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Nest site selection by Forster's terns (*Sterna forsteri*)

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NEST SITE SELECTION BY FORSTER'S TERNS (*STERNA FORSTERI*)

A Thesis

Presented to

The Faculty of the Department of Biological Sciences

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Robin Elizabeth Dakin

May 2000

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ABSTRACT

NEST SITE SELECTION BY FORSTER'S TERNS (*STERNA FORSTERI*)

By Robin Elizabeth Dakin

I compared nest site microhabitat characteristics of Forster's Terns (*Sterna forsteri*) to randomly chosen sites within three colonies in south San Francisco Bay to show whether birds selected certain nest site characteristics, and evaluated the effect of these nest site characteristics on reproductive success. In addition, I evaluated differences in habitat characteristics of the three colonies.

Forster's Terns selected nest sites with vegetation cover when vegetation was available and nest sites withing 0.4 m of a wall. There was a negative correlation between reproductive success and the number of neighbors within 2 m. Forster's Terns use topography as cover from predation and extreme weather conditions. Significant differences were found between habitat characteristics of the three colony sites. Decreased nest success with increased nest density could have been due in part to an artifact or a density dependant factor such as increased visibility to predators.

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INTRODUCTION

All birds are dependent on terrestrial environments for their nesting habitat, so the selection of nest sites is an important factor in the success of a species (Buckley and Buckley 1980). Both physical and biotic factors serve as the cues for habitat and nest site selection in birds. The purpose of this study was to determine whether Forster's Terns (*Sterna forsteri*) selected specific nesting microhabitat characteristics, or if nest sites were randomly chosen. In addition I investigated how those factors influence reproductive success. By understanding the process of nest site selection, future management of the salt pond habitat could include the preservation and construction of optimal Forster's Tern breeding sites.

Forster's Terns can be found in large numbers along the California coast, concentrated around bays, salt ponds and marshes during their breeding season, which runs from April through August (Small 1994). Nests are found in salt and fresh water marshes, lakes, salt ponds and beaches. In southern San Francisco Bay, nests are placed on dredge spoil islands and levees (Gill 1972, Baicich and Harrison 1997). Dredge spoil islands and levees are constructed and maintained with bottom sediment removed from the bay, salt evaporation ponds or slough channels. Levees, which define the borders of salt ponds, erode as a result of wind and wave action. Dredge spoil islands, placed at the corners and edges of

salt ponds help to slow this erosion (Parnell et al. 1986). The nests themselves are mostly scrapes in the substrate with small pieces of driftwood, shells, dried fish, bones and feathers (Gill 1972). Others are built on mounds of vegetation (SFBBO unpublished data). In areas with short, dense vegetation such as alkali heath (*Frankenia grandifolia*), terns will make a nesting depression in the vegetation (personal observation). As colonial nesters, Forster's Terns are found in groups of up to 600 nests (Rigney and Rigney 1981). Their eggs are laid in clutches of 2 to 4, and are incubated in shifts by both parents for a period of about 25 days. Young hatch in a semiprecocial state, meaning they are born mobile but remain at the nest for several days to be fed. Fledging occurs after 28 days (Baicich and Harrison 1997).

Prior to 1948, Forster's Terns were considered only a migrant or a visitor to San Francisco Bay during winter months (Grinnell and Miller 1944). They first bred in San Francisco Bay in 1948, when a colony of roughly 100 pairs was located on the east side of the San Mateo Bridge. Two additional colonies were found in Newark in 1951 and 1953 near the present site of the Don Edwards San Francisco Bay National Wildlife Refuge. (Sibley 1953). They have increased in number and currently inhabit 21 sites in the south bay and 5 sites in the north bay (Ryan in press). Carter et al. (1990) showed that between 1989 and 1990, 100% of the breeding population of Forster's Terns (consisting of about 3,550 birds), in northern and central California nested on the San Francisco Bay.

Prior to large-scale human settlement in the early 1800's salt marsh, natural salt ponds, sloughs and mud flats surrounded the bay. Following the Gold Rush of 1849, the natural habitat began to be rapidly filled and diked for agriculture and industry. In 1856 the first salt factory was established. By diking the tidal salt marshes surrounding the bay, evaporation ponds were created for the production of salt. This enterprise was very successful and many similar operations soon followed. By the mid 1900's, in excess of 160 km² had been converted to diked salt ponds. These small salt harvesting operations were acquired over time by larger companies until Cargill Salt Division (Cargill), formerly Leslie Salt Company, became the sole industry of its kind in the area (Josselyn 1983). At present, Cargill harvests salt from about 13,600 ha of the south San Francisco Bay (Harvey et al. 1992).

The creation of salt ponds around the bay has been a mixed blessing for wildlife. With the loss of over 123,400 ha of tidal marsh, organisms that depend on this habitat for survival have suffered large decreases in population. On the other hand, wildlife that benefits from the presence of the salt ponds has now become established in this area and is now becoming quite successful. Forster's Terns are one of the latter groups. The almost exclusive use of salt ponds for nesting habitat on the San Francisco bay suggests that this new habitat has played a pivotal role in the success of these birds.

The evolutionary mechanisms involved in the selection of habitat in animals include both proximate and ultimate factors (Lack 1954, Hilden 1965, Orians 1971). Ultimate factors are the characteristics of the habitat itself, which restrict the range of the organism and improve the survival and reproductive success of the species. Ultimate factors include the presence of food, appropriate habitat and protection from predation (Immelman 1972). Proximate factors are internal mechanisms such as the physiology and behavior of the animal that ensure that the organism selects habitat to which it is best adapted (Lack 1954). These factors include habitat characteristics such as stimuli provided by the presence of nest sites, lookout points, conspecifics, desirable foodstuffs, protection offered by topography or vegetation as well as the internal motivation of the animal itself (Hilden 1965).

Several studies have explored the relationship between habitat characteristics and nest density, as well as the relationship between habitat quality and reproductive success (Ramos and del Nevo 1995, Pribil and Picman 1997, Stokes and Boersma 1998). Pribil and Picman (1997) found a significant increase in Red-winged Blackbird (*Agelaius phoeniceus*) nest density as water depth increased. Stokes and Boersma (1998) found a positive correlation between nest cover and fledgling success in Magellanic Penguins (*Spheniscus magellanicus*) as a result of reduced exposure of nest contents to predators and high temperatures. Ramos and del Nevo (1995) found that Roseate Terns (*Sterna*

dougallii) selected sites that had tall vegetation and/or were surrounded by topographical features that offered cover. Increased nest cover was not associated with greater hatching success in Roseate Terns, however. Common Terns (*Sterna hirundo*) prefer open areas with soft substrates. Those areas in the habitat range of a species that are most productive, and thus are selected by the greatest number of individuals of that species, are thought to be that organism's optimal habitat (Hilden 1965). Thus by studying the relationship between species abundance and habitat characteristics, the proximate factors in habitat selection can be identified (Orians 1971, Partridge 1978). This used a design similar to the previous studies by measuring specific microhabitat characteristics of the dredge spoil island habitat selected by Forster's Terns as nest sites. By showing which habitat characteristics are specifically selected by birds, the ultimate factors involved in nest site selection by Forster's Terns were clarified.

STUDY AREA

Three Forster's Tern breeding colonies, all located at the southern end of San Francisco Bay, California (Figure 1) were selected for this study. They were south of Alameda Creek in Union City, Alameda County (Turk)(Figure 2), east of Mallard / Artesian Slough in Alviso, Santa Clara County (EEC) (Figure 3), and on a levee southeast of the KGO Tower located at the east end of the Dumbarton Bridge, Fremont, Alameda County (Dumbarton) (Figure 4). These sites were known to be well-established nesting sites, based on unpublished data collected over the past 15 years by the San Francisco Bay Bird Observatory (SFBBO).

Turk consisted of four separate islands that were treated as one colony due to their close proximity. Vegetation ranged from sparse to heavy with large unvegetated areas on each of the four islands. Only three of these islands were included in this study due to time constraints imposed by permits and the large number of birds nesting within this colony. The Turk colony was discovered in 1988 when 8 birds nested there. This colony grew quickly, ranging between 200 and 571 adults between 1990 and 1998. The Dumbarton colony is located on a sparsely-vegetated levee. Fluctuating water levels can partially submerge this levee, but 2 of the more elevated sections nearly always remain above water, creating 2 large islands that are suitable nesting sites for terns. As water levels drop, these 2 islands become a single one. Terns have nested at Dumbarton since

Figure 2: Turk colony, located south of Alameda Creek in Union City.

Figure 3: EEC Colony, located east of Mallard/Artesian Slough in Alviso.

Figure 4: Dumbarton colony, located southeast of the KGO towers in Fremont.

before 1982. Since 1982 this colony has averaged 178 adults, ranging from a low of 23 in 1994 to a high of 363 in 1986. At the time this research was conducted the EEC location consisted of one unvegetated island. SFBBO began monitoring this colony in 1984, and has visited it every year since, with the exception of 1985, 1989 and 1991. Since 1984 the colony has averaged 67 adults, ranging from a low of 16 in 1984 to a high of 180 in 1990 (SFBBO unpublished data).

METHODS

The study consisted of two parts: estimations of reproductive success and measurements of nest microhabitat characteristics. In order to be able to locate nest scrapes after young birds had fledged, I placed stakes at each nest between 21 May and 28 May, 1997. I placed stakes approximately 20 cm from the edge of the nest and oriented them so they could easily be seen from the nearest levee. All stakes were placed in a similar orientation within a colony. In July of 1997 after all chicks had fledged from the breeding sites, I measured nest site characteristics. I described the position of each nest within the confines of the colony as either edge or center. Nests were considered to be located on the edge if their corresponding stakes fell along the outermost portion of the colony. Nests whose stakes were closer to the center than those that made up the edge were described as being located in the center (Figure 5). This variable was later

Figure 5: I defined edge nests, as those with stakes at the outermost portion of the colony, and all others as center nests.

discarded from the analysis because it greatly underestimated the actual number of nests that would experience an edge effect.

To measure the distance from each nest to its nearest neighbor when nest cups were clearly evident, I measured distance from the center of one nest cup to the center of the nearest nest cup. If the nest cup was not clearly evident, I measured the distance from stake to stake (Figure 6). In addition, I counted the number of neighbors for each nest. Neighbors were defined as nests located within 2 m of the nest in question.

I measured the percentage of cover provided by vegetation by laying down a 0.5m² quadrat frame over each nest and estimating the percentage of vegetation or bare ground present. Percent cover was classified as bare ground 0%, sparse 1% to 24%, low moderate 25% to 49%, high moderate 50% to 74% and heavy 75% to 100%. I measured the height of the nearest vegetation with the base of the ruler placed in what was estimated to be the nest cup. If the nearest vegetation was greater than 150 cm away from the nest cup, the height was recorded as not applicable since it was assumed to offer little or no cover to the nest. Where the nest cup was not clearly evident the ruler was placed at the stake. (Figure 7). This was designed to provide a bird's eye measurement of the cover provided to the nest by nearby vegetation. I made a notation if there was no vegetation within 150 cm. I measured the distance to the nearest vegetation from what was estimated to be the edge of the nest. The edge of the nest was

Figure 6: I measured distance between nests from the middle of one nest to the middle of the nearest nest. When nest cups were not evident, I measured distance from stake to stake.

Figure 7: I measured the height of the nearest vegetation with the base of the ruler placed in what was estimated to be the nest cup.

assumed to be 20 cm in front of the stake. Distances to nearest vegetation were classified as close if within 50 cm, moderate if within 51 to 150 cm, or far if greater than 150 cm. Nests built directly on vegetation were indicated by a vegetation height of 0.0 cm, and a distance to vegetation of 0.0 cm. I decided to use this convention since nests built on large areas of short vegetation were afforded little or no protection by this vegetation. I described the type of the nearest vegetation as none, pickleweed, alkali heath or a mix of both vegetation types.

I measured the slope and aspect of the substrate upon which the nest rested using a Silva Type 15 compass and clinometer (Figure 8). I counted the number of walls around the nest and determined the distance to, height of and amount of overhang of the nearest wall. Walls were defined as moderately steep areas of substrate that may provide some cover to the nest or restrict its visibility from above. In order to be classified as a wall, the base of the slope needed to be within 0.50 m of the center of the nest cup and have a slope of 46% or greater (Figure 9). Where nest cups were not clearly evident, distance to the nearest slope was measured from the nest stake. Overhang of walls was defined as none, partial or complete.

I repeated each of the above measurements at one randomly chosen location within the colony, hereafter referred to as habitat points, within the colony for every 2.5 nests. Comparison of habitat characteristics of the nest sites

Figure 8: I measured slope and aspect using a compass and clinometer.

Figure 9: To be classified as a wall, the base of the slope had to be within 0.5 m of the center of the nest cup with a slope of 46% or greater.

to those of habitat points allowed me to determine whether the characteristics of the nest sites were significantly different from randomly chosen sites, and therefore if the nest sites were preferentially selected or simply placed randomly.

Between 21 May and 28 May, 1997, I estimated nest success by recording the initial numbers of eggs at each nest. I then revisited each marked nest between 10 June and 12 June 1997, immediately after hatching and recorded the number of eggs or chicks in the nest. I used hatch date estimates provided by SFBBO to time my second visit to coincide with the early-nestling stage. SFBBO researchers had visited the colonies during late incubation and had established the age of eggs by floating them in water, a technique suggested by Hays and LeCroy (1971).

Forster's Tern chicks leave the nest site permanently by 4 days of age (Hall 1988). The second visit to the colony was made when birds were an estimated average of 1.64 days old. Nesting success was assessed at that time, rather than following birds through fledging, because of the dispersal of young birds from the nests.

To address difficulties associated with measuring nest success, such as underestimating initial nest numbers and late occurrences of fledgling loss, Mayfield (1975) developed a formula to extrapolate nest success. Based on the probability that a nest or part of its contents will be lost on any given day, Mayfield used a unit of measure he referred to as "egg-days". A nest with 2 eggs

monitored for a total of 2 days would constitute 4 egg-days. To obtain, mortality and survival rates for eggs, Mayfield suggested that the number of losses be divided by the total number of egg-days during which monitoring occurred. The same calculation can be repeated for the hatchling period. By combining probabilities, it is possible to estimate reproductive success from the start of incubation to fledging. This is a widely used and accepted method for estimating nest success (Erwin and Custer 1982, Ramos and del Nevo 1995, Kirsch 1996)

Measurements of habitat characteristics that were recorded in continuous numerical values were converted to discrete values to meet the constraints of the logistic regression. A Pearson Correlation matrix was used to detect highly correlated variables that would violate the constraints of the logistic regression analysis. Variables with an r-value of 0.6 or higher were excluded from the logistic regression if they were correlated with multiple variables. I eliminated nest distance to vegetation since it was correlated with percent cover at the nest, height of vegetation at the nest and type of vegetation at the nest. Height of vegetation at the nest was eliminated since it was correlated with distance to vegetation and type of vegetation. Number of walls around the nest was eliminated because it was correlated with both distance of the nest to the wall and amount of wall overhang. Wall overhang was eliminated because it was correlated with number of walls around the nest and wall distance from the nest.

Logistic regression was used to determine the relationship between the measured habitat characteristics and the presence or absence of nests. Logistic regression is used to describe the relationship between some dichotomous outcome variable, and a series of independent variables (Hosmer and Lemeshow 1989). For the purposes of this study I used it to assess predictability of the measured variables for the presence or absence of nests. If a variable was found to be highly predictive for the presence of nests, it was probable that birds were selecting that particular habitat characteristic.

Pribil and Picman (1997) suggested showing a preference by birds for certain nest site characteristics by comparing available nest sites to those actually chosen by birds. I used a Chi-square Goodness-of-Fit test to compare characteristics of nest sites to the characteristics of randomly selected habitat points. If a significant difference was found between the habitat characteristics of nest sites and those of habitat points, then I assumed that nest sites were not chosen randomly, and that the given characteristic was being selected by birds.

Pribil and Picman (1997) suggest that a Spearman rank order correlation be used to establish which habitat characteristics were actually selected by birds, as opposed to those that were simply covariate with chosen characteristics. I used this method to show whether nest density was correlated with any habitat characteristics. Nest density was established using the measurement of the number of neighbors within 2 meters. I assumed that most nests within 2 meters

of a particular sample shared many of the same microhabitat characteristics as that sample.

A Spearman Rank order correlation determined whether reproductive success as calculated by Mayfield (1975), was correlated with any microhabitat characteristics. For this test, the number of neighbors was lumped into smaller categories as follows: zero, 1 to 4, 5 to 8, 8 to 12 and 13 to 16 neighbors. A Mann-Whitney U Test was used to determine whether reproductive success differed between nests at the edge versus the center of the colony.

To establish whether significant differences existed in the microhabitat characteristics of the three study sites, I compared microhabitat characteristics using a Kruskal-Wallis ANOVA by ranks.

RESULTS

Logistic regression analysis showed that the presence of bare ground could be used to distinguish with 78% accuracy, the difference between nest sites and habitat points. The model predicted nest presence with 98% accuracy, but was only able to predict nest absence with 29% accuracy. A Chi-square generated by the logistic regression ($X^2=86.46$, $df=8$, $p<0.001$) indicated a significant interaction between nest absence and both bare ground and colony edge (Table 1).

Chi-square Goodness of Fit results indicated that Forster's Terns had a strong preference for nest sites with any amount of vegetation cover versus those with bare ground when vegetation was present ($X^2=256.67$, $df=4$, $p<0.001$)(Figure 10). In colonies where alkali heath and pickleweed were both present, birds showed a strong preference for nesting in alkali heath ($X^2=46.57$, $df=4$, $p<0.001$)(Figure 11) versus pickleweed ($X^2=19.34$, $df=4$, $p<0.001$)(Figure 11). A strong preference was found for nest sites with one or more neighbors within 2 m versus those with no neighbors ($X^2=103.44$, $df=4$, $p<0.001$), with the strongest preference being for sites with 5 to 12 neighbors (Figure 12). A strong preference was found for sites within 4 m of another nest ($X^2=56.81$, $df=4$, $p<0.001$) versus sites greater than 4 m from another nest (Figure 13). Irrespective of the presence or absence of vegetation, Forster's Terns have a strong preference ($X^2=36.35$,

Table 1: Chi-square analysis showing predictive value of Logistic Regression model for nest presence and absence.

		Predicted		
Observed	Nest Absence	Nest Absence	Nest Presence	Percent Correct
	Nest Presence	23	55	29.49
		4	182	97.85
Overall Effectiveness:				77.65%

Figure 10: Birds showed a preference for vegetated areas ($X^2=256.67$, $df=4$, $p<0.001$) when vegetation was available.

Figure 11: Forster's Terns showed a preference for Alkali Heath ($X^2=46.57$, $df=4$, $p<0.001$) over pickleweed ($X^2=19.34$, $df=4$, $p<0.001$) in vegetated areas where both types were available.

Figure 12: Forster's Terns showed a preference ($\chi^2 = 103.44$, $df=4$, $p<0.001$) for nests with one or more neighbors, with the strongest preference being for nests with between 5 and 12 neighbors.

Figure 13: Forster's Terns showed a preference ($\chi^2 = 56.81$, $df=4$, $p<0.001$) for nests within 400 cm of another nest versus those greater than 400 cm.

df=3, $p<0.001$) for sites within 40 cm of a wall (Figure 14). Forster's Terns were not found to have a preference for any other measured habitat characteristics.

Nest density was correlated with only two habitat characteristics; demonstrating preferential selection by Forster's Terns rather than their covariance with another selected variable. Spearman Rank Order Correlation showed a strong positive correlation ($R=0.514$, $p<0.001$) between nest density and percent cover of vegetation. A positive correlation ($R=0.182$, $p<0.003$) was found between distance to the nearest wall and nest density. I found no other variables that were correlated with nest density indicating that nonrandom distribution of nests with respect to other measured habitat characteristics was probably due to covariation with percent cover or distance to nearest wall.

A Spearman Rank Order Correlation showed a negative correlation between reproductive success and the number of neighbors within 2 m ($R=-0.226$, $p=0.004$). No other habitat characteristics were correlated with survival of eggs and young.

A Kruskal-Wallis ANOVA by ranks showed significant differences in distance to the nearest nest ($H=22.92$ $p<0.001$), between the three sites. There were also significant differences in percent cover ($H=64.18$, $p<0.001$) between the three sites. EEC was completely unvegetated. Dumbarton was 66% bare ground and some areas of sparse to moderate vegetation. Turk had roughly equal amounts of bare ground, sparse vegetation and heavy vegetation, with slightly

Figure 14: Forster's Terns showed a preference ($\chi^2=36.35$, $df=3$, $p<0.001$) for nests within 40 cm of a wall versus nests greater than 40 cm from a wall.

smaller areas of moderate vegetation (Table 2). The type of vegetation was significantly different ($H=94.30$, $p<0.001$) between the 2 vegetated study sites (Table 2). There were significant differences in the number of walls around the nests ($H=78.80$, $p<0.001$) and the height of walls around the nests ($H= 64.30$, $p<0.001$) between the EEC and the other 2 sites (Table 2).

Table 2: Summary of significant differences in habitat characteristics of the three study sites.

	Dumbarton	EEC	Turk
Mean Distance to Nearest Nest (cm)	258.5	86.5	169.3
Percent Cover	66% Bare Ground 34% Sparse to Moderate	No Vegetation	29% Bare Ground 45% Sparse to Moderately Heavy 26% Heavy
Vegetation Type	50% Alkali heath 50% Bare ground	No Vegetation	45% Alkali heath 23% Pickleweed 16% Mix of both 15% Bare ground
Mean Number of Walls Within 500 cm of the Nest	0.65	2	0.33
Mean Wall Height (cm)	7.2	14.9	3

DISCUSSION

The results of both the Logistic Regression Analysis and the Chi-Square Analysis indicated that Forster's Terns exhibit preference and select for the presence of some type of vegetation versus sites with no vegetation where vegetation is present. This reaffirmed the findings of other studies of nest site selection in colonial nesters. Burger and Gochfeld (1986) found that Sooty Terns (*Sterna fuscata*) prefer to nest near or under tall vegetation which provides protection from weather, human disturbance and predation. Burger and Gochfeld (1990) found that Least Terns (*Sterna antillarum*) selected nest sites closer to vegetation on sparsely vegetated beaches. In this case they concluded that vegetation may provide chicks with protection from heat stress, cold and rain.

Also important in the selection of nest sites, was the proximity of the site to an available wall, regardless of the presence of vegetation. This finding was in agreement with Ramos and del Nevo (1995) who found that Roseate Terns selected sites in which the topography itself provided cover. In their study, predation was not found to be a factor in the selection of concealed nests, and they concluded that, in this case, interspecific competition with Common Terns (*S. hirundo*) could have been a more important factor. Black-necked Stilt (*Himantopus mexicanus*) nests were found at all of the Forster's Terns nesting sites I investigated. I know of no study that has examined interspecific competition

between Forster's Terns and Black-necked Stilts. Further study of this relationship and possible competition between other colonial nesters should be a part of future research. Since a large body of research points to the fact that vegetation cover at or near the nest is beneficial in reducing visibility of the nest to predators, it is likely that Forster's Terns use available topographical features as well as vegetation in this manner. Another factor influencing the selection of nest sites near walls, may be the protection they offer from strong winds that are a typical feature of salt ponds, particularly during summer afternoons. During periods of strong winds, a thick froth is produced at the surface of the salt ponds which then blows across the dredge spoil islands, covering exposed areas of lower elevation (Dakin personal observation). Birds nesting in these areas will be covered by froth as they incubate eggs. It is safe to assume that eggs left briefly unattended and hatchlings that have not yet moved from the nest site will also be affected by these conditions. While I know of no study that has evaluated the effect of this froth on nest success, it is likely that nests in areas protected from froth will have a higher success rate.

While result of the Spearman rank order correlation showed that birds did not specifically select nest sites based on the number of neighbors, the importance of this factor is obvious in a colonial nester. In colonially nesting species the presence of conspecifics probably plays a more important role in the initial selection of macrohabitat for a colony rather than the selection of

microhabitat for the nest itself. Hutto (1985) suggested that the process of habitat selection was based on a hierarchy of decisions, with innate factors such as migratory routes, which determine where the birds settle geographically for breeding, setting the broadest criterion. Within those boundaries, factors such as prey abundance, the presence of conspecifics and other macrohabitat characteristics are considered before microhabitat characteristics.

The nature of the relationship between nest density and reproductive success is not easily quantified, based on the results of my research or other's. My finding that as nest density increased, there was a decrease in reproductive success, could have been the result of some density dependant factor such as predation or availability of suitable nesting sites. Some studies have found high nest densities to be beneficial to colonial nesters in the form of increased predator defense (Cullen 1960, Kruuk 1964) and dilution of the effects of predation (Darling 1938), while others have suggested that reproductive success may actually increase in areas of low nest density. Cullen (1960) and Tinbergen et al. (1967) suggested that eggs and young may be easier to conceal in areas of low nest density. Houde (1983) found that larids will desert a colony rather than mob a nocturnal predator, thus high nest density is only a benefit to colonies faced with diurnal predators. In addition, Houde (1983) concluded that there may be upper limit to the effectiveness of mobbing behavior. Above a certain density nest success is not helped by increased density due to the risk of collision

and injury during mobbing. This was supported by my finding that Forster's Terns had the strongest preference for nest sites with between 5 and 12 neighbors, and a weaker preference for sites with greater than 12 neighbors. Forster's Terns' preference for nest sites within 400 cm of another nest was another indication that there is some optimal range of nest density above and below which nest success may decrease.

It is likely that the effect of nest density and vegetation density on reproductive success should not be considered separately. Conclusions by Houde (1983) and Burger and Gochfeld (1990) suggested they are closely related issues. Both studies suggested that in habitats with high vegetation cover, high nest densities offer little benefit because each nest is more detectable to predators, particularly mammalian predators. In these areas of dense vegetation, mammalian predators were also harder to detect and thus to mob. Forster's Terns' preference for the shorter alkali heath vegetation over taller pickleweed, supported this conclusion. In areas with scarce vegetation cover, Houde concluded that high nest densities offer a greater benefit because of the increased visibility of mammalian predators and greater efficiency of mobbing behavior.

The differences between the microhabitat characteristics of the three colony sites indicate the ability of Forster's Terns to nest successfully in sites with varying vegetation and topographical features. Forster's Terns have been known to nest on extremely varied habitat types. Hall (1988) found Forster's Terns

nesting on islands with cobblestone substrate vegetated with absinthe (*Atemisia absinthium*), northern buckwheat (*Ergonium compostium*) and Columbia River grindelia (*Grindelia columbiana*) in the Columbia River in Washington State. At Delta Marsh, Manitoba, Forster's Terns were found nesting on floating rafts of dead *Scirpus* and muskrat (*Ondatra zibethicus*) houses in a large marsh (McNicholl 1982). In Coastal North Carolina, Forster's Terns nested on both diked and undiked dredged-material deposition sites (Parnell et al. 1986). On the eastern shore of Virginia and in Chincoteague Bay, Maryland they built short nests, on elevated mats of dead vegetation in salt marsh habitat (Storey 1987).

Macrohabitat characteristics such as size of the island, the absence of land bridges, distance from human disturbance, the presence of prey species, and the presence of conspecifics may have played an important role in the selection of nesting sites, however I did not measure these. Gochfeld (1983) studied Least Terns nesting on western Long Island, New York, an area with limited suitable nesting sites due to human disturbance. He found they select colony sites on wide sand flats, or knobs adjacent to inlets in preference to long narrow beaches where they are forced to be near the high tide line. Goutner (1990) found that Little Terns (*S. albifrons*) select, sand, sand-mud, shell substrate in coastal and saltmarsh habitat in Evros Delta, Greece, an area where they experience competition from other larid species. In order to gain a better understanding of all aspects of Forster's Tern nest site selection, future studies should be directed

at macrohabitat characteristics. Since they are found nesting almost exclusively in man-made habitat, it is likely that while sufficient to support large populations of Forster's Terns, local nesting habitat is not optimal habitat for this particular species.

RECOMMENDATIONS

The findings of this research indicated that future construction of dredge spoil islands in salt pond habitat should be done in such a way as to encourage the growth of vegetation. Areas on the islands that were at a lower relative elevation tended to be remain under water for a longer periods during the early rainy season and thus were more likely to be unvegetated. Since they tended to be under water or muddy during the early part of the nesting season, these areas of lower elevation were thus unavailable as nesting substrate to the birds. Increasing the height and surface area of dredge spoil islands or reducing pond water levels during the nesting season, may increase vegetation growth over a greater part of the island.

Dredge spoil islands should be constructed with protective topographic features, such as mounded areas of substrate. This could serve as shelter for birds from predation and wind, particularly on islands that are unvegetated.

Finally, providing additional surface area for nesting, by constructing larger islands and a greater number of islands, would reduce nest density by maximizing available habitat.

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