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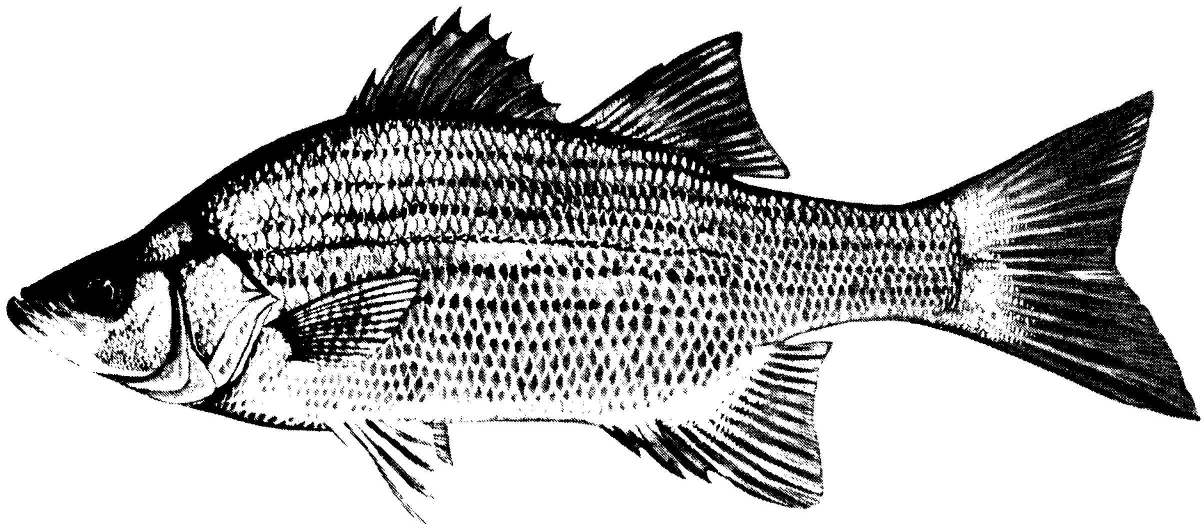
HABITAT SUITABILITY INDEX MODELS AND INSTREAM FLOW SUITABILITY INDEX CURVES: WHITE BASS



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HABITAT SUITABILITY INDEX MODELS AND INSTREAM FLOW SUITABILITY INDEX CURVES: WHITE BASS

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PREFACE

Information presented in this document is for use with the Habitat Evaluation Procedures (HEP) and the Instream Flow Incremental Methodology (IFIM). The information also should be useful for impact assessment and for developing management recommendations and mitigation alternatives for the species using methodologies other than HEP or IFIM. The comparison and recommendations for use of HEP and IFIM presented by Armour et al. (1984)[1] should help potential users of these two methodologies determine the most efficient way to utilize the information in this publication.

The Suitability Index (SI) curves and graphs and Habitat Suitability Index (HSI) models presented in this report are based primarily on a synthesis of information obtained from a review of the literature concerning the habitat requirements of the species. The HSI models and SI curves are scaled to produce an index between 0 (unsuitable habitat) and 1 (optimal habitat). Assumptions used to transform habitat use information into an index are noted, and guidelines for application of the curves and models are described. A discussion of IFIM and white bass SI curves available for use with IFIM is included.

The SI curves and HSI models are starting points for users of HEP or IFIM to develop their own curves and models. Use of the SI curves and HSI models within project-specific applicational constraints is likely to require modification of the SI curves or graphs and HSI models to meet those constraints and to be applicable to local habitat conditions. Users of the SI graphs and/or HSI models with HEP should be familiar with the standards for developing HSI models (U.S. Fish and Wildlife Service 1981)[1] and the guidelines for simplifying HSI models and recommended measurement techniques for model variables (Terrell et al. 1982; Hamilton and Bergersen 1984).[1] Users of the SI curves with IFIM should be familiar with the Guide to Stream Habitat Analysis (Bovee 1982)[1] and the User's Guide to the Physical Habitat Simulation System (Milhous et al. 1984).[1] Material for use with IFIM is presented in English units of measure because flow-related data are normally collected in English units.

The HSI models and SI curves are hypotheses of species-habitat relationships, not statements of proven cause and effect relationships. The curves and models are based on the literature and professional judgment. They have not been applied in the field. For this reason, the U.S. Fish and Wildlife

[1]Citation included in References.

Service encourages model users to convey comments and suggestions that may help us increase the utility and effectiveness of this habitat-based approach to fisheries planning. Please send comments to:

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CONTENTS

ACKNOWLEDGMENTS

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WHITE BASS (*Morone chrysops*)

HABITAT USE INFORMATION

General

The range of the white bass (*Morone chrysops*) originally was restricted to the large lakes and rivers of the Great Lakes and Mississippi River drainages, with its center in the Lake Erie drainage (Van Oosten 1942; Sigler 1949b). Depletion of white bass in the Great Lakes and increased stocking in newly constructed reservoirs resulted in a southward shift in its center of abundance (Riggs 1955). This species is an excellent game fish in large reservoirs, and its range now reaches from coast to coast because of introductions. It is a productive, easily harvested sport fish, particularly suitable for reservoirs where fishing success for other species has declined (Jenkins and Elkin 1957).

Age, Growth, and Food

Female white bass grow faster and get larger than males. Both sexes grow faster in southern regions than northern regions, but the average life span in southern areas is only about 4 years (Howell 1945; Ward 1949; Thompson 1951; Tompkins and Peters 1951), compared to 7 to 10 years in northern regions (Forney and Taylor 1963; Priegel 1971). The fastest rate of growth occurs in the first year, but white bass have demonstrated growth compensation the year following a season of reduced growth (Ruelle 1971). First-year growth ranges from 4 inches in the North to 8 inches (10 to 20 cm) in the South (Jenkins and Elkin 1957). White bass weight increased an average of 0.60 lb (272 g)/year, with a range of 0.25 to 0.85 lb (113 to 385 g)/year, in Oklahoma reservoirs and lakes (Jenkins and Elkin 1957). Male white bass usually mature 1 year earlier than females. In northern waters (approximately 40° north latitude), females mature at age II to IV (Sigler 1949a,b; Priegel 1971). In the South, they mature at age I to III (Tompkins and Peters 1951; Webb and Moss 1968).

White bass are opportunistic feeders. They form large schools near the water's surface, moving in search of prey. Feeding activities of these schools are the most conspicuous when forage fish and emerging insects are concentrated (Pflieger 1975). The dominance of fish, benthic invertebrates, and zooplankton in the diet of young-of-the-year can vary hourly, seasonally, and annually, depending on prey availability (Olmsted and Kilambi 1971; Ruelle 1971; Voigtlander and Wissing 1974). Larvae feed on zooplankton, selecting larger species as they grow (Ruelle 1971; Nelson 1980). Young white bass near 20 mm long commonly eat macroinvertebrates, but piscivory has been observed in white bass as small as 23 mm in length (Bonn 1953). Fish normally start to increase in dietary importance when the white bass reach about 40 mm long, often becoming the dominant food item before the end of the first season of growth (Sigler 1949a,b; Ruelle 1971). White bass grow best when young percids, centrarchids, or clupeids are plentiful, and a piscivorous diet is initiated soon after hatching (Bonn 1953; Jenkins and Elkin 1957; Ruelle 1971).

Although adult white bass are usually piscivorous, they will readily change to macroinvertebrates or even zooplankton when forage fish populations are depleted (Sigler 1949a; Forney and Taylor 1963; Olmsted and Kilambi 1971; Voigtlander and Wissing 1974). Shad and alewife are preferred forage, and white bass production is high where large populations of these species exist (Jenkins and Elkin 1957; Moser 1968; Olmsted and Kilambi 1971; Ruelle 1971).

Reproduction

White bass spawn earlier in the year than most fish species and prefer running water for spawning (Bonn 1953; Jenkins and Elkin 1957; Chadwick et al. 1966). However, they spawn over rocky shoals in lakes and reservoirs when tributary streams are not accessible (Bonn 1953). White bass have spawned successfully in Elephant Butte Reservoir (New Mexico), when the Rio Grande River flows were inadequate (Jester 1971). In Lake McConaughy, Nebraska, they spawn both in the reservoir and in the North Platte River (McCarraher et al. 1971).

When water temperatures reach 12 to 16° C, mature white bass form large, unisex schools and migrate to the spawning grounds, with the males arriving several weeks before the females (Riggs 1955). White bass may home to a specific site in the lake or reservoir (Hasler et al. 1969) or migrate as much as 150 miles upstream from the reservoir (Chadwick et al. 1966).

Spawning begins when the water temperature reaches 12 to 24° C (Riggs 1955; Webb and Moss 1968; Ruelle 1971). Webb and Moss (1968) observed that spawning stopped when the temperature fell below 12° C and resumed when it rose above 12° C. Spawning lasts 5 to 25 days (Riggs 1955; Ruelle 1971). The eggs are fertilized as they sink and then stick to gravel, rocks, or vegetation (Riggs 1955). White bass apparently prefer to spawn over a firm substrate in water 0.5 to 6 m deep, most commonly at depths of 0.6 to 2 m (Riggs 1955; Chadwick et al. 1966; Webb and Moss 1968). White bass return to deeper water immediately after spawning.

White bass eggs develop quickly; Horrall (1961) reported that eggs hatched in 45 h at 20.2° C and in 41 h at 21.5° C under laboratory conditions. Larvae in reservoirs have been captured most often near the mouth of an inundated stream used by spawning adults (Beckman and Elrod 1971; Storck et al. 1978). Thus, it is assumed that white bass larvae, after hatching, drift downstream to a reservoir or lake or until they come to a riverine backwater.

Specific Habitat Requirements

Although white bass are native to large rivers, research has focused on their natural history in lentic waters, particularly reservoirs. Successful populations have been found in waters that were turbid or clear (Thompson 1951), deep or shallow, fluctuating or stable, and which ranged in size from 162 to 37,337 hectares (Tompkins and Peters 1951; Jenkins and Elkin 1957; McNaught and Hasler 1961; Webb and Moss 1968; Olmsted and Kilambi 1971; Priegel 1971; Ruelle 1971). However, white bass generally are associated with the epipelagic zone of moderately large to large lakes; important fisheries also occur in the tailwaters of some reservoirs (Chadwick et al. 1966; Walburg et al. 1971) and in some streams during spawning migrations (Webb and Moss 1968; Becker 1983).

Mount (1961) reported that a dissolved oxygen (DO) concentration of 1 ppm at 21 to 24° C was lethal to white bass. A concentration of 2 ppm was extremely stressful and probably would have been lethal within 72 hrs. There was a pronounced decrease in activity and coloration and increased ventilation below 3 ppm. Because activity and the presence of toxic materials can raise the DO concentration at which stress occurs, it is assumed that 5 ppm DO is the lower optimum limit, as recommended for aquatic life by the U.S. Environmental Protection Agency (1976). Although some lentic waters exhibit hypolimnetic oxygen deficiencies, white bass inhabit the epilimnion where low DO concentrations are uncommon or localized.

Upper and lower pH levels tolerated by white bass have not been investigated. The optimum pH range is assumed to be 6.5 to 9.0, based on recommendations by the U.S. Environmental Protection Agency (1976).

White bass do not appear to be physiologically sensitive to normal levels of total dissolved solids (TDS) or alkalinity, but the species may indirectly benefit from dissolved solids ranging from approximately 100 to 800 mg/l. These levels often are associated with productive waters, and successful populations of white bass are reported most often from waters within this TDS range (e.g., Sigler 1949a,b; Tompkins and Peters 1951; Jenkins and Elkin 1957; Jester 1971; McCarraher et al. 1971; Walburg 1977). White bass tolerate brackish water but always spawn in fresh water. They have been reported to die when chlorides reached 6,000 ppm (Chadwick et al. 1966).

Turbidity has no observable effect on white bass spawning success, larval survival, or growth (Jenkins and Elkin 1957; Jester 1971; Summerfelt 1971; Walburg 1976; Nelson 1980). However, they avoid areas with continuous turbidity and have become abundant in sections of rivers where impoundments have decreased turbidity (Pflieger 1975).

A large forage fish population appears to be the key to a successful white bass population (Jenkins and Elkin 1957; Chadwick et al. 1966). Shad (*Dorosoma* spp.) probably are the preferred forage, particularly threadfin shad (*D. petenense*) because of its abundance, availability, and smaller size (Olmsted and Kilambi 1971). Gizzard shad (*D. cepedianum*) tolerate colder temperatures and are more widespread, but either gizzard or threadin shad nearly always are present where white bass are abundant. Abundance of white bass fluctuates in Ozark reservoirs in response to changes in the gizzard shad population (Houser and Bryant 1970; Pflieger 1975). Yellow perch (*Perca flavescens*), alewife (*Alosa pseudoharengus*), emerald shiner (*Notropis* atherinoides), and bluegill (Lepomis macrochirus) also serve as forage species (Sigler 1949a,b; Walburg et al. 1971; Olmsted and Kilambi 1971; Kohler and Ney 1981). The negative correlation between white bass harvest and water level fluctuations in many reservoirs (Jenkins and Morais 1971) may be at least partially due to the negative effect of water level fluctuation on the reproductive success of forage fish (Nelson 1974; Walburg 1976).

Adult. Reproducing populations of white bass have been reported from lakes as small as 81 hectares in Texas (Luebke, pers. comm.). Growth in Oklahoma lakes smaller than 162 hectares was slower than growth in larger waters (Jenkins and Elkin 1957). Growth was positively correlated with percent change in surface area of Lake Oahe, South Dakota, but may have been indicative of increased forage fish production with the increased littoral area (Nelson 1974).

Summer temperatures in white bass habitats typically are 19 to 28° C (Gasaway 1970; Jester 1971; Nelson 1974; Kohler and Ney 1981). Growth is greater in the South where these temperatures are maintained for a longer period (Webb and Moss 1968). Thermal zones in the Wabash River created by cooling effluent from power plants were analyzed by Gammon (1973) for selection and avoidance by white bass. He suggested that the probable optimum temperature for white bass lies between 28.0 and 29.5° C.

Data about white bass riverine habitat requirements are scarce in the literature. Kallemeyn and Novotny (1977) captured white bass in chutes, pools, and sand bars in unchannelized segments of the Missouri River and near structures, such as notched dikes and revetments, in channelized segments. Catch per unit effort was highest where water velocity was 0.6 to 0.7 m/sec, intermediate in areas with a velocity of 0.2 m/sec, and lowest in areas where the velocity was 0.4 to 0.5 m/sec or 0.9 to 1.0 m/sec. Depth at all sites was 1 to 2 m.

White bass seem to be more sensitive to prey location than to habitat features. For example, Gammon (1973) reported that white bass and gizzard shad both were concentrated in slow moving water. Similarly, emerald shiners often were relatively abundant where white bass were caught in the Missouri River (Kallemeyn and Novotny 1977), and gizzard shad accounted for the greatest percentage of biomass where white bass were captured in the Mississippi River (Pennington et al. 1983).

Spawning/embryo. White bass prefer to spawn in running water but will spawn in lakes and reservoirs (Howell 1945; Bonn 1953; Riggs 1955; Jester 1971; Walburg 1976). White bass will spawn over silt and mud, but rock, gravel, firm sand substrate, or vegetation is preferred (Sigler 1949b; Riggs 1955; Webb and Moss 1968). Silt and mud are assumed to be less than optimum spawning substrates.

Water temperature must reach 12 to 14° C in the spring before spawning begins (Riggs 1955; Webb and Moss 1968; Ruelle 1971). Embryo development and hatching was 2 to 4 days at 16 to 21° C under laboratory conditions (Horrall 1961; Ruelle 1971; Siefert et al. 1974). Yellayi and Kilambi (1970) suggested that 15.5 to 16.7° C was the optimum development temperature range, based on laboratory culture of eggs. Embryo survival decreases when DO drops to 20% saturation or less (Siefert et al. 1974).

A large, rapid drop in water level can result in the exposure and loss of large numbers of eggs (Webb and Moss 1968) and reduced spawning success (Walburg 1976).

Larvae. White bass larvae are 2 to 3 mm in length at hatching (Ruelle 1971). They drift with wind induced currents in a lake or downstream to a nursery area where other small fish and invertebrates also are concentrated (Horrall 1961; Storck et al. 1978; Nelson 1980). The nursery area is usually an embayment of an impounded river, a sheltered bay, or a backwater.

Newly hatched larvae were captured most often at depths of 1 to 2 m over sandy beaches; they avoided dense vegetation and organic bottoms (Moser 1968; Taber 1969; Walburg 1976). Larvae greater than 10 mm in length were found offshore, near water that was 2 to 4 m deep, during the day (Taber 1969; Storck et al. 1978), but moved into shore at sunset to feed on zooplankton and invertebrates until sunrise (Bonn 1953; Olmsted and Kilambi 1971; Voigtlander and Wissing 1974).

Juvenile. Young-of-the-year growth is strongly correlated with temperature and insect and forage fish availability (Jenkins and Elkin 1957; Ruelle 1971; Walberg 1976; Kohler and Ney 1981). In lacustrine environments, juvenile white bass have the same habitat requirements as adults. However, juveniles in riverine habitats seemed to be associated with slower water than adults until they reached about 100 mm in length (Kallemeyn and Novotny 1977). Moser (1968) reported that juvenile white bass in lacustrine habitats were associated with sandy littoral areas.

HABITAT SUITABILITY INDEX (HSI) MODELS

Model Applicability

Geographic area. This model is applicable throughout the native and introduced range of white bass in the 48 contiguous United States. The standard of comparison for each variable is the optimum value of the variable that occurs anywhere within this region. The model will not provide an HSI of 1.0 when applied to northern waters because day-degrees above 16° C (V_5) does not reach the optimum values that occur in the southern portion of the range.

Season. The model provides a rating for a body of water based on its ability to support a reproducing population of white bass throughout the year.

Cover types. The model is applicable to riverine and lacustrine habitats, as described by Cowardin et al. (1979).

Verification level. The model has not been tested in the field. The model produces an index between 0 and 1 that we believe should have a positive relationship with spawning success, growth, and standing crop of adults, juveniles, and larvae.

Model Description - Lacustrine

The success of a white bass population appears to be most strongly affected by the quantity and quality of the food source and by the availability of spawning sites. The model is used to evaluate the ability of the habitat to meet food and reproduction requirements. Habitat variables that have been associated with growth, standing crop, and feeding behavior are included in the model. The relationships between the habitat variables and life requisite components of the model for lacustrine conditions are diagrammed in Figure 1.

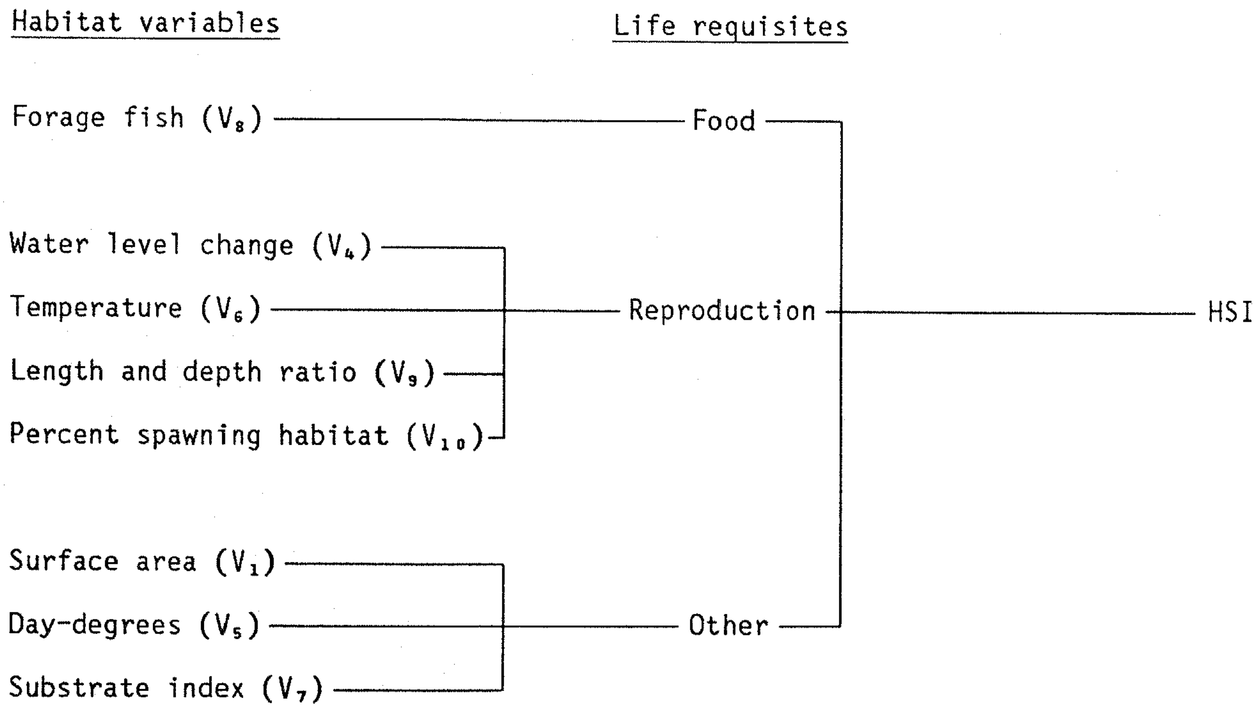


Figure 1. Tree diagram illustrating relationships between model variables, model components, and an HSI for white bass in lacustrine environments.

It is assumed that the water quality standards defined by the U.S. Environmental Protection Agency (1976) for aquatic life apply to white bass. Specifically, the optimum range for dissolved oxygen is ≥ 5 mg/l, and the optimum pH range is 6.5 to 9.0.

Food component. The species composition and abundance of small forage fishes (V_8) is important because they nearly always are the main food source of a large, rapidly growing white bass population. Shad (*Dorosoma* spp.), particularly threadfin shad, are particularly desirable forage species.

Reproduction component. Water temperature determines the onset of spawning and must be maintained for continued spawning and normal embryonic development (V_6). There is some evidence that high temperatures permit fungal growth, which kills the eggs (Yellayi and Kelambi 1970).

The percent habitat suitable for spawning (V_{10}) is defined based on the preference of white bass for the specified spawning substrates. It also is assumed that soft substrates could result in suffocation of the eggs. White bass prefer running water for spawning; therefore, this variable never receives a Suitability Index (SI) of 1 because a lake or reservoir without a suitable river spawning site is considered suboptimum. Accessible river spawning habitat is described by V_9.

A change in water level (V_4) could expose the eggs and reduce the reproductive success of both white bass and forage fish. The SI curve should be adjusted to reflect the potential effects of a water level change at a specific spawning site.

Other component. The "other" component contains variables that help describe habitat suitability for reasons not easily classified into a single component described above. Surface area (V_1) is included because white bass do not appear to survive or grow well in ponds or small impoundments. Day-degrees above 16° C (V_5) combines length of growing season and water temperature, both of which affect white bass growth. A substrate index, combined with depth curves, (V_7) is included because juvenile white bass prefer to forage over sandy littoral or shoal areas, while deeper water is needed for overwintering.

Model Description - Riverine

The riverine model includes the same components as the lacustrine model. However, stream order (V_2) is substituted for surface area to describe the preference of white bass for large bodies of water. Percent area with a current velocity less than 0.4 m/sec (V_3) is included because white bass are rarely found in the mainstream and because forage fish occur in low velocity areas. The relationship between the habitat variables and life requisite components of the model for riverine conditions are diagrammed in Figure 2.

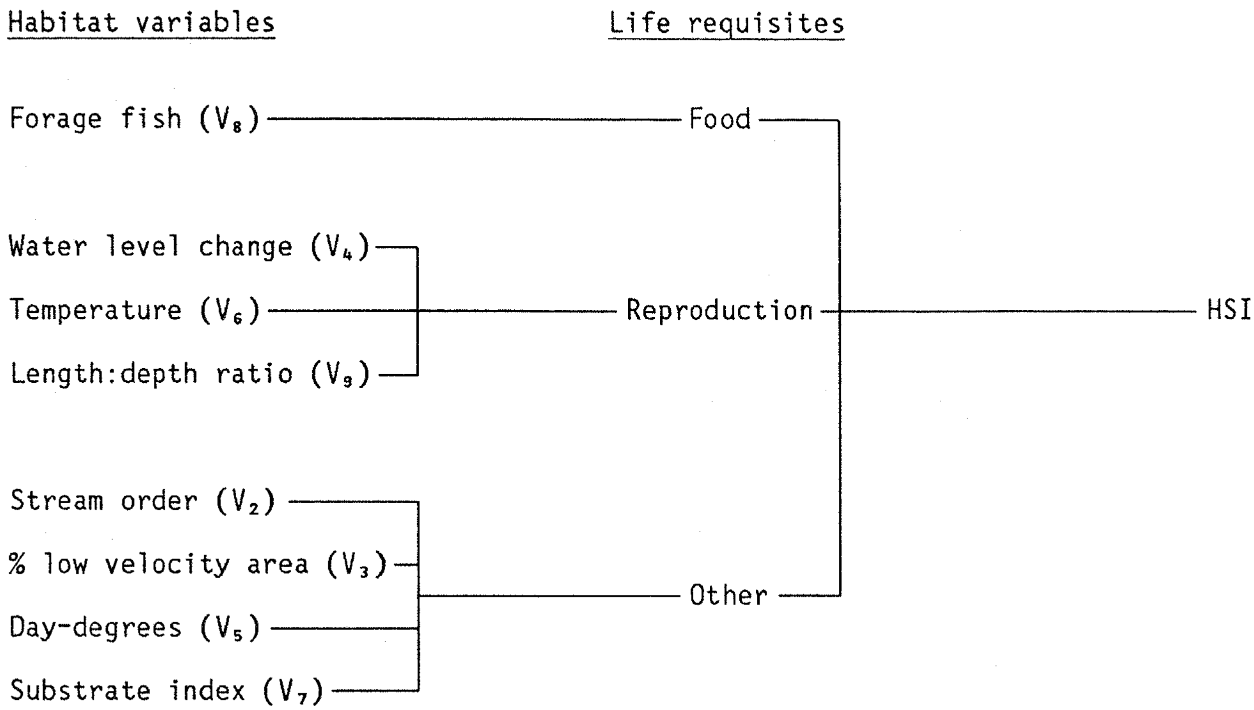
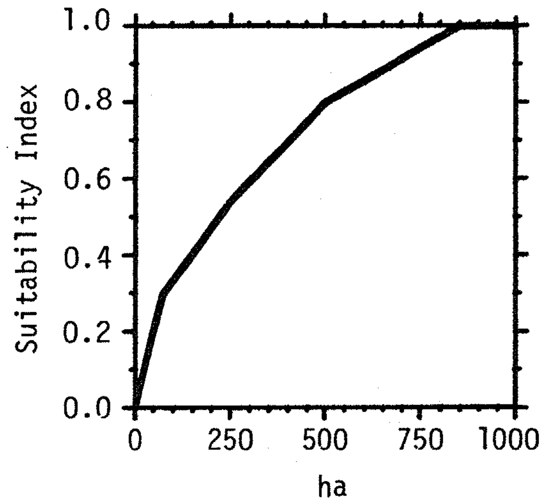
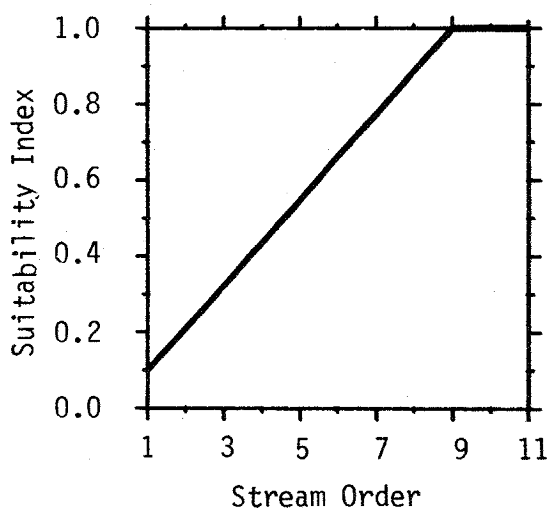


Figure 2. Tree diagram illustrating relationships between model variables, model components, and an HSI for white bass in riverine environments.

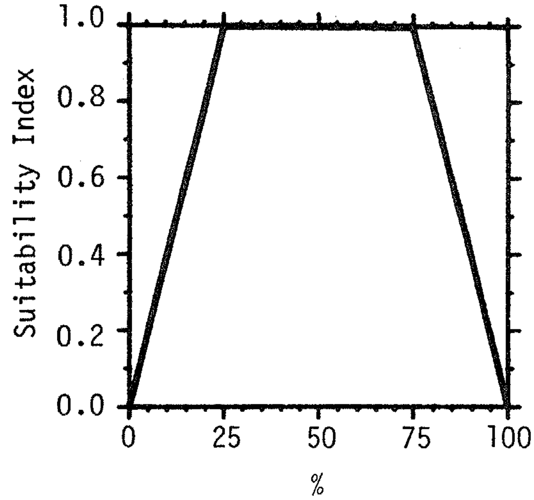
Suitability Index (SI) Graphs for Model Variables

This section contains suitability index graphs for the variables described above and equations for combining the indices into a species HSI. Variables are measured in either a riverine (R) habitat, a lacustrine (L) habitat, or both.

Habitat	Variable		Suitability graph
L	V_1	Surface area.	
R	V_2	Stream order. First order streams are perennial streams having no tributaries; second order streams are formed by the convergence of two first order streams, third order streams are formed by the convergence of two second order streams and so on (Hynes 1970).	

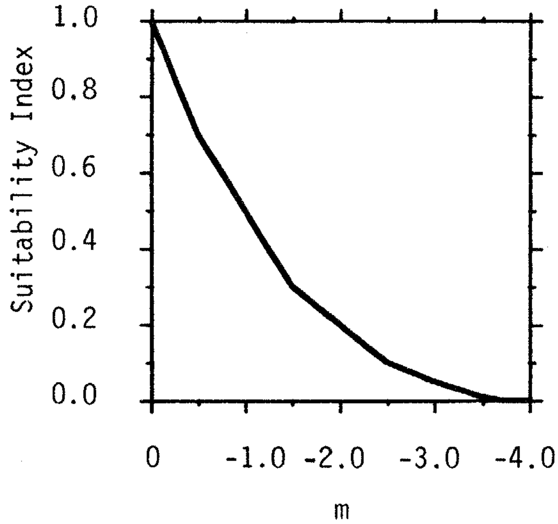
R V_3

Percent surface area with a surface current velocity ≤ 0.4 m/sec. Low velocity areas can be in-channel (e.g., deep pools or behind protective structures) or off-channel.



R,L V_4

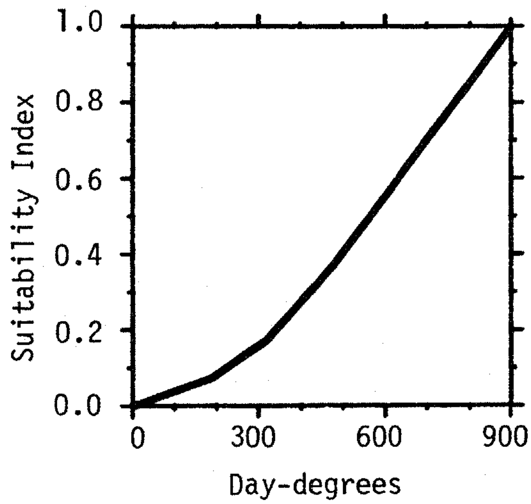
Maximum water level change from the onset of white bass spawning to the hatching of fry.



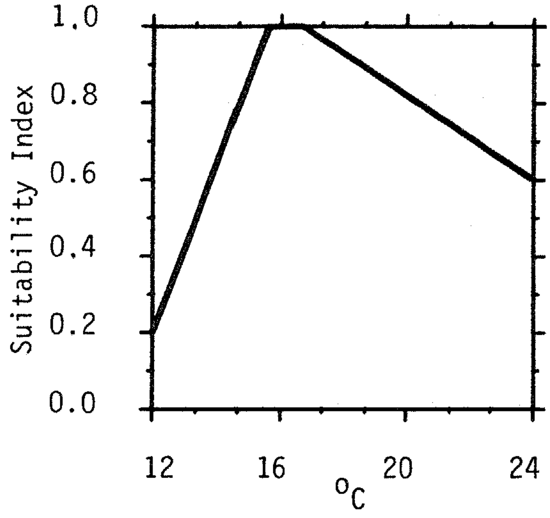
R,L V_5

Day-degrees above 16° C in upper 2 m from onset of spawning to fall when water temperatures decrease to 16° C.

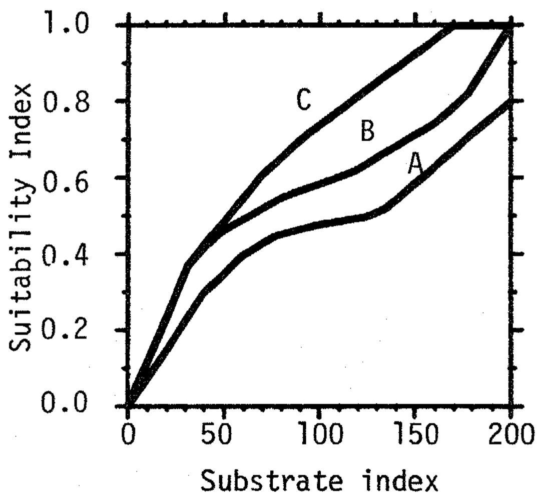
To calculate, subtract 16° C from the daily average temperature for each day the average temperature exceeds 16° C, then sum the remainders.



R,L V_6 Average weekly water temperature during spawning and incubation.



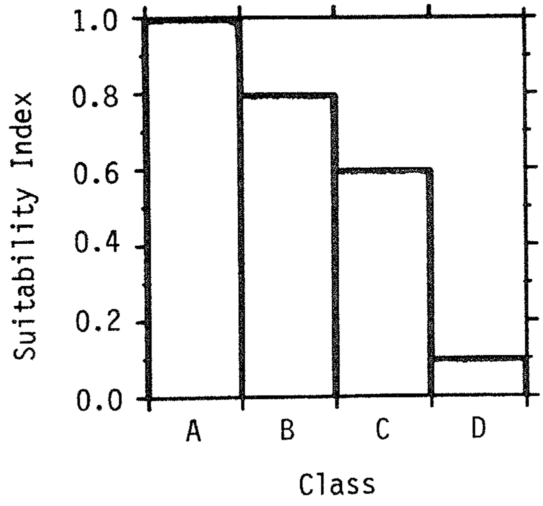
R,L V_7 Substrate index of habitat between 0.5 and 5.0 m deep (lacustrine) or 0.5 and 3.0 m deep (riverine). Substrate index = 2 (% of area that is ≥ 75% sand) + 1 (% area that is gravel/rubble) + 0.5 (% area that is boulder/rubble/gravel) + 0.5 (% area that is dense vegetation) + 0 (% area that is silt, detritus, or other soft bottom).



Curve A: 75 to 100% of the habitat is ≤ 5 m in lacustrine environments (≤ 1 m in riverine environments) deep.

Curve B: 30 to 75% of the habitat is 1 to 5 m deep (lacustrine environments) or 0.5 to 1.0 m deep (riverine environments); at least 90% of the remainder is deeper.

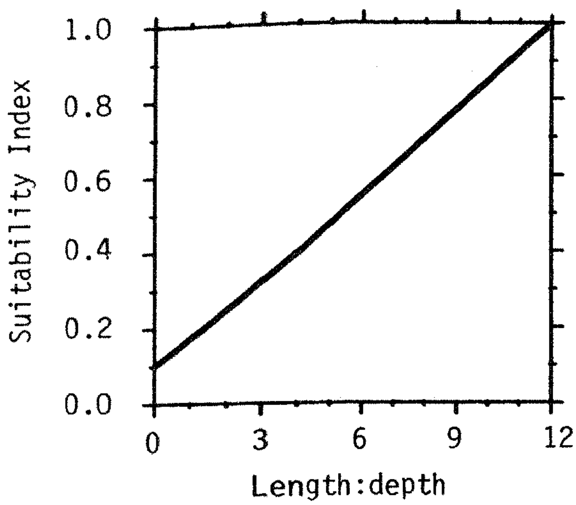
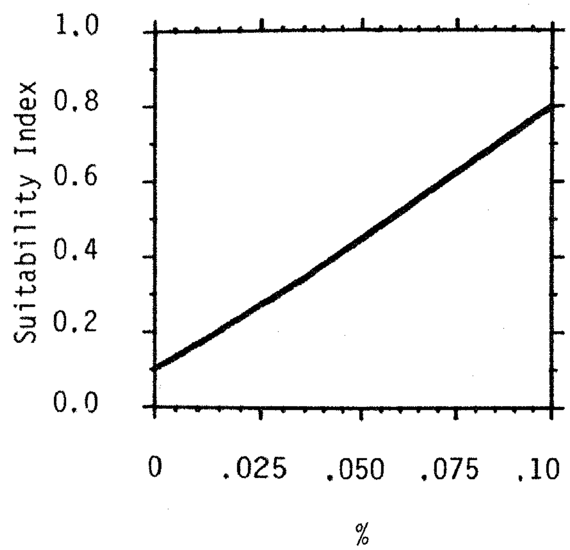
Curve C: 10 to 30% of the habitat is 1 to 5 m deep (lacustrine environments) or 0.5 to 1.0 m deep (riverine environments); at least 90% of the remainder is deeper.

R,L	V_8	Forage fish composition. A. Forage fish abundant; ≥ 50% clupeids < 20 mm long. B. Forage fish abundant; clupeids, atherinids, cyprinids, and other species < 20 mm long present in approximately equal proportions. C. Forage fish abundant; other species < 20 mm long predominate. D. Forage fish not abundant; benthic invertebrates and zooplankton abundant.	

Note: Clupeids include gizzard shad (*Dorosoma cepedianium*), threadfin shad (*Dorosoma petenense*), and alewife (*Alosa pseudoharengus*). Atherinids include brook silversides (*Labidesthes sicculus*), Atlantic silversides (*Menidia menidia*), and inland or Mississippi silversides (*Menidia beryllina*). Cyprinids include shiners (*Notropis* spp.), and dace (*Phoxinus* spp.). Other species include *Lepomis* spp., crappies (*Pomoxis* spp.), and yellow perch (*Perca flavescens*)

"Abundant forage fish" may be defined by the user or as populations that reproduce successfully where: (1) night catches from surface and midwater tows of meter nets in May to June for larvae, or midwater trawls for juveniles later than June, normally exceed 800 fish/1,000 m^3; or (2) where 40-ft or greater beach seine catches over sandy beaches or backwaters in late spring or early summer exceed 2,000 fish/ha. Use catch rates for similar, nearby reservoirs to estimate this variable for planned reservoirs.

Abundant zooplankton are defined as at least 5,000 individuals/m^3. Abundant invertebrates are defined as readily available *Hyallela*, crayfish, chironomids, and mayflies.

R	V_9	Bank length: average depth ratio of largest suitable spawning site. A spawning site is an accessible tributary stream with rocky, gravelly, or sandy sites 0.3 to 3 m deep.	
L	V_{10}	Percent of habitat that is suitable for spawning. Spawning sites are windswept, rocky, gravelly, or sandy sites 0.5 to 5.0 m deep. Sparse substrate vegetation is acceptable but areas covered with dense vegetation should not be included.	

Lacustrine Habitat Suitability Index Equations

These equations use the life requisite approach and contain three components: food; reproduction; and other.

Food (C_F)

$$C_F = V_8$$

Reproduction (C_R)

$$C_R = \frac{V_4 + V_6 + V_{10}}{3}$$ if no suitable tributary streams are accessible during spawning season.

When suitable tributary streams are accessible during spawning,

C_R = the highest of $\frac{V_4 + V_6 + V_9 + V_{10}}{4}$, $\frac{V_4 + V_6 + V_9}{3}$, or the above equation.

Other (C_{OT})

$$C_{OT} = \frac{(V_1^2 \times V_5)^{1/3} + V_7}{2}$$

HSI determination

$HSI = (C_F \times C_R \times C_{OT})^{1/3}$ or

if C_F, C_R, or $C_{OT} \leq 0.4$, the HSI equals the lowest value of C_F, C_R, or C_{OT}.

Riverine Habitat Suitability Index Equations

These equations use the life requisites approach and contain food, reproduction, and other components.

Food (C_F)

$C_F = V_8$

Reproduction (C_R)

$$C_R = \frac{V_4 + V_6 + V_9}{3}$$

Other (C_{OT})

$$C_{OT} = \frac{(V_2^2 \times V_3 \times V_5)^{1/4} + V_7}{2}$$

HSI determination

$$HSI = (C_F \times C_R \times C_{OT})^{1/3}$$

Sources of information and a synopsis of the assumptions used in developing suitability indices are presented in Table 1.

Sample data sets from which HSI's were calculated using the lacustrine and riverine models are included in Tables 2 and 3. These data sets are not actual field measurements from a specific site but describe conditions assumed to represent logical combinations of habitat conditions. For example, lacustrine data set 3 could represent a small impoundment on a tributary of the Missouri River, and riverine data set 3 could describe the lower reaches of a typical mountain stream. HSI's derived from both data sets indicated poor habitat, as would be expected.

Interpreting Model Outputs

This model is based on a review of the literature on white bass and has not been applied in the field to determine if the model variables can be easily estimated. It is designed as an indicator of excellent, good, fair, or poor habitat for white bass. The model should be a useful tool for the preliminary evaluation of a specific study site as white bass habitat.

The model is not expected to predict standing crop or production because habitat alone does not determine the survival and success of a white bass population. The accuracy of the model-generated HSI as a description of habitat quality is unknown and is likely to vary in different geographical areas. The model should be evaluated with field measurements in the proposed area of model application to determine which, if any, model variables are important before it is used as a predictive tool.

Table 1. Data sources and assumptions for white bass suitability indices. "Excellent" habitat for white bass was assumed to correspond to an SI of 0.8 to 1.0, "good" habitat to an SI of 0.6 to 0.8, "fair" habitat to an SI of 0.4 to 0.6, and "poor" habitat to an SI of 0 to 0.4.

Variable	Assumptions and sources
V_1	White bass populations do poorly in lakes or reservoirs smaller than 400 acres (162 ha) (Jenkins and Elkin 1957), but are successful in large bodies of water when food and spawning requirements are met (Riggs 1955).
V_2	The native range of white bass includes the large rivers of the Great Lakes and Mississippi drainages (Van Oosten 1942; Sigler 1949b). Although white bass may be associated with low order streams during spawning migrations, they commonly inhabit large rivers. Where their range has been extended by reservoir stocking, white bass have become established in larger rivers, such as the Missouri River in Missouri (Pflieger 1975), or in the tailwaters of large reservoirs (Walburg et al. 1971). Rivers from which large populations of resident white bass have been reported are stream order 9 or greater. Stream orders 4 and below are considered poor year around habitat because white bass are found in such lower order streams only during spawning.
V_3	Riverine white bass are not found in the mainstream but frequent areas where natural or man-made structures slow the current (Gammon 1973; Kallemeyn and Novotny 1977; Pennington et al. 1983). Adult white bass apparently withstand velocities ≥ 1 m/sec, but low velocity areas are necessary for forage fish survival and as nursery areas for larval bass (Beckman and Elrod 1971; Storck et al. 1978). Based on our best judgement, a habitat in which at least 25% of the area is low-velocity should provide sufficient nursery or feeding sites. A riverine habitat in which more than 75% of its area is low-velocity is atypical of rivers where white bass are abundant.
V_4	White bass spawn at depths of 0.5 to 6.0 m, and the demersal eggs develop while attached to the substrate. A decrease in water level that exposes the eggs results in embryo mortality. The effect on white bass year class strength depends on the extent and rapidity of the decrease at the spawning site. Water level reductions can indirectly affect white bass survival and growth when developing forage fish embryos are exposed and die (Martin et al. 1981). Because forage fish

Table 1. (continued).

Variable	Assumptions and sources
	and white bass often spawn in water less than 1.5 m deep, and because water level can affect spawning success as well as potential food supply, a decrease in water level greater than 1.5 m is considered poor.
V_5	White bass growth has been strongly correlated with the length of the growing season and water temperature (Webb and Moss 1968; Ruelle 1971; Walburg 1976). The day-degree curve was based on similar curves for white bass from northern reservoirs and rivers and seasonal water temperature data from southern reservoirs. Growth is most rapid where a long growing season and warm temperatures provide more than 900 day-degrees. In northern waters when day-degrees were above 600, growth tended to be relatively good. Below 500 day-degrees indicates a short growing season and cool waters, which are not conducive to good white bass growth.
V_6	Spawning has been reported to commence when temperatures reach 12° C (Webb and Moss 1968), but more commonly occurs when temperatures reach 14 to 16° C (Riggs 1955; Ruelle 1971). Horrall (1961) reported rapid development of eggs at 20 to 21.5° C; Yellayi and Kilambi (1970) suggested that the optimal incubation temperature was 15.6 to 16.7° C.
V_7	White bass prefer a firm substrate (especially sand or gravel) for spawning and avoid dense vegetation and organic bottoms (Chadwick et al. 1966; Moser 1968). Juveniles move into sandy shoal or littoral areas at night to feed (Taber 1969), but this behavioral pattern has not been reported for adults. This variable combines substrate rating with depth. Some shallow water seems to be attractive to juveniles and perhaps to adults because forage fishes often are more concentrated in these areas. Deep water reduces turbidity problems and provides a heat-storage reservoir during the winter (Carter 1967). Thus, even if the substrate is optimum, the habitat must have applicable areas of shallow water. However, if too much of the area is shallow (Curve B), escape to warmer waters in the winter may not be possible, and the potential of turbidity problems becomes greater. Habitats with some shallow, sandy, or sandy-gravelly areas are considered optimum, whereas habitats without shoals and areas of firm substrate are considered poor. This substrate-depth concept is similar for rivers, but the range of shallow water depths in the riverine curve were reduced to reflect the morphometry of rivers where bass are found.

Table 1. (concluded).

Variable	Assumptions and sources
V_8	Vigorous white bass populations have been more closely related to abundant forage fish populations than any other variable (Jenkins and Elkin 1957; Houser and Bryant 1970; Pflieger 1975). Shad are the preferred forage where they are available, but larval atherinids, centrarchids, and cyprinids are also good forage (Sigler 1949b; Olmsted and Kilambi 1971; Walburg et al. 1971). Although they generally are piscivorous, white bass are opportunistic and forage on invertebrates and zooplankton when they are plentiful (Sigler 1949b; Bonn 1953; McNaught and Hasler 1961; Olmsted and Kilambi 1971).
V_9	When a stream tributary to a reservoir or river used by adult bass is accessible, it will probably be used for spawning (Riggs 1955). Firm substrates at depths of 0.3 to 3.0 m are preferred sites (Riggs 1955; Webb and Moss 1968; Becker 1983), and one or two sites are used by the entire population. It is important that the eggs sink onto a suitable substrate. The length of the spawning site must increase (or velocity decrease) as depth increases so that the eggs sink before being swept away by the current. The assignment of an SI to different length:depth ratios was based on the authors' judgement of the probable sinking rate for the eggs, typical spawning stream velocity and depth, and the congregating spawning behavior of white bass.
V_{10}	Lake spawning sites are commonly used successfully. However, white bass prefer running water, so a lake site will never be assigned an SI of 1.0. A relatively small area is required for spawning because white bass spawn as a group at one site rather than make individual nests (Riggs 1955). This curve was constructed subjectively and should be adjusted if local conditions suggest a different relationship.

Table 2. Sample data sets using lacustrine HSI model.

Variable		Data set 1		Data set 2		Data set 3	
		Data	SI	Data	SI	Data	SI
Surface area	V_1	25,000	1.00	10,000	1.00	250	0.50
Water level change	V_4	-0.5	0.70	-1.0	0.50	-1.0	0.50
Day-degrees	V_5	900	1.00	750	0.80	500	0.60
Temperature	V_6	16	0.80	16	0.80	14	0.40
Substrate	V_7	75% sand 25% gravel Curve C	1.00	25% gravel 75% silt/mud Curve C	0.30	25% gravel 75% silt Curve B	0.30
Forage fish	V_8	abundant clupeids	1.00	abundant clupeids	1.00	centrar-chid larvae	0.60
% spawning habitat	V_{10}	0.10%	0.80	0.07%	0.60	0.07%	0.60
Component SI							
C_F =			1.00		1.00		0.60
C_R =			0.76		0.63		0.50
C_{OT} =			1.00		0.61		0.42
HSI =			0.91		0.72		0.50

Table 3. Sample data sets using riverine HSI model.

Variable		Data set 1		Data set 2		Data set 3	
		Data	SI	Data	SI	Data	SI
Stream order	V_2	10	1.00	7	0.70	3	0.30
% slow velocity	V_3	50	1.00	20	0.80	10	0.50
Water level change	V_4	0	1.00	-0.5	0.70	-1.0	0.50
Day-degrees	V_5	750	0.80	500	0.60	250	0.10
Temperature	V_6	16	0.80	14	0.40	12	0.20
Substrate type	V_7	50% sand 25% gravel 25% silt Curve C	0.80	50% gravel 25% sand 25% silt Curve B	0.60	50% gravel 50% boulder Curve A	0.50
Spawning site Length:depth ratio	V_9	12	1.00	6	0.50	6	0.50
Forage fish	V_8	centrarchids clupeids	0.80	centrarchids	0.60	inverte- brates	0.30
Component SI							
C_F =			0.80		0.60		0.10
C_R =			0.93		0.53		0.40
C_{OT} =			0.87		0.65		0.48
HSI =			0.86		0.59		0.27

ADDITIONAL HABITAT MODELS

Model 1

Optimal lacustrine habitat for white bass is characterized by a large (> 800 ha) surface area; sandy littoral and shoal areas covering 10 to 30% of the total habitat; long, warm summers (≥ 900 degree-days); an accessible tributary stream with rocky or gravelly substrate; and an abundant clupeid population of small individuals.

$$HSI = \frac{\text{number of above criteria present}}{5}$$

Model 2

Optimal riverine habitat for white bass is characterized by high order rivers; low velocity (≤ 0.4 m/sec) areas, such as deep pools, protected sites downstream of dikes or other structures, backwaters, or stream margins; accessible tributary streams with a rocky or gravelly substrate; long, warm summers (≥ 900 day-degrees); and an abundant clupeid population of small individuals.

$$HSI = \frac{\text{number of above criteria present}}{5}$$

INSTREAM FLOW INCREMENTAL METHODOLOGY (IFIM)

The U.S. Fish and Wildlife Service's Instream Flow Incremental Methodology (IFIM), as outlined by Bovee (1982), is a set of ideas used to assess instream flow problems. The Physical Habitat Simulation System (PHABSIM), described by Milhous et al. (1984), is one component of IFIM that can be used by investigators interested in determining the amount of available instream habitat for a fish species as a function of streamflow. The output generated by PHABSIM can be used for several IFIM habitat display and interpretation techniques, including:

1. Optimization. Determination of monthly flows that minimize habitat reductions for species and life stages of interest;

2. Habitat Time Series. Determination of the impact of a project on habitat by imposing project operation curves over historical flow records and integrating the difference between the curves; and

3. Effective Habitat Time Series. Calculation of the habitat requirements of each life stage of a fish species at a given time by using habitat ratios (relative spatial requirements of various life stages).

Suitability Index Graphs as Used in IFIM

PHABSIM utilizes Suitability Index graphs (SI curves) that describe the instream suitability of the habitat variables most closely related to stream hydraulics and channel structure (velocity, depth, substrate, temperature, and cover) for each major life stage of a given fish species (spawning, egg incubation, fry, juvenile, and adult). The specific curves required for a PHABSIM analysis represent the hydraulic-related parameters for which a species or life stage demonstrates a strong preference (i.e., a species that only shows preferences for velocity and temperature will have very broad curves for depth, substrate, and cover).

Terminology pertaining to four categories of SI curves is described below. All species curves for use with HEP and IFIM are referred to collectively as suitability index (SI) curves or graphs. The designation of a curve as belonging to a particular category does not imply that there are differences in the quality or accuracy of curves among the four categories.

Category one curves are the most common type presently available for use with HEP or IFIM. Category one curves usually have, as their basis, one or more literature sources. Some SI curves may be derived from general statements made in the literature about fishes (i.e., rainbow trout spawn in gravel; fry prefer shallow water). Some category one curves may come from literature sources, which include variable amounts of field data (i.e., from a sample size of 300, fry were observed in velocities ranging 0.0 to 3.0 ft/sec, and 80% were found in velocities less than 1.0 ft/sec). Other category one curves may be based entirely on professional opinion, by using the Delphi technique or educated guesswork (i.e., an expert believes that velocities ranging 1.0 to 8.0 ft/sec are necessary for successful spawning of striped bass). Most category one curves are the result of a combination of sources; the final curve may include information from the literature, combined with field data, and smoothed or modified using professional judgement. Category one curves usually are intended to reflect general habitat suitability throughout the entire geographic range of the species and throughout the year, unless they are identified as being applicable only to a given area or season. In the latter case, curves developed for a specific area or stream may not accurately reflect habitat utilization in other areas. Curves meant to describe the general habitat suitability of a variable throughout the entire range of a species may not be as sensitive to small changes of the variable within a specific stream (i.e., rainbow trout generally utilize silt, sand, gravel, and cobble for spawning substrate, but utilize only cobble in Willow Creek, Colorado).

Category two curves are derived from frequency analyses of field data and basically are curves fit to a frequency histogram. Each curve describes the observed utilization of a habitat variable by a life stage. Category two curves, unaltered by professional judgment or other sources of information, are referred to as utilization curves. When modified by judgment, they become category one curves. Utilization curves from one set of data are not applicable for all streams and situations (i.e., a depth utilization curve from a shallow stream cannot be used for the Missouri River). Category two curves, therefore, are usually biased because of limited habitat availability. An ideal study stream would have all substrate and cover types present in equal amounts; all depth, velocity, and percent cover intervals available in equal proportions; and all combinations of all variables present in equal proportions. Utilization curves from such a perfectly designed study theoretically should be transferable to any stream within the geographical range of the species. Curves from streams with high habitat diversity are generally more transferable than curves from streams with low habitat diversity. Users of a category two curve should first review the stream description to see if conditions were similar to those present in the stream segment to be investigated. Some variables to consider might include stream width, depth, discharge, gradient, elevation, latitude and longitude, temperature, water quality, substrate and cover diversity, fish species associations, and data collection descriptors (time of day, season of year, sample size, and sampling methods). If one or more of these factors deviate significantly from those at the proposed study site, curve transference is not advised, and the investigators should develop their own curves.

Category three curves are derived from utilization curves that have been corrected for environmental bias and, therefore, represent the preference of the species. To generate a preference curve, habitat utilization data and habitat availability data must be simultaneously collected from the same area. Habitat availability should reflect the relative amount of different habitat types in the same proportions as they exist throughout the stream study area. A curve is developed for the habitat frequency distribution in the same way as for fish utilization observations, and the equation coefficients of the availability curve are subtracted from the equation coefficients of the utilization curve, resulting in preference curve coefficients. Theoretically, category three curves should be unconditionally transferable to any stream, although this has not been validated. At present, very few category three curves exist because most habitat utilization data sets are without concomitant habitat availability data sets. In the future, the need to collect habitat availability data should be impressed on investigators.

Category four curves (conditional preference curves) describe habitat requirements as a function of interaction among variables. For example, fish depth utilization may depend on the presence or absence of cover, and velocity utilization may depend on time of day or season of year. Category four curves are just beginning to be developed.

IFIM analyses may utilize any or all categories of curves, but category three and four curves should yield the most precise results. Category two curves should yield accurate results if they are transferable to the stream segment under investigation. If category two curves are not transferable for a particular application, category one curves may be a better choice.

For an IFIM analysis of riverine habitat, an investigator may wish to utilize the curves available in this publication, modify the curves based on new or additional information, or collect field data to generate new curves. For example, if an investigator has information that spawning habitat utilization in his or her study stream is different from that represented by the SI curves, they may want to modify the existing SI curves or collect data to generate new curves. Once a decision has been made on the curves to be used, the curve coordinates are used to build a computer file (FISHFIL), which is a necessary component of PHABSIM analyses (Milhous et al. 1984).

Availability of Graphs for Use in IFIM

A great deal of variability in habitat requirements or preferences exists among different populations within the range of the white bass in the United States. Some white bass populations complete their life cycles in lakes or reservoirs, some spend their lives in rivers, some inhabit lakes and spawn in tributary streams, and some reside and spawn in lakes, but will spawn in tributaries if the streamflow is above a certain level.

Little is known about the physical microhabitat requirements of riverine populations of white bass. Many of the available SI curves (Table 4; Figs. 3 through 7) are based on studies of white bass in lentic environments, which may or may not be applicable to lotic environments. The SI curves available for IFIM analyses of white bass habitat are crude at best, and investigators are encouraged to develop their own curves whenever possible or modify existing curves to reflect habitat utilization at their selected study sites.

White bass spawning periods range from 5 to 25 days and generally occur between April and June. Spawning has been reported to occur in quiet waters of lakes, under falls, and in riffles of streams. However, not enough quantitative information was found to develop an SI curve for water velocity. Reported spawning depths have ranged from 2 to 20 ft in lakes and from 2 to 4 ft in streams. Females scatter eggs near the water surface, over a variety of substrate types, including mud, silt, sand, gravel, rocks, logs, rooted plants, and algae. Spawning temperatures range from 54 to 75° F (Chadwick et al. 1966).

Egg incubation requires 2 to 4 days at water temperatures ranging from 60 to 71° F (Riggs 1955; Horrall 1961). Eggs are demersal and adhesive, and suitable substrate includes gravel, cobble, boulders, logs, submerged vegetation, and filamentous algae, as long as dissolved oxygen requirements are met. Water depths utilized for spawning are assumed to be suitable for egg incubation. No information was found in the literature concerning velocity tolerances of incubating eggs, although velocities of zero are thought to be suitable because eggs can incubate successfully in lentic environments. Eggs that are hidden are probably less susceptible to predation, but an SI curve for cover is not necessary because it is assumed that suitable substrate satisfies cover requirements.

White bass are assumed to be fry at lengths less than 2.0 inches. SI curves for velocity and depth were derived from the only source of data available (n = 23), collected in the Missouri River by Kallemeyn and Novotny (1977). The upper range of the depth curve was extended based on information in Taber (1969) and Storck et al. (1978). Insufficient information was found for developing a substrate curve. Fry have been collected over silt and sand (Kallemeyn and Novotny 1977), which may be more a function of velocity preferences than of substrate preferences. No information was located regarding

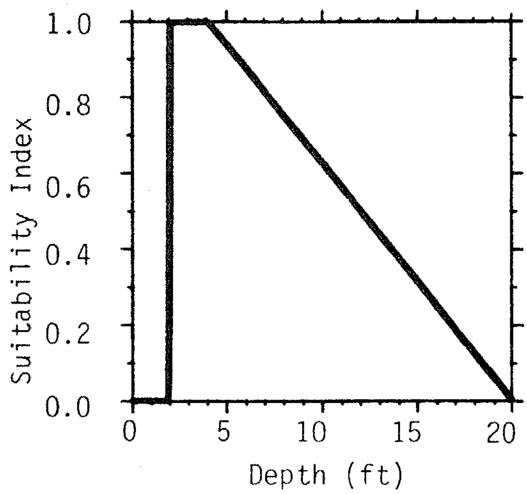
Table 4. Availability of SI curves for IFIM analyses of white bass habitat.[a]

	Velocity	Depth	Substrate	Temperature	Cover
Spawning	No curve available.	Use SI curve, Fig. 3.	Use SI curve, Fig. 3.	Use SI curve for V_6.	No curve necessary.
Egg incubation	No curve available.	Use SI curve, Fig. 4.	Use SI curve, Fig. 4.	Use SI curve for V_6.	No curve necessary.
Fry	Use SI curve, Fig. 5.	Use SI curve, Fig. 5.	No curve available.	Use SI curve, Fig. 5.	No curve available.
Juvenile	Use SI curve, Fig. 6.	Use SI curve, Fig. 6.	No curve available.	Use SI curve, Fig. 6.	No curve available.
Adult	No curve available.	Use SI curve, Fig. 7.	No curve available.	Use SI curve, Fig. 7.	No curve available.

[a]When use of SI curves is prescribed, refer to the appropriate curve in the HSI or IFIM section.

Coordinates

x	y
0.0	0.0
1.9	0.0
2.0	1.0
4.0	1.0
20.0	0.0
100.0	0.0



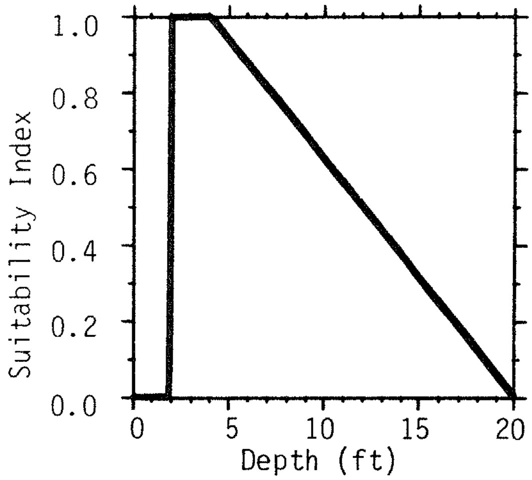
x	y
1	1.0
2	1.0
3	1.0
4	1.0
5	1.0
6	1.0
7	1.0
8	1.0

Enter 1.0 as the Suitability Index for all substrates.

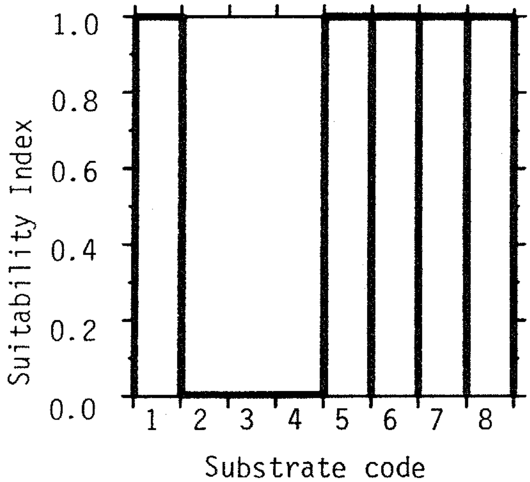
Figure 3. Category one SI curves for white bass spawning depth and substrate suitability.

Coordinates

x	y
0.0	0.0
1.9	0.0
2.0	1.0
4.0	1.0
20.0	0.0
100.0	0.0



x	y
1	1.0
2	0.0
3	0.0
4	0.0
5	1.0
6	1.0
7	1.0
8	1.0

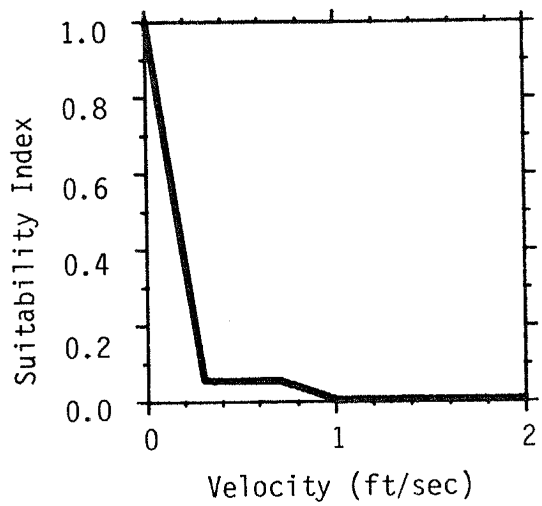


1 = plant detritus/organic material, logs, submerged vegetation, filamentous algae
2 = mud/soft clay
3 = silt (particle size < 0.062 mm)
4 = sand (particle size 0.062-2.000 mm)
5 = gravel (particle size 2.0-64.0 mm)
6 = cobble/rubble (particle size 64.0-250.0 mm)
7 = boulder (particle size 250.0-4000.0 mm)
8 = bedrock (solid rock)

Figure 4. Category one SI curves for white bass egg incubation depth and substrate suitability.

Coordinates

x	y
0.0	1.00
0.3	0.05
0.7	0.05
1.0	0.00
100.0	0.00



x	y
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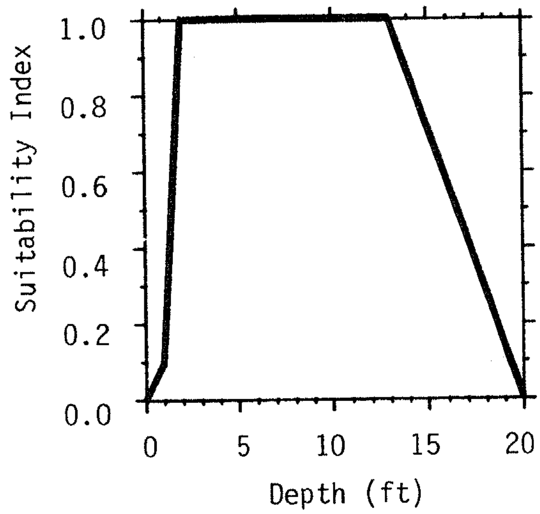
1.0	0.1
2.0	1.0
13.0	1.0
20.0	0.0
100.0	0.0



x	y
0.0	0.0
32.0	0.0
50.0	1.0
89.0	1.0
90.0	0.0
100.0	0.0

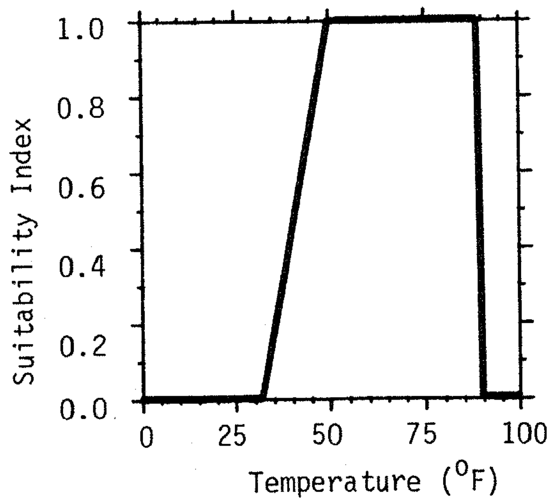
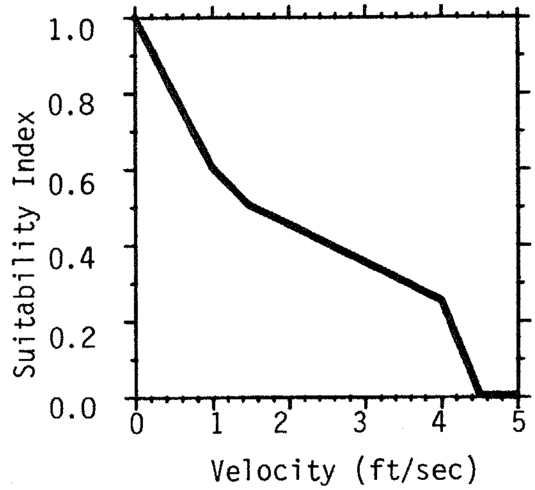


Figure 5. Category one SI curves for white bass fry velocity, depth, and temperature suitability.

Coordinates

x	y
0.0	1.00
1.0	0.60
1.5	0.50
4.0	0.25
4.5	0.00
100.0	0.00



x	y
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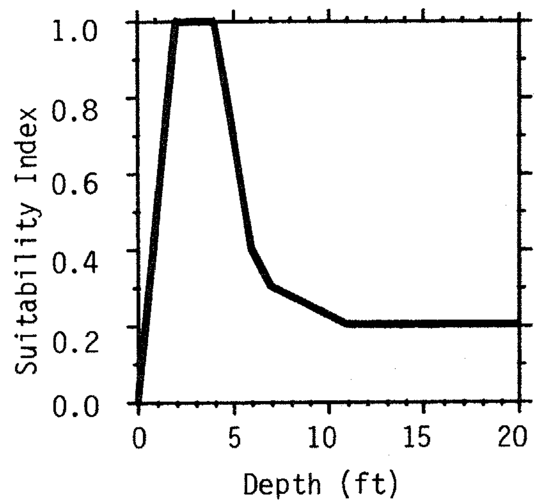
4.0	1.0
6.0	0.4
7.0	0.3
11.0	0.2
100.0	0.2



x	y
0.0	0.0
32.0	0.0
54.0	1.0
86.0	1.0
87.0	0.0
100.0	0.0

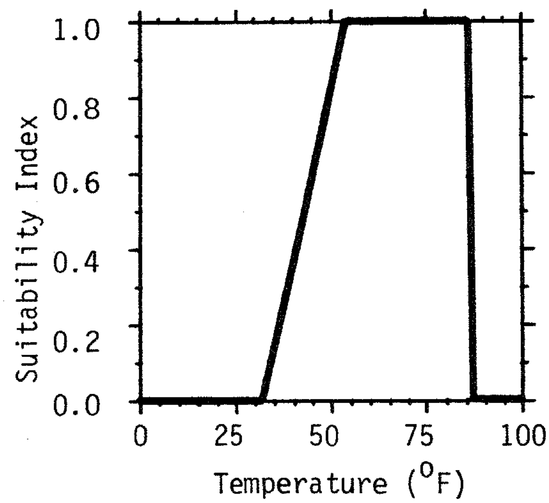
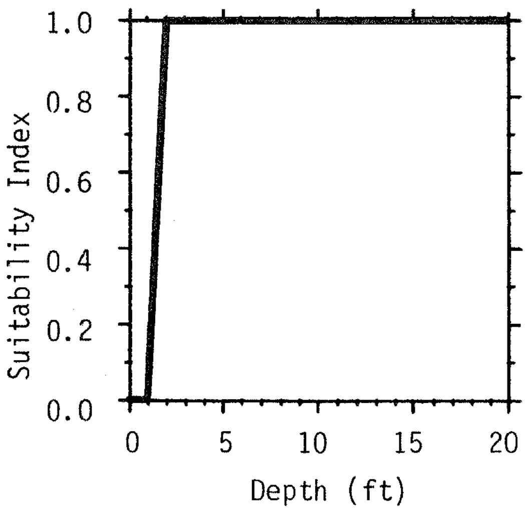


Figure 6. SI curves for white bass juvenile velocity and depth (category two), and temperature (category one) suitability.

Coordinates

x	y
0.0	0.0
1.0	0.0
2.0	1.0
100.0	1.0



x	y
0.0	0.0
32.0	0.0
54.0	1.0
86.0	1.0
87.0	0.0
100.0	0.0

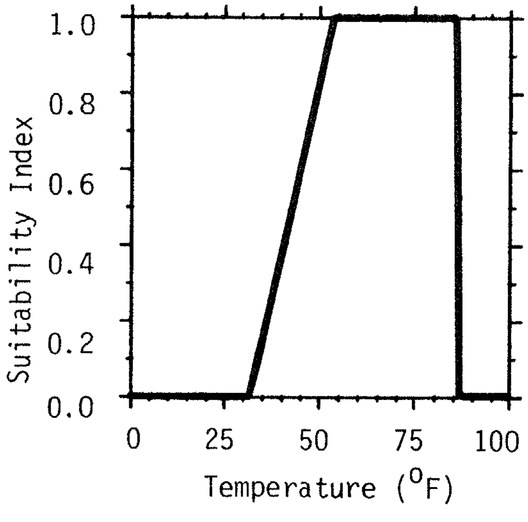


Figure 7. Category one SI curves for white bass adult depth and temperature suitability.

cover, and it is unknown if cover is a habitat requirement of fry. Temperatures preferred by young-of-year white bass have been reported to range from 50 to 89° F (Coutant 1977).

Juvenile white bass are within the range of 2 to 9 inches long, and juvenile habitat is required year-round. SI curves for depth and velocity were derived from a frequency analysis of data (n = 130) collected in the Missouri River by Kallemeyn and Novotny (1977). Juvenile substrate and cover preferences, if they exist, are unknown. Temperatures preferred by juvenile white bass are assumed to be similar to those preferred by adults, which range from 54 to 86° F (Coutant 1977).

White bass become sexually mature at age I or II, and adults are individuals over 9.0 inches in length. Insufficient information was found in the literature to develop SI curves for velocity, substrate, or cover preferences. The SI curve for depth was based on reports that white bass reside in the epilimnion of lakes and the assumption that all depths greater than the minimum are suitable. Temperatures preferred by adults ranged from 54 to 86° F (Coutant 1977).

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16. Abstract (Limit: 200 words)

Habitat characteristics important to white bass (Morone chrysops) are reviewed in this report using two techniques developed by the U.S. Fish and Wildlife Service, the Habitat Evaluation Procedures (HEP) and the Instream Flow Incremental Methodology (IFIM). The Suitability Index (SI) curves and graphs and Habitat Suitability Index (HSI) models developed in this report are based primarily on a synthesis of information obtained from a review of the literature concerning the habitat requirements of the species. A discussion of IFIM and white bass SI curves available for use with IFIM is included.

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