Appendix D. Habitat Use Information and HSI Model for the Channel Catfish

D.1 Introduction. HSI models should be documented so that the model can be consistently applied and improved, and the HSI outputs estimated by the model can be properly interpreted. This appendix provides an example HSI model for channel catfish with documentation as described in 103 ESM 3.4. Section D.2 below provides documentation of habitat use information. Section D.3 provides an HSI model derived from this information, and includes assumptions and limitations of the model.

An HSI model used in HEP does not have to be of the same type as the one presented in this appendix. Other HSI models for channel catfish are available in Aggus and Morais (1979) or could be developed from the information presented in D.2.

D.2 Habitat use information for channel catfish

A. Distribution. 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 conterminous 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).

B. Habitat. Channel catfish populations occur over a broad range of environmental conditions, although they are most abundant in large riverine systems (Sigler and Miller 1963; Scott and Crossman 1973). Optimal riverine habitat for channel catfish consists of 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). They thrive in large, clear, moderately swift prairie streams with rocky substrates (Scott and Crossman 1973; Pflieger 1975), and large, sluggish, moderate-to-low gradient, turbid rivers, such as the Mississippi and Missouri Rivers (Hanson and Campbell 1963; Miller 1966; Bryan et al. 1975). They are rarely found in small or high-gradient streams (Pflieger 1971).

Adults in rivers are found near the bottom during the day in large, deep pools and near cover of logs, boulders, and debris. They move to shallower, faster areas of riffles and runs at night to feed (McCammon 1956; Davis 1959; Pflieger 1971, 1975). Fry and juveniles occupy shallow areas strewn with rocks or other cover (Davis 1959; Pflieger 1971, 1975; Cross and Collins 1975). They overwinter under boulders in riffles (Miller 1966) or move to cover in deeper water (Cross and Collins 1975).

Channel catfish also thrive in a variety of lacustrine environments including reservoirs (LaRivers 1962; Jester 1971), lakes (Scott and Crossman 1973), bayous (Lantz 1970; Bryan et al. 1975), and farm ponds (Regier 1963). Adults in reservoirs and lakes favor reefs and deep, protected areas with rocky substrates or other cover. They move to shallow shoreline areas and tributaries at night to feed (Davis 1959; Jester 1971; Scott and Crossman 1973). Fry and juveniles are on the bottom in cover during the day (Marzolf 1957; Brown et al. 1970; Cross and Collins 1975). Optimal reservoir habitat for channel catfish appears to be large, fertile, warm reservoirs with clear to moderate turbidities, and with abundant cover of logs, boulders, and cavities (Davis 1959; Pflieger 1975).

Channel catfish are quite mobile (Harrison 1953; Ziebell 1973) and disperse readily to favorable habitats in riverine (Bailey and Harrison 1948; Pflieger 1971) and lacustrine (LaRivers 1962) environments. They strongly prefer warm temperatures and concentrate in the warmest sections of rivers and reservoirs (Ziebell 1973; Stauffer et al. 1975; McCall 1977). Movements become restricted during winter (McCammon 1956; Jester 1971) and they apparently move to deep water to overwinter (Jester 1971) as temperatures drop below 5-10° C (Bailey and Harrison 1948). They are generally inactive and in cover at temperatures < 4° C (Brown et al. 1970).

C. 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 and are able to locate suitable food in a variety of habitats. They have 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

> 500 cm in length (Starostka and Nelson 1974). Channel catfish diet in rivers and reservoirs does not appear to be significantly different (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 at the surface (Scott and Crossman 1973).

D. 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).

E. Specific habitat requirements

(1) Species in general. All life stages of channel catfish strongly seek cover, but precise quantitative data on cover requirements of channel catfish in rivers and reservoirs are not available. Debris, logs, cavities, boulders, and cutbanks in low velocity (< 15 cm/sec) areas of deep pools and backwaters will provide cover for channel catfish (Bailey and Harrison 1948). Cover 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 optimal for all life stages. Turbidities > 25 ppm but < 100 ppm may somewhat moderate the need for fixed cover (Bryan et al. 1975).

High velocity riffle and run areas of rivers (velocities of ≥ 30 cm/sec) with rubble substrate (≥ 60% of bottom) and overhanging vegetation, and quiet areas with debris and aquatic vegetation, provide optimal conditions for food production (Bailey and Harrison 1948). Channel catfish prefer a diversity of velocities and structural features, therefore it is assumed that a riverine habitat with 40-60% pools would be optimal. It 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.

Total dissolved solids (TDS) provides an index of fish production (Ryder 1965) and water fertility. Jenkins (1976) found high standing crops of warmwater fish correlated with a range of TDS in reservoirs of 100-350 ppm (with ionic concentrations of carbonate-bicarbonate exceeding those of sulfate-chloride). Thus, 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, clear 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 channel catfish peaked at an SR of 0.75. Finally, standing crops of channel catfish were positively correlated to growing season length (Jenkins 1970), with highest standing crops reported in reservoirs with ≥ 200 frost-free days (Jenkins and Morais 1971).

Dissolved oxygen (DO) levels of 5 mg/l are adequate for growth and survival of channel catfish, but DO levels of ≥ 7 mg/l are optimal (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 DO levels < 5 mg/l (Randolph and Clemens 1976).

(2) Adult. 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).

Adults do not have strict substrate requirements but they are most abundant in areas with sand, gravel, or rubble substrates which may be mixed with silt. When they are found over silt substrates the water is usually flowing (Bailey and Harrison 1948).

(3) Embryo. Dark and secluded areas are used for nesting (Marzolf 1957); males build and guard nests in cavities, burrows, under rocks, and in other protected sites (Davis 1959; Pflieger 1975). Nesting in large impoundments generally occurs 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 considered the upper limit for embryo habitat suitability because it 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.

(4) 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 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). Optimal salinities for fry range from 0-5 ppt and salinities ≥ 10 ppt are marginal for fry as growth is greatly reduced at this level (Allen and Avault 1970).

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

(5) 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.

D.3 HSI model for channel catfish

A. Model applicability:

(1) Geographic area: The model provided in Section C 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 found in the southern States.

(2) Season. The model provides a rating for a water body based on its ability to support a reproducing population of channel catfish through all seasons of the year.

(3) Cover types. The model is applicable in Riverine, Lacustrine, Palustrine, and estuarine habitats, as described by Cowardin et al. (1979).

(4) Minimum habitat area. Minimum habitat area is defined as the minimum area of contiguous suitable habitat that is required for a species to successfully live and reproduce. No attempt has been made to establish a minimum habitat size for channel catfish, although this species prefers larger water bodies.

(5) Verification. The acceptable output of this channel catfish model is to produce an index between 0 and 1 which the author believes has a positive relationship to carrying capacity. In order to verify that the model output was acceptable, the author developed data sets and habitat suitability indices were then calculated for each data set (Tables D-1, D-2, D-3, and D-4).

The data sets are not from actual field measurements, but represent combinations of variable values the author believes could occur in a water body. The HSI's calculated from the data reflect what the author thought carrying capacity trends would be in water bodies with the listed characteristics. Thus, the model meets the acceptance goal.

B. Model description. The model is based on the assumption that any variable that has been shown to have an impact on the growth, survival, distribution, abundance or other measure of well being of

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Table D-1. Sample data sets using the 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	15%	0.4	5%	0.2
Substrate for food production	V_4	silt-gravel	0.6	silt-sand	0.3	sand	0.2
Temperature (Adult)	V_5	26° C	1.0	32° C	0.4	23° C	0.5
Growing season	V_6	180	0.8	-	-	-	-
Turbidity	V_7	50	1.0	170	0.5	130	0.8
Dissolved oxygen	V_8	5.5	0.6	5.0	0.5	5.0	0.5
Salinity (Adult)	V_9	< 1	1.0	< 1	1.0	< 1	1.0
Temperature (Embryo)	V_{10}	24° C	0.8	22° C	0.5	28° C	0.5
Salinity (Embryo)	V_{11}	< 1	1.0	< 1	1.0	< 1	1.0
Temperature (Fry)	V_{12}	26° C	0.8	32° C	0.7	24° C	0.5
Salinity (Fry/Juvenile)	V_{13}	< 1	1.0	< 1	1.0	< 1	1.0
Temperature (Juvenile)	V_{14}	29° C	1.0	32° C	0.7	23° C	0.5
Velocity - Cover	V_{19}	15	1.0	5	1.0	30	0.3

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Temperature (Adult)	V_5	26° C	1.0	32° C	0.4	23° C	0.5
Growing season	V_6	180	0.8	-	-	-	-
Turbidity	V_7	50	1.0	170	0.5	130	0.8
Dissolved oxygen	V_8	5.5	0.6	5.0	0.5	5.0	0.5
Salinity (Adult)	V_9	< 1	1.0	< 1	1.0	< 1	1.0
Temperature (Embryo)	V_{10}	24° C	0.8	22° C	0.5	28° C	0.5
Salinity (Embryo)	V_{11}	< 1	1.0	< 1	1.0	< 1	1.0
Temperature (Fry)	V_{12}	26° C	0.8	32° C	0.7	24° C	0.5
Salinity (Fry/Juvenile)	V_{13}	< 1	1.0	< 1	1.0	< 1	1.0
Temperature (Juvenile)	V_{14}	29° C	1.0	32° C	0.7	23° C	0.5
Velocity - Cover	V_{18}	15	1.0	5	1.0	30	0.3

Table D-2. HSI calculation using data from Table D-1.

Component	Data Set 1 SI	Data Set 2 SI	Data Set 3 SI
C_F =	0.80	0.35	0.20
C_C =	1.00	0.62	0.31
C_{WQ} =	0.81	0.40*	0.56
C_R =	0.81	0.48	0.38*
HSI =	0.84	0.40*	0.38*

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

Table D-4. HSI calculation using data from Table D-3.

Component	Data Set 1 SI	Data Set 2 SI	Data Set 3 SI
C_F =	1.00	0.70	0.47
C_C =	1.00	0.46	0.60
C_{WQ} =	0.74	0.30*	0.20*
C_R =	0.81	0.52	0.30
C_{OT} =	0.95	0.55	1.00
HSI =	0.86	0.30*	0.20*

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

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channel catfish, or closely related species, can be expected to have an impact on the carrying capacity of channel catfish habitat. Channel catfish habitat is assumed to consist of four major components: food, cover, water quality, and reproduction. Variables that affect habitat quality, which do not easily fit in these major components, are considered as a minor "other" component. A schematic diagram of the relationship of these components to habitat suitability is provided in Figure D-1. A rating is provided for each component by combining ratings for selected variables, and the component ratings combined into a species HSI.

The component with the lowest rating is assumed to have the greatest impact on the suitability for the species. This assumption can easily be quantified in one of two ways. The first is by use of a geometric mean, which responds more to a change in the lowest value used to calculate the mean than to a change in the other values. The second is a limiting factor approach, whereby the lowest component score is selected as the HSI. The limiting factor approach is used only where there is evidence that a low value cannot be compensated by higher values of another component. This occurs in the water quality and reproduction components because poor water quality causes stress and poor reproductive success would depress populations. If these component ratings are less than or equal to 0.4, the limiting factor approach is used to quantify the assumption that water quality or reproduction is limiting at some low level of suitability. No precise information exists on how the components interact to determine habitat suitability. However, channel catfish occur in a wide variety of habitats and it is likely that a low rating for one component can be compensated by a higher rating in another component, except for low suitabilities for water quality and reproduction.

The model provides a method of rating habitat suitability utilizing the results of both laboratory and field studies on a variety of physiological and population responses to variable changes. The greatest weakness of the model is that the validity of the assumed relationships between the measurable physiological or population response and habitat suitabilities are unknown.

Each variable identified as important in the documentation of species habitat use information was placed in the appropriate component as shown in Figures D-2 and D-3. Some variables (e.g., oxygen concentration) vary on a diurnal or seasonal basis and must be precisely defined so that they may be estimated from field data.

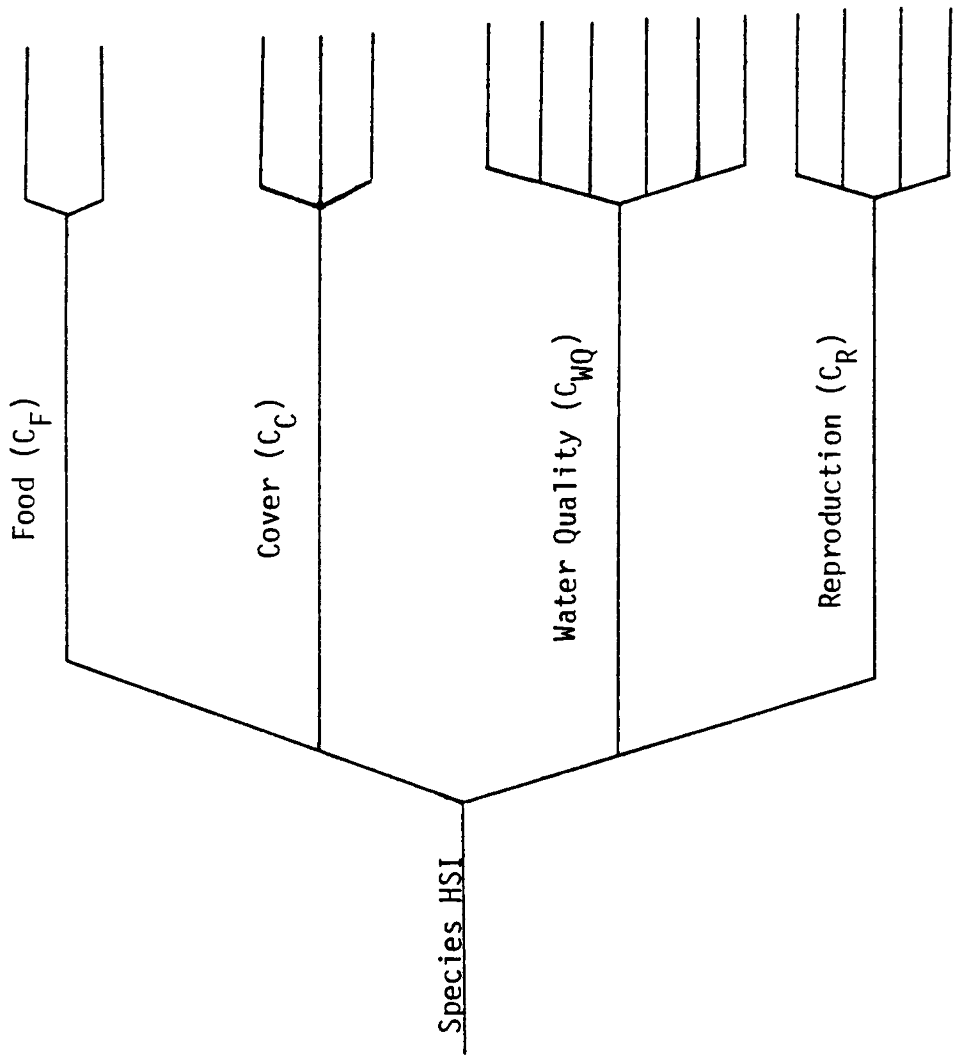


Figure D-1. Schematic diagram of channel catfish habitat model.

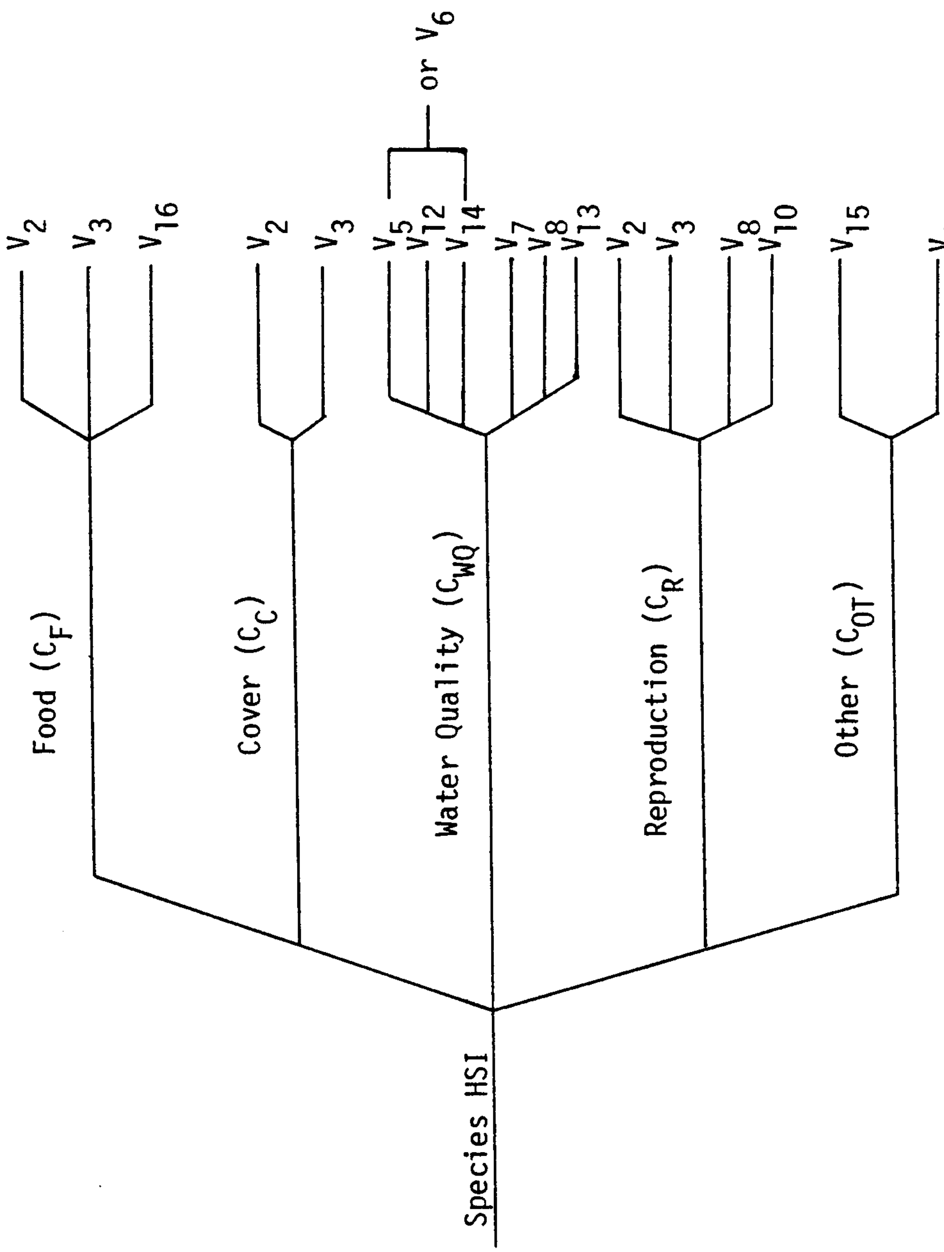


Figure D-2. Variables for each component of the lacustrine version of the channel catfish model.

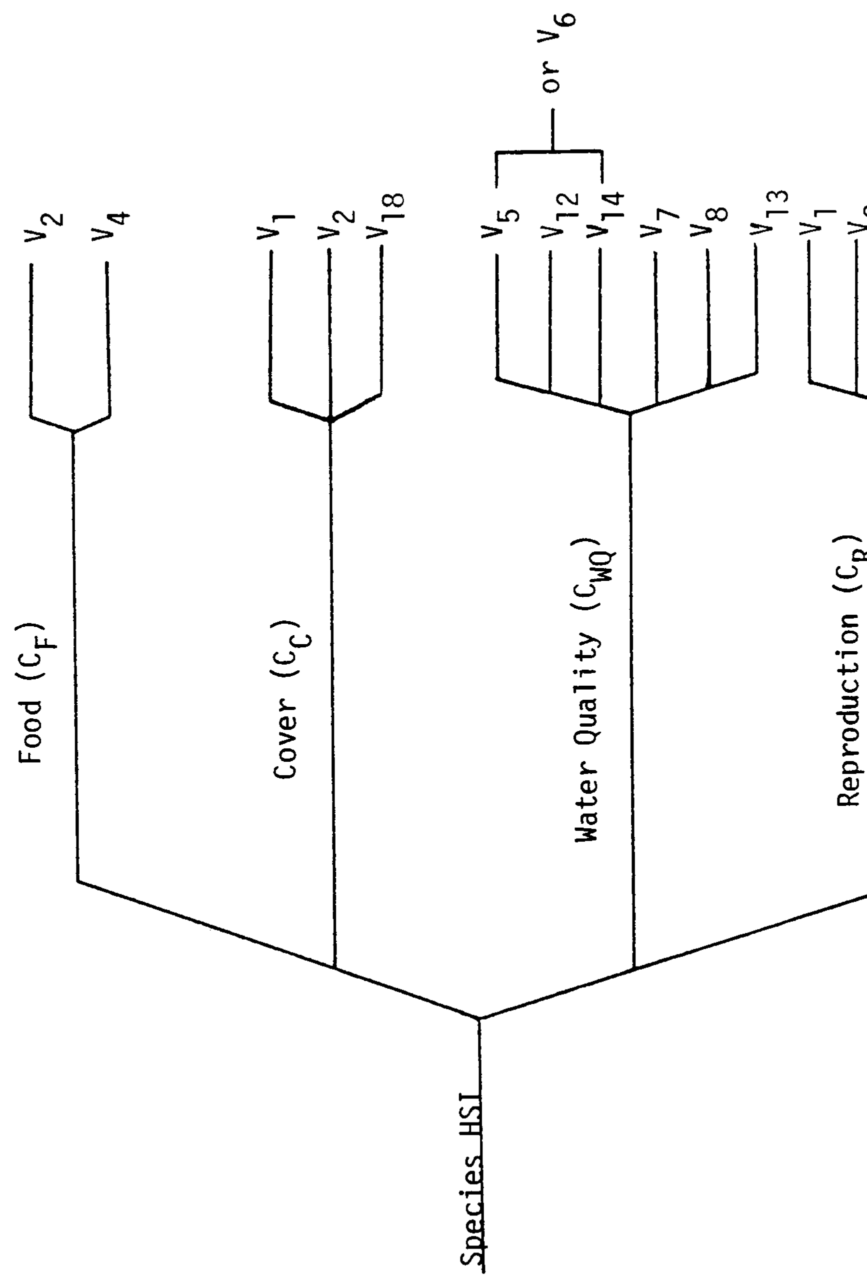


Figure D-3. Variables for each component of the riverine version of the channel catfish model.

Suitability index graphs are based on the assumption that the suitability of a variable can be represented by a two dimensional response surface that is independent of the values of other variables that contribute to overall habitat suitability. This is a critical assumption, because the impact of the variable on the measurable response from which the graphs are derived is often dependent on the value of other variables. For example, the effect of temperature on growth may vary depending on availability of food and the oxygen concentration. Interaction of variables in determining habitat suitability is represented by different aggregation techniques used to combine individual suitability indices. Thus, each graph represents habitat suitability for the variable independent of other variables unless otherwise noted. Weights were assigned to variables based on the opinion of the author (Tom McMahon, Western Energy and Land Use Team, Ft. Collins, Colorado). Sources of data, and assumptions made in drawing each graph are given in Table D-5.

(1) Food component. Percent cover (V_2) is assumed to be important in all habitats 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 for riverine habitats because substrate type in streams and rivers has a great impact on production of aquatic insects which are consumed directly by both channel catfish and channel catfish prey species. Percent littoral area (V_3) is included because littoral areas generally produce the greatest amount of food for catfish. Total Dissolved Solids (TDS) (V_{16}) is in the food component because adult channel catfish eat fish and fish production is correlated to TDS. The component rating is derived by taking an arithmetic mean of the variable ratings because it was assumed that food produced from one source would be just as valuable as food produced from another source.

(2) Cover component. Percent pools (V_1) is included because channel catfish seek cover in deep water, and pools tend to be the deepest portions of riverine habitats. Percent cover (V_2) is an index of all types of objects, including logs and debris, used for cover in lakes and streams. Percent littoral area (V_3) is in the cover component because littoral areas tend to have vegetation that serves as cover, and the cover is especially important when it is near an area likely to produce food. Average current velocity in cover areas (V_{18}) is important since the useable habitat near a cover object decreases if cover objects are surrounded by high velocities.

Table D-5. Data sources and assumptions for channel catfish suitability indices.

	Variable and Source	Assumption
V_1	Bailey and Harrison 1948	Optimum diversity of velocities, depths, and structural features 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	Cover seeking behavior indicates that some cover must be present to reach maximum carrying capacity.
V_3	Bailey and Harrison 1948 Marzolf 1957 Cross and Collins 1975	Food and cover adequate to support maximum population levels can be provided by less than 100% littoral area
V_4	Bailey and Harrison 1948	The substrate that produces the greatest number of insects is considered 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 Jenkins and Morais 1971	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	Near-lethal levels of dissolved oxygen are unsuitable. D.O. levels that reduce feeding are suboptimal.

Table D-5. (continued)

Variable	Source	Assumption
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 suitability.
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 juvenile are optimal, 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 optimal. 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.

Table D-5. (continued)

Variable and Source		Assumption
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 Lantz 1970 Scott and Crossman 1973 Cross and Collins 1975	High average velocities near cover objects will decrease the amount of useable habitat around the objects. Even with high average current velocities, some habitat will be available because velocities immediately behind cover objects will be low.

It is assumed that the lowest individual variable rating in the cover component will be the most important. Some compensation should occur; therefore, a geometric mean is used to combine variable ratings.

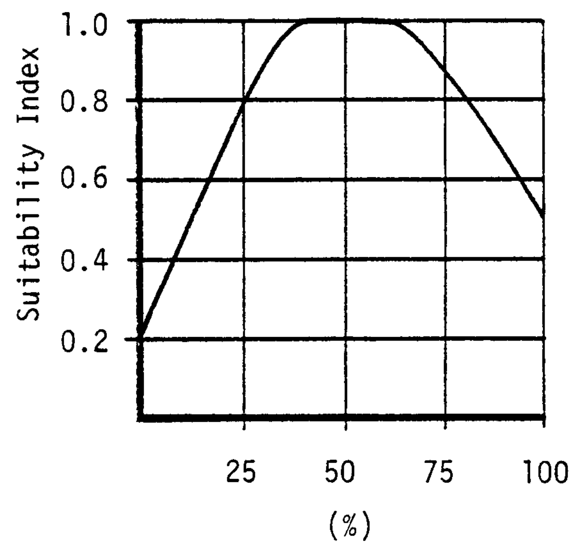
(3) Water quality component. The water quality component is limited to temperature, oxygen, turbidity, and salinity measurements. These parameters have been shown to effect growth or survival, or have been correlated with changes in standing crop, as documented in D.2. Variables related to temperature, oxygen, and salinity were assumed to be limiting when they reach near-lethal levels. Toxic substances are not considered in this model.

(4) Reproductive component. Percent pools during average summer flow (V_1) is in the reproductive component because channel catfish spawn in shallow flooded areas in rivers, and these types of areas are likely to occur if pools (i.e., wide low gradient areas) are present in the summer. Percent cover (V_2) is in the reproductive component since channel catfish use cover to spawn, and if cover objects are inundated during summer water levels, they also should be inundated in spring when the fish spawn. If average minimum dissolved oxygen (D.O.) levels within pools, backwaters, or littoral areas during midsummer (V_8) are adequate during midsummer, they should be adequate during spawning, which occurs earlier in the year. D.O. levels measured during spawning and embryo development could be substituted for V_8. Two additional variables, average water temperatures within pools, backwaters, and littoral areas during spawning and embryo development (V_{10}) and maximum salinity during spawning and embryo development (V_{11}) are selected that describe water quality conditions that effect embryo development.

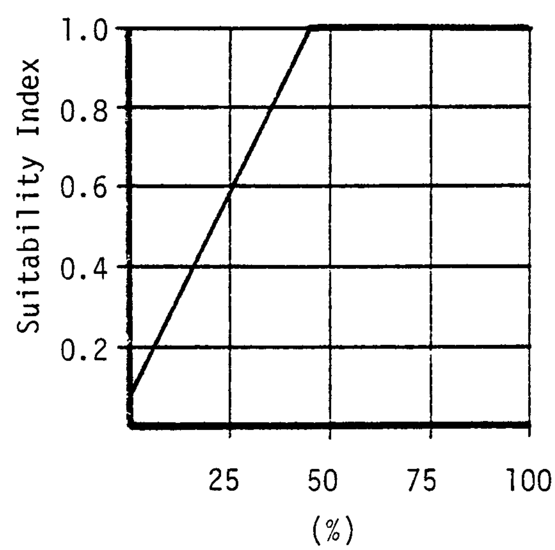
(5) Other component. For reservoirs, the variables storage ratio (V_{15}) and flushing rate when fry are present (V_{17}) were placed in the optional "other" component. Storage ratio may effect standing crop, and the flushing of fry out of a reservoir does not mean reproductive failure, only that the fry are removed from the reservoir.

C. Model relationships. 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.

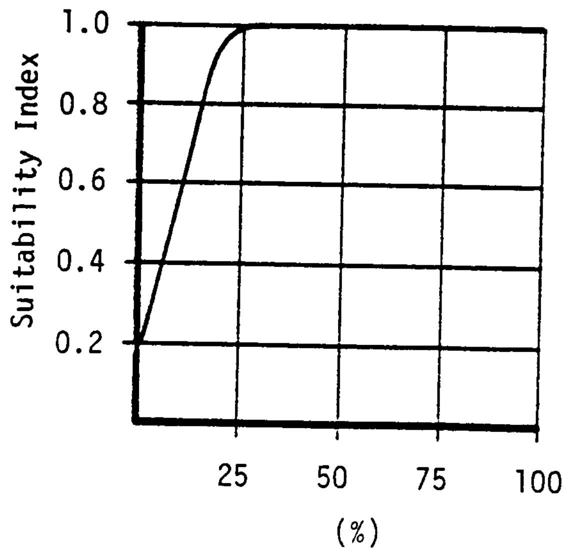
Habitat	Variable	
R	(V_1)	Percent pools during average summer flow.



Habitat	Variable	
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.

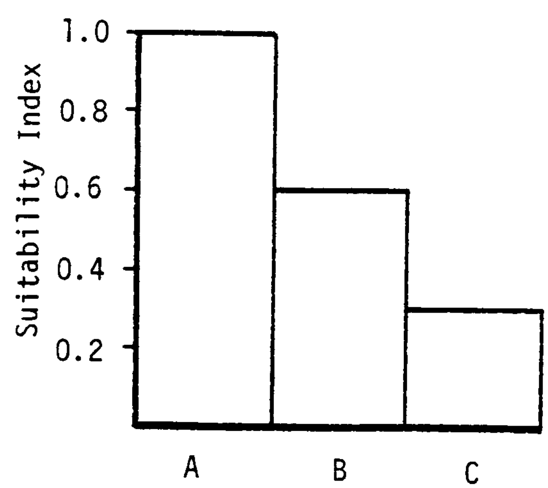


R (V_4) Dominant substrate type--for food production.

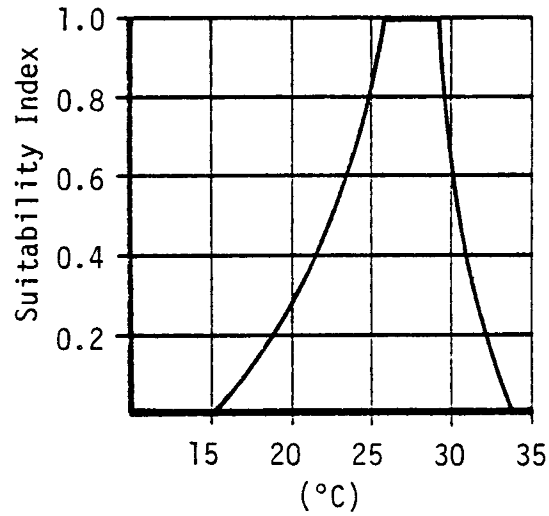
A) Rubble, or aquatic vegetation in spring areas, dominant with limited amounts of gravel and small boulders. Fines and bedrock are not common in riffle/run areas.

B) Rubble, gravel, boulders, and fines occur in approximately equal amounts. Aquatic vegetation may or may not be present.

C) Fines, bedrock, or boulders are dominant. Rubble and gravel are insignificant (≤ 10%).

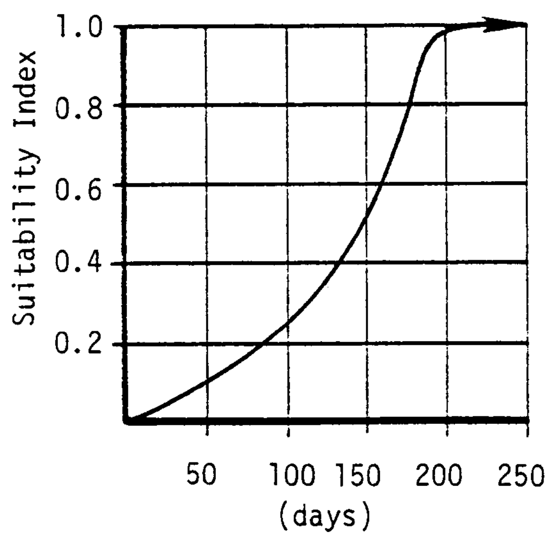


R,L (V_5) Average midsummer water temperature within pools, backwaters, or littoral areas (Adult).

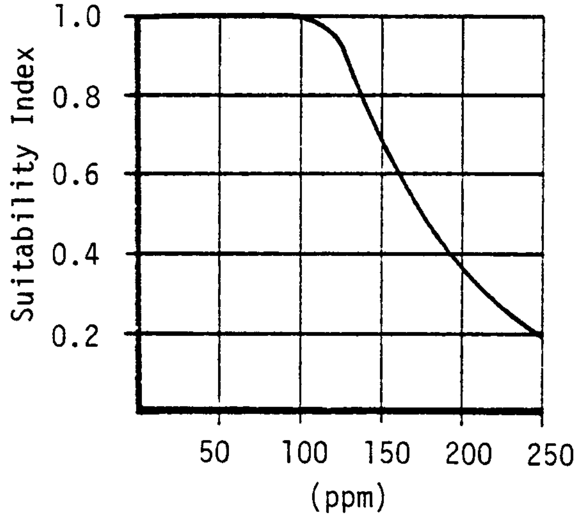


R,L (V_6) Length of agricultural growing season (frost-free days).

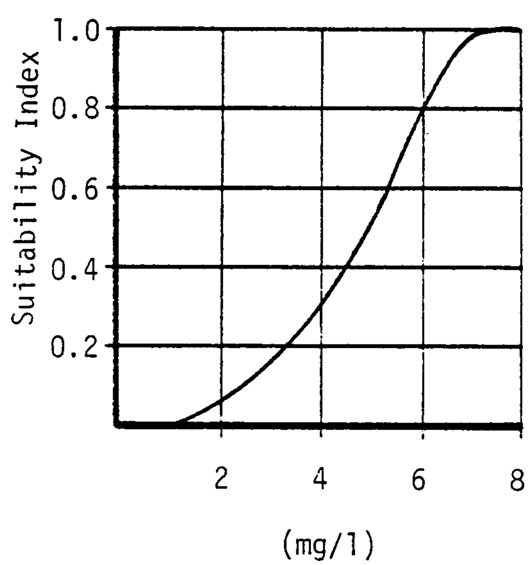
Note: This variable is optional--see Riverine model.



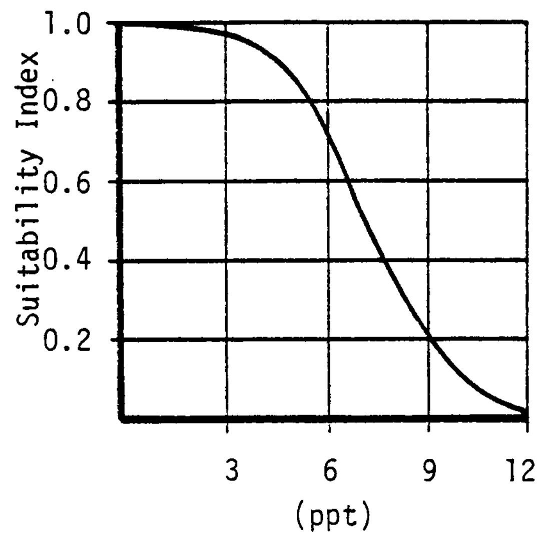
R,L (V_7) Maximum monthly average turbidity during summer.



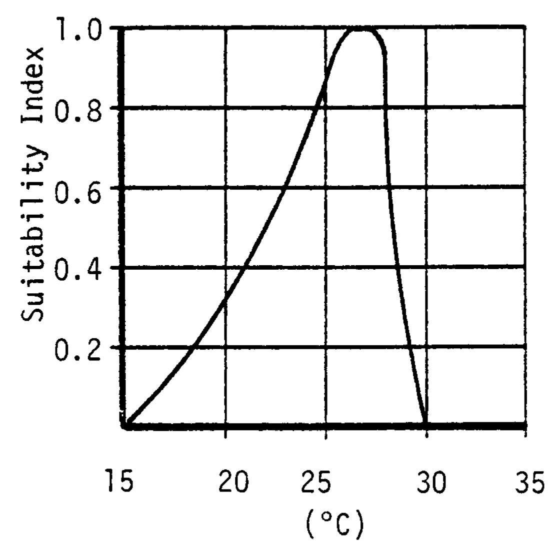
R,L (V_8) Average minimum dissolved oxygen levels within pools, backwaters, or littoral areas during midsummer.



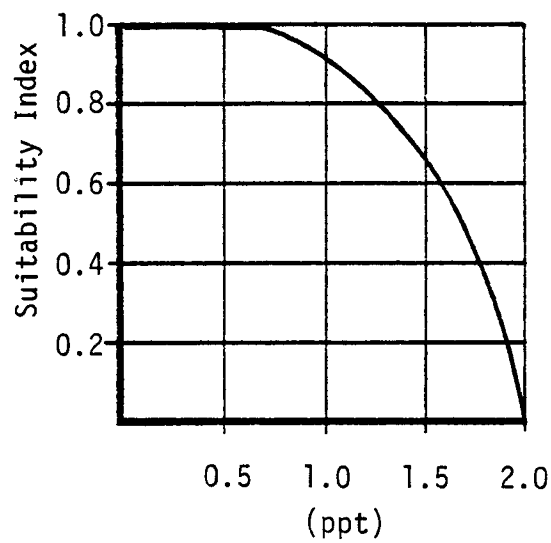
R,L (V_9) Maximum salinity during summer (Adult).



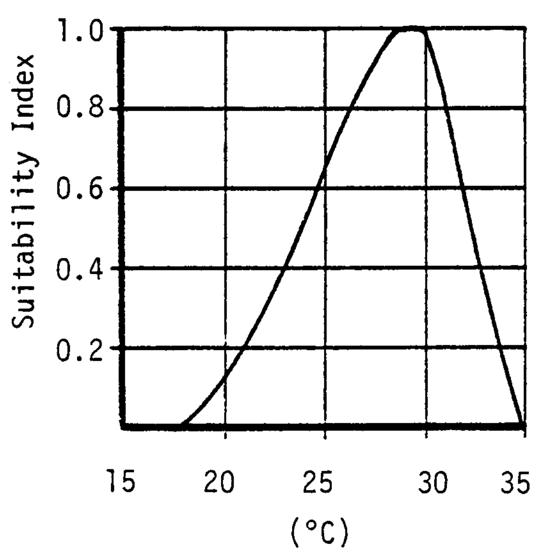
R,L (V_{10}) Average water temperatures within pools, backwaters, and littoral areas during spawning and embryo development (Embryo).



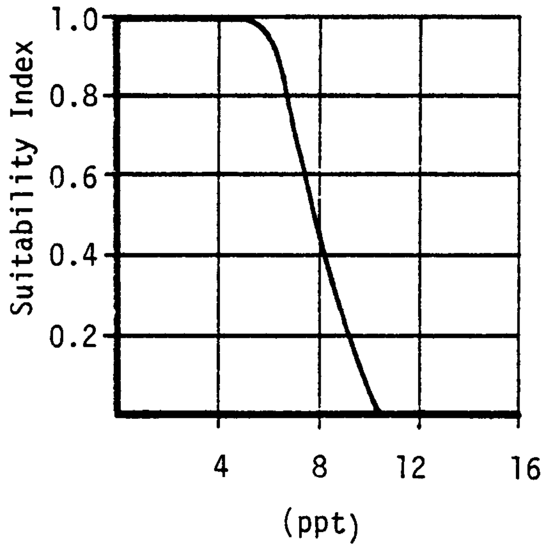
R,L (V_{11}) Maximum salinity during spawning and embryo development.



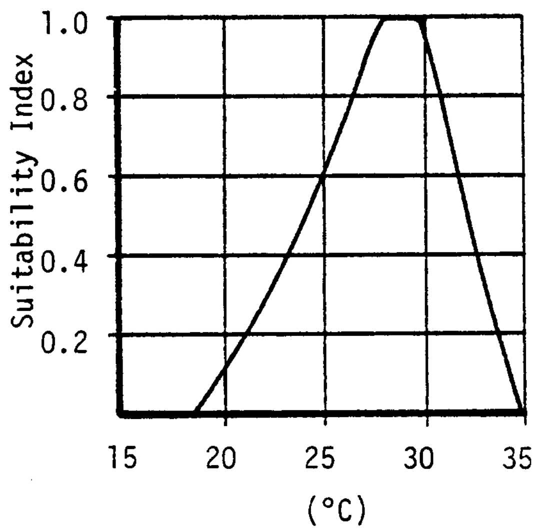
R,L (V_{12}) Average midsummer water temperature within pools, backwaters, or littoral areas. (Fry)



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).



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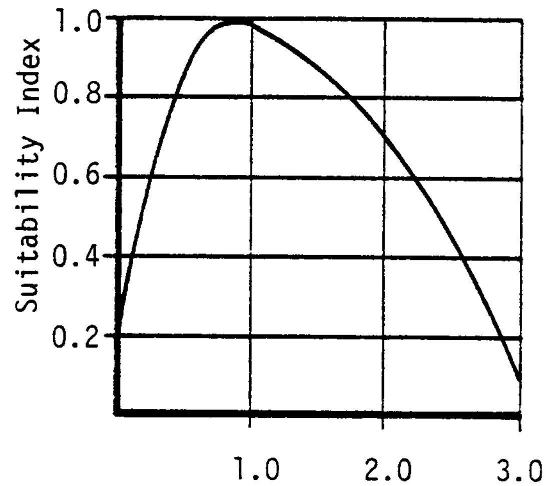
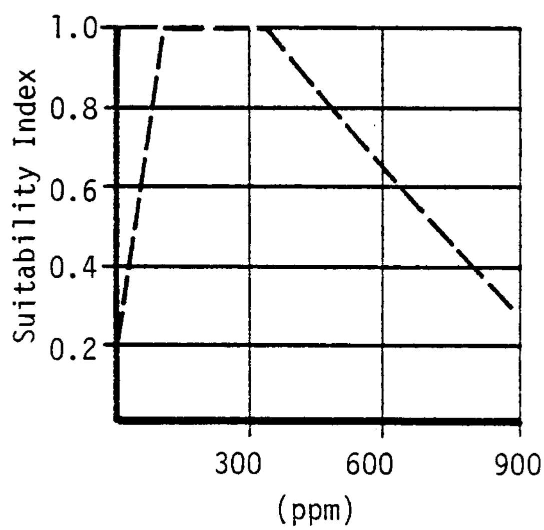
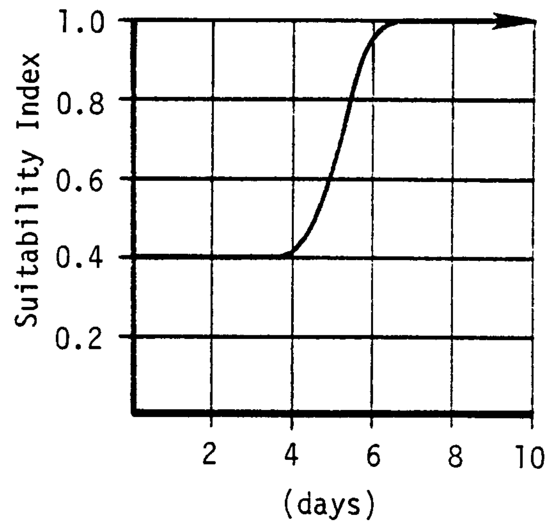
L (V_{15}) Storage ratio.



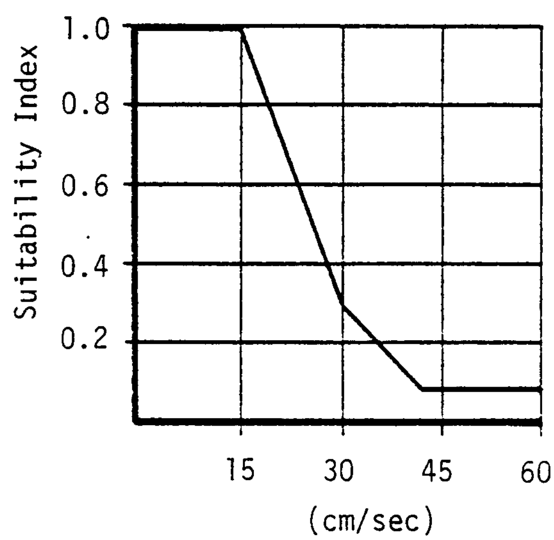
L (V_{16}) Monthly average TDS (total dissolved solids) during summer.



L (V_{17}) Reservoir flushing rate while fry present.



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



D.4 Riverine habitat suitability index equation

A. This equation utilizes the life requisite approach and consists of four components: Food, Cover, Water Quality, and Reproduction.

(1) Food (C_F)

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

(2) Cover (C_C)

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

(3) Water Quality (C_{WQ})

If V_9 and V_{13} both have 1.0 ratings,

$$C_{WQ} = \frac{\frac{2(V_5 + V_{12} + V_{14})}{3} + V_7 + 2(V_8)}{5}, \text{ or}$$

If V_9 and V_{13} have < 1.0 ratings, then

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

Also, for both equations, if V_5, V_6, V_{12}, V_{14}, or V_8 is ≤ 0.4, then C_{WQ} equals the lowest of the following: V_5, V_6, V_{12}, V_{14}, V_8, or the above equations.

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

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

(4) Reproduction (C_R)

If V_{11} rating is 1.0, then

$$C_R = (V_1 \times V_2^2 \times V_8^2 \times V_{10}^2)^{1/7}$$

If V_{11} rating is < 1.0, then

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

(5) HSI determination

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

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.

B. Lacustrine habitat suitability index equation. This equation utilizes the life requisite approach and consists of five components: Food, Cover, Water Quality, Reproduction, and Other.

(1) Food (C_F)

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

(2) Cover (C_C)

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

(3) Water Quality (C_{WQ})

C_{WQ} = same as in Riverine HSI Model

(4) Reproduction (C_R)

If V_{11} rating is 1.0,

$$C_R = (V_2^2 \times V_3 \times V_8^2 \times V_{10}^2)^{1/7}$$

If V_{11} rating is < 1.0, then

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

(5) Other (C_{OT})

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

(6) 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.

D.5 Application of the model

A. Step 1: Select the appropriate model for either riverine or lacustrine-palustrine environments.

B. Step 2: Determine if the model is appropriate to the problem. The model must be sensitive to proposed changes if used for impact assessment, and variable values under future conditions must be predictable. The model is a habitat model, not a population model, and if it is necessary to predict population levels at any point in time a different model may be more appropriate.

C. Step 3: Determine which variables to use in the model. For example, if the average summer temperatures (variables V_5, V_{12}, and V_{14}) cannot be estimated within time and budget constraints, the length of growing season (variable V_6) may be substituted.

D. Step 4: Estimate each variable in the study area based upon the descriptors included in the variable description. Model variables based on parameters that are expected to have spatial variability (e.g. V_{15}, average current velocity during average summer flow), should be calculated from measurements taken along transects. Stream measurements should be taken within a representative reach. Lacustrine-palustrine measurements associated with the shore should be taken within a shore area that is representative of the entire water body. When shore areas are heterogeneous, different sampling strata should be identified. Each variable in the model may be estimated by normally accepted field procedures, data from similar water bodies, or estimates based on experience or visual inspection. The method used to obtain the variable estimate must be recorded. Otherwise, it is impossible to determine if accurate or inaccurate HSI values are due to factors intrinsic or extrinsic to the model.

D.6 Interpreting model output. Habitats with an HSI of 0 may contain some channel catfish; habitats with a high HSI may contain few. If the model is a good representation of channel catfish habitat, then in water bodies where channel catfish population levels are due primarily to habitat related factors, the model should be correlated to long-term, average population levels. However, this has not been tested. The proper interpretation of the HSI produced by the model is one of comparison. If two water bodies have different 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 model assumptions have not been violated.

The HSI is based on how well the sampled area meets all of the requirements of a channel catfish for completing its life cycle. The channel catfish HSI determined by use of this model will not necessarily represent the population of channel catfish present in the sample area. This is because the population of a sample area of a stream or lake does not depend on the ability of that area to meet all life requisite requirements of the species, as is assumed by the model.

D.7 Additional habitat suitability index models. The regression equations for catfishes (Ictaluridae) standing crop developed by Aggus and Morais (1979) may be used to calculate an HSI.

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