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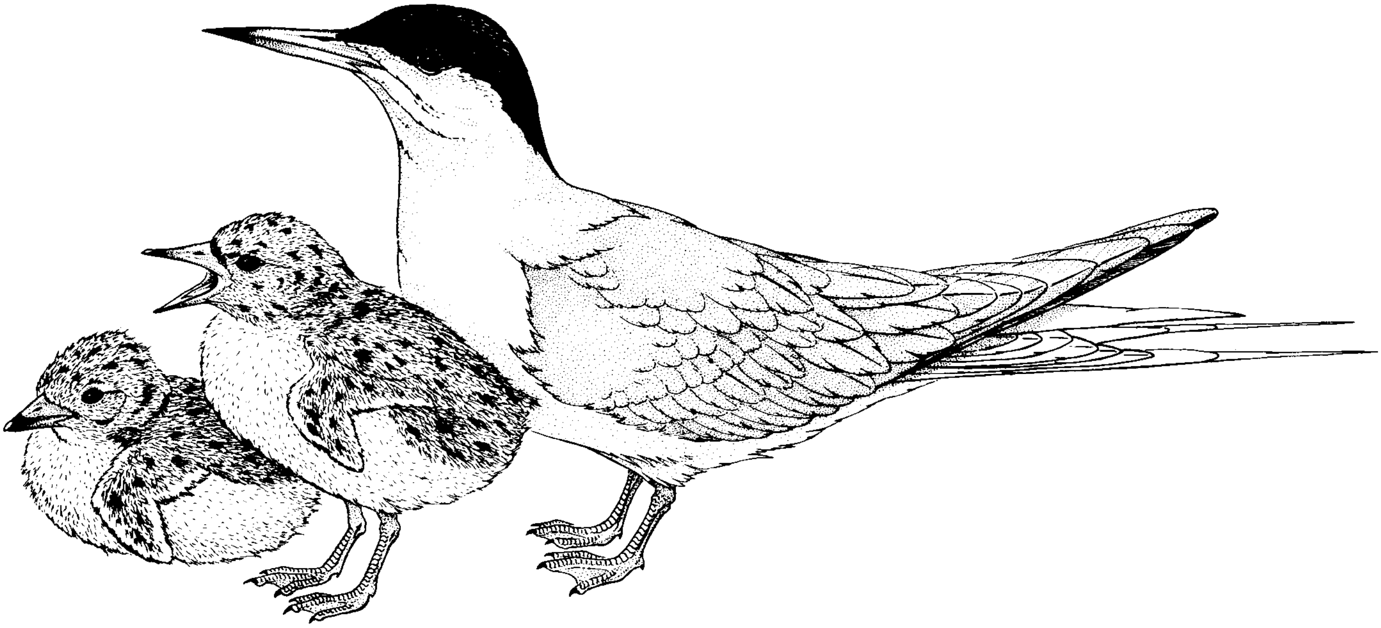

Fish and Wildlife Service

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HABITAT SUITABILITY INDEX MODELS: FORSTER'S TERN (BREEDING)--GULF AND ATLANTIC COASTS

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PREFACE

The habitat suitability index (HSI) model in this report on the Forster's tern is intended for use in the U.S. Fish and Wildlife Service's (1980) habitat evaluation procedures for impact assessment and habitat management. The model was developed from a review and synthesis of existing information and is scaled to produce an index of habitat suitability between 0 (unsuitable habitat) and 1 (optimally suitable habitat). Assumptions used to develop the model and guidelines for model applications, including methods for measuring model variables, are described.

This model is a hypothesis of species habitat relationships, not a statement of proven cause and effect. The model has not been field-tested. For this reason, the U.S. Fish and Wildlife Service encourages model users to convey comments and suggestions that may help increase the utility and effectiveness of this habitat-based approach to fish and wildlife management. Please send any comments or suggestions you may have to the following address.

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ACKNOWLEDGMENTS

The narrative and habitat suitability index model for the Forster's tern was reviewed by the following individuals who have some knowledge of the nesting requirements of this species: J. Burger, Rutgers-The State University, New Brunswick, New Jersey; J. Parnell, University of North Carolina, Wilmington; and G. Peterson, Center for Wetland Resources, Louisiana State University, Baton Rouge. Evaluation of model structure and functional relationships were provided by personnel in the U.S. Fish and Wildlife Service Ecological Services Offices at Lafayette, Louisiana, Corpus Christi, Texas, and Annapolis, Maryland, and by R. Hamilton and D. Pashley, School of Forestry, Wildlife and Fisheries, Louisiana State University, Baton Rouge.

Special thanks go to D. Hewitt for typing the draft document. Funding for the model development and publication was provided by the U.S. Fish and Wildlife Service. Patrick Lynch illustrated the cover.

FORSTER'S TERN (*Sterna forsteri*)

INTRODUCTION

Distribution

The nesting range of Forster's terns hosts three allopatric breeding populations. The first and most important breeding area, in terms of the number of nesting pairs, includes the western gulf coast from the Louisiana-Mississippi border to northern Tamaulipas, Mexico (American Ornithologists' Union [AOU] 1983). In addition, small numbers of Forster's terns have nested in Mobile County, Alabama (Imhof 1976). Although this species has not been recorded nesting in Mississippi (J. Jackson, Mississippi State University, Starkville; pers. comm.), it is observed in the coastal regions of that State every summer, and several thousand nest in adjacent Louisiana (Portnoy 1977; Clapp et al. 1983). The two largest colonies of Forster's terns documented in the literature were both in Louisiana: one of 2,750 pairs in Lake Borgne on the Louisiana-Mississippi border and one of 2,263 pairs in Calcasieu Lake (Portnoy 1977).

The second nesting region extends from Long Island, New York, south along the Atlantic coast to Cape Lookout, North Carolina (Erwin 1979; Portnoy et al. 1981; Parnell and McCrimmon 1984). About 6,000 birds breed in this region annually (Erwin 1979; Portnoy et al. 1981). Louisiana is the most important nesting area for Forster's terns along the Atlantic or Gulf of Mexico coasts in terms of total number of breeding birds and mean colony size (Table 1).

The third and largest breeding area extends from southeastern British Columbia east to south-central Manitoba, south to central California, northern Utah and Colorado, northwestern Kansas, and northern Iowa, Illinois and Indiana (AOU 1983). The number of nesting birds in this area has not been documented, but the largest concentrations of nesting birds are apparently in the San Francisco Bay region and Manitoba (Gerrard and Whitfield 1971; Gill and Mewaldt 1979).

Some northward and westward dispersal of Forster's terns is apparent prior to the southward migration. The southward migration is primarily through interior North America (AOU 1983). Forster's terns winter along coastal areas from central California south to Costa Rica on the Pacific coast, along the Atlantic-gulf coast from Virginia to Costa Rica, and in the Bahamas and Greater Antilles (AOU 1983). The greatest concentrations of wintering terns occur along the Texas and Louisiana coasts, and coastal southern California (Rubega et al. 1984; Drennan et al. 1985).

Table 1. Recent distribution of Forster's tern colonies along the Atlantic and gulf coasts of the United States.

State	Colonies	Pairs	References
New Jersey	6	463	Erwin 1979
Maryland	7	520	Erwin 1979
Virginia	21	1,095	Erwin 1979
North Carolina	13	931	Parnell and McCrimmon 1984
Alabama	a	a	Imhof 1976
Louisiana	34	9,608	Portnoy 1977
Texas	64	1,773	Texas Colonial Waterbird Society 1982
Total	145	14,390	

[a] A few pairs may nest annually but adequate data are not available.

Oberholser (1974) and Blacklock et al. (1978, in Clapp et al. 1983) indicated that the number of Forster's terns nesting on the Texas coast has declined since the mid-1940's because of the development of the larger offshore islands and possibly because of bioaccumulation of DDT and PCB. Recent investigators, however, have postulated that the number of nesting terns has been stable (Texas Colonial Waterbird Society 1982). This maintenance of population size may be due to increased availability of suitable nesting areas on dredged spoil islands. Because of the limited availability of quantitative historical data, the trend for nesting Forster's terns in Louisiana cannot be determined.

Life History Overview

Forster's terns along the Atlantic and gulf coasts tend to nest in single-species colonies of 10 to several hundred birds in saline or brackish marshes on near-shore islands (Erwin 1979; Portnoy et al. 1981). Only a small proportion of the gulf coast population nests in mainland marshes: 3.1% of the colonies and 0.5% of the breeding birds in Louisiana, and 8.5% of the colonies and 2.8% of the breeding birds in Texas. In inland areas, floating mats of aquatic vegetation ("pop-ups") appear to provide important nesting substrate (P. Yakupsak, Lacassine National Wildlife Refuge, Louisiana; pers. comm.).

The majority of adult terns arrive at the nesting areas during April (Erwin 1979). Along the Atlantic and gulf coasts they usually lay eggs in April and May, and most nesting is completed by the end of July (Kopman 1907, 1908; Bent 1910; Oberholser 1938; Portnoy 1977; Erwin 1979; Parnell and Soots 1979). Chaney et al. (1978) calculated the mean clutch size of this species to be about 2 eggs per nest for 92 nests examined along the Texas coast in 1977. Few published data are available on the incubation period of Forster's terns along the gulf coast, but Chaney et al. (1978) calculated the period to be 23 days for 6 nests examined. The mean length of time from the initiation of hatching to emergence is about 2.8 days for each egg (McNicholl 1983). Fledging apparently occurs at approximately 40 days, but varies with prey abundance (Clapp et al. 1983).

Data on the extent of renesting by Forster's terns are not available for the gulf coast colonies, but Parnell and Soots (1979) and J. Burger (Rutgers-The State University, New Brunswick, New Jersey; pers. comm) have recorded renesting after storm damage in North Carolina and New Jersey. Bergman et al. (1970) postulated that some renesting may occur in the interior population if the original nest is destroyed.

SPECIFIC HABITAT REQUIREMENTS

Food and Foraging Habitat

Forster's terns tend to forage in protected shallow bays and lagoons near the nesting colony (Oberholser 1974; Baltz et al. 1979; Chapman 1984). When foraging over open water away from the coastal marsh, they concentrate in the zone between the foreshore and the first bar (Chapman 1984). Forster's terns selected water less than 1 m deep during two foraging ecology studies in coastal California (Salt and Willard 1971; Baltz et al. 1979).

Few data on prey size and type are available; however, the diet apparently consists primarily of small fish, crustaceans, and aquatic insects (McAtee and Beal 1912; Salt and Willard 1971; Baltz et al. 1979). Menhaden (*Brevoortia tyrannus*) and silvery anchovies (*Engraulis eurystole*) were important prey items in the late fall and winter in birds collected from coastal South Carolina, Georgia, and Florida (McAtee and Beal 1912). Baltz et al. (1979) determined that juvenile shiner perch (*Cymatogaster aggregata*) and northern anchovy (*Engraulis mordax*) were the predominant food items found in stomachs of birds collected at Elkhorn Slough, Monterey County, California. Prey size ranges from 1 to 10 cm with a mean of about 1.5 cm (Baltz et al. 1979; Salt and Willard 1971).

Forster's terns are apparently not limited by foraging habitat or prey availability. They nest in or near brackish and salt marshes, which are important nursery areas for many marine fishes and crustaceans and provide a dependable source of appropriate-sized prey.

Nesting Cover

Formerly, nesting colonies were established on natural marshy islands that were generally within 2 km of the mainland (Kopman 1907, 1908; Job 1908; Bent 1910). The development of artificial islands by deposition of dredged spoil has created additional suitable nesting areas (Portnoy 1977; Chaney et al. 1978; Texas Colonial Waterbird Society 1982). Almost all of the recent colonies in Louisiana were located on natural islands: only 0.8% of the breeding birds were found on dredged spoil islands in 1976 (Portnoy 1977). Artificial islands are apparently more important as colony sites in Texas because of the lack of undisturbed natural islands; 55.6% of the colonies examined along the Texas coast during 1973-80 were located on artificial islands (Texas Colonial Waterbird Society 1982). Dredged spoil islands in saline waters along the upper gulf coast are initially vegetated by smooth cordgrass (*Spartina alterniflora*), and sufficient vegetative cover for the establishment of nesting colonies of Forster's terns should develop within 2 to 5 years (Chaney et al. 1978; Lewis and Lewis 1978).

Forster's terns in coastal colonies characteristically nest on small marshy islands vegetated with *S. alterniflora* in saline marsh and *S. patens* (saltmeadow cordgrass) in brackish marsh (Bent 1921; Oberholser 1938; Oberholser 1974; Portnoy 1977; Parnell and Soots 1979; Texas Colonial Waterbird Society 1982; Clapp et al. 1983; G. Peterson, Center for Wetland Resources, Louisiana State University, Baton Rouge, pers. comm.).

The availability of wind- and wave-accumulated mats of vegetation or wood (wrack) within *Spartina* spp. marsh is apparently one of the most important factors influencing the establishment of tern colonies, although Forster's terns may occasionally nest in marshes that lack wrack. Wrack is usually deposited above the mean high-tide line by storm tides and wind during the winter, and provides quality nesting substrate the following spring. The presence of wrack was noted by most authors describing the substrate of Forster's tern nests in the eastern and southern United States (Job 1908; Bent 1921; Oberholser 1938; Chaney et al. 1978; Parnell and Soots 1979; Texas Colonial Waterbird Society 1982; G. Peterson, pers. comm.). Because wrack normally accumulates parallel to the island shore, tern colonies tend to be long and narrow. Wrack consisting of aquatic vegetation such as *Zostera marina* is usually only 5 to 10 cm in depth, while wrack composed of coarse material, such as *S. alterniflora* culms, regularly accumulates to 0.5 m (J. Parnell, University of North Carolina; pers. comm.). Apparently, the important factor determining colony establishment is a quantity of wrack sufficient to completely cover the underlying marsh vegetation, thus creating an open ridge within the marsh suitable for nest placement; Forster's terns will not utilize wrack deposits that have a large amount of marsh vegetation penetrating the mat (J. Parnell, pers. comm.). Wide wrack deposits are probably superior to narrow deposits because nests are less readily located by predators using the elevated ridge as a travel lane. Bleached wrack is particularly suitable as a nest substrate as it provides good camouflage for tern eggs and chicks (Burger and Lesser 1978). Because tern nests are generally shallow platforms (Bent 1921; Chaney et al. 1978), the increased elevation afforded by nesting on wrack protects the nest and contents from potential wave and storm tide damage, which is apparently the primary source of nest failure in Texas and North Carolina (Chaney et al. 1978; Parnell and Soots 1979). Occasionally, terns will establish small nesting colonies on sand or shell beaches if wrack deposits are present and vegetative cover is available nearby (Oberholser 1938; Parnell and Soots 1979). Common terns that used wrack as a nest substrate had greater nesting success than pairs that nested on the ground (Burger and Lesser 1978).

Vegetative density does not appear to be important except that ground cover must be sufficient to trap a dense mat of wrack for a nesting substrate and to provide some protective cover for young chicks (Burger and Lesser 1978; J. Parnell, pers. comm.).

Water

The physiological water requirement of Forster's terns is probably met within the saline and brackish habitats surrounding the nesting colonies and need not be considered as a factor of habitat suitability (Welty 1982).

Special Considerations

Predation. Some characteristics of islands are related to their potential to sustain terrestrial predators. Rats (*Rattus* spp.), raccoons (*Procyon lotor*) and mink (*Mustela vison*) are predators of nesting terns (Provost 1947; Austin 1948; Sprunt 1948; G. Peterson, pers. comm.). Thus, the perceived potential of an island to support a viable population of terrestrial predators is important when estimating the suitability of the site as tern nesting habitat. Island elevation, island size, and distance from the mainland are probably the most important variables determining successful predator colonization.

Islands with little relief (less than 0.5 m maximum elevation) tend to have low vegetative diversity and are periodically flooded, so probably would not support viable populations of terrestrial predators. As island size increases the maximum elevation tends to increase, thereby increasing vegetative diversity and the potential to support predators. Islands with some topographic variability also provide refuge for predators from high tides; however, Chaney et al. (1978) postulated that islands less than 20 ha in size, even if they had some topographical relief and vegetative diversity, would not support large predators indefinitely.

In Texas, the largest tern colonies were found on small islands up to 1 ha in area (Texas Colonial Waterbird Society 1982). Similar quantitative data are not available for Louisiana, but Kopman (1907) stated that colonies tended to be established on "small" islands and G. Peterson (pers. comm.) and S. Cardiff (Museum of Zoology, Louisiana State University, Baton Rouge; pers. comm.) stated that the Forster's tern colonies they examined were on islands 1 ha or less in area.

As the distance from the colony island to the mainland increases, the probability of predator colonization decreases (McArthur and Wilson 1967). In this model, "mainland" refers to contiguous habitat greater than 20 ha in area.

Avian predators, especially herring gulls (Larus argentatus), can cause serious egg or chick loss in tern colonies along the northern Atlantic coast. However, the smaller laughing gull (Larus atricilla) is the common nesting gull along the southern Atlantic and gulf coast in the United States; and predation by this species does not appear to be an important limiting factor of nesting terns (Portnoy 1977; Burger and Lesser 1978).

Disturbance. Human disturbance and development of traditional nesting areas are often cited as reasons for tern colony abandonment (Davis 1965; Gochfeld 1974, 1976; Portnoy 1977). Development of the larger offshore islands along the Texas coast is considered the reason Forster's terns abandoned some traditional colony sites (Oberholser 1974). The extremely large colony of 2,750 pairs of nesting terns in Lake Borgne in Louisiana was deserted with no apparent fledging of young after the colony was intentionally disturbed by humans, and some adult birds were apparently shot (Portnoy 1977). Even if human disturbance does not cause complete colony abandonment, it can cause the adults to leave temporarily, exposing the eggs and young to heat stress and predation (Portnoy 1977). Only 1 of 32 colonies in Louisiana and 14 of 64 colonies in Texas were noted as being included in State, Federal, or private refuges and thereby protected from most disturbances (Portnoy 1977; Texas Colonial Waterbird Society 1982).

Although we could not find documented reports of Forster's tern susceptibility to oil pollution, the potential for adverse effects is great because this species nests and roosts at the high-tide line (Chapman 1984). In addition, the method of feeding (aerial plunging) brings the birds into regular contact with the water surface. Because the Louisiana and Texas coasts are important oil production areas and because a large proportion of the world's breeding and wintering Forster's terns are found there, special attention should be given to important nesting and roosting islands should a major spill occur.

HABITAT SUITABILITY INDEX (HSI) MODEL

Model Applicability

Geographic area and season. The habitat suitability index model in this report was developed for application within the normal breeding range of the Forster's tern along the gulf coast of Louisiana and Texas. There are apparently few differences in nesting habitat requirements along the Atlantic coast; therefore, the HSI model may also be used to evaluate potential habitat in coastal New Jersey, Maryland, Virginia, and North Carolina. The HSI model was developed to evaluate Forster's tern habitat during the breeding season (March through July).

Cover types. Forster's terns are extremely selective in their choice of nesting habitat, with a vast majority of the colonies established in saline or brackish marsh habitats classified as "estuarine intertidal persistent emergent" by Cowardin et al. (1979).

Minimum habitat area. Minimum habitat area is defined as the minimum amount of contiguous habitat that fulfills all life requisites for a species; however, the minimum habitat area principle is not readily applicable to colonial nesting species that travel to a food source. Published data on the minimum area required by Forster's terns were not found. If quantitative data on minimum area were collected in the future and the size of the site under evaluation is less than the minimum, the HSI for this species would be zero.

Verification level. The output of this HSI model is an index between 0 and 1.0 that is believed to reflect habitat potential for Forster's terns. Earlier drafts of this model were reviewed by J. Burger, Department of Biology, Rutgers-The State University, New Brunswick, New Jersey; J. Parnell, Department of Biological Sciences, University of North Carolina, Wilmington; G. Peterson, Center for Wetland Resources, Louisiana State University, Baton Rouge. Personnel in the U.S. Fish and Wildlife Service Ecological Services Offices at Lafayette, Louisiana; Corpus Christi, Texas; and Annapolis, Maryland, also reviewed the model. This model has not been field-tested.

Model Description

Overview. Habitat suitability for Forster's terns is dependent on several factors. Five factors that influence nesting habitat quality are incorporated in this model: two variables that describe cover, two variables describing the physical characteristics of the nesting island, and the amount of human disturbance in or near the study area. The relationships of habitat variables to the nesting HSI value are illustrated in Figure 1.

Although waves and storm tides can cause serious nest loss, they are environmental factors and not a component of the habitat per se, so are not included in this model. An additional factor that may be important when assessing habitat quality, although quantitative data are lacking, is the influence of tidal amplitude on colony establishment and success. Wrack deposition on low marshy islands would be reduced in areas exposed to great fluctuations in tidal range. In those areas, wrack would tend to accumulate on islands with some topographic relief. Colonies established in areas of large tidal amplitude would also have an increased potential for colony damage by waves and storm tides. In North Carolina, Forster's terns only nest in Pamlico and Cove Sounds, which are exposed to relatively little tidal fluctuation, indicating that colony site selection may be influenced by tidal amplitude (J. Parnell, pers. comm.).

The availability of water and prey is assumed to be non-limiting within the breeding range of Forster's terns; therefore, those variables are not considered in the model.

The HSI model uses the known habitat requirements of Forster's terns to assess the potential suitability of a given site to support a nesting colony. The assumptions for each variable and the associated primary data sources are presented in Table 2. The following section explains the logic used in the formulation of the HSI equation.

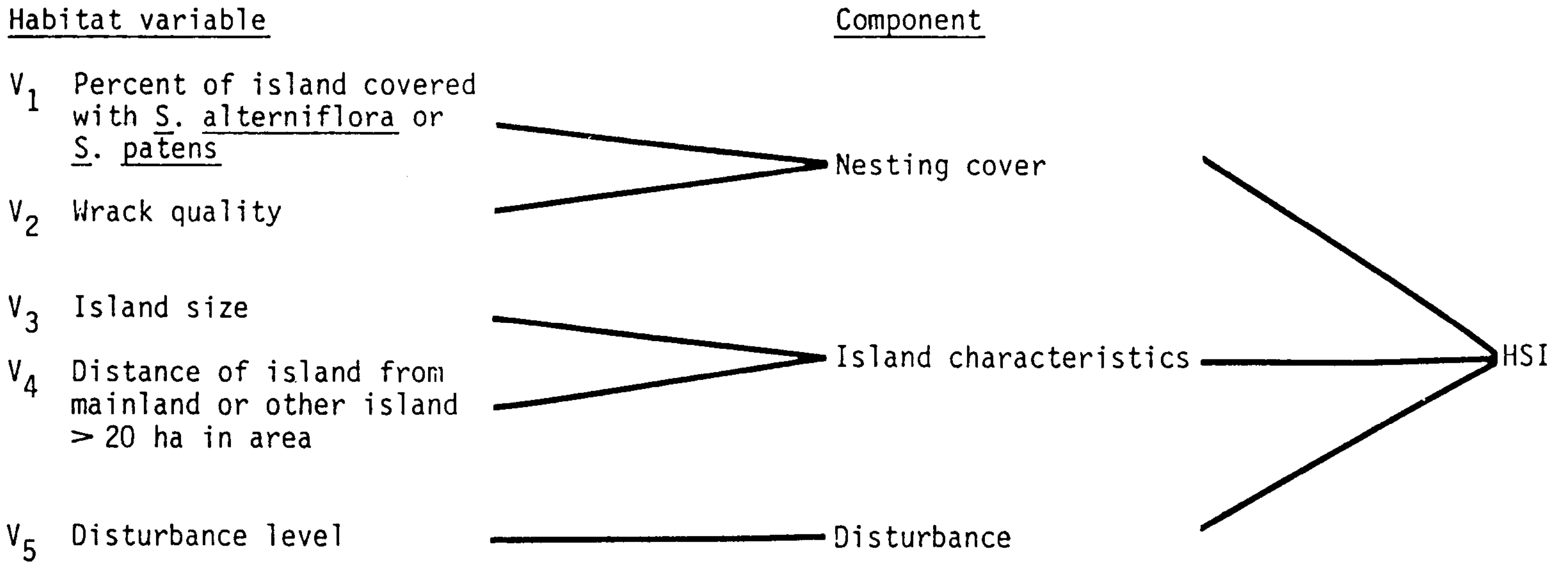


Figure 1. Relationship of habitat variables to the habitat suitability index (HSI) for nesting Forster's terns.

Table 2. Variable sources and assumptions for Forster's tern suitability indices.

Variable	Source	Assumption
V_1	Oberholser 1938 Chaney et al. 1978 Burger and Lesser 1978	Marsh vegetation (*Spartina alterniflora* or *S. patens*) is necessary for wrack accumulation, nest support, and chick cover.
V_2	Oberholser 1938 Portnoy 1977 Texas Colonial Waterbird Society 1982 Parnell and Soots 1979 J. Burger, pers. comm.	Optimal sites contain an abundance of wrack for nest substrate.
V_3	Chaney et al. 1978 J. Parnell, pers. comm. G. Peterson, pers. comm.	The relative protection from wave damage afforded a colony and the potential of an island to support terrestrial predators are dependent on island size.
V_4	McArthur and Wilson 1967 Portnoy 1977 Texas Colonial Waterbird Society 1982	The potential for predator colonization decreases as the island becomes increasingly isolated from the mainland.
V_5	Davis 1965 Gochfeld 1974 Gochfeld 1976 Portnoy 1977	Human disturbance is detrimental to tern colony establishment and nesting success.

Cover component. Vegetative cover is an important component of Forster's tern nesting habitat. Coastal nesting colonies are normally located in stands of *S. alterniflora* in saline marsh and, occasionally, *S. patens* in brackish marsh. *Spartina* spp. are important components of the nesting habitat because they trap and are a major component of wrack and provide escape cover for chicks. Decumbent patches of *Spartina* spp. also provide secondary nesting sites. This model assumes that optimal nesting habitat is found on low, periodically flooded saltmarsh islands vegetated with near-monotypic stands of *S. alterniflora* with canopy cover of at least 25% (V_1).

Islands with some elevational relief have increased vegetative diversity when compared with low, regularly flooded islands (Lewis and Lewis 1978). Because vertebrate species diversity is correlated with increased spatial heterogeneity and plant species diversity (MacArthur and MacArthur 1961), the potential for an island to sustain a viable population of one or more predators increases with an increase in elevation. Islands with a maximum elevation less than 0.5 m above mean high tide are normally only vegetated with Spartina spp. and do not support woody vegetation. Because vegetative composition is dependent on island topography, the cover variable, V_1, includes an elevational component.

The presence of wrack (V_2) is very important for colony establishment. Quantifying this variable is difficult, so it should be measured on a relative scale. Optimum habitat contains extensive wrack deposits that completely cover the underlying marsh vegetation and provide a substrate that elevates the nest above mean high tide. The importance of annual replenishment of wrack is supported by the observation that common terns that used wrack as a nest substrate generally did not use wrack from previous years due to compaction and decomposition (Burger and Lesser 1978).

Island characteristics. Two variables--size and distance from the mainland--are used to quantify the potential of islands to support tern predators and provide protection from wave damage to the colony. As the size of the island (V_3) increases, the potential to support a viable predator population increases, primarily because of increased topographic diversity. Islands greater than 20 ha are relatively unsuitable for the establishment of nesting colonies because they potentially support large predators. The minimum island size required to support Rattus spp. is not known, although these predators probably do not persist on small, periodically flooded, marshy islands. However, rice rats (Oryzomys palustrus) are widely distributed in marsh habitats along the Atlantic and gulf coasts (Wolfe 1982), and although they can be an important predator of marsh wren (Cistothorus palustris) eggs (Kale 1965), we could not find any published data documenting rice rat predation of tern eggs. It is assumed that the SI score for island size is low (0.2) for islands up to 0.1 ha in size, is equal to 1.0 between 0.1 and 1.0 ha, and decreases to 0.1 at greater than 20 ha. The suitability of very small islands (i.e., less than 0.1 ha) is low due to the high probability of a colony being damaged by waves: colonies established deep within a marsh on larger islands are protected by the wave-damping effect of the vegetation.

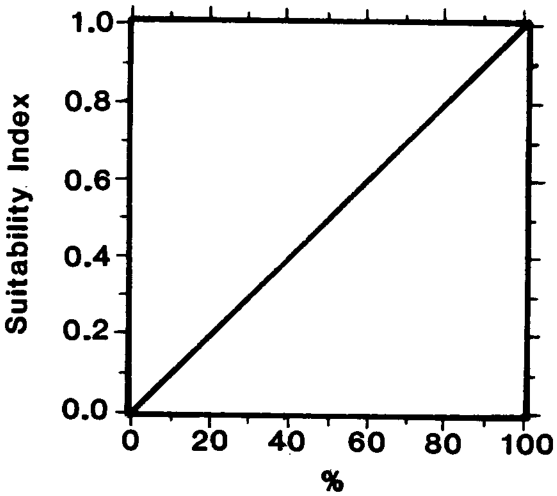
The island isolation variable (V_4) is derived from the island biogeography theories of MacArthur and Wilson (1967); as the distance from the mainland increases, the potential for successful predator colonization decreases. Conversely, increasing insularity exposes the nesting colony to potential severe wave and tidal damage, which may impose an upper limit on the distance of high quality island study sites from the mainland. Optimum nesting islands are assumed to be separated from the mainland by 1 to 3 km of water sufficiently deep to create an effective predator barrier (greater than 0.5 m deep at mean low tide).

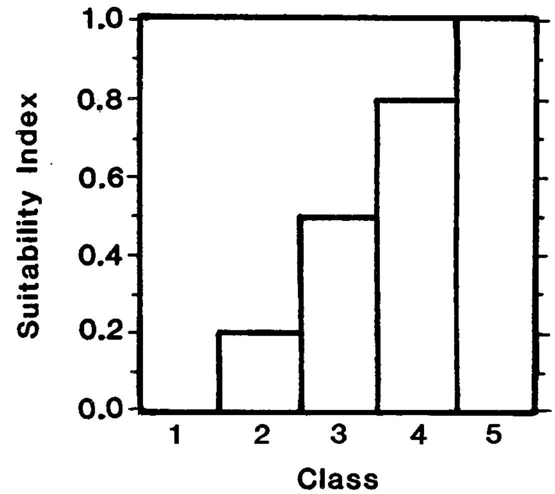
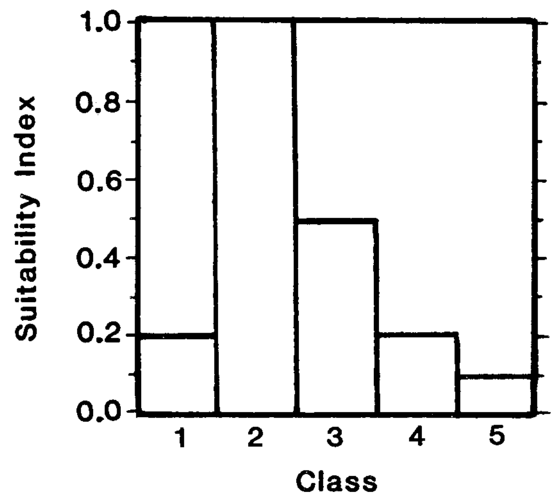
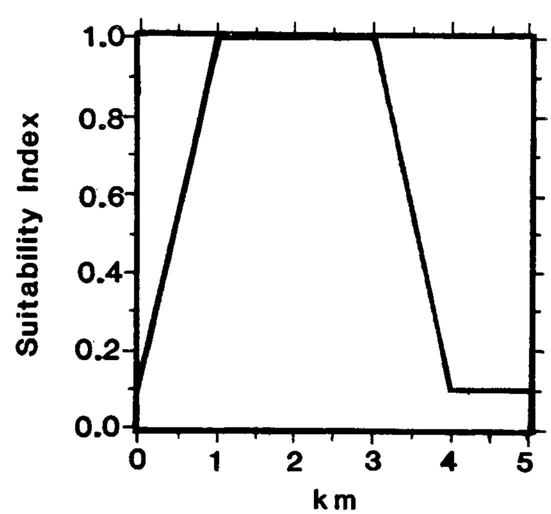
Disturbance. Forster's terns are sensitive to human disturbance of the nesting colony (V_5). It is assumed that commercial or recreational boating near a nesting colony does not adversely affect nesting success if the vessels do not approach closer than 100 m. The impact of occasional, short duration human disturbance on the ground in or near the colony is also limited. Apparently, nesting gulls can become habituated to regular, low-intensity disturbance so the effects of a given level of disturbance may vary among colonies: the level of disturbance is most critical in previously undisturbed colonies (Burger 1981). Nearby occupied houses, especially if free-roaming pets are present, are signs of potentially serious disturbance. Frequent use of the study area by recreational vehicles is not compatible with tern nesting. Optimum nesting habitat is found in areas such as refuges where human disturbance between 1 March and 30 July can be restricted.

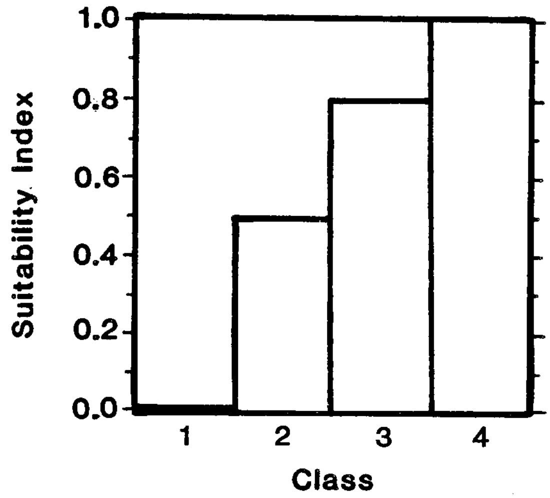
Suitability Index (SI) Graphs for Model Variables

This section provides graphic representation of the relationship between individual habitat variables and habitat suitability for Forster's terns on islands with estuarine (E) intertidal persistent emergent cover. The SI values for each variable are read directly off the Y axis of each graph; 1.0 = optimum suitability, 0.0 = unsuitable.

The SI graphs are based on the assumption that the suitability of a particular variable can be represented by a two-dimensional linear response surface.

Habitat	Variable		Suitability Graph
E	V_1	Percentage of the study area vegetated with *Spartina alterniflora* or *S. patens* with canopy cover at least 25%.	

Habitat	Variable		Suitability Graph
E	V_2	Quality of wrack deposits during the nesting season (1 March to 30 July) (see Appendix for class definitions) 1) unsuitable 2) poor 3) fair 4) good 5) optimum.	
E	V_3	Island size 1) less than 0.1 ha 2) 0.1-1.0 ha 3) 1.1-10 ha 4) 10.1-20 ha 5) greater than 20 ha.	
E	V_4	Distance of the island from nearest mainland or island greater than 20 ha (water must be a minimum of 0.5 m deep at mean low tide).	

Habitat	Variable		Suitability Graph
E	V_5	Disturbance during the nesting season (see Appendix for level definitions) 1) extreme 2) moderate 3) minimal 4) none.	

HSI Determination

The following equations integrate the five individual SI values to obtain the final HSI value for Forster's tern nesting habitat.

Component	Equation
Cover (C)	$(SI_{V_1} \times SI_{V_2})^{1/2}$
Island Characteristics (IC)	$\dfrac{SI_{V_3} + SI_{V_4}}{2}$
Disturbance (D)	SI_{V_5}
HSI =	$\left[\left(\dfrac{2C + IC}{3}\right) \times D\right]^{1/2}$

The variables V_1 and V_2 were assumed to be very important; therefore any compensatory interaction would be weak and the equation for cover incorporates a geometric mean of those variables. An arithmetic mean is calculated from the individual SI values for V_3 and V_4 because those variables interact in a compensatory fashion: a low SI score for one of the variables can be compensated by a high score for the other variable.

An intermediate calculation utilizing the cover (weighted) and island characteristic components is necessary prior to calculating the overall HSI.

This step is important because a large island, while scoring low on the characteristic component, could be a potentially high-quality nesting area if it scored high on the cover component. It is conceivable that a large island vegetated almost entirely with *Spartina* would be more suitable than a small marshy island because of the wave-damping effect.

A geometric mean is then calculated using the resulting two components of the equation because the compensatory relationship is perceived to be weak.

Sample HSI values were derived from three hypothetical study areas (Table 3). The first study area represents a relatively large expanse of coastal marsh recently separated from the mainland by subsidence. Habitat suitability of the area is limited primarily by size and proximity to the mainland, which would indicate a high potential for predators. Study area 2 represents a large island that exhibits a relatively great amount of topographic relief and, therefore, marsh vegetation is restricted to the perimeter. This scenario can develop on natural islands or by deposition of dredged material. These islands are preferred by sportsmen and recreationists, so disturbance is likely. The third study area is a small, low, marshy island. The only limiting factor would be the ability to trap and retain a large, dense mat of wrack.

Table 3. Calculation of suitability indices (SI), component indices, and habitat suitability indices for three hypothetical study areas using habitat variable (V) measurements and Forster's tern HSI model equations.

Model component	Study area 1		Study area 2		Study area 3	
	Data	SI	Data	SI	Data	SI
V_1	100%	1.0	20%	0.2	100%	1.0
V_2	Good	0.8	Optimum	1.0	Good	0.8
V_3	15 ha	0.2	100 ha	0.1	0.5 ha	1.0
V_4	0.1 km	0.2	3.0 km	1.0	2.5 km	1.0
V_5	Minimal	0.8	Moderate	0.5	None	1.0
C	0.89		0.45		0.89	
IC	0.2		0.55		1.0	
D	0.8		0.5		1.0	
HSI	0.73		0.49		0.96	

Field Use of Models

Since HSI models are often based on limited data, the biological precision of the model should not be overestimated and intensive ground evaluation of the study site is usually not warranted. Variables V_1 through V_4 can be adequately evaluated by examining high-resolution aerial photography (Table 4).

While examination of wrack quality immediately prior to the breeding season will provide data on the suitability of the site for the current nesting period, a projection of future wrack conditions may be difficult. Wrack accumulation is dependent on island characteristics such as elevation and vegetative cover; however, stochastic events such as storm tides are also important and are not predictable. If wrack is present during the on-site investigation it can be assumed that future wrack quality will remain constant unless the proposed project will alter the island's characteristics. However,

Table 4. Suggested methods for field measurement of variables used in the Forster's tern model.

Variable	Suggested technique
V_1	The proportion of the study site covered by *Spartina alterniflora* or *S. patens* can be visually estimated from aerial photographs and validated by field examination of the area.
V_2	Wrack quality can be estimated from high resolution, large-scale aerial photography or by ground reconnaissance for the period immediately prior to the breeding season. If wrack is absent, consultation with persons familiar with the site will be necessary.
V_3	Island size can be measured with a planimeter from aerial photography.
V_4	The distance of the study site from the nearest mainland can be estimated from aerial photography or maps.
V_5	Potential colony disturbance can be determined from interviews with local residents, sportsmen, or refuge personnel. On-site inspection and aerial photography will reveal signs of extreme or permanent sources of disturbance.

the absence of wrack does not necessarily indicate that the island will be unsuitable in future years: assigning a SI of 0.0 for V_2 based on the absence of wrack may result in an overall low HSI value for an otherwise high-quality site. If wrack is absent, future wrack quality can be estimated by consulting persons familiar with the site: an average over the past 3-5 years would be acceptable.

Interpreting Model Outputs

The breeding HSI for Forster's terns derived from field application of this model only represents habitat potential, and may not accurately predict nesting density. The model should be used to compare the potential of two or more sites to support nesting terns. If different study areas are examined, the one with the higher HSI should have the potential to support a larger colony of nesting Forster's terns. In addition, this model can be used to estimate the effect of a proposed project on the habitat suitability of a specific site.

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APPENDIX

DEFINITIONS OF SI MODEL CLASSES

Quality of wrack deposits

Optimum. Wrack composed of dense mat of *Spartina* spp. culms or other vegetation relatively resistant to decay. Mat should be greater than 30-cm deep and greater than 5-m wide. Little or no underlying marsh vegetation should penetrate mat.

Good. Wrack mat characteristics similar to "optimum," but depth less than 30 cm or width less than 5 m, or both.

Fair. Wrack composed of mat of old or readily decomposable vegetation such as *Zostera marina*. Little or no underlying marsh vegetation should penetrate mat.

Poor. Wrack characteristics similar to "fair" but some underlying marsh vegetation beginning to penetrate mat. This class also includes wrack deposits on bare sand or shell beaches with potential vegetation cover for chick nearby.

Unsuitable. Wrack old or decomposed with extensive areas of underlying marsh vegetation penetrating mat. Wrack deposits on bare sand or shell beaches with no vegetation nearby for chick cover are also unsuitable.

Disturbance

Extreme. Site regularly used (e.g., daily) for obtrusive recreation (dune buggies, motorcycles, etc.) or near heavily traveled water routes or both. Permanent dwellings within 300 m of the site may also be present.

Moderate. Site occasionally used (e.g., weekly) for obtrusive recreation or with light water traffic near the colony or both.

Minimal. Site visited by sportsmen no more than once a week, and/or water traffic light and greater than 100 m from site. Recreational use of site regulated.

None. The site is protected during the nesting season (e.g., a refuge) or is not suitable for human use (such as low, regularly flooded, marshy islands).

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15. Supplementary Notes

16. Abstract (Limit: 200 words)

A review and synthesis of existing information were used to develop a model for evaluating the quality of breeding habitat for Forster's tern (*Sterna forsteri*). The model is applicable within the nesting range of Forster's terns along the Gulf of Mexico and Atlantic coast. It is scaled to produce an index between 0 (unsuitable habitat) and 1.0 (optimal habitat). Habitat suitability index models are designed for use with the Habitat Evaluation Procedures previously developed by the U.S. Fish and Wildlife Service. Guidelines for model application and techniques for measuring model variables are provided.

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