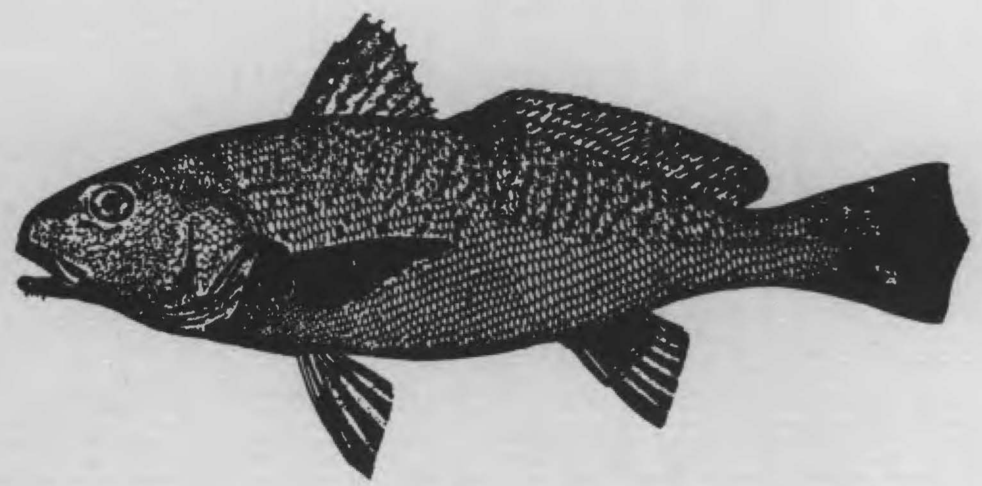
Biological Report 82(10.98)
JUNE 1985

HABITAT SUITABILITY INDEX MODELS: JUVENILE ATLANTIC CROAKER (Revised)



Fish and Wildlife Service

U.S. Department of the Interior

This model is designed to be used by the Division of Ecological Services in conjunction with the Habitat Evaluation Procedures.

This is one of the first reports to be published in the new "Biological Report" series. This technical report series, published by the Research and Development branch of the U.S. Fish and Wildlife Service, replaces the "FWS/OBS" series published from 1976 to September 1984. The Biological Report series is designed for the rapid publication of reports with an application orientation, and it continues the focus of the FWS/OBS series on resource management issues and fish and wildlife needs.

MODEL EVALUATION FORM

Habitat models are designed for a wide variety of planning applications where habitat information is an important consideration in the decision process. It is impossible, however, to develop a model that performs equally well in all situations. Each model is published individually to facilitate updating and reprinting as new information becomes available. Assistance from users and researchers is an important part of the model improvement process. Please complete this form following application or review of the model. Feel free to include additional information that may be of use to either a model developer or model user. We also would appreciate information on model testing, modification, and application, as well as copies of modified models or test results. Please return this form to the following address.

National Coastal Ecosystems Team
U.S. Fish and Wildlife Service
1010 Gause Boulevard
Slidell, LA 70458

Thank you for your assistance.

Species________________ Geographic Location______________________________

Habitat or Cover Type(s)______________________________

Type of Application: Impact Analysis____ Management Action Analysis__________
Baseline_______ Other______________________________

Variables Measured or Evaluated______________________________

Was the species information useful and accurate? Yes___ No___

If not, what corrections or improvements are needed?______________________________

Were the variables and curves clearly defined and useful? Yes____ No____

If not, how were or could they be improved?____________________________________

____

____

____

Were the techniques suggested for collection of field data:

Appropriate? Yes____ No____

Clearly defined? Yes____ No____

Easily applied? Yes____ No____

If not, what other data collection techniques are needed?______________________

____

____

____

Were the model equations logical? Yes____ No____

Appropriate? Yes____ No____

How were or could they be improved?____

____

____

____

____

____

____

Other suggestions for modification or improvement (attach curves, equations, graphs, or other appropriate information)_______________________________________

____

____

____

Additional references or information that should be included in the model:

____

____

____

____

____

____

____

Model Evaluator or Reviewer_________________________ Date____________________

Agency____

Address____

____

____

Telephone Number Comm:__________________________ FTS__________________________

Biological Report 82(10.98)
June 1985

HABITAT SUITABILITY INDEX MODELS: JUVENILE ATLANTIC CROAKER (Revised)

by

Robert J. Diaz
Department of Invertebrate Ecology
Virginia Institute of Marine Science
College of William and Mary
Gloucester Point, VA 23062

and

Christopher P. Onuf
National Coastal Ecosystems Team
U.S. Fish and Wildlife Service
1010 Gause Boulevard
Slidell, LA 70458

Performed for
National Coastal Ecosystems Team
Division of Biological Services
Research and Development
Fish and Wildlife Service
U.S. Department of the Interior
Washington, DC 20240

This report should be cited as:

Diaz, R.J., and C.P. Onuf. 1985. Habitat suitability index models: juvenile Atlantic croaker (revised). U.S. Fish Wildl. Serv. Biol. Rep. 82(10.98). 23 pp.

First printed July 1982 as FWS/OBS-82/10.21; revised June 1985.

PREFACE

The habitat use information and habitat suitability index (HSI) model in this report on juvenile Atlantic croaker is intended for use in 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 transform habitat use information into the HSI model, and guidelines for model applications, including methods for measuring model variables, are described.

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

National Coastal Ecosystems Team
U.S. Fish and Wildlife Service
1010 Gause Boulevard
Slidell, LA 70458

CONTENTS

ACKNOWLEDGMENTS

Development of the habitat suitability index model and narrative for juvenile Atlantic croaker was monitored, expertly reviewed, and constructively criticized by Michael Weinstein, Virginia Commonwealth University, Richmond; John Lunz, Environmental Laboratory, U.S. Army Corps of Engineers, Vicksburg, Mississippi; and Brenda Norcross, Virginia Institute of Marine Science, Gloucester Point. 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 (NCET) and Western Energy and Land Use Team (WELUT). Model and supportive narrative reviews were also provided by representatives of the National Marine Fisheries Service and by Regional personnel of the U.S. Fish and Wildlife Service. Finally, funding for model development and publication was provided by the U.S. Fish and Wildlife Service.

ATLANTIC CROAKER (Micropogonias undulatus)

INTRODUCTION

The Atlantic croaker is an important commercial and recreational species. In the 1940's, the foodfish catch of Atlantic croakers was concentrated in Chesapeake Bay; in the 1950's and early 1970's, the catch was concentrated in the Gulf of Mexico; and in the late 1970's, the catch was concentrated in the South Atlantic States (Wilk 1981). Industrial and recreational catches of Atlantic croakers have been concentrated in the Gulf of Mexico, where the Atlantic croaker is the most important species of bottomfish for industrial uses (Knudsen and Herke 1978), and has ranked first, second, or third in number caught by recreational anglers, depending on survey year (Nakamura 1981). Today, Virginia or Delaware is considered to be the northern extent of the species. During climatically warmer periods, such as the 1930's and 1940's, the croaker extended its range north at least to New York, where it was commercially fished. The southern extent of its range is Argentina.

Life History Overview

Croakers spawn in the fall in marine waters. Spawning grounds are not clearly defined and can range from tidal passes and the mouths of estuaries to Continental Shelf depths of at least 54 m (177 ft) (Pearson 1929; Hildebrand and Cable 1930; Hoese 1965; Fruge and Truesdale 1978; Johnson 1978; Etzold and Christmas 1979). Eggs are pelagic, and upon hatching, the larvae and postlarvae move into estuaries. Actual mechanisms for larval transport into the estuarine nursery grounds are unclear and may be a combination of both passive current transport (Weinstein et al. 1980a; Norcross and Austin 1981; Miller et al. 1984) and active swimming (Pearson 1929).

Once recruited from nearshore marine waters in the fall and winter, larvae 10 to 18 mm (0.4 to 0.7 inches) total length (TL) move up the estuary to areas of brackish water (Bearden 1964), where the transition to juveniles occurs at a size range of 18 to 30 mm (0.7 to 1.2 inches) TL. Juveniles then take up residence in their estuarine nursery areas. Juveniles are also common in tidal riverine habitats (Raney and Massmann 1953).

Juveniles are abundant in estuarine nursery areas as early as September in some areas, but as late as March in others; they remain through June to August, depending on location and year (Parker 1971; Chao and Musick 1977; Yakupzack et al. 1977; Copeland et al. 1984). Growth of juveniles in the nursery areas is rapid, as much as 35 mm (1.4 inches) TL per month (Knudsen and Herke 1978). Most emigrate at around 100 mm (4 inches) TL. Emigration can be either direct to open coastal waters (Parker 1971; Yakupzack et al. 1977; Knudsen and Herke 1978) or gradual, with larger individuals occurring closer to the mouth of estuaries in more saline waters (Haven 1957; Bearden 1964). Reported sizes of Atlantic croakers after one year of life range from 100 to 250 mm (4 to 10 inches) TL (Knudsen and Herke 1978) but estimates of 120 to

180 mm (5 to 7 inches) are most common. Reported sizes after two years of life range from 200 to 310 mm (8 to 12 inches) (Johnson 1978). A validated method of age determination based on microscopic examination of scales yielded estimates of approximately 160 mm and 280 mm (6 and 11 inches) mean total length at age I and age II, respectively (White and Chittenden 1977).

Atlantic croakers mature by the end of their first year of life south of Cape Hatteras at lengths of 140 to 180 mm (5.5 to 7 inches) and seldom survive longer than one or two years. North of Cape Hatteras maturity occurs a year later, at lengths greater than 200 mm (8 inches), and individuals may live for several years (Johnson 1978). Fecundity is 350,000 to 500,000 eggs per female of 350 to 500 mm (14 to 20 in) length (Powles 1981), but must be much less in the typically much smaller reproductive females south of Cape Hatteras.

SPECIFIC HABITAT REQUIREMENTS

The estuarine nursery areas for Atlantic croaker populations differ considerably among locations, apparently in response to tidal range. Where the tidal range is less than 0.5 m (20 inches), shallow open water areas are used at the landward extremities of large bays (Parker 1971), as are shallow creeks, ponds, and lakes intimately associated with marsh (Parker 1971; Yakupzack et al. 1977; Knudsen and Herke 1978; Copeland et al. 1984). Where the tidal influence is stronger, large numbers of small juveniles have been collected from small tidal streams in the spring (Turner and Johnson 1974, in South Carolina); however, according to most other reports, shallow areas are avoided and juvenile croakers are concentrated in the deep, main channels of estuaries as in the Delaware River (Thomas 1981), Chesapeake Bay (Haven 1957), and the Cape Fear River (Weinstein 1980b). Apparently, shallow areas become less suitable for juvenile croakers as daily fluctuations of water level increase. Despite this major difference, the basic life requisites of water quality and cover seem to be similar throughout the range of the Atlantic croaker.

Temperature

Croakers tolerate wide ranges of temperature. Juvenile croakers have been caught at water temperatures ranging from 0° to 36°C (32° to 97°F) (Parker 1971) and grow over a range from 6° to 32°C (43° to 90°F) (Johnson 1978). In general, the early life stages of the croaker are most cold tolerant and adults are least cold tolerant (Johnson 1978). Since croaker recruits immigrate to their nursery grounds from their spawning grounds in winter, very low temperatures may be the major cause of larval and young juvenile mortality. This climatic influence affects a whole region (Norcross and Austin 1981), and it, rather than habitat factors, may often control the abundance of croakers.

Temperature also has been suggested to be an important localized habitat variable when considered in terms of the wide variation and duration of temperature extremes. The tolerance of juvenile croakers to rapid changes in temperature (thermal shock) is limited by their thermal history, with an increase of 17°C (31°F) incapacitating croakers acclimated at 18°C (64°F) and an increase of 9°C (16°F) incapacitating croakers at 33°C (91°F) (Copeland et al. 1974). These findings indicate that temperature variation in the spring should not play as great a role as would temperature variations in summer when overall temperatures are higher. In both spring and summer, temperature variation in deep water habitats is less than it is in shallow areas. This factor is consistent with the concentration of juvenile croakers in deeper areas in most reports from estuaries with large tidal ranges. Large tidal fluctuations expose shallow water to the extreme temperatures of alternately exposed and submerged tidal flats.

Salinity

The tolerance of croakers to salinity is impressive. The species has been found in waters ranging from 0 ppt (Johnson 1978) to 70 ppt (Simmons 1957); however, this is an extreme range that includes all life stages combined. Highest numbers of juveniles are associated with salinities in the oligohaline and mesohaline range (0.5 to 18 ppt) (Parker 1971; Kobylinski and Sheridan 1979; Weinstein 1979; Weinstein et al. 1980b). As croakers grow, they are more likely to be found at higher salinities (Parker 1971, Chao and Musick 1977, Sheridan 1979). The one exception to this pattern was in Barataria Bay, Louisiana (Rogers 1979), and may have resulted from the mortality of croakers incidental to the inshore shrimp fishery in the higher salinity parts of the study area. Rogers (1979) noted the high frequency of large catches of croakers prior to the shrimping season and the rarity of large catches during the shrimping season, just when large croakers should have been most abundant. Shrimping did not extend into the low salinity sampling areas.

Stability of the salinity regime within croaker nursery areas may also be a factor in controlling croaker distribution. Gerry (1981) found croakers most abundant in habitats where salinity fluctuations were the least. Juvenile croakers tend to avoid areas of fluctuating salinity (Herke 1971; Gerry 1981). Rapid changes in salinity, on the order of 5 ppt/h, affect the behavior of juvenile croakers while changes of 1 ppt/h do not (Perez 1969). Avoidance of fluctuating salinity may in part be a reason that croakers in some strongly tidal areas seem to prefer deeper tidal creeks over shallow flats and marsh creeks, since the magnitude of salinity change should be less in deeper water for a given period.

Food

Croakers forage for a variety of organisms on and in the surface layers of sediments (Darnell 1961; Parker 1971; Diener et al. 1974; Stickney et al. 1975; Chao and Musick 1977; Overstreet and Heard 1978; Etzold and Christmas 1979; Kobylinski and Sheridan 1979; Sheridan 1979; Weinstein 1979; Schwartz 1980). Mysids, decapods, amphipods, copepods and polychaetes form the bulk of the croaker diet. At times, mollusks, finfishes, and detritus are also consumed in large quantities.

Polychaetes and copepods (calanoid and harpacticoid) are the major dietary components for small croakers. As fish grow into young adults, 120 to 180 mm (5 to 7 inches) TL, their diet includes more fish. The reported consumption of detritus by all sizes of croakers may be incidental and of little nutritive value. Stickney and Shumway (1974) found croakers to lack the ability to digest cellulose. Detritus in the guts of croakers, therefore, is most likely a byproduct of bottom feeding over unconsolidated mud of high organic content.

Substrate

Substrate quality, in terms of dominant substrate type and organic content, plays an important role in determining juvenile croaker distribution. Sand and hard substrates are not suitable at all for juvenile croakers. Mud is most suitable (Chittenden and McEachran 1976; Kobylinski and Sheridan 1979; Weinstein 1979). Bottoms where juvenile croakers occur most abundantly usually are covered with large quantities of detritus (Bearden 1964; Kobylinski and Sheridan 1979). This suggests that there is a positive correlation between occurrence of juvenile croakers and the amount of organic matter in the surface sediments. Weinstein et al. (1980b) found highest abundances of juvenile croakers in areas of high organic content, up to 33%. Croakers do not use organic-rich sediments directly; however, the organic content of sediment may determine habitat suitability for their prey and, therefore, indirectly for croakers themselves.

Turbidity

Juvenile croakers tend to be found in highly turbid runoff areas (Bearden 1964; Parker 1971; Kobylinski and Sheridan 1979) and in the low salinity, maximum turbidity zone of estuaries (Weinstein et al. 1980b). It is typically an area of high sedimentation where salt water flocculates and traps much of the alluvial load brought into the estuary (Nichols 1972). Highly turbid areas, in general, also tend to have high organic loads which may cause an increase in food availability to croakers. Turbidity does not pose any feeding problem to croakers since they are morphologically adapted for tactile feeding (Chao and Musick 1977). Based on data of Livingston (1984), croakers in Apalachicola Bay were abundant at sites with turbidities exceeding 15 Formazin Turbidity Units (FTU) during the period of residence and were rare at lower turbidities. No comparable data are available for other estuaries; however, less detailed information for St. Andrew Bay, Florida, indicates that croakers occur in substantial numbers at turbidities as low as 3 FTU (Ogren and Brusher 1977), which is lower than the lowest measured at Apalachicola Bay. Consequently, high turbidity may be optimal but low turbidity does not appear to exclude croakers.

Water Depth

The abundance of juvenile croakers is not consistently related to depth. In areas of small tidal fluctuations, such as the Gulf of Mexico Coast and the North Carolina sounds, juvenile croakers are densest in shallow peripheral areas (Parker 1971; Ogren and Brusher 1977; Yakupzack et al. 1977; Kobylinski and Sheridan 1979; Copeland et al. 1984). In Lake Pontchartrain, an area of low tidal fluctuation, young croakers were only caught offshore and were heavily concentrated in deep channels in November and December; from January on, however, they were caught in inshore areas (Suttkus 1955). In areas of greater tidal fluctuation, such as Delaware Bay, Chesapeake Bay, and the Cape Fear River Estuary, juvenile croakers were concentrated in deep channels and were rare in shallow areas (Haven 1957; Weinstein et al. 1980b; Thomas 1981; Weinstein and Brooks 1983); however, in South Carolina, large numbers of juvenile croakers also have been caught in small marsh creeks subject to large tidal fluctuations (Turner and Johnson 1974).

Cover

Juvenile croakers occur over bare, soft muddy bottoms. Structural cover does not appear to be a habitat requirement for croakers. Behavioral and morphological adaptations of the Atlantic croaker for feeding are directed toward the exploitation of the surface layers of soft muddy bottoms and are not useful where vegetation or rocks replace or interfere with access to a soft bottom. In addition, other functions commonly associated with structural cover are served by other features of habitat. Protection from visual predators may be provided by high turbidity (Parker 1971). Observations of higher incidences of scarring on juvenile menhaden (Brevoortia patronus) in clear than in turbid estuaries are consistent with this hypothesis (Kroger and Guthrie 1972). The occurrence of small juveniles in areas and seasons of low salinity also may reduce vulnerability to predators. For example, juvenile croakers appear to be a preferred prey of striped bass (Morone saxatilis), when available (Dovel 1968). In Chesapeake Bay in the winter, striped bass congregate in areas of 21 to 22 ppt, while juvenile croakers occur in highest concentrations at salinities less than 20 ppt. Although this pattern of distribution could be the result of physiological preferences for low salinity, the pattern also is consistent with an effect of predation. Either losses to predators virtually eliminate croakers at salinities greater than 20 ppt, or adaptations that restrict young croakers to low salinities have evolved as a means of predator avoidance. Finally, the function of structural cover for protection from the rigors of the physical environment appears to be served by areas of deep water, where necessary.

Dissolved Oxygen

Juvenile croakers are abundant in conditions that often result in low concentrations of dissolved oxygen. They occur in areas with highly organic sediments, high concentrations of suspended solids, and high water temperatures. When dissolved oxygen concentrations drop, most fish, including croakers, will leave an area (Markle 1976; Chao and Musick 1977). Although the tolerance of croakers to low dissolved oxygen is not specifically known, oxygen concentrations below 3 mg/l are limiting to other species and oxygen concentrations that do not drop below 4.5 mg/l have highest suitability (Doudoroff and Shumway 1970; Hoss and Peters 1976). Limiting conditions may be reached, especially in deep habitats during the summer, when biological and chemical oxygen demand are high, and thermal or salinity stratification prevents mixing of the water column.

HABITAT SUITABILITY INDEX (HSI) MODEL

Model Applicability

This model is developed for juvenile croakers. Factors that influence the successful survival and recruitment of larvae from coastal marine waters are complicated and outside the influence of the estuarine system (Norcross and Austin 1981; Miller et al. 1984). Adult croakers do not usually occur in oligohaline areas and are less tolerant of low temperature than juveniles. In addition, adults occur in coastal marine waters. Consequently, the model is not applicable to adults. Also, the model is not applicable where environmental contaminants seriously affect habitat quality.

Geographic area. The geographic areas covered by this model are the southeast Atlantic coast and the Gulf of Mexico coast. The basic life requisites of water quality and cover seem to be similar throughout the range of the Atlantic croaker, except that in some locations deep creeks and channels are heavily utilized while in other locations shallow areas are strongly preferred. The HSI model attempts to account for this major difference in nursery habitat between locations but assumes other variables to be operating similarly in all areas.

Season. The HSI model is designed to evaluate spring and summer conditions, because they are the most critical. Some of the variables pertain to environmental conditions that occur only during these seasons.

Cover types. Croakers typically use estuarine and nearshore marine habitats. Spawning occurs in the marine habitat and near the transition to the estuarine habitat. The estuarine habitat is used as the nursery ground. This model is intended only for the estuarine habitat and applies to areas of Estuarine Unconsolidated Bottom (E1UB), and to a lesser extent to Estuarine Intertidal Unconsolidated Shore (E2US), according to the classification of Cowardin et al. (1979).

Minimum habitat area. The minimum habitat area is that area of contiguous suitable habitat that is required for croakers to develop and reproduce successfully. No minimum habitat size requirements for the Atlantic croaker have been identified in the literature.

Verification level. Three biological experts outside the U.S. Fish and Wildlife Service were identified to review and evaluate the croaker HSI model throughout its development. These experts were John Lunz, U.S. Army Corps of Engineers, Vicksburg, Mississippi; Michael Weinstein, Virginia Commonwealth University, Richmond; and Brenda Norcross, Virginia Institute of Marine Science, Gloucester Point. Ideas and suggestions from these experts were incorporated into the model-building effort. Additional comments from users and U.S. Fish and Wildlife Service field offices and new sources of data have been used in revising the model.

Model Description

Overview. This HSI model for the juvenile Atlantic croaker considers water quality and cover life requisites in the estuarine habitat. The relationship of habitat variables, life requisites, and life stage to the HSI is illustrated in Figure 1.

The two basic life requisites used in the model are not independent. There is a great deal of overlap and correlation between the habitat variables and life requisites. For example, turbidity in estuarine systems is directly related to both salinity and depth (Nichols 1972). The grouping of habitat variables into water quality, cover, and food is primarily for the development of the HSI and is not intended to imply that water quality and cover variables, for example, are mutually exclusive.

Water quality. The value of the water quality component is determined by turbidity, dissolved oxygen, salinity, and temperature. Turbidity (V_1) is positively correlated with the abundance of juvenile croakers. Suitability is assumed to increase as the logarithm of turbidity as measured by a turbidity meter from 2 to 20 Formazin Turbidity Units (FTU) and remain optimal at higher turbidities. Alternatively, turbidity can be measured as the concentration of suspended solids. Suitability is assumed to increase as the logarithm of the concentration of suspended solids from 2 to 20 mg/l and remain optimal at higher concentrations.

The dissolved oxygen variable -- the minimum summer concentration of dissolved oxygen (V_2) -- is assumed to be limiting at 2 mg/l and optimal above 5 mg/l. Adjustments have been made to the range cited in the previous section for fishes in general to account for behavioral responses that can buffer croakers from unsuitable conditions on the bottom and also to account for limitations in a HEP sampling program for detecting the actual minimum concentration.

The salinity variables -- mean spring (March to May) salinity near the bottom (V_3) and mean summer (June to September) salinity near the bottom (V_4) -- are based on seasonal relationships between catch of juvenile croakers per unit of effort and salinity in South Carolina estuarine areas (Miglarese et al. 1982), supplemented by and checked for consistency with more general compilations of abundance versus salinity (Haven 1957; Parker 1971; Chao and Musick 1977; Kobylinski and Sheridan 1979; Weinstein et al. 1980a; Ross and Epperly, in press). The essential features of the salinity variables are (1) although low salinity areas are most suitable, areas that are fresh throughout the year are unsuitable in most locations, and (2) higher salinities are more acceptable in the summer than in the spring. In the spring, salinities of 0 to 15 ppt are most suitable and salinities greater than 24 ppt are unsuitable. In the summer, salinities of 6 to 26 ppt are most suitable and salinities less than 1 ppt are unsuitable.

Variables V_3 and V_4 together account for all these factors in most locations; however, the Barataria Bay and its marsh system in Louisiana are an exception. There, not only were freshwater areas used by croakers in summer as well as spring (Rogers 1979), but also catches in the spring were positively

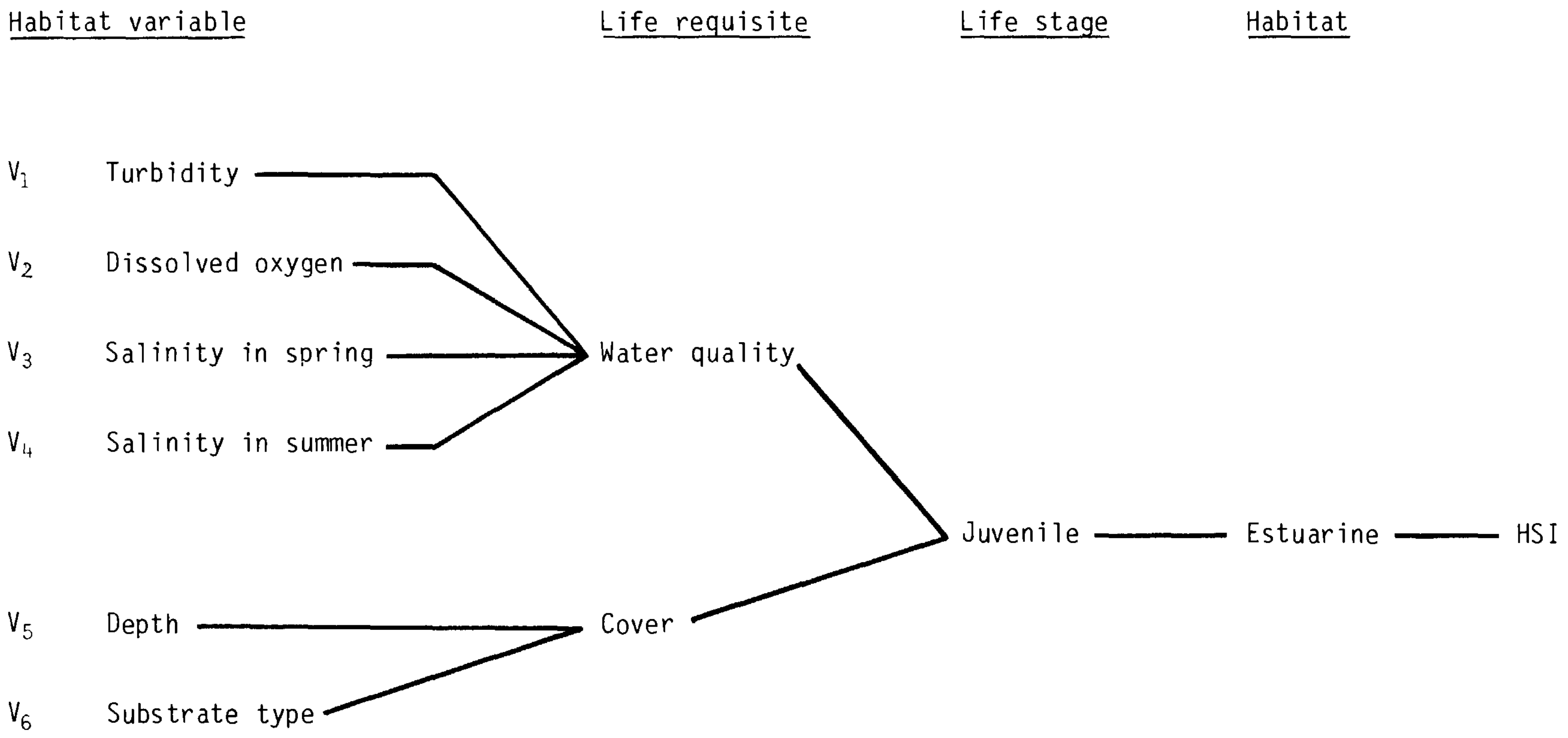


Figure 1. Relationship of habitat variables and life requisites to the HSI for juvenile Atlantic croaker.

correlated within the salinity range of 0 to 10 ppt. In most locations, highest abundances in the spring occur anywhere between 0 and 15 ppt, with no consistent trend within that range. This discrepancy is not caused by a direct response to salinity but by the low accessibility of freshwater parts of the Barataria Bay system to small juveniles entering from the Gulf of Mexico. The brackish zone is so broad and the water connections across it are so indirect that relatively few croakers get to the fresh part of the system. The freshwater zone is so extensive that the fish are not concentrated within it. In most other estuaries, low salinity fringes may be much more accessible, because the distances are small or currents exist that transport young juveniles close to suitable low salinity areas (salt wedges up drowned river estuaries, wind-driven circulation in large bays and sounds). To account for these differences, an alternative form of the spring salinity variable (V_3) is provided for the Barataria Bay system, in which the low salinity end is really a surrogate variable for accessibility from the Gulf of Mexico. This alternative should be evaluated for use in other areas with broad (10 to 100 km, 6 to 60 mi) brackish and freshwater zones, and perhaps applies to other large marsh-lake-bayou systems of coastal Louisiana.

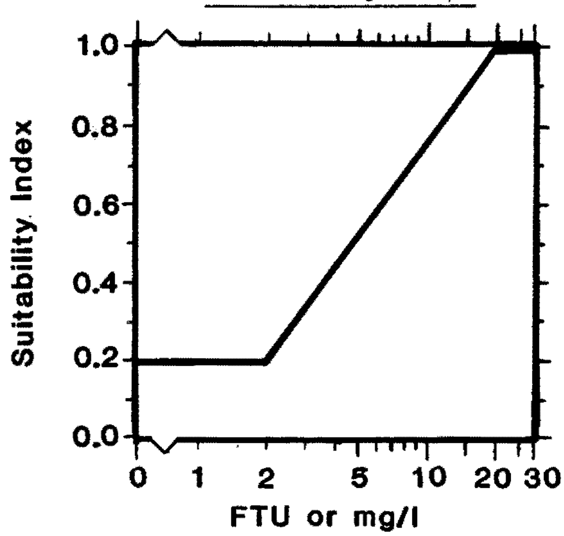
Although changes in salinity of 5 ppt per hour have been shown to alter the activity of croakers in a way that would reduce local abundance (Perez 1969) given sufficient time, the amount of time during which the conditions of rapid salinity change occur in any area is assumed to be small and the effect is ignored. Temperature undoubtedly is important in setting the northern limit of the Atlantic croaker's geographic distribution, influencing year-class strength, and determining the timing of entry and exit from nursery areas, but is not assumed to make a difference among areas within a region. Although rapid increases in temperature have been demonstrated to be harmful to croakers in the laboratory, the minimum increase causing observable effects -- 33°to 40°C at 1°C/min (91° to 104°F at 1.8°F/min) (Copeland et al. 1974) -- is extreme under natural conditions. Since thermal tolerance is greater at the temperatures that are usually encountered in estuaries, temperature change is ignored as a possible determinant of habitat suitability.

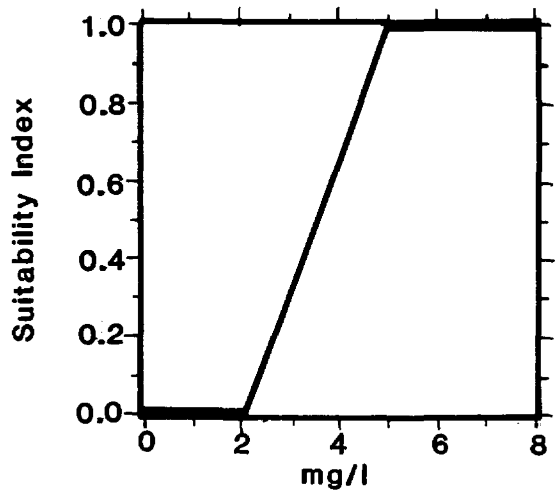
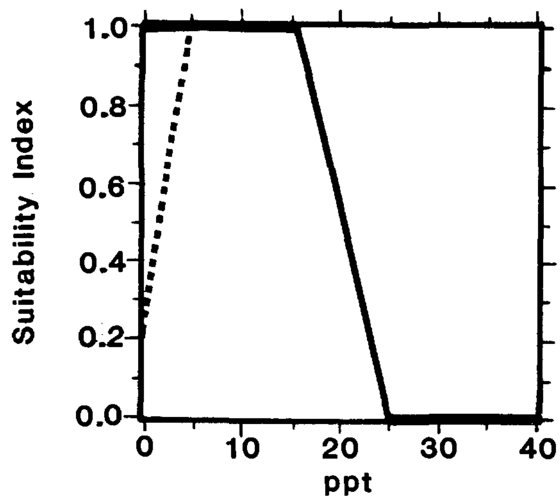
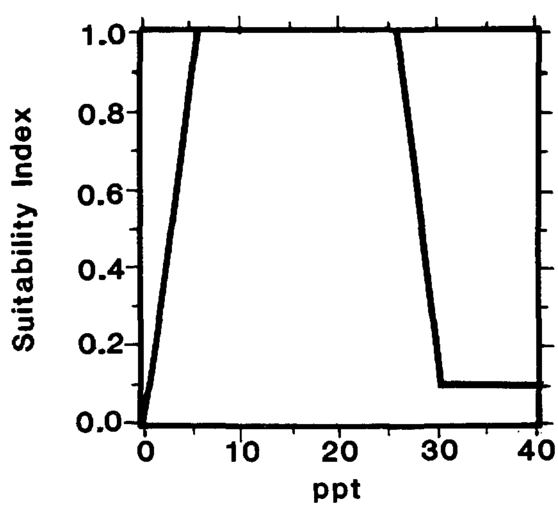
Food/cover. The value of the cover component is determined by depth and substrate; however, habitat suitability is related to the depth variable (V_5) differently, depending on tidal range. In regions of weak tidal influence, shallow areas closely associated with marsh are most suitable, and shallow and deep open water areas are progressively less suitable. In regions of stronger tidal influence, the main stem channels of drowned river estuaries can be heavily utilized by juvenile croakers, and deep areas are commonly considered to be most suitable (Haven 1957; Weinstein 1979). However, Chao and Musick (1977) showed that croakers were concentrated in shoal areas rather than in the channel of the York River Estuary, Virginia in spring and summer, and Turner and Johnson (1974) collected very high densities in marsh creeks near Charleston, South Carolina in the spring. In view of the variety of situations in which juvenile croakers are abundant in regions of strong tidal influence, no depth variable is incorporated in assessing habitat suitability for these areas.

Soft muds are regarded as the most suitable substrate type (V_6) in all areas; half sand, half silt and mud are intermediate in suitability; sandy bottoms are low in suitability; and shell, gravel, or rock bottoms or seagrass beds are unsuitable. Although Bearden (1964) and Kobylinski and Sheridan (1979) note that juveniles occur in high densities in areas with large quantities of detritus, the only report of a positive correlation with sediment organic content was for tidal creeks of the Cape Fear River Estuary, North Carolina (Weinstein (1980b), sites regarded as only of minor importance as nursery habitat for croakers in this system (Weinstein 1980a). In an analysis of 51 primary nursery areas in Pamlico Sound, North Carolina, Ross and Epperly (in press) found no correlation between catch per unit of effort and sediment organic content, even though the substrates of the sites also were described as covered with detritus. Apparently, areas in Pamlico Sound are suitable over a broad range of sediment organic content, at least as low as 2%, and suitability is limited by other factors. This finding is consistent with inferences drawn from comparisons of nursery utilization by juvenile croakers and another bottom-feeding sciaenid, the spot (*Leiostomus xanthurus*), in one of the Pamlico Sound nurseries. Miller et al. (1984) documented higher productivity of croakers than spots, even though the latter were more abundant initially and were more abundant in deeper areas where the biomass of benthic invertebrates was greater. They attributed this outcome to greater predation in the deeper areas. Consequently, no indicator of food availability, such as sediment organic content or benthic biomass, has been incorporated in the model.

Suitability Index (SI) Graphs for Habitat Variables

This section provides graphic representations of the relations previously described between the habitat variables and estuarine (E) habitat suitability for the Atlantic croaker. An SI value of 1.0 indicates optimal conditions and a value of 0 indicates unsuitable conditions. Data sources and assumptions associated with documentation of the SI graphs are listed in Table 1.

Habitat	Variable		Suitability Graph
E1UB E2US	V_1	Mean turbidity during March through September.	

Habitat	Variable		Suitability Graph
E1UB E2US	V_2	Minimum concentration of dissolved oxygen during July through September.	
E1UB E2US	V_3	Mean salinity during March through May. (Use dotted line for estuaries with broad brackish and fresh wetland zones.)	
E1UB E2US	V_4	Mean salinity during June through September.	

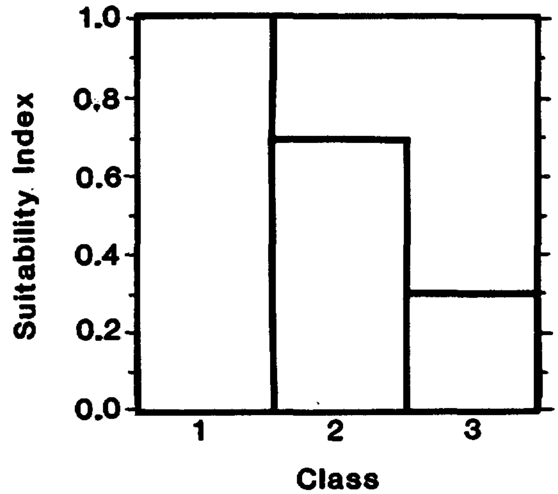
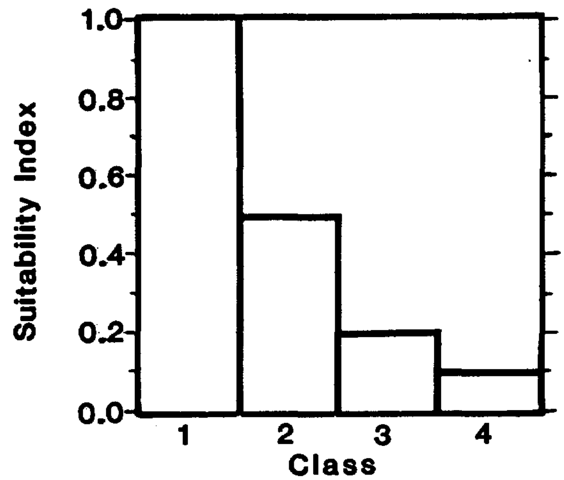
Habitat	Variable		Suitability Graph
E1UB E2US	V_5	Depth category: 1) Shallow areas closely associated with marsh. 2) Open water <2 m deep. 3) Open water >2 m deep. (Use area-weighted mean when more than one depth category occurs in an evaluation area.)	
E1UB E2US	V_6	Dominant substrate type: 1) >75% mud. 2) 25% to 75% mud. 3) >75% sand, shell, or other hard material. 4) Seagrass beds or mostly rock and shell; no soft material.	

Table 1. Data sources and assumptions for Atlantic croaker suitability indices.

Variable and source		Assumption
V_1	Bearden 1964 Parker 1971 Kobylinski and Sheridan 1979 Livingston 1984	High turbidity levels are positively related to the abundance of juvenile croakers.
V_2	Doudoroff and Shumway 1970 Hoss and Peters 1976 Chao and Musick 1977	Low levels of dissolved oxygen are not suitable.
V_3	Parker 1971 Rogers 1979 Weinstein et al. 1980b Miglarese et al. 1982 Ross and Epperly, in press	In the spring juvenile croakers are caught at salinities from 0 to 24 ppt. Salinities of 0 to 15 ppt are most suitable, except in Barataria Bay. There, abundances are positively correlated with salinity from 0 to approximately 5 ppt.
V_4	Parker 1971 Weinstein et al. 1980b Miglarese et al. 1982 Ross and Epperly, in press	In the summer fresh water is unsuitable. Salinities from 6 to 26 ppt are most suitable. Salinities greater than 30 ppt are low in suitability.
V_5	Parker 1971 Yakupzack et al. 1971 Sheridan 1983 Miller et al. 1984	In regions with small tides only, shallow areas closely associated with marsh are most suitable, shallow open water is intermediate in suitability, and deep open water is least suitable.
V_6	Chittenden and McEachran 1976 Kobylinski and Sheridan 1979 Weinstein 1979 Ross and Epperly, in press	Soft mud is most suitable. Sandy mud is less suitable. Hard and coarse substrates and seagrass beds are unsuitable.

Component Index Equations and HSI Determination

The HSI equation considers two life requisite components: water quality and food/cover. Water quality comprises turbidity, dissolved oxygen, and salinity. Food/cover comprises depth and substrate type. To obtain an HSI for the Atlantic croaker, the SI values for habitat variables and components must be combined as follows:

Component	Equation	
Water quality (WQ)		
Coastal Louisiana	SI_{V_3} or $(SI_{V_1} x SI_{V_2} x SI_{V_3})^{1/3}$	whichever is lower
Other locations	SI_{V_3}, SI_{V_4}, or $(SI_{V_1} x SI_{V_2} x SI_{V_3} x SI_{V_4})^{1/4}$	whichever is lowest
Food/cover (FC)		
Tidal range <0.5 m	SI_{V_5} or SI_{V_6}	whichever is lower
Tidal range >0.5 m	SI_{V_6}	

HSI = WQ or FC, whichever is lower

Low SI values for either of the salinity variables are assumed to be limiting factors on the water quality component SI value. Partial compensation for low values of the other variables is assumed to occur. Therefore, for areas of coastal Louisiana with broad brackish and freshwater wetland zones, the water quality component SI is determined by spring salinity or the geometric mean of the three water quality SI values, whichever is lower. In other locations, the water quality component SI is determined by spring salinity, summer salinity, or the geometric mean of the four water quality SI values, whichever is lowest.

The food/cover component is determined differently for regions of strong and weak tidal influence. Where the tidal range is less than 0.5 m (20 inches), the lower of the SI values for the depth and substrate variables is assumed to be limiting. Where the tidal range exceeds 0.5 m (20 inches), the food/cover component is determined by substrate alone.

The relative importance of the water quality and food/cover components to the potential of a particular habitat to support the Atlantic croaker is not known. The model assumes that either component can act as a limiting factor. Therefore, the HSI for juvenile Atlantic croakers in estuarine habitats is determined by the value of whichever component -- water quality or food/cover -- is lower.

Suitability indices, component indices, and habitat suitability index values have been generated by using the equations for four sample data sets (Table 2). Two data sets are shown for areas of weak tidal influence and two are also shown for areas of strong tidal influence. The data sets are actual field measurements, to the extent available. Missing variables have been estimated and are believed to be consistent with the documented characteristics of the sites. The HSI's calculated from these data are consistent with the relative abundances observed in habitats with the characteristics listed in Table 2; however, they do not constitute an independent test of the model, because some of the same data were used in formulating the model.

Table 2. Calculations of suitability indices (SI), water quality (WQ) and food/cover (FC) component indices, and habitat suitability indices (HSI) for four sample data sets using habitat variable (V) measurements and the Atlantic croaker HSI model equations. Data for the York River are adapted from Chao and Musick (1977), and data for Apalachicola Bay are adapted from Livingston (1984).

Model element	Tides >0.5 m: York River				Tides <0.5 m: Apalachicola Bay			
	50 km upriver		Near mouth		Upper Bay		Lower Bay	
	Data	SI	Data	SI	Data	SI	Data	SI
V_1 (FTU)	30	1.0	5	0.52	30	1.0	13	0.85
V_2 (mg/l)	4.5	0.8	4.5	0.8	4	0.6	5	1.0
V_3 (ppt)	5	0.8	18	0.67	2	1.0	19	0.56
V_4 (ppt)	10	1.0	27	0.75	5	0.84	22	1.0
V_5 (depth)	-	-	-	-	2	0.7	2	0.7
V_6 (substrate)	1	1.0	1	1.0	1	1.0	4	0.1
WQ	0.8		0.67		0.84		0.56	
FC	1.0		1.0		0.7		0.1	
HSI	0.8		0.67		0.7		0.1	

Field Use of the Model

Model precision will vary according to the level of detail of the input variables. Detailed evaluation of all variables yields the most reliable HSI values. Recognizing the time and financial constraints of most environmental assessments, previously reported data will often yield more reliable estimates of variables than the limited field measurements that could be made during an analysis. The necessary data can be frequently gathered from published or unpublished resource agency sources (Table 3). However, the user must decide whether extrapolation to a project site is justified. Field observations

Table 3. Suggested methods for field measurements of variables used in the croaker HSI model.[a]

Variable	Methods
V_1	Turbidity can be measured directly in Florazin Turbidity Units (FTU) with a turbidity meter. FTU are equivalent to Jackson Turbidity Units (JTU) in older procedures. Since most turbidity in estuaries is from suspended solids, turbidity also can be measured as mg/l of suspended solids. FTU are approximately equivalent to mg/l. Water samples for turbidity determinations should be collected within approximately 30 cm (1 ft) of the bottom when possible.
V_2	Dissolved oxygen within approximately 30 cm (1 ft) of the bottom can be measured using Winkler titration or an oxygen meter.
V_3	Salinity within approximately 30 cm (1 ft) of the bottom can be measured by titration, refractometer, or salinity meter.
V_4	Same as for V_3.
V_5	Define evaluation area on topographic maps or navigation charts. Open water is more than 30 m (100 ft) from the nearest shore or the nearest emergent vegetation in areas of flooded marsh. Depth can be determined from bathymetric charts or by direct measurement. Use an area-weighted mean when more than one depth category occurs within an evaluation area.
V_6	Substrate type is defined as the amount of coarse or fine sediment in the top 5 cm (2 inches) of a core. Substrate type is determined by sieving a known weight of sediment through a 0.063 mm sieve (Tyler series No. 250). The material retained on the sieve is the sand or coarser fraction from which the percentage of sand or coarser material can be calculated. What goes through the sieve is mud (silts and clays). The percentage of mud is 100% minus the previously calculated percentage of coarser material retained on the sieve.

[a] Details for water quality methods can be found in Standard Methods for Examination of Water and Waste Water (Anonymous 1981).

should be used to check the suitability of extrapolations from other sources. Suggested methods for measuring model variables are given in Table 3. Sources of data should be documented.

Average values have been used for some model variables. The literature suggests that the tolerance of the Atlantic croaker to changes in temperature and salinity depends on the rapidity of the change. Variables of rates of change in temperature and salinity have been excluded from this model for reasons discussed previously. It should be recognized that these variables cannot be ignored in applications involving discharges of hot or fresh water directly into estuarine areas. Guidance should be sought to adapt the model in these cases.

This model has been written for the common case of estuarine residence by juvenile croakers in the spring and summer. There are exceptions for which the model should be modified. For instance, use of the upper Barataria Bay system is so low by June (Rogers 1979) that only the spring salinity variable should be applied. Low dissolved oxygen may make the area unsuitable in the summer, judging from reports of fish kills attributed to the die-off of algal blooms and low oxygen in nearby areas of coastal Louisiana (Yakupzack et al. 1977). However, unsuitability in summer did not prevent heavy utilization earlier in the year.

Interpreting Model Outputs

The proper use of the HSI is one of comparison. This model can be used to compare different habitats or the same habitat through time. The higher HSI should correspond to the area that could potentially support more juvenile Atlantic croakers. The accessibility of an area to larval recruits is an important determinant of the level of utilization of some areas that may be highly suitable in all other regards. In the case of Barataria Bay and similar areas, the salinity variable is a correlate of accessibilty. In other areas, it has not been possible to incorporate accessibility as a factor in this HSI model; calculated HSI values may not be correlated with long-term estimates of population density in these cases.

ADDITIONAL HABITAT MODELS

This model is a revision of an earlier habitat suitability index model for juvenile Atlantic croakers in this series. The revision incorporates new information about habitat requirements and responds to comments received since the first printing. Additional comments were solicited from field offices of the U. S. Fish and Wildlife Service in the geographic range of the Atlantic croaker. This revision supersedes the original version, except for evaluations involving thermal or freshwater discharges. Variables in the original model may apply in these cases.

REFERENCES

Anonymous. 1981. Standard methods for examination of water and waste water. 15th ed. American Public Health Administration, American Water Works Association, American Public Health Service, Washington, D.C.

Bearden, C.M. 1964. Distribution and abundance of Atlantic croaker, Micropogon undulatus, in South Carolina. Bears Bluff Lab. Prog. Rep. 40. 23 pp.

Chao, L.N., and J.A. Musick. 1977. Life history, feeding habits, and functional morphology of juvenile sciaenid fishes in the York River Estuary, Virginia. U.S. Natl. Mar. Fish. Serv. Fish. Bull. 75:657-702.

Chittenden, M.E., Jr., and J.D. McEachran. 1976. Composition, ecology, and dynamics of demersal fish communities on the northwestern Gulf of Mexico Continental Shelf, with a similar synopsis for the entire gulf. Tex. A&M Univ. Sea Grant Coll. TAMU-SG 76-208. 104 pp.

Copeland, B.J., R.W. Laney, and E.C. Pendleton. 1974. Heat influences in estuarine ecosystems. Pages 423-437 in J.W. Gibbons and R.R. Sharitz, eds. Thermal ecology. AEC Symposium Series (CONF-730505).

Copeland, B.J., R.G. Hodson, and S.R. Riggs. 1984. The ecology of the Pamlico River, North Carolina: an estuarine profile. U.S. Fish Wildl. Serv. FWS/OBS-82/06. 83 pp.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish Wildl. Serv. Biol. Serv. Program FWS/OBS-79/31. 103 pp.

Darnell, R. 1961. Trophic spectrum of an estuarine community, based on studies of Lake Pontchartrain, Louisiana. Ecology 42:553-568.

Diener, R.A., A. Inglis, and A.B. Adams. 1974. Stomach contents of the fishes from Clear Lake and tributary waters, a Texas estuarine area. Contrib. Mar. Sci. 18:7-17.

Doudoroff, P. and D.L. Shumway. 1970. Dissolved oxygen requirements of freshwater fishes. FAO Fish. Tech. Pap. 86.

Dovel, W.L. 1968. Predation by striped bass as a possible influence on population size of the Atlantic croaker. Trans. Am. Fish. Soc. 97:313-319.

Etzold, D.J., and J.Y. Christmas. 1979. A Mississippi marine finfish management plan. Miss.-Ala. Sea Grant Consortium MASGP-78-046. 36 pp.

Fruge, D.J., and F.M. Truesdale. 1978. Comparative larval development of Micropogon undulatus and Leiostomus xanthurus (Pisces: Sciaenidae) from the northern Gulf of Mexico. Copeia 4:643-648.

Gerry, L.R. 1981. The effect of salinity fluctuations and salinity gradients on the distribution of juvenile spot (Leiostomus xanthurus) and croaker (Micropogonias undulatus). M.S. Thesis. North Carolina State University, Raleigh. 51 pp.

Haven, D.S. 1957. Distribution, growth, and availability of juvenile croaker, Micropogon undulatus, in Virginia. Ecology 38:88-97.

Herke, W.H. 1971. Use of natural, and semi-impounded, Louisiana tidal marshes as nurseries for fishes and crustaceans. Ph.D. Dissertation. Louisiana State University, Baton Rouge. 264 pp.

Hildebrand, S.F., and L.E. Cable. 1930. Development and life history of fourteen teleostean fishes at Beaufort, North Carolina. Bull. U.S. Bur. Fish. 46:383-488.

Hoese, H.D. 1965. Spawning of marine fishes in the Port Aransas, Texas area as determined by the distribution of young and larvae. Ph.D. Dissertation. University of Texas, Austin.

Hoss, D.E., and D.S. Peters. 1976. Respiratory adaptations: fishes. Pages 345-356 in M. Wiley, ed. Estuarine processes. Vol. I. Academic Press, New York.

Johnson, G.D. 1978. Development of fishes of the mid-Atlantic Bight. Vol. IV: Carangidae through Ephippidae. U.S. Fish. Wildl. Serv. FWS/OBS-78/12.

Knudsen, E.E., and W.H. Herke. 1978. Growth rate of marked juvenile Atlantic croakers, Micropogon undulatus, and length of stay in a coastal marsh nursery in southwest Louisiana. Trans. Am. Fish. Soc. 107:12-20.

Kobylinski, G.J., and P.F. Sheridan. 1979. Distribution, abundance, feeding, and long-term fluctuations of spot, Leiostomus xanthurus, and croaker, Micropogonias undulatus, in Apalachicola Bay, Florida, 1972-1977. Contrib. Mar. Sci. 22:149-161.

Kroger, R.L., and J.F. Guthrie. 1972. Effect of predators on juvenile menhaden in clear and turbid estuaries. Mar. Fish. Rev. 34:78-80.

Livingston, R.J. 1984. The ecology of the Apalachicola Bay system: an estuarine profile. U.S. Fish Wildl. Serv. FWS/OBS-82/05. 148 pp.

Markle, D.F. 1976. The seasonality of availability and movements of fishes in the channel of the York River, Virginia. Chesapeake Sci. 17:50-55.

Miglarese, J.V., C.W. McMillan, and M.H. Shealy, Jr. 1982. Seasonal abundance of Atlantic croaker (Micropogonias undulatus) in relation to bottom salinity and temperature in South Carolina estuaries. Estuaries 5:216-223.

Miller, J.M., J.P. Reed, and L.P. Pietrafesa. 1984. Patterns, mechanisms and approaches to the study of migrations of estuarine-dependent fish larvae and juveniles. Pages 209-225 in J.D. McCleave, G.P. Arnold, J.J. Dodson, and W.H. Neill, eds. Mechanisms of migration in fishes. Plenum Publishing Corp., New York.

Nakamura, E.L. 1981. Sciaenid resources in the Gulf of Mexico. Pages 29-39 in H. Clepper, ed. Marine Recreational Fisheries 6. Sportfishing Institute, Washington, D.C.

Nichols, M.M. 1972. Sediments of the James River, Virginia. Geol. Soc. Am. Mem. 133:169-211.

Norcross, B.L., and H.M. Austin. 1981. Climate scale environmental factors affecting year class fluctuations of Chesapeake Bay croaker, Micropogonias undulatus. Va. Inst. Mar. Sci. Spec. Sci. Rep. 110. 78 pp.

Ogren, L.H., and H.A. Brusher. 1977. The distribution and abundance of fishes caught with a trawl in the St. Andrew Bay system, Florida. Northeast Gulf Sci. 1:83-105.

Overstreet, R.M., and R.W. Heard. 1978. Food of the Atlantic croaker, Micropogonias undulatus, from Mississippi Sound and the Gulf of Mexico. Gulf Res. Rep. 6:145-152.

Parker, J.C. 1971. The biology of the spot, Leiostomus xanthurus Lacepede, and Atlantic croaker, Micropogon undulatus (Linnaeus), in two Gulf of Mexico nursery areas. Tex. A&M Univ. Sea Grant Coll. TAMU-SG 71-210. 182 pp.

Pearson, J.C. 1929. Natural history and conservation of the redfish and other commercial sciaenids of the Texas coast. Bull. U.S. Bur. Fish. 44:129-214.

Perez, K.T. 1969. An orthokinetic response to rates of salinity change in two estuarine fishes. Ecology 50:454-457.

Powles, H. 1981. Eggs and larvae of North American sciaenid fishes. Pages 99-109 in H. Clepper, ed. Marine Recreational Fisheries 6. Sportfishing Institute, Washington, D.C.

Raney, E.C., and W.H. Massmann. 1953. Ichthyology. The fishes of the tidewater section of the Pamunkey River, Virginia. J. Wash. Acad. Sci. 43:424-432.

Rogers, B.D. 1979. The spatial and temporal distribution of Atlantic croaker, Micropogon undulatus, and spot, Leiostomus xanthurus, in the upper drainage basin of Barataria Bay, Louisiana. M.S. Thesis. Louisiana State University, Baton Rouge. 96 pp.

Ross, S.W., and S.P. Epperly. In press. Utilization of shallow estuarine areas by fishes in Pamlico Sound, North Carolina and adjacent tributaries. In A. Yanez-Arancibia, ed. Fish community ecology in estuaries and coastal lagoons. Instituto de Ciencias del Mar y Limnologia, Universidad Nacional Autonoma de Mexico, Ciudad Universitaria.

Schwartz, F.J. 1980. Food analyses of selected fishes captured in Cape Fear Estuary and adjacent Atlantic Ocean, 1973-1978. Report for Carolina Light and Power Company, Raleigh, North Carolina. Institute of Marine Sciences, University of North Carolina, Morehead City. 254 pp.

Sheridan, P.F. 1979. Trophic resource utilization by three species of sciaenid fishes in a northwest Florida estuary. Northeast Gulf Sci. 3:1-15.

Sheridan, P.F. 1983. Abundance and distribution of fishes in the Galveston Bay system, 1963-1964. Contrib. Mar. Sci. 26:143-163.

Simmons, E.G. 1957. An ecological survey of the Upper Laguna Madre of Texas. Publ. Mar. Sci. Univ. Texas 41:156-200.

Stickney, R.R., and S.E. Shumway. 1974. Occurrence of cellulose activity in the stomachs of fishes. J. Fish. Biol. 6:779-790.

Stickney, R.R., G.L. Taylor, and D.B. White. 1975. Food habits of five young Southeastern United States estuarine Sciaenidae. Chesapeake Sci. 16:104-114.

Suttkus, R.D. 1955. Seasonal movements and growth of the Atlantic croaker, Micropogon undulatus, along the east Louisiana coast. Proc. Gulf Caribb. Fish. Inst., Seventh Annual Session, November 1954:151-158.

Thomas, D.L. 1981. Comparative ecology of drums from the Delaware River Estuary. Pages 111-123 in H. Clepper, ed. Marine Recreational Fisheries 6. Sportfishing Institute, Washington, D.C.

Turner, W.R., and G.N. Johnson. 1974. Standing crops of aquatic organisms in tidal streams of the lower Cooper River system, South Carolina. Pages 13-20 in F.P. Nelson, ed. The Cooper River environmental study. South Carolina Water Resources Commission Report No. 117.

Weinstein, M.P. 1979. Shallow marsh habitats as primary nurseries for fishes and shellfish, Cape Fear River, North Carolina. Fish. Bull. 77:339-357.

Weinstein, M.P., and H.A. Brooks. 1983. Comparative ecology of nekton residing in a tidal creek and an adjacent seagrass meadow: community composition and structure. Mar. Ecol. Prog. Ser. 12:15-27.

Weinstein, M.P., S.L. Weiss, R.G. Hodson, and L.R. Gerry. 1980a. Retention of three taxa of postlarval fishes in an intensively flushed tidal estuary, Cape Fear River, North Carolina. U.S. Natl. Mar. Fish. Serv. Fish. Bull. 78:419-436.

Weinstein, M.P., S.L. Weiss, and M.F. Walters. 1980b. Multiple determinants of community structure in shallow marsh habitats. Mar. Biol. 58:227-243.

White, M.L., and M.E. Chittenden, Jr. 1977. Age determination, reproduction, and population dynamics of the Atlantic croaker, Micropogonias undulatus. U.S. Natl. Mar. Fish. Serv. Fish. Bull. 75:109-123.

Wilk, S.J. 1981. The fisheries for Atlantic croaker, spot, and weakfish. Pages 15-27 in H. Clepper, ed. Marine Recreational Fisheries 6. Sportfishing Institute, Washington, D.C.

Yakupzack, P.M., W.H. Herke, and W.G. Perry. 1977. Emigration of juvenile Atlantic croakers, Micropogon undulatus, from a semi-impounded marsh in southwestern Louisiana. Trans. Am. Fish. Soc. 106:538-544.

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. Biological Report 82(10.98)	2.	3. Recipient's Accession No.

4. Title and Subtitle Habitat Suitability Index Models: Juvenile Atlantic Croaker (Revised)	5. Report Date June 1985
	6.
7. Author(s) Robert J. Diaz[a] and Christopher P. Onuf[b]	8. Performing Organization Rept. No.
9. Addresses of Authors	10. Project/Task/Work Unit No.
[a] Dept. Invertebrate Ecology Virginia Inst. Marine Science College of William and Mary Gloucester Point, VA 23062 [b] National Coastal Ecosystems Team U.S. Fish and Wildlife Service 1010 Gause Boulevard Slidell, LA 70458	11. Contract(C) or Grant(G) No. (C) (G)
12. Sponsoring Organization Name and Address National Coastal Ecosystems Team Division of Biological Services Fish and Wildlife Service U.S. Department of the Interior Washington, DC 20240	13. Type of Report & Period Covered
	14.

15. Supplementary Notes

Revision of FWS/OBS-82/10.21, published July 1982.

16. Abstract (Limit: 200 words)

A review and synthesis of existing information were used to develop an estuarine habitat model for juvenile Atlantic croaker (Micropogonias undulatus). The model is scaled to produce an index of habitat suitability between 0 (unsuitable habitat) and 1 (optimally suitable habitat) for estuarine areas of the Atlantic and Gulf of Mexico coasts. Habitat suitability indices are designed for use with Habitat Evaluation Procedures previously developed by the U.S. Fish and Wildlife Service. Guidelines for juvenile Atlantic croaker model applications and techniques for estimating model variables are described.

17. Document Analysis a. Descriptors

Habitability
Fishes
Estuaries

b. Identifiers/Open-Ended Terms

Habitat
Habitat Suitability Index
Atlantic Croaker
Micropogonias undulatus

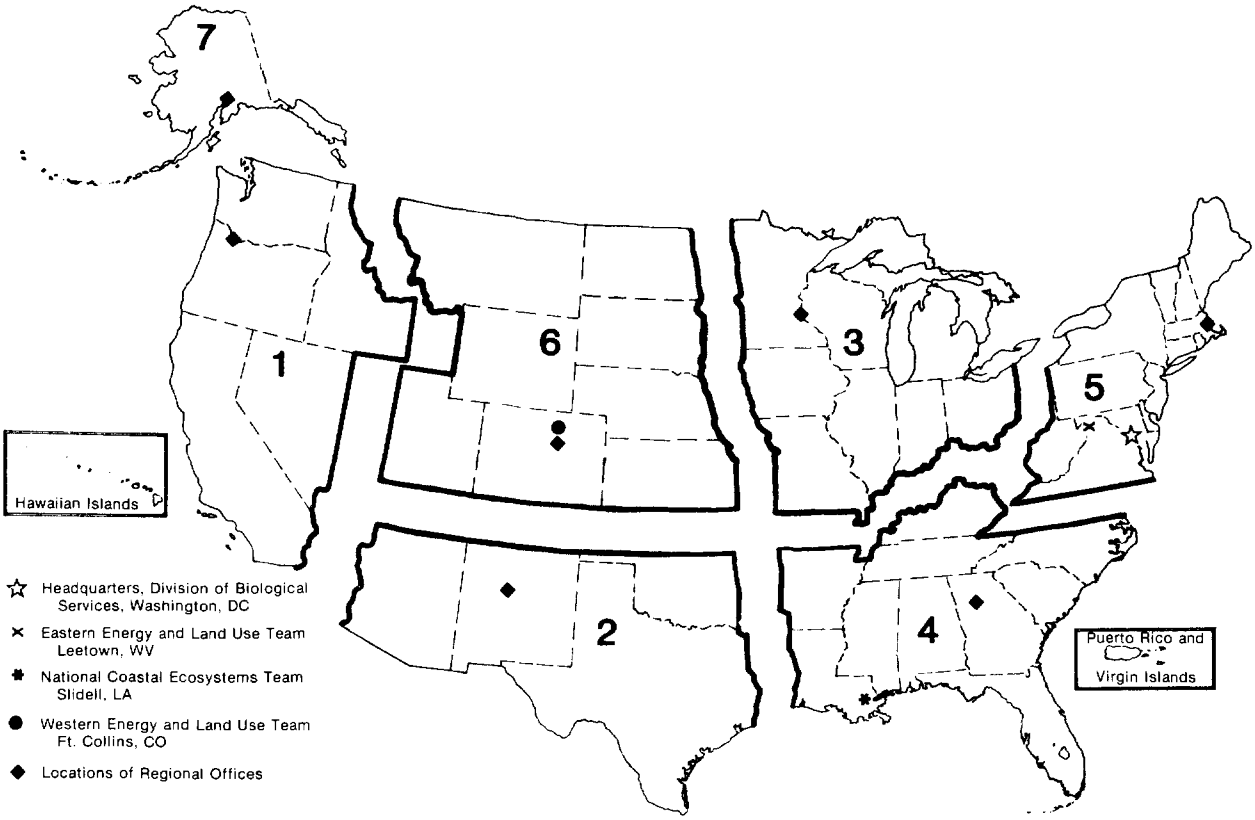
c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Unlimited	Unclassified	vi + 23
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI-Z39.18)

☆U.S. GOVERNMENT PRINTING OFFICE: 1985 — 573-260

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce



REGION 1
Regional Director
U.S. Fish and Wildlife Service
Lloyd Five Hundred Building, Suite 1692
500 N.E. Multnomah Street
Portland, Oregon 97232

REGION 2
Regional Director
U.S. Fish and Wildlife Service
P.O. Box 1306
Albuquerque, New Mexico 87103

REGION 3
Regional Director
U.S. Fish and Wildlife Service
Federal Building, Fort Snelling
Twin Cities, Minnesota 55111

REGION 4
Regional Director
U.S. Fish and Wildlife Service
Richard B. Russell Building
75 Spring Street, S.W.
Atlanta, Georgia 30303

REGION 5
Regional Director
U.S. Fish and Wildlife Service
One Gateway Center
Newton Corner, Massachusetts 02158

REGION 6
Regional Director
U.S. Fish and Wildlife Service
P.O. Box 25486
Denver Federal Center
Denver, Colorado 80225

REGION 7
Regional Director
U.S. Fish and Wildlife Service
1011 E. Tudor Road
Anchorage, Alaska 99503

DEPARTMENT OF THE INTERIOR
U.S. FISH AND WILDLIFE SERVICE

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.