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Understanding the use of barrier islands as nesting habitat for Louisiana birds of concern

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UNDERSTANDING THE USE OF BARRIER ISLANDS AS NESTING HABITAT FOR LOUISIANA BIRDS OF CONCERN

A Thesis

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ABSTRACT

Colonial nesting seabirds are threatened by habitat loss and degradation, human disturbance, predation, and climate change. Several species of conservation concern concentrate high percentages of their total U.S. populations in Louisiana breeding colonies. We studied seabirds, including Royal Terns, Sandwich Terns, and Black Skimmers, nesting on Isles Dernieres barrier islands along the Gulf coast of Louisiana. Two of the four islands in this chain host extensive seabird colonies and two do not.

We used an experimental approach to test the hypothesis that large terns and skimmers are prevented from nesting on Trinity Island, the largest of the Isles Dernieres, by lack of social stimuli. Decoys and call broadcast attracted Royal Terns to visit experimental sites, but they did not nest. Sandwich Tern and Black Skimmer visits to the sites were not significantly affected by the social stimuli; however, isolated nesting attempts imply interest. Lack of colony establishment in response to the experiment indicates that social factors alone are not responsible for the lack of nesting by these species on Trinity Island.

Scent station transects revealed the presence of raccoons, rats, and coyotes on two non-colony islands, and no mammalian predators on two colony islands, suggesting that seabirds avoid predator-infested areas. Least Terns were an exception, nesting on islands with mammalian predators. In 2008 and 2009, we monitored 53 and 80 Least Tern nests on Trinity Island and modeled nest success using logistic exposure. A subset of nests was protected by fences in each year (n= 3 in 2008, n= 19 in 2009). For unprotected nests, model-estimated nest success was 20% in 2008 and 53% in 2009. Fenced nest success was 83% and 49% in 2008 and 2009, respectively. We believe the increase in nest success between years reflects effects of Hurricanes Gustav and Ike on predator populations on Trinity Island. Rats and raccoons declined in surveys

and anecdotal field observations. The impact of mammalian predators on this Least Tern population supports the hypothesis that predation limits seabird colonization of Trinity Island.

CHAPTER 1: INTRODUCTION

COLONIAL BREEDING IN SEABIRDS

Colonial breeding can be defined as breeding in extremely high densities at sites used for no other purpose (Danchin and Wagner 1997). Colonial breeding is found in some fish (stickleback), reptiles (marine iguana), and mammals (most pinnipeds), but is most common in birds, where 13% of all species breed colonially (Lack 1968). Seabirds as a group are almost entirely colonial breeders (95%, Danchin and Wagner 1997), and colonial breeding is believed to be an evolutionary precursor to the marine habitat in birds (Rolland et al. 1998). There exist both costs and benefits to colonial breeding, and there has been much debate among researchers over how these factors have influenced the evolution of coloniality. Seabird breeding habitat is threatened globally by erosion, coastal development, and climate change (Hunter et al. 2006, NABCI 2010). In light of current threats to seabird habitat, it is important for managers to understand the dynamics of colony site selection.

Coloniality is problematic in light of density dependence, which suggests that selective pressures should operate more strongly on populations at high densities. The functional approach to explaining coloniality states that the benefits to such aggregations must therefore outweigh the costs (Lack 1968). Potential reproductive costs of colonial breeding include competition for nest sites, predation and cannibalism, distance to foraging sites, and increased parasite and disease transmission. Benefits include group defense against predators, increased foraging efficiency, and maximization of limited breeding sites (Wittenberger and Hunt 1985, Siegel-Causey and Kharitonov 1990).

Predation risk has been cited as both cost and benefit to colonial breeding in seabirds (Varela et al. 2007). Seabird colonies are notoriously loud, smelly, and visually obvious. Some studies have shown that increasingly large or dense nesting aggregations attract predators, thereby increasing per capita predation risk and reducing local reproductive success (Burger 1984, Stokes and Boersma 2000). Others have demonstrated increased reproductive success with increasing colony density (Anderson and Hodum 1993, Murphy and Schauer 1996). This benefit can be attributed to increased vigilance, group defense against predators ("mobbing" or attacking intruders), or decreased individual risk due to predator satiation (Wittenberger and Hunt 1985, Siegel-Causey and Kharitonov 1990).

While the functional approach implies that reproductive benefits led to the origin of coloniality, an alternative view, the "commodity selection hypothesis," states that these benefits are actually byproducts of coloniality, contributing not to its origin but to its maintenance. According to this view, the origin of coloniality is related to individuals selecting for the best commodities, especially limited nesting sites and mates, and conspecific attraction is integral to individual-level site selection (Reed and Dobson 1993). Seabirds not only use presence or absence of conspecifics to select breeding sites, but also evaluate "public information" about local reproductive success of potential nesting areas (Boulinier and Danchin 1997, Danchin et al. 1998). These tendencies, combined with strong natal philopatry, can lead to intense local concentrations of seabirds at breeding colonies, even to the exclusion of other, potentially suitable sites (Forbes and Kaiser 1994). The presence of conspecifics confers confidence about the favorability of local breeding conditions, and offers the intrinsic benefits of group nesting. However, avoidance of available habitat can mean that some individuals will not breed for lack of space in colonies, and leave populations vulnerable to stochastic effects (Nisbet 1989).

Social facilitation, or the mimicking of conspecific presence, has been used with great success by managers to attract seabirds to desirable breeding sites (Kress 1983, Kotliar and Burger 1984, Burger 1988, Dunlop et al. 1991, Collis et al. 2002, Parker et al. 2007). These techniques have included the placement of seabird decoys and call broadcast of colony sounds. Such methods are attractive in areas where apparently suitable habitat is available but not utilized by breeding seabirds and where it is desirable to distribute breeding effort over a larger area, especially when younger individuals may be competitively excluded from occupied colonies. However, seabirds use a variety of cues in colony site selection. We used an experimental approach to evaluate the relative importance of social facilitation and predation risk in seabird colony formation and to help determine the best management techniques to maximize reproductive output for these species of conservation concern.

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CHAPTER 2: SOCIAL FACILITATION AND PREDATION RISK AS FACTORS IN NEW COLONY FORMATION BY SEABIRDS ON LOUISIANA BARRIER ISLANDS

INTRODUCTION

Colonial nesting seabirds and their habitats

Colonial nesting seabirds face a variety of threats throughout their ranges in North America. Loss or alteration of habitat, human disturbance, and increasing populations of avian and mammalian predators all cause conservationists to be concerned about the future of these species (Jackson et al. 1982, Burger 1984, Visser and Peterson 1994, Goodrich and Buskirk 1995, Erwin et al. 2003). Another potential problem facing these species is the vulnerability inherent in colonial breeding. Colonially nesting seabirds tend to concentrate much of their breeding effort in relatively few sites; for example, 38,258 pairs of Sandwich Terns (*Thalasseus sandvicensis*) bred on only 6 sites in Louisiana in 2001 (Michot et al. 2003). This extreme concentration makes the population vulnerable to stochastic events that could affect the survival or breeding success of a large proportion of individuals (Clapp and Buckley 1984). Therefore, it is desirable from a management perspective to increase the number of colonies used by these birds.

Birds in the family Laridae, including gulls, terns, and skimmers, exhibit both site fidelity (the tendency to nest in the same location each year) and group adherence (the tendency to nest near the same neighbors each year) (McNicholl 1975, Sanchez et al. 2004). They form large, dense breeding colonies, often with heterospecifics (Langham 1974, Erwin 1977, Sears 1978). Different species vary in age at first reproduction, but if space in a colony is limited, younger birds may not be able to breed that year (Nisbet 1989). Increasing the number of colonies offers more individuals the opportunity to establish nest sites, and younger birds are more likely to move into new breeding areas (Tims et al. 2004).

As natural habitats have become lost and/or degraded, many seabirds have come to rely increasingly upon man-made areas as nesting grounds (Parnell et al. 1997, Erwin et al. 2003). Seabird habitat is damaged by human activity and also by natural causes such as erosion and vegetative succession. Humans create new seabird nesting habitat when they dredge sediment from the bottom of a body of water and redeposit this material elsewhere, either on a mainland beach, on existing islands, or in a body of water as a new island. Redeposited sediment replaces substrate that was eroded away while also setting back succession by covering the vegetation.

In Louisiana, dredge spoil is used to create or supplement barrier islands along the northern coast of the Gulf of Mexico. Coastal islands in the Gulf of Mexico are important areas for many bird species of conservation concern, including Snowy Plover (*Charadrius alexandrines*), Wilson's Plover (*C. wilsonia*), Piping Plover (*C. melodus*), American Oystercatcher (*Haematopus palliates*), Gull-billed Tern (*Gelochelidon nilotica*), Caspian Tern (*Hydroprogne caspia*), Royal Tern (*Thalasseus maxima*), Sandwich Tern (*T. sanvicensis*), Common Tern (*Sterna hirundo*), Forster's Tern (*S. forsteri*), Least Tern (*Sternula antillarum*), and Black Skimmer (*Rynchops niger*). Louisiana's largest colonies of some of these species are located on dredge spoil islands (Mallach and Leberg 1999). This state is of particular importance to Sandwich Terns, Forster's Terns, and Black Skimmers: the national atlas of coastal waterbird colonies in the contiguous United States found that, from 1976-1982, these three species concentrated 77%, 52%, and 44%, respectively, of their total U.S. breeding populations in this state (Spendelow and Patton 1988).

Social facilitation

For highly gregarious colonial nesting seabirds, the perceived presence of conspecifics may stimulate nesting behaviors and communicate to individuals that a location is acceptable for breeding (Burger 1988). Social attractants (decoys and call broadcast) have been successful in establishing new breeding areas for a variety of colonial waterbirds, including herons, egrets, ibises, terns, and skimmers (Kress 1983, Kotliar and Burger 1984, Dusi 1985, Burger 1988, Dunlop et al. 1991, Collis et al. 2002, Crozier and Gawlik 2003, Parker et al. 2007).

Beach-nesting colonial seabirds have been the focus of several social attraction studies. Kress (1983) used decoys and sound recordings of Arctic Terns (*Sterna paradisaea*) to re-establish breeding at an abandoned colony site off the coast of Maine. Terns responded in the third year, perhaps due to a time lag in impact of the predator control methods (Kress 1983). Not only did Arctic Terns return to breed at this site, but they were also joined by Common Terns and Roseate Terns (*Sterna dougallii*). In New Jersey, Least Terns were attracted to one and bred at another of two abandoned colony sites where there were decoys but not sound recordings (Kotliar and Burger 1984). Burger (1988) later went on to characterize the role of colony size, spacing pattern, and mating status of the decoy colonies in attracting Least Terns. Least Terns were more attracted to large groups than to small groups, to more widely spaced decoys than to more densely packed decoys, and to combinations of paired and single birds than to groups of either alone (Burger 1988). Common Terns in Ontario that had experienced degradation of their habitat due to vegetative succession, erosion, and displacement by Ring-billed Gulls (*Larus delawarensis*) were readily induced to nest on wooden rafts covered with sand and gravel when decoys were present (Dunlop et al. 1991). Highly endangered New Zealand Fairy Terns (*Sterna nereis davisae*) were attracted to, but did not breed at, a site where decoys and sound recordings were used (Jeffries and Brunton 2001). However, in that study, the decoy trials only lasted 16 days, apparently a pilot study to determine whether the terns could be attracted using decoys. In the Columbia River estuary in Washington, Caspian Terns were relocated to reduce their predation on endangered juvenile salmonids. When their former colony site was made unavailable, the terns quickly established a large colony on a sand-covered barge on which decoys and sound recordings were present (Collis et al. 2002). On dredge spoil islands in the Atchafalaya River delta in Louisiana, Pius and Leberg (2002) found that Black Skimmers could be induced to initiate nests near decoys of both Gull-billed Terns and Black Skimmers, although they showed a significant preference for nesting near conspecifics.

In many successful social attraction experiments, circumstances other than the decoys and sound may have facilitated seabird colonization of the focal site. Predators may have been removed from the attraction site, the attraction site may have been used by the birds in the past, or the birds may have been displaced from their original colony site. Undoubtedly social attraction techniques draw birds in, but whether or not they stay to form new colonies may be more dependent on the intrinsic value of the site than the presence of conspecifics. Our study sought to attract seabirds to nest in a new location close to existing colonies due to the fragile nature of the colony islands.

Predation

Nest predation by both avian and mammalian predators is a significant cause of reproductive failure for terns and skimmers (Burger 1984, Massey and Fancher 1989, Goodrich and Buskirk 1995, Brunton 1997, Quintana and Yorio 1997, Brunton 1999). This appears to be a logical cost of nesting in large, noisy, conspicuous colonies (Danchin and Wagner 1997, Brunton 1997, Arnold et al. 2006). Colonial birds are likely to favor locations with few or no predators when establishing breeding colonies. Burger (1982) reported higher colony abandonment rates for Black Skimmers that had suffered losses due to predation than to flooding, implying that these birds distinguish between threats that are likely to be repeated and those that are more random events. Likewise, when Black Skimmers were disturbed (by humans) frequently prior to laying eggs, they were likely to leave a colony and nest in an area that suffered a lower frequency of disturbance (Safina and Burger 1983). Black Skimmers and Royal Terns were among the species most sensitive to human disturbance in one study, flushing from nests in response to intruders up to 200 m distant (Erwin 1989).

Hypotheses

We tested two hypotheses to explain why seabirds have not established breeding colonies on apparently suitable habitat in the Isles Dernieres: (1) social inertia: because terns and skimmers are highly gregarious, they are unlikely to form new colonies in the absence of social stimulation; (2) predation: terns and skimmers reject new colony sites due to the presence of potential predators.

<u>Social inertia.</u> Our social inertia hypothesis asserts that terns and skimmers do not initiate new colonies on potential sites because they are at least partially dependent on social cues to do so (Burger 1981). Based on this hypothesis we predicted that, given suitable habitat, if we could convince birds that the social structure exists on a currently vacant site, they would be stimulated to initiate a new colony there. Decoys and call-broadcast have been used with success to attract a variety of waterbird species to novel or abandoned colony sites (Kress 1983, Kotliar and Burger

1984, Dusi 1985, Burger 1988, Jeffries and Brunton 2001, Collis et al. 2002, Crozier and Gawlik 2003, Parker et al. 2007).

Predation. Our second hypothesis to explain the lack of seabird colonies on some islands is that terns and skimmers attempt to colonize new areas, but are disturbed by predators early in colony formation and thus reject the new sites. Based on this hypothesis, we predict that (1) active colony islands should have lower predator abundance than unused islands, and (2) social attraction plots that were not disturbed by predators (fenced) would be more likely to be colonized than those that were disturbed (unfenced).

METHODS

Study area

The study area includes the four islands of the Isles Dernieres Barrier Island Refuge (IDBIR) located off the Louisiana coast in Terrebonne Parish (29º 03'N, 90º 57'W to 29º 05'N, 90º 36'W; Fig. 1). From West to East, the islands in this 33 km chain are: Raccoon, Whiskey, Trinity, and Wine. Historically, all four were one large barrier island; however, the combined effects of storms, subsidence, sediment diversion, and erosion have eliminated the islands' connectivity and reduced their sizes (Stone and McBride 1998, Lindstedt 2005, Day et al. 2007). Since the 1990s, the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) has funded over $41 million in restoration projects on these islands, which constitute a physical barrier that helps to protect the state's coastal marsh and inland areas from storm surges (Stone 2005). Despite the surfeit of funds and dredged sediments that have been invested in these islands, relatively little data have been collected concerning use by wildlife.

Two of the islands (Raccoon and Wine) support large colonies of breeding seabirds, but the others (Trinity and Whiskey), despite having apparently suitable nesting habitat, and being adjacent to foraging habitat, are relatively underutilized. Species of interest that have been reported to breed on these islands include Caspian Tern, Royal Tern, Sandwich Tern, Forster's Tern, Least Tern, and Black Skimmer (Spendelow and Patton 1988, Visser and Peterson 1994, Michot et al. 2003). Trinity is the largest of the four islands, 11km long and located approximately 21 km from the mainland. It has been restored multiple times via applications of dredged material, dune fences, and vegetation plantings, but it has not been known to host breeding seabird colonies. The island is characterized by areas of open sand and shell, especially along the Gulf side shoreline and on the spits at both ends. Vegetation on the island includes salt tolerant grasses and shrubs in higher areas in the center of the island and patches of black mangrove marsh on the back (bay side) of the island. The Louisiana Department of Wildlife and Fisheries (LDWF) would like to know what management strategies might be most effective in expanding the birds' use of this area as breeding habitat. We therefore tested two hypotheses related to social inertia and predation.

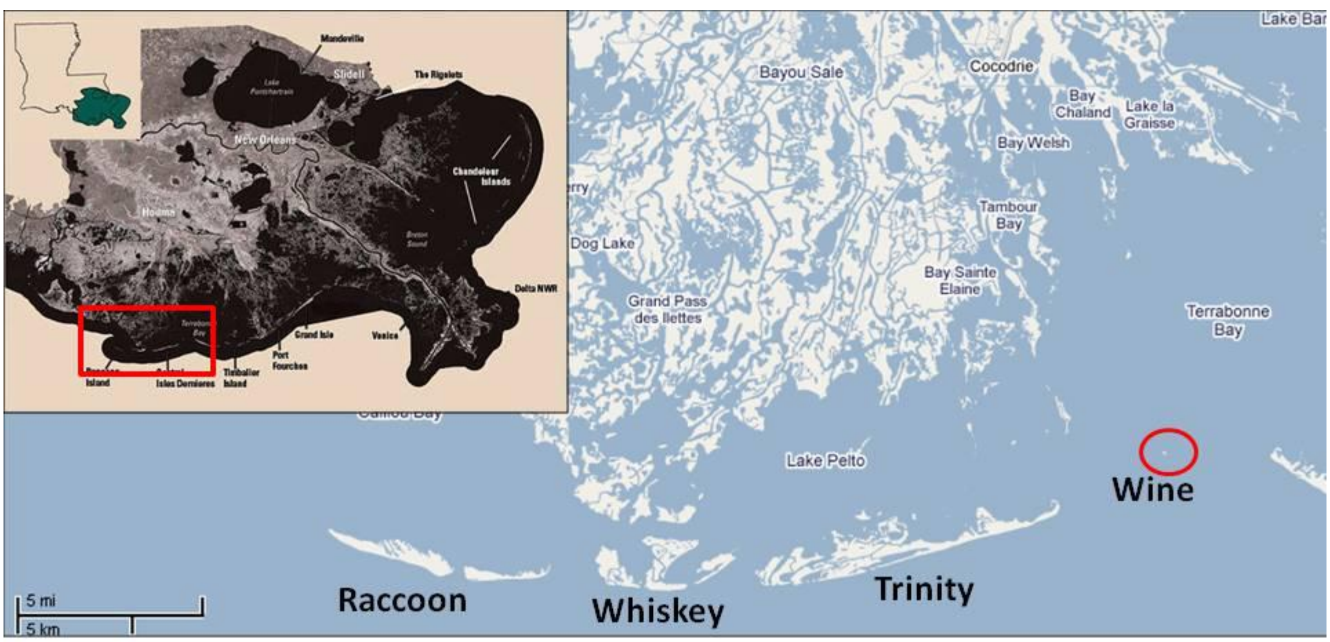

Figure 1. Isles Dernieres Barrier Island Refuge, Terrebonne Parish, LA.

Social facilitation

We used decoys and call-broadcast to mimic mixed-species seabird colonies at potential breeding sites on Trinity Island. Our focal species were Sandwich Terns, Royal Terns, and Black Skimmers. Because Royal Terns initiate nesting earlier than Sandwich Terns, and because decoys of one species have been known to attract both that species and others (Kress 1983, Pius and Leberg 2002), we used only Royal Tern and Black Skimmer decoys. To make decoys, we modified the protocol of Fancher (1984). Using carved wooden decoys, we first created molds using liquid latex rubber, and then cast decoys from these molds using powdered water putty.

We selected eight sites on Trinity Island to use as replicates for our decoy plots. Two to four observers familiar with seabird habitat on Louisiana barrier islands walked the length of Trinity Island and rated, on a scale of one to five, all sites of sufficient size for the social facilitation plots. Only sites with an average score of three or higher were considered; eight sites were chosen as a stratified random sample from among these. We required our eight selected sites to include two sites in each of four general locations on the island: newly restored Gulf side, newly restored Bay side, spits at the East and West ends, and older (not recently restored) areas. All sites were at least 400m apart. We selected new sites in 2009 using the same method.

At each site, we set up both a control and an experimental plot (Fig. 2, Table 1). Both plots were 30 m in diameter, the perimeter of each was marked with either stakes or fencing, and their closest edges were 30 m apart. We randomly assigned which plot was the control and which the experimental. On each experimental plot we placed 32 decoys (16 Royal Terns and 16 Black Skimmers) in two hexagonal groupings 7.5 m across (Fig. 2). Spacing within these “subcolonies” was relatively wide (Burger 1988) at 1.5 m on average, and the two groups of decoys were 4 m apart. Decoys were arranged to represent both paired (two decoys placed close together, facing the same direction) and unpaired (solitary) individuals.

In 2009 only, we installed sound equipment on half of the experimental plots to constantly broadcast recorded seabird colony sounds. We randomly selected one site at each location to receive the sound treatment. At each site, a waterproof speaker and small CD player were powered by a car battery, which was charged by a solar panel. Recordings were made by the Macaulay Library at the Cornell Lab of Ornithology, Ithaca, New York, and included calls of Royal Terns, Sandwich Terns, and Black Skimmers from the Gulf coast. By placing speakers at only half of the potential colony sites, we hoped to compare the attractiveness of decoys alone versus decoys and sounds. Some studies indicate that there is no difference between the two, and that the visual cue is really what attracts the birds (Kotliar and Burger 1984, Jeffries and Brunton 2001).

We conducted behavioral observations from a blind situated equidistant from the centers of the control and experimental plots at each of the eight sites (Fig. 2). Two observers conducted 2-hour behavioral observation sessions. Morning observation sessions began between sunrise and 1000, afternoon sessions began between 1300 and 1600. During each session, we identified and recorded all seabirds flying over the plots and classified their behavior as flyover (flies directly over the plot), look (looks down at plot while flying over), circle (flies over then doubles back to fly over again), dip (flies low toward the plot without landing), or land (lands on the plot). We also noted any interactions between birds and decoys or birds and other birds. At each observation session, we surveyed the plots for predator tracks, nest scrapes, or nests with eggs. We conducted observations from April 27- June 11, 2008 and March 21- June 3, 2009. Due to low bird numbers, we dropped the first two weeks of observations from analysis in 2009, so that the effective start date was April 7. To allow for possible seasonal differences in bird numbers and behavior, we divided each season into six time periods (hereafter, “weeks”), and observed each site twice per week, with one morning and one afternoon session each, for six weeks in each year. Royal and Sandwich Tern initiated nests on the Isles Dernieres in late April and early May, Black Skimmers in late May (E. J. Raynor, unpublished data).

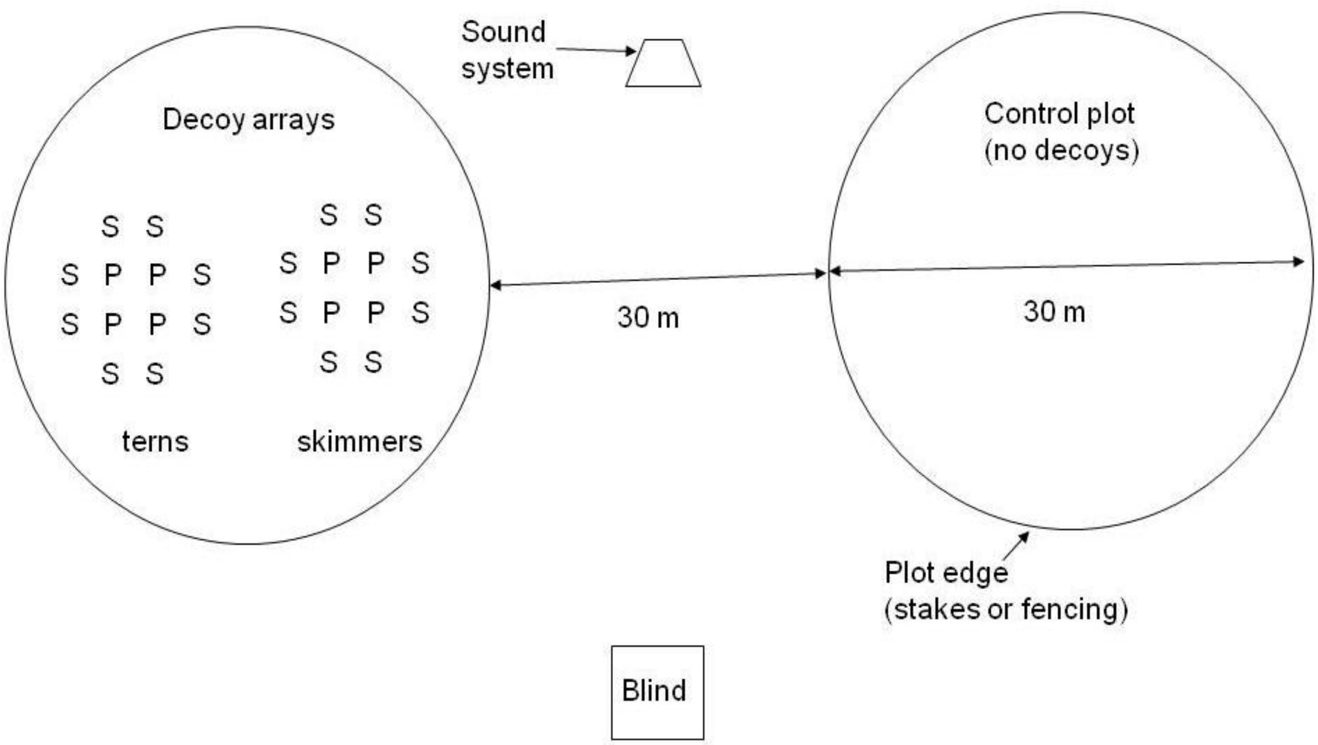

Figure 2. Experimental design for social attraction sites for terns and skimmers on Trinity Island, LA, showing a paired experimental plot (with decoys) and its control plot (no decoys). Solitary and paired decoys are represented by S or P. Figure not to scale.

Table 1. Treatment design for 8 experimental social facilitation plots for terns and skimmers on Trinity Island, LA. Each site had 2 plots, one experimental plot with decoys, one control without. Both plots had the same fence/no fence and sound/no sound treatment.

	2008			2009			
location	site	decoys	fence	site	decoys	fence	sound
West spit	1	x	x	1	x	x	x
Unrestored	2	x	x	2	x	x	
Unrestored	3	x		3	x		x
Restored Gulf side	4	x	x	4	x		
Restored Gulf side	5	x		5	x	x	x
Restored Bay side	6	x	x	6	x	x	
Restored Bay side	7	x		7	x		x
East spit	8	x		8	x		

Predation

Fencing. To determine whether plots that exclude mesocarnivore mammalian predators would be more successful in attracting seabirds, we added fencing to half of our social attraction sites (Fig. 1). Fencing can be a useful technique for excluding terrestrial predators from the nesting areas of shorebirds and seabirds, and birds nesting inside fenced areas consistently enjoy greater reproductive success than those nesting in unfenced areas (Rimmer and Deblinger 1992, Vaske et al. 1994, Fancher et al. 2002, Spear et al. 2007). We randomly selected four of the eight social attraction sites (Table 1) to receive the fencing treatment in each year, and at those sites we placed fences instead of boundary stakes around both the control and experimental plots. We used welded wire mesh fencing with 5x10 cm openings and a height of 0.92 m placed around the perimeter of half of our 30m diameter plots. The size of the openings was chosen to allow safe passage out of the exclosures for any chicks that might hatch, but we recognize that this also allowed rats to enter. Although avian predators (e.g., night-herons, gulls, raptors) may also limit tern and skimmer breeding success, they seem unlikely to preclude nesting on uncolonized areas in the Isles Dernieres. The islands are close enough to one another that an avian predator active in the area might be expected to have equal access to all islands, whereas an individual mammalian predator is more likely to be restricted to a single island. Laughing Gulls are known to nest on both Raccoon and Wine Islands in close proximity to Royal and Sandwich Tern colonies. From a management perspective, mammalian predators are also much more feasible to control, since they can be excluded via fences or removed from islands.

Predator surveys. We conducted scent station track surveys to quantify terrestrial predator activity on the four islands (Linhart and Knowlton. 1975, Sargeant et al. 2003). Number of stations varied with island size: 45 on Trinity, 30 on Raccoon in 2008, (25 in 2009, due to loss of area after Ike), 25 on Whiskey, and 5 on Wine. Scent stations were set out in transect lines at least 400 m apart, each consisting of five stations spaced at 50-m intervals. We laid out stations in the afternoon and evening preceding the survey. At each station, observers traced a 1-m diameter circle in the ground, covered it with sifted sand and mineral oil to create a suitable tracking surface, and placed a Fatty Acid Scent (Pocatello Supply Depot, ID) tablet in the center. We checked stations within three hours of sunrise the following day, recording all tracks left inside the circles (Diefenbach et al. 1994). Surveys were conducted once monthly June-July 2008 and April-July 2009; however, for consistency, only June-July surveys were included in analyses.

Scent stations provide an index of activity rather than absolute abundance estimates, and are notoriously difficult to interpret (Sargeant et al. 1998). However, this method has been widely used for determining relative abundances and population trends of carnivores (Linhart and Knowlton 1975, Roughton and Sweeny 1982, Conner et al. 1983, Nottingham et al. 1989, Diefenbach et al. 1994, Sargeant et al. 1998, Sargeant et al. 2003). In this study, we were primarily interested in between-island comparisons. Methods were identical at all sites; therefore, we can determine the relative abundance of predators on used and unused islands. There is also an issue of sampling unit used for analysis. Generally the transect line is considered the unit, as an individual predator may visit all of the stations on a line. On small islands, predators may have access to the whole island and therefore lines may not even be independent. To be conservative, we chose to use the island as the sampling unit. This reduces our analysis to presence or absence of each potential predator species on each island, which we can then relate to breeding bird use. Although predators were purposely attracted to the scent stations, this attraction was consistent among islands, and therefore does not bias our relative abundance estimates.

Statistical analyses

We used ANOVA and logistic ANOVA to test for differences in seabird reactions among the different treatments. We separately analyzed each species for which we had sufficient observations (Royal Tern, Sandwich Tern, and Black Skimmer). Because we added a sound treatment in 2009, we did separate analyses for 2008 and 2009. Due to low numbers of responses in several behavioral categories, we summed all five behaviors into one response variable, which represents the number of times a bird landed on or passed through the airspace directly above a plot (hereafter, “visit”). We used ANOVA to analyze the natural log-transformed data when this transformation allowed the data to be normally distributed (Royal Tern). This transformation is commonly used for count data, which tend to follow a binomial distribution. For the other two species, log transformation did not yield normally distributed data, so we transformed the response variable into a binary (0 or 1) and used a logistic ANOVA (Sandwich Tern and Black Skimmer).

The independent variables of interest in 2008 were social (decoy or no decoy) and fence (fenced or unfenced); location (newly restored Gulf side, newly restored Bay side, spit, or not recently restored), and week (1-6) were treated as random variables. In 2009, we added the sound treatment (with or without call broadcast). A split plot design was used, where fence and sound were main effects and decoy treatment was the subplot effect. Repeated measures was deemed inappropriate because there was no evidence that birds seen in one observation period influenced birds seen in subsequent periods.

RESULTS

Behavioral observations

In 2008, we conducted 188 hours of behavioral observations and recorded 5,704 individual observations of the three focal species (Royal Tern, Sandwich Tern, and Black Skimmer). In 2009, we conducted 258 hours of behavioral observations; however, due to low bird numbers in the early part of the season, we dropped the first two weeks. For the 2009 analyses, we used 190 hours of observations, in which time we recorded 1,320 individual observations of the focal species.

In both years, Royal Tern was the most abundant species, followed by Sandwich Tern, then Black Skimmer (Table 2). Royal Tern in 2008 was the only dataset for which, after log-transformation, the assumption of normality was met. We therefore performed ANOVA on the log number of visits per 2-hour observation period. For Sandwich Tern and Black Skimmer in 2008 and all three species in 2009, we used logistic ANOVA to analyze the probability of seeing a bird given a certain set of conditions.

For all three species, we observed more birds visiting decoy than non-decoy plots in 2008 (Figs. 3-5). This pattern was very weak in 2009, and was significant only in the Royal Tern 2008 model.

Table 2. Number of individual records of three focal species during behavioral observations on Trinity Island, LA, April-June, 2008-2009.

	# observations (visits)		
Species	2008	2009	Total
Royal Tern	3584	901	4485
Sandwich Tern	1827	335	2162
Black Skimmer	293	84	377
Total	5704	1320	7024

2008

Royal Tern. In 2008, model-estimated Royal Tern visits were significantly affected by social facilitation ($F = 11.4$, $df = 1$, $p = 0.001$), location ($F = 80.1$, $df = 3$, $p < 0.0001$), fence ($F = 14.9$, $df = 1$, $p = 0.0002$), and week ($F = 14.3$, $df = 5$, $p < 0.0001$), along with the interactions of location by week ($F = 8.28$, $df = 15$, $p < 0.0001$), location by fence ($F = 3.49$, $df = 3$, $p = 0.0176$), and location by fence by week ($F = 2.53$, $df = 15$, $p = 0.0024$). Social facilitation plots with decoys had significantly more bird visits per observation period than did control plots (12.0 ± 1.06 vs. 8.73 ± 1.06). Locations on the spits (32.7 ± 1.09) had more visits than those on the older restored area (10.2 ± 1.09), which had more visits than both the newly restored Gulf side (5.73 ± 1.10) and the newly restored Bay side (5.36 ± 1.09; Fig. 6). Unfenced sites (12.3 ± 1.06) had more Royal Tern visits than fenced sites (8.52 ± 1.06). Royal Tern visits showed a significant quadratic trend over the six weeks ($F = 55.66$, $df = 1$, $p < 0.0001$), where week one was

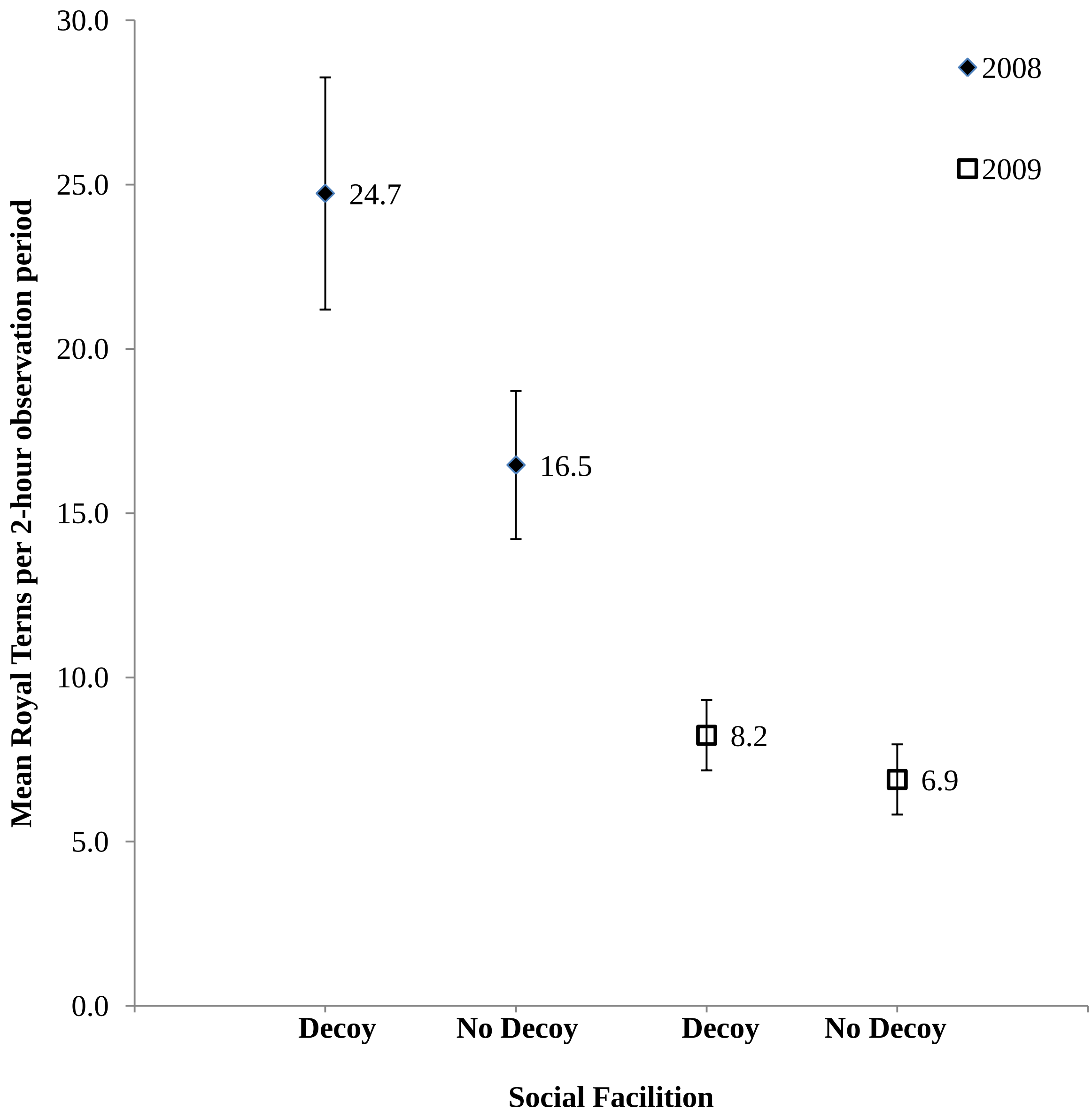

Figure 3. Mean Royal Tern visits per 2-hour observation period to decoy and no-decoy plots, Trinity Island, LA, 2008-2009. Weeks cropped to represent only overlapping time periods, April 27-June 3; vertical bars represent standard error.

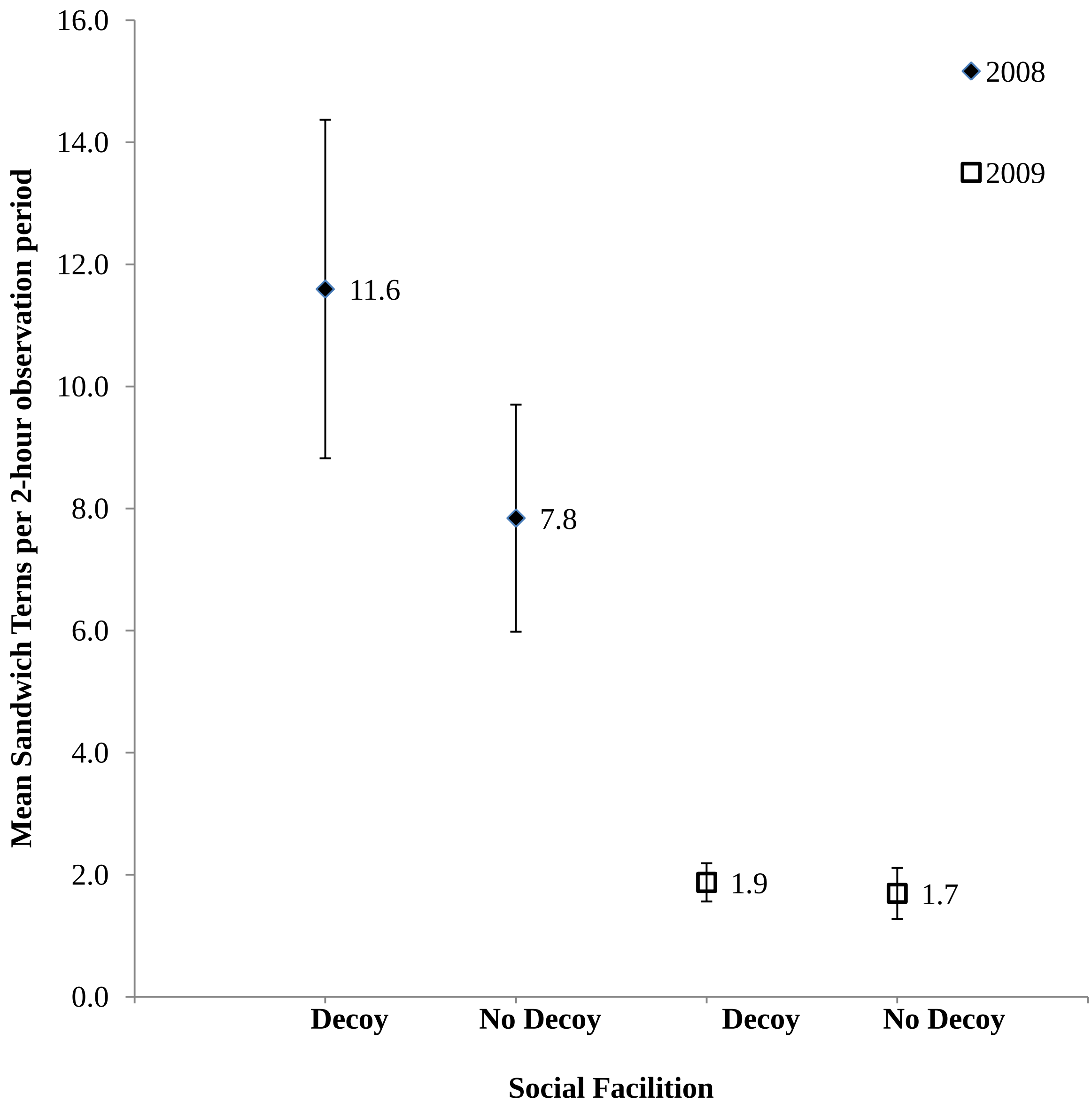

Figure 4. Mean Sandwich Tern visits per 2-hour observation period to decoy and no-decoy plots, Trinity Island, LA, 2008-2009. Weeks cropped to represent only overlapping time periods, April 27-June 3; vertical bars represent standard error.

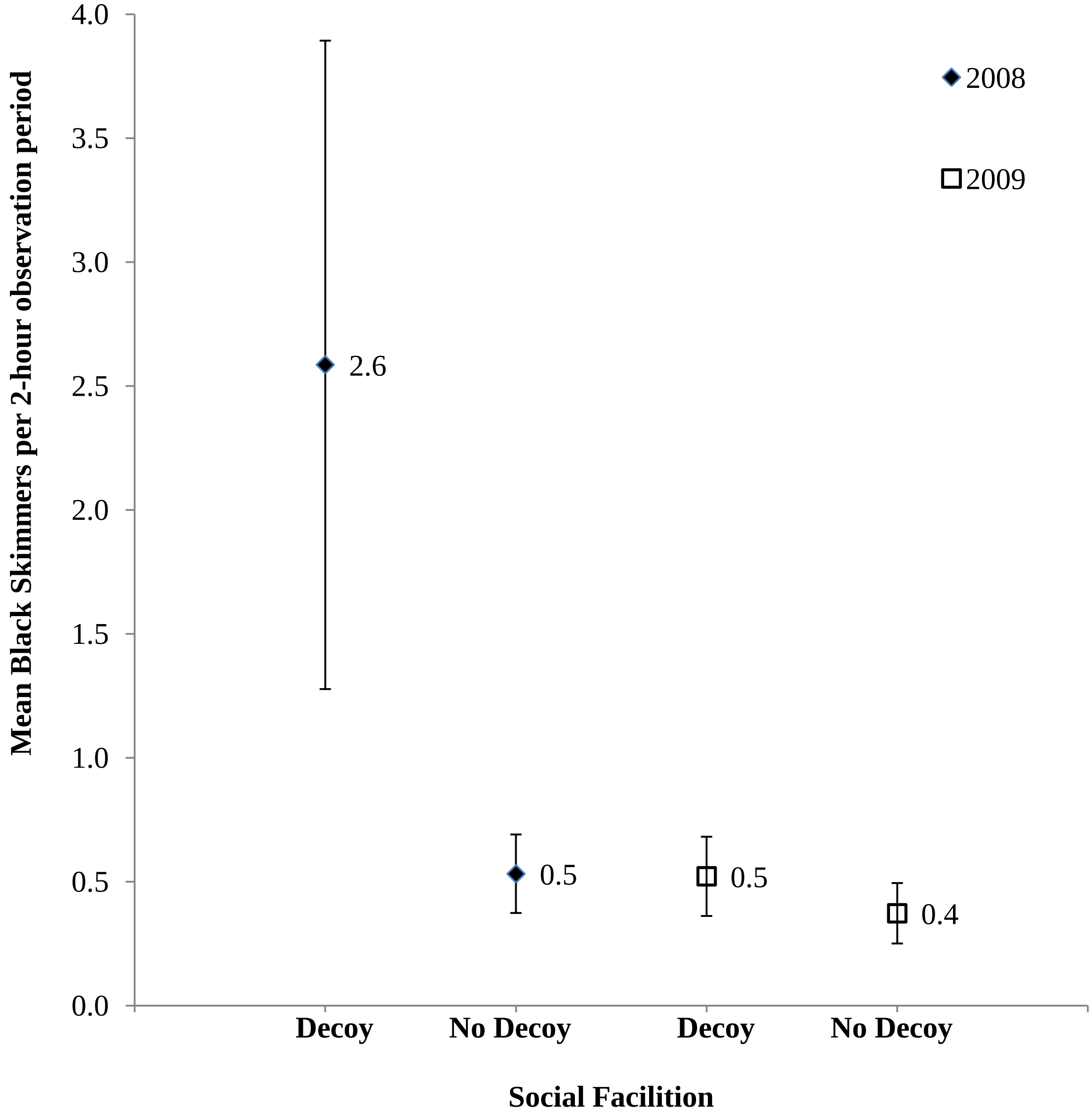

Figure 5. Mean Black Skimmer visits per 2-hour observation period to decoy and no-decoy plots, Trinity Island, LA, 2008-2009. Weeks cropped to represent only overlapping time periods, April 27-June 3; vertical bars represent standard error of the mean.

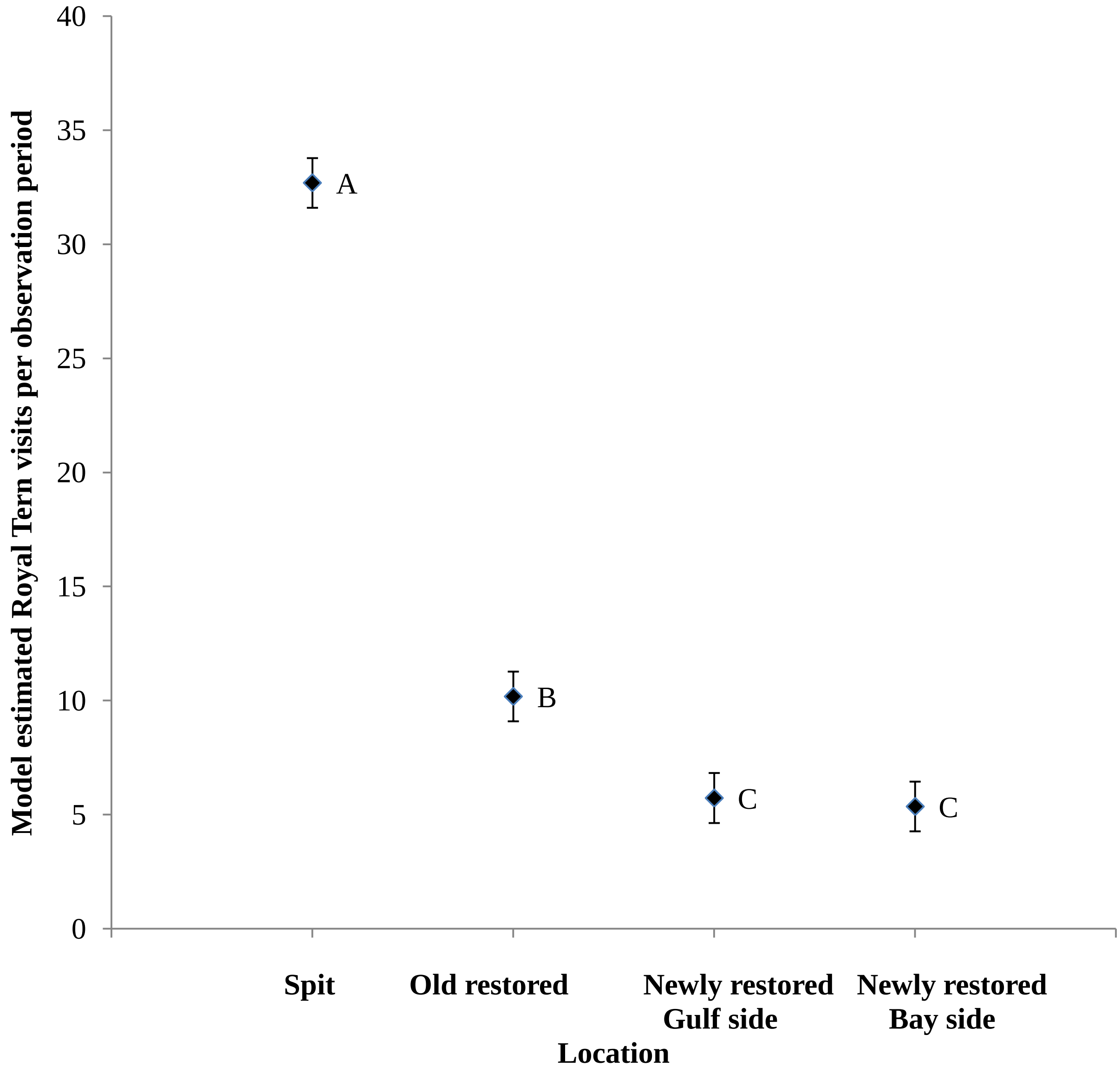

Figure 6. Royal Tern visits varied by location on Trinity Island, LA, April 27 – June 11, 2008. Vertical bars represent standard error of the model-based estimate.

significantly lower than weeks two, five, and six, which were significantly lower than weeks three and four (Fig. 7).

The location by week interaction indicated that, although the older restored locations had more Royal Tern visits overall than the newly restored locations, this pattern was only true for weeks two and six (Fig. 8). The location by fence interaction shows that the better performance of unfenced sites was driven by the spits and old restored sites (Fig. 9). The location by fence by week interaction shows that for the spit locations, the unfenced site did significantly better, while results were mixed for the other locations (Fig. 10).

Sandwich Tern. In 2008, the probability of Sandwich Tern presence was significantly affected by location ($\chi^2 = 12.1$, df = 3, p = 0.0072) and week ($\chi^2 = 35.7$, df = 5, p < 0.0001). Sites on the spits had the highest probability of presence for all weeks (Fig. 11).

Black Skimmer. In 2008, the probability of Black Skimmer presence was significantly affected by location ($\chi^2 = 15.4$, df = 3, p = 0.0015). Sites on the spits had the highest overall probability of presence (Fig.12).

2009

Royal Tern. In 2009, the probability of Royal Tern presence was significantly affected by location ($\chi^2 = 13.4$, df = 3, p = 0.004), sound ($\chi^2 = 8.01$, df = 1, p = 0.005), and week ($\chi^2 = 27.7$, df = 5, p < 0.0001). Spit locations had highest probabilities of Royal Tern presence, and sites with sound were more likely to be visited by Royal Terns than those without sound. All sites followed a generally increasing trend with week (Fig. 13).

Sandwich Tern. In 2009, the probability of Sandwich Tern presence was significantly affected by week ($\chi^2 = 41.6$, df = 5, p < 0.0001). There was a strong linear increasing trend with week ($\chi^2 =$

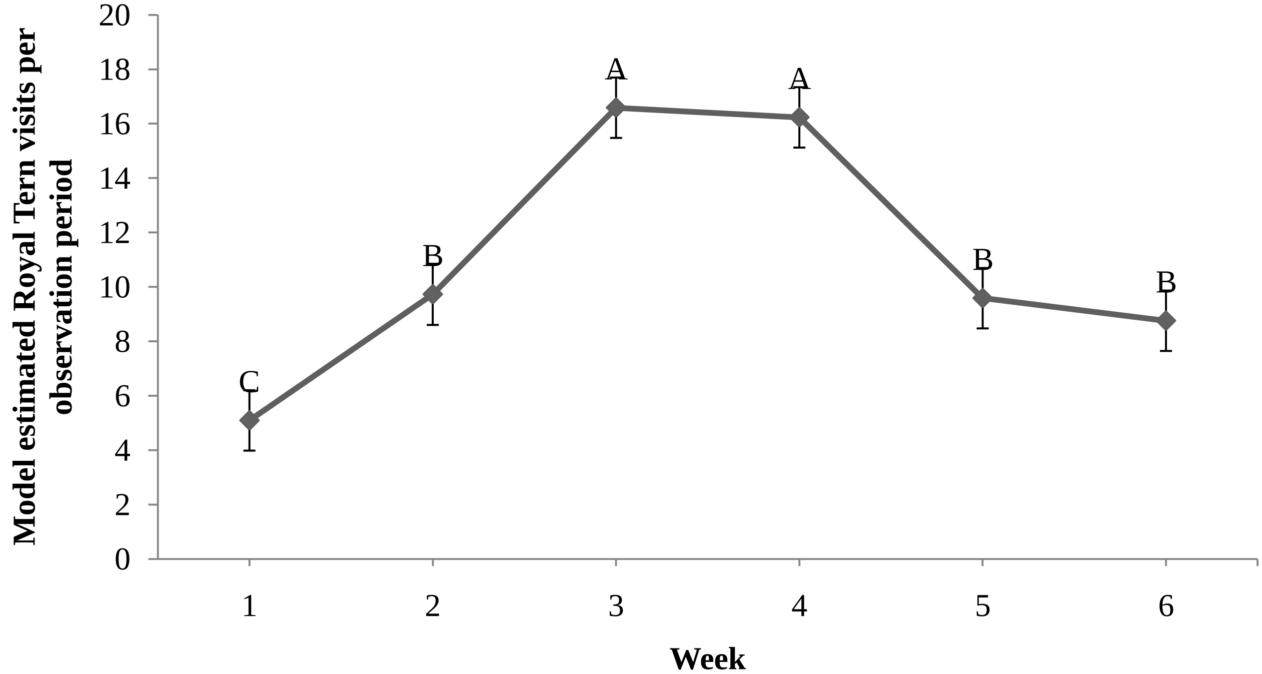

Figure 7. Royal Tern visits onTrinity Island, LA, April 27 – June 11, 2008 show quadratic effect of week ($p < 0.0001$). Vertical bars represent standard error of the model-based estimate.

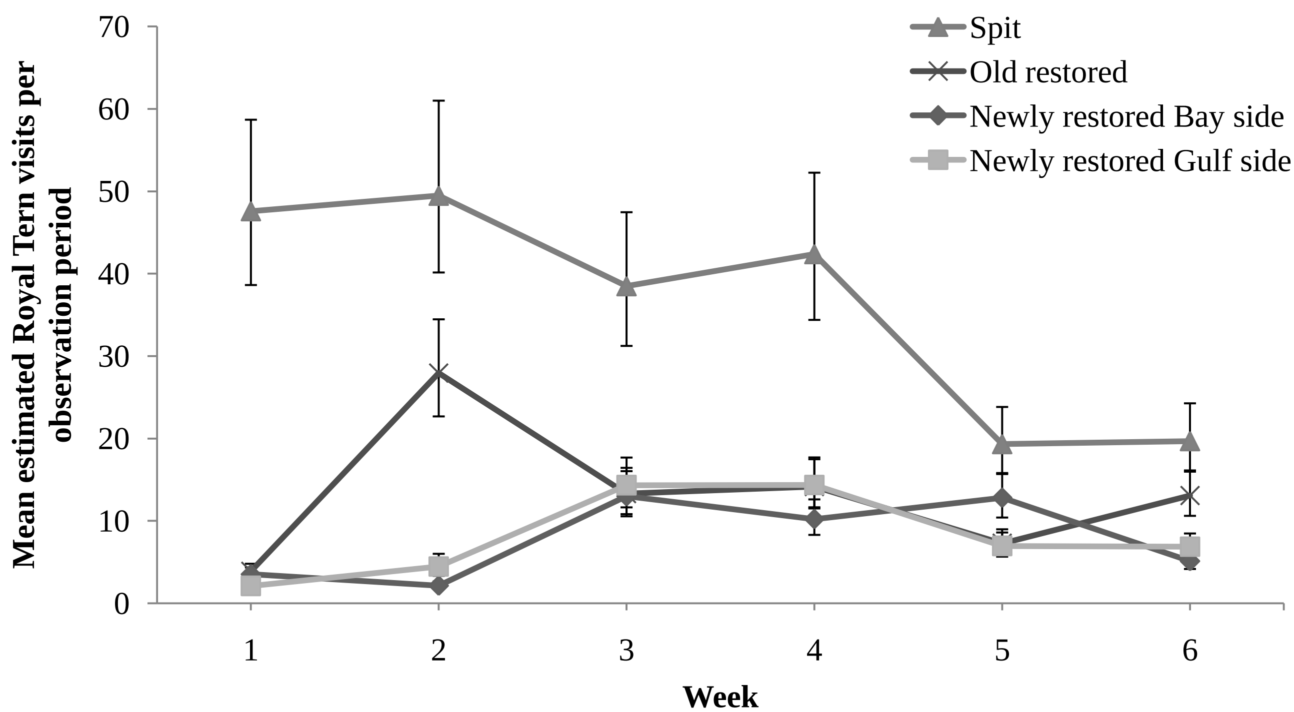

Figure 8. Interaction of location and week for Royal Tern visits on Trinity Island, LA, April 27 – June 11, 2008. Vertical bars represent standard error of the model-based estimate.

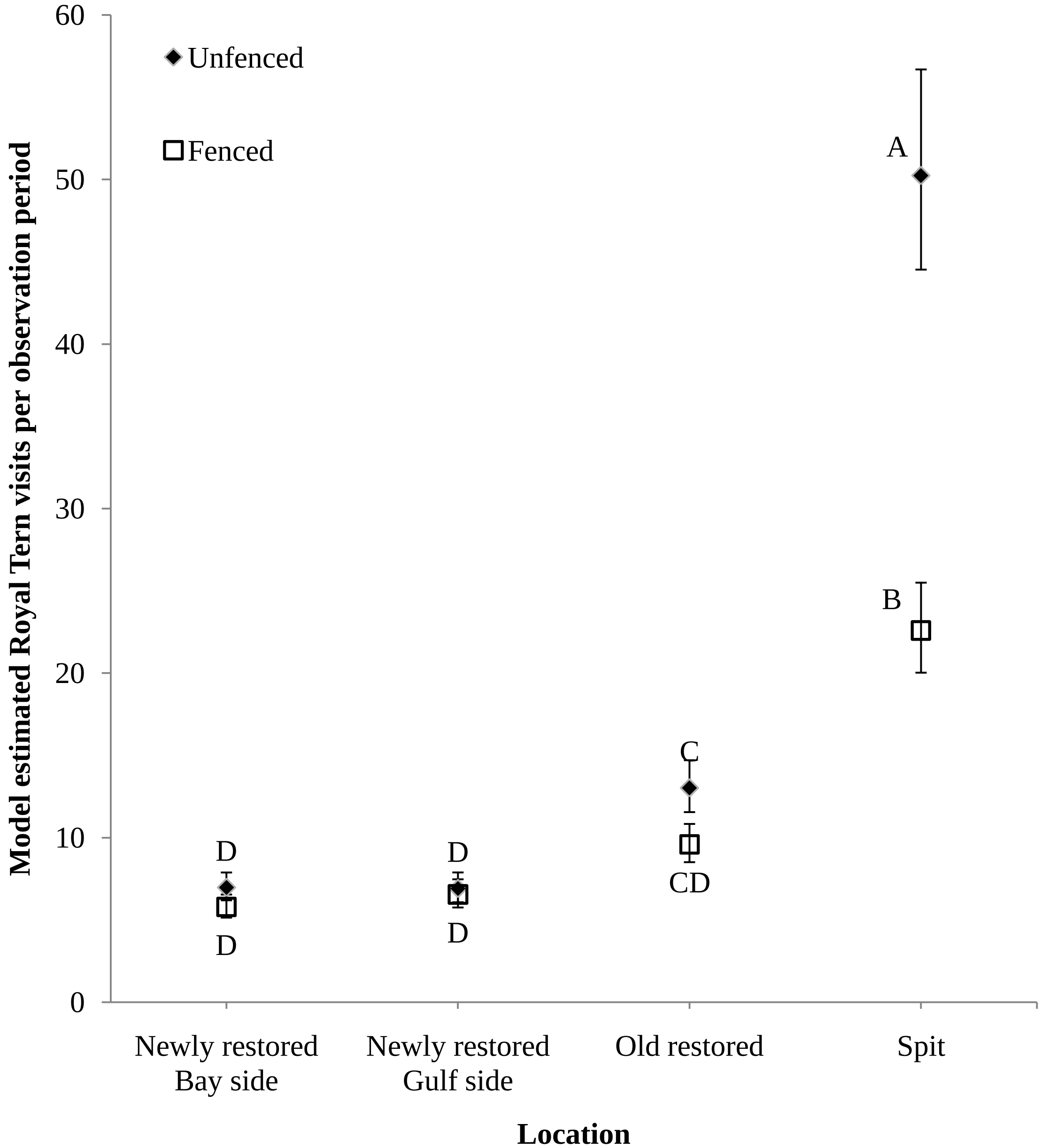

Figure 9. Interaction of location and fencing treatment for Royal Tern visits on Trinity Island, LA, April 27 – June 11, 2008. Vertical bars represent standard error of the model-based estimate.

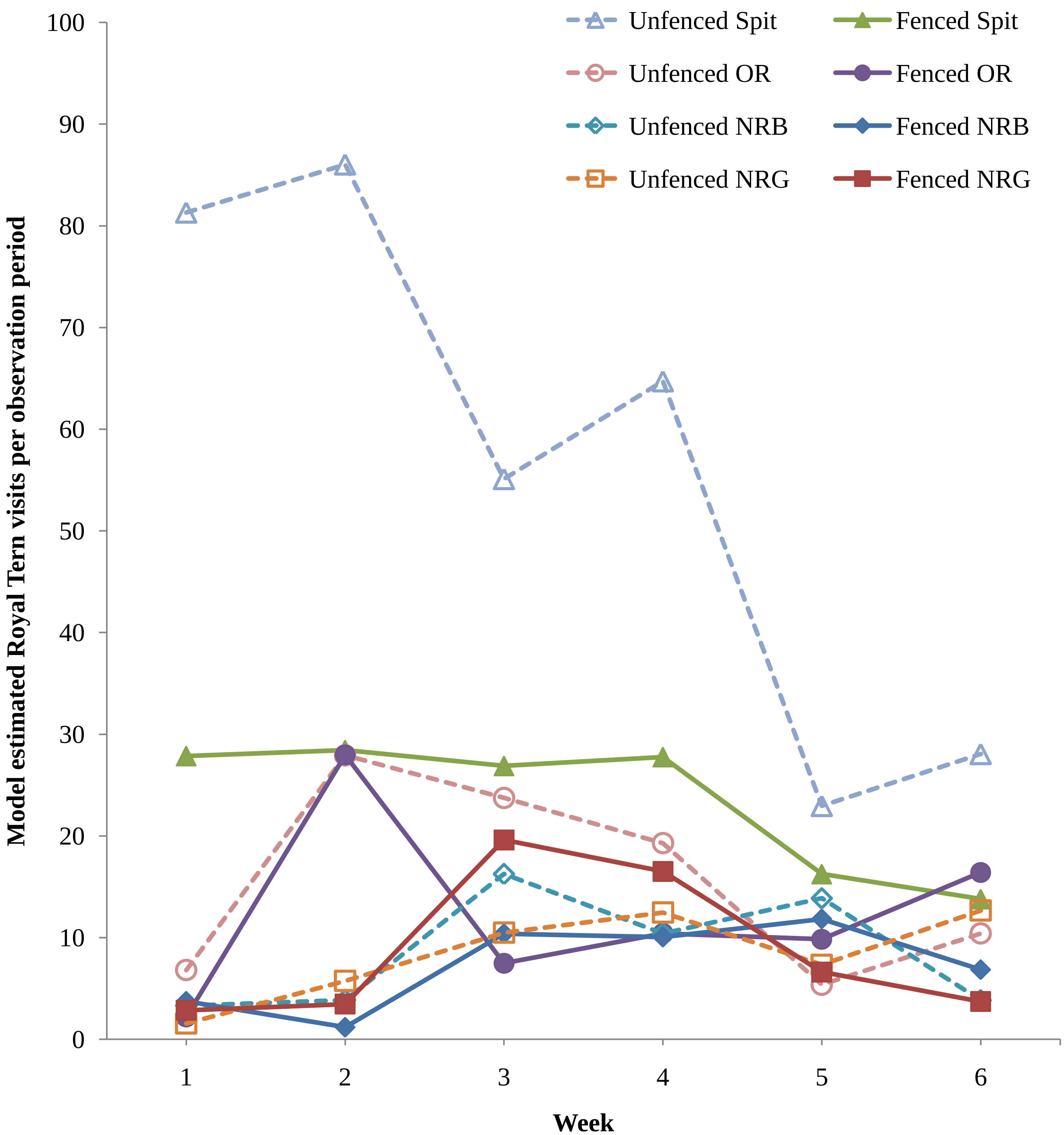

Figure 10. Interaction of location, fencing treatment, and week for Royal Tern visits on Trinity Island, LA, April 27 – June 11, 2008. Locations: Spit = east and west ends of the island; NRB = newly restored bay side; OR = older restored; NRG = newly restored Gulf side.

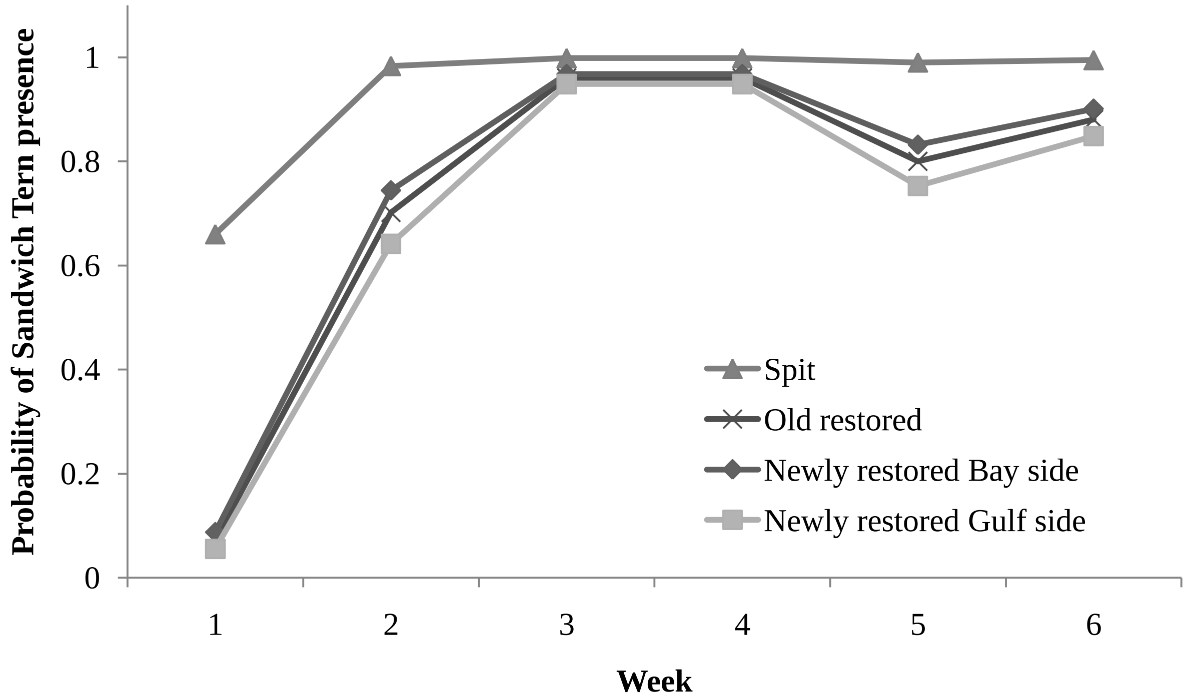

Figure 11. Probability of Sandwich Tern presence on Trinity Island, LA, April 27 – June 11, 2008 varied by week and location.

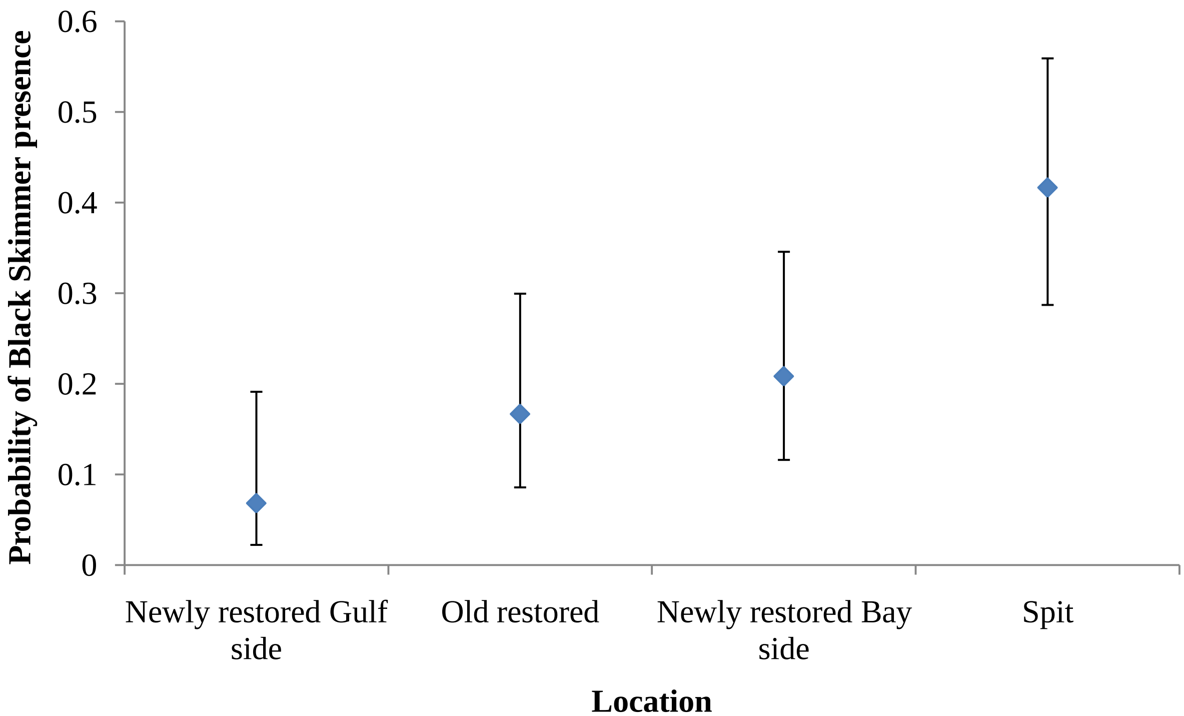

Figure 12. Probability of Black Skimmer presence on Trinity Island, LA, April 27 – June 11, 2008 varied by location. Vertical bars represent 95% confidence intervals.

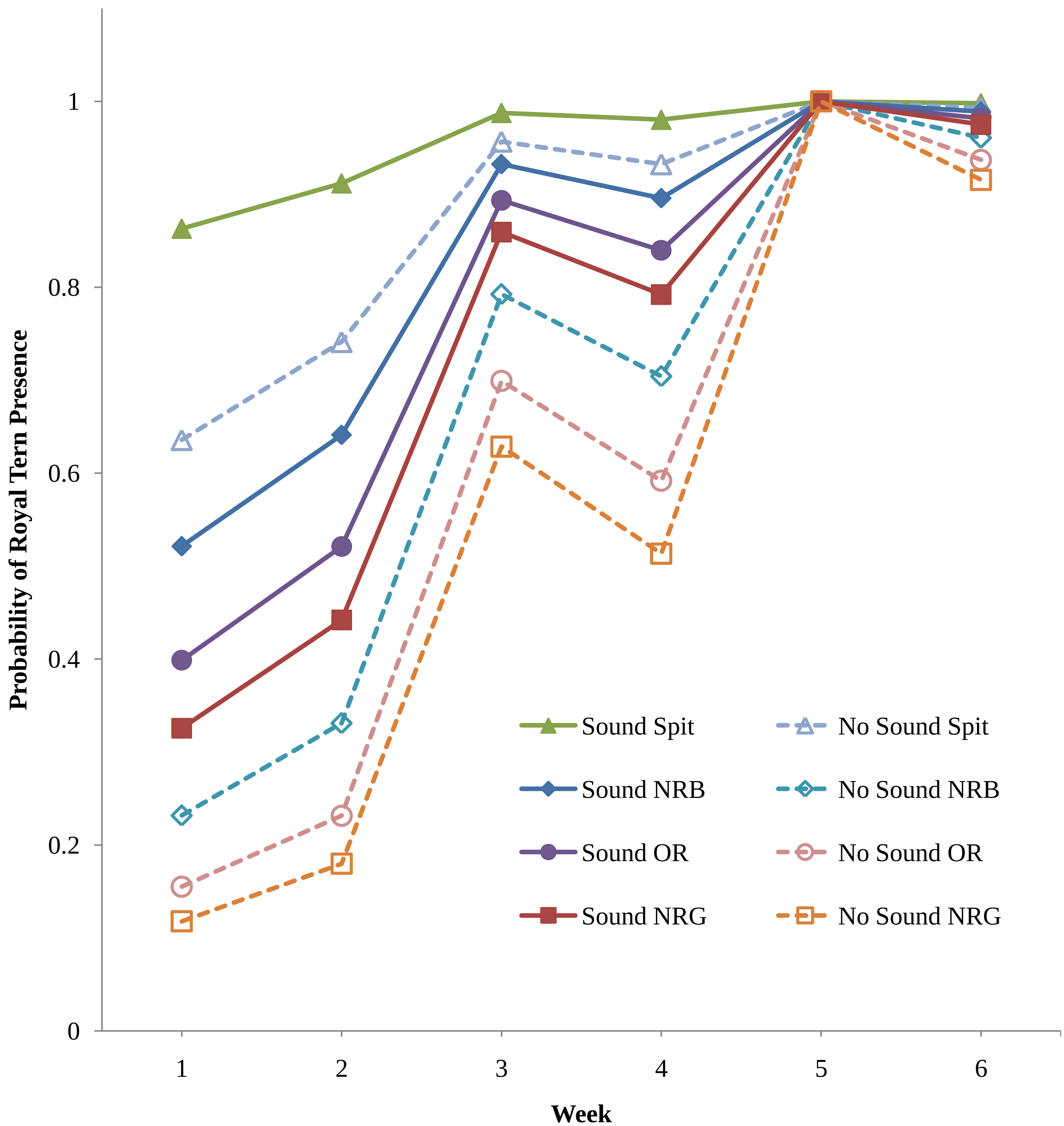

Figure 13. Probability of Royal Tern presence on Trinity Island, LA, April 7 – June 3, 2009 varied by location, sound treatment, and week. Locations: Spit = east and west ends of the island; NRB = newly restored bay side; OR = older restored; NRG = newly restored Gulf side.

28.4, df = 1, $p < 0.0001$) driven by the fact that Sandwich Terns were seen in every observation period in week 5 (Fig. 14).

Black Skimmer. In 2009, the probability of Black Skimmer presence was significantly affected by fence ($\chi^2 = 5.54$, df = 1, $p = 0.0186$) and week ($\chi^2 = 30.4$, df = 5, $p < 0.0001$). Unfenced sites were more likely than fenced to have Black Skimmers, and week 6 had the highest probability of all weeks (Fig. 15).

Table 3. Variables predicting abundance (ANOVA) or presence (logistic ANOVA) of three seabird species on Trinity Island, LA, April-June, 2008-2009.

Species	Year	N	Analysis	Significant variables
Royal Tern	2008	3584	ANOVA	decoy, fence, location, week, loca*fence, loca*week, loca*week*fence
Sandwich Tern	2008	1827	logistic ANOVA	location, week
Black Skimmer	2008	293	logistic ANOVA	week
Royal Tern	2009	901	logistic ANOVA	location, sound, week
Sandwich Tern	2009	335	logistic ANOVA	week
Black Skimmer	2009	84	logistic ANOVA	fence, week

Predator surveys

On two of the four islands, our scent station surveys revealed the presence of mammalian nest predators, including raccoons, rats, and coyotes. Although we recorded bird and crab tracks on the transects, scent station methodology is meant to index terrestrial mammal activity, and is not considered a good measure of avian or crustacean activity or abundance. We also detected nutria, which, as terrestrial mammals, should be well-indexed by this method. However, nutria are

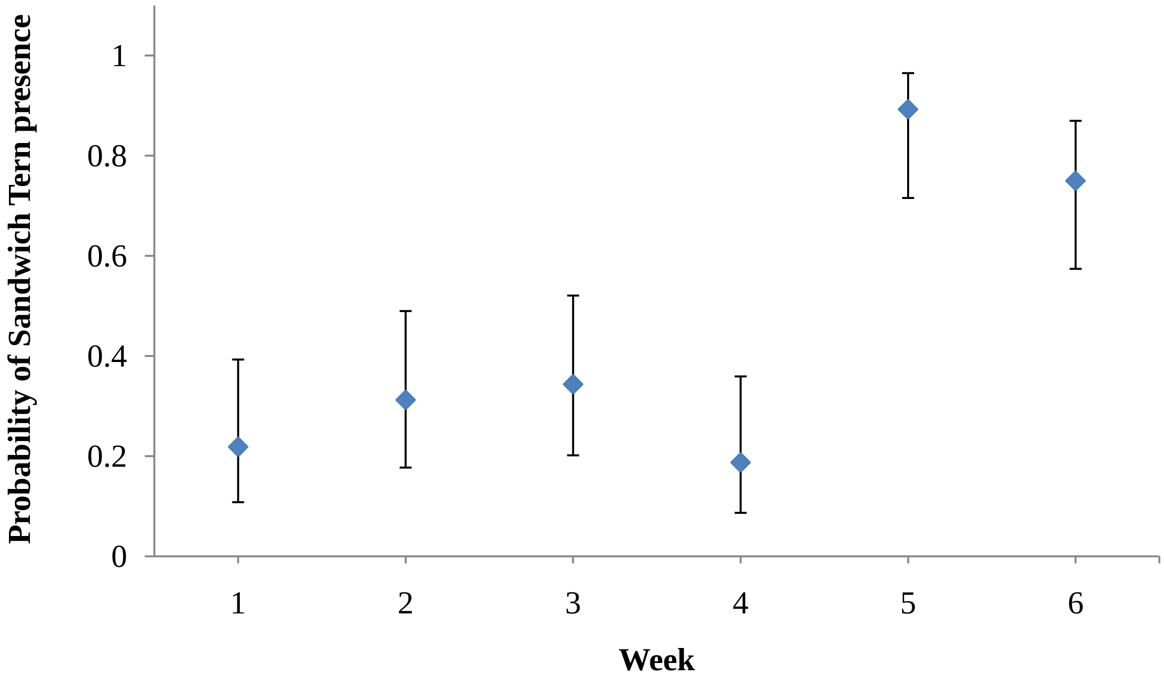

Figure 14. Probability of Sandwich Tern presence on Trinity Island, LA, April 7 – June 3, 2009 varied by week. Vertical bars represent 95% confidence intervals.

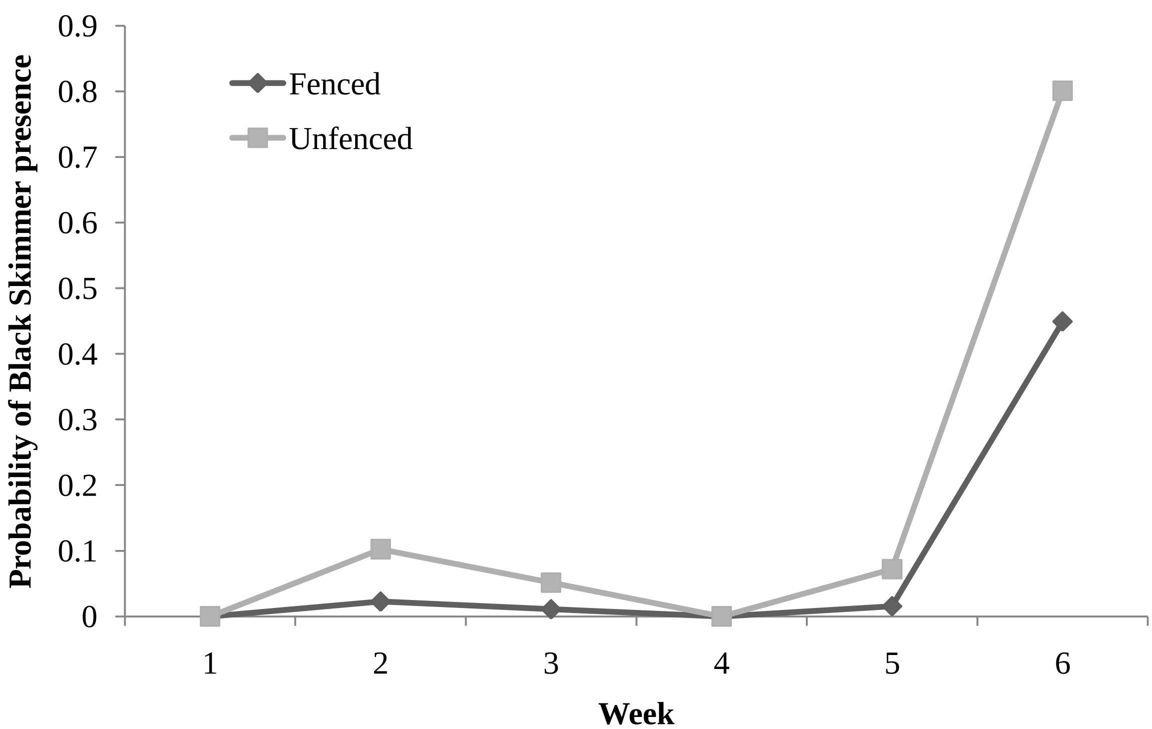

Figure 15. Probability of Black Skimmer presence on Trinity Island, LA, April 7 – June 3, 2009 varied by fence and week.

herbivores and not considered a threat to eggs or nestlings. Indeed, in 2008 we found evidence of a nutria walking right past an active Least Tern nest and leaving its contents undisturbed.

There were differences in detections among islands and between years (Table 4). In 2008, we detected raccoon and rat tracks on Trinity Island transects and coyote tracks on Whiskey Island transects. In 2009, the only mammals we detected were raccoons on Trinity Island. In the course of other field work on the islands, we had additional detections only on Whiskey Island: raccoon in July 2008 and April- May 2009; coyote in April and June 2009. Whiskey is the closest island to mainland marsh, and mammals could more easily move on and off that island than any of the others (Fig. 1).

Table 4. Mammal occurrence by island, Isles Dernieres Barrier Island Refuge, LA, June- July 2008-2009. N = number of transects per island in 2008 and 2009, respectively, where each line had five stations. Dashes indicate no detection; percentages indicate percent of transects containing tracks of a species.

	2008 Predator			2009 Predator		
Island	Raccoon	Rat	Coyote	Raccoon	Rat	Coyote
Raccoon (n = 6, 5)	-	-	-	-	-	-
Trinity (n = 9, 9)	44%	22%	-	39%	-	-
Whiskey (n = 5, 5)	-	-	20%	-	-	-
Wine (n = 1, 1)	-	-	-	-	-	-

DISCUSSION

In this study, we set out to investigate why colonial seabirds nest in high concentrations on two of the four Isles Dernieres barrier islands and not on the others. Our two hypotheses involved social facilitation and predation risk, factors that are important in seabird colony site selection elsewhere.

Social facilitation

We believe that this study represents a relatively unique situation for a social facilitation experiment. Many researchers have used social attraction techniques to attract seabirds to nesting areas. However, this has generally been done in conjunction with habitat manipulations, predator removal, or following a disturbance to local breeding colonies. In our system, we set up social attraction sites in close proximity to active and available breeding colonies. Our goal was to find out whether social mechanisms were preventing seabirds from colonizing Trinity Island. If social facilitation had been the limiting factor, and assuming the decoys and call broadcast adequately imitated social stimuli, nesting colonies should have been initiated.

We found evidence, both quantitative and anecdotal, of seabird interest in the social facilitation experiments. Our ANOVA on 2008 Royal Tern reactions to the social facilitation plots revealed a significant difference between the number of visits to decoy vs. control plots, providing evidence that the decoys did attract the birds. In 2009, Royal Terns were significantly more likely to occur at sites with sound recordings than at those without. Sandwich Terns and Black Skimmers were less abundant than Royal Terns in both years, and with degrees of freedom limited by having many variables in the models and few replicated sites, we were unable to draw conclusions about attraction for those species from the behavioral observation data. Week was a consistent predictor of seabird presence or abundance in our models, a result that is not surprising given seasonal variation in activity. Bird abundances peaked in weeks 3-4 in 2008 and weeks 5-6 in 2009, encompassing middle and late May of each year. Location was significant in several models, a result largely driven by the propensity of birds to gather near the spits of the islands, giving them an increased chance to visit those sites.

Despite the lack of quantifiable interest from Sandwich Tern and Black Skimmer observations, we did note several incidents that demonstrate attraction of those species to the decoys and sound. In 2008, a Sandwich Tern made a nest scrape among a group of Royal Tern decoys, but never laid an egg. Also in 2008, a group of 11 Black Skimmers landed among a group of skimmer decoys for 15 minutes and engaged in courtship behaviors. In 2009, a pair of Black Skimmers landed and courted among our skimmer decoys at a site that also had sound, ultimately nesting about 25m away from that plot. Both the Black Skimmer nest and the Sandwich Tern scrape occurred in the vicinity of nesting Least Terns, which could potentially have attracted the larger birds. Black Skimmers are known for nesting with various tern species, including Common, Gull-billed, and Least, and are hypothesized to benefit from tern anti-predator behavior (Gore 1991, Gochfeld and Burger 1994, Pius and Leberg 1998). Because the social facilitation equipment did attract seabirds, yet no new colonies were initiated on Trinity Island, we conclude that other factors limit seabird use of this island.

Predation

Predation is a leading cause of nest failure in birds (Nisbet 1975, Erwin 2001). In this study, we found that two efficient nest predators, raccoons and rats, occur on the two non-colony islands but not on the active colony islands. Despite the lack of highly concentrated large seabird colonies, Trinity Island is not completely devoid of breeding birds. Least Tern, Willet, Common Nighthawk, and Red-winged Blackbird are among the most common breeding species. In 2008, a colony of Least Terns was present on the newly restored area in the center of the island. We monitored 52 nests; of these, we confirmed only 3 hatched nests, all of which were inside predator exclusion fences. One additional fenced nest failed, while 44 of the 48 unfenced nests failed, and 4 had unknown outcomes. These results indicate heavy predation pressure on the island in 2008. Although some failures may have been due to Laughing Gull predation, this pressure is also present on the large colony islands. Hurricanes Gustav and Ike impacted the Isles Dernieres in the fall between our two field seasons, giving us the opportunity to compare nest success before and after this event. In 2009, we monitored 80 Least Tern nests; of these, 35 hatched, 32 failed, and 13 had unknown outcomes. Fenced and unfenced nests had similar success in 2009, but fencing treatment differed between years (see Chapter 2). Combined with declines in rat and raccoon observations post-storms, the improved nest success rate in 2009 indicates that Least Tern productivity on Trinity Island is limited by predation.

Annual variation

The two years of our field study differed in abundances of birds and in significant predictor variables in our six statistical tests (three species, two years). Possible causes of these differences include direct and indirect effects of the hurricanes, acclimation of the birds to the decoys, or natural annual variation.

Declines in bird visits to our experimental plots on Trinity Island were more pronounced than declines in numbers of breeding pairs on the active colonies. Pair numbers declined from 2008 to 2009 on colonies by 43% for Royal Terns, 36% for Sandwich Terns, and 26% for Black Skimmers (E. J. Raynor, unpublished data). These species declined in our behavioral observations by 75%, 82%, and 71%, respectively. A probable cause of declines is loss of breeding habitat area due to hurricanes. Direct mortality from storms is also a possibility, as these species all have wintering populations along the Gulf coast and/or in the Caribbean (Gochfeld and Burger 1994, Shealer 1999, Buckley and Buckley 2002) and could therefore have been impacted by Hurricanes Fay, Gustav, Hannah, or Ike. Interestingly, Least Terns leave the area to winter primarily in northern South America (Thompson et al. 1997), and were among few species on the Isles Dernieres that did not decline between 2008 and 2009.

Lack of attraction to decoy plots in 2009 may have been related to the increased activity of Least Terns on Trinity Island. Although not conspecifics, these real breeding birds may have distracted our focal species from the decoys. Conversely, Least Terns may have drawn attention to some of our plots that were near their colonies. These effects, if real, would be difficult to uncouple from the effects of location, week, and experimental treatments.

Future directions/management implications

It is apparent from this study that social facilitation, although it has led to colony establishment elsewhere, did not work on Isles Dernieres. Seabirds may have been attracted to the decoys and call broadcast, but this attraction did not result in new nesting colonies. It is possible that adding chick decoys might have made our arrays more effective. Seabirds prospecting for future breeding locations use reproductive success of conspecifics as an indicator of good breeding habitat (Boulinier et al. 1996, Danchin et al. 1998). However, we feel that predation pressure on Trinity Island precludes colony formation there. The two large colony islands in this chain are both free of mammalian predators, providing safe nesting sites. Nest success was near 80% for both Royal and Sandwich Terns on Wine and Raccoon Islands (E. J. Raynor, unpublished data), indicating that these are highly successful colonies. Least Tern nest success on Trinity was 20% in 2008 and 53% in 2009.

Predator reduction would benefit Least Terns and other species that currently nest on Trinity Island, and potentially allow species on other islands to expand their populations on Isles Dernieres. Trapping or poisoning during winter months would reduce the likelihood of impacting non target (bird) species. The only mammals on this island are raccoons, rats, and nutria, which are all highly abundant or, in the case of nutria, invasive exotic species. Following successful predator removal, social attraction techniques could be used to bring birds to nest on suitable areas of Trinity Island. If this is attempted in the future, we recommend using both decoys and call broadcast, since these were positively associated with our Royal Tern visit data, and both Sandwich Terns and Black Skimmers showed interest in the decoys. We emphasize that without predator control, we believe Trinity Island is unsuitable as a colony site for colonial nesting seabirds in the Isles Dernieres. The intensive restoration efforts being funneled into this island chain will undoubtedly contribute to the battle against coastal land loss in Louisiana; however, with the addition of predator control, their ecological value could be expanded to include breeding habitat for multiple bird species of conservation concern.

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CHAPTER 3: TEMPORARILY IMPROVED NESTING CONDITIONS FOR GULF COAST LEAST TERNS AFTER HURRICANES

INTRODUCTION

Hurricanes are unpredictable, severe disturbance events that impact vegetative and mammalian communities on barrier islands (Snyder and Boss 2002, Scoggin 2008, Miller et al. 2010). Hurricanes also have direct negative effects on seabird chick growth and survival as well as adult survival and colony use (White et al. 1976, Marsh and Wilkinson 1991, Langham 1986, Aebischer 1993, Morris and Chardine 1995, Leberg et al. 2007, Spendelow et al. 2008). However, little research has been done on indirect effects of hurricanes on seabird nesting success. Undeveloped barrier islands, including many along the Gulf Coast of the United States, allow seabirds to nest with minimal human disturbance. However, predation, vegetative succession, and erosion remain significant threats to breeding success (Erwin et al. 2001)

Least Terns (*Sternula antillarum*) nest in loose colonies on areas of open sand or shell beaches and barrier islands along the Atlantic and Gulf coasts of North America (Thompson et al. 1997, Kushlan et al. 2002, Hunter et al. 2006), areas that are subject to hurricanes from June-November. The coastal subspecies (*Sternula antillarum antillarum*) is classified as a species of both continental and regional concern in Louisiana (Hunter et al. 2006). Threats to this species include predation, loss of habitat to human development, vegetative succession, and erosion (Erwin et al. 2001, Thompson et al. 1997).

Hurricane Gustav made landfall at Cocodrie, LA, as a Category 2 storm on September 1, 2008, passing directly over our study site, Trinity Island, LA. On September 13, 2008 Hurricane Ike made landfall as a Category 2 at Galveston Island, TX. Ike was an unusually large storm in diameter, encompassing nearly the entire Gulf of Mexico (NOAA:

http://www.ncdc.noaa.gov/sotc/?report=tropical-cyclones&year=2008&month=9). So although Ike's center passed to the south of Trinity, its storm surge washed over the island. (NOAA: http://www.noaanews.noaa.gov/stories2009/20090501_names.html). Our objective for this study was to determine whether distribution and success of Least Tern nests differed between the two years. We hypothesized that storm surges from hurricanes would make the island temporarily more suitable for beach nesting birds by scouring vegetation and reducing predator populations. We predicted that loss of vegetation would allow Least Terns to expand their nesting range and numbers on the island. We further predicted that negative impacts of the storms on terrestrial mammals, especially raccoons and rats, would lead to improved nest success for Least Terns.

Aside from year effects, numerous covariates may influence nest success. Nest age and seasonality have variable impacts on daily survival rate (DSR) throughout the nesting period (Grant et al. 2005, Pieron and Rohwer 2010). Fencing is commonly employed to reduce predation risk and increase nest survival for Least Terns and other beach-nesting birds, and generally increases nest success (Rimmer and Deblinger 1992, Spear et al. 2007, Pauliny et al. 2008). A secondary objective of this study was to evaluate the impact of fences, nest age, and seasonality on DSR.

METHODS

Study Area

Trinity Island is one of four islands that formerly comprised Last Island, or Isle Derniere, and currently make up Isles Dernieres Barrier Island Refuge. It is 11 km long, less than 2 km wide at any point, and located approximately 7 km off the Louisiana coast in Terrebonne Parish. The island is characterized by a sand-shell beach along the Gulf edge, a slight elevation increase in the center (dunes up to 3m), and back barrier marsh/black mangrove habitat on the mainland side. The east and west ends of the island taper to narrow sand-shell spits. Numerous restoration efforts over the last two decades have involved the addition of dredged sediment, creation of dunes, and vegetation plantings (Lee et al. 2006).

Nest monitoring and fences

From April to June, 2008 and 2009, we searched for nests on Trinity Island wherever Least Tern activity was observed. We placed a wooden marker in the sand 2m south of each nest for identification and revisited nests approximately every 3 days. In 2009, we floated eggs to determine nest age. We categorized nest fates as successful (≥ 1 egg hatched), abandoned (adults absent, eggs cold), failed (evidence of predation or eggs missing prior to hatch date based on 21 day incubation period [Thompson et al. 1997]), or unknown fate. We identified causes of failure where possible via tracks, eggshell fragments, water, or evidence of flooding. Nests found empty prior to their earliest possible hatch date we classified as unknown failures unless clear evidence allowed classification of destruction.

In 2008, four Least Tern nests were found inside fences that were built for a separate study. The fences were 30m in diameter, 1.2m high, and made of welded wire mesh with 5x10 cm openings. It did not appear that the terns were attracted to these fences but rather that the fences were in the colony and nests were placed within them by chance. Due to the success of these nests, we decided in 2009 to place smaller fences around individual nests to compare protected and unprotected nests. We randomly chose odd-numbered nests for the fencing treatment, such that every other nest was fenced within 24 hours of discovery. Fence enclosures were 2.4m in diameter and 0.91m high, supported by four-0.91m lengths of steel rebar. In both years, fences were buried at least 10cm into the sand and checked frequently; we never found evidence of an animal entering an exclosure by digging under a fence. Fence construction could be completed in less than 10 minutes by one or two workers. The fence design was chosen to minimize disturbance to the terns while protecting nests from raccoons, and was based in part on designs used for plover nest exclosures (Deblinger et al. 1992, Melvin et al. 1992, Rimmer and Deblinger 1992, Mabee and Estelle 2000). We observed nests from a distance after building fences. Adults usually returned to the nest within 20 minutes, and entered both by walking and flying. In two cases adults failed to resume incubation for over an hour, and on the second such case we removed that fence. Most nests were still active in the nest check following fence construction, indicating that fences did not cause nest abandonment. However, several fenced nests were predated by raccoons in 2009, so while we began by adding fences to every other nest, we stopped when it became apparent that they were not serving their intended purpose as predator exclosures.

Logistic exposure nest success estimation method

We modeled daily survival rate (DSR) with the logistic exposure method (Shaffer 2004, Pieron and Rohwer 2010) using PROC GENMOD (SAS Institute Inc. 2009). This method allowed us to simultaneously examine variables that may have contributed to survival. It also allowed for inclusion of nests with unknown fate by truncating at the last known fate. Logistic exposure models DSR for any nest during any nest check interval and does not assume homogeneous DSR among or within nests. Nest success was calculated by raising DSR to the power of 21, the number of days for incubation (Mayfield 1961, Ehrlich et al. 1988).

Combined model. We began with a saturated model that contained year, Julian date (proxy for seasonal effects), fence, colony, and quadratic date effect, and sequentially reduced the model using backwards elimination of nonsignificant variables ($P > 0.05$, based on Type III generalized estimating equations). We assessed model overdispersion using Pearson's chi-square goodness-of-fit statistics from our full model. We used LSMEANS and ESTIMATE statements to produce model-based predicted values of DSR and associated standard errors (Shaffer and Thompson 2007) and used a 21-day exposure period to convert DSR to nest success (Thompson et al. 1997). Because the fence treatment differed in 2008 and 2009, we treated this as a three-level categorical variable: no fence, big fence (2008), and small fence (2009). We were unable to test for a fence by year interaction since only two of the three variable levels occurred in each year.

2009-only model. In 2009, we estimated nest age by floating eggs of each nest (Mabee et al. 2006). Because we did not have these data in 2008, we ran a second model using only the 2009 data to test for nest age effect. We defined nest age as the average age of a nest during a given exposure interval (Schaffer 2004). We included the same set of variables as the in first model but eliminated year and added linear and quadratic terms for nest age.

Predator surveys

We conducted scent station track surveys to quantify terrestrial predator activity on Trinity Island (Roughton and Sweeny 1982, Sargeant et al. 2003). Forty-five scent stations were deployed in 9 transect lines at least 400m apart, each consisting of 5 stations spaced at 50m intervals. We set up transects in the afternoon and evening preceding the survey. At each station, observers traced a 1m diameter circle in the ground, covered it with sifted sand and mineral oil to create a suitable tracking surface, and placed a Fatty Acid Scent tablet (USDA Pocatello Supply

Depot, ID) in the center. We checked stations < 3 hours after sunrise the following day, recording all tracks left inside the circles. Surveys were conducted once monthly in June and July of both years. We conducted Fisher's exact tests using PROC FREQ (SAS Institute Inc. 2009) to compare frequency of encounter by transect line between years for each species detected in the surveys.

RESULTS

Nest distribution

In 2008, all Least Tern nests were located in a single loose colony in a central portion of the island that was restored in January-July, 2007. In 2009, after Hurricane Ike's storm surge washed away vegetation and opened up new areas of bare sand and shell on the island, nests were located in at least five distinct colonies, including the site of the 2008 colony.

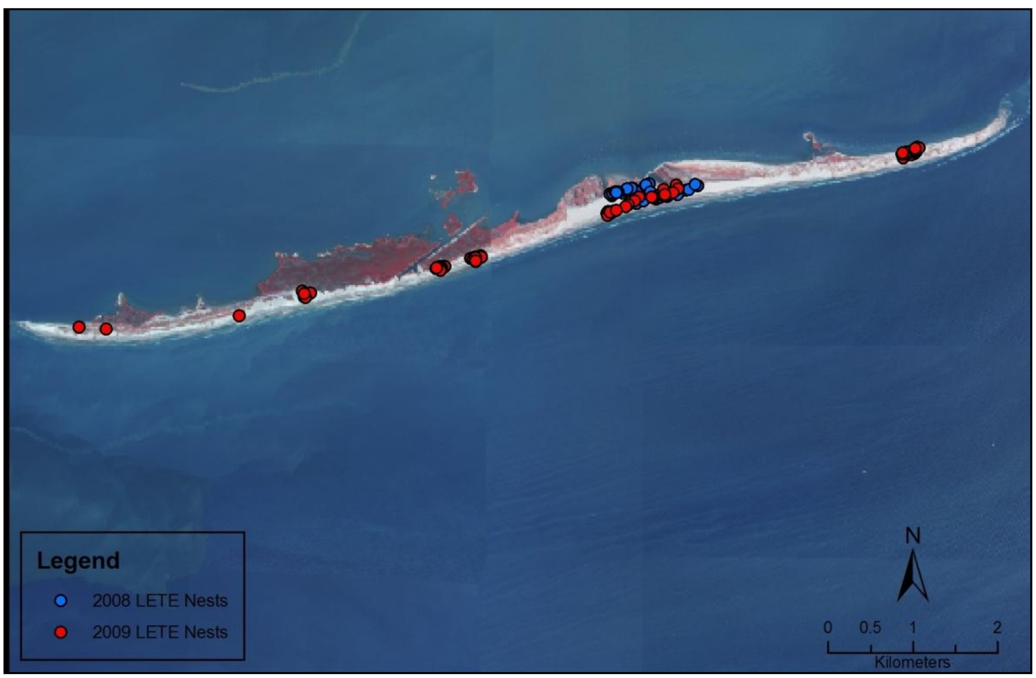

Figure 16. Distribution of Least Tern nests on Trinity Island, LA, 2008-2009. Points represent individual nests.

Nest success

In 2008, we found 49 unprotected nests and 4 nests inside large fences that were erected weeks before any nests were initiated. One fenced nest was found with a chick already hatched and therefore could not be used in our analyses. In 2009, we found 80 nests; 19 were fenced and 61 unfenced. No nests in 2009 were found inside large fences, though there was the same number of large fences on the island.

Combined model . The best model indicated that daily survival rate (DSR) was significantly impacted by fence treatment (χ^2 = 6.84, df = 2, p = 0.033), year (χ^2 = 5.99, df = 1, p = 0.014), and colony (χ^2 = 12.38, df = 4, p = 0.015; Table 5). Overdispersion was negligible ($\hat{c}$ = 1.22). The effect of fencing treatment differed between years. In 2008, nest success was higher for fenced (83%) than unfenced nests (20%). But in 2009, there was no significant difference in nest success between unfenced nests and nests with small fences (53% and 49%; Fig. 17). Unfenced ("control") nest success was significantly higher in 2009 (53%) than in 2008 (20%; Fig. 17).

2009-only model. The best 2009 model included a positive effect of nest age (χ^2 = 6.90, df = 1, $p < 0.01$; Fig. 18) and a significant colony effect (χ^2 = 10.41, df = 4, p = 0.034) on DSR. Seasonality (time of season that a nest was active), did not affect DSR (χ^2 = 3.51, p = 0.061), and was therefore excluded from the model. Overdispersion was negligible ($\hat{c}$ = 1.10).

Predator Changes

Potential Least Tern nest predators detected at our scent stations were: raccoons, rats, crabs, and birds. Although we recorded occasional bird tracks and frequent crab tracks on the transects, scent station methodology is meant to index terrestrial mammal activity, and is not considered a

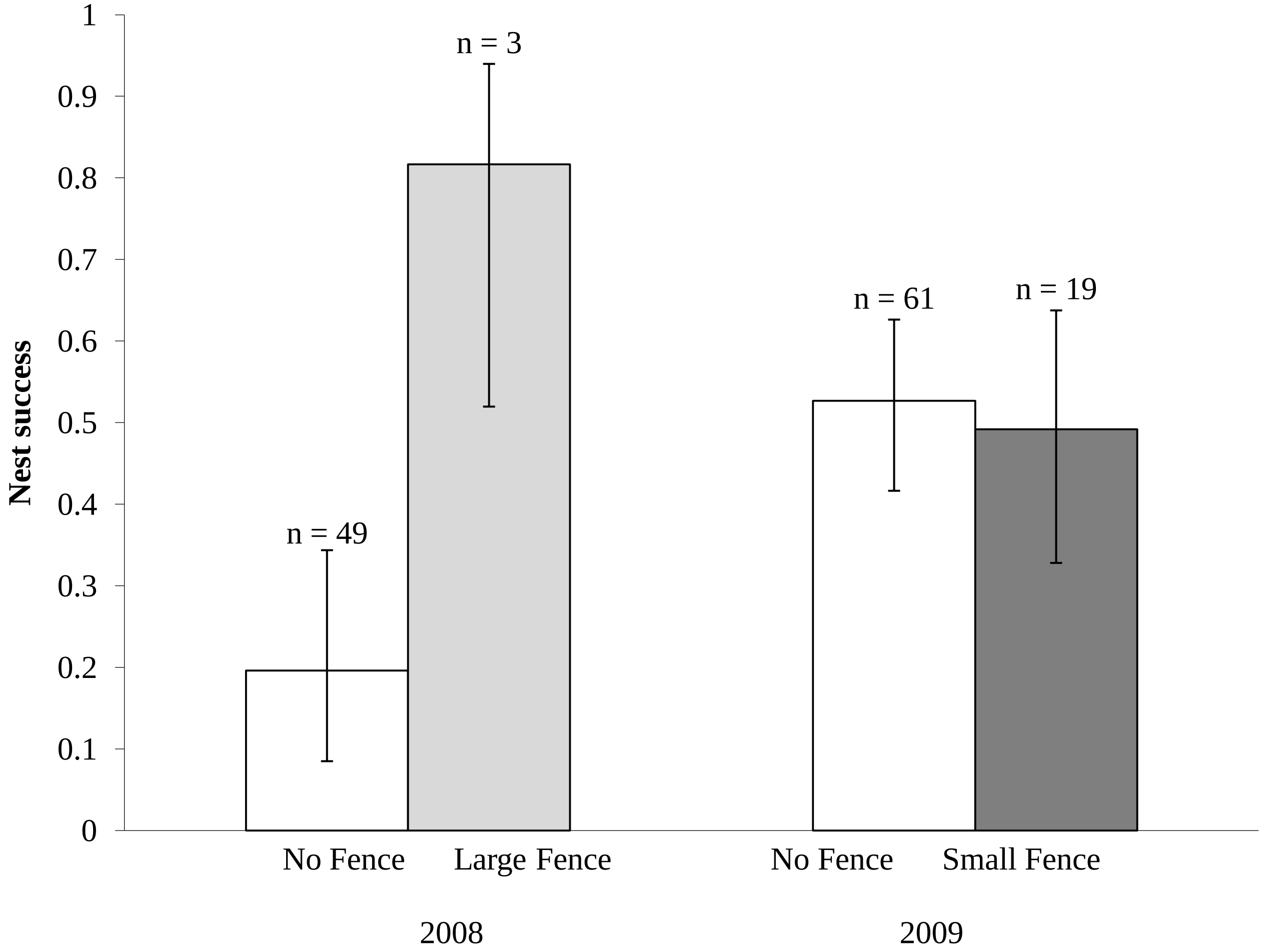

Figure 17. Model-based mean (LSMEANS; $\bar{X}$) nest success estimates and standard errors for Least Tern nests in fenced and non-fenced areas, Trinity Island, LA, 2008-2009. We weighted colonies equally.

Table 5. Factors affecting daily survival rates (DSR) of Least Tern nests on Trinity Island, 2008-2009. Parameter estimates, confidence intervals, and test statistics are from a reduced logistic exposure model.

			95% CI			
Variable	df	β	lower	upper	χ^2	p
Intercept	1	2.527	1.858	3.339	45.94	<0.0001
Fence	2				6.84	0.033
Large, 2008	1	2.119	0.418	5.460	3.48	0.062
Small, 2009	1	-0.104	-0.989	0.874	0.05	0.825
Year	1				5.99	0.014
2008	1	-0.956	-1.814	-0.183	5.35	0.021
Colony	4				12.38	0.015
3	1	1.781	-0.061	5.157	2.30	0.130
4	1	1.696	0.461	3.168	6.46	0.011
5	1	1.139	-0.198	2.847	2.35	0.125
6	1	0.116	-0.880	1.077	0.06	0.813

Table 6. Factors affecting daily survival rates (DSR) of Least Tern nests on Trinity Island, 2009 only. Parameter estimates, confidence intervals, and test statistics are from a reduced logistic exposure model.

			95% CI			
Variable	df	β	lower	upper	χ^2	p
Intercept	1	1.6018	0.5540	2.7461	8.34	0.0039
Age	1				6.90	0.0086
Colony	4				10.41	0.034
3	1	1.667	-0.141	4.804	2.19	0.139
4	1	1.490	0.251	2.905	5.16	0.023
5	1	0.994	-0.343	2.625	1.86	0.172
6	1	0.083	-0.930	1.032	0.03	0.867

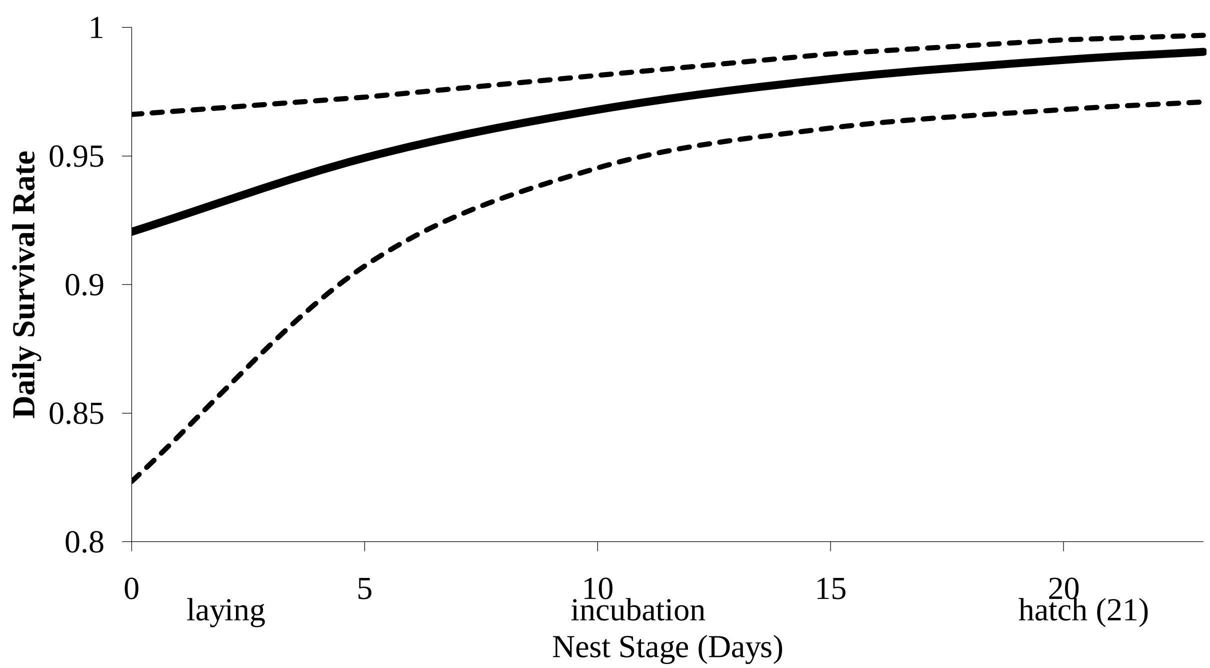

Figure 18. Model-based estimates of daily survival rate (DSR) and 95% confidence intervals for Least Tern nests in relation to nest age on Trinity Island, LA, 2009. We weighted colonies equally.

good measure of avian or crustacean activity or abundance. We also detected nutria, which, as terrestrial mammals, should be well-indexed by this method. However, nutria are herbivores and not considered a threat to eggs or nestlings. Indeed, in 2008 we found evidence of a nutria walking right past an active Least Tern nest and leaving its contents undisturbed.

Frequency of encounter of mammalian predator tracks on scent station transects declined between years for both species, with rat encounters declining to zero in 2009 (Fig. 3). Scent station surveys revealed a significant decline in rat ($p = 0.038$) activity from 2008 to 2009, but did not reveal changes in raccoon ($p = 0.773$) activity. However, the field crew living on the island for 16 weeks each year noted that while in 2008 raccoons were seen almost daily, in 2009 they were seen only rarely, and that rat and nutria sightings likewise declined noticeably (C. Leumas, E. Raynor, pers.obs.).

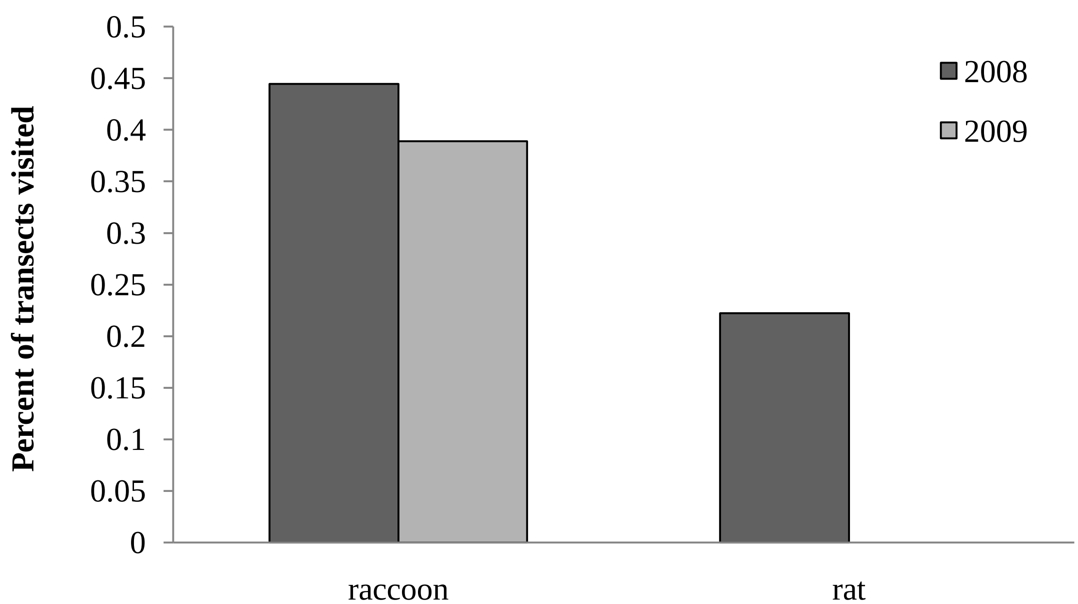

Figure 19. Frequency of encounter of mammal tracks on scent stations, shown as percent of transects with at least one encounter. Trinity Island, LA 2008-2009.

DISCUSSION

Success of unfenced Least Tern nests more than doubled from 2008 to 2009, suggesting that nesting conditions improved on Trinity Island. Hurricanes Gustav and Ike severely impacted the island in the fall of 2008, removing vegetation and likely reducing populations of some mammalian predators. Significant rat declines, detected by scent station transects, support field observations of reduced overall terrestrial mammal activity on the island in 2009. Raccoons are more mobile than rats, and we suggest that a decrease in actual abundance was masked by their curiosity and tendency to cover greater distances in a single night. Scent stations index activity level rather than absolute abundance, and raccoons may have been equally active in both years without being equally abundant. Raccoon depredation was the leading known cause of nest failure in both years, though many nests failed due to unknown causes. The sand-shell substrate used by Least Terns for nesting makes track reading challenging, but raccoon tracks were more easily detected than rats. We therefore suggest that many “unknown failures” may have been due to predation by rats.

Increasing DSR with nest age supports the use of a non-Mayfield nest success estimation method. The logistic exposure method models DSR for any exposure interval or for any given set of nests, thereby avoiding the biases of apparent nest success as well as Mayfield (1961) estimates. Our data suggest that nests are more likely to survive the longer they are active. This result is intuitive if central-place foraging predators are the primary cause of nest loss. We suspect that increasing DSR through incubation is representative of early loss in high risk areas, and increased odds of survival after that initial “high risk” period.

Fencing greatly increased nest success for Least Terns in 2008 (83% fenced, 20% unfenced) but not in 2009 (49% fenced, 53% unfenced). Three possible explanations exist for this disparity. First, higher "background" nest success in 2009, may have precluded any improvement in nest success by fencing. This seems unlikely, since fenced nest success in 2008 was 83%, suggesting that, if completely protected from predation, Least Terns could hatch most of their nests. A second, more likely, explanation is that the small diameter (2.4m) fences used in 2009 were not effective as predator exclosures. The predator exclosures used in 2008 were much larger (30m diameter), so that tern nests inside fences were likely more difficult to detect. We believe that when a raccoon walked past one of the smaller exclosures, an incubating tern would flush, alerting the raccoon to its presence. Within larger exclosures, nests were typically farther from the edge, so birds might not flush and thereby alert predators to potential rewards. We never found evidence of raccoons entering the large exclosures, of which there were eight on the island in each year. These predator exclosures were checked several times per week for signs of predator entry. A final explanation for the between-year disparity in fencing effect is low fenced sample size, especially in 2008. In that year, only four nests were established inside large predator exclosure fences. Terns did not appear to actively select or avoid fences. Four nests were found inside fences; of these, three hatched and one failed, although one successful nest was found already hatched and was therefore excluded from analysis. Avian or rat predation may have accounted for the one fenced failure.

Least Terns were the only Larids that successfully formed nesting colonies on Trinity Island during our study. Closely related but more conspicuous terns (Royal and Sandwich) are absent from Trinity Island but breed in large colonies on two neighboring islands that lack mammalian predators. Black Skimmers, which are known to abandon breeding sites that fail due to predation

(Burger 1982), formed a colony on the western tip of Trinity Island in 2008. That colony failed due to raccoon and Laughing Gull predation; no renesting occurred in that year, nor was the site used in 2009. In 2009, skimmers initiated a colony on the eastern tip of Trinity but failed early and abandoned that site. Least Terns appeared to be more persistent nesters in the presence of predators, possibly due to their relatively dispersed and cryptic nests. However, our nest success results suggest that the 2008 predation level on Trinity was unsustainably high, and that reduced predation pressure allowed many more successful nests in 2009. We believe that mammalian predator abundance did actually decline, but that low sample size and high raccoon mobility contributed to our inability to demonstrate this statistically.

Disturbances such as Hurricanes Gustav and Ike are important in maintaining suitable conditions for Least Tern nesting on Trinity Island. Nesting Least Terns exclusively utilize open areas of bare ground, making them vulnerable to both predators and vegetative encroachment. Birds in the family Laridae, including Least Terns, exhibit varying levels of philopatry and site fidelity. Least Terns have relatively high site fidelity and will often continue to use a site even in years following unsuccessful nesting, especially if these have been active for several years (Burger 1984, Atwood and Massey 1988, Brunton 1999). However, colonies are sometimes abandoned due to presence of predators, human disturbance, or vegetative encroachment (Burger 1984, Erwin et al. 2001). Disturbances that control predator populations and vegetative succession are therefore critical to the continuity of Least Tern nesting.

Although hurricanes may benefit some seabird species via predator reduction and vegetation clearing, these storms are a significant cause of erosion and contribute to coastal land loss (Stone et al. 2005, Miner et al. 2009). Nesting habitat for colonial waterbirds necessarily decreases as land is subsumed by water. Beach-nesting seabirds face loss of breeding habitat throughout their ranges due to both natural and anthropogenic habitat alteration, especially development of beachfront property (Kushlan et al. 2002, Hunter et al. 2006). The Isles Dernieres represent critical habitat for seabirds because of their isolation from humans and protected status as a state refuge. Due to their importance in coastal wetland protection from storm surges, they are also the focus of intensive restoration efforts. Because natural sediment accretion has been disrupted by the channelization of the Mississippi River, continual restoration via addition of dredged material appears necessary for the persistence of this island chain. Dune vegetation plantings are often used to attempt to hold dredged material in place; however, this strategy counteracts the secondary goal of management for breeding seabird habitat on Isles Dernieres, as many species require open sand-shell substrate; moreover, the vegetation provides cover for nest predators. Natural predator reduction via hurricane disturbance helped Least Terns breed successfully in 2009, but predator populations will likely rebound. Predator control on Trinity Island might be feasible to help maintain favorable breeding conditions for Least Terns and other breeding waterbirds.

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VITA

Cecilia Leumas was born in Columbia, Maryland, to parents hailing from New Orleans, Louisiana. She attended Catholic schools for 12 years, and graduated from Mount de Sales Academy in 1999. Her environmental awareness was formed through playing in the woods and attending, then later working at, nature camp. She earned her B. S. degree in 2003 from Tulane University in New Orleans, where she double-majored in English and ecology and evolutionary biology. At Tulane, she had the opportunity to conduct undergraduate research in tropical bird ecology. This research, in addition to assisting with field work in the swamps and marshes of Louisiana, introduced her to the joys of field ornithology. After college, she spent four years working as a field technician on avian research projects in various locations, including the Channel Islands of California, rainforest in Costa Rica, and Grand Canyon National Park, Arizona. She also worked in environmental education in California and Missouri. Cecilia returned to Louisiana in the fall of 2007 to study colonial nesting seabirds on Gulf coast barrier islands. While in graduate school at the School of Renewable Natural Resources at Louisiana State University, she has also served as a teaching assistant, tutor, and community volunteer.