FEEDING HABITS AND THE EFFECTS OF PREY MORPHOLOGY ON PELLET PRODUCTION IN DOUBLE-CRESTED CORMORANTS, *PHALACROCORAX AURITUS*

A Final Report of the Tibor T. Polgar Fellowship Program

Colin Grubel

Polgar Fellow

Biology Program
CUNY Graduate Center and Queens College
New York, NY 10016

Project Advisor:

John Waldman
Biology Department
Queens College
Flushing, NY 11367

Grubel, C. and J. R. Waldman. 2009. Feeding habits and the effects of prey morphology on pellet production in Double-crested Cormorants, *Phalacrocorax auritus*. Section VIII:1-28 pp. *In* S.H. Fernald, D. Yozzo and H. Andreyko (eds.), Final Reports of the Tibor T. Polgar Fellowship Program, 2008. Hudson River Foundation.

ABSTRACT

The contents of pellets and boli collected from the New York Harbor population of Double-crested cormorants, *Phalacrocorax auritus*, were analyzed for species composition to investigate possible biases associated with use of cormorant pellets for diet studies. During the breeding and chick-rearing seasons, boli and pellet samples were collected from three island colonies, Hoffman, Swinburne and South Brother. Comparison between the two largest colonies, Swinburne and South Brother, generated a Schoener Index value of 0.337, indicating a medium level of dietary overlap . The most common species found in the boli were black seabass, *Centropristis striata* (14.4%), and scup, *Stenotomus chrysops*, (12.9%). Neither of two local species with conservation concerns (striped bass, *Morone saxatilis*, and winter flounder *Pseudopleuronectes americanus*) made up a significant portion of the diet. The samples were also analyzed to examine a possible bias in pellet production associated with the spininess of prey species. Ninety-five percent of species found in pellets were spiny compared to 63% in the boli. This and other evidence suggest that spininess of prey species is a factor affecting their representation in pellets. Other morphological factors such as prey size and otolith morphology were shown to be unlikely to account for the observed differences in species makeup; however, boniness is one morphological factor which could not be eliminated. Even so, the evidence for the effect of prey spininess on pellet composition remains strong. Future research including is recommended to further investigate the issue.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

INTRODUCTION

The Double-crested Cormorant, *Phalacrocorax auritus*, is a large, colonial waterbird that catches its prey through foot-pedaled pursuit diving (Carss 1997). Most of their hunting is restricted to shallow waters less than 8 m deep and within 30 km of their roosts (Hatch and Weseloh 1999). This research was conducted on the Double-crested Cormorant population of New York Harbor, which has been growing and breeding since its appearance in 1984 (Parsons 1987). Their numbers have flourished locally during the last three decades with the 2008 breeding population consisting of over 1300 pairs spread out among seven colonies (S. Elbin, NYC Audubon, personal communication). The subspecies found in New York Harbor area is *Phalacrocorax auritus auritus* (Hatch and Weseloh 1999).

Cormorants primarily eat schooling and bottom-dwelling fish, and invertebrates (Hatch and Weseloh 1999), a diet which often leads to conflict with humans, particularly commercial and recreational fishermen. The only way to determine whether a local population is exploiting the same resources as humans is through studies of their diet. Diet studies on cormorants have been numerous, with results varying by area and approach. While some studies have found that the local cormorant population depleted fish populations sufficiently to warrant cormorant population control (Collis et al. 2002; Johnson et al. 2005; Rudstam et al. 2004), research in other locations found that the proposed threat posed by the local colony was exaggerated (Glahn et al. 1998; Somers et al. 2003; Withers and Brooks 2004).

There are three primary methods used to assess the diet of cormorants – direct stomach content analysis, identification of bolus contents, and identification of pellet contents. Stomach content analysis involves dissection of the gizzard and esophagus of dead birds (Derby and Lovvorn 1997). Bolus and pellet analyses both rely on studying regurgitated material. A bolus is a partially digested food item, usually regurgitated by young cormorants in response to disturbance, such as a perceived predator near their nest. Pellets are gelatinous sacs containing otoliths and other bones that can be used to identify the species of fish eaten. Otoliths – small, white structures found in the heads of all fishes other than sharks , rays and lampreys -- are used for hearing and balance, and are highly species-specific in morphology, making them useful to researchers for species identifications (Campana 2004). The most commonly used method is the dissection of pellets, which are popular for diet analysis because they greatly increase the number of food items identified, compared to boli, which often represent one food item in each bolus (Derby and Lovvorn 1997).

Sources of error associated with the use of pellets are well known. They can be damaged in the digestive processes, rendering them unidentifiable; smaller otoliths are especially susceptible to this which could cause some species to be underrepresented (Carss 1997). Damage from digestion can also lead to errors in estimating fish size (Carss 1997; Johnson et al. 2001). Secondary consumption, in which otoliths from the latest meals eaten by the cormorants' prey show up in the pellets, has also been shown to be problematic (Carss 1997). Despite these findings, little research has been performed on the process of pellet production and its effects on diet analysis. One such study found that European shags, *Phalacrocorax aristotelis*, a closely related species, produced pellets over the course of 1 to 7 days, with an average of 3.5 days (Russell et al. 1995), but many researchers still go by the older assumption of one pellet being produced per day (Derby and Lovvorn 1997; Johnson et al. 2001).

The hypothesis was tested that fish species with difficult-to-digest spiny fins (and other bony protrusions and large hard parts, such as the head plates of searobins, *Prionotus* spp.) would show up in pellets in higher proportions than those species with soft-rayed fins, relative to their proportions in the bolus samples. A possible cause of this hypothetical bias could be a protective response to the sharp nature of the spines themselves, prompting the birds' digestive tracts to encase the spines and other hard parts in pellets and eject them sooner than might otherwise occur. The specific goals of our research were to assess the dietary composition of the New York Harbor Double-crested Cormorant population, and to examine a possible artifact affecting the accuracy of pellets in such work. The first aspect of the study was an analysis of the local population's diet through the study of boli and pellets. Major questions were: (1) which species of fish the cormorants eat, and (2) in what proportions they eat these species. Also of concern was identifying to what extent, if any, they preyed on local species valuable to humans – striped bass, *Morone saxatilis* and winter flounder, *Pseudopleuronectes americanus*. The second aspect of the research was an investigation into the role of prey morphology on pellet production.

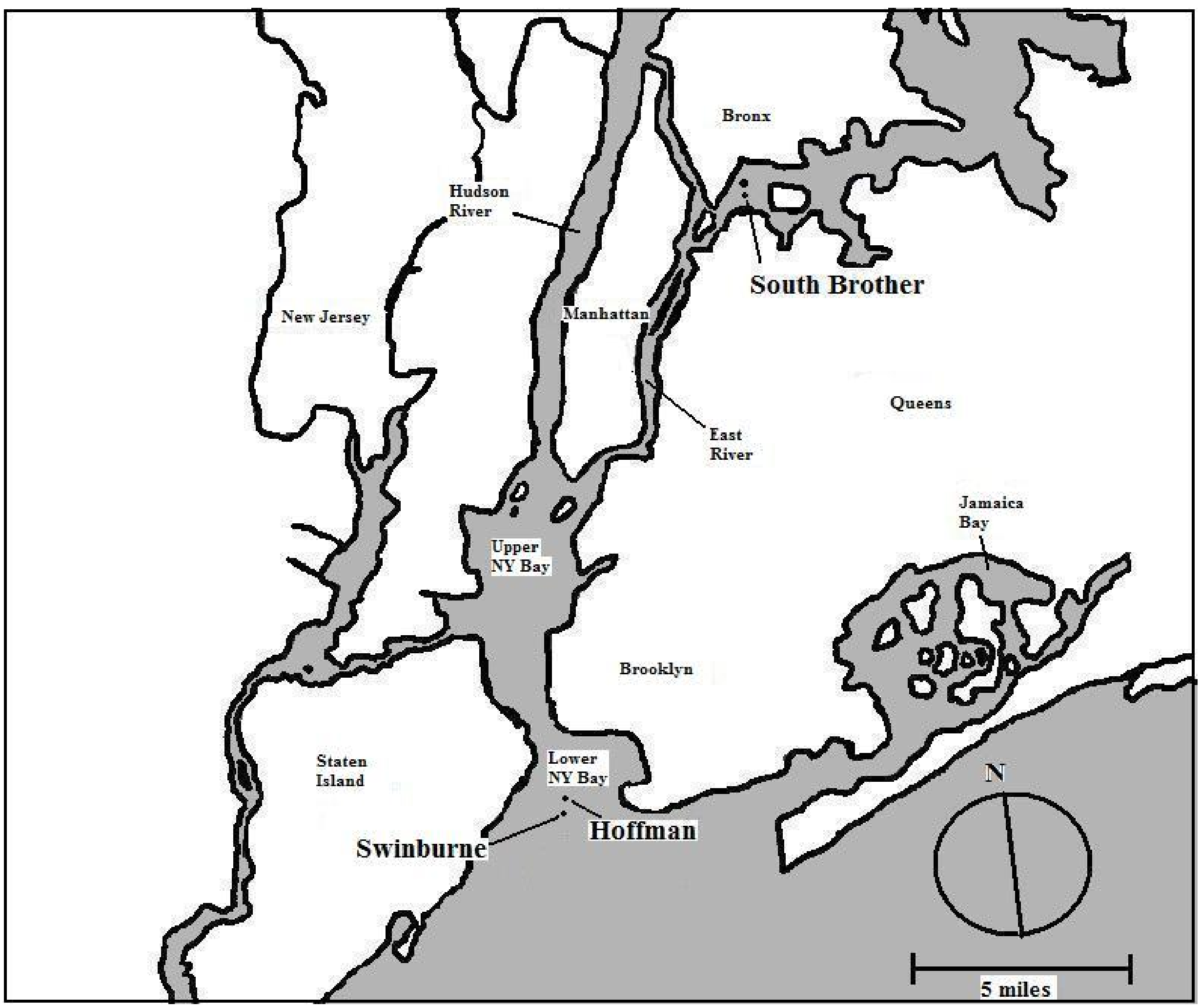
METHODS

Samples consisting of boli and pellets were collected between May and July 2008. Three islands were visited: Hoffman and Swinburne, located off the east coast of Staten Island, and South Brother, located in the East River between Queens and the Bronx

(Figure 1). Hoffman and Swinburne are man-made islands located in Lower New York Bay between Staten Island Brooklyn; both were completed in the early 1870's (Figure 1). Hoffman's four hectares are now devoid of the buildings that once stood on it, instead the island is covered in vegetation comprising 34 identified species (Seitz and Miller 1996, Bernick 2007). Cormorants were first recorded nesting on the island in 2002; today the colony is primarily located on the southern end of the island in a stand of black locust trees, *Robinia pseudo-accacia* (Bernick 2007). Construction of Swinburne Island was completed in 1870. There are still three buildings standing on the island, one without a roof, and the foundations of other buildings are also present. The cormorants have probably been nesting on the island since the early 1990's (Kerlinger 1998). Nests are found on the buildings as well as a group of black locusts and several other trees (Bernick 2007). South Brother Island is a naturally occurring 5 ha island located in the East River between the Bronx and Queens (Figure 1) (Seitz and Miller 1996, Parsons 1987). Covered in a dense canopy of trees, the islands flora are diverse with 27 species recorded in a survey conducted in 2007 (Bernick 2007). There is a large wading bird colony on the island, nesting, for the most part separate from the cormorant colony. The cormorants primarily inhabit the central portion of the island, nesting in a stand of black locust (Bernick 2007). Boat troubles throughout the season limited our access to the islands, particularly South Brother, which was only sampled twice. Swinburne was visited five times, and Hoffman was visited once.

The collected boli and pellets were stored in freezers for further analysis. Boli were weighed, measured and identified to the lowest taxonomic level possible. Pellets were dissolved in a solution of detergent and water before being dissected and examined for otoliths and other parts, which could be used to identify food items. When multiple otoliths from a species were found, the total number was divided in half to get the estimated number of fish present. Otoliths which showed a high degree of wear or which could not be identified with a high degree of confidence were listed as unknowns and excluded from further analyses.

Figure 1: Map of New York Harbor area, Hoffman, South Brother and Swinburne colonies indicated.



The composition of species between the two main colonies surveyed – Swinburne and South Brother – was examined using the Schoener index. This index can be used to quantify the dietary overlap of two species, and to compare the diets of neighboring communities of the same species (Schoener 1968). The diet of the South Brother colony was compared with the combined diets of the Swinburne and Hoffman colonies. The two samples collected from Hoffman were combined with those from Swinburne due to their low number (n=2) (Table 1), and the islands' close proximity of 1.1 km (Figure 1).

The Schoener Index is:

$$PSI_{xy} = 1 - 0.5\ (\Sigma|P_{xi} - P_{yi}|)$$

where Pxi is the proportion of species i in the diet of population x and
Pyi is the proportion of species I in the diet of population y.

Values can range from 0, indicating no overlap, to 1 indicating complete overlap.

The Shannon-Weaver Index was used to estimate the diet diversity as well as to quantify the difference in the diversity of food items as identified in boli and pellets. The formula is:

$$H' = -\Sigma\ P_i(\log P_i),$$

where P_i is the proportion of items of species i in the sample (Cortes et al. 2002). Diet diversity increases as the index increases.

Due to the similarities among the otoliths of the three herring species identified, the counts for those species were combined to avoid errors caused by misidentifications. It was likewise useful to group other closely related species together for the analysis. Due to decomposition of the boli due to digestion, several searobins could not be identified beyond the level of their genus, *Prionotus*; however, the morphologies of the two occurring species are similar enough that, for this analysis, identification down to the species level was deemed unnecessary. The same was also true of the hakes, genus *Urophycis*, and sculpins, genus *Myoxocephalus*. Cunner (*Tautogolabrus adspersus)*, and tautog (*Tautoga onitis)*, though not congeneric, were too similar in appearance to be identified down to species and were combined as the family Labridae. The final such grouping was for eel specimens that could not be identified as either American eels, *Anguilla rostrata*, or conger eels, *Conger oceanatus*; these species, though not congeneric, are nearly identical in morphology.

RESULTS

Over the field season, a total of 434 boli and 88 pellets were collected. Four of these were combinations of boli and pellets, each containing one bolus along with the normal pellet contents, and were removed from the comparison analysis. Of the boli, 402 were identified and included in the analysis. There were 32 species of fish and two species of crustacean identified in the boli (Table 1). In the pellets, all 88 samples were analyzed, with 249 food items were identified, comprising 17 fish and three crustacean species (Table 1). Species found included those associated with marine, freshwater, and estuarine environments. The most common species were black seabass (*Cetropristis striata)*, which made up 14.4% of the items identified in the boli and scup (*Stenotomus chrysops)*, which made up 12.9%.

Table 1: Species found in samples, numbers in parentheses indicate species identified in pellets, numbers outside parentheses indicate species identified in boli.

Species	Number		
Fish	South Brother	Swinburne	Hoffman
american eel, *Anguilla rostrata*	1	3	-
atlantic thread herring, *Opisthonema oglinum*	-	9	-
bay anchovy, *Anchoa mitchilli*	12	-	-
black seabass, *Centropristis striata*	2	55 (71)	-
blueback herring, *Alosa aestivalis*	-	1	-
bluefish, *Pomatomus saltatrix*	-	1	-
bluegill, *Lepomis macrochirus*	1	3 (2)	-
brown bullhead, *Amerius nebulosus*	1	-	-
conger eel, *Conger oceanitus*	-	5	-
cunner, *Tautogolabrus adspersus*	7 (6)	10 (20)	-
goldfish, *Carassius auratus*	1	-	-
grubby sculpin, *Myoxocephalus aenaeus*	1	15 (3)	-
gulf stream flounder, *Citharichthys arctifrons*	-	2	-
hogchoker, *Trinectes maculatus*	3	-	-
lined seahorse, *Hippocampus erectus*	-	1	-
menhaden, *Brevoortia tyrannus*	2	20 (2)	-
mummichog, *Fundlus heteroclitus*	22	24	-
northern pipefish, *Syngnathus fuscus*	4	-	-
northern searobin, *Prionotus carolinus*	-	16 (28)	-
oyster toadfish, *Opsanus tau*	3	12 (1)	-
pumpkinseed, *Lepomis gibbosus*	18 (10)	-	-
red hake, *Urophycis chuss*	-	1	-
rock gunnel, *Pholis faciata*	-	2	-
silverside, *Menidia sp.*	1	0	-

Table 1 (continued):

Species	Number		
Fish	South Brother	Swinburne	Hoffman
spotted hake, *Urophycis regis*	3	4	-
striped searobin, *Prionotus evolans*	-	17 (24)	1
summer flounder, *Paralichthus dentatus*	-	2	-
tautog, *Tautoga onitis*	-	9 (4)	-
weakfish, *Cynoscion regalis*	0 (2)	-	1
white perch, *Morone americana*	20 (17)	3 (1)	-
winter flounder, *Pseudopleuronectes americanus*	-	7	-
yellow perch, *Perca flavescens*	-	1	-
unidentified *Anguillaformes*	-	2	-
unidentified *Clupeid sp.*	-	1 (8)	-
unidentified *Labridae sp.*	1	4	-
unidentified *Myoxocephalus sp.*	-	2	-
unidentified *Prionotus sp.*	-	6 (4)	-
unidentified *Urophicys sp.*	-	5	-
Crustaceans			
blue crab, *Callinectes sapidus*	-	0 (2)	-
lady crab, *Ovalipes ocellatus*	0 (1)	0 (1)	-
sand shrimp, *Crangon septemspinosa*	2	0 (2)	-
crustacean sp.	-	0 (2)	-
Combined species			
Anguilliform sp. (american eel, conger eel, unidentified *Anguilliform sp.*)	1	10	-
Clupeid sp. (atlantic thread herring, blueback herring, menhaden, unidentified *Clupeid sp.*)	2	30 (10)	-
Labridae sp. (cunner, tautog, unidentified *Labridae sp.*)	7 (6)	19 (24)	-
Myoxocephalus sp. (grubby sculpin, unidentified *Myoxocephalus sp.*)	1	17 (3)	-
Prionotus sp. (nothern searobin, spotted searobin, unidentified *Prionotus sp.*)	-	39 (56)	-
Urophycis sp. (red hake, spotted hake, unidentified *Urophycis sp.*)	3	10	-

The Schoener Index value for the overlap between South Brother and the Swinburne and Hoffman colonies was 0.108, indicating a low amount of overlap. Slightly different results were obtained by analyzing boli and pellets separately. Looking at pellets only, the score remained low at 0.106, but the score derived from the bolus samples was higher, 0.337, indicating a medium level of overlap.

Bolus samples, comprising 33 species, showed greater diversity than pellets, which had 18 species (Table 2). Every species of fish identified in the pellets was also identified in the boli. There were 62 otoliths which could not be identified due to erosion. It could not be determined if some of these belonged to species not found in the boli. All of the otoliths in good condition were identified to species. The reverse trend was true of crustaceans – several were found in the pellets compared to one in the bolus samples.

Table 2: Proportions of spiny vs. non-spiny fish species in pellets and boli. Spininess column indicates whether each species is spiny or not; y = yes, n = no.

Species	Spiny?	P pellets	P boli
american eel, Anguilla rostrata	n	-	1.01%
bay anchovy, *Anchoa mitchilli*	n	-	3.02%
black seabass, *Centropristis striata*	y	30.09%	14.36%
bluefish, *Pomatomus saltatrix*	y	-	0.25%
bluegill, Lepomis macrochirus	y	0.88%	1.01%
brown bullhead, *Amerius nebulosus*	y	-	0.25%
conger eel, *Conger oceanicus*	n	-	1.26%
cunner, *Tautogolabrus adspersus*	y	8.85%	4.28%
goldfish, *Carassius auratus*	n	-	0.25%
grubby sculpin, *Myoxocephalus aenaeus*	y	1.33%	4.03%
gulf stream flounder, *Citharichthys arctifrons*	n	-	0.50%
hake sp.	n	-	1.26%
hogchoker, *Trinectes maculatus*	y	-	0.76%
lined seahorse, *Hippocampus erectus*	n	-	0.25%

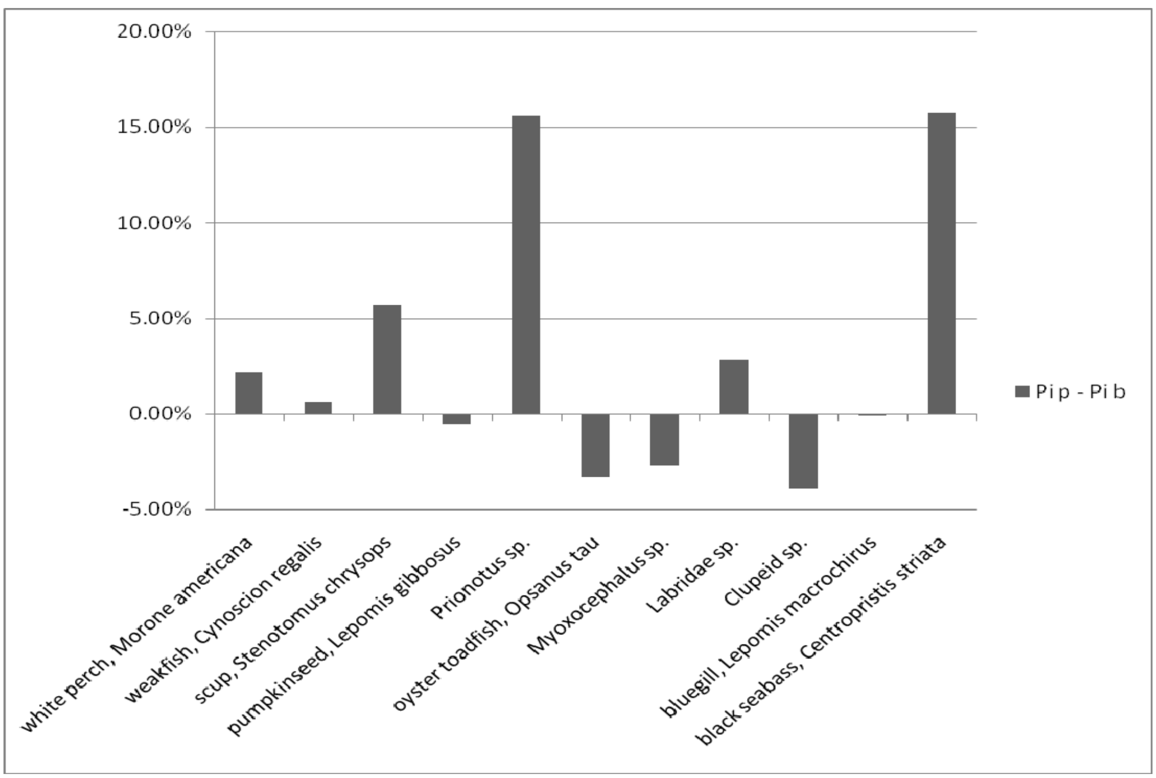
Table 2 (continued):

Species	Spiny?	P pellets	P boli
mummichog, *Fundlus heteroclitus*	n	-	11.08%
northern pipefish, *Syngnathus fuscus*	n	-	0.76%
oyster toadfish, *Opsanus tau*	n	0.44%	3.78%
pumpkinseed, *Lepomis gibbosus*	y	3.98%	4.53%
hake, red, *Urophycis chuss*	n	-	0.25%
rock gunnel, *Pholis faciata*	y	-	0.50%
sculpin sp.	y	-	0.50%
scup, *Stenotomus chrysops*	y	18.58%	12.85%
searobin sp.	y	1.77%	1.51%
searobin, northern, *Prionotus carolinus*	y	11.95%	4.03%
searobin, striped, *Prionotus evolans*	y	10.62%	4.53%
hake, spotted, *Urophycis regis*	n	-	1.76%
summer flounder, *Paralichthus dentatus*	n	-	0.50%
tautog, *Tautoga onitis*	y	1.77%	2.27%
weakfish, *Cynoscion regalis*	y	0.88%	0.25%
white perch, *Morone americana*	y	7.96%	5.79%
winter flounder, *Pseudopleuronectes americanus*	n	-	1.51%
yellow perch, *Perca flavescens*	y	-	0.25%
Combined species			
Anguilliform sp.	n	-	2.27%
Clupeid sp.	n	4.42%	8.31%
Labridae sp.	y	10.62%	7.81%
Myoxocephalus sp.	y	1.33%	4.53%
Prionotus sp.	y	25.66%	10.08%
Urophycis sp.	n	-	3.27%

Comparing the proportions of spiny and non-spiny food items in pellets, several important observations were made: 1) 11 of the 13 species found in pellets had spiny fins compared to the ratio of 14 out of 31 species found in boli (Table 2); 2) spiny fish species made up 63% of items identified in the bolus samples versus 95% of items identified in pellets; 3) every fish species which was found in the pellets with frequency of greater than 5% was spiny; and 4) when non-spiny species did occur in pellets, their relative frequencies were always less than their relative frequencies in the bolus samples. This trend was reversed for 5 of the 8 spiny species found in the pellets (Figure 2).

The biggest differences could be seen in black seabass which collectively increased 15.7% in relative frequency between boli and pellets, and the searobin species which collectively increased 15.6% in frequency in the same measure. The largest decrease could be seen in the clupeids which decreased 3.9%.

Figure 2: Differences in species proportions between pellets and boli. Columns indicate the difference in relative frequencies of fish species found in pellets (Pi p) versus their relative frequencies in the boli (Pi b). The non-spiny species listed are oyster toadfish and the clupeid spp.



DISCUSSION

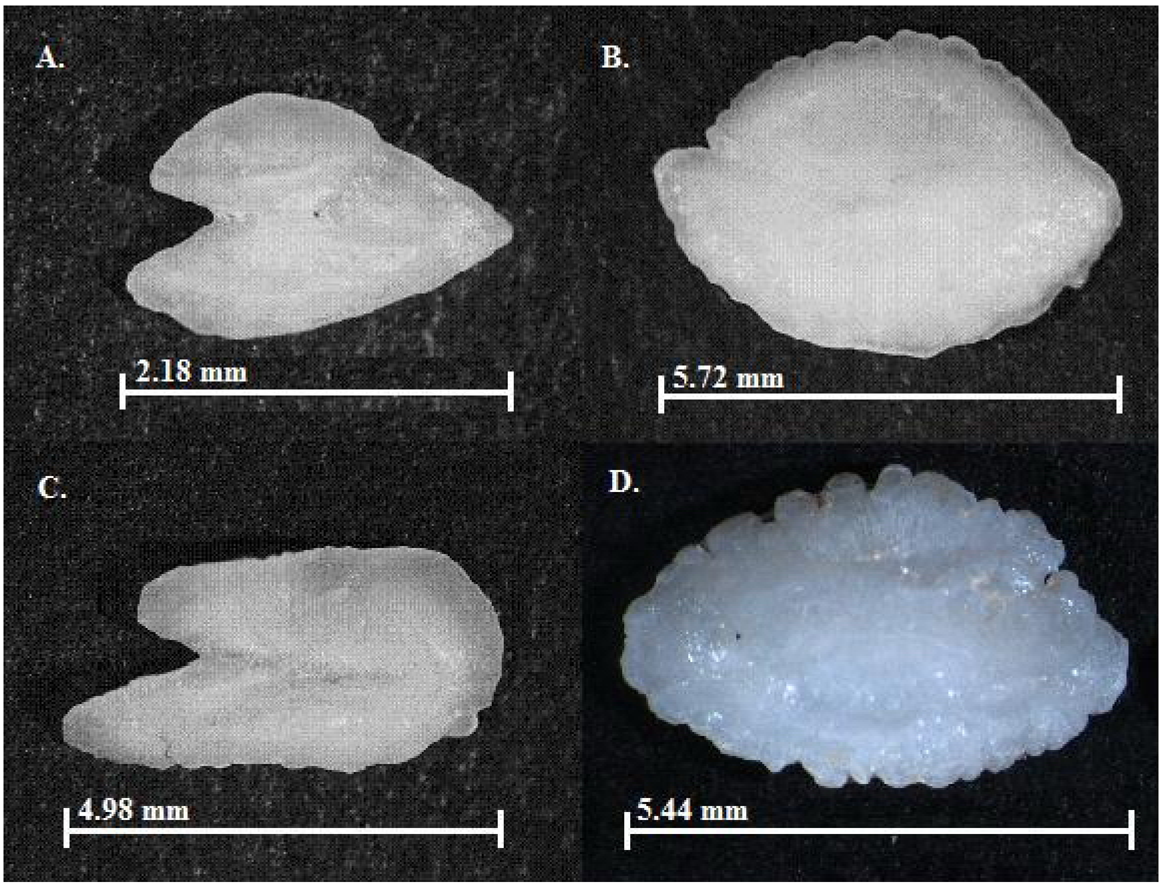
Comparison of Boli and Pellets

The species assemblages of the boli and pellets were very different, with boli being more diverse than pellets (Table 2). All fish species found in pellet samples were also found in the bolus samples while less than half of the species found in the boli were also found in the pellets. An important difference between the species which were common in pellets and those which were not, is that the former are spiny and the latter are not (Table 2). Previous studies have also shown that pellets do not represent all species equally, and that the time in which pellets are produced can vary greatly, (Casaux et al. 1995; Russell et al. 1995). Russell et al. (1995) showed that for shags, the age and sex of the birds did not affect pellet production, the only exceptions being the nestlings, which were not found to produce pellets. It was hypothesized that this was due to their having a more acidic gastric environment (Russell et al. 1995). The possibility that prey morphology could play a part in pellet production has been raised before but not well studied (Carss 1997, Caseaux et al. 1995). Three possibilities are fish size, otolith morphology and bone content (Carss 1997, Caseaux et al. 1995); of these, only otolith morphology has been previously studied (Johnstone et al. 1990, Caseaux et al. 1995).

Fish size is often mentioned as a factor that could affect the production of pellets (Carss 1997). The digestion processes render accurate estimation of fish size difficult for both pellets and boli (Carss 1997). The effects of fish size on pellet production are hard to quantify. Most boli are partially digested, and using them to estimate the sizes of the fish before digestion is problematic. Some soft-fleshed species are rarely found as intact boli. For example, all the hakes, genus *Urophycis*, found in 2008 were unrecognizable balls of flesh and could only be identified through the discovery of identifiable otoliths, skin or bones. Although accurate estimation of fish size is difficult, by using fairly complete bolus samples, it was shown not to be the major morphological aspect acting on pellet production. There were a few examples of this. Both herring species and oyster toadfish, *Opsanus tau* tended to be sizeable but rarely showed in the pellets, while cunner showed more frequently in pellets than boli, despite generally being smaller. Both mummichogs and grubby sculpins, *Myoxocephalus aenaeus*, are very small species, their average weights in the bolus samples being 4.5 g and 10.6 g, respectively, and yet sculpins showed up in the pellets three times while mummichogs never did (Table 1). This shows that observed differences cannot be easily explained by prey size, however additional research is needed.

Otolith morphology is another possible factor in species representation in pellets. Casaux et al. (1995) conducted a feeding trial involving the Imperial Cormorant, *Phalacrocorax atriceps*. Seven species of fish were fed to a captive bird, which was monitored for its rate of pellet production and how well the fish species were represented in the pellets. The researchers were able to show a large variation in the number of otoliths lost by different fish species. They hypothesized that the differences observed were due to differences in the morphologies of the otoliths but, because this was a preliminary study and their primary interest was in providing estimates in the correction of pellet analysis data for the local cormorant population, they did not actually provide much evidence to support their hypothesis. All seven species used in the trial were spiny, so it is not possible to draw conclusions on the importance of spininess from their data.

Figure 3: Otolith morphologies. Otoliths of different species have different shapes. Otoliths with thin projections might be more vulnerable to digestion than those compact in shape. Depicted are the otoliths of A) cunner, B) Atlantic thread herring, C) striped searobin, and D) oyster toadfish. Pictures are not to scale.



The feeding trial conducted by Caseaux et al. (1995) involved only one bird and was not comprehensive enough to truly answer the question. The study by Caseaux et al. (1995) involved only one bird and was not comprehensive enough to truly answer the question of how otolith morphology affects species representation in the pellets but it did lend support for the idea, and so it was considered here as well. The sizes and shapes of otoliths in the observed species varied greatly. Labrids have very small otoliths compared to the sizes of the fish and yet cunner otoliths often survive to be regurgitated in pellets. In addition, their shape is roughly similar to that of clupeid otoliths (Figure 3), which in this study were found in pellets less frequently than would be expected given the proportion of herring in the boli. In contrast, the large otoliths of striped searobins, *Prionotus evolans*, and oyster toadfish (Figure 3) are similar in size and shape and yet while striped searobins increased in frequency between boli and pellets by 4.5%, oyster toadfish decreased in frequency by 3.8%. This indicates that while otolith morphology can affect their survival in pellets, this is not enough to discount the affects of spininess.

The total bone content, and the size and shape of large bones of prey species is another possible morphological factor in pellet production. Data on the relative boniness on these species is not available, and will be explored in future research. The presence of soft-shelled crustaceans in the pellets is possible evidence of this, however. None of the five pellets containing soft-shelled crustaceans contained evidence of any other species. This could indicate that the pellets were ejected immediately due to the high load of indigestible material contained in these food items. More evidence of this was the presence of searobin skulls in the pellets. Searobins were the only species for which whole skulls could be found in the pellets. Their thick skulls along with the bony plates covering their heads could prove too much for the cormorant digestive processes, requiring them to be ejected in pellets faster than spininess alone would account for. Finally, the importance of crustaceans in the diet is probably overstated by the biases associated with pellets. Five of the crustaceans found in the pellets were soft-shelled forms of crabs or other crustaceans. The others were crabs very small in size (carapace width <10 mm) that likely were found as a result of secondary consumption, which has been shown to be a source of error with pellets (Blackwell & Sinclair 1995). Species such as blue crabs, *Callinectes sapidus,* are spiny, but the fact that all large individuals found in the pellets were soft-shelled lends evidence to another factor being responsible for their appearance in the pellets. Although the carapaces of these species were soft and often damaged beyond a point where species recognition was possible, there was always enough material left to fill a pellet, and it is likely that this lends support to the hypothesis that boniness is also an important factor in pellet production.

A further complication is the existence of empty pellets. While a number of pellets had nothing in them which could be used to identify prey species, two apparently intact pellets found were entirely empty, consisting only of the outer gelatinous coating. Their presence indicates that the factors influencing the production of pellets are more complicated than simply the morphology of the prey. It is known that young birds tend not to produce pellets (Derby and Lovvorn 1997), and one possibility is that pellet production is a process mediated in part by a bird's metabolism, hastened by the collection of hard material but occurring even without it.

Diet Analysis

Due to reasons discussed later in this section, an accurate picture of the birds' diet is easiest to obtain through consideration of bolus samples alone. For this reason, the analysis of the birds' general diet will cover the results obtained from boli only.

The diet of the local population, as indicated by the diets observed on the three islands visited, was shown to be broad, with a Shannon-Weaver Index value of 3.03.

This takes into account not only the number of species found but also the proportions of each species within the samples. The number of species and their evenness varied considerably by day, with Swinburne showing more diversity overall. However, the disparity between the number of visits to Swinburne and South Brother may account for the differences in estimates of diversity and species abundance.

Several species stood out as constituting a particularly large proportion of the diet. Black seabass was the most common species, making up 14.4 % of all food items identified. Scup was also frequent, making up 12.9% of boli. Other common species included mummichog, *Fundulus heteroclitus* (11.44%), Atlantic menhaden, *Brevoortia tyrannus* (5.5%), and white perch, *Morone americana* (5.8%) (Table 2). Raw proportions alone though, are not sufficient to understand the importance of different species in the local population's diet. For example, some species such as bay anchovy were present in large numbers (Table 1) but this is mediated by the fact that all the fish were contained in one aggregate bolus. With that taken into consideration, the species' estimated importance in the local diet or even in the diet of the South Brother colony diminishes.

Total species diversity did not change much over time, although the occurrence of particular species did. The main prey species identified, black seabass, scup, menhaden and the two searobins, were each present on four days, each only being absent from the samples collected on one of the two trips to South Brother where those species were not as common. The limited number of trips to South Brother makes accurate evaluation of temporal changes in prey impossible.

The Schoener Index value of 0.337 indicates that the two colonies partly overlap in their diets. Looking at the species compositions for each area gives a more detailed picture. Immediate differences were observed as to which species made up the largest proportions of food items in each area. In contrast to Swinburne where black seabass and scup were the most common species, on South Brother, white perch (18.9%) and mummichog, *Fundulus heteroclitus* (20.8%) were the most common (Table 1). Swinburne showed more diversity with 32 species compared to 20 species at South Brother. The differences are important, possibly reflecting the relative positions of the colonies, with South Brother being located much deeper into the estuary than Swinburne. This is possibly reflected in the greater proportion of food items found in cormorants at the South Brother location that were derived from regional fresh waters, including the sunfish species bluegill, *Lepomis macrochirus,* and pumpkinseed, *Lepomis gibbosus*. The exact locations of the fresh water foraging areas is unknown but there are numerous city ponds which could be utilized as well as the Hudson River itself.

Although the Schoener Index is scaled to take into account different sample sizes, it does not consider the numbers of specimens within individual samples. This is a possible source of error as seen in the large number of fish with small body sizes found on South Brother. Three species – bay anchovy, mummichog and white perch, were found in high numbers but had small body mass throughout. While the abundance of these species suggest they are important to the colony's diet, their small sizes (largest of these was a mummichog of 13.1 g) likely exaggerate their significance. To compensate for this, the Schoener Index was computed without those species, yielding a value of 0.416, which indicates a slightly higher amount of overlap, though still in the midrange of the index. More samples from South Brother would likely have decreased the biases associated with these species.

Finally, studies conducted in 2006 and 2007 (Grubel and Waldman, unpublished data), indicated that black seabass were a much smaller part of the local diet. Overall, the data from those years show a similar range but different make up of prey species. In those years, cunner was found to be a much more important part of the diet, making up 24% of the boli in 2006 and 17% of boli in 2007, while seabass was much less important, making up 1% and 3% of the boli respectively. A wide range of factors including recruitment, fishing, environmental quality, water temperature, and competition with other species can affect which fish species are to be found in the harbor as well as in what proportions (Waldman 2006). Future research will help us understand the exact of nature different species in the diet over time.

These results were obtained through the use of bolus samples only. This is of major importance when we take into account the results of the first part of the study – the comparison of fish assemblages in pellets with those in boli. Failing to properly consider this bias while analyzing the diet would have caused us to overestimate the importance of spiny species. For example, searobins would have been estimated to make up 17.9% of the diet instead of 10.1%, and black seabass would have been estimated at 22.2% instead of at 14.4%. Conversely, the importance of non-spiny species such as herrings would have been estimated to make up only 6.35% of the diet instead of 8.31%, and oyster toadfish would have been estimated at 2.1% instead of at 3.8%. These differences are large enough to potentially affect the decisions of resource managers and others who rely on such diet studies to evaluate the ecological impacts of cormorants.

CONCLUSIONS

Continued research into the diet of the local Double-crested Cormorant population is important for the proper management of the species in the New York City region. Of particular interest is the extent to which certain fish species are exploited by the cormorants. Neither of the species valued by humans, commercially and recreationally, were common in the samples, indicating that the local cormorant population is not a threat to the local populations of those species.

This research has uncovered a likely cause for the observed differences in both the species representation and the time in which pellets are produced. The differences observed between boli and pellets seem to be upheld by the hypothesis that spininess is an important factor in the formation of pellets. This is seen in the different proportions with which spiny and non-spiny species are found in boli and pellets. Although our results indicate that spininess is an important factor in pellet production, we cannot estimate exactly how important a component it is. Controlled feeding trials would help answer this question. In addition, it is unlikely to be the only morphological factor affecting pellet production and species representation in pellets and to that end, further research into other factors is needed as well.

The results of this study will be useful for those parties with an interest in managing the local marine resources as well as those concerned with managing Double-crested Cormorant populations elsewhere. One of the primary concerns of government agencies is the impact which cormorants have on fish populations and, through that, on the people who depend on those fish for recreation and livelihood. Thus, it is extremely important that the needs of local fishermen and others who rely on the fish must be considered, however, to proceed in instituting policy without first obtaining the required data will only lead to problems later on.

ACKNOWLEDGMENTS

This research would not have been possible without the following organizations and people: The Hudson River Foundation, NYS DEC, The Jamaica Bay Institute, Gateway Marina, Mary Cool, Theresa Duhon, Don Riepe, American Littoral Society, Kate Ruskin, NJ Audubon**,** Tom Veltre, The Really Interesting Picture Company, from the National Parks Service: Kathy Garofalo, Great Kills Park and Sean Seagriff, Jamaica Bay Institute, from NYC Audubon: Susan Elbin, Elizabeth Craig, and Alexis Marie Mychajliw, from NYC Parks: Mike Feller, Nate McVay, Ellen Pehek, Susan Stanley, and Alex Summers.

REFERENCES

Bernick, A. J. 2007. New York City Audubon's Harbor Herons Project: 2007 nesting survey. Report to the New York City Audubon Society, New York, NY. Unpub.

Blackwell, B. F. and J. A. Sinclair. 1995. Evidence of secondary consumption of fish by double crested cormorants. Marine Ecology Progress Series 123:1-4.

Campana, S. E. 2004. Photographic atlas of fish otoliths of the Northwestern Atlantic Ocean. NRC Research Press, Ottowa.

Carss, D. N. 1997. The Diet Assessment and Food Intake Working Group. Supplement di Ricerche Biologia Selvaggia, XXVI. 197-230.

Caseaux, R. J., M. Favero, E. R. Barrera-Oro and P. Silva. 1995. Feeding trail on an imperial cormorant *Phalacrocorax atriceps*: preliminary results on fish intake and otolith digestion. Marine Ornithology 23:101-106.

Collis, K., D. D. Roby, D. P. Craig, S. Adamany, J. Y. Adkins, and D. E. Lyons. 2002. Colony size and diet composition of piscivorous waterbirds on the lower Columbia River: implications for losses of juvenile salmonids to avian predation. Transactions of the American Fisheries Society 131:537-550.

Cortes, A., E. Miranda, and J. E. Jimenez. 2002. Seasonal food habits of the endangered Long-tailed chinchilla (*Chinchilla lanigera*): the effect of precipitation. Mammalian Biology 67:167-175.

Derby, C. E. and J. R. Lovvorn. 1997. Comparison of pellets versus collected birds for sampling diets of Double-crested Cormorants. The Condor 99:549-553.

Glahn, J. F., J. B. Harrell and C. Vyles. 1998. The diet of wintering Double-crested Cormorants feeding at lakes in the southeastern United States. Colonial Waterbirds 21:431-437.

Hatch, J. J. and D. V. Weseloh. 1999. Double Crested Cormorant (*Phalacrocorax auritus*). pp. 1-36 in: Poole A. and F. Gill eds. The Birds of North America, No. 441. The Birds of North America, Inc., Philadelphia.

Johnson, J. H., R. M. Ross, R. D. McCullough, and B. Edmonds. 2001. Diet composition and fish consumption of double-crested cormorants from the Little Galloo Island colony of eastern Lake Ontario in 2000. NYSDEC, Report to Lake Ontario Committee on the Great Lakes Fishery Commission, Albany.

Johnson, J. H., R. M. Ross, R. D. McCullough, and B. Edmonds. 2005. Diet composition and fish consumption of Double-crested Cormorants from the Little Galloo Island colony of eastern Lake Ontario in 2003. NYSDEC to the Great

Lakes Fishery Commission's Lake Ontario Committee on the Great Lakes Fishery Commission, Albany.

Johnstone, J. G., M. P. Harris, S. Wanless and J. A. Graves. 1990. The usefulness of pellets for assessing the diet of adult shags *Phalacrocorax aristotelis*. Bird Study 37: 5-11.

Kerlinger, P. 1998. The New York City Audubon Society harbor ecosystem study: nesting population of aquatic birds of the New York Harbor, 1998. New York City Audubon Society, New York, NY.

Kerlinger, P. 2002. New York City Audubon Society's Harbor Herons Project: 2002 nesting survey. New York City Audubon Society, New York, NY.

Parsons, K. C. 1987. The Harbor Herons Project, 1987. Report to the New York City Audubon Society, New York, NY. Unpub.

Rudstam, L. G., A. J. VanDeValk, C. M. Adams, J.T. H. Coleman, J. L. Forney, and M. E. Richmond. 2004. Cormorant predation and the population dynamics of walleye and yellow perch in Oneida Lake. Ecological Applications 14:149-163.

Russell, A. F., S. Wanless and M. P. Harris. 1995. Factors affecting the production of pellets by Shags, *Phalacrocorax aristotelis*. Seabird 17:44-49.

Schoener, T. W. 1968. The *Anolis* lizards of Bimini: Resource partitioning in a complex fauna. Ecology 49:704-726.

Sommers, C. M., M. N. Lozer,, V. A. Kjoss, J. S. Quinn. 2003. The invasive round goby (*Neogobius melanostomus*) in the diet of nestling Double-crested Cormorants (*Phalacrocorax auritus*) in Hamilton Harbour, Lake Ontario. Journal of Great Lakes Research 29:392-399.

Waldman, J.W. 2006. The diadromous fish fauna of the Hudson River: life histories, conservation concerns, and research avenues. pp. 171-188 in: Levinton, J. S. and J. W. Waldman, eds. The Hudson River Estuary. Cambridge University Press: New York.

Withers, K., and T. S. Brooks. 2004. Diet of the Double-crested Cormorants (*Phalacrocorux auritus)* wintering on the central Texas coast. The Southwest Naturalist 49: 48-53.