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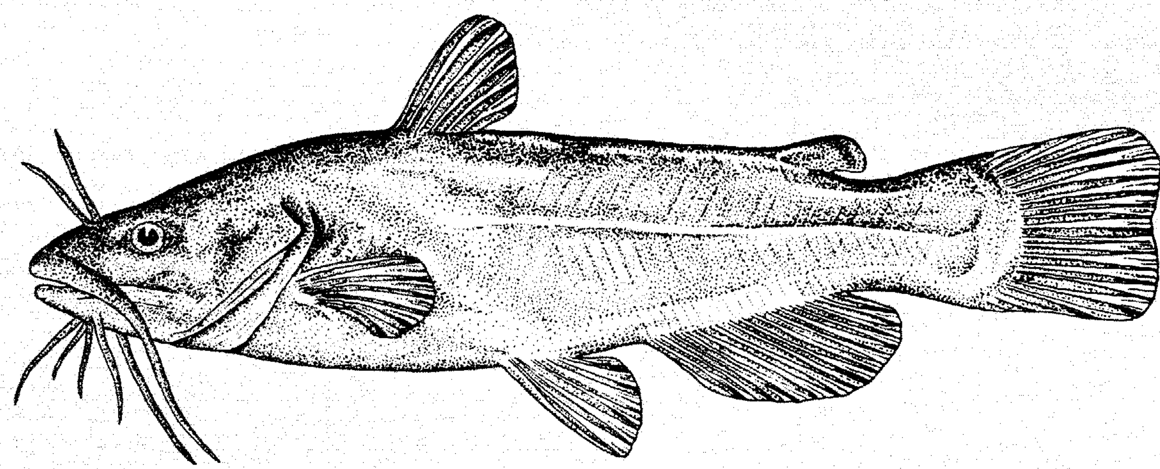
JULY 1982

HABITAT SUITABILITY INDEX MODELS: BLACK BULLHEAD



Fish and Wildlife Service

S. Department of the Interior

FWS/OBS-82/10.14
July 1982

HABITAT SUITABILITY INDEX MODELS: BLACK BULLHEAD

by

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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 habitat 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 prep.).[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 FWS 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. Fish and Wildl. Serv. Div. Ecol. Serv. n.p.

CONTENTS

ACKNOWLEDGMENTS

I would like to thank Branley Branson and Richard Applegate for their suggestions and comments on an earlier manuscript. Word processing was provided by Dora Ibarra and Carolyn Gulzow. The cover of this document was illustrated by Jennifer Shoemaker.

BLACK BULLHEAD (*Ictalurus melas*)

HABITAT USE INFORMATION

General

The native range of the black bullhead (*Ictalurus melas*) extends from North Dakota eastward through southern Canada to the upper tributaries of the St. Lawrence River and southward and westward to Texas and northern Mexico (Trautman 1957; Hubbs and Lagler 1958; Scott and Crossman 1973). It has been widely introduced throughout temperate North America and parts of Europe (Scott and Crossman 1973; Wheeler 1978).

Age, Growth, and Food

Age at maturity is variable (II-V), depending on geographic location. Size at maturity ranges from 170 to 250 mm (Barnickol and Starrett 1951; Carlander 1969; Dennison and Bulkley 1972; Olson and Koopman 1976). Maximum size varies from 43 cm and 1.3 kg in southern waters to 38 cm and 0.9 kg in central waters and to 32 cm in Canadian waters (Trautman 1957; Carlander 1969; Scott and Crossman 1973).

Young-of-the-year black bullheads are planktivorous, feeding on cladocerans, copepods, and ostracods (Applegate and Mullan 1966; Williams 1970; Olson 1971; Campbell and Branson 1978). Juveniles and adults utilize a variety of food organisms: clams; snails; chironomids; amphipods; decapods; and filamentous algae. Forage fish are utilized by larger adults, especially as summer progresses (Welker 1962; Seaburg and Moyle 1964; Applegate and Mullan 1966; Williams 1970; Olson 1972; Repsys et al. 1976; Campbell and Branson 1978).

Reproduction

Black bullheads excavate saucer-shaped nests (15-35 cm in diameter) beneath logs or other large objects, if available (Pflieger 1975). In lacustrine environments, nests are located in weedy areas at depths of 0.5-1.5 m (Forney 1955; Harlan and Speaker 1956). Spawning takes place between May and July, when water temperatures reach 20° C (Breder and Rosen 1966; Olson 1971; Dennison and Buckley 1972; Scott and Crossman 1973; Olson and Koopman 1976). Both parents guard the nest, fanning the water above the developing eggs to provide adequate oxygen (Breder and Rosen 1966; Olson and Koopman 1976).

Specific Habitat Requirements

Optimal riverine habitat is characterized by a mixture of low velocity pools or backwaters with moderate to extensive cover and riffle/run areas (Minckley 1963; Taylor 1969; Lohmeyer 1972; Pflieger 1975). Black bullheads are most numerous in low velocity (≤ 4 cm/sec) areas associated with low stream gradients (Lohmeyer 1972). The species is usually found within the vegetative cover of pools, but will also move into riffle/run areas to feed (Darnell and Meierotto 1965). No specific information regarding current velocity tolerances is available, but it is assumed that velocities > 40 cm/sec would be unsuitable. Substantial populations have been reported in streams ranging from 1.5 m wide (Hanson and Campbell 1963) to very large rivers, such as the Mississippi (Cvancara et al. 1977). Because the species seems to prefer a diversity of velocities and structural features, it is assumed that 50-80% pool/backwater areas with ≥ 20% cover (e.g., vegetation, brush, or debris) would be optimal.

The species is associated with cover in shallow portions of lacustrine environments (Bowen 1931; Ridenhour 1960; Houser and Grinstead 1961; Seaburg and Moyle 1964; Bulkley 1970). Highest standing crops of black bullhead populations occur in smaller (< 200 ha) lakes and reservoirs (Houser and Collins 1962; Turner 1971). It is assumed that smaller bodies of water provide more food and cover habitat. It is also assumed that optimal lacustrine habitat would include extensive littoral area (≥ 25% of surface area) with moderate to abundant (≥ 20%) cover within this area.

The suitability of a habitat for food production in lacustrine environments can be measured by total dissolved solids (TDS), because TDS is an index of water fertility and fish production (Ryder 1965). Finnell (1979) reported abundant black bullhead populations in six eastern Colorado reservoirs with TDS values ranging from 280-4430 ppm. Jenkins (1976) reported that the highest crops of freshwater sport fishes (including bullheads) occurred in waters with TDS levels between 100 and 350 ppm (carbonate-bicarbonate > sulfate-chloride ionic concentration). Based on these two studies, it is assumed that optimal ratings for black bullheads correspond to a TDS range of 100-600 ppm.

Black bullheads can withstand low levels of dissolved oxygen (D.O.). The lethal oxygen concentration during summer months (water temperature > 18° C) is 3.0 mg/l (Moore 1942). The lethal oxygen threshold of the species decreases markedly during winter, because black bullheads can survive oxygen tensions as low as 0.2-0.3 mg/l (Moore 1942; Cooper and Washburn 1946). Based on quantitative data for other catfishes, it is assumed that optimal dissolved oxygen levels are ≥ 7 mg/l (Carlson et al. 1974).

Black bullheads tolerate a wide range of turbidities in both riverine and lacustrine habitats (Cross 1967; Pflieger 1975; Campbell and Branson 1978). No quantitative information is available on the optimal turbidity range. However, Buck (1956) reported that the growth of channel catfish (*Ictalurus punctatus*) was greater in clear water (suspended solids < 25 ppm), yet survival was greater in muddy water (suspended solids > 100 ppm). It is assumed that the black bullhead would exhibit a similar response, and it is inferred that optimal Suitability Index (SI) ratings correspond to an intermediate turbidity range of 25-100 ppm.

Substantial populations of black bullheads have been found in both riverine and lacustrine environments with pH values ranging from 5.8 to 9.6 (Applegate et al. 1973; Campbell and Branson 1978). Information is not available on optimal pH ranges or tolerance limits for black bullheads. Klarberg and Benson (1975) found that the brown bullhead was distributed over the widest pH range (3.4-7.7) of any species in a Virginia stream. The black bullhead is more tolerant of pollutants than the brown (Scott and Crossman 1973); thus it probably tolerates a pH as low as 3.4. Stroud (1967) felt that a pH range of 6.5-8.5 allowed full production and growth for all life stages of freshwater fish. Hence, this range will correspond to an optimal SI rating, and habitats outside this range will receive a lesser rating.

Adult. Data about thermal optima for black bullheads are somewhat conflicting. Kayes (1977) stated that a discrete thermal optimum cannot be applied, because growth is insensitive to differences in temperature between 18-29° C. Hill (1972-73) reported that the best weight conversion was at 23-24° C. Upper lethal temperature for all life stages is between 35-39° C (Black 1953; Cvancara et al. 1977; Leidy and Jenkins 1977; Campbell and Branson 1978). Feeding, and subsequent growth, commences near 10° C (Campbell and Branson 1978). Optimal ratings for growth correspond to the average of mean weekly water temperatures in the 18-29° C range for a period greater than 20 weeks.

No specific information was found concerning the salinity tolerance of the black bullhead. However, optimal levels for adults are assumed to be ≤ 2 ppt, with lethal levels near 14 ppt, based on data from other catfishes (Mansueti and Hardy 1967; Allen and Avault 1970; Perry 1973).

Embryo. Incubation time of embryos ranges from 5-10 days, depending on ambient water temperature (Fowler 1917; Miller 1966). Optimal temperatures for successful development are 20-22° C (Miller 1966; Olson and Koopman 1976), and the range for development is 20-27° C, based on brown bullhead data (Brungs and Jones 1977). Optimal substrate composition for spawning within pools and littoral areas consists of a predominance (> 50%) of fines (Pflieger 1975; Olson and Koopman 1976). Because nests are often constructed in association with cover (Forney 1955; Harlan and Speaker 1956; Pflieger 1975), it is assumed that ≥ 20% cover within pools, backwaters, or littoral areas during spawning will represent optimal conditions. Optimal salinity levels are assumed to be ≤ 2 ppt, and development is impaired above 8 ppt, based on channel catfish data (Allen and Avault 1970; Perry 1973). Because nests are located at depths between 0.5-1.5 m (Forney 1955; Harlan and Speaker 1956), reservoir drawdown should not exceed 1.5 m during spawning to ensure optimal survival of developing eggs.

Fry. Temperature requirements for fry are assumed to be similar to adults. Optimal and tolerable salinity levels are assumed to be the same as for black bullhead embryos. Other habitat requirements are assumed to be similar to those for the species in general.

Juvenile. Habitat requirements for juveniles are assumed to be the same as those for the species in general, with the exception of temperature and salinity requirements, which are assumed to be similar to the adult life stage.

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 that variable which occurs anywhere within this region. Therefore, the models will never provide an HSI of 1.0 when applied to northern bodies of water where temperature related variables do not reach the optimal values found in the southern portion of the region.

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

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

Minimal habitat area. Minimal habitat area is defined as the minimal area of contiguous suitable habitat that is required for a species to live and reproduce. No attempt has been made to establish a minimal habitat size for black bullheads.

Verification level. The acceptable output of the black bullhead habitat suitability models is to produce an index between 0 and 1 which has a positive relationship to carrying capacity. In order to verify that the model output was acceptable, sample data sets were developed 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 models.

Model Description - Riverine

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

Food component. Percent cover (V_2) is included because bottom cover provides habitat for aquatic insects, invertebrates, and forage fish, which are the predominant riverine food items of black bullheads. Percent pools and backwaters (V_1) is included to quantify the amount of food habitat.

Cover component. Percent cover (V_2) is included because the species is associated with cover. Percent pools (V_1) is important because black bullheads utilize pools as resting areas. This variable also serves to quantify the amount of cover habitat. Average current velocity (V_3) is included because

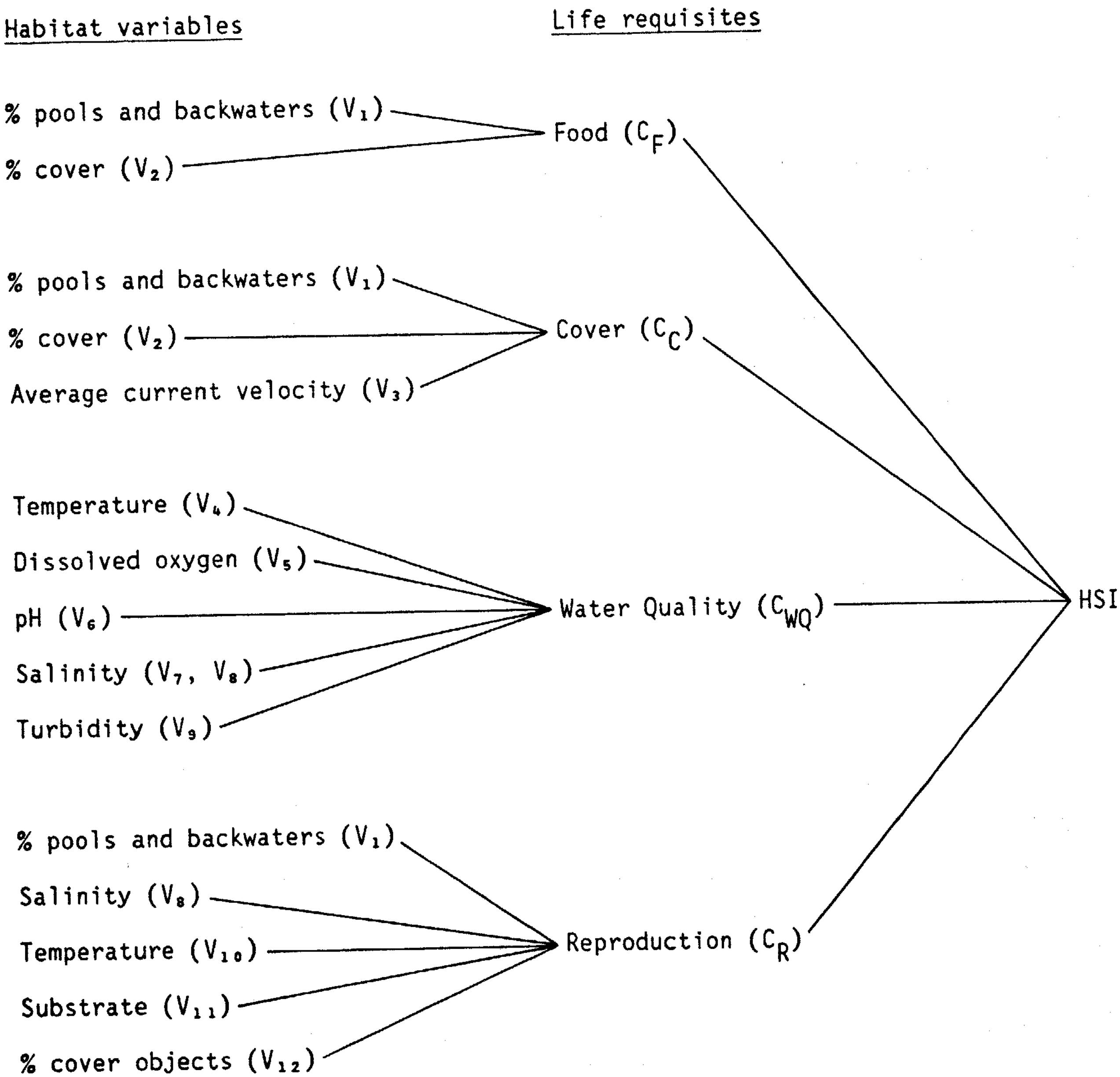


Figure 1. Tree diagram illustrating relationships among model variables and components (life requisites) for riverine black bullhead model.

the useable habitat near cover objects decreases if cover objects are surrounded by water with high velocities.

Water quality component. The water quality component is limited to temperature (V_4), dissolved oxygen (V_5), pH (V_6), salinity (V_7, V_8), and turbidity (V_9) 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. Salinity (V_8) and temperatures most suitable for spawning (V_{10}) describe water quality conditions which affect embryonic development. Substrate (V_{11}) is important in determining spawning success. Percent cover objects (V_{12}) is included because nests are often found in association with cover. Percent pool or backwater area (V_1) quantifies the amount of spawning habitat.

Model Description - Lacustrine

The structure of the lacustrine HSI model for black bullhead is shown in Figure 2.

Food component. Average TDS (V_{13}) is included because there is a positive correlation between catfish standing crops (including black bullheads) and TDS levels, presumably due to the greater amount of food organisms produced at higher TDS levels.

Cover component. Percent cover (V_2) is included because black bullheads are associated with cover. Cover provides resting areas and protection from predation. Percent littoral area (V_{14}) quantifies the amount of cover habitat. Reservoir or lake size (V_{15}) is included because species abundance is related to the size of lacustrine habitat, and it is assumed that the size of a body of water is related to the amount of cover habitat.

Water quality component. See explanation in the riverine model description.

Reproductive component. Salinity (V_8) and temperature most suitable for spawning (V_{10}) describe water quality conditions which affect embryonic development. Substrate (V_{11}) is important in determining spawning success. Percent cover objects (V_{12}) is included because nests are usually found in association with cover. Percent littoral area (V_{14}) quantifies the amount of spawning habitat. Reservoir drawdown (V_{16}) is included because optimal embryo development and survival is dependent on stable water levels during spawning.

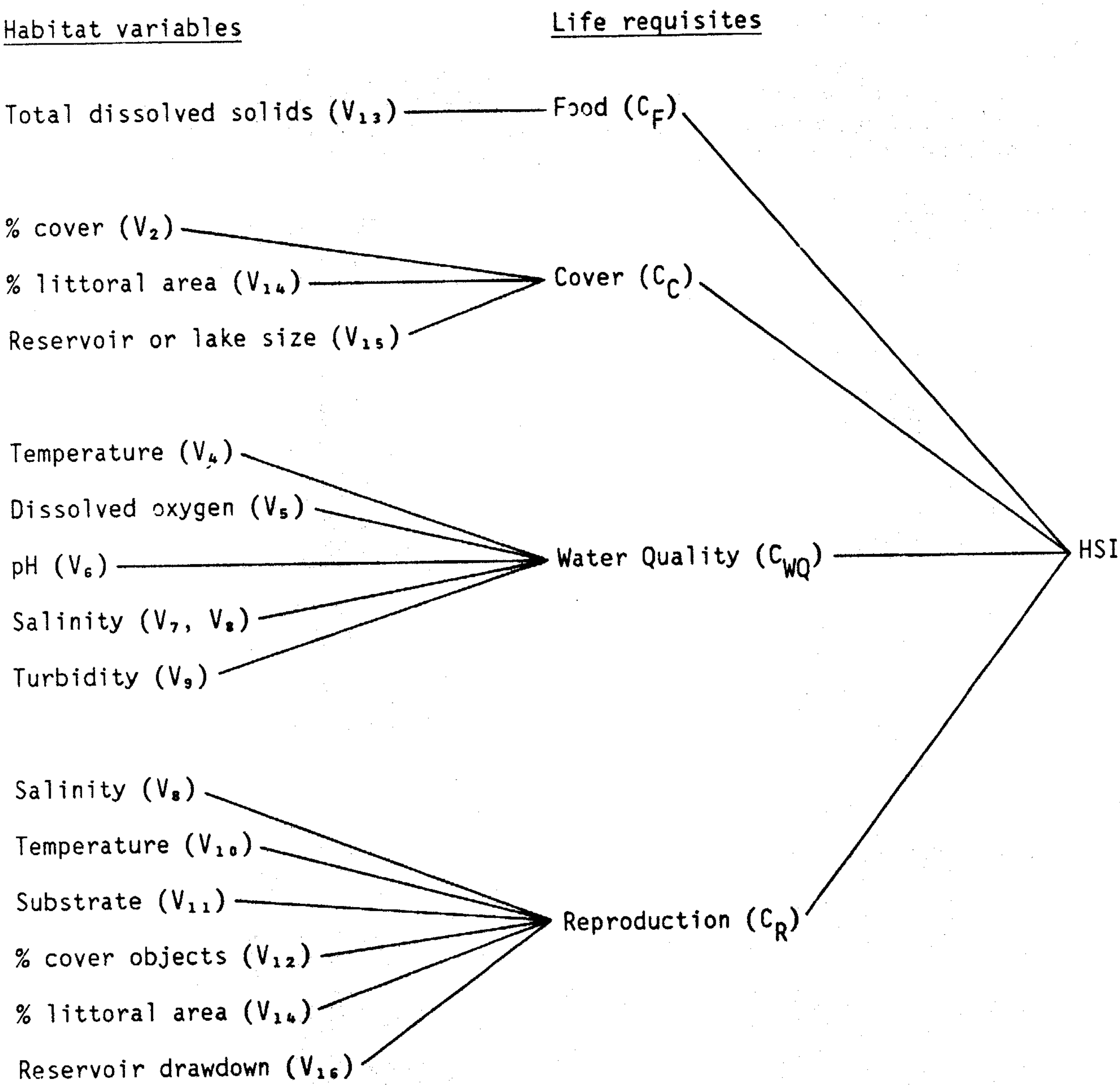
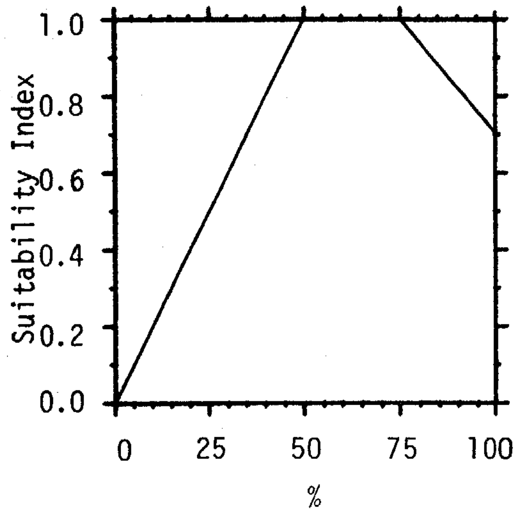
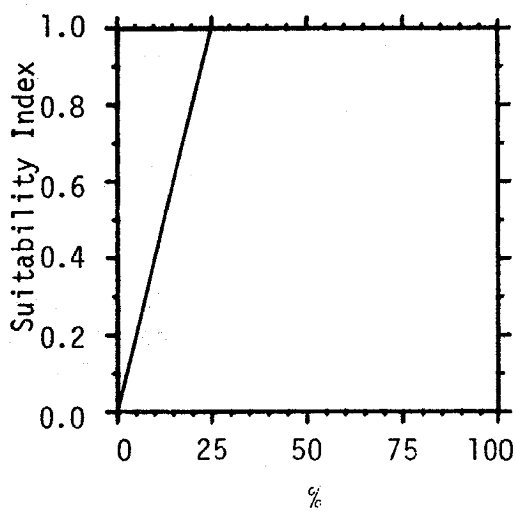


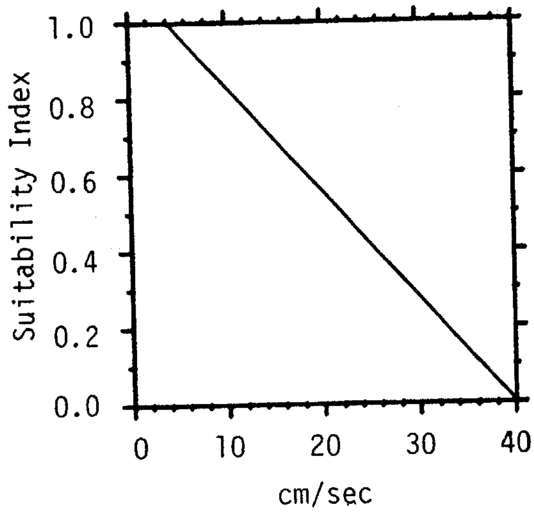
Figure 2. Tree diagram illustrating relationships among model variables and components (life requisites) for the lacustrine black bullhead model.

Suitability Index (SI) Graphs for Model Variables

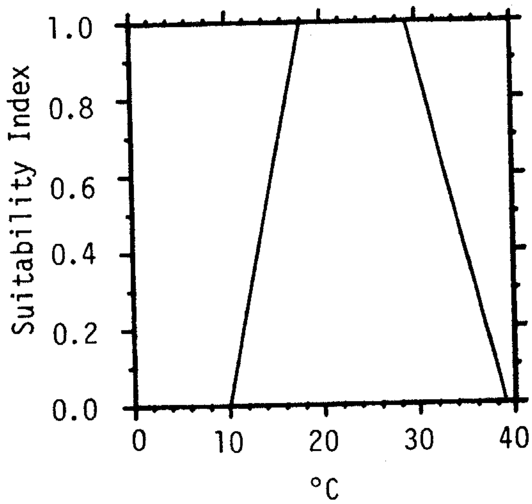
This section contains suitability index graphs for the 16 variables described above and equations for combining selected variable indices into a species HSI using the component approach. The "R" pertains to riverine habitat variables, and the "L" refers to lacustrine habitat variables.

Habitat	Variable		Suitability Graph
R	V_1	Percent pools and backwaters during average summer flow.	
R,L	V_2	Percent cover (e.g., vegetation, brush, or debris) within pools, backwaters, or littoral areas during summer.	

R V$_3$ Average current velocity at 0.6 depth during average summer flow.

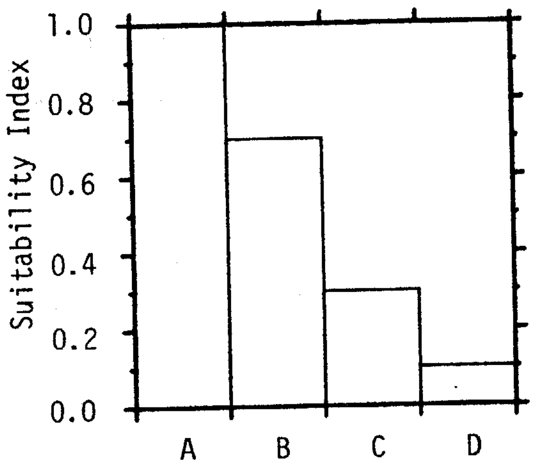


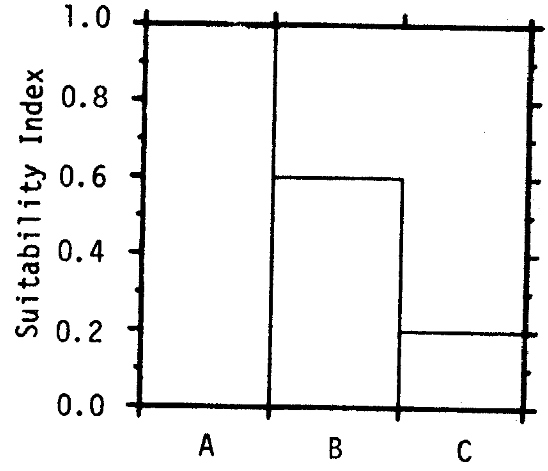
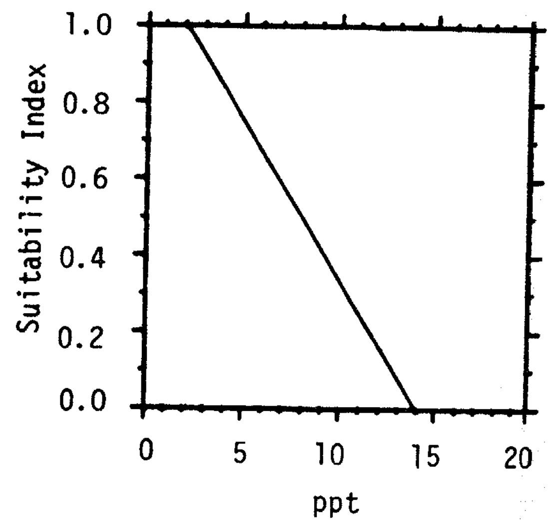
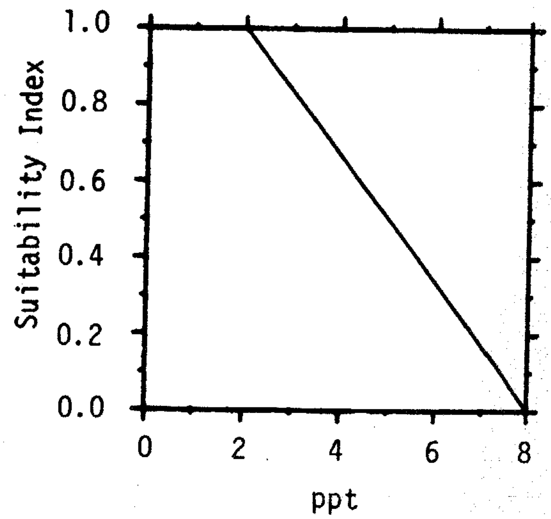
R,L V$_4$ Maximum midsummer water temperature within pools, backwaters, or littoral areas.



R,L V$_5$ Dissolved oxygen range within pools, backwaters, or littoral areas during summer.

A) Seldom < 6 mg/l
B) Usually 4-6 mg/l
C) Usually 2-4 mg/l
D) Frequently < 3 mg/l (near-lethal D.O. concentrations)

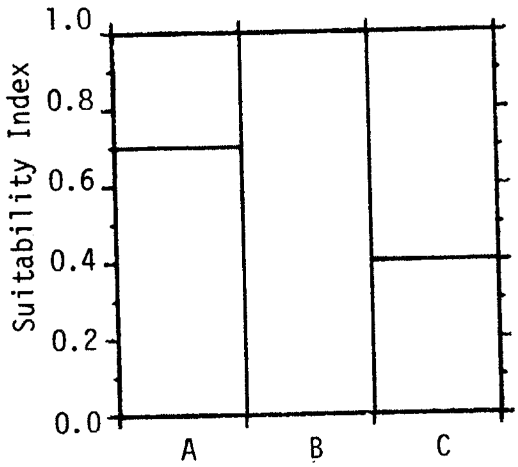


R,L	V_6	pH range during the year. A) Usually 6.5-8.5 B) Usually 4.5-6.5 or 8.5-10.0 C) Frequently < 4.5 or > 10.0.	
R,L	V_7	Maximum salinity during summer (adult and juvenile).	
R,L	V_8	Maximum salinity during early summer (May-July) (embryo and fry).	

R,L V_9

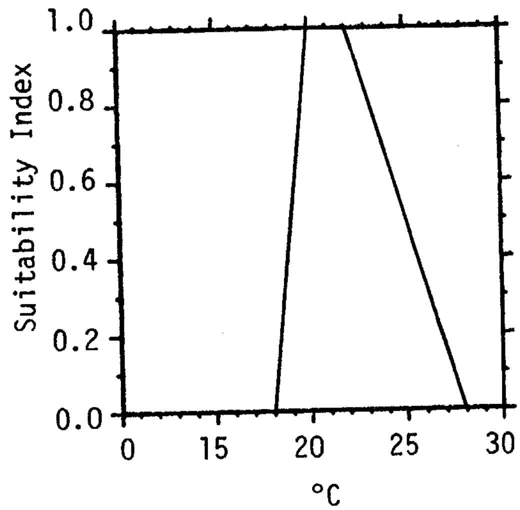
Maximum monthly average turbidity (suspended solids) during growing season.

A) Clear (< 25 ppm)
B) Moderate (25-100 ppm)
C) Turbid (> 100 ppm)



R,L V_{10}

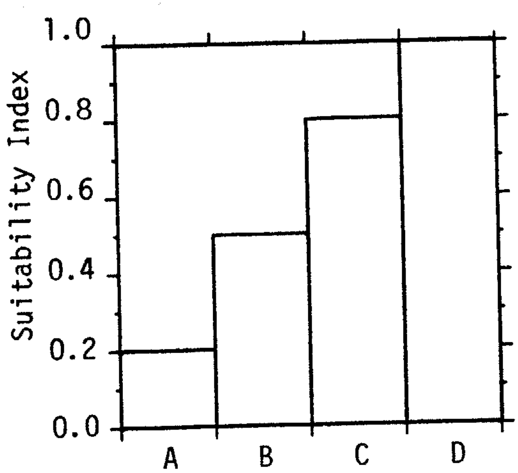
Average water temperatures within pools, backwaters, or littoral areas during spawning and embryonic development (embryo).

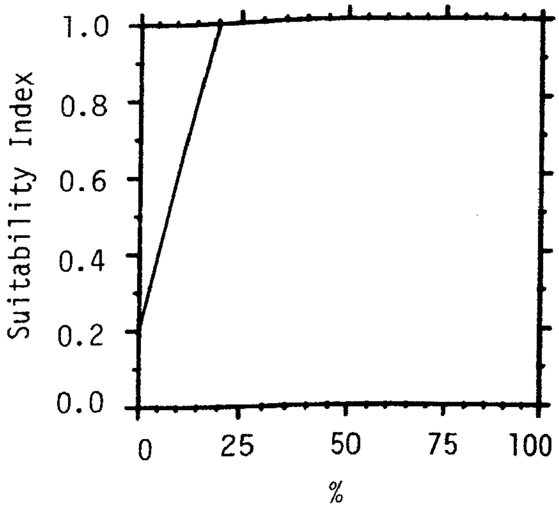
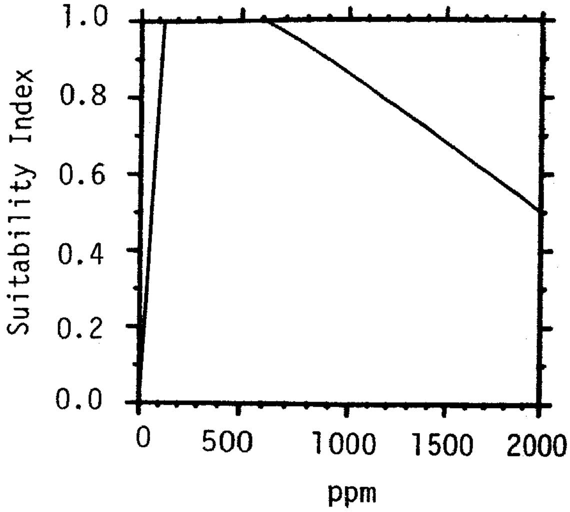
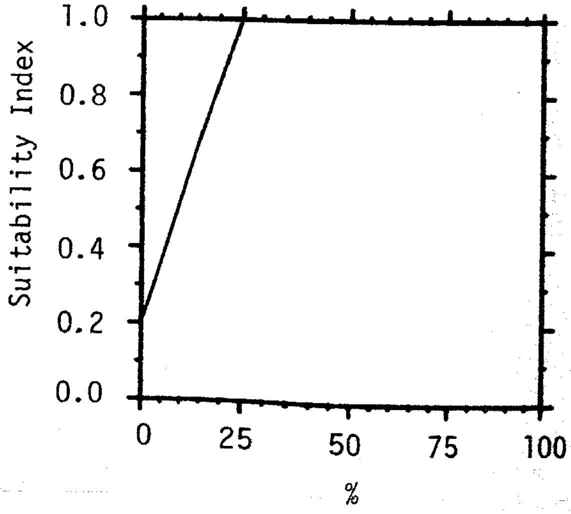


R,L V_{11}

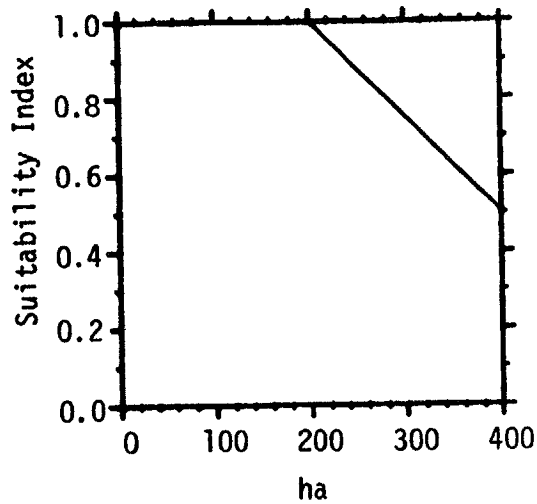
Dominant substrate type within pools, backwaters, or littoral areas for spawning (embryo).

A) Fines (< 2 mm diameter) and gravel insignificant (≤ 10%)
B) Fines noticeable (> 10 - ≤ 25%)
C) Fines and gravel present in equal amounts, combined (> 25 - ≤ 50%)
D) Fines dominant (> 50%)

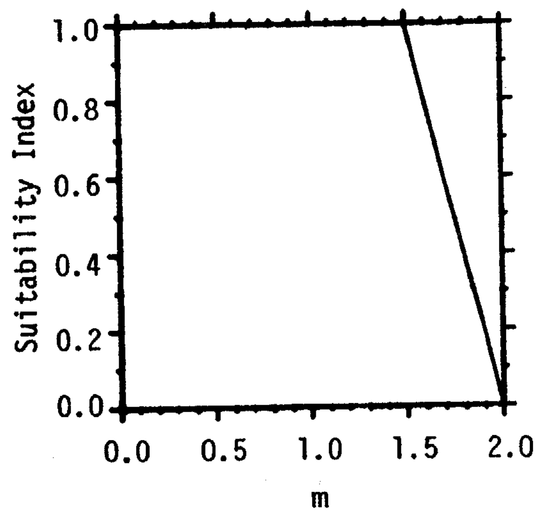


R,L	V_{12}	Percent cover objects (e.g., vegetation, brush, and debris) within pools, backwaters, or littoral areas during spawning (embryo).	
L	V_{13}	Average total dissolved solids (TDS) during summer. If the sulfide-chloride > carbonate-bicarbonate ion concentration, the SI rating should be reduced by 0.2.	
L	V_{14}	Percent littoral area during summer.	

L V_{15} Lake or reservoir size.



L V_{16} Reservoir drawdown during spawning and embryonic development (embryo).



Sources of data and assumptions made in constructing the suitability index graphs for the habitat variables are presented in Table 1.

Riverine Model

This model utilizes the life requisite approach and consist of four components: Food; Cover; Water Quality; and Reproduction.

Food (C_F)

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

Table 1. Data sources and assumptions for black bullhead suitability indices.

Variable and source		Assumption
V_1	Minckley 1963 Taylor 1969	The preference of black bullheads for a diversity of velocities and structural features indicates that some pool/backwater areas must be present for optimal conditions to occur.
V_2	Minckley 1963 Taylor 1969 Lohmeyer 1972 Pflieger 1975	The preference of the species for cover indicates that moderate to extensive cover must be present for optimal conditions to occur.
V_3	Minckley 1963 Taylor 1969 Lohmeyer 1972 Pflieger 1975	Current velocities where the species is most abundant are optimal; higher velocities are less suitable.
V_4	Black 1953 Miller 1966 Hill 1972-73 Cvancara et al. 1977 Campbell and Branson 1978	Optimal temperatures are those where the growth rate is highest. Temperatures at which the growth rates are lower are suboptimal, and those at which no growth or death occurs are unsuitable.
V_5	Moore 1942 Carlson et al. 1974 (CC) Campbell and Branson 1978	Dissolved oxygen levels where growth and survival of channel catfish are highest are optimal. Levels that reduce growth and survival are suboptimal. Levels which may be lethal to black bullheads are unsuitable.
V_6	Stroud 1967 (FW) Applegate et al. 1973 Klarberg and Benson 1975 (BB)	Optimal pH levels for freshwater fish are those which allow for successful growth and reproduction. Levels which impair growth and reproduction are suboptimal, and those which result in death are unsuitable.
V_7	Mansueti and Hardy 1967 (BB) Allen and Avault 1970 Perry 1973 (CC)	Salinity levels where adult and juvenile catfishes are most abundant are optimal; those which impair growth or result in death are suboptimal to unsuitable.
V_8	Allen and Avault 1970 (CC)	Same as V_7, except that it applies to the embryo and fry life stages.

Table 1. (concluded).

Variable and source		Assumption
V_9	Buck 1956 (CC) Cross 1967 Pflieger 1975 Campbell and Branson 1978	Turbidity levels where growth and survival of catfishes are greatest are optimal; those which may reduce growth or survival are suboptimal.
V_{10}	Miller 1966 Olson and Koopman 1976 Brungs and Jones 1977 (BB)	Temperatures which result in successful spawning and subsequent embryonic development are optimal. Those which lead to little or no embryonic survival in brown bullheads are unsuitable.
V_{11}	Eddy and Underhill 1974	The substrate which is preferred for spawning is optimal for embryonic development. Other substrate types are suboptimal.
V_{12}	Forney 1955 Harlan and Speaker 1956 Pflieger 1975	The preference of the species for cover during spawning indicates that some cover must be present for optimal spawning and subsequent embryonic development.
V_{13}	Jenkins 1976 Finnell 1979	Total dissolved solids (TDS) levels correlated with high standing crops and species abundance are optimal; those correlated with lower standing crops or species abundance are suboptimal. The data used to develop this curve are primarily from southeastern and Great Plains reservoirs.
V_{14}	Welker 1962 Seaburg and Moyle 1964 Repsys et al. 1976	The preference of the species for shallow areas indicates that extensive littoral areas provide optimal conditions.
V_{15}	Houser and Collins 1962 Turner 1971	Smaller impoundments have a greater proportion of cover areas and are optimal because the species has a definite preference for cover.
V_{16}	Forney 1955 Harlan and Speaker 1956	Reservoir drawdowns which exceed average depth of nests are suboptimal to unsuitable.

BB = brown bullhead, CC = channel catfish, FW - freshwater fish; all other citations refer to black bullhead data.

Cover (C_C)

$$C_C = (V_1 \times V_2 \times V_3)^{1/3}$$

Water Quality (C_{WQ})

If V_7 and V_8 both have 1.0 ratings,

$$C_{WQ} = \frac{2V_4 + 2V_5 + V_6 + V_9}{6} \text{, or}$$

If V_4 or V_5 is ≤ 0.4, C_{WQ} equals the lowest of the following: V_4; V_5; or the above equation.

If V_7 or $V_8 < 1.0$,

$$C_{WQ} = \frac{2V_4 + 2V_5 + V_6 + \frac{V_7 + V_8}{2} + V_9}{7} \text{, or}$$

If V_4 or V_5 is ≤ 0.4, C_{WQ} equals the lowest of the following: V_4; V_5; or the above equation.

Reproduction (C_R)

If $V_8 = 1.0$,

$$C_R = (V_1 \times V_{10} \times V_{11} \times V_{12})^{1/4}$$

If $V_8 < 1.0$,

$$C_R \quad (V_1 \times V_8 \times V_{10} \times V_{11} \times V_{12})^{1/5}$$

HSI determination

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

If C_{WQ} or $C_R \leq 0.4$, 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 consists of four components: Food; Cover; Water Quality; and Reproduction.

Food (C_F)

$$C_F = V_{13}$$

Cover (C_C)

$$C_C = (V_2 \times V_{14} \times V_{15})^{1/3}$$

Water Quality (C_{WQ})

Use riverine habitat suitability index equations for water quality.

Reproduction (C_R)

If $V_8 = 1.0$,

$$C_R = (V_{10} \times V_{11} \times V_{12} \times V_{14} \times V_{16})^{1/5}$$

If $V_8 < 1.0$, then

$$C_R = (V_8 \times V_{10} \times V_{11} \times V_{12} \times V_{14} \times V_{16})^{1/6}$$

HSI determination

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

If C_{WQ} or $C_R \leq 0.4$, HSI equals the lowest of the following: C_{WQ}; C_R; or the above equation.

Sample data sets from which HSI's have been generated using the riverine HSI equations are given in Table 2. Similar data sets using the lacustrine HSI equations are given in Table 3. The data sets are not actual field measurements, but represent combinations of habitat variable values that could realistically occur. The HSI's calculated from the data reflect what carrying capacity trends would be in riverine and lacustrine habitats with the listed characteristics. Thus, the models meet the acceptance goal of producing an index between 0 and 1 which is believed to have a positive relationship to the carrying capacity of black bullheads.

Interpreting Model Outputs

The black bullhead HSI determined by use of these models will not necessarily represent the population of black bullheads in the study area. Habitats with an HSI of 0 may contain some black bullheads; habitats with a high HSI may contain few. This is because the population of a study area of a stream does not totally depend on the ability of that area to meet all life requisite requirements of the species, as is assumed by the model. If the models are a good representation of black bullhead habitat, then in riverine and lacustrine environments where black bullhead population levels are determined primarily by 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 black bullheads than the one with the lower HSI, given the model assumptions have not been violated.

ADDITIONAL HABITAT SUITABILITY INDEX MODELS

Model 1

Optimal riverine habitat for black bullheads is characterized by the following conditions, assuming that water quality is adequate: warm (greater than 20° C), stable, summer water temperatures; soft bottoms in more than 40% of the stream; at least 50% of surface area in pools at average summer flow; at least 15% of the stream area with dense aquatic vegetation in the summer; and maximum surface velocities less than 15 cm/sec at average summer flow.

Table 2. Sample data sets using riverine HSI model.

Variable		Data set 1 Data	SI	Data set 2 Data	SI	Data set 3 Data	SI
% pools/backwaters	V_1	25	0.5	20	0.4	50	1.0
% cover	V_2	5	0.2	10	0.4	40	1.0
Average current velocity (cm/sec)	V_3	22	0.5	12	0.8	6	0.9
Maximum temperature (° C)	V_4	19	1.0	24	1.0	25	1.0
Dissolved O_2 (mg/l)	V_5	7.0	1.0	5.5	0.7	6.5	1.0
pH	V_6	8.7	0.6	7.2	1.0	8.2	1.0
Maximum salinity (ppt) (adult and juvenile)	V_7	8.0	0.5	1.5	1.0	1.0	1.0
Maximum salinity (ppt) (embryo and fry)	V_8	6.0	0.3	1.0	1.0	0.5	1.0
Maximum turbidity (ppm)	V_9	20	0.7	45	1.0	15	0.7
Average temperature (embryo) (° C)	V_{10}	15	0.6	20	0.7	22	1.0
Dominant substrate type (embryo)	V_{11}	Fines noticeable (≤ 25%)	0.5	Fines dominant (> 50%)	1.0	Fines dominant (> 50%)	1.0
% cover (embryo)	V_{12}	5	0.4	10	0.6	35	1.0
<u>Component SI</u>							
C_F =			0.3		0.4		1.0
C_C =			0.4		0.5		1.0
C_{WQ} =			0.8		0.9		0.9
C_R =			0.4		0.6		1.0
HSI =			0.4[a]		0.6		1.0

[a]HSI = 0.4 due to C_R = 0.4

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
% cover	V_2	5	0.2	10	0.4	75	1.0
Maximum temperature (° C)	V_4	32	0.7	23	1.0	26	1.0
Dissolved oxygen (mg/l)	V_5	4.5	0.7	5.6	0.7	7.5	1.0
pH	V_6	9.5	0.6	7.8	1.0	8.2	1.0
Maximum salinity (ppt) (adult and juvenile)	V_7	10	0.3	2	1.0	0.5	1.0
Maximum salinity (ppt) (embryo and fry)	V_8	6	0.3	2	1.0	0.5	1.0
Maximum turbidity (ppm)	V_9	120	0.4	45	1.0	20	0.7
Average temperature (embryo) (° C)	V_{10}	26	0.3	20	1.0	22	1.0
Dominant substrate type (embryo)	V_{11}	Fines, gravel	0.8	Fines	1.0	Fines, gravel	0.8
% cover (embryo)	V_{12}	5	0.4	10	0.6	75	1.0
Average TDS (ppm)	V_{13}	2400	0.3[a]	220	1.0	175	1.0
% littoral area	V_{14}	10	0.5	10	0.5	25	1.0
Reservoir size (ha)	V_{15}	350	0.6	5	1.0	400	0.5
Reservoir drawdown (m) (embryo)	V_{16}	1.8	0.4	1.0	1.0	0.2	1.0

Table 3. (concluded).

Variable	Data set 1		Data set 2		Data set 3	
	Data	SI	Data	SI	Data	SI
Component SI						
C_F =		0.3		1.0		1.0
C_C =		0.6		0.6		0.8
C_{WQ} =		0.6		0.9		1.0
C_R =		0.4		0.8		0.9
HSI =		0.5		0.8		0.9

[a] SI value lowered 0.2 because sulfate-chloride > carbonate-bicarbonate ionic concentration.

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

Model 2

Optimal lacustrine habitat is characterized by the following conditions, assuming water quality is adequate: warm (greater than 20° C) summer water temperature; high fertility (TDS greater than 100 ppm); surface area of ≤ 200 ha; extensive shallow areas; and dense aquatic vegetation in at least 15% of lake area.

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

Model 3

Use one of the standing crop models for catfishes developed by Aggus and Morais (1979) to calculate an HSI.

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This is one of a series of publications that provide information on the habitat requirements of selected fish and wildlife species. Literature describing the relationship between habitat variables related to life requisites and habitat suitability for the Black bullhead (Ictalurus melas) 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.

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