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Goal: Monitor seabird colonies on protected islands and collect baseline measures of breeding parameters to better evaluate the health and condition of seabird populations in South Carolina in relation to new regulations and for future comparisons.

Introduction: Several islands along the South Carolina coast have supported breeding grounds and migratory stopover locations for numerous seabird, shorebird, and wading bird species during the previous three decades (e.g. Jodice et al. 2007). Islands that support breeding colonies of seabirds are generally devoid of mammalian predators, nearby to food resources, and possess physical features that provide suitable habitat for nesting and rearing young (Erwin et al. 1995, Visser et al. 2005). There are a limited number of islands meeting these criteria, and as such protection of available and suitable islands is critical for the protection of these species.

Human disturbance to seabirds and shorebirds on coastal islands is an important management issue along the eastern coast of the U.S. Human disturbance has been defined as “those activities of humans and pets that lead to changes in the behavior, distribution and abundance of wildlife” (Lafferty *et al*. 2006). In response to human disturbance in or near nesting areas, entire colonies of seabirds may leave their nests, thereby exposing eggs or young to lethal temperatures and potential predators. Over time, effects of disturbance may result in reduced reproductive success (Beale and Monaghan 2004) and increased energy expenditure on the part of adults and young (Regel and Putz 1997). Human disturbance can also lead to permanent abandonment of the colony. While the posting of signs around the perimeter of a colony may reduce the risk of disturbance within nesting areas, even compliant visitors may cause disturbance to birds as they occupy locations adjacent to protected areas (Lafferty *et al.* 2006).

Human disturbance has been identified as a primary concern for the management of colonial seabirds in South Carolina (South Carolina Comprehensive Wildlife Conservation Strategy, 2005) and may be one of several factors contributing to recent statewide declines in reproductive effort of Brown Pelicans (*Pelecanus occidentalis*) and Royal Terns (*Sterna maxima*) (Jodice *et al.* 2007). While protection of nesting areas is crucial for the success of breeding pairs, areas used for loafing (resting away from the nest) and feeding (which extends into nearshore marine areas) are also essential components of the breeding habitat that require protection. Disturbance in any part of the breeding habitat can affect incubation, resting, and feeding activities and thereby may alter reproductive success.

Beginning in 2006 SCDNR enacted new management regulations aimed at the reduction of human disturbance to three nesting islands; Crab Bank (Charleston Harbor), Bird Key (mouth of the Stono River), and Deveaux Bank (mouth of the North Edisto River). The new regulations prohibited dogs from all islands, closed Crab Bank and Bird Key to visitors from 15 March– 15 October, and limited visitor access at Deveaux Bank to those areas below the high-tide line (the intertidal area) and a within a designated recreational area. Seabird species implicitly protected by these new regulations included Brown Pelicans, Royal Terns, Sandwich Terns (*Sterna sandvicensis*), Gull-billed Terns (*Sterna nilotica*), and Black Skimmers (*Rynchops niger*). Brown Pelicans typically nest on the ground in vegetated dunes set back from the sandy beach. Royal and Sandwich terns nest together in dense colonies located in open sandy areas of the back-beach or on exposed dunes. Black Skimmers nest directly on the sandy, open beach and initiate egg-laying later in the season (late May) compared to pelicans and terns. Here we report on research activities that were designed to examine the breeding biology and behavior of these seabirds under these new regulations. Data to meet these objectives were collected during the 2006, 2007, and 2008 breeding seasons.

Our first objective was to measure reproductive and behavioral parameters of seabirds and to establish baseline measures for current and future comparison of the impact of management actions. Our focal species was the Black Skimmer, a sensitive species that nests on the sand above the high tide line. When skimmers are threatened during incubation or brooding, they vacate their nests leaving eggs and chicks vulnerable to predation or lethal temperatures. We examined the nest success of Black Skimmers and placed temperature loggers in select nests to determine variability in nest temperature.

Our second objective was to map habitat use by seabirds during the breeding season, with a concentration on use of the intertidal area of the protected islands. The intertidal area is an essential component of seabird breeding habitat and is used for loafing, feeding, courtship, and chick-rearing by seabirds and shorebirds. During this study, we conducted surveys at Deveaux Bank, Bird Key, and Crab Bank to examine bird use of the intertidal area throughout the breeding season. We also examined the spatial and temporal distribution of bird use of Deveaux Bank intertidal areas in relation to habitat characteristics.

Our third objective was to determine condition and health of seabird populations at protected seabird islands. For this objective, we focused on the health of Brown Pelican nestlings. We performed health evaluations of Brown Pelican nestlings to establish reference values for a wild population of birds during early development. Information on basic health parameters of seabirds is lacking and these data will contribute greatly to our understanding of the species and conservation efforts on its behalf.

Objective 1: Measure reproductive and behavioral parameters of seabirds on protected state lands and establish baseline measures for current and future comparison of the impact of management actions.

Bird Key (2007, 2008), Crab Bank (2006-2008), and Deveaux Bank (2006-2008) served as study sites. Bird Key was excluded from the study in 2006 because seabirds did not nest there that year. In 2006, research at colonies began on 22 May and continued through 16 August. We completed 200 hours of field work during 27 visits to Crab Bank and 240 hours of field work during 20 visits to Deveaux Bank. In 2007, colony work began on 19 April and continued through 5 September. We completed 250 hours of field work during 21 visits to Bird Key, 300 hours during 25 visits to Crab Bank, and 400 hours during 26 visits to Deveaux Bank. In 2008, colony work began on 24 April and continued through 9 October. We completed 275 hours of field work during 24 visits to Bird Key, 168 hours of field work during 15 visits to Crab Bank, and 360 hours of field work during 30 visits to Deveaux Bank.

We monitored nesting seabirds at study colonies throughout the breeding season and collected information regarding peak incubation, first and peak hatching, and predicted fledging time for species, whenever possible. Behavioral parameters and influential factors such as weather events, known food shortages, abandonment, and high levels of ectoparasite infestation were recorded. To meet this objective, we focused our efforts on Black Skimmers, but include information when possible on three other seabird species protected by the new regulations: Brown Pelicans, Royal Terns, and Sandwich Terns.

• Nesting Seabird Community

Methods.-- Researchers assisted SCDNR biologists with censuses of seabird colonies in all study years. Pelican and tern censuses were conducted in mid-late May of each year during the peak of incubation activities. Peak nesting for Black Skimmers varied among islands and years due to repeated nest failures. Black Skimmer nests were counted at Bird Key on 6 July 2007 and 13 June 2008. At Crab Bank, skimmer nests were counted on 29 June 2006, 4 July 2007, and 11 June 2008. At Deveaux Bank, skimmer nests were counted on 21 June 2006, 13 June 2007, and 9 June 2008.

Results and Discussion.-- Seabird nest counts on the three seabird islands, as surveyed by SCDNR over the past five years, are displayed in Table 1. The number of skimmer nests on Crab Bank increased following the enactment of the new regulations. The number of Royal Tern nests at Deveaux Bank was moderately lower in the years following the new regulations, though Deveaux Bank was not entirely closed to public access. High variability and low sample size may have contributed to the lack of statistical differences for some species and locations.

Table 1. Nest counts on Bird Key, Crab Bank, and Deveaux Bank SC, 2004-2008.

		Before new regulations			After new regulations			
		2004	2005	Mean ± SD	2006	2007	2008	Mean ± SD
Brown Pelican	Bird Key	344	0	172.00 ± 243.24	0	0	0	0
	Crab Bank	290	444	367.00 ± 109.89	392	615	766	591.00 ± 188.15
	Deveaux Bank	1260	1576	1418.00 ± 223.44	2310	1268	1637	1738.33 ± 528.34
Royal Tern	Bird Key	0	0	0	0	0	0	0
	Crab Bank	943	346	644.50 ± 422.14	1639	1212	602	1151.00 ± 521.18
	Deveaux Bank	3316	3274	3295 ± 29.70	2565	452	219	1078.67 ± 1292.46*
Sandwich Tern	Bird Key	0	0	0	0	0	0	0
	Crab Bank	3	0	1.50 ± 2.12	0	35	6	13.67 ± 18.72
	Deveaux Bank	1085	1646	1365.50 ± 396.69	2196	79	7	760.67 ± 1243.55
Black Skimmer	Bird Key	121	74	97.50 ± 33.23	0	70	37	35.67 ± 35.02
	Crab Bank	49	43	46.00 ± 4.24	200	179	175	184.67 ± 13.43***
	Deveaux Bank	293	112	202.50 ± 127.99	155	24	218	132.33 ± 98.97

* P < 0.10, *** P < 0.01 based on t-test with unequal variance

- Black Skimmers

Methods.-- The Black Skimmer is a beach nesting species that is sensitive to disturbance near its nesting areas. When incubating or brooding skimmers are threatened, they vacate nests leaving eggs and chicks vulnerable to predation or lethal temperatures. We selected skimmers as the focal species for this portion of the study due to the sensitivity of the species and the positive response in nesting numbers observed after the new regulations were enacted in 2006. In 2007 and 2008, we monitored nesting effort and productivity (chicks fledged per nest) of Black Skimmers at Bird Key, Crab Bank, and Deveaux Bank. Nests and eggs were marked for identification using small wooden stakes and GPS. Temperature data loggers in plastic decoy eggs were placed in nests at all three colonies during early incubation to gauge patterns of adult nest attendance and temperature profiles of the nest. Characteristics of skimmer nests at Bird Key were measured in 1 m^2 plots at the completion of the breeding season. Habitat characteristics of areas that were available to skimmers but not used for nesting were also measured at the completion of the breeding season and before nests were initiated. Pre-nesting locations were in proximity to Black Skimmer decoys and sound machines that were placed by SCDNR biologists in potential and previously used skimmer nesting locations to attract nesting birds to the island. Nest site characteristics were not measured at Crab Bank or Deveaux Bank. Behavioral observations (1 hr) were conducted on Bird Key and Deveaux Bank to provide comparative data for measurements obtained from loggers. When possible, nestlings were marked with a non-toxic marker to monitor survival.

Results and Discussion.-- Black Skimmers nested on all study islands in 2007 and 2008, but not on Bird Key in 2006. Skimmers eggs were first observed at Bird Key during the last week of May in 2007 and 2008. At Crab Bank, eggs were first observed during the third week in May of 2006 and 2008, and during the last week of May in 2007. At Deveaux Bank, eggs were observed on May 28, 2008, 13 June, 2007, and into the third week of July in 2006. In 2006, chicks were first observed on 21 June on Deveaux Bank and fledglings were first observed in mid-July. In 2007, chicks were first observed at Bird Key on 19 June, at Crab Bank on 20 June, and no chicks were observed on Deveaux Bank in 2007 (new nests were observed here as late as 23 July). Fledglings were first observed on 25 July. In 2008, the first skimmer chicks were observed at Bird Key on 19 June, at Crab Bank on 11 June, and at Deveaux Bank on 18 June. Fledglings were first observed on 16 July. Estimates of island wide reproductive parameters for Black Skimmers on Bird Key, Crab Bank, and Deveaux Bank are found in Table 2.

Table 2. Reproductive parameters of Brown Pelicans and Black Skimmers, 2006-2008.

Species	Colony	Average clutch (eggs/nest)			Hatching success (hatched chicks/pair)			Productivity estimate (fledged chicks/pair)		
		2006	2007	2008	2006	2007	2008	2006	2007	2008
Brown Pelicans	Crab Bank	2.6[a]	2.42[a]	2.76[a]	2.0[a]	1.58[a]	2.12[a]	1.6[a]	1.12[a]	1.44[a]
	Deveaux Bank	2.6[a]	2.69[a]	2.49[a]	0.5-1.9[a]	2.31[a]	2.20[a]	1.7-2.2[b]	1.77[a]	1.23[a]
Black Skimmers	Bird Key	n/a	2.40[b]	3.32[b]	n/a	0.41[b]	0.73[b]	n/a	0.03[b]	0.03[b]
	Crab Bank	n/a	2.56[b]	2.78[b]	n/a	0.45[b]	0.46[b]	0.5[c]	0.40[c]	0.43[c]
	Deveaux Bank	n/a	1.08[b]	2.80[b]	n/a	0[b]	0.67[b]	0.1[c]	0[b]	0.40-0.50[c]

[a] Estimated from study plots

[b] Estimated from nest checks of the colonies

[c] Estimated from ratio of nests and nestlings counted from a distance late in the season

Disturbance at skimmer colonies appeared to vary by island. At Deveaux Bank, skimmer colonies were in close proximity to human use areas. Coincidentally, skimmers there did not hatch or fledge any chicks during 2007. At Crab Bank, the skimmer colony quadrupled in size from 2005 (before island closure) to 2006 (after island closure) and chicks successfully fledged in all years the island was closed. At Bird Key, an owl depredated nesting skimmer adults and the colony had poor nest success in 2007 and 2008. Anecdotally, these examples illustrate the benefits of the island closures and the need to keep multiple nesting islands protected for black skimmers.

We are conducting additional analyses on behavior of adult skimmers during incubation and behavior of adults and chicks during brood-rearing. These data will be presented in the dissertation.

- Brown Pelicans

Methods.-- We estimated reproductive parameters of Brown Pelicans on Crab Bank and Deveaux Bank in all years of the study. Estimates were obtained from colony visits throughout the nesting season. During the 2006 field season, behavioral observations of pelican adults and chicks at the nest were conducted at Crab Bank (Elena Sachs, MS Student). Observers scanned and recorded pelican behavior at approximately 10 nests every 5 minutes, for a duration of 3 hrs. Frequency of feeding, nestling behavior (i.e. begging, brooding, preening, sibling aggression), adult behavior (i.e. feeding, brooding, preening, defense behavior), and adult attendance were recorded. These observation periods were conducted during morning (700-1200) and late afternoon (1400-1900).

Results and Discussion.-- Pelicans did not nest on Bird Key. In 2006, pelican eggs began hatching in mid May, and peaked in late May-early June. Pelican fledging began in early August. In 2007, pelican nests were first observed on Crab Bank in mid-April. Nests initiated at Deveaux Bank during this time were lost to storms and no active nests were observed on the island by 19

April. Soon thereafter, nesting resumed on Deveaux Bank and eggs were found in nests on 11 May. Hatched nestlings were first observed in mid-May at Crab Bank and began hatching in early June at Deveaux Bank. Fledglings were first observed in early August. In 2008, pelican nests were initiated in mid-April at Crab Bank and Deveaux Bank. Hatched nestlings were first observed in mid-May and fledglings were first observed in mid-July, slightly earlier than in the previous two years. Estimates of reproductive parameters are presented in Table 2.

Results from the observation studies of pelicans at Crab Bank appear in Sachs and Jodice (2009) although a brief summary is provided here. Rates of parental attendance, chick begging, and chick aggression all peaked when chicks were approximately 21 d post-hatching and then declined. Direct feeding events were never observed when chicks were < 11 d of age and indirect feeding events were rarely observed after chicks were > 15 d of age. The transition from indirect to direct feeding was not accompanied by a change in begging rates. Shifts in the frequencies of both parent and chick behaviors occurred at approximately 3 weeks post-hatching, when chicks achieve thermoregulatory independence and become more mobile. Our data suggest that any spatial or temporal comparisons of parent or chick behavior should be assessed in relation to the age category of the parent and the age of the chicks.

The soft tick *Carios capensis* was found in pelican nests and on chicks at Deveaux Bank, at times in large numbers. In 2008, tick load ranged from 0-102 ticks on the neck and pouch area, and several heavily infested chicks were later found dead. At Crab Bank, ticks were found in small numbers on pelican chicks and did not appear to influence productivity.

- Royal and Sandwich terns

Methods.-- Counts of tern adults and fledged young were recorded during colony visits and surveys to determine nesting phenology and estimate productivity. Data loggers were placed in 10 Royal Tern nests on Crab Bank and Deveaux Bank (plus controls) in 2007. Colony locations and areas used by nestlings were marked with GPS.

Results and Discussion.-- Peak hatch for tern species was in mid-June, and many terns had fledged and left the islands by early August in all years of the study. We did not conduct regular checks of tern nests to avoid disturbance to the colonies, and counts of tern nestlings in the intertidal area appeared to underestimate the number of nestlings present on the islands, particularly at Deveaux Bank. Therefore, we were unable to estimate reproductive parameters for Royal and Sandwich Terns.

Temperature logger eggs placed alongside Royal Tern eggs in 2007 did not appear to be incubated. Terns were probably able to move their egg away from the temperature logger egg and thereby avoid incubating the decoy. A banded Royal Tern fledgling was opportunistically observed on Deveaux Bank during a July 29 2008 visit (pers. obs. F. Sanders) and on Bird Key during a 9 October visit (pers. obs. L. Eggert). The bands could not be read, however no tern chicks were banded in SC in 2008. These sightings indicate that fledgling terns from colonies outside the state are using the intertidal areas of SC seabird sanctuaries. Royal and Sandwich Terns did not nest on Bird Key in 2008. However, Royal Terns, Gull-billed Terns, and Least Terns were seen in May among skimmer and tern decoys and near the sound system. Three Least

Tern nests and scrapes were found on Bird Key in mid-June; nests were lost during early incubation. Additionally, a Royal Tern fledgling was observed on 25 August at Bird Key (band was not readable), which did not support a tern colony in 2008.

Factors affecting nesting success.-- Reproductive success of all species was affected by factors such as parasitism, weather events, human disturbance, and predation, though the extent of each varied by island, species, and year. Weather and tide events affected nest numbers and reproductive parameters, particularly during the 2007 breeding season. During that year, storm events at the start of the nesting season, in mid-April and early May, impacted nesting phenology at Deveaux Bank, particularly for Brown Pelicans, and may have resulted in birds breeding elsewhere or not at all in 2007. A third storm, Tropical Strom Barry, occurred in early June and resulted in the loss of approximately 75 tern nests, 21 skimmer nests, and at least 10 pelican chicks on Crab Bank. Ectoparasite infestation was evident on pelican chicks on Deveaux Bank but did not appear to have a significant effect on any of the colonies during incubation or chick-rearing in 2007. Major storms or flooding did not appear to have a significant effect on these colonies during incubation or chick-rearing in 2006, though a small skimmer colony on Deveaux Bank was lost to high tides.

Predation also affected reproductive success of seabirds and was especially costly for Black Skimmers. Laughing Gulls nested near the skimmer colonies and were frequently observed standing along the perimeter of the colony or flying over during our visits. Even though less than 5 Laughing Gull pairs were thought to have nested on Bird Key in 2007 and 2008, as many as 35 gulls were observed in or flying above the skimmer colony and decoys there. We commonly observed signs of egg predation and nest loss due to Laughing Gull predation throughout incubation. Predation pressure from Laughing Gulls often escalated after skimmer nestlings had hatched. These events occurred when skimmers left their nests due to disturbance by researchers, people recreating, or other causes of disturbance. Aggressive Gull-billed Terns (*Sterna nilotica*) nesting within the skimmer colony on Crab Bank may have helped protect both species from gull predation to some degree. Laughing Gulls depredated nests of others species, including American Oystercatcher and Royal, Sandwich, and Least terns on Bird Key. Skimmer eggs were also lost to ghost crabs (*Ocypode quadrata*). We observed ghost crabs in skimmer nests, ghost crab tracks with eggs leading out of skimmer nests, and skimmer egg shells in crab burrows. At Bird Key, predation of skimmers by a Great-Horned Owl (*Bubo viginianus*) was evident in 2007 and 2008. Remains from multiple skimmer adults, a fledgling, and one Least Tern were found.

People were observed on all islands during the breeding season, and human disturbance impacted reproductive success for seabirds, especially the Black Skimmer. On Crab Bank, skimmers experienced disturbance from kayakers and boaters, with severe events occurring in 2006 and 2007 that likely resulted in chick mortality. We observed people on the beaches causing disturbance to nesting Black Skimmers on Deveaux Bank, though the recreators were in the open area of the island (intertidal area). During all years of the study, we observed footprints leading behind closure signs on Deveaux Bank and into a skimmer colony and close to skimmer nesting areas, which often were just beyond (<10 m) the signs, on several occasions, though such intrusions were never directly observed. We did not observe a single successful skimmer nest at Deveaux Bank in 2007; no nests survived more than five days. As mentioned in the introduction. Skimmers are particularly sensitive to disturbance. For example, chick mortality for skimmers may occur within 25 minutes of exposure to full sun (Gochfeld and Burger 1994). Therefore even brief disturbance events may be critical to nesting success.

The potential positive effects of the new seabird conservation regulations may be best demonstrated by the increased colony size and success of the Black Skimmer colony on Crab Bank during the first year of closure. Black Skimmers prefer to nest on open sandy beaches. Suitable nesting habitat such as this is found on Crab Bank's west tip which, in previous years, was the most visited section of the island due to ease of watercraft landing. Closure of the entire island in 2006 coincided with an increase in the number of skimmer nests from an average of 46 nests in 2004 and 2005 to an average of 185 nests in the years following island closure. Though productivity measures were not estimated in previous years, the success of nest attempts on the west tip was followed during routine visits to the pelican colony. The majority of skimmer nest attempts in 2004 and 2005 failed and productivity in those years was low to none (LE, personal observations). Decreased disturbance from the island closure likely contributed to the success of the Black Skimmer colony on Crab Bank. Productivity for skimmers in 2006 was 0.53, or one chick fledged for 50% of the nesting pairs, similar to the average reported across the species range (Gochfeld and Burger 1994). Gull-billed Terns nested within the Black Skimmer colony at Crab Bank in 2008 and appeared to have a relatively successful season as well.

The re-establishment of seabird nesting on Bird Key in 2007 was another positive event since the island closures. Black Skimmers nested on the island in both 2007 and 2008, Least Terns initiated nests in 2008, Gull-billed Terns initiated nests in 2007, and Gull-billed and Royal terns were present early in the 2008 breeding season. Though hatching success has been relatively high for Black Skimmers at this colony, nestling survival is low. This is likely due to the direct or indirect effects of predation (e.g. Great-horned Owl).

Comparison of reproductive parameters such as hatching success, fledging success, and productivity at Crab Bank and Bird Key, which are entirely closed to visitors during the breeding season, and Deveaux Bank, where public access is limited to areas below the high tide line, may improve our understanding of the effect of human disturbance to breeding seabird populations within the state. Though focal species currently nest on both Crab and Deveaux banks, a number of differences exist between the breeding habitat, public use, and current management policies between the islands. For example, breeding birds are condensed within the available breeding habitat on Crab Bank (7 ha), while the distribution of breeding seabirds on Deveaux Bank (87 ha) is much more expansive. Additionally, Crab Bank is located within Charleston Harbor, is easily accessible, and received frequent visitation until the island was closed in its entirety to visitors during the breeding season. In contrast, Deveaux Bank is more remote and difficult to access, receives less frequent visitation, but the intertidal portion of the shoreline remained open to visitation during the 2006 – 2008 breeding seasons. Differences in island structure, use, and management policies may influence habitat use, reproductive parameters, and possibly health of breeding seabird species.

Objective 2: Map habitat use by seabirds during the breeding season.

Methods.-- Patterns of intertidal bird use observed during the 2006 field season were used to construct questions and methodologies for the more detailed habitat use surveys that were conducted in 2007 and 2008. Surveys were designed to capture bird use of the intertidal portion of the islands during the low tide period. Deveaux Bank was the primary island of interest for the intertidal use surveys as it has the greatest need for habitat use information as it relates to management practices. Bird use of intertidal areas was quantified for all islands, but habitat analysis was only conducted for Deveaux Bank surveys.

The same methods were used to conduct surveys at Bird Key and Deveaux Bank. Surveys were conducted from May through October 2007 and 2008 during morning (7:00-11:00) low tides (± approx 1.5 hr, and in all cases were completed within 3.5 hrs). One survey was conducted during each tidal cycle (i.e., two weeks), weather and conditions permitting. Survey plots (Bird Key, n = 9; Deveaux Bank, n = 21) were delineated in May of each year and systematically spaced at 200 m intervals around the perimeter of the island. The location of plots was retained between years to the extent possible given interannual changes in island configuration. Plots were approximately 100 m in length and varied naturally with the width of the beach (Deveaux Bank: Figure 1; Bird Key: Figure 2). The high tide boundary of plots was marked with handheld GPS (Garmin GPSmap 76, GPS 76) and survey flags at the midpoint and endpoints. The remainder of the plot was visually estimated during each survey; surveyors practiced estimates together at the start of the season prior to conducting surveys. Surveys were conducted by two researchers, each simultaneously surveying approximately half of the plots. Researchers took care to walk slowly between plots and select a path that caused the least amount of disruption to birds in the intertidal and elsewhere. Upon arriving at the midpoint of a plot, researchers waited at least 1 min or until birds appeared to acclimate to their presence, and then counted all birds in the plot using binoculars and spotting scopes for approximately 5 min. During this period, all birds in the plot were enumerated by species and age class (adult, juvenile, young of year), and the behavior (analyzed only for Deveaux Bank) and location of each individual within the plot was recorded and grouped into 5 categories (Tables 3 & 4). If it appeared that approach to the survey location would cause excess disturbance to birds in the intertidal area and thus alter results, counts were conducted from just outside the plot, rather than midpoint.

Table 3. Behavior categories for bird surveys conducted on Deveaux Bank, 2007 – 2008.

Behavior	Includes	Examples of observed behavior
FORAGE	Beg	chick display of begging (posture, vocalization), adult interaction with begging chick
	Forage	forage in sand or water
	Feed	chick fed by adult, adult feeding chick
	Drink	drinking in water's edge or water feature in plot
LOAF	Rest	loaf, roost
MAINTENANCE	Bath	bathing in water's edge or water feature in plot
	Preen	self-maintenance
	Other	flap or stretch wings
LOCOMOTION	Walk	walk, run
	Fly in/out	bird landing in or departing plot (not bird flying over plot)
	Swim	swimming within water's edge or water feature in plot
SOCIAL	Social	chase, aggression, copulation, court, display (e.g. with fish)

Table 4. Location and summary of all birds during surveys of Deveaux Bank and Bird Key, 2007 – 2008.

		Deveaux Bank				Bird Key			
Location	Description	Sum		Percent		Sum		Percent	
		Combined		Combined		Combined		Combined	
		2007	2008	2007	2008	2007	2008	2007	2008
Water's edge	submerged sand (~3m)	842		0.09		59		0.07	
		144	698	0.04	0.12	5	54	0.01	0.16
Lower beach	wet sand area	5456		0.60		603		0.69	
		2433	3023	0.76	0.52	417	186	0.76	0.56
Mid beach	moist sand area	2385		0.26		134		0.15	
		536	1849	0.17	0.32	62	72	0.11	0.22
Upper beach	dry sand area	359		0.04		80		0.09	
		90	269	0.03	0.05	62	18	0.11	0.05

Survey methods at Crab Bank differed from the other islands due to the constrained area available to nesting birds and the potential for excessive disturbance caused by walking the perimeter of the island. We therefore conducted boat-based surveys along the south facing side and west tip of Crab Bank (Figure 3). This stretch consists mainly of sandy beaches that are easily approached (within 15 m) by motor boat at low tide. Eighteen segments of approximately 50m were marked in late April along the portion of the island to be surveyed. The boat was idled around the island while one researcher recorded all individuals (species, age class, location, behavior) in each 50m segment. Digital photos were taken if conditions were too rough to conduct surveys, and birds were then enumerated from photos. Surveys were conducted around low tides (± 3.5 hours) in the early part of the day whenever possible. In 2008, one survey was conducted per month. The northern stretch of the island is primarily salt marsh and is not easily accessed at low tide; therefore this area was not included in the surveys. As our objective was to examine bird use of the intertidal area, we included birds that flew or walked into plots during the survey, but did not include birds flying over the plot. Similarly, birds that moved from one plot to another were counted in both; therefore our counts reflect bird abundance relative to each plot rather than overall bird abundance on the island. Location within the plot was not considered. Weather, temperature, wind speed, and wind direction were recorded at the start of each survey (Kestrel 2000 anemometer).

For each plot on Deveaux Bank, we measured habitat characteristics at the plot and landscape scale. At the plot scale, we recorded slope, width, dominant substrate, and human use. The slope and width of each plot were measured using a clinometer (Suunto PM-5/360; Colwell and Sundeen 2000, Neuman et al 2008) and handheld GPS, respectively. To account for human use of the island, we recorded signs of people and dogs (e.g. footprints) and presence of people, dogs, and boats in/adjacent to plots during each survey and indexed the proportion of surveys that human use was observed in each plot for both years (Manor and Saltz 2005). We considered human use to be a plot-scale variable because human disturbance operates primarily at the local level (Schlesinger et al. 2008). Landscape-scale factors included presence of dunes adjacent to the plot, presence of sandbars in nearshore waters, distance from each plot to a standing water feature, and distance from each plot to seabird colonies. Distance features were derived using Geographic Information System (GIS; ArcGIS 9.3) and were based on the minimum distance between centroids of each plot and centroids of seabird colonies and water features. The boundaries of all previously mentioned features were recorded in the field each year using GPS. Sand was the dominant substrate and was present in all plots; areas with mud substrate and ephemeral water features occurred to a lesser degree. Substrate was categorized but there was not enough variability among plots (at the scale we measured) to evaluate the affect substrate might have on habitat use.

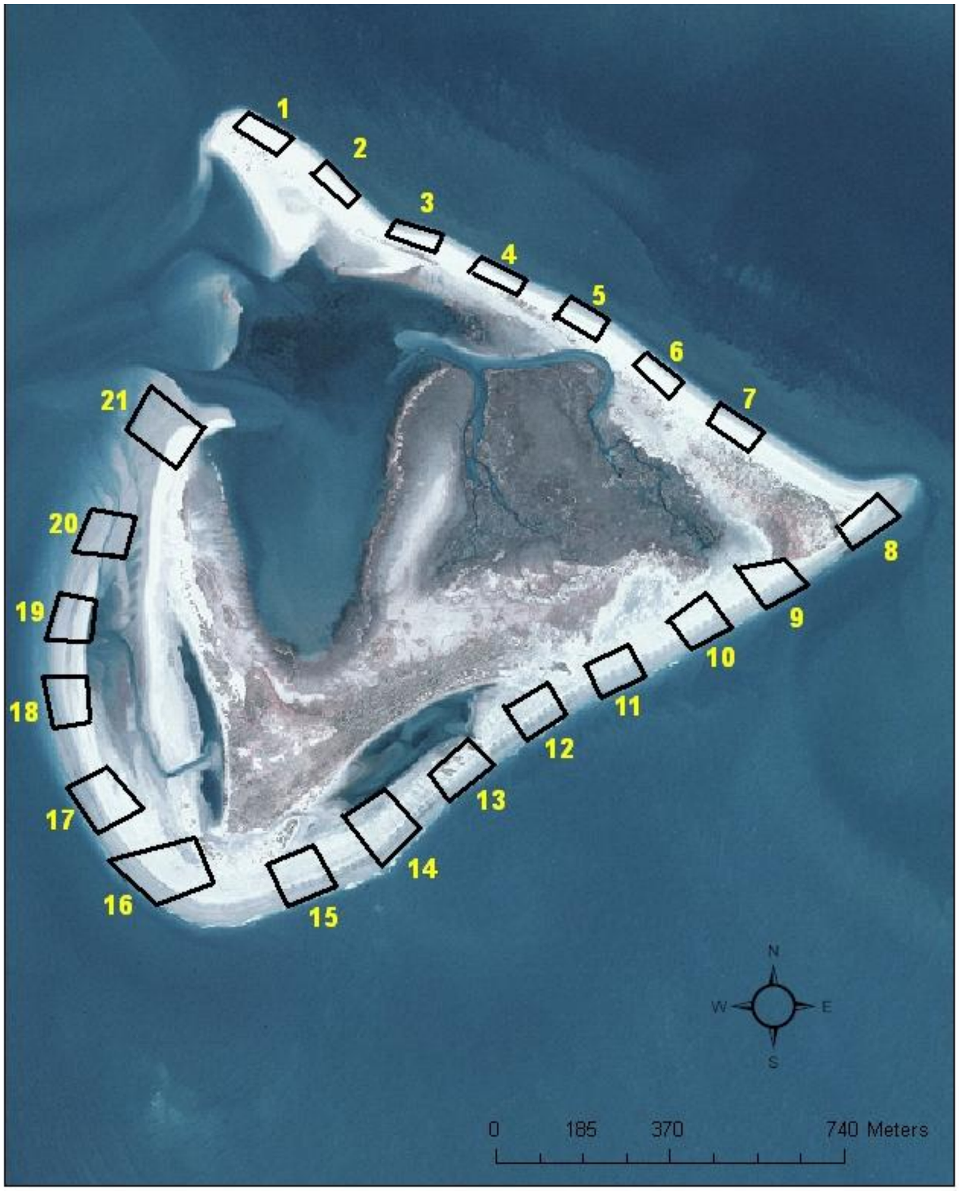


Figure 1. Location of intertidal survey plots on Deveaux Bank, May – October 2007 and 2008.

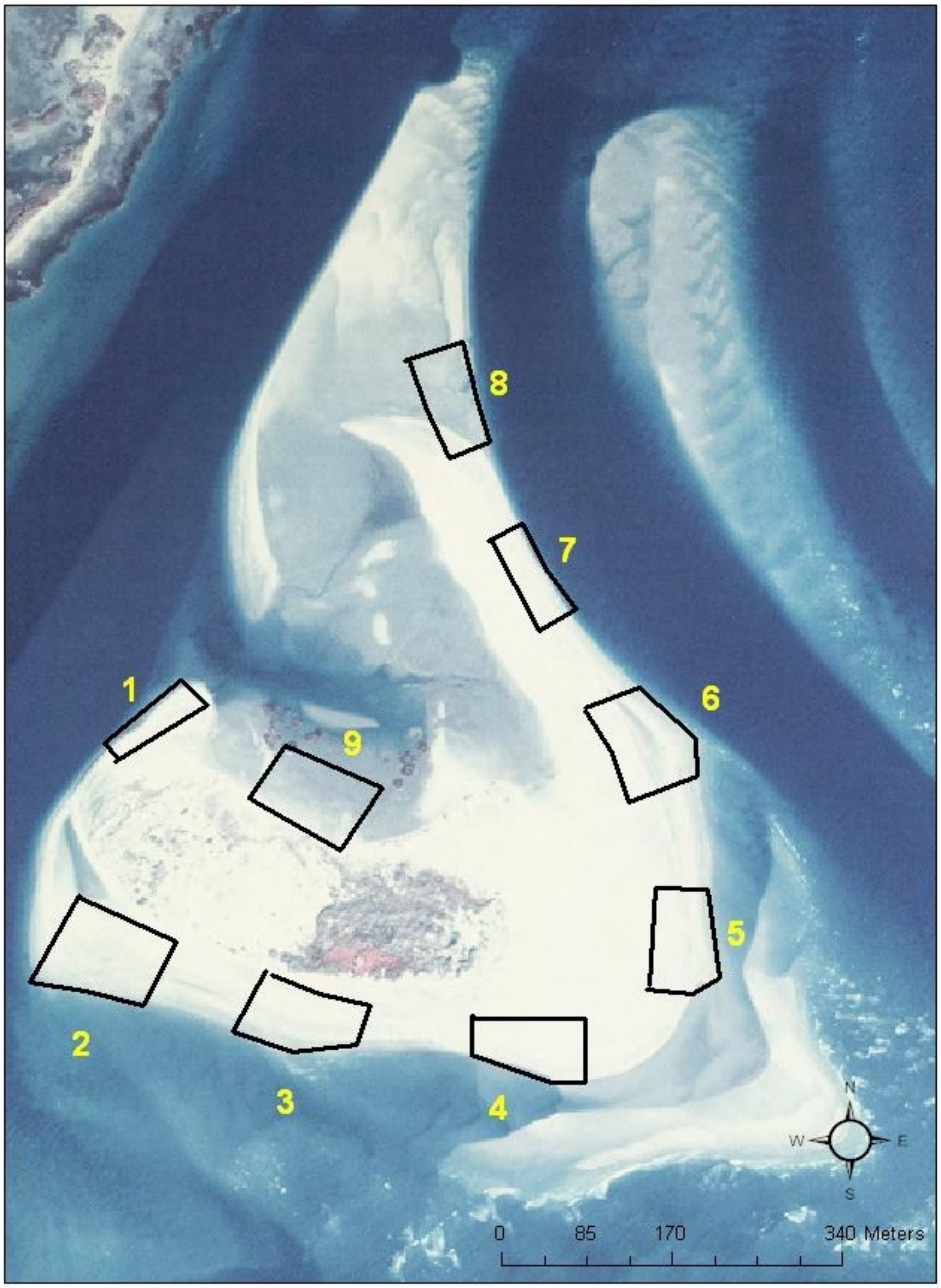


Figure 2. Location of intertidal survey plots on Bird Key, May – October 2007 and 2008.

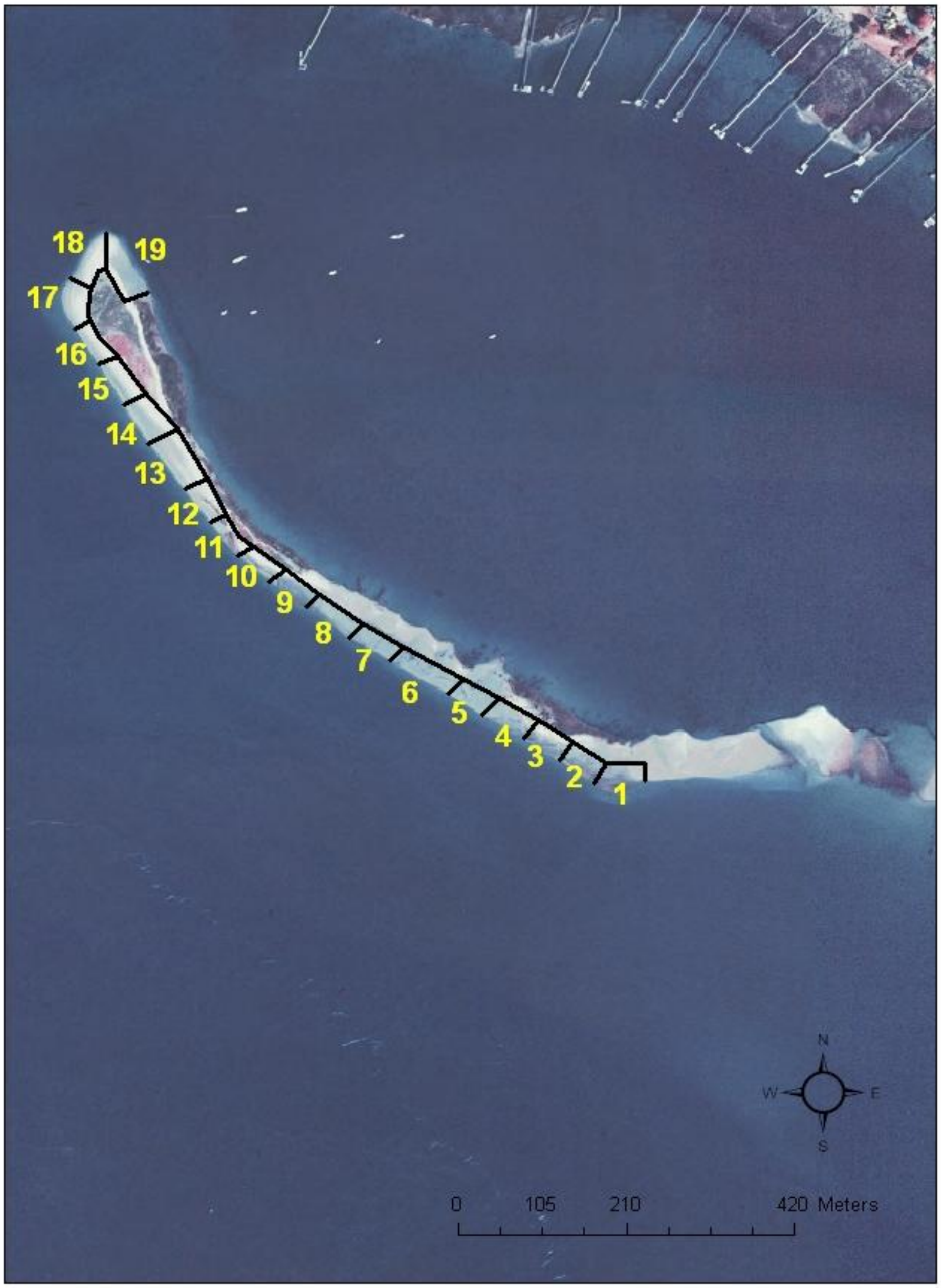


Figure 3. Location of intertidal survey plots surveyed on Crab Bank May – October 2007 and 2008.

Results and Discussion.-- We recorded observations or signs of human use of the seabird islands during surveys and other field work in 2007 and 2008. In 2007, visitors were observed on Deveaux 14 days (1-30 visitors at a time), on Bird Key 4 days (4-9 visitors at a time), and on Crab Bank 2 days (1 and 3 visitors). Prints of bare feet (which suggests prints belonged to recreators and not other biologists) were recorded on at least 8 separate instances on the closed islands or in closed areas (including nesting areas) of Deveaux Bank. We saw visitors accompanied by dogs once at Deveaux (1 dog) and Bird Key (3 dogs). Additionally, we recorded tracks from dogs on 4 separate instances on the islands (dogs are not permitted on any island). We spoke with at least seven groups of people to inform them of SCDNR policy concerning seabird islands. In 2008, 141 people (66 groups) were observed on Deveaux Bank during our visits. One person was observed in a closed area and footprints were observed on five separate instances behind the signs in closed areas. Several times footprints were observed in or near nesting bird areas. Dogs were seen on Deveaux Bank two times (one chasing birds) and multiple dog prints were observed on the island. The majority of visitors used the recreational area and the stretch of beach facing Seabrook Island (39 groups) or the Botany Bay side of the island (24 groups). Two groups visited the ocean facing side of the island and one group we encountered walked the perimeter of the island. A charter boat was observed three times bringing visitors (>5 people per visit) to the northeast portion of Deveaux Bank (near 2006-2007 pelican and tern nesting area).

During our visits to the access-prohibited islands in 2008, 36 people were observed on Bird Key and two people were observed inside the skimmer colony on Crab Bank. Additional reports of people on the closed islands were conveyed to us during the breeding season, and included four children chasing and handling birds in the skimmer colony on Crab Bank (Felicia Sanders, pers. obs.) and a family on Crab Bank that refused to leave after being informed of the closure regulations by a local kayak guide. Two dogs were observed on Bird Key. Evidence of a large Memorial Day party on Bird Key included footprints of many people, prints from dogs, an abandoned grill, beer cans, food, and a large hole. Footprints were observed on Bird Key an additional six times and on Crab Bank one time. We spoke to people whenever possible to explain the SCDNR policy concerning seabird islands. If people were in prohibited areas, we informed them of the existing policy and requested they leave the island or prohibited area.

Over 30 waterbird species were counted during our surveys. At Deveaux Bank, we counted 9,042 birds (2007: n = 3203 birds, 2008: n = 5839 birds; Table 5) during 17 surveys (2007: n = 8 surveys, 2008: n = 9 surveys). Total count of all birds during an individual survey ranged from 252 – 1678 birds (mean = 532 ± 88 birds per survey, both years combined). The greatest number of birds was counted during surveys in early August of 2007 and late July of 2008, while the fewest birds were counted during surveys conducted in late June of both years. Thirty-two species were counted. Figure 1 illustrates survey plot location on Deveaux Bank. Mean bird abundance was 25.3 ± 39.8 birds per plot and varied by year. The average number of birds and total number of species counted per plot on Deveaux Bank are displayed in Figure 4. Of the 8739 birds for which behavior was analyzed (96.6 % of all birds counted), the greatest percentage of birds observed during both survey years were loafing (57.6 %). Other behaviors recorded during surveys included maintenance behaviors (23.9 %), foraging (16.3 %), locomotion (1.7 %), and social behaviors (0.5 %). Behavior differed among seabirds and shorebirds.

At Bird Key, we counted a total of 876 birds (2007: n = 546, 2008: n = 330 birds; Table 6) during 18 surveys (2007: n = 8, 2008: n = 10). Total count of all birds during an individual survey ranged from 9 – 97 birds (mean = 49 ± 29 birds per survey, both years combined). At least 25 species were counted. Figure 2 illustrates survey plot location on Bird Key. Mean bird abundance was 48.7 ± 47.9 birds per plot. The average number of birds and total number of species counted per plot on Bird Key are displayed in Figure 5. Approximately 76 % of birds were located along the water and on the lower portion of the beach during surveys (Table 4).

At Crab Bank, we counted a total of 7898 birds (2007: n = 5181, 2008: n = 2717 birds; Table 7) during 13 surveys (2007: n = 9, 2008: n = 4). Total count of all birds during an individual survey ranged from 69 – 1245 birds (mean = 607 ± 332 birds per survey, both years combined). At least 19 species were counted. Figure 3 illustrates survey plot location on Crab Bank. Mean bird abundance was 207.8 ± 188.3 birds per plot. The average number of birds and total number of species counted per plot on Crab Bank are displayed in Figure 6.

Human use observed during surveys was less apparent on Bird Key and Crab Bank where use was prohibited entirely during the breeding season. On Bird Key, human use was observed from 0 – 2 times per year during surveys and no human use was observed on Crab Bank.

Brown Pelican, Laughing Gulls, Black Skimmers, and Royal, Sandwich, and Gull-billed terns were most frequently engaged in loafing and maintenance behavior in the intertidal zone, while shorebirds were most often observed foraging there (Table 4). Approximately 70% of birds were located along the water and on the lower portion of the beach during surveys (Table 4). The abundance of most species and species groups was significantly affected by interactions of the independent variables, including human use, beach slope, distance to colonies, and presence of dunes and offshore sandbars. The strength and direction of the relationships between habitat characteristics and bird use varied among species and species groups. These findings suggest that a management plan intended to increase the level of protection afforded to seabirds using intertidal areas may be difficult to design and implement because of the complex and inconsistent habitat associations observed in this study. Maintaining an open corridor for visitor use along the lower beach (i.e. furthest distance from the colonies) would create a conflict of use with birds that frequently use this beach zone for loafing, maintenance, and foraging behaviors.

Human disturbance has been identified as one of the greatest challenges for colonial birds in South Carolina (South Carolina Comprehensive Wildlife Conservation Strategy, 2005). Our data suggest that enhanced protection of breeding islands (e.g. Deveaux Bank, which supports at least 27 bird species of concern during crucial life stages) would reduce interactions between seabirds and humans particularly in the intertidal zone where many species loaf, forage, or rear young. Enhanced protection also would mitigate disturbance at nest sites and dune areas that support adults and chicks during the breeding season.

Table 5. Species counted during surveys of Deveaux Bank, 2007-2008.

Common Name	Scientific Name	Breeding status	2007 Total count	2008 Total count	2007-2008 Total count	2007 surveys Proportion present	2008 surveys Proportion present	2007-2008 surveys Proportion present	2007 Avg / survey	2008 Avg / survey	2007-2008 Avg / survey
Brown Pelican	*Pelecanus occidentalis*	B	491	384	875	1.00	1.00	1.00	61.38	42.67	51.47
Double-crested Cormorant	*Phalacrocorax auritus*	NC	5	0	5	0.38	0.00	0.18	0.63	0.00	0.29
Reddish Egret	*Egretta rufescens*	NC	3	3	6	0.38	0.33	0.35	0.38	0.33	0.35
Tricolored Heron	*Egretta tricolor*	B	1	7	8	0.13	0.44	0.29	0.13	0.78	0.47
Black-bellied Plover	*Pluvialis squatarola*	NB	4	74	78	0.25	0.78	0.53	0.50	8.22	4.59
Semipalmated Plover	*Charadrius semipalmatus*	NB	46	82	128	0.75	0.89	0.82	5.75	9.11	7.53
Piping Plover	*Charadrius melodus*	NB	20	42	62	0.38	0.44	0.41	2.50	4.67	3.65
Wilson's Plover	*Charadrius wilsonia*	B	3	16	19	0.25	0.67	0.47	0.38	1.78	1.12
American Oystercatcher	*Haematopus palliatus*	B	42	66	108	0.50	0.67	0.59	5.25	7.33	6.35
Yellowlegs^											
Greater Yellowlegs	*Tringa melanoleuca*	NB	1	3	4	0.13	0.33	0.24	0.13	0.33	0.24
Lesser Yellowlegs	*Tringa flavipes*	NB									
Willet	*Tringa semipalmatus*	B	35	59	94	0.88	1.00	0.94	4.38	6.56	5.53
Marbled Godwit	*Limosa fedoa*	NB	4	0	4	0.13	0.00	0.06	0.50	0.00	0.24
Hudsonian Godwit	*Limosa haemastica*	NB									
Ruddy Turnstone	*Arenaria interpres*	NB	13	38	51	0.50	1.00	0.76	1.63	4.22	3.00
Sanderling	*Calidris alba*	NB	247	424	671	1.00	1.00	1.00	30.88	47.11	39.47
Red Knot	*Calidris canutus*	NB	1	32	33	0.13	0.33	0.24	0.13	3.56	1.94
Dunlin	*Calidris alpina*	NB	2	34	36	0.13	0.56	0.35	0.25	3.78	2.12
Peep^			56	177	233	0.88	0.78	0.82	7.00	19.67	13.71
Semipalmated Sandpiper	*Calidris pusilla*	NB									
Western Sandpiper	*Calidris mauri*	NB									
Least Sandpiper	*Calidris minutilla*	NB									
Dowicher^			1	33	34	0.13	0.22	0.18	0.13	3.67	2.00
Long-billed Dowitcher	*Limnodromus scolopaceus*	NB									
Short-billed Dowitcher	*Limnodromus griseus*	NB									
Unknown shorebirds^			26	3	29	0.50	0.33	0.41	3.25	0.33	1.71
Lauging Gull	*Leucophaeus atricilla*	B	1411	2612	4023	1.00	1.00	1.00	176.38	290.22	236.65
Ring-billed Gull	*Larus delawarensis*	NB	5	18	23	0.25	0.33	0.29	0.63	2.00	1.35
Herring Gull	*Laus argentatus*	NB	16	10	26	0.88	0.56	0.71	2.00	1.11	1.53
Great Black-backed Gull	*Larus marinus*	NB	1	0	1	0.13	0.00	0.06	0.13	0.00	0.06
Unknown gulls^			3	0	3	0.13	0.00	0.06	0.38	0.00	0.18
Black Tern	*Chlidonias niger*	NB	37	130	167	0.13	0.11	0.12	4.63	14.44	9.82
Gull-billed Tern	*Gelochelidon nilotica*	B	4	3	7	0.38	0.33	0.35	0.50	0.33	0.41
Royal Tern	*Thalasseus maxima*	B	408	1178	1586	1.00	0.89	0.94	51.00	130.89	93.29
Sandwich Tern	*Thalasseus sandvicensis*	B	49	40	89	0.88	0.67	0.76	6.13	4.44	5.24
Common Tern	*Sterna hirundo*	NC	2	13	15	0.13	0.22	0.18	0.25	1.44	0.88
Forster's Tern	*Sterna forsteri*	NC	5	5	10	0.25	0.22	0.24	0.63	0.56	0.59
Least Tern	*Sternula antillarum*	NC	3	8	11	0.25	0.11	0.18	0.38	0.89	0.65
Unknown terns^			13	6	19	0.25	0.22	0.24	1.63	0.67	1.12
Black Skimmer	*Rynchops niger*	B	245	339	584	0.63	0.89	0.76	30.63	37.67	34.35

^species grouped that could not be reliably identified to species

B = nested on Deveaux Bank 2007-2008

NC = nest in SC; did not nest on Deveaux Bank 2007-2008

NB = does not nest in SC

Table 6. Species counted during surveys of Bird Key, 2007 – 2008.

Common Name	Scientific Name	Breeding status	2007 Total count	2008 Total count	2007-2008 Total count	2007 surveys Proportion present	2008 surveys Proportion present	2007-2008 surveys Proportion present	2007 Avg / survey	2008 Avg / survey	2007-2008 Avg / survey
Brown Pelican	*Pelecanus occidentalis*	NC	23	3	26	0.50	0.10	0.28	2.88	0.30	1.44
Double-crested Cormorant	*Phalacrocorax auritus*	NC	1	0	1	0.13	0.00	0.06	0.13	0.00	0.06
Snowy Egret	*Egretta thula*	B	10	26	36	0.13	0.30	0.22	1.25	2.60	2.00
Tricolored Heron	*Egretta tricolor*	B	32	33	65	0.38	0.50	0.44	4.00	3.30	3.61
Black-crowned Night-heron	*Nycticorax nycticorax*	B	0	2	2	0.00	0.10	0.06	0.00	0.20	0.11
Black-bellied Plover	*Pluvialis squatarola*	NB	1	7	8	0.13	0.40	0.28	0.13	0.70	0.44
Semipalmated Plover	*Charadrius semipalmatus*	NB	30	27	57	0.75	0.70	0.72	3.75	2.70	3.17
Piping Plover	*Charadrius melodus*	NB	6	8	14	0.50	0.40	0.44	0.75	0.80	0.78
Wilson's Plover	*Charadrius wilsonia*	B	11	20	31	0.50	0.60	0.56	1.38	2.00	1.72
American Oystercatcher	*Haematopus palliatus*	B	24	23	47	0.50	0.60	0.56	3.00	2.30	2.61
Willet	*Catoptrophorus semipalmatus*	B	19	31	50	0.50	0.80	0.67	2.38	3.10	2.78
Ruddy Turnstone	*Arenaria interpres*	NB	8	8	16	0.50	0.40	0.44	1.00	0.80	0.89
Sanderling	*Calidris alba*	NB	58	58	116	0.63	0.80	0.72	7.25	5.80	6.44
Red Knot	*Calidris canutus*	NB	1	0	1	0.13	0.00	0.06	0.13	0.00	0.06
Dunlin	*Calidris alpina*	NB	0	2	2	0.00	0.10	0.06	0.00	0.20	0.11
Peep^			68	27	95	0.88	0.40	0.61	8.50	2.70	5.28
Semipalmated Sandpiper	*Calidris pusilla*	NB									
Western Sandpiper	*Calidris mauri*	NB									
Least Sandpiper	*Calidris minutilla*	NB									
Dowicher^			24	2	26	0.63	0.10	0.33	3.00	0.20	1.44
Long-billed Dowitcher	*Limnodromus scolopaceus*	NB									
Short-billed Dowitcher	*Limnodromus griseus*	NB									
Unknown shorebirds^			18	1	19	0.25	0.10	0.17	2.25	0.10	1.06
Lauging Gull	*Larus atricilla*	B	85	32	117	0.88	0.50	0.67	10.63	3.20	6.50
Ring-billed Gull	*Larus delawarensis*	NB	1	1	2	0.13	0.10	0.11	0.13	0.10	0.11
Herring Gull	*Laus argentatus*	NB	1	0	1	0.13	0.00	0.06	0.13	0.00	0.06
Unknown gulls^			9	0	9	0.25	0.00	0.11	1.13	0.00	0.50
Gull-billed Tern	*Sterna nilotica*	B	3	0	3	0.13	0.00	0.06	0.38	0.00	0.17
Royal Tern	*Sterna maxima*	NC	37	4	41	0.50	0.10	0.28	4.63	0.40	2.28
Sandwich Tern	*Sterna sandvicensis*	NC	4	0	4	0.25	0.00	0.11	0.50	0.00	0.22
Least Tern	*Sterna antillarum*	B	16	3	19	0.25	0.20	0.22	2.00	0.30	1.06
Unknown terns^			5	0	5	0.38	0.00	0.17	0.63	0.00	0.28
Black Skimmer	*Rynchops niger*	B	51	12	63	0.75	0.30	0.50	6.38	1.20	3.50

^species grouped that could not be reliably identified to species

B = nested on Bird Key 2007-2008

NC = nest in SC; did not nest on Bird Key 2007-2008

NB = does not nest in SC

Table 7. Species counted during surveys of Crab Bank, 2007 – 2008.

Common Name	Scientific Name	Breeding status	2007 Total count	2008 Total count	2007-2008 Total count	2007 surveys Proportion present	2008 surveys Proportion present	2007-2008 surveys Proportion present	2007 Avg / survey	2008 Avg / survey	2007-2008 Avg / survey
Brown Pelican	*Pelecanus occidentalis*	B	1253	420	1673	1.00	1.00	1.00	139.22	105.00	128.69
Double-crested Cormorant	*Phalacrocorax auritus*	NC	3	0	3	0.33	0.00	0.23	0.33	0.00	0.23
Tricolored Heron	*Egretta tricolor*	B	3	0	3	0.11	0.00	0.08	0.33	0.00	0.23
Black-bellied Plover	*Pluvialis squatarola*	NB	7	6	13	0.33	0.50	0.38	0.78	1.50	1.00
Semipalmated Plover	*Charadrius semipalmatus*	NB	12	49	61	0.44	0.50	0.46	1.33	12.25	4.69
American Oystercatcher	*Haematopus palliatus*	B	84	24	108	0.89	0.50	0.77	9.33	6.00	8.31
Willet	*Catoptrophorus semipalmatus*	B	5	3	8	0.33	0.50	0.38	0.56	0.75	0.62
Marbled Godwit	*Limosa fedoa*	NB	1	0	1	0.11	0.00	0.08	0.11	0.00	0.08
Ruddy Turnstone	*Arenaria interpres*	NB	37	15	52	0.56	0.75	0.62	4.11	3.75	4.00
Sanderling	*Calidris alba*	NB	34	40	74	0.44	0.75	0.54	3.78	10.00	5.69
Peep^			56	9	65	0.56	0.50	0.54	6.22	2.25	5.00
Semipalmated Sandpiper	*Calidris pusilla*	NB									
Western Sandpiper	*Calidris mauri*	NB									
Least Sandpiper	*Calidris minutilla*	NB									
Dowicher^			38	8	46	0.22	0.25	0.23	4.22	2.00	3.54
Long-billed Dowitcher	*Limnodromus scolopaceus*	NB									
Short-billed Dowitcher	*Limnodromus griseus*	NB									
Unknown shorebirds^			50	6	56	0.44	0.75	0.54	5.56	1.50	4.31
Lauging Gull	*Larus atricilla*	B	1038	745	1783	1.00	0.75	0.92	115.33	186.25	137.15
Ring-billed Gull	*Larus delawarensis*	NB	10	0	10	0.67	0.00	0.46	1.11	0.00	0.77
Herring Gull	*Laus argentatus*	NB	78	12	90	1.00	0.50	0.85	8.67	3.00	6.92
Unknown gulls^			18	9	27	0.33	0.75	0.46	2.00	2.25	2.08
Gull-billed Tern	*Sterna nilotica*	B	39	19	58	0.56	0.75	0.62	4.33	4.75	4.46
Royal Tern	*Sterna maxima*	B	1937	1127	3064	1.00	0.75	0.92	215.22	281.75	235.69
Sandwich Tern	*Sterna sandvicensis*	B	10	13	23	0.22	0.50	0.31	1.11	3.25	1.77
Black Skimmer	*Rynchops niger*	B	468	212	680	0.89	0.75	0.85	52.00	53.00	52.31

^species grouped that could not be reliably identified to species

B = nested on Crab Bank 2007-2008

NC = nest in SC; did not nest on Crab Bank 2007-2008

NB = does not nest in SC

Table 8. Maximum and total number of seabirds counted during intertidal surveys at Bird Key, Crab Bank, and Deveaux Bank, 2007-2008.

		Bird Key				Crab Bank				Deveaux Bank			
		2007		2008		2007		2008		2007		2008	
		Maximum	Total	Maximum	Total	Maximum	Total	Maximum	Total	Maximum	Total	Maximum	Total
Brown Pelicans	Adult	17	22	3	3	169	635	102	165	132	405	80	315
	Young	1	1	0	0	176	611	152	258	43	44	24	69
Royal Terns	Adult	32	37	4	4	242	737	244	435	110	340	279	1109
	Young	0	0	0	0	322	675	478	726	58	73	47	69
Sandwich Terns	Adult	3	4	0	0	5	10	5	9	17	48	15	39
	Young	0	0	0	0	0	0	4	4	1	2	1	1
Black Skimmers	Adult	18	51	5	12	126	397	98	180	108	245	103	286
	Young	0	0	0	0	27	74	56	60	0	0	39	53

Table 9. Intertidal bird use by age class at Bird Key, Crab Bank, and Deveaux Bank 2006-2008. Surveys were not conducted at Bird Key in 2006. 'X' indicates presence in at least one survey in each survey year.

		Bird Key		Crab Bank			Deveaux Bank		
Species	Age	2007	2008	2006	2007	2008	2006	2007	2008
Brown Pelican	Adult	X	X	X	X	X	X	X	X
	Young	X		X	X	X	X	X	X
Black Skimmer	Adult	X	X	X	X	X	X	X	X
	Young				X	X	X		X
Royal Tern	Adult	X	X	X	X	X	X	X	X
	Young			X	X	X	X	X	X
Sandwich Tern	Adult	X			X	X	X	X	X
	Young					X	X	X	X
Gull-billed Tern	Adult	X			X	X	X	X	X
	Young				X	X			X
Laughing Gull	Adult	X	X	X	X	X	X	X	X
	Young	X	X	X	X	X	X	X	X
American Oystercatcher	Adult	X	X	X	X	X		X	X
	Young			X	X	X		X	X

Figure 4. Average number of birds and total species counted in each plot during intertidal surveys conducted in 2007 and 2008 at Deveaux Bank.

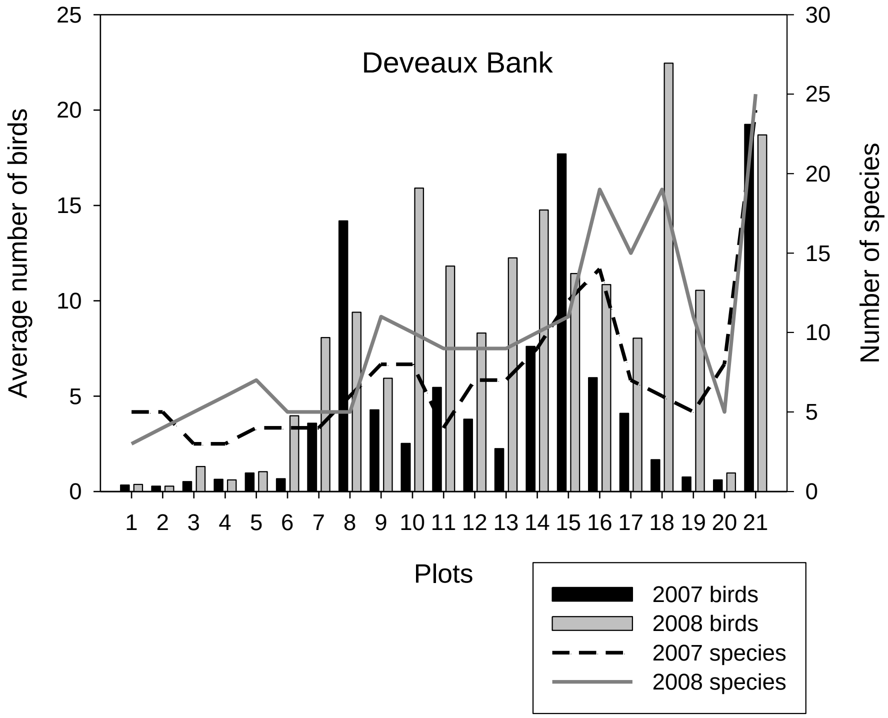


Figure 5. Average number of birds and total species counted in each plot during intertidal surveys conducted in 2007 and 2008 at Bird Key.

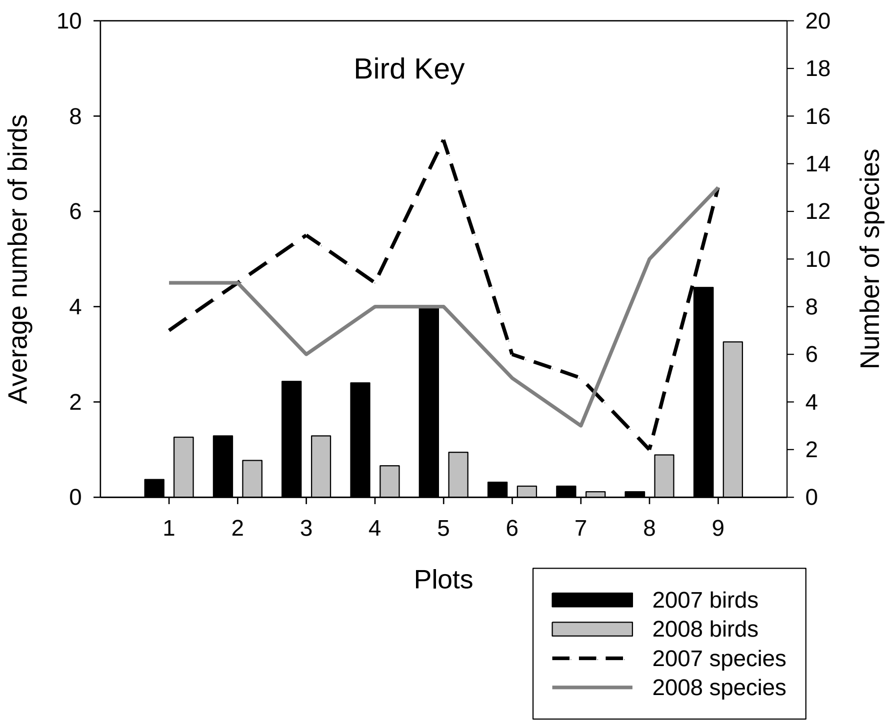
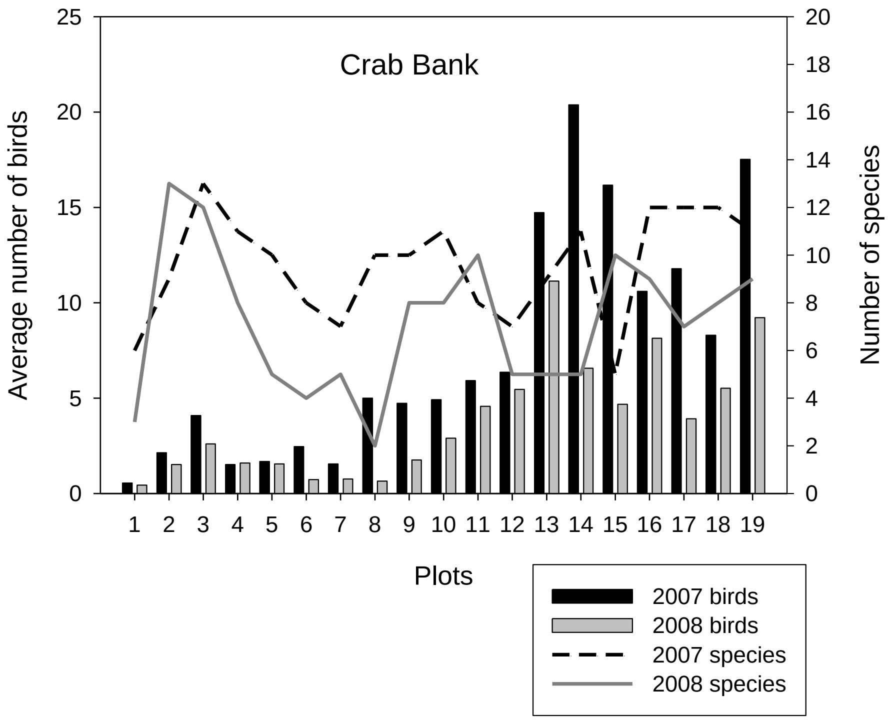


Figure 6. Average number of birds and total species counted in each survey area during intertidal surveys conducted in 2007 and 2008 at Crab Bank.



Objective 3: Determine condition and health of seabird populations at protected seabird islands.

The Brown Pelican (*Pelecanus occidentalis*) is one of the most conspicuous and easily identified avian species that resides and breeds in colonies along all three coasts of the United States. The species is thus commonly associated with the coastal environment and, as a top-consumer in near-shore marine system, is considered an indicator of coastal health (Burger and Gochfield 2004) reflecting catastrophic changes to or chronic conditions in the coastal environment. Brown Pelicans populations face many threats, including habitat loss, contamination with oil and pesticides, disease, parasitism, and food shortages. One means of assessing the impact of such population-level threats is the study of health of wild seabirds (Newman et al. 1997). The health of nestlings and adults has the potential to impact population dynamics by influencing survival, dispersal, reproductive success, and abundance (Scott 1988) and can provide insight into results from traditional field studies. Health studies can also be used to establish reference values for comparison as ecological conditions, environmental circumstances, or management practices change over time (Deem et al. 2001), which is important for threatened species and those that are recently recovered, such as the Brown Pelican. Health parameters have not been studied previously at the early stages of Brown Pelican development (i.e., pre-fledgling). Our goal was to develop reference ranges of various health parameters from a wild population of pelican nestlings and to examine the effects of age, sex, and colony on these parameters. We also examined the effect of a natural threat, tick infestation (*Carios capensis*). Though this species of soft tick does not appear to have a negative effect on growth of nestling pelicans (Eggert and Jodice 2008), ticks can cause mortality and can directly affect health of pelicans by causing anemia, inflammation, dermal necrosis, paralysis and through transmission of bacterial, viral, and rickettsial diseases, all of which may ultimately affecting reproductive success if numbers of ticks are high (Wall and Shearer 2001).

Methods.-- We measured hematological and biochemical factors from nestlings at 3 different pelican colonies in the southeast region of the US. In 2007, pelicans were sampled from two colonies, Crab Bank (n = 10) and Egg Island Bar (n = 10), located near the mouth of the Altamaha River in Georgia. We also included nestlings from Marsh Island (Cape Romain National Wildlife Refuge, SC) that were sampled in 2005 (n = 10). Pelican nestlings were also sampled from Crab Bank (n = 11) and Egg Island Bar (n = 12) in 2008, but are not included in the following analyses. All colonies are known to harbor ticks, though abandonment due to heavy tick infestation of pelican nests has only been reported from EIB and Marsh.

Sampling was conducted during morning hours of clear days to limit thermal stress. Nests selected were either marked (i.e., part of a larger study on Crab Bank of chick growth and survival) or were selected haphazardly based on accessibility of nest and age of nestlings (Egg Island Bar). Two nestlings were removed from the colony at a time and processed simultaneously before being returned to their nest. Nestlings were removed from their nest and transported to a location outside of the colony for a physical examination, body measurements, and collection of a blood sample. During the physical examination, each nestling was scanned for abnormalities, abrasions, signs of stress or injury, and assigned a body condition value (scale: 1-5) based on musculature development and fat deposits of the keel. All physical examinations were performed by the same researcher (Terry Norton, D.V.M.). We inspected the neck and pouch of each nestling for presence of ticks (presence, absence) and tallied those present (Eggert and Jodice 2008). Nestling mass, wing chord, culmen length, and tarsus length were measured. All tick counts and body measurements were conducted by the same researcher (LE). Nestling age was estimated based on size of culmen (Eggert and Jodice 2008), known hatch date, and feather development. Approx. 3 - 5 ml of blood was collected from the medial metatarsal vein into a heparinized syringe (22-25 gauge) for hematological, plasma biochemical, and protein electrophoresis testing. Immediately after collection, blood was transferred to serum separator tubes (for tests needing plasma) and vials (for tests requiring whole blood), four slides were prepared for erythrocyte counts and a small amount of blood (approx. 0.2 ml) was place on Whatman FTA cards for genetic sex determination. All items were individually labeled and placed in a cooler with ice packs until processing.

Upon completion of sampling, serum separator tubes were centrifuged for 5 min (Vulcan Technologies portable centrifuge) in the boat, truck, or laboratory (depending on the location of colony sampled). A small amount of plasma was used to determine total solids (TS) for each sample using a refractometer (Schuco model 5711-2021). Packed cell volume (PCV) was determined using a portable microhematocrit centrifuge (Hematastat II, Separation Technology, Inc., Altamonte Springs, FL, USA). Blood cell counts were conducted the day of sampling. Remaining plasma and blood samples were stored in a cooler, transported to the laboratory and stored in an ultra low freezer until shipping. Samples were shipped to selected laboratories for further analysis. Biochemical analysis of plasma samples was conducted at the University of Miami and included measured parameters related to liver and kidney function: alanine aminotransferase (ALT), aspartate aminotransferase (AST), creatine phosphokinase (CPK), gamma glutamyl transferase (GGT), lactate dehydrogenase (LDH), amylase, bile acids (BA), blood urea nitrogen (BUN), calcium (CA), cholesterol (CHOL), CO_2, creatine (CR), glucose, lipase, phosphorus (P), potassium (K), sodium (NA), triglycerides (TRIG), uric acid (UA). Plasma protein electrophoresis determined concentrations of total protein (TP), prealbumin, albumin, and globulins (alpha 1, alpha 2, beta, gamma). Additionally, plasma antibody levels to Chlamydia and Aspergillus spp and Aspergillus antigen were measured at the University of Miami. Liproprotein analysis was conducted at the University of Miami and included CHOL, TRIG, HDL, LDL, and VLDL (no data for birds sampled in 2005; University of Miami). Nutritional evaluation included measurement of plasma vitamin A and E using Reversed Phase high performance liquid chromatography (Mystic Aquarium, Mystic, CT, USA). WBC differentials were determined at the White Oak Conservation Center (Yulee, FL, USA) using 300 cell count and determine the percentage of heterophils, lymphocytes, monocytes, eosinophils, basophils per total WBC count. Sex was determined via the polymerase chain reaction process (no data for birds sampled in 2005; Zoogen Services Inc., Davis, CA, USA). Kruskal-Wallis tests and Wilcoxon rank sum tests were used to examine the effect of sex, age category, and presence of ticks. Summary data are presented are mean ± SE. Because our sample sizes were small we include all data were retained in our analysis; no outliers were removed. Values presented are mean ± SE.

Results and Discussion.-- We measured 30 nestlings that ranged in age from 18 – 40 days. Mean age was 26.9 ± 1.3 days. Although there was some overlap in age among colonies, nestlings tended to be younger at Egg Island Bar. For this reason colony comparisons are not addressed here. Summary statistics for measured health parameters of all nestlings sampled are listed in Table 10. Most parameters did not differ by sex although Vitamin E was lower in males (10.18 ± 1.57 µg/ml, $n = 7$) compared to females (13.15 ± 0.91µg/ml, $n = 12$; $P = 0.03$). To examine the effects of age, Brown Pelican nestlings were divided into two age categories: < 27 days ($n = 17$, range = 18-26 days) and > 26 days ($n = 13$, range = 27-40 days). Several factors differed between age categories ($P < 0.05$). Factors that increased with age included: PCV, CPK, TP, albumin, alpha 1 globulin, beta globulin, gamma globulin, cholesterol, LDL, retinol, and lymphocytes. Factors that decreased with age included: sodium, lipase, ALT, bile acids, A:G ratio, and pre-albumin. We examined a subset of health variables and compared these between nestlings that were infested with ticks at the time of sampling ($n = 11$) and those that were not ($n = 19$). Examined variables included PCV, TS, TP, WBC, and differential white blood cell percentages. Nestlings that were infested with ticks had a lower TS value (2.80 ± 0.16) and lower percentage of eosinophils (5.00 ± 0.60) than those without ticks (TS: 3.07 ± 0.03, $P = 0.02$; Eosinophils: 8.32 ± 1.34, $P = 0.05$). Finally, we compared our results to published values of wild Brown Pelicans juveniles and adults (Figure 7).

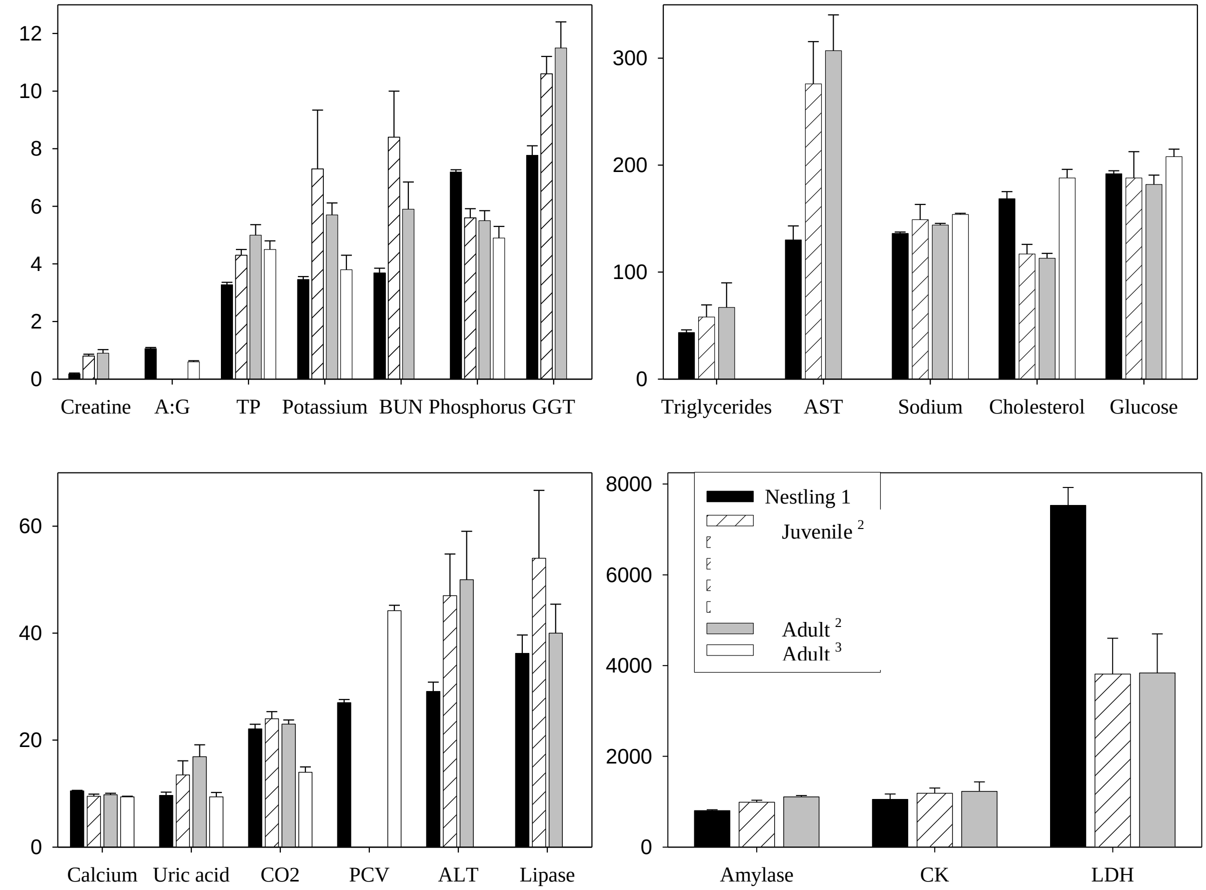
In general, nestlings included in this health study appeared in good condition. Five nestlings from the Georgia colony tested weakly positive for Aspergillus antigen and 5 nestlings from the South Carolina colonies tested positive for Chlamydia. Our analyses indicated that age was a significant factor affecting many health parameters of Brown Pelican nestlings. Packed cell volume increased with age in our sample and also when compared to wild adults (Wolf et al. 1985). Levels of proteins and cholesterol were higher in the older age category, which may be necessary to support physiological development. Elevated values of calcium and phosphorus, also observed in captive fledgling and hatch year Brown Pelicans, likely relates to bone growth and development at this early stage (Wolf et al. 1985). Age-related differences between Brown Pelicans were not reported by Zaias et al. (2000). We observed little effect of sex on health parameters at the nestling stage. Sex related differences in health parameters have been observed in pelicans (Wolf et al. 1985, Zaias et al. 2000) as well as in nestlings of other species (Lanzarot et al. 2005). Differences in hematologic values with regard to tick presence were only observed in 2 of the 9 values examined. Total solids and eosinophil values were both lower in nestlings infested with ticks at the time of sampling. Pelicans seem to have higher than expected levels of uric acid, which may be due to high protein diet, energy deficiency, dehydration, possibly over-heating. Collection of baseline data such as that collected in this study provides a means to monitor the health of nesting population and provides baseline data for comparative and long-term studies. These data are particularly valuable after catastrophic disease outbreak or environmental contamination event.

Table 10. Reference values for Brown Pelican nestlings captured in 2005, 2007.

MEASURE	N	MEAN	SE	RANGE
PCV (%)	30	27.00	0.59	22 - 33.3
Total solids	30	2.97	0.06	2.2 - 4
Hematologic values				
WBC (103/µL)	29	23.81	1.43	13 - 45.9
Heterophils (%)	29	44.34	1.93	26 - 67
Lymphocytes (%)	29	42.10	1.75	25 - 58
Monocytes (%)	29	3.28	0.24	0 - 5
Eosinophils (%)	29	7.17	0.94	2 - 28
Basophils (%)	29	3.10	0.32	1 - 7
Plasma biochemical values				
Glucose (mg/dL)	30	192.03	2.73	142 - 211
Sodium (mmol/L)	29	136.21	1.24	113 - 146
Potassium (mmol/L)	28	3.46	0.10	2.7 - 4.6
CO2 (mmol/L)	29	22.10	0.88	0 - 27
BUN (mg/dL)	29	3.69	0.16	3 - 6
Creatinine (mg/dL)	29	0.18	0.03	0.1 - 1.0
Calcium (mg/dL)	26	10.52	0.09	9.3 - 11.3
Phosphorus (mg/dL)	30	7.19	0.08	6.4 - 8.1
Uric acid (mg/dL)	30	9.68	0.61	3.5 - 16.6
ALT (U/L)	29	29.10	1.73	16 - 70
AST (U/L)	30	130.20	13.01	47 - 468
LDH (U/L)	30	7529.70	393.37	5433 - 13692
GGT (mg/dL)	30	7.77	0.33	5 - 11
CPK (mg/dL)	30	1053.17	116.10	440 - 4081
Amylase (U/L)	30	805.50	18.43	635 - 1008
Lipase (U/L)	30	36.23	3.43	1 - 104
Bile acids (umol/L)	30	10.03	1.03	2.4 - 23.7
Lipoprotein values				
Cholesterol (mg/dL)	20	168.70	6.56	119 - 245
Triglycerides (mg/dL)	20	43.55	2.53	28 - 67
HDL (mg/dL)	20	51.00	1.09	42 - 61
LDL (mg/dL)	20	108.95	6.29	69 - 185
VLDL (mg/dL)	20	8.60	0.49	6 - 13
Protein elctrophoresis values				
Total Protein (g/dL)	30	3.28	0.08	2.4 - 4.2
Prealbumin (g/dL)	30	0.13	0.02	0 - 0.4
Albumin (g/dL)	30	1.53	0.04	1 - 2
Alpha 1 globulin (g/dL)	30	0.13	0.01	0.1 - 0.3
Alpha 2 globulin (g/dL)	30	0.43	0.02	0.3 - 0.9
Beta globulin (g/dL)	30	0.72	0.03	0.2 - 1
Gamma globulin (g/dL)	30	0.34	0.02	0.2 - 0.9
A:G ratio	30	1.06	0.04	0.6 - 1.7
Nutritional values				
Retinol (ug/mL)	29	1.30	0.03	1 - 1.7
Vitamin E (ug/mL)	29	12.21	0.66	6.7 - 21.3

PCV = packed cell volume; WBC = white blood cells; BUN = blood urea nitrogen; ALT = alanine aminotransferase; AST = asparatate aminotransferase; LDH = lactate dehydrogenase; GGT = gamma glutamyltransferase; CPK = creatine phosphokinase; HDL = high densit

Figure 7. Comparisons of health parameters among wild Brown Pelican nestlings, juveniles, and adults. [1] This study; [2] Zaias et al. 2000; [3] Wolf et al. 1985.



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