SEABIRD ATTENDANCE AT SHRIMP TRAWLERS IN NEARSHORE WATERS OF SOUTH CAROLINA

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SUMMARY

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Many seabirds attend commercial fishing vessels to obtain food, but the effect on their distribution and abundance has received virtually no attention off the southeastern United States. We examined distribution and abundance of four locally breeding seabirds (Brown Pelicans *Pelecanus occidentalis*, Laughing Gulls *Leucophaeus atricilla*, Royal Terns *Sterna maxima*, and Sandwich Terns *Sterna sandvicensis*) in relation to shrimp trawling activity in the nearshore waters of South Carolina from May to August, 2006 and 2007. Since 1992, numbers of breeding Brown Pelicans and Royal Terns have declined substantially in South Carolina, while the shrimp fleet has declined concurrently for economic reasons. We counted more than 36 000 birds in surveys conducted on 39 commercial trawler-days. All four locally breeding seabirds attended trawlers regularly, but pelagic seabirds were rare. Laughing Gulls were the most abundant species observed, and Laughing Gulls and Royal Terns were each observed on >90% of surveys. Seabird abundance was highest when trawlers were discarding bycatch. Spatial distributions varied among species but abundance of each species appeared to be relatively consistent out to 30 km from colonies. Given their abundance at trawlers, Laughing Gulls may be affected most strongly by the availability of discarded bycatch, but terns and Brown Pelicans forage at trawlers frequently enough that changes in the size of the shrimp fleet might affect their foraging ecology as well.

Key words: Brown Pelican, Laughing Gull, Royal Tern, Sandwich Tern, seabird-fisheries interactions, shrimp fishery, South Carolina USA, trawlers

INTRODUCTION

Commercial fisheries are prevalent in the global marine environment and directly or indirectly affect target and nontarget species (Gislason *et al.* 2000). Direct impacts such as mortality of target and nontarget fish (bycatch) from commercial harvesting operations are readily quantifiable and often measured. In contrast, indirect impacts of marine fishing—competition between fisheries and marine predators for fish (Oro & Ruiz 1997) and changes in the trophic structure or abundance of both marine fish stocks and their predators—are more difficult to quantify (Gislason *et al.* 2000). This appears to be especially true for apex predators such as seabirds which frequently scavenge at fishing vessels (Garthe *et al.* 1996, Oro & Ruiz 1997, Gonzalez-Zevallos & Yorio 2006, Arcos 2001, Barrett *et al.* 2007), are long-lived, wide-ranging, and habitual in terms of migratory pathways, and often include taxa of conservation concern (Boersma *et al.* 2002). The potential for nontarget species such as seabirds to experience both short- and long-term impacts from commercial fisheries is therefore considerable and extends across the marine ecosystem from nearshore to pelagic waters.

Ecological relationships between fisheries and seabirds include interactions that, at least proximately, may be considered negative, mutualistic, or positive. For example, mortality of seabirds as bycatch in commercial fisheries has been widely documented (across taxa, geographic regions, and types of fisheries) and the negative effects extend from individuals to entire populations (Melvin & Parrish 2001, Baker *et al.* 2007). Research has also been conducted on competitive and mutualistic relationships between commercial fishing vessels, seabirds, and subsurface predators (Camphuysen & Webb 1999, Furness 2003, Hebshi *et al.* 2008). A topic that has received far less attention, but that may have an equally strong effect on foraging ecology of seabirds and ultimately on demographics, is the enhanced availability of food to marine predators when nontarget fish are discarded from commercial fishing boats. These artificial and ephemeral food patches may attract thousands of birds, and the increased availability of food they represent may lead to changes in seabird distribution, abundance, and population dynamics (Furness & Monaghan 1987, Garthe & Hüppop 1994). For example, studies in the North Sea suggest discarded bycatch supports about 6 million seabirds (Garthe *et al.* 1996) and that the dynamics of nearshore fisheries, such as shrimp fleets, strongly affect the distribution, abundance, and population trends of seabirds in the region (Walter & Becker 1997). There have been few examinations of similar relationships outside of Europe, however, or in nearshore waters, despite the high degree of overlap in the distribution of commercial fishing operations and seabirds in such systems.

South Carolina has a long history of shrimp trawling. Despite an economic decline in the shrimp fishery during the past decade, it is still the largest and most economically valuable commercial fishery in the state (South Carolina Sea Grant Consortium 2009). Waters used by the shrimp fishery are adjacent to colonies of Brown Pelicans *Pelecanus occidentalis*, Laughing Gulls *Leucophaeus atricilla*, Royal Terns *Sterna maxima*, and Sandwich Terns *Sterna sandvicensis*. Nest counts of Brown Pelicans and Royal Terns have declined in the state since the late 1990s, while numbers of Sandwich Terns and Laughing Gulls have increased. The mechanisms underlying these trends remain unclear, and it is likely that multiple factors are responsible (Jodice *et al.* 2007).

In light of the population trends in seabirds, the general decline in the shrimp fishery, and the potential of seabird populations to indicate the health and condition of marine systems, we examined the abundance and distribution of seabirds in relation to commercial shrimp trawlers. Our goal was to detect interactions between seabirds and the fleet, and thereby gauge the likelihood that changes in size or operational nature of the fleet could affect seabirds in the region. We conducted seabird surveys from commercial shrimp trawlers operating in the nearshore waters of the central South Carolina coast during May – August, 2006 and 2007. We examined counts of seabirds by species in relation to study area, year, date, time of day, number of shrimp trawlers operating, and the activities of the trawler from which surveys were being conducted. We also examined the spatial distribution of seabirds foraging at trawlers in relation to colony locations. These data add to a growing body of literature on the relationship between seabirds and commercial fisheries and, to our knowledge, are the first such contribution from this region.

METHODS

Study area

Dates of commercial shrimp trawling along the South Carolina coast vary annually, but operations generally begin in May or June and end in December or January. Data were collected during the seabird breeding season (May – August, 2006 and 2007) in two localities on the central South Carolina coast—waters around the mouth of Charleston Harbor and waters adjacent to Cape Romain

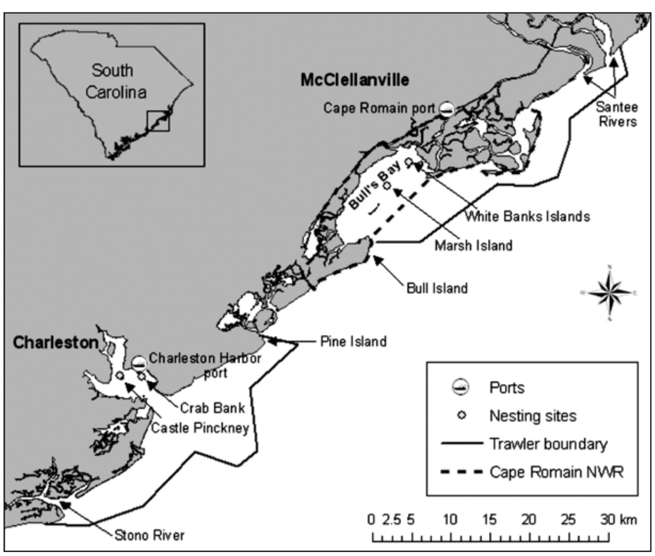

Fig. 1. Locations of commercial shrimp ports, seabird nesting colonies, and trawler survey areas along the central coast of South Carolina. All trawler cruises from which data were collected occurred within the indicated trawler boundary.

National Wildlife Refuge (hereafter CRNWR, or more generally, Cape Romain) (Fig. 1). The gap between the northern and southern trawl areas was not surveyed because trawls were not conducted there. Approximately 15 commercial vessels trawled each area, 11 – 13 km offshore in 3 – 14 m of water, for brown shrimp *Farfantepenaeus aztecus* and white shrimp *Litopenaeus setiferus*. Once landed, the catch was sorted on deck and bycatch (nontarget) species were discarded. All tow nets included turtle exclusion and bycatch reduction devices. The Charleston Harbor area supported a seabird colony on Crab Bank, the Cape Romain area supported seabird colonies on Marsh Island and smaller islands adjacent to it, and a third seabird colony existed at Deveaux Bank, about 35 km south of Charleston Harbor at the mouth of the North Edisto River (Table 1; see Jodice *et al.* 2007 for history and detailed descriptions of colonies).

We conducted seabird surveys from the fishing vessels *Winds of Fortune*, *Miss Georgia*, *Cape Romain*, and *Village Lady* and on one day from the research vessel *Lady Lisa*. All trawls were completed at a speed of ca. 2.5 knots, trawl times for each tow were 2 – 4 h, each cruise typically included 2 – 3 hauls/day, and cruises typically occurred from ca. 05:00 to ca. 18:00. We categorized trawler operations as: (1) dragging, the period during which the net was dragged (beginning, for second and subsequent hauls, after all bycatch had been discarded), (2) haulback, the process of bringing the net onto the vessel, and (3) discarding, the process of sorting and discarding bycatch while running to another fishing location or after resetting the net in the same location (Gonzalez-Zevallos & Yorio 2006). Dragging was the longest of the three activities, comprising about 75% of the haul time.

We counted ship-attending seabirds in surveys at 40-min intervals throughout the duration of each cruise (39 cruises, 434 surveys). During each survey, the observer (LCW) stood in the stern corner of the vessel. This provided 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, we scanned repeatedly a 270° arc around the ship (the area obstructed by the wheel-house being excluded) counting all birds of each species in turn until all birds within a 50 m radius were counted. The 50-m radius was calibrated periodically

TABLE 1
Nest counts from the three primary colony sites in South Carolina for each of the seabird species observed most frequently from commercial shrimp trawlers operating in the nearshore waters of South Carolina, May – August 2006 and 2007[a]

	Charleston Harbor		Cape Romain		Deveaux Bank	
Species	2006	2007	2006	2007	2006	2007
Brown Pelican	611	615	957	685	2310	1268
Laughing Gull	1128	na[b]	na[b]	na[b]	na[b]	na[b]
Royal Tern	1639	1212	841	2537	2565	452
Sandwich Tern	0	35	17	321	2196	79

[a] Source: South Carolina Department of Natural Resources, unpubl. data.
[b] Nest counts not conducted.

throughout the day using a range finder (Heinemann 1981, McGinnis & Emslie 2001). All seabirds in the study were plunge-divers and surface feeders, thus we did not need to account for diving time. Additionally, the number of species attending (usually <5) and total counts (usually <80 birds) were relatively low, so it was not difficult to identify or count the individuals present during any survey. As with most similar surveys (e.g. Abello *et al.* 2003, Garthe & Scherp 2003, Oro & Ruiz 1997), individuals were not classified by age group due to the difficulty of accurately assessing plumage differences during surveys. During each survey we also recorded geographical coordinates, date, time of day, weather conditions, vessel activity, pull number, and number of trawlers within 5 km of the observer vessel.

TABLE 2
Models relating trawler activity (AC), number of trawlers in vicinity of observer (NT), study area (SA), time block within day (TB)[a], Julian date within year (JD), and year (YR) to counts of seabirds conducted from commercial shrimp trawlers operating in nearshore waters of South Carolina, May – August 2006 and 2007

Model	Hypothesis description	Model structure
1	Count constant	Intercept only
2	Count affected by trawler activity (dragging, haulback, or discarding)	AC
3	Count affected by Julian date within year	JD
4	Count affected by year (2006 or 2007)	YR
5	Count affected by time of day (four time blocks)	TB
6	Count affected by study area (Charleston Harbor or Cape Romain)	SA
7 & 8	Count affected by location and activity (with and without interaction)	SA + AC; SA + AC + (SA * AC)
9 & 10	Count affected by time and activity (with and without interaction)	TB + AC; TB + AC + (TB * AC)
11 & 12	Count affected by location and time (with and without interaction)	SA + TB; SA + TB + (SA * TB)
13 & 14	Count affected by location and year (with and without interaction)	SA + YR; SA + YR + (SA * YR)
15 & 16	Count affected by date and activity (with and without interaction)	JD + AC; JD + AC + (JD * AC)
17 & 18	Count affected by date and year (with and without interaction)	JD + YR; JD + YR + (JD * YR)
19 & 20	Count affected by date and time (with and without interaction)	JD + TB; JD + TB + (JD * TB)
21 & 22	Count affected by location and date (with and without interaction)	SA + JD; SA + JD + (SA * JD)
23	Num. trawlers within 5 km of observer vessel	NT
24	Global	All main variables and two-way interactions

[a] Time blocks as defined in Methods.

We mapped spatial distributions of birds counted during the surveys (UTM 17N NAD83) following Walter & Becker (1997), Abello *et al.* (2003), and Garthe & Scherp (2003). We use graduated proportional symbols to represent the number of seabirds counted and plot symbols only at locations where surveys were conducted, i.e., blank areas in maps (see below) indicate an absence of surveys, not an absence of birds.

Statistical analysis

Analyses were restricted to counts of Brown Pelicans, Laughing Gulls, and Royal and Sandwich terns, which comprised >99% of the individuals counted (see Results). Autocorrelation between consecutive counts within a species within a day ranged from 0.38 to 0.56 (all $P < 0.05$) for each of the four focal species. To eliminate this temporal autocorrelation, we 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 followed by haulback and discarding). Although summary tables are based on the complete data set, we used calculated mean values (274 means, transformed by square root + 3/8; Sokal & Rohlf 1981) for all analyses that include count data. We calculated partial correlation coefficients among species in a MANOVA to express the correlative relationship between two species given the main effects also in the model.

Generalized linear models and a model selection approach (Burnham & Anderson 2002) were used to assess the relationship between abundance of each species and a suite of potential explanatory variables. The model selection approach allows for testing of specific hypotheses (models) and does not rely on a stepwise or similar procedure. Variables examined included trawler activity (dragging, haulback, or discarding), numbers of trawlers within 5 km of the observer vessel, year (2006, 2007 treated as a categorical variable), location (Charleston Harbor or Cape Romain), date within year, and time of day (time block [TB] 1 = sunrise + 3 h, TB 2 = end of TB 1 to sunrise + 6 h, TB 3 = end of TB 2 to sunrise + 9 h, TB 4 = end of TB 3 to sunrise +12 h).

In all, we tested 24 models, including both global and null (intercept only) hypotheses (Table 2). We ran each model using PROC GLM (SAS/STAT system version 9.1, SAS Inc., Cary, NC), then ranked models based on Akaike Information Criteria (AIC) statistics, with an adjustment for small sample size (AICc). The difference in AICc (ΔAICc) between the highest ranked model and other models considered was used to assess model separation. AICc weight was interpreted as the probability that the model in question was the best model tested, given the data available and the models under consideration (Burnham & Anderson 2002). Here we report only models with AICc weights >0.05—those with at least a 5 % chance of being the best model among the candidate set (hereafter 'best models'). Model-averaged estimates of coefficients and unconditional estimates of standard errors were calculated following Burnham & Anderson (2002). We regarded only variables or interaction terms included in best model sets as important, and calculated parameter estimates for those terms alone. Variables appearing in only one model were not suited to parameter estimation via model averaging; in such cases we used the single coefficient and standard error estimates from the appropriate model. Cases in which a variable included in the best model set had a large standard error in comparison to the estimated coefficient are noted.

We used a Poisson regression (PROC GENMOD; SAS/STAT 9.1) with backward selection to assess the relationship between seabird abundance and distance to nearest colony. The scale parameter was estimated by the square root of deviance/df (DSCALE). With count of each species during discarding as the dependent variable, independent variables included distance to nearest colony (km), year, and their interaction. We removed variables when $P > 0.10$. We omitted distance as an independent variable in the model selection process described above, because those models used a mean of several counts as the dependent variable. Unlike other independent variables in the same models, distance was not consistent among the several counts.

Unless stated otherwise, all reported values are untransformed means ± SE.

RESULTS

Seabird surveys

We conducted 435 seabird surveys on 39 cruises during May – August 2006 and 2007. In the Charleston Harbor region, most vessels trawled along the shipping channel just beyond the harbor entrance. Occasionally cruises extended north and south of the entrance (Fig. 1). Vessels in the Cape Romain region trawled along the entrance to Bull's Bay (adjacent to nesting colonies in CRNWR), and north and northeast of CRNWR. Several trawl routes included waters near the mouth of the North and South Santee rivers (Fig. 1). The number of trawlers operating within 5 km of the observer vessel ranged from 0 to 8 among all cruises, with a mean of 4.5 ± 1.9.

We counted 36 511 birds during all surveys (Table 3). Brown Pelicans, Laughing Gulls, and Royal and Sandwich terns comprised >99% of the individuals counted. Laughing Gulls were 65.1% of the birds around trawlers, followed by Royal Terns (18.6%), Brown Pelicans (9.8%), and Sandwich Terns (6.4%). We also observed 22 Herring Gulls *Larus argentatus*, 5 Great Shearwaters *Puffinus gravis*, 4 Common Terns *Sterna hirundo*, and a single juvenile Magnificent Frigatebird *Fregata magnificens*. Laughing Gulls and Royal Terns were present during >90% of surveys in both locations each year, and Brown Pelicans were present during 59% of surveys in both locations and years. Sandwich Terns were present in <40% of surveys during both years off Charleston Harbor and in >76% of surveys off Cape Romain each year.

Model ranking

Partial correlation coefficients for pairs of species ranged from 0.094 – 0.330, suggesting no strong correlation in counts among species. In the analysis of count data, neither global nor intercept-only models ever appeared as highly ranked models. Global models explained 28 – 36% of the variability in count data for the four focal species. The sets of best models for each species included only 2-5 of the original 24 models (Table 4).

The highest ranked models for Brown Pelicans, Laughing Gulls, and Sandwich Terns were 2.6 – 15.9 times more likely to be the best model compared to the second ranked model (ratio of AICc weights

TABLE 3
Proportion of total birds counted, mean (± 1 SE) count per survey (n = 435), maximum (max.) count among all surveys, and incidence of occurrence for seabirds counted from commercial shrimp trawlers operating in nearshore waters of South Carolina, May –August 2006 and 2007

	2006				2007			
Location/species	**% total**	**Mean (SE)**	**Max**	**% occurrence**	**% total**	**Mean (SE)**	**Max**	**% occurrence**
Charleston Harbor[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	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
Otherc	0.3	0.3 (0.06)	3	23.4	0.2	0.2 (0.05)	2	12.6

[a] 84 surveys in 2006, 7059 total birds; 153 surveys in 2007, 10 870 total birds.
[b] 111 surveys in 2006, 11 072 total birds; 87 surveys in 2007, 7510 total birds.
[c] Other species included Herring Gulls (22), Great Shearwaters (5), Common Terns (4), and a Magnificent Frigatebird.

TABLE 4
Model selection statistics for the four most common seabirds attending commercial shrimp trawlers in nearshore waters of South Carolina, May – August 2006 and 2007[a]

Species / model	Δ AICc	AICc weight
Brown Pelican		
(7) Trawler activity, study area		0.75
(8) Trawler activity, study area, trawler activity X study area	3.4	0.14
(9) Trawler activity, time block	5.0	0.06
Laughing Gull		
(15) Trawler activity, date		0.86
(16) Trawler activity, date, trawler activity X date	5.5	0.05
Royal Tern		
(2) Trawler activity		0.28
(15) Trawler activity, date	0.4	0.22
(16) Trawler activity, date, trawler activity X date	0.7	0.19
(7) Trawler activity, study area	1.5	0.13
(9) Trawler activity, time block	1.9	0.11
Sandwich Tern		
(13) Study area, year		0.72
(14) Study area, year, study area X year	1.9	0.28

[a] Only models with an AICc weight > 0.05 are presented. Model numbers from Table 2.

for first and second-ranked models; Table 4). For Royal Terns, the highest ranked model was 1.2 times as likely to be the best model compared to the second-ranked model (Table 4). Activity of the trawler appeared as a variable in every highly ranked model for pelicans, Royal Terns, and Laughing Gulls, and counts of those species were higher during discarding compared to either dragging or hauling (Tables 5 & 6). There were no other consistent patterns in highly ranked models among species. Laughing Gulls became slightly more abundant with advancing date each year (Table 5). Pelicans were more abundant on surveys near Charleston Harbor compared to Cape Romain (Table 3). In contrast, Sandwich Terns were more abundant at Cape Romain than at Charleston Harbor, and more abundant in 2007 than in 2006 (Table 3).

Distribution and abundance

In the Charleston Harbor region, Brown Pelicans appeared to be distributed throughout the survey area, with high counts recorded as far as 10 km from shore and >20 km from the nesting colonies (Fig 2a). There was a positive relationship (coefficient estimate = 0.04 ± 0.01, $\chi^2_1 = 13.0$, $P = 0.003$) between distance to the nearest colony and count of Brown Pelicans in the Cape Romain area. The distribution of Laughing Gulls appeared relatively even throughout the Cape Romain survey area (Fig. 2b), although there was a negative relationship (coefficient estimate = –0.30 ± 0.009, $\chi^2_1 = 12.8$, $P = 0.004$) between distance from the nearest colony and count of Laughing Gulls. Royal Terns occurred throughout the Charleston Harbor and Cape Romain areas (Fig. 2c), and there was no relationship between their abundance and distance to nearest colony ($P > 0.10$). At Cape Romain, higher numbers of Sandwich Terns were recorded during trawls conducted close to the nesting colony, whereas lower counts occurred at the mouth of the North and South Santee rivers (Fig. 2d). Sandwich Terns appeared to be more abundant to the north than to the south of Charleston Harbor. We found a negative relationship (coefficient estimate = –0.04 ± 0.02, $\chi^2_1 = 5.2$, $P = 0.02$) between distance to nearest colony and abundance of Sandwich Terns in the Cape Romain area.

TABLE 5
Coefficient estimates ± SE[a] for main independent variables[b] related to counts (square-root transformed) of the four most common seabirds recorded from commercial shrimp trawlers in nearshore waters of South Carolina, May – August 2006 and 2007[c,d].

Variable	Brown Pelican	Laughing Gull	Royal Tern	Sandwich Tern
Trawler activity (dragging)	*-1.6 ± 0.25*	*-2.9 ± 0.43*	*-1.6 ± 0.47*	–
Trawler activity (hauling)	*-1.1 ± 0.25*	*-2.1 ± 0.45*	*-0.8 ± 0.45*	–
Study area (Charleston Hbr)	*0.59 ± 0.22*	–	0.12 ± 0.16	*-0.58 ± 0.07*
Date	–	*0.02 ± 0.007*	-0.007 ± 0.008	–
Time block (1)	-0.05 ± 0.42	–	*-0.62 ± 0.36*	–
Time block (2)	*0.55 ± 0.41*	–	*-0.37 ± 0.35*	–
Time block (3)	0.41 ± 0.43	–	-0.25 ± 0.37	–
Year (2006)	–	–	–	*-0.64 ± 0.07*

[a] Coefficient estimates and standard errors calculated via model averaging (see Methods) when variable included in >1 model from Table 4, otherwise derived from single model.
[b] Reference levels were trawler activity = discarding, study area = Cape Romain, time block = 4, and year = 2007. Coefficient estimates are the differences between the variable levels in parentheses and reference levels.
[c] Only variables occurring in models where AICc weights >0.05 are included in the table. A dash indicates that the variable was not included in a best model.
[d] Variables with SE < coefficient estimates are italicized. Variables with SE > coefficients are presented when the variable was included in at least one of the best models for a species from Table 4.

DISCUSSION

To date, most research on the abundance and distribution of seabirds at trawlers has occurred in Europe (Walter & Becker 1997, Abello *et al.* 2003), with limited data from South America (Yorio & Caille 1999, Gonzalez-Zevallos & Yorio 2006) and Australia (Blaber *et al.* 1995, Hill & Wassenberg 2000). The lack of similar data from North America is striking (Tasker *et al.* 2000) given the prevalence of nearshore fisheries in close proximity to nesting colonies and conservation concerns for many of the breeding seabirds affected. Evidence from the northwest Atlantic suggests changes in the availability of discards affects seabird foraging behavior (Stenhouse and Montevecchi 1999b) and, potentially, population dynamics (Stenhouse and Montevecchi 1999a). To date, however, researchers in North America have largely ignored this aspect of seabird ecology.

Patterns in South Carolina

The four species that comprised >99% of the birds observed at trawlers (Laughing Gulls, Brown Pelicans, and Royal and Sandwich Terns) each nested at colonies within about 30 km of most of the surveys we conducted. Although foraging ranges of these species during chick-rearing have not been studied extensively, trip distances of 20 – 30 km are probably feasible (Burger 1996, Shealer 1999, Buckley & Buckley 2002, Shields 2002). Furthermore, the relative abundance of species observed at trawlers reflected their relative abundance at nearby colonies (i.e., Laughing Gulls > Royal Terns > Brown Pelicans > Sandwich Terns). In contrast, there would seem to be little opportunity for Laughing Gulls, Brown Pelicans, or Royal and Sandwich terns from more distant colonies to forage within our study area. The nearest colonies north of Cape Romain (180 km away) and south of Deveaux Bank (80 km away) were beyond the likely foraging ranges of the four focal species. The scarcity of highly pelagic species (e.g. shearwaters) during trawl surveys was not surprising given that the shelf break and western edge of the Gulf Stream—areas more likely to support foraging pelagic seabirds—lay at least 65 km seaward of the trawl areas.

Few, if any, published studies examine the composition and abundance of seabirds at commercial trawlers in U.S. waters, thus direct comparisons are lacking. Surveys conducted from commercial trawlers in nearshore waters in Europe and South America found that, as in our study, Larus gulls were abundant and widespread trawler associates (Furness *et al.* 1992, Walter & Beacker 1997, Yorio & Caille 1999, Garthe & Scherp 2003). While we detected no gaps in the distributions of gulls attending trawlers in our survey areas, there was an inverse relation between distance to the Cape Romain colony site and abundance of gulls recorded at a trawler. The relationship appeared to be driven primarily by lower counts at the northernmost trawl locations. The increase in abundance in Laughing Gulls with date possibly reflected an increase in juvenile birds attending trawlers later in the breeding season.

Sandwich and Royal terns regularly attended trawlers in nearshore waters of Europe and South America (Arcos 2001, Martinez-Abrian *et al.* 2002, Abello *et al.* 2003, Valeiras 2003, Yorio & Caille 1999). Similar to our observations, the abundance of terns was relatively low during surveys, often with <15 individuals per count. But whereas each tern species was usually present at <50% of hauls in the studies mentioned, we observed Royal Terns during >90% of surveys and Sandwich Terns during > 50% of surveys. The fact that both species are single-prey loaders that return frequently to the colony to feed chicks may account for the frequent attendance but limited abundance of terns at trawlers. We found no relationship between distance to the nearest colony and abundance of Royal Terns, which may forage up to 65 km from colonies (McGinnis & Emslie 2001). As such, individuals from Marsh Island, Deveaux Bank, or Charleston Harbor may have foraged throughout our study areas. Sandwich Terns were seen more frequently at trawlers in the Cape Romain region (~300 nests) compared to Charleston Harbor (~30 nests). In 2006, Sandwich Terns also nested at Deveaux Bank (~2200 nests), but in 2007 many terns of both species relocated to Tomkins Island (about 80 km south of Deveaux Bank). The scarcity of Sandwich Terns at Charleston Harbor suggests the species was not regularly travelling ~30 km from Marsh Island or Deveaux Bank to forage in our survey area. Similarly, we found a negative relationship between distance to colony and abundance of Sandwich Terns in the Cape Romain area. These findings presumably reflect limits to the daily foraging range of Sandwich Terms in this region.

We find no published data on the relationship of Brown Pelicans to commercial trawler activity. Compared to Laughing Gulls and Royal Terns, pelicans were less abundant and less frequently seen at trawlers in this study. The positive relationship between pelicans and distance to nearest colony in the Cape Romain area reflected the high counts of pelicans north of the colony at the mouths of the North and South Santee rivers. Taken together, these observations suggest pelicans were attending the trawlers more opportunistically than the other three seabird species—i.e. not 'following' the trawlers per se. Notably, the prey types available as discards at trawlers (e.g. Spot *Leiostomus xanthurus*, Atlantic Croaker *Micropogonias undulates*, and Star Drum *Stellifer lanceolatus*; Wickliffe 2008) are atypical in the diet of pelicans in the southeastern U.S. (>80% of the diet being Atlantic Menhaden *Brevoortia tyrannus*; Shields 2002). Information on the diet of pelican chicks at the Crab Bank and Cape Romain colonies would shed further light on the relationship of Brown Pelicans to the shrimp fishery.

Trawler activity and abundance

Increased attendance of seabirds at trawlers during discarding was found in this study and a variety of others, including studies conducted from trawlers for Hake *Merluccius hubbsi* (Gonzalez-Zevallos & Yorio 2006), purse seiners (Arcos & Oro 2002), and both coastal and demersal trawl and longline vessels (Bertellotti & Yorio 2000). The effect shows that seabirds are able to detect and

TABLE 6
Mean count (± SE) of birds within each trawler activity within each haul within each day from commercial shrimp trawlers in nearshore waters of South Carolina, May – August 2006 and 2007[a]

Species	Dragging (n = 92)	Haulback (n = 91)	Discarding (n = 91)
Brown Pelican	4.0 ± 0.6	7.9 ± 1.3	13.7 ± 1.3
Laughing Gull	34.3 ± 2.5	50.7 ± 4.7	77.2 ± 4.0
Royal Tern	10.0 ± 0.7	16.1 ± 1.2	21.0 ± 1.3
Sandwich Tern	4.0 ± 0.6	5.1 ± 0.6	5.3 ± 0.6

[a] Within each activity, data pooled across study areas and years.

respond rapidly to the increased biomass of food. This is not to say that birds were absent or unable to forage during other phases of operation. Off South Carolina, gulls and pelicans, along with sharks (primarily Blacktip Sharks *Carcharhinus limbatus*]), and Bottlenose Dolphins *Tursiops truncatus*, commonly followed trawlers during dragging and fed on fish that may have escaped nets.

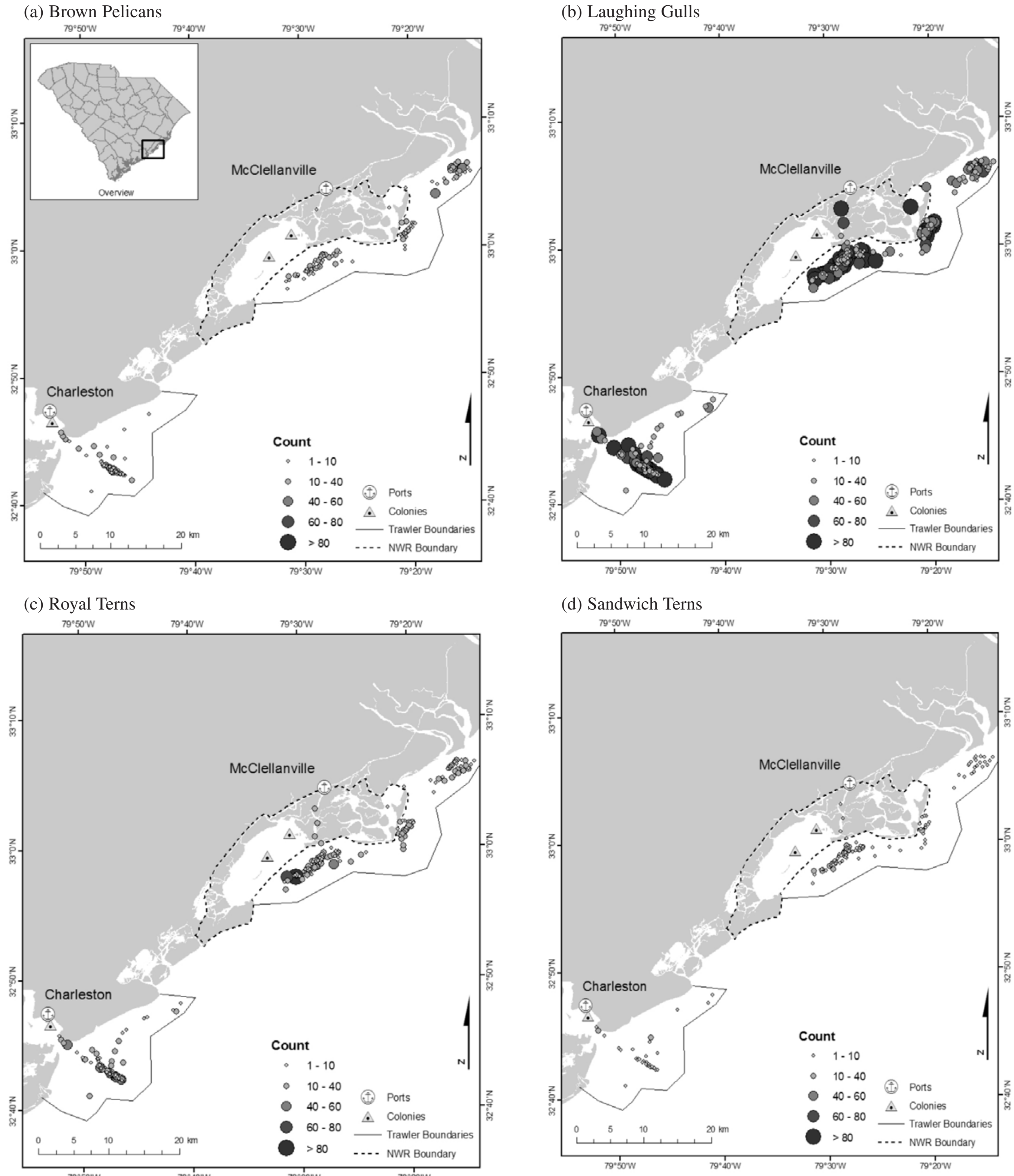

Fig. 2. Distribution and abundance of (a) Brown Pelicans, (b) Laughing Gulls, (c) Royal Terns, and (d) Sandwich Terns along the central coast of South Carolina in 2006 and 2007. Circles represent single counts; size increases in proportion to the number of birds counted (refer to legend at bottom right). All trawler cruises from which data were collected occurred within the indicated trawler boundary. Surveys were not conducted in areas without trawls.

We did not find an effect of trawler density on abundance of seabirds in our surveys. Other have noted scavenging birds moving among vessels (Gonzalez-Zevallos & Yorio 2006), presumably to benefit from the staggered fishing operations of different vessels. The probability of bycatch being discarded at any time and the chances of an individual obtaining food should be greater when more trawlers are operating. Possibly, the variability in number of trawlers operating during our surveys was too low (i.e., trawlers were consistently present) to detect such an effect on seabird abundance. The size of the fleet may be relevant to seabird abundance in the region, but our study design was likely insufficient to fully assess that relationship.

Conclusions and recommended research

Our data clearly show that shrimp trawlers are a strong, local attractor for seabirds in the nearshore waters of South Carolina. Though it remains unclear how the ongoing decline of shrimp fishing in South Carolina will affect breeding seabirds (Jodice *et al.* 2007), our data demonstrate that locally nesting birds attended trawlers regularly and usually in large numbers. Any changes in fleet size, activity, or location of operation may affect those species by altering the amount of discards available. The degree of competition between seabirds and shrimp trawlers for forage fish also could be affected by changes in fleet size or activity (Furness 2003), but in this fishery the target species (adult shrimp) and the bycatch (benthic fish) are not natural prey for these seabirds. Additional research should investigate the abundance of seabirds at trawlers during the postbreeding season (e.g. September – January), when juvenile terns and pelicans rely to some degree on parental feeding (Shealer 1999, Buckley & Buckley 2002, Shields 2002). An examination of post-fledging abundance at trawlers may reveal juvenile reliance on discards as parental care declines, self-feeding is learned, and weather conditions become less benign. Radio telemetry could provide important insight on daily interactions between individual birds and the fishing fleet. Studies of seabird diets at the colonies are needed, not least because we do not yet know how or whether fishery discards differ from the typical, 'natural' diet.

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