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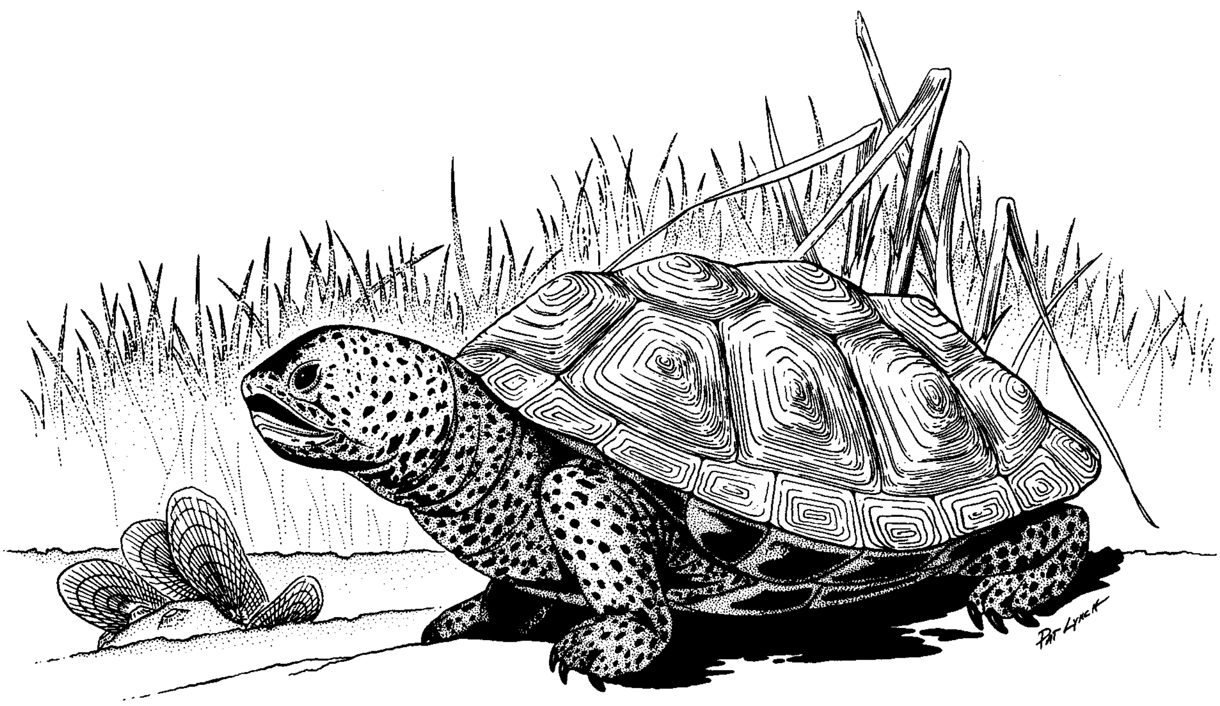

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HABITAT SUITABILITY INDEX MODELS: DIAMONDBACK TERRAPIN (NESTING)--ATLANTIC COAST

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PREFACE

The habitat suitability index (HSI) model in this report on the diamondback terrapin 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 provides a framework for evaluating the quality of diamondback terrapin habitat and is not necessarily based upon proven cause and effect relationships. The model has not been field-tested, and the U.S. Fish and Wildlife Service encourages model users to provide 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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CONTENTS

ACKNOWLEDGMENTS

The narrative and habitat suitability index model for the diamondback terrapin were reviewed by the following individuals who have studied the life history and habitat requirements of the species on the Atlantic coast: J. Burger, Rutgers-The State University, New Brunswick, New Jersey; and R.A. Seigel, Savannah River Ecology Laboratory, Aiken, South Carolina. Evaluation of model structure and functional relationships were provided by personnel in the U.S. Fish and Wildlife Service Ecological Services Offices at Annapolis, Maryland, and Charleston, South Carolina.

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DIAMONDBACK TERRAPIN (*Malaclemys terrapin*)

INTRODUCTION

Distribution and Importance

The diamondback terrapin occurs in a narrow strip of salt and brackish water habitats along the Atlantic and gulf coasts of the United States from Cape Cod, Massachusetts, to Corpus Christi Bay, Texas. Early reports of these turtles from more southern areas of the Texas coast and from Mexico (Strauch 1890; Hay 1904; Carr 1952) have not been verified (Smith and Smith 1979; Ernst and Bury 1982).

Seven subspecies of the diamondback terrapin (*Malaclemys terrapin*) are recognized (Ernst and Barbour 1972; Conant 1975; Behler and King 1979; Smith and Brodie 1982), but geographic variation throughout the range of the species has not been studied and the taxonomic status of some races is problematic (Mount 1975; Ernst and Bury 1982). Three subspecies have been reported from the Atlantic coast: (1) northern diamondback (*M. t. terrapin*) from Massachusetts to the vicinity of Cape Hatteras, North Carolina; (2) Carolina diamondback (*M. t. centrata*) from Capa Hatteras to northeastern Florida; and (3) Florida east coast diamondback (*M. t. tequesta*) from most of the eastern Florida coast. Geographic patterns of intergradation between the subspecies have not been defined. Ernst and Bury (1982) provided a comprehensive list of the literature treating *Malaclemys*.

Diamondback terrapins were collected in great numbers as food for humans from around the turn of the century until the late 1920's, and commercial hunters seriously depleted some populations (Hay 1904, 1917; Coker 1906; Babcock 1926; Hildebrand 1929; McCauley 1945; Finneran 1948). The "terrapin fad" fortunately waned and, in most places, these turtles have recovered from earlier exploitation. The alteration of estuarine areas, however, poses an imminent threat to many populations today.

Life History Overview

Terrapins live in coastal marshes, tidal creeks and channels, coves, estuaries, and lagoons behind barrier beaches. During the spring and summer, and occasionally on warm days in winter, terrapins forage in aquatic areas on a variety of crustaceans, mollusks, and other invertebrates (Carr 1952; Ernst and Barbour 1972; Spagnoli and Marganoff 1975). When not feeding, individuals often bask on exposed mudflats (Ernst and Barbour 1972).

During the winter, diamondback terrapins burrow in the mud of tidal creeks and ponds to hibernate (Coker 1906; Carr 1952; Ernst and Barbour 1972).

Along salt-marsh creeks on the Cape May Peninsula in southern New Jersey, Yearicks et al. (1981) found adult terrapins hibernating singly and in small groups below the surface in the sides of banks and in shallow depressions on creek bottoms. Individuals may hibernate in dune areas above the mean high tide level on rare occasions (Lawler and Musick 1972). Hatchlings enter hibernation shortly after hatching in autumn and may remain buried in the mud well into the next spring (Ernst and Barbour 1972).

Mating occurs in the water with the onset of spring (Hay 1904; Seigel 1980a). Females leave their aquatic habitats only during the nesting season, which varies with latitude (Ernst and Barbour 1972). Oviposition has been reported from April 28 to July 1 in Florida (Seigel 1980b), June 9 to July 23 in New Jersey (Burger and Montevecchi 1975; Burger 1977), and June 10 to July 20 in Massachusetts (Lazell and Auger 1981). Nearly all observations of nesting terrapins were in the daytime, from 0700 to 1900, during high tides.

The eggs are deposited in triangular or flask-shaped nests dug and covered by the females (Reid 1955; Ernst and Barbour 1972; Burger 1977). Depths of 43 New Jersey nests ranged from 10.80 to 20.30 cm (mean 14.98 cm; Montevecchi and Burger 1975). The topmost eggs in most nests usually hatch first (Burger 1976a), and the hatching success of all eggs is greater in moderately deep (average 18.2 cm) rather than in very deep or very shallow nests (Burger 1976b, 1977).

Clutch sizes vary from 4 to 18 eggs (Montevecchi and Burger 1975), and females in the South tend to produce fewer but larger eggs than females in the North (Montevecchi and Burger 1975; Seigel 1980b). Large females tend to lay the most eggs (Montevecchi and Burger 1975; Burger 1976b), and some females may deposit several clutches in a season (Barney 1922; Hildebrand 1932; Ernst and Barbour 1972; Seigel 1980b; Lazell and Auger 1981). When freshly laid, the ellipsoidal or oblong eggs are pinkish white with dimply, leathery shells that fill out during early incubation (Ernst and Barbour 1972; Montevecchi and Burger 1975). The length of the eggs shortly after oviposition ranges from 26.3 to 40.8 mm, the width from 15.9 to 24.0 mm, and the weight from 5.0 to 13.2 g (McCauley 1945; Montevecchi and Burger 1975; Seigel 1980b). Average length, width, and weight of eggs produced by New Jersey females were 31.1 mm, 21.2 mm, and 7.7 g, respectively (Montevecchi and Burger 1975). Comparable averages of eggs from Florida terrapins were 39.0 mm, 22.3 mm, and 12.48 g (Seigel 1980b).

Incubation periods vary with temperature (Burger 1976b), and some hatchlings may overwinter in the nests (Ernst and Barbour 1972). In New Jersey, incubation of eggs in natural nests varied from 61 to 104 days, eggs in individual nests hatched over a period of 1 to 4 days, and neonates emerged from the nests 1 to 9 days after hatching and usually in the daytime (Burger 1976a, 1977). Carapace length of hatchlings ranges from 2.5 to 3.4 cm (McCauley 1945; Reid 1955; Conant 1975; Burger 1977; Seigel 1980b). The weight of 207 hatchling northern diamondbacks varied from 5 to 9 g (mean 6.8 g) (Burger 1977); weights of 29 Florida hatchlings varied from 6 to 10.8 g (mean 8.8 g) (Seigel 1980b).

Growth rates of diamondback terrapins in captivity have been studied at the U.S. Fisheries Biological Station (National Marine Fisheries Service) at Beaufort, North Carolina (Coker 1906; Barney 1922; Hildebrand 1929, 1932). Growth rates in wild populations may vary according to latitude or various environmental factors, and there is even variation within local populations. The plastron length of northern diamondbacks reportedly increases about 2.5 cm during each of the first 2 years after hatching, slightly less during the third year, and only about 1.3 cm in each of the fourth and fifth years (Babcock 1919). Some North Carolina terrapins, hatched and reared in captivity, attained plastron lengths of 14 to 15 cm in 6 years; others required 12 or more years to reach such sizes (Hildebrand 1932). Two hundred diamondbacks (mostly intergrades between the northern and Carolina subspecies), held captive for two years, had an initial average plastron length of 30.65 mm and an average weight of 6.485 g. At the end of the first year, plastron lengths averaged 61.93 mm and weights averaged 81.83 g. Comparable averages of 100 individuals at the end of the second year indicated increases to 89.63 mm and 143.08 g (Allen and Littleford 1955). At Merritt Island National Wildlife Refuge, Seigel (1984) found that growth rates in Florida east coast terrapins were greatest during the first 2 years after hatching and declined considerably as the animals reached maturity (at plastron lengths of 9.0 to 9.5 cm in males and 13.5 to 14.0 cm in females).

The age at sexual maturity of terrapins along the Atlantic coast probably varies. Most captive females from North Carolina deposited eggs for the first time when they were 7 years old, but first clutches were produced by some terrapins as young as 4 years and others as old as 8 years (Hildebrand 1932). In a wild population at Dulac, Terrebonne Parish, Louisiana, males attained maturity in their third year of growth; females did not become mature until after their sixth year (Cable 1952). In the Florida population studied by Seigel (1984), male terrapins attained sexual maturity at ages of 2 to 3 years and females at 4 to 5 years. Maximum longevity of the species may exceed 40 years (Hildebrand 1932).

Sexual dimorphism is conspicuous in adult diamondback terrapins. Males differ from females in that they are considerably smaller and have narrower heads and longer, thicker tails, with the vent located posterior rather than anterior to or even with the margin of the carapace. Carapace lengths of the Atlantic subspecies range from 15 to 23 cm in mature females and 10 to 14 cm in mature males (Ernst and Barbour 1972; Conant 1975). Among 221 gravid females from New Jersey, plastron lengths ranged from 13.2 to 18.4 cm (mean 15.44 cm) (Montevecchi and Burger 1975). Males with plastron lengths of 8 to 9 cm usually have developed secondary sexual characteristics (Hildebrand 1932).

Predation on eggs and hatchlings probably represents the major source of mortality in most terrapin populations. Other sources include egg mortality caused by rootlets of the grass *Ammophila breviligulata* invading the nests (Lazell and Auger 1981), entrapment of terrapins in crab pots and subsequent drowning, and, to a limited extent, direct harvest (Bishop 1983). Although the small openings of typical crab pots selectively exclude most adult females, the great number of pots fished each year in diamondback terrapin habitats "may account for more adult terrapin mortalities than any other single factor" (Bishop 1983).

Harvest for human consumption, which has decreased considerably in recent years, is virtually restricted to mature females, the largest individuals in the population (Hay 1904; Coker 1906; Bishop 1983). Because of low recruitment rates caused by high nest and hatchling mortality, it is doubtful that diamondback terrapins can survive long-term direct harvesting (Bishop 1983).

Natural predators on the eggs and hatchlings include foxes (Vulpes fulva), raccoons (Procyon lotor), crows (Corvus brachyrhynchos), and gulls (Larus atricilla) (Burger 1977). Raccoons killed an estimated 10% of the female diamondback terrapins that nested over several years at Merritt Island, Florida, where habitat alteration in the area apparently had resulted in an increase in the raccoon population and forced the terrapins to use manmade dikes rather than natural habitats for their nesting sites (Seigel 1980c). In New Jersey, predators were responsible for egg losses of 51% and 71% in two consecutive years; predators took 22% of the hatchlings in one year (Burger 1977). Barnacle infestations often occur on the carapaces and plastrons of diamondback terrapins, and heavy fouling by these organisms may cause shell erosion, mating and nesting interference, and occasionally death (Seigel 1983). Mortality of both adults and hatchlings resulting from motorized vehicles (boats, automobiles, bikes, etc.) has not been quantified but may be significant in some areas (J. Burger, Rutgers University , New Brunswick, New Jersey, pers. comm.; R. A. Seigel, Savannah River Ecology Laboratory, Aiken, South Carolina, pers. comm.).

SPECIFIC HABITAT REQUIREMENTS

Diamondback terrapins along the Atlantic coast have been reported in brackish estuarine environments including salt marshes, tidal flats and creeks, sounds behind barrier islands, and brackish lagoons and impoundments (Hay 1904; Coker 1906; Carr 1952; Ernst and Barbour 1972; Burger and Montevecchi 1975; Conant 1975; Martof et al. 1980; Seigel 1980b; Bishop 1983). Carolina terrapins were caught in salinities of 4.3 to 22.0 parts per thousand (ppt), with most captures in the 10.1 to 15.0 ppt range (Bishop 1983). Two lagoons supporting populations of Florida east coast terrapins had mean salinities of 27.6 and 31.6 ppt (Seigel 1983). Records of terrapins inhabiting fresh water (Hay 1904) and the ocean (Carr 1952; Neill 1958) are poorly documented.

Food and Foraging Habitat

Marsh grass or cord grass (Spartina alterniflora) is the typical vegetation associated with the aquatic habitats of diamondback terrapins along the Atlantic coast (Coker 1906; Carr 1940; Burger and Montevecchi 1975; Hurd et al. 1979; Martof et al. 1980). A Florida salt-marsh habitat continued to support a thriving population of Malaclemys after being transformed by the construction of dikes for mosquito control into a series of lagoons and impoundments of brackish water (Seigel 1979). Vegetation in this area consisted of dense growths of rooted seagrasses, principally Cymodocea filiforme, Thalasia testudinum, and Halodule wrightii (Snelson and Bradley 1978).

Diamondback terrapins feed chiefly on a variety of crustaceans, mollusks, and other invertebrates occurring in brackish- and salt-marsh habitats (Carr 1952; Ernst and Barbour 1972; Spagnoli and Marganoff 1975). Food items of 14 North Carolina diamondbacks caught in Beaufort Harbor included snails (Littorina irrorata, Melampus lineatus), marine annelids (Nereis sp.), fragments of crabs (including Gelasimus), a sargassum bulb, and pieces of grass (Coker 1906). Northern terrapins from a Delaware salt marsh voided shell fragments of blue mussels, Mytilus edulis (Hurd et al. 1979). Predation by terrapins on adult Atlantic silversides (Menidia menidia) has been recorded in South Carolina (Middaugh 1981). Quantitative studies of their feeding-habitat relationships have not been conducted, but shallow tidal creeks and subtidal mudflats probably represent the most important feeding areas for terrapins. For example, near Charleston, South Carolina, terrapins were caught in crab traps most often during April and May in water less than 3 m deep; it was thought that they were feeding extensively at this time of year and tended to concentrate on the subtidal mudflats where the traps were placed (Bishop 1983).

In Delaware, it was estimated that 1,655 diamondback terrapins occupied the lower 0.9 km of a 6-km long tidal creek draining a 200-ha Spartina alterniflora marsh (Hurd et al. 1979). The width of this apparently prime habitat ranged from 8 to 12 m at spring low tides and from 17 to 25 m at high tides. The channel depth during lower water ranged from 1.3 to 1.7 m, with occasional holes 3-m deep. Maximum current velocities were 1.45 m/s on the flood tides and 1.21 m/s on the ebb tides. Sizable catches of terrapins in Georgia were made in stop nets placed over shell bottoms and near oyster banks in tidal creeks 50 to 200 m wide (Carr 1952).

Reproduction and Nesting Habitat

Observations of Florida east coast diamondbacks revealed that individuals moved from large, open lagoons into small canals and ditches for courtship and mating. The mating process, initiated and completed in the water, seemed only to require conditions calm enough to permit copulation (Seigel 1980a).

Nesting habitats probably vary throughout the range of the species. Most nests have been reported near the aquatic habitats of the terrapins, although females in New Jersey were observed moving 150 m overland to nesting places (Burger and Montevecchi 1975). In Delaware, a large female was seen laying eggs on a site some 8 km from the creek where she was originally tagged (Hurd et al. 1979). At the Merritt Island National Wildlife Refuge, Brevard County, Florida, most terrapins nested on diked roads (Seigel 1979, 1980b). All accounts of nesting activities in areas subject to tidal influence agree that nests are consistently constructed in sandy substrates above the levels of normal high tides.

Although terrapins usually nested on high dunes in New Jersey, they selected flat locations within these dune areas for their nests (Burger and Montevecchi 1975). The mean slope of 35 nest locations was 7.2° (0° to 24°), which was significantly different ($p < .001$) from the mean slope of 18.1° recorded for random points in the high dune area.

The density of vegetation near nests and the percentage of cover also vary. Twenty nests in Massachusetts were equally distributed in vegetated and virtually bare areas (Lazell and Auger 1981). Nests in New Jersey averaged 11.2 cm from the nearest vegetation, principally dune- or beachgrass (Ammophila breviligulata), in areas with a mean cover of 8.2% (0 to 36%) (Burger and Montevecchi 1975). Nests of Florida east coast terrapins were constructed in areas having a mean vegetative cover of 20% (0 to 75%) (Seigel 1979).

Vegetation provides terrapins protection from predators, but heavily vegetated areas also provide habitat for predators. Predation of terrapin eggs by crows and gulls in New Jersey was highest in open sand areas; predation of hatchlings by red foxes (Vulpes fulva) and raccoons (Procyon lotor) was highest in nesting areas surrounded by trees and shrubs (Burger 1977).

Special Considerations

The habitat requirements and activity patterns of juveniles and hatchlings after leaving the nests have not been determined. One of the earliest studies of the species (Coker 1906) noted an unexplained scarcity of hatchlings and small juveniles in the marshes near Beaufort, North Carolina. Although several collecting techniques were employed during a 2-year study of a salt marsh in Delaware, no terrapins with carapace lengths of 30 to 90 mm were found among 792 individuals collected (Hurd et al. 1979). The smallest of 281 South Carolina diamondbacks caught in crab traps was 76 mm in plastron length (Bishop 1983). From late May to October, over a 3-year period at Barnegat Bay, New Jersey, Pitler (1985) found 12 juvenile diamondback terrapins with shell lengths ranging from 2.5 to 7.5 cm. They were discovered under mats of Spartina and various other kinds of sheltering objects at low tides. All were on well-drained ground in a tidal mud flat about 91 m from the water's edge.

Little is known about the specific habitat requirements of diamondback terrapins during cold weather. In North Carolina and Georgia, individuals reportedly burrow "in the 'pluff mud' of tidal flats, often in or near little trickles of water from the exposed marshes, in late October or early November, although any warm day is sufficient to bring them out again and they may be active off and on all through the winter. From the first of March they are rarely in hibernation . . ." (Carr 1952). One juvenile Virginia terrapin, 54 mm in carapace length, was found on November 7 buried about 0.3 m deep in moist sand above the high tide mark along the lower York River at Gloucester Point (Lawler and Musick 1972). Hibernating terrapins at Cape May, New Jersey, were discovered on the bottoms of tidal creeks under water 1.5 to 2.5 m deep at low tides, beneath undercut banks in the intertidal zone, and buried in banks near the upper tide limit (Yearicks et al. 1981).

Terrapins must drink fresh or brackish water to replenish body water stores (Dunson 1970), but the optimum amount of water required to support local populations is not known. Rainfall provides freshwater for hatchlings that cannot grow at salinities found near most nest sites. However, a quantitative description of coastal sites offering optimum access to rainwater in the form of runoff was not found in the literature.

HABITAT SUITABILITY INDEX (HSI) MODEL

Model Applicability

Geographic area. The HSI model for the diamondback terrapin was developed for application along the Atlantic coast from New Jersey to Florida. With some modification, the model should be useful for evaluating habitat in other parts of the range of the species.

Season. The model was designed to produce an index of habitat suitability for diamondback terrapin nesting areas on a year-round basis.

Cover types. The model was designed for application in the coastal upland (U) cover type. This cover type includes dunes near estuarine areas, sandy mounds within marshes, natural sand levees, diked areas, and other coastal elevations above normal high tides.

Minimum habitat area. Minimum habitat area is defined as the minimum amount of contiguous suitable habitat required by a species to complete all or a portion of its life requirements. Specific information on minimum nesting areas required by diamondback terrapins was not found in the literature. If local information is available to define the minimum area needs of terrapins, and less than this amount of area is available, the HSI for the species will be zero.

Verification level. The diamondback terrapin HSI model was developed as a synthesis of existing information on habitat requirements of the species. Model structure was based on the authors' interpretation of the existing data base and the review comments of Dr. Joanna Burger, Rutgers University, New Brunswick, New Jersey; and Dr. Richard A. Seigel, Savannah River Ecology Laboratory, Aiken, South Carolina. The model has not been field-tested.

Model Description

Overview. Diamondback terrapins occur basically in two cover types: estuarine open waters (EOW) (Cowardin et al. 1979), where they feed, bask, hibernate, and mate; and coastal uplands (U) where they nest. This model assumes that it is the suitability of nesting areas that primarily limits terrapin populations. For this reason, and because quantitative data were not found for factors that may be limiting to terrapins in estuarine waters, the model only incorporates variables associated with upland nesting habitat. Terrapins tolerate a wide salinity range within their natural environment, and this factor is also assumed to be non-limiting. The model further assumes that the physiological needs of terrapins for freshwater can be met by rainfall and runoff.

Optimum interspersion or juxtaposition of the two cover types for terrapins is not known, although both must be present to sustain local populations. The model assumes that the nearest boundary of a suitable nesting area must be within 250 m of a tidal creek or other estuarine waters to support a viable terrapin population. The relationship between the nesting habitat variables and the HSI is illustrated in Figure 1.

The following sections provide documentation of the rationale, including the logic and assumptions, used to translate information on diamondback terrapin habitat use to the variables and equations used in the HSI model.

Nesting habitat variables. Diamondback terrapins construct nests above the level of normal high tides in substrates composed of sand or a mix of sand and fine shell fragments. Suitability of sandy uplands for nesting is dependent on three variables: the percent canopy cover of shrubs (V_1); the percent canopy cover of grasses (V_2); and the mean substrate slope (V_3).

Shrubs growing on uplands used by nesting terrapins may provide a protective benefit to hatchlings by serving as a visual screen between hatchlings and avian predators. The model, however, assumes that the absence of shrubs does not result in any significant increase in avian predation, since upland grasses can provide the same protection. On the contrary, shrubs provide habitat for mammalian predators that may consume eggs, hatchlings, and adult females. The model assumes, therefore, that optimum suitability of sandy uplands for nesting terrapins occurs when the shrub canopy cover is $\leq$25%. Cover values $\geq$75% are assumed to render an area unsuitable for nesting. Cover values between 25% and 75% are assumed to affect suitability in a linear fashion.

Grasses growing on open (nonshrub-covered), sandy uplands also affect the suitability of these areas for nesting terrapins. The absence of grass cover exposes hatchlings to increased predation by birds. Too much cover, on the other hand, makes nest construction difficult or impossible, and dense grass-root systems can destroy existing nests. Optimum suitability is assumed to occur when the grass canopy cover is in the range of 5% to 25%. As cover

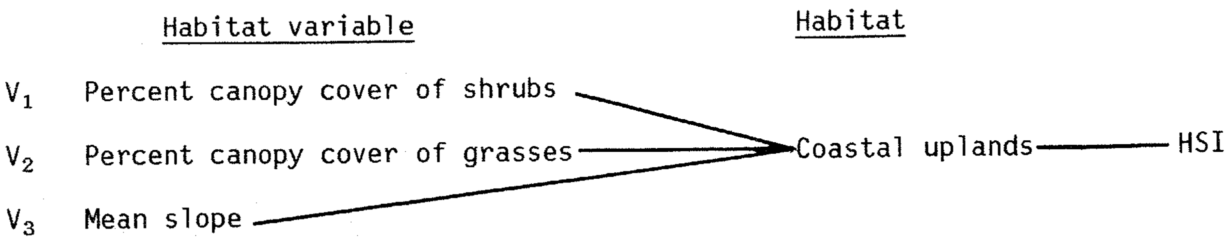


Figure 1. Relationship between the nesting habitat variables and the HSI for the diamondback terrapin.

values decrease below 5% or increase above 25%, the model further assumes that an area's suitability for nesting decreases in a linear fashion. Sandy areas devoid of grass (0% cover) and those completely covered (100% cover) are considered unsuitable for nesting terrapins.

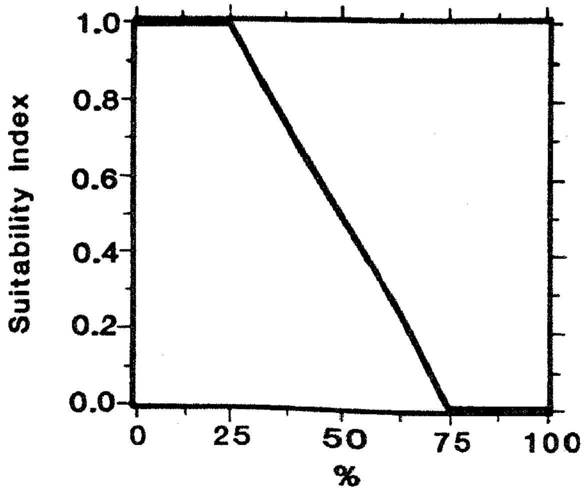
Mean substrate slope is an additional limiting factor on upland nesting sites. Flat substrates facilitate digging and egg laying by terrapins and are less susceptible to erosion than sloping substrates. The model assumes that an area has optimum suitability for nesting terrapins when the mean slope of open, sandy substrates is $\leq 7°$. An area with a mean slope of $\geq 25°$ is considered unsuitable. The model further assumes that suitability decreases linearly as mean slope values increase from 7° to 25°.

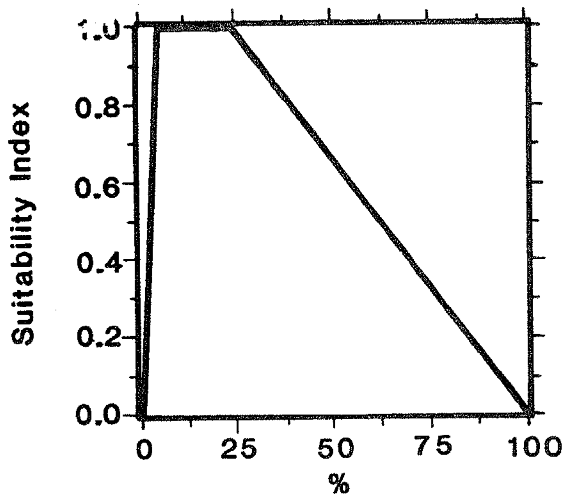
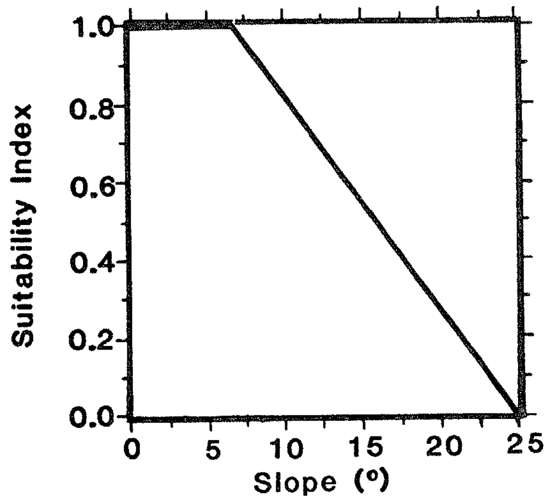
Suitability Index (SI) Graphs for Model Variables

This section provides graphic representation of the relationship between habitat variables and habitat suitability for the diamondback terrapin in sandy upland (U) cover types. The SI values for each variable are read directly from the graph (1.0 = optimum suitability, 0.0 = no suitability).

Major assumptions used in developing the SI graph for each variable are summarized in Table 1. The SI graphs are based on the assumption that suitability can be represented by a two-dimensional linear response surface. Each variable is further assumed to operate independently over the range of the others. Additional model assumptions are found in the text.

Habitat	Variable		Suitability Graph
U	V_1	Percent canopy cover of shrubs.	



Habitat	Variable		Suitability Graph
U	V_2	Percent canopy cover of grasses.	
U	V_3	Mean substrate slope.	

HSI Determination

Each of the three nesting habitat variables is assumed to be of equal importance in determining the distribution and abundance of terrapin nests in an area. A high suitability rating for one variable cannot compensate for or offset a low rating in another. It is further assumed that female terrapins construct their nests in open (nonshrub-covered), sandy areas.

The following equation is suggested for combining individual variable SI values for deriving the overall HSI. The HSI is set at 0 if the shortest distance between the boundaries of estuarine aquatic and sandy upland areas exceeds 250 m, as measured from the point of Mean High Water (MHW).

$$HSI = (SI_{V_1} \times SI_{V_2} \times SI_{V_3})^{1/3}$$

Examples of SI and HSI values determined from three hypothetical data sets are shown in Table 2.

Table 1. Variable sources and major assumptions for diamondback terrapin suitability indices.[a]

Variable and source		Assumption
V_1	Burger (1977) Seigel (1980a)	Suitability of nesting habitat is related to the percent canopy cover of shrubs. Optimum suitability occurs when ≤25% of the upland area is shrub covered. Cover values ≥75% are unsuitable.
V_2	Burger and Montevecchi (1975) Burger (1977) Seigel (1979) Lazell and Auger (1981)	Suitability of nesting habitat is related to the percent canopy cover of grasses on sandy substrates. Optimum suitability occurs when cover values are 5%-25%.
V_3	Burger and Montevecchi (1975)	Suitability of nesting habitat is related to the mean slope of sandy substrates. Optimum suitability occurs when the mean slope is ≤7°. Slopes greater than 25° are unsuitable.

[a]Other assumptions are found in the text.

Table 2. Calculations of the suitability index (SI) for each habitat variable (V), and the habitat suitability index (HSI) for three sample data sets using the diamondback terrapin HSI model equation.

Model element	Data set 1		Data set 2		Data set 3	
	Data	SI	Data	SI	Data	SI
Variable						
V_1	40%	0.80	75%	0.33	10%	1.0
V_2	3%	0.60	40%	0.80	25%	1.0
V_3	10°	0.83	18°	0.39	5°	1.0
HSI	0.74		0.47		1.0	

Field Application of the Model

The diamondback terrapin HSI model is designed primarily for mitigation planning purposes. It is not designed as a research or management tool for increasing terrapin numbers. Variables included in the model can be estimated to reduce costs of model application. Increased use of subjective estimates, however, decreases model replicability. When estimates are used, they should be accompanied by appropriate documentation to ensure that persons making decisions understand both the method of HSI determination and the quality of the data used to arrive at these determinations. Techniques for measuring variables included in the model are suggested in Table 3.

Table 3. Suggested measurement techniques for habitat variables used in the diamondback terrapin HSI model.

Variable		Suggested technique
V_1	Percent canopy cover of shrubs.	Estimate canopy cover from aerial photos or vegetation maps or make site visits to measure the ground surface shaded by a vertical projection of all shrubby vegetation at random or selected sample sites. Relate canopy cover for sample areas to total upland area.
V_2	Percent canopy cover of grasses.	Refer to aerial photos or vegetation maps or make site visits to measure the ground surface shaded by a vertical projection of grasses at random or selected sample sites. Relate canopy cover for the sample sites to total area of open sandy substrate.
V_3	Mean substrate slope.	Select sample sites in the habitat area and measure the maximum slope angle at various sampling points with a protractor or surveyor's transit. Sum angles and divide by number of sample points to determine the mean slope for the area. or Refer to U.S. Geological Survey quadrangle maps and estimate slope angle for individual sample sites by determining the following: arctan $(\frac{\Delta h}{d})$ where Δh is the difference between two contour values being considered, and d is the distance between the two contours on the map for each sample site. Sum slope angles and divide by number of sample sites to obtain the estimated mean slope for the area.

The major assumption of the HSI model is that an area's potential value to terrapins is determined by its habitat features. There are, however, at least two non-habitat factors that may affect this potential: commercial crabbing operations and recreational activities. Crab traps, outboard motors, and all-terrain vehicles may be responsible for unusually high mortalities among both adults and hatchlings in some localities. Field users of this HSI model may wish to take these factors into account when assessing an area's suitability for terrapins. Unfortunately, quantitative data on the impacts of crab traps and motorized vehicles on terrapins are generally lacking.

Interpreting Model Output

The HSI value obtained by applying the terrapin model may have no relationship to actual population levels. Terrapin population levels may be determined by non-habitat factors such as competition, seasonal storms, and, as mentioned above, commercial crabbing and the operation of motorized vehicles in the animal's habitat. Outputs for this model, however, can be used (1) to compare the habitat potential of two areas to support terrapins at a single point in time, or (2) to compare the potential of a single area to support terrapins at future points in time.

SOURCES OF OTHER HABITAT MODELS

No other habitat models of the type developed here for the evaluation of diamondback terrapin habitat were located in the literature.

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A review and synthesis of existing information were used to develop a Habitat Suitability Index (HSI) model for the diamondback terrapin (Malaclemys terrapin). The model is scaled to produce an index between 0.0 (unsuitable habitat) and 1.0 (optimum habitat). HSI models are designed to be used with Habitat Evaluation Procedures previously developed by the U.S. Fish and Wildlife Service.

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