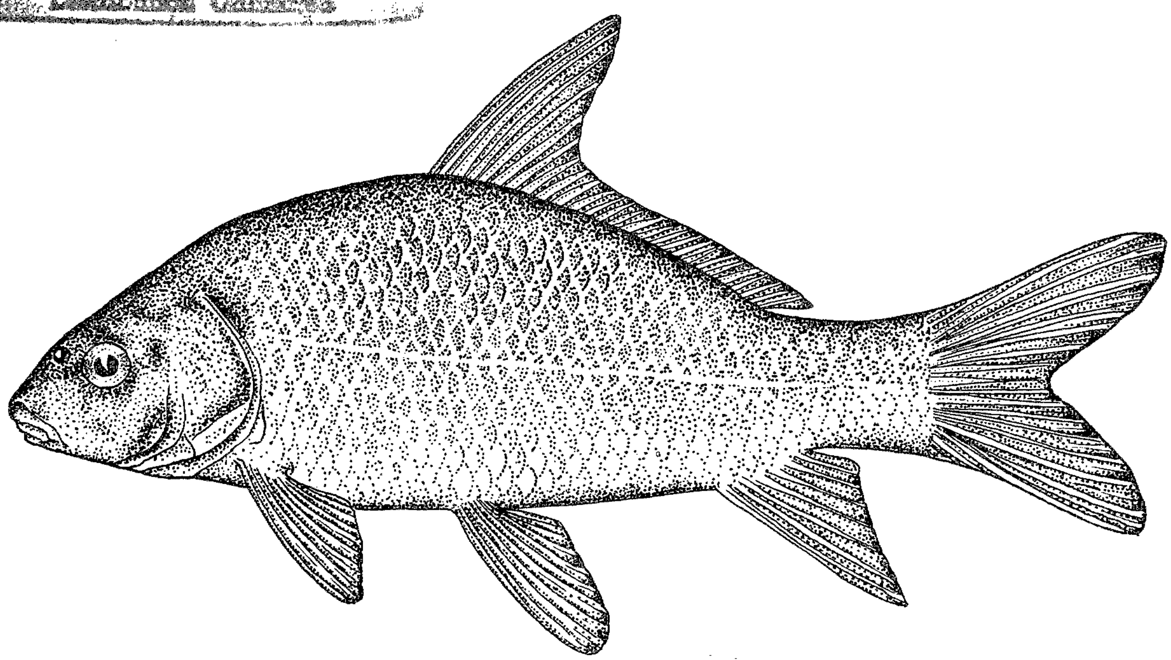
Biological Services Program
and
Division of Ecological Services

FWS/OBS-82/10.13
JULY 1982

HABITAT SUITABILITY INDEX MODELS: SMALLMOUTH BUFFALO



Fish and Wildlife Service

U.S. Department of the Interior

The Biological Services Program was established within the U.S. Fish and Wildlife Service to supply scientific information and methodologies on key environmental issues that impact fish and wildlife resources and their supporting ecosystems. The mission of the program is as follows:

- To strengthen the Fish and Wildlife Service in its role as a primary source of information on national fish and wildlife resources, particularly in respect to environmental impact assessment.

- To gather, analyze, and present information that will aid decisionmakers in the identification and resolution of problems associated with major changes in land and water use.

- To provide better ecological information and evaluation for Department of the Interior development programs, such as those relating to energy development.

Information developed by the Biological Services Program is intended for use in the planning and decisionmaking process to prevent or minimize the impact of development on fish and wildlife. Research activities and technical assistance services are based on an analysis of the issues, a determination of the decisionmakers involved and their information needs, and an evaluation of the state of the art to identify information gaps and to determine priorities. This is a strategy that will ensure that the products produced and disseminated are timely and useful.

Projects have been initiated in the following areas: coal extraction and conversion; power plants; geothermal, mineral and oil shale development; water resource analysis, including stream alterations and western water allocation; coastal ecosystems and Outer Continental Shelf development; and systems inventory, including National Wetland Inventory, habitat classification and analysis, and information transfer.

The Biological Services Program consists of the Office of Biological Services in Washington, D.C., which is responsible for overall planning and management; National Teams, which provide the Program's central scientific and technical expertise and arrange for contracting biological services studies with states, universities, consulting firms, and others; Regional Staffs, who provide a link to problems at the operating level; and staffs at certain Fish and Wildlife Service research facilities, who conduct in-house research studies.

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

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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 subjective 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 may 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 Appendix A. A description of various methods used to develop an HSI model is provided in U.S. Fish and Wildlife Service (1981)[1].

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 convey comments and suggestions that may 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]U.S. Fish and Wildlife Service. 1981. Standards for the development of habitat suitability index models. U.S. Dept. Int. Fish Wildl. Serv. Washington, DC. 103 ESM n.p.

CONTENTS

ACKNOWLEDGMENTS

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SMALLMOUTH BUFFALO (Ictiobus bubalus)

HABITAT USE INFORMATION

General

The smallmouth buffalo (Ictiobus bubalus) ranges from the western portion of the Hudson Bay drainage in Canada to the Ohio River and southward in the Mississippi Valley to the Gulf States and northeastern Mexico (Hubbs and Lagler 1947; Eddy 1957; Jester 1973). The species also has been reported in the Missouri River drainage in Montana (Brown 1971) and South Dakota (Bailey and Allum 1962) and has been introduced west of the Continental Divide in Arizona (Johnson and Minckley 1972). Hybridization of the smallmouth buffalo with the black buffalo (I. niger) (Giudice 1964) and possible hybridization with the bigmouth buffalo (I. cyprinellus) (Giudice 1964; Johnson and Minckley 1969, 1972) has been reported.

Age, Growth, and Food

Size, rather than age, determines maturity in the smallmouth buffalo. Maturity is attained at approximately 450 g, which corresponds to ages of II in Arkansas ponds and VII-X in Lewis and Clark Reservoir, South Dakota (Walburg and Nelson 1966). Smallmouth buffalo may reach a weight of about 18 kg, but adults are usually 1-8 kg in weight and 38-78 cm in length (Pflieger 1975).

Cladocerans and copepods are the major food items of young smallmouth buffalo (McComish 1964). Adults are opportunistic bottom feeders, and their diet includes organisms that are abundant, such as zooplankton, algae, or insect larvae. The occurrence of certain items in the digestive tract is probably governed by the availability of those organisms (McComish 1967; Jester et al. 1969; Minckley et al. 1970; Perry 1970; Tafanelli et al. 1970). In reservoirs, the species feeds primarily in shallow shoreline areas (McComish 1967; Minckley et al. 1970). Buffalo growth is usually better over mud flats and in shallow water than in rocky, deep portions of reservoirs (Jenkins 1953). This is probably due to the increased abundance of benthic organisms and attached algae in these areas.

Reproduction

Spawning is initiated by rising water levels and increasing temperatures (Canfield 1922; Walker and Frank 1952; Jester 1973). Spawning has been reported during spring and summer (March-September) when temperatures range from 13-28° C (Wrenn 1968, 1969; Moody 1970; Padilla 1972; Jester 1973). The adhesive eggs are scattered over the bottom and left unattended by the adults (Harlan and Speaker 1956; Jester 1973). Spawning will occur over virtually any type of bottom (Jester 1971).

Specific Habitat Requirements

Smallmouth buffalo typically inhabit large rivers (Johnson 1963), preferring deep, clear, warm waters with a current (Trautman 1957; Martin 1963). They are characteristically found in firm-bottomed channels, chutes, and cut-off areas (Trautman 1957; Minckley 1959; Brown 1971; Kozel 1974) of medium to large-sized rivers (Finnell et al. 1956; Pflieger 1975; Smith 1979). Smallmouth buffalo frequent low velocity areas, such as pools, creekmouths, and backwaters of large rivers (Kallemeyn and Novotny 1977). The species is found less frequently in small streams (Deacon 1961; Brown 1971).

Smallmouth buffalo can do well in large reservoirs or lakes and their standing crop increases as the storage ratio (SR) (ratio of mean reservoir water volume to annual discharge volume) decreases (Jenkins 1976). Fairly shallow water (1.2-1.4 m) with abundant aquatic or inundated terrestrial vegetation and a silt bottom is the most productive habitat for smallmouth buffalo (Dalquest and Peters 1966). Cover may not be a critical requirement in lakes and reservoirs. The species may also be found in upstream headwaters of reservoirs, adjoining inflowing streams, or areas with moderate current (Jenkins 1953; Dalquest and Peters 1966; Beckman and Elrod 1971). Smallmouth buffalo lacustrine distributions are strongly associated with the bottom, and the species is found in relatively uniform densities at all depths along the bottom (Jester 1971). There is no heavy seasonal concentration or movement, except to spawning areas in the spring. However, there is a tendency for smallmouth buffalo to move to shallower water in spring and summer and deeper water in fall and winter (Huntington and Hill 1956; Jester 1973).

Smallmouth buffalo can tolerate turbid waters (> 100 JTU), but growth is better in moderately turbid to clear waters (25-100 JTU) (Trautman 1957; Pflieger 1975; Willis 1978)

A pH range of 6.5-8.5 is considered to be essential for good production of freshwater fish (Stroud 1967), and a pH range of 5.0-6.5 or 8.5-9.0 can be detrimental to fish populations (Doudoroff and Katz 1950; European Inland Fisheries Advisory Commission 1969). Smallmouth buffalo populations are apparently unaffected in waters up to a pH of 8.5 in Southwest reservoirs and rivers (Jester, personal communication). Thus, a range of 6.5-8.5 is assumed to be optimum for smallmouth buffalo.

Adult. Moderately warm temperatures are necessary for growth and reproduction in the smallmouth buffalo. In 90% of the streams sampled along the Texas coast and in the Mississippi Valley which contained smallmouth buffalo, weekly mean summer (July-August) temperatures ranged from 17-32° C, with an overall mean of 24° C (Biesinger, personal communication). It is assumed that these temperatures are adequate for growth of smallmouth buffalo. In South Dakota, seasonal growth begins when water temperatures reach 18° C (Shields 1957). Gammon (1973) reported that smallmouth buffalo were collected in water near a thermal effluent with a temperature of 31-34° C.

The specific dissolved oxygen (DO) requirements of smallmouth buffalo are not known, but 5.0 mg/l is considered the minimum level for maintaining good freshwater fish populations (Environmental Protection Agency 1976). Carp are able to live for short periods at a DO level as low as 3 mg/l, but optimum DO levels are > 6 mg/l (Huet 1970). It is assumed that smallmouth buffalo are somewhat less tolerant of low DO levels than carp (Jester, personal communication).

Smallmouth buffalo adults are commonly found in rivers with currents up to 100 cm/sec (Trautman 1957; Kallemeyn and Novotny 1977). There is some evidence that elimination of currents and chutes by dams may decrease smallmouth buffalo populations (Trautman 1957). In New Mexico, there are almost no buffalo in the Rio Grande below Elephant Butte Dam down to Caballo Lake, yet they are abundant in both lakes (Jester, personal communication). The species can inhabit high velocity areas (up to 160 cm/sec) of main channels for short periods (Kallemeyn and Novotny 1977). Pools and backwaters of rivers (with velocities of < 20 cm/sec) are generally utilized for resting and nursery areas (Kallemeyn and Novotny 1977).

Smallmouth buffalo salinity tolerances are not known, but bigmouth buffalo are tolerant of relatively saline conditions. Bigmouth buffalo juveniles can tolerate salinities up to 12 ppt in the laboratory for short periods (Hollander 1974). It is assumed that smallmouth buffalo also can tolerate salinities at this level. However, normal salinity levels for reservoirs range from about 2,200 ppm to 20 ppm (2.2 to 0.02 ppt) TDS (Jenkins 1967). Jenkins (1967, 1976) correlated an increase in TDS levels with an increase in standing crops of all reservoir fish, including buffalo.

Embryo. In rivers, spawning usually occurs in areas with very little current (≤ 20 cm/sec), such as backwaters, marshes, and pools (Wrenn 1968; Kallemeyn and Novotny 1977). In reservoirs, spawning occurs in embayments and along recently flooded shorelines (Wrenn 1968; Walburg 1976; Moody 1970) at depths of approximately 1.2-6.1 m (Moody 1970; Padilla 1972). Smallmouth buffalo will scatter their eggs over all bottom types but show a preference for spawning over vegetation and submerged objects when available (Moody 1970; Benson 1973; Jester 1973; Willis and Owen 1978). In a reservoir with fluctuating water levels, reproduction may still be successful even though the extent of optimum spawning habitat is reduced (Jester 1971).

Optimum spawning temperatures are 17-24° C, within a range of 13-28° C (Wrenn 1969; Padilla 1972; Jester 1973). The maximum weekly average temperature for spawning is 21° C (Heard 1958; Giudice 1964; Brungs and Jones 1977). Incubation takes 4-12 days at 14-21° C (Walburg and Nelson 1966; Wrenn 1969).

The dissolved oxygen requirements of smallmouth buffalo embryos have not been reported, but it is assumed that they are slightly less tolerant than carp embryos (Jester, personal communication; Willis, personal communication). Survival of carp embryos can occur at DO levels as low as 1.2 mg/l, but development is slowed and only 4% survive (Kaur and Toor 1978). Percent hatching of carp embryos increased as DO levels increased; 65% hatched at 6 mg/l and 92% hatched at 9 mg/l (Kaur and Toor 1978).

Bigmouth buffalo eggs do well at salinities as high as 9 ppt in the laboratory (Hollander 1974). Smallmouth buffalo are assumed to tolerate similar salinity levels.

Fry. Warm, shallow, vegetated tributary embayments of reservoirs (Jester 1973) and quiet pools, marshes, and backwaters (< 20 cm/sec velocity) of rivers (Kallemeyn and Novotny 1977) provide optimum conditions for survival and growth of smallmouth buffalo fry. Temperature requirements for smallmouth buffalo fry have not been reported and are assumed to be slightly more restricted than those for carp fry. Under laboratory conditions, carp fry will tolerate temperatures as high as 36° C and die at 38° C (Tatarko 1970). In 90% of the streams sampled along the Texas coast and in the Mississippi Valley where smallmouth buffalo were found, weekly mean temperatures for June and July ranged from 16-32° C (Biesinger, personal communication). It is assumed that backwaters and marshes would be slightly warmer for fry; maximum growth of fry would occur at the warmer end of the range.

Bigmouth buffalo fry can tolerate salinities up to 9 ppt in the laboratory (Hollander 1974), and smallmouth buffalo fry are assumed to tolerate similar levels.

Juvenile. The specific habitat requirements of juvenile smallmouth buffalo are not known. Their requirements may be similar to those of adults, except that juveniles probably prefer only warm, shallow, vegetated areas not in the main current. They were collected almost exclusively at velocities of < 20 cm/sec in pools or marsh and backwater areas of the Missouri River (Kallemeyn and Novotny 1977).

It is assumed that juvenile smallmouth buffalo temperature requirements are similar to those of fry since they primarily utilize the same habitat.

Salinity tolerance levels for smallmouth buffalo juveniles are unknown, but since juvenile bigmouth buffalo are able to tolerate salinities up to 12 ppt in the laboratory for short periods (Hollander 1974), it is assumed that levels for juvenile smallmouth buffalo are similar.

HABITAT SUITABILITY INDEX (HSI) MODELS

Model Applicability

Geographic area. The model is applicable throughout the native and introduced range of the smallmouth buffalo in North America. The standard of comparison for each individual variable suitability index is the optimum value of the variable that occurs anywhere within this region. Therefore, the model may never provide an HSI of 1.0 when applied to waters in the North where temperature-related variables may not reach the optimum values found in the South.

Season. The model provides a rating for waters based on their ability to support a reproducing population of smallmouth buffalo through all seasons of the year. The model will provide an HSI of 0.0 if any reproduction-related variable indicates that the species is not able to reproduce.

Cover types. The model is applicable in riverine and lacustrine 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 smallmouth buffalo, although this species prefers larger rivers and reservoirs.

Verification level. The acceptance goal of the model is to produce an index between 0 and 1 which has a positive relationship to spawning success of adults and carrying capacity for fry, juveniles, and adults. In order to verify that the model ouput was acceptable, HSI's were calculated from sample data sets. These sample data sets and their relationship to model verification are discussed in greater detail later.

Model Description - Riverine

Analysis of smallmouth buffalo habitat quality is based on basic habitat components consisting of food, cover, water quality, and reproduction requirements. Variables that have been shown to affect growth, survival, abundance, or other measures of well-being of smallmouth buffalo are placed in the appropriate component (Figures 1 and 2).

Food-cover component. Food and cover have been aggregated into one component because the variables within this component describe both food and cover suitability. In pools and off-channel areas of rivers, cover (V_{15}) provides resting areas for adults and feeding areas and protection from predation for fry and juveniles. Vegetative cover also may be an indication of the productivity of an area. Smallmouth buffalo are opportunistic feeders and abundance of aquatic vegetation may be a measure of food availability for this species in backwaters and marshes since aquatic vegetation and algae may be injested. Percent pools and off-channel areas (V_2) are included to quantify the amount of food-cover habitat.

Water quality component. Temperature levels for adults, juveniles, and fry (V_5 and V_7), along with dissolved oxygen (V_8) and pH (V_4), are important since these parameters may affect growth, survival, and feeding in smallmouth buffalo. Turbidity (V_3) is included because high species abundance has been correlated with moderate to low turbidities. Salinity (V_{12}) is an optional variable since it is not considered to be a potential problem in most areas where smallmouth buffalo are found.

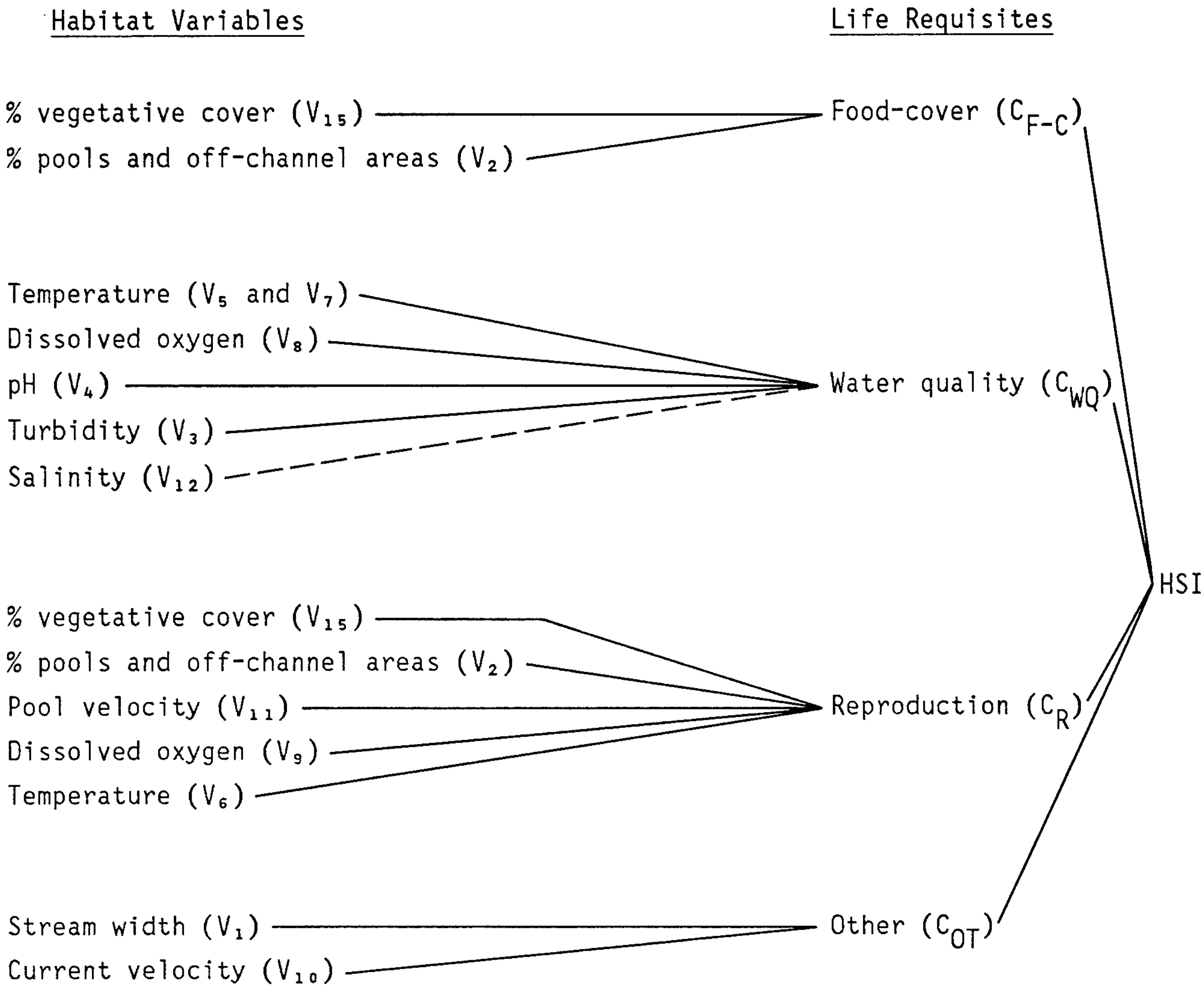


Figure 1. Tree diagram illustrating relationship of habitat variables and life requisites in the riverine model for the smallmouth buffalo. Dashed line indicates an optional variable in the model.

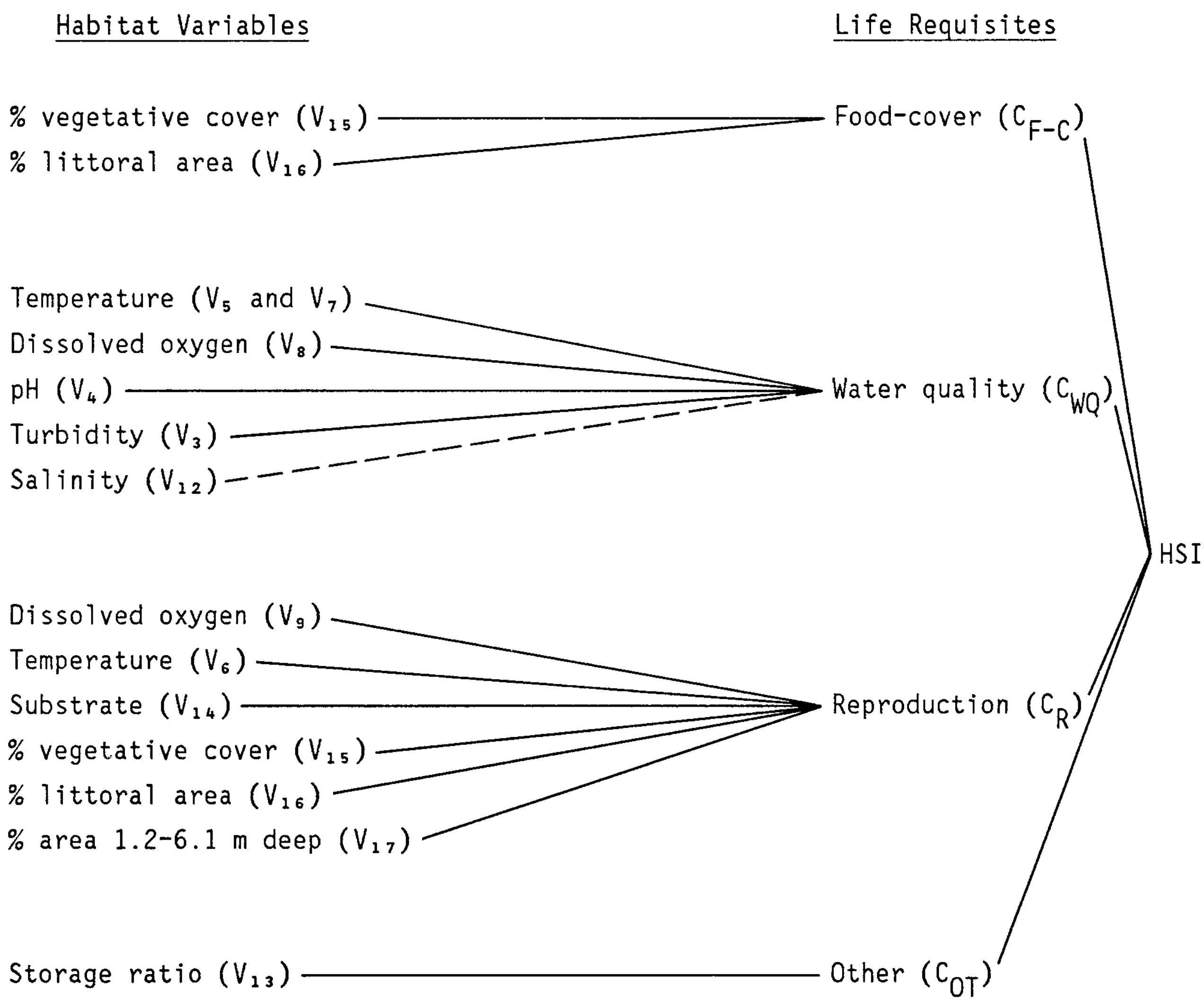


Figure 2. Tree diagram illustrating relationship of habitat variables and life requisites in the lacustrine model for the smallmouth buffalo. Dashed line indicates an optional variable in the model.

Reproduction component. Percent vegetative (aquatic and inundated terrestrial) cover (V_{15}) reflects the quality of the spawning habitat which can affect survival and production of the embryo. Percent pools and off-channel areas (V_2) quantify the amount of spawning habitat. Average pool velocity (V_{11}) is included since the development of quality nursery habitat depends on very low velocities. Dissolved oxygen (V_9) and average temperature (V_6) are parameters that can limit embryo survival and development.

"Other" component. The variables within the "other" component are those which aid in describing habitat suitability for smallmouth buffalo, yet are not specifically related to life requisite components already presented. Average stream width (V_1) is included since smallmouth buffalo are seldom found in smaller streams. Average current velocity (V_{10}) is included since adults frequent areas of the river with strong current velocities, as well as low velocity areas.

Model Description - Lacustrine

Food-cover component. Food and cover have been aggregated into one component since the variables within this component describe both food and cover suitability. In shallow shoreline areas, cover (V_{15}) provides resting and feeding areas for the species. Primary production (aquatic vegetation) also may be an indication of reservoir productivity. Smallmouth buffalo are opportunistic feeders and vegetation abundance would be a relative measure of food availability for the species. Percent littoral area (V_{16}) is included since this variable quantifies the amount of food-cover habitat.

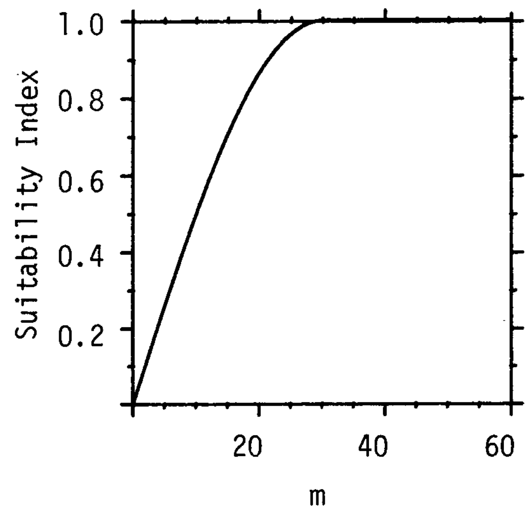
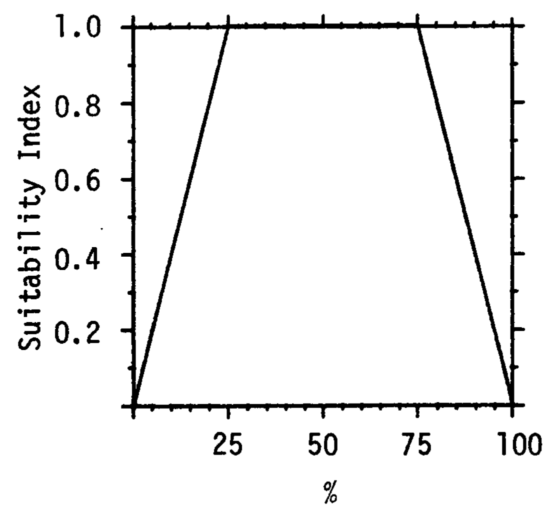
Water quality component. See riverine model description for the water quality component.

Reproduction component. Dissolved oxygen (V_9) and average temperatures during spawning (V_6) are parameters that can limit embryo survival and development. Substrate type (V_{14}) available for spawning is included since there is a preference by the species for vegetation (especially inundated vegetation) even though they will spawn over any substrate. Percent littoral area (V_{16}) quantifies the amount of spawning habitat that may have vegetation. Since the species spawns at a specific depth, percent area that is 1.2-6.1 m deep during spawning (V_{17}) is included to quantify the total area available for spawning.

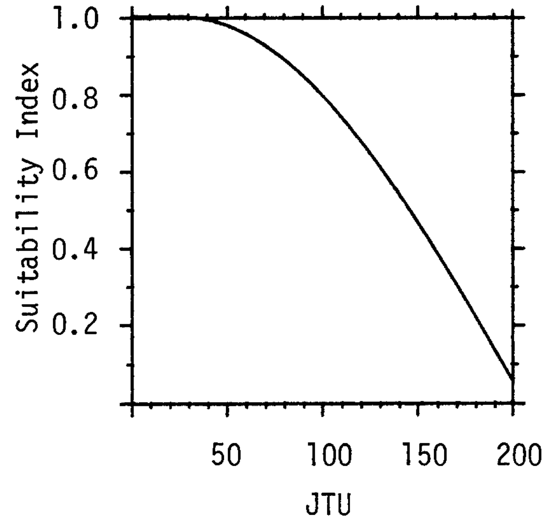
"Other" component. Storage ratio (SR) (V_{13}) is included since an increase in standing crop of large and smallmouth buffalo has been positively correlated with a decrease in SR.

Suitability Index (SI) Graphs for Model Variables

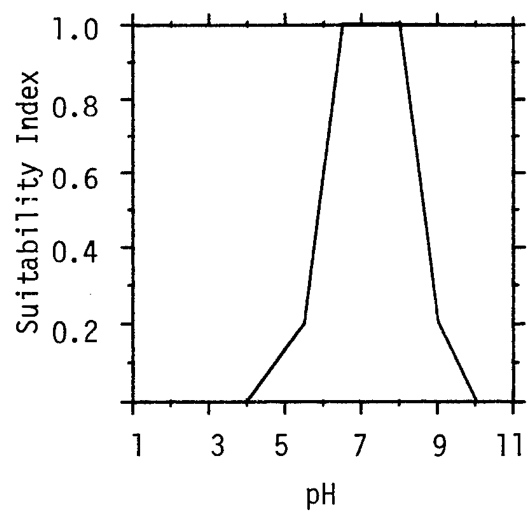
This section contains suitability index graphs for the 17 variables described above and equations for combining selected variable indices into a species HSI using the component approach. Variables may pertain to either a riverine (R) habitat, a lacustrine (L) habitat, or both.

Habitat	Variable		Suitability Graph
R	V_1	Average stream width during average summer flow.	
R,L	V_2	Percent pools and off-channel areas (e.g., ponds and marshes) during spring and summer (adult, embryo, juvenile, and fry).	

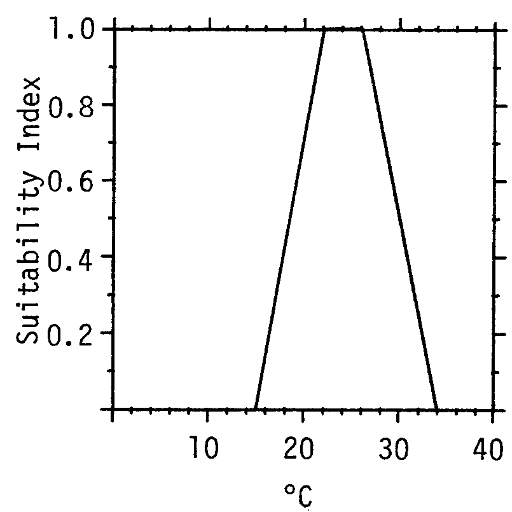
R,L V$_3$ Maximum monthly average turbidity during average summer flow or summer stratification.

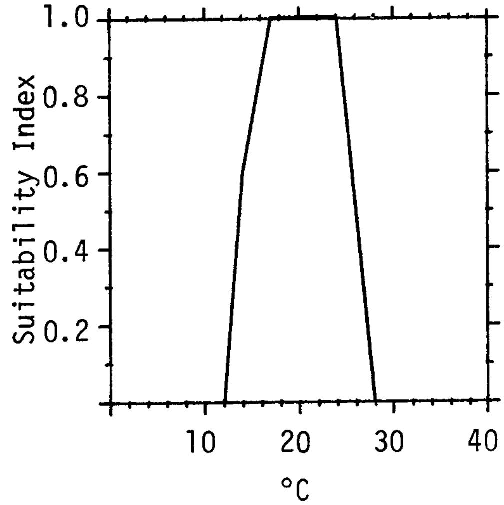
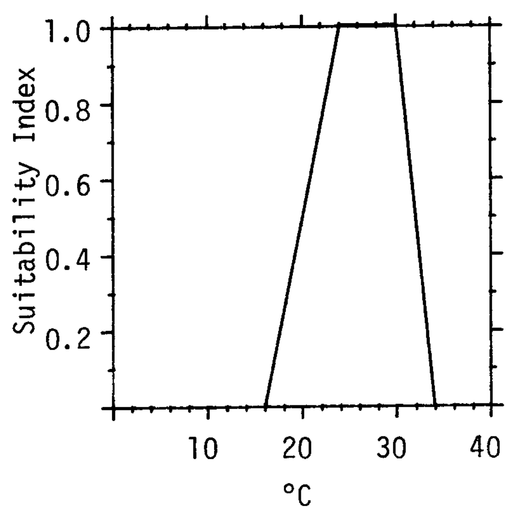
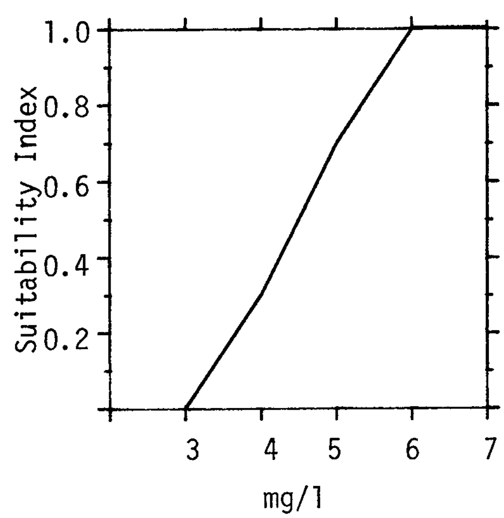


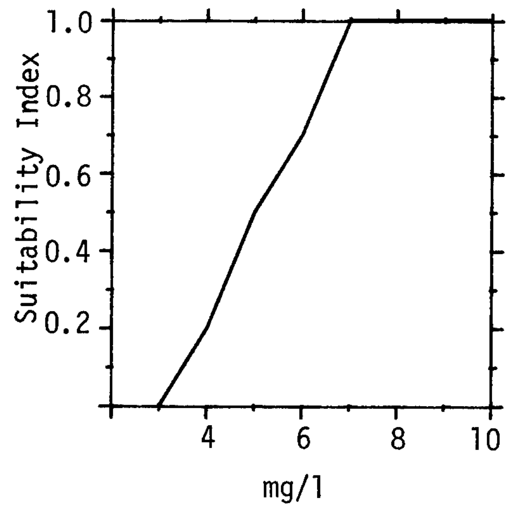
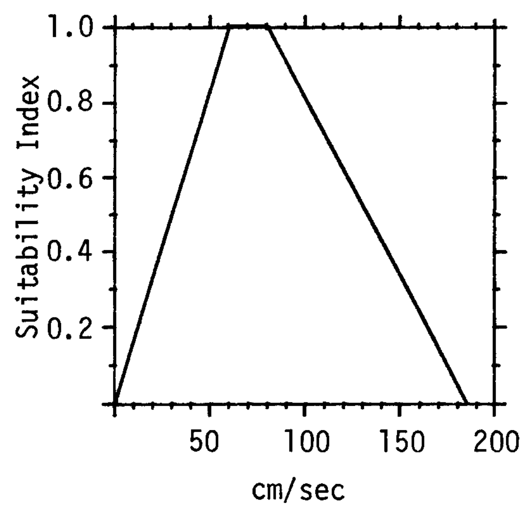
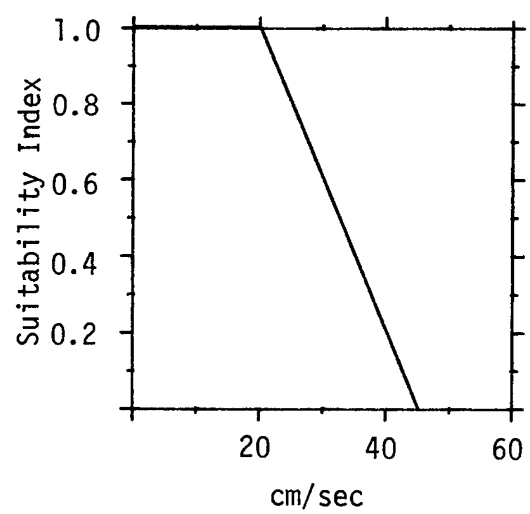
R,L V$_4$ pH levels during the year.



R,L V$_5$ Average water temperatures where the species occurs during July-August (adult).

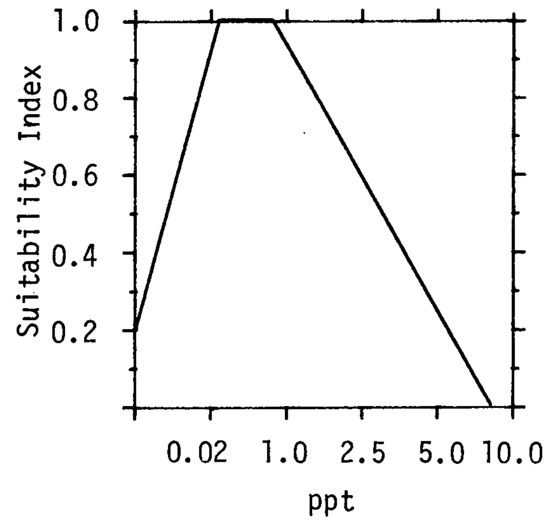


R,L	V_6	Average maximum water temperatures during spring and summer (embryo).	
R,L	V_7	Average water temperatures during June-July (fry and juvenile).	
R,L	V_8	Average minimum dissolved oxygen levels during the summer (adult, fry, and juvenile).	

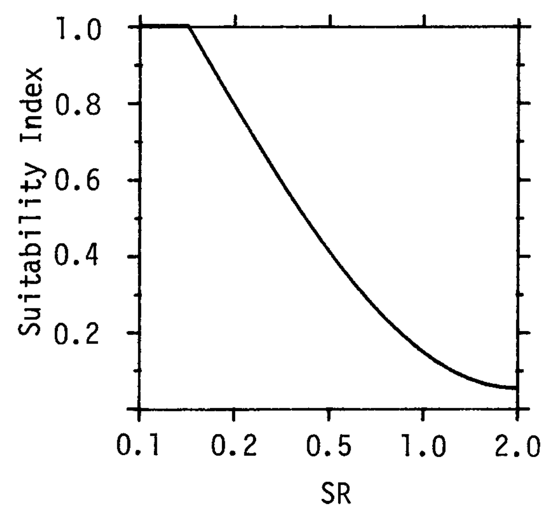
R,L	V_9	Minimum dissolved oxygen levels during spawning (embryo).	
R	V_{10}	Average current velocity of the river during average summer flow (adult).	
R	V_{11}	Average pool velocity (embryo, fry, and juvenile).	

R,L V_{12} Maximum salinity during spring and summer.

Note: V_{12} may be omitted if salinity is not considered to be a potential problem within the study area.

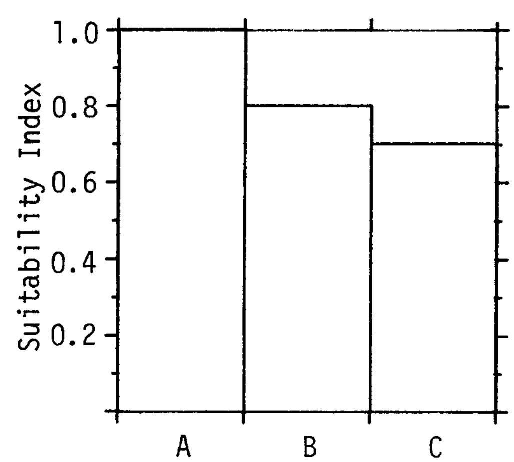


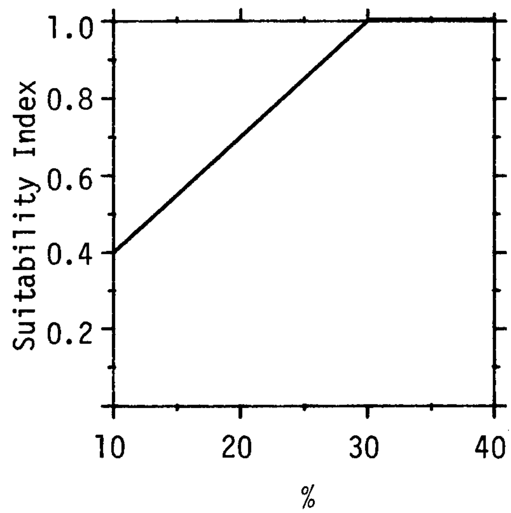
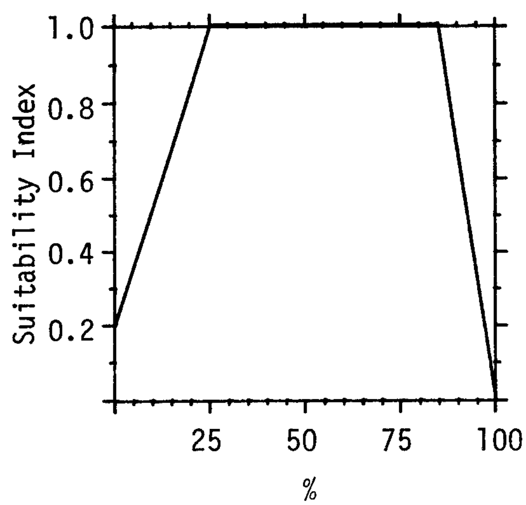
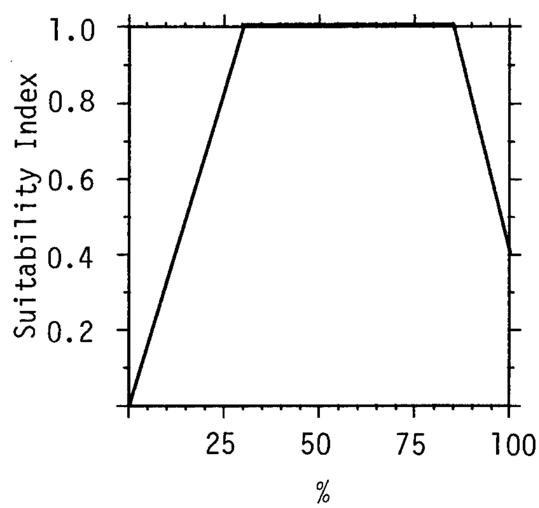
L V_{13} Storage ratio (SR).



L V_{14} Dominant substrate type for spawning (embryo)

A) Inundated terrestrial, submergent or emergent aquatic vegetation;
B) Logs, brush, detritus, and other objects;
C) Mud, gravel, and sand.



R,L	V_{15}	Percent vegetative cover (aquatic and inundated terrestrial) in pools and off-channel areas or along the shoreline during spring and summer (fry and juvenile).	
L	V_{16}	Percent littoral area during summer.	
L	V_{17}	Percent area of the lacustrine environment 1.2-6.1 m deep during spawning (spring and summer).	

Riverine Model

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

Food-Cover (C_{F-C})

$$C_{F-C} = (V_2 \times V_{15})^{1/2}$$

Water Quality (C_{WQ})

$$C_{WQ} = \frac{V_3 + V_4 + 2\,[(V_5 \times V_7)^{1/2}] + 2V_8}{6}\text{ , or}$$

If $(V_5 \times V_7)^{1/2}$ or V_8 is ≤ 0.4, then C_{WQ} equals the lowest of the following: $(V_5 \times V_7)^{1/2}$; V_8; or the above equation. If either V_5 or V_7 is ≤ 0.4, then the lowest rating should be substituted in the above equation for the expression $(V_5 \times V_7)^{1/2}$. Note: If V_{12} (optional salinity variable) is added,

$$C_{WQ} = \frac{V_3 + V_4 + 2\,[(V_5 \times V_7)^{1/2}] + 2V_8 + V_{12}}{7}$$

Reproduction (C_R)

$$C_R = (V_2 \times V_{11} \times V_{15} \times V_6{}^2 \times V_9{}^2)^{1/7}$$

Other (C_{OT})

$$C_{OT} = \frac{V_1 + V_{10}}{2}\text{ , or } V_1\text{, whichever is lower.}$$

HSI determination

$$HSI = (C_{F-C} \times C_{WQ} \times C_R^2 \times C_{OT})^{1/5}\text{, or}$$

If any component ≤ 0.4, then the HSI equals the lowest of the components or the above equation.

Lacustrine Model

This model utilizes the life requisite approach and consists of four components: food-cover; water quality; reproduction; and other.

Food-Cover (C_{F-C})

$$C_{F-C} = (V_{15} \times V_{16})^{1/2}$$

Water Quality (C_{WQ})

Same as riverine model for water quality.

Reproduction (C_R)

$$C_R = (V_6^2 \times V_9^2 \times V_{14} \times V_{15} \times V_{16} \times V_{17})^{1/8}$$

Other (C_{OT})

$$C_{OT} = V_{13}$$

HSI determination

$$HSI = (C_{F-C} \times C_{WQ}^2 \times C_R^2 \times C_{OT})^{1/6}$$

If C_{WQ} or C_R is ≤ 0.4, 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.

Sample data sets for the riverine and lacustrine HSI models are listed in Tables 2 and 3. The data sets are not actual field measurements, but represent combinations that could occur in a riverine or lacustrine habitat. The HSI's calculated from the data reflect what the carrying capacity trends would be in riverine and lacustrine habitats with the listed characteristics and, therefore, meet the acceptance goal.

Table 1. Data sources and assumptions for smallmouth buffalo suitability indices.

	Variable and source	Assumption
V_1	Finnell et al. 1956 Trautman 1957 Pflieger 1975 Smith 1979	The size of river associated with abundant numbers of fish has high suitability.
V_2	Kallemeyn and Novotny 1977	Since pools and off-channel areas of rivers are necessary for resting, spawning, and nurseries, it is assumed that the river habitat must contain a certain percentage of these areas for habitat to be suitable. Yet, too much pool area is suboptimum to unsuitable since adults also prefer main channel areas.
V_3	Trautman 1957 Pflieger 1975 Willis 1978	Turbidity levels associated with high numbers are optimum. Levels that are tolerated but which slow growth are suboptimum.
V_4	Doudoroff and Katz 1950 (FW) Stroud 1967 (FW) EIFAC 1969 (C)	The pH levels that promote good production of freshwater fish are assumed to be optimum for smallmouth buffalo.
V_5	Shields 1957 Gammon 1973 Biesinger 1980	Average midsummer temperatures where smallmouth buffalo are found are adequate for growth. Temperatures must reach levels that permit growth in order for habitat to be suitable. Preferred temperatures near a thermal effluent or under laboratory conditions are not necessarily optimum.
V_6	Heard 1958 Giudice 1964 Wrenn 1969 Padilla 1972 Jester 1973 Brungs and Jones 1977	Temperatures where normal development and maximum survival occur are optimum. Temperatures that result in little or no survival are unsuitable.

Table 1. (Continued).

	Variable and source	Assumption
V_7	Tatarko 1970 Biesinger 1980	Same assumption as V_5.
V_8	Doudoroff and Shumway 1970 (C) Huet 1970 (C) Environmental Protection Agency [1976 (FW)]	Dissolved oxygen levels that promote maximum growth and survival for freshwater fish are optimum. Levels that are adequate for carp but which reduce growth are suboptimum. Levels that can cause death of carp after prolonged exposure have very low suitability.
V_9	Kaur and Toor 1978	Percent hatching of carp embryos increases as dissolved oxygen levels increase. Levels where greater than 60% of the embryos survived have high suitability. Optimum levels do not necessarily mean maximum survival. Lack of survival is unsuitable.
V_{10}	Trautman 1957 Kallemeyn and Novotny 1977	Average current velocities where adults are predominantly found are optimum. Adults need areas of both strong and slow currents.
V_{11}	Kallemeyn and Novotny 1977	Current velocities that are associated with an abundance of fry and juvenile and maximum survival of embryo are optimum. Velocities that are associated with fair to poor nursery habitat are suboptimum to unsuitable.
V_{12}	Jenkins 1967 Hollander 1974 (BB) (Optional variable)	Salinities (TDS) that are associated with high standing crops are optimum. Normal salinity levels for reservoirs are optimum to suboptimum. Sea water salinity levels tolerated for short periods in laboratory conditions are unsuitable.
V_{13}	Jenkins 1976	Storage ratios associated with high standing crop are optimum.

Table 1. (Concluded).

	Variable and source	Assumption
V_{14}	Moody 1970 Jester 1971 Benson 1973 Jester 1973	The substrate type that is associated with maximum spawning success is optimum. Successful spawning will occur on other substrates that have high suitability.
V_{15}	Dalquest and Peters 1966 Jester 1973	The amount of vegetation associated with high numbers of juvenile and fry is optimum. However, abundant vegetation is not required for suitable habitat.
V_{16}	Jenkins 1953 Dalquest and Peters 1966 McComish 1967 Minckley et al. 1970	Since shallow water with vegetation is the most productive habitat for smallmouth buffalo, it is assumed that the percentage of littoral area with the highest species abundance is optimum. Since smallmouth buffalo need deeper water in winter, too much littoral area is assumed to be suboptimum to unsuitable.
V_{17}	Moody 1970 Padilla 1972	Successful spawning depends on the amount of area 1.2-6.1 m deep. The percent area associated with high standing crop is optimum.

Note: C = carp data
FW = data for freshwater fish in general
BB = bigmouth buffalo data

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
River width (m)	V_1	32	1.0	17	0.8	7	0.5
% pools, creekmouths, and backwater areas	V_2	15	0.6	17	0.7	10	0.4
Turbidity (JTU)	V_3	50	0.9	120	0.4	110	0.6
pH	V_4	6.2	0.7	8.2	0.9	5.6	0.3
Temperature (adult) (° C)	V_5	26	1.0	21	0.8	29	0.6
Temperature (embryo) (° C)	V_6	22	1.0	14	0.6	27	0.2
Temperature (fry and juvenile) (° C)	V_7	32	0.8	23	0.9	33	0.3
Dissolved oxygen (adult, fry, and juvenile) (mg/l)	V_8	7.0	1.0	5.5	0.8	4.0	0.3
Dissolved oxygen (embryo) (mg/l)	V_9	7.0	1.0	4.8	0.4	4.0	0.2
Average velocity (adult) cm/sec	V_{10}	55	0.9	100	0.8	120	0.6
Pool velocity (embryo, fry, and juvenile) (cm/sec)	V_{11}	20	1.0	5	1.0	35	0.4
Salinity (ppt)	V_{12}	2	0.7	2.5	0.6	3	0.5
% vegetative cover	V_{15}	40	1.0	10	0.6	10	0.6

Table 2. (concluded).

Variable	Data set 1		Data set 2		Data set 3	
	Data	SI	Data	SI	Data	SI
Component SI						
C_{F-C} =		0.77		0.65		0.49
C_{WQ} =		0.87		0.74		0.30
C_{R} =		0.93		0.59		0.29
C_{OT} =		0.95		0.80		0.50
HSI =		0.89		0.67		0.29

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
Turbidity (JTU)	V_3	50	0.9	120	0.4	110	0.6
pH	V_4	6.2	0.7	8.5	0.6	4.8	0.1
Temperature (adult) (° C)	V_5	26	1.0	20	0.7	29	0.6
Temperature (embryo) (° C)	V_6	22	1.0	14	0.6	28	0.0
Temperature (fry, juvenile) (° C)	V_7	31	0.8	22	0.7	32	0.5
Dissolved oxygen (adult, fry, and juvenile) (mg/l)	V_8	7.0	1.0	5.0	0.7	4.0	0.3
Dissolved oxygen (embryo) (mg/l)	V_9	4.0	0.2	5.5	0.6	4.0	0.2
Salinity (ppt)	V_{12}	2.0	0.7	2.5	0.6	3.0	0.5
Storage ratio (SR)	V_{13}	0.25	0.7	0.5	0.4	0.1	1.0
Substrate (embryo)	V_{14}	Vegetation	1.0	Mud	0.7	Gravel	0.7
% vegetative cover (fry and juvenile)	V_{15}	40	1.0	10	0.4	10	0.4
% littoral	V_{16}	30	1.0	20	0.8	5	0.3
% area 1.2-6.1 m	V_{17}	30	1.0	25	0.8	12	0.4

Table 3. (concluded).

Variable	Data set 1		Data set 2		Data set 3	
	Data	SI	Data	SI	Data	SI
Component SI						
C_{F-C} =		1.00		0.57		0.35
C_{WQ} =		0.87		0.63		0.41
C_R =		0.67		0.62		0.00
C_{OT} =		0.70		0.40		1.00
HSI =		0.79		0.57		0.00

Interpreting Model Outputs

The smallmouth buffalo HSI determined by use of these models will not necessarily represent the population of smallmouth buffalo in the study area; habitats with an HSI of 0 may contain some smallmouth buffalo and habitats with a high HSI may contain very few. This is because the standing crop does not totally depend on the ability of a habitat to meet all life requisite requirements of the species. If the model is a good representation of smallmouth buffalo riverine or lacustrine habitat, then in areas where smallmouth buffalo population levels are due primarily to habitat related factors, the model should be positively correlated with long-term average population levels. However, this has not been tested. The proper interpretation of the HSI is one of comparison. If two habitats have different HSI's, the one with the higher HSI should have the potential to support more smallmouth buffalo than the one with the lower HSI, given the model assumptions have not been violated.

ADDITIONAL HABITAT MODELS

Model 1

Optimum riverine habitat consists of the following conditions, assuming water quality is not limiting: large to medium sized rivers (> 5 m width), with some current (< 100 cm/sec); warm summer temperatures (22-26° C); clear (< 25 JTU) waters; and vegetated, shallow shoreline areas, backwaters, or marshes for spawning.

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

Model 2

Optimum lacustrine habitat consists of the following conditions, assuming water quality is not limiting: large reservoirs; warm summer water temperatures (22-26° C); clear(< 25 JTU) waters; and vegetated littoral zones for spawning.

$$HSI = \frac{\text{number of above criteria met}}{4}$$

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15. Supplementary Notes

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. Literature describing the relationship between habitat variables related to life requisites and habitat suitability for the Smallmouth buffalo (Ictiobus bubalus) 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

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Fishes
Habitability
Mathematical models

b. Identifiers/Open-Ended Terms

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Ictiobus bubalus
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