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Nesting Substrate Preference and Breeding of Common Terns (Sterna hirundo) and Black Skimmers (Rynchops niger) on the Hampton Roads Bridge-Tunnel

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Nesting Substrate Preference and Breeding Success of Common Terns (<u>Sterna hirundo</u>) and Black Skimmers (<u>Rynchops niger</u>) on the Hampton Roads Bridge-Tunnel

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ABSTRACT

The nesting preference and subsequent success of Common Terns (Sterna hirundo) and Black Skimmers (Rynchops niger) based on the nesting substrate was analyzed on a maintenance island on the Hampton Roads Bridge-Tunnel in Virginia from April, 1990 to September, 1991. Because of the continued development pressure of the natural barrier beaches on which these species nest, it is important to determine the nesting preferences of these birds at the present time. These preferences can then be used to manage colony sites to increase the species' nesting success in the future.

To determine the nesting preferences, four substrate conditions and seven treatment areas were created based on the application of rock salt and the clearing of vegetation. The birds were monitored with nest-marking and daily counts of adults, hatchlings and fledglings. Furthermore, the percent of vegetative cover within each of the treatment areas and the vegetative substrate within the immediate vicinity of the nests were measured.

Common Terns had the greatest number of adults, hatchlings and fledglings in the areas that had been either salted or cleared, compared to areas with the natural vegetation. Approximately 80% of all nests, regardless of the area in which they were found, were surrounded by either sparse or no vegetation. Thus, the salted and cleared areas support the greatest success by providing the greatest amount of the preferred nesting microhabitat.

Black Skimmer adults preferred and had greatest success in areas in which the vegetation had been removed. 67% of all nests were found in areas with no vegetation, 29% were surrounded by sparse vegetation. No nests were surrounded by dense vegetation.

Such microhabitats, those with sparse vegetation for terns and no vegetation for skimmers, provide several apparent advantages for both adults and young. Compared to birds nesting in dense vegetation, adults maintain unobstructed vision of potential predators and of the responses of their neighbors for social cohesion. Furthermore, movement and landing at the nest site is relatively unrestricted. Hatchlings are provided with protection in the vegetation from the high temperatures and avian predators if not brooded by the parents.

Management strategies based on these results include creating sparsely vegetated microhabitats for Common Terns through mowing and clearing and for Black Skimmers through total vegetation removal.

Nesting Substrate Preference and Breeding Success of Common Terns (*Sterna hirundo*) and Black Skimmers (*Rynchops niger*) on the Hampton Roads Bridge-Tunnel

INTRODUCTION

Common Terns (*Sterna hirundo*) and Black Skimmers (*Rynchops niger*) are fish-eating birds that nest primarily on sand and shingle beaches and sand dunes, typical habitats on the natural barrier islands found on the mid-Atlantic coast (Palmer, 1941; Erwin, 1977; Burger and Lesser, 1978; Burger and Lesser, 1979; Erwin 1980). More recently, greater attention has been paid to the apparent shift in breeding sites from the beach habitat to coastal salt marshes and dredge spoil islands (Soots and Parnell, 1975; Burger and Lesser, 1978; Burger and Lesser, 1979; Erwin *et al.*, 1981; Buckley and Buckley, 1982; Safina *et al.*, 1989). While controversy exists over the suboptimal nature of these nest sites (Soots and Parnell, 1975; Safina *et al.*, 1989), the shift to such areas may be based on the high incidence of human use and disturbance on the traditional barrier beach sites (Erwin, 1977; Erwin *et al.*, 1981). Because development of barrier beaches and subsequent use by humans will undoubtably continue in the future, it is important to determine the status and success of colonial-nesting birds using these marshes and man-made islands as substitutes for the barrier beaches. More importantly, because of the general decline of Common Terns and other shorebirds in the eastern United States (Scharf, 1981; Shields and Townsend, 1985; McKearnan and Cuthbert, 1989), it is necessary to determine those factors that most influence the reproductive success of these species. With such practical knowledge, it will be possible to manage colony breeding sites, particularly the man-made islands, to provide for the greatest reproductive success.

One factor that has received a great deal of past consideration as influencing the nesting success of Common Terns and Black Skimmers is that of vegetation. Greer et al. (1988) note that while "seabirds are highly visible, their habitat requirements are poorly understood." Numerous studies compare the habitats of salt marshes to barrier beaches, considering the vegetation on the entire colony site, and provide valuable information about the relative success of the birds based on these differences (Burger and Lesser, 1978; Erwin, 1980; Erwin et al., 1981; Erwin and Smith, 1985). Other studies compare islands or marshes with colonies to similar available sites without colonies (Hanssen, 1984). However, the habitats being compared in these studies are often separated by considerable distances, so that results may be affected by many confounding variables such as differences in resources, meteorological phenomena, and differing predation pressure between colonies. Furthermore, all of the above studies are descriptive in nature.

A few researchers have attempted to experimentally determine the substrate preferences or requirements of Common Terns and Black Skimmers at the individual nest site. Austin (1932) constructed quadrats with three conditions of increasing vegetative ground cover. He found that the Common Terns nested in higher density in the partly grassed quadrat, followed by the grassless quadrat, and lastly the heavily grassed quadrat. Furthermore, the hatching success was inversely proportional to the amount of vegetation. Austin concluded that the heavy grass is detrimental to the terns' nesting because it provides cover for predatory animals such as rats. Dense grass also makes nest construction difficult for the birds. Austin also explained that a certain amount of grass is necessary to provide shelter for the young from the sun.

Severinghaus (1982) found similar results. She created experimental substrates in 1.5 m X 4.5 m parallel strips for the nesting Common Terns by providing dried grass and areas with small, medium, and large rocks. The greatest concentration of nests was found in the areas with additional dried grass, followed by the naturally occurring "control" areas of dried grass on various sizes of rock. The proportion of nests on the bare stone substrate increased during the latter half of the breeding season, which Severinghaus notes is only after the grass areas have been saturated or when "vegetation growth left very little area available elsewhere."

In a similar manner, Richards and Morris (1984) created three conditions for the nesting substrate on an artificial breakwall: bare concrete with scattered concrete chips; enhanced areas with a 5 cm layer of small rocks and gravel; and super-enhanced areas with the addition of clumps of Mossy Stonecrop (Sedum acre) and driftwood logs. Common Terns favored the super-enhanced areas, followed by the enhanced areas, and then the bare concrete areas. They note that these "findings of a preference by terns for high relief or vegetated areas is neither new nor surprising" based on their previous work on the same colony (Morris et al., 1976).

Several descriptive studies in which the nest-site vegetation was measured provide similar evidence for the presence of this substrate preference. Soots and Parnell (1975), in their study on plant and bird succession on man-made dredge spoil islands, found that Common Terns prefer the areas on the islands providing 10-30% vegetative cover (average 28%). They used areas on the recently formed islands that ranged from 2 to 8 years old in the spoil deposition and provided nest sites of bare shell to moderate cover by forbs. However, in the plant succession from bare substrate and sparse forbs to dense forbs and shrubs, the terns discontinued their use of the site for nesting.

Blokpoel et al. (1978) found that Common Terns nesting on a man-made elevated headland chose nest sites immediately surrounded by 41% of vegetative cover. The birds avoided areas with little or no vegetation and preferred sites adjacent to either plants or objects or both. Furthermore, the vegetation around the nests was primarily less than 26 cm in height.

Burger and Gochfield (1988), in their comparison of Common Terns and Roseate Terns (Sterna dougallii), found that Common Terns nested in areas within the colony with the sparsest vegetation. These nest sites also provided a much higher level of visibility and a greater distance to the nearest vegetation. Within 1 m of the nest, they found an average of only 5% vegetative cover.

While these studies do provide a basis for further research for Common Terns, much less is known about the nesting preferences of Black Skimmers. Erwin (1977) notes the lack of research completed on the breeding ecology of this species. In both his 1977 and 1980 papers, he tells of their success on both open, overwashed sand beaches and on recently-deposited spoil on man-managed islands; however, Erwin does not discuss the substrate preference based on the immediate vicinity of the nest. Soots and Parnell (1975), in the study of dredge islands, found that skimmers preferred the nesting substrate ranging from bare sand to moderate forbs, with an average cover of only 8.9%. Burger (1982) does not address the role of vegetation in her discussion of colony-site selection and abandonment for

Black Skimmers.

The purpose of this study is to determine experimentally the individual nest-site preferences of both Common Terns and Black Skimmers based on the amount of vegetation composing the nesting substrate and to determine the success of the birds based on these preferences. This was accomplished through substrate manipulation within a single colony at the Hampton Roads Bridge-Tunnel in Norfolk, Virginia.

The island at the bridge-tunnel provides an ideal site for this type of experimental study. Many of the confounding factors that plague other such studies are minimal or nonexistent in this colony. Human disturbance within the colony is limited because of the restricted access except to maintenance personnel and stranded motorists. Predation, particularly by avian predators, is rare. Finally, because of the nature of this man-made island, it is not affected by tides, floods and adverse weather conditions, which are the factors that commonly wipe out entire colonies of both skimmers and terns (Palmer, 1941; Burger, 1982). This colony site is stable and well protected; therefore, the results will not be biased by the above factors.

This study approaches the question of substrate preferences differently from the research previously completed. In addition to measuring the vegetation around individual nests, as most of the previous studies did exclusively, this study experimentally determined the nesting preference, densities and success based on vegetatively distinct areas. While some of the other studies created unnatural nesting substrates to determine preferences, this study provided areas in which different aspects of the natural substrate were emphasized. Thus, this study looks at nest-site selection on both a broad and fine scale. Finally, the large size of the study site, treatment areas and of the colony greatly exceed that of most other studies, as this is the largest Common Tern colony in Virginia (R. Beck, pers. comm.).

MATERIALS AND METHODS

Common Terns (*Sterna hirundo*) and Black Skimmers (*Rynchops niger*) are two bird species both classified within the Order Charadriiformes and the Family Laridae. Both species are primarily fish-eaters, although their diets occasionally include aquatic invertebrates. Common Terns breed from Labrador south along the Atlantic Coast to the Caribbean and across northern United States to Wisconsin and north to Alberta. They winter from Florida to southern South America. Within this range, they are found in both fresh and salt water environments, such as lakes ponds, rivers, coastal beaches and islands. Black Skimmers breed from Massachusetts and Long Island along the Atlantic and Gulf Coasts to Florida and Texas, and from Mexico to southern South America. They winter from North Carolina southward.

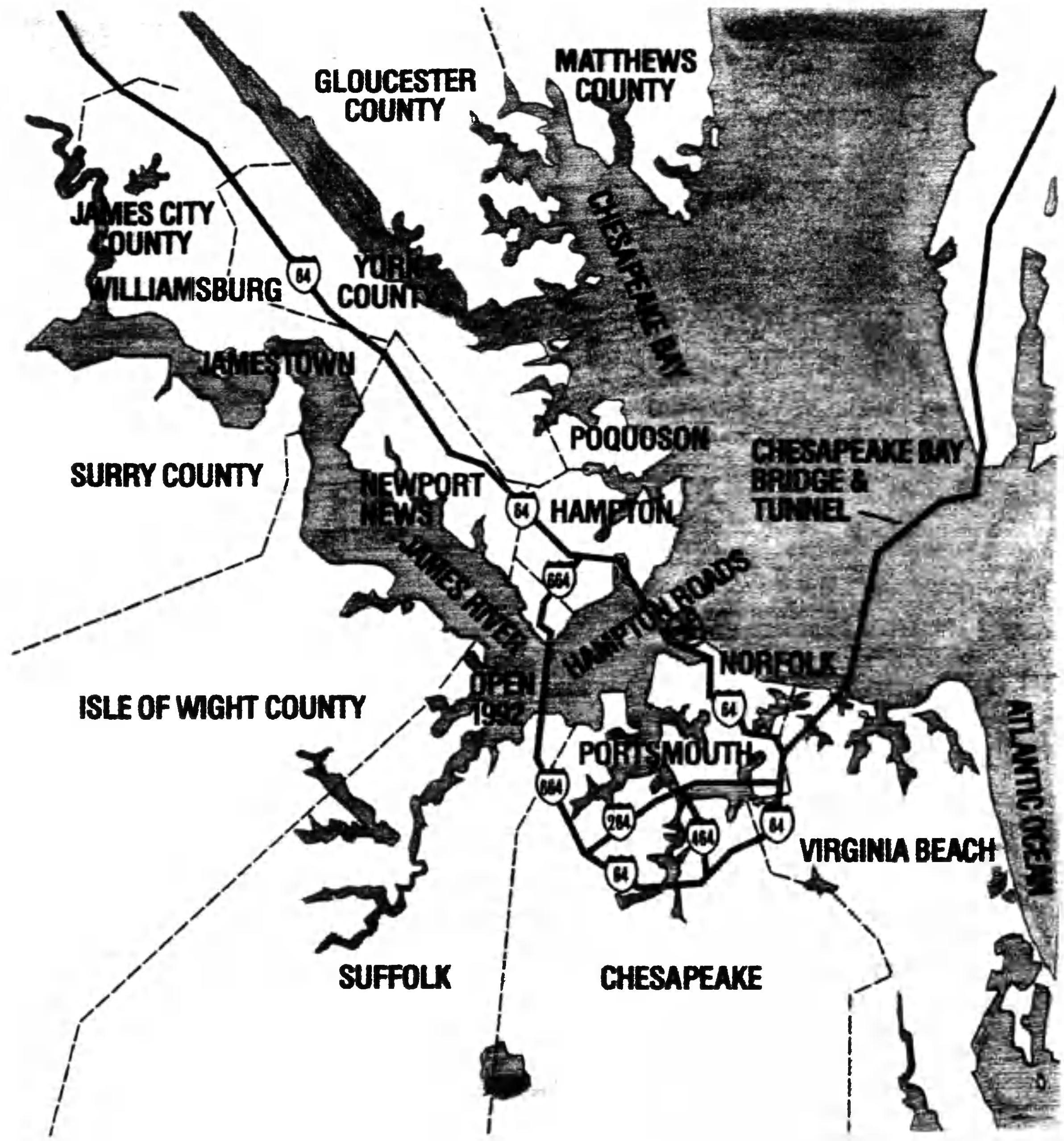
Common Terns and Black Skimmers are colonial-nesting species with a synchronous breeding season. These characteristics, that the birds nest in colonies and in synchrony, allow for several aspects of the breeding biology of both species to be studied for a large number of birds in a short period of time. Both species also build their nests either directly on the bare ground or with some amount of vegetation under or around the nest. This study examined this aspect of the birds' breeding behavior--the preferred amount of vegetation at the individual nest site.

Data were collected for this study beginning in April, 1990 and ending in September, 1991. It was carried out on the Hampton Roads Bridge-Tunnel, which spans the James River at the mouth of the Chesapeake Bay (36 degrees 55' N, 76 degrees 30' W). Fig. 1 shows the location of the study site. The bridge-tunnel is part of the Interstate 64 highway, which connects the city of Hampton to Norfolk, VA. The south-side island was built from 1969 to 1972 along with the bridge-tunnel as a maintenance base by the Virginia Department of Transportation. This man-made structure is approximately 460 m in length and 215 m wide. A maintenance road runs around the periphery of the island, connecting the highway to three maintenance buildings on the island.

The surface of the island is composed of a sandy base covered with 15-25 cm of gravel, which allows for quick and immediate percolation of large amounts of rainwater. This substrate supports a moderate to dense cover of grasses and other herbaceous plants, generally clumped in their distribution, with no woody vegetation. An analysis of the vegetation on the island has been completed by R.A. Beck and D.M.E. Ware (unpublished report). The vegetation on the island is maintained through regular mowing by the highway maintenance staff every year immediately following the breeding season. The mowing was delayed until February or

Figure 1

Map of Southeastern Virginia, showing the study site on the southside island of the Hampton Roads Bridge-Tunnel (*), north of Norfolk.



March in 1990 and 1991 to allow time for vegetation measurements to be taken.

The experimental area was located on the southwestern side of the island, facing the James River. It was chosen for its distance from the maintenance buildings, relative lack of human disturbance, and equal access of the birds to all resources. The experimental area measured 128 m in length, facing both the water and maintenance road, and 53 m deep.

In order to determine any substrate preference of both bird species, four conditions in seven treatment areas were created, each treatment area being 18 m in length and 53 m deep (Table 1). From this point forward, the seven areas will be referred to by their abbreviated names, which are presented in Table 1.

Kress (1989) suggested that rock salt application be used as a method of controlling vegetative growth of both ragweed and perennial plants in tern colonies. In this study, rock salt was applied to determine its effectiveness in reducing vegetation to the level previously shown to provide a suitable nesting habitat for tern and skimmers. In 1990, 144 kg (.15 kg/square meter) of coarse grade rock salt was spread evenly over the surface of all salted areas. In 1991, the amount of rock salt was increased to 324 kg (.34 kg/square meter) for each area to further increase the contrast between salted and unsalted areas. However,

Table 1

Substrate manipulation for all conditions and treatment areas for both 1990 and 1991 Hampton Roads Bridge-Tunnel study site.

Conditions	Treatment Areas	Substrate Manipulation
Cleared and Salted 1 area	CS	Vegetation cleared and rock salt applied
Vegetative Control 3 areas	Va, Vb and Vc	Vegetation left intact
Salted Only 2 areas	SOa and SOb	Rock salt applied and vegetation left intact
Cleared Only 1 area	CO	Vegetation cleared but no rock salt applied

because of the potential sensitivity of the surrounding areas to such materials, the rock salt application rate was considerably lower than that suggested by Kress, which was 2.2 kg/square meter.

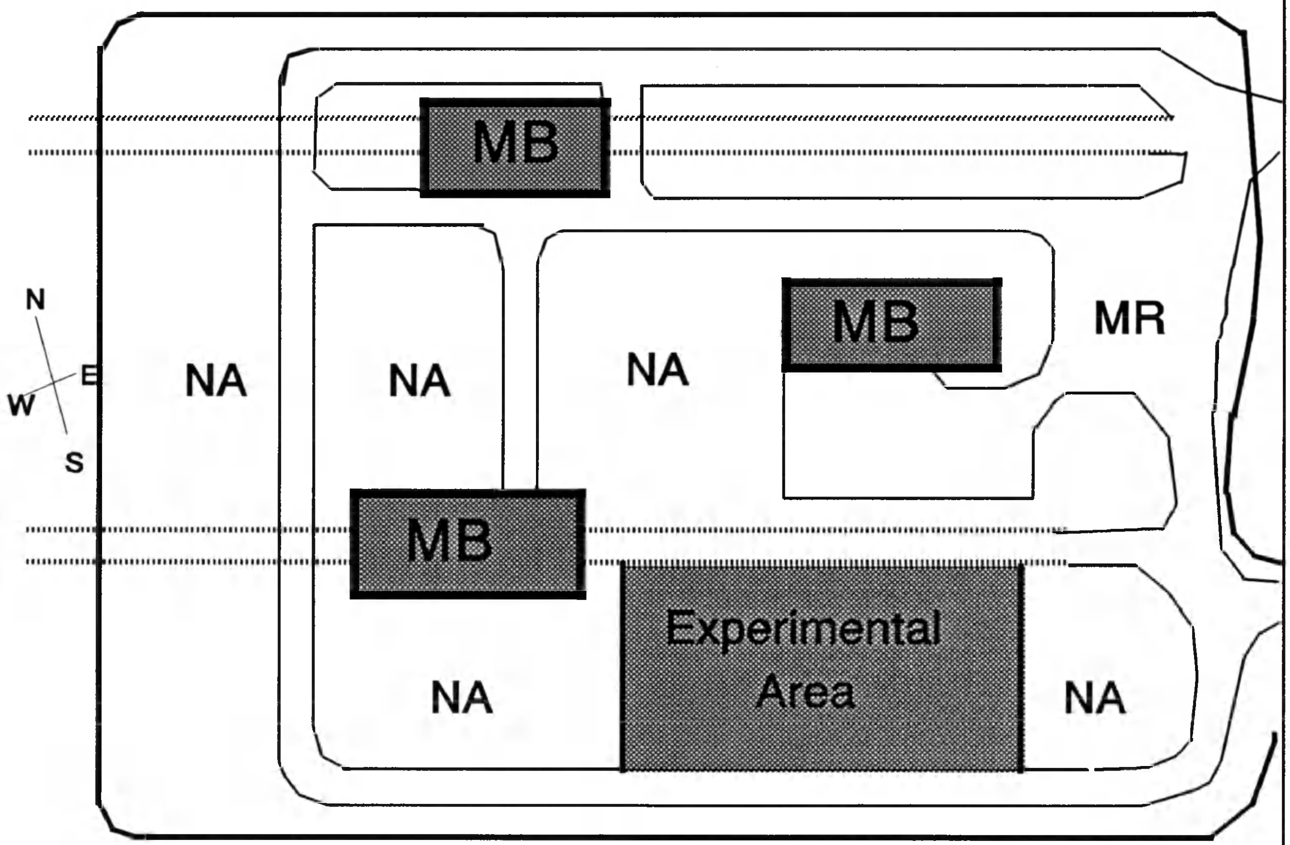
Both cleared areas (CS and CO) and salted areas were manipulated in early April. The treatment areas were in the same location for both years of the study in the following order, from the Northwest to the Southeast: CS-Va-SOa-Vb-SOb-Vc-CO. Figure 2 illustrates the island study site, and Figure 3 shows the treatment areas. For the cleared treatment areas, all live standing vegetation was removed, leaving only dead matted grass in the treatment areas. This is similar to the wrack found on the natural barrier beaches that the Common Terns often use to line their nests (Burger and Lesser, 1976).

After the substrate manipulation and the birds' arrival in late April, both Common Terns and Black Skimmers were monitored daily to ascertain their relative abundance within each of the treatment areas and on the entire island. All adult birds were counted in the individual treatment areas and on the entire island study site 5-6 days a week, usually between the hours of 08:00-12:00. This census was completed from an automobile driven along the maintenance road and stopped at regular intervals. The automobile also served as a blind to which the birds were already habituated.

In addition, nest site preference and subsequent

Figure 2

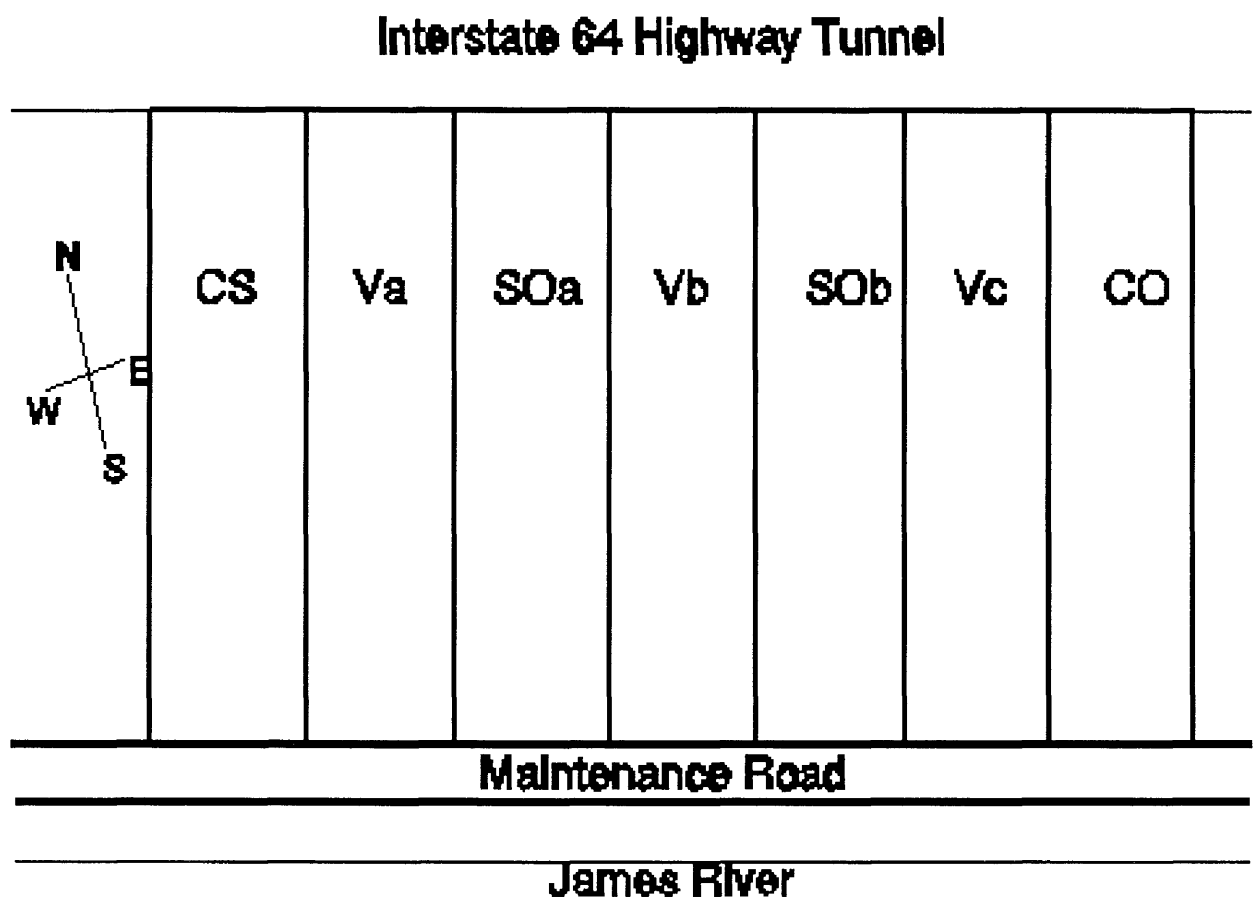
Map of the Hampton Roads Bridge-Tunnel, showing the Interstate Highway 64 tunnel (dotted lines), the maintenance buildings (MB), the maintenance road and parking area (MR), and the experimental area within the birds' nesting area (NA).



MB
MB
MR
N
E
W
S
NA
NA
NA
MB
Experimental
Area
NA
NA

Figure 3

Map of the experimental area on the Hampton Roads Bridge-Tunnel, showing the location of the treatment areas within the experimental area and their proximity to the maintenance road and James River. Interstate Highway 64 is located beneath the island in the tunnel.


Interstate 64 Highway Tunnel
N
E
W
S
CS
Va
SOa
Vb
SOb
Vc
CO
Maintenance Road
James River

reproductive success were measured based on the number of nests and number of eggs per nest in each area. To minimize disturbance of the birds, this activity was carried out after the adult census for each day had been completed and was limited to 20-30 minutes at a time in the colony. Nests were marked and monitored from the time the first active nest was found in the area to the time the first hatchling was found in the area. To assure no bias in marking nests between areas, an equal amount of time was spent in each treatment area, marking as many nests as possible. The large size of the treatment areas and the time constraints, both daily and from the onset of incubation to the first hatching, limited the number of nests that could be marked in treatment areas with very large numbers of nests. Therefore, in 1990, only 50 randomly chosen tern nests were marked and monitored in the Vc and CO areas and 75 nests in the SOb area. In 1991, all nests that could be identified prior to the hatching date were marked and monitored for all areas. All skimmer nests were marked and monitored for all areas both years. Most marked nests were checked every 3 to 4 days for egg loss and egg deposition, with all marked nests checked at least once prior to hatching. For both years, a final nest count was conducted on the day the first chick was observed to determine the final clutch size for all nests (both marked and unmarked nests combined) in each area.

Nests were marked with numbered tongue depressors in 1990 and numbered white utility flags in 1991. The inconspicuous tongue depressors were not necessary because of the lack of observed avian predators in 1990. Therefore, the flags were substituted in 1991 because they allowed greater visibility in relocating marked nests.

The vegetation within the treatment areas was not homogenous in its distribution but was often clumped. At the beginning of the breeding season, the vegetative areas (Va, Vb and Vc) had sections with bare gravel and matted grass. In contrast, the cleared areas (CS and CO) had a great deal of vegetative growth by the middle and end of the breeding season. Therefore, the proportion of live vegetative cover within each area was measured, contrasted to the areas with either dead matted grass, rock or sand. The measurements were taken in late fall after the breeding season had ended. Also, during the 1991 breeding season, the proportions of live vegetation, standing dead vegetation, and clear areas were estimated from photographs taken following substrate manipulation during the incubation period on 5/21/91. The pictures were taken both in the center of each area and at the border of all treatment areas 15 m and 35 m from the maintenance road. All of these measurements were used to determine any correlations between the amount of vegetation in a treatment area and all indices of the birds' reproduction success.

In 1991, additional measures were adopted to attempt to examine further the nesting preference based on the amount of vegetation on a finer scale. The inter-nest distance (nearest neighbor) to the nearest conspecific was measured for 10 randomly chosen nests in each area. For the same nests, the distance to the nearest significant live vegetation (greater than 5 cm in height) was measured in four cardinal directions from the center of each nest. Because of the difficulty in measuring distances greater than one meter to vegetation from the nests, for statistical purposes, any distance greater than one meter was considered one meter for the calculation of a mean for each nest. This technique necessarily biased the measure toward closer vegetative distances, particularly for the two cleared areas.

Also in 1991, all nests, those marked and unmarked, within the treatment areas were classified into four categories based on the relative amount and type of vegetation within one meter of the nest at the time of the final nest count prior to the first hatching. This nest classification is described in Table 2.

Because a nest may be surrounded by both live and dead vegetation, the classification of each nest was based on the relative proportion of each type of vegetative cover. In other words, if a nest was determined to have a greater proportion of dead vegetation compared to live vegetation,

Table 2

1991 Nest-site classification for Common Terns and Black Skimmers based on the type and amount of vegetative cover.

Nest site	Nest Characteristics (surrounding substrate)
Type A	Gravel, sand or dead matted grass (wrack); No live vegetation.
Type B	Standing dead vegetation greater than 5 cm in height.
Type C	Sparse live vegetation, surrounding no more than half of the nest.
Type D	Dense live vegetation, surrounding at least half of the nest.

it was classified as type B. If a nest was surrounded by more live vegetation than standing dead vegetation, it was classified as type C if the combined total vegetation was sparse and type D if the combined total vegetation was dense.

For both 1990 and 1991, hatchlings (1-23 days old) and fledglings (24 days after hatching) were counted daily from the car on the maintenance road, as was done for the adult census. These daily counts of hatchlings began 5/28/90 and 5/29/91, although they were first observe on 5/25, 24 days after the onset of incubation. The first fledglings within this synchronous colony were counted 26 days after hatching when they were capable of sustained flight.

Because the young move away from the nest shortly after hatching, it was not possible to assign them to a particular nest in this study. Banding of the young was not a feasible option because of the large number of birds within the experimental area. No attempt was made to confine them to the nest site or to the treatment area in which they hatched. Therefore, while it is impossible to quantify with any certainty the reproductive success of the birds in any particular treatment area, it is possible to ascertain the vegetative preference of the hatchlings and fledglings based on the area in which they spend their time. The chicks' location within a particular treatment area, even though it may not be their origin, may be deemed their preferred area.

Thus, if more terns hatch in a vegetation treatment area but move into one of the adjacent areas prior to fledging, the new area may be the preferred area for the young birds.

Although the colony is highly synchronous, younger or previously unsuccessful nesters may hatch young considerably later than the majority of the colony. To account for these late-nesting birds when determining the success of the colony, the number of hatchlings within the treatment areas was estimated based on the length of time from hatching to fledging--26 days. By combining the maximum count of hatchlings with the hatchlings counted at 26 day intervals, the total number of hatchlings for the entire breeding season could be estimated. Because the hatchlings and fledglings could not be assigned to a particular nest or even treatment area, this is the only index that could be used to estimate the total reproductive success. Also, because the fledglings were able to fly to other areas around the island and to roosting areas inaccessible to the experimenter, an estimate of the total number of fledglings and, consequently, a more accurate estimate of the total reproductive success of both species was not possible.

RESULTS

Vegetation: The estimated vegetative cover following substrate manipulation during the incubation period for all treatment areas for 1991 is presented in Table 3. As can be seen in the table, even at the beginning of the 1991 breeding season, the vegetative treatment areas all contained at least 29% of clear (vegetation-free) substrate. Furthermore, only the Va area had a majority of live vegetated substrate compared to the dead vegetated substrate and clear substrate. The Vc area had less live vegetated substrate (27.5%) than either dead vegetated substrate (36.7%) and the clear substrate (35.8%). Both cleared areas (CS and CO) had no standing dead vegetation and very little vegetative growth (3% and 6.3%, respectively), as these were both removed during the substrate manipulation. Salting resulted in over half of the SOb area being covered with standing dead vegetation. The SOa area had the third greatest concentration of dead vegetated substrate, surpassed by only the SOb and Vc areas.

The percent live vegetated substrate, taken immediately following the breeding season for both 1990 and 1991, is presented in Table 4. For both years, CS and CO had the least amount of vegetative growth at the end of the breeding season, with the vegetative cover not even exceeding 50% for

Table 3

Estimated percent live vegetative substrate, standing dead vegetative substrate and clear substrate for all treatment areas, estimated during the 1991 incubation period (5/21/91).

	Percent type of vegetative substrate		
Area	Live	Standing dead	Clear (no veg.)
CS	3.0	0.0	97.0
Va	66.4	4.3	29.3
SOa	43.1	21.9	35.0
Vb	47.5	10.8	40.8
SOb	10.0	52.9	37.1
Vc	27.5	36.7	35.8
CO	6.3	0.0	93.7

Table 4

Post-breeding season measurements of percent vegetative cover and relative rank for all experimental areas for 1990 and 1991.

Area	1990	1991
CS	69.2% (7)	49.7% (7)
Va	97.7% (1)	91.5% (2)
SOa	87.1% (4)	81.6% (5)
Vb	85.4% (5)	83.1% (4)
SOb	95.8% (3)	89.1% (3)
Vc	96.6% (2)	96.5% (1)
CO	81.7% (6)	77.3% (6)

CS in 1990. Except for SOb (ranked 3) and Vb (ranked 4 in 1990 and 5 in 1991), all of the manipulated areas had less vegetative growth than the vegetative control areas within the experimental area. In general, a similar trend is seen for both years.

Common Terns: For both 1990 and 1991, Analysis of Variance (ANOVA) tests revealed significant differences among the treatment areas for several measurements of adult terns. The average number of adults from the census for the entire breeding season was significantly different among areas for 1990 (F=5.433, df=6, 399; P<.01) and 1991 (F=7.223, df=6, 252; p<.01). These data and the significance values are presented in Table 5 for the 1990 data and Table 6 for 1991. For both years, the three areas farthest to the southeast had the highest number of adults: SOb>Vc>CO for 1990 and SOb>CO>Vc for 1991.

The census data revealed a great deal of variation from the start of the breeding season to the end in the number of adults within the treatment areas and on the entire study site. The trend, an increase in the number of adults on the island up to the time of hatching, followed by a steady decrease in the number of adults, led to a great deal of variation in the ANOVA tests. Therefore, the total adult count from the census was divided into two parts, based on the maximum fledging date (7/5/90 and 7/3/91). As mentioned above, since the birds nest in synchrony and because the fledglings do not generally remain in the treatment areas within the colony, most of the adults within the nesting colony at this time were probably late breeders. These birds may have been first-time breeders or renesting birds

Table 5

1990 adult Common Tern census data for the first half, second half and entire breeding season averages ± S.E.

Area	1st half	2nd half	Season average
CS	111.5 ± 6.0	58.7 ± 5.4	90.5 ± 5.5
Va	153.7 ± 10.8	52.7 ± 7.6	114.6 ± 9.9
SOa	165.9 ± 9.7	43.8 ± 7.4	118.5 ± 10.3
Vb	192.7 ± 9.3	44.7 ± 7.9	135.3 ± 11.5
SOb	246.1 ± 12.4	51.4 ± 10.0	169.6 ± 15.2
Vc	235.4 ± 14.3	49.5 ± 10.9	161.3 ± 15.4
CO	222.1 ± 13.4	51.9 ± 11.4	154.0 ± 14.3

ANOVA:	$F=18.70$ $df=6, 245$ $p<.001$	$F=0.31$ $df=6, 154$ $p>.05$ ns	$F=5.43$ $df=6, 399$ $p<.01$

Table 6

1991 averages for adult Common Tern census data for first half, second half and entire breeding season ± S.E.

Area	1st half	2nd half	Season average
CS	97.2 ± 3.5	60.0 ± 4.1	88.2 ± 3.9
Va	76.4 ± 4.8	18.7 ± 0.9	62.3 ± 5.5
SOa	99.8 ± 6.8	24.1 ± 3.2	81.4 ± 7.4
Vb	106.7 ± 7.6	19.2 ± 1.8	85.5 ± 8.4
SOb	150.7 ± 8.8	63.0 ± 2.9	129.4 ± 9.1
Vc	145.9 ± 11.2	26.3 ± 3.7	116.8 ± 12.0
CO	162.5 ± 14.0	14.1 ± 2.0	126.4 ± 14.9
ANOVA	F=13.45 df=6, 189 p<.01	F=45.17 df=6, 56 p<.01	F=7.22 df=6, 252 p<.01

that lost their original clutch. In 1990, significant differences were found among the areas for the first half of the breeding season for tern adults but not for the second. An ANOVA test also revealed significant differences for both halves of the season in 1991. The highest counts of adults were in the CO area, followed by SOb and Vc for the first half and SOb, followed by CS and Vc for the second half of the year. This is illustrated in Tables 5 and 6.

The differences of means between areas were further analyzed and the significant differences were identified with Tukey's t Test for multiple comparisons of means (in Blackwell and Solomon, 1964). The values presented in Table 7 are the differences between the means of two treatment areas. The three adjacent areas on the southeastern end of the experimental area (SOb, Vc, CO) are all significantly different from the remaining areas in 1990 ($p<.05$), except for Vb compared to CO. Furthermore, these three areas are not significantly different from each other. This same trend is seen in 1991; this time, however, Vb and CO are significantly different.

Based on these differences, the CO, Vc and SOb areas at one end of the experimental area appear to be distinct from the CS, Va and SOa areas at the other end of the experimental area, with the Vb area being a "transition" area between the separate groups. Because each of the two groups have one treatment area representing each condition,

Table 7

Tukey's t test for pairwise comparisons of adult Common Terns for all treatment areas, for 1990 and 1991. Values represent the differences between means of two areas.

1990

	CS	Va	SOa	Vb	SOb	Vc
CS	--					
Va	24.1 *	--				
SOa	28.0 *	3.9	--			
Vb	44.9 *	20.7 *	16.8	--		
SOb	79.1 *	55.0 *	51.1 *	34.3 *	--	
Vc	70.8 *	46.7 *	42.8 *	26.0 *	8.3	--
CO	63.5 *	39.4 *	35.5 *	18.7	15.6	7.3

* significant difference between means >19.97, df=342; p<.05.

1991

	CS	Va	SOa	Vb	SOb	Vc
CS	--					
Va	25.9 *	--				
SOa	6.8	19.1 *	--			
Vb	2.7	23.2 *	4.1	--		
SOb	41.2 *	67.1 *	48.0 *	43.9 *	--	
Vc	28.6 *	54.5 *	35.4 *	31.3 *	12.6	--
CO	38.2 *	64.1 *	45.0 *	40.9 *	3.0	9.6

* significant difference between means >16.08, df=216; p<.05.

the two groups (hereafter referred to as Group I for CS, Va and SOa, and Group II for SOb, Vc, and CO) were analyzed separately with an ANOVA test for both years. There were no significant differences within groups for 1990 adult Common Terns. For 1991, CS and SOa in Group I contained significantly more adults than the Va area ($F=5.23$, $df=2, 108$; $p<.01$). In Group II, although CO and SOb had higher averages of adult terns, these differences were not significant for 1991 ($F=.280$, $df=2, 108$; $p>.05$).

The number of nests also differed significantly among the treatment areas. For both years, the first nests were found on May 1. In 1990, a total of 2890 nests were found on the Bridge-Tunnel island study site, while 1392 nests were monitored within the treatment areas. In 1991, 2790 nests were counted on the entire island, while 1379 were found within the treatment areas. The Chi-Square test revealed highly significant differences among the treatment areas for the total number of nests for both 1990 (Chi-Square=253.67, $df=6$; $P<.001$) and 1991 (Chi-Square=98.42, $df=6$; $P<.001$). As can be seen in Table 8 for 1990 and Table 9 for 1991, the Vc area had the greatest number of nests for both years, followed by CO in 1990 and SOb in 1991. Furthermore, the final average clutch size, calculated after subtracting the number of eggs lost, was also significantly different among the areas for 1990 ($F=5.21$, $df=6, 700$; $P<.01$) and 1991 ($F=29.14$, $df=6, 1372$; $P<.001$). As is

Table 8

1990 nesting data for Common Terns for all treatment areas.

Area	Number of nests	Final clutch size ± S.E.	Number and % eggs lost
CS	84	2.38 ± .088	6 (2.7%)
Va	115	2.12 ± .085	19 (7.2%)
SOa	134	2.18 ± .079	16 (5.2%)
Vb	203	2.16 ± .063	34 (7.2%)
SOb	267	2.33 ± .092	28 (4.3%)
Vc	317	2.64 ± .025	0 (0.0%) **
CO	272	2.64 ± .079	0 (0.0%) **

** only 50 nests monitored

Table 9

1991 nesting data for Common Terns for all treatment areas.

Area	Number of nests	Final Clutch size ± S.E.	Number and % eggs lost
CS	92	1.96 ± .088	14 (7.2%)
Va	167	2.11 ± .062	16 (4.3%)
SOa	177	2.24 ± .056	7 (1.7%)
Vb	224	2.23 ± .046	11 (2.2%)
SOb	241	2.35 ± .043	7 (1.2%)
Vc	260	2.40 ± .040	4 (0.6%)
CO	218	2.26 ± .055	16 (3.1%)

illustrated in Table 8, in 1990, both cleared areas (CO and CS) and the Vc area had the greatest clutch size. The Vc area again had the highest clutch size in 1991, shown in Table 9, followed by SOb. However, because of the limited access into the colony after hatching began, the final clutch size may have been reached after the final measurements were taken. In other words, the observed final clutch may not have been the actual final clutch, since eggs were laid in some nests even after eggs hatched in other nests. Therefore, the averages can be used only as relative measures between areas. Finally, the percentage of eggs lost shows considerable variation between years, suggesting that it is independent of the experimental condition. The minimal rates of egg loss for the Vc and CO areas in 1990 may be based on the small sample size; only 50 random nests were marked and monitored for each area.

As is illustrated in Tables 8 and 9, egg loss for Common Terns was different between years. In 1990, Va and Vb had the highest percentage of eggs lost at 7.2%. In 1991, the Vc area again had the lowest incidence of egg loss at 0.6%. The highest rate of loss was in the CS area at 7.2%, followed by the Va area at 4.3%.

The data for hatchlings and fledglings are presented in Table 10 for 1990 and Table 11 for 1991. The average number of hatchlings and fledglings were compared among all treatment areas for each week of the breeding season. For

Table 10

1990 Common Tern hatchling and fledgling data for all treatment areas.

	Hatchlings		Fledglings	
Area	Maximum count	Total Estimated	Maximum count	Maximum weekly average
CS	71	115	31	20.0
Va	70	122	16	10.3
SOa	99	164	21	19.3
Vb	148	184	49	32.0
SOb	264	315	54	45.0
Vc	268	298	63	41.0
CO	261	291	31	55.3

Chi-Square test (df=6):				
	=308.3	=210.9	=49.5	=49.4
	$p<.001$	$p<.001$	$p<.001$	$p<.001$

Table 11

1991 Common Tern hatchling and fledgling data for all treatment areas.

	Hatchlings		Fledglings	
Area	Maximum count	Total estimated	Maximum count	Maximum weekly average
CS	64	82	12	9.5
Va	62	69	10	11.0
SOa	91	93	13	8.5
Vb	92	98	14	11.5
SOb	102	127	28	20.5
Vc	99	106	21	15.5
CO	105	114	30	32.0

Chi-Square test (df=6):			
=21.4	=23.2	=21.5	=27.0
$p<.01$	$p<.01$	$p<.01$	$p<.001$

the first four weeks prior to fledging in both years, the CO area consistently had the highest hatchling counts, followed by the Vc and SOb areas. At the time of fledging, significantly more hatchlings were found in the CS area and SOb area from 6/26 to 7/25/91 for the weekly averages at the .05 level of significance. Such a trend was not as obvious for 1990 after birds began to fledge.

As was done with the adult census averages, the maximum weekly average of hatchlings were also compared with Tukey's t Test to determine the significance between areas based on multiple comparisons. These differences are presented in Table 12. For 1990, the Group II areas were significantly different from all other hatchling averages but were not significantly different among themselves. A similar pattern was found for Group I: the differences among them were not significant. The comparisons of these treatment areas to all others were significant except for the difference between SOa and VB. In 1991, the pattern was not quite as clear for maximum weekly hatchling average. While the Group II treatment areas were not significantly different when compared to each other, Vc was also not different from Vb and SOa. Furthermore, SOa was significantly different from CS and Va within Group I, but not from all other treatment areas.

Based on these differences, the Groups were again compared separately with an ANOVA test. For both years, SOa

Table 12

Tukey's t test for multiple comparisons of the difference between Common Tern maximum weekly hatchling averages for all treatment areas, 1990 and 1991. Numbers presented represent the difference between two means.

1990

	CS	Va	SOa	Vb	SOb	Vc
CS	--					
Va	11.7 *	--				
SOa	27.4 *	15.7	--			
Vb	80.8 *	69.1 *	53.4	--		
SOb	157.6 *	145.9 *	130.2 *	76.8 *	--	
Vc	177.5 *	165.8 *	150.1 *	96.7 *	19.9	--
CO	169.8 *	158.1 *	142.4 *	89.0 *	12.2	7.7

* significant differences between averages >57.14, df=24; p<.05.

1991

	CS	Va	SOa	Vb	SOb	Vc
CS	--					
Va	10.0	--				
SOa	32.3 *	22.3 *	--			
Vb	24.3 *	14.3	8.0	--		
SOb	46.0 *	36.0 *	13.7	21.7 *	--	
Vc	37.6 *	27.6 *	5.3	13.3	8.4	--
CO	44.6 *	34.6 *	12.3	20.3 *	1.4	7.0

* significant differences between averages >19.87, df=18; p<.05.

had significantly more hatchlings than did CS and Va within Group I (1990--$F=17.08$, df=2, 12; $p<.01$; 1991--$F=5.52$, df=2,6; $p<.05$). For the Group II, the differences were not significant either year (1990--$F=.732$, df=2, 12; $p>.05$; 1991--$F=.362$, df=2, 6; $p>.05$).

For fledglings in 1990, the areas contained significantly different numbers of fledglings for 5 out of 7 weeks, $p<.05$. For 1991, the differences were significant among treatment areas for only 2 out of 5 weeks (7/1 and 7/22/91). These trends are similar to the data for maximum counts of fledglings in Tables 10 and 11. Chi-Square tests that revealed very significant differences among areas for maximum counts of both hatchlings and fledglings are also presented in these charts. The differences in the numbers of both hatchlings and fledglings between years with little difference in the number of nests for the treatment areas cannot be explained from this 2 year study.

Tukey's test for the weekly fledgling average did not follow the same trends as those discussed above (Table 13). In 1990, Groups I and II were different except for the comparison between CS and Vc. However, in 1991, based on the comparisons with Tukey's test, all variation among treatment areas as revealed in the ANOVA is based on the relatively high number of fledglings in the CO area. All averages for the treatment areas were significantly different from the CO area except for SOb. No other

Table 13

Tukey's t test multiple comparisons of the means for Common Tern maximum weekly fledgling averages for all treatment areas, 1990 and 1991. Numbers presented represent the differences between the means of two treatment areas.

1990

	CS	Va	SOa	Vb	SOb	Vc
CS	--					
Va	9.7	--				
SOa	0.7	9.0	--			
Vb	12.0	21.7 *	12.7	--		
SOb	25.0 *	34.7 *	25.7 *	13.0	--	
Vc	21.0	30.7 *	21.7 *	9.0	4.0	--
CO	35.3 *	45.0 *	36.0 *	23.3 *	10.3	14.3

* significant differences between averages >21.14, df=12; p<.05.

1991

	CS	Va	SOa	Vb	SOb	Vc
CS	--					
Va	1.5	--				
SOa	1.0	2.5	--			
Vb	2.0	.5	3.0	--		
SOb	11.0	9.5	12.0	9.0	--	
Vc	6.0	4.5	7.0	4.0	5.0	--
CO	22.5 *	21.0 *	23.5 *	20.5 *	11.5	16.5 *

* significant differences between averages >13.85, df=6; p<.05.

significant differences were found with Tukey's test.

The difference in most breeding measurements between the two groups may have been based on the presence of contract workers in the colony following the substrate manipulation during the nest-site selection period. Although the workers were not in the experimental area, the maintenance work was completed closest to the southwestern side of the colony, near the CS area. This apparent location effect substantiates the analysis of Groups I and II separately.

The vegetation measurements presented in Tables 3 and 4 were compared to all of the data previously discussed using the raw score calculation of correlations. The initial comparisons presented are those based on the percent of live substrate, dead substrate and clear substrate from measurements taken during the 1991 incubation period. While they may not be as accurate as those taken after the birds left the study site because the percentages were estimated from photographs, they may be more valuable than later vegetative measurements. The early measurements were taken at the same time as the other breeding statistics, particularly the number of nests, clutch size, and nest-type, to which the vegetation is being compared. Also, if vegetation was present, it was identified as either live or standing dead vegetation, similar to the categories used in the nest classification system. The correlation data based on the early substrate measurements are presented in Table 14.

The number of nests and total estimated hatchlings both correlated strongly with the percent of dead substrate, but just fail to be significant at p<.05. The maximum weekly fledgling average correlated negatively with the percent live substrate (r=-.892, p<.01). This fledgling average was also correlated positively with the percent clear substrate (r=.683), but this correlation just failed to reach significance (p>.05).

Of the measurements of the three types of substrate during the breeding season, only the percent of substrate with no vegetation is correlated significantly with the percent of live vegetative cover measured at the end of the breeding season (-.816, p<.02). Both the percent of live vegetation (r=.522) and percent of dead vegetation (r=.559) correlate positively but do not reach significance. Such a difference in the amount of live vegetative ground cover based on growth during the breeding season results in discrepancies between the correlations of the early and late vegetation measurements with the breeding measurements.

In 1990, the measures of Common Tern success and preference did not correlate significantly with the percent of vegetative cover measured at the end of the breeding season. These correlation coefficients are presented in Table 15 for both 1990 and 1991. One interesting trend in

Table 14

Correlation coefficients for 1991 early vegetative substrate measurements and the average proportion of nest-site types. Numbers presented represent the r value.

	Type A	Type B	Type C	Type D
% Live Substrate	-.680 *	.004	.866 @	.879 @
% Dead Substrate	-.570	.947 @	.078	.172
% Clear Substrate	.957 @	-.656 *	-.293	-.848 **

* $p<.10$

** $p<.05$

@ $p<.01$

the correlations is found when the average number of adults in each area is compared to the percent of vegetative cover (Table 16). For the average of the entire season, the positive correlation is moderately high but not significant at $p<.05$. When the breeding season is divided in half based on the time of maximum fledging, the first half shows a similar positive correlation. However, when compared to the second half of the season, the correlation is negative ($r=-.393$), although not statistically significant. Because the number of nests, clutch size and hatching success of the late nesting birds (first-time breeders and renesting birds) could not be monitored like the birds initiating nests prior to 5/25, the adult census is the only index to the preference of the late nesting birds. Furthermore, the vegetation measures were taken at the end of the breeding season, and although the vegetation trends are similar immediately following the manipulation and at the end of the breeding season, the measurements of the adult birds taken later in the season may be more reliable in their comparison to the end of season vegetation.

This trend in the correlation between the number of adult terns and the vegetative cover measured at the end of the breeding season is similar in 1991. The correlations of the average of adults for the entire year ($r=.142$) and the first half of the year ($r=.235$) are positive but not significant at the .05 level of significance, while for the

Table 15

1990 and 1991 correlation coefficients for breeding measurements of Common Terns and late vegetative cover. Numbers presented represent the r value.

	# Nests	Final Clutch Size	% Eggs Lost	% Nests Lost	Total Hatch. Est.	Max. Weekly Fledg. Ave.
1990 % Veg. Cover	.450	-.120	—	—	.398	.058
1991 % Veg. Cover	.816 **	.762 **	-.828 **	-.779 **	.274	.230

-- no measurement possible

** p<.05

Table 16

Correlation coefficients for 1990 and 1991 Common Tern adult census during the first half, second half, and entire breeding season, with the percent vegetative cover measured after the breeding season. Numbers presented represent the r value.

	1st Half	2nd Half	Entire Season
1990 % Vegetative Cover	.588	-.393	.585
1991 % Vegetative Cover	.235	-.463	.142

p>.10 for all correlations.

second half of the season it is negative (r=-.436) and not significant.

Other 1991 correlations with the percent of vegetative cover from the late measurements illustrate some trends not found in 1990. This difference may be based on the larger number of terns nesting on the Bridge-Tunnel in 1990 compared to 1991. The larger number of nesting birds may have led to some adults using areas that were "suboptimal" in 1990.

The number of nests is positively correlated to the vegetative cover (r=.816), as is the final clutch size (r=.762). However, the percent of eggs lost (r=-.828) and nests abandoned (r=-.779) is negatively correlated with the percent cover. All are significant at the .05 level of significance. Neither of these measurements could be calculated with any accuracy in 1990 because of the low number of nests monitored in the Group II areas. Based on these 1991 correlations, areas with greater vegetative cover had more nests and a greater clutch size, with fewer eggs lost and nests deserted. This was not the trend found with the vegetation measurements taken earlier in the breeding season.

Because of the inconclusive preliminary results in 1990, additional measurements were employed in 1991 that were more sensitive to the region within the immediate vicinity of the nests because of the inconclusive preliminary results in 1990. The average distance to the nearest vegetation was significantly different among areas ($F=11.02$, $df=6, 63$; $p<.01$). Except for the SOa and Va areas, all treated areas have a greater distance to the vegetation than the vegetative control areas. This measure of distance to vegetation just fails to be significantly correlated to the post-breeding percent of vegetative cover ($r=-.629$, $.05<p<.1$), which is most likely based on the difference in the time when the two measures were taken. Other correlations with the distance to vegetation are not significant: number of nests ($r=-.451$); final clutch size ($r=-.371$); total hatchlings ($r=-.216$); maximum fledgling count ($r=.371$).

The differences in internest distances for Common Terns among the 7 treatment areas were not significant ($F=.556$, $df=6, 63$; $P>.10$). Internest distance did not correlate significantly with any other reproductive measure: number of nests ($r=-.184$); final clutch size ($r=.283$); percent total eggs lost (.263); total number of hatchlings ($r=.519$). Internest distance did not reach significance when compared to the percent live vegetation measured during the breeding season ($r=-.534$). The values for both distance to vegetation and internest distance are given in Table 17.

Finally, all of the nests within each treatment area were categorized based on the amount and type (alive or dead) of vegetation within 1 meter of the nest. Table 18

Table 17

1991 average distance to vegetation and internest distance for Common Terns, n=10 for each treatment.

Area	Distance to vegetation (cm) and rank ()	Average internest distance (cm)
CS	82.9 (1)	136.9
Va	39.5 (4)	111.0
SOa	36.0 (5)	134.4
Vb	16.0 (7)	131.1
SOb	67.3 (2)	133.4
Vc	35.5 (6)	113.0
CO	66.7 (3)	131.3
ANOVA:	F=11.02 df=6,63 p<.01	F=0.56 df=6,63 p>.05 n.s.

Table 18

1991 percent of Common Tern nest-site types within each treatment area (see Table 2 for site characteristics).

Area	N	Type A	Type B	Type C	Type D
CS	92	80.4	1.1	18.5	0.0
Va	167	23.4	4.8	64.1	7.8
SOa	177	15.8	26.0	50.3	7.9
Vb	224	16.6	8.5	64.6	10.3
SOb	241	24.5	32.4	39.4	3.7
Vc	260	14.2	26.2	53.8	5.8
CO	218	60.1	0.0	39.9	0.0
Average:		29.4%	16.0%	49.3%	5.4%

ANOVA of differences between averages of nest-site types: $F=8.856$, $df=3, 24$; $p<.01$

shows the percentage of each nest-type within each treatment area and the overall average of the combined treatment areas for each type of nest. When analyzed with the ANOVA test, a significant difference was found among the nest types based on the percentage of nests from the combined treatment areas ($F=8.856$, $df=3, 24$; $P<.01$). Significantly more terns nested in sparse vegetation (Type C) and no vegetation (Type A) when compared to standing dead (Type B) and particularly dense vegetation (Type D).

Tukey's test for pairwise comparisons identified the significant differences in both the final number of successful nests and the percent of nests classified within each nest type (Table 19). The pattern for both tests was the same: significant differences existed among all comparisons between nest types except for type A compared to type B, and type B compared to type D. Type C nests were significantly more numerous than all other types of nests.

Several comparisons, which are presented in Table 20, can be made among the four nest types for other breeding measurements. The difference in the number of successful Common Tern nests, which were those with no egg loss prior to hatching, was significant when based on the type of nest ($F=9.151$, $df=3, 24$; $P<.01$). The total number of eggs in the treatment areas was also significantly different among the nest types ($F=8.619$, $df=3, 24$; $P<.01$); however, this significance is most likely based on the total number of

Table 19

Tukey's t test for multiple comparisons of the average percent of nests classified in each nest-site type for 1991, and Tukey's t test for comparisons of the average number of successful Common Tern nests for 1991. Numbers presented represent the differences between the means of two nest types.

Average Percent Nest-site

	Type A	Type B	Type C
Type A	--		
Type B	13.4	--	
Type C	19.9 *	33.3 *	--
Type D	24.0 *	10.6	43.9 *

* significant differences between averages >17.18, df=18; $p<.05$.

Final number of successful nests

	Type A	Type B	Type C
Type A	--		
Type B	24.1	--	
Type C	38.9 *	63.0 *	--
Type D	44.8 *	20.7	83.7 *

* significant differences between averages >32.23, df=18; $p<.05$.

Table 20

1991 average of treatment area breeding data for Common Terns based on the nest classification.

	Average # successful nests	% number eggs lost	Final # eggs	Final clutch size	Distance to veg. (cm)
Type A	55.4	3.06%	125.7	2.17	76.0
Type B	31.3	0.44%	73.0	2.38	48.4
Type C	94.3	2.81%	220.6	2.32	31.1
Type D	10.6	0.0%	24.7	2.34	11.2
ANOVA:	F=9.15 df=3, 24 p<.01	F=4.79 df=3, 22 p<.05	F=8.62 df=3, 24 p<.01	F=1.22 df=3,24 p>.05 ns	F=26.64 df=3, 24 p<.001

nests, because the differences in clutch size among nest types were not significant (F=1.215, df=3, 21; P>.05). The average percent of eggs lost for each of the nest types was significant (F=4.79, df=3, 22; P<.05). Finally, the average distance to the nearest vegetation for each nest type was highly significant (F=26.64, df=3, 66; P<.001), as both measurements are based on the vegetation within 1 meter of the nest.

The correlations of the proportions of nest-types with the percent substrate measurements taken during the incubation period are presented in Table 21. In general, each percent of the nest-types correlated significantly with the type of substrate that defines the nest-type: Type A and clear substrate, r=.957; Type B and dead substrate, r=.947; Type C and Type D and live vegetated substrate, r=.866 and r=.879, respectively.

Although the type C and type A nests were most numerous within the experimental area, this may be based on the habitat availability rather than on the nest-site preference, particularly when considering the strong correlations between the nest type and percent habitat type (type A and clear areas, type B and standing dead vegetation, and type C and D and live vegetation). Therefore, a Chi-square test was run on the percent of nest types observed in each treatment area compared to the percent expected based on the percent of habitat type

Table 21

1991 Correlation coefficients for all breeding measurements of Common Terns with the early vegetation measures. Numbers presented represent the r value.

	# Nests	Ave. Clutch Size	Total Est. Hatch.	Max. Weekly Hatch. Ave.	Max. Daily Fledg. Count	Max. Weekly Fledg. Ave.
Live Substrate	-.213	.013	-.590	-.271	-.644 *	-.892 @
Standing Dead Substrate	.630 *	.718 **	.648 *	.613	.422	.079
Clear Substrate	-.480	-.456	.037	-.199	.240	.683 *

* p<.10

** p<.05

@ p<.01

measured during the incubation period in each treatment area. Because both type C and type D nests associated with live vegetation, it was assumed for the test that the live vegetation percentage was composed of half dense and half sparse live vegetation. For all treatment areas and nest types combined, the percent of nest types observed was significantly different from that expected (Chi-square=860.8, df=21; p<.001). For all areas, there were fewer type A (Chi-square=58.3, df=6; p<.001) and type D nests (=40.5, df=6; p<.001) than was expected by chance. Conversely, a higher percentage of type C nests was observed than was expected in all areas (Chi-square=748.7, df=6; p<.001). The observed proportion of type B nests was higher than expected in the CS, Va and SOa areas, while the opposite trend was found for the Vb, SOb and Vc areas. These expected and observed values are presented in Table 22.

Because of the extremely high level of significance based mostly on the variation of percent type C nests above the expected values, another Chi-square test was run in which all of the live vegetation was assumed to be sparse vegetation. Thus, the expected percent of type C nests was much higher than in the previous test. Type D nests were excluded from this analysis. In all but the Va area, the observed percent of type C nests was still higher than expected (Chi-square=378.3, df=6; p<.001). Va was the only

Table 22

1991 Chi-Square showing the expected and observed proportions of each nest-type based on the availability of habitat type.

		Type A	Type B	Type C	Type D
CS	Observed	80.4	1.1	18.5	0.0
	Expected	97	0.0	3.0	0.0
Va	Observed	23.4	4.8	64.1	7.8
	Expected	29.3	4.3	33.2	33.2
SOa	Observed	15.8	26.0	50.3	7.9
	Expected	35.0	21.9	21.6	21.5
Vb	Observed	16.6	8.5	64.6	10.3
	Expected	40.8	10.8	23.8	23.7
SOb	Observed	24.5	32.4	39.4	3.7
	Expected	37.1	52.9	5.0	5.0
Vc	Observed	14.2	26.2	53.8	5.8
	Expected	35.8	36.7	13.8	13.7
CO	Observed	60.1	0.0	39.9	0.0
	Expected	93.7	0.0	6.3	0.0

Chi-Square=	58.3	13.5	748.7	40.5
df=6	p<.001	p<.05	p<.001	p<.001

Chi-Square for all areas and all nest-types =860.8, df=21; p<.001

area that did not have a significant difference between the expected and observed values (Chi-square=1.3, df=3; $p>.05$). For all areas combined, a significant difference was found between the expected and observed percent nest types (Chi-square=450, df=14; $p<.001$).

Black Skimmers: For the adult census data, presented in Table 23, ANOVA tests of the average number of adults for the entire year revealed highly significant differences among areas for both 1990 ($F=45.58$, $df=6, 399$; $P<.01$) and 1991 ($F=98.31$, $df=6, 252$; $P<.01$). For both years, the two cleared areas (CS and CO) and one of the salted areas (SOa) had the largest number of adults; however, in 1990, the middle vegetative treatment area (Vb) had the greatest number. Differences among the areas for weekly averages of adults were also all significantly different ($P<.01$) for both years.

The means of adult counts were also analyzed for pairwise comparisons with Tukey's t test. For 1990, all comparisons between treatment areas were significant except for the comparisons of Va, SOb and Vc to each other. Vb, which had less vegetative cover than the other vegetative treatment areas, had significantly more adults than all other treatment areas, followed by CS and CO. For 1991, both cleared areas had a significantly higher average than all other areas, with CS containing the most adult skimmers. Neither year showed the same pattern as was seen with the Common Tern analysis. The differences in means from Tukey's test are presented in Table 24.

The adult counts may be the best index to the preference of the species in this study for two main reasons. First, the skimmers nested considerably later than

Table 23

Entire breeding season average ± S.E. of adult Black Skimmer daily counts for 1990 and 1991.

Area	1990	1991
CS	29.4 ± 3.2	93.2 ± 7.1
Va	0.0 ± 0.0	3.8 ± 0.4
SOa	11.0 ± 1.1	11.7 ± 1.0
Vb	36.9 ± 3.6	12.5 ± 2.3
SOb	0.7 ± 0.4	0.1 ± 0.1
Vc	0.2 ± 0.1	0.0 ± 0.0
CO	22.5 ± 3.3	56.5 ± 5.7

ANOVA:

	1990	1991
	$F=45.58$	$F=98.31$
	$df=6, 399$	$df=6, 252$
	$p<.01$	$p<.01$

Table 24

Tukey's t test for pairwise comparisons for the average number of adult Black Skimmers for all treatment areas for 1990 and 1991. Numbers presented represent the differences between the means for two treatment areas.

1990

	CS	Va	SOa	Vb	SOb	Vc
CS	--					
Va	29.4 *	--				
SOa	18.4 *	11.0 *	--			
Vb	7.5 *	36.9 *	25.9 *	--		
SOb	28.7 *	0.7	10.3 *	36.2 *	--	
Vc	29.7 *	0.2	10.8 *	36.7 *	0.5	--
CO	6.9 *	22.5 *	11.5 *	14.4 *	21.8 *	22.3 *

* significant differences between averages >4.60, df=342; p<.05

1991

	CS	Va	SOa	Vb	SOb	Vc
CS	--					
Va	89.4 *	--				
SOa	81.5 *	7.9	--			
Vb	80.7 *	8.7	0.8	--		
SOb	93.1 *	3.7	11.6 *	12.4 *	--	
Vc	93.2 *	3.8	11.7 *	12.5 *	0.1	--
CO	36.7 *	52.7 *	44.8 *	44.0 *	56.4 *	56.5 *

* significant differences between averages >10.27, df=216; p<.05.

the terns, and not all of the nests could be monitored after the terns began hatching. Furthermore, a large proportion of the adults did not nest each year. The maximum count of skimmers on the entire island was 687 taken on 8/3/90 and 733 taken on 7/9/91. Both of these dates are much later than the time that most skimmers nested on the Bridge-Tunnel and the time required to successfully bring off young prior to migration. These may have been birds that did not nest successfully elsewhere within the state or in other nearby areas (R. Beck, unpublished report).

Nesting data for Black Skimmers are presented in Table 25 for 1990 and Table 26 for 1991. There are not proportionally as many nests in the CS area as would be expected based on the number of adults counted in that treatment area. Again, this discrepancy shows the large number of adults not nesting. These nests represent only the early nesting skimmers. The number of nests for each area was significantly different for 1990 (Chi-Square=45.82, df=6; P<.001) and 1991 (Chi-Square=32.01, df=6; P<.001). The difference in the final number of eggs among the treatment areas was also significant (1990: Chi-Square=76.7, df=6; P<.001. 1991: Chi-Square=68.38, df=6; P<.001).

Predation at the Bridge-Tunnel varied considerably between years for Black Skimmers. In 1990, a total of 41 out of 81 eggs in 27 nests were lost in the treatment areas. In the SOa area 64% of the eggs were lost while 49% were

Table 25

1990 nesting data for Black Skimmers for all treatment areas.

Area	# of nests	Final # of eggs	# of eggs lost	Final clutch size
CS	0	--	--	--
Va	0	--	--	--
SOa	7	8	14	1.14 ± .13
Vb	6	10	4	1.67 ± .70
SOb	0	--	--	--
Vc	0	--	--	--
CO	14	23	22	1.64 ± .46

-- no nests and no eggs

Chi-Square

	=45.82	=76.70
	df=6	df=6
	p<.001	p<.001

Table 26

1991 nesting data for Black Skimmers for all treatment areas.

Area	# of nests	Final # of eggs	# of eggs lost	Final clutch size
CS	3	8	0	2.67 ± .54
Va	1	1	0	1.00 ± .00
SOa	6	12	1	2.00 ± .53
Vb	8	15	0	1.88 ± .37
SOb	0	--	--	--
Vc	0	--	--	--
CO	13	26	2	2.00 ± .29
Chi-Square	=32.01 df=6 p<.001	=68.38 df=6 p<.001		

lost in the CO area. This high incidence of egg loss resulted in the very low final clutch sizes of 1.14, 1.64 and 1.67 for the areas with skimmer nests (SOa, CO, and Vb, respectively). In 1991, the number of eggs lost totalled only 3 out of 65 eggs (4.6%). These data are presented in Tables 24 and 25.

The first Black Skimmer hatchlings were observed on 6/12/90 and 6/6/91. Compared to the number of adults, the number of hatchlings and fledglings was very low for both years. In 1990, the maximum count of hatchlings was only 7 out of 40 eggs not lost during monitoring for the treatment areas. In 1991, the maximum count increased to 13 young. For the entire island, a total of 71 birds fledged for 1990 and 64 for 1991. When analyzed with an ANOVA test, the difference in the weekly average of hatchlings among areas was significant ($P<.01$) for 4 out of 7 weeks in 1990 and 5 out of 7 weeks in 1991. The numbers follow the same trends as is illustrated in the maximum count of hatchlings in Table 27, with the most hatchlings in the CO area for both years, followed by Vb and SOa in 1990, and CS and SOa in 1991. The weekly average of skimmer fledglings was also significant for 2 out of 5 weeks for 1990 and only 1 out of 3 weeks in 1991, with the most fledglings counted in the CO area.

The correlations of these measurements to the nesting substrate measured during the incubation period are

Table 27

1990 and 1991 maximum daily Black Skimmer hatchling count.

Area	1990 hatchlings	1991 hatchlings
CS	0	3
Va	0	0
SOa	1	3
Vb	2	0
SOb	0	0
Vc	0	0
CO	4	7

presented in Table 28. The skimmers show a very strong trend based on the vegetation. The season average of adult skimmers correlated very highly and positively with the percent of clear area (r=.888, p<.01). This correlation is negative but not quite significant when compared to the percent standing dead vegetative substrate and percent live vegetative substrate. Also, the maximum weekly hatchling average showed a strong significant correlation with the percent clear substrate (r=.822, p<.02).

The measurements of skimmers are all negatively correlated to the percent of vegetative cover measured at the end of the breeding season. The average number of adults is strongly and negatively correlated to the vegetation for 1990 (r=-.805, p<.02) and 1991 (r=-941, p<.001). In 1991, the final clutch size also shows this negative trend with the vegetation (r=-.803, p<.02). Other numbers for skimmers are only moderately correlated with the percent of vegetative cover and are also presented in Table 28.

In 1991 for skimmers, the same nest classification technique based on the amount of vegetation around the nest used for Common Terns was employed. The total number and percentage of Black Skimmer nests classified in each category for each area is given in Table 29. Both the difference in the number of nests among nest types (F=3.427, df=6, 24; p<.05) and the proportion of nests among nest

Table 28

Correlation coefficients for Black Skimmer breeding data and the % substrate type, measured during the incubation period, and the 1990 and 1991 % vegetative cover, measured after the breeding season. Numbers presented represent the r value.

	# Adults	# Nests	Final Clutch Size	Maximum Weekly Hatchlings
% Live Substrate	-.617	-.152	-.100	-.533
% Dead Substrate	-.644 *	-.572	-.814 **	-.574
% Clear Substrate	.888 @	.647 *	.822 **	.849 @
1990 % Veg. Cover	-.805 **	-.301	-.234	-.421
1991 % Veg. Cover	-.941 @	-.266	-.803 **	-.574

* p<.1

** p<.05

@ p<.01

Table 29

Number and percent of Black Skimmer nest-site types based on the amount and type of vegetation surrounding the nest within each treatment area for 1991.

Area	Type A		Type B		Type C		Type D	
CS	2	67%	0	0%	1	33%	0	0%
Va	1	100%	0	0%	0	0%	0	0%
SOa	2	33%	1	16%	3	50%	0	0%
Vb	6	75%	0	0%	2	25%	0	0%
SOb	0	--	0	--	0	--	0	--
Vc	0	--	0	--	0	--	0	--
CO	10	77%	0	0%	3	23%	0	0%
Total:	21		1		9		0	
Average:	67.7%		3.2%		29.0%		0.0%	

types (F=7.546, df=6, 24; p<.01) for the combined treatment areas were significant. Also, the average percent of nest types for areas with skimmer nests (SOb and Vc areas excluded) was significantly different (F=21.757, df=3, 16; P<.01). Furthermore, there was a significant difference in the total number of eggs among nest types when the number of eggs for areas with skimmer nests was averaged (F=3.901, df=3, 16; P<.05). Type A nests were most common and had the largest clutch size, followed by type C nests and then type B nests. Out of 31 nests monitored in 1991, 67% of all nests were surrounded by bare substrate with no vegetative cover. There were no skimmer nests surrounded by dense vegetation, which would have been classified as type D.

Predators: While some of the egg loss for both years may be from the incubating parents or invading neighbors crushing them, this phenomenon would not explain the difference between years, so predation must have been a factor. Predators at the Hampton Roads Bridge-Tunnel were rare. Gulls in particular were an extremely uncommon visitor until the breeding season was over in late August. Only an occasion immature Herring Gull (Larus argentatus), Laughing Gull (Larus atricilla) or Ring-billed Gull (Larus delawarensis) would fly over the colony, but they never landed on the island. While Ruddy Turnstones (Arenaria interpres) have been cited for their egg predation (Parkes et al., 1971), they were found on the island for only 3 days at the end of May, 1990 and for a week at the end of May, 1991. This was after the eggs began hatching and after predation statistics were collected.

Because of the lack of avian predators, Norway rats (Rattus norvegicus) were the only predators on the Bridge-Tunnel that could have caused significant egg loss. Only one rat, which was run over on the maintenance road, was observed during the 1990 and 1991 breeding seasons; however, rat holes and broken eggs with teeth marks both years provided evidence of their continued survival. Because of the high incidence of egg loss due to rats in 1987 and 1988, the Virginia Department of Transportation and Department of Agriculture worked in conjunction with Ruth Beck to try to eradicate the rats through chemical means following the breeding seasons. This practice continues today.

Skimmers were subjected to the highest rate of predation in 1990, losing 49% of their eggs for all nests monitored. This percentage decreased in 1991 to only 4.6%. This difference may be due to increased efforts by the Virginia Department of Transportation to eradicate the rats on the island between years. Common Terns were not as affected by rat predation as were the skimmers.

DISCUSSION

The strong positive correlations between the proportion of type A nests and percent clear area (r=.957), the proportion of type B nests and percent standing dead vegetation (r=947), and the proportion of type C nests and type D nests and percent live vegetation (r=.866 and r=.879, respectively) may appear to indicate that Common Terns nest on any available substrate with no obvious preference. However, the terns preferentially choose sparsely vegetated nest sites at a much higher rate than would be expected based on the percent of available habitat. Furthermore, the birds utilize the densely vegetated areas and bare areas much less than is expected based on Chi-square analysis. For example, while the Va area supported 66.4% live vegetative cover, most likely including a large proportion of dense vegetation, only 7.8 of the nests were surrounded by dense vegetation.

Perhaps the measure revealing the most accurate insight to the terns' nesting preference is that of the nest classification. As shown above, 79% of all nests, regardless of the treatment area in which they were found, were initiated at a site with less than 50% vegetative cover one meter around the nest (types A and C). Of the remaining nests, 16% were surrounded by dead vegetation. This dead vegetation posed no threat to the nesting birds through vegetative overgrowth of the nest. Only 5% of the 1379 nests in the experimental area were found in dense vegetation.

Thus when considering the microhabitat, which for this study was defined as the area within one meter of the nest, it appears that Common Terns prefer nest sites with sparse vegetation. This preference is followed by nest sites with no vegetation within the microhabitat and sites with standing dead vegetation, based on multiple comparisons. Dense vegetation does not support as large a proportion of nests as is expected based upon the available proportion of habitat.

With a nest site in sparse vegetation, the adults and young may gain several advantages (Austin, 1932; Palmer, 1941). Compared to those in dense vegetation, the adults maintain relatively clear vision to potential avian predators and to the responses of their neighbors in social cohesion. Some amount of vegetation provides shade for the hatchlings, as it was not uncommon for the ground temperature to approach 120 degrees Fahrenheit (Beck, pers. comm.). Some vegetation also provides an area for the young to hide from predators. A small amount of vegetation, then, could provide enough cover to greatly increase the survivability of the young. Conversely, in dense grass, movement is restricted, which may limit the birds' response to surrounding threats. It also may increase the difficulty of landing at the nest site and responding to a brooding mate. Dense vegetation may also make nest building more difficult. Based on these advantages and disadvantages, sparse vegetation may be a compromise between the adult's requirements of no vegetation and the hatchling's need of substantial vegetative cover.

In terns, in contrast to skimmers, there is a negative correlation between percent vegetative cover and both the number of eggs lost and number of nests lost. This is the opposite trend suggested by Austin (1932): "But too much grass may be unsuitable for both [Roseate and Common Terns], for not only does it make nest-building difficult, but it affords cover for predatory animals such as rats." Thus, it may be that in the current study area, the rats find cover in the dense vegetation but venture to the cleared areas where the nests are not obscured by vegetation to prey upon the nests.

In their descriptive studies, Palmer (1941), Blokpoel <u>et al.</u> (1978), Burger and Gochfield (1988), and Soots and Parnell (1975) among others, have found or mentioned this preference of Common Terns for sparse vegetation at the nest site. Soots and Parnell found a vegetative cover averaging between 10-30%, which is similar to the sparse vegetative preference and most nest type for the current study. Blokpoel <u>et al.</u> (1978) measured a vegetative cover of 41%

immediately surrounding the nest. Both of these percentages are similar to the sparse vegetative preference (0-50%) associated with the type C nests from the current study. However, Burger and Gochfield (1988) found only a 5% vegetative cover within 1 meter of the nest. While still considered "sparse" vegetation, this average is considerably lower than that found on the Hampton Roads Bridge-Tunnel.

The findings from the current experiment also correspond to the three experimental studies discussed above. Austin (1932) found that the terns were most abundant in the partly grassed quadrats followed by the grassless areas. Severinghaus (1982) found that the birds preferred areas with dried grass added compared to areas with different sizes of rock. Although the added grass appears to be more similar to the bare areas with dead matted grass in the current study, it is the area with the greatest amount of relief provided by Severinghaus. Richards and Morris (1984) found that the terns preferred areas enhanced with moss and logs followed by areas with added rocks and gravel. The moss and logs would provide benefits similar to those provided by sparse vegetation. Furthermore, the bare areas were also the second most preferred area in the current study.

The substrate preference for Black Skimmers from all measurements appears to be a bit more straightforward, even though the sample size was considerably smaller. Adults preferred the two cleared areas (CS and CO) both years, along with the Vb area. This is not unexpected, because this vegetative treatment area has the third lowest percent vegetative cover, following the two cleared areas. Furthermore, when compared to the percent clear substrate, all correlations with breeding measurements were positive and most were significant, indicating greater success and preference with an increase in the amount of cleared nesting substrate. Two of the significant correlations were the positive correlations of the number of adults and maximum weekly hatchling average with the percent clear substrate.

As illustrated above, Black Skimmers showed a significant trend towards bare ground, sand, and dead, matted vegetation for the nesting substrate based on the nest classification. Not only were 68% of all nests found on this type of substrate, but only one successful nest with 2 eggs was surrounded by standing dead vegetation. Even more significant is that out of 31 nests monitored, none were initiated in dense vegetation. Based on all of these results, the preferred Black Skimmer microhabitat is a site with sandy or rocky ground and no vegetation. This substrate also provides the greatest success, followed by nests surrounded by sparse vegetation.

One of the differences between Black Skimmers and Common Terns leading to this difference in substrate preferences may be based on the time of foraging. While

Common Terns are active throughout the day, particularly at the time of hatching, Black Skimmers are most active immediately after sunset and prior to sunrise. Therefore, while 3-day-old and older tern chicks are often left unattended in the colony during the day, this is rarely the case for adult skimmers and their young. Thus, the threat of high temperatures and adverse weather is not as great a factor in choosing nest sites for Black Skimmers as it is for the terns.

CONCLUSIONS

Common Terns and Black Skimmers can have great success nesting on a man-made island such as the Hampton Roads Bridge-Tunnel. Soots and Parnell (1975) note that man-made islands, such as dredge islands, " provide nesting conditions superior to those found on most natural sites." Such colony sites cannot be overlooked when considering the future success of both species. This is illustrated in the fact that while only 18% of all skimmers in the state of Virginia nested on the Hampton Roads Bridge-Tunnel, they produced 90% of all fledglings for the state (R.A. Beck, unpublished report). While not as extreme, the same trend is found in 1991. The low level of success of skimmers in Virginia compared to the Hampton Roads Bridge-Tunnel is most likely based on the heavy storms coupled with high tides, which did not affect the Bridge-Tunnel, that wiped out other colonies on barrier beaches. Therefore, because of the continued increased pressure of beach development and intervention by humans, leading to greater disturbance, such man-made sites will become more valuable in the future. For this reason, determining the substrate preference of both species will provide the necessary information for managing such sites to increase both species success.

Based on this study, Common Terns had the greatest success in the macrohabitats that provided the greatest number of the preferred microhabitats. Such areas provided sparsely vegetated substrate for the adults with some shade for the hatchlings. Black Skimmers showed a marked preference for macrohabitats cleared of vegetation. They avoided areas with moderate to thick vegetation, and nested in areas with no vegetation in their microhabitat.

MANAGEMENT STRATEGIES

The Hampton Roads Bridge-Tunnel provides a deviation from the usual colony site for Common Terns and Black Skimmers in that it is relatively free from avian predators and from the effects of weather. Therefore, management strategies for the Bridge-Tunnel based on the above conclusions may not necessarily be appropriate for colonies on natural barrier beaches where high tides and storms often wash out colonies, or in areas with a great deal of contact with nesting gull species. However, these strategies do pertain to colonies on man-made islands and protected nesting sites similar to the Hampton Roads Bridge-Tunnel.

The most obvious management strategy to increase the success of both species is to increase the amount of preferred substrate within the colony site. While the birds choose the site based on the amount and type of vegetation within the microhabitat, management of the site must be carried out at the level of the macrohabitat, as was done in this experiment. For skimmers, as mentioned above, the substrate needs to be clear of vegetation. This may be accomplished either through vegetation removal or rock/sand application, both of which would provide areas vegetation-free. The latter option is based on the success of Black Skimmers in a small sandpit outside of the experimental area and is discussed below. For Common Terns, the macrohabitat needs to include the maximum number of nest sites with sparse vegetation. This can be accomplished by clearing as well as mowing large areas of vegetation in strips prior to the birds' arrival. Furthermore, the vegetation within 5 meters of the maintenance road should be left to grow throughout the year. Such a buffer will provide additional areas for protection from the sun for the young and will perhaps discourage them from entering the road, where they may be run over (see below).

Because of the high incidence of predation by rats, particularly during the 1990 breeding season, their eradication is necessary to increase the success of both bird species. While the dense vegetation may provide them cover, the highest levels of predation was found in areas with less vegetative cover. Because of the preference of both species to the low percent of vegetative cover, any vegetation removal must be accompanied by rat eradication. Furthermore, because the Hampton Roads Bridge-Tunnel is connected to Fort Wool, a Civil War fort and current tourist attraction, eradication on the Bridge-Tunnel must performed in conjunction with eradication on Fort Wool.

In both 1990 and 1991, the greatest threat to survival of hatchlings and fledglings at the Bridge-Tunnel was from maintenance personnel's vehicles (trucks) and disabled vehicles from motorists (cars) pulled off of the road. On the maintenance road that circles the island, a total of 339 Common Terns hatchlings and fledglings and 26 Black Skimmer hatchlings were hit and killed in 1990. In 1991, 50 tern hatchlings, 81 tern fledglings, 3 tern adults, 32 skimmer and 2 skimmer adults were killed in the road. Such a high level of mortality, nearly 33% of all tern young for 1990, must be addressed to significantly improve the success of both species on the island.

The greatest number of skimmers and the highest number of young were found in a small sandpit, approximately 10 X 8 meters, next to the road on the northwestern side of the island. It was also here, however, that skimmer hatchling mortality was extremely great as hatchlings wandered into the road. Based on this observation and the stated preference of skimmers for such bare ground for nesting, one recommendation for the Bridge-Tunnel would be to close this sandpit and open a new one in an area further from the road, providing protection from vehicular travel. Continued monitoring will help to determine the feasibility and practicality of this management strategy.

Other, more general options available to reduce this problem in both terns and skimmers include strict enforcement of the 5 mph speed limit, education of maintenance staff and visiting contractors about the birds' breeding biology and behavior, continued placement of warning signs around the boundary of the colony, and placement of temporary barriers, such as 12" staked erosion cloth, around the boundary of the colony to reduce the number of birds in the road.

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