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Foraging Ecology of Seabirds in Relation to Commercial Shrimp Trawler Activity

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FORAGING ECOLOGY OF SEABIRDS IN RELATION TO COMMERCIAL SHRIMP TRAWLER ACTIVITY

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ABSTRACT

Population dynamics of seabirds have been linked to the availability of bycatch discarded from commercial fishery operations. This issue has been examined primarily in Europe where studies demonstrated that tens of thousands of seabirds each year may be supported by discards from a regional fishery, and that discards from commercial fisheries contributed to the increase in seabird abundance and to changes in their distribution in the North Sea and Northeast Atlantic. To date, however, little to no research has been conducted on seabird-fisheries interactions in the United States. This research examined this issue in the coastal waters of South Carolina where populations of two common seabirds, brown pelicans (*Pelecanus occidentalis*) and royal terns (*Sterna maxima*), are declining but where two other species, laughing gulls (*Larus atricilla*) and sandwich terns (*Sterna sandvicensis*) are increasing. The South Carolina coastal region also supports a substantial commercial shrimping industry that operates primarily in inshore waters and has fluctuated greatly in fleet size during the past two decades. This research investigated the relative abundance and distribution of ship-following seabirds at shrimp trawlers during the seabird breeding season, determined the composition of bycatch, particularly items that are appropriately sized for capture by seabirds, and also measured the consumption fate of fish species collected as bycatch. Shrimp trawlers appeared to be a strong, local attractor for seabirds out to 30km from the nesting colonies. All of the four locally breeding seabird species attended trawlers regularly, and the most generalist of these, laughing gulls, were the most abundant and frequently observed. Trawler activity, (i.e., phase of the trawler operations) was the factor which most affected the abundance in seabirds and spatial distributions varied from species to species. Brown pelicans consumed more discards than predicted based on their frequency while the other three seabirds each consumed fewer discards than predicted based on their frequency. Seabirds selected smaller discard items compared to larger items, and selected benthic fish (i.e., drum species) that typically would not be available to this suite of seabirds. Approximately 70% of the discarded bycatch in experiments was consumed by seabirds, suggesting that bycatch possibly makes up a large part of their diet at certain times of year (i.e., breeding months). My findings suggest that laughing gulls may be affected most strongly by the availability of additional food via discarded bycatch but that tern species as well as brown pelicans forage at trawlers frequently enough that changes in the size of the shrimp fleet would have the potential to affect their foraging ecology as well.

DEDICATION

This work is dedicated to the memory of my father, Walter Harry Wickliffe, who always encouraged and supported me in my goals and aspirations. I also dedicate this to Dr. Janet Zeigler and her colleagues at the University of South Carolina for their unconditional support and endless guidance in my life. Additional thanks to Gaye Betcher, Dr. Steve Stancyk, Dr. Joe Staton, and Dr. Bruce Coull. Without these people, I would not be here today.

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CHAPTER ONE

INTRODUCTION

Commercial fisheries are globally abundant in both nearshore and pelagic marine zones and affect both target and non-target species. Increasing evidence suggests that the increased levels of anthropogenic influence brought about by commercial fisheries create a range of changes at the marine ecosystem-level and can influence overall trophic structure including top marine predators such as seabirds and marine mammals (Gislason et al. 2000, Arcos 2001). For these reasons, current fisheries policies not only focus on sustainability of the target species but also the structure and functioning of the overall ecosystem (Gislason et al. 2000).

One aspect of fisheries operations that is receiving increasing attention for its potential ecosystem level effect is the interaction of commercial fisheries with both nearshore and pelagic seabirds. Much of the research that has been conducted in the realm of seabird-fisheries interactions has focused on issues pertaining to the monitoring and reduction of seabird mortality due to bycatch (Melvin et al. 2001) and to the assessment of the potential impact of competition between seabirds and commercial fisheries for forage fish (Oro & Ruiz 1997). Less attention has been given to the potential effect that discarded bycatch can have on ship-following seabirds, i.e. the role of discarded bycatch in seabird diets (Furness 1982, Garthe et al. 1996). For example, it is estimated that ca. 25% of the 110 million tons of marine catch is discarded from fisheries each year (Alverson et al. 1994, Gislason et al. 2000), although this figure varies considerably among fisheries and regions. Top marine predators, such as seabirds, can consume a significant proportion of this discarded bycatch (Furness 1978, Furness 1982, Furness and Cooper 1982) and it appears that the availability of this discarded bycatch may affect population dynamics, species composition, diet composition, and spatial distribution of seabirds in some regions (Garthe and Hüppop 1987, others). This issue has been examined primarily in Europe where studies have demonstrated that tens of thousands of seabirds each year may be supported by discards from a single regional fishery, and that discards from commercial fisheries may have contributed to the increase in seabird abundance and changes in distribution in both the North Sea and Northeast Atlantic (Furness et al. 1988). In the North Sea, for example, it has been estimated that energy available in bycatch from commercial fishery operations (3.4×10^{12} kJ) could support ca. 5.9 million seabirds (Garthe et al. 1996). These North Sea studies indicate that the dynamics of inshore fisheries, such as shrimp fleets, may play a crucial role in the foraging ecology and the distribution of seabirds in a given geographic area.

To date little to no similar research has been conducted on the potential importance of discarded bycatch to seabirds in the United States. Few estimates are available that examine either the abundance of seabirds foraging at commercial fishing vessels or the success with which they scavenge prey from these vessels despite the often close proximity of seabird breeding sites and commercial fishing operations. For example, the central South Carolina coast supports a substantial commercial shrimping industry that operates primarily in inshore waters which also provide the primary foraging habitat for brown pelicans (*Pelecanus occidentalis),* sandwich terns (*Sterna sandvicensis*), royal terns (*Sterna maxima*), and laughing gulls (*Larus atricilla*). In South

Carolina, these species are primarily limited to four colony locations along the central coast: (1) Marsh Island, which occurs in Cape Romain National Wildlife Refuge and has supported seabird colonies since at least the early 1900s, (2) Crab Bank, which occurs within Charleston Harbor and has supported seabird colonies since the mid 1990s, (3) Deveaux Bank, which occurs at the mouth of the North Edisto River and has supported seabird colonies since at least the mid 1900s, and (4) Bird Key Stono, which occurs at the mouth of the Stono River and which at one time supported the largest colony of brown pelicans on the eastern coast of the U.S. Annual nest count data from South Carolina show that populations of brown pelicans and royal terns have declined since the early 1990's, while populations of sandwich terns and laughing gulls have remained stable or increased (Fig. 1.1; also see Wilkinson 1997, Jodice et al. 2007). The reasons underlying these population changes remain unclear and may be attributed to multiple environmental factors. Given that food availability can effect reproductive success in temperate seabirds (Burger 1982), it is necessary to investigate the extent to which the four aforementioned seabird species utilize fisheries bycatch as a food source.

The goal of this research was to examine the relationship between seabirds and commercial shrimp trawlers operating adjacent to seabird colony sites. The objectives were to (1) determine the relative abundance and distribution of ship-following seabirds at shrimp trawlers during the seabird breeding season, (2) determine the species composition of bycatch from commercial shrimp operations, particularly items that are appropriately sized for capture by seabirds, and (3) for each of the most common species collected as bycatch, determine which items were most likely consumed by each of the four focal seabird species observed foraging at trawlers.

Chapter two of this thesis, "Abundance and distribution of seabirds in relation to shrimp trawling in nearshore waters of South Carolina, USA" examines the association of seabirds with shrimp trawling vessels in South Carolina. I conducted seabird surveys during 39 cruises on commercial shrimp trawlers operating from the Cape Romain and Charleston Harbor ports during May – August, 2006 and 2007. I examined survey data from each species and sought to determine if the abundance of species during surveys was related to the location, year, date, time of day, or activity that was occurring onboard the trawler (i.e. dragging, hauling, and discarding). Data from these seabird surveys will provide insight into not only the abundance of seabirds at trawlers but also which environmental and operational factors may affect that abundance.

Chapter three, "Seabird use of discards from a shrimp fishery in the nearshore waters of South Carolina, USA" examines the composition of bycatch discarded by shrimp trawlers and the extent to which these items are consumed by scavenging seabirds in South Carolina (i.e., laughing gulls, brown pelicans, royal terns, sandwich terns). Fieldwork was conducted on commercial shrimp trawlers operating in the Charleston Harbor and Cape Romain regions of South Carolina during the 2006 and 2007 seabird breeding seasons. I collected a sample of bycatch each time the trawler net was hauled to characterize the composition of the bycatch. Additionally, I conducted discard experiments to determine which bycatch items were most frequently consumed by each of the aforementioned seabird species and measured foraging efficiency and prey selection as they related to discarded items.

This research will substantially increase our knowledge of seabird ecology in the nearshore waters of the South Atlantic Bight as it relates to commercial fisheries. Surprisingly little research has been conducted in this area despite documented changes in population sizes and breeding ranges (Jodice et al. 2007) of many seabirds in the region and long-term changes in commercial fishing intensity (ASMFC 2005). These data also will allow management agencies to begin to understand the potential effect that the commercial shrimping fleet may have on seabird foraging ecology and ultimately population dynamics.

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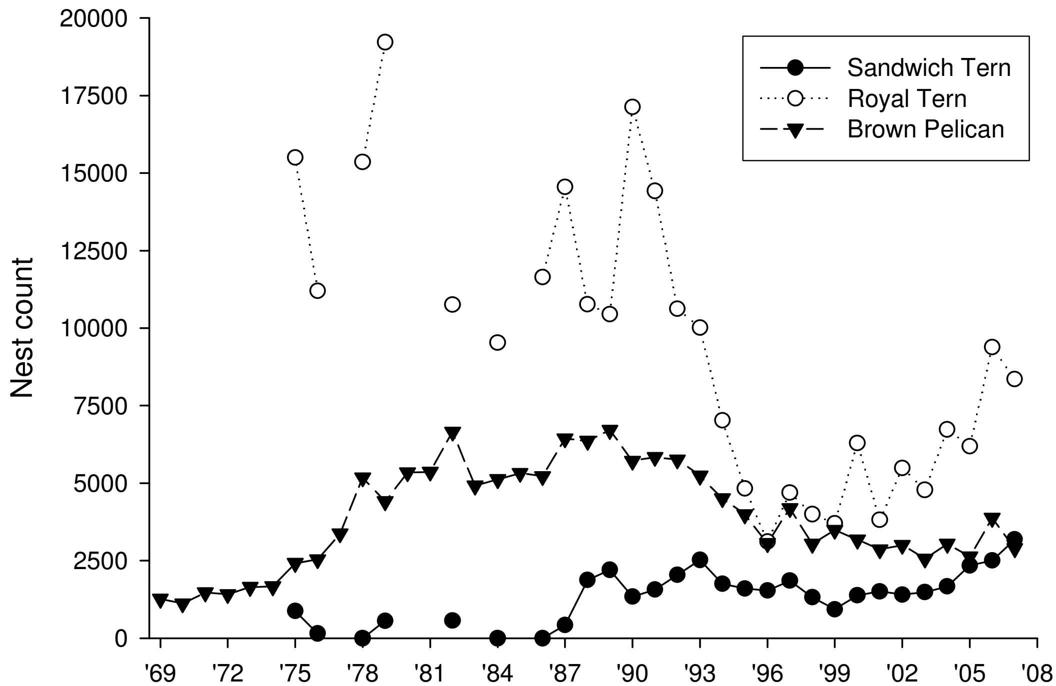
Figure 1.1 Annual statewide nest counts of brown pelicans, royal terns, and sandwich terns in South Carolina from 1969-2007 (modified from Jodice et. al. 2007). There are no longterm data available for nest counts of laughing gulls in South Carolina.



Modified from Jodice et al. (2007)

CHAPTER TWO

ABUNDANCE AND DISTRIBUTION OF SEABIRDS IN RELATION TO SHRIMP TRAWLING ACTIVITY IN NEARSHORE WATERS OF SOUTH CAROLINA, USA

Introduction

Commercial fisheries are globally abundant in both nearshore and pelagic marine zones and affect both target and non-target species. Ecosystem effects of fishing may be classified as direct or indirect (Gislason et al. 2000). Direct impacts such as mortality of target and nontarget (i.e., bycatch) fish from trawling are readily quantifiable and often measured. In contrast, indirect impacts of marine fishing operations such as changes in the trophic structure or changes in abundance of both marine fish stocks and the predators that prey upon them are more difficult to quantify compared to direct effects and are often poorly understood (Gislason et al. 2000). This appears to be especially true for apex predators such as seabirds and marine mammals which are integral parts of the marine ecosystem and also are often long-lived, wide-ranging, habitual in terms of migratory pathways, and of conservation concern. Given these characteristics, the potential for non-target species such as seabirds to experience long-term impacts from commercial fisheries is considerable and extends across all portions of the marine ecosystem from inshore to pelagic waters.

While negative effects of fisheries operations on apex predators are of high concern, potential positive effects such as the provisioning of food via discarded bycatch of non-target fish is also of great concern and has received far less attention. For example, the distribution of seabirds at sea is patchy at various temporal and spatial scales (Garthe & Hüppop 1994) and their abundance and distribution away from breeding sites may be affected by a variety of factors including prey availability, social behavior, and oceanographic processes (Garthe & Hüppop 1994, Hunt 1988). The abundance and distribution of commercial fishing vessels also may affect the distribution of seabirds (Garthe & Hüppop 1994). Seabirds are known to use fishing vessels, specifically demersal trawlers, to obtain food (Arcos 2001, Barrett et al. 2007). These trawlers produce large quantities of potential prey via the discarding of non-target fish (i.e., bycatch). These artificial and ephemeral food patches may attract thousands of seabirds which subsequently may lead to changes in their distribution and abundance (Furness & Monaghan 1987, Garthe & Hüppop 1994). For example, studies from the North Sea suggest that the estimated energy in bycatch (3.4×10^{12} kJ) is enough to support ca. 6 million seabirds in that region (Garthe et al. 1996) and that the dynamics of inshore fisheries, such as shrimp fleets, may have strongly affected the distribution, abundance, and population trends of specific seabird species (Walter & Becker 1997) during the past few decades. There have been, however, few examinations of similar relationships outside of Europe and within inshore waters despite the high degree of overlap in the distribution of commercial fishing operations and seabirds in these regions.

The state of South Carolina has a long history of inshore shrimp trawling that extends over eighty years (http://www.scseagrant.org/Content/?cid=43). Despite an economic decline in the shrimp fishery during recent years, it is still the largest and most economically valuable commercial fishery in the state (http://www.scseagrant.org/Content/?cid=43). The region within which the shrimp fishery operates also supports thousands of beach-nesting seabirds each year with the near shore waters providing the primary foraging habitat for brown pelicans (*Pelecanus occidentalis),* sandwich terns (*Sterna sandvicensis*), royal terns (*Sterna maxima*), and laughing gulls (*Larus atricilla*). In South Carolina, these species nest primarily at colonies in Cape Romain NWR, Charleston Harbor, and at the mouth of the N. Edisto and Stono rivers; refer to Jodice et al. (2007) for a map of all seabird nesting colonies in South Carolina. Recent research has demonstrated that nest counts of brown pelicans and royal terns have declined in the state since the late 1990s while nest counts of sandwich terns and laughing gulls have apparently increased (Jodice et al. 2007). The mechanisms underlying these trends remain unclear and it is likely that multiple influential factors exist.

In light of these population trends, the general decline in the shrimp fishery in this region, and usefulness of seabird populations in tracking the proliferation or loss of commercial fishing operations, I sought to examine the distribution and abundance of the four aforementioned species in relation to commercial shrimp trawlers. I conducted seabird surveys during 39 cruises on commercial shrimp trawlers operating from the Cape Romain and Charleston Harbor ports during May – August, 2006 and 2007. I examined counts of seabirds by species in relation to location, year, date, time of day, and the activities of the trawler. Data from these seabird surveys will provide insight into not only the abundance of seabirds at trawlers but also which environmental and operational factors may affect that abundance and distribution.

Methods

Study Area

The primary bathometric feature offshore of South Carolina is the Charleston Bump which is located southeast of Charleston on the Blake Plateau. The bump deflects the Gulf Stream offshore in the South Atlantic Bight which results in oceanic upwelling that brings high loads of nutrients to the surface and increases the primary productivity of South Carolina's coastal waters (Sedberry & Loefer 2001). This increase in primary productivity makes the central coastline of South Carolina a key location for commercial fisheries such as the shrimping industry.

Data were collected along the central South Carolina coast (Fig. 2.1) during the seabird breeding season (June-August 2006, May-August 2007) from two study areas. The southern areas (hereafter Charleston Harbor) included the nearshore waters from the Stono River north to Pine Island and included the mouth of Charleston Harbor. The northern study area (hereafter Cape Romain) included the nearshore waters from the North Santee River south to Bull Island and included the mouth of Bulls Bay and waters adjacent to Cape Romain National Wildlife Refuge. Each of the study areas supported seabird nesting colonies during 2006 and 2007 (Table 3.1) and ca. 15 commercial vessels trawled each region 11 to 13 km offshore from May through the beginning of January each year for brown shrimp (*Penaeus aztecus*) and white shrimp (*Penaeus setiferus*). These vessels were ca. 15.0 to 21.0 m in length, towed nets with a 4.7 cm mesh size, and used bags, which gathered the catch, with a mesh size of 4.1 cm. Vessels operating from Charleston Harbor towed 4 nets, 2 on either side of the boat, while vessels operating from

Cape Romain towed 2 nets, with one net on either side of the boat. The depth of the trawls ranged from ca. 3-14 m. Once landed, the catch was sorted on deck and bycatch species (i.e., non-target species) were discarded. All tow nets included turtle exclusion devices (TEDs) and bycatch reduction devices (BRDs), which are mandatory for commercial fishing vessels in South Carolina.

I conducted seabird surveys from the fishing vessels (hereafter F/V) *Winds of Fortune*, *Miss Georgia, Cape Romain*, and *Village Lady*. Data also were collected on one day (28June2006) on the r/v *Lady Lisa* from Charleston Harbor. Cruises generally left port at ca. 0500 h and generally returned at ca. 1800 h. All trawls were completed at a speed of ca. 2.5 knots, trawl times for one pull generally lasted 2 to 4 hours, and each cruise typically included 2 to 3 hauls/day. I categorized trawler operations into three activities: (1) dragging, the period during which the net was dragged (after the first haul this occurs after all bycatch is discarded); (2) haulback, the process of bringing the net into the vessel; and (3) discarding, the process of sorting and discarding fish bycatch while towing the net (see Gonzalez-Zevallos & Yorio 2006). Dragging was the longest of the three activities taking ca. 75% of the haul time.

I counted ship-attending seabirds every 40 mins for the entire duration of each cruise (n =39 cruises, n = 434 surveys). This survey interval was chosen to provide a large number of surveys each day while still allowing for sufficient time to elapse between surveys to result in biologically independent samples (e.g. Oro and Ruiz 1997). During each survey I stood in the far left corner of the stern of the boat. This provided me with the least obstructed view of the active fishing area at the stern of the trawler and also minimized observer disturbance to fishing operations (Camphuysen et al. 1995). At the start of each survey I scanned a 270^{o} arc around the ship (the area obstructed by the wheel-house was excluded), counting all of one species present at that time, and then counting the next species, until all birds within a 50 m radius were counted. The area within the 50 m radius was estimated periodically throughout each day with a range finder (sensu McGinnis and Emslie 2001, Heinemann 1981). All seabirds in this region are either plunge-divers (e.g. pelicans) or surface feeders (e.g. gulls) so I did not need to account for effects of underwater activity on surveys. Additionally the species richness was relatively low (usually $\leq$ 5 species) as were the total counts (usually <80) and therefore it was not difficult to identify or count the individuals present during any survey. I recorded geographical coordinates with a handheld GPS at the start and end of each survey. During each survey I also noted the date, time of day, weather conditions, vessel activity, pull number, and number of trawlers within 5km of the vessel I was attending.

I mapped spatial distributions of seabird species counted during surveys following Walter and Becker (1997), Abello et al. (2003), and Garthe and Scherp (2003). I used ArcGIS 9.1 and 9.2 to construct maps using the geographical coordinates obtained during each seabird survey. I then inserted seabird count data associated with each pair of geographical coordinates into the attribute table. Graduated proportional symbols were then generated to represent the relative number of seabirds counted at each geographical coordinate. Divisions for each symbol were made by using the natural distribution of the data. All data was set to UTM 17N NAD83. Buffer rings of 5, 10, and 20 km were generated around the nesting colonies at Crab Bank and Marsh Island so that spatial distribution from the focal point of the colony could be easily viewed.

Statistical Analysis

Count data resulting from seabird surveys were positively skewed and not normally distributed so I transformed these data by applying a square root transformation (count + 3/8) (Sokal & Rohlf 1981). Although the median may be considered a more appropriate measure of central tendency for data with non-normal distributions, the median value from my counts was often zero and hence the mean was considered to provide more useful information (Arcos 2001). The count data also displayed temporal autocorrelation. The autocorrelation (AR1) between consecutive counts within species ranged from 0.38 to 0.56 for each of the four focal species ($P < 0.05$ for each). To eliminate this temporal autocorrelation I calculated the mean count of each species within each activity within each haul within each day (where a haul was defined as a complete sequence of dragging, haulback, and discarding). These means (n=274) were used in all subsequent analyses that include count data unless stated otherwise.

I then used a MANOVA to generate partial correlation coefficients among species. This considers the correlative relationship between two species given the main effects also in the model. I found that correlations between counts were relatively weak (i.e., r values ranging from -0.06 to 0.51) and counts could be considered independent. The highest r value, 0.51, was detected for sandwich terns because so many of the counts were zero for this species.

Once the data were transformed and autocorrelation issues were addressed I used a general linear model with manual backward selection (removal criteria $P>0.05$) to assess the relationship between the count of each seabird species and a suite of independent variables that included trawler activity (dragging, haulback, or discarding), year (2006, 2007 treated as a categorical variable), location (Charleston Harbor or Cape Romain), Julian date within each year, and time of day (time category (TC) 1= sunrise + 3hrs, TC 2 = end of TC 1 to sunrise + 6hrs, TC3 = end of TC2 to sunrise + 9hrs, TC 4= end of TC 3 to sunrise +12hrs). Differences between levels for categorical variables were assessed using Fisher's LSD post-hoc test. All statistical tests were analyzed using a 5% level of significance ($P=0.05$), although marginal values are also discussed in some cases (Stoehr 1999). All reported values are untransformed means and include 95% confidence intervals.

Results

Trawler Cruises

The total number of cruises attended each month at each location is presented in Table 2.2. In the Charleston Harbor region, most shrimp trawlers followed the same general course, towing their nets along the path marked as the shipping channel just beyond the harbor entrance although occasionally cruises extended north and south of the entrance as well (Figure 2.1). Trawlers in the Cape Romain region trawled along the entrance to Bull's Bay (i.e., adjacent to the nesting colonies in CRNWR) and adjacent to and north/northeast of CRNWR. Several trawl routes also included the waters near the mouth of the North and South Santee Rivers (Figure 2.1).

Seabird Surveys

The species of seabirds observed during surveys from commercial trawlers included laughing and herring gull (*Larus argentatus*); royal, sandwich and common tern (*Sterna hirundo*); brown pelican; greater shearwater (*Puffinus gravis*); and magnificent frigatebird (*Fregata magnificens*). Laughing gulls, royal terns, brown pelicans, and sandwich terns comprised > 99% of the total counts in each region each year (Table 2.3) and therefore all subsequent analyses are restricted to these four species.

Laughing gulls were the most abundant species present at trawlers comprising ca. 65 - 70% of the total seabirds counted each year. Royal terns comprised ca. 17 – 20 % of the seabirds present at trawlers each year while brown pelicans comprised ca. 8 - 14% of the seabirds present at trawlers each year. Counts of sandwich terns were highly variable and were the least frequent of the four primary species observed at trawlers. Other species observed at trawlers included herring gull (n=22), common tern (n=4), greater shearwater (n=5), and one juvenile magnificent frigatebird.

Laughing gulls and royal terns were present during a very high proportion (82 – 100%) of surveys in both locations each year (Table 2.3). Brown pelicans were present less frequently but regularly (51 – 62% of surveys) during surveys in both locations each year. Sandwich terns were present at $\leq$ 40% of surveys during both years in Charleston Harbor but more frequently (> 76%) in Cape Romain each year. Other species were also observed more frequently in the Cape Romain region compared to the Charleston Harbor region.

Results of the general linear model with backward selection are presented in Table 2.4. There was a significant relationship between activity and abundance for each species except sandwich terns. Few other variables or interaction terms were consistently significant across species. The interaction terms of year*location and year*date each appeared in the final models for two species (brown pelican and laughing gull, and laughing gull and sandwich tern, respectively). All other significant terms were unique and appeared in only one model. Below I review the final model for each species.

Abundance of brown pelicans was most strongly affected by trawler activity (Table 2.4). Brown pelicans were most abundant during the discarding phase and least abundant during dragging (Table 2.5). Counts of brown pelicans were also affected by an interaction between year and location (Figure 2.2). Pelicans were more abundant in the Charleston Harbor region during 2007 compared to the same region in 2006 and the Cape Romain region in 2007. The abundance of brown pelicans also was affected by an interaction of year and time of day. In 2007, TC 1 had significantly fewer brown pelicans ($\bar{x}$=3.12, 95%CI=1.59, 5.15) compared to TC 2 ($\bar{x}$=9.80, 95%CI=6.91, 13.24) and TC 3 ($\bar{x}$=9.87, 95%CI=5.83, 15.06).

The number of laughing gulls also differed by activity (Table 2.4). Laughing gulls were most abundant during discarding and least abundant during dragging (Table 2.5). There was a significant effect of year*location on laughing gull abundance (Table 2.4). Laughing gulls were most abundant in Cape Romain in 2007 (Figure 2.2). Although statistically significant differences ($F_{1,262}$=4.5, P=0.03) were detected for mean number of laughing gulls over time (i.e. Julian date) between 2006 and 2007, no biological trends were apparent.

The mean number of royal terns also differed significantly among activities (Table 2.4). Royal terns were most abundant during discarding and least abundant during dragging (Table 2.5). The mean count of royal terns also was greater during 2007 (15.7, 95% CI 3.9 - 17.6) compared to 2006 (11.3, 95% CI 9.5 - 13.2).

The mean number of sandwich terns was significantly different among time categories and location (Table 2.4). For Charleston Harbor, no detectable differences were noted between the four time categories. In contrast, the mean number of sandwich terns in TC 3 ($\bar{x}$=2.8, 95%CI=1.70, 4.04) was significantly lower compared to TC 1 ($\bar{x}$=7.2, CI=4.51, 10.45) and TC 2 ($\bar{x}$=4.6, CI=3.35, 6.18) in the Cape Romain region. A significant difference ($F_{1,257}$=8.3, P=0.004) was also detected for mean number of sandwich terns over time between 2006 and 2007, but no biological trends were apparent.

The ANOVA with post hoc comparisons indicated significant differences in the mean number of each species recorded for activity when data were pooled among both years and both locations (Table 2.5). Laughing gulls were the most abundant and royal terns the next most abundant species during each of the three activities. Sandwich terns were the least abundant species during discarding and together with brown pelicans were least abundant during dragging and hauling. There were no strong correlations in counts among species when data were analyzed across all surveys and activities (partial $r < 0.25$ for all pairwise comparisons).

The distribution and relative abundance of each species observed during trawler surveys are presented in Figure 2.3. Brown pelicans in the Charleston Harbor region (Fig. 2.3a) appeared to be distributed throughout the survey area with high counts (e.g. 31-60 individuals) recorded as far as 10 km from shore and 20km for the nesting colonies. In Cape Romain, the highest numbers of brown pelicans were generally recorded adjacent to the nesting colony but also >20km out north of the colony near the mouth of the South Santee River. Laughing gulls (Fig. 2.3b) appeared to be distributed relatively evenly throughout the survey area with high and low counts recorded throughout most trawling areas. Royal terns (Fig. 2.3c) appeared to be most abundant closer to the colonies in both the Charleston Harbor and Cape Romain regions, although high counts were also recorded near the South Santee River mouth. The highest counts of royal terns were recorded in the Cape Romain directly off of the Marsh Island colony. In Cape Romain, higher numbers on sandwich terns (Fig. 2.3d) were recorded along trawls close to the nesting colony and lowest at the mouth of the North and South Santee Rivers. Sandwich terns appeared to be more abundant north of Charleston Harbor.

Discussion

Species Composition

Seabirds breed at very few locations along the South Carolina coast and two of the three largest and most important colony sites in the state were within 20 km of the two shrimp ports from which trawling activity originated (Marsh Island in CRNWR and Crab Bank in Charleston Harbor; Jodice et al. 2007). The Marsh Island and Crab Bank colonies included breeding laughing gulls, royal terns, brown pelicans, and sandwich terns during my study. The seabird assemblage observed at commercial shrimp trawlers in the Charleston Harbor and Cape Romain regions of South Carolina strongly reflected the composition at the colonies, with ca. 99% of the birds observed at trawlers being species that were breeding at the two nearby colonies. Furthermore, the abundance of each species observed at the trawlers (laughing gulls > royal terns > brown pelicans > sandwich terns) also reflected the abundance of each species at the colonies.

There appears to be little opportunity for breeding individuals of these four seabird species from other colonies to forage within my study area. The nearest colony to the north of Marsh Island is located in the Cape Fear region of North Carolina (ca. 180 km) while the nearest colony to the south of Crab Bank occurs at the mouth of the North Edisto River at Deveaux Bank (ca. 35 km). Each of these colonies is located beyond what is considered to be the typical foraging range of the four focal species while most trawls occurring in the two study regions are within 20km of the breeding colonies and therefore likely occur within the foraging ranges of the four most abundant species at Crab Bank and Marsh Island (Shields 2002, Burger 1996, Buckley & Buckley 2002, Shealer 1999).

Infrequent observations of seabirds considered to be more pelagic in their habitat use during trawl surveys (e.g., shearwater spp.) was not surprising given that the shelf break and western edge of the gulf stream, both areas more likely to support foraging pelagic seabirds, were located ca.65 km offshore of trawl areas. It appears, therefore, that within my study area the assemblage of seabirds observed at trawlers was relatively 'local'. Any effect commercial shrimp trawlers may have on seabird foraging dynamics, or ultimately on seabird population dynamics, may therefore also be considered 'local' in this study.

One infrequently observed seabird of interest at trawlers was the herring gull. This species is experiencing a southward range expansion along the eastern coast of the U.S. (Perotti & Good 1994) and is considered an aggressive competitor at both foraging and nesting areas, as well as a predator of eggs and chicks of other beach-nesting birds. Although no nests have yet to be located for this species in South Carolina, herring gulls are frequently observed at colony sites (Jodice et al. 2007). Although only recorded in low numbers, my data indicated that herring gulls were present in both study areas. Management agencies may therefore view surveys from shrimp trawlers as one means to assess herring gull abundance in the area.

There are few, if any, published studies that examine the composition and abundance of seabirds at trawlers in southeastern U.S. waters and therefore direct comparisons regarding species composition and abundance are not readily available. Nonetheless, surveys conducted from commercial trawlers in nearshore waters in both northern and southern Europe found that, as in my study, *Larus*-gulls were typically abundant and widespread (see Walter & Beacker 1997, Yorio & Caille 1999, Garthe &

Scherp 2003). Most gulls are considered generalists that often scavenge not only at trawlers but also at other anthropogenic food sources (Burger 1996) and hence their attendance at trawlers is not surprising. Sandwich terns have been observed foraging at trawlers in studies conducted in nearshore waters of southern Europe (Arcos 2001, Martinez-Abrian et al. 2002, Abello et al. 2003, Valeiras 2003; common terns also were observed regularly) while royal terns were observed during trawler surveys from nearshore waters in southern South America (Yario and Caille 1999). Each of these terns was typically present at < 50% of hauls, far less frequently than I observed. Similar to my observations, however, the abundance of these two terns appeared to be relatively low during surveys, often with < 15 individuals per count. It appears common, therefore, for single-prey loaders such as terns to attend trawlers operating in nearshore waters frequently but in relatively low numbers. Their limited abundance at trawlers may be due in large extent to the fact they are single-prey loaders that must return frequently to the colony to feed chicks. Hence, one individual is not as likely to follow a trawler for extensive periods of time as may be the case with gulls. Similar to gulls, brown pelicans can transport large meals to chicks at colonies. This may allow individuals to remain with trawlers for extended periods of time and in turn this may account for their relatively consistent frequency and abundance during my surveys.

Activity and Location Effects

Seabird abundance at trawlers during this study was most strongly affected by the activity of the trawler. Seabird abundances were higher during discarding compared to either the dragging or haulback phases of the trawler operation for all four species.

Similar results of variable seabird attendance among trawler activity were reported in a wide variety of studies including those conducted from hake trawlers (Gonzalez-Zevallos & Yario 2006), purse seiners (Arcos & Oro 2002), and both coastal and demersal trawl and longline vessels (Bertellotti & Yario 2000). Each of these studies, despite the different types of fisheries, all found that birds were most abundant during the discarding phase and in some cases the haulback phase when bycatch were readily available to scavenging seabirds. These data also suggest that future studies could conduct seabird surveys during the haulback and discarding phase with little to no loss of information.

Despite the strong effect I observed of activity on abundance, the general linear models for each of the four focal species only accounted for a low percentage of variability, with R^2 values ranging from 0.22 to 0.28. This indicates that other factors unaccounted for in this study are also affecting the abundance of seabirds at trawlers (e.g. nest attendance patterns, unmeasured environmental variables). One variable that was not included in my models but that may contribute to the variability in abundance I observed was the number of vessels trawling in the same general area (e.g. $\leq$3km radius). Seabirds move among vessels while scavenging for food (Gonzalez-Zevallos & Yario 2006), taking advantage of the fact than each vessel is operating on a different time frame, and therefore possibly at different operational phases (i.e., activities). For example, in > 90% of hauls during which I conducted surveys, I also observed at least one and as many as eight vessels trawling within 3km of my survey vessel. If an individual seabird forages at one vessel which is in a discarding phase, then after that activity has ended proceeds to another proximate vessel discarding bycatch, it potentially increases its chances of obtaining food by increasing its exposure to the food source. Species such as laughing gulls or brown pelicans, which are multiple prey-loaders, may consume a greater volume of food in a shorter time period by utilizing this strategy. Tern species using this strategy may be able to decrease time away from the colony and hence return to nesting colonies sooner or more frequently when feeding in an area that supports multiple trawlers.

The general linear models detected some level of temporal variability for all four species of seabirds between the 2006 and 2007 sampling periods. However, there were no consistencies among the seabird species. Brown pelicans and laughing gulls were more abundant in 2007 in Charleston Harbor and Cape Romain, respectively. Although nest counts were not conducted for laughing gulls in Cape Romain in 2007, it is not unreasonable to expect their population increased there as they appear to be increasing in abundance statewide and there also was an increase in the number of royal and sandwich tern nests there in 2007. There was, however, no difference in nest counts for brown pelicans in Charleston Harbor in 2007 compared to 2006 and therefore the increased abundance of this species at trawlers in 2007 was likely not due to an increase in the number of nesting individuals in the area.

Both royal terns and sandwich terns had an increased presence at the trawler vessels in the 2007 sampling period. For royal terns, this increase coincided with a nearly three-fold increase in the number of nesting pairs at Marsh Island, although there was a slight decrease in nesting effort at Charleston Harbor. Royal terns also have been reported foraging up to 65 km from colonies (McGinnis & Emslie 2001). This may mask any location effect as, for example, individuals from Marsh Island may have foraged in the

Charleston Harbor region which appears to be well within their foraging range. The number of sandwich terns nesting at both colonies also increased sharply in 2007, especially in Cape Romain. Buckley and Buckley (1972) speculated that sandwich terns may increase nesting success by settling where royal terns are already productive, or by following them to food sources, providing suitable reasoning for the increase in numbers at the colony and at the trawlers.

Time of day significantly affected the presence of brown pelicans and sandwich terns at the trawlers. Brown pelicans were more abundant in TC2 and TC3 during 2007 than in TC1. For sandwich terns, the significant difference in time blocks was seen only in Cape Romain. Here there were greater numbers of sandwich terns in TC1 and TC2 than in TC3. The significant difference in number of sandwich terns during different time blocks was possibly only detected in Cape Romain because of the high number of nesting pairs in the region as compared to Charleston Harbor nesting colonies (e.g., Cape Romain=321, Charleston Harbor=35). There are multiple factors for both species that may affect daily cycles in abundance, the most likely being that patterns were related to meal delivery schedules at the colony. Unfortunately these data are not available for these two years and hence it is not possible to completely assess the effect of meal delivery rates on daily cycles in abundance.

Spatial Distribution

Spatial distributions (i.e., locations of abundance or absence) varied among species. The highest numbers of brown pelicans and royal terns appeared to be counted during surveys that occurred in close proximity to the nesting colony in Cape Romain.

These species also were abundant (i.e., high counts were recorded) throughout the survey area, however, including areas as distant as Cape Romain and the mouths of the North and South Santee rivers. If the seabirds were traveling from the nesting colony to these trawling locations, the distance is well within the foraging ranges of both species and would not be surprising (Sheilds 2002, Buckley & Buckley 2002). The even distributional patterns of laughing gulls appear to be a common occurrence of *Larus*-gulls attending fishing vessels in nearshore coastal areas, as all of the trawls I attended were. For example, Furness et al. (1992) and Garthe & Scherp (2003) each observed high numbers of some *Larus* species, with the highest numbers being recorded for herring gulls, regardless of season or geographic area in which the commercial fishing vessels were present. The highest densities of sandwich terns were seen around the Cape Romain nesting colonies where the largest numbers of nesting pairs were counted (ca. 300), indicating that there is a possible correlation between number of nesting pairs and number of sandwich terns seen foraging at the trawlers. Also, sandwich terns were not observed at distances from the colony as great as royal terns were. This may in part due to diet of sandwich terns which may mainly be comprised of anchovies and clupeiforme species, as was found for sandwich terns in North Carolina (see McGinnis & Emslie 2001); anchovies and clupeiforme species comprised a much smaller fraction of the bycatch in my study (see chap.3) as compared to drum species, meaning that trawlers may not have been the optimal place to forage. In contrast, royal terns were recorded in higher numbers farther away from the colonies because their diet is comprised of ca. 40%

drums (McGinnis & Emslie 2001), which were in greater abundance in the bycatch from the trawlers I boarded (see chap. 3).

Conclusions

To date, most of the research that has examined the abundance and distribution of seabirds at trawlers has occurred in European waters (e.g., Walter & Becker 1997, Abello et al. 2003, Ganzalez-Zevallos & Yario 2006). Results from those studies have clearly demonstrated that seabirds are common attendees at trawlers in both nearshore and pelagic systems, and that population dynamics of seabirds may be linked positively to the abundance of discards provided by trawlers (Garthe & Hüppop 1994, Walter & Becker 1997). Little to no similar data are available in the U.S. despite the prevalence of nearshore fisheries near seabird nesting colonies and conservation concerns about many of the breeding seabirds. My data clearly showed that in my study area shrimp trawlers appeared to be a strong, local attractor for seabirds. All of the four locally breeding species attended trawlers regularly, and the most generalist of these (i.e., the laughing gull) was the most abundant and frequently observed. Based on the abundance and frequency of presence of each species during surveys it appears that if policies change for the shrimp fishery or if the shrimping industry continues to decline (i.e. local fleet reduction) then changes in the distribution and abundances of locally breeding seabirds also may occur. Annual surveys at colonies should therefore be continued along with annual assessments of the size of the shrimp fleet. A regular survey for laughing gulls at colony sites (e.g., once every 2 – 3 years) also would be valuable. Additional research should consider assessing the abundance of seabirds at trawlers during the post-breeding season to determine if juvenile birds are relying upon this locally reliable food source. An assessment of movement patterns of individual seabirds via radio telemetry also would provide insight into the extent to which individuals remain with or revisit trawlers throughout the day. Studies of seabird diets at the colonies also would provide much-needed information on the importance of discarded bycatch species in chick diets, and hence the degree to which brood-rearing seabirds may rely on trawlers.

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Figure 2.1 Locations of commercial shrimp ports, seabird nesting colonies, and trawler survey areas along the central South Carolina coast. Studies were conducted from June to August, 2006 and from May to August, 2007. All trawler cruises from which data were collected occurred within the indicated trawler boundary.

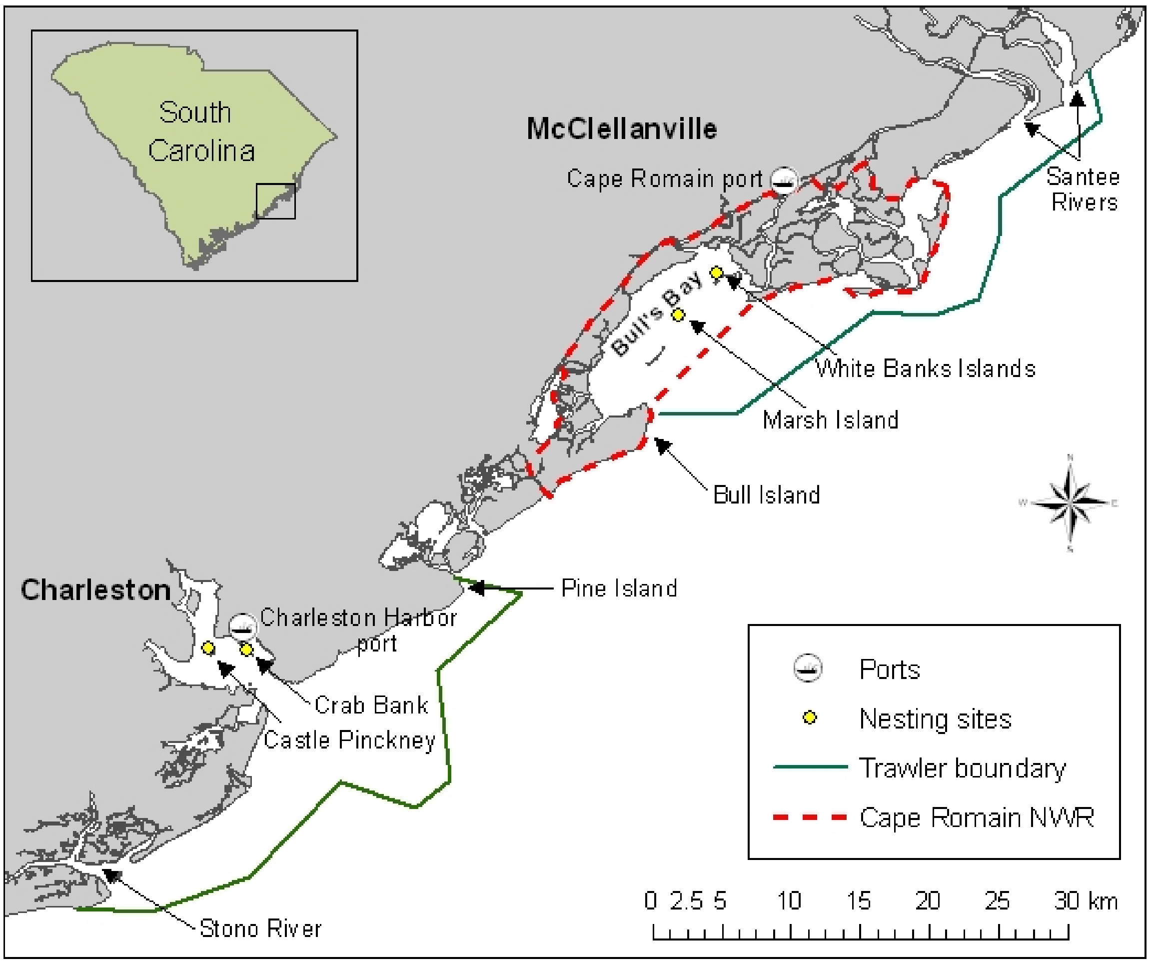


Figure 2.2 Comparison of mean number of seabirds (± 1SE) per species present at shrimp trawlers in Cape Romain 2006, Cape Romain 2007, Charleston Harbor 2006, and Charleston Harbor 2007. The number of surveys (n) varied for each year and location.

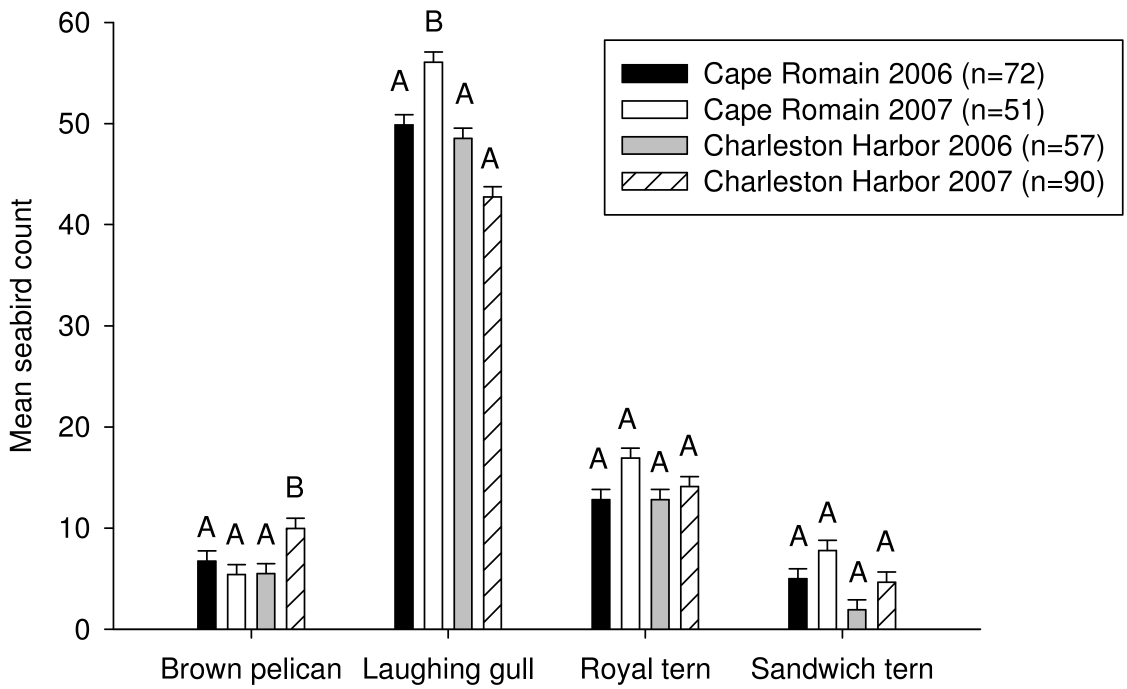
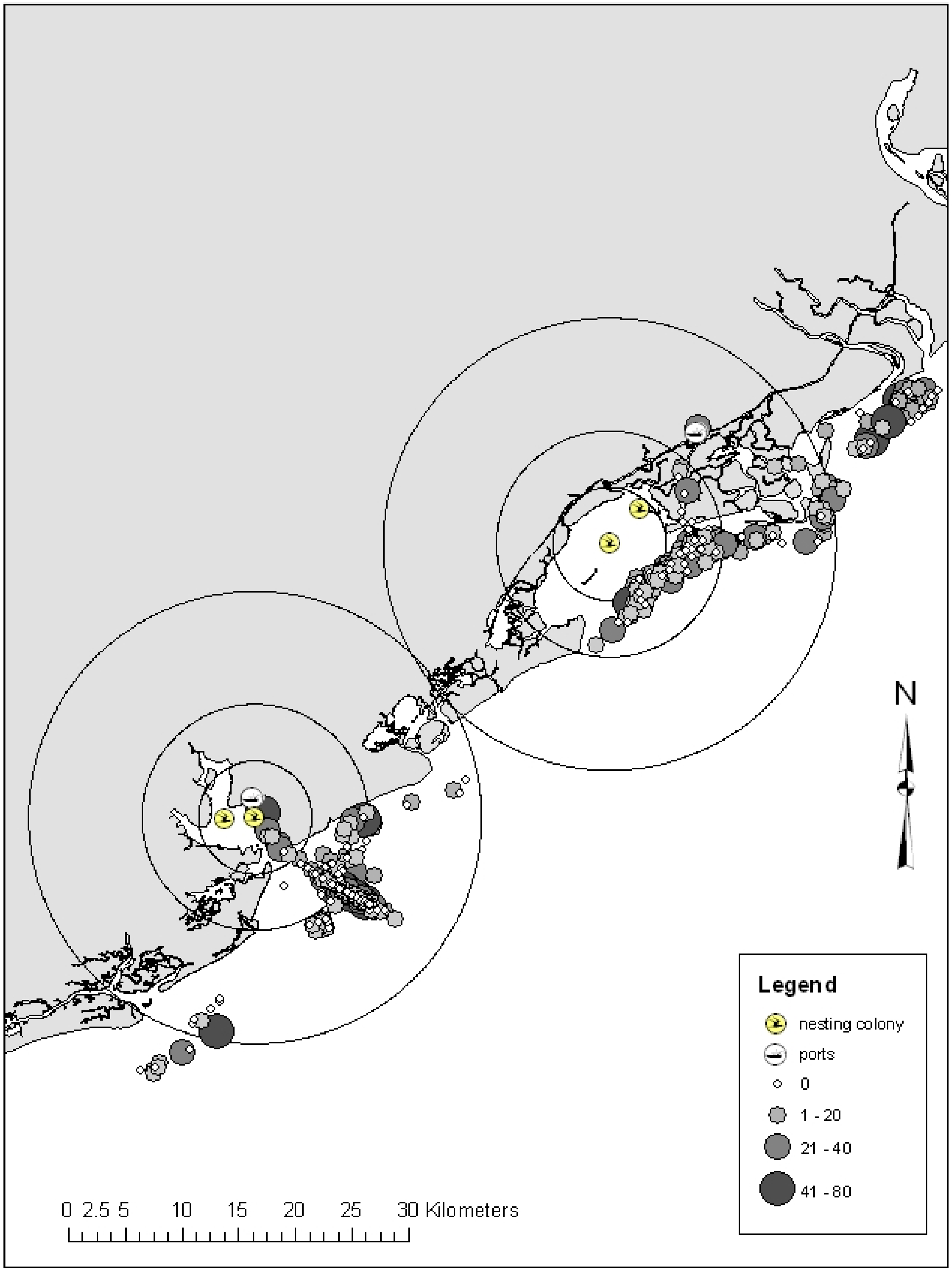
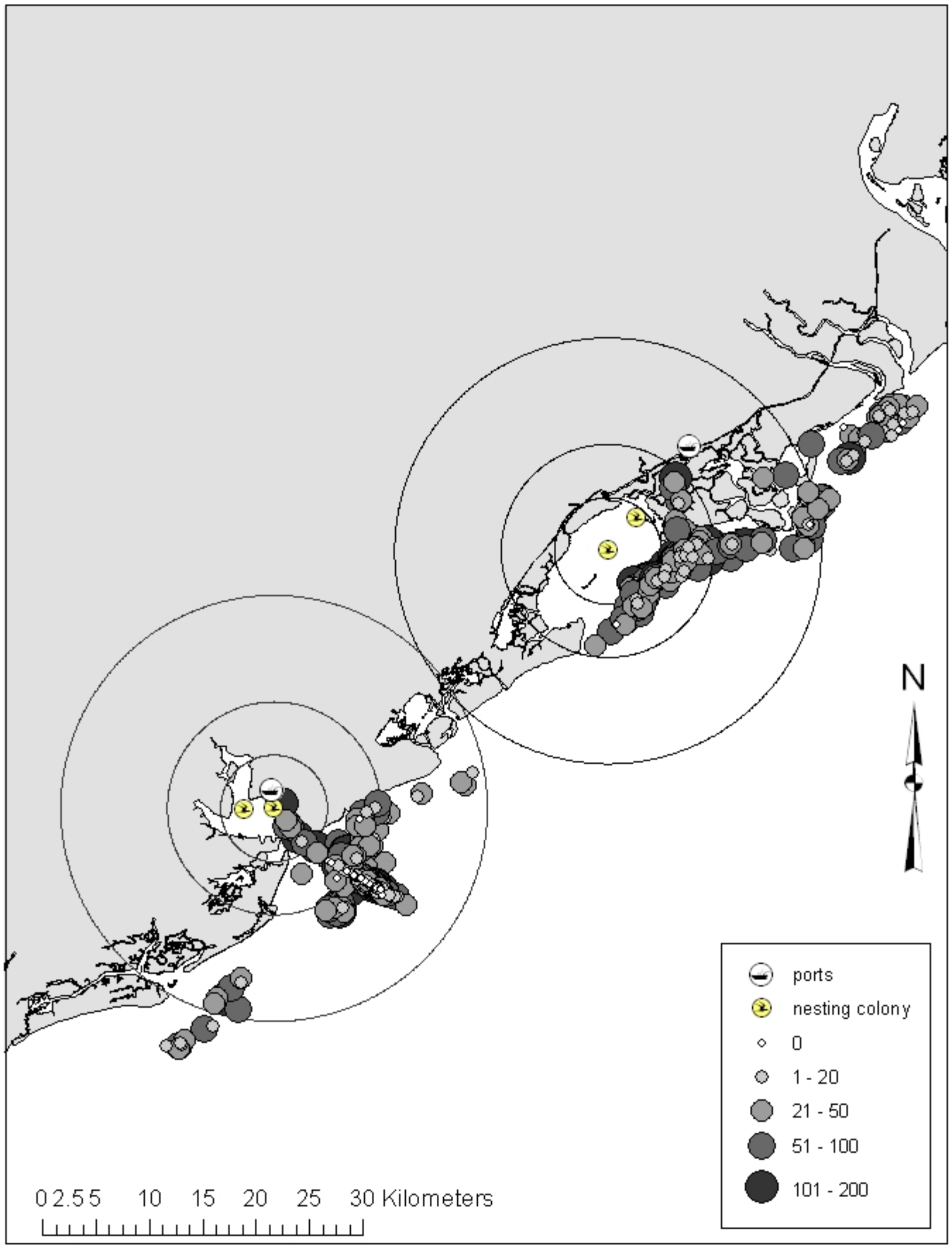


Figure 2.3 Distribution and abundance of (a) brown pelicans, (b) laughing gulls, (c) royal terns, and (d) sandwich terns in the Charleston Harbor and Cape Romain regions, 2006 and 2007. Each circle represents a single count; the size of the circle increases in proportion to the number of birds of that species present (refer to scale in bottom right hand corner, note that the scale changes for each map.). Radii of 5km, 10km, and 20km are centered at the Crab bank and Marsh Island colonies.

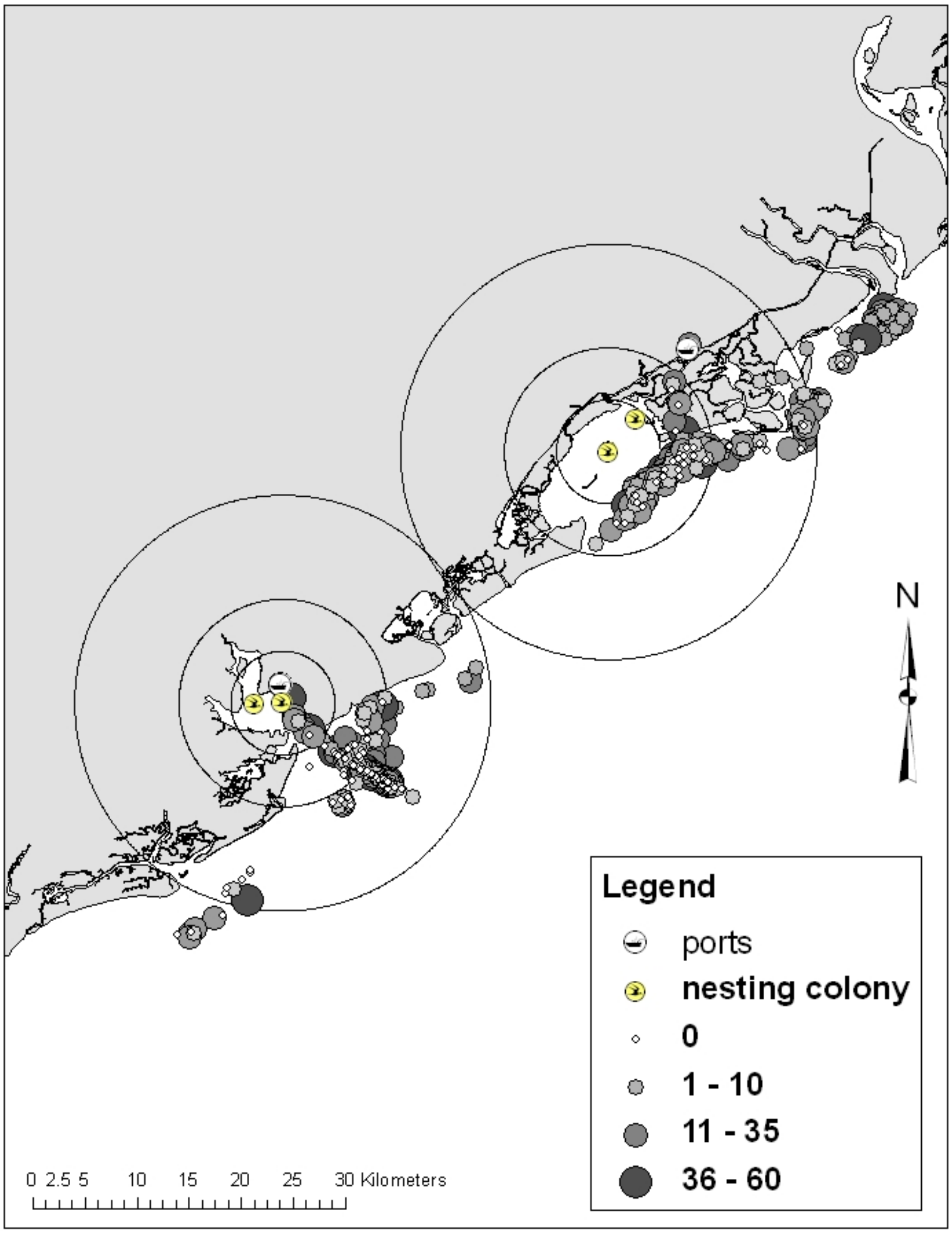
(a) Brown pelican



(b) Laughing gull



(c) Royal tern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1 - 10
11 - 35
36 - 60
0 2.5 5 10 15 20 25 30 Kilometers

(d) Sandwich tern

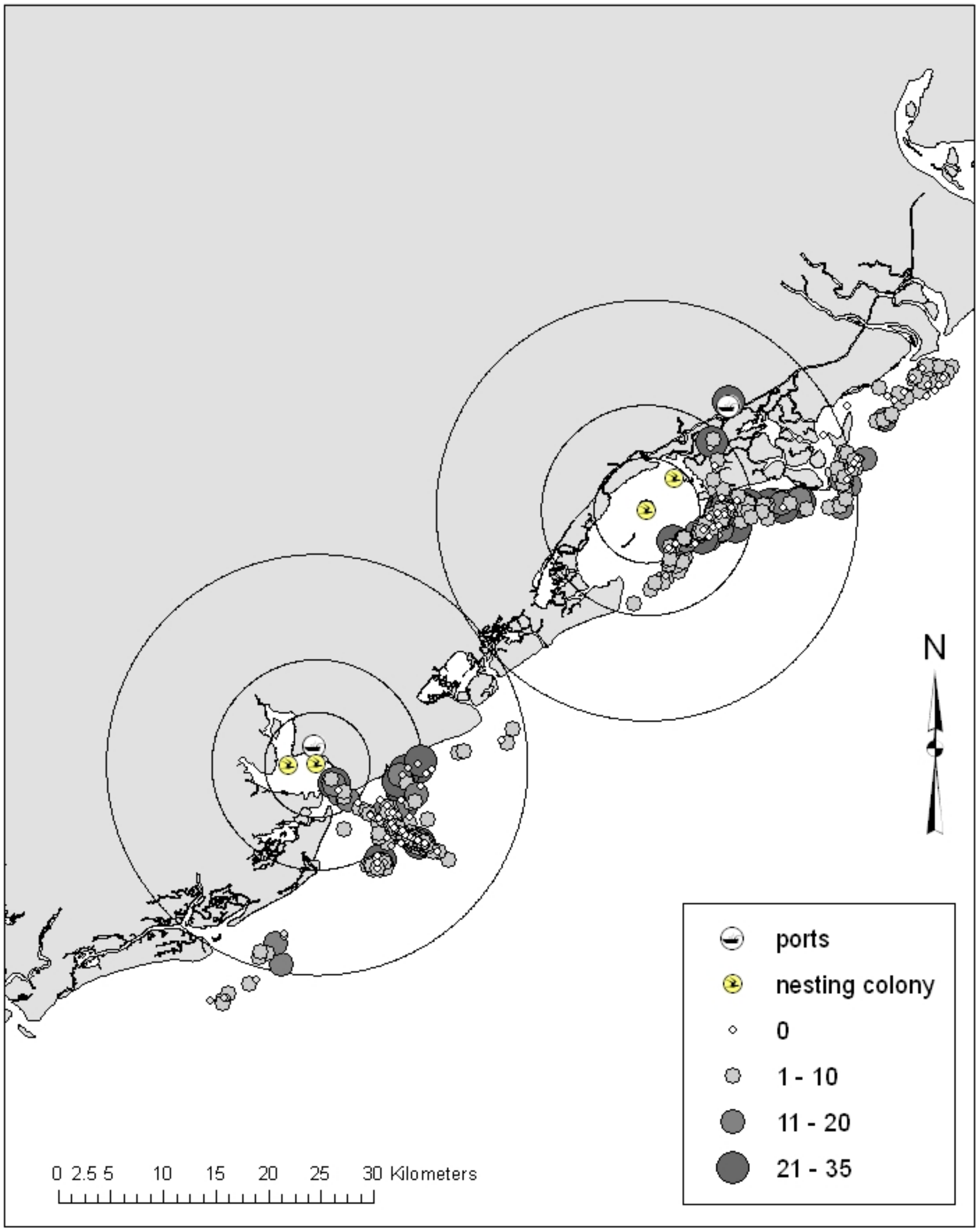

Table 2.1 Nest counts for each of the four focal seabird species in the Charleston Harbor and Cape Romain regions, South Carolina, 2006 and 2007 (South Carolina Department of Natural Resources unpubl. data).

	Charleston Harbor		Cape Romain	
	2006	2007	2006	2007
Brown pelican	611	615	957	685
Laughing gull	1128	na[a]	na[a]	na[a]
Royal tern	1639	1212	841	2537
Sandwich tern	0	35	17	321

[a] nest counts were not conducted for the species

Table 2.2 Number of commercial shrimp cruises, hauls, and surveys conducted in the Charleston Harbor and Cape Romain regions, South Carolina, May – August 2006 and 2007. A dash indicates that no data were collected.

	Charleston Harbor		Cape Romain	
Month	2006	2007	2006	2007
May	-	1, 2, 11	-	1, 4, 18
June	4, 8, 31	4, 11, 47	1, 3, 15	2, 4, 20
July	4, 9, 43	5, 9, 55	6, 18, 80	4, 9, 49
August	1, 2, 11	4, 8, 40	2, 4, 14	-
Total	9, 19, 85	14, 30, 153	9, 25, 109	7, 17, 87

Table 2.3 Proportion of total birds counted, mean (± 1 SE) count per survey (n=435), maximum (max.) count among all surveys, and percentage of surveys during which species was present for seabirds observed at commercial shrimp trawlers in Charleston Harbor and Cape Romain regions, South Carolina, May – August 2006 and 2007.

	2006				2007			
	%Total	Mean (SE)	Max	%Present	%Total	Mean (SE)	Max	%Present
Char.Hbr.[a]								
Brown pelican	8.1	6.7 ± 1.1	55	62.3	13.9	10.0 ± 1.2	83	61.8
Laughing gull	71.5	50.1 ± 4.2	165	94.1	59.8	46.8 ± 3.7	203	94.7
Royal tern	17.5	12.7± 1.3	60	82.3	19.7	14.1± 1.6	60	90.8
Sandwich tern	2.8	1.9 ± 0.4	31	40.0	6.5	4.7 ± 0.5	31	64.5
Other[c]	0.01	0.01± 0.01	1	1.2	0.1	0.05± 0.02	1	4.6
Cape Romain[b]								
Brown pelican	9.1	5.2 ± 0.8	55	56.9	6.3	5.4 ± 1.0	55	51.7
Laughing gull	66.4	44.7 ± 3.7	150	96.3	64.9	56.1 ± 4.1	150	97.7
Royal tern	17.4	12.5± 1.2	78	93.6	19.6	16.9 ± 1.1	48	100
Sandwich tern	6.8	5.0 ± 0.6	35	76.1	9.0	7.8 ± 0.7	24	87.3
Other[c]	0.3	0.3 ± 0.06	3	23.4	0.2	0.2 ± 0.05	2	12.6

[a] 2006 n = 84 surveys, 7059 total birds; 2007 n = 153 surveys, 10,870 total birds

[b] 2006 n = 111 surveys, 11,072 total birds; 2007 n = 87 surveys, 7,510 total birds

[c] Other species observed included Herring Gull (n = 22), Common Tern (n =4), Greater Shearwater (n =5), and Magnificent Frigatebird (n = 1).

Table 2.4 Significant variables from backward selection models of counts of each of the four focal species attending shrimp trawlers in the Cape Romain and Charleston Harbor regions, South Carolina, May – August 2006 and 2007. F statistics and P values for terms that appear in significant interaction terms are not listed as main variables.

Species	Variable 1	Variable 2	Variable 3
Brown pelican	Activity	year*location	year*time
	$F_{2,258} = 23.0$,	$F_{1,258} = 4.0$,	$F_{3,258} = 3.6$,
	$P < 0.0001$	$P = 0.05$	$P = 0.01$
Laughing gull	Activity	year*location	year*date
	$F_{2,262} = 34.1$,	$F_{1,262} = 12.1$,	$F_{1,262} = 4.5$,
	$P < 0.0001$	$P < 0.0001$	$P = 0.03$
Royal tern	Activity	Year	
	$F_{2,263} = 20.9$,	$F_{1,263} = 16.0$,	
	$P < 0.0001$	$P < 0.0001$	
Sandwich tern	location*time	year*date	
	$F_{3,257} = 5.9$,	$F_{1,257} = 8.3$,	
	$P = 0.0007$	$P < 0.004$	

Table 2.5 Mean (± SE) count of individuals observed at commercial shrimp trawlers during each of three operational activities on commercial shrimp trawlers in Cape Romain and Charleston Harbor, South Carolina in 2006 and 2007. Within each activity data were pooled among both study areas and both years. Different uppercase letters (e.g. A, B, C) indicate significant differences within species among activities while lower case letters indicate differences within activity among species as indicated by a fisher's LSD post-hoc test ($P \leq 0.05$). For both cases, letters that are the same indicate that no significant difference was detected.

	Dragging (n = 91)	Haulback (n = 90)	Discarding (n = 89)
Brown pelican	4.0 ± 0.6(A, a)	7.9 ± 1.3(B, a)	13.7 ± 1.3(C, a)
Laughing gull	34.3 ± 2.5(A, b)	50.7 ± 4.7(B, b)	77.2 ± 4.0(C, b)
Royal tern	10.0 ± 0.7(A, c)	16.1 ± 1.2(B, c)	21.0 ± 1.3(C, c)
Sandwich tern	4.0 ± 0.6 (A, a)	5.1 ± 0.6(A, a)	5.3 ± 0.6(A, d)

CHAPTER THREE

SEABIRD USE OF DISCARDS FROM THE INSHORE SHRIMP FISHERY ALONG THE CENTRAL COASTLINE OF SOUTH CAROLINA, USA

Introduction

The interactions between seabirds and commercial fisheries have received a great deal of research attention during the past two decades in northern temperate waters (Furness 1982, Furness et al. 1988, Montevecchi 1988, Garthe et al. 1996), the Central and North Pacific (Jones and DeGange 1988), the Northeast and Southwest Atlantic (Furness et al. 1992, Bertellotti & Yario 2000), Australia and New Zealand (Blaber et al. 1995, Petyt 1995), and South Africa (Ryan & Molony 1988). Primarily, research and management have focused on issues pertaining to the monitoring and reduction of bycatch-related mortality of seabirds (Melvin et al. 2001) and to the assessment of the potential for competition between seabirds and commercial fisheries for forage fish (Garthe and Hüppop 1998). Less attention has been given to the role of discarded bycatch in seabird diets which may subsequently have strong effects on seabird population dynamics (Furness 1982, Garthe et al. 1996).

Many species of piscivorous seabirds forage upon fishery waste which is generated in large quantities by demersal fisheries such as trawlers (Arcos 2001). On average, 25% of global annual marine catch is discarded, creating ca. 27.5 million tons of potential food for seabirds and other marine species worldwide (Alverson et al. 1994, Gislason et al. 2000). Studies from the North Sea demonstrated that scavenging seabirds forage upon offal, roundfish, and to a lesser extent flatfish, cephalopods and benthic invertebrates, utilizing many organisms of different sizes and type that would otherwise be unavailable to them (Garthe et al. 1996, Camphuysen 1995). Furness et al. (1992) found that benthic prey items that were typically unavailable to surface-foraging seabirds such as black-backed gulls (*Larus marinus*) and herring gulls (*Larus argentatus*) comprised a large portion of their diet during portions of the annual cycle in regions where trawler discards were available. At the population and community level, tens of thousands of seabirds each year may be supported by discards from a single regional shrimp fishery, and discards may have contributed to the increase in seabird abundance and distribution in the North Sea and Northeast Atlantic (Furness et al. 1988, Walter & Becker 1997). Similarly, Oro and Ruxton (2001) found that populations of Audouin's gulls (*Larus audouinii*) in the Northwestern Mediterranean have likely increased due to their ability to successfully forage upon discards from trawlers. In contrast, seabirds with more specialized foraging behaviors or diets may not benefit as readily from the availability of discards or may face strong competition for this food source (Furness et al. 1988). Ultimately, this may lead to divergent shifts in population dynamics of generalist and specialist seabirds, particularly if there is competition between the same species for nest sites.

To date, little to no research has been conducted on the foraging aspect of seabird-fisheries interactions in the United States. Therefore, my goal was to determine the extent to which breeding seabirds foraged upon discarded bycatch from commercial trawlers operating nearby two colony sites and to determine which bycatch items these seabirds consumed. I conducted this study in the inshore coastal waters of South Carolina, USA.

The central South Carolina coast supports a substantial commercial shrimping industry that mainly operates in the same inshore waters that provide the primary foraging habitat for brown pelicans (*Pelecanus occidentalis),* sandwich terns (*Sterna sandvicensis*), royal terns (*Sterna maxima*), and laughing gulls (*Larus atricilla*), the four most abundant breeding seabirds in the region. In South Carolina, these species are primarily limited to three nesting locations (Cape Romain, Charleston Harbor, and Deveaux Bank; see Jodice et al. 2007) and each of these areas also supports a commercial shrimp fleet. Annual nest count data show that numbers of nesting brown pelicans and royal terns have declined in South Carolina since the early 1990's, while numbers for sandwich terns have increased (Table 1.1; see Jodice et al. 2007). Annual surveys of nesting laughing gulls are not conducted as frequently although their populations appear to be increasing within the state as they are throughout the southeastern U.S. (Wilkinson 1997, SCDNR unpubl. data). The mechanisms underlying these population trends remain unclear and it is likely that more than one factor is responsible (Jodice et al. 2007). Nonetheless, given that food availability can affect reproductive success in temperate seabirds (Burger 1982), and that bycatch appears to be readily available in the region, it stands to reason that changes in the amount or type of discarded bycatch could affect seabird population dynamics if those seabird species frequently forage upon discards.

My objectives were to determine the composition of bycatch from shrimp trawlers and to determine the extent to which each of the four aforementioned local seabirds foraged upon discards during trawling operations. I collected data on 39 commercial shrimp trawler cruises out of two ports, Charleston Harbor and Cape Romain, along the central coastline of South Carolina and completed 49 discard experiments over a two year period. I also sampled bycatch in order to characterize the species regularly presented to the foraging seabirds as prey items. I formulated the null hypotheses that (1) seabird species would consume discarded bycatch in proportion to their abundance at trawlers (2) all bycatch discarded to seabirds would be taken regardless of prey type (i.e., taxonomic order of bycatch), (3) all bycatch discarded to seabirds would be taken regardless of length of discarded item, and (4) bycatch composition would be consistent regardless of region (Cape Romain or Charleston Harbor) or year (2006, 2007).

Methods

Study Area

Data were collected along the central South Carolina coast (Fig. 3.1) during the seabird breeding season (June-August 2006, May-August 2007) from two study areas. The southern area (hereafter Charleston Harbor) included the nearshore waters from the Stono River north to Pine Island and included the mouth of Charleston Harbor. The northern study area (hereafter Cape Romain) included the nearshore waters from the North Santee River south to Bull Island and included the mouth of Bulls Bay and waters adjacent to Cape Romain National Wildlife Refuge. Each of the study areas supported seabird nesting colonies during 2006 and 2007 (Table 3.1; also see Jodice et al. 2007) and ca. 15 commercial vessels trawled each region 11 to 13 km offshore from May through the beginning of January each year for brown shrimp (*Penaeus aztecus*) and white shrimp (*Penaeus setiferus*). These vessels were ca. 15.0 to 21.0 m in length, towed nets with a 4.7 cm mesh size, and used bags, which gathered the catch, with a mesh size of 4.1 cm. Vessels operating from Charleston Harbor towed 4 nets, 2 on either side of the boat, while vessels operating from Cape Romain towed 2 nets, with one net on either side of the boat. The depth of the trawls ranged from ca. 3-14 m. Once landed, the catch was sorted on deck and bycatch species (i.e., non-target species) were discarded. All tow nets included turtle exclusion devices (TEDs) and bycatch reduction devices (BRDs), which are mandatory for commercial fishing vessels in South Carolina.

Bycatch Composition and Discard Experiments

Samples of bycatch were collected each time the net was pulled in from a tow (i.e., haulback phase) and emptied onto the boat deck. A representative sample (ca. 4l) was collected from the left (bag 1), right (bag 2) and middle (bag 3) of the bycatch pile. Each collected item was identified (species) and its length measured (±5 mm) before discarding the item overboard. I also recorded latitude and longitude coordinates of each haulback.

The fate of discarded items was determined via 'discard experiments'. Discards were defined as all non-target and non-commercial fish and invertebrates caught by shrimp trawlers and subsequently discarded after a haul. After preliminary observations with discarded bycatch species, elasmobranches, echinoderms, cnidarians, and ctenophores were excluded based on the fact that they were not consumed by the four seabirds present. Methods for discard experiments followed Hudson and Furness (1988), Garthe and Hüppop (1994), Garthe et al. (1996), Garthe and Hüppop (1998) and Arcos (2001).

A representative sample (n = 6-10 items) of species that appeared to be relatively abundant in the bycatch on each trawl were collected following the first tow of the day. I selected items between 50 – 600 mm as these were the size most likely to be consumed by the most common seabirds in the area. All items to be used in discard experiments were either discarded within 30 minutes of appearing on deck or stored on ice to preserve the freshness of the sample until discarded. Items were identified to the species level, measured to ± 5 mm, and then discarded individually by hand (ca. 5 fish min^{-1}). I observed each discarded item until its final fate could be determined as (1) consumed (if so, by the seabird species that did so) or (2) not consumed, which resulted in sinking or consumption by other marine organisms (e.g., dolphins, porpoises, or sharks). I did not record kleptoparasitism during these experiments as these events often occurred as birds were flying away from the vessels. Following Arcos et al. (2001), all discard experiments were conducted during the operational discarding and sorting of bycatch to ensure that an artificial feeding environment was not created by our single item discards. I attempted to conduct two discard experiments per cruise, although discard experiments were not conducted if the catch from the haul was small (i.e., discard time $\leq$ 10mins). Moreover, only discard experiments with > 30 items discarded were taken into consideration to avoid biases associated with small sample size (Garthe and Hüppop 1998). I also noted the start time and end times of the discard experiments in order to match the discard experiment with the appropriate seabird survey conducted during that period of time.

A foraging success index (SI) was calculated for each species of seabird for each discard experiment. The SI measured the relative efficiency of each of the four most common seabird species at capturing discarded items (Arcos and Oro 2001). The SI used was based on Ivlev's electivity index (Krebs 1989),

$$SI_j = \frac{O_j - E_j}{O_j + E_j}$$

where SI_j is the foraging success index for each species j, O_j is the observed number of discarded items consumed by species j, and E_j is the expected number of items swallowed, estimated by multiplying the total number of items offered by the percent of that species behind the trawler during that discard experiment (Arcos 2001). The success index (SI) ranged from 1 to -1, where positive values indicate a species of seabird is consuming bycatch in greater proportion to that same seabird's abundance. The null hypothesis tested with the SI was that each species of seabird scavenging upon discarded items had an equal likelihood of obtaining a discarded item, i.e., SI did not differ among species (Oro & Ruiz 1997, Camphuysen 1994).

Statistical Analysis

A negative binomial regression model was used to determine if there were differences in the frequency of occurrence of the four most common taxonomic orders of bycatch between years (2006, 2007) and locations (Charleston Harbor, Cape Romain). I used a one-way ANOVA to determine if there were differences in SIs among the four most common seabird species. A general linear model with manual backward selection (removal criteria was $P<0.10$) was used to determine which independent variables (year, location, date, time of day, taxonomic order, length of item, and usual depth category of items (e.g., benthic, pelagic), affected the SI for each species of seabird. I used a binomial logistic regression model with a stepwise selection procedure to determine which independent variables affected the fate (consumed, not consumed) of discarded items. Independent variables included size of discarded items (small = 50-99mm, medium = 100-199mm, large = 200-399 mm, extra large = 400-600mm), location (Cape Romain or Charleston Harbor), taxonomic order of each species (clupeiformes, pleuronectiformes, perciformes, other), year (2006 or 2007 as a categorical variable), depth category of each discarded species (benthic, pelagic), and time of day (TC1= 6:00am-11:00am, TC2=11:01am-5:00pm). For the variable order of species, *other* orders included teuthida, tetraodontiformes, decapoda, aulopiformes, and scorpaeniformes which made up $\leq$2% of the fish discarded. Taxonomic orders were chosen based on abundance of each group in the bycatch and because each order acts as an indicator of body-type and depth-range. Contrast statements were generated to allow for comparisons among all categories for each categorical variable. Means are reported ± 1 SE and analyses were considered as significant if $P \leq 0.05$, although actual P values are reported throughout.

Results

Bycatch Composition

Bycatch composition is presented in Table 3.2. I identified 5,428 items from 37 species of fish and invertebrates from samples collected during 92 hauls (excluding items from those groups identified as unlikely seabird prey; see Methods). Atlantic croaker (*Micropogonias undulatus*), Atlantic cutlassfish (*Trichiurus lepturus*), star drum (*Stellifer lanceolatus*), and spot (*Leiostomus xanthurus*) were the most abundant bycatch items. In Cape Romain in 2006, Atlantic menhaden (*Brevoortia tyrannus*) comprised 5% of the bycatch, but this same species comprised <2% of the bycatch in Cape Romain in 2007 and in Charleston Harbor in 2006 and 2007. Silver seatrout (*Cynoscion nothus*) comprised ca. 8-9% of the bycatch in Charleston Harbor in both years, but <3.5% in Cape Romain in both sampling years. Species richness was 34 in Charleston Harbor in 2007 and 30 in the other three location-years. The diversity of the bycatch, as measured by Shannon's diversity index (H'), was nearly identical among the four location-years, ranging only from 2.3 to 2.7. The evenness index (E_H) also was nearly identical among the four location-years, ranging only from 0.69 to 0.76. Highest values for both H' and E_H were measured in Charleston Harbor in 2007.

I found several significant differences between either locations or years in the proportion of common bycatch items. Croaker, drum, and menhaden all comprised a greater proportion of the bycatch in Cape Romain compared to Charleston Harbor ($\chi^2 \geq 6.9$, $P \leq 0.008$ for each). In contrast, spot and silver seatrout comprised a greater proportion of the bycatch in Charleston Harbor ($\chi^2 \geq 14.2$, $P \leq 0.0002$ for each). Spot and menhaden comprised a greater proportion of the bycatch in 2007 ($\chi^2 \geq 4.9$, $P \leq 0.03$ for each) while croaker were more common in 2006 ($\chi^2 = 13.22$, $P = 0.0003$). There were substantial shifts in the rank of the abundance of the five most frequently occurring items of bycatch. Spot was the highest or second highest ranked item in all location-years except Cape Romain in 2007 when it was the fourth ranked item. Croaker also was the highest or second highest ranked item in all location-years except Charleston Harbor in 2006 when it was the fifth ranked item. Menhaden was the fifth ranked item in Cape Romain each year but was not among the top five items in the Charleston Harbor region in either year.

Discard Experiments

Of the 1,706 items discarded during experiments in 2006 and 2007, 1,313 (77%) were perch-like fish (i.e., perciformes), 192 (11.3%) were herring-like fish (i.e., clupeiformes), 105 (6.2%) were flatfishes (i.e., pleuronectiformes), and the remaining 95 were from a variety of orders each comprising <2% of the total items discarded during experiments. Laughing gulls consumed 32.7% of the discarded items, brown pelicans consumed 21.2%, royal terns consumed 12.6%, and sandwich terns consumed 2.6% of discarded bycatch. The remaining 30.9% of the discarded items sank or were consumed by other organisms (e.g., sharks, marine mammals). The fate of an item (consumed by seabird or not consumed) was affected most strongly by the length of the item ($\chi^2 = 155.8$, $P < 0.0001$) and the taxonomic order of the item ($\chi^2 = 43.1$, $P < 0.0001$), both of which had an interaction with Julian date ($\chi^2 = 12.4$, $P = 0.006$). In order to adjust odds ratios for length category and taxonomic order appropriately for changes that occurred over the sampling season, odds ratios were estimated at the mean Julian date (i.e., day 72). The odds of consumption for small items were 1.7 to 4.8x more likely compared to the odds of consumption of all other sizes (Table 3.3). The odds of consumption of Clupeiformes were 1.3 to 14.5x more likely compared to the odds of consumption of perciformes, pleuronectiformes, and all other items (Table 3.4). The odds of perciformes, the most frequently occurring group of fish in the bycatch, being consumed were ca. 6x more likely compared to the odds of pleuronectiformes and all other items.

Success Indices

There were significant differences in the mean SI among the four focal seabird species (Fig. 3.2). Brown pelicans were the only species which obtained more bycatch than predicted relative to their abundance, i.e., a positive SI. The SI for royal terns and laughing gulls were weakly negative and there was no difference in the SI between these two species. The SI for sandwich terns was significantly lower ($F_{3,175}= 40.2$, $P < 0.0001$) compared to the other three seabirds.

The SI for each species except laughing gulls varied with date (Table 3.5). The SI of both brown pelicans and sandwich terns tended to increase with date; however royal terns showed a weak trend towards decreased SI with date. These trends cannot be reliably interpreted due to the small sample size early in the season. The SI for brown pelicans also was affected by two interaction terms: sum of birds*year and sum of birds*time of day (Table 3.3). In 2006, there was an inverse relationship between the SI for brown pelicans and the total number of birds foraging at a trawler. In 2007, brown pelican success index did not change with varying levels of individuals present. As with date, a small sample size at the beginning of the sampling season, particularly in 2006, could have affected my detection of trends occurring in the data. Brown pelican success index values in both TC1 and TC2 increased with an increase in sum of birds. The SI of sandwich terns also slightly decreased as the sum of birds increased.

Discussion

Bycatch Composition

Although there were 30-34 bycatch species consistently recorded in each year and each location, four items comprised 56-70% of the items in each year and location. Each of the species of bycatch comprising >5% of the bycatch (e.g. Atlantic croaker, Atlantic cutlassfish, star drum, and spot) in both years and both regions were either benthic or benthopelegic fish (McErlean et al. 1973). Since these fish generally have benthic diurnal activities, it seems more probable that these fishes would be caught in demersal trawler nets which scrape the sediment (Lokkeborg 2005) compared to pelagic species.

Three of the most abundant bottom-dwelling fish in South Carolina are spot, star drum, and Atlantic croaker (Bearden 1964, Miglarese et al.1982, Wenner & Sedberry 1989). Moreover, drum tend to be most common in waters with temperatures >24^{o}C (Miglarese et al. 1982); in South Carolina these temperatures occur during the summer months which coincided with my sampling efforts. Atlantic menhaden, a primary prey item for brown pelicans and a key species to the coastal ecosystems (Pernell & Peters 1994), were found relatively infrequently in each location year. The reasons for the inconsistencies in frequency are unclear and could be attributed to a variety of factors such as food availability, current movement, or success of spawning events. Atlantic menhaden are also schooling pelagic fish, which are more likely to be missed by the trawler nets relative to drum species.

There were significant differences in the abundance of the six most frequently occurring species from the bycatch samples between locations and years. Environmental variables such as differences in depth, salinity, temperature, and bottom composition between regions could account for some of the differences. The timing and locations of trawls also may have contributed to some of the observed differences. Nevertheless, some trends were apparent and deserve further attention. For example, Atlantic croaker increased in frequency for both regions from 2006 to 2007. Although catch and stock data are lacking for this non-commercial species in this region it appears that substantial fluctuations in annual abundance are not uncommon within this region (http://www.dnr.sc.gov/cwcs/pdf/Croaker.pdf). The slight increase in abundance I observed from 2006 to 2007 was, however, inconsistent with what appears to be a decline in catch per unit effort (CPUE) data for this species between 2000 and 2004 (http://www.dnr.sc.gov/cwcs/pdf/Croaker.pdf). Differences in the abundance of star drum and spot between years were also observed although reasons underlying each remain unclear.

Within each year, Atlantic croaker, star drum, and Atlantic menhaden comprised a greater proportion of bycatch items from Cape Romain compared to Charleston Harbor. In contrast, spot comprised a greater proportion of the bycatch in Charleston Harbor as compared to Cape Romain. The spatial differences I observed may be due in part to differences in the habitat quality of the two study areas. For example, Charleston Harbor and the adjacent waters are best described as a high-traffic location with a substantial shipping channel and high amounts of recreational activity. Lower levels of dissolved oxygen and photosynthesizing phytoplankton likely occur in Charleston Harbor because of the constant maintenance and dredging of the shipping channel (Army Corps of

Engineers 1972). Hence spot, which are better adapted to physiologically stressful environments (e.g. low levels of dissolved oxygen and high carbon dioxide; Cochran 1994), may be more common in the Charleston Harbor system and other species which are not as well adapted to these stressful environments may be less common there.

Success Indices

The foraging success index (SI), while useful in providing an estimate of foraging capabilities of seabirds, should be considered with caution because of biases that may affect the actual efficiency of seabirds capturing discards (Arcos 2001). For example, Arcos (2001) suggests that success indices may be biased by not taking into account the time spent following the vessel by different seabird species, leaving the possibility that some species frequent the vessel more so than others and therefore are present during more discard experiments. The success index I calculated only accounted for, on average, 35% of the variability in seabird foraging success. Furness et al. (1992), Garthe and Hüppop (1994), and Arcos (2001) also found significant variability in their estimation of success indices in discard experiments. The indices do not account for differences in size and type of prey selection, which would result in differences in energy obtained by consuming a fish, energetic requirements, or for individual differences in efficiency (Garthe & Hüppop 1994, Camphuysen et al. 1995, Arcos et al. 2001).

The mean positive success index for brown pelicans can most likely be attributed to the surface-seizing strategy (Shields 2002) they employ when scavenging for prey behind trawlers, rather than the more common plunge-diving strategy utilized while hunting for natural prey items. Laughing gulls, which made up ca. 70% of ship-following seabirds (see chap. 2), had a negative SI quite possibly because they frequently engaged in kleptoparasitizing food. Although I did not quantify it, I often recorded laughing gulls obtaining food through kleptoparasitism of terns species and other laughing gulls, as did Arcos (2001) and Bertellotti and Yario (2001) in *Larus*-gulls in the North Sea and off the coast of Patagonia, respectively. Additionally, even though laughing gulls had a negative SI, they were still proportionally higher numbers of laughing gulls behind trawlers (see chap. 2) relative to the other three focal species, and they also consumed the highest percentage of discarded bycatch suggesting they likely were deriving some benefit from trawler discards. Sandwich and royal terns showed negative success indices most likely because they are single prey loaders and also may be more selective feeders compared to gulls. Additionally sandwich terns may be limited to a smaller range of consumable bycatch lengths due to their smaller size compared to the other three focal seabird species. Similar to my study, Arcos (2001) found that sandwich terns had a low success index and had a low percent presence as well in his trawler studies in the Northwest Mediterranean. Even though royal terns had a mean negative SI, this value is not a clear indication that they were not benefiting from trawler discards. Based on the high proportion of surveys during which royal terns were present (see chap. 2), it is likely some benefit is being derived from the trawler discards or they would not consistently follow the vessels.

The general linear model with manual backward selection indicated changes in success index (SI) for three of the four focal seabird species occurred over time (i.e., date). However, because of the lack of samples early in the breeding season it is difficult to determine with any accuracy the true temporal pattern. SI for brown pelicans and sandwich terns was affected by the sum of birds present attending the trawlers. For brown pelicans, SI varied based on the sum of birds behind trawlers at different times of day and different times of year. Variations occurring in brown pelican SI with sum of birds*time of day showed that brown pelicans were more successful at foraging in both morning and afternoon hours when the sum of birds was higher, the reason for which is unclear. For sandwich terns, as the sum of birds increased, SI slightly decreased indicating that sandwich terns are to some extent less competitive when overall seabird abundance increases. Smaller, more specialized seabird species, in this case sandwich terns, potentially have difficulties feeding at fishing vessels especially when competition is strong, as suggested by Furness et al. (1988) and Arcos et al. (2001).

Discard Experiments

My estimated consumption of discarded items (i.e., ca. 70%) is similar to values estimated in trawler studies in the North Sea (i.e., 68-90%; Berghahn & Rosner 1992). The fate of discarded bycatch items in my study was strongly affected by the length of the item. Small fish (50 – 99 mm) were selected more frequently compared to the other three size classes, and medium fish were the next size class most likely to be consumed by seabirds. Small and medium fish (50mm- 199mm) made up 84.5% of the fish discarded in my experiments, indicating a large portion of the fish discarded were in the length range preferred by seabirds. Small items are less likely to be kleptoparasitized than larger items indicating it would be more advantageous to take a smaller fish than a larger one, regardless of seabird size, based on the increased success of consuming the item

(Hudson & Furness 1988, Arcos et al. 2001). Arcos (2001) found that discard items <200mm were the most likely to be consumed by seabirds in the Northwest Mediterranean although various size classes could be taken at different frequencies by different seabirds. Discard length preference in Arcos (2001) can legitimately by compared to this study because of the wide range in sizes of seabirds present (e.g. northern gannet (*Sula bassana*) to sandwich tern) which could consume different lengths of fish. I also found extra large fishes were more likely to be taken than large items. The majority of the extra large fishes discarded (98.5 %) were Atlantic cutlassfish which are snake-like in shape, easily swallowed, and float. This is in contrast to the bulky roundfish (e.g. southern kingfish) comprising the majority (61.7%) of the large category in my study, which are >200mm in length and quickly sink upon discard from the trawler. Oro and Ruiz (1997) found similar results in their Northwest Mediterranean studies where snake-like fish species in discard experiments were some of the most likely items to be consumed by seabirds in discard experiments.

The taxonomic order of the discarded item also affected its fate. Clupeiformes, herring-like fish, which typically constitute a substantial portion of the natural diets of brown pelicans, royal terns, and sandwich terns (McGinnis and Emslie 2001, Shields 2002), were the items most likely to be consumed by seabirds. In contrast, pleuronectiformes (i.e., flatfishes), generally not part of the natural diet of any of the seabird species in my study (see Burger 1996, Shealer 1999, Buckley & Buckley 2002, Shields 2002) were the least likely item to be consumed. The apparent preference for Clupeiformes compared to Pleuronectiformes may be due to differences in the shape of the body between these two orders. For example, the flatfishes are typically wide-bodied compared to the more round-bodied Clupeiformes. Walter and Becker (1997) found that body shape and body width significantly affected seabird prey selection of discard items and that specifically round-bodied prey were consumed more frequently.

Small and medium sized clupeiformes, while slightly more likely to be consumed than perciformes, were only present in relatively low frequencies in my bycatch samples (<6% of bycatch). It appears, therefore, that seabirds would be unlikely to scavenge at trawlers specifically to seek clupeiforme fishes given this low frequency of occurrence. However, small and medium-sized perciformes, which were consumed readily by seabirds during discard experiments, represented a much larger portion of the bycatch sampled (66.5%). Although perciformes may not be a common item in the natural diet for these four seabird species in South Carolina, the relative abundance of this group as discarded bycatch and the apparently preferable round body shape of this group may make them a preferred discard item for these four seabird species in South Carolina. Further support for this comes for the North Carolina study of sandwich and royal tern diets, where McGinnis and Emslie (2001) found drum species comprised 41% of the royal tern diet.

Conclusions

This research demonstrates that breeding seabirds in South Carolina are successfully foraging upon discarded bycatch provided by regional shrimp trawlers despite the fact that many of the discarded items were benthic species that typically would be unavailable to seabirds in their natural diets. Approximately 70% of the bycatch discarded in experiments was consumed by seabirds, suggesting that bycatch possibly makes up a large part of their diet at certain times of year (i.e., breeding months). Laughing gulls, the most abundant species following trawlers in South Carolina (see Chap. 2), consumed the greatest number of items discarded during experiments (ca. 33% of items). The potential benefit of discarded bycatch from shrimp trawlers on seabirds still requires further investigation of proximate composition of bycatch species, bioenergetic modeling, total mass of discards available and diet composition at nesting colonies. These findings should be viewed as a foundation for understanding the effects that inshore shrimp fisheries may have on local breeding seabirds. With further investigation, a more comprehensive management plan can be formulated for ship-following seabirds in South Carolina.

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Figure 3.1 Locations of the two commercial shrimp ports and important seabird nesting colonies in and adjacent to Charleston Harbor and Cape Romain National Wildlife Refuge, South Carolina. Studies were conducted from June to August, 2006 and from May to August, 2007 from each of these ports. Each trawler boundary line represents the area within which all trawls were conducted and all data were collected.

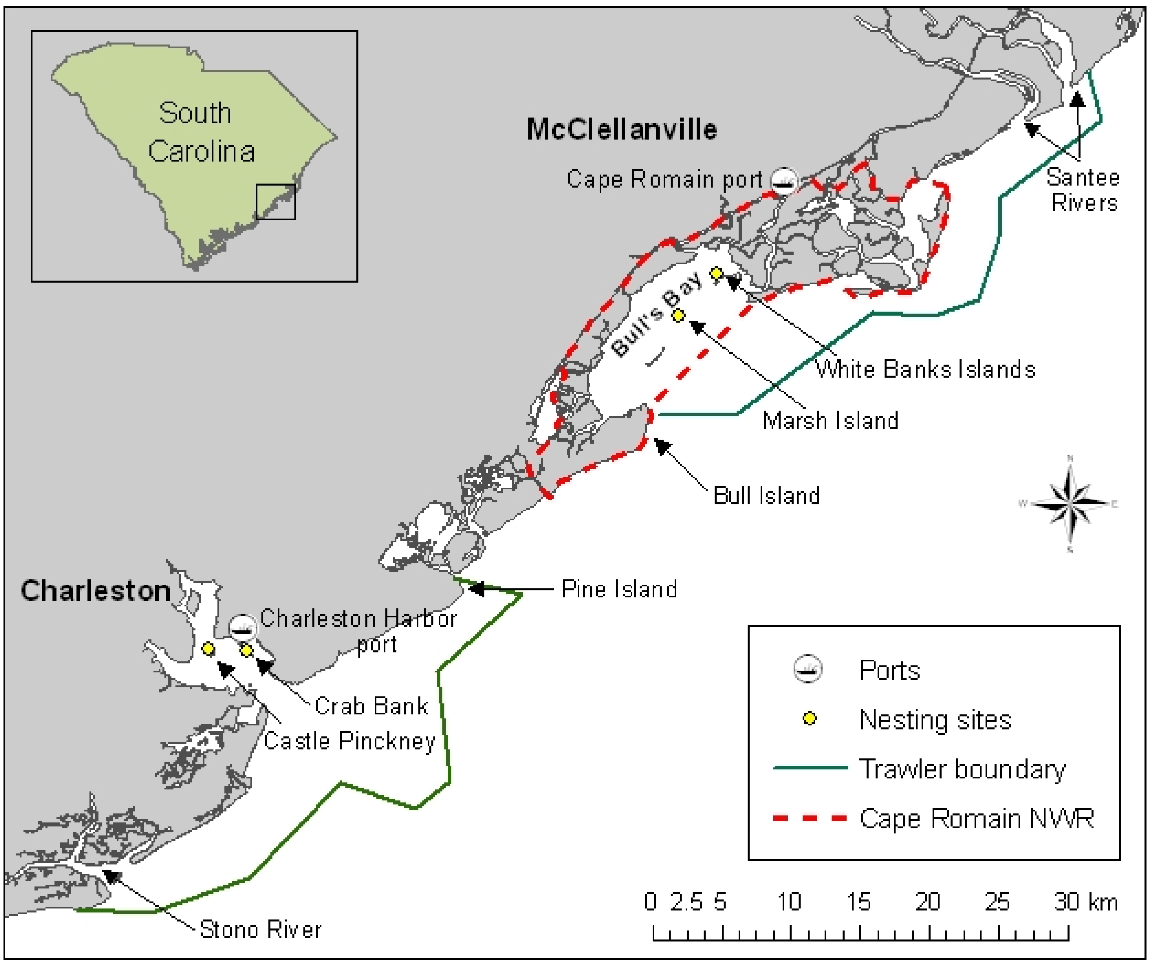

Figure 3.2 Foraging success index (mean ± 1 SE) for brown pelicans, laughing gulls, royal terns, and sandwich terns scavenging discarded bycatch at shrimp trawlers in the Cape Romain and Charleston Harbor regions of South Carolina, May through August, 2006 and 2007. Species sharing identical letters above the x-axis had success indices which were not significantly different (P > 0.05, Fisher's LSD test). The line at zero is a reference for positive vs. negative success indices.

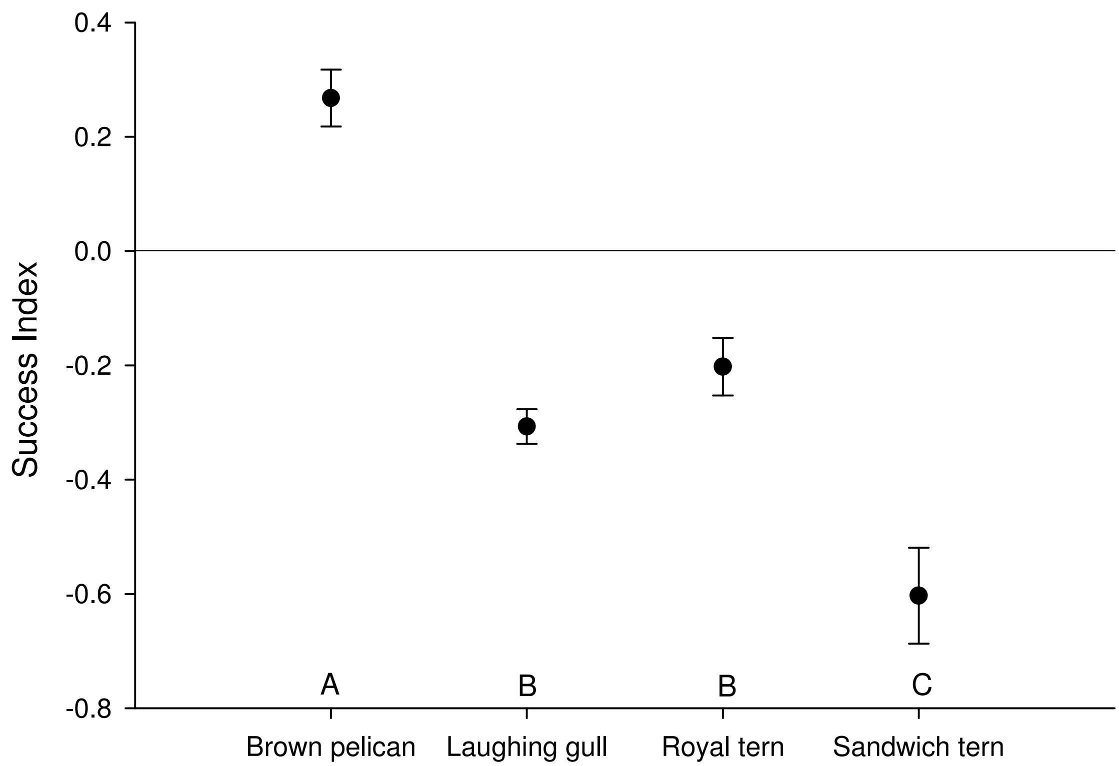

Table 3.1 Nest counts for each of the four focal seabird species in the Charleston Harbor and Cape Romain regions, South Carolina, 2006 and 2007 (South Carolina Department of Natural Resources unpubl. data).

	Charleston Harbor		Cape Romain	
	2006	2007	2006	2007
Brown pelican	611	615	957	685
Laughing gull	1128	na[a]	na[a]	na[a]
Royal tern	1639	1212	841	2537
Sandwich tern	0	35	17	321

[a] nest counts were not conducted for the species in SCDNR seabird census

Table 3.2 Composition of bycatch (% of items among all hauls) collected from Cape Romain (n = 42 hauls) and Charleston Harbor (n = 50 hauls), South Carolina, May-August 2006 and 2007. Bolded values indicate species that comprised >5% of the bycatch for that location-year. Of the six species that comprised >5% of the bycatch, italicized values indicate significant differences (*P*<0.05) between years within region and an asterisk indicates significant differences between regions determined from a negative binomial model.

	Cape Romain		Charleston Harbor	
Common name (*Genus species*)	2006 n=1306	2007 n=1195	2006 n=916	2007 n=2011
Atlantic bumper *(Chloroscombrus chrysurus)*	0.67	0.38	3.5	1.3
Atlantic croaker *(Micropogonias undulatus)**	***22.4***	***33.3***	***7.2***	***18.7***
Atlantic cutlassfish *(Trichiurus lepturus)*	**7.0**	**10.6**	**11.3**	**10.4**
Atlantic menhaden *(Brevoortia tyrannus)*	***5.0***	1.9	1.0	0.16
Atlantic moonfish (*Selene setapinnis*)	0	1.5	0	3.6
Atlantic threadfin herring *(Opisthonema oglinum)*	1.5	1.3	4.1	4.4
Banded drum *(Larimus fasciatus)*	1.3	2.9	4.2	3.12
Bighead searobin *(Prionotus trilobus)*	0.83	0.96	0.61	0.91
Bluefish (*Pomatomus saltatrix)*	0	0.14	0.27	1.13
Blunthead puffer (*Sphoeroides pachygaster)*	0.08	0	0	0
Broad-striped anchovy (*Anchoa hepsetus*)	0.60	2.3	1.1	1.2
Butterfish *(Peprilus triacanthus)*	2.4	1.24	5.4	3.4
Gulf flounder (*Paralichthys albigutta)*	0	0	0	0.03
Harvest fish *(Peprilus alepidotus)*	0.04	1.8	2.4	1.6
Hogchoaker (*Trinectes maculates*)	3.0	3.3	0.14	1.3
Inshore lizardfish (*Synodus foetens*)	0.12	0.43	0.27	0.60
Leopard searobin (*Prionotus scitulus*)	3.0	0.10	0.41	0.63
Lookdown (*Selene vomer*)	1.0	0.70	0.27	0.44
Oscillated flounder (*Ancylopsetta quadrocellata*)	0	0	0	0.06
Offshore tonguefish (*Symphurus civitatus*)	0.40	0.10	0.28	0.19
Planehead filefish (*Monocanthus ciliatus*)	0	0	0.07	0.03
Rock sea bass (*Centropristis philadelphica*)	0.16	0	0.20	0.06
Scup (*Stenotomus chrysops*)	0.12	0.10	0.81	0.03
Silver perch (*Bairdiella chrysoura*)	0.04	0.05	0	0.50
Silver seatrout *(Cynoscion nothus)**	1.4	3.3	**7.8**	**8.8**
Southern flounder (*Paralichthys lethostigma*)	0.71	0.05	1.2	0.85
Southern hake (*Urophycis floridana*)	0	0.05	0	1.0
Southern kingfish *(Menticirrhus americanus)*	3.1	2.6	1.1	3.8
Southern stargazer (*Astroscopus y-graecum*)	0	0	0	0.03
Spadefish (*Chaetodipterus faber*)	0.12	0	0.14	0
Spanish mackerel (*Scomberomorus maculates*)	0.32	0.89	0.20	1.9
Spot *(Leiostomus xanthurus)*	***23.6***	***6.1***	***32.0***	***14.7***
Squid (*Loliguncula brevis*)	3.0	1.2	0.88	0.47
Star drum (*Stellifer lanceolatus*)*	**16.9**	**18.3**	**9.7**	**12.4**
Striped burrfish (*Chilomycterus schoepfi*)	0.08	0.14	0.55	0

Summer flounder (*Paralichthys dentatus*)	0.28	1.67	1.7	0.66
Weakfish (*Cynoscion regalis*)	0.83	2.6	1.2	1.6
TOTAL	100	100	100	100

Table 3.3 Odds ratios and 95% confidence intervals of item fate (consumed by seabirds or not) in discard experiments conducted from commercial shrimp trawlers in Cape Romain and Charleston Harbor, South Carolina, May – August 2006 and 2007. Length categories were developed based on the relative abundance of lengths of discarded prey items; small = 50 – 99 mm, medium = 100 – 199 mm, large = 200 – 399 mm, extra large = 400 – 600 mm.

Length category contrast	Odds ratio	95%CI	χ^2	*P*-value
Small vs. medium	1.79	1.02, 2.21	4.29	0.007
Small vs. large	4.82	2.67, 8.33	31.50	<0.001
Small vs. extra large	1.81	1.28, 2.54	9.04	0.007
Medium vs. large	2.68	1.83, 3.49	25.67	<0.001
*Medium vs. extra large	1.01	0.79, 1.42	0.25	0.625
Large vs. extra large	0.37	0.27, 0.53	30.71	<0.001

* No significant difference ($P > 0.05$)

Table 3.4 Odds ratios and 95% confidence intervals of item fate (consumed by seabirds or not) in discard experiments conducted from commercial shrimp trawlers in Cape Romain and Charleston Harbor, South Carolina, May – August 2006 and 2007. Taxonomic categories were developed based on the relative abundance of different orders in discarded prey items; categories include clupeiformes, perciformes, pleuronectiformes, and *other*. The *other* category was a combination of the orders teuthida, tetraodontiformes, decapoda, aulopiformes, and scorpaeniformes, each of which made up $\leq$2% of the fish discarded.

Group category contrast	Odds ratio	95%CI	χ^2	*P*-value
*Clupeiformes vs. perciformes	1.27	0.87, 1.86	1.52	0.205
Clupeiformes vs. other	7.77	4.44, 13.59	51.59	<0.001
Clupeiformes vs. pleuronectiformes	15.74	8.74, 28.34	84.36	<0.001
Other vs. pleuronectiformes	2.03	1.08, 3.82	4.78	0.034
Other vs. perciformes	0.16	0.10, 0.26	60.49	<0.001
Pleuronectiformes vs. perciformes	0.08	0.05, 0.13	101.46	<0.001

* No significant difference ($P > 0.05$)

Table 3.5 Significant variables that affected the success index of each of the four focal seabirds attending shrimp trawlers in the Cape Romain and Charleston Harbor regions, South Carolina, May – August 2006 and 2007. P values for terms that appear in significant main variables and interactions are bolded (removal criteria was *P*<0.10).

Brown pelican	Laughing gull	Royal tern	Sandwich tern
F_{df} ; *P*	F_{df} ; *P*	F_{df} ; *P*	F_{df} ; *P*
Time of day $0.02_{1,34}$; 0.9	NS	Julian date $2.9_{1,47}$; 0.09	Julian date $3.1_{1,37}$; 0.09
Julian date $4.7_{1,34}$; 0.04			Sum of birds $6.3_{1,37}$; 0.02
Sum of birds $10.6_{1,34}$; 0.003			
Year $34.9_{1, 34}$; 0.1			
Sum of birds*year $32.6_{1,34}$; <0.0001			
Sum of birds*time of day $11.3_{1,34}$; 0.002			
$R^2 = 0.71$	$R^2 = 0.16$	$R^2 = 0.23$	$R^2 = 0.28$

CHAPTER FOUR

CONCLUSION

Population dynamics of seabirds have been linked to availability of bycatch discarded from commercial fishery operations. In my study, I investigated the extent to which breeding seabirds foraged upon discarded commercial trawler bycatch as well as the spatial distribution and relative abundance of seabirds behind trawlers operating nearby to colony sites throughout the breeding season. I also recorded the composition of the bycatch from shrimp trawlers along the central South Carolina coastline and which of these discarded items were most likely to be consumed by foraging seabirds.

The second chapter of this thesis, "Abundance and distribution of ship-following seabirds in nearshore waters of South Carolina, USA" assessed the association of seabirds with shrimp trawling vessels in South Carolina. Specifically, I examined the distribution and abundance of ship-following seabirds associated with shrimp trawlers in South Carolina. I conducted seabird surveys during 39 cruises on commercial shrimp trawlers operating from the Cape Romain and Charleston Harbor ports during May – August, 2006 and 2007. I examined counts of seabirds by species in relation to location, year, date, time of day, and the activity that was occurring onboard the trawler (i.e. dragging, hauling, and discarding). I found that in my study area shrimp trawlers appeared to be a strong, local attractor for seabirds. All of the four locally breeding species attended trawlers regularly, and the most generalist of these (i.e, the laughing gull) was the most abundant and frequently observed. Trawler activity (i.e., phase of trawler operations) was the factor which most affected the abundance in seabirds and spatial distributions varied from species to species.

Chapter three, "Seabird use of discards from the inshore shrimp fishery along the central coastline of South Carolina, USA" discusses the significance of discarded bycatch in the diets of the four most abundant species of ship-following seabirds in South Carolina (i.e., laughing gulls, brown pelicans, royal terns, sandwich terns). I collected bycatch each time the trawler net was hauled to characterize the composition of the bycatch. Additionally, I conducted discard experiments to determine which bycatch items were most frequently consumed by each of seabird species and measured foraging efficiency and prey selection as they related to discarded items. I found that Atlantic croaker, star drum, spot, and Atlantic cutlassfish were the most abundant species in the bycatch. Approximately 69% of the discarded bycatch in experiments was consumed by seabirds, suggesting that bycatch possibly makes up a large part of their diet at certain times of year (i.e., breeding months). Brown pelicans consumed more discards than predicted based on their frequency while the other three seabirds each consumed fewer discards than predicted based on their frequency. Seabirds selected smaller items compared to larger items, and selected benthic fish that typically would not be available to this suite of seabirds.

This research substantially increases our knowledge of seabird ecology in the South Atlantic Bight as it relates to commercial fisheries, particularly because no similar data are available in the U.S. despite the prevalence of nearshore fisheries in close proximity to seabird nesting colonies. My study suggests that if policies change for the shrimp fishery in South Carolina or if the shrimping industry continues to decline (i.e., local fleet reduction), then changes in the foraging ecology of locally breeding seabirds also may occur. Therefore, monitoring of seabird abundances, distribution, and consumption of discards should continue in order to track changes not only for the benefit of declining seabird populations, but as an indicator of the health of the overall coastal ecosystem.