Longterm Trends in Nest Counts of Colonial Seabirds in South Carolina, USA

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Abstract.—We analyzed temporal and spatial trends in annual nest counts of Brown Pelicans (*Pelecanus occidentalis*), Royal Terns (*Sterna maxima*), and Sandwich Terns (*Sterna sandvicensis*) throughout South Carolina from 1969 through 2005. There was an increase in the number of active pelican nests from 1969 through the mid 1980s, although this was followed by a steady decline that continued through 2005. Numbers of Royal Tern nests have declined during the study period, especially since 1990. In contrast, annual counts of active Sandwich Tern nests remained relatively stable through the mid 1980s, then increased substantially and have since remained stable. During the early years of the study, a greater proportion of nests from each species occurred on colonies within the Cape Romain region, although this distribution appears to have shifted with a greater proportion of nests now occurring along the southern coast. At the statewide level and at each of the primary colonies, we observed a positive correlation in counts of Brown Pelican and Royal Tern nests. Mechanisms underlying the observed trends are unclear. We suggest that priorities for research include (1) determination of diet and foraging locales for all three species, (2) impacts of ectoparasites on condition and survival of pelican chicks, and (3) metapopulation structure of all three species. Management activities should focus primarily on protection of colony sites. *Received 21 March 2006, accepted 24 October 2006.*

Key words.—Brown Pelican, Royal Tern, Sandwich Tern, South Carolina, population trends, *Pelecanus occidentalis, Sterna maxima, Sterna sandvicensis.*

Waterbirds 30(1): 40-51, 2007

Coastal South Carolina supports a diverse array of breeding and wintering seabirds and shorebirds. Wilkinson (1997) estimated that during the late 1980s at least 23 different nesting colonies and ca. 28,000 nests of seabirds and shorebirds occurred along the South Carolina coast each year. Populations of some beach-nesting birds (e.g., American Oystercatchers [*Haematopus palliatus*] and Brown Pelicans [*Pelecanus occidentalis*]) appear, however, to be declining although the underlying causes remain unclear (Wilkinson 1997; Sanders *et al.* 2004). The nearshore zone of South Carolina is subjected to anthropogenic disturbances including development pressure and recreation which can affect colonial nesting seabirds through habitat loss, habitat modification, and disturbance at the colonies. Natural disturbances also play an important role in this coastal system. The South Carolina coast receives frequent hurricane landfalls which can both create and destroy nesting beaches and islands and can be responsible for the direct mortality of beach-nesting birds (Marsh and Wilkinson 1991). Other biotic factors such as predation, parasitism, or food availability may affect population dynamics as well.

Our goal was to analyze trends in annual nest counts of three colonial seabirds in South Carolina; Brown Pelicans, Royal Terns (*Sterna maxima*), and Sandwich Terns (*Sterna sandvicensis*). These three species are the most common seabirds (excluding Laughing Gulls [*Larus auritus*]) nesting along the South Carolina coast and have been the focus of intermittent surveys since the 1940s (Baldwin 1946; Beckett 1966) and of annual surveys for over three decades. Furthermore, breeding colonies of Brown Pelicans, Royal Terns, and Sandwich Terns often co-occur in South Carolina and therefore questions regarding availability of or disturbance to nest-

ing habitat are more readily addressed. Nesting records for pelicans and Royal Terns in South Carolina extend back to at least the early 1900s and include some of the same colony sites used presently (Sprunt 1925).

We sought to assess trends at three spatial scales; statewide, regionally within the state (i.e., by pooling data among proximal colonies), and at the colony level. We also assess the relationship in nest counts among species at the same colony location. These analyses will provide resource management agencies with insights into statewide and local trends and, by examining data across species within locations, will provide information critical for understanding the spatial and ecological context of any trends identified. These data also will contribute to regional management plans for these species, such as those being developed by the Royal Tern Working Group (Royal Tern Working Group 2005).

METHODS

Details pertaining to census techniques for Brown Pelicans, Royal Terns, and Sandwich Terns can be found in Wilkinson (1991) and Wilkinson (1997), although here we present a brief overview. Each year, colony sites were located through a variety of methods including reports of nesting activity, aerial and boat surveys, and site examination based on historical records (Wilkinson 1997). Concentrations of pelicans and terns were recorded and locations noted. In most survey years, single ground counts for each species were conducted at each colony during peak incubation. Between 1988 and 1992, however, the census of pelican nests consisted of interval counts (Wilkinson 1997). For these years, we reexamined the raw data and chose data from the survey date with the highest nest count, i.e., that date most comparable to a single survey conducted during peak incubation. In all cases surveys resulted in a total nest count for each species at each colony during each year. All colonies within the state were surveyed for Brown Pelicans in every year from 1969 to 2005. For terns, statewide surveys were initiated in 1975 but not conducted in 1977, 1980, 1981, 1983, or 1985. Surveys for terns were only conducted at one colony, Marsh Island located in Cape Romain National Wildlife Refuge (CRNWR), in 1982 and 1984.

Temporal trends in annual nest counts were analyzed at the state level and at each major colony site (i.e., Marsh Island, Bird Key Stono, and Deveaux Bank). We used simple linear regression models to analyze temporal trends in nest counts when a single trend appeared to best fit the data and segmented regression models when multiple trends appeared to best describe the data. We conducted segmented regressions using the PROC NLIN function in SAS Ver 9.0. We also assessed trends in regional abundance of nests for each species. We grouped colonies into three clusters. Cape Romain included the colonies at Marsh Island, Middle White Banks, West White Banks, Lighthouse Island, and Bird Key Bulls Bay. Charleston Harbor included the colonies at Crab Bank and Castle Pinckney. The southern colonies included Bird Key Stono, Deveaux Bank, Joiner Bank, Egg Island, and Tomkins Island. Percentage data were transformed for regressions using the arc sine square root function. We present means ± 1 SD unless otherwise noted and present actual P-values throughout. Regression coefficients are presented ± 1 SE.

RESULTS

Brown Pelicans, Royal Terns, and Sandwich Terns nested at eleven different sites between 1969 and 2005 (Fig. 1). Annual nest count data clearly indicate recent statewide declines in nest counts of Brown Pelicans and Royal Terns, while nest counts of Sandwich Terns have increased (Fig. 2). Data for each species are analyzed below.

Brown Pelicans

Nine islands have supported pelican colonies during the study period (Table 1). Marsh Island, Bird Key Stono, and Deveaux Bank each supported a pelican colony in more than 50% of the survey years, although only Marsh Island supported a pelican colony during all survey years. The mean annual proportion of nests supported on these three colonies combined was 88.8 ± 14.3%. Only in 1997 was the combined proportion of nests

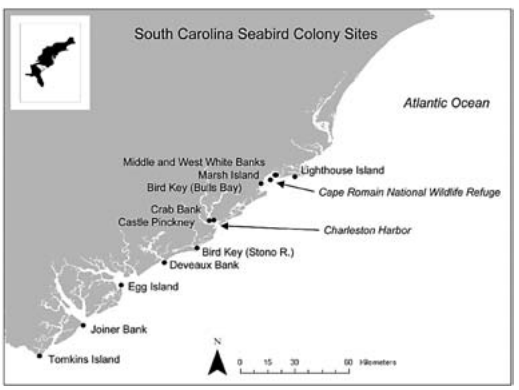

Figure 1. Colony sites for Brown Pelicans, Royal Terns, and Sandwich Terns in South Carolina, 1969-2005. West and Middle White Banks are represented by a single symbol because their locations are indistinguishable at this scale.

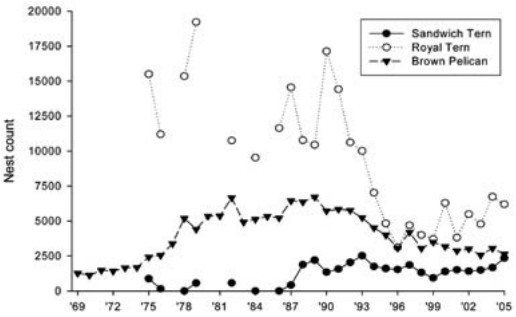

Figure 2. Annual statewide nest counts of (A) Brown Pelicans, (B) Royal Terns, and (C) Sandwich Terns in South Carolina. Surveys conducted for Brown Pelicans all years 1969-2005. Surveys for terns were initiated in 1975 but not conducted in 1977, 1980-81, 1983, and 1985. During 1982 and 1984 surveys for terns were conducted only at Marsh Island.

on these three colonies <50%; in that year, Crab Bank in Charleston Harbor supported ca. 40% of the state's pelican nests.

The statewide trend in pelican nest counts between 1969 and 2005 (Fig. 2) was best fit by a two-segment linear model ($F_{3,33}$ = 68.1, $P < 0.0001$, $R^2 = 0.93$). Nest counts increased from 1969-1987 (segment 1 slope = 319.2 ± 29.8 nests yr^{-1}) while a significant decrease in nest counts (segment 2 slope = -244.5 ± 27.5 nests yr^{-1}) occurred from 1989 through 2005.

Trends in annual nest counts of pelicans differed among colonies. The trend at Marsh Island (Fig. 3A) was best fit by a two-segment linear model ($F_{3,33}$ = 38.4, P < 0.0001, $R^2 = 0.88$) with an increasing slope from 1969 through 1982 (segment 1 slope = 190.3 ± 26.0 nests yr^{-1}) and a decreasing slope from 1983 through 2005 (segment 2 slope = -96.7 ± 12.3 nests yr^{-1}). The count of pelican nests at Deveaux Bank (Fig. 3A) increased significantly between 1969 and 1979 (b_1 = 148.6 ± 20.7, $t_9 = 7.2$, $P < 0.0001$, $R^2 = 0.85$). Following the 1979 nesting season Deveaux Bank was severely eroded by Hurricane David and pelicans did not nest there during the following nine years. Between 1989 and 2005 pelican nesting on Deveaux Bank increased significantly (b_1 = 91.6 ± 18.5 nests yr^{-1}, t_{15} = 4.9, P = 0.0002, $R^2 = 0.62$). There was no trend in the number of pelican nests at Bird Key Stono (Fig. 3A) between 1980 and 1994 (P = 0.13).

We examined trends in the spatial distribution of pelican nests throughout the state by grouping colonies within regions (Fig. 4A; regions defined in Methods). The proportion of South Carolina's pelican nests located in the Cape Romain region declined significantly from ca. 80% in 1969 to ca. 23% in 2005 (b_1 [% nests in region] = -0.96 ± 0.14, $t_{35} = 6.9$, $P < 0.0001$, $R^2 = 0.58$). The proportion of nests at the southern colonies fluctuated with no apparent linear trend ($t_{35} = 0.5$, P = 0.6). At a finer spatial scale, however, nesting shifted between Deveaux Bank and Bird Key Stono within the southern region as

Table 1. Percentage of years that each location identified in Figure 1 supported at least one nest of Brown Pelicans (1969-2005), Royal Terns, or Sandwich Terns (1975-2005).*

	Brown Pelicans	Royal Terns	Sandwich Terns
Marsh Island	100.0	88.5	76.9
Middle White Banks	27.0	12.5	4.2
West White Banks	21.6	16.7	8.3
Bird Key (Bulls Bay)	27.0	25.0	4.2
Lighthouse Island	0.0	8.3	8.3
Crab Bank	32.4	45.8	12.5
Castle Pinckney	16.2	4.2	0.0
Bird Key (Stono R.)	54.0	37.5	33.0
Deveaux Bank	75.7	95.8	83.3
Egg Island	2.7	8.3	0.0
Joiner Bank	0.0	4.2	4.2

*All colonies were surveyed for Brown Pelicans in all years 1969-2005. For terns, surveys were not conducted in 1977, 1980, 1981, 1983, and 1985. Surveys for terns were only conducted at Marsh Island in 1982 and 1984. Tomkins Island, a dredge spoil island created in 2005, is not included in Table 1; counts are reported in the Discussion.

evidenced by a significant negative correlation in annual nest counts between these two colonies (r = -0.75, P < 0.0001). The trend in the Charleston Harbor region was best fit by a two-segment linear model with an increase in the proportion of nests there between 1994 and 1998, and a decrease thereafter ($F_{3,8}$ = 12.1, P < 0.002, R^2 = 0.91). At the regional scale, there was a positive correlation (r = 0.60, P = 0.0001) between nest counts in the southern region and those in the Cape Romain region, but a moderate negative correlation (r = -0.48, P = 0.008) between nest counts in the southern region and those in the Charleston Harbor region.

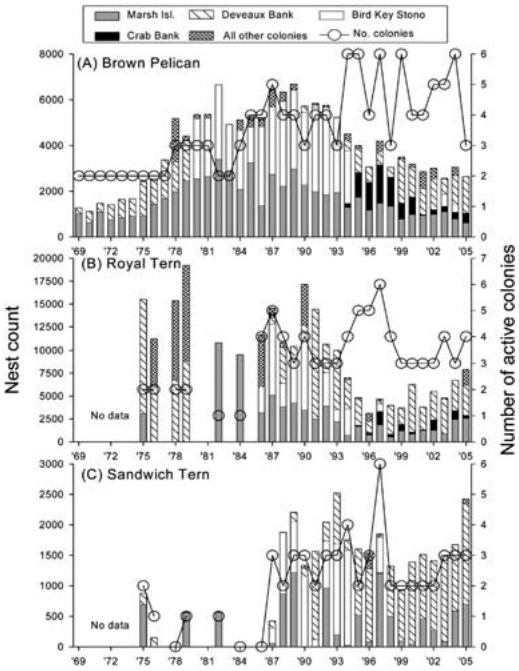

Figure 3. Annual nest counts of (A) Brown Pelicans, (B) Royal Terns, and (C) Sandwich Terns in South Carolina by colony, and number of breeding colonies occupied each year, 1969-2005. Surveys conducted for Brown Pelicans all years 1969-2005. Surveys for terns were initiated in 1975 but not conducted in 1977, 1980-81, 1983, and 1985. During 1982 and 1984 surveys for terns were conducted only at Marsh Island. Note the difference in scale on the y-axis for each species.

Royal Terns

Surveys of Royal Terns occurred every year since 1986 but only intermittently by year and location prior to then (see Methods). Eleven locations have supported Royal Tern colonies during the study period (Table 1). No sites supported a Royal Tern colony during all survey years, although Marsh Island and Deveaux Bank each supported a Royal Tern colony in more than 50% of the survey years. Nests occurred rarely at Egg Island and Joiner Bank and intermittently at Bird Key Stono (Fig. 1). Trends in nest counts of Royal Terns were assessed taking these intermittent patterns into account.

There was a significant negative trend in the nest counts of Royal Terns between 1975 and 2005 (Fig. 2) at the statewide level (b_1 = -394.7 ± 68.5 nests yr^{-1}, t_{24} = 5.8, P < 0.0001, R^2 = 0.58). Because surveys for terns were conducted only at Marsh Island during 1982 and 1984 these years represent minimum statewide estimates. The direction of the observed trend would not be affected by the restricted surveys and the magnitude of the decline is likely underestimated. There was no significant trend in nest counts of Royal Terns at Marsh Island between 1975 and 2005 (P = 0.17; Fig. 3B) although there was a significant negative trend there between 1986 and 2005 (i.e., those years during which surveys were conducted every year) (b_1 = -152.6 ± 40.1 nests yr^{-1}, t_{18} = 3.8, P = 0.001, R^2 = 0.44). There was no trend in nest counts at Crab Bank for the period 1995-2005 (P = 0.9) or at Bird Key Stono for the period 1986-1994 (P = 0.3). We compared mean annual nest counts at Deveaux Bank prior to the hurricane-related erosion event in 1979 with counts following recolonization in 1988. The mean count of nests prior to the erosion event in 1979 (8503 ± 2860) was greater than the man count since recolonization in 1988 (3227 ± 1556; t_4 = 2.8 assuming unequal variance, P = 0.02).

We examined trends in the spatial distribution of Royal Tern nests from 1975 to 2005 (excluding 1982 and 1984 when terns were only counted at Marsh Island) by grouping colonies within regions (Fig. 4B). The proportion of South Carolina's Royal Tern nests located in Charleston Harbor increased (b_1 [% nests in region] = 0.73 ± 0.2, t_{22} = 3.7, P = 0.001, R^2 = 0.39), the proportion located in

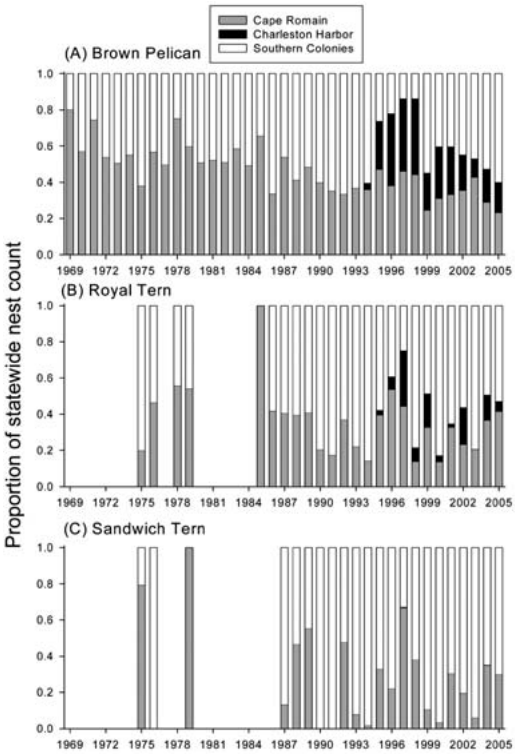

Figure 4. Proportion of statewide nest count for (A) Brown Pelicans, (B) Royal Terns, and (C) Sandwich Terns in the Cape Romain region, the Charleston Harbor region, and the southern coast region, 1969-2005. Surveys conducted for Brown Pelicans all years 1969-2005. Surveys for terns were initiated in 1975 but not conducted in 1977, 1980-81, 1983, and 1985. During 1982 and 1984 surveys for terns were conducted only at Marsh Island.

Cape Romain decreased slightly (b_1 [% nests in region] = - 0.35 ± 0.19, t_{22} = 1.9, P = 0.07, R^2 = 0.14), and the proportion located in the Southern region did not change (P = 0.7). There was a positive correlation in nest counts between Marsh Island and Bird Key Stono (r = 0.76); all other pairwise correlations between colonies were weak (|r| < 0.44).

Sandwich Terns

Nine locations have supported Sandwich Tern colonies during the study period (Table 1). Marsh Island and Deveaux Bank each supported a Sandwich Tern colony in more than 50% of the survey years. The annual mean proportion of nests supported on these two colonies combined was 78.7 ± 30.1%. Nests occurred rarely at Lighthouse Island and Joiner Bank (Fig. 1).

There was a positive trend in the statewide nest counts of Sandwich Terns (Fig. 2) between 1975 and 2005 (b_1 = 53.9 ± 13.1 nests yr^{-1}, t_{24} = 4.1, P = 0.0004, R^2 = 0.41). There was no significant trend at either Bird Key Stono for the eight consecutive years during which Sandwich Terns nested there or at Marsh Island ($P > 0.4$ for each; Fig. 3C). We compared mean nest counts at Deveaux Bank prior to the 1979 erosion event with mean nest counts following recolonization in 1988. The mean annual count of nests was greater after recolonization in 1988 (777 ± 553) than before the 1979 erosion event (82 ± 96; t_{21} = 2.8, P = 0.02).

We examined trends in the spatial distribution of Sandwich Tern nests from 1986 to 2005 (excluding 1982 and 1984 when terns were only counted at Marsh Island) throughout the state by grouping colonies within regions (Fig. 4C). There was a slight negative trend in the proportion of nests in the Cape Romain region (b_1 [% nests in region] = -1.0 ± 0.6, t_{21} = 1.7, P = 0.10) and a comparable slight positive trend in the Southern Region (b_1 [% nests in region] = 1.0 ± 0.6, t_{21} = 1.7, P = 0.10). There were no significant correlations in annual counts of Sandwich Tern nests between colonies (|r| < 0.33 for each pairwise correlation).

Interspecific Comparisons

We examined correlations in nest counts among species between 1975 and 2005 (excluding 1982 and 1984 when terns were surveyed only at Marsh Island). At the statewide level (Fig. 2), there was a moderate positive correlation between nest counts of Royal Terns and Brown Pelicans (r = 0.52) but no correlation between Sandwich Terns and either pelicans or Royal Terns (|r| < 0.4). Between 1986 and 2005 (i.e., that time period during which all colonies and species were surveyed every year) there was a strong, positive correlation in nest counts of pelicans and Royal Terns (r = 0.80, P < 0.0001). During this same time period there were no significant correlations in counts between

Sandwich Terns and the other two species ($|r| < 0.13$). At the colony level, there were positive correlations in nest counts between Royal Terns and Brown Pelicans at Marsh Island, Bird Key Stono, and Crab Bank ($0.57 < r < 0.72$, $0.003 < P < 0.001$) between 1975 and 2005. There also was a strong positive correlation between all three species at Bird Key Stono ($r > 0.58$, $P < 0.003$ for each pairwise comparison).

DISCUSSION

Each of the focal species experienced a significant statewide trend in nesting numbers during the study period. A decline in the nest counts of Brown Pelicans and Royal Terns began in the late 1980s and has persisted through 2005 while nest counts for Sandwich Terns have increased during this time period. Moderate to strong correlations in nest counts of Brown Pelicans and Royal Terns at the colony-site and statewide level compared to the weak correlations between nest counts of these two species and Sandwich Terns suggest either that different factors were underlying nesting population trends for each species or that the same factors may have different effects on each species. Here, we review what is known about various population parameters of each species (e.g., mortality, productivity) during the study period and we review a select suite of ecological factors (e.g., food availability, predation) that may have affected nesting counts of these species (Table 2).

Population Parameters

While a decline in the number of Brown Pelican and Royal Tern nests is clearly indicative of a decrease in the number of nesting adults in the state, it is unclear if this decrease is due to increases in adult mortality, emigration, or poor recruitment. Unfortunately, long-term quantitative data are not available for any of these parameters, although some anecdotal information is available with which to assess productivity and inter-colony movements.

Annual productivity of Brown Pelicans ranged from 0.7 to 1.7 chicks per nest structure during the period of population growth from 1969 to 1984 (Mendenhall and Prouty 1978; Blus 1982; Wilkinson 1982). These values are consistent with productivity values for Eastern Brown Pelicans in other portions of their range (Shields 2002; Holm *et al.*

Table 2. Major hypotheses proposed to explain the trends observed in nest counts of Brown Pelicans from 1969 to 2005, and Royal Terns and Sandwich Terns from 1975 to 2005, South Carolina, USA, and proposed research and management priorities.

Hypothesis	Evidence; consistency with observed trends	Research priority/management priority
H1: Loss of nesting habitat	Periodic colony losses; inconsistent with opposing trends between co-nesting tern species	Primary (inter-colony –state movements)/ Primary (renourishment to enhance number of colonies)
H2: Food availability	Limited availability of longterm data; not inconsistent with opposing trends between species	Primary (diet composition, seabird-fisheries interactions)/Secondary (existing regulations)
H3: Contaminants	Significant in other local marine predators; not inconsistent with opposing trends	Secondary (species- and colony-specific contaminant loads)/Secondary (existing regulations)
H4: Parasitism	Abandonment & mortality from ectoparasites at pelican but not tern colonies; not inconsistent with trends	Primary (test tick control methods)/Secondary (monitoring)
H5: Predation of nests/ chicks	Predation rarely observed; inconsistent with opposing trends between co-nesting terns	Secondary (observations to determine predation rates at colonies)/Secondary (predator control if needed)
H6: Human disturbance	Colony disturbance and mortality at fishing vessels observed; not entirely inconsistent with opposing trends	Secondary (fishing vessel observations)/ Primary (enhance protection at colonies)

2003). Productivity estimates are not available for the time period coinciding with the observed decline in nest counts, although colony visits during that time period did not report evidence of continuously poor productivity or periods of extensive colony failure. Productivity estimates for 2004 and 2005 from Marsh Island averaged ca. 1.0 chick per nest structure (Ferguson and Jodice unpubl. data) and are similar to values obtained prior to the decline. Therefore, it appears that productivity has not decreased since the decline in nest numbers began in the late 1980s. More importantly, productivity estimates immediately prior to the onset of decline in 1988 were not particularly or consistently low (Mendenhall and Prouty 1978; Blus 1982; Wilkinson 1982) and did not differ from those reported for other areas within the species range. Unfortunately, there are no productivity data available for Royal or Sandwich terns in South Carolina between 1975 and 2005. Given the relative ease with which productivity data can be gathered for each of these species, we recommend that at least periodic estimates be compiled over the next decade in an effort to establish a baseline for future monitoring efforts.

Few data are available with which to assess immigration and emigration, although evidence suggests that for Brown Pelicans each may have affected the observed trend. For example, between 1969 and 1989 the nesting population of pelicans in South Carolina grew by ca. 10% per year, and, based on productivity measures and other breeding characteristics, immigration to colonies in South Carolina appears likely. Movement among colonies within the state also appears to have occurred in the early 1980s. For example, based on observations of banded birds Wilkinson (1982) reported that pelicans breeding on Deveaux Bank prior to its erosion in 1979 emigrated to nearby Bird Key Stono but that pelicans that were hatched on Marsh Island tended to nest there in subsequent years. Similarly, there is some evidence that emigration also has occurred recently (Wilkinson 1997). While the nesting population of pelicans in South Carolina was declining by ca. 265 nests per year from 1988 to 2005 (Fig. 2), pelican colonies were being established in Georgia (the statewide population has subsequently increased to 3,500 nests; B. Winn, unpubl. data) and Virginia (Watts 2004), and nest counts increased in North Carolina (D. Allen unpubl data). During this time the nesting population of pelicans along the Florida Atlantic coast did not appear to be declining (Wilkinson *et al.* 1994). These observations suggest that immigration and emigration likely affected the observed trend in South Carolina, that shifts among colony sites within the state occur, and that high natal philopatry occurs when conditions permit.

The potential roles of immigration and emigration in population dynamics of Royal and Sandwich terns in South Carolina are less clear. Although longterm banding data exist for terns in North Carolina, Virginia, and Maryland (Boettcher 2006; J. Weske unpubl. data), these data are lacking in South Carolina. Nonetheless, since the late 1980s (i.e., the time period that coincides with the decline of Royal Terns in South Carolina) nesting populations of Royal Terns appear to be decreasing throughout the middle-Atlantic states (Denmon and Jodice 2005). These observations are not strongly suggestive of large-scale emigration from South Carolina colonies, although an ongoing assessment of population dynamics of Royal Terns from Maryland through South Carolina may elucidate this further (Emslie unpubl data).

Factors Underlying Population Trends

Recent research on all three focal species has been limited both throughout their range and specifically in South Carolina (Shealer 1999; Buckley and Buckley 2002; Shields 2002), making it difficult to determine with any certainty which factors may have affected the population dynamics of each species. This knowledge gap should not preclude an attempt to discern which factors may be the most likely to result in the trends we observed, which are the most promising for future research, and which are the most likely to be positively affected by management activities. Here, we assess any evidence

that alteration of nesting habitat, shifts in food availability, contaminants, predation and parasitism, or human disturbance may be underlying the trends we observed.

Nesting Habitat.—Four sites served as primary nesting locations throughout the survey period; islands in CRNWR, at the mouths of the Stono and N. Edisto rivers, and in Charleston Harbor.

Two sites within CRNWR supported substantial seabird colonies since at least the early 1900s; Bird Key Bulls Bay and Marsh Island (Phillip 1910; Sprunt 1925; Baldwin 1946). Bird Key Bulls Bay supported colonies of terns and pelicans during the early years of the study period but, along with Deveuax Bank, eroded in 1979 following Hurricane David. A lack of surveys for terns in 1980-81 makes it difficult to assess the impact of the loss of Bird Key Bulls Bay on their populations. A decline in nest numbers of Royal Terns in the state during the ensuing seven to eight years, however, suggests that the loss of Bird Key Bulls Bay along with Deveaux Bank may have negatively affected populations in the short term. In contrast, nesting efforts of pelicans did not decline in the state during this time, but instead increases in nest counts occurred at Marsh Island and Bird Key Stono. In contrast to Bird Key Bulls Bay, Marsh Island has supported relatively large colonies of each species during most years of the study period.

Bird Key Stono, a sand island located at the mouth of the Stono River, was an important colony site for all three species during the 1980s and early 1990s. Between 1980 and 1994 Bird Key Stono supported 54 ± 27%, 52 ± 10%, and 32 ± 18% of the annual Sandwich Tern, Brown Pelican, and Royal Tern nesting populations, respectively. Bird Key Stono was severely eroded in 1994, coincident with dredging activity in the area. Thereafter, nesting declined sharply at this site and the number of pelican and tern colony sites in South Carolina also increased (Fig. 2), suggesting breeders from Bird Key Stono may have relocated to other sites within the state (Fig. 3). Following renourishment in 2003 Bird Key Stono was recolonized, but numbers for all species were still low as of 2005. Deveaux Bank, a sand island located at the mouth of the N. Edisto River, also has been a primary nesting colony for each species for significant portions of the study period and earlier (Beckett 1966). Deveaux Bank eroded in 1979 following Hurricane David, was recolonized by pelicans and terns in the early 1990s following substantial accretion, and since that time numbers for each species have remained relatively steady or increased there.

New sites also were colonized by terns and pelicans within the state during the study period. Crab Bank (a sand spit island) and Castle Pinckney (a revolutionary war era fort on a small island) are each located in Charleston Harbor and have been in existence for over a century. These sites were colonized by Brown Pelicans and Royal Terns in the mid-1990s (Figs. 2 and 3). This coincided with the loss of nesting at Bird Key Stono. Sandwich Terns have yet to nest in Charleston Harbor in any substantial numbers. Tomkins Island, a dredge-spoil island in Savannah Harbor, was created in 2005 specifically with the intention of attracting colonial seabirds. Tomkins Island supported ca. 1,700 Royal and 75 Sandwich tern nests during the first year it was available.

Although loss of nesting islands and habitat appears to have negatively affected each species at some point during the study period, it does not appear to be the sole mechanism underlying population change. For example, nest counts of Royal Terns at Bird Key Stono and Deveaux Bank both began declining in the early 1990s prior to the loss of Bird Key Stono. During this same time period Sandwich Terns were experiencing an increase throughout the state. Given that both terns co-nest at most colonies, this suggests that loss of nesting habitat may not have been the primary factor underlying declines in numbers of nesting Royal Terns. Similarly, following the loss of Deveaux Bank and Bird Key Bulls Bay after the 1979 nesting season, the number of pelican nests in the state remained relatively stable, apparently due to increases in nest numbers at Bird Key Stono and Marsh Island (Wilkinson 1982). Following the loss of Bird Key Stono, pelican nesting increased at Deveaux Bank and Charleston

Harbor although the statewide decline which occurred prior to the loss of Bird Key Stono continued. In general, the incremental loss of nests for Royal Terns and Brown Pelicans throughout the state, and particularly at Marsh Island, suggest that loss of entire colony sites was not the sole mechanism underlying population declines in these two species.

Food Availability.—Opposing population trends among species in the same region stemming from shifts in the forage fish community are not untenable if diet composition differs among the species. Although there are limited diet data available for seabirds in South Carolina, studies in adjacent states indicate diet may differ between Royal and Sandwich terns. For example, McGinnis and Emslie (2001) demonstrated that the diet composition of Sandwich Terns included more marine species compared to that of Royal Terns at seven mixed-species colonies in North Carolina. During chick-rearing, Sandwich Terns relied primarily on anchovies (*Anchoa* spp.) while Royal Terns relied primarily on a group of forage fish including drums (Sciaenidae), porgies (Sparidae), and mullet (*Mugil cephalus*). In North Carolina and South Carolina, Brown Pelicans appear to forage predominantly on Atlantic menhaden (*Brevoortia tyrannus*) and mullet (Blus 1982; Shields 2002).

Longterm fisheries data or diet composition data are required to determine if changes in food availability may be underlying the population trends we observed. Unfortunately, only limited data are available. For example, trawl data from 1990 to 2002 suggest that anchovy abundance was high in the early 1990s, declined for a four-year period in the mid 1990s, and has since rebounded (Southeast Area Monitoring and Assessment Program [SEAMAP] 2005). These trawl data appear to positively track the shift in Sandwich Tern abundance. Longterm trends in menhaden landings indicate that stocks were building in the 1970s, maintained intermediate levels during the 1980s, but then declined by ca. 50% during the ensuing 12 years (Atlantic States Marine Fisheries Commission 2004). This decline coincides with the decline we observed in nest counts of Royal Terns and Brown Pelicans, although the menhaden data are not specific to South Carolina. Integration of fisheries data and colony-based diet data would be valuable for understanding future population dynamics.

Contaminants.—The three focal species have been adversely affected by contaminants in the past (Blus *et al.* 1974, 1979) and opposing population trends among species could occur if contaminants were food-web based and if diets differed among species. Within the state, organochlorines are detectable in marine predators and new bioaccumaltive contaminants of concern (e.g., perfluorinated compounds and brominated flame retardants) may be prevalent as well (Houde *et al.* 2005; Young *et al.* 2005; Keller *et al.* 2005). For example, polybrominated diphenyl ethers (PBDEs) were common in pelican eggs collected during the 2005 breeding season from both Marsh Island and Crab Bank (Stuckey 2006). Concentrations appeared to be similar between the two colonies despite the Marsh Island colony being located in a relatively pristine location and the Crab Bank colony being located near a large city and within a developed harbor. These data suggest that PBDEs may be widespread along the South Carolina coast. Additionally, the highest concentrations of perfluorooctanesulfonate (PFOS) ever documented in wildlife have been measured in bottlenose dolphin (*Tursiops truncatus*) residing in and around Charleston Harbor (Houde *et al.* 2005). Recent observations at the seabird colonies, however, do not indicate poor hatching success or high rates of nestling abnormalities (Ferguson and Jodice unpubl. data), both indications of high contaminant loads in seabirds (Burger and Gochfeld 2002). Nonetheless, we have no data on post-fledging survival or adult survival, either of which could be affected by contaminant loads. Therefore, data from within the region and from other marine species dictate that contaminants and pollution cannot be dismissed entirely as potential mechanisms underlying the observed trends.

Ectoparasites.—Ticks and other ectoparasites are commonly found at seabird colonies within nesting material or on adults and

nestlings and high densities may have negative effects on seabird populations (Duffy 1983; Norcross and Bolen 2002). The soft tick *Ornithodoros capensis* was first identified in pelican colonies in South Carolina at Bird Key Stono and Marsh Island in 1987 (Keirans *et al.* 1992). Soft ticks now occur at all pelican colonies in the state but have not been observed within the tern colonies (Ferguson and Jodice unpubl. data). Soft ticks are very difficult to survey accurately, but annual nest checks do not suggest chronic infestation (Sanders unpubl. data). Nonetheless, ticks appear to have caused localized abandonment of pelican nests and have contributed to some chick mortality (Keirans *et al.* 1992; Ferguson 2006). Under low to moderate tick infestation levels, however, tick presence does not appear to have a significant negative effect on growth rates or physiological condition of pelican chicks (Ferguson 2006). Ectoparasites remain as a possible top-down factor affecting trends in nest counts of pelicans (especially when infestation periodically peaks), but do not appear to be affecting terns.

Predation.—All of the breeding islands listed in Table 1 have remained free of mammalian predators during the study period and predation by raptors does not appear to be excessive (e.g., abandonment has not been observed). Predation by gulls on colonial nesting seabirds is a major concern along much of the Atlantic coast (Watts 1999). Laughing Gulls nest at all of the primary colony sites in South Carolina and, although their population appears to be increasing (Wilkinson 1997) observations suggest that their impact on eggs and chicks of pelicans and terns appears to be slight (Sanders and Murphy pers obs., Ferguson and Jodice pers. obs.). Herring Gulls (*Larus argentatus*) are present in limited numbers at colony sites in South Carolina during the breeding season but do not currently nest there. Nonnative fire ants (*Solenopsis invicta*) can negatively impact ground-nesting birds (Allen *et al.* 2004) and occur on South Carolina seabird colonies (Parris 2002). While predation by fire ants on chicks and eggs has been observed at pelican colonies during recent years, it does not appear to be extensive at this time (Ferguson and Jodice pers. obs). In total, these observations suggest that predation does not appear to be the primary factor underlying the trends we observed. Furthermore, it is not likely that predation would result in the opposing trends we observed between co-nesting Royal and Sandwich Terns.

Human Disturbance at Colony Sites.—Colonies at Crab Bank, Deveaux Bank, and Bird Key have been subjected to considerable disturbance from human recreation which has resulted in direct destruction of nests, disturbance to incubating or brooding adults, and periodic losses of productivity (Sanders and Murphy unpubl. data). Human disturbance could result in the opposing trends observed among species if each exhibited differential responses to disturbance, although this appears unlikely to be the case in co-nesting terns. Human visitation to Marsh Island is rare, however, and therefore colony disturbance is not likely to be driving the negative trend we observed there in pelicans. Nonetheless, periodic but severe losses of productivity due to human disturbance, especially as observed at Crab Bank, Bird Key Stono, and Deveaux Bank may affect colony fidelity and potentially lead to emigration (Yorio *et al.* 2001).

Research and Management Recommendations

We suggest that research should focus on those mechanisms most likely to result in opposing population trends for species nesting in the same locations (Table 2). The areas considered highest priority for research include: (1) diet/food availability, which should focus on interactions between seabirds and commercial fishing vessels within South Carolina's inshore waters and on diet composition within and among species and colonies; (2) an examination of metapopulation structure and intercolony movements (Shealer 1999; Buckley and Buckley 2002), and; (3) additional research on contaminants that includes assessments of other piscivorous colonial species nesting at the same

colony sites. Continued research on the effects of ectoparasites on pelicans is considered as a secondary focus, with efforts directed at determining an effective method of tick control and on developing efficient survey techniques for ticks.

Management activities should be prioritized based on their potential for quick and lasting impact (Table 2). We suggest a focus on limiting human access to colony islands and renourishment. Breeding colonies in South Carolina are closed to human entrance and prior to the 2006 breeding season access to the islands supporting the colonies was also curtailed. Given the paucity of colony sites in South Carolina and the potential for even a single disturbance event to negatively impact productivity, we suggest that human access to islands supporting seabird colonies continue to be restricted. Enhanced protection at Bird Key Stono, Deveaux Bank, and Crab Bank (i.e., colonies situated in high-traffic recreation areas), in particular, may benefit each of the three focal species as well as other beach-nesting birds not included in this study (e.g., Least Terns [*Sterna antillarum*], Black Skimmers [*Rynchops niger*], and American Oystercatchers). Renourishment of islands with fresh dredge material has positively impacted seabird nesting in the state. The rapid colonization of Tomkins Island in 2005 was highlighted above, and pelican nesting at Bird Key Stono has always responded positively to renourishment. Colonies also should be monitored for Herring Gull activity, fire ant abundance, and tick infestation levels.

There is a strong need to continue monitoring these three species in the state of South Carolina. Nearby states have initiated regular monitoring programs and as such a larger scale view of population dynamics for these species should emerge in the upcoming decade. Wilkinson (1982) stated that it was easy to be optimistic about the future of pelicans in South Carolina in the early 1980s. Obviously the situation has changed since that time and it also has become clear that numbers of Royal Terns nesting in the state and along the middle Atlantic coast have declined as well. Although these declines are relatively clear, the mechanisms underlying them are not. Therefore, we strongly urge management agencies to continue monitoring these species throughout the middle and southern Atlantic states, that research be initiated as suggested above, and that management activities that serve to better protect the few nesting islands available in South Carolina be increased.

ACKNOWLEDGMENTS

We would like to acknowledge the many biologists who conducted nest counts over the years including L. Blus, M. Dodd, S. Dodd, P. Wilkinson, and M. Spinks. M. Peden-Adams provided valuable information regarding contaminants research in South Carolina. Cape Romain NWR provided logistical support throughout all survey years. Clemson University, the South Carolina Department of Natural Resources, and the U.S. Geological Survey jointly support the South Carolina Cooperative Fish and Wildlife Research Unit.

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