gain a better understanding of the pairing of Pigeon Guillemot mating pairs and their utilization of a specific burrow could be made easier to identify through banding. This banding process have been conducted successfully in the past by researchers on the South Farallon Islands (Tenaza, 1966). The format utilized in that study of banding allowed Tenaza to not only confirm that the mated pairs returned the following year but returned to their prior nesting burrow (1966). By having such a process completed in the past reinforces the fact it could possibly be done on a larger scale in the Puget Sound.

The survey currently does not specify which burrow was being utilized by the mating pairs, a marking system could be devised such as painting rocks and wood near the burrows to improve identification to allow surveyors to mark them down on the surveys. Such a marking system would also assist in more in-depth scientific research on specific mating pairs, their eggs/chicks, and reproduction success. An additional way to mark sites would be by utilizing GIS to mark the colonies on digitally formatted pictures of the colonies. An established layout of the burrows would help reduce misinformation.

As the organizations involved in the Pigeon Guillemot Program increase their expertise will continue to help the organization and its success grow. Data collected could help reveal more in-depth knowledge of Pigeon Guillemot abundance, colony shifts, die-offs, and the like.

While the diet of the Pigeon Guillemot is key to their chick's survival and the return rates for following years, this project did not demonstrate clear evidence of correlation between prey counts the previous year and colony abundance. A handful of sites, primarily in Whidbey Island, had statistically significant correlations but these were both positive and negative, and always weak (between -0.10 and 0.10). There are some colonies which show near significance between 0.05 and 0.010, so this supports more in-depth study with larger data sets to be conducted in the future. The fact that the Whidbey Island abundance counts positive linear trend points towards some statistical significance is a sign that the data is important. Each region was analyzed independently of one another due to their varied abundance counts and regions distance, and the results shows how differently the two regions are. The idea of Pigeon Guillemot as a marine indicator is still a conversation to have, though Whidbey Island does seem to have enough data to support its use as information used in conservation and management.

Gunnel is obviously an important prey source for breeding Pigeon Guillemots in the Puget Sound, and future study into their relationship could prove rather important to the overall success of both species (Figure 6,7, Appendix 1, 2). Understanding the reasons for this finding is important for the future management of the Pigeon Guillemot. Combined with the lack of correlation with prey types this may support the findings that Pigeon Guillemot forages for their prey within 4 miles from their colony (Litzow, 2000). While there are many suggestions to why their mostly observed feeding their chicks gunnel, this study cannot confirm any of those hypotheses. There is a lack of data specifically on gunnel and sculpin in Puget Sound which makes determination of their influence on Pigeon Guillemot feeding habits impossible currently. A study in the future to test if Pigeon Guillemot prefer gunnel would be an interest addition to the research done on the Pigeon Guillemot.

Bibliography

A.I. McLeod (2011). Kendall: Kendall rank correlation and Mann-Kendall trend test. R package version 2.2. https://CRAN.R-project.org/package=Kendall

Bishop, E., Rosling, G., Kind, P., & Wood, F. (2016). Pigeon Guillemots on Whidbey Island, Washington: A Six-Year Monitoring Study. *Northwestern Naturalist*, 97(3), 237–245. https://doi.org/10.1898/nwn15-31.1

Bixler, K. S. (2010). *Why Aren't Pigeon Guillemots in Prince William Sound, Alaska Recovering from the Exxon Valdez Oil Spill?* [Oregon State University]. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/rb68xg25k

Bolton, M., Conolly, G., Carroll, M., Wakefield, E. D., & Caldow, R. (2019). A review of the occurrence of inter-colony segregation of seabird foraging areas and the implications for marine environmental impact assessment. *Ibis*, 161(2), 241–259. Blackwell Publishing Ltd. https://doi.org/10.1111/ibi.12677

Bull, J. W., Gordon, A., Law, E. A., Suttle, K. B., & Milner-Gulland, E. J. (2014). Society for Conservation Biology Importance of Baseline Specification in Evaluating Conservation Interventions and Achieving No Net Loss of Biodiversity. *Biology*, 28(3), 799–809. https://doi.org/10.1111/cobi

Cairns, D. (1979). Censusing Hole-Nesting Auks by Visual Counts. *Bird-Banding*, 50(4), 358-364. https://doi.org/10.2307/4512487

Cornell Lab of Ornithology (n.d). *Pigeon Guillemot Overview, All About Birds, Cornell Lab of Ornithology*. Overview, All About Birds, Cornell Lab of Ornithology. https://www.allaboutbirds.org/guide/Pigeon_Guillemot/overview.

Cusack, J. J., Duthie, A. B., Rakotonarivo, O. S., Pozo, R. A., Mason, T. H. E., Månsson, J., Nilsson, L., Tombre, I. M., Eythórsson, E., Madsen, J., Tulloch, A., Hearn, R. D., Redpath, S., & Bunnefeld, N. (2019). Time series analysis reveals synchrony and asynchrony between conflict management effort and increasing large grazing bird populations in northern Europe. *Conservation Letters*, 12(1). 10-11. https://doi.org/10.1111/conl.12450

Dall S. R. X., and I. C. Cuthill. 1997. The information costs of generalism. *Oikos* 80:197–202.

Department of Fish and Wildlife. (1970, April 06). Washington Department of Fish & Wildlife. Retrieved February 09, 2021, from https://wdfw.wa.gov/

Drent, R. H. (1965). Breeding biology of the Pigeon Guillemot, Cepphus Columba. *Ardea*, 53(3-4). University of British Columbia.Thesis.

Drew, G. S., Piatt, J. F., & Hill, D. F. (2013). Effects of currents and tides on fine-scale use of marine bird habitats in a Southeast Alaska hotspot. *Marine Ecology Progress*, 487, 275–286. https://doi.org/10.2307/24892125

Emms, S. K., & Verbeek, N. A. M. (1991). Brood Size, Food Provisioning and Chick Growth in the Pigeon. *The Condor*, 93(4), 943-951. https://www.jstor.org/stable/3247729

Ewins, P. J. (2020). Pigeon Guillemot (Cepphus columba), version 1.0. In Birds of the World (A. F. Poole and F. B. Gill, Editors). Cornell Lab of Ornithology, Ithaca, NY, USA. https://doi.org/10.2173/bow.piggui.01

Gaydos, J. K., & Pearson, S. F. (2011). Birds and mammals that depend on the Salish Sea: A compilation. *Northwestern Naturalist*, 92(2), 79-92. https://www.jstor.org/stable/41300886

Golet, G. H., Kuletz, K. J., Roby, D. D., & Irons, D. B. (2000). Adult prey choice affects chick growth and reproductive success in Pigeon Guillemot. *The Auk*, 117(1), 82-91. https://academic.oup.com/auk/article-abstract/117/1/82/5561605

Harkness, B. (2017). *An assessment of population genetic structure in Guillemots* (Cepphus). http://hdl.handle.net/1974/23632

Henson, S. M., Cushing, J. M., & Hayward, J. L. (2011). Socially induced ovulation synchrony and its effect on seabird population dynamics. *Journal of Biological Dynamics*, 5(5), 495-516. doi:10.1080/17513758.2010.529168

Hernández-Matías, A., Jover, L., & Ruiz, X. (2003). Predation on common Tern eggs in relation to sub-colony Size, Nest aggregation and Breeding Synchrony. *Waterbirds*, 26(3), 280-289

Kenn Kaufman. (2019). *Pigeon Guillemot* Cepphus columba. https://www.audubon.org/field-guide/bird/pigeon-guillemot

Lee, T., & Grant, J. (2018). *South Puget Sound and Nisqually Reach Aquatic Reserve Pigeon Guillemot Breeding Surveys 2016-2018 Monitoring Report Prepared for: Nisqually Reach Aquatic Reserve Citizen Stewardship Committee*. https://www.aquaticreserves.org/,

Lewis, D. G. A. and T. J. (1974). The History of Farallon Island Marine Bird Populations , 1854-

1972 *The Condor*, *76*(4), 432–446.

Litzow, M. A., Piatt, J. F., Abookire, A. A., & Robards, M. D. (2004). Energy density and variability in abundance of pigeon guillemot prey: Support for the quality-variability trade-off hypothesis. *Journal of Animal Ecology*, 73(6), 1149–1156. https://doi.org/10.1111/j.0021-8790.2004.00890.x

Litzow, M. A., Piatt, J. F., Abookire, A. A., Speckman, S. G., Arimitsu, M. L., & Figurski, J. D. (2004). Spatiotemporal predictability of schooling and nonschooling prey of Pigeon Guillemots. *Condor*, 106(2), 410–415. https://doi.org/10.1650/7330

Litzow, M. A., Piatt, J. F., Prichard, A. K., & Roby, D. D. (2002). Response of pigeon guillemots to variable abundance of high-lipid and low-lipid prey. *Oecologia*, 132(2), 286-295.

Mills, A., Lee, T., & Joyce, J. (2014). *Pigeon Guillemot Foraging and Breeding Survey in and Near the Nisqually Reach Aquatic Reserve 2014 Monitoring Report*. Olympia, WA: Nisqually Reach Aquatic Reserve Citizen Stewardship Committee.

Nelson, D. A. (1991). Demography of the Pigeon GUILLEMOT on southeast FARALLON Island, California. *The Condor*, *93*(3), 765-768. doi:10.2307/1368213

Nelson, D. A. (1987). Factors Influencing Colony Attendance by Pigeon Guillemots on Southeast Farallon Island. *The Condor*, 89(2), 340-348.

Österblom, H., Olsson, O., Blenckner, T., & Furness, R. W. (2008). Junk-Food in Marine Ecosystems. *Oikos*, 117(7), 967-977.

Piatt, J. F., Sydeman, W. J., & Wiese, F. (2007). Introduction: A modern role for seabirds as indicators. *Marine Ecology Progress Series,* 352, 199–204. https://doi.org/10.3354/meps07070

Romano, M. (1997). *Effects of Diet on Growth and Development of Nestling Seabirds*. January 1999, 1–39.Thesis.

Romano MD, Piatt JF, Roby DD (2006) Testing the junk-food hypothesis on marine birds: effects of prey type on growth and development. Waterbirds 29:407–516

Stier, A. C., Olaf Shelton, A., Samhouri, J. F., Feist, B. E., & Levin, P. S. (2020). Fishing, environment, and the erosion of a population portfolio. *Ecosphere*, 11(11). https://doi.org/10.1002/ecs2.3283

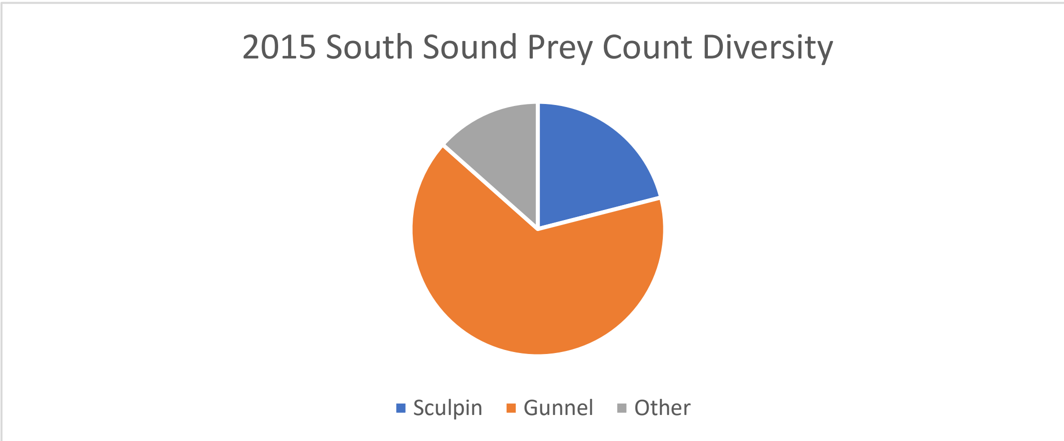
Tenaza, R. (1966). Pigeon Guillemot Banding Returns. *Bird-Banding*, 37(4), 288-289.

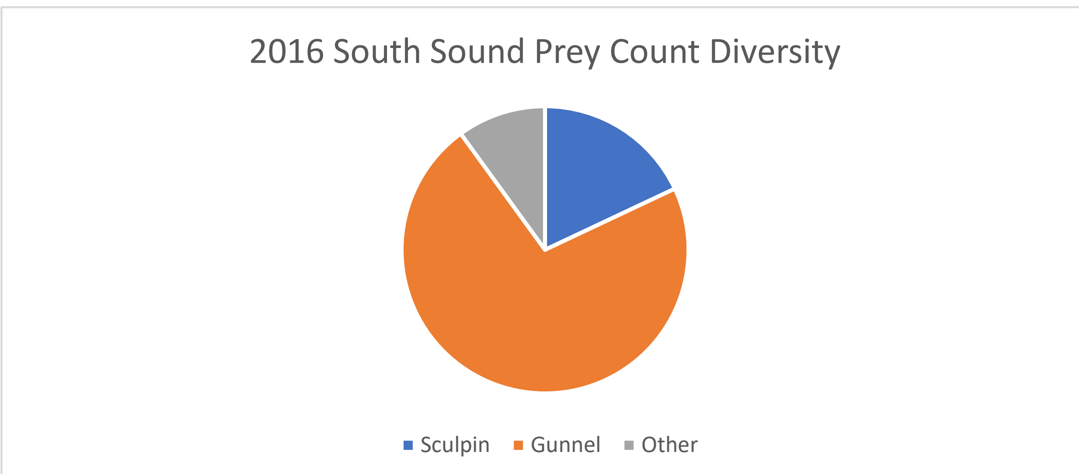
Vermeer, K., Morgan, K. H., & Smith, G. E. J. (1993). Colony Attendance of Pigeon Guillemots as Related to Tide Height and Time of Day. *Colonial Waterbirds*, 16(1), 1-8.

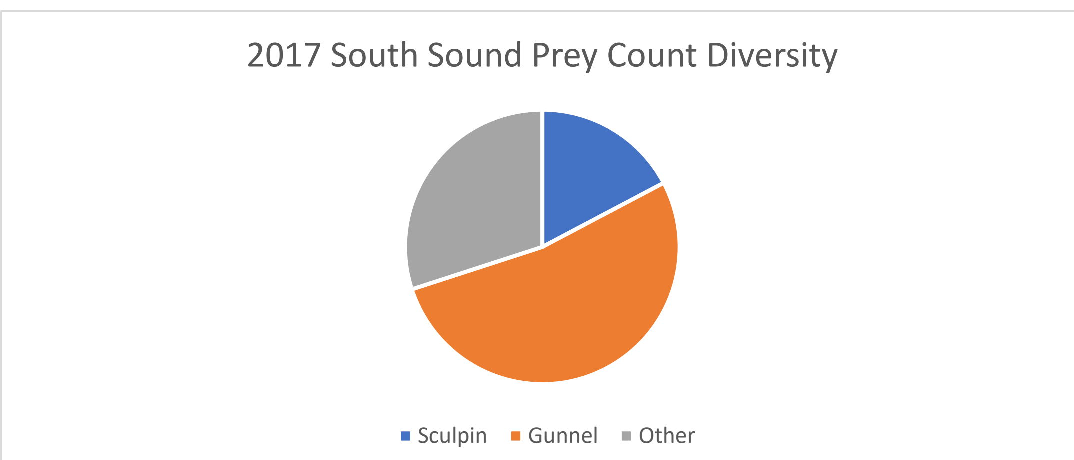
Vermeer, K., Morgan, K. H., & Smith, G. E. J. (1993b). Nesting Biology and Predation of Pigeon Guillemots in the Queen Charlotte Islands, British. *Waterbirds*, 16(2), 119-127.

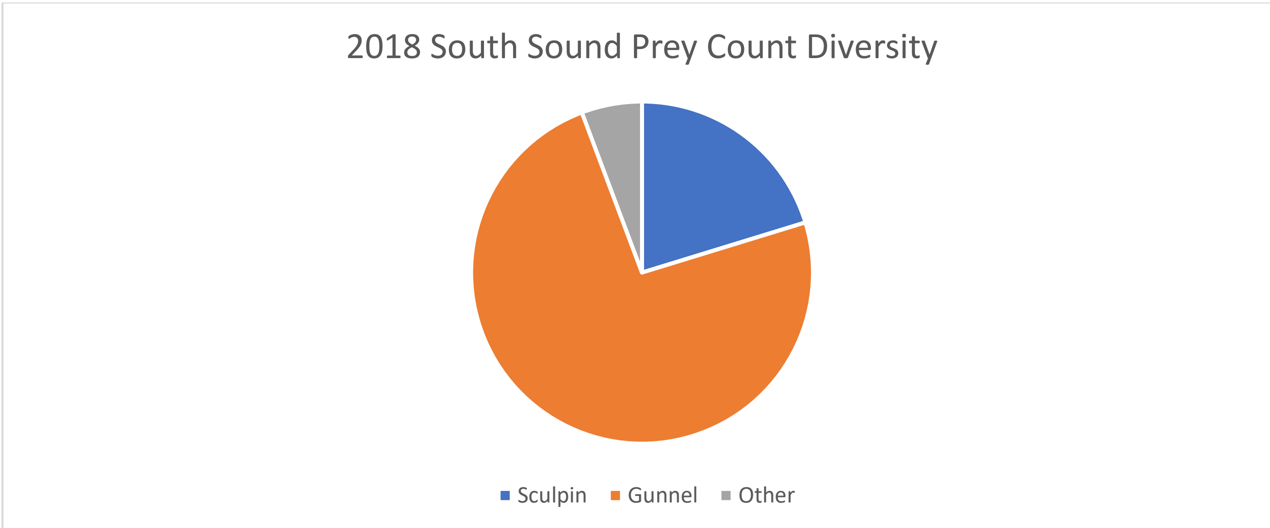
Appendix 1: South Sound Prey Count Dynamics

Appendix 1 contains a breakdown of prey count totals for South Sound by year showing the overall diversity. Showing a large focus on gunnel by the colonies.





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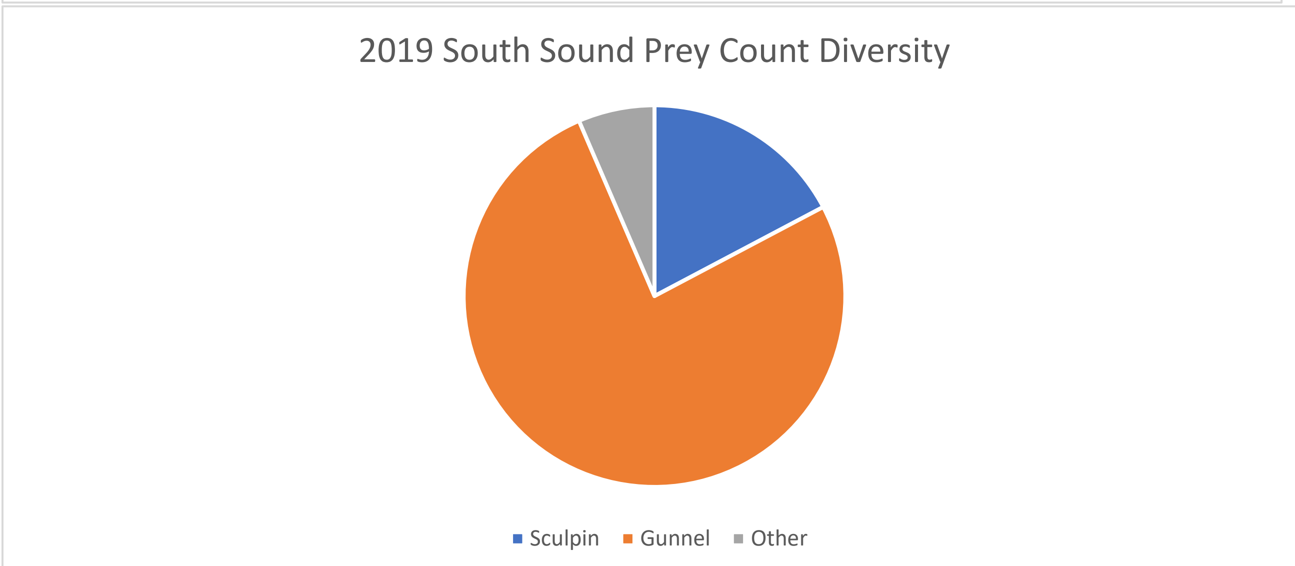
Gunnel
Other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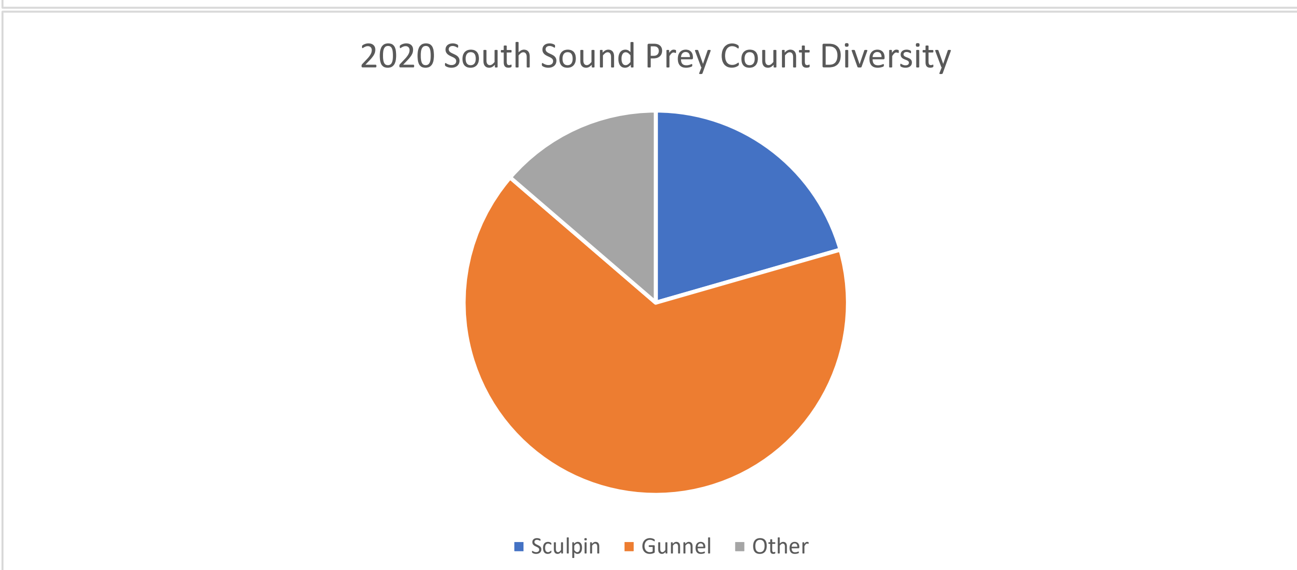
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Sculpin
Gunnel
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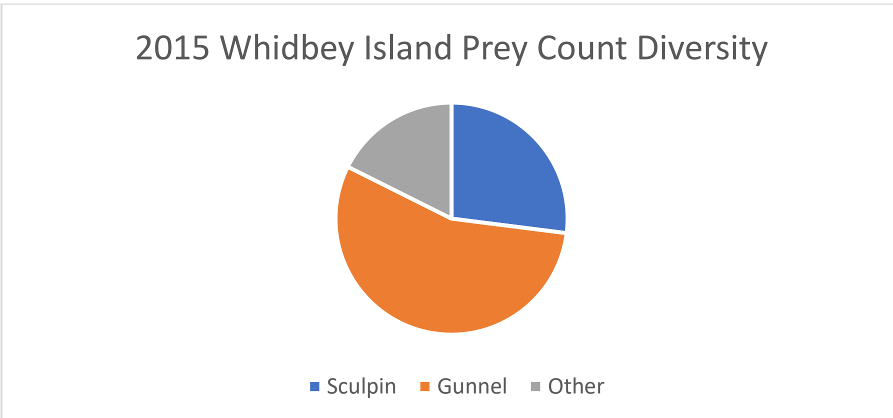
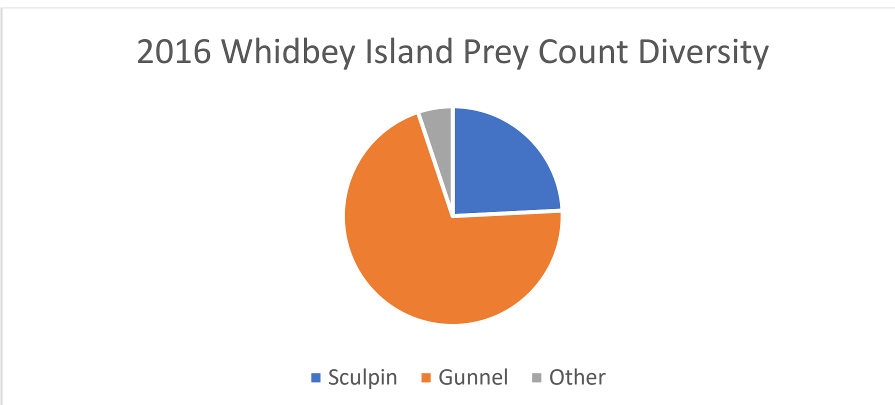
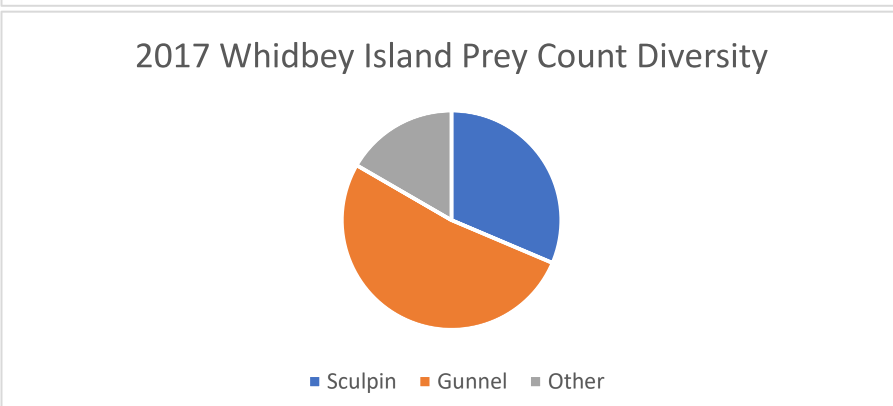
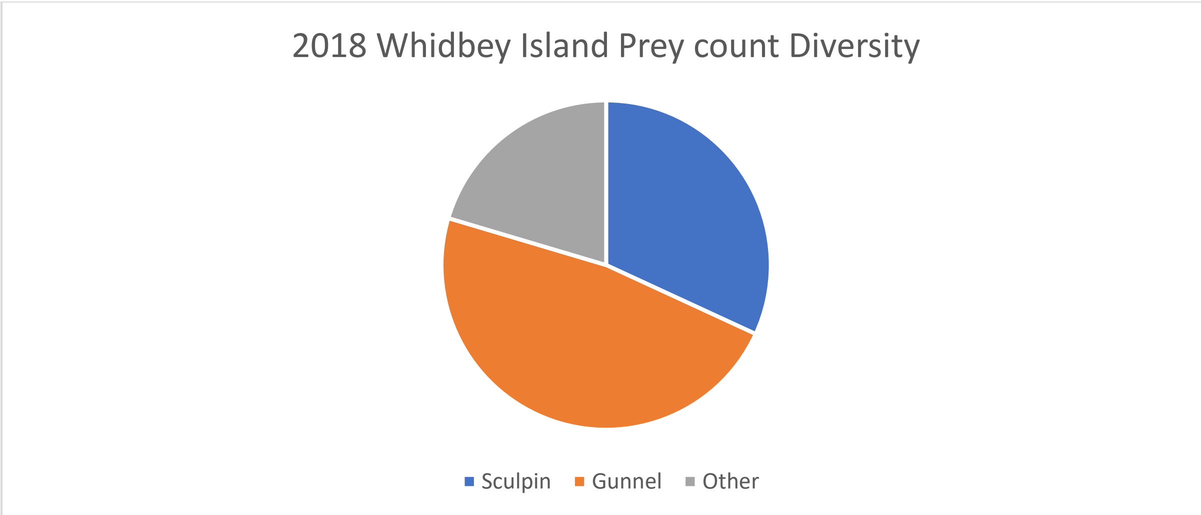
Appendix 2: Whidbey Island 2 Prey Count Dynamics

Appendix 2 contains a breakdown of prey count totals for Whidbey Island by year showing the overall diversity. Showing a large focus on gunnel by the colonies.





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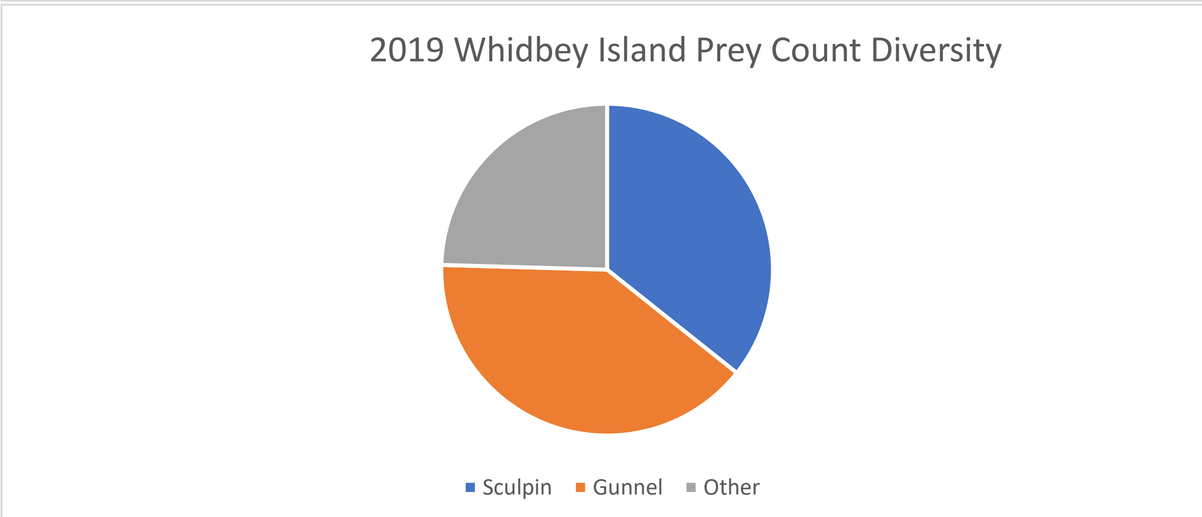
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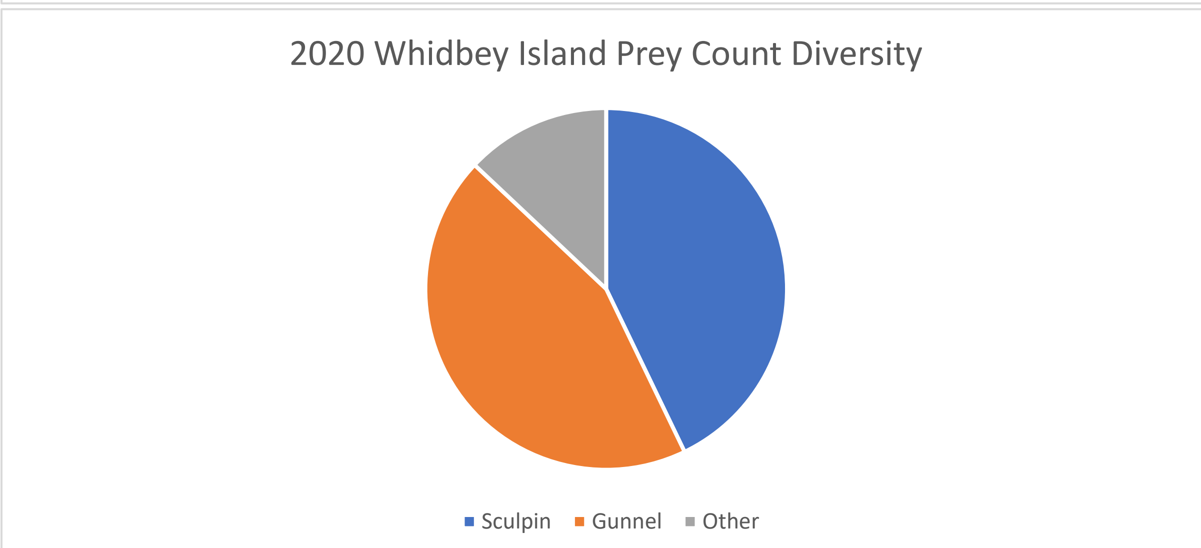
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Gunnel
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