Negative effects of climate change and fishing activities on Alaskan seabird populations (2002-2011)

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ABSTRACT

Seabird populations along the Alaskan coast have been rapidly declining due to anthropogenic climate change and other associated factors. This study examines the effects of sea surface temperature (SST) and fishing activity on the abundance of Alaskan seabird species. We downloaded bird observation data from the International Pacific Halibut Commission (IPHC) and then matched the seabird abundance data with SST data from the National Oceanic and Atmospheric Administration (NOAA) and fishing data from the NOAA Fisheries Longline Survey. We analyzed relationships between bird abundance and fish caught or SST. Our findings reveal that seabirds exhibit an optimal temperature range for thriving, with a clear Gaussian distribution of observations relative to SST. Non-migratory birds showed higher average SST preferences compared to all species combined. In addition, we also observed a significant positive correlation between bird abundance and fish caught, likely driven by nutrient-rich upwellings in heavily fished areas. This result suggests that overfishing can pose significant risks to seabird populations by reducing fish density and food resources. These include reduced prey availability, bycatch mortality, and nutrient-deficient discards that harm seabird populations. This study highlights the need for improved fishing practices and climate mitigation efforts to preserve seabird populations and their ecosystems.

Introduction

In recent decades, seabird populations along the Alaskan coast have been rapidly declining, fueled by anthropogenic climate change and other related factors. While most Seabird species tend to live in a certain temperature range, this range is being stretched due to increasing sea-surface temperatures fueled by climate change (Yang et al. 2023), leading to effects such as changes in bird migration and breeding patterns, as well as spreading of diseases such as avian influenza (Prosser et al. 2023). Birds that seek snow cover have also shifted their habitats, leading to more invasion and negative interactions with humans and urban areas. Shifting patterns in seabird migration patterns have resulted in many negative effects on the environment and other animal species (Brown et al. 2023). Knowledge of climate change has led to policies such as the Anchorage Climate Action Plan to be enacted, however greater knowledge of the exact causes of declining Seabird rates is still unknown. The impacts of overfishing are also extensive, with fishing vessels causing disturbances in feeding areas and causing depletion of local food stocks, as well as the tangling of birds in fishing gear and picking up floating debris (Tasker et al. 2000).

This study analyzes how sea surface temperatures and the amount of fish caught are related to the population abundance of common seabird species along the Alaskan coast. Changes in climate patterns and overfishing can impact fish populations and vegetation among other factors, and this extends the range maps of all of these species. We predicted that each species of bird that we studied would have an optimal temperature range and increases or decreases from the ideal temperature would lead to decreased species abundance. We also predicted that the total number of fish caught should contribute positively to bird population abundance as an increase in fish caught indicates an abundance of food sources available for the seabirds. Results of the study can help better understand the factors that affect Alaskan Seabird populations and better address the issue before these birds go extinct.

Materials and Methods

Study Area and Study Species

Seabirds are a good study system to understand the effects of temperature and fishing on the ecosystem, as slight changes in any weather or food patterns can affect Seabird populations which also means that other species in the ecosystem are also being affected. We examined bird observation data from the International Pacific Halibut Commission (IPHC) stock assessment surveys from 2002-2011 which provided us with 33,174 observations with dates, species names, longitudes, and latitudes. The survey gathered data with standardized protocols from research vessels at every station, and trained samplers would identify the bird species within a 50-meter radius of their station base. The number of participating stations varied from a low of 1,218 to a high of 1,284 per year and this gives us a large study area for which we can identify any trends. Additionally, the use of trained samplers in the IPHC survey gives us more research-grade data compared to other citizen scientist datasets with more records such as eBird or iNaturalist. We then cleaned the data by removing unidentified species and removed all observations for species with less than 100 recorded observations to account for irregular trends.

The primary birds used in the study include Northern fulmar (*Fulmarus glacialis*), Black-footed albatross (*Phoebastria nigripes*), Sooty shearwater (*Puffinus griseus*), Fork-tailed storm petrel (*Oceanodroma furcata*), Glaucous-winged gull (*Larus glaucescens*), Leach's storm petrel (*Oceanodroma leucorhoa*), Short-tailed albatross (*Phoebastria albatrus*), Short-tailed shearwater (*Puffinus tenuirostris*), Black-legged kittiwake (*Rissa tridactyla*), European herring gull (*Larus argentatus*), and Laysan albatross (*Phoebastria immutabilis*). All the birds are considered migratory except F. glacialis, L. argentatus, L. glaucescens, and O. Furcata which mostly migrate occasionally to breeding grounds and migration numbers tend to be highly variable. All the birds listed are also opportunistic feeders, and fish consists of a major part of their diet except for L. argentatus and L. glaucescens which also scavenge on other plant and animal matter.

Data Collection

To match species observations with temperature records, we used the NOAA OI SST V2 High Resolution Dataset data provided by the NOAA PSL, Boulder, Colorado, USA, from their website at https://psl.noaa.gov, which provided daily values of sea-surface temperature for our desired time period. We matched each temperature and observation records to the nearest 0.25 degrees latitude and longitude which makes it very precise, and were able see a peak in observations at certain temperatures. We were also able to match every bird observation to a temperature record without any discrepancies.

To match bird observations to data on fish abundance, we obtained data from the NOAA Fisheries Longline Survey Station dataset for 2002-2011 which contained data primarily for pacific cod, giant grenadier, pacific halibut, shortspine thornyhead, rougheye rockfish, and shortraker to estimate fish abundance; it’s used to predict population estimates and trends which are presented to the North Pacific Fisheries Management Council (NPFMC) for setting annual fishery quotas. Thus, areas with higher fishing quotas should lead to a higher number of fish caught, indicating that more fish are present in the area.

Data Analyses

To match bird observations with fishing survey data, we merged both datasets by their recorded years and then matched their respective latitude and longitude coordinates to the nearest fishing catch data coordinates using a Scipy cKD Tree. We then filtered our results to only include matches within 0.1°, or approximately 11 kilometers. While the fishing catch survey did not contain the day or month of any given catch, the entire groundfish survey was conducted from June 1 to August 28 ensuring that results would be fairly consistent throughout the study, as most fish migration patterns, and specifically Pacific Cod, undergo seasonal migration from winter spawning areas to summer foraging areas in the middle of March (Bryan et al. 2021). We then plotted the resulting matched data points using a Matplotlib scatterplot and used NumPy Polyfit to calculate the best-fit line with linear regression. To evaluate the relationship between the total number of fish caught and bird observations, we used the Statsmodel package to generate an OLS Linear Regression test.

To match bird observations NOAA daily sea-surface temperature records, we rounded each temperature data coordinate the nearest 0.25 degrees latitude and longitude and matched it with seabird observation data points into a single Pandas Dataframe. After plotting the matched points on a Matplotlib scatterplot, there was a clear normal distribution with observations for each individual bird species having a peak at a certain point. To calculate a best fit !(#!$)& curve, we used a Gaussian function: $f(x) = a\,e$ &'& as most bird species tend to have an "optimal" temperature range in which they thrive. To evaluate the curve fit, we used Scikit-learn to determine the r squared and p values for each fit. Additionally, the temperature (x-value) with the most matched bird observations according to the best fit line was annotated as it is considered the most optimal temperature according to our predictions. The temperature of the annotated arrow was then displayed beneath the figure for all the species collectively and each individual species as well. These analyses were performed in Python 3.8.17.

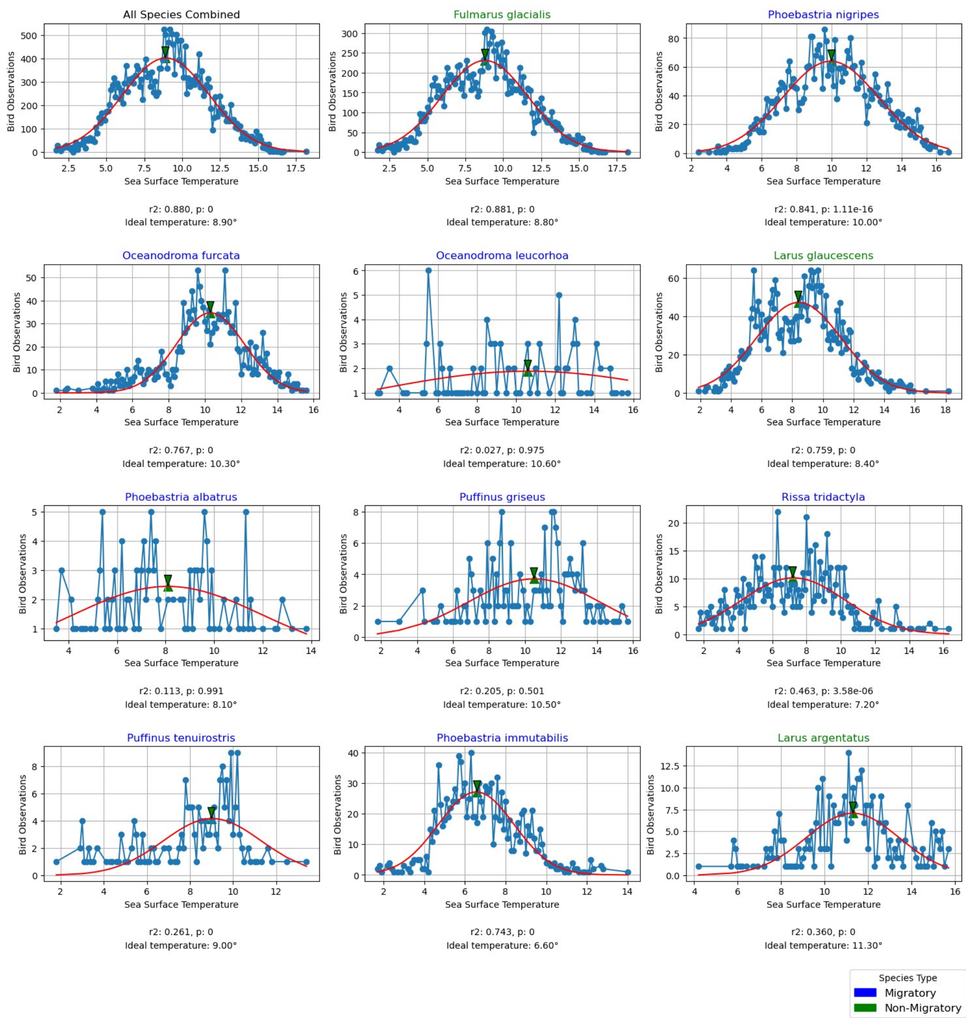

Figure 1. The changes in seabird population abundance in relation to sea surface temperature (C). The blue dots and line represent a data pair matched between bird observations and temperature data; The red line represents a best fit curve using a Gaussian curve fit; Green triangle represents the point with the highest number of bird observations. R-square and P value for each best-fitted line is indicated below each species' panel.

Results

Almost all seabird species follow a bell-shaped distribution with SST and have an ideal temperature region where they thrive. For all species combined, the data follows a Gaussian fit (Figure 1; $r^{!}$= 0.880; P < 0.001) whereas other species such as *O. Leucorhoa*($r^{!}$= 0.0207; P = 0.975) tend to have a poor fit due to a lack of observations present. Other migratory species such as *R. Tridactyla* ($r^{!}$= 0.463; P < 0.001) are migratory birds which only go to Northern Islands and the mainland for nesting, and this greatly affects its temperature range as most observations would be during nesting. Additionally, the average optimal sea surface temperature of non-migratory birds (T = 9.70°) appears to be higher than that of all species combined (T = 8.90°) but was not statistically significant (t-test P = 0.381) . There is a significant positive linear relationship between fish caught and bird abundance (Figure 2; Adj $r^{!}$ = 0.017; P = 0.03).

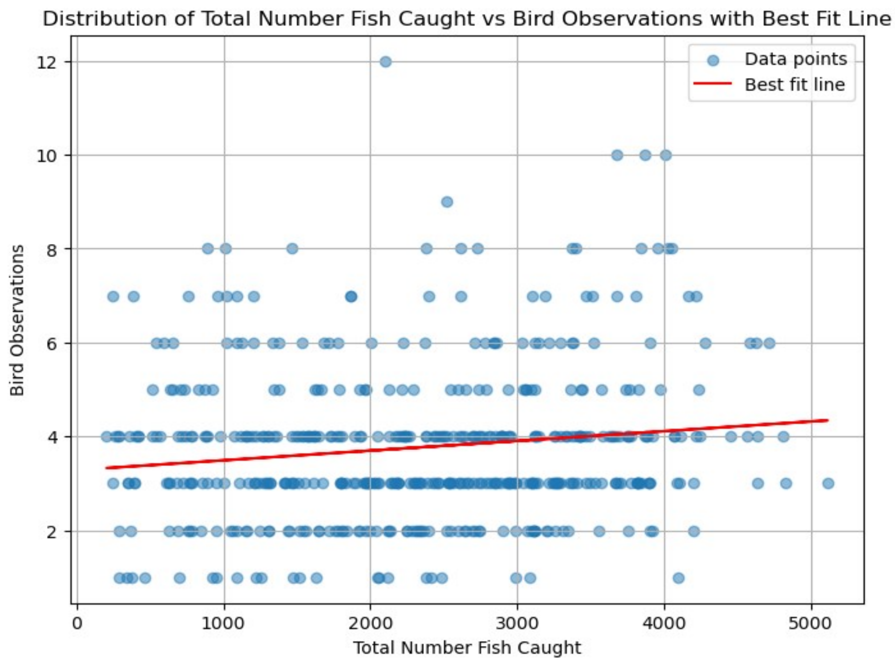

Figure 2. The changes in seabird population abundance in relation to the total number of fish caught. Each blue dot represents a data pair matched between bird abundance and fish abundance data. The red line is the best-fit line using linear regression.

OLS Regression Results

Dep. Variable: gbifID R-squared: 0.019
Model: OLS Adj. R-squared: 0.017
Method: Least Squares F-statistic: 9.158
Date: Thu, 17 Oct 2024 Prob (F-statistic): 0.00261
Time: 20:31:25 Log-Likelihood: -934.35
No. Observations: 487 AIC: 1873
Df Residuals: 485 BIC: 1881
Df Model: 1 Covariance Type: nonrobust
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coef std err t P>|t| [0.025 0.975]

Intercept 3.2827 0.176 18.682 0.000 2.937 3.628
Total Number Fish Caught 0.0002 6.840e-05 3.026 0.003 7.267e-05 0.000

Omnibus: 95.771 Durbin-Watson: 1.762
Prob(Omnibus): 0.000 Jarque-Bera (JB): 177.108
Skew: 1.117 Prob(JB): 3.48e-39
Kurtosis: 4.932 Cond. No. 6.03e+03

Table 1. OLS Regression Test Results for Figure 2. Important statistics for the relationship between the total number of fish caught and bird observations.

Discussion

Overfishing can lead to a seabird decline in the future by reducing the availability of food sources available to seabirds. Additionally, most migratory seabirds feed on forage fish such as sandeel, krill, and crustaceans which are also commonly fished. Fisheries also produce millions of tons of discards each year, and while this discard has the potential to lead to population growth for generalist species such as F. glacialis and Morus bassanus, it often contains harmful metals and can be lacking in nutrients compared to the regular diet of a seabird (demersal species lacking fat). Overfishing also poses a risk to seabird abundance through the risk of bycatching, and the effects of long-line fishing in particular on albatross and petrel species (Votier et al. 2023). Given that seabird diet consists of more than just fish, and the fish data used consists of just major groundfish species surveyed from the Eastern Bering Sea, Aleutian Islands, and the Gulf of Alaska, many other factors can also affect this relationship. Although the relationship is weak, areas that are more heavily fished tend to have more food available for birds. These areas are often in upwelling zones and are nutrient-rich, allowing prey species (such as crustaceans, krill, zooplankton, and other invertebrates) of seabirds to thrive (Benoit-Bird et al. 2019). Additionally, some seabirds such as the *L. argentatus* are often found near human settlements and fishing towns during nesting and other periods of life because urban settlements are advantageous for their survival, and this also increases the strength of the relationship.

Overall, we see that all seabirds tend to have an optimal temperature range in which they thrive and that the average temperature of non-migratory birds was not significantly greater than that of all seabird temperatures averaged. Considering the average sea surface temperature of Alaska which varies from 5° to 15 °C (Danielson et al. 2022), we see that *L. argentatus* specifically falls outside of that range. *L. argentatus* is also known to have a range map across the United States, and observations likely included large areas with different climates as the species is hardy. Given most birds are either migratory or migrate to islands for nesting, this affects the data to be studied, as more observations would be from areas with nesting sites clustered with birds and these sites usually are South of the Gulf of Alaska, where waters tend to be warmer. Overall, many factors can be associated with the trend in average sea surface temperature seen.

We also found that areas with a high number of fish caught tend to have more bird observations, and this is likely due to the increased presence of nutrients from phenomena like upwelling which allows more fish populations for trolleys and seabirds alike. The relationship between fishing and seabird abundance produces a positive trend. This indicates that long-line fishing, bycatch, and discards will likely ultimately lead to a decrease in seabird populations as well.

This study underscores the significant relationship between climate change, overfishing, and seabird population dynamics along the Alaskan coast. The findings show that seabirds thrive within specific temperature ranges, with non-migratory species showing higher optimal SST preferences than all species combined. While heavily fished areas can be beneficial through increased nutrient availability, the long-term impacts of overfishing—such as prey depletion, bycatch, and discards—pose significant threats to seabird survival, emphasizing the urgent need for sustainable fishing practices and climate policies to be enforced in order to reduce these risks.

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