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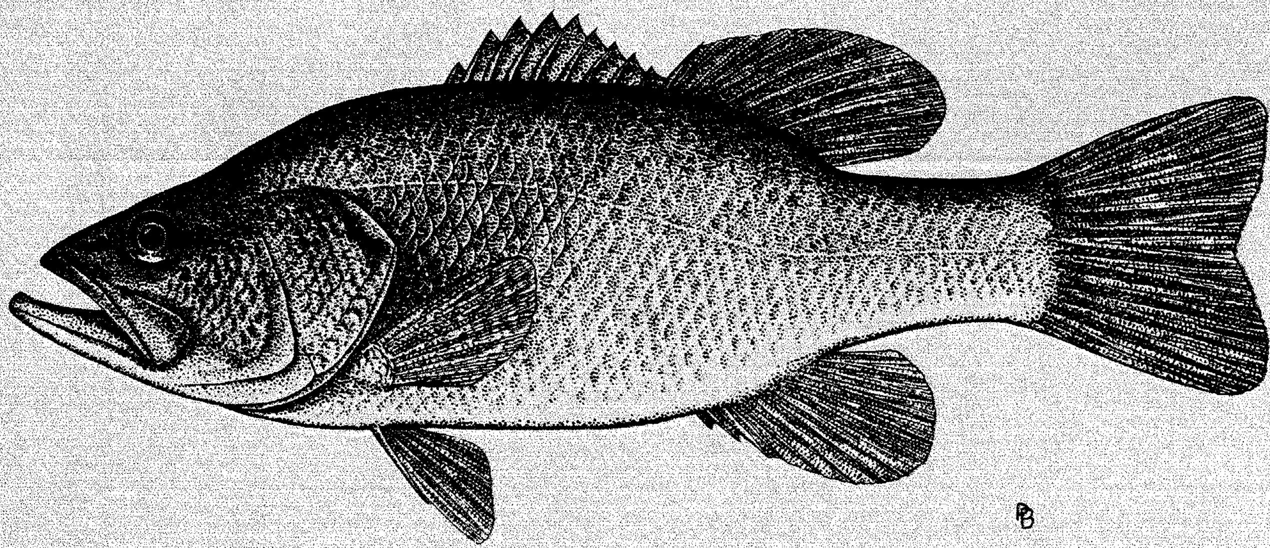
HABITAT SUITABILITY INDEX MODELS: LARGEMOUTH BASS



Fish and Wildlife Service

U.S. Department of the Interior

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HABITAT SUITABILITY INDEX MODELS: LARGEMOUTH BASS

by

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Washington, DC 20240

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PREFACE

The habitat use information and Habitat Suitability Index (HSI) models presented in this document are an aid for impact assessment and habitat management activities. Literature concerning a species' habitat requirements and preferences is reviewed and then synthesized into HSI models, which are scaled to produce an index between 0 (unsuitable habitat) and 1 (optimal habitat). Assumptions used to transform habitat use information into these mathematical models are noted, and guidelines for model application are described. Any models found in the literature which can also be used to calculate an HSI are cited, and simplified HSI models, based on what the authors believe to be the most important characteristics for this species, are presented.

Use of the models presented in this publication for impact assessment requires the setting of clear study objectives and may require modification of the models to meet those objectives. Methods for reducing model complexity and recommended measurement techniques for model variables are presented in Terrell et al. (in press).[1] A discussion of HSI model building techniques, including the component approach, is presented in U.S. Fish and Wildlife Service (1981).[2]

The HSI models presented herein are complex hypotheses of species-habitat relationships, not statements of proven cause and effect relationships. Results of model performance tests, when available, are referenced; however, models that have demonstrated reliability in specific situations may prove unreliable in others. For this reason, the U.S. Fish and Wildlife Service encourages model users to send comments and suggestions that might help us increase the utility and effectiveness of this habitat-based approach to fish and wildlife planning. Please send comments to:

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[1]Terrell, J. W., T. E. McMahon, P. D. Inskip, R. F. Raleigh, and K. W. Williamson (in press). Habitat Suitability Index Models: Appendix A. Guidelines for riverine and lacustrine applications of fish HSI models with the habitat evaluation procedures. U.S. Dept. Int. Fish Wildl. Serv. FWS/OBS 82-10.A.

[2]U.S. Fish and Wildlife Service. 1981. Standards for the development of Habitat Suitability Index models. 103 ESM. U.S. Dept. Int. Fish Wildl. Serv., Div. Ecol. Serv.

CONTENTS

ACKNOWLEDGMENTS

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LARGEMOUTH BASS (*Micropterus salmoides*)

HABITAT USE INFORMATION

General

The largemouth bass (*Micropterus salmoides*) is native to the eastern United States, excluding the Northeastern States (MacCrimmon and Robbins 1975), and has been introduced throughout the United States (Robbins and MacCrimmon 1974). Two subspecies are recognized, the northern subspecies, *M. salmoides salmoides*, and the Florida subspecies, *M. salmoides floridanus* (Bailey and Hubbs 1949; Hart 1952; Ramsey 1975).

Age, Growth, and Food

The maximum known age of largemouth bass is 15 years, and the normal rate of growth for adult largemouth is approximately 454 g per year (Bennett 1937; Anderson 1975). Largemouth bass mature and spawn as early as age I near the southern limit of their range (Morgan 1958; Clugston 1964; La Faunce et al. 1964; Smitherman 1975). Maturity is delayed among more northern populations (Eipper and Regier 1962; Bennett 1971; Carlander 1977). In Canada, maturity is reached in 3-4 years for males and 4-5 years for females (Scott and Crossman 1973).

Largemouth bass fry feed mainly on microcrustaceans and small insects, juveniles consume mostly insects and small fish, and adults feed primarily on fish and crayfish (Emig 1966; Zweiacker and Summerfelt 1974; Carlander 1977). Adults often feed near vegetation within shallow areas. Largemouth bass feeding intensity is bimodal, with peaks in the early morning and late evening (Snow 1971; Olmstead 1974).

Reproduction

Spawning typically begins in the spring when the water temperature reaches 12.0-15.5° C (Mraz 1964; Miller and Kramer 1971). Spawning has been recorded between 11.5 and 29.0° C, but most occurs between 16 and 22° C (Kramer and Smith 1960; Badenhuizen 1969; Carlson and Hale 1972). Incubation time ranges from 2 to 7 days, depending on water temperature (Kramer and Smith 1960; Badenhuizen 1969). The Florida subspecies nests and spawns earlier than the northern subspecies and at a 1 to 3° C lower temperature (Bottroff 1967).

A gravel substrate is preferred for spawning (Newell 1960; Robinson 1961; Mraz 1964), but largemouth bass will nest on a wide variety of other substrates, including vegetation, roots, sand, mud, and cobble (Harlan and Speaker 1956; Mraz and Cooper 1957; Mraz et al. 1961). Nests are constructed by the male at water depths averaging 0.3-0.9 m, with depths ranging from about 0.15 m to 7.5 m (Swingle and Smith 1950; Harlan and Speaker 1956; Mraz 1964; Clugston 1966; Allan and Romero 1975). Nests have been found as deep as 8.23 m in a reservoir where depth increased during the spawning period (Miller and Kramer 1971).

Specific Habitat Requirements

Lacustrine environments are the preferred habitat of largemouth bass (Emig 1966; Scott and Crossman 1973). Optimal conditions are lakes with extensive (≥ 25% of surface area) shallow (≤ 6 m depth) areas to support submergent vegetation, yet deep enough (3-15 m mean depth) to successfully overwinter bass (Robbins and MacCrimmon 1974; Carlander 1977; Winter 1977). Thus, it is assumed that 40-60% of the lake area should be > 6 m depth to provide optimal overwintering habitat in northern latitudes.

Optimal riverine habitat for largemouth bass is characterized by large, slow moving rivers or pools of streams with soft bottoms, some aquatic vegetation, and relatively clear water (Trautman 1957; Larimore and Smith 1963; Scott and Crossman 1973). First and second order streams are generally poor habitat (Anderson, personal communication). Deacon (1961) reported that largemouth bass abundance increased in rivers during dry years when the flow was reduced and the water pooled. Thus, it is assumed that a river with a high percent (≥ 60%) of pool and backwater area is optimal. Also, largemouth bass prefer low gradient (≤ 1 m/km) streams; abundance declines as gradient increases toward headwater areas (Finnell et al. 1956; Trautman 1957; Moyle and Nichols 1973). It is assumed that gradients > 4 m/km would be unsuitable.

Growth of largemouth bass is reduced at dissolved oxygen levels < 8 mg/l, and a substantial reduction occurs below 4 mg/l (Stewart et al. 1967). Distress may be evident at 5 mg/l (Katz et al. 1959; Whitmore et al. 1960; Dahlberg et al. 1968; Petit 1973). Levels below 1.0 mg/l are considered lethal (Moss and Scott 1961; Mohler 1966; Petit 1973).

Standing crops of black basses (*Micropterus* spp.) are positively correlated with total dissolved solid levels of 100-350 ppm (Jenkins 1976).

Largemouth bass are considered intolerant of suspended solids (turbidity) and sediment (Muncy et al. 1979). High levels of suspended solids may interfere with reproductive processes and reduce growth. Bulkley (1975) felt that high levels of suspended solids reduced the available food for largemouth bass to the extent that growth of maturing fish was reduced enough that they were physically incapable of reproduction. Buck (1956a; 1956b) found that the greatest survival and growth of largemouth bass occurred in ponds with turbidities (suspended solids) < 25 ppm. Growth was intermediate in ponds with 25-100 ppm turbidity levels and lowest in ponds with turbidities > 100 ppm. Also, no young-of-the-year bass were found in the ponds with high turbidities, while they were recovered from the ponds with low and intermediate turbidities. Thus, optimum suspended solid levels are assumed to be 5-25 ppm, and levels < 5 ppm indicate low productivity.

Largemouth bass require a pH between 5 and 10 for successful reproduction (Swingle 1956; Buck and Thoits 1970). Using Stroud's (1967) criteria for freshwater fish, optimal pH range is 6.5-8.5. Largemouth bass can tolerate short term exposures to pH levels of 3.9 and 10.5 (Calabrese 1969).

Adult. Adult largemouth bass are most abundant in areas with vegetation (Jenkins et al. 1952; Miller 1975) and other forms of cover (e.g., logs, brush, and debris). Optimal cover corresponds to 40-60% of the pool or littoral area; too much cover may reduce prey availability (Saiki and Tash 1979). Adults are most abundant in areas of low current velocity, based on catch data of Kallemyn and Novotny (1977) from the Missouri River. Optimal current velocities are ≤ 6 cm/sec, and velocities > 20 cm/sec are unsuitable based on probability of use curves developed by Hardin and Bovee (1978). Increased water levels in reservoirs may reduce prey availability due to increased cover for prey species. Stable to decreased water levels concentrated prey, which increased feeding and growth rates of adult bass (Heman et al. 1969). Thus, stable to slightly negative midsummer fluctuations (0-3m) are considered optimal for adult largemouth bass.

Optimal temperatures for growth of adult bass range from 24-30° C (Mohler 1966; Coutant 1975; Brungs and Jones 1977; Carlander 1977; Venables et al. 1978). Very little growth occurs below 15° C (Mohler 1966) or above 36° C (Carlander 1977). Salinity levels above 4 ppt cause sharp declines in abundance Tebo and McCoy 1964). Kilby (1955) found no bass in Mississippi River coastal marshes with salinities above 11.8 ppt, whereas Bailey et al. (1954) reported finding adult largemouth in water with salinities as high as 24.4 ppt in the Escambia River, Alabama and Florida.

Embryo. Optimal spawning substrate is gravel (Newell 1960; Robinson 1961), but other substrates, such as vegetation, roots, sand, and mud, are suitable (Harlan and Speaker 1956; Mraz and Cooper 1957; Mraz etal. 1961). Silty, mucky bottoms are unsuitable (Robinson 1961). Exposed, shallow water (< 1.5 m) nests are vulnerable to destruction by wave action (Miller and Kramer 1971). Boulders, irregular bottoms, and other forms of shelter may protect these nests. Water velocities as low as 40 cm/sec may result in mortality of embryos (Dudley 1969), and Hardin and Bovee (1978) reported that velocities > 10 cm/sec were avoided by the species. Stable water levels during spawning are optimal; drawdowns often result in poor survival (Jester et al. 1969). Since largemouth bass spawn at depths ranging from 0.15 m to 7.5 m, it is assumed that drawdowns > 7.5 m are unsuitable for successful embryonic development during spawning.

Optimal temperatures for successful spawning and incubation are 20-21° C (Clugston 1966; Badenhuizen 1969), with a range of 13-26° C (Carr 1942; Kelley 1968). Survival is very low at temperatures > 30° C (Strawn 1961; Kelley 1968; Badenhuizen 1969; McCormick and Wegner 1981) and < 10° C (Kramer and Smith 1960). Survival of embryos is impaired at salinities > 1.5 ppt, and zero at levels > 10.5 ppt (Tebo and McCoy 1964).

Fry. Optimal current velocities for fry are < 4 cm/sec (Hardin and Bovee 1978), and fry cannot tolerate current velocities > 27 cm/sec (MacLeod 1967; Laurence 1972). Cover, in the form of flooded terrestrial vegetation, is an important requirement for fry habitat suitability, because the amount of cover has been positively correlated to number of fry (Aggus and Elliot 1975). However, too much cover constitutes poor spawning habitat (R. O. Anderson, personal communication). Thus, it is assumed that optimal pools or littoral areas contain 40-80% cover. Also, stable to increased summer water level is optimal, because it increases cover availability. It is assumed that decreasing (> 1 m) water levels would be suboptimal because fry would be more susceptible to predation with the decrease in available cover.

Optimal temperatures for fry growth are 27-30° C. Little growth occurs below 15° C or above 32° C (Strawn 1961). The growth rate of fry declined at salinities > 1.66 ppt and was zero at 6 ppt (Tebo and McCoy 1964).

Juvenile. Specific habitat requirements of juveniles are presumed to be similar to those of adult largemouth bass.

HABITAT SUITABILITY INDEX (HSI) MODELS

Model Applicability

Geographic area. The models provided are applicable throughout the 48 conterminous States. The standard of comparison for each individual variable suitability index is the optimal value of the variable that occurs anywhere within this region. Therefore, the models will never provide an HSI of 1.0 when applied to northern waters where temperature related variables do not reach the optimal values found in the southern United States.

Season. The models provide a rating for a body of water based on its ability to support a reproducing population of largemouth bass through all seasons of the year.

Cover types. The models are applicable in riverine, lacustrine, palustrine, and estuarine habitats, as described by Cowardin et al. (1979).

Minimum habitat area. Minimum habitat area is defined as the minimum area of contiguous suitable habitat that is required for a species to live and reproduce. No attempt has been made to establish a minimum habitat size for largemouth bass.

Verification level. The acceptable output for each of these largemouth bass models is an index between 0 and 1 which the author believes has a positive relationship to carrying capacity. In order to verify that the model output is acceptable, the author developed sample data sets from which HSI's were calculated. These sample data sets and their relationship to model verification will be discussed in greater detail following presentation of the model.

Model Description - Riverine

The structure of the riverine HSI model is depicted graphically in Figure 1.

Food component. Percent bottom cover (V_3, V_4) is assumed to be important because bottom cover provides habitat for aquatic insects, crayfish, and forage fish, which are the predominant food items of largemouth bass. Percent pool and backwater area (V_1) is included to quantify the amount of food habitat.

Cover component. Percent bottom cover (V_3, V_4) is included because largemouth bass are most abundant in areas with cover. Percent pool and backwater area (V_1) quantifies the amount of cover habitat. Water level fluctuation (V_{16}, V_{18}) is assumed to be important because the amount of available cover is dependent on fluctuations.

Water quality component. The water quality component is limited to dissolved oxygen (V_6), pH range (V_7), temperature (V_8, V_{10}), turbidity (V_{11}), and salinity (V_{12}, V_{13}) measurements. These parameters have been shown to affect growth or survival. Variables related to temperature and oxygen are assumed to be limiting when they reach near lethal levels. Toxic substances are not considered in this model.

Reproductive component. Temperature (V_9) and salinity (V_{14}) during spawning and embryonic development describe water quality conditions which affect reproduction. Maximum water level fluctuation (V_{17}) is included because optimal development and survival is dependent on stable water levels during spawning. Current velocity (V_{20}) is important because embryos require areas of little or no velocity. Percent pool and backwater area (V_1) quantifies the amount of low velocity spawning areas.

Other component. The variables which are in the other component are those which also describe habitat suitability for the largemouth bass, yet are not specifically related to the life requisite components already presented. Stream gradient (V_{22}) is included because largemouth bass prefer slow moving streams. Current velocity (V_{19}, V_{21}) is an alternative way of describing the habitat suitability of a riverine environment, because of the positive relationship between gradient and current velocity.

Model Description - Lacustrine

Lacustrine model structure is depicted graphically in Figure 2.

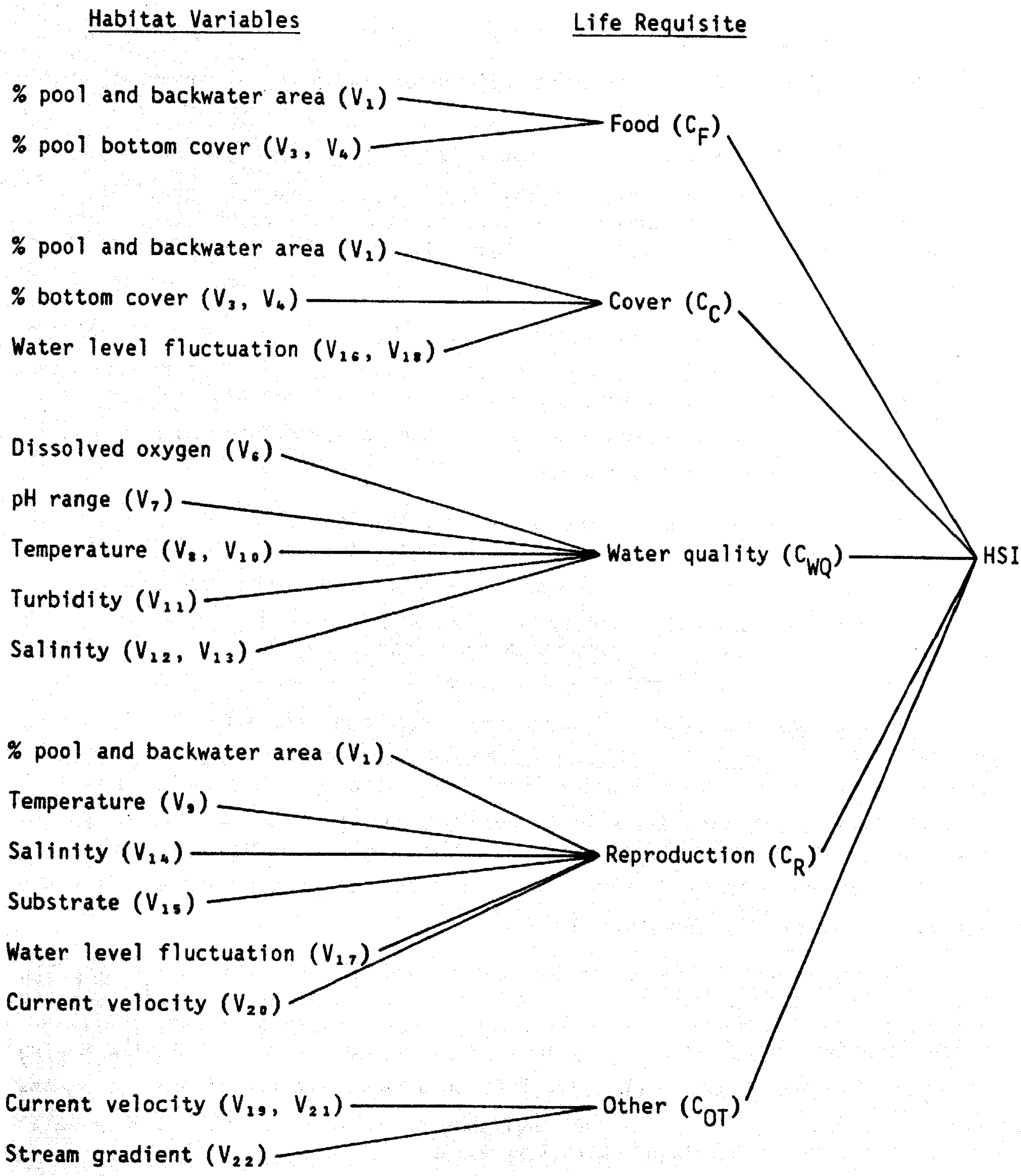


Figure 1. Tree diagram illustrating conceptual structure of riverine model for largemouth bass.

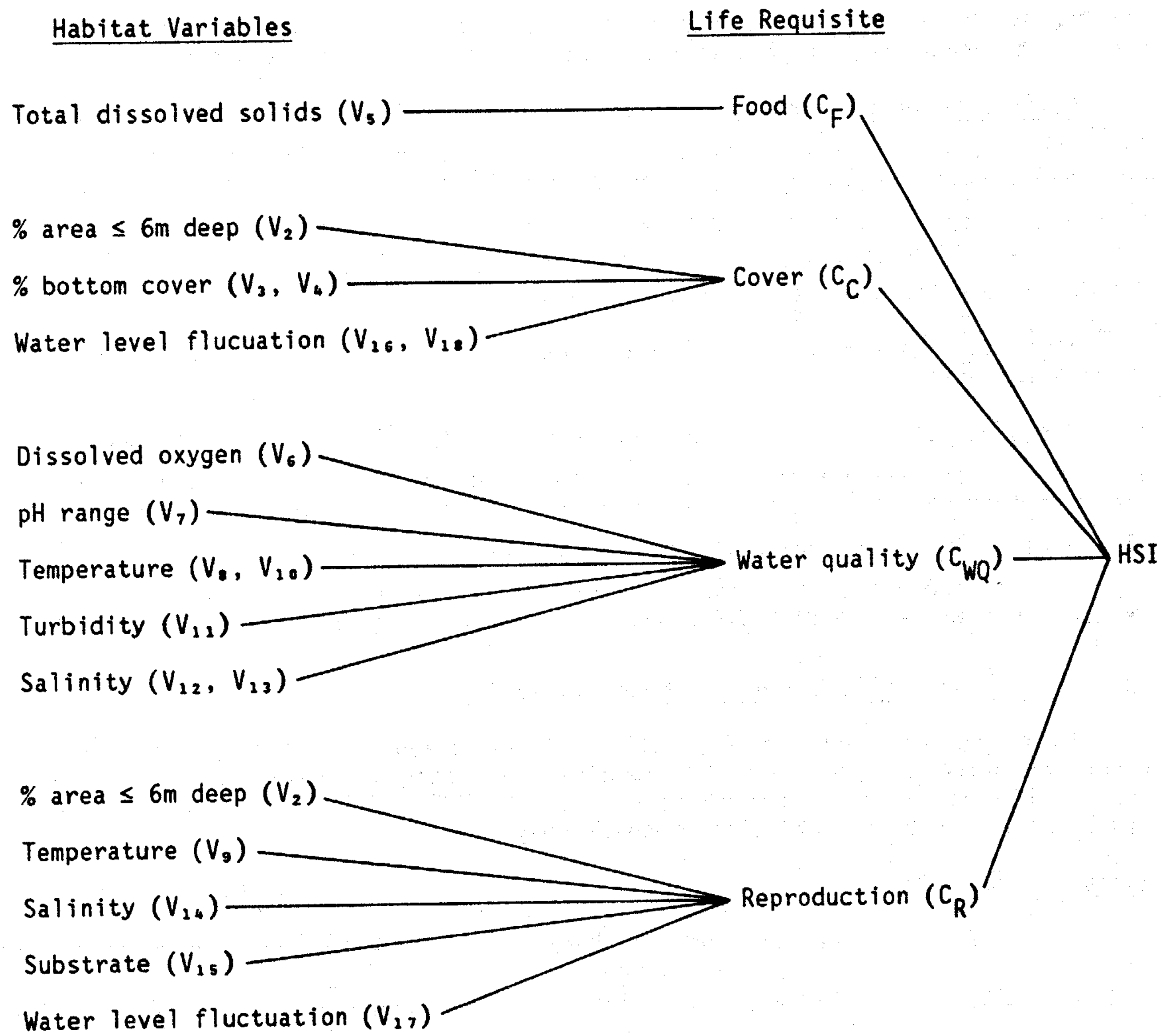


Figure 2. Tree diagram illustrating conceptual structure of lacustrine model for largemouth bass.

Food component. Average TDS (V_5) is included because there is a positive correlation between standing crops of black bass and TDS levels, presumably due to the greater amount of food organisms produced at higher TDS levels.

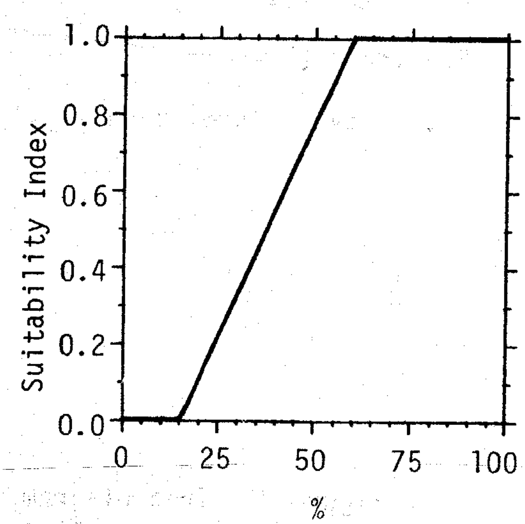
Cover component. Percent bottom cover (V_3, V_4) is included because largemouth bass are most abundant in areas with cover. Percent lacustrine area ≤ 6 m depth (V_2) quantifies the amount of cover habitat. It also serves to quantify the amount of overwintering habitat in northern latitudes. Water level fluctuation (V_{16}, V_{18}) is assumed to be important because the amount of available cover is dependent on fluctuations.

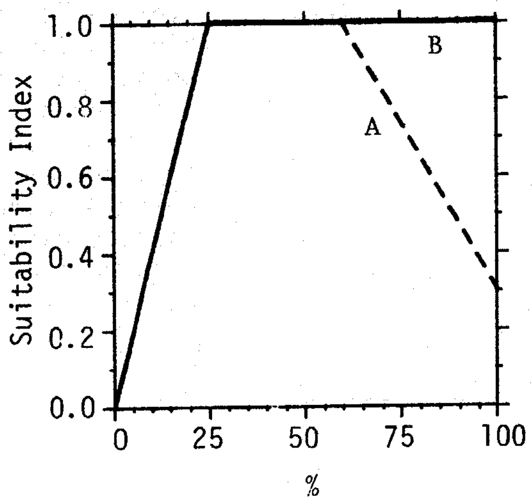
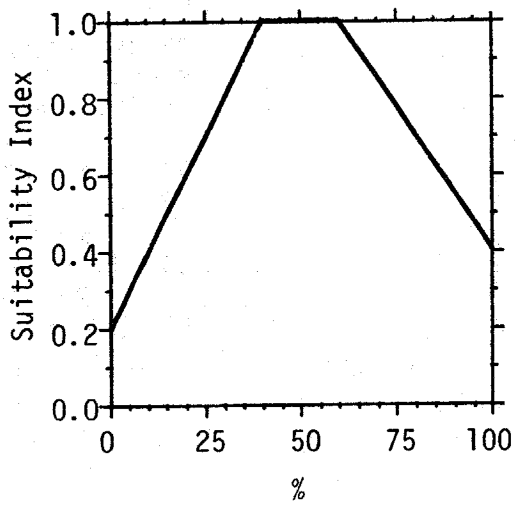
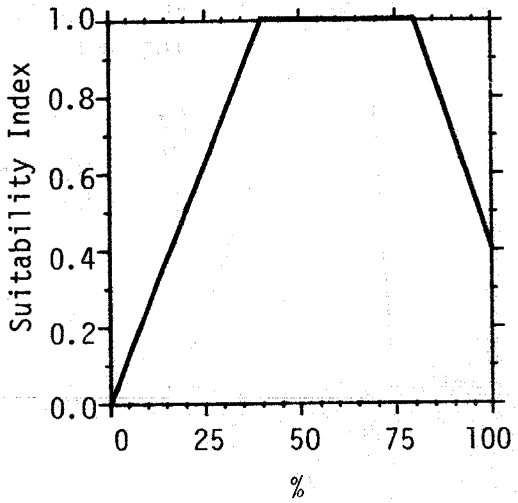
Water quality component. Same explanation as presented in the riverine model description.

Reproduction component. Temperature (V_9) and salinity (V_{14}) for spawning and embryonic development describe water quality conditions which affect reproduction. Substrate (V_{15}) is important for spawning success. Water level fluctuation (V_{17}) is included because optimal development and survival of embryos is dependent on stable water levels during spawning. Percent lacustrine area ≤ 6 m depth (V_2) quantifies the amount of spawning habitat.

Suitability Index (SI) Graphs for Model Variables

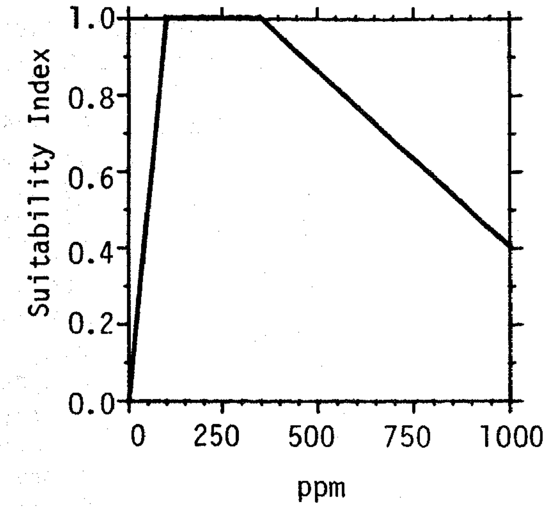
This section contains suitability index graphs for the 22 variables described above and equations for combining selected variable indices into a species HSI using the component approach. The "R" and "L" refer to riverine and lacustrine habitat variables, respectively.

Habitat	Variable		Suitability Graph
R	V_1	Percent pool and back-water area during average summer flow.	

L	V_2	Percent lacustrine area ≤ 6 m depth. Note: A regional consideration is made for bodies of water in more southern latitudes where overwintering requirements are not as rigorous. A. Northern latitudes B. Southern latitudes	
R,L	V_3	Percent bottom cover (e.g., aquatic vegetation, logs, and debris) within pools, backwaters, or littoral areas during summer. (Adult, Juvenile)	
R,L	V_4	Percent bottom cover (e.g, aquatic vegetation, logs, and debris) within pools, backwaters, or littoral areas during summer. (Fry)	

L V_5

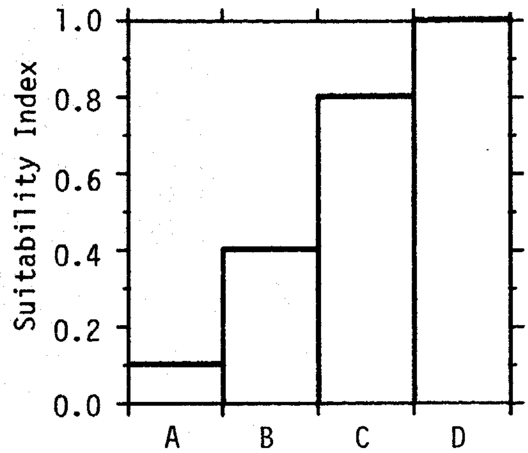
Average TDS concentration during growing season when carbonate-bicarbonate > sulfate-chloride ionic concentration. If sulfate-chloride concentration exceeds carbonate-bicarbonate, reduce SI rating for TDS by 0.2.



R,L V_6

Minimum disssolved oxygen levels during midsummer within pools or littoral areas.

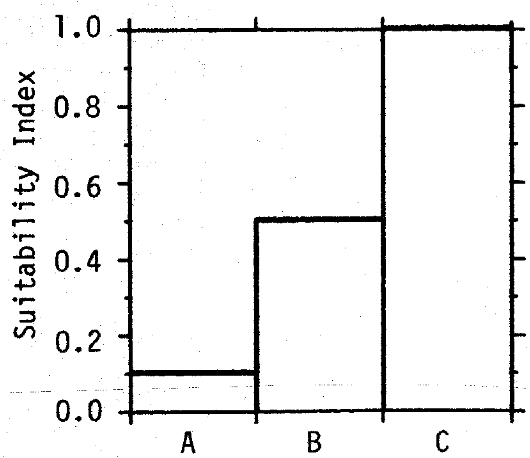
A) Frequently < 2 mg/l
B) Usually ≥ 2 and < 5 mg/l
C) Usually ≥ 5 and < 8 mg/l
D) Often > 8 mg/l



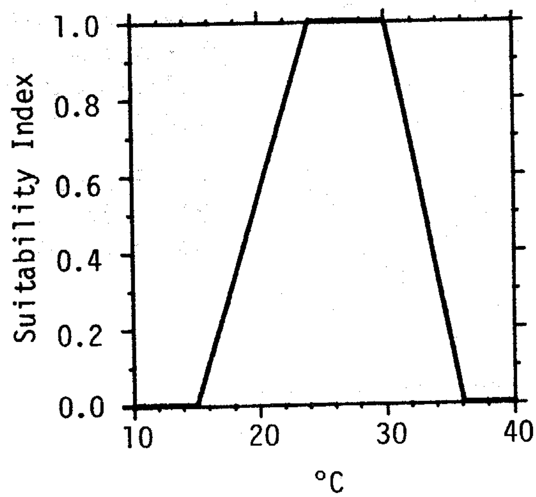
R,L V_7

pH range during growing season.

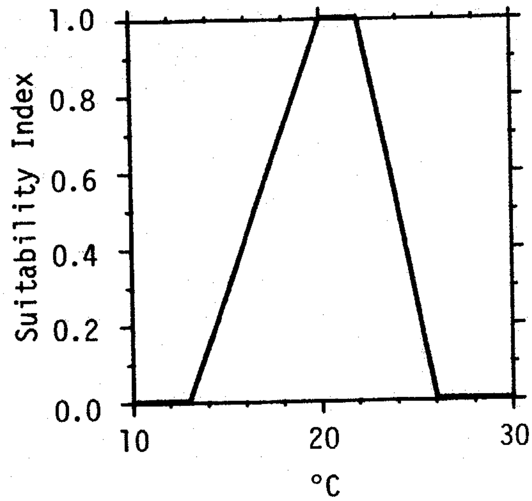
A) < 5.0 or > 10.0
B) ≥ 5 and < 6.5 <u>or</u> > 8.5 and ≤ 10.0
C) 6.5-8.5



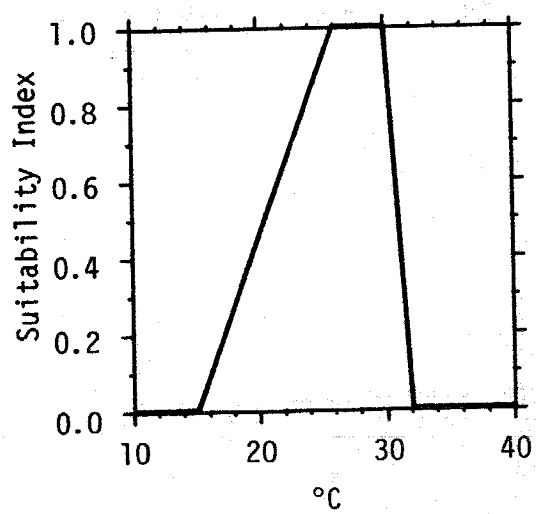
R,L V_8 Average water temperature within pools, backwaters, or littoral areas during the growing season. (Adult, Juvenile)



R,L V_9 Average weekly mean temperature within pools or littoral areas during spawning and incubation. (Embryo)

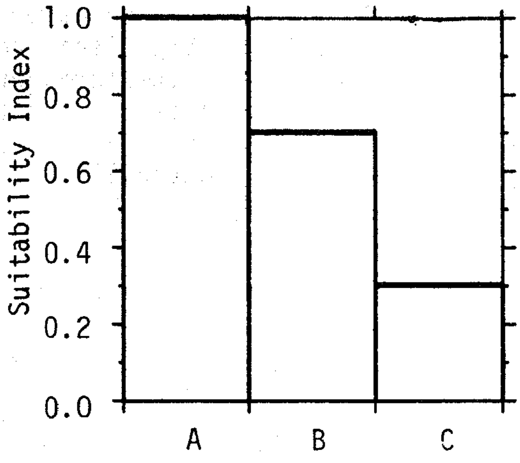


R,L V_{10} Average water temperature within pools, backwaters, or littoral areas during the growing season. (Fry)

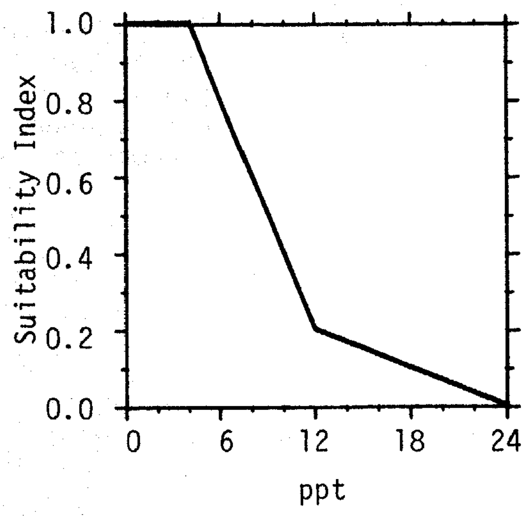


R,L V_{11} Maximum monthly average turbidity (suspended solids) during growing season.

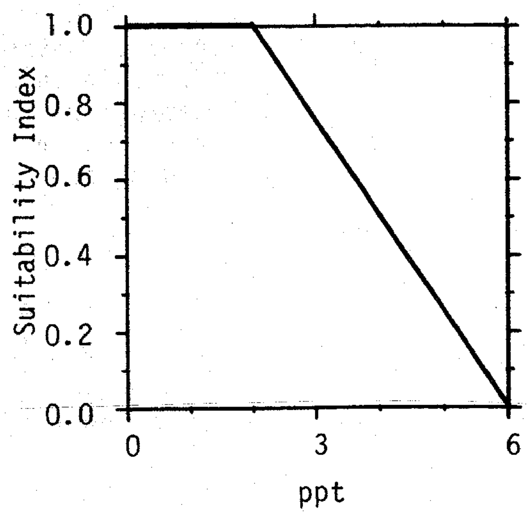
A) 5-25 ppm
B) > 25 and ≤ 100 ppm
C) < 5 ppm, > 100 ppm



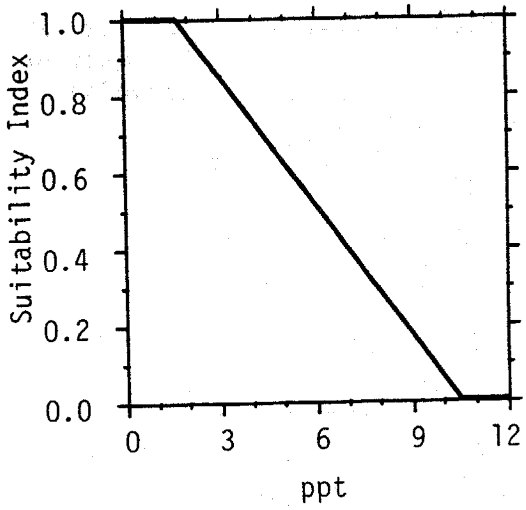
R,L V_{12} Maximum salinity during summer. (Adult, Juvenile)



R,L V_{13} Maximum salinity during summer. (Fry)

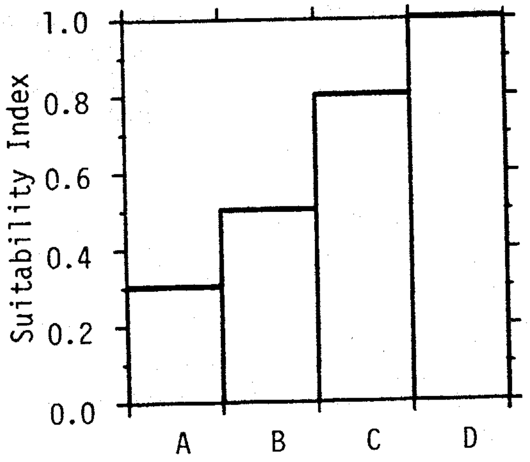


R,L V_{14} Maximum salinity during spawning and incubation. (Embryo)

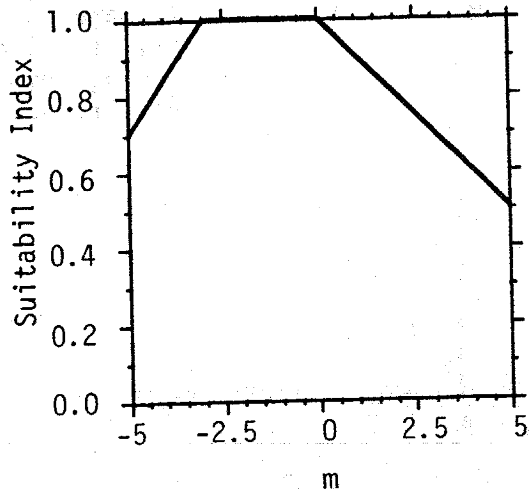


R,L V_{15} Substrate composition within riverine pools and backwaters or lacustrine littoral areas. (Embryo)

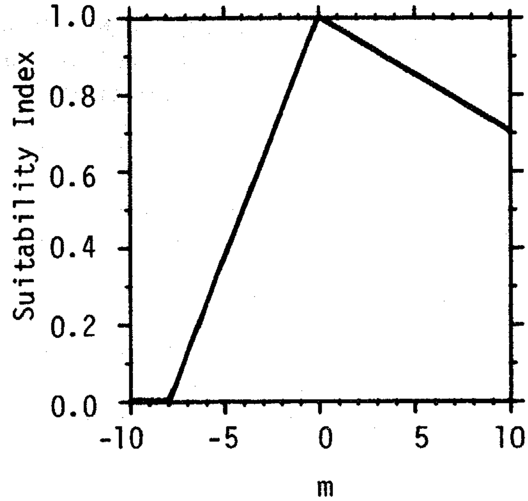
A) Boulders and bed-rock predominate (≥ 50%)
B) Sand (0.062-2.0 mm) predominates
C) Silt and clay (0.0-0.004 mm) predominate
D) Gravel (0.2-6.4 cm) predominates



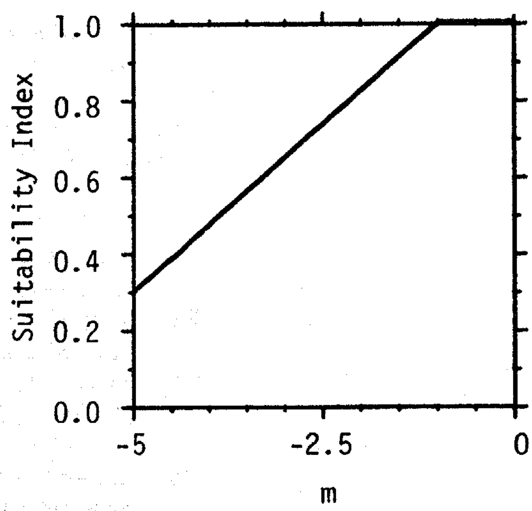
R,L V_{16} Average water level fluctuation during growing season. (Adult, Juvenile)



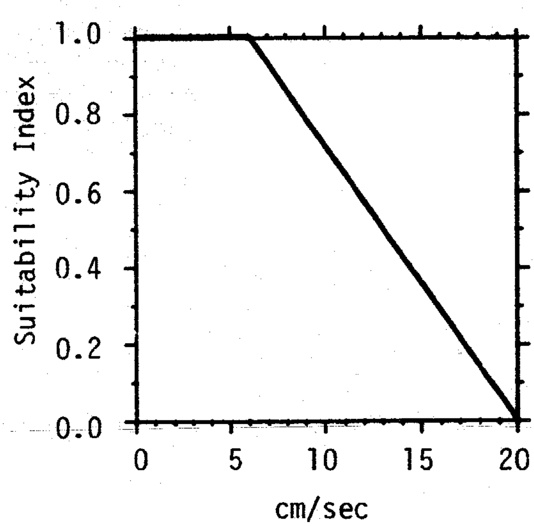
R,L V_{17} Maximum water level fluctuation during spawning. (Embryo)



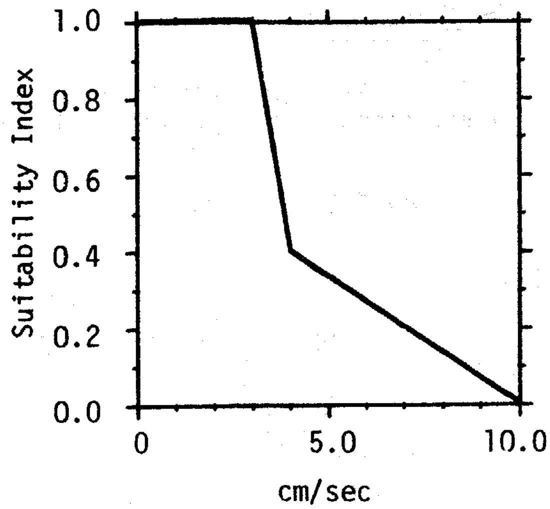
R,L V_{18} Average water level fluctuation during growing season. (Fry)



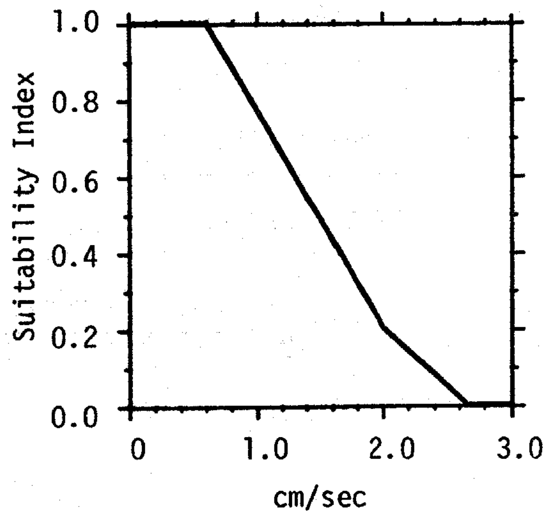
R V_{19} Average current velocity at 0.6 depth during summer. (Adult, Juvenile)



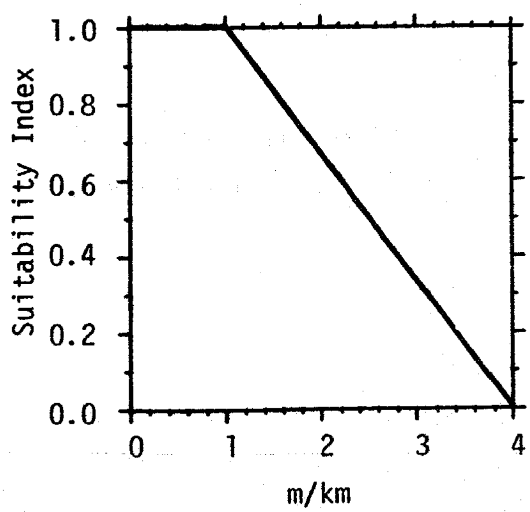
R V_{20} Maximum current velocity at 0.8 depth within pools or backwaters during spawning (May-June). (Embryo)



R V_{21} Average current velocity at 0.6 depth during summer. (Fry)



R V_{22} Stream gradient within representative reach.



Riverine Model

These equations utilize the life requisite approach and consist of five components: food, cover, water quality, reproduction, and other.

Food (C_F).

$$C_F = \left[V_1 \times \frac{(V_3 + V_4)}{2} \right]^{1/2}$$

Cover (C_C).

$$C_C = \left[V_1 \times \frac{(V_3 + V_4)}{2} \times \frac{(V_{16} + V_{18})}{2} \right]^{1/3}$$

Water Quality (C_{WQ}).

If V_{12} and $V_{13} = 1.0$,

$$C_{WQ} = \frac{2V_6 + V_7 + 2V_8 + V_{10} + V_{11}}{7}$$

If V_{12} or $V < 1.0$,

$$C_{WQ} = \frac{2V_6 + V_7 + 2V_8 + V_{10} + V_{11} + \frac{(V_{12} + V_{13})}{2}}{8}$$

If V_6, V_8, or $V_{10} \leq 0.4$, C_{WQ} equals the lowest of the following: V_6, V_8, V_{10}, or the above equation.

Reproduction (C_R).

If $V_{14} = 1.0$,

$$C_R = (V_1 \times V_9 \times V_{15} \times V_{17} \times V_{20})^{1/5}$$

If $V_{14} < 1.0$,

$$C_R = (V_1 \times V_9 \times V_{14} \times V_{15} \times V_{17} \times V_{20})^{1/6}$$

Other (C_{OT}).

Note: Since there is a correlation between stream gradient and current velocity, the user has two options for the "other" component:

A) $C_{OT} = \dfrac{V_{19} + V_{21}}{2}$, or

B) $C_{OT} = V_{22}$

HSI determination.

$$HSI = (C_F \times C_C \times C_{WQ} \times C_R \times C_{OT})^{1/5}$$

If C_{WQ} or C_R is ≤ 0.4, then the HSI equals the lowest of the following: C_{WQ}, C_R or the above equation.

Lacustrine Model

These equations utilize the life requisite approach and consist of four components: food, cover, water quality, and reproduction.

Food (C_F).

$$C_F = V_5$$

Cover (C_C).

$$C_C = \left[V_2 \times \frac{(V_3 + V_4)}{2} \times V_{16} \times V_{18} \right]^{1/4}$$

Water Quality (C_{WQ}).

Same as the riverine habitat suitability index equations for water quality.

Reproduction (C_R).

If $V_{14} = 1.0$,

$$C_R = (V_2 \times V_9 \times V_{15} \times V_{17})^{1/4}$$

If $V_{14} < 1.0$,

$$C_R = (V_2 \times V_9 \times V_{14} \times V_{15} \times V_{17})^{1/5}$$

HSI determination.

$$HSI = (C_F \times C_C \times C_{WQ} \times C_R)^{1/4}$$

If C_{WQ} or C_R is ≤ 0.4, then the HSI equals the lowest of the following: C_{WQ}; C_R; or the above equation.

Sources of data and assumptions made in developing the suitability indices are presented in Table 1.

Table 1. Data sources and assumptions for largemouth bass suitability indices.

	Variable and source	Assumption
V_1	Trautman 1957 Deacon 1961 Larimore and Smith 1963 Branson 1967 Scott and Crossman 1973 Funk 1975	Largemouth bass typically inhabit pool and backwater areas of streams; optimal habitat consists of at least 60% pool/backwater area.
V_2	Robbins and MacCrimmon 1974 Carlander 1977 Winter 1977	Cover adequate to support large populations can be provided by greater than 25% area ≤ 6 m depth. However, lacustrine habitats in northern latitudes need to be deep enough to successfully overwinter bass.
V_3	Jenkins et al. 1952 Miller 1975 Saiki and Tash 1979	Adult largemouth bass are most abundant in areas which contain cover; too much cover may reduce prey availability.
V_4	Kramer and Smith 1960 Newell 1960 Aggus and Elliot 1975 Anderson 1981	The amount of cover has been positively correlated with the number of fry. Too much cover constitutes poor spawning and rearing habitat.
V_5	Jenkins 1976	Total dissolved solids (TDS) levels correlated with high standing crops are optimal; those correlated with lower standing crops are suboptimal. The data used to develop this curve are primarily from southeastern reservoirs.
V_6	Katz et al. 1959 Whitmore et al. 1960 Moss and Scott 1961 Mohler 1966 Stewart et al. 1967 Dahlberg et al. 1968 Petit 1973	Dissolved oxygen levels where growth is not impaired are optimal, those where growth is reduced are suboptimal, and those where death may occur are unsuitable.
V_7	Swingle 1956 Stroud 1967 (FW)[a] Calabrese 1969 Buck and Thoits 1970	Optimal pH range is presumably the same as those for all freshwater fish. Levels which impair growth of largemouth bass are suboptimal; those which can result in death are unsuitable.

Table 1. (continued).

Variable and source		Assumption
V_8	Hart 1952 Johnson and Charlton 1960 Mohler 1966 Coutant 1975 Venables et al. 1978	Temperatures where growth of adult and juvenile largemouth bass is highest are optimal, those where growth is reduced are suboptimal, and those where little or no growth occurs are unsuitable.
V_9	Carr 1942 Kramer and Smith 1960 Strawn 1961 Clugston 1966 Kelley 1968 Badenhuizen 1969	Temperatures which result in greatest survival of embryos are optimal, those where survival is reduced are suboptimal, and those where little or no survival occurs are unsuitable.
V_{10}	Strawn 1961	Same assumption as V_9, only applied to fry life stage.
V_{11}	Buck 1956a; 1956b Bulkley 1975 Muncy et al. 1979	Turbidity (suspended solid) levels where the greatest survival and growth occur are optimal. Levels which reduce growth and interfere with reproductive processes are suboptimal.
V_{12}	Bailey et al. 1954 Tebo and McCoy 1964	Salinity levels where adult and juvenile largemouth bass are most abundant are optimal. Those where abundance declines are suboptimal to unsuitable.
V_{13}	Tebo and McCoy 1964	Salinity levels where the growth rate of fry are not impaired are optimal, those where growth rates decline are suboptmal, and those where no growth occurs are unsuitable.
V_{14}	Tebo and McCoy 1964	Salinity levels which do not affect embryonic survival are optimal, those where survival is impaired are suboptimal, and levels where no survival occurs are unsuitable.
V_{15}	Harlan and Speaker 1956 Mraz and Cooper 1957 Newell 1960 Mraz et al. 1961 Robinson 1961 Mraz 1964	The substrate type on which most spawning takes place is optimal; other substrate types are suboptimal.

Table 1. (concluded).

	Variable and source	Assumption
V_{16}	Heman et al. 1969	Water level fluctuations which concentrate prey and lead to increases in growth rates of adult and juvenile largemouth bass are optimal; those which reduce prey availability are suboptimal.
V_{17}	Harlan and Speaker 1956 Mraz 1964 Clugston 1966 Jester et al. 1969 Allan and Romero 1975	Fluctuations in water level which do not affect survival of embryos are optimal; those fluctuations which exceed the average depth of nests (and reduce survival) are suboptimal to unsuitable.
V_{18}	Aggus and Elliot 1975	Water level fluctuations which lead to increased cover availability for fry are optimal. Those which decrease the amount of cover are suboptimal.
V_{19}	Bailey et al. 1954 Kallemeyn and Novotny 1977 Hardin and Bovee 1978	Current velocities where abundance of adult and juvenile largemouth bass is greatest are optimal; those where abundance declines are suboptimal to unsuitable.
V_{20}	Deacon 1961 Dudley 1969	Velocities which do not impair embryonic survival are optimal, those which reduce survival are suboptimal to unsuitable.
V_{21}	MacLeod 1967 Laurence 1972 Hardin and Bovee 1978	Same assumption as V_{19}, only applicable to fry life stage.
V_{22}	Finnell et al. 1956 Trautman 1957 Moyle and Nichols 1973	Gradients where species abundance is greatest are optimal; those which lead to a decline in abundance are suboptimal to unsuitable.

[a](FW) = Freshwater fish; remaining citations are largemouth bass data.

Sample data sets from which HSI's have been generated using the riverine HSI equations are presented in Table 2. Similar sets using the lacustrine HSI equations are given in Table 3. The data sets are not actual field measurements, but represent combinations of variable values we believe could occur in a riverine or lacustrine habitat. The HSI's calculated from the data reflect what we believe carrying capacity trends would be in riverine and lacustrine habitats with the listed characteristics. Accuracy of the models in predicting population trends has not been tested.

Interpreting Model Outputs

The largemouth bass HSI determined by use of these models will not necessarily represent the population of largemouth bass in the study area. Habitats with an HSI of 0 may contain some largemouth bass; habitats with a high HSI may contain few. This is because the population of a study area of a stream or lake does not totally depend on the habitat variables, as is assumed by the model. If the models are a good representation of largemouth bass habitat, then in riverine and lacustrine environments where largemouth bass population levels are due primarily to habitat related factors, the models should be positively correlated to the long term average population levels. However, this has not been tested. The proper interpretation of the HSI is one of comparison. If two riverine or lacustrine habitats have different HSI's, the one with the higher HSI should have the potential to support more largemouth bass than the one with the lower HSI, given the model assumptions have not been violated.

This model does not specifically address the effects of wind induced turbulence on bass reproductive success, but wave destruction of nests may be locally important (Miller and Kramer 1971; Summerfelt 1975). The direction of prevailing winds, surrounding topography, lake morphometry, and the placement of objects which might provide shelter for nests (e.g., boulders and ledges) may be relevant criteria in specific cases.

ADDITIONAL HABITAT MODELS

Model 1

Assuming water quality is adequate, optimal riverine habitat for largemouth bass may be characterized as follows: large, low (≤ 1 m/km) gradient streams; abundant (40-80% of pool and backwater area) cover in the form of aquatic vegetation, brush, logs, or other cover items; warm (24-30° C) midsummer water temperatures; low (< 25 ppm) turbidity; and a predominance (> 60% stream area) of pools.

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

Table 2. Sample data sets using riverine HSI model.

Variable		Data set 1		Data set 2		Data set 3	
		Data	SI	Data	SI	Data	SI
% pool, backwater area	V_1	20	0.1	40	0.5	70	1.0
% bottom cover-adult, juvenile	V_3	10	0.4	25	0.7	60	1.0
% bottom cover	V_4	10	0.2	25	0.6	60	0.8
Dissolved O_2 (mg/l)	V_6	3.0	0.4	5.1	0.8	6.4	0.8
pH range	V_7	7.8	1.0	8.1	1.0	7.5	1.0
Average temperature-adult, juvenile (°C)	V_8	22	0.8	23	0.9	27	1.0
Average temperature-embryo (°C)	V_9	19	0.8	22	1.0	24	0.5
Average temperature-fry (°C)	V_{10}	20	0.4	23	0.7	25	0.9
Maximum turbidity-JTU	V_{11}	150	0.3	25	1.0	40	0.7
Maximum salinity-adult, juvenile (ppt)	V_{12}	1.2	1.0	2.1	1.0	0.8	1.0
Maximum salinity-fry (ppt)	V_{13}	1.2	1.0	2.1	1.0	0.8	1.0
Maximum salinity-embryo (ppt)	V_{14}	1.2	1.0	2.1	0.9	0.8	1.0
Substrate type-embryo	V_{15}	silt/clay	0.8	sand	0.5	gravel	1.0

Table 2. (concluded).

Variable		Data set 1		Data set 2		Data set 3	
		Data	SI	Data	SI	Data	SI
Water level fluctuation-adult, juvenile	V_{16}	-0.5	1.0	0	1.0	0	1.0
Water level fluctuation-embryo (m)	V_{17}	-1.0	0.9	-0.5	0.9	0	1.0
Water level fluctuation-fry (m)	V_{18}	-0.6	1.0	0	1.0	0	1.0
Current velocity-embryo (cm/sec)	V_{20}	0.8	1.0	0.5	1.0	0.2	1.0
Stream gradient (m/km)	V_{22}	2	0.7	1.2	0.9	0.7	1.0
Component SI							
C_F =			0.2		0.6		1.0
C_C =			0.3		0.7		1.0
C_{WQ} =			0.6		0.9		0.9
C_R =			0.6		0.8		0.9
C_{OT} =			0.7		0.9		1.0
HSI =			0.4		0.8		1.0

Table 3. Sample data sets using lacustrine HSI model.

Variable		Data set 1		Data set 2		Data set 3	
		Data	SI	Data	SI	Data	SI
% lacustrine area ≤ 6 m depth	V_2	5	0.2	15	0.6	65	0.9
% bottom cover adult, juvenile	V_3	5	0.3	30	0.8	75	0.8
% bottom cover (fry)	V_4	5	0.1	30	0.7	75	1.0
Average TDS (ppm)	V_5	50	0.4	20	0.2	200	1.0
Dissolved O_2 (mg/l)	V_6	6.5	0.8	7.0	0.8	6.4	0.8
pH range	V_7	8.2	1.0	8.7	0.5	7.9	1.0
Average temperature-adult, juvenile (°C)	V_8	21	0.7	28	1.0	26	1.0
Average temperature-embryo (°C)	V_9	20	1.0	25	0.3	23	0.8
Average temperature-fry (°C)	V_{10}	22	0.6	27	1.0	25	0.9
Maximum turbidity (ppm)	V_{11}	15	1.0	70	0.7	25	1.0
Maximum salinity adult, juvenile (ppt)	V_{12}	1.3	1.0	1.5	1.0	0.5	1.0
Maximum salinity (ppt)	V_{13}	1.3	1.0	1.5	1.0	0.5	1.0

Table 3. (concluded).

Variable		Data set 1		Data set 2		Data set 3	
		Data	SI	Data	SI	Data	SI
Maximum salinity (ppt)	V_{15}	1.3	1.0	1.5	1.0	0.5	1.0
Substrate type-embryo	V_{15}	sand	0.5	gravel	1.0	silt/clay	0.8
Water level fluctuation-adult, embryo (m)	V_{16}	-5	0.7	0	1.0	0	1.0
Water level fluctuation-embryo (m)	V_{17}	+2	0.9	+0.3	1.0	0	1.0
Water level fluctuation-fry (m)	V_{18}	-5	0.3	0	1.0	0	1.0
Component SI							
C_F =			0.4		0.2		1.0
C_C =			0.3		0.8		0.9
C_{WQ} =			0.8		0.8		0.9
C_R =			0.5		0.7		0.9
HSI =			0.5		0.5		0.9

Model 2

Assuming water quality is adequate, optimal lacustrine habitat for largemouth bass may be characterized as follows: fertile (TDS levels 100-350 ppm) lakes; abundant (40-80% of littoral area) bottom cover; warm (24-30° C) midsummer water temperatures; and extensive (25-60% for northern latitudes; ≥ 25% for southern latitudes) shallow (≤ 6 m depth) areas.

$$HSI = \frac{\text{Number of above criteria present}}{4}$$

Model 3

Use the regression models for largemouth bass standing crop in reservoirs presented by Aggus and Morais (1979) to calculate an HSI.

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16. Abstract (Limit: 200 words)

This is one of a series of publications that provide information on the habitat requirements of selected fish and wildlife species. Literaure describing the relationship between habitat variables related to life requisites and habitat suitability for the Largemouth bass (Micropterus salmoides) are synthesized. These data are subsequently used to develop Habitat Suitability (HSI) models. The HSI models are designed to provide information that can be used in impact assessment and habitat management.

17. Document Analysis a. Descriptors

Animal behavior
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Fishes
Habitability
Mathematical models

b. Identifiers/Open-Ended Terms

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Micropterus salmoides
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