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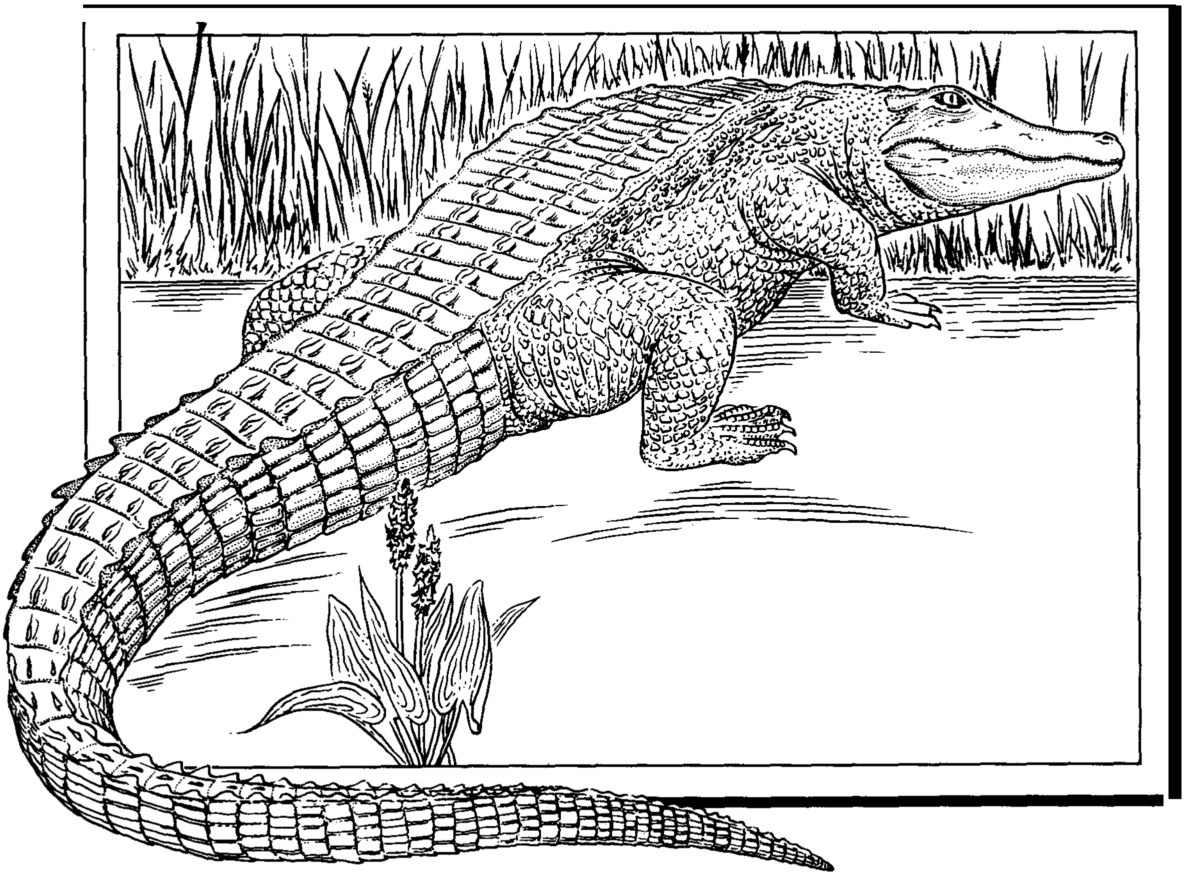

Fish and Wildlife Service

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HABITAT SUITABILITY INDEX MODELS: AMERICAN ALLIGATOR

by

John D. Newsom
Professional Wildlife Service
6973 N. Rothmer Drive
Baton Rouge, LA 70808

Ted Joanen
Rockefeller Wildlife Refuge
Louisiana Department of Wildlife and Fisheries
Grand Chenier, LA 70643

and

Rebecca J. Howard
National Wetlands Research Center
U.S. Fish and Wildlife Service
1010 Gause Boulevard
Slidell, LA 70458

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National Wetlands Research Center
Research and Development
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PREFACE

The habitat suitability index (HSI) model for the American alligator is intended for use in the habitat evaluation procedures (HEP) developed by the U.S. Fish and Wildlife Service (1980) 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 nesting alligator habitat suitability between 0 (unsuitable) and 1 (optimally suitable). Assumptions involved in developing the HSI model and guidelines for model applications, including methods for measuring 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 and suggestions you may have on the HSI model to the following address.

Information Transfer Specialist
National Wetlands Research Center
U.S. Fish and Wildlife Service
1010 Gause Boulevard
Slidell, LA 70458

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ACKNOWLEDGMENTS

Development of the habitat suitability index model and narrative for the American alligator was reviewed by L.L. McNease, Louisiana Department of Wildlife and Fisheries, Grand Chenier, and Robert H. Chabreck, Louisiana State University, Baton Rouge. Evaluation of the model structure and functional relationships was provided by personnel of the U.S. Fish and Wildlife Service's (FWS) National Wetlands Research Center. Model and narrative reviews were also provided by representatives of the FWS Division of Ecological Services in Corpus Christi, Texas; Houston, Texas; Lafayette, Louisiana; and Panama City, Florida. Funding for model development and publication was provided by the FWS. Patrick Lynch prepared the cover illustration for this report.

AMERICAN ALLIGATOR (Alligator mississippiensis)

INTRODUCTION

Distribution and Commercial Importance

The American alligator (Alligator mississippiensis) is a North American reptile of the order Crocodilia, family Crocodylidae. It and A. sinensis, a species found in China, are the only known members of the genus existing in the world (Ditmars 1964). Other closely related members of the order Crocodilia, the crocodiles, number 21 species worldwide and are represented by a single species in the United States, Crocodylus acutus. This species has a limited range in southern Florida.

The American alligator is characteristically a resident of river swamps, lakes, bayous, and marshes of the Gulf and Lower Atlantic Coastal Plains from Texas to North Carolina (Conant 1958).

Alligator skins have been a highly prized article of commercial trade in the leather industry for many years, and a source of income to trappers and landowners. Because of this demand and a relatively unrestricted harvest in the first half of this century, the alligator population declined to its lowest level about 1960. Growing concern for the future of the species prompted the Louisiana Department of Wildlife and Fisheries and, ultimately, the Louisiana Legislature to impose certain harvest restrictions in 1960. All commercial harvest in Louisiana was prohibited in 1964. In 1967, the species was placed on the Federal endangered species list throughout its range (National Fish and Wildlife Laboratory 1980). Response to these actions was spectacular. By 1972 the population had increased to the point where Louisiana petitioned the U.S. Fish and Wildlife Service to change the status of the alligator to allow controlled harvest (Palmisano et al. 1973). The status was changed to "Threatened by Similarity of Appearance" [T(S/A)] in a limited number of parishes (counties) in Louisiana in 1975, and restricted harvesting began. The current Federal status of the American alligator is as follows: T(S/A) in Texas and Louisiana, threatened in Florida and areas of Georgia and South Carolina, and endangered in the remainder of its range (Federal Register, 50 CFR 17.11 and 17.12, January 1, 1986).

In recent years alligator meat has become a highly regarded gourmet food item. The market is developing to the extent that with adequate slaughter and processing facilities, it may equal the commercial value of the skins.

Life History Overview

Alligators are amphibious reptiles requiring both land and water to meet their needs; they prefer fresh to brackish water and generally avoid saline habitats. Adults often dig dens at the edges of rivers or lakes and in marshes; dens have underwater entrances that lead to an underground hollow (National Fish and Wildlife Laboratory 1980).

Adult male and female alligators in south Louisiana gather together in the deeper open water lakes, canals, and bayous as the spring breeding season approaches. Courtship and breeding occur from April through mid-June (Joanen and McNease 1980). Following the mating season, males remain in the deep water areas. Males occupied summer home ranges with an average minimum size of 887 ha (Joanen and McNease 1972). The males show no fidelity toward den sites until late autumn, when they return to established dens and remain in the close vicinity through the winter. Females disperse to nesting areas after successful mating and remain until the following spring. The amount of habitat used by females varies according to season; the average home range size for four adult females during the spring, summer and fall was 8.5 ha (range 2.6 to 16.6 ha) (Joanen and McNease 1970). The female constructs a nest of mud and any available vegetation. Joanen (1969) described the nesting ecology of alligators in southwest Louisiana. The nests averaged 1.8 m in diameter and 0.6 m in height. Egg laying began about mid June and ended usually in the first week of July. Eggs averaged 39 per clutch and hatched after 65 days of incubation. Females usually released the young, which averaged 23 cm in length, from the egg chamber at hatching by removing the top layer of nest material. About 50% of the young liberated themselves from two nests to which nesting females failed to return.

Young alligators grow fairly rapidly during the first 10 years, at which time males average 2.55 m and females 2.10 m. After 10 years, the growth rate declines rapidly in females; males continue to grow until about age 20 (Chabreck and Joanen 1979). Joanen and McNease (1980) reported that most alligators, both male and female, were sexually mature at 1.83 m total length. Captive female alligators raised in outdoor enclosures first nested at 9 yr 10 mo, and 2.10 m total length.

HABITAT REQUIREMENTS

Food

McIlhenny (1935) stated that an alligator will eat any living thing small enough to kill, whether it flies, walks, swims, or crawls. Delaney and Abercrombie (1986) examined the contents of 350 alligator stomachs collected during late summer and early fall by hunters on three lakes in north-central Florida. They found that alligators ingested a wide variety of food items; variation in diet was attributed to type of habitat occupied, prey species encountered, prey vulnerability and size, and alligator size. Fish species were the most important food item in terms of percentage volume (57%), but ranked second to snails in frequency of occurrence. Invertebrates (including snails) had a low (0.8%) percentage volume. Reptiles ranked second in percentage volume (23%) and third in frequency of occurrence. Turtles (primarily *Pseudemys nelsoni*, *P. floridana*, and *Sternotherus odoratus*) were the most common reptile and the most important food for alligators exceeding 3 m in length. Subadult alligators consumed more invertebrates and terrestrial prey (primarily round-tailed muskrat [Neofiber alleni] and marsh rabbit [Sylvilagus palustris]) than did larger alligators. Adult females also consumed more mammals than did adult males. The variation in diet by size and sex was probably due to the tendency of large alligators, primarily males, to spend more time in open water. Delaney and Abercrombie noted that alligators in Florida consumed more fish and turtles and fewer mammals than did alligators in other parts of this species' range. Diverse wetland habitat that can provide a variety of foods was suggested as an essential component of alligator habitat.

McNease and Joanen (1977) studied adult alligator diets in various marsh types in southwestern Louisiana and found vertebrates (mammals, birds, reptiles, and fish) to be the most important class of foods taken. Based on percentage weight of food items in the stomachs of 314 freshly killed alligators in September of 1972 and 1973, the most important foods in fresh and intermediate marshes were mammals, arthropods (crabs, shrimp and crawfish), fish, birds, and reptiles, respectively. In brackish marshes, fish, arthropods, mammals, birds and reptiles, respectively, were most important.

Valentine et al. (1972) examined stomach contents of 413 alligators taken during 1961-62 and 1964 by hunters on Sabine National Wildlife Refuge (southwest Louisiana), where water salinities range from near-fresh to brackish. They found crustaceans and fish to be important foods for alligators 1.5 m long and greater. Reptiles, birds, and mammals were also well represented. A comparison of this study with that of Giles and Childs (1949), who examined 318 stomachs of alligators killed by hunters in 1946, revealed that mammals were eaten in proportion to their availability. In 1946, remains of muskrats (Ondatra zibethicus rivalicius) occurred in 17% of the stomachs collected, while those of nutria (Myocastor coypus) were absent. Muskrats were near the peak of their population cycle in 1946 (O'Neal 1949), but nutria had not yet become well established in the coastal marshes. In 1961, however, nutria remains were found in 56% of the alligator stomachs collected and muskrat remains were absent. Muskrat populations had declined and nutria were abundant in 1961 (Greg Linscombe, Louisiana Department of Wildlife and Fisheries, New Iberia; pers. comm.).

Chabreck (1971) examined stomach contents of 20 young Louisiana alligators less than 1.8 m long. Ten were from saline environments and 10 from freshwater environments. Basing his data on fresh total weight, he found crustaceans, mostly crawfish and crabs, were the principal foods taken in both areas. This study suggested that young alligators in saline environments eat less and grow slower than those in freshwater environments.

Investigators studying the food habits of young alligators (less than 1.2 m long) in Florida documented heavy predation on invertebrates. Fogarty and Albury (1967) found that invertebrates made up about 98% of the diet of 36 alligators: snails (Pomacea paludosa), 66%, and crawfish (Procambarus sp.), 32%.

Cover

Reproduction. During the breeding season in southwest Louisiana, alligators congregated in deep, open water areas of the marsh (e.g., ponds, lakes, canals), where courtship and copulation occurred (Joanen and McNease

1970, 1972). Following successful mating, females moved to marsh characterized by small, shallow pot holes and ponds interspersed with wiregrass (Spartina patens). Few nests were placed in marshes where salinities exceeded 10 parts per thousand (ppt) (McNease and Joanen 1978). Females at Rockefeller Refuge in Louisiana occupied areas ranging from an average of about 2 ha during nest construction to about 0.1 ha during the first half of the incubation period (Joanen and McNease 1970). In areas considered to be excellent habitat on Rockefeller Refuge, alligator nests averaged one per 5.2 ha (Ted Joanen, unpubl. data).

Most (80%, n = 315) nesting females studied at Rockefeller Refuge from 1964-68 used the natural marsh (i.e., outside impounded areas) and constructed nests of wiregrass (Joanen 1969). When other plants, including Scirpus robustus, Phragmites communis, Spartina alterniflora, and Scirpus olneyi, were present they were used along with wiregrass. Baccharis halmifolia was usually mixed with other nest materials when nests were on or near levees. Goodwin and Marion (1978) found that alligators in Florida nested close to permanent water and used a wide variety of plant materials for nest construction.

Alligators in lakes of inland Louisiana nested on sloping banks, usually within a few meters of the water's edge but sometimes as far as 54 m from the edge. Swamp-dwelling alligators nested on elevated areas including old road beds and canal banks. Nesting materials consisted of whatever vegetation was available; in most cases, alligators in swamps use more soil in nest construction than did marsh-dwelling alligators (Dave Taylor, Louisiana Department of Wildlife and Fisheries, Bernice; pers. comm.).

In the Okefenokee National Wildlife Refuge, 90% (n = 99) of the alligators studied nested in the wet prairie and 10% in elevated areas of the swamp forest (Metzen 1977). About two-thirds of nests in the wet prairie were on peat batteries (formed from sections of peat that break away, float to the surface, and become vegetated with various wetland species, primarily maidencane [Panicium hemitomon]). The remaining nests in the wet prairie were supported by tree houses (elevated areas densely vegetated with various shrubs and vines). As in other alligator nesting studies, the most readily available vegetation was used as nest material.

Hatchlings and Immatures. Cover requirements for alligators newly hatched to about one year of age appear to be met by habitat used by females as nesting and den sites because they usually remain in the vicinity in close association with the female (McIlhenny 1935).

McNease and Joanen (1974) found immature alligators (from 1.1 to 1.8 m) of both sexes utilizing deep water areas during summer, autumn, and winter and moving into shallower areas and the emergent marsh in the spring. They believed that temperature, interspersion of water and vegetated areas, water levels, and the availability of food influenced habitat use by immatures. A preference for the intermediate marsh type (as defined by Chabreck 1970) was noted.

Adults. Adult alligators apparently find suitable cover where permanent fresh to brackish water is available, including lakes, streams, canals, swamps, and marshes. In coastal Louisiana, the intermediate marsh type contained a greater density of alligators than fresh or brackish marshes (McNease and Joanen 1978). Joanen and McNease (1970, 1972) reported that adult male alligators preferred deep water canals and lakes throughout the year. They believed that the deep waters buffered the effects of extreme temperatures during the various seasons. Adult females, however, spent the entire year, except during the breeding season, in and around their dens in the marsh. In a north-central Florida lake, Goodwin and Marion (1979) noted that female alligators were more sedentary than males throughout the year. During summer, males preferred open lakes while females restricted themselves to surrounding swamps.

HABITAT SUITABILITY INDEX (HSI) MODEL

Model Applicability

Geographic area and season. The habitat suitability index (HSI) model for the American alligator is applicable in northern Gulf of Mexico coastal marshes, principally in Louisiana and Texas. It provides an index to habitat suitability during the alligator nesting season, from the onset of mating to hatching of the eggs. Variables should therefore be sampled during May through September.

Cover types. This model was developed to evaluate fresh, intermediate, and brackish marshes in coastal Texas and Louisiana as habitat for nesting alligators. These wetlands are described by Cowardin et al. (1979) as palustrine emergent (fresh) and estuarine emergent (intermediate and brackish). The fresh marsh is dominated by *Panicum hemitomon*. *Alternanthera*, *Eleocharis*, and *Sagittaria* are also common in the fresh marsh. The brackish and intermediate marshes are dominated by *Spartina patens*; other common genera are *Sagittaria*, *Eleocharis*, *Scirpus*, *Juncus* and *Distichlis* (Chabreck 1972). The model is not designed to evaluate riverine or interior lacustrine habitats.

Minimum habitat area. Minimum habitat area is considered to be the minimum amount of contiguous habitat required in order to be occupied by a species. Minimum habitat area for the alligator has not been described in the literature. However, an average of one nest per 5.2 ha of habitat considered to be excellent has been found on Rockefeller Refuge in southwest Louisiana. Therefore, it is recommended that the model be applied to areas larger than 5 ha.

Verification level. The model was evaluated by biologists in Louisiana who are active in alligator management or research along the coastal marshes of the northern Gulf of Mexico. L. McNease, Louisiana Department of Wildlife and Fisheries, Grand Chenier, and R. Chabreck, Louisiana State University, Baton Rouge, reviewed the model. Their comments were considered in preparing the model, but the final version is the responsibility of the authors. The model has not been field-tested.

Model Description

Overview. This model has been developed for determining the suitability of coastal marsh as habitat for nesting alligators. Habitat requirements of alligators not nesting are assumed to be provided by an environment that is suitable for nesting. The model evaluates habitat in terms of a single life requisite--cover--for breeding adults and for nesting females. As described previously in this report, the alligator's diet varies greatly and its composition depends on the local abundance of prey species. Food was assumed, therefore, to be adequate and readily available in all areas with appropriate cover; food as a life requisite was not included in this model. The relationship of five habitat variables to the cover life requisite for both breeding adult and nesting female alligators and to the overall HSI value is illustrated in Figure 1. The model should only be applied in wetlands with salinity less than 10 ppt.

Flooding of alligator nests during incubation is a major cause of egg mortality. Flooding may result in almost complete absence of an age class for coastal populations in areas where storm tides or heavy rainfall occur during the critical nesting period. These factors are, however, unpredictable and unmanageable and therefore not addressed in the model.

Breeding cover. Alligators breed in relatively deep, open water. Suitability of an area as breeding habitat is influenced by the amount and type of open water. Open water, defined as that with less than 10% canopy cover of emergent vegetation, over 20% to 40% of the wetland area (V_1) is assumed to be optimal for both breeding and nesting. Bayous, canals, and deeper water areas of lakes and ponds are the preferred areas for breeding, but shallow open water is important for prey species and is used by young alligators. Habitat is optimal when 10% to 20% of the open water is bayous, canals or deeper than 1.2 m in ponds or lakes (V_2). Suitability decreases as this value increases above 20%, and habitat becomes unsuitable when bayous, canals, and deep water represent 100% of the open water.

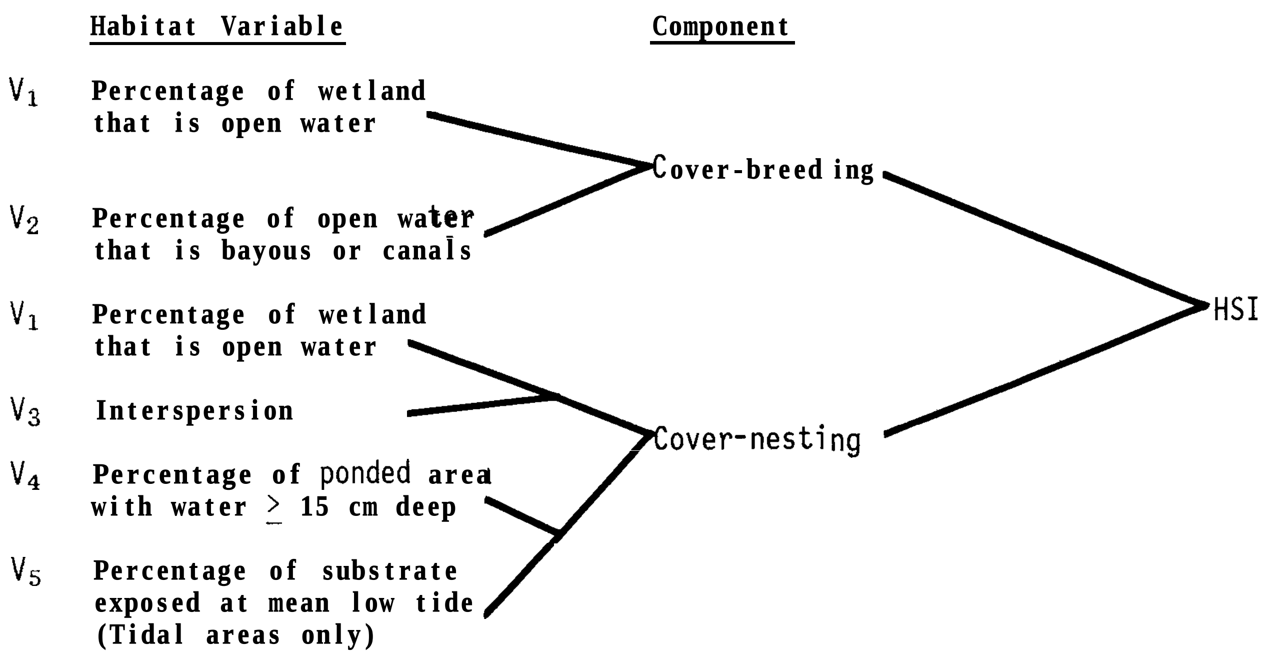


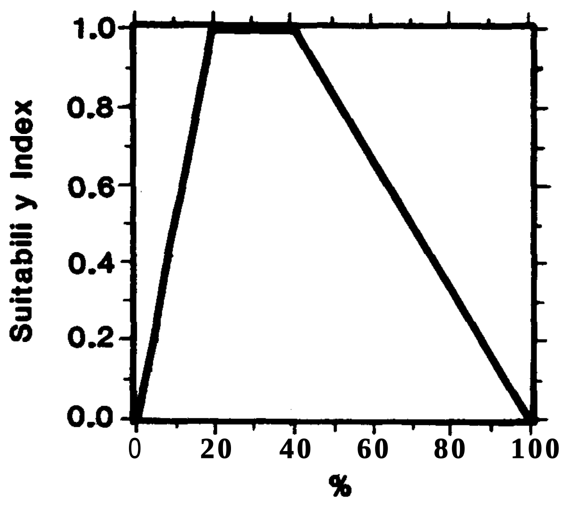
Figure 1. Relationship of habitat variables and the cover life requisite for breeding adults and nesting females in the alligator HSI model.

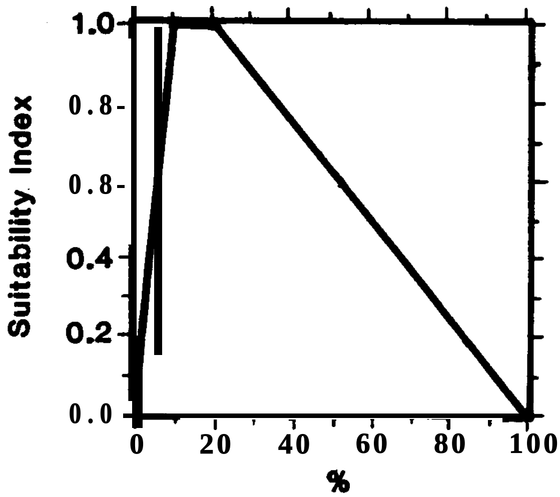
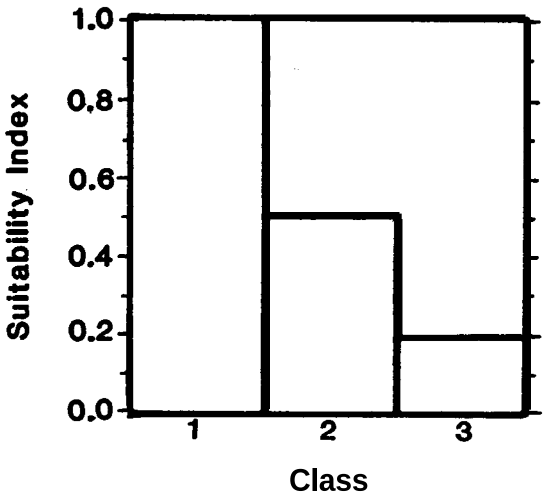
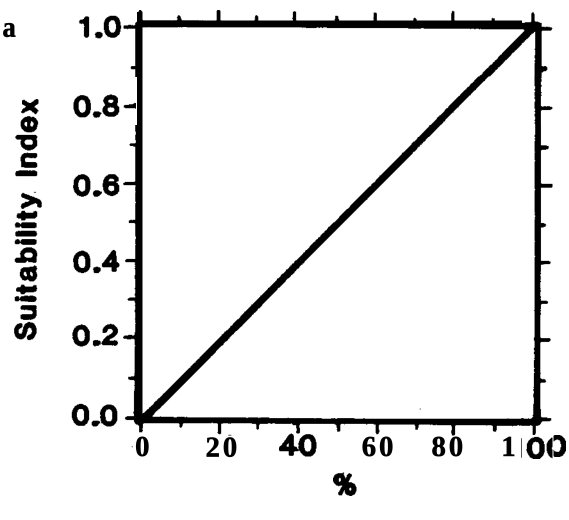
Nesting cover. As mentioned above, 20% to 40% of the wetland area covered by open water (V_1) is assumed to be optimal for nesting female alligators as well as breeding adults. Two additional variables--the interspersion of vegetation and open water and the amount of ponded area that retains water--affect nesting habitat suitability in nontidal wetlands. Optimal habitat has a high interspersion of water and vegetation (V_3). The categories provided in the model for determining the SI value for V_3 are subjective (i.e., high, medium, or low interspersion). Information on the number of ponds greater than or equal to 0.2 ha per 6 ha of wetland habitat is provided as one way to quantify the categories. The percentage of ponds that retain water should also be considered; it is assumed that at least 15 cm of water must be present throughout the nesting period for alligators to use a pond. Suitability increases as the percentage of ponds retaining this water depth increases (V_4).

Fluctuating water levels have an adverse impact on alligator nesting success (Joanen, pers. obs.). A fifth variable--the percentage of substrate exposed at mean low tide (V_5)--is added to the model for use in tidal wetlands. Suitability for this variable decreases as the percentage of exposure at mean low tide increases; the SI becomes 0 at 100% exposure.

Suitability Index (SI) Graphs for Model Variables

The graphs presented in this section illustrate the relationship of each variable to alligator habitat suitability in coastal palustrine emergent (PEM) and estuarine intertidal emergent (E2EM) marshes and associated open water areas with a mean annual salinity less than 10 ppt. The SI values (1.0 = optimum suitability, 0.0 = unsuitable) for each variable are read directly from the graphs. Assumptions involved in developing the graphs are summarized in Table 1.

Habitat	Variable		Suitability Graph
PEM,E2EM	V_1	Percentage of wetland that is open water (ponds, bayous, canals).	

Habitat	Variable		Suitability Graph
PEM,E2M	V_2	Percentage of open water area in bayous, canals, or greater than 1.2 m deep in lakes and ponds.	
PEM,E2EM		V_3 Interspersion class 1. High interspersion; 10-15 ponds (≥0.2 ha) per 6 ha. 2. Medium interspersion; 3-9 ponds per 6 ha or 15-20 ponds per 6 ha. 3. Low interspersion; 2 or fewer ponds per 6 ha, or highly eroded and fragmented marsh.	
PEM,E2EM	V_4	Percentage of ponded area with water ≥ 15 cm deep from May to September.	

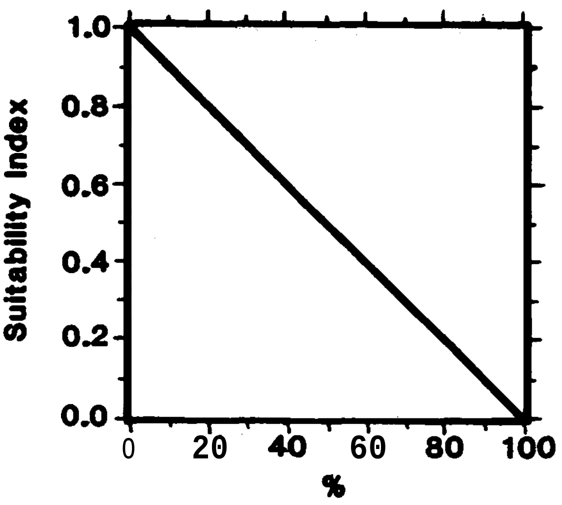
Habitat	Variable		Suitability Graph
PEM,E2EM	V_5	Percentage of substrate exposed at mean low tide from May to September (used in tidal areas only).	

Table 1. Data sources and assumptions for variables used to calculate the HSI for nesting American alligators.

Variable and source	Assumptions
V_1 Joanen (pers. obs.)	Optimal nesting alligator habitat is composed of 20% to 40% open water and 60% to 80% vegetated wetland.
V_2 Joanen and McNease 1970, 1972 McNease and Joanen 1974	Deepwater areas in bayous, canals, ponds, and lakes are essential habitat components for adult alligators during the breeding season and for immatures year round. However, shallow water must also be present to support prey species.
V_3 McNease and Joanen 1974	Nesting alligator habitat quality is directly related to the degree of interspersion of water bodies within the vegetated wetlands.
V_4 Joanen and McNease 1970	Ponds that dry out during the spring and summer tend to restrict the movements of alligators and increase the vulnerability of the young to predation.

(continued)

Table 1. (Concluded).

Variable and source	Assumptions
V_5 Joanen (pers. obs.)	In marsh areas affected by tidal influences, nesting alligator habitat is negatively impacted by any degree of substrate exposure at mean low tide.

Component Index (CI) Equations and HSI Determination

Before applying the alligator HSI model, the user should review the model assumptions to decide the validity of the model for the area in question. Following acceptance of the model, suitability index values for each variable can be read off the appropriate suitability index graph by using collected field data. The following equations are suggested for aggregating the individual SI values into component values and the overall HSI value.

Component	Equation
Cover-Breeding (C_b)	$(SI_{V_1} \times SI_{V_2})^{1/2}$
Cover-Nesting, Nontidal wetlands (C_{nn})	$(SI_{V_1} \times SI_{V_3} \times SI_{V_4})^{1/3}$
Cover-Nesting, Tidal wetlands (C_{nt})	$[SI_{V_1} \times SI_{V_3} \times (SI_{V_4} \times SI_{V_5})^{1/2}]^{1/3}$

$$HSI = (C_b \times C_{nn \text{ or } nt})^{1/2}$$

Sample data sets representing tidal and nontidal areas are presented in Table 2. The outputs derived by using the HSI model equations are believed to be reasonable representations of the value of hypothetical study areas as habitat for American alligators.

Field Use of Model

Although not included as a variable in the model, flooding may have a serious impact on the quality of alligator nesting habitat (Joanen et al. 1977). Local information may be available concerning the tendency of a marsh to flood to a depth above the average height of the nest cavity. Despite the HSI value obtained from application of the model, the HSI becomes 0 if the marsh is flooded above the egg chamber for more than 2 h at any time from June through August.

While field sampling of all variables is desirable for greatest reliability in the determination of HSI values, it should be kept in mind that the level of field sampling required to address all the variables would likely be cost prohibitive. The use of infrared photography and water-level information will greatly facilitate the use of the model. It is therefore suggested that field reconnaissance with intensive use of available maps and water level data will provide the most reliable output from this model. Suggested methods for measuring model variables are presented in Table 3.

Interpreting Model Outputs

This model will only provide information on the potential of a coastal marsh area to support alligators. Other factors (e.g., poaching, storm tides) may, within a particular time frame, exert a greater influence on the alligator population than any of the habitat variables discussed. This model cannot, therefore, be used to calculate alligator populations in any given area. It can be used to compare the potential of different habitats to support alligators at a single point in time or to compare the potential of a single area to support alligators at two points in time.

Table 2. Calculations of suitability indices (SI) and habitat suitability indices (HSI) for three hypothetical data sets on the basis of habitat variables (V) and model equations.

Model component	Data set 1		Data set 2		Data set 3	
	Data	SI	Data	SI	Data	SI
V_1 %	15	0.75	30	1.00	80	0.33
V_2 %	30	0.88	60	0.50	70	0.38
V_3 Class	1	1.00	2	0.50	3	0.20
V_4 %	80	0.80	40	0.40	60	0.60
V_5 %	--	----	55	0.45	--	----
C_b	0.81		0.71		0.35	
C_{nn}	0.84		---		0.34	
C_{nt}	---		0.60		---	
HSI	0.82		0.65		0.34	

Table 3. Suggested methods for measuring habitat variables included in the American alligator HSI model.

Variable	Method
V_1	The percentage of open water can be determined from aerial photography by planimetry.
V_2	Canals and bayous can be identified on aerial photographs, and their area determined by using a planimeter. The area of ponds and lakes with water exceeding 1.2 m in depth may be available from existing maps, or it may need to be determined in the field. The total area can then be expressed as a percentage of the area determined for V_1.
V_3	A grid of 6-ha cells can be superimposed on an aerial photograph. The number of cells in each of the three interspersion categories is counted. These numbers are multiplied by the corresponding SI for the category. The three products are added and then divided by the total number of cells to determine the SI for V_3.
V_4	The percentage of the ponded area with water $\geq$ 15 cm in depth must be determined by field measurement at the probable lowest water level during the May to September period. In tidal areas, measurements should be made at low tide. Biologists familiar with the study area may be able to provide this information.
V_5	In those areas affected by tidal influences, the amount of exposed substrate is determined by field observation at predicted mean low tide (National Ocean Survey tide tables) during May to September. The area exposed is expressed as a proportion of total study site.

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15. Supplementary Notes Authors' affiliations:

[a]Professional Wildlife Service
6973 N. Rothmer Drive
Baton Rouge, LA 70808

[b]Rockefeller Wildlife Refuge
Louisiana Dept. of Wildlife and Fisheries
Grand Chenier, LA 70643

[c]National Wetlands Research Center
NASA-Slidell Computer Complex
1010 Gause Boulevard
Slidell, LA 70458

16. Abstract (Limit: 200 words)

A review and synthesis of existing information were used to develop a model for evaluating American alligator habitat quality. The model is applicable in marshes along the northern Gulf of Mexico. 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 described.

17. Document Analysis a. Descriptors

Mathematical models
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Habitat Suitability Index
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