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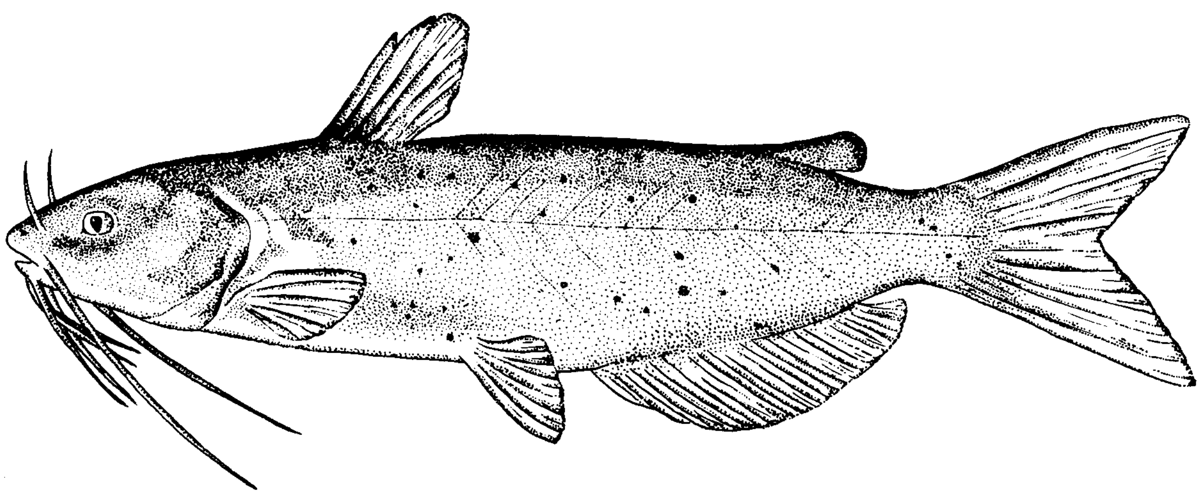
HABITAT SUITABILITY INDEX MODELS: CHANNEL CATFISH



n and Wildlife Service

S. Department of the Interior

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HABITAT SUITABILITY INDEX MODELS: CHANNEL CATFISH

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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 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.

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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CONTENTS

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[1]U.S. Fish and Wildlife Service. 1981. Standards for the development of habitat suitability index models. U.S.D.I. Fish and Wildlife Service, Division of Ecological Services, Washington, D.C. 103 ESM. n.p.

CHANNEL CATFISH (Ictalurus punctatus)

HABITAT USE INFORMATION

General

The native range of channel catfish (Ictalurus punctatus) extends from the southern portions of the Canadian prairie provinces south to the Gulf states, west to the Rocky Mountains, and east to the Appalachian Mountains (Trautman 1957; Miller 1966; Scott and Crossman 1973). They have been widely introduced outside this range and occur in essentially all of the Pacific and Atlantic drainages in the 48 contiguous states (Moore 1968; Scott and Crossman 1973). The greatest abundance of channel catfish generally occurs in the open (unleveed) floodplains of the Mississippi and Missouri River drainages (Walden 1964).

Age, Growth, and Food

Age at maturity in channel catfish is variable. Catfish from southern areas with longer growing seasons mature earlier and at smaller sizes than those from northern areas (Davis and Posey 1958; Scott and Crossman 1973). Southern catfish mature at age V or less (Scott and Crossman 1973; Pflieger 1975) while northern catfish mature at age VI or greater for males and at age VIII or greater for females (Starostka and Nelson 1974).

Young-of-the-year (age 0) catfish feed predominantly on plankton and aquatic insects (Bailey and Harrison 1948; Walburg 1975). Adults are opportunistic feeders with an extremely varied diet, including terrestrial and aquatic insects, detrital and plant material, crayfish, and molluscs (Bailey and Harrison 1948; Miller 1966; Starostka and Nelson 1974). Fish may form a major part of the diet of catfish > 50 cm in length (Starostka and Nelson 1974). Channel catfish diets in rivers and reservoirs do not appear to be significantly different (see Bailey and Harrison 1948; Starostka and Nelson 1974). Feeding is done by both vision and chemosenses (Davis 1959) and occurs primarily at night (Pflieger 1975). Bottom feeding is more characteristic but food is also taken throughout the water column (Scott and Crossman 1973). Additional information on the composition of adult and juvenile diets is provided in Leidy and Jenkins (1977).

Reproduction

Channel catfish spawn in late spring and early summer (generally late May through mid-July) when temperatures reach about 21° C (Clemens and Sneed 1957; Marzolf 1957; Pflieger 1975). Spawning requirements appear to be a major factor in determining habitat suitability for channel catfish (Clemens and Sneed 1957). Spawning is greatly inhibited if suitable nesting cover is unavailable (Marzolf 1957).

Specific Habitat Requirements

Channel catfish populations occur over a broad range of environmental conditions (Sigler and Miller 1963; Scott and Crossman 1973). Optimum riverine habitat is characterized by warm temperatures (Clemens and Sneed 1957; Andrews et al. 1972; Biesinger et al. 1979) and a diversity of velocities, depths, and structural features that provide cover and food (Bailey and Harrison 1948). Optimum lacustrine habitat is characterized by large surface area, warm temperatures, high productivity, low to moderate turbidity, and abundant cover (Davis 1959; Pflieger 1975).

Fry, juvenile, and adult channel catfish concentrate in the warmest sections of rivers and reservoirs (Ziebell 1973; Stauffer et al. 1975; McCall 1977). They strongly seek cover, but quantitative data on cover requirements of channel catfish in rivers and reservoirs are not available. Debris, logs, cavities, boulders, and cutbanks in lakes and in low velocity (< 15 cm/sec) areas of deep pools and backwaters of rivers will provide cover for channel catfish (Bailey and Harrison 1948). Cover consisting of boulders and debris in deep water is important as overwintering habitat (Miller 1966; Jester 1971; Cross and Collins 1975). Deep pools and littoral areas (≤ 5 m deep) with ≥ 40% suitable cover are assumed to be optimum. Turbidities > 25 ppm but < 100 ppm may somewhat moderate the need for fixed cover (Bryan et al. 1975).

Riffle and run areas with rubble substrate and pools (< 15 cm/sec) and areas with debris and aquatic vegetation are conditions associated with high production of aquatic insects (Hynes 1970) consumed by channel catfish in rivers (Bailey and Harrison 1948). Channel catfish are most abundant in river sections with a diversity of velocities and structural features. Therefore, it is assumed that a riverine habitat with 40-60% pools would be optimum for providing riffle habitat for food production and feeding and pool habitat for spawning and resting cover (Bailey and Harrison 1948). It also is assumed that at least 20% of lake or reservoir surface area should consist of littoral areas (≤ 5 m deep) to provide adequate area for spawning, fry and juvenile rearing, and feeding habitat for channel catfish.

High standing crops of warmwater fishes are associated with total dissolved solids (TDS) levels of 100 to 350 ppm for reservoirs in which the concentrations of carbonate-bicarbonate exceed those of sulfate-chloride (Jenkins 1976). It is assumed that high standing crops of channel catfish in lakes or reservoirs will, on the average, correspond to this TDS level.

Turbidity in rivers and reservoirs and reservoir size are other factors that may influence habitat suitability for channel catfish populations. Channel catfish are abundant in rivers and reservoirs with varying levels of turbidity and siltation (Cross and Collins 1975). However, low to moderate turbidities (< 100 ppm) are probably optimal for both survival and growth (Finnell and Jenkins 1954; Buck 1956; Marzolf 1957). Larger reservoirs (> 200 ha) are probably more suitable reservoir habitat for channel catfish populations because survival and growth are better than in smaller reservoirs (Finnell and Jenkins 1954; Marzolf 1957). Other factors that may affect reservoir habitat suitability for channel catfish are mean depth, storage ratio (SR), and length of agricultural growing season. Jenkins (1974) found that high mean depths were negatively correlated with standing crop of channel catfish. Mean depths are an inverse correlate of shoreline development (Ryder et al. 1974), thus higher mean depths may mean less littoral area would be available. Jenkins (1976) also reported that standing crops of catfishes (Ictaluridae) peaked at an SR of 0.75. Standing crops of channel catfish were postively correlated to growing season length (Jenkins 1970). However, harvest of channel catfish reported in reservoirs was not correlated with growing season length (Jenkins and Morais 1971).

Dissolved oxygen (DO) levels of 5 mg/l are adequate for growth and survival of channel catfish, but D.O. levels of ≥ 7 mg/l are optimum (Andrews et al. 1973; Carlson et al. 1974). Dissolved oxygen levels < 3 mg/l retard growth (Simco and Cross 1966), and feeding is reduced at D.O. levels < 5 mg/l (Randolph and Clemens 1976).

Adult. Adults in rivers are found in large, deep pools with cover. They move to riffles and runs at night to feed (McCammon 1956; Davis 1959; Pflieger 1971; 1975). Adults in reservoirs and lakes favor reefs and deep, protected areas with rocky substrates or other cover. They often move to the shoreline or tributaries at night to feed (Davis 1959; Jester 1971; Scott and Crossman 1973).

The optimal temperature range for growth of adult channel catfish is 26-29° C (Shrable et al. 1969; Chen 1976). Growth is poor at temperatures < 21° C (McCammon and LaFaunce 1961; Macklin and Soule 1964; Andrews and Stickney 1972) and ceases at < 18° C (Starostka and Nelson 1974). An upper lethal temperature of 33.5° C has been reported for catfish acclimated at 25° C (Carlander 1969).

Adult channel catfish were most abundant in habitats with salinities < 1.7 ppt in Louisiana, although they occurred in areas with salinities up to 11.4 ppt (Perry 1973). Salinities ≤ 8 ppt are tolerated with little or no effect, but growth slows above this level and does not occur at salinities > 11 ppt (Perry and Avault 1968).

Embryo. Dark and secluded areas are required for nesting (Marzolf 1957). Males build and guard nests in cavities, burrows, under rocks, and in other protected sites (Davis 1959; Pflieger 1975). Nests in large impoundments generally occur among rubble and boulders along protected shorelines at depths of about 2-4 m (Jester 1971). Catfish in large rivers are likely to move into shallow, flooded areas to spawn (Bryan et al. 1975). Lawler (1960) reported that spawning in Utah Lake, Utah, was concentrated in sections of the lake with abundant spawning sites of rocky outcrops, trees, and crevices. The male catfish fans embryos for water exchange and guards the nest from predators (Miller 1966; Minckley 1973). Embryos can develop in the temperature range of 15.5 to 29.5° C, with the optimum about 27° C (Brown 1942; Clemens and Sneed 1957). They do not develop at temperatures < 15.5° C (Brown 1942). Embryos hatch in 6-7 days at 27° C (Clemens and Sneed 1957).

Laboratory studies indicate that embryos three days old and older can tolerate salinities up to 16 ppt until hatching, when tolerance drops to 8 ppt (Allen and Avault 1970). However, 2 ppt salinity is the highest level in which successful spawning in ponds has been observed (Perry 1973). Embryo survival and production in reservoirs will probably be high in areas that are not subject to disturbance by heavy wave action or rapid water drawdown.

Fry. The optimal temperature range for growth of channel catfish fry is 29-30° C (West 1966). Some growth does occur down to temperatures of 18° C (Starostka and Nelson 1974), but growth generally is poor in cool waters with average summer temperatures < 21° C (McCammon and LaFaunce 1961; Macklin and

Soule 1964; Andrews et al. 1972) and in areas with short agricultural growing seasons (Starostka and Nelson 1974). Upper incipient lethal levels for fry are about 35-38° C, depending on acclimation temperature (Moss and Scott 1961; Allen and Strawn 1968). Optimum salinities for fry range from 0-5 ppt; salinities ≥ 10 ppt are marginal as growth is greatly reduced (Allen and Avault 1970).

Fry habitat suitability in reservoirs is related to flushing rate of reservoirs in midsummer. Walburg (1971) found abundance and survival of fry greatly decreased at flushing rates < 6 days in July and August.

Channel catfish fry have strong shelter-seeking tendencies (Brown et al. 1970), and cover availability will be important in determining habitat suitability. Newly hatched fry remain in the nest for 7-8 days (Marzolf 1957) and then disperse to shallow water areas with cover (Cross and Collins 1975). Fry are commonly found aggregated near cover in protected, slow-flowing (velocity < 15 cm/sec) areas of rocky riffles, debris-covered gravel, or sand bars in clear streams (Davis 1959; Cross and Collins 1975), and in very shallow (< 0.5 m) mud or sand substrate edges of flowing channels along turbid rivers and bayous (Bryan et al. 1975). Dense aquatic vegetation generally does not provide optimum cover because predation on fry by centrarchids is high under these conditions, especially in clear water (Marzolf 1957; Cross and Collins 1975). Fry overwinter under boulders in riffles (Miller 1966) or move to cover in deeper water (Cross and Collins 1975).

Juvenile. Optimal habitat for juveniles is assumed to be similar to that for fry. The temperature range most suitable for juvenile growth is reported to be 28-30° C (Andrews et al. 1972; Andrews and Stickney 1972). Upper lethal temperatures are assumed to be similar to those for fry.

HABITAT SUITABILITY INDEX (HSI) MODELS

Model Applicability

Geographic area. The model is applicable throughout the 48 conterminous States. The standard of comparison for each individual variable suitability index is the optimum value of the variable that occurs anywhere within the 48 conterminous States. Therefore, the model will never provide an HSI of 1.0 when applied to water bodies in the Northern States where temperature-related variables do not reach the optimum values for channel catfish found in the Southern States.

Season. The model provides a rating for a water body based on its ability to support a self-sustaining population of channel catfish through all seasons of the year.

Cover types. The model is 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 succesfully live and reproduce. No attempt has been made to establish a minimum habitat size for channel catfish, although this species is most abundant in larger water bodies.

Verification level. The acceptable output of these models is an index between 0 and 1 which the authors believe has a positive relationship to carrying capacity. In order to verify that the model output was acceptable, sample data sets were developed for calculating HSI's from the models.

The sample data sets and their relationship to model verification are discussed in greater detail following the presentation of the models.

Model Description

It is assumed that channel catfish habitat quality is based primarily on their food, cover, water quality, and reproduction requirements. Variables that have been shown to have an impact on the growth, survival, distribution, abundance, or other measure of well-being of channel catfish are placed in the appropriate component and a component rating derived from the individual variable suitability indices (Figs. 1 and 2). Variables that affect habitat quality for channel catfish, but which do not easily fit into these four major components, are combined under the "other component" heading. Levels of a variable that are near lethal or result in no growth cannot be offset by other variables.

Model Description - Riverine

Food component. Percent cover (V_2) is assumed to be important for rating the food component because if cover is available, fish would be more likely to occupy an area and utilize the food resources. Substrate (V_4) is included because stream production potential of aquatic insects (consumed directly by both channel catfish and their prey species) is related to amount and type of substrate.

Cover component. Percent pools (V_1) is included because channel catfish utilize pools as cover. Percent cover (V_2) is an index of all types of objects, including logs and debris, used for cover in rivers. Average current velocity in cover areas (V_{18}) is important because the usable habitat near a cover object decreases if cover objects are surrounded by high velocities.

Water quality component. The water quality component is limited to temperature, oxygen, turbidity, and salinity measurements. These parameters have been shown to effect growth or survival, or have been correlated with changes in standing crop. Variables related to temperature, oxygen, and salinity are assumed to be limiting when they approach lethal levels. Toxic substances are not considered.

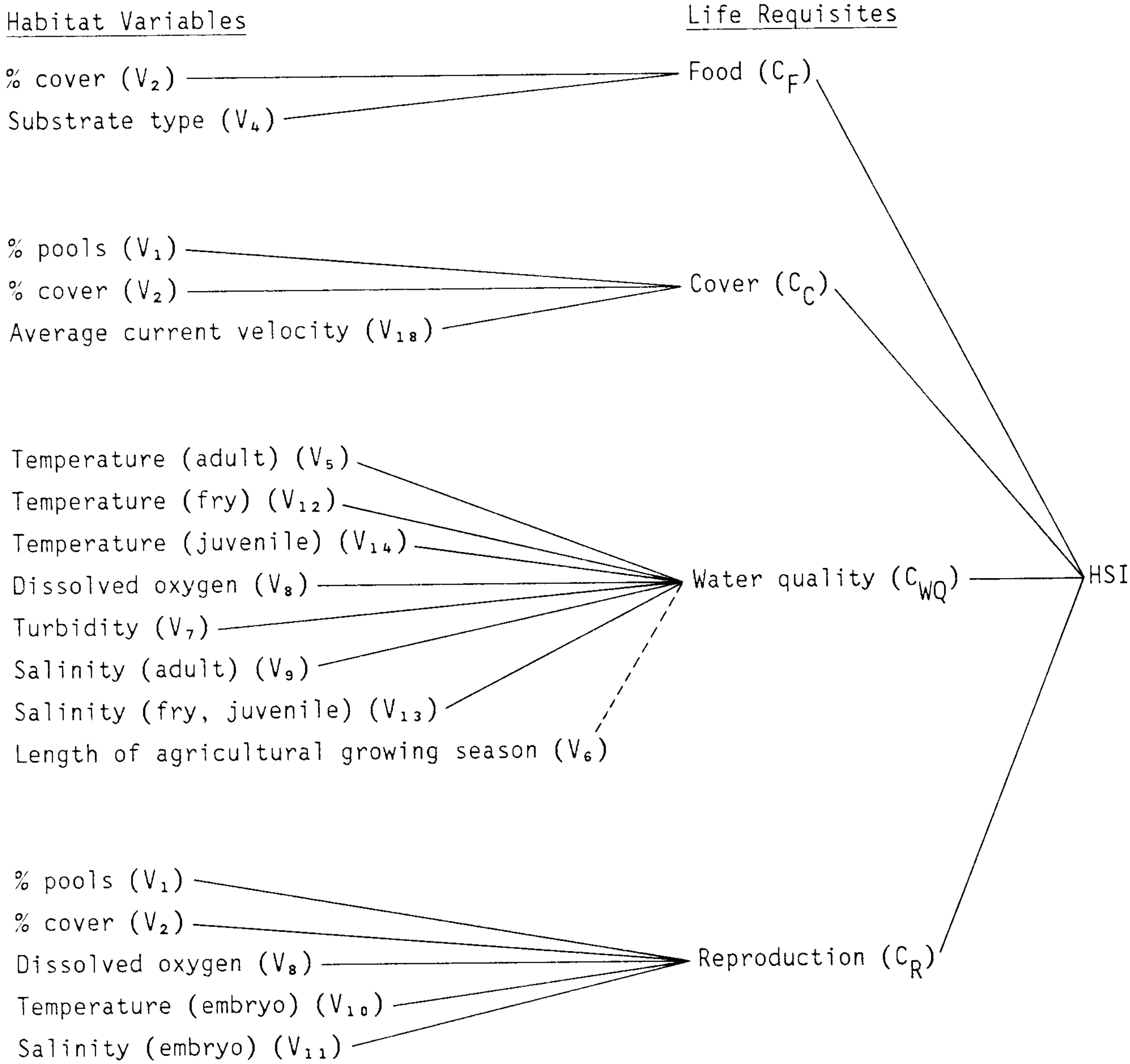


Figure 1. Tree diagram illustrating relationship of habitat variables and life requisites in the riverine model for the channel catfish. Dashed lines indicate optional variables in the model.

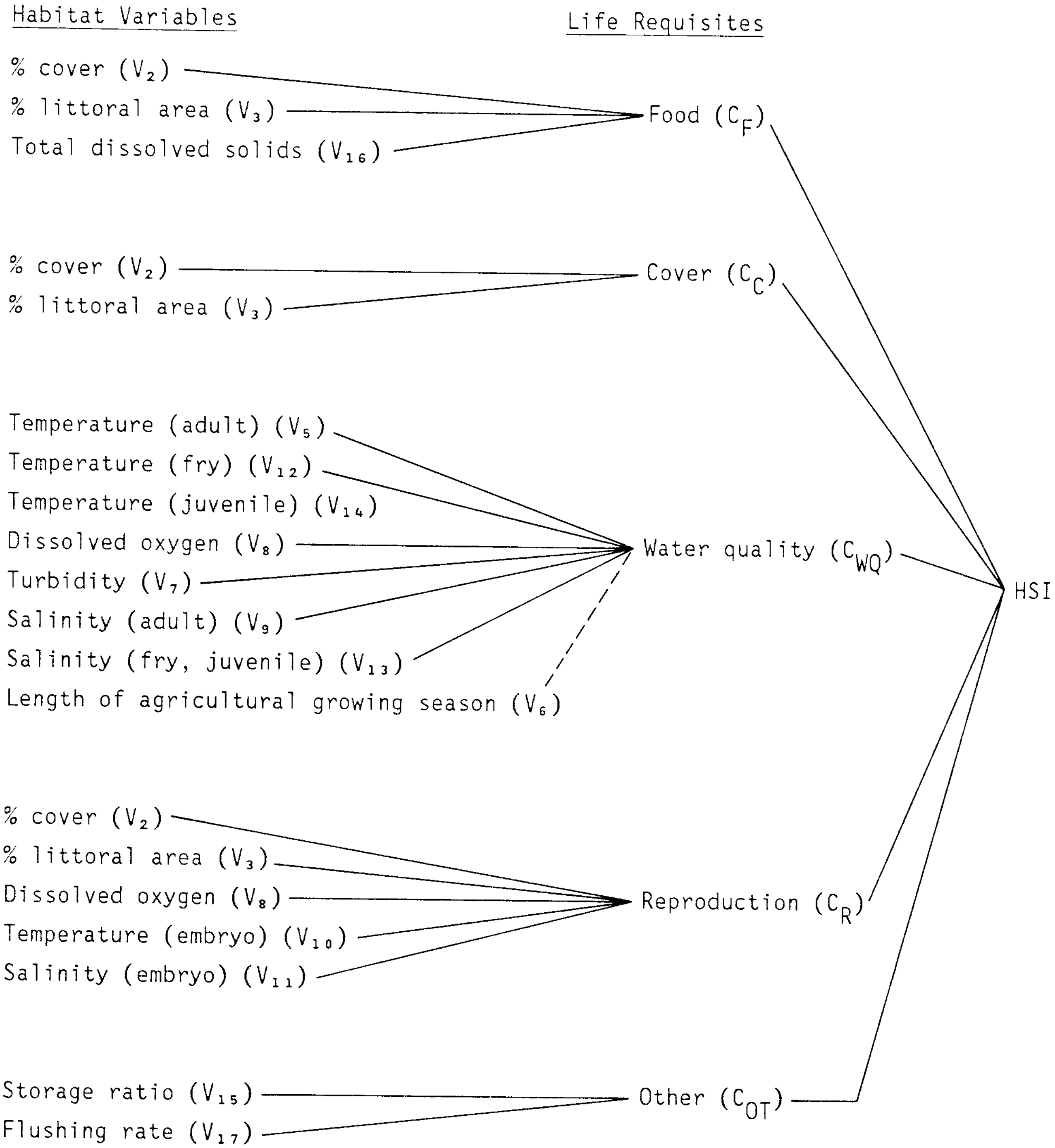


Figure 2. Tree diagram illustrating relationship of habitat variables and life requisites in the lacustrine model for the channel catfish. Dashed lines indicate optional variables in the model.

Reproduction component. Percent pools (V_1) is in the reproductive component because channel catfish spawn in low velocity areas in rivers. Percent cover (V_2) is in this component since channel catfish require cover for spawning. If minimum dissolved oxygen (DO) levels within pools and backwaters during midsummer (V_8) are adequate, they should be adequate during spawning, which occurs earlier in the year. DO levels measured during spawning and embryo development could be substituted for V_8. Two additional variables, average water temperatures within pools and backwaters during spawning and embryo development (V_{10}) and maximum salinity during spawning and embryo development (V_{11}) are included because these water quality conditions affect embryo survival and development.

Model Description - Lacustrine

Food component. Percent cover (V_2) is included since it is assumed that if cover is available, channel catfish would be more likely to utilize an area for feeding. Percent littoral area (V_3) is included because littoral areas generally produce the greatest amount of food and feeding habitat for catfish. Total dissolved solids (TDS) (V_{16}) is included because adult channel catfish eat fish, and fish production in lakes and reservoirs is correlated with TDS.

Cover component. Percent cover (V_2) is included since channel catfish strongly seek structural features of logs, debris, brush, and other objects for shelter. Percent littoral area (V_3) is included because all life stage predominantly utilize cover found in littoral areas of a lake.

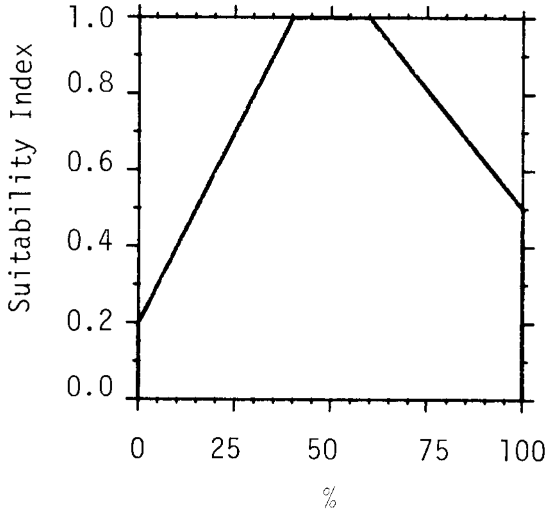
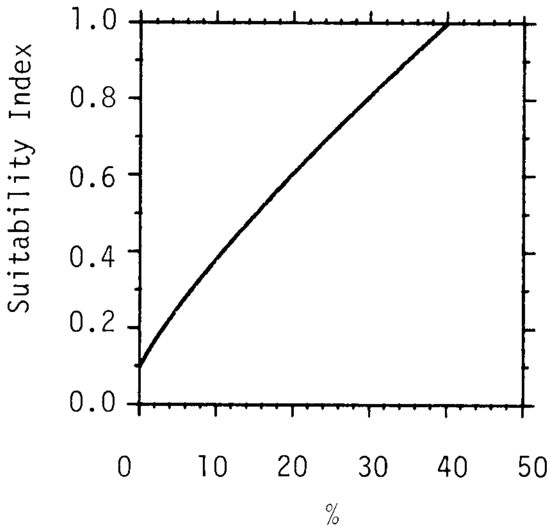
Water quality component. Refer to riverine model description.

Reproduction component. Percent cover (V_2) is included since catfish build nests in dark and secluded areas; spawning is not observed if suitable cover is unavailable. Percent littoral area (V_3) is included since catfish spawning is concentrated along the shoreline. DO (V_8), temperature (V_{10}) and salinity (V_{11}) are included because these water quality parameters affect embryo survival and development.

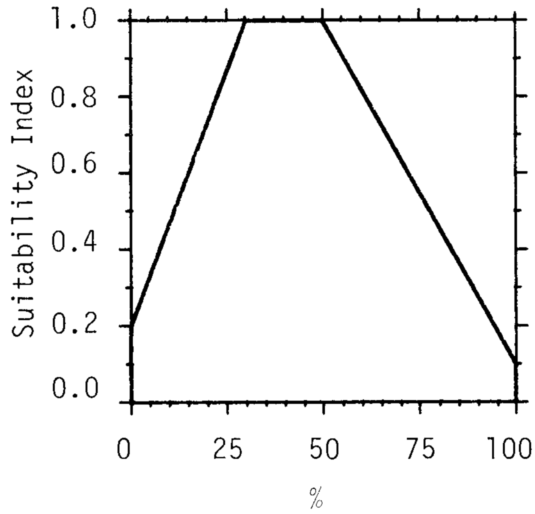
Other component. For reservoirs, storage ratio (V_{15}) and maximum flushing rate when fry are present (V_{17}) are included in this component because storage ratio may affect standing crop and the flushing of fry from a reservoir outlet can reduce the abundance of fry.

Suitability Index (SI) Graphs for Model Variables

This section contains suitability index graphs for the 18 variables described above, and equations for combining selected variables into a species HSI using the component approach. Variables pertain to a riverine (R) habitat, lacustrine (L) habitat, or both (R, L).

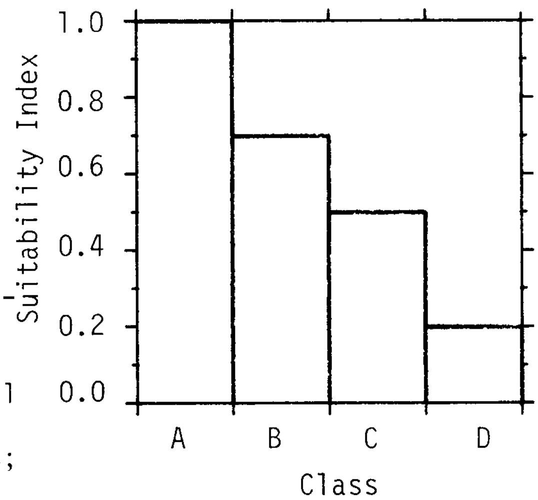
Habitat	Variable		Suitability Graph
R	(V_1)	Percent pools during average summer flow.	
R,L	(V_2)	Percent cover (logs, boulders, cavities, brush, debris, or standing timber) during summer within pools, backwater areas, and littoral areas.	

L (V$_3$) Percent littoral area during summer.

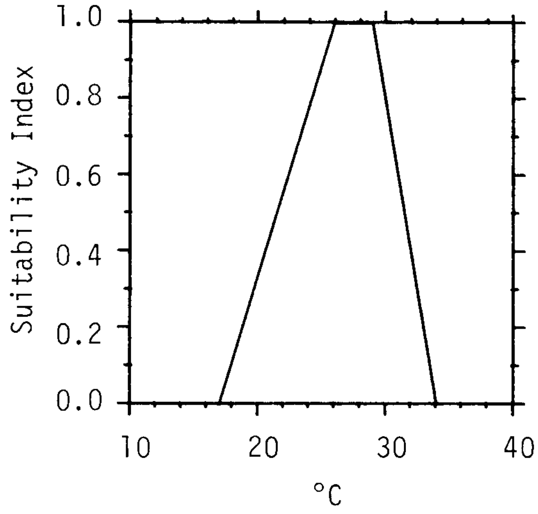


R (V$_4$) Food production potential in river by substrate type present during average summer flow.

A) Rubble dominant in riffle-runs with some gravel and/or boulders present; fines (silt and sand) not common; aquatic vegetation abundant (≥ 30%) in pool areas.
B) Rubble, gravel, boulders, and fines occur in nearly equal amounts in riffle-run areas; aquatic vegetation is 10-30% in pool areas.
C) Some rubble and gravel present, but fines or boulders are dominant; aquatic vegetation is scarce (< 10%) in pool areas.
D) Fines or bedrock are the dominant bottom material. Little or no aquatic vegetation or rubble present.

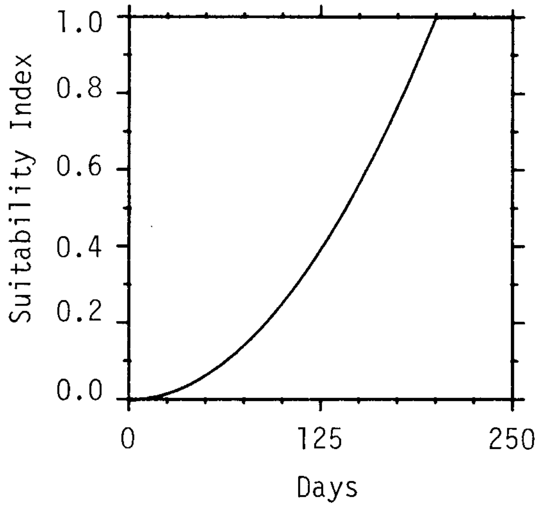


R,L (V$_5$) Average midsummer water temperature within pools, backwaters, or littoral areas (Adult).

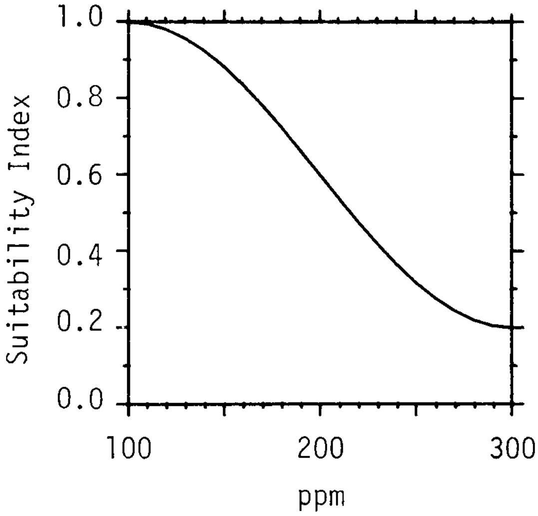


R,L (V$_6$) Length of agricultural growing season (frost-free days).

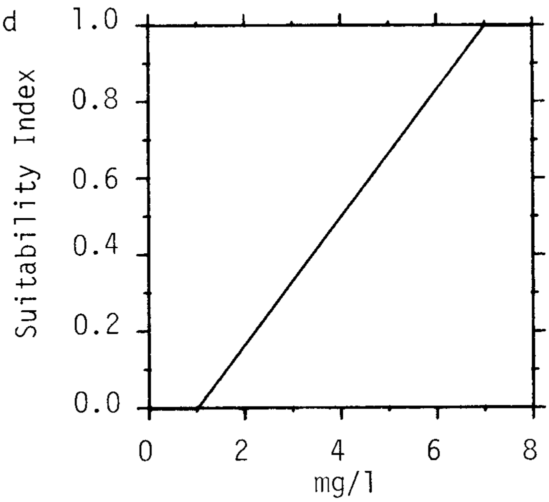
Note: This variable is optional.



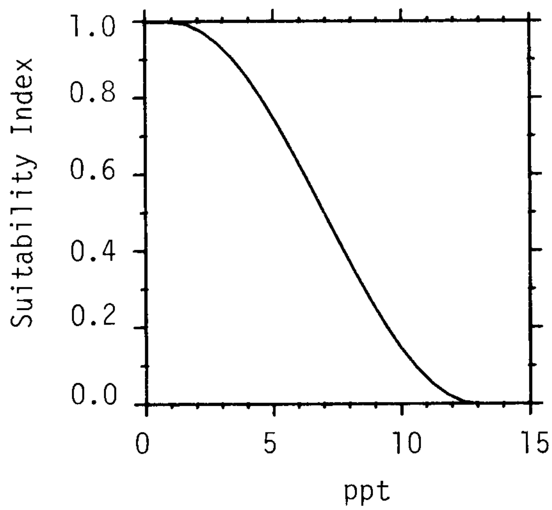
R,L (V$_7$) Maximum monthly average turbidity during summer.



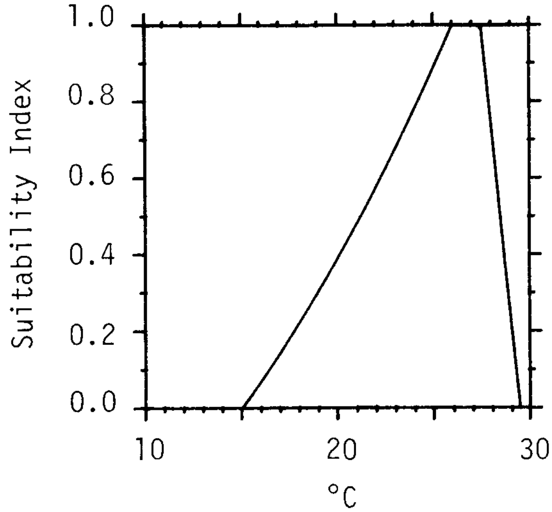
R,L (V_8) Average minimum dissolved oxygen levels within pools, backwaters, or littoral areas during midsummer.



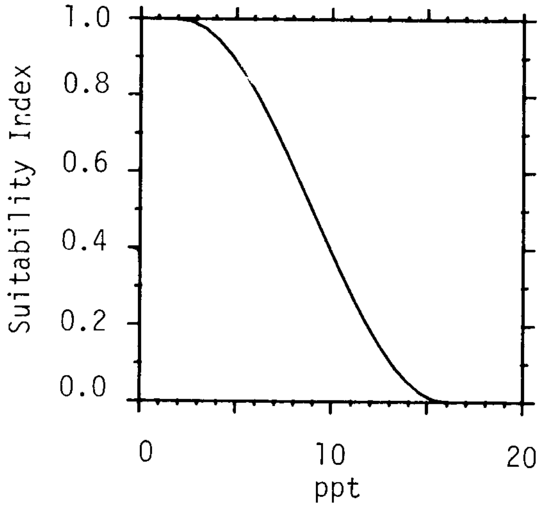
R,L (V_9) Maximum salinity during summer (Adult).



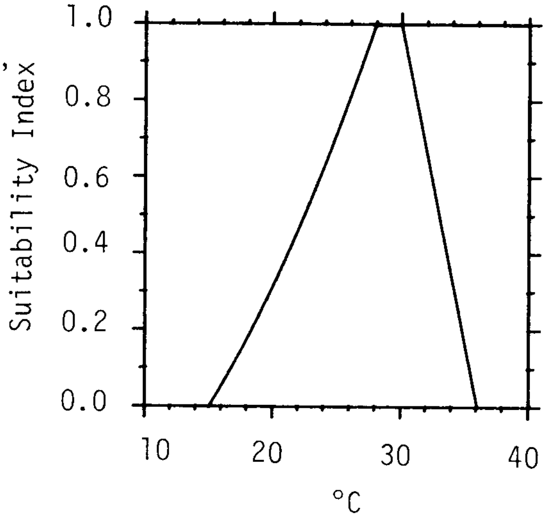
R,L (V_{10}) Average water temperatures within pools, backwaters, and littoral areas during spawning and embryo development (Embryo).



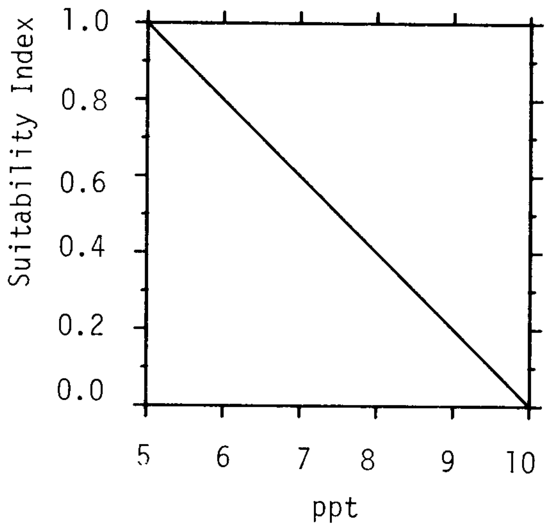
R,L (V_{11}) Maximum salinity during spawning and embryo development (Embryo).



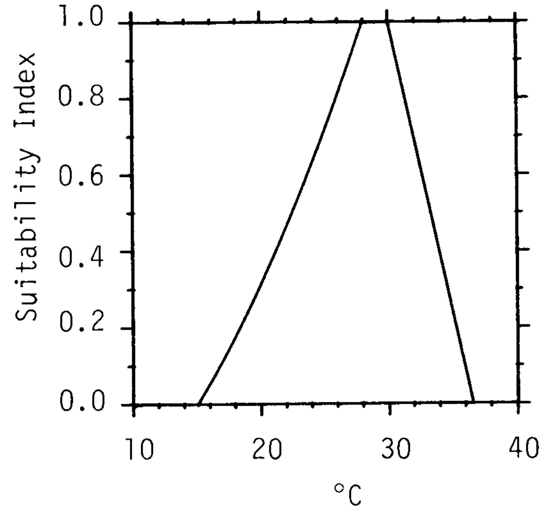
R,L (V_{12}) Average midsummer water temperature within pools, backwaters, or littoral areas (Fry).



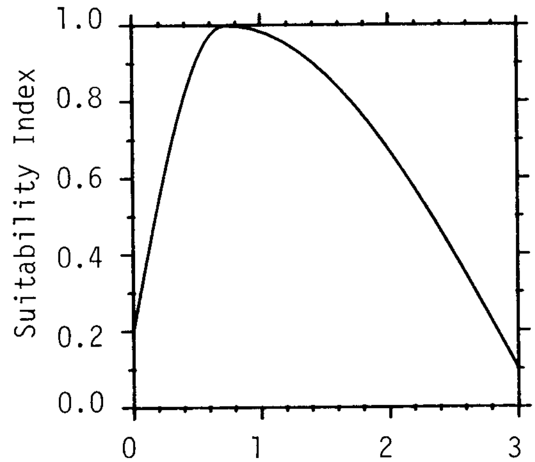
R,L (V_{13}) Maximum salinity during summer (Fry, Juvenile).



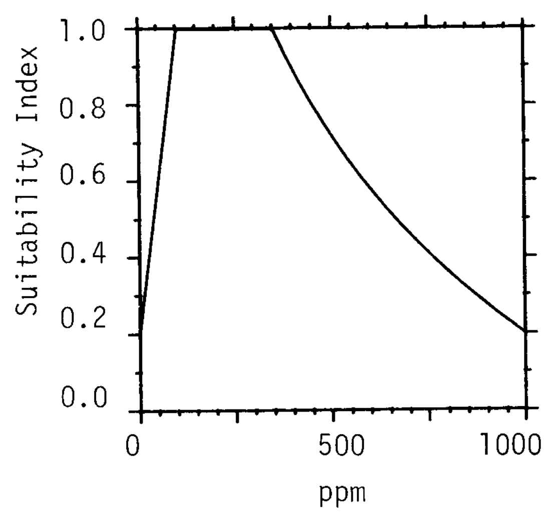
R,L (V$_{14}$) Average midsummer water temperature within pools, backwaters, or littoral areas (Juvenile).



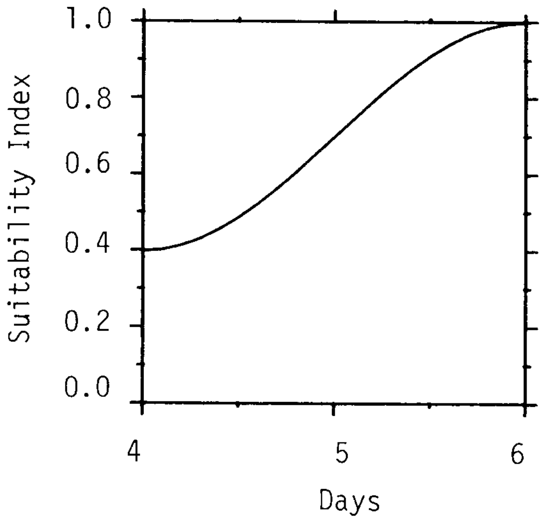
L (V$_{15}$) Storage ratio.



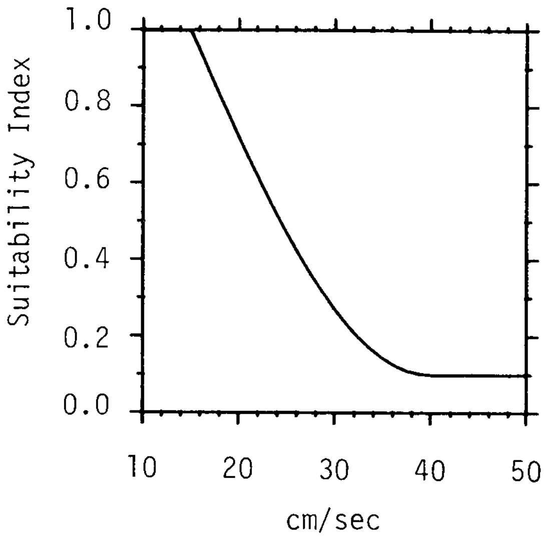
L (V$_{16}$) Monthly average TDS (total dissolved solids) during summer.



L (V₁₇) Maximum reservoir flushing rate while fry present (Fry).



R (V_{18}) Average current velocity in cover areas during average summer flow.



Riverine Model

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

Food (C_F).

$$C_F = \frac{V_2 + V_4}{2}$$

Cover (C_C).

$$C_C = (V_1 \times V_2 \times V_{18})^{1/3}$$

Water Quality (C_{WQ}).

$$C_{WQ} = \frac{\frac{2(V_5 + V_{12} + V_{14})}{3} + V_7 + 2(V_8) + V_9 + V_{13}}{7}$$

If V_5, V_{12}, V_{14} V_8, V_9, or V_{13} is ≤ 0.4, then C_{WQ} equals the lowest of the following: V_5, V_{12}, V_{14}, V_8, V_9, V_{13}, or the above equation.

Note: If temperature data are unavailable, $2(V_6)$ (length of agricultural growing season) may be substituted for the term

$\frac{2(V_5 + V_{12} + V_{14})}{3}$ in the above equation

Reproduction (C_R).

$$C_R = (V_1 \times V_2{}^2 \times V_8{}^2 \times V_{10}{}^2 \times V_{11})^{1/8}$$

If V_8, V_{10}, or V_{11} is ≤ 0.4, then C_R equals the lowest of the following: V_6, V_{10}, V_{11}, or the above equation.

HSI determination.

$$HSI = (C_F \times C_C \times C_{WQ}{}^2 \times C_R{}^2)^{1/6}$$, or

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.

Sample data sets using riverine HSI model are listed in Table 2.

Lacustrine Model

This model utilizes the life requisite approach and consists of five components: food, cover, water quality, reproduction, and other.

Food (C_F).

$$C_F = \frac{V_2 + V_3 + V_{16}}{3}$$

Cover (C_C).

$$C_C = (V_2 \times V_3)^{1/2}$$

Water Quality (C_{WQ}).

C_{WQ} = same as in Riverine HSI Model

Reproduction (C_R).

$$C_R = (V_2{}^2 \times V_3 \times V_8{}^2 \times V_{10}{}^2 \times V_{11})^{1/8}$$

If V_8, V_{10}, or V_{11} is ≤ 0.4, then C_R equals the lowest of the following: V_8, V_{10}, V_{11}, or the above equation.

Other (C_{OT}).

$$C_{OT} = \frac{V_{15} + V_{17}}{2}$$

Table 1. Data sources and assumptions for channel catfish suitability indices.

Variable	and source	Assumption
V_1	Bailey and Harrison 1948	Optimum conditions for a diversity of velocities, depths, and structural features for channel catfish will be found when there are approximately equal amounts of pools and riffles.
V_2	Bailey and Harrison 1948 Marzolf 1957 Cross and Collins 1975	The strong preference of all life stages of channel catfish for cover indicates that some cover must be present for optimum conditions to occur.
V_3	Bailey and Harrison 1948 Marzolf 1957 Cross and Collins 1975	Lakes with small littoral area will provide less area for cover and food production for channel catfish and are therefore less suitable.
V_4	Bailey and Harrison 1948	The amount and type of substrate or the amount of aquatic vegetation associated with high production of aquatic insects (used as food by channel catfish and channel catfish prey species) is optimum.
V_5	Clemens and Sneed 1957 West 1966 Shrable et al. 1969 Starostka and Nelson 1974 Biesinger et al. 1979	Temperatures at the warmest time of year must reach levels that permit growth in order for habitat to be suitable. Optimum temperatures are those when maximum growth occurs.
V_6	Jenkins 1970	Growing seasons that are correlated with high standing crops are optimum.
V_7	Finnell and Jenkins 1954 Buck 1956 Marzolf 1957	High turbidity levels are associated with reduced standing crops and therefore are less suitable.
V_8	Moss and Scott 1961 Andrews et al. 1973 Carlson et al. 1974 Randolph and Clemens 1976	Lethal levels of dissolved oxygen are unsuitable. DO levels that reduce feeding are suboptimal.
V_9	Perry and Avault 1968 Perry 1973	Salinity levels where adults are most abundant are optimum. Any salinity level at which adults have been reported has some suitabilty.

Table 1. (concluded)

Variable and source		Assumption
V_{10}	Brown 1942 Clemens and Sneed 1957	Optimum temperatures are those which result in optimum growth. Temperatures that result in death or no growth are unsuitable.
V_{11}	Perry and Avault 1968 Perry 1973	Salinity levels at which spawning has been observed are suitable.
V_{12}	McCammon and LaFaunce 1961 Moss and Scott 1961 Macklin and Soule 1964 West 1966 Allen and Strawn 1968 Andrews 1972 Starostka and Nelson 1974	Optimum temperatures for fry are those when growth is best. Temperatures that result in no growth or death are unsuitable.
V_{13}	Allen and Avault 1970	Salinities that do not reduce growth of fry and juveniles are optimum. Salinities that greatly reduce growth are unsuitable.
V_{14}	Andrews et al. 1972 Andrews and Stickney 1972	Temperatures at which growth of juveniles is best are optimum. Temperatures that result in no growth or death are unsuitable.
V_{15}	Jenkins 1976	Storage ratios correlated with maximum standing crops are optimum; those correlated with lower standing crops are suboptimum.
V_{16}	Jenkins 1976	Total dissolved solids (TDS) levels correlated with high standing crops of warmwater fish are optimum; those correlated with lower standing crops are suboptimum. The data used to develop this graph are primarily from southeastern reservoirs.
V_{17}	Walburg 1971	Flushing rates correlated with reduced levels of fry abundance are suboptimal.
V_{18}	Miller 1966 Scott and Crossman 1973 Cross and Collins 1975	High velocities near cover objects will decrease the amount of usable habitat around the objects and are thus considered suboptimum.

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
% pools	V_1	60	1.0	90	0.6	15	0.5
% cover	V_2	50	1.0	10	0.4	5	0.2
Substrate for food production	V_4	silt-gravel	0.7	silt-sand	0.5	sand	0.2
Temperature-Adult (° C)	V_5	28	1.0	32	0.4	22	0.5
Growing season	V_6	180	0.8	-	-	-	-
Turbidity (ppm)	V_7	50	1.0	210	0.5	160	0.8
Dissolved oxygen (mg/l)	V_8	4.5	0.6	4.0	0.5	4.0	0.5
Salinity-adult (ppt)	V_9	< 1	1.0	< 1	1.0	< 1	1.0
Temperature-Embryos (°C)	V_{10}	25	0.8	21.5	0.5	28.5	0.5
Salinity-Embryo (ppt)	V_{11}	< 1	1.0	< 1	1.0	< 1	1.0
Temperature-Fry (° C)	V_{12}	26.5	0.8	32	0.7	23	0.5
Salinity-Fry/ Juvenile (ppt)	V_{13}	< 1	1.0	< 1	1.0	< 1	1.0
Temperature-Juvenile (° C)	V_{14}	29	1.0	32	0.7	22	0.5
Velocity	V_{18}	15	1.0	5	1.0	30	0.3

Table 2. (concluded)

Variable	Data set 1		Data set 2		Data set 3	
	Data	SI	Data	SI	Data	SI
Component SI						
C_F =		0.85		0.45		0.20
C_C =		1.00		0.62		0.31
C_{WQ} =		0.87		0.40*		0.69
C_R =		0.86		0.58		0.47
HSI =		0.88		0.40*		0.43

*Note: $C_{WQ} \leq 0.4$; therefore, HSI = C_{WQ} in Data Set 2.

HSI determination.

$$HSI = (C_F \times C_C \times C_{WQ}^2 \times C_R^2 \times C_{OT})^{1/7} \text{ , or}$$

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.

Sample data sets using lacustrine HSI model are listed in Table 3.

Interpreting Model Outputs

The proper interpretation of the HSI produced by the models is one of comparison. If two water bodies have large differences in HSI's, then the one with the higher HSI should be able to support more catfish than the water body with the lower HSI, given that the model assumptions have not been violated. The actual differences in HSI that indicate a true difference in carrying capacity are unknown and likely to be high. We have aggregated a large number of variables into a single index with little or no quantitative information on how the variables interact to effect carrying capacity. The probability that we have made an error in our assumptions on variable interactions is high. However, we believe the model is a reasonable hypothesis of how the selected variables interact to determine carrying capacity.

Before using the model, any available statistical models, such as those described under model 3 in the next section, should be examined to determine if they better meet the goals of model application. Statistical models are likely to be more accurate in predicting the value of a dependent variable, such as standing crop, from habitat related variables than the HSI models described above. A statistical model is especially useful when the habitat variables in the data set used to derive the model have values similar to the proposed model application site. The HSI models described above may be most useful when habitat conditions are dissimilar to the statistical model data set or it is important to evaluate changes in variables not included in the statistical model.

The sample data sets consist of different variable values (and their corresponding SI score), which although not actual field measurements, are thought to represent realistic conditions that could occur in various channel catfish riverine or lacustrine habitats. We believe the HSI's calculated from the data reflect what carrying capacity trends would be in riverine or lacustrine habitats with the characteristics listed in the respective data sets.

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	50	1.0	10	0.4	5	0.2
% littoral area	V_3	40	1.0	20	0.7	70	0.6
Temperature-Adult (° C)	V_5	26	1.0	20	0.3	33	0.2
Growing season	V_6	180	0.8	-	-	-	-
Turbidity	V_7	175	0.7	210	0.5	250	0.3
Dissolved oxygen	V_8	4.5	0.6	4.5	0.6	2.5	0.2
Salinity-Adult (ppt)	V_9	< 1	1.0	< 1	1.0	< 1	1.0
Temperature-Embryo (° C)	V_{10}	25	0.8	21.5	0.5	28	0.5
Salinity-Embryo (ppt)	V_{11}	< 1	1.0	< 1	1.0	< 1	1.0
Temperature-Fry (° C)	V_{12}	26.5	0.8	32	0.7	23	0.5
Salinity-Fry/ Juvenile (ppt)	V_{13}	< 1	1.0	< 1	1.0	< 1	1.0
Temperature-Juvenile (° C)	V_{14}	29	1.0	32	0.7	22	0.5
Storage ratio	V_{15}	1.5	0.9	.3	0.7	0.8	1.0
TDS (ppm)	V_{16}	200	1.0	300	1.0	600	0.6
Flushing rate while fry present (days)	V_{17}	15	1.0	4	0.4	11	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 =		1.00		0.70		0.47
C_C =		1.00		0.52		0.33
C_{WQ} =		0.82		0.30*		0.20*
C_R =		0.83		0.56		0.20
C_{OT} =		0.95		0.55		1.00
HSI =		0.89		0.30*		0.20*

*Note: $C_{WQ} \leq 0.4$; therefore, HSI = C_{WQ} in Data Sets 2 and 3.

ADDITIONAL HABITAT MODELS

Model 1

Optimal riverine habitat for channel catfish is characterized by the following conditions, assuming water quality is adequate: warm, stable water temperatures (summer temperatures of 25-31° C); an approximate 40-60% area of deep pools; and abundant cover in the form of logs, boulders, cavities, and debris (> 40% of pool area).

$$HSI = \frac{\text{number of above criteria present}}{3}$$

Model 2

Optimal lacustrine habitat for channel catfish is characterized by the following conditions, assuming water quality is adequate: warm, stable water temperatures (summer temperatures of 25-30° C); large surface area (> 500 ha); moderate to high fertility (TDS 100-350 ppm); clear to moderate turbidities (< 100 JTU); and abundant cover (> 40% in areas < 5 m deep).

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

Model 3

Use the reservoir standing crop regression equations for catfishes presented by Aggus and Morais (1979) to predict standing crop, then divide the predicted standing crop by the highest standing crop value used to develop the regression equation, in order to obtain an HSI.

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15. Supplementary Notes

16. Abstract (Limit: 200 words)

Literature concerning the habitat requirements of the channel catfish (Ictalurus punctatus) is reviewed, and the data is then synthesized into Habitat Suitability Index models.

This is one in a series of publications developed to provide information on the habitat requirements of selected fish and wildlife species. Numerous literature sources have been consulted in an effort to consolidate scientific data on species-habitat relationships. These data have subsequently been synthesized into explicit Habitat Suitability Index (HSI) models. The models are based on suitability indices indicating habitat preferences. Indices have been formulated for variables found to affect the life cycle and survival of each species. Habitat Suitability Index (HSI) models are designed to provide information for use in impact assessment and habitat management activities. The HSI technique is a corollary to the U.S. Fish and Wildlife Service's Habitat Evaluation Procedures.

17. Document Analysis a. Descriptors

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