An Analysis of Prey Selection in Brandt's Cormorants:

A three year study of foraging on Alcatraz Island

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Abstract

We assessed prey consumption and foraging strategies of Brandt's Cormorants, *Phalacrocorax penicillatus*, in the San Francisco Bay Area. Our study site was located on Barker Beach, Alcatraz Island where sampling was conducted over a three-year period (2003, 2004, and 2005). Using pellet samples and otolith identification, we found no significant difference in the diversity of species consumed from 2003-2005 (ANOVA). Through the use of the Shannon-Wiener's Index we found an increase in the diversity of prey consumed (2003: 0.5715, 2004: 0.9354, and 2005: 1.0853). The location of foraging shifted significantly (X^2=74.62; d.f. 4; X^2_{crit}= 9.49) from primarily bottom feeding to a more generalized strategy. Changes in the diversity of prey species, as well as cormorant foraging strategies, may be a consequence of decreased upwelling and declining fish species diversity and abundance in the San Francisco Bay. The information gathered from these analyses may be particularly important in monitoring cormorant population dynamics and the status of multiple trophic levels within an ecosystem.

Introduction

The San Francisco Bay is home to several fish species, including those that are commercially important such as Pacific Herring, Striped Bass and English Sole. The Bay Institute (2003)**,** in conjunction with the California Department of Fish and Game, periodically surveys the San Francisco Bay's fish community using trawls to determine the abundance and diversity of fish species. Reports from 1980-2001 stated that the abundance of native fishes within the Bay decreased dramatically and that fish diversity in the Bay fluctuates between peaks and troughs (TBI 2003).

Resident seabirds subsist on the fish populations present within their home range, especially during breeding seasons. Thus, analyzing the diet of seabirds may prove to be a useful means to monitor the abundance and diversity of fishes within the Bay. There are several methods used to assess the diet of sea birds. Some include: observing birds feeding in the wild, inducing regurgitation, analyzing bird carcasses, and dissecting stomach contents by flushing out the food inside bird stomachs (Johnstone et al 1990). Another method focuses on examining naturally regurgitated bird pellets. Some seabirds produce mucus covered pellets for parasite control (Ainley et al. 1981) and to remove non-digestible parts of prey, such as otoliths, from their stomachs (Johnstone et al. 1990). Also known as sagittae, otoliths are calcareous components of the fish's middle ear. They are typically oval and longitudinally flattened, but vary according to fish species and size. Because of the species-specific shape of otoliths, many scientists have used them as a means of identifying seabird diet.

Each of the methods used for seabird diet analysis have limitations and biases. Inducing regurgitation can prove detrimental to the health of seabirds and bird carcasses do not occur regularly. Furthermore, several of these methods can be financially costly and pellets may bias the results toward larger fish. Pellets, however, can be easily collected with the least amount of disturbance to seabirds and are highly abundant in a colony setting. They are also inexpensive and contain otoliths, as well as other hard parts, that make possible the identification of fish species (Voitier et al. 2002). For these reasons, bird pellets have become increasingly preferred for diet analysis, determining species diversity and relative fish abundance (Johnstone 1990, Voitier et al. 2002).

For the purposes of our study we focused on Brandt's Cormorants: deep diving, benthic foragers that spend the majority of their foraging time submerged. Although deep diving is energetically costly, prey profitability increases exponentially with dive depth (Wilson and Wilson 1988). Cormorant diet and foraging strategy vary depending on fish availability. This variation can be analyzed through the use of cormorant pellet dissection. Most cormorants produce one pellet daily either in the early morning or the evening, but the frequency of pellet production varies. (Johnstone et al. 1990). Therefore, pellet samples are equivalent to stomach samples in cormorants and can provide us with information on the composition of cormorant daily diet (Johnstone et al. 1990).

We expect that using pellets as a dietary reference will allow us to assess cormorant foraging and prey consumption. Specifically, we predict the number of fish species consumed by cormorants will increase as a result of a decreased abundance in fish at the San Francisco Bay (TBI 2003). This study can provide valuable information for conservation efforts. For example, analysis of cormorant diet can be applied to both the health of the cormorant population as well as the overall stability of the ecosystem (Wilson and Wilson 1988).

Methods & Materials

We analyzed possible changes in foraging and prey consumption through the dissection of Brandt's Cormorant pellets. Over a period of three years (2003-2005) pellets were collected each September at Barker Beach on Alcatraz Island in San Francisco, CA. All samples were taken from the same month for each year of the study to account for temporal variation in feeding behavior. This study consists of four main components: pellet collection, pellet dissection, otolith identification and analysis.

Study Site and Pellet Collection

Our study site on Alcatraz Island in San Francisco, California, was chosen due to the large colony of Brandt's Cormorants located on Barker Beach. Marine ecologists from the Point Reyes Bird Observatory (PRBO) collected 15-20 wet and dry pellets from Barker Beach each year in September, after the breeding season. It is important to collect after the breeding season because nesting cormorants are highly sensitive to disturbances. PRBO ecologists divided the site into four sections (North, South, East, and West) to ensure that pellet samples were random and representative of the population within the site. They stored pellets in Whirl-paks marked with the date, site, bird species, and sample number.

Pellet Dissection

Only dry pellets were dissected in this study. We removed the pellets from their Whirl-paks and soaked them in jars of water for 48 hours prior to dissection. Soaking pellets in water allowed us to easily sift through the highly compacted pellet material. We transferred all labeled information from the Whirl-paks onto the soaking jars for identification purposes. Upon

rehydration the pellet contents were poured into a 0.05 mm sieve and, through the use of forceps, we extracted otoliths and other hard parts. These hard parts were stored in a separate vial and labeled for future use by PRBO Conservation scientists.

Otolith Identification

We placed the otoliths from a pellet onto a Petri dish and examined them under a 2X dissecting scope. We grouped similar shaped otoliths for species identification using the PRBO reference collection and otolith photos from Harvey et al. (2000). If possible, we determined handedness (right and left otoliths) of similarly sized otoliths to account for individual fish. We recorded the number of left, right, or partial otoliths for each species on our data sheet. From this information we determined the total number of fish species present in the pellet sample and recorded any relevant notes. We transferred identified otoliths onto labeled archaeological slide(s)**,** separating species into different compartments.

Statistical Tests

We applied several types of statistical tests to analyze our data. We used an ANOVA Post-Hoc: Tukey Test in SYSTAT 10 (2003) to determine if there were changes in the types of species present in cormorant pellets between 2003-2005. We calculated a Shannon-Wiener Index to evaluate possible changes in prey diversity contained in pellets, considering abundance. We then used a power analysis to conclude if our sample size of 12 was sufficient to yield a power of 0.8. We divided the water column into categories based on previous work by Ainley et al. (1981). Using these categories, we applied a X^2 Test to evaluate differences in the foraging location of cormorants across the years of our study.

Data Analysis and Results

We dissected four pellets for each of the three years of our study, totaling 12 pellets. We found 18 species: pacific sandlance, plainfin midshipman, speckled sanddab, night smelt, gopher rockfish, pacific sanddab, striped bass, sand sole, slender sole, butter sole, english sole, northern anchovy, flatiron herring, bay goby, padded sculpin, pacific tomcod, staghorn sculpin, and pile surfperch.

ANOVA: Estimate Model- Tukey Test

We used an ANOVA, Post-Hoc: Tukey Test in Systat (α= 0.05) to determine whether the number of fish species consumed significantly changed over the three year period in our sample of 4 pellets. Results indicate that the number of fish species did not significantly change from 2003-2005 ($F = 0.386$, $P = 0.702$). The values for the pair-wise comparison probabilities were: 0.977 between 2003 and 2004, 0.698 between 2003 and 2005, and 0.814 between 2004 and 2005.

Power Analysis

The power analysis for the ANOVA was used to determine if the sample size of the experiment was large enough to warrant significant conclusions regarding the overall population. A total sample size of 378 for all 3 years (or a sample of about 125 pellets each year) would be necessary to obtain a power of 0.80. Therefore, this study would require an additional 366 pellets to state with certainty that there is no difference in the number of species consumed by cormorants per year.

Shannon-Wiener Index

The Shannon's Index tested for the change in fish diversity considering their abundance over the three year span. The diversity of fish steadily increased during this time (2003: 0.5715,

2004: 0.9354, and 2005: 1.0853) (Figure 1). The highest diversity and abundance occurred in 2005 and the lowest in 2003.

X^2: Goodness of Fit

To determine whether there were differences in the distribution of the foraging location of Brandt's Cormorants**,** we categorized the species found in the pellets according to their habitat within the water column (Ainley et al 1981). Fish species were categorized as follows: Bottom dwelling - plainfin midshipman, night smelt, pacific sanddab, sand sole, bay goby, pacific tomcod, english sole, and speckled sanddab; Mid dwelling - pacific sandlance, striped bass, butter sole, flatiron herring, staghorn sculpin, and pile surfperch; and Surface dwelling - gopher rockfish, slender sole, northern anchovy, and padded sculpin.

We found a significant difference in the distribution of cormorant feeding locations across each year (X^2=74.62; d.f. 4; X^2_{criti}= 9.49). Although the X^2 Test determines whether there was a difference between distributions, it does not determine which year was different. Therefore, we assessed the percent distribution of Brandt's Cormorants**'** feeding locations. We found that in 2003 79.5% of the feeding took place on the bottom water column, while the percent of mid and surface feeding were equal (approximately 10%). In 2004, 61.2% of feeding took place in the mid water region, while surface feeding increased to 28.6% and bottom feeding was reduced to 10.2%. 2005 demonstrated a more equal distribution with approximately 33%, 44%, and 22% of feeding taking place in the bottom, mid, and surface locations, respectively (Figure 2).

Discussion

Our results indicate that the number of fish species consumed by cormorants did not significantly change between the years 2003-2005 (ANOVA). However, our diversity index demonstrates that the diversity of fish species eaten increased during this time (Shannon-Weiner's Index: 2003-0.5715; 2004-0.9354; 2005-1.0853). Once fish species were categorized by habitat, we determined yearly differences in percent distribution of foraging in bottom, mid and surface strata (X^2=74.62; d.f. 4; X^2_{crit}= 9.49). Foraging strategy shifted from bottom feeding in 2003 to mid water feeding in 2004, and a more generalist strategy in 2005.

Changes in the diversity of prey species, as well as cormorant foraging strategies, may be a consequence of decreased upwelling and declining fish species diversity and abundance in the San Francisco Bay. The onset and intensity of coastal upwelling are critical factors influencing the productivity and structure of marine ecosystems (Schwing et al. 2005). Declines in upwelling between 2003 and 2005 had a bottom-up affect that limited food availability for higher trophic levels (JISAO 2005; Schwing et al. 2005). An increased limitation of food availability may have lead to our observed shift in cormorant foraging location.

If cormorants are unable to meet their metabolic needs by foraging where they have an adaptive advantage, their foraging strategy may shift to a more general approach. The shift from bottom to mid-water foraging between 2003 and 2004 exemplifies this relationship. Higher upwelling levels in 2003 (JISAO 2005) resulted in greater fish abundance (TBI 2003), which corresponds with the bottom feeding observed in our study. This behavior is typical of cormorants under normal foraging pressures. The decline in upwelling during 2004 correlates with a shift toward mid and surface water feeding. Furthermore, unusually low levels of upwelling in 2005 (JISAO 2005) may be responsible for the increase in surface foraging (Figures 2 and 3).

The Bay Institute (2005) found a decline in species diversity and abundance between 2003 and 2004 (Figure 4). In contrast to this decline, we observed an increase in the diversity of

prey species consumed. We believe this is an adjustment of cormorant foraging strategy that enables them to utilize resources from a broader range of the water column, thereby encompassing a greater diversity of prey species.

We recognize several potential confounding factors in this study. First, the use of otoliths as an accurate representation of cormorant diet is not entirely reliable. Johnstone et al. (1990) found that otoliths can be completely digested in cormorant stomachs, skewing species consumption analysis. As a result, our data may not include all fish species consumed. However, species-specific otolith degradation allows for consistency of this sampling bias throughout our study. Second, partial digestion of otoliths can make the process of species identification difficult. Therefore, we did not include partial otoliths in our analysis. Third, our inexperience with otolith identification may have resulted in inaccurate species classification. To control for this, we used several sources to identify otoliths, which included two species identification books and an otolith reference collection (Harvey et al. 2000). Furthermore, a group consensus was established for all species in question.

To evaluate long-term trends in cormorant diet, future studies should encompass a broader range of years and include a larger sample size. Further assessment of cormorant pellets may allow for multiple applications, including comparisons between trends in cormorant diet and both abiotic and biotic factors (Ainley et al. 2004). The information gathered from these analyses may be particularly important in monitoring cormorant population dynamics and the status of multiple trophic levels within an ecosystem.

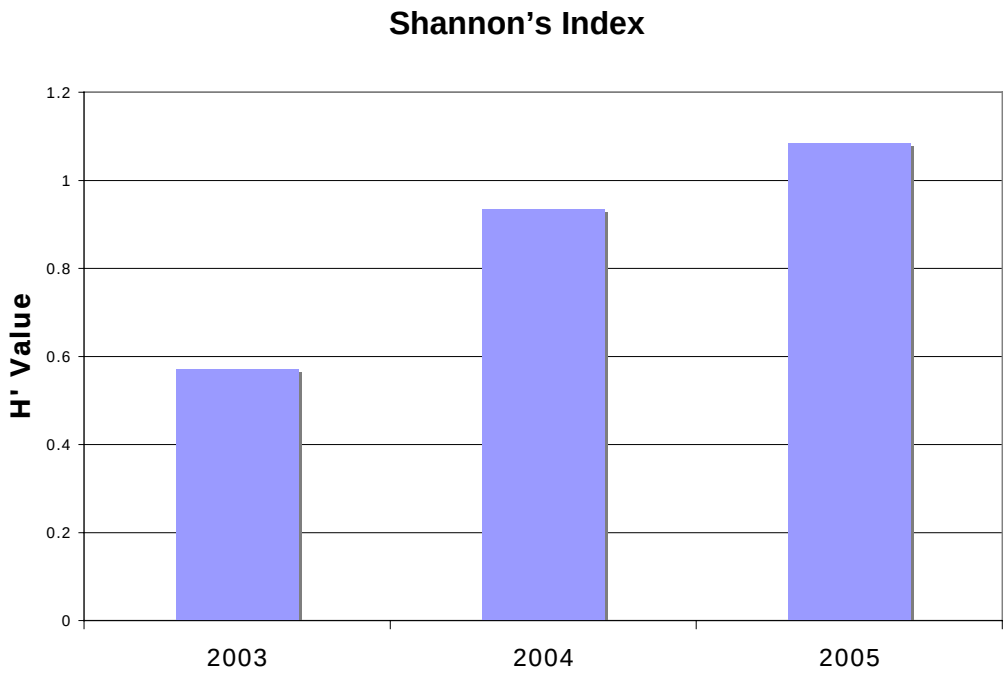
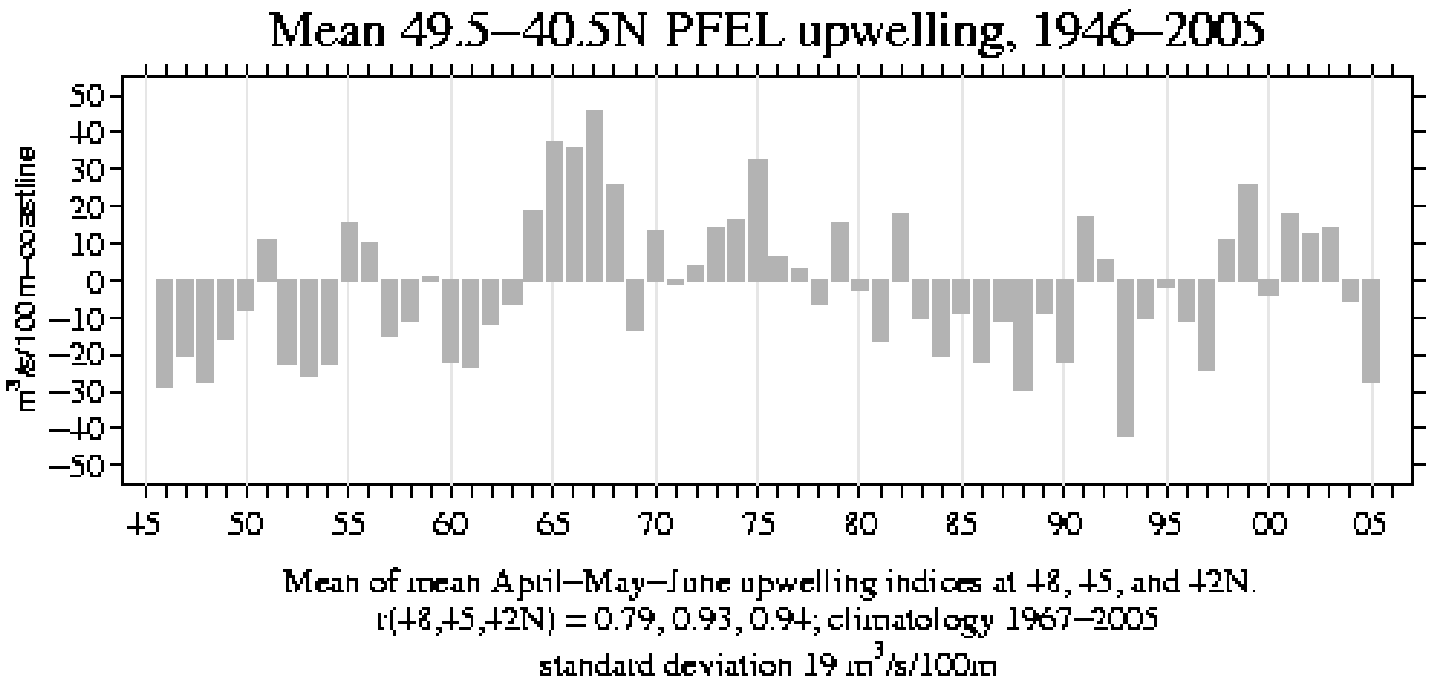


Figure 1. This graph indicated the Shannon's Index values for the years of our study. 2003: 0.5715, 2004: 0.9354, and 2005: 1.0853.



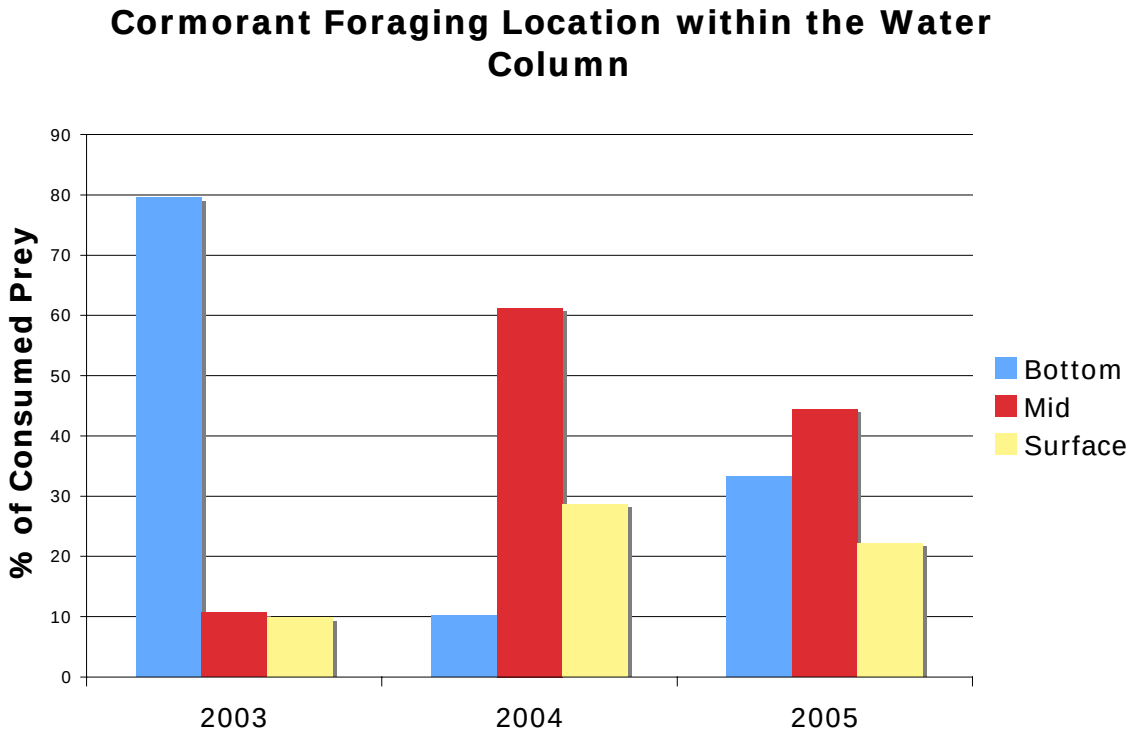


Figure 2. Percent prey consumed per year based on foraging location within the water column.
Figure 3. This graph was taken from the JISAO 2005 report.

Percentage of Fish Abundance and Diversity in the San Francisco Bay between 1980-2004

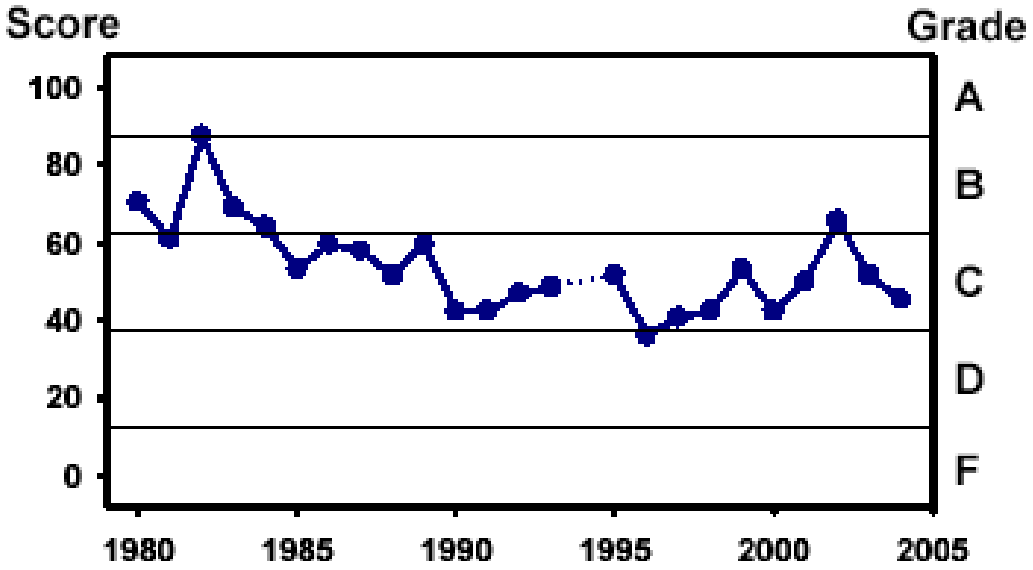


Figure 4. This graph was originally published in TBI (2005). The fish index uses four indicators and species composition of the Bays native fish community to measure fish diversity and abundance.

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