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A population survey and foraging analysis of the Double-crested cormorant (Phalacrocorax auritus) on the Santee lakes, South Carolina

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A POPULATION SURVEY AND FORAGING ANALYSIS OF THE DOUBLE-CRESTED CORMORANT (*PHALACROCORAX AURITUS*) ON THE SANTEE LAKES, SOUTH CAROLINA

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ABSTRACT

This study was designed to determine whether Double-crested cormorants (*Phalacrocorax auritus*) were having an impact on the Santee lakes fishery for Striped bass (*Morone saxatilis*). I surveyed the lakes' population in the summer of 2007 and winter of 2008 to determine population levels and 76 birds were necropsied in order to determine foraging preferences. Summer populations were estimated at 203 birds and winter at 6000. Clupeids (primarily Gizzard, Threadfin, and American shads) made up the bulk of the diet in both seasons with an overall percentage of 86.19%. No bass of any size or species were found in the stomachs of birds collected. Though this most likely indicates there is no direct impact by the Double-crested cormorants on the Striped bass fishery; however indirect effects are more difficult to quantify and more data is required before any conclusions can be drawn about effects from interspecific competition. The Double-crested cormorants do share a prey base with the Striped bass, and further examination of the energetic needs of the Striped bass as well as population estimates for the forage fish are necessary. Bomb calorimetry yielded the energetic densities for primary target fish and I estimated daily fish consumption for Double-crested cormorants on the Santee lakes to be approximately 8 fish/day. Management recommendations consist of continued population monitoring on lakes and roost harassment if local stakeholders continue to take issue with the birds' presence.

DEDICATION

This thesis is dedicated whole-heartedly to my wife and son, both of whom made this, and everything else worthwhile and a joy.

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First and foremost I need to acknowledge Dr. Greg Yarrow for his constant availability throughout this sometimes stressful and always interesting process. It would be hard to imagine this experience without his guidance. I'd also like to thank Dr. Pat Jodice for his insight into the ornithological side of things and for the availability of his time and lab. Dr. Bryan Brown's assistance was hugely helpful on the analytical aspects of this thesis as well as answers to several random questions throughout this project. Noel Myers and his staff at the South Carolina division of USDA-Wildlife Services were a huge help both in their interest in the project and willingness to participate through sample collection. South Carolina Department of Natural Resources provided the bulk of the funding for this project and deserve credit and acknowledgement for their financial support, as does the National Park Service. Santee Cooper Country also supplied funding as well as unlimited interest in the project. Lastly, this project literally could not have happened without the staff at the Dennis Wildlife Center. Scott Lamprecht, Jim Glenn, Chad Holbrook, and Mary Katherine were all incredibly helpful and always open to, and contributing ideas. Lastly I'd like to thank Evelyn Wenk for her sorely needed advice in the use of the bomb calorimetry.

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CHAPTER ONE

INTRODUCTION

Cormorants are a highly cosmopolitan taxon, containing over 30 species and appearing on every continent (Gremillet et al. 2006). This particular study focuses on just one species, the Double-crested cormorant (*Phalacrocorax auritus*). The Double-crested cormorant (also referred to as cormorant in this thesis) is a large piscivorous bird from the order Pelicaniformes that is native to much of North America. It is migratory through the bulk of its range, though there are areas that maintain year-round populations. The Double-crested cormorant has gained attention, primarily negative, through the past few decades due to a population increase and the subsequent effects (both real and perceived) on desirable fisheries (Blackwell et al. 1997, Collis et al. 2001). The threats and damages attributed to this bird include diminishing sport fisheries, foraging heavily on aquaculture ponds, competing for commercial fisheries, and habitat degradation in areas where the Double-crested cormorants are known to roost.

The issues at the core of this study are potential effects on a historically and economically important Striped bass (*Morone saxatilis*) fishery in the Coastal Plain of South Carolina, that of lakes Marion and Moultrie. The Double-crested cormorant population on these lakes generates a lot of interest and most of the concerns of local stakeholders remain unexamined. This lack of extant information was the impetus for the current study into the foraging selection and population size of the Double-crested cormorants on the Santee lakes.

Foraging Ecology of the Double-crested Cormorant

An opportunistic piscivore, the Double-crested cormorant is implicated throughout much of its range for its ability and success as a predator. Gremillet et al. (2004) suggest that their findings indicate that Double-crested cormorants may be as high 30 times more successful per unit effort in foraging than other seabirds. Though this is partly to make up for an increased metabolic demand (cormorants have wettable feathers and thus limited insulatory capabilities when foraging under water), it still speaks to why there is concern that this particular species may be responsible for diminishing returns in a sport or recreational fishery. In states such as Mississippi and Louisiana, studies indicate they have a negative impact on aquaculture (Glahn and Dorr 2002). Double-crested cormorants prefer to forage in water that is 8 m or shallower with minimal vegetation in the substrate (Coleman et al. 2005, Gibbons and Withers 2006). The primary foraging strategy of the Double-crested cormorant is to swim on the surface of the water and then dive down and chase potential prey items under the water. In some instances, Double-crested cormorants were recorded staying under for as long as 70 seconds in a given dive (Enstipp et al. 2001), though most dives observed during this study were of a much shorter duration.

Forage fish, such as those from the family Clupeidae, tend to be a primary target of the Double-crested cormorant (Fenech et al. 2004, Glahn et al. 1998, Rail and Chapledaine 1998, Simmonds et al. 2000), because these are mostly small, schooling fish that allow the bird to more easily increase it success rate due to the high number of prey items present. There is a twofold reason that this foraging success can lead to concerns for a particular fishery. First, when Double-crested cormorants are seen to have high foraging success rates, it is assumed that that success rate is evenly distributed across all species of fish. This may or may not be the case. Secondly, there are concerns of an indirect impact by exploiting similar prey resources as those utilized by fish that are economically or recreationally important. Exploitation competition occurs when one species or individual exploits a resource and by doing so reduces the availability of that resource for another species or individual (Townsend et al. 2003). In a case specific example, the anglers of the Santee community are concerned that even if Double-crested cormorants do not pose a predation risk to Striped bass, they will cause harm to the lakes' population by consuming too large a portion of the prey base of Striped bass. Perhaps exacerbating the issue is the fact that cormorants have been shown to prefer larger reservoirs (Simmonds et al. 1997) which are more likely to be utilized by a large and devoted group of anglers and stakeholders. Smaller reservoirs would be less likely be used by large groups and in other habitats such as the open ocean, it is likely that the foraging of the cormorants would be much less conspicuous.

Though relatively less common, there are cases which indicate that Double-crested cormorants can occasionally take sport fish. Derby and Lovvorn (1997a) observed Double-crested cormorants switching their primary prey base from suckers (family Catostomidae) to stocked trout (*Oncorhyncus mykiss* and *O. clarki*) when the trout were introduced into rivers. These stocking dates, however, coincided with peak metabolic demands in the birds and could therefore bias dietary estimates since cormorants were likely taking more prey than usual. Lovvorn et al. (1999) showed a similar effect on trout, however, they also introduced the idea that hatchery raised fish may be less likely to show a prey response, and therefore be easier prey. Conversely, hatchery-raised steelhead (anadromous form of *Oncorhyncus mykiss*) smolts had higher survival rates than their non-hatchery raised conspecifics in one study (Collis et al. 2001). Although Double-crested cormorants were indicated to take steelhead smolts, those that came from a hatchery were less likely to be preyed upon because they swam higher in the water column than Double-crested cormorants typically forage. Regardless, across the literature results indicate there is some validity to the concern that Double-crested cormorants may have an impact on some fisheries (Blackwell et al. 1997); therefore, necessitating continued research in the field of cormorant foraging behavior.

Population Biology and Double-crested Cormorant Concerns

One of the most likely reasons for stakeholder disdain for the Double-crested cormorant has been the recent population rise. There have been two recorded declines in Double-crested cormorant numbers in the past two hundred years, one in the 1800s and one in the 1950s (Wires and Cuthbert 2006). As with most cases of population decline in the 1800s, it was largely due to overexploitation and lethal control of the birds with no regulation. The population decline in the 1950s is attributed to the buildup of DDT, which led to similar population decreases in many populations of birds across a wide range of species. Members of the order Pelicaniformes, which includes the Double-crested cormorant, are highly sensitive to the presence of organochlorines in the environment (Harris et al. 2005). In the context of this study, however, the population declines are not as important as the population increases that followed. Double-crested cormorants are appearing in record numbers across an ever-expanding range and are causing problems in these new areas with everything from perceived fishery depletion to aesthetic damage. The increasingly visible status of the bird has made it the target of many organizations both public and private.

There are several hypotheses as to the recent increase in Double-crested cormorants throughout their range. Most of these hypotheses involve anthropogenic factors. This includes the creation of stocked ponds that artificially inflate levels of forage fish and therefore increase the prey base of the Double-crested cormorant, to human-created reservoirs increasing the amount of suitable inland habitat for all of the birds' basic needs (foraging, roosting, nesting, etc.). Also, reduced human persecution and lower ambient levels of DDE (Dichlorodiphenyldichloroethylene**,** what is left in the environment after DDT breaks down) in the environment have been indicated as helping to increase the numbers of these birds (Neuman et al. 1997). Cormorants are also prolific breeders; with some pairs successfully rearing 4 or more hatchlings (Hunt and Evans 1997) per year.

Other key issues that correspond with the marked increase in bird number ands are not correlated with the aforementioned foraging of the birds. Aesthetics can be a concern, as the large amounts of droppings accumulated under cormorant colonies can be a big detractor for tourism groups and people who live on lakes and beaches. These droppings also cause other concerns, as they can greatly increase ammonia and nitrate levels in the soil (Ellis et al. 2006), which in some cases has even been shown to reduce vegetation and forest cover (Hebert et al. 2005). Cormorant colonies can be very disruptive to neighboring waterbird colonies, in some instances even causing nest abandonment in other species (Quinn et al. 1996, Skagen et al. 2001). It has also long been suspected that Double-crested cormorants can damage other populations of birds through harassment and outcompeting for resources other than nests such as food or roosting habitat. In my study, the only birds found nesting in close proximity to the birds were ospreys (*Pandion haliaetus*).

The Santee Lakes

The Santee lakes, lakes Marion and Moultrie, were constructed between 1939 and 1942. Lake Marion is the largest lake in South Carolina, and Moultrie is the third largest. Lake Moultrie lies primarily within Berkeley County; however, Lake Marion is spread across Orangeburg, Berkeley, Calhoun, Clarendon, and Sumter counties. Both lakes are characterized by their large size, the presence of several swamps, and multiple cypress stands spread across the lakes. Consequently, there is plenty of suitable habitat for a variety of colonial waterbirds, including the Double-crested cormorant. Santee National Wildlife Refuge is also found within this area and provides ideal habitat for Double-crested cormorants. Due to the lakes' large size and highly developed shorelines, a strong stakeholder group of anglers and concerned citizens who are very interested in conserving the Striped bass population of the lakes.

Study Objectives

The primary objective of this study is to to determine which species of fish the Double-crested cormorants prey on in the Santee lakes, as well as any potential impacts on the Striped bass fishery. Stakeholder groups have all presented concerns to the South Carolina Department of Natural Resources (SCDNR) about the increasing Double-crested cormorant populations on these lakes. Some private stakeholder groups, such as Santee Cooper Country, have even given money to support research efforts to better understand the effects these birds may or may not be having on the Striped bass fishery.

This objective will be addressed primarily through the necropsies of Double-crested cormorants and by energetics analysis, as well as corresponding SCDNR data. Energetic analysis will give some indication of whether or not the cormorants may be having an impact on the forage fish populations of the lakes.

The second objective of this study is to examine the location and size of the Double-crested cormorant population on the Santee lakes system. Anecdotal evidence suggests that Double-crested cormorants are present in extremely high numbers. Also, habitat conditions where these birds are found will be recorded and monitored.

The third objective of this study is to develop management recommendations for the Double-crested cormorants on the Santee lakes that may be used in other systems as well. This will take into account the data I collect during my study, as well as including successful management practices from the literature.

CHAPTER TWO

METHODS

Surveying Techniques

An accurate population estimate of the Double-crested cormorant population on the Santee lakes was an integral part of this study To adjust for counting error it was decided that the double-observe method of sampling would be most advantageous for the habitat type and manpower available.The double-observer method is widely utilized throughout the field of ornithology for the purposes of population estimation. Since its inception for usage in quadrat counts in aerial flights (Cook and Jacobson 1979) the model has been adapted and utilized in many ornithological counts (Barbraud and Gelinaud 2005, Borchers et al. 2006, Forcey et al. 2006, Moore et al. 2004, Nichols et al. 2000). The addition of a second observer adds to the reliability of data gathered and helps account for individuals present but unobserved (Forcey et al. 2006). This particular model allows the observers to estimate the probability of detection of individuals in order to obtain an estimate of a given population size. This allows the observers to take as accurate a survey estimate as possible in an effort to truly represent the population in consideration.

In some situations, the double-observer method utilizes many of the same assumptions as mark-recapture models (Fletcher and Hutto 2006). (However, it should be noted that while Fletcher and Hutto use what is known as “independent double-observer" sampling they use the term "double-sampling" due to slight variations.) The primary assumptions of this method are as follows (Barbraud and Gelinaud 2005):

1. Observers must be independent
2. Each observer has an equal probability of observing an individual
3. A population is closed during the count. (Alldredge et al. 2006).

Since all located Double-crested cormorant colonies were over water, counts were conducted from a small boat that was either idling very low or turned off. The observers moved slowly through the colony, counting birds tree by tree until the entire colony had been counted. Due to the forward motion of the boat, there was a greatly decreased chance that a particular tree would be counted twice. Nests were counted in a similar matter, but no attempt was made to account for error.

Counts were conducted beginning at sunrise (normally around 7 AM) and lasted until around 9 AM. This is the time when most of the birds were observed to leave roosts in order to forage. Counts were conducted when the Double-crested cormorant young were in their nestling stage as Ewins et al. (1995) discovered that numbers were higher then than during incubation or post-fledging periods. Time bias was reduced by keeping the boat at a constant speed so that no more time was spent counting birds in one area than another for summer bird count. We were unable to utilize the double-observer method for our winter bird surveys.

Due to changing lake conditions discussed later, previous known areas of activity were completely dry and inactive. Many areas of the lake were inaccessible, with only one boat ramp available for Lake Moultrie at one point during the study. Due to these circumstances, methodologies from summer work were not possible and instead birds were counted in foraging floats. By following clupeid migration through the system I was able to pinpoint where birds would be at a certain time of day, every day. Clupeid locations were generated via observation and data from previous years. Observers were placed at other areas of known activity to make sure significant numbers were not missing from floats.

I estimated the number of birds in the float via quadrat sampling. The float was not contiguous and I divided each smaller float into fourths and counted the number of Double-crested cormorants in one quarter of the float and then extrapolated it out to the rest of that smaller float. These numbers were added together to get the resultant population estimate. Error was not accounted for, but counts were made by multiple observers.

When designing this study, I initially attempted to conduct aerial surveys to census the Double-crested cormorant population on the lakes, as this is a frequently applied method for waterbird population sampling (Pehlak et al. 2006) and has also been verified to be accurate when surveying Double-crested cormorants (Glahn et al. 1996). This is also the technique that the SCDNR uses when doing most of their waterbird surveys. Despite this, after conducting an aerial survey followed by extensive ground-truthing, the effectiveness of this type of survey came into question. Very few Double-cresetd cormorants were spotted from the air, and those that I observed were in very low densities. Aerial observation was further complicated by most nesting taking place in live trees with plenty of foliage.

Bird Collection and Necropsy

There are several methods of conducting foraging analysis with waterbirds that have been used in the literature. These include fecal analysis, regurgitate analysis, and necropsying birds to stomach contents for direct examination. Necropsy was chosen for this study due to the fact that it is a much more reliable method. Regurgitate analysis presents several problems, as Johnson et al. (1997) point out. They documented secondary consumption of invertebrates (i.e. the Double-crested cormorants were eating fish that were eating invertebrates) that was showing up in cormorant pellets as possibly a remnant from primary consumption. This would obviously introduce false data into the study. Another issue with regurgitate analysis is that the pellets do not always get attributed to the correct bird, and some birds may produce multiple pellets. With necropsy it can be ensured that each forage item is recorded as coming from the correct bird. These two different dietary analyses can lead to very different conclusions about the foraging activity of Double-crested cormorants (Derby and Lovvorn 1997b).

Specimens were collected under a US Fish &Wildlife Services (USFWS) permit by the South Carolina division of USDA-Wildlife Services. Every effort was made to collect birds in mid-morning after they had a 2 hour minimum to forage in order to maximize chances of birds having fish in their stomachs. Collections were conducted on the Santee lakes, Parr Reservoir, the Florence Lake community, and in Brosnan Forest. All birds were collected with steel birdshot from conventional shotguns. In total, 40 birds were collected for summer necropsy analysis (23 from the Santee lakes, 7 from Brosnan Forest, and 10 from Parr Resevoir) and 36 were collected for winter diet analysis (26 from the Santee lakes and 10 from the Florence Lake community). The sample size was based on the availability of samples collected by South Carolina USDA-Wildlife Services. However, existing dietary studies suggest that this is an appropriate sample size for the dietary analysis of Double-crested cormorants (Derby and Lovvorn 1997a).

Once birds were collected, formalin was injected down their esophagi in order to slow any further chemical digestion that may have occurred inside the stomach. Birds were moved to freezers as soon as possible after collection in order to preserve the specimens. Necropsies were conducted on each specimen individually, weighing and sexing each bird, and removing the stomach for further examination of its contents (USDA-Wildlife Services protocol Appendix C). Every sample was given an identification number and marked in case there was any need at a later date to take further measurements or otherwise collect more data from that specimen. Each fish found in the stomach of the bird was grouped into one of three size classes (less than 6 cm, 6-10 cm, or more than 10 cm) and then identified as specifically as possible. These size classes were selected after initial measurements were taken of prey items. The condition of many of these prey items prevented an exact measurement, consequently I determined size classes were necessary. In most cases consumed fish were identifiable all the way down to the species level. This was accomplished via dichotomous key (Foltz 2001). Once all fish had been identified, the sample was refrozen and then incinerated at a later date.

Several statistical analyses were run on the data collected during the Double-crested cormorant necropsies. Results were deemed significant if the acceptable Type I error rate was 5% ($p<0.05$). Frequency tables were constructed in order to determine preferred prey species and sizes. After checking for normality via the PROC UNIVARIATE function, it was determined the data in any of the comparisons examined (i.e. prey abundance in males vs. females, by season, or abundance of one species vs. another) were not normally distributed. As such, a T-test could not be used for analyzing differences in means. Wilcoxon Rank Sum Test and the Kruskal-Wallis ANOVA (PROC NPAR1WAY) were used instead, neither of which assume normality in data. The Kruskal-Wallis p-value was used for determining significance in all comparisons since SAS automatically reverts Kruskal-Wallis back to the Wilcoxon Rank Sum Test when only two samples are present. Comparisons were then made between sexes and between seasons to look at how these factors affected consumption of prey items. In order to give visual representation to the analyzed comparisons, boxplots were constructed using RLPLOT 1.5. SAS 9.1.3 (version 2000-2004) was used for all analyses.

Bomb Calorimetry

I used bomb calorimetry to ascertain the energetic values of fish species found in necropsied Double-crested cormorants. Selected samples were desiccated in a drying oven until all moisture was removed. This was established when the weight did not fluctuate by more than 0.01 g for three consecutive days. All specimens were kept at a constant temperature of 150° Celsius. Once samples were sufficiently dry they were homogenized using a mortar and pestle, grinding up the entire body until it was fine powder. This powder was placed into the bomb calorimeter.

I conducted the bomb calorimetry via instructions in the user manual for the utilized model (for this work the IKA C200 was used.). Each fish represented one unit sample. Each unit sample was divided into at least two separate specimens. A specimen was prepared by measuring out a portion of the sample that weighed approximately 1.3 grams. This sample size was selected because the calorimeter can most accurately determine energy content when the water surrounding the combustion chamber rises 2.7° Celsius. It was determined that, based on the energy content of the sampled fish, a 1.3g sample would raise the water temperature the correct amount for American shad (*Alosa sapidissima*), and 1.5g sample would accomplish this for White perch (*Morone americana*). When a sample of appropriate size had been obtained the specimen was then compressed into a pellet form and placed into the calorimeter. After the combustion reaction was completed, temperature changes as well as the energy densities of samples were recorded. This procedure was repeated for 10 fish of each species.

The energy density was ascertained for all species that made up more than 5% of the samples collected from the Double-crested cormorant diet. This was accomplished by both laboratory work and finding corresponding studies in the literature. This includes the unknown shads (those included in further analysis were the American shad and the Threadfin shad (*Dorosoma petenense*)), Gizzard shad, and White perch. Though neither the American nor Threadfin shads were ever identified directly via necropsy, cormorants were observed preying on schools of American shad in the field. As for Threadfin shad, it is likely that their abundance would make them prey for Double-crested cormorants.

To calculate potential consumption, figures from several existing studies were utilized. Glahn and Brugger (1995) looked at cormorant diets in the Mississippi delta in the winters of 1989-1990 and 1990-1991 and discovered that during these two seasons cormorants consumed an average of 22% of their body weight every day. There are similar studies done throughout the country, but the Mississippi delta system most closely resembles the Santee lakes. Assuming similar consumption rates for the Santee lakes, each cormorant would consume 468.35g of fish /day during the winter and 432.21g of fish/day during the summer. I assumed similar consumption rates because of the climatic similarities between Mississippi and the Santee lakes, which would place similar energetic demands on the Double-crested cormorants from a thermoregulatory perspective and may result in similar consumption rates. This same study suggested the daily energy budget (DEB) of Double-crested cormorants was 1926.7 kJ/day. Since a large portion of the shads could not be identified to species, they are added together to get an average energetic value to calculate potential numbers that could be taken by the Double-crested cormorant every year.

CHAPTER THREE

RESULTS

Surveys

Three large roosts colonies were counted in the survey, Bass Island 1 (33°25.339'N 80°11.389'W), Bass Island 2 (33°25.478'N 80°11.523'W), and Russellville (33°23.247N 80°00.761W). One colony much smaller than the others was found and counted in the Stumphole region (33°34.897N 80°31.033W). Probability of observation was successfully calculated for all colonies except Stumphole (Table 1). Nests were also counted at each colony and are included in the table.

The last colony counted was in the Stumphole region of Lake Moultrie. Maximum likelihood and probability of detection were not used because only 6 birds (not including 2 young of the year) were counted. Also the birds roosted in dead trees with no foliage and it was readily apparent there were no other birds in the area. It should also be noted that, though there is an abundance of anecdotal evidence of widespread cormorant activity throughout the lakes, very little activity was observed away from central locations of colonies. The Santee Dam and Pinopolis Dam were the only two non-colony areas where significant activity was noted.

While making point counts, anecdotal observations were also made about the habitat occupied by Double-crested cormorants and the raising of chicks in the colonies. Bass Island and Russellville colonies were all in live cypress stands with little to no damage observed to trees from Double-crested cormorant presence. How long cormorants have nested here is unknown; however, according to the wide majority of literature (Cuthbert et al. 2002, Ellis et al. 2006 Hebert et al. 2005) on Double-crested cormorant colonies and their effect on the surrounding vegetation, this lack of readily observable damage is rare. In the two Bass Island colonies and the colony at Russellville, all nests were relatively low to the water, and all were over standing water. Stumphole is unique from the other three in that all of these birds were nesting much higher in the trees and all the trees in the area were dead. However, they were still roosting over water.

As stated previously, observations were also made on the reproductive habits of the cormorants during point counts. Although no mating was observed, nearly all active nests had nestlings by the first week of June and fledging was observed in all colonies, except Stumphole, by the 23-25 of July 2007.

<u>Winter 2008</u>

The raft of birds was estimated at 6000. No roosts or colonies were ever discovered despite multiple weeks of effort due to much of the terrain becoming extremely impassable by foot or boat. Probability of detection was not calculated.

Bird Collection and Necropsy

<u>Summer 2007</u>

Of the 40 summer birds collected, 27 were females and 13 were males. There was an average of 1.9 ± 2.7 fish per bird. The abundances recorded for the various species and size can be found in Tables 2.1 and 2.2. The most common prey item was Gizzard shad between 6 and 10 cm. The data were not normally distributed and simple transformations did not work to normalize them, so I analyzed them using the Wilcoxon Rank Sum Test and no significant difference was found in abundance of species (Kruskal Wallis p-value =0.08). A finding of a lack of significance may be attributed to the highly variable nature of the data so a boxplot (Figure 1) was constructed to better illustrate the nature of the relationship between species.

Winter 2008

Of the 36 Double-crested cormorants collected in the winter of 2008 there was an average of 3.69$\pm$3.87 fish per bird. The abundances recorded for the various species and sizes can be found in Tables 3.1 and 3.2.

As with the summer foraging data, the data were not normally distributed and could not be normalized via simple transformations. The results of the Wilcoxon Rank Sum Test for the winter data also failed to reject the null hypothesis of no significant difference (Kruskal Wallis p-value=0.18) in frequency between fish species found in Double-crested cormorant diets. A boxplot was constructed to better illustrate the relationship (Figure 2).

Seasonal Differences

Analysis was also performed to see if there was a significant difference in prey items between summer and winter. The Wilcoxon Rank Sum Test failed to reject the null hypothesis that there was no difference in mean number of fish per bird by season (Kruskal Wallis p-value=0.12); however, there was a difference of almost two more fish per bird. Though analysis indicates this as an insignificant difference, whether this is coincidental or due to an increased energetic demand in the winter months warrants further study. Figure 3 shows that cormorants collected during the summer had a much wider range of values but the median was higher for birds collected in winter.

Total Diet

When the data from summer and winter were combined, the Wilcoxon Rank Sum Test found a significant difference (Kruskal Wallis p-value =0.04) among fish species collected during necropsy. The pooled data is the only analysis to suggest significant differences in prey species abundance.

Energetics

The various shad species (Table 4) made up 93% of the samples collected in winter and would account for 1791.83 kJ/day of the total required for the cormorants' daily energy budget. All the shad species in this study are very similar in size and mass, and shad specimens that fell within the 6-10 cm size range had a mean weight of 13.8 ± 1.5 g (based on 10 samples). Table 4 shows the amount of fish of each fish species analyze potentially consumed per day. The percentage of unknown shad was split evenly between American and Threadfin shad.

CHAPTER FOUR

DISCUSSION

No bass of any size or species were recovered at any point during the necropsy analysis (Table 4.1). The results of the necropsies in this study agree with the published literature on cormorant dietary composition (Fenech et al. 2004, Glahn et al. 1998, Rail and Chapdelaine 1998, Simmonds et al. 2000). These results indicate that Double-crested cormorants currently do not have a direct effect on the Striped bass population by consuming the Striped bass or any other bass species in the Santee lakes system. It should be noted however that bass and cormorants do share a common prey base and that these forage fish (Gizzard, Threadfin, and American shads) made up approximately 86% of the total prey items in the diets of the necropsied cormorants.

The Double-crested cormorants were not all collected from the same bodies of water on in the same immediate time-frame, and this may be the reason for some of the variation in fish species found in the birds' stomachs. For instance, the Redear sunfish (*Lepomis microlophus*), Bluegill sunfish (*Lepomis macrochirus*), and the two White crappie (*Pomoxis annularis*) all came from stocked ponds that most likely had artificially concentrated populations of these fish species. This information, in addition to the fact that only one or two of each species were found seems to indicate that they are not a standard prey item. However, even though these sampling techniques may contribute variation into the results, they also helped to validate data already collected. Even from these stocked areas, clupeids were still the bulk of the prey items recovered, indicating that even in situations where other fish are in unnatural abundance, clupeids remain a more commonly consumed prey item.

Though seeing shad in high numbers was expected at the outset of this study, the abundance of White perch in the diet (Tables 2.1, 3.1, 4.1) was unexpected. Neuman et al. (1997) noted Double-crested cormorant consumption of White perch but in a very different system (the Great Lakes). Though this is not a large portion of the diet by any means, it still warrants noting because White perch are from the same genus as the Striped bass and share some very slight superficial appearances from a distance. It also worth noting that White perch are invasive throughout much of the state and can also compete with multiple species of bass when they are present in the same system.

The estimates of Double-crested cormorants obtained in my surveys (Table 1) are much lower than those expected from initial local reports and from the little population data I had for the cormorants on the lakes. Aerial surveys were likely unsuccessful for the reasons stated in the Methods section, but also because this type of survey can be more effective when the Double-crested cormorants are in larger groupings (Rodgers et al. 2005), and most of the Double-crested cormorants observed from the air were present in low numbers and in dense foliage. Two major roosts were found using boats on the lake that were not spotted from the air. Several apparent areas of activity spotted from the air were revealed to simply be serving as loafing areas (no sign of extended Double-crested cormorant presence) when checked from the ground. This is most likely due to the fact that on these lakes the Double-crested cormorants prefer lush, dense cypress stands of live trees out over the water. Also, the presence of Anhingas (*Anhinga*

anhinga), which look similar from the air to Double-crested cormorants, made aerial surveying difficult and probably less accurate. It was due to these difficulties that I determined that comprehensive ground counts would be necessary by boat.

The higher numbers from previous years may represent negative bias by local stakeholders and a decrease in nesting as the drought began in summer of 2007. Though much of the swamp regions of these lakes are near impassable, every effort was made to check every area where previous cormorant activity had been reported. Outside of the four nesting colonies, no other birds were observed. As stated earlier, there was even very little cormorant activity away from these lakes, i.e. very little loafing or foraging was noted away from the population centers. For the colonies that were counted though, there was an exceptionally high probability of observing Double-crested cormorants that were present. This would indicate that for the areas counted in the summer of 2007, the estimate achieved (203) is reliable. The methodology was changed substantially for winter counts. Almost all suitable habitat (as observed in this study) was dried out. This constituted losing one of the primary observed habitat characteristics, which was roosting cover over water. All activity centers observed in summer were abandoned and no new roosts or colonies were located. Attempts were made to observe Double-crested cormorant flights at sunrise with no success at determining point of origin. It is likely that the lakes did not have the normal number of wintering birds that would typically have inhabited the lakes. This warrants further study as there are reports of tens of thousands of birds on the lakes during the winter.

Another way the drought potentially affected the number of birds that arrived, or more importantly, stayed was the alteration of fish migrations. Within the lakes, the shallower water never reached temperatures as low as is typical of this time of year and therefore the large congregations of fish in shallow water seeking thermal relief did not occur (personal comm., Jim Glenn, SCDNR). These schools are typically comprised mainly of clupeids, one of the cormorants' most common prey items. Obviously a lack of these large congregations, coupled with the reduced area of preferred habitat, would lessen the attraction of the lakes as a wintering site.

In order to better survey these lakes in a year with ideal conditions, more manpower would be required. One of the main issues confronted in the field was the sheer size of the lakes in question, and the inhospitable nature of several parts with reported cormorant activity. For summer one or two observers works well but in winter (under normal conditions) the censusing efforts would likely benefit from more observers.

It is important to note that though the rate of consumption of forage fish (Table 5) by Double-crested cormorants every year seems high, at this time the current populations of these species in the lakes is unknown and comprehensive surveys would be both time and manpower prohibitive. Approximately 8 fish/bird/day is not an extraordinary amount of consumption for waterbirds. Gremillet et al. (2004) showed that Great cormorants in West Greenland were capable of consuming up to 1376 g of fish/day. Hebert and Morrison (2003) showed on Lake Erie that diving ducks consumed more fish per season than Double-crested cormorants. The Gremillet and Hebert studies show that in context, Double-crested cormorants do not consume an extraordinarily high level of fish and perhaps other bird species consume as much or more than the cormorants. It should also be noted that the energetic analysis involved several assumptions. For the purposes of analysis I assumed a standard mean weight of a common size of fish. Also, the unknown shads were broken down evenly into Threadfin and American, and it is highly unlikely that this represents a true species distribution. The analysis of energetics and estimates of fish removal are meant to be descriptive and not definitive. It is necessary to get some grasp on the abundance of the prey species found in this study in order to determine whether or not the Double-crested cormorants are having an indirect effect on Striped bass in the Santee lakes system. Without this data, it is impossible to determine whether or not the prey base represents a limiting resource. Further investigation into the energetic demands of the Striped bass and other game fish in the Santee lakes is also necessary to determine the biomass of forage fish necessary to support a healthy Striped bass fishery.

It is an observable pattern in nature for one species to outcompete another, and the Double-crested cormorant is a highly successful predator that is relatively new to the system. The Competitive Exclusion Principle states (Townsend et al. 2003):

-If two competing species coexist in a stable environment, then they do so as a result of niche differentiation, i.e., differentiation of their realized niches.

-If however, there is no such differentiation, or if it is precluded by the habitat, then one competing species will eliminate or exclude the other.

If the Double-crested cormorants and the Striped bass do not have differentiated niches then it is entirely possible for them to have overlapping (limiting) resources. In the future, this is where impacts may occur, or may have already occurred. Anecdotal evidence suggests that the Double-crested cormorant populations increase every year, and that increase would result in a commensurate increase in energetic demand placed on the lake. With decreasing Striped bass populations and possibly increasing Double-crested cormorant populations there is certainly an increased chance of an indirect effect.

There are several aspects of this study that if expanded upon, could help clarify the potential impacts of Double-crested cormorants on the Santee lake system. Though our sample size for necropsy was similar to other analyses, the birds were not taken from uniform locations or time frames and this undoubtedly increased the variability of the data. Also, if more birds had been processed there likely would have been reduced variability and a more normal distribution, which would have been more conducive to analysis. Recording different data (i.e. age class, reproductive condition) or similar data in different ways would create more levels and degrees of freedom for further analysis. To continue to better understand impacts on the fish species involved, more technical identification through the use of such distinguishing characteristics as otoliths or other key bony elements (Ross et al. 2005) would be beneficial. This would reduce or eliminate the number of prey items that could not be identified down to a species level. To truly know roosting and colony habits of cormorants on this system, telemetry would be a beneficial tool as during the winter the birds proved highly mobile and difficult to locate for most of the day. If the desire is to understand the effect of these birds across the state and not just the Santee lakes, a foraging analysis on different types of systems (i.e. coastal, riverine, estuarine) would yield interesting results into possible energetic impacts on these areas. Most importantly, due to occurrences such as drought, data need to be recorded over multiple years. This study is just a snapshot of a dynamic population and lake system and it is during a highly irregular period (drought). Continued and expanded monitoring and analysis of cormorant populations and diets, forage fish abundance, and game fish energetic demands are vital to better understand these early findings.

CHAPTER FIVE

MANAGEMENT RECOMMENDATIONS AND CONCLUSION

From a purely biological standpoint, all data collected and analyzed in this study and from SCDNR indicates that Double-created cormorants are not having a direct impact on the Striped bass fishery of the Santee lakes by consuming Striped bass or other game fish. As stated in the Results section, no bass of any size or species were collected during necropsy. Indirect effects on the Striped bass fishery are possible due to the large percentage of shad consumed by cormorants; however, further data is needed to support this assumption. It should also be noted that these data were taken during a drought year when Double-crested cormorant numbers were likely much lower than they have been and foraging habits were most likely altered. Even though this is the case, past studies during non-drought conditions have found similar results. The best management practice at the current time would be continued population monitoring of Double-crested cormorants with continued systematic collection of birds to also monitor foraging habits.

In order to determine management needs, some accurate assessment of the relative abundance of forage fish in the lake would be most beneficial. This would help to determine the likelihood of any potential effects through competition. Though a complete census is likely prohibitive, calculating relative abundances via population indices from data recorded during gillnetting might yield helpful results.

That being said, not all management is based purely on science and there are invested stakeholder groups, particularly in the region where this study was conducted.

During the winter, harassment to relocate cormorant roosts would be a very visible form of management that is reasonably effective (Tobin et al. 2002). However, it simply moves cormorants around from one roost to another, and the birds may eventually become inured to any harrassment. Effigies have also been proven to be temporarily effective in dispersing cormorant roosts (Stickley et al. 1995). Management during the summer, at the current time, does not seem necessary until the breeding population becomes more pronounced. If this were to become an issue, egg oiling has been shown to be highly effective (Shonk et al. 2004). Currently, lethal management does not seem necessary at any time of the year, particularly due to the cost and man hours it would involve in order to have any real effect on the Santee lakes cormorant population.

Results of this study, recommendations, and conclusions are drawn from measurements and observations almost solely taken from the Santee lakes. Caution should be used applying this information to other systems or parts of the state.

APPENDICES

Appendix A. Tables

Table 1.1. The probability of observation and estimated numbers at roosts counted in summer of 2007. Estimates of probability and Double-crested cormorant population estimates were calculated using the double-observer method (see "Methods"). The numbers in the estimated Double-crested cormorants present column represent count numbers adjusted for error.

Location	**Probability of Observation by Primary Observer (%)**	**Probability of Observation by Secondary Observer (%)**	**Overall Probability of Observation (%)**	**Estimated Double-crested cormorants Present**	**Estimated Nests Present**
Russellville	84.16	94	99	78.8	60
Bass Island 1	85	81	91	33.9	6
Bass Island 2	89	93	99	83.7	33
Stumphole				6	4
Total Estimated Double-crested cormorants				203	

Table 2.1. Frequency table showing percentages per species of fish recovered from summer necropsied birds. This table shows the frequency with which prey items of particular species showed up in necropsied cormorants, and the representative percentage of total items collected from the summer of 2007.

Species	**Frequency**	**Percent**
Blueback herring (*Alosa aestivalis*)	3	3.9
Channel catfish (*Ictalurus punctatus)*	4	5.19
Gizzard shad (*Dorosoma cepedianum*)	33	42.86
Redear sunfish (*Lepomis microlophus*)	1	1.3
Unknown shad	24	31.17
White perch (*Morone americana*)	12	15.58

Table 2.2. Total frequency of size classes in all specimens necropsied. This table shows the frequency with which prey items of a particular size showed up in necropsied cormorants, and the representative percentage of total items collected in the summer of 2007.

Size Class	**Frequency**	**Percent**
<6 cm	18	23.38
6-10 cm	34	44.16
>10 cm	25	32.47

Table 3.1 Frequency table showing percentages per species of fish recovered from winter necropsied birds. This table shows the frequency with which prey items of particular species showed up in necropsied cormorants, and the representative percentage of total items collected from the winter of 2008.

Species	***Frequency***	***Percent***
Bluegill sunfish (*Lepomis macrcochirus*)	1	.75
Gizzard shad (*Dorosoma cepedianum*)	42	31.58
Unknown	3	2.25
Unidentified shad	82	61.65
White crappie (*Pomoxis annularis*)	2	1.50
White perch (*Morone americana*)	3	2.25

Table 3.2 Total frequency of size classes in all specimens necropsied. This table shows the frequency with which prey items of a particular size showed up in necropsied cormorants, and the representative percentage of total items collected in the winter of 2008.

Size	**Frequency**	**Percent**
<6 cm	2	1.50
6-10 cm	75	56.39
>10 cm	56	42.11

Table 4.1. Total frequency of species in all specimens necropsied. This table shows the frequency with which prey items of particular species showed up in necropsied cormorants, and the representative percentage of total items collected.

Species	**Frequency**	**Percent**
Blueback herring (*Alosa aestivalis*)	3	1.43
Bluegill sunfish (*Lepomis macrcochirus*)	1	.48
Channel catfish (*Ictalurus punctatus)*	4	1.90
Gizzard shad (*Dorosoma cepedianum*)	75	35.71
Redear sunfish (*Lepomis microlophus*)	1	0.48
Unknown	3	1.43
Unidentified shad	106	50.48
White crappie (*Pomoxis annularis*)	2	.95
White perch (*Morone americana*)	15	7.14

Table 4.2. Total frequency of size classes in all specimens necropsied. This table shows the frequency with which prey items of a particular size showed up in necropsied cormorants, and the representative percentage of total items collected.

Size	**Frequency**	**Percent**
<6 cm	20	9.52
6-10 cm	109	51.90
>10 cm	81	38.57

Table 5.1. Energy density values for common prey items in cormorant foraging. Items were removed from necropsied cormorants and identified. 10 specimens of each common species were then prepared (see "Methods") and placed into a bomb calorimeter. The table shows the mean energy density in kJ/g, the percentage of the diet from the samples collected, and estimated consumption/bird/day.

Species	**Mean Energy Density (kJ/g)**	**Percent of Diet**	**Daily consumption per bird (based on DEB of 1926.7 kJ/day)**
Gizzard shad (Dorosoma cepedianum)	19.935[1]	31.58	2
Threadfin shad (*Dorosoma petenense*)	20.23[1]	30.83	2
American shad (*Alosa sapidissima*)	14.25	30.83	3
White perch (*Morone americana*)	10.53	2.25	<1
Total fish consumed/bird/day			~8

[1] Strange and Felton (1987)

Appendix B. Figures

Figure 1.1. Boxplot of the different species abundances in the summer 2007 analysis. A Kruskal-Wallis test indicated no significant difference between prey item abundances in the stomachs of ollected samples. The boxplot below plots these abundances by species.

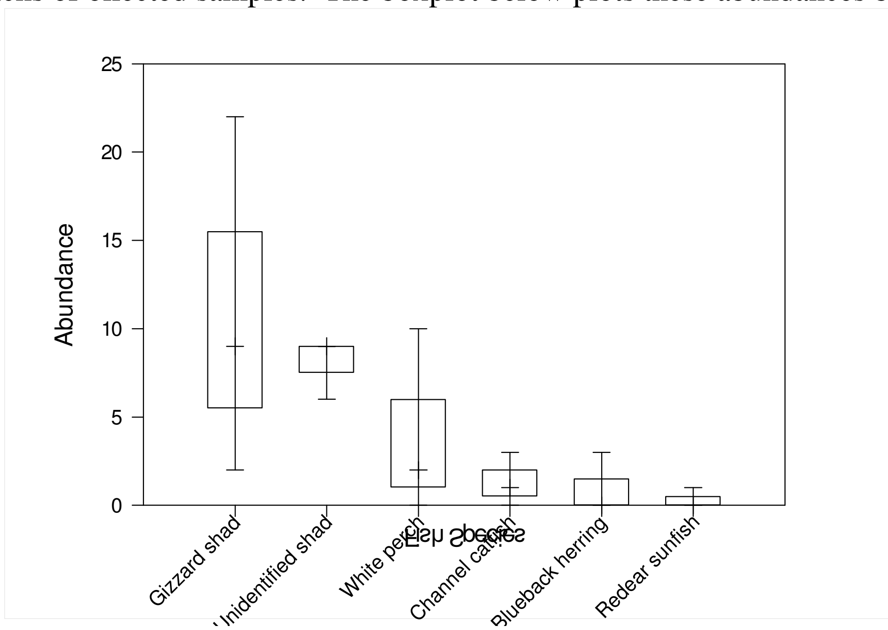


Figure 2.1. Boxplot of the different species abundances in the winter analysis. A Kruskal-Wallis test indicated no significant difference between prey item abundances in the stomachs of the collected samples. The boxplot below plots these abundances by species.

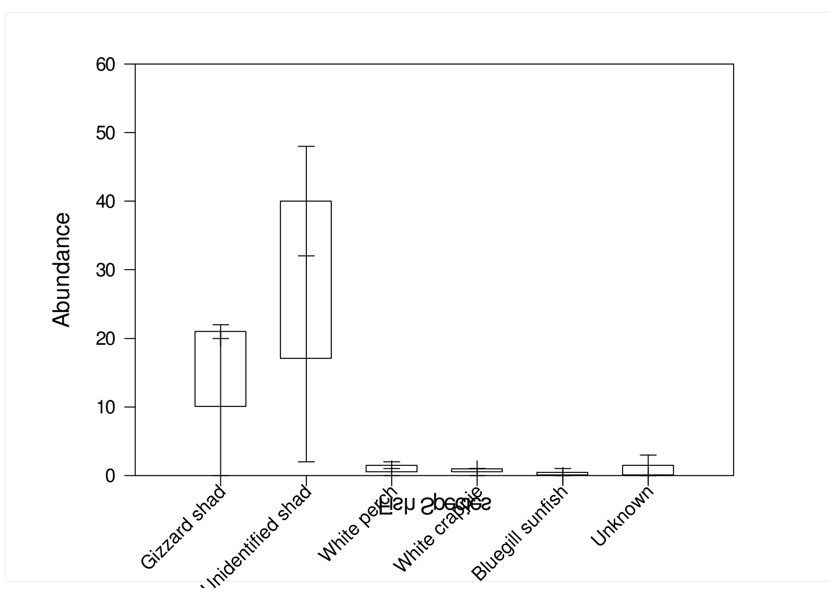


Figure 3.1. Boxplot of summer and winter fish abundances. Boxplot of all prey species. A Kruskal-Wallis test indicated no significant difference between prey item abundances in the stomachs of collected samples. The boxplot below plots these abundances by season. There is a wider range of values for summer birds but a lower median value.

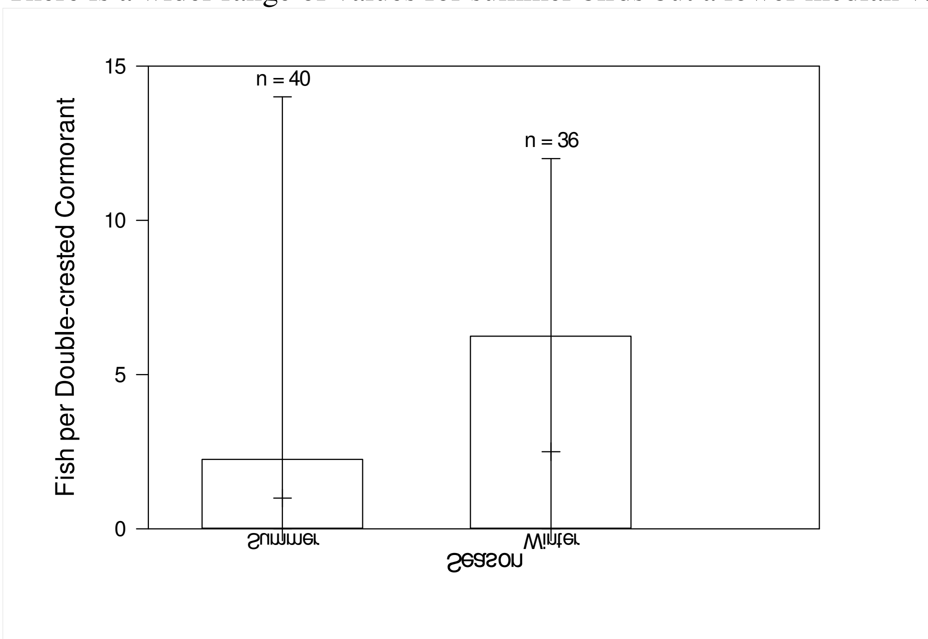
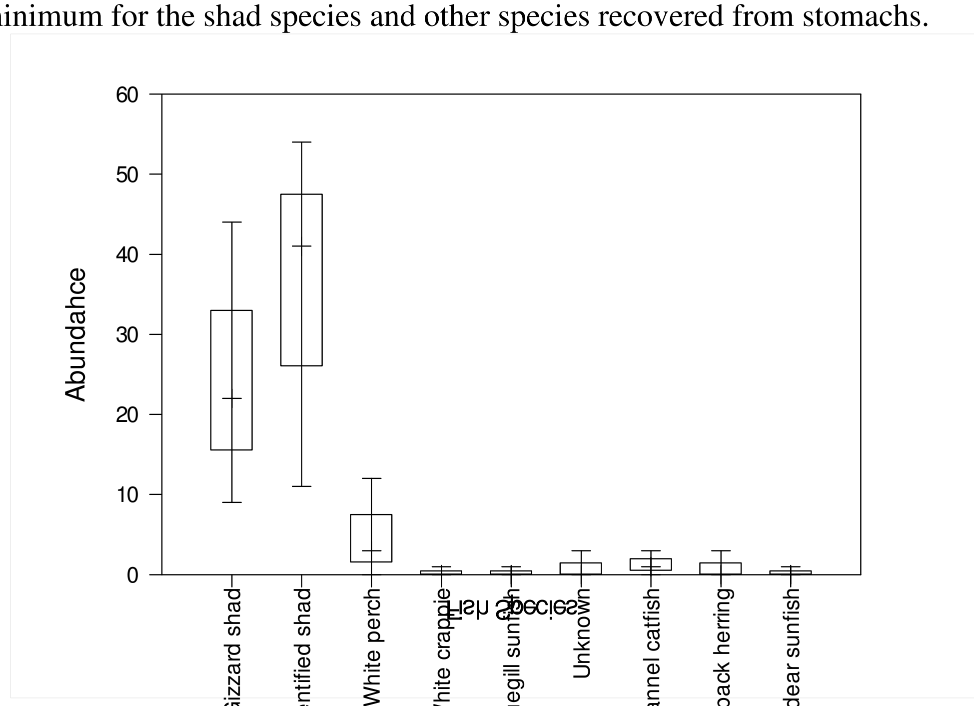


Figure 4.1. Boxplot of all prey species. A Kruskal-Wallis test indicated no significant difference between prey item abundances in the stomachs of collected samples. The boxplot below plots these abundances by species. Note the difference in the maximum and minimum for the shad species and other species recovered from stomachs.



Appendix C. USDA Wildlife Services Necropsy Protocol

National Wildlife Research Center

Standard Operating Procedure

Title: Necropsy procedures for fish-eating birds	***Number:*** XX 000.00 ***Effective date:***
	Replaces:
Prepared by: Katie Hanson ***Date:***	***QAU:***

1.0 PURPOSE

1.1 To describe procedures for conducting necropsies and collection of tissues from cormorants, wading birds, and pelicans at the Mississippi Field Station.

2.0 PROCEDURES

2.1 All morphological measurements should be collected prior to any other collection of tissues. This includes body mass, culmen length, tarsus length, and wing chord length (Appendix A).

2.1.1 Body mass should be measured using a digital benchtop or pesola scale to the nearest 0.01 kg.

2.1.2 Culmen and tarsus lengths should be measured using dial calipers as illustrated in Appendix A to the nearest 0.01 mm.

2.1.3 Wing chord length should be measured to the nearest 1.0 mm by using a ruler as illustrated in Appendix A.

2.2 Collection of skin samples for pentosidine analysis.

2.2.1 Prior to opening the body cavity for necropsy and collecting internal organs and tissues, a skin sample should be collected for pentosidine analysis to determine age.

2.2.2 Remove all feathers and down from the upper breast. Remove a 5 cm x 5 cm section of skin with scalpel and forceps. Place in sterile plastic container and fully cover skin sample with distilled water. Label the container with the bird band number, sample number, date and QA number. Store frozen until analysis can be completed.

2.3 Collection of muscle and feather samples for DNA analysis.

2.3.1 Prior to opening the body cavity for necropsy and collecting internal organs and tissues, feather and muscle samples should be collected for DNA analysis.

2.3.2 Remove 10 tail feathers or as many as available. Cut off feathered portion approximately 1-2 inches above the base. Place the quills in a whirl-pak bag labeled with bird band number, sample number, and QA number. Store frozen until analysis can be completed.

2.3.3 Make sure the scalpel is new for each sample and any forceps used for sample collection are clean to avoid any cross contamination between samples. Change gloves between samples if necessary. Remove a small (~1 g) muscle tissue sample from the breast and place in microcentrifuge vial. Label vial with assigned sample number. Microcentrifuge vials should be stored in a container labeled as muscle samples and with the QA number. Store frozen until analysis can be completed.

2.4 Opening of body cavity.

2.4.1 Care should be taken to avoid damaging any tissues or organs of interest.

2.4.2 Place the bird on its back with the head pointed away. Using a scalpel or sharp filet knife, make a lateral cut through the skin and body wall muscles just anterior to the cloacal opening. The cut should extend from the left leg, across the abdomen to the right leg.

2.4.3 Using a scalpel or scissors, continue to make a longitudinal incision towards the head, up both sides of the body and through the ribs (See attached diagram in Appendix B).

2.4.4 Lift the sternum cranially to expose the thorax and abdomen and allow for collection of organs and tissues.

2.5 Collection of stomachs for food habits.

2.5.1 If specimens are collected for food habits analysis, birds should be allowed enough time to forage to ensure the stomach is full.

2.5.2 As soon as possible after collection/euthanasia of specimens, a rigid tube (copper, plastic, ~1 cm diam., 45 cm length) should be passed through the mouth into the stomach. Using a 60 mL syringe, inject 10% buffered formalin into the stomach tube until throat is filled (typically 30-60 ml) to stop digestion of stomach contents. A zip-tie should be placed tightly around the neck if stomachs are not removed immediately.

2.5.3 To remove stomachs, open the body cavity as explained in Section 2.4. Grasp the distal end of the stomach where the esophagus joins and pull until the head of the bird retracts. Recover any food items that may be in the esophagus and place in sample bag. Cut the esophagus and small intestine ~2 inches from the stomach. Place the stomach in a zip-lock bag labeled with sample ID, collection date and location, and QA number.

2.5.4 Alternatively, stomachs can be removed immediately after collection of specimens and 10% buffered formalin can be directly injected using a 60 mL syringe and 18 gauge needle through the stomach wall or down the esophagus to stop digestion of stomach contents.

2.5.5 Stomachs should be kept on ice until they can be stored frozen.

2.6 Collection of reproductive organs for determination of sex and reproductive status.

2.6.1 Open the body cavity as explained in Section 2.4. Determine the sex of the bird by locating the gonad near the left kidney. The paired testes are located in the body cavity just ventral to the anterior end of the kidneys. The left ovary is attached to the body wall next to the left kidney. (Appendix C).

2.6.2 If the bird is male, remove the left testis (located on the right side of the bird if he is on his back). Record the mass of the testis (±0.001 g). Measure and record the length and width of the testis using a pair of dial calipers (±0.01 mm).

2.6.3 If the bird is female, remove the ovary and oviduct. Separate the oviduct from the ovary and record the mass of each (±0.001 g). Measure the length (± 1.0 mm) of the oviduct using a ruler. Measure the diameter (±0.01 mm) of the oviduct at the widest part using dial calipers.

2.6.4 For female birds collected during the breeding season:
A.) Describe the oviduct as either 1) smooth and straight, or 2) striated and convoluted.
B.) Examine the ovary under a dissecting microscope. Determine the number of pre-ovulatory, mature follicles, if present. Pre-ovulatory, mature follicles will be large, spherical and extremely vascular. Using calipers, measure and record the diameter of any pre-ovulatory follicles.
C.) Determine the number of post-ovulatory, ruptured follicles. Post-ovulatory follicles will be flattened and roughly circular. Using calipers, measure and record the diameter of any post-ovulatory follicles.

2.7 All carcasses, waste tissues and blood will be properly disposed of by either incineration or burial.

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