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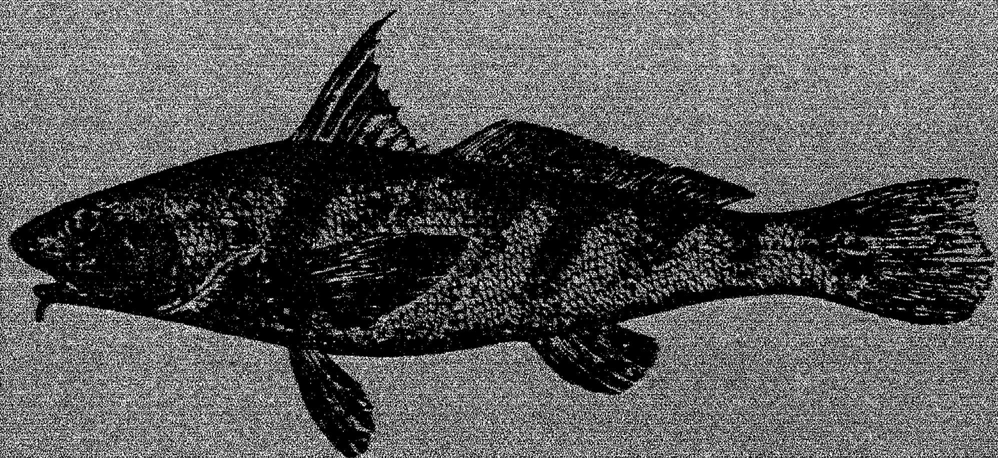
HABITAT SUITABILITY INDEX MODELS: SOUTHERN KINGFISH



Fish and Wildlife Service

U.S. Department of the Interior

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HABITAT SUITABILITY INDEX MODELS: SOUTHERN KINGFISH

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PREFACE

The habitat use information and habitat suitability index (HSI) models in this report on southern kingfish are intended for use in impact assessment and habitat management. The models were developed from a review and synthesis of existing information and are scaled to produce an index of habitat suitability between 0 (unsuitable habitat) and 1 (optimally suitable habitat). Assumptions used to transform habitat use information into HSI models and methods for measuring model variables are described.

These models are hypotheses of species-habitat relationships, not statements of proven cause and effect relationships. The models have not been field-tested, but they have been applied to three data sets taken from published studies on coastal estuaries. Users are encouraged 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 on the southern kingfish HSI models to:

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CONTENTS

ACKNOWLEDGMENTS

Development of the habitat suitability index models and narrative for the southern kingfish was monitored, expertly reviewed, and constructively criticized by Dr. Stephen T. Ross, University of Southern Mississippi, Hattiesburg, Mississippi, and Dr. Thomas D. McIlwain, Gulf Coast Research Laboratory, Ocean Springs, Mississippi. Thorough evaluations of model structure and functional relationships were provided by personnel of the U.S. Fish and Wildlife Service's National Coastal Ecosystems Team and Western Energy and Land Use Team and by Mr. John Lunz, Environmental Laboratory, U.S. Army Corps of Engineers, Vicksburg, Mississippi. Model and supportive narrative reviews were also provided by Regional personnel of the U.S. Fish and Wildlife Service and by representatives of the Division of Marine Resources, Department of Natural Resources, State of Florida. Finally, funding for model development and publication was provided by the U.S. Army Corps of Engineers and the U.S. Fish and Wildlife Service.

SOUTHERN KINGFISH (*Menticirrhus americanus*)

HABITAT USE INFORMATION

The most commonly accepted name for *Menticirrhus americanus* is the southern kingfish (Bailey et al. 1970). It is also known as channel mullet, ground mullet, black mullet, and king whiting in different parts of its range, and landings are reported under different names in different areas. Landing records for commercial species in Mississippi showed that the southern kingfish ranked third among edible finfish taken by trawls, and ninth in economic value for all fisheries in 1978 (Fritzsche and Crowe 1981). Irwin (1970) reported that southern kingfish ranked second to menhaden in total weight of catch landed commercially in Louisiana. It is also important as a sport fish in some waters.

Distribution

The southern kingfish has been collected along the coasts from Long Island Sound, New York, to Port Isabel, Texas. Adults are not resident in any one area, but appear to move out to deeper, more saline waters after their first summer as water temperatures drop. Distribution of juvenile southern kingfish appears to be limited by water current speeds found at the inlets to the estuarine nursery grounds. Large numbers of juveniles have been collected from estuarine nursery areas of Chesapeake Bay, Virginia (Hildebrand and Schroeder 1928; McHugh 1967; Johnson 1978), with entrance currents of 0.5 to 0.8 m/s (1.6 to 2.6 ft/s); from Beaufort Inlet, North Carolina (Hildebrand and Cable 1934), with currents of 0.3 m/s (1.0 ft/s); and from Kiawah Island to Bloody Point, South Carolina (Bearden 1963), in currents from 0.6 to 0.8 m/s (2.0 to 2.6 ft/s). No juveniles, however, have been recorded from Cape Fear, North Carolina (Weinstein et al. 1980), which has relatively rapid estuarine entrance currents of 1.5 to 2.1 m/s (4.9 to 6.9 ft/s); or from North Inlet, South Carolina (Cain and Dean 1976; Shenker and Dean 1979; Bozeman and Dean (1980), with 1.4 m/s (4.6 ft/s) currents.

A similar juvenile distribution pattern appears in the Gulf of Mexico estuarine nursery areas. Juveniles were recorded from Tampa Bay, Florida (Springer and Woodburn 1960), with entrance currents of 0.5 to 0.7 m/s (1.6 to 2.3 ft/s); from Barataria Bay, Louisiana (Gunter 1938), with currents of 0.2 to 0.7 m/s (0.6 to 2.3 ft/s); and from Aransas Bay, Texas (Gunter 1945), with currents of 0.5 to 0.7 m/s (1.6 to 2.3 ft/s). Juveniles were not collected from Lake Pontchartrain, Louisiana (Sutkus et al. 1954; Thompson and Verret 1980), with currents in Chef Menteur and The Rigolets Passes of 1.4 and 1.0 m/s (4.6 and 3.3 ft/s), respectively.

Age, Growth, and Food

Three major developmental stages are recognized for the southern kingfish: larval, juvenile, and adult. After hatching, larval southern kingfish move from offshore spawning grounds to estuarine nursery areas. Although many authors describe this early migration, none have described the food of the larvae. Some authors speculate that the larvae are transported into estuarine nursery areas in surface waters, while others propose that they are carried by bottom currents, or salt wedges. Examination of gut contents to establish either planktonic or benthic feeding has not been reported for larvae. Juveniles (> 8 mm or 0.3 inch total length, TL) are benthic feeders. Irwin (1970) listed the food taken by 50 small southern kingfish juveniles (17 to 50 mm or 0.7 to 2.0 inches standard length, SL) as worms (nematodes and polychaetes) and crustaceans (copepods, mysid shrimp, isopods, and amphipods). Larger prey are taken as the juveniles grow. Fritzsche and Crowe (1981) reported the food habits of larger juveniles (99 to 175 mm or 3.9 to 6.9 inches SL). Crustaceans (mostly penaeid shrimp, some mysids and small blue crabs) made up 71% of the diet by volume, followed by polychaetes and fish. Larger individuals (176 to 270 mm or 6.9 to 10.6 inches SL), predominantly adults, consumed more shrimp, fewer polychaetes, and more fish (usually bottom fish such as flounders and spotted worm eels) than juveniles (Hildebrand and Schroeder 1928; Hildebrand and Cable 1934; Gunter 1945; Reid 1954; Springer and Woodburn 1960; Bearden 1963; Irwin 1970; Fritzsche and Crowe 1981).

Growth in the estuarine nursery grounds is rapid, with increases in length exceeding 20 mm (0.8 inch) per month from spring to fall (Hildebrand and Cable 1934; Springer and Woodburn 1960; Bearden 1963; Christmas and Waller 1973; Fritzche and Crowe 1981). Little increase in mean standard length is seen during the colder, winter months (Fritzsche and Crowe 1981). Southern kingfish reach 100 mm (3.9 inches) SL (Bearden 1963), 116 mm (4.6 inches) SL (Hildebrand and Cable 1934), or 117 mm (4.6 inches) SL (Springer and Woodburn 1960) by the end of the first summer after spawning. They attain average lengths of 150 to 160 mm (5.9 to 6.3 inches) SL by the end of the second summer, and 220 to 230 mm (8.7 to 9.1 inches) SL by the end of the third summer (Bearden 1963). Hildebrand (1954) reported an average winter length of 216 to 320 mm (8.5 to 12.6 inches) SL for southern kingfish taken in trawls in the Gulf of Mexico.

Reproduction

Males reach sexual maturity at a smaller size and younger age than females. Gulf of Mexico populations appear to reach sexual maturity at a smaller size than South Atlantic coast populations. Males from South Carolina were found to have fully ripe gonads when 2 years old, and were at least 195 mm (7.7 inches) SL. The gonads of females were not fully ripe until the fish were 3 years old and at least 230 to 250 mm (9.1 to 9.8 inches) SL. In Mississippi, the gonads of females were fully ripe when the fish were 195 to 291 mm (7.7 to 11.5 inches) long (Fritzsche and Crowe 1981). It is probable that the Gulf of Mexico populations are maturing at a slightly younger age than the east coast populations since the growth rates for both areas are quite similar (Bearden 1963; Fritzsche and Crowe 1981).

There is slight variation in the onset and duration of the spawning season throughout the range of the southern kingfish (Table 1). They spawn in

Table 1. Spawning seasons recorded for southern kingfish in offshore waters for different geographic locations.

Spawning season	Location	Source
May through August	Virginia	Hildebrand and Schroeder 1928
April through September	North Carolina	Hildebrand and Cable 1934
April through September	South Carolina	Bearden 1963; Shealy et al. 1974
April through September	Georgia	Dahlberg 1972
April through October	Georgia	Miller and Jorgensen 1969
April through November	Florida	Springer and Woodburn 1960
March through November	Florida	Gunter and Hall 1965
May through October	Mississippi	Modde 1980
April through October	Mississippi	Fritzche and Crowe 1981
March through November	Mississippi	Christmas and Waller 1973
March through November	Texas	Gunter 1945

deep, offshore marine waters when bottom water temperature reaches 15°C (59°F) in the spring (Gunter 1938; Bearden 1963; Miller 1965; Irwin 1970). Fecundity is dependent on the size of the female. Although fecundity ranged from 46,000 to 332,000 eggs per female (Fritzsche and Crowe 1981), a constant ratio of approximately 500 eggs per gram body weight was found. No information on spawning behavior is available.

Specific Habitat Requirements

The southern kingfish occupies somewhat different habitats during different life stages. Specific habitat requirements are summarized for each life stage.

Adults. Large individuals (> 150 mm or 5.9 inches SL) that can be classified as male or female by the structure of the rapidly maturing gonads are considered adults. Adult southern kingfish generally inhabit waters from 9 to 36 m (29.5 to 118 ft) deep (Fritzche and Crowe 1981; Lagarde 1981) and are frequently found in the vicinity of barrier islands (Irwin 1970).

Adults are frequently taken in trawls in areas of high salinity (> 20 parts per thousand, ppt) characterized as white shrimp (*Penaeus setiferus*) or pink shrimp (*P. duorarum*) grounds. The southern kingfish is the most abundant sciaenid captured on pink shrimp grounds. It occurs in 95% of the trawls, and often is the only commercial-sized fish taken (Hildebrand 1955). In addition, adult southern kingfish appear to be taken most frequently in areas where longshore currents or strong counter currents occur.

The southern kingfish is taken less frequently on brown shrimp (*Penaeus aztecus*) fishing grounds. Although it is among the 20 most common fish taken, it rarely exceeds 5% of the fish caught in brown shrimp trawls. Brown shrimp grounds are usually in the deeper waters (> 20 m or 66 ft) off the continental shelf (Hildebrand 1954) and in softer sediments than, for instance, pink shrimp (Perez-Farfante 1969).

Kingfish are slow swimmers that feed on the bottom. They have proportionately smaller eyes than other sciaenids, and have sensory pores on the tip of the snout, the tip of the lower jaw, and the tip of the single barbel. This indicates that they are not sight feeders, but find their prey by "smell" or by touch (Chao and Musick 1977). They are more active at night than during the day (Livingston 1976), and they do not require light for feeding. These nocturnal habits decrease their vulnerability to predation by sight feeders. Specific causes of mortality other than predation include large losses to commercial gill and trammel net fisherman (Adkins et al. 1979), industrial bottom-fish trawlers for petfood plants (Dunham 1972), and shrimp trawlers (Gunter 1938).

Egg. Southern kingfish eggs are small and pelagic, with multiple oil globules (Breder 1948). They have been measured at 0.8 to 1.2 mm (0.03 to 0.05 inch) before fertilization (Fritzsche and Crowe 1981). They hatch in the offshore waters (salinity > 20 ppt, temperature 15°C or 59°F). Time from spawning to hatching is not known. Fish eggs floating among plankton are probably preyed upon by non-selective plankton feeders, but no estimates for the magnitude of this cause of mortality are known (Dahlberg 1979).

Larvae. The larval stages of the southern kingfish are relatively poorly studied. Two investigations of their development (Hildebrand and Cable 1934; Johnson 1978) included descriptions of 1.7 mm (0.07 inch) TL larvae with the yolk sac resorbed and a continuous finfold. At 5 to 8 mm (0.2 to 0.3 inch) SL the larvae have a full complement of fin rays and are considered juveniles. No information is given on the time required to complete the larval stage.

During the larval period, southern kingfish are transported from the offshore spawning grounds and the higher salinity (> 20 ppt) water necessary for their earlier development into the shallow estuarine nursery grounds, which are often of much lower salinity. The transport process is poorly documented. Hildebrand and Cable (1934) were most successful collecting small southern kingfish (< 10 mm or 0.4 inch SL) by running meter plankton nets just above the bottom. Surface tows yielded only a few percent of the specimens collected. They inferred that the larvae are "chiefly bottom dwelling" like the adults. Bearden (1963) described the larvae as being transported in more saline bottom currents through estuarine areas into tidal streams of lower salinity, traveling in a "salt wedge," similar to the larval or postlarval white shrimp.

Predation is assumed to be the major cause of larval mortality, although estimates of the extent of this loss are not documented (Dahlberg 1979).

Juvenile. In contrast to the poorly documented egg and larval stages of the southern kingfish, the juveniles are collected with sufficient frequency to make information concerning preferred habitats somewhat reliable. Juveniles have been collected from offshore marine waters in early spring, soon after the adults have spawned (Gunter 1938; Bearden 1963; Miller 1965; Irwin 1970; Fritzsche and Crowe 1981), but are reported to immigrate into shallow water habitats while still less than 25 mm (1.0 inch) SL.

Juvenile southern kingfish may be transported far up tidal rivers by higher salinity bottom currents during the first few weeks of life (Johnson 1978). They have been taken in oligohaline tidal creeks (Dahlberg 1972), tidal rivers and estuaries (Bearden 1963; Shealey et al. 1974), protected bays and sounds (Gunter 1938; Swingle 1971; Dunham 1972), and along sandy beaches (Miller and Jorgenson 1969; Dahlberg 1972; Modde 1980; McMichael 1981). Records do not indicate their occurrence in small intertidal creeks that empty rapidly and completely during low tides.

The presence of juvenile southern kingfish in estuaries is limited by current speeds found at inlets to the estuary (discussed in the section on distribution), current speeds in the estuary, and food availability. Juvenile shrimp are stronger swimmers than small (< 25 mm or 1.0 inch SL) juvenile southern kingfish, and are thus not restricted in their distribution by swift inlet currents. They do, however, have similar requirements for food since both are benthic surface feeders. Since shrimp will be one to several hundreds of times more numerous than the southern kingfish in any habitat, their presence in an area otherwise suitable for small juvenile southern kingfish would be an indication of an adequate food supply.

Juveniles are common, though never abundant, in the estuarine nursery areas. They are taken in a wide range of salinities, although not as frequently in waters < 10 ppt. They have been recorded in salinities of 0.9 ppt

(Shealy et al. 1974), 1.5 ppt (Dahlberg 1972), and 2.0 ppt (Perret et al. 1971; Fritzsche and Crowe 1981).

As with many estuary-dependent marine species, a strong size-salinity relationship is found in the southern kingfish (Christmas and Waller 1973). Only the smaller juveniles are found in waters with salinities less than 10 ppt. Larger individuals (> 150 mm or 5.9 inches SL) are rarely taken in waters with salinities less than 20 ppt and are generally found in deeper waters such as in sounds, near the mouths of passes, or near barrier islands (Irwin 1970). They move to deeper waters as the water temperature decreases in the fall (Lagarde 1981).

Although the range of salinities and temperatures where juvenile southern kingfish are found is broad, other water quality parameters are more restricted. They are not found in waters with oxygen concentrations as low as those tolerated by other sciaenids such as spotted seatrout (Cynoscion nebulosus), spot (Leiostomus xanthurus), or Atlantic croaker (Micropogonius undulatus) (Burdon 1978). The dissolved oxygen range reported for southern kingfish taken in Louisiana was 4.0 to 11.3 parts per million (ppm) (Burdon 1978). It is not clear if this is an actual lack of tolerance for low oxygen concentrations, since no physiological studies on southern kingfish have been published, or if it is related to their preference for moving water when in shallow (< 1 m or 3.3 ft) areas. Areas with moving water are assumed to be more likely to have adequate levels of dissolved oxygen than areas of calm water because of enhanced diffusion from the atmosphere. Southern kingfish usually feed facing into the current, thereby enabling them to stay just off the bottom with less effort. They lack a functional swim bladder (Bearden 1963), which makes the fish less buoyant. This is an advantage for demersal, benthic-feeding fish, but lack of buoyancy causes the fish to compensate by expending additional energy to move along the bottom while feeding. Preferred habitats of juveniles include shallow, open areas of estuaries, beaches, tidal rivers, bays, and creeks. These areas often have longshore drift currents, or gentle steady currents in the littoral zone (Richard W. Heard, Gulf Coast Research Laboratory, Ocean Springs, MS 39564; personal communication).

Juvenile southern kingfish appear to prefer firm bottoms, with some silt or sand, and slight scour. Soft bottoms with large accumulations of detritus, indicative of minimal water movement, are unsuitable. Juvenile southern kingfish do not appear as frequently as their congener, the gulf kingfish (Menticirrhus littoralis), in the high-energy, sandy beaches of the surf zone of coastal barrier islands (Gunter 1958; McFarland 1963; Dahlberg 1972; Modde 1980; Modde and Ross 1981).

Although the southern kingfish occurs over a wide range of temperatures, it is not characterized as a eurythermal species. Small juveniles are tolerant of the high temperature waters found in shallow areas along beaches, barrier islands, estuarine flats, and creeks. It appears, however, that the major portion of the inshore population of this species moves offshore to deeper water of 10 to 50 m (33 to 164 ft) during the winter when water temperatures fall below 10°C or 50°F (Bearden 1963).

Predation is presumably the chief cause of juvenile mortality. Small juveniles (< 100 mm or 3.9 inches SL) are probably preyed upon by larger fishes such as redfish and the spotted seatrout, while larger juveniles

(> 100 mm or 3.9 inches SL) and adults are reported to be prey for sharks, particularly the sand shark (*Carcharius taurus*) (Bearden 1963).

Special considerations. No information on the standing stock of southern kingfish from one year to another is available. There is not a sufficient data base in most regions to know when variations in numbers are within the natural fluctuations of year-class size expected in a fish population, or are the result of alterations of habitat that cause decreases in southern kingfish survival. It is, therefore, important to use caution when applying habitat evaluation procedures that do not, or can not, distinguish natural variations in numbers from habitat-induced changes in density.

HABITAT SUITABILITY INDEX (HSI) MODELS

Model Applicability

These models are designed to apply to southern kingfish throughout their range along the continental United States, since requirements and tolerances of Atlantic coast and Gulf of Mexico coast populations are similar.

Since the southern kingfish, like other sciaenids, is less tolerant of kepone and toxaphene in the environment (Schimmel et al. 1976; Bahner et al. 1977; Hansen et al. 1977) than many other fish, models are not applicable for use in areas with known or suspected contamination by such toxic substances.

Season. The habitat suitability index models are designed to apply only during those seasons when habitats are used by southern kingfish.

Habitat types. Southern kingfish use both marine and estuarine habitats during their life cycle. Habitat requirements are governed by the size of the fish, or its developmental stage.

Verification level. The HSI model has an output between 0 and 1 that will serve to distinguish optimal estuarine and marine habitats from those judged less suitable. Published data sets were used to verify that HSI's determined with these models were realistic. These data sets are presented later.

Two biological experts outside the U.S. Fish and Wildlife Service reviewed and evaluated the southern kingfish HSI models. They were Dr. T. D. McIlwain, Gulf Coast Research Laboratory, Ocean Springs, Mississippi, and Dr. S. T. Ross, University of Southern Mississippi, Hattiesburg, Mississippi.

Model Descriptions

Separate marine and estuarine HSI models were developed for the southern kingfish. Habitat variables are based upon two life requisites, food and water quality, which are assumed to be the primary basis for southern kingfish habitat quality. Figure 1 illustrates the relationship of habitat variables to life requisite components for southern kingfish in marine and estuarine habitats.

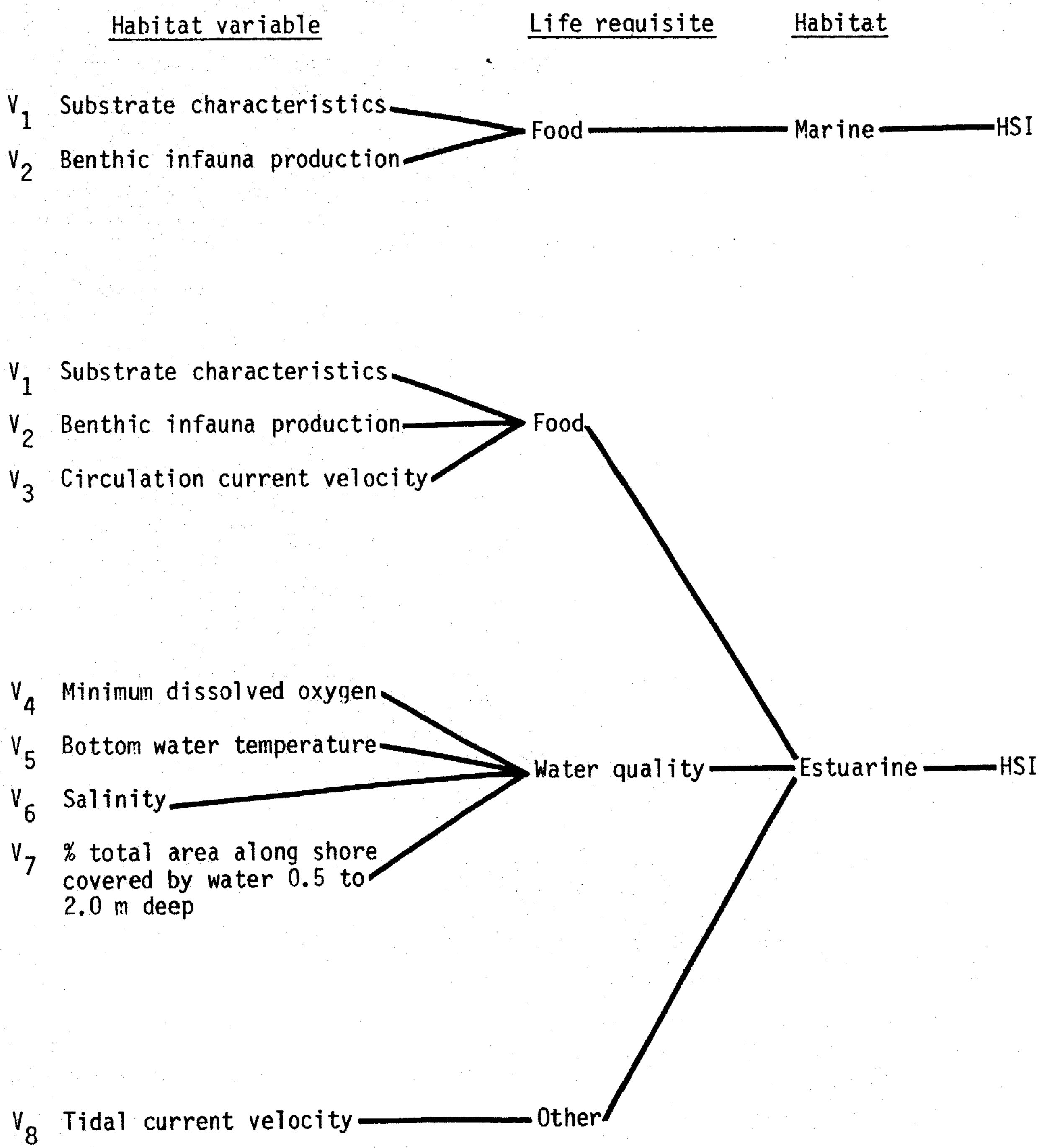


Figure 1. Relationship of habitat variables and life requisites to the habitat suitability index (HSI) for southern kingfish in marine and estuarine habitats.

Marine Model

Food component. Substrate characteristics (V_1) and benthic infauna production (V_2) are considered to be the two most important variables for rating the food component or life requisite for juveniles and adults in the marine habitat. Feeding efficiency and growth in southern kingfish are greatest in areas with firm, sandy substrates and with annual benthic infauna production values greater than 20 g/m^2 (ash-free dry weight).

Studies that have quantified and correlated substrate characteristics and benthic infauna production with southern kingfish standing stocks are not known. For this reason, estimates of the suitability index corresponding to each set of substrate characteristics and to each class of benthic infauna production values identified in the marine HSI model were arbitrarily determined from the general life history literature and from field experience with southern kingfish.

A water quality component was not included in the marine model. It was assumed, for the intended use of this model in impact assessment, that water depth, salinity, and other water quality variables would not be significantly affected by the type of project expected to be evaluated by Fish and Wildlife Service personnel. Suitability of marine habitat for spawning by southern kingfish, primarily dependent on bottom water temperature, was also omitted for this reason. It was assumed that larval requirements during transportation to estuarine nursery areas are met in habitats capable of supporting adults.

Estuarine Model

Food component. Substrate characteristics (V_1) and benthic infauna production (V_2) are as important to southern kingfish in the estuarine habitat as they are in the marine habitat. In addition, circulation current velocity within the estuary (V_3) is also an important variable. Current velocities in the range of 0.15 to 0.3 m/s (0.5 to 1 ft/s) are assumed to be optimum for the species.

Water quality component. Minimum dissolved oxygen (V_4), bottom water temperature (V_5), salinity (V_6), and percent of the littoral zone covered by shallow waters at mean tide (V_7) make up the water quality component of the estuarine HSI model. Juvenile southern kingfish are abundant in the shallow (< 2 m or < 6.6 ft deep) littoral zone of estuarine habitats and have been collected from areas with water temperatures up to 35°C (95°F). In these shallow water areas, dissolved oxygen concentrations may become limiting to southern kingfish, especially when levels drop below 8 mg/l. Optimal salinities are considered to be between 10 and 25 ppt.

Other component. Tidal current velocity (V_8) at entrances (e.g., inlets and passes) to an estuary is assumed to be critical to the successful transport of larvae and young juvenile southern kingfish from marine to estuarine habitats. Some estuaries with swift currents at one entrance may have slower, more suitable currents for the transport of larvae at another. Quantitative information on the transport of larvae is lacking, and optimal tidal current velocities of 0.2 to 0.8 m/s (0.7 to 2.6 ft/s) were estimated from general studies on southern kingfish in a number of different estuaries.

Suitability Index (SI) Graphs for Habitat Variables

This section presents graphic representation of the various measurements of habitat variables and the habitat suitability for the southern kingfish in marine (M) and estuarine (E) habitats. The suitability index (SI) values are to be read directly from the graph. Optimal suitability for a habitat variable is read as 1.0; SI values less than 1.0 indicate the corresponding values of the variable are less suitable for southern kingfish.

Equations for combining habitat varibles into a composite HSI for marine or estuarine habitats are presented in a following section, as are suggestions for measuring or estimating the habitat variables. Data sources and assumptions associated with documentation of the SI graphs are presented in Table 2.

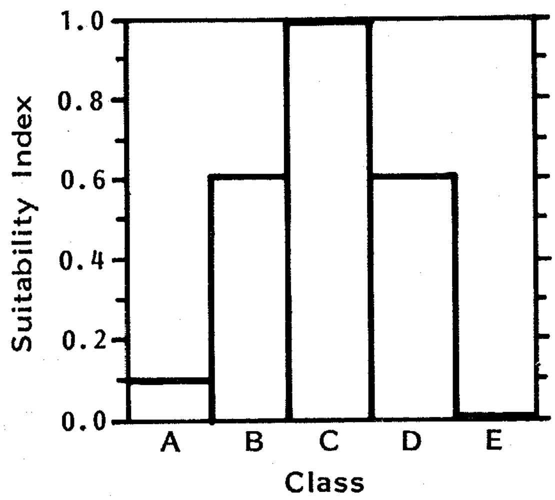
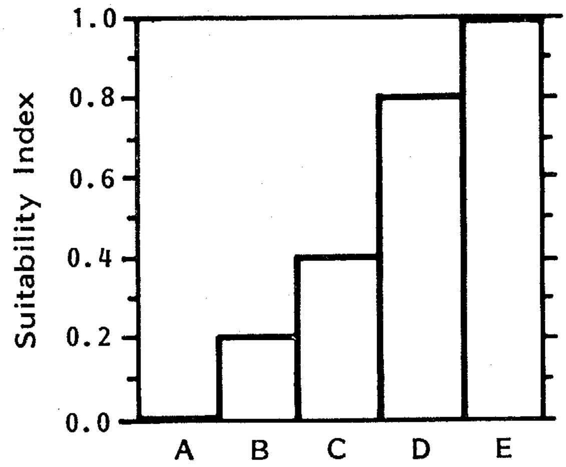
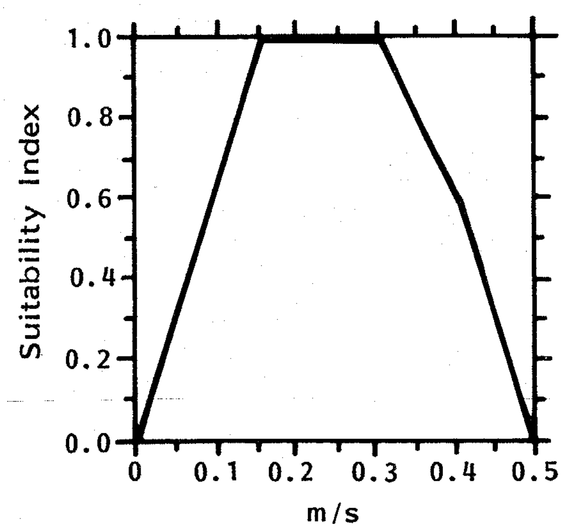
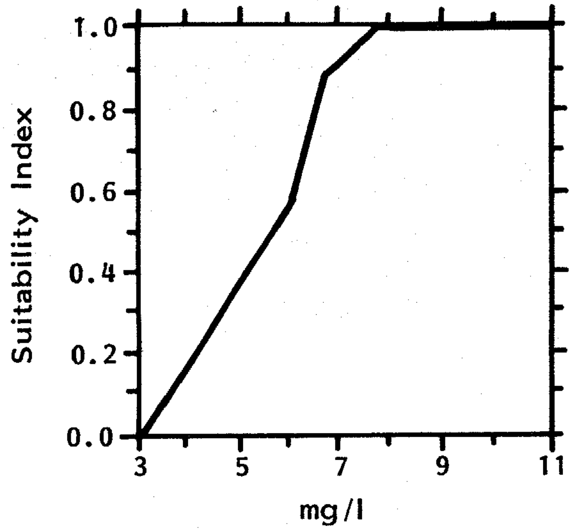
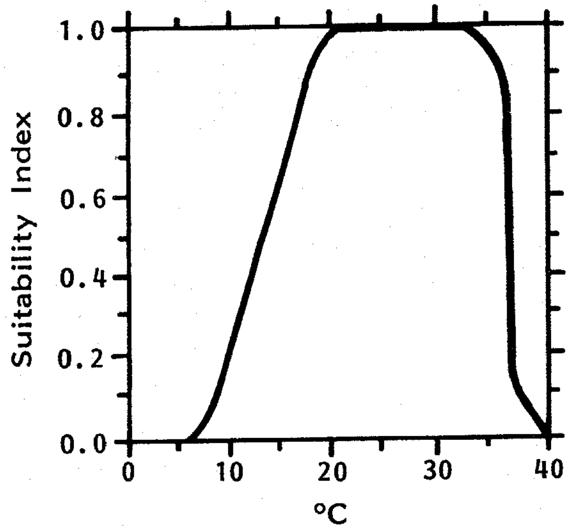
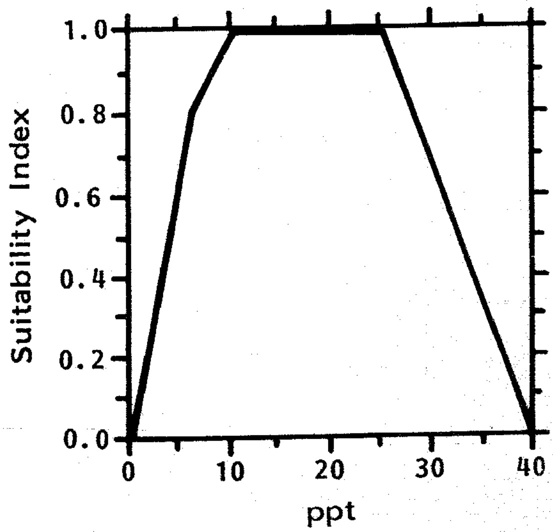
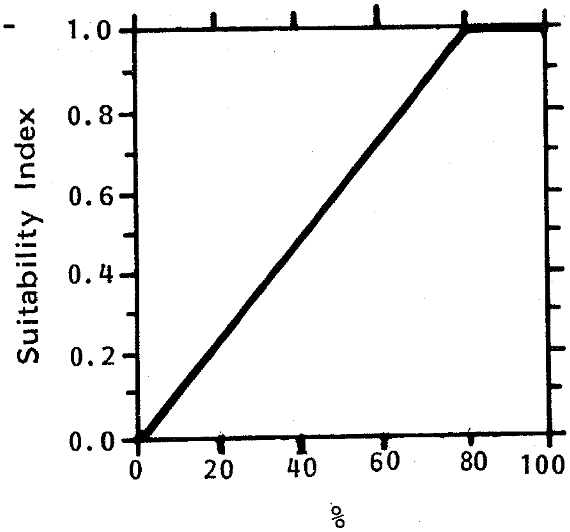
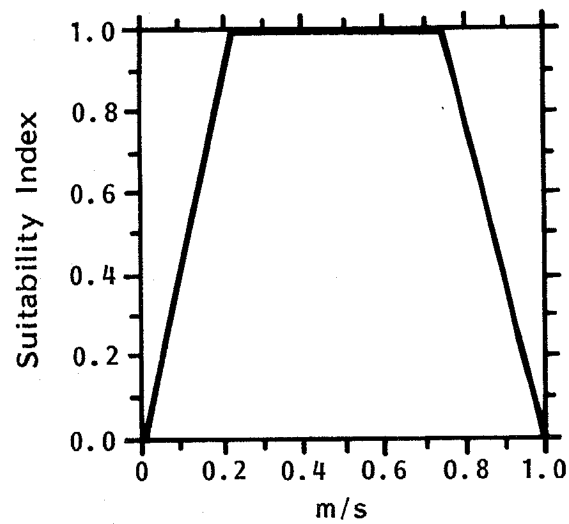
Habitat	Variable		Suitability Graph
M, E	V_1	Substrate characteristics. A) Soft, detritus-covered mud; 5% sand, bulk density (B.D.) < 1.4, mean grain size (ϕ) > 8.0. B) Mud; 5%-30% sand, B.D. = 1.4-1.5, ϕ = 8.0-7.0. C) Firm, silty to sandy mud; 30%-90% sand, B.D. = 1.5-1.9, ϕ = 7.0-2.5. D) Hard sand; 90%-100%, B.D. = 1.9-2.0, ϕ = 2.5-1.0. E) Rock or coral; no sand, B.D. > 2.0, ϕ < 1.0.	

Table 2. Data sources and assumptions for southern kingfish suitability indices.

Variable and source		Assumptions
V_1	Irwin 1970 Chao and Musick 1977 Richard W. Heard, personnel communication	The type of substrate on which southern kingfish can feed with the highest efficiency (most food gained for energy expended feeding) is optimum.
V_2	Bearden 1963 Irwin 1970 Fritzsche and Crowe 1981	Southern kingfish are selective benthic feeders. Areas of bottom containing an abundance of food items known to be preferred from gut content analyses are optimum.
V_3	Richard W. Heard, personal communication	Gentle to moderate currents increase feeding efficiency of southern kingfish.
V_4	Burdon 1978	Lethal levels of dissolved oxygen are unsuitable. Levels that reduce feeding are suboptimal.
V_5	Springer and Woodburn 1960 Bearden 1963 Perret et al. 1971 Lagarde 1981	Optimum temperatures are those that result in optimum growth.
V_6	Dahlberg 1972 Shealy et al. 1974 Fritzsche and Crowe 1981	Salinity levels affect growth of southern kingfish.
V_7	Irwin 1970 Fritzsche and Crowe 1981	The smallest fish are found at the shallowest depths. Depths which permit feeding with the least interference from other species are optimal.
V_8	Hildebrand and Cable 1934 Gunter 1938 Bearden 1963 Dahlberg 1972 Shealy et al. 1974 Johnson 1978 Weinstein et al. 1980	No juveniles are reported from estuaries where the entrance currents exceed 1 m/s (3.3 ft/s). All estuaries reported to have juveniles had at least one entrance with currents under 1 m/s.

Habitat	Variable		Suitability Graph
M, E	V_2	Benthic infauna production. A) Benthic infauna sparse or absent; macrofauna colonial or encrusting, such as corals, bryozoans, or serpulid polychaetes. B) Benthic infauna annual mean standing crop < 5 g/m^2 ashfree dry weight (AFDW), or annual mean production < 10 g/m^2 AFDW. C) Benthic infauna annual mean standing stock < 10 g/m^2 AFDW, or annual mean production < 20 g/m^2 AFDW. D) Benthic infauna dominated by molluscs; crustaceans and polychaetes present; annual mean production > 20 g/m^2 AFDW. E) Benthic infauna dominated by crustaceans and polychaetes, with an annual mean production > 20 g/m^2 AFDW.	
E	V_3	Circulation current velocity within the estuary.	

Habitat	Variable		Suitability Graph
E	V_4	Average minimum summer dissolved oxygen.	
E	V_5	Average summer bottom water temperature.	
E	V_6	Average summer salinity.	

Habitat	Variable		Suitability Graph
E	V_7	% total area along shoreline of estuary, tidal creeks, etc. covered by water 0.5 to 2.0 m (1.6 to 6.6 ft) deep at mean tide.	
E	V_8	Tidal current velocity at entrance to estuary.	

Life Requisite and Habitat Suitability Index (HSI) Equations

To obtain an HSI for southern kingfish in marine or estuarine habitats, the SI values for each habitat variable or life requisite must be combined. Suggested equations for combining variables or life requisites follow:

Marine HSI. Food is the only life requisite considered in the marine HSI equation, and it is based upon two habitat variables. The two variables are assumed to be interrelated and of equal importance to kingfish. Thus, the HSI for southern kingfish in the marine habitat is calculated as follows:

$$HSI = (V_1 \times V_2)^{1/2}$$

Estuarine HSI. The estuarine HSI equation considers three components: a food life requisite; a water quality life requisite; and the tidal current velocity at the entrance to the estuary. The suitability index equation for each of these components and the overall HSI equation for estuarine habitats is as follows:

Component	Equation
Food (F)	$(V_1 \times V_2 \times V_3)^{1/3}$
Water quality (WQ)	$(V_4 \times V_5 \times V_6 \times V_7)^{1/4}$
Tidal current velocity (TCV)	V_8

$$HSI = (F \times WQ \times TCV)^{1/3}$$

Field data collected for three estuarine systems were used to calculate SI, life requisite, and HSI values for southern kingfish. These data sets were derived from published studies and are shown in Table 3. The HSI's calculated from these data sets are believed by the authors to accurately reflect the relative carrying capacities of these areas for southern kingfish.

Field Use of the Models

Much of the information necessary for the use of these models may be available from published or resource agency reports. Table 4 lists equipment or techniques suitable to obtain measurements needed to use the suitability graphs for the southern kingfish HSI models.

Interpreting Model Outputs

A southern kingfish HSI determined by field application of these models may not reflect the actual population density of the species in the habitat being evaluated since factors other than habitat-related ones may be significant in determining population size. It is hoped, however, that the models presented here will yield HSI's that are representative of long-term trends in population density.

The proper use of these models is for the purpose of comparing either two habitats, or the same habitat at different times or under different conditions The higher HSI should correspond to the area, time, or condition that has the capacity to support more southern kingfish than that with the lower HSI.

Table 3. Calculations of the suitability indices (SI) for habitat variables, component indices for food (F), water quality (WQ), tidal current velocity (TCV), and habitat suitability indices (HSI) for Lake Pontchartrain, Louisiana, Barataria Bay, Louisiana, and Ashepoo River and St. Helena Sound, South Carolina, using the southern kingfish habitat variables (V) and estuarine HSI model equations.

Model component	Lake Pontchartrain		Barataria Bay		St. Helena Sound	
	Data	SI	Data	SI	Data	SI
V_1	-	-	B	0.6	C	1.0
V_2	-	-	E	1.0	D	0.8
V_3	-	-	0.15 m/s	0.9	0.25 m/s	1.0
V_4	-	-	7 mg/l	0.9	8 mg/l	1.0
V_5	-	-	27°C	1.0	18°C	0.9
V_6	-	-	10 ppt	1.0	19 ppt	1.0
V_7[a]	-	-	80%	1.0	85%	1.0
V_8	1.0-1.4 m/s	0	0.2-0.7 m/s	1.0	0.6-0.8 m/s	1.0
F		-		0.81		0.93
WQ		-		0.97		0.97
TCV		0		1.0		1.0
HSI		0		0.93		0.97

[a]Data values not measured and considered to be hypothetical.

Table 4. Suggested techniques[a] for measuring variables in estuarine and marine habitats for application in the southern kingfish HSI model.

Habitat variable	Technique
V_1	Substrate samples can be obtained with a coring device such as an Ekman corer, or a grab such as a Ponar, and examined. Descriptions of techniques and additional references appear in Buchanan and Kain (1971) and Sikora and Sikora (1982).
V_2	Benthic infauna production can be determined with precision by analyzing the benthic infauna populations in the habitat under evaluation. Care must be taken that the analysis is designed to answer the question with adequate precision. Green (1979) described techniques for establishing the numbers and size of the samples, and Birkett and McIntyre (1971) provided techniques for the treatment and sorting of samples. Ash-free dry weight determination is described in Crisp (1971) and Sikora and Sikora (1982).
V_3	Estuarine habitat current can be determined similarly to V_8, or with the use of a small flowmeter or a current speed tube (Everest 1967).
V_4	Dissolved oxygen can be determined by using an oxygen electrode or by titration.
V_5	Bottom water temperatures can be obtained using a themistor, or a thermometer and a water sample obtained with a closed sampler such as a kemmerer bottle. Since shallow estuarine water temperature is usually within ± 1°C of air temperature, the climatological data for the previous year (available from the National Climatic Center, Asheville, NC 28801, or from the nearest airport weather station; or consult a large library).
V_6	Salinity can be determined using a refractometer, a conductivity meter, or by titration.
V_7	Depth can be determined by using a fathometer, or lowering a weight on a line (sounding) and measuring the line. Isobaths may also be obtained from navigational charts, if available. Measure the area along the shoreline of beaches, tidal creeks, etc. out to the 2.0 m (6.6 ft) depth contour or isobath and compare this total area with that portion covered by water 0.5 to 2.0 m (1.6 to 6.6 ft) deep at mean tide. The greater the percentage of the total area covered by water 0.5 to 2.0 m deep, the higher the suitability index for southern kingfish.
V_8	Entrance currents can be found in Tidal Current Tables published each year by the National Oceanic and Atmospheric Administration, or can be determined by the use of current meters, or current crosses (Pritchard and Burt 1951; Foerster 1968).

[a]All chemical methods can be found in American Public Health Association (1976), physical and biological methods in Holme and McIntyre (1971) and Sikora and Sikora (1982).

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A review and synthesis of existing information were used to develop marine and estuarine habitat models for Southern Kingfish (*Menticirrhus americanus*). The models are scaled to produce an index of habitat suitability between 0 (unsuitable habitat) and 1 (optimally suitable habitat) for marine and estuarine areas of the continental United States. Habitat suitability indexes are designed for use with Habitat Evaluation Procedures previously developed by the U.S. Fish and Wildlife Service.

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