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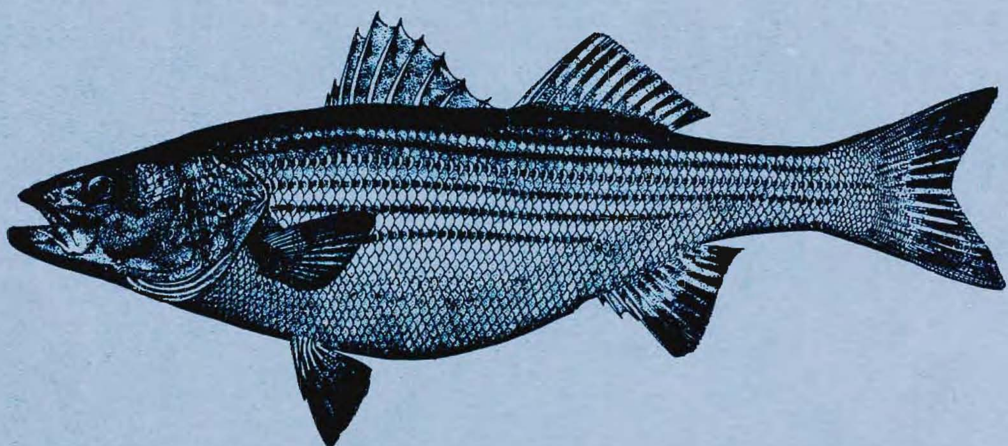
HABITAT SUITABILITY INDEX MODELS: COASTAL STOCKS OF STRIPED BASS



Fish and Wildlife Service

U.S. Department of the Interior

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HABITAT SUITABILITY INDEX MODELS:
COASTAL STOCKS OF STRIPED BASS

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PREFACE

The habitat use information and habitat suitability index (HSI) models presented in this report on coastal stocks of striped bass are intended for use in impact assessment and habitat management activities. 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 the HSI models, and guidelines for model applications, including techniques for measuring model variables, are described.

The HSI models presented herein are hypotheses of species-habitat relationships, <u>not</u> statements of proven cause and effect relationships. The models have not been field-tested, but they have 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 planning. Please send any comments or suggestions you may have on the striped bass HSI models to the National Coastal Ecosystems Team, U.S. Fish and Wildlife Service, 1010 Gause Boulevard, Slidell, Louisiana 70458.

CONTENTS

ACKNOWLEDGMENTS

Development of the habitat suitability index models for the striped bass was monitored and evaluated by Dr. John Boreman, National Marine Fisheries Service, and Dr. John J. Ney, Virginia Polytechnic Institute and State University. Messrs. James Terrell, James M. Barkuloo, and John Cooper, Fish and Wildlife Service, respectively provided technical assistance in model construction, peer review, and preparation of the manuscript for publication. Useful comments and suggestions were also received from field biologists. Funding for model construction and publication was provided by the Fish and Wildlife Service.

STRIPED BASS (Morone saxatilis)

HABITAT USE INFORMATION

The striped bass is a major sport and commercial fish. The species has a large natural range that includes freshwater, estuarine, and marine habitats. Although this fish is tolerant of a variety of environmental conditions, several physicochemical and biological factors limit striped bass survival and abundance.

Striped bass populations occur along the Atlantic coast from the St. Lawrence River, Canada, to the St. Johns River, Florida. Along the Gulf of Mexico, striped bass were once common in riverine and estuarine habitats from the Suwannee River in north Florida to Lake Pontchartrain, Louisiana (Hardy 1978; Setzler et al. 1980; Crateau et al. 1981). Following introduction into California's Sacramento and San Joaquin River estuary in 1879, the striped bass population expanded tremendously and now dominates the sport fishery in the estuary (Chadwick et al. 1977). Since 1879, striped bass have been found from the Columbia River, Washington, to Ensenada, Mexico. Striped bass populations have also been established in many freshwater reservoirs across the United States.

One of the most important spawning and nursery grounds for striped bass is Chesapeake Bay and its tributaries (Kernehan et al. 1981). Chesapeake Bay may account for as much as 90% of the recruitment in the Atlantic coastal fishery and is also a major contributor to the fishery in the lower Hudson River and New York Bight (Berggren and Lieberman 1978). Albemarle Sound and the Hudson River are also important sources of striped bass on the Atlantic coast (Raney et al. 1954; Berggren and Lieberman 1978).

Age, Growth, and Food

For purposes of this habitat account, three major developmental stages are recognized for striped bass: adult, larval, and juvenile. Female striped bass generally reach maturity at 3 to 4 years of age and at total lengths (TL) of 432 to 457 mm, while males mature at 2 years and 174 to 254 mm TL (Merriman 1941; Raney 1952; Lewis 1962). Age and size at maturity, however, may vary significantly between stocks. Adult striped bass feed primarily on fish. Manooch (1973) suggested that soft-rayed fish species are preferred prey, but other workers consider striped bass to be generalists in prey choice (Merriman 1941; deSylva 1973).

The larval stage of development begins with the hatching of the fertilized egg and ends after 35 to 50 days. At approximately 8 days and 6 to 7 mm TL, striped bass larvae begin active feeding (Doroshev 1970). Larvae less than 10 mm feed primarily on crustacean nauplii. At sizes greater than 10 mm, they feed primarily on larger zooplankton and macroinvertebrates (Humphries and Cumming 1973). The availability of sufficient concentrations of suitable prey during the first several days of feeding is a critical factor influencing larval survival (Setzler et al. 1980; Cooper and Polgar 1981; Eldridge et al. 1981). Miller (1977) estimated that a minimum concentration of 1,864 nauplii/l is required for successful initial feeding.

The juvenile stage is relatively long compared to other life stages and encompasses the period from larval transformation at 35 to 50 days until maturity. Young striped bass feed on zooplankton, macroinvertebrates, and fish. Stevens (1966) reported that juveniles in the Sacramento and San Joaquin River estuary feed mainly on invertebrates in the winter and spring. When small fish prey become available in the summer, juvenile striped bass change their diet and feed upon them. Juvenile striped bass begin feeding on larger fish in their second summer (Stevens 1966). In general, juveniles are not highly selective and consume food items based on availability (Heubach et al. 1963; Stevens 1966; Hester and Stevens 1970; Manooch 1973; Boynton et al. 1981).

Reproduction

Spawning may begin in mid-February in the southern portion of the striped bass range, whereas, in the extreme northern portions of the range, spawning does not begin until June or July (Hardy 1978). A reservoir of small eggs is maintained in the ovaries of mature females. Egg maturation begins slowly in summer and proceeds rapidly as the spawning season is approached (Jackson and Tiller 1952; Lewis 1962). Female striped bass produce approximately 14,000 to 65,000 eggs annually in initial spawning years, while very old and large individuals may produce over 5,000,000 eggs (Jackson and Tiller 1952; Raney 1952).

Adult striped bass migrate to fresh or nearly freshwater to spawn. Typically, spawning takes place in riverine habitat closely associated with the upper estuary, approximately within the first 45 km (28 mi) of freshwater (Talbot 1966). In some stocks, particularly those in estuarine systems lacking pronounced tidal cycles, spawning may occur at greater distances upstream of the estuary.

Males reach the spawning grounds before females. As spawning occurs, several males will surround a single female and create commotion by splashing on the surface of the water. Females broadcast their semibuoyant eggs near the water surface when fertilization occurs (Merriman 1941; Raney 1952). Striped bass refrain from feeding only immediately before and during spawning (Morgan and Gerlach 1950; Hollis 1952). Depending on the estuary, there may be one to three peaks in spawning each season which are thought to result from major increases in water temperature (Hardy 1978). Reports documenting spawning time for striped bass vary widely. Spawning activity has been noted in late afternoon and early evening (Morgan and Gerlach 1950), as well as late evening and early morning (Hardy 1978).

Environmental factors play a major role in determining the spawning success of striped bass stocks (Talbot 1966; Ulanowicz and Polgar 1980). Water volume in the spawning river is a significant factor determining spawning habitat suitability (Fish and McCoy 1959; Turner and Chadwick 1972). Suitability of a spawning area appears to increase with greater river discharge (expressed as the percent of natural flow). Fish and McCoy (1959) found that a sustained minimum flow was necessary for suitable spawning conditions in the Roanoke River, North Carolina, and rapid fluctuations in streamflow were detrimental to spawning.

Shannon and Smith (1967) reported that optimal spawning temperatures are approximately 17° to 19°C (63° to 66°F) with no spawning observed below 13°C (55°F) or above 22°C (72°F). With minor variations, these temperature ranges correspond with observations by Calhoun et al. (1950), Raney (1952), Dickson (1957), Farley (1966), and Talbot (1966). Calhoun et al. (1950) and Farley (1966) reported that a sudden drop in water temperature can terminate spawning.

Salinity and total dissolved solids (TDS) concentrations are important factors during the spawning period and may be responsible for deterring spawning or reducing spawning success. Farley (1966) found that the number of eggs deposited reached a maximum when TDS were less than 0.18 parts per thousand (ppt). Spawning migrations into the San Joaquin River, California, did not occur at a critical salinity concentration of 0.35 ppt (TDS) (Radtke and Turner 1967). However, highly successful spawning was observed in the Chesapeake and Delaware Canal at salinities of 0.70 to 1.5 ppt (TDS) by Johnson and Koo (1975). Stevens (1979) reported that striped bass may not spawn where salinities exceed 5 ppt.

Specific Habitat Requirements

Striped bass occupy various habitats depending on life stage. Variations in habitat utilization also occur between individual stocks. Known striped bass habitat requirements are presented for each life stage in the following sections.

Adult. In some striped bass stocks from Cape Hatteras, North Carolina, north to New England (predominantly Chesapeake Bay), substantial numbers of striped bass leave the estuaries and migrate along the coast. The migrating fish move north in the summer and south in the winter (Merriman 1941; Clark 1968). Large adults, predominantly females, move farther distances on their migratory sojourns. Adults in the southern portion of the range and on the Pacific coast tend to remain in the estuary or in nearby offshore waters. Sandy beaches, rocky shores, and shallow bays are inhabited in both marine and estuarine environments (Bigelow and Schroeder 1953). Striped bass are generally not found more than 6 to 8 km (4 to 5 mi) offshore at any time.

Limited information is available concerning the physicochemical requirements and tolerances of adult striped bass. The adults appear to have similar water temperature and dissolved oxygen requirements as juveniles. Preferred temperatures vary depending on ambient acclimation temperatures (Meldrim and Gift 1971). The maximum upper avoidance temperature is 34°C (93°F) for striped bass acclimated to 27°C (81°F) in late August, while striped bass acclimated to 5°C (41°F) in December avoid 13°C (55°F) water. A maximum preferred temperature of 25° to 27°C (77° to 81°F) during the growing season was reported by Merriman (1941). Adult striped bass are known to avoid areas of 44% (of saturation) or less in dissolved oxygen concentration (Meldrim et al. 1974).

Information on specific causes of mortality in adults is lacking, although sport and commercial fishing are suspected of having a significant effect on some populations.

Egg. Striped bass eggs are spherical, semibuoyant, nonadhesive, and approximately 1.3 mm in diameter at fertilization (Pearson 1938). Within 12 hours of release, eggs will be water hardened and approximately 3.4 to 3.8 mm in diameter (Pearson 1938; Johnson and Koo 1975). Survival of striped bass eggs to hatching is primarily associated with narrow tolerances to certain physicochemical factors including temperature, dissolved oxygen, and current velocity (Cooper and Polgar 1981).

A temperature range of 17° to 20°C (63° to 68°F) is optimal for egg survival (Barkuloo 1970; Doroshev 1970; Morgan et al. 1981). Morgan and Rasin (1973) and Rogers et al. (1977) indicated that egg survival rapidly declines as water temperature approaches 23°C (73°F) and gradually declines as water temperature drops below 17°C (63°F), with few eggs surviving at 12°C (54°F). These temperature ranges are similar to those required for spawning.

Low dissolved oxygen concentrations (2.0 to 3.5 mg/l) were determined to be responsible for the absence of eggs and larvae in the Delaware River (Murawski 1969; Chittenden 1971). Turner and Farley (1971) reported that even moderate reductions in dissolved oxygen concentrations (from 5 to 4 mg/l) decreased the survival of eggs.

A critical factor for egg survival is sufficient current velocity to maintain egg suspension (Talbot 1966). Either tidal turbulence or river discharge can provide sufficient water movement to suspend the eggs. A minimum average velocity of 30 cm/s (1 ft/s) is necessary to prevent the concentration of eggs on the bottom (Albrecht 1964). Egg distribution in the water column appears to be random at velocities in excess of 30 cm/s. The density gradient of the water column may also influence egg suspension since striped bass eggs are only slightly heavier than pure water (specific gravity = 1.0005, Hardy 1978).

Certain factors that are usually regarded as important determinants of egg survival in other fish species do not appear to be important to striped bass. Salinities typically encountered by eggs are not detrimental to survival, although low salinity is considered optimal for water hardening (Albrecht 1964; Morgan et al. 1981). While high turbidity and heavy suspended sediment loads have been found to be detrimental to egg survival for many fish species, striped bass eggs appear to be adapted to these conditions. Neither turbidity nor suspended sediments have been observed to significantly decrease hatching success (Talbot 1966; Schubel and Auld 1974). Although predation may have a significant effect on egg survival, quantitative estimates of the magnitude of predation are lacking for larval fish in general (Dahlberg 1979).

The egg stage is brief in comparison to other striped bass life stages. Several authors documented hatching at approximately 48 hours after fertilization at a temperature of 18°C (64°F). However, hatching time varies from 29 hours at 22°C (72°F) to 80 hours at 11°C (52°F) (Pearson 1938; Raney 1952; Mansueti 1958; Hardy 1978).

Larval. The larval stage is the period from hatching to the time when the appearance of the young corresponds with that of an adult. The duration of this stage and the size ranges of striped bass larvae have been summarized from a detailed review by Setzler et al. (1980). The larval stage is commonly divided into three distinct phases: yolk sac, finfold, and post-finfold. At hatching, striped bass range from 2.0 to 3.7 mm long and possess an easily identified yolk sac. The yolk sac phase lasts 3 to 9 days and is terminated when the yolk sac is absorbed at about 5 to 8 mm TL (Figure 1a). The finfold (metamorphosing) phase lasts approximately 11 days during which larvae attain a maximum length of 12 mm (Figure 1b). The final metamorphosing phase, post-finfold, lasts 20 to 30 days with a maximum larval length of 20 mm.

Larval survival is a crucial factor in the determination of adult population size (Eldridge et al. 1981). As in the egg stage, larval survival is associated with a narrow tolerance range for certain physicochemical factors. In natural estuarine systems, both food availability and environmental conditions influenced by climatic events are particularly important for early striped bass survival (Cooper and Polgar 1981).

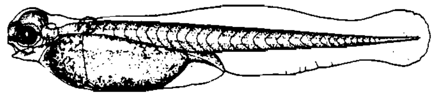
Dissolved oxygen, temperature, and salinity appear to play important roles in determining larval survival. Striped bass larvae need a minimum of 3 mg/l dissolved oxygen to survive (Chittenden 1971). Even moderate reductions in dissolved oxygen (from 5 to 4 mg/l) reduced the survival of larvae (Turner and Farley 1971). Dissolved oxygen requirements for larvae are essentially identical to those reported for striped bass eggs. A temperature range of 18° to 21°C (64° to 70°F) is considered optimal for larvae (Rogers et al. 1977), but temperatures from 12° to 23°C (54° to 73°F) are tolerated (Doroshev 1970). A salinity range of 3 to 7 ppt is optimal for growth and survival (Lal et al. 1977). However, striped bass larvae can tolerate salinities from 0 to 15 ppt (Albrecht 1964).

Other factors which may influence striped bass larval survival are not well understood or do not appear to be significant. While they may initially require turbulence to maintain position in the water column, striped bass larvae rapidly become very motile, positively phototaxic, and continually self suspended (Doroshev 1970). The larvae characteristically remain in the open surface waters of the estuary (Raney 1952).

A potentially significant cause of larval mortality is predation. Data on losses of larvae to predators, however, are lacking for most fish species (May 1974; Dahlberg 1979) and striped bass in particular (Setzler et al. 1980).

Juvenile. Juvenile striped bass (Figure 1c) are able to tolerate a considerably broader range of environmental conditions than egg and larval life stages. Some habitat requirements for juveniles are similar to those of adult striped bass.

As young juvenile striped bass grow, they move into nearshore areas and gradually migrate to higher salinity portions of the lower estuary (Raney 1952; Calhoun 1953). Bason (1971) reported that the largest concentrations of juveniles were in protected areas of moderate salinity. Shoals have also been reported as nursery areas for striped bass by Sasaki (1966) and Carlson and McCann (1968). Rathjen and Miller (1957) noted that the largest catches of



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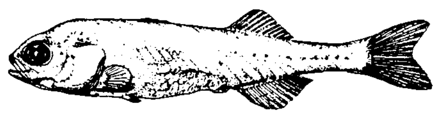

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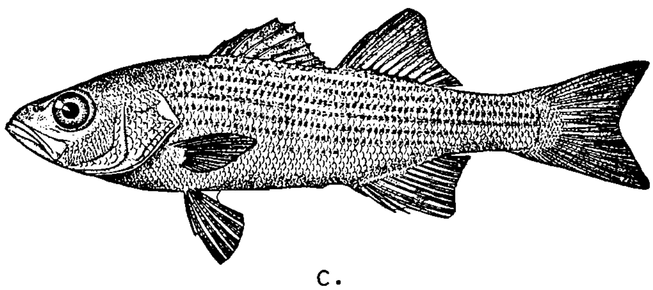


c.

Figure 1. Larval and juvenile development stages of the striped bass. Figure 1a depicts the yolk sac larval phase of a 5.3-mm TL specimen (from Mansueti 1958). Figure 1b shows a 12-mm TL striped bass larva beginning the post-finfold phase, prior to full development of the second dorsal fin (from Mansueti 1958). Figure 1c depicts the juvenile development stage of a 130-mm TL specimen (from Pearson 1940). Development stages are not drawn to scale.

juvenile striped bass were near clean sandy bottoms, although differential sampling efficiency may have been responsible for high catches in these areas. Apparently juvenile striped bass will use various nearshore microhabitats and do not appear to require specific microhabitat conditions.

Temperature and dissolved oxygen are important factors affecting growth and survival of juvenile striped bass. A temperature range of 14° to 21°C (57° to 70°F) during the growing season is optimal (Krouse 1968; Doroshev 1970). However, a temperature range of 10° to 27°C (50° to 81°F) can be tolerated by juveniles (Davies 1970; Hester and Stevens 1970). For dissolved oxygen levels, Krouse (1968) found no survival of juvenile striped bass at 1 mg/l, intermediate survival at 3 mg/l, and high survival at 5 mg/l.

Although large piscivores, such as bluefish and weakfish, probably prey on juvenile striped bass, definitive information on, or confirmation of, the extent of predation is not currently available (Setzler et al. 1980).

Special considerations. Striped bass populations are characterized by dramatic fluctuations in year-class size. Traditionally, survival during the larval stage has been considered to determine year-class size in species exhibiting large fluctuations in abundance (May 1974; Dahlberg 1979). Recent research indicates that this concept is particularly applicable to striped bass (Polgar et al. 1975; Cooper and Polgar 1981; Eldridge et al. 1981). Merriman (1941) first noted the occasional occurrence of unusually large year classes of striped bass and suggested a relationship between certain climatic conditions and strong year classes.

While some conclusions are tentative, current thinking links strong striped bass year classes to high food availability (abundant zooplankton) during the larval stage (Heinle et al. 1975; Eldridge et al. 1981). Although zooplankton abundance fluctuates widely over time in any estuary, the potential for an abundance of zooplankton appears to be related to estuarine productivity. The level of productivity in an estuary is a function of both freshwater nutrient (detritus) input to the estuary (Biggs and Flemer 1972; Hobbie et al. 1973; Saila 1973; Day et al. 1975; Polgar et al. 1975) and detritus production in the salt marsh (Teal 1962; Odum and Heald 1973; Reimold et al. 1973; Stevenson et al. 1975). Detrital input to the estuary from freshwater inflow is typically greatest during the late winter and early spring. Heinle et al. (1975) and others have proposed that certain climatic events, which affect nutrient release from the salt marsh and nutrient contribution by freshwater input, can influence plankton abundance during the critical larval stage and consequently affect year-class size in striped bass.

The complex relationship of estuarine productivity, zooplankton abundance, and larval striped bass survival appears to have important ramifications for the success of striped bass in estuarine systems and on the evaluation of habitat suitability. Apparently, even optimal habitat will only occasionally produce ideal conditions for striped bass survival. However, the loss of habitat suitability, which would diminish the potential to produce strong year classes, may ultimately have serious consequences for maintenance of a viable striped bass population.

HABITAT SUITABILITY INDEX (HSI) MODEL

Model Applicability

Striped bass are widely distributed and thrive in many habitats. Few generalized statements concerning habitat requirements will be precisely applicable to all populations. Consequently, it is desirable that information pertaining to a particular striped bass stock under consideration be evaluated with regard to model criteria.

The use of this model is not always appropriate, such as where partial or extensive reduction in habitat availability has occurred due to toxic wastes. The unavailablity of potential habitat resulting from the presence of environmental contaminants will interfere with proper interpretation of model applications.

Several model variables utilize average values for certain habitat parameters. While no clear guidance is available in striped bass literature regarding tolerances to rapidly fluctuating conditions, sudden changes in water temperature and river discharge during spawning and early life are detrimental. Caution should be used in calculating average values in situations marked by extreme variability.

Geographic area. This model is suitable for use on estuarine-associated striped bass stocks located on the Atlantic, Pacific, or Gulf of Mexico coasts of the United States. The model and included variables are generalized to reflect the life cycle and requirements of striped bass throughout its coastal range. Therefore, minor deviations in habitat requirements may occur for any specific stock.

Season. The habitat suitability index model is designed for use in year-round applications. In applications involving only portions of the life cycle, the HSI values obtained will apply to seasons in which the life stage(s) of interest occur. Some of the variables included in the model pertain to environmental conditions that would only occur during a particular season. However, it is assumed that as long as those life requisites are available, habitat suitability in other seasons is not limiting.

Cover types. Striped bass typically use at least two habitats during their life cycle: riverine and estuarine. In many stocks, spawning occurs near the transition between riverine and estuarine habitats, whereas, in other stocks, spawning occurs well within riverine habitat. Similarly, egg development varies in its proximity to either type of habitat.

This model is not intended for the evaluation of marine habitat, although in some stocks the adult stage uses this habitat type. When particular life stages are not associated with the estuarine and near-riverine habitats, the model can be manipulated to account for the absence of these life stages.

Minimum habitat area. The minimum habitat area is that area of contiguous suitable habitat that is required for striped bass to live and reproduce. No minimum habitat size requirements for this species or the distinct life stages have been established.

Verification level. The acceptable output of this HSI model is an index between 0 and 1 which is believed to have a positive relationship to carrying capacity. Hypothetical data sets were used to verify that HSI's determined with the striped bass models were reasonable and acceptable. These data sets and their relationship to model verification are discussed later.

Two biological experts outside of the U.S. Fish and Wildlife Service were identified to review and evaluate the striped bass HSI models throughout their development. Ideas and suggestions from these experts were incorporated into the model-building effort. These experts were: Dr. John Boreman, National Marine Fisheries Service, Woods Hole, Massachusetts; and Dr. John Ney, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Model Description

The striped bass HSI model is composed of individual components corresponding to the spawning, egg, larval, juvenile, and adult life stages. When all components are used, the model will produce one habitat suitability index value for the entire life cycle. Individual life stage HSI values can be calculated by using individual components. Partial life cycle HSI values can also be calculated.

The model considers the quality of habitat requirements (variables) for each life stage of the species. Habitat requirements are combined for life requisite categories. It is assumed that habitat suitability is primarily associated with water quality (physicochemical conditions) during most life stages. Food availability and water quantity are considered particularly important life requisites in some life stages. The spawning and egg stages are generally associated with riverine habitat, while the later life stages predominantly occur in estuarine habitats. Figure 2 illustrates how the HSI is related to variables, life requisites, and life stages for striped bass.

Following sections document the assumptions and justification for the variables and equations included in this model. Specifically, these sections cover the identification of variables used in each model component and a description of the assumed relationship between variables within each model component.

Adult component. Limited information is available concerning specific habitat requirements of adult striped bass in estuaries, but they are assumed to be adaptable with respect to food and aquatic cover. Many stocks of adult striped bass remain in the estuaries, while others undertake coastal migrations during the growing season. This model is not intended for evaluation of marine habitat and, in the case of some migratory stocks, the component index for adults (CIa) should be deleted.

Habitat suitability for adult striped bass is limited primarily by water quality. Adult requirements appear to be similar to those for juveniles, and the same variables and calculations used to compute the juvenile component index are used for the adult component index.

Spawning component. Striped bass have limited tolerances to water temperature and total dissolved solids during spawning. Spawning is reduced at temperatures above and below the optimal range. A total dissolved solids

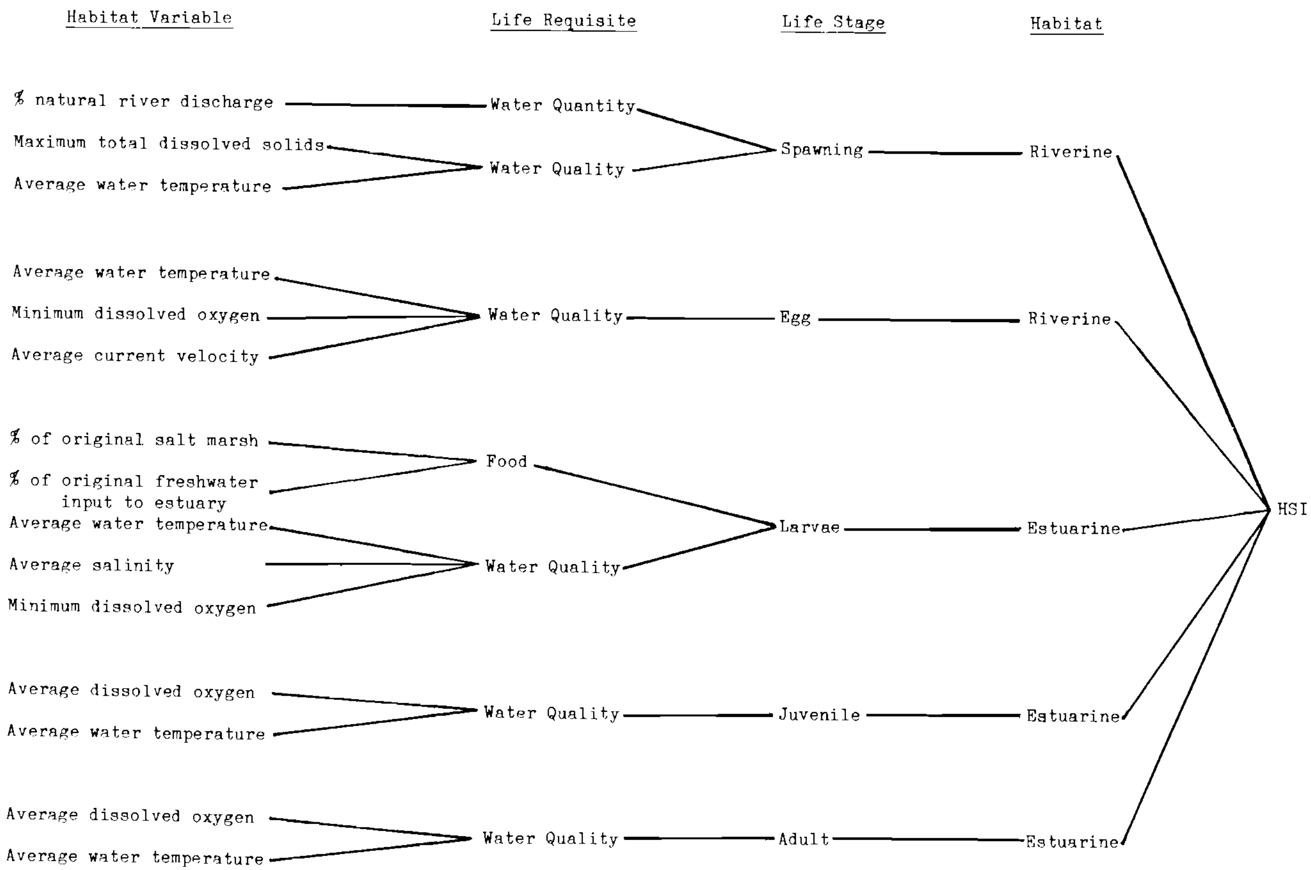


Figure 2. Tree diagram illustrating the relationship of habitat variables, life requisites, life stages, and habitat types to the Habitat Suitability Index (HSI) for coastal stocks of striped bass.

(TDS) concentration over 5 ppt may block spawning. Maximum egg deposition has been observed at TDS concentrations less than 0.18 ppt, but discrepancies have been noted in the literature. Therefore, specific data for available stocks should be used to determine the applicability of this variable.

River discharge (m^3/s) influences spawning habitat suitability. Although critical values have not been established, it is assumed that 100% of the natural river discharge (average during spawning) will provide optimal spawning conditions. River discharge above the average (100% of natural) is not assumed to reduce habitat suitability. Natural river discharge may be considered to be mean discharge prior to human modifications of the system or the discharge that would occur if diversions and withdrawals ceased. Reduced river discharge is assumed to result in a proportional reduction in habitat suitability. In situations involving limitations to upstream passage due to low flows, a minimum discharge should be determined that would still allow access to spawning habitat.

It is assumed that a riverine habitat will not provide suitable conditions for spawning if the suitability index (SI) for any variable is equal to zero. Therefore, the geometric mean of the suitability indexes for these variables is used to compute the component index (CI) for spawning habitat (CIs). Using this approach to combine variables, the resulting CI will be zero if any variable SI is zero.

Egg component. Egg survival to hatching primarily depends on defined tolerances to certain water quality parameters. The temperature optima and tolerances reported for striped bass eggs closely correspond with those reported for spawning. Therefore, a single suitability index graph for water temperature is used in calculating both component indexes. Dissolved oxygen levels below 5 mg/l result in reduced egg survival. There is little chance of egg survival at dissolved oxygen levels below 3.5 mg/l. Striped bass eggs require suspension in the water column for survival. Lack of suspension results in limited hatching success, presumably due to siltation and insufficient dissolved oxygen. It is assumed that egg suspension is related to maintenance of proper water quality around the eggs. A critical value for current velocity of 30 cm/s (1 ft/s) has been documented for adequate egg suspension. However, the suitability index graph for water velocity allows a limited range for intermediate index values because the necessary suspension velocity will vary somewhat due to the precise density of the river water.

It is assumed in the calculation of the component index for eggs (CIe) that low SI values for water temperature are not as crucial as low SI values for dissolved oxygen and current velocity. When temperature has the lowest SI, the component index is calculated by the geometric mean. However, if dissolved oxygen or current velocity are limiting, it is assumed to be unlikely that even optimal temperatures will mitigate the undesirable conditions. As a result, in situations in which dissolved oxygen or current velocity variables have the lowest SI, the lowest value is considered limiting and becomes the component index.

Larval component. Larval survival appears to be primarily associated with narrow tolerances for certain physicochemical factors. Striped bass larvae can withstand a considerable range of water temperatures from 12° to

23°C (54° to 73°F), although the highest survival occurs within a narrow range from 18° to 21°C (64° to 70°). As in the egg stage, dissolved oxygen levels below 5 mg/l result in reduced survival. A critical and optimal range for salinity has also been identified. These factors are averaged geometrically to yield a subcomponent index for water quality (WQ) during larval development.

The importance of sufficient food (zooplankton) during larval development emphasizes the need to evaluate this requirement in determining habitat suitability. While it is currently impossible to easily predict zooplankton abundance at a given point in time, indirect measures can be used to reflect the potential of an estuarine habitat to provide sufficient zooplankton prey. It is assumed that potential zooplankton abundance is associated with estuarine productivity, which is believed to be a function of freshwater input during late winter and early spring and the extent of salt marsh. Optimal habitat suitability is assumed to occur when freshwater input and extent of salt marsh are in their original condition.

Reductions in both the freshwater input to the estuary during early year high flows and in the original areas of salt marsh are associated with reduced habitat suitability. Original conditions are those known to have occurred prior to human modification or as the conditions that would occur if current or planned alterations were eliminated. The late winter and spring high flow period is defined as the period in which the river hydrograph near the estuary exceeds the average annual discharge.

Although the true relationships between habitat suitability and the indirect variables of freshwater input and extent of salt marsh are not known, a sigmoid curve is assumed to be an adequate approximation. This form of the SI relationship was chosen to allow for the resilience known to exist in many ecological systems. A sigmoid curve reflects a healthy system's ability to withstand minor perturbations. More importantly, this relationship reflects a system's declining ability to absorb incremental deterioration. Both variables are averaged together to form a subcomponent index for food (F).

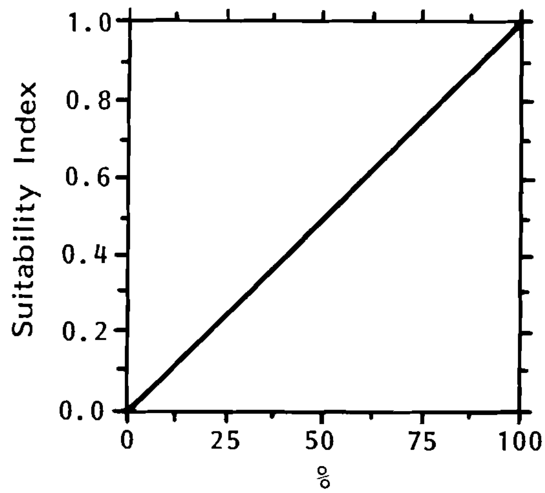
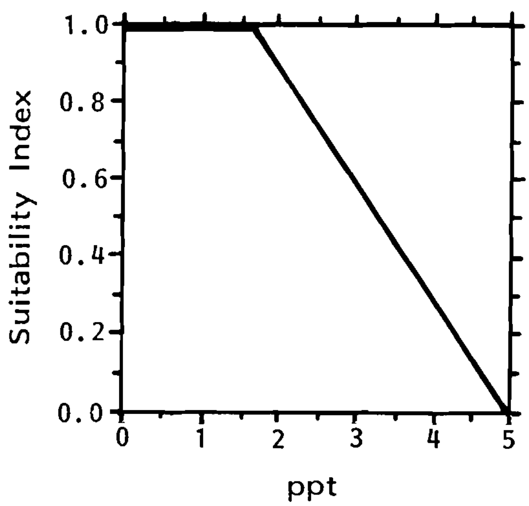
The component index for the larval stage of striped bass (CIl) is the geometric mean of the subcomponent indexes for water quality and food. The food subcomponent is weighted due to the emphasis placed on the importance of food availability in the recent literature on striped bass biology.

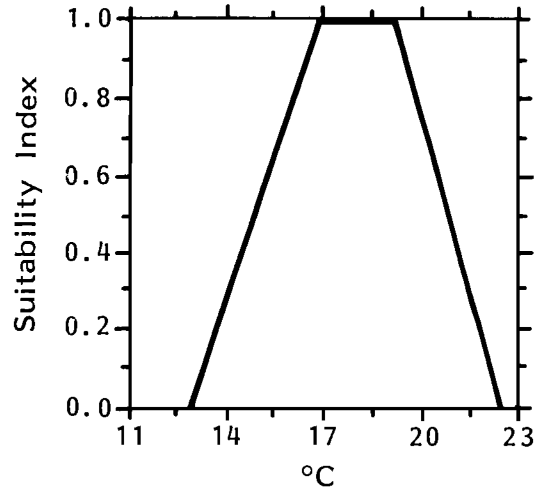
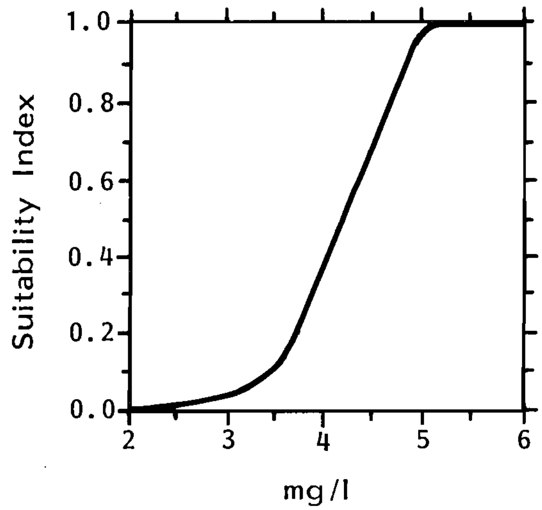
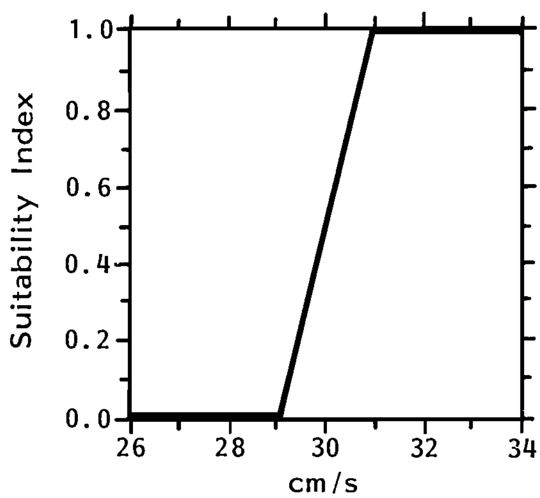
In calculating the overall habitat suitability index (HSI) for striped bass, the larval stage is given critical importance because the literature indicates that success of this stage principally determines population size. It is assumed that limitations in larval striped bass habitat suitability will not be compensated for by better conditions in other life stages.

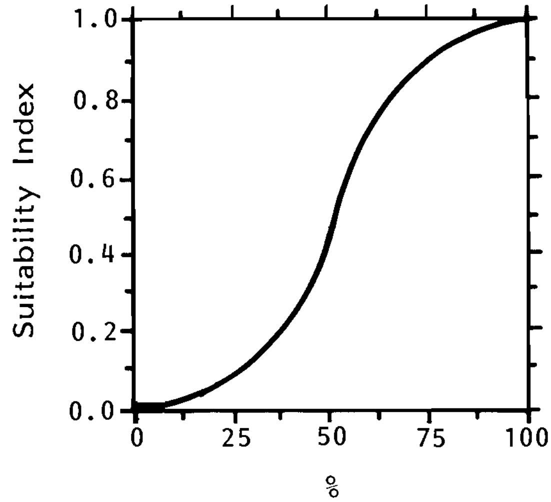
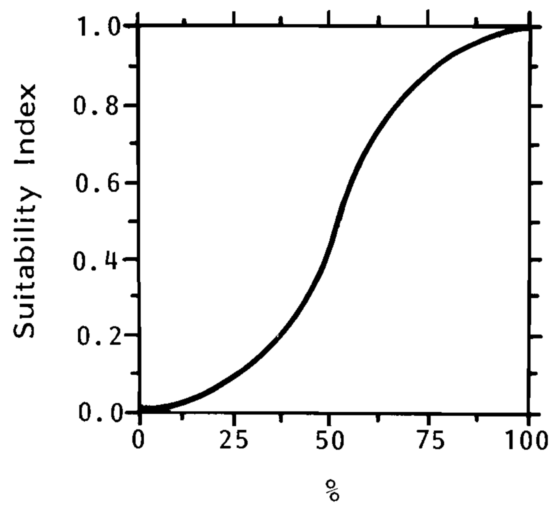
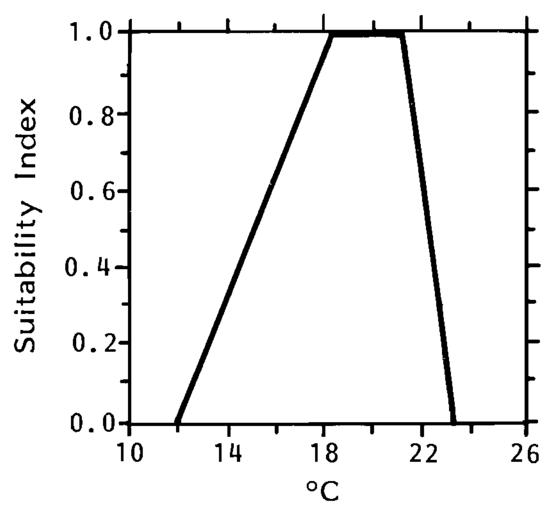
Juvenile component. Limited information is available for specific habitat requirements of juvenile striped bass. Juvenile survival does not appear to be limited by food and aquatic cover. Therefore, these habitat variables are not included in model. However, juvenile striped bass do appear to have a limited tolerance to certain physicochemical factors associated with water quality. The optimal temperature range for growth and survival during the growing season is approximately 14° to 21°C (57° to 70°F), although water temperatures from 10° to 27°C (50° to 81°F) are tolerated. Juvenile striped bass cannot survive dissolved oxygen levels of 1 mg/l. Intermediate survival occurs at 3 mg/l, with optimal survival at dissolved oxygen levels of 5 mg/l or more. The component index for the juvenile stage (CIj) is the geometric mean of the dissolved oxygen and temperature suitability indexes.

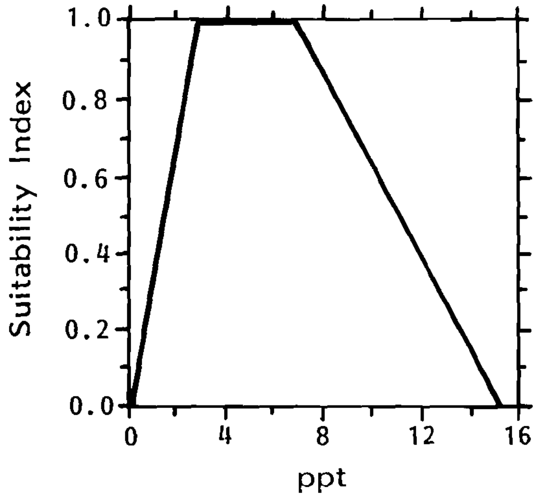
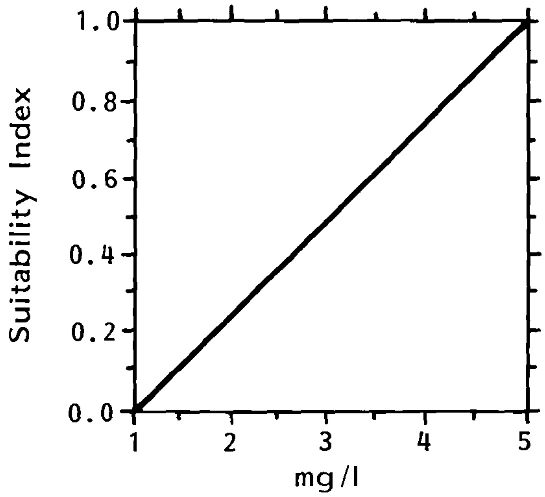
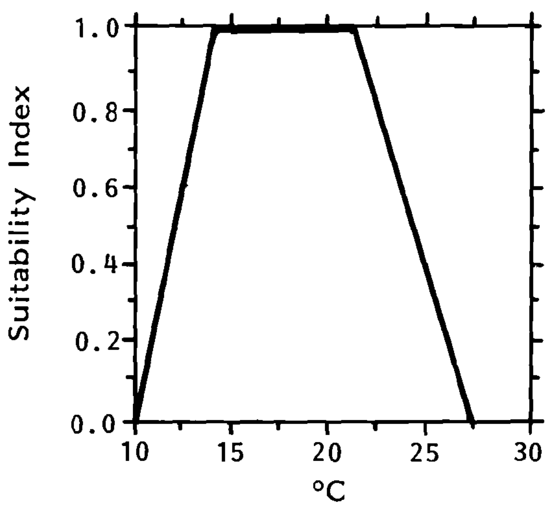
Suitability Index (SI) Graphs for Model Variables

This section provides graphic representation of the relationships between various measurements of habitat variables and habitat suitability for striped bass. The variables are identified with the habitat category (R = riverine, E = estuarine) indicated. The suitability index (SI) values are read directly off the graph (1.0 = optimal habitat, 0.0 = no habitat) for any variable value.

Habitat	Variable		Suitability Graph
R	V_1	Percent natural river discharge during the spawning season.	
R	V_2	Maximum total dissolved solids (TDS) concentration during the spawning season.	

Habitat	Variable		Suitability Graph
R	V_3	Average water temperature during the spawning season and period of egg development	
R,E	V_4	Minimum dissolved oxygen level during egg and larval development.	
R	V_5	Average current velocity in water column during period of egg development.	

Habitat	Variable		Suitability Graph
E	V_6	Percent original salt marsh in estuary.	
E	V_7	Percent of original freshwater input (average volume) to estuary during the late winter and spring high flow period.	
E	V_8	Average water temperature during period of larval development.	

Habitat	Variable		Suitability Graph
E	V_9	Average salinity during period of larval development.	
E	V_{10}	Average dissolved oxygen during the growing season.	
E	V_{11}	Average water temperature during growing season.	

Component Index Equations

To obtain component index scores for each life stage of striped bass, the SI values for appropriate variables must be combined by the use of the equations presented below.

LIFE STAGE	EQUATION
Adult	$CIa = V_{10}$ or V_{11}, whichever is lowest
Spawning	$CIs = (V_1 \times V_2 \times V_3)^{1/3}$
Egg	if $V_3 < V_4$ and V_5, then $CIe = (V_3 \times V_4 \times V_5)^{1/3}$
	if $V_3 \geq V_4$ or V_5, then $CIe = V_4$ or V_5, whichever is lowest
Larval	$CIl = (F^2 \times WQ)^{1/3}$
	where $F = (V_6 + V_7)/2$
	and
	$WQ = (V_4 \times V_8 \times V_9)^{1/3}$
Juvenile	$CIj = V_{10}$ or V_{11}, whichever is lowest

HSI Determination

The following steps must be taken to determine an HSI for any application.

1. Following a review of habitat use information, determine which life stages are found in the habitats (riverine, estuarine, or both) to be evaluated. Also, identify the time periods in which each life stage may be present. This step identifies the appropriate components for the application.

2. Review the section on model applicability for validity of the model for the intended application.

3. Obtain necessary data for each model variable used in the model components to be included in the application. Using the SI graphs and equations, calculate the component indexes.

4. Calculate the HSI:

   a. If the component index for the larval stage (CIl) is the lowest component index, then

      HSI = CIl;

b. If the component index for the larval stage is not the lowest component index, then

$$HSI = (CIs \times CIe \times CIl \times CIj \times CIa)^{1/5}$$

or

$$HSI = (CI \times \ldots \times CIn)^{1/n}$$

if less than 5 components are used.

Four sample data sets from which suitability indices, component indices, and habitat suitability index values have been generated using the model equations are presented in Table 1. Data set 2 represents conditions where adult striped bass are absent from the estuary during the growing season. Data set 4 represents a situation where only the estuarine habitat is being evaluated.

The data sets are not actual field measurements, but represent the kinds of values that one could expect to obtain in riverine and estuarine habitats used by striped bass. The HSI's calculated from these hypothetical data sets reflect carrying capacity trends which the authors believe are appropriate for water bodies with the characteristics listed in Table 1. Thus, the models meet the acceptance goal of producing an index between 0 and 1 that is believed to have a positive relationship to a habitat's carrying capacity for striped bass.

Field Use of the Model

The level of detail needed for a particular application of this model will vary depending on time, money, and accuracy constraints. Detailed evaluation of all variables will produce the most reliable and replicable HSI values. Use of previously collected data for any or all variables may produce a satisfactory application of the model with minimal expense. Data required by this model are frequently available from published or resource agency sources. Table 2 presents suggested techniques for measuring model variables and notes references to consult for more detailed guidance.

Any or all variables can be estimated for preliminary applications of the model. Subjective estimates will decrease model reliability and replicability. When subjective estimates are used, they should be made by experienced professionals, if possible, and accompanied by full documentation of the basis on which estimates were made.

Interpreting Model Outputs

A striped bass HSI determined by field application of these models may not reflect the population density of the species in the study area, since factors other than habitat related ones may be significant in determining population size. However, in coastal areas where striped bass populations are primarily regulated by habitat-based factors, the models presented here should yield HSI's that are positively correlated with long-term average population levels. This correlation, however, has not been tested.

Table 1. Calculations of the suitability indices (SI), component indices (CI) and the habitat suitability index (HSI) for four sample data sets, using the striped bass habitat variables (V) and model equations.

Model component	Data set 1		Data set 2[a]		Data set 3		Data set 4[b]	
	Data	SI	Data	SI	Data	SI	Data	SI
V_1	90	0.90	75	0.75	75	0.75	-	-
V_2	1.3	1.00	2.9	0.60	1.1	1.00	-	-
V_3	16	0.75	22	0.48	18	1.00	-	-
V_4	4.5	0.70	4.5	0.70	4.2	0.50	4.6	0.75
V_5	32	1.00	30	0.50	30	0.50	-	-
V_6	85	0.95	55	0.65	50	0.50	95	0.99
V_7	85	0.95	75	0.90	50	0.50	90	0.97
V_8	19	1.00	22	0.46	22	0.46	15.5	0.60
V_9	3	1.00	12	0.37	12	0.37	4	1.00
V_{10}	4.5	0.88	3	0.50	4.2	0.80	5	1.00
V_{11}	20	1.00	16	1.00	23	0.67	23	0.67
CIs		0.88		0.60		0.91		-
CIe		0.70		0.55		0.50		-
CIl		0.93		0.67		0.48		0.90
CIj		0.88		0.50		0.67		0.67
CIa		0.88		-		0.67		0.67
HSI		0.85		0.58		0.48		0.74

[a] Adults absent from estuary during the growing season.

[b] Only estuarine habitat is evaluated.

Table 2. Description of striped bass HSI model variables and suggested techniques for measuring variables for riverine and estuarine habitats.

Habitat	Variable	Variable description	Suggested technique	Reference source
Riverine	V_1	% of natural river discharge in the spawning area during the spawning season.[a]	Historical U.S. Geological Survey gage data or river information to estimate altered and unaltered conditions.	Stalnaker and Arnette 1976 Buchanan and Somers 1976
Riverine	V_2	Maximum total dissolved solids (TDS) during the spawning season.	Existing data, literature, or field sampling in spawning area and laboratory analysis.	American Public Health Association 1976 U.S. Environmental Protection Agency 1979
Riverine	V_3	Average water temperature during spawning and egg development.	Existing data, literature, or field sampling in areas of spawning and egg development using thermometers.	American Public Health Association 1976 Lind 1974
Riverine Estuarine	V_4	Minimum dissolved oxygen during egg and larval development.	Existing data, literature, or field sampling in areas which contain eggs and larvae by using dissolved oxygen meters or laboratory analysis.	American Public Health Association 1976 U.S. Environmental Protection Agency 1979 Lind 1974
Riverine	V_5	Average current velocity in water column during egg development.	Existing data, literature, or field measurements in areas with eggs.	Stalnaker and Arnette 1976 Buchanan and Somers 1976
Estuarine	V_6	% of original salt marsh in estuary.[b]	Historical maps and information or current topographic maps and data to estimate prior conditions.	Lind 1974

Table 2. (Concluded).

Habitat	Variable	Variable description	Suggested technique	Reference source
Estuarine	V_7	% of original freshwater input to estuary during early-year high flow period.[c]	Historical U.S. Geological Survey gage data or river basin information to estimate altered and unaltered conditions.	Stalnaker and Arnette 1976
Estuarine	V_8	Average surface water temperature during larval development.	Existing data, literature, or field measurements in areas with larvae by using thermometers.	American Public Health Association 1976 Lind 1974
Estuarine	V_9	Average surface water salinity during larval development.	Existing data, literature or field sampling in areas with larvae by using salinometers or laboratory analysis.	American Public Health Association 1976 U.S. Environmental Protection Agency 1979
Estuarine	V_{10}	Average dissolved oxygen during the growing season.	Existing data, literature, or field sampling of the estuary by using dissolved oxygen meters or laboratory analysis.	American Public Health Association 1976 U.S. Environmental Protection Agency 1979 Lind 1974
Estuarine	V_{11}	Average water temperature during the growing season.	Existing data, literature or field sampling of the estuary by using thermometers.	American Public Health Association 1976 Lind 1974

[a]Defined as percent of original or unaltered average discharge (m^3/s) during spawning period.

[b]Defined as estimated hectares of salt marsh prior to human alteration.

[c]Defined as average water volume entering the estuary during time period when river hydrograph exceeds average annual flow.

The proper interpretation of the HSI is one of comparison. If two different areas, or the same area at different points in time, have different HSI's, then the area with the higher HSI should have the potential to support more striped bass than that with the lower HSI.

ADDITIONAL HABITAT SUITABILITY INDEX MODELS

The Western Energy and Land Use Team (WELUT) of the U.S. Fish and Wildlife Service at Fort Collins, Colorado, has developed an HSI model for freshwater striped bass habitats. Striped bass stocks in certain estuarine systems undergo spawning migrations that typically extend inland, beyond the first 45 km (28 mi) of the freshwater riverine habitat. The riverine HSI model developed by WELUT may be substituted for the spawning and egg components of this model. While both HSI models are similar with respect to the riverine habitat, the inland freshwater model does include some additional variables. The estuarine striped bass HSI model is primarily intended for use on stocks which complete the spawning and egg stages close to the estuary.

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16. Abstract (Limit: 200 words)

A review and synthesis of existing information were used to develop estuarine habitat models for coastal stocks of striped bass (Morone saxatilis). Models for five life stages are scaled to produce an index of habitat suitability between 0 (unsuitable habitat) and 1 (optimally suitable habitat) for 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. Guidelines for coastal striped bass 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
Striped bass
Morone saxatilis

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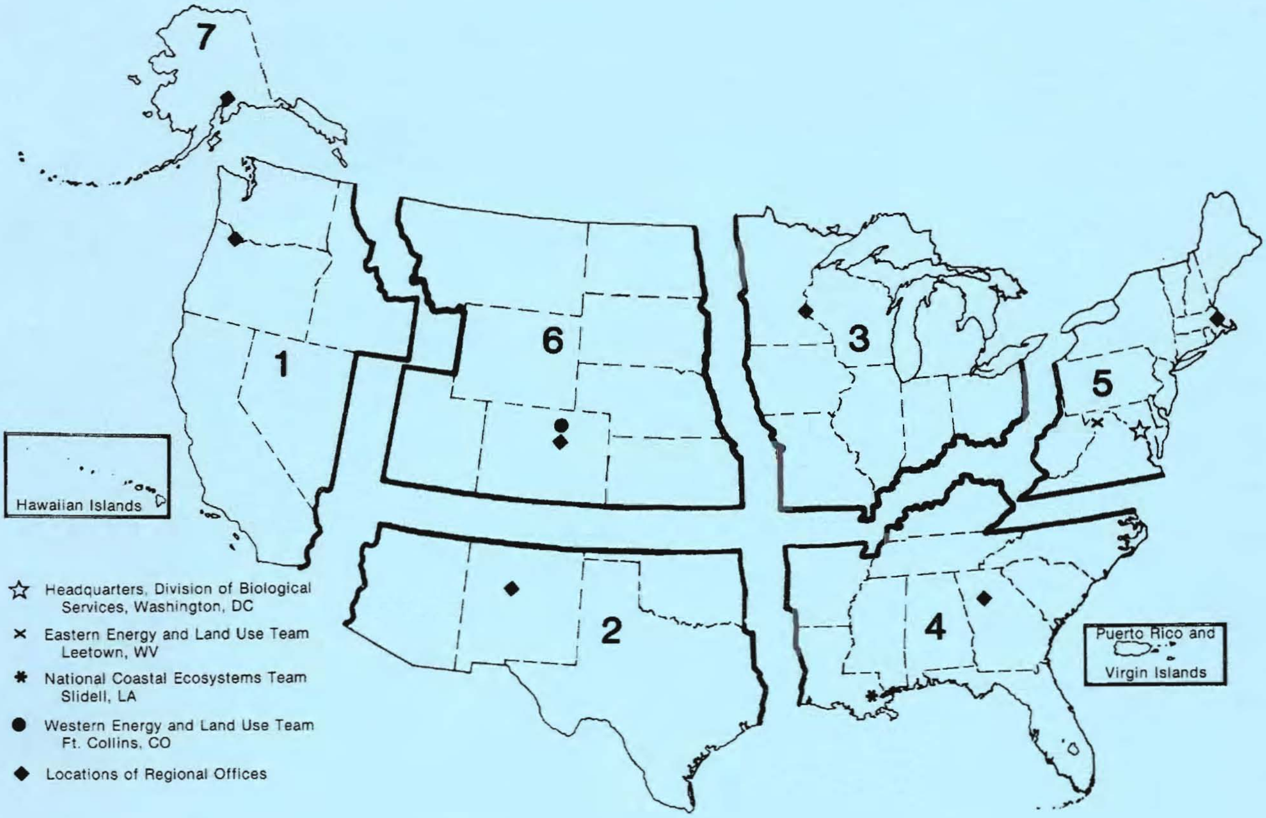

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