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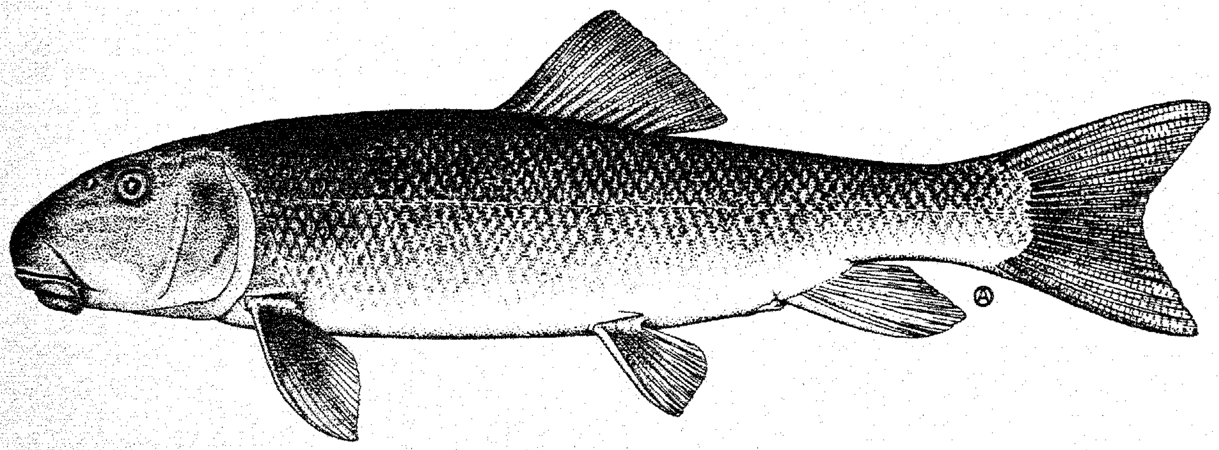
HABITAT SUITABILITY INDEX MODELS AND INSTREAM FLOW SUITABILITY CURVES: WHITE SUCKER



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September 1984

HABITAT SUITABILITY INDEX MODELS AND INSTREAM FLOW SUITABILITY CURVES: WHITE SUCKER

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PREFACE

The habitat use information and Habitat Suitability Index (HSI) models presented in this publication aid in 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 the most important habitat characteristics for the species, are presented. Also included is a brief discussion of Suitability Index (SI) curves as used in the Instream Flow Incremental Methodology (IFIM), and a discussion of SI curves available for the IFIM analysis of white sucker habitat.

Use of habitat information 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 modifying HSI models and recommended measurement techniques for model variables are presented in Terrell et al. (1982).[1] A discussion of HSI model building techniques, including the component approach is presented in U.S. Fish and Wildlife Service (1981).[2]

The HSI models presented herein are complex hypotheses of species-habitat relationships, not statements of proven cause and effect relationships. Results of model performance tests, when available, are referenced; however, models that have demonstrated reliability in specific situations may prove unreliable in others. For this reason, the FWS encourages model users to 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] Terrell, J. W., T. E. McMahon, P. D. Inskip, R. F. Raleigh, and K. L. Williamson. 1982. Habitat suitability index models: Appendix A. Guidelines for riverine and lacustrine applications of fish HSI models with the Habitat Evaluation Procedures. U.S. Fish Wildl. Serv. FWS/OBS-82/10.A. 54 pp.

[2] U.S. Fish and Wildlife Service. 1981. Standards for the development of habitat suitability index models. 103 ESM. U.S. Fish Wildl. Serv., Div. Ecol. Serv. n.p.

CONTENTS

Page

PREFACE iii
TABLES vi
FIGURES vii
ACKNOWLEDGMENTS viii

HABITAT USE INFORMATION 1
    General 1
    Age, Growth, and Food 1
    Reproduction 1
    Specific Habitat Requirements 3
HABITAT SUITABILITY INDEX (HSI) MODELS 6
    Model Applicability 6
    Model Description - Riverine 7
    Model Description - Lacustrine 10
    Suitability Index (SI) Graphs for Model Variables 10
    Riverine Model 18
    Lacustrine Model 21
ADDITIONAL HABITAT MODELS 23
    Model 1 23
    Model 2 23
    Model 3 23
    Model 4 24
    Model 5 24
SUITABILITY INDEX (SI) GRAPHS FOR MODEL 5 26
    Riverine Model 35
INSTREAM FLOW INCREMENTAL METHODOLOGY (IFIM) 38
    Suitability Index Graphs as Used in IFIM 38
    Availability of Graphs for Use in IFIM 40

REFERENCES 52

TABLES

Number		Page
1	Sources of information and assumptions used in construction of the suitability index graphs	15
2	Data sets from application of the riverine HSI model for white suckers at LaGarde Creek, Colorado	19
3	Data sets from application of the riverine HSI model for white suckers at St. Vrain Creek and Big Thompson River, Colorado (Propst 1982a)	20
4	Sample data sets using lacustrine HSI model	22
5	Sources of information and assumptions used in construction of the suitability index graphs	33
6	Sample data sets using HSI Model 5	36
7	Availability of SI curves for the IFIM analyses of white sucker habitat	41

FIGURES

Number Page

1 Tree diagram illustrating relationship of habitat variables and life requisites in the riverine model for the white sucker 8

2 Tree diagram illustrating relationship of habitat variables and life requisites in the lacustrine model for the white sucker 9

3 Tree diagram illustrating relationship of habitat variables and life requisites in riverine HSI Model 5 for the white sucker 25

4 SI curves for white sucker spawning velocity, depth, substrate, cover, and temperature 42

5 SI curves for white sucker egg incubation velocity, depth, substrate, cover, and temperature 44

6 SI curves for white sucker fry velocity, depth, substrate, cover, and temperature 46

7 SI curves for white sucker juvenile velocity, depth, substrate, cover, and temperature 48

8 SI curves for white sucker adult velocity, depth, substrate, cover, and temperature 50

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WHITE SUCKER (Catostomus commersoni)

HABITAT USE INFORMATION

General

The white sucker (Catostomus commersoni) is a highly adaptable, freshwater fish species found in lacustrine and riverine environments from the Mackenzie River, Hudson Bay drainage, and the Labrador Peninsula; south along the Atlantic Coast to western Georgia; along the northern extremes of the Gulf States to northern Oklahoma; north through the eastern sections of Colorado, Wyoming, and Montana; and through Alberta, north-central British Columbia and southeastern Yukon territory (Carlander 1969; Scott and Crossman 1973).

Age, Growth, and Food

Male white suckers typically reach maturity between ages II (Hayes 1956) and VI (Campbell 1935; Geen et al. 1966), depending on geographic location. Females usually mature 1 to 2 years later than males (Spoor 1938). Like most fishes, populations in northern latitudes or at higher altitudes generally have slower growth, mature later, and live longer than more southern or lower elevation populations. Size at sexual maturity ranges from 15 to 23 cm in males (Hayes 1956; Geen et al. 1966) and up to 27 cm in females (Hayes 1956). Ages of X to XII have been reported (Dence 1948; Olson 1963) and a maximum age of XVII was recorded by Beamish (1973).

Sac-fry feed on surface associated zooplankton (e.g., copepods, cladocerans, and rotifers) (Olson 1963; Siefert 1972; Lalancette 1977) or on suspended phytoplankton (Nurnberger 1928; Siefert 1972). After complete yolk absorption (20 to 29 days, at 14 to 18 mm), the mouth moves from a terminal to a ventral position, and an associated shift to bottom feeding occurs (Stewart 1926; Siefert 1972). The diet after yolk absorption consists of benthic organisms, such as chironomid larvae, pupae, and fingernail clams (Olson 1963; Pflieger 1975; Krieger 1980). Juveniles feed primarily on benthic organisms. As size increases with maturation, the size range of food items ingested increases to include amphipods, gastropods, and large immature aquatic insects (Stewart 1926; Dence 1948). White suckers are active and feed throughout the year. Maximum growth occurs from June to August but growth is inhibited during gonadal development and spawning (Lalancette 1977).

Reproduction

White suckers start their upstream spawning migration in spring to early summer, when the daily maximum water temperature reaches 10° C (Olson 1963; Geen et al. 1966; Fuiman 1978; Curry 1979; Walton 1980). The migration continues until the water temperature reaches about 18° C (Raney 1943; Hayes 1956; Olson 1963). Initiation of spawning migrations appears to be either temperature-dependent (Raney and Webster 1942; Dence 1948) and/or stream discharge-dependent (Walton 1980). Sudden temperature drops may diminish or stop migration (Raney and Webster 1942; Dence 1948). White suckers usually migrate from lentic systems or stream pools to spawning riffles; therefore, it is assumed that distance to spawning habitat may be a factor in determining optimum habitat. Raney and Webster (1942) observed white suckers migrating from only a few hundred meters to as much as 6.4 km upstream where obstructions blocked further passage. Dence (1948) reported that a rock ledge 2.5 feet (76.2 cm), with a moderately fast current, stopped the migration of most dwarf suckers, Catostomus commersoni utawana (closely related to the white sucker). Suckers depend to some degree on local landmarks and primarily on olfaction during the spawning run (Dence 1948; Werner 1979); therefore, it is assumed that impacts which could change the spawning stream integrity may affect spawning run success.

White sucker spawning habitat is generally considered to be areas in inlets, outlets, small creeks, and rivers with relatively swift shallow waters running over a gravel bottom (Forbes and Richardson 1920; Dence 1948; Nelson 1968; Carlander 1969; Schneberger 1977). Reighard (1913) suggested that the essential breeding habitat requirement is suitable substrate, not running water, but Curry (1979) indicated that spawning site selection is influenced primarily by water velocity and depth of substrate type. Nelson (1968) reported that spawning over gravel was usually at water depths less than 30 cm. Fuiman (1978) stated that egg collections in his study typically took place in shallow (15 to 20 cm deep) gravel riffles. Curry (1979) reported spawning site depths of 20 to 25 cm.

A clean bottom of coarse sand (Minckley 1963) or gravel is an essential quality of the spawning habitat for white suckers (Dence 1948). Curry (1979) reported that, after white suckers cleaned out a spawning site, the remaining gravel was larger and more free of silt and sand than when the site was selected. Curry (1979) reported that white suckers spawned over medium-sized gravel (2 to 16 mm). Nelson (1968) reported that white suckers apparently seldom spawn in deep waters with a sand bottom, although Raney (1943) observed spawning in a relatively deep, quiet pool with a gravel substrate. Pflieger (1975) reported spawning in gravelly areas near the lower end of pools, in quiet water or where the current begins to quicken. Gravel appears to be the preferred substrate. If access to streams with suitable spawning habitat is limited, lacustrine populations may spawn on sand or gravel shoals subject to wave action (Reighard 1913; Hayes 1956; Olson 1963; Krieger 1980).

Nelson (1968) reported that the velocity in rivers where white suckers congregated for spawning varied from a low of 14 cm/sec to a high of 90 cm/sec. White suckers also were observed in streams with mean spring velocities of 60 to 90 cm/sec (Minckley 1963; Curry 1979). Although white suckers have been observed at velocities > 60 cm/sec, Symons (1976) reported that white suckers in an artificial stream with fast velocity were most often located at modal velocities of 30 to 49 cm/sec. Curry (1979) reported spawning site velocities for white suckers of 50 to 59 cm/sec. Although Dence (1948) never observed suckers in the act of spawning in deep pools where the current was very slow, he suggested that these habitats might be used if more desirable habitats were not available. Therefore, it is assumed that white sucker adults select moderate stream velocities for spawning.

The fertilized eggs adhere to the gravel in riffles or drift downstream where they adhere to the substrate in areas with water of slow velocity (Geen et al. 1966). White sucker fry emerge about 9 to 11 days after hatching and drift downstream at night.

Specific Habitat Requirements

White suckers tolerate a relatively broad range of environmental conditions. Even though white suckers are generalists, optimum habitat conditions for the species can be described.

Stream populations of white suckers reach maximum abundance in low to moderate gradient streams (Stewart 1926). Minckley (1963) and Hocutt and Stauffer (1975) reported white suckers in streams with an average gradient of 6 m/km; Hocutt and Stauffer (1975) collected 70 white suckers at gradients of 2.8 to 7.8 m/km, 28 suckers at gradients of 10 to 13.4 m/km, and only 5 suckers at a gradient of 28.4 m/km. Curry (1979) observed white suckers spawning in streams with gradients of 1.2 to 2.3 m/km.

Adult white suckers (> 150 mm TL) primarily inhabit pools (Propst 1982b) and are common in areas of slow to moderate velocity (approximately 40 cm/sec), although smaller individuals (< 150 mm TL) occur in a greater variety of habitats than adults (Stewart 1926; Scherer 1965; Pflieger 1975; Propst 1982b).

Stewart (1926) was unable to find white suckers in pools that were entirely isolated from any inflow; Propst (1982b) supported the idea that water movement was important because suckers were uncommon or absent at pothole sites with no flow. Symons (1976) reported that white suckers appeared to have trouble maintaining equilibrium in fast or turbulent water and that suckers were sighted more often in artificial streams with slow runs at modal velocities of 10 to 19 cm/sec. Propst (1982b) did not find white suckers in pools with flows > 10 cm/sec and Minckley (1963) found white suckers in pools with flows that were usually near 15 cm/sec. Propst (1982b) reported that substrates in pools inhabited by adult white suckers were a mixture of rubble, gravel, and sand with a silt overburden.

Propst (1982b) reported a high correlation between pool cover and white sucker populations. Minckley (1963) observed that when aggregations of white suckers in pools were disturbed they moved quickly into debris or other cover. Cover, including both streamside cover and within-stream cover, is a very important, if not essential, component of spawning areas for dwarf suckers, *C. c. utawana* (Dence 1948). Thompson and Hunt (1930), Dence (1948), and Propst (1982b) described white sucker habitats with exposed tree roots, numerous drifts of brush and logs against fallen trees, bridge supports, riprapped and undercut banks, and large boulders available as cover. Dence (1948) reported that the dwarf sucker seeks out streams in shaded woods during breeding season. Thompson and Hunt (1930) described white sucker habitat as commonly shaded by trees on the bank or by overhanging grass, weeds, and shrubs.

Pool depth also can provide cover. Dwarf suckers frequently congregate in deeper pools when not spawning (Dence 1948). Suckers are generally easily disturbed and quickly retreat to pools (Stewart 1926). Propst (1982b) collected white suckers at water depths of 21 to 110 cm, but most common depths were 61 to 90 cm. Thompson and Hunt (1930) observed white suckers in slow water habitat at depths of 15 to 240 cm. The value of pools as white sucker habitat is greatly improved when logs, brush, or other types of cover are present (Dence 1948).

Symons (1976) demonstrated that cover-seeking behavior increased significantly as stream velocity increased. Minckley (1963) reported that most white suckers were in deeper pools, with fewer suckers in swifter, shallower water. When white suckers were present in shallow water with an appreciable current, they were usually in the shelter of vegetation. When vegetation was lacking in the stream current, the suckers were in the deepest pools. When white suckers were found in smaller, shallow pools there was an accumulation of debris and overhanging riparian vegetation for cover.

Pools provide habitat with a slower current in which fish can rest. Suckers recuperate in pools after negotiating a difficult stream obstruction during migration or after breeding (Stewart 1926; Dence 1948). Optimum white sucker habitat is assumed to have a pool to riffle/run ratio of 1:1.

White suckers avoided areas in reservoirs where the dissolved oxygen (DO) was ≤ 2.4 mg/l (Dence 1948), but specific information on adult and juvenile dissolved oxygen (DO) requirements generally are lacking. Siefert and Spoor (1974) reported that embryos could not survive DO levels ≤ 1.2 mg/l and that the growth of fry was reduced at DO levels < 2.5 mg/l. Minckley (1963) described an abundant white sucker population in a portion of a stream that had yearly DO values ranging from 4.3 mg/l to an occasional average supersaturation level of 14.79 mg/l.

White suckers have been collected from areas with a pH as low as 4.3 (Dunson and Martin 1973), but Beamish (1974) reported sharp declines in white sucker populations in Canadian lakes when the pH was lowered to 4.5 to 5.0 as a result of acid precipitation. Laboratory studies on the effects of pH on white sucker growth and survival indicated that feeding stops at a pH of 4.5 and death occurs at a pH of 3.0 to 3.8 (Beamish 1972). Maximum successful reproduction occurs at a pH above 5.8 (Trojnar 1977). The pH range which is generally considered not harmful to fish is 5.0 to 9.0; the further the pH varies from this range, the lower the water quality. Laboratory data indicate that a pH between 9 and 10 may be harmful to some fish species, and that a pH above 10 usually is lethal to all species (EIFAC 1969).

White suckers can survive in turbid waters, but they are more common in clearer streams (< 50 JTU) and lakes (Pflieger 1975) and prefer relatively clear spawning streams (Raney and Webster 1942). Young-of-the-year, juveniles, and adults have been reported in the Missouri and James Rivers (North Dakota) at relatively consistent turbidities of 50 to 135 JTU's. Smaller numbers of white suckers occur in the Colorado and Yampa Rivers (Colorado) at more variable turbidities of 85 to 100 and up to 350 JTU's (R. Muth, pers. comm.). Pflieger (1971) stated that white suckers are uncommon in large turbid rivers.

Adult. White suckers have broad temperature tolerances, and optimum temperatures vary geographically. White suckers occur in Illinois headwater streams with summer temperatures up to 32° C (Thompson and Hunt 1930). A preferred temperature range of 19 to 21° C was reported for a Colorado reservoir (Horak and Tanner 1964). Experimental evidence suggests an optimum summer water temperature of 24° C (Reynolds and Casterlin 1978). Reutter and Herdendorf (1976) reported a critical thermal maximum for white suckers of 31.6° C. Brett (1944) reported an upper lethal temperature of 31.2° C for suckers acclimated at 26° C. Specific minimum temperatures have not been reported, but the wide distribution of white suckers indicates that they can survive temperatures as low as 1 to 2° C. For example, Minckley (1963) reported average January temperatures between 1.1 and 2.2° C in Doe Run, Kentucky, where white suckers occurred.

Embryo. Embryo development is temperature dependent (Raney and Webster 1942; Geen et al. 1966). Fuiman (1978) collected eggs in streams with water temperatures ranging from 11 to 16° C. McCormick et al. (1977) reported maximum hatching success at 15° C. Hatching success diminished significantly at temperatures $< 9°$ C or $> 17°$ C, and upper and lower lethal limits were 24° C and 6° C, respectively.

Larval. White sucker larvae apparently prefer water temperatures of 23 to 25° C, but occur in water temperatures of 13 to 25° C (Marcy 1976). The greatest growth was obtained experimentally in water that was 27° C, and the upper lethal limit was 30 to 32° C (McCormick et al. 1977). Krieger (1980) reported that the highest larval densities in lacustrine habitats were in shoreline areas with sand and sand/gravel substrate combinations. Few larval fish occurred in areas with a rock substrate, and no larval fish occurred in areas with silty sand or boulders. Thompson and Hunt (1930) usually found young suckers in streams where the substrate was a mixture of sand and gravel. White sucker fry prefer moderate currents and do not occur in rapids or still pools, although they may be present in intermediate situations where the stream enters deep, quiet stretches (Stewart 1926). Young suckers in the surface-feeding stage appear to congregate in eddies and backwaters in response to gentle currents.

Juvenile. Upper lethal temperature limits for juvenile white suckers were 26 to 31° C at acclimation temperatures of 5 to 25° C (Brett 1944; Carlander 1969). At acclimation temperatures of 20 to 25° C, the reported lower lethal temperatures were 2 to 6° C (McCormick et al. 1977). Small white suckers (< 150 mm TL) have been collected from shallow backwaters, riffles with moderate water velocity (approximately 50 cm/sec), and sand-rubble bottom runs (Propst 1982b).

HABITAT SUITABILITY INDEX (HSI) MODELS

Model Applicability

Geographic area. This model is applicable throughout North America where white suckers occur. The standard of comparison for each individual variable Suitability Index (SI) is the optimum value that occurs anywhere within this geographic range.

Season. The lacustrine model provides a rating for lake or reservoir habitat based on its ability to support all life stages of white suckers throughout the year. The riverine model can be used two ways: (1) to provide a rating for streams and rivers used by resident white sucker populations throughout the year; or (2) it may be incorporated into the lacustrine model to provide a rating for tributary streams or rivers during the spawning and fry migration period when these streams serve as recruitment areas for the lake population.

Cover types. Riverine and lacustrine.

Minimum habitat area. Minimum habitat area is defined as the minimum area of contiguous suitable habitat that is required for a population to maintain itself indefinitely. The minimum habitat area necessary for a white sucker population has not been established.

Verification level. The acceptance level of the lacustrine and riverine model is that it produces an index between 0 and 1 which the authors believe has a positive relationship to carrying capacity for white suckers. Data from LaGarde Creek, Colorado, was used to evaluate the riverine HSI model (Table 2). The low HSI's generated for LaGarde Creek indicated poor habitat, and white suckers did not occur in the study reach.

The riverine HSI model also was tested with data from eight sites in the St. Vrain Creek and Big Thompson River, Colorado, that had viable white sucker populations. Sites with low HSI's were assumed to have a correspondingly lower relative abundance of white suckers than sites with higher HSI's. A poor correlation or lack of correlation between relative abundance and HSI's might indicate that the model is inadequate or that species interactions may have a significant influence on relative abundance. The correlation coefficient between the relative abundance of white suckers and the HSI's was moderate (r = 0.477) (Propst 1982a). The data sets determined by sampling are given in Table 3. This moderate correlation between the HSI's and the relative abundance of white suckers may be the result of two factors. The first factor is that there may have been inadequate differentiation between life stage requisites. White sucker fry and juveniles occur in a greater variety of habitats (shallow riffles, slow runs, along edges, and backwater pools), while white sucker adults (> 150 TL mm) are usually more common to pool habitats (Propst 1982b). The second factor is that white suckers of all life stages have the ability to survive in a variety of conditions. In stressed streams (or sections) which would have low HSI's, white suckers may account for 50 to 80% of the relatively few species (3 or 4) of the fish population found. While in less stressed environments more species are present and the relative abundance of white sucker is lower (Propst 1982a). This phenomenon could occur when the high tolerance of white suckers allows them to survive periods of stress that are lethal to other species, thus affecting the HSI and relative abundance correlation.

In order to achieve a better correlation between HSI's and white sucker relative abundance in riverine habitats, an additional model (Model 5) was developed. More importance was given to cover with the addition of variables for stream cover, percent shade, and pool depth. The importance of pool velocity was considered by adding pool velocity and gradient variables. These variables were intended to better define adult white sucker habitat. This model has not been field tested. Decisions on which, if any, model to use should be made by the potential user and will depend on the user's needs and resources available.

The lacustrine model was tested by entering reasonable combinations of habitat variable values into the model (Table 4) and examining the model output. The HSI's resulting from the model reflected assumed carrying capacity trends in habitats with the same characteristics as the sample data sets.

Model Description

Because white suckers are opportunistic feeders, we did not consider food to be important in determining white sucker habitat suitability. In unproductive lakes and streams food may influence abundance. However, measures of lake and stream productivity for white suckers have not been quantified. We assumed that habitat quality is determined primarily by cover, water quality, and spawning habitat. These were used as model components. Component ratings were derived from individual variable suitability indices (Figs. 1 and 2). Reasons for placing individual variables in specific components and assumed variable interactions are described below.

Model Description - Riverine

Water quality component. The water quality component consists of turbidity (V_1), pH (V_2), dissolved oxygen (V_3), and temperature (V_4). These variables affect growth, survival, and/or distribution of white suckers. Suboptimum levels of these variables, as defined by the suitability index graphs, result in negative effects on individuals. Toxic substances are not considered in this model.

Reproduction. Temperature during spawning (V_6) is included in the reproduction component because it is believed to be a primary factor influencing initiation of spawning migration. Discharge may also be important, but would be variable depending on the size of a river or stream. Also, less suitable discharge levels can likely be compensated for by selection of more favorable

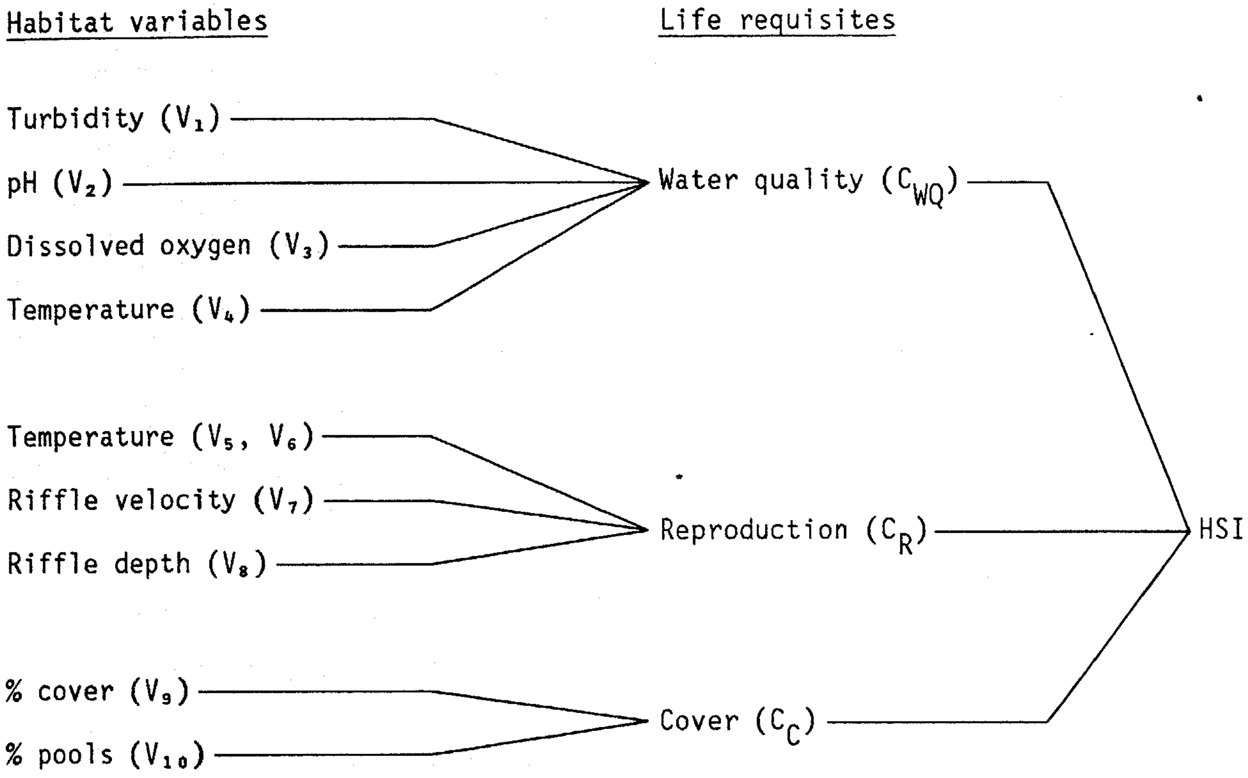


Figure 1. Tree diagram illustrating relationship of habitat variables and life requisites in the riverine model for the white sucker.

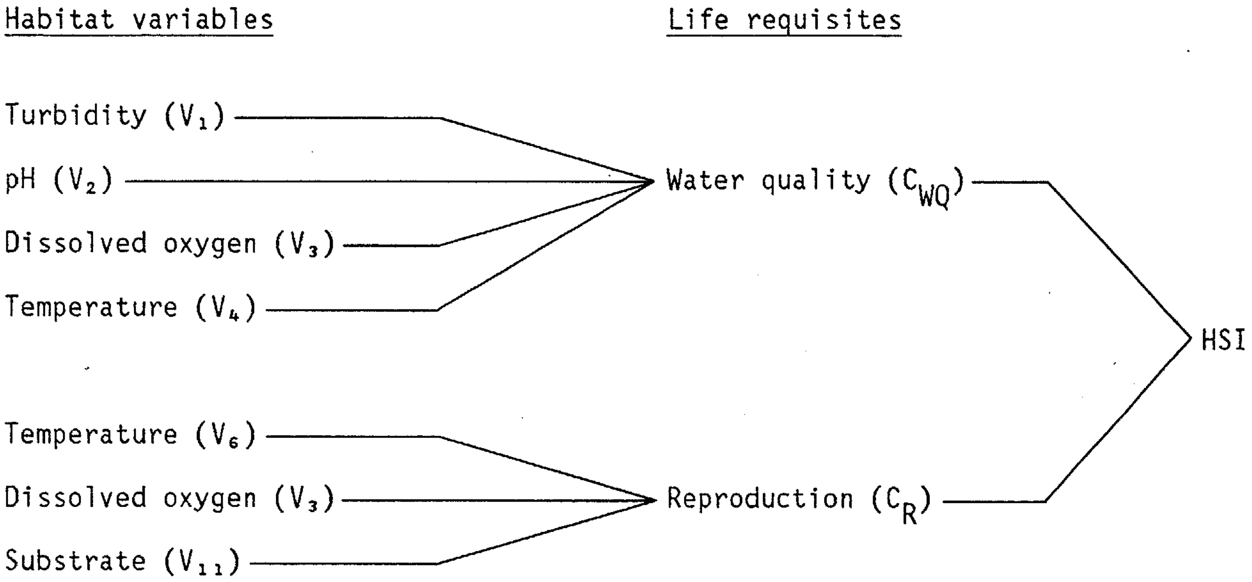


Figure 2. Tree diagram illustrating relationship of habitat variables and life requisites in the lacustrine model for the white sucker. When spawning occurs in inlet streams, riverine measurements for reproduction and water quality may be substituted for the reproduction component.

velocity and depth. Riffle velocity (V_7) and depth (V_8) are important for spawning site selection. Temperature during larval development (V_5) is important to larval ontogeny and survival and to the timing of migration of larvae to a lake or riverine rearing area. The time periods specified for each variable (e.g., April through July) indicate when the variables are important for the specified life stage throughout the entire range of the species. If one of these suitability indices is used in an HSI model developed to rate habitat, the time period when the life stage is actually present, or expected to be present, should be used.

Cover. Shelter availability and presence of resting areas (V_9) is assumed to enhance the carrying capacity of streams for white suckers. Percent pools (V_{10}) was included because pools serve as resting areas before spawning and provide cover in the form of deeper water.

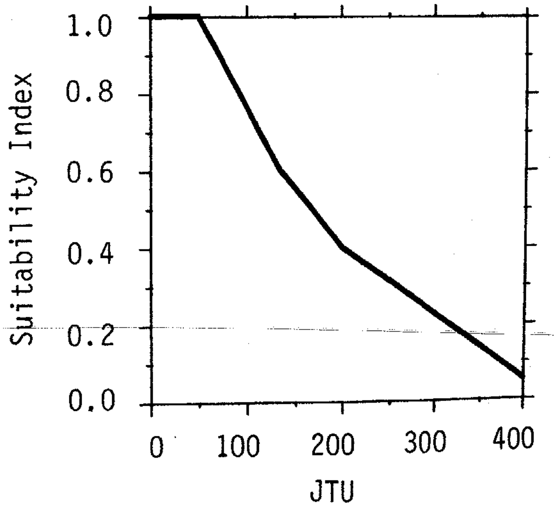
Model Description - Lacustrine

Water quality component. Refer to riverine model description.

Reproduction component. Lacustrine populations of white suckers spawn in tributary streams or in littoral areas over sand and sand/gravel substrates (V_{11}) at suitable temperatures (V_6) and dissolved oxygen levels (V_3), any of which can be limiting. If stream spawning occurs, the reproduction component rating is derived from measurements taken in the riverine environment.

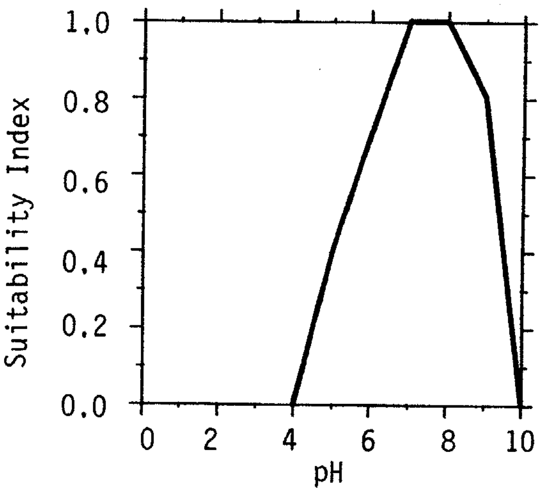
Suitability Index (SI) Graphs for Model Variables

Suitability indices for selected variables are given below. The "R" for riverine and "L" for lacustrine, under the heading "Habitat", describe where the variable should be measured. Sources of data and assumptions used to develop the suitability indices are listed in Table 1.

Habitat	Variable		Suitability graph
R,L	V_1	Maximum monthly average turbidity during the year.	

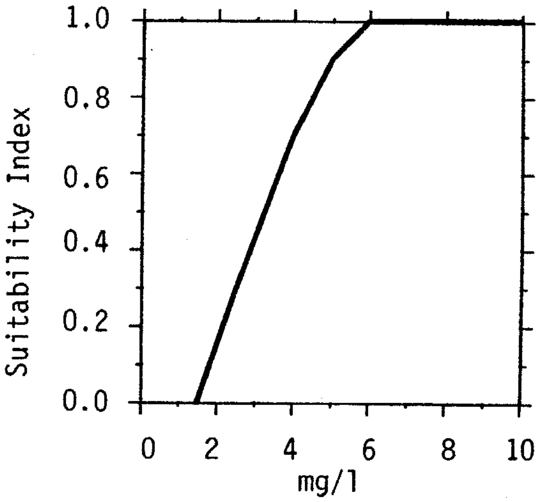
R,L V_2

Weekly average pH during year under stable conditions. If frequent (diurnal), large (> 1.0 pH unit) changes occur, SI score should be reduced by 10%.



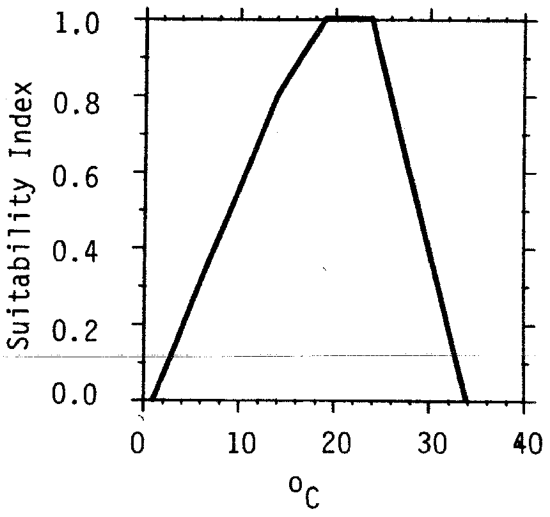
R,L V_3

Minimum dissolved oxygen levels near sunrise during May through August in areas of most suitable water temperature.

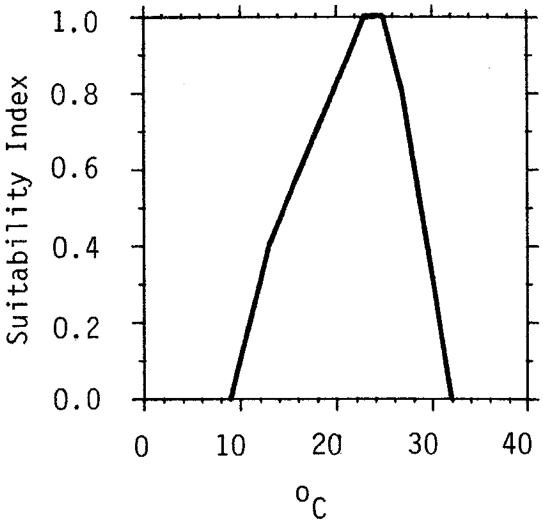


R,L V_4

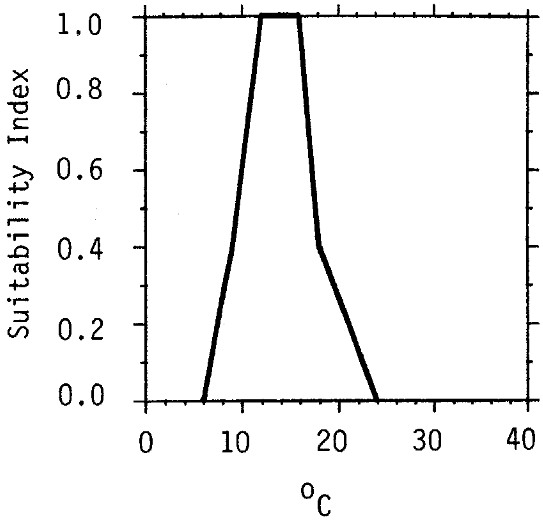
Average of mean weekly water temperatures at mid-afternoon during July and August (Adult and Juvenile).



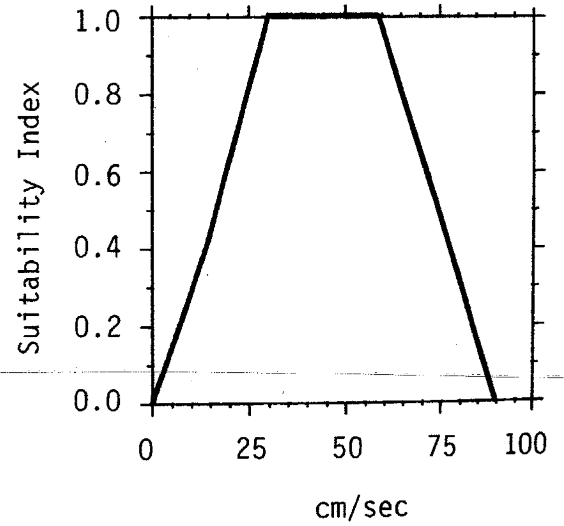
R,L V_5 Average of mean weekly water temperatures during July and August (Fry).



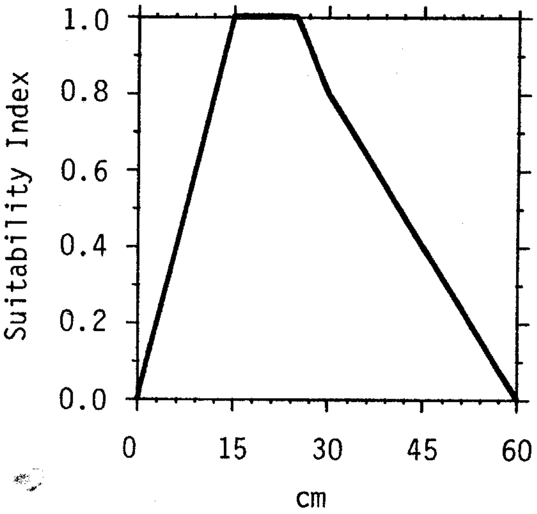
R,L V_6 Average of mean weekly water temperatures during spawning and incubation (April through July) (Embryo).



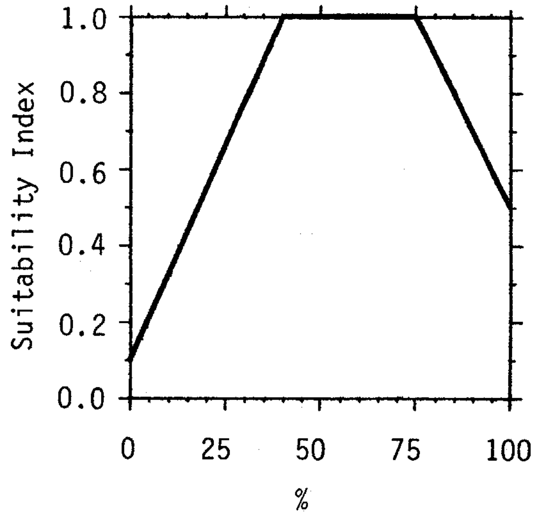
R V_7 Average riffle velocity during spawning and incubation (April through July) (Embryo).



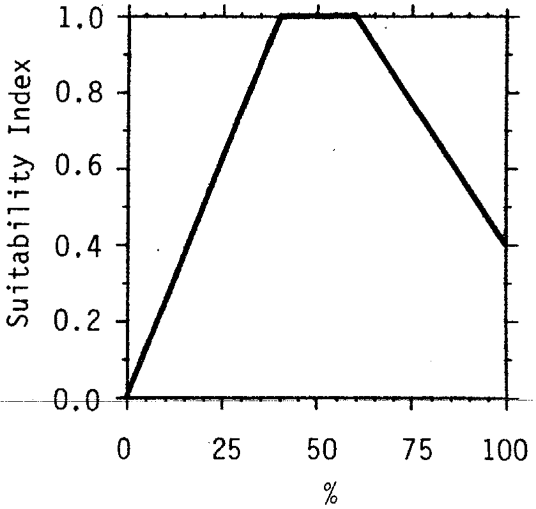
R V_8 Mean riffle depth during spawning and incubation (April through July) (Embryo).



R V_9 Percent instream and overhanging shoreline cover (e.g., roots, brush, logs, willows, undercut banks, and grass).



R V_{10} Percent pools during average summer flows (July through August) (Adult, Juvenile, and Fry).



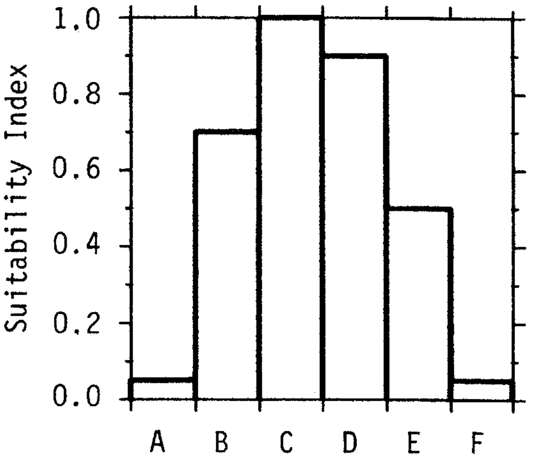
L	V_{11}	Littoral spawning substrate. A. Clay, silt, very fine sand (< 0.25 mm), SI = 0.05. B. Medium to coarse sand (0.25 to 1 mm), SI = 0.7. C. Very coarse sand (1 to 2 mm), SI = 1.0. D. Gravel-granule (2 to 4 mm), SI = 0.9. E. Gravel-small pebble (4 to 16 mm), SI = 0.5. F. Pebble (large), cobble, boulders, (> 16 mm), SI = 0.05. Adjust SI according to mixture of substrate sizes, by judgment. (Substrate categories adapted from Cummins 1962; Cummins and Lauff 1969).	

Table 1. Sources of information and assumptions used in construction of the suitability index graphs. "Excellent" habitat for the white sucker was assumed to correspond to an SI of 0.8 to 1.0, "good" habitat to an SI of 0.5 to 0.7, "fair" habitat to an SI of 0.2 to 0.4, and "poor" habitat to an SI of 0.0 to 0.1.

Variable	Assumption and sources
V_1	Although white suckers can tolerate a wide range of turbidities, clear waters (< 50 JTU) are considered excellent (Raney and Webster 1942; Pflieger 1975). Waters of 50 to 150 JTU are good to fair depending on the range of turbidity variability. Rivers exhibiting constant turbidities are more conducive to stable, wide spread white sucker populations than rivers which have widely variable turbidities even if moderate (Muth pers. comm. 1983). High turbidities are judged to be fair to poor depending on the variability and length of time a habitat is turbid because reduced populations have been reported in turbid waters (Muth pers. comm. 1983; Pflieger 1971).
V_2	The pH ranges which cause population declines or result in slower growth are suboptimal (EIFAC 1969; Beamish 1972, 1974). Levels of pH which allow maximum growth and reproduction are optimum (EIFAC 1969; Trojnar 1977). It is assumed that frequent pH fluctuations are suboptimum.
V_3	Dissolved oxygen levels which are low enough to cause white suckers to avoid the area (2.4 mg/l) (Dence 1948), or are inadequate for reproductive success (≤ 1.2 mg/l), or decrease growth (< 2.5 mg/l) (Siefert and Spoor 1974) are poor. Dissolved oxygen levels ≥ 6 mg/l are generally considered optimum and D.O. levels in which white sucker populations can be successfully maintained, reproduce, and grow would be judged as at least fair to good.
V_4	Temperatures which correspond to optimum growth and activity are considered excellent (Horak and Tanner 1964; Reynolds and Casterlin 1978). Temperatures which are lethal are judged poor (Brett 1944; Carlander 1969; McCormick et al. 1977). White suckers, when acclimated, can survive a wide range of temperatures when the temperature extremes are common to the area and seasonal. These temperatures are rated poor to fair (Thompson and Hunt 1930; Minckley 1963).

Table 1. (continued).

Variable	Assumption and sources
V_5	Temperatures which allow larval white suckers optimum growth are excellent (McCormick et al. 1977) and temperatures in which the larvae can be commonly found are good (Marcy 1976). Temperatures which are lethal, cause high incidence of deformities, or allow little or no growth are considered poor (McCormick et al. 1977).
V_6	Temperatures which allow maximum hatching rates and at which collection of viable eggs occurs are good to excellent (McCormick et al. 1977; Fuiman 1978; Kreiger 1980; Curry 1979). If hatching rates are diminished, the temperatures are considered fair and if hatching rates are very low or nonexistent the temperatures are judged poor.
V_7	White suckers have not been observed spawning in areas of no flow or in very fast (> 90 cm/sec) riffle areas, therefore, these riffle velocities are judged as poor (Dence 1948; Symons 1976). White suckers, when in fast waters, preferred areas of moderate velocities (30 to 49 cm/sec) (Symons 1976) and were observed spawning at velocities of 50 to 59 cm/sec (Curry 1979), these velocities are assumed excellent.
V_8	Spawning is reported most often to take place in shallow riffles (Dence 1948; Geen et al. 1966). Spawning has been reported to take place at depths of 30 cm (Nelson 1968) and 20 to 25 cm (Curry 1979) and Fuiman (1978) has collected white sucker eggs at depths of 15 to 20 cm. Depths at which eggs were deposited or spawning observed are considered excellent. Increasing depths and decreasing depths were assumed to exhibit less optimum to poor conditions, respectively.
V_9	Propst (1982b) reported a high correlation between pool cover and white sucker populations. Total cover is considered good and cover of 40 to 75% is assumed excellent. An absence of stream cover is assumed poor.

Table 1. (concluded).

Variable	Assumption and sources
V_{10}	White suckers utilize pools for resting after negotiating obstructions during migration and spawning (Stewart 1926; Dence 1948). Larval white suckers feed in quiet eddies and gentle currents (Stewart 1926); adult white suckers are primarily pool inhabitants (Propst 1982b) and seek out pools for cover (Stewart 1926; Raney 1943; Dence 1948; Nelson 1968). Streams without pools are suboptimum and streams with 40% to 60% pools are considered optimum.
V_{11}	It has been reported that lacustrine populations spawn on sand or gravel shoals subject to wave action (Reighard 1913; Hayes 1956; Olson 1963) and that the highest larval densities were found over sand and sand/gravel substrates in littoral regions (Krieger 1980). It is assumed that optimum lentic spawning substrate is coarse sand and/or granule gravel. Large pebbles and boulders or silt substrates are poor. Medium sand or small pebble substrates are good to fair.

Riverine Model

This model utilizes the life requisite approach and consists of three components: cover; water quality; and reproduction. The generated HSI applies to resident fish in streams. However, the water quality and reproduction components can also be used for deriving a reproduction component score in the lacustrine model.

Water Quality (C_{WQ}).

C_{WQ} = the lowest SI rating of V_1, V_2, V_3, or V_4.

Reproduction (C_R).

C_R = the lowest SI rating of V_5, V_6, V_7, V_8.

Cover (C_C).

$$C_C = \frac{(V_9 + V_{10})}{2}$$

HSI determination.

$$HSI = (C_{WQ} \times C_R \times C_C)^{1/3}$$

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

Data from application of the riverine HSI model at LaGarde Creek, Colorado, are listed in Table 2. Data from application of the riverine HSI model at St. Vrain Creek and Big Thompson River, are listed in Table 3.

Table 2. Data sets from application of the riverine HSI model for white suckers at LaGarde Creek, Colorado.

Variable		Data set 1		Data set 2		Data set 3	
		Data	SI	Data	SI	Data	SI
Turbidity (JTU)	V_1	Visually observed	1.00	Visually observed	1.00	Visually observed	1.00
pH	V_2	7.5	1.00	7.7	1.00	7.7	1.00
Dissolved oxygen (mg/l)	V_3	-	1.00	-	1.00	-	1.00
Temperature - adult/juvenile (°C)	V_4	20.0	1.00	12.2	0.70	16.0	0.90
Temperature - fry (°C)	V_5	20.0	0.85	11.0	0.28	18.0	0.75
Temperature - embryo (°C)	V_6	19.0	0.30	12.0	1.00	17.8	0.40
Riffle velocity spawning/embryo (cm/sec)	V_7	0.00	0.00	8.10	0.23	3.00	0.10
Riffle depth (cm)	V_8	16.0	1.00	26.0	0.95	25.0	1.00
Percent cover	V_9	18.5	0.50	4.0	0.20	3.0	0.18
Percent pools	V_{10}	82.0	0.70	53.0	1.00	49.0	1.00
Component SI							
C_{WQ} =			1.00		0.70		0.90
C_R =			0.00		0.23		0.10
C_C =			0.60		0.60		0.59
HSI =			0.00		0.23		0.10

Table 3. Data sets from application of the riverine HSI model for white suckers at St. Vrain Creek and Big Thompson River, Colorado (Propst 1982a).

Variable		St. Vrain Creek								Big Thompson River							
		Hygiene		Longmont		RR		Gowanda		Mtn. View		Sewage		Pond		Johnstown	
		Data	SI	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI
Turbidity (JTU)	V_1	a	1.00	a	1.00	a	1.00	a	1.00	4.1	1.00	7.1	1.00	7.7	1.00	16.0	1.00
pH	V_2	7.8	1.00	8.5	0.90	8.3	0.95	8.8	0.83	8.0	1.00	7.8	1.00	8.5	0.90	8.5	0.90
Dissolved oxygen (mg/l)	V_3	9.2	1.00	8.4	1.0	8.4	1.00	8.8	1.00	10.6	1.00	7.4	1.00	8.0	1.00	10.0	1.00
Temperature (adult/juvenile) (° C)[b]	V_4	21.5	1.00	12.0	0.70	13.5	0.80	20.0	1.00	14.0	0.80	13.0	0.75	16.0	0.90	19.0	1.00
Temperature (fry)[b] (° C)	V_5	21.5	0.93	12.0	0.35	13.5	0.45	20.0	0.85	14.0	0.48	13.0	0.45	16.0	0.60	19.0	0.80
Temperature (spawning/embryo)[c] (° C)	V_6	10.0	0.65	10.0	0.65	10.0	0.65	10.0	0.65	10.0	0.65	10.0	0.65	10.0	0.65	10.0	0.65
Riffle velocity (spawning/embryo) (cm/sec)	V_7	d	0.9	d	1.00	d	1.00	d	0.85	d	1.00	d	1.00	d	1.00	d	0.85
Riffle depth (cm)[e]	V_8																
Spawning substrate	V_9	c	0.80	c	0.80	c	0.80	a/b	0.30	c/d	0.90	c	0.80	c/d	0.90	c	0.80
% cover	V_{10}	37.6	0.95	80.0	0.9	15.0	0.43	0.0	0.1	0.3	0.15	16.8	0.45	6.0	0.20	2.0	0.10
% pools	V_{12}	10.8	0.26	10.0	0.25	25.0	0.63	6.6	0.15	8.9	0.21	0.0	0.00	26.5	0.70	5.0	0.10
Component SI																	
C_{WQ} =		1.00		0.70		0.80		0.83		0.80		0.75		0.90		0.90	
C_R =		0.65		0.35		0.45		0.30		0.48		0.45		0.60		0.65	
C_C =		0.61		0.58		0.53		0.13		0.18		0.23		0.45		0.10	
HSI =		0.74		0.35		0.58		0.30		0.41		0.43		0.63		0.39	

[a] No measurements were taken at these four sites on the St. Vrain Creek, but it is assumed that turbidity would be very close or the same as the turbidity in the Big Thompson River, which has SI's of 1.0.

[b] Tested as the same.

[c] April to June temperature measurements were only recorded at the St. Vrain River, Hygiene site, so it is assumed that the other sites also had early spring temperatures of 10° C.

[d] No direct measurements were taken for riffle velocity, but gradient (m/km) was taken at all sites. The gradients ranged from 1.5 to 9.1 m/km, with SI ratings of 1.0 to 0.95, respectively. From this information, it was assumed that the riffle velocities ranged from low to moderate, and were given SI ratings of 0.85 to 1.0.

[e] No riffle depth measurements were taken, thus the riffle depth variable was not included in this model.

Lacustrine Model

This model utilizes the life requisite approach and consists of two components: water quality and reproduction.

Water Quality (C_{WQ}).

C_{WQ} = the lowest SI rating of V_1, V_2, V_3, or V_4.

Reproduction (C_R).

Two options exist:

1) If there is evidence of spawning or it is suspected within a lake and a windswept shoreline is available for lake or reservoir spawners,

   $C_R = V_3$, V_6, or V_{11}, whichever is lower

   provided that the lake or reservoir is not subject to extreme drawdown or fluctuation from March through July. If drawdown is ≥ 2 m, reduce C_R by 0.3; if drawdown is ≥ 5 m, reduce C_R by 0.5, with a minimum C_R value of 0.

2) If there is evidence of spawning or it is suspected to take place in a suitable inlet stream,

   $$C_R = [(\text{lowest of } V_1, V_2, V_3, \text{ or } V_4) \times (\text{lowest of } V_5, V_6, V_7, \text{ or } V_8)]^{1/2}$$

   where all C_R variables are measured in the inlet stream.

HSI determination.

$$HSI = (C_{WQ} \times C_R)^{1/2}$$

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

Sample data sets using the lacustrine HSI model are listed in Table 4.

Table 4. 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_1	65	0.9	40	1.0	200	0.4
pH	V_2	8.0	1.0	8.0	1.0	6.2	0.8
Dissolved oxygen (mg/l)	V_3	7.1	1.0	5	0.9	4	0.7
Temperature - adult/juvenile (°C)	V_4	25	0.9	20	1.0	16	0.9
Temperature - spawning/embryo (°C)	V_6	10.5	0.8	9.5	0.6	13	1.0
Littoral spawning substrate	V_{11}	B/C	0.8	B/C	0.9	C/D	0.95
Component SI							
C_{WQ} =			0.90		0.90		0.40
C_R[a] =			0.80		0.60		0.70
HSI =			0.85		0.73		0.40

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[a] Assumes spawning is in lake.

ADDITIONAL HABITAT SUITABILITY INDEX MODELS

Model 1

Optimum riverine habitat for white suckers is characterized by the following conditions (assuming water quality is adequate): clear (< 50 JTU) streams with cool to moderate summer temperatures (18 to 24° C); 40 to 60% pools; and greater than 40% of the stream area with cover, such as aquatic vegetation, brush, logs, and undercut banks.

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

Model 2

Optimum lacustrine habitat for white suckers is characterized by the following conditions (assuming water quality is adequate): majority of water body moderately clear (< 75 JTU); greater than 30% of littoral area with aquatic vegetation; and an available spawning stream or windswept lake shore with sand or gravel substrate.

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

Model 3

The appropriate catostomid standing crop model from Aggus and Morais (1979) can be used to calculate an HSI in lakes and reservoirs. The data base was developed from fish standing crop, angler use and harvest, and environmental data from United States reservoirs with surface areas of 500 acres or larger. The analytical method used includes the application of correlation-regression analysis to experimental data to identify and quantify important relationships between fish standing crop and environmental features in reservoirs. To make the method compatible with HEP, it was necessary to: (1) locate and quantify important standing crop/environmental relations; (2) reduce these to a single estimate of standing crop of a particular species using multiple regression analysis; and (3) convert these to an index of habitat suitability compatible with the Habitat Evaluation Procedures for comparison to other habitat types.

The National Reservoir Research Program utilizes standing crop of fish as a direct measure of abundance. Therefore, suitability of a particular reservoir habitat to a particular fish species or species group is considered to be positively related to the average standing crop biomass. This approach assumes that total biomass of a particular species reflects successful reproduction, feeding, and presence of suitable habitat for other life processes. In Aggus and Morais (1979), catostomid standing crops were used to develop regionalized reservoir fisheries predictive equations.

Model 4

Use the appropriate reservoir description and suitability rating list from McConnell et al. (1982) to calculate an HSI for white suckers in planned reservoirs.

Model 5

This model was developed after testing the original riverine model in the summer in LaGarde Creek, St. Vrain Creek, and Big Thompson River, Colorado. The model was expanded to include additional variables to better assess adult habitat, spawning habitat and cover. This model follows a life requisite approach, as used in the original riverine model (page 26). Many of the variables are the same used in the original riverine model (turbidity, pH, dissolved oxygen, temperature [adult/juvenile, fry, embryo], riffle velocity, riffle depth, percent cover, percent pools). The new variables include: riverine spawning substrate; pool depth; percent shade; gradient; pool velocity; and spawning distance. Propst (1982b) felt cover was most important in determining the suitability of a stream for white suckers.

This alternate riverine model combines the variables into components of water quality, reproduction, and cover (Fig. 3), which are used to derive the habitat suitability index. Reasons for placing individual variables in specific components are described below.

Water quality component. Refer to riverine model description (page 14).

Reproduction. Spawning temperature (V_6) is included because it influences spawning migrations, reproductive success, and hatching rates. Larval temperature (V_5) is included because of its influence on larval growth and activity. Riffle velocity (V_7) and riffle depth (V_8) are important in spawning site selection. White suckers prefer to spawn in moderately fast, shallow riffle areas, although they are tolerant of a relatively wide range of riffle depths. Spawning substrate (V_{12}) is included because spawning has been observed over sand and gravel substrates and not over mud or boulders. Spawning habitat distance (V_{17}) is included because we assume the distance fish must migrate to spawn influences reproductive success. White suckers can migrate to and spawn successfully in small streams that do not contain habitat for adults, but do contain spawning habitat and habitat that can support sizable fry and juvenile populations. Quantitative data on the effect of distance on reproductive success are not available, thus, this variable is based solely on professional judgment.

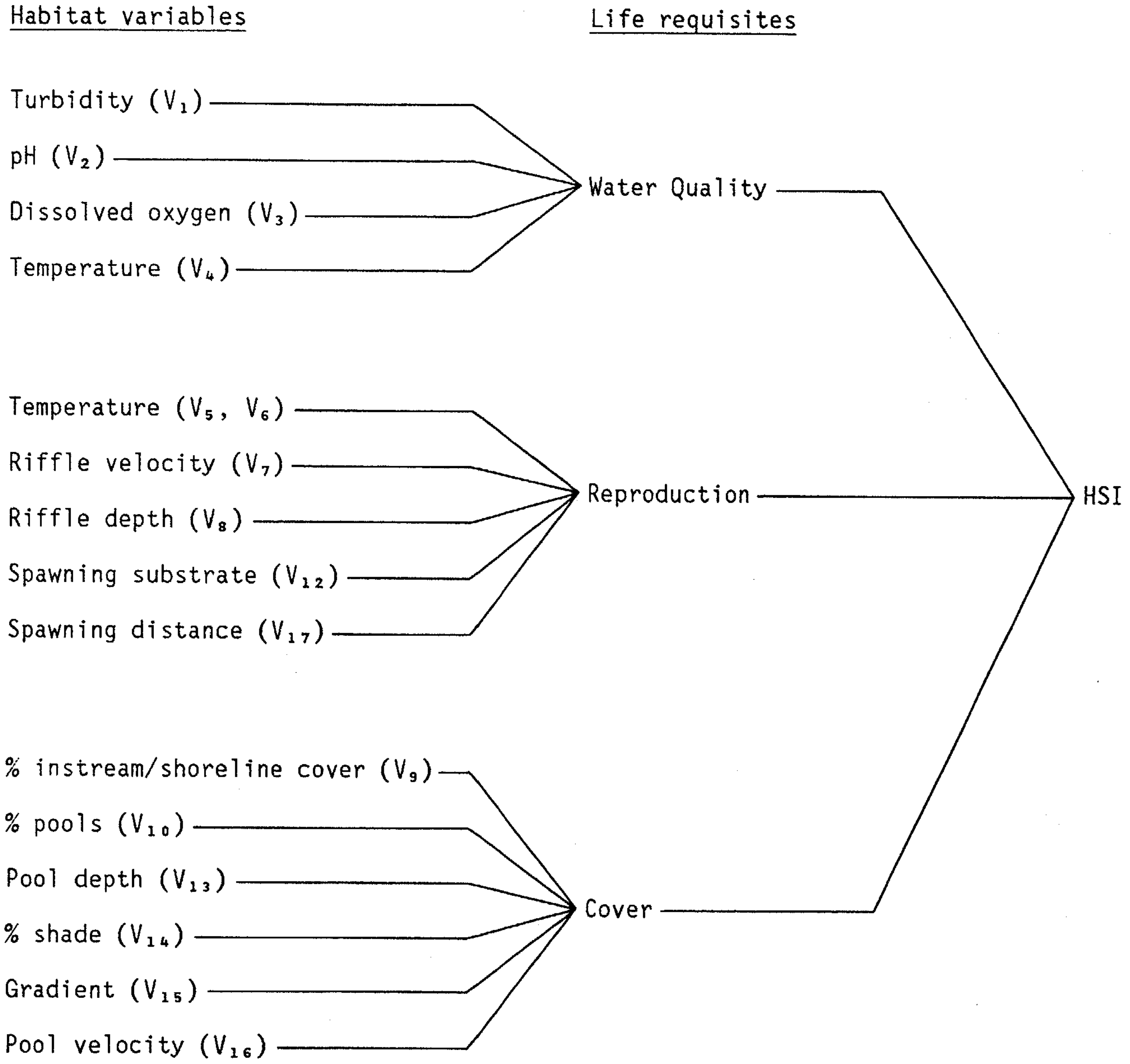
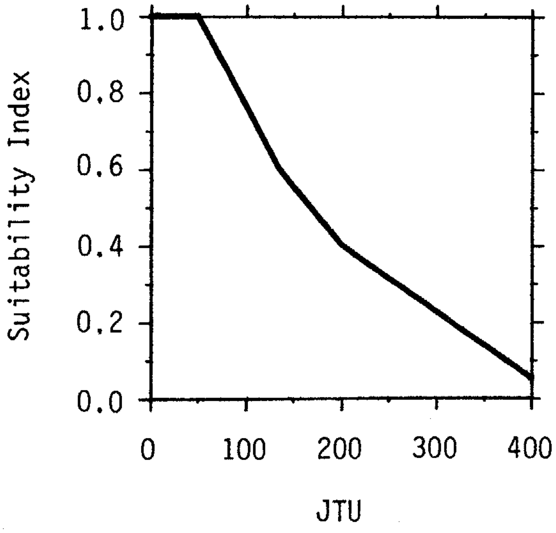


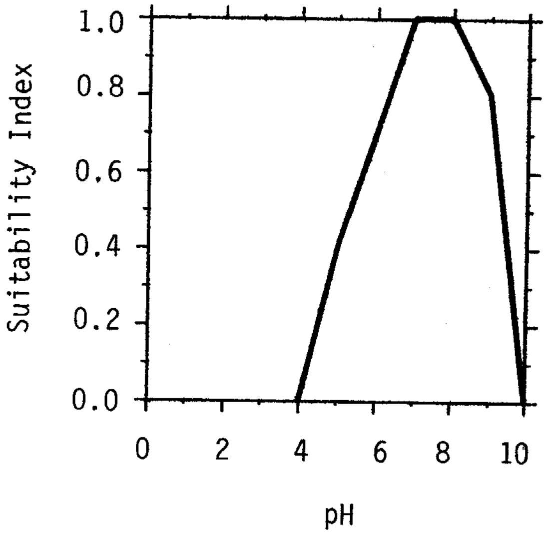
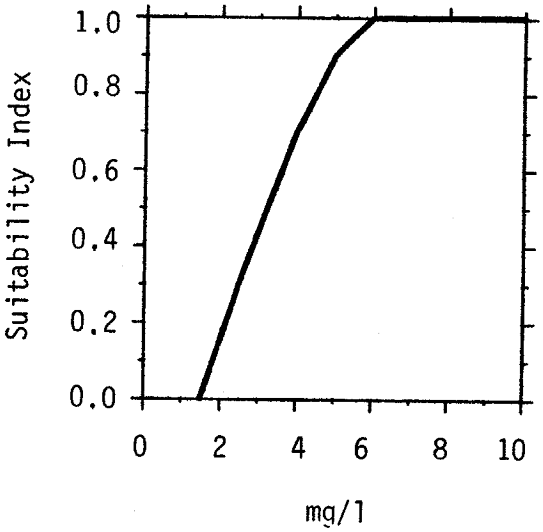
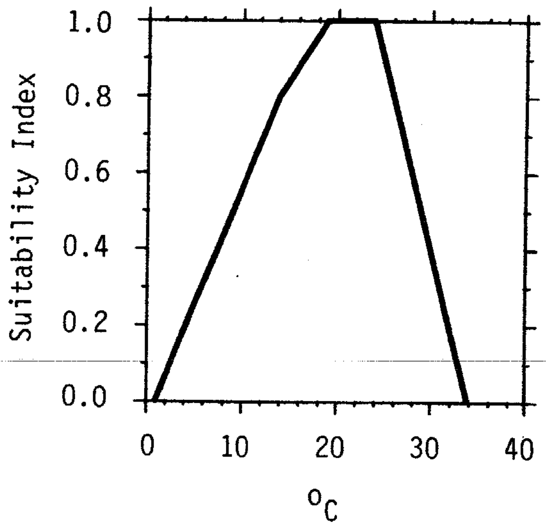
Figure 3. Tree diagram illustrating relationship of habitat variables and life requisites in riverine HSI model 5 for the white sucker.

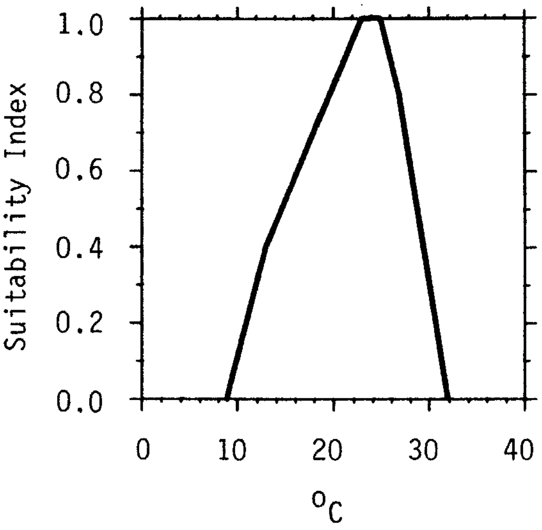
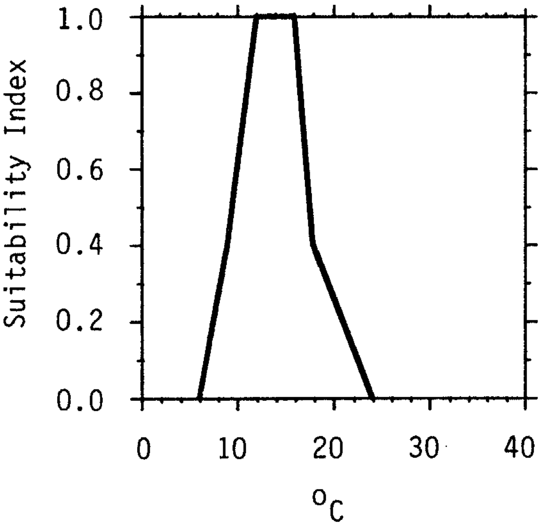
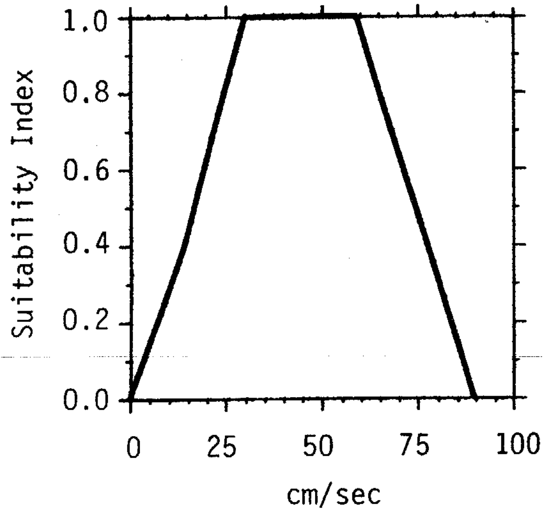
Cover. Pool velocity (V_{16}) and gradient (V_{15}) are included because white suckers show a marked preference for slow to moderate velocities and do not occur where there is no flow. Juveniles and adults prefer water of low velocity, while fry are found in a wider range of velocities. Shade (V_{14}) is an indication of cover, and white suckers are observed in shaded pools. Instream cover (root systems, uprooted trees, undercut banks, brush) and shoreline cover (willows, grass) (V_9) are very important to white suckers, especially in pools. A high correlation between pool cover and white sucker populations was observed by Propst (1982b) and white suckers flee to the cover of pools when disturbed. Pool depth (V_{13}) is included because depth offers cover and greater numbers of white suckers are found in deeper pools, especially those lacking in instream cover. Percent pools (V_{10}) is important because adult and juveniles are common pool inhabitants and pools allow resting areas for white suckers moving upstream to spawn or waiting to spawn.

SUITABILITY INDEX (SI) GRAPHS FOR MODEL 5

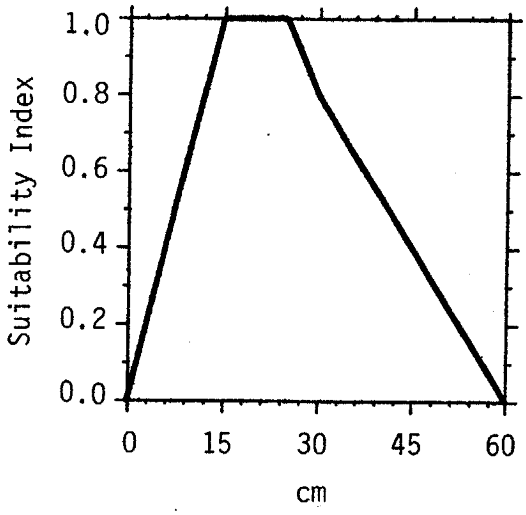
Suitability indices for model 5 are given below. The model is for riverine (R) habitats. The rationale for the alternative variables is listed in Table 5.

Habitat	Variable		Suitability graph
R	V_1	Maximum monthly average turbidity during the year.	

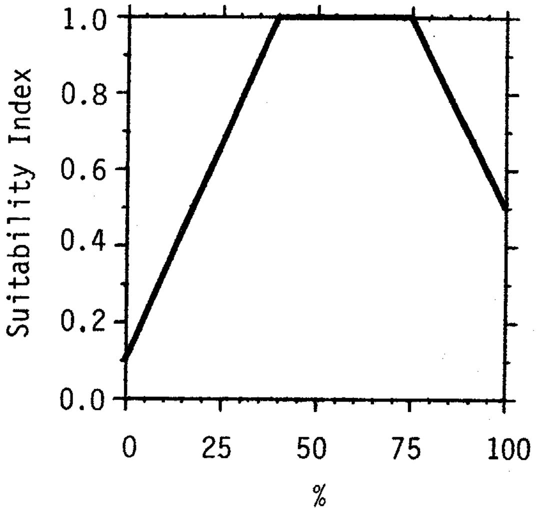
R	V_2	Weekly average pH during year under stable conditions. If frequent (diurnal), large (> 1.0 pH unit) changes occur, SI score should be reduced by 10%.	
R	V_3	Minimum dissolved oxygen levels near sunrise during May through August in area of most suitable water temperature.	
R	V_4	Average of mean weekly water temperatures at mid-afternoon during July and August (Adult and Juvenile).	

R	V_5	Average of mean weekly water temperatures during July and August (Fry).	
R	V_6	Average of mean weekly water temperatures during spawning and incubation (April through July) (Embryo).	
R	V_7	Average riffle velocity during spawning and incubation (April through July) (Embryo).	

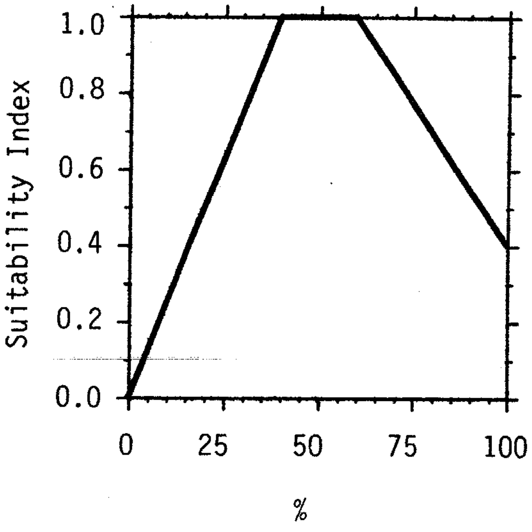
R V_8 Mean riffle depth during spawning and incubation (April through July) (Embryo).



R V_9 Percent instream and overhanging shoreline cover (e.g., roots, brush, logs, willows, undercut banks, grass).



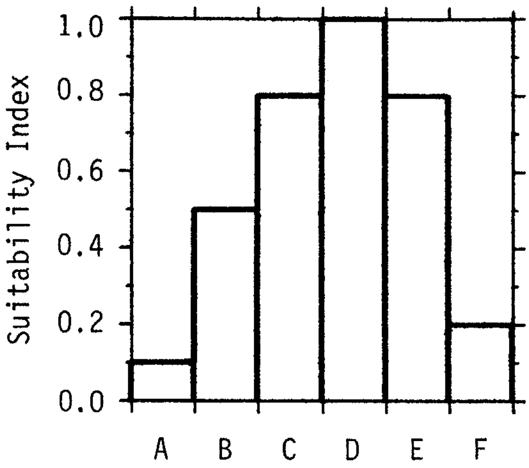
R V_{10} Percent pools during average summer flows (July through August) (Adult, Juvenile, and Fry).



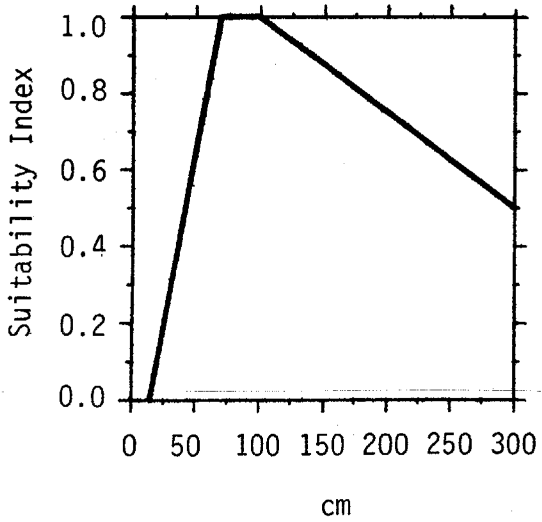
R V$_{12}$ Riverine spawning substrate.

A. Clay, silt, very fine sand (< 0.0039 to 0.125 mm), SI = 0.1
B. Fine sand, medium sand (0.125 to .5 mm), SI = 0.5
C. Coarse sand, very coarse sand (0.5 to 2 mm), SI = 0.8
D. Gravel-granule (2 to 4 mm), SI = 1.0
E. Gravel-small pebble (4 to 16 mm), SI = 0.8
F. Pebble, cobble, boulders (> 16 mm), SI = 0.2

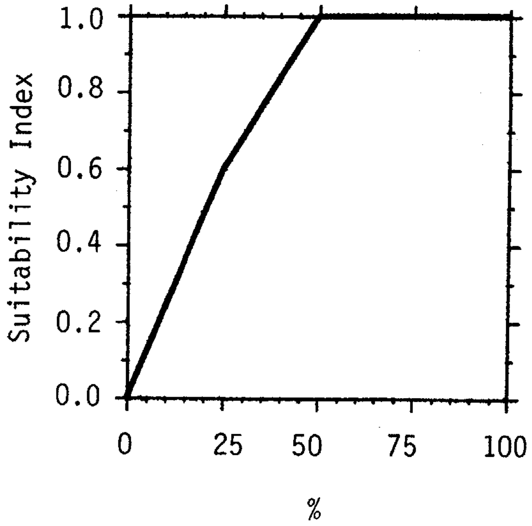
Adjust SI according to mixture of substrate sizes, by judgment. (Substrate categories adapted from Cummins 1962; Cummins and Lauff 1969).



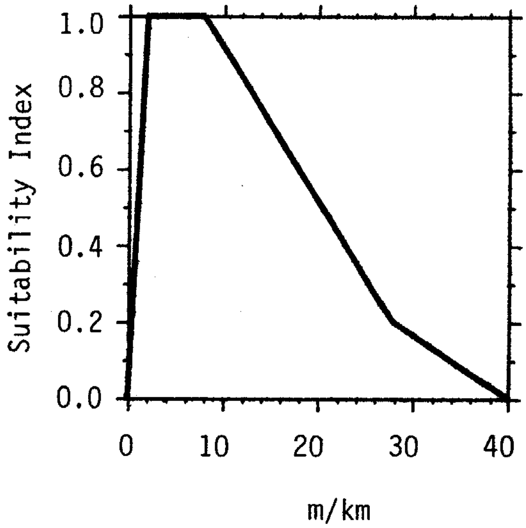
R V$_{13}$ Depth of pools in study reach.



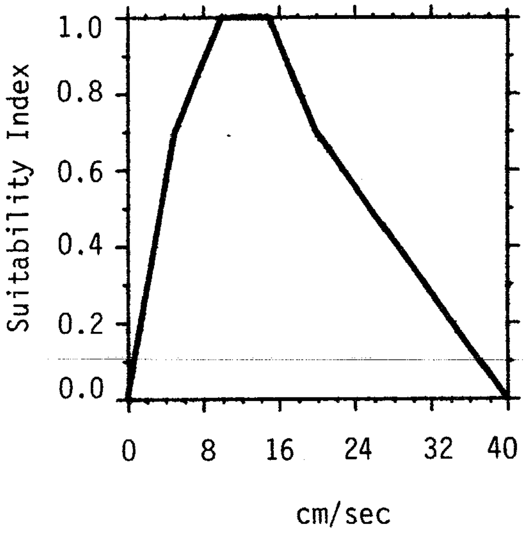
R V_{14} Percent shade.



R V_{15} Stream gradient in study reach.



R V_{16} Mean water velocity in pools during year.



R V_{17} Distance of potential spawning habitat from lentic or pool habitat. (Adjust SI on judgments on the passability of obstructions).

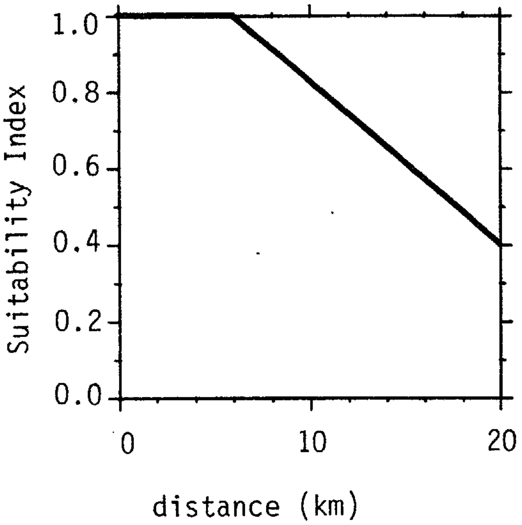


Table 5. Sources of information and assumptions used in construction of the suitability index graphs are listed. "Excellent" habitat for the white sucker was assumed to correspond to an SI of 0.8 to 1.0, "good" habitat to an SI of 0.5 to 0.7, "fair" habitat to an SI of 0.2 to 0.4, and "poor" habitat to an SI of 0.0 to 0.1.

Variable	Assumptions and source
V_1	Refer to the general riverine HSI turbidity variable (V_1).
V_2	Refer to the general riverine HSI pH variable (V_2).
V_3	Refer to the general riverine HSI dissolved oxygen variable (V_3).
V_4	Refer to the general riverine HSI temperature (adult, juvenile) variable (V_4).
V_5	Refer to the general riverine HSI temperature (fry) variable (V_5).
V_6	Refer to the general riverine HSI spawning temperature (embryo) variable (V_6).
V_7	Refer to the general riverine HSI riffle velocity variable (V_7).
V_8	Refer to the general riverine HSI riffle depth variable (V_8).
V_9	Refer to the general riverine HSI instream/shoreline cover variable (V_9).
V_{10}	Refer to the general riverine HSI percent pool variable (V_{10}).
V_{12}	White suckers have been observed spawning over gravel (Curry 1979) and sand/gravel substrates. These substrates are considered to be excellent (Dence 1948; Minckley 1963). It is assumed that substrates of silt, mud, and large gravel and boulders are suboptimum.

Table 5. (concluded).

Variable	Assumptions and source
V_{13}	Pool depth is important as cover (Stewart 1926). Pool depths at which white suckers are commonly found (60 to 90 cm) (Propst 1982b) are considered optimum. Very shallow depths (< 25 cm) are considered poor and very deep pools were assumed to contribute to a good to fair habitat because white suckers are found at varying pool depths in streams (Thompson and Hunt 1930; Propst 1982b). Deeper pool depths are usually not considered a habitat detriment because the white sucker inhabits many depths in lacustrine habitats (Reighard 1913).
V_{14}	Shade is an indication of cover and streams with ≥ 50% shade are considered excellent. Thompson and Hunt (1930) and Dence (1948) report that suckers are commonly found in shaded portions of streams. Unshaded streams are assumed to be poor to fair depending on other cover available.
V_{15}	White suckers reach maximum abundance in low to moderate gradients (Stewart 1926). Since Propst (1982b) failed to find white suckers where there was no flow, very low gradients (< .5 m/km) were considered poor. Very high gradients (> 25 m/km) were also considered poor because white suckers appeared to have trouble maintaining equilibrium in turbulent waters (Symons 1976). Minckley (1963), Curry (1979), and Hocutt and Stauffer (1975) reported on white suckers occupying streams with gradients of 1.2 to 13 m/km, which are considered excellent to fair, respectively, as the gradient increases.
V_{16}	White suckers are common in pools with slow to moderate velocities (< 40 cm/sec), but Minckley (1963), and Symons (1976) most frequently found adult white suckers at velocities of 10 to 19 cm/sec which were assumed excellent. As mentioned in V_{15}, turbulent velocities (Symons 1976) or zero velocities (Propst 1982b) are considered poor.
V_{17}	Suckers have been reported to successfully spawn after migrating up to 6.4 km (Dence 1948). Spawning habitat up to these distances, without known obstructions, are considered excellent. It is assumed that longer distances would be progressively less suitable.

Riverine Model

This model utilizes the life requisite approach and consists of three components: cover; water quality; and reproduction. The generated HSI applies to resident fish in streams.

Water Quality (C_{WQ}).

C_{WQ} = The lowest SI rating of V_1, V_2, V_3, or V_4

Reproduction (C_R).

C_R = the lowest SI rating of V_5, V_6, V_7, V_8, V_{12}, or V_{17})

Cover (C_C).

$$C_C = \frac{\frac{(V_9 + V_{14})}{2} \times V_{10} + V_{13} + \frac{(V_{15} + V_{16})}{2}}{4}$$

HSI determination.

$$HSI = (C_{WQ} \times C_R \times C_C)^{1/3}$$

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

Sample data sets for model 5 are listed in Table 6.

Table 6. Sample data sets using HSI model 5.

Variable		Data set 1		Data set 2		Data set 3	
		Data	SI	Data	SI	Data	SI
Turbidity (JTU)	V_1	25	1.00	30	1.00	75	0.9
pH	V_2	6.0	0.73	7.0	1.00	6.0	0.73
Dissolved oxygen (mg/l)	V_3	6.0	1.00	7.0	1.00	5.0	0.90
Temperature - adult/juvenile (°C)	V_4	19.0	1.00	10.0	0.60	15.0	0.85
Temperature - fry (°C)	V_5	17.5	0.70	14.0	0.50	14.0	0.50
Temperature - embryo (° C)	V_6	12.0	1.00	10.1	0.65	12.0	1.00
Riffle velocity - spawning/embryo (cm/sec)	V_7	75.0	0.50	80.0	0.30	60.0	1.00
Riffle depth (cm)	V_8	19.0	1.00	19.0	1.00	38.0	0.60
Percent cover	V_9	50.0	1.00	12.0	0.40	50	1.00
Percent pools	V_{10}	23.0	0.60	15.0	0.40	36.0	0.90
Spawning substrate	V_{12}	B/C	0.60	C	0.80	C/D	0.90
Pool depth	V_{13}	75.0	1.00	55	0.80	40.0	0.50
Percent shade	V_{14}	50	1.00	25	0.6	60	1.00
Gradient (m/km)	V_{15}	2.5	1.00	11.0	0.90	6.0	1.00
Pool velocity (cm/sec)	V_{16}	10.0	1.00	8.0	0.9	12.0	1.00
Spawning distance (km)	V_{17}	2	1.00	0.5	1.00	0.2	1.00

Table 6. (concluded).

Variable	Data set 1		Data set 2		Data set 3	
	Data	SI	Data	SI	Data	SI
Component SI						
C_{WQ} =		0.73		0.60		0.73
C_R =		0.50		0.30		0.50
C_C =		0.90		0.65		0.85
HSI =		0.69		0.30		0.68

INSTREAM FLOW INCREMENTAL METHODOLOGY (IFIM)

The U.S. Fish and Wildlife Service's Instream Flow Incremental Methodology (IFIM), as outlined by Bovee (1982), is a set of ideas used to assess instream flow problems. The Physical Habitat Simulation System (PHABSIM), described by Milhous et al. (1981), is one component of IFIM that can be used by investigators interested in determining the amount of available instream habitat for a fish species as a function of streamflow. The output generated by PHABSIM can be used for several IFIM habitat display and interpretation techniques, including:

1. Optimization. Determination of monthly flows that minimize habitat reductions for species and life stages of interest;

2. Habitat Time Series. Determination of the impact of a project on habitat by imposing project operation curves over historical flow records and integrating the difference between the curves; and

3. Effective Habitat Time Series. Calculation of the habitat requirements of each life stage of a fish species at a given time by using habitat ratios (relative spatial requirements of various life stages).

Suitability Index Graphs as Used in IFIM

PHABSIM utilizes Suitability Index graphs (SI curves) that describe the instream suitability of the habitat variables most closely related to stream hydraulics and channel structure (velocity, depth, substrate, temperature, and cover) for each major life stage of a given fish species (spawning, egg incubation, fry, juvenile, and adult). The specific curves required for a PHABSIM analysis represent the hydraulic-related parameters for which a species or life stage demonstrates a strong preference (i.e., a species that only shows preferences for velocity and temperature will have very broad curves for depth, substrate, and cover).

WELUT has standardized the terminology pertaining to SI curves and designated four categories of curves. All species curves for HEP and IFIM are referred to collectively as suitability index (SI) curves or graphs. The designation of a curve as belonging to a particular category does not imply that there are differences in the quality or accuracy of curves among the four categories.

Category one curves are the most common type presently available for use with HEP or IFIM. Usually category one curves have as their basis one or more literature sources. Some SI curves may be derived from general statements made in the literature about fishes (i.e., rainbow trout spawn in gravel; fry prefer shallow water). Some category one curves may come from literature sources which include variable amounts of field data (i.e., from a sample size of 300, fry were observed in velocities ranging 0.0 to 3.0 ft/sec, and 80% were found in velocities less than 1.0 ft/sec). Other category one curves may be based entirely on professional opinion, by using the Delphi technique or educated guesswork (i.e., an expert believes that velocities ranging 1.0 to 8.0 ft/sec are necessary for successful spawning of striped bass). Most category one curves are the result of a combination of sources; the final curve may include information from the literature, combined with field data, and smoothed or modified using professional judgement. Category one curves usually are intended to reflect general habitat suitability throughout the entire geographic range of the species and throughout the year, unless they are identified as being applicable only to a given area or season. In the latter case, curves developed for a specific area or stream may not accurately reflect habitat utilization in other areas. Curves meant to describe the general habitat suitability of a variable throughout the entire range of a species may not be as sensitive to small changes of the variable within a specific stream (i.e., rainbow trout will generally utilize silt, sand, gravel, and cobble for spawning substrate, but utilize only cobble in Willow Creek, Colorado).

Category two curves are derived from frequency analyses of field data, and are basically curves fit to a frequency histogram. Each curve describes the observed utilization of a habitat variable by a life stage. Category two curves unaltered by professional judgment or other sources of information are referred to as utilization curves. When modified by judgment they then become category one curves. Utilization curves from one set of data are not applicable for all streams and situations (i.e., a depth utilization curve from a shallow stream cannot be used for the Missouri River). Category two curves, therefore, are usually biased because of limited habitat availability. An ideal study stream would have all substrate and cover types present in equal amounts; all depth, velocity, and percent cover intervals available in equal proportions; and all combinations of all variables in equal proportions. Utilization curves from such a perfectly designed study theoretically should be transferable to any stream within the geographical range of the species. Curves from streams with high habitat diversity, then, are generally more transferable than curves from streams with low habitat diversity. Users of a category two curve should first review the stream description to see if conditions are similar to those present in the stream segment to be investigated. Some variables to consider might include stream width, depth, discharge, gradient, elevation, latitude and longitude, temperature, water quality, substrate and cover diversity, fish species associations, and data collection descriptors (time of day, season of year, sample size, sampling methods). If one or more deviate significantly from those of the proposed study site, then curve transference is not advised, and the investigator should develop his own curves.

Category three curves are derived from utilization curves which have been corrected for environmental bias and therefore represent preference of the species. To generate a preference curve, one must simultaneously collect habitat utilization data and habitat availability data from the same area. Habitat availability should reflect the relative amount of different habitat types in the same proportions as they exist throughout in the stream-study area. A curve is then developed for the habitat frequency distribution in the same way as for fish utilization observations, and the equation coefficients of the availability curve are subtracted from the equation coefficients of the

the utilization curve, resulting in preference curve coefficients. Theoretically, category three curves should be unconditionally transferable to any stream, although this has not been validated. At present, very few category three curves exist because most habitat utilization data sets are without concomitant habitat availability data sets. In the future, the need to collect habitat availability data will be impressed upon investigators.

Category four curves (conditional preference curves), describe habitat requirements as a function of interaction among variables. For example, fish depth utilization may depend on the presence or absence of cover; or velocity utilization may depend on time of day or season of year. Category four curves are just beginning to be developed by IFASG.

HSI models generally utilize category one curves for habitat evaluation. IFIM analyses may utilize any or all categories of curves, but category three and four curves yield the most precise results in IFIM applications; and category two curves will yield accurate results if they are found to be transferable to the stream segment under investigation. If category two curves are not felt to be transferable for a particular application, then category one curves may be a better choice.

For an IFIM analysis of riverine habitat, an investigator may wish to utilize the curves available in this publication; modify the curves based on new or additional information; or collect field data to generate new curves. For example, if an investigator has information that spawning habitat utilization in his study stream is different from that represented by the SI curves, he may want to modify the existing SI curves or collect data to generate new curves. Once the curves to be used are decided upon, then the curve coordinates are used to build a computer file (FISHFIL) which becomes a necessary component of PHABSIM analyses (Milhous et al. 1981).

Availability of Graphs for Use in IFIM

All curves available for IFIM analysis of white sucker habitat are category one (Table 7). Investigators are asked to review the curves (Figs. 4 to 8) and modify them, if necessary, before using them.

Spawning. For IFIM analyses of white sucker spawning habitat, use curves for the time period during which spawning occurs (sometime between March and July, depending on locale). Spawning curves are broad and, if more accuracy is desired, investigators are encouraged to develop their own curves which will specifically reflect habitat utilization at the selected site.

There are two approaches for determining the amount of spawning/egg incubation habitat for a given stream reach. The recommended approach for the white sucker is to treat spawning and egg incubation as separate life stages, each with its own set of criteria (Figs. 4 and 5). If the spawning/egg incubation weighted useable area varies by more than 10% during the 5 to 14 day egg incubation period, then investigators may wish to determine the effective spawning habitat, using methods outlined by Milhous (1982).

Table 7. Availability of SI curves for the IFIM analyses of white sucker habitat.

	Velocity[a]	Depth[a]	Substrate[a,b]	Temperature[a]	Cover[a]
Spawning	Use SI curve, Fig. 4.	Use SI curve, Fig. 4.	Use SI curve, Fig. 4.	Use SI curve, Fig. 4.	No curve necessary.
Egg incubation	Use SI curve, Fig. 5.	Use SI curve, Fig. 5.	Use SI curve, Fig. 5.	Use SI curve Fig. 5.	No curve necessary.
Fry	Use SI curve, Fig. 6.	Use SI curve, Fig. 6.	Use SI curve, Fig. 6.	Use SI curve Fig. 6.	Use SI curve, Fig. 6.
Juvenile	Use SI curve, Fig. 7.	Use SI curve, Fig. 7.	Use SI curve, Fig. 7.	Use SI curve Fig. 7.	Use SI curve, Fig. 7.
Adult	Use SI curve, Fig. 8.	Use SI curve, Fig. 8.	Use SI curve, Fig. 8.	Use SI curve Fig. 8.	Use SI curve, Fig. 8.

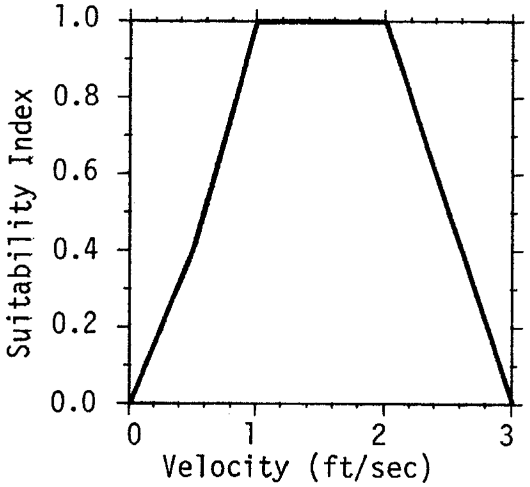
[a] When use of SI curves is prescribed, refer to the appropriate curve in the HSI or IFIM section.

[b] The following categories may be used for IFIM analyses (see Bovee 1982):

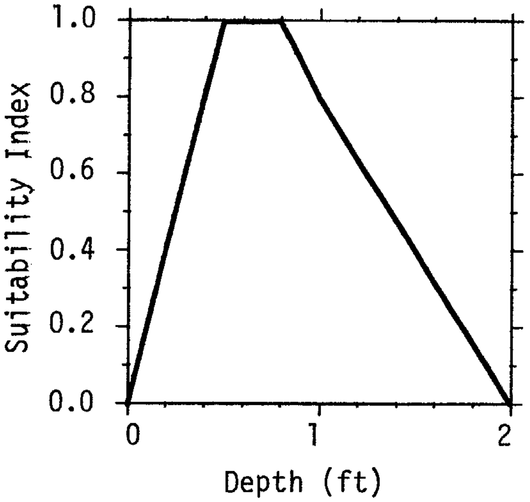
1 = plant detritus/organic material
2 = mud/soft clay
3 = silt (particle size < 0.062 mm)
4 = sand (particle size 0.062-2.000 mm)
5 = gravel (particle size 2.0-64.0 mm)
6 = cobble/rubble (particle size 64.0-250.0 mm)
7 = boulder (particle size 250.0-4000.0 mm)
8 = bedrock (solid rock)

Coordinates

x	y
0.0	0.0
0.5	0.4
1.0	1.0
2.0	1.0
3.0	0.0
100.0	0.0



x	y
0.0	0.0
0.5	1.0
0.8	1.0
1.0	0.8
2.0	0.0
100.0	0.0



x	y
0.000	0.00
0.001	0.00
0.002	0.05
0.009	0.05
0.010	0.80
0.039	0.80
0.040	1.00
0.078	1.00
0.079	0.90
0.156	0.90
0.157	0.50
0.629	0.50
0.630	0.05
100.000	0.05

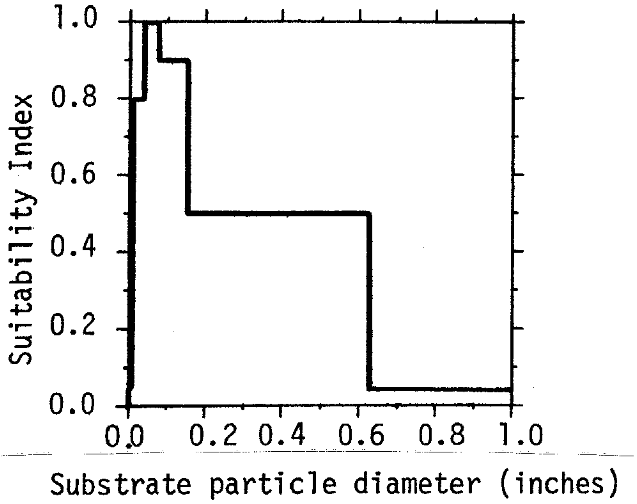


Figure 4. SI curves for white sucker spawning velocity, depth, substrate, cover, and temperature.

Cover is assumed not to be important for white sucker spawning. No curve is necessary.

Coordinates

x	y
0.0	0.0
43.0	0.0
54.0	1.0
61.0	1.0
64.0	0.4
75.0	0.0
100.0	0.0

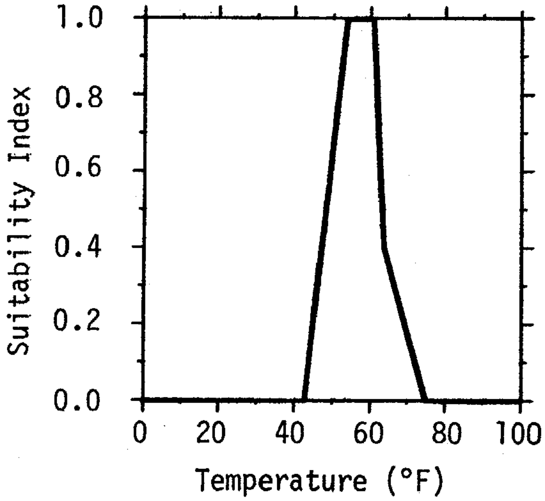
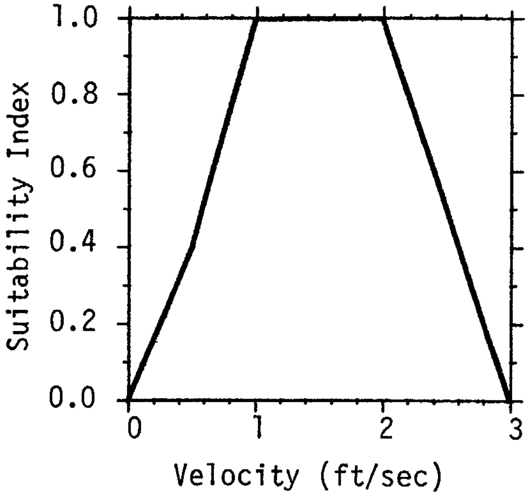


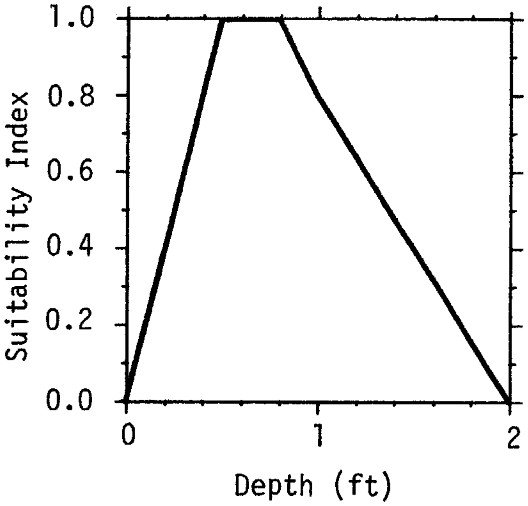
Figure 4. (concluded).

Coordinates

x	y
0.0	0.0
0.5	0.4
1.0	1.0
2.0	1.0
3.0	0.0
100.0	0.0



x	y
0.0	0.0
0.5	1.0
0.8	1.0
1.0	0.8
2.0	0.0
100.0	0.0



x	y
0.000	0.00
0.001	0.00
0.002	0.05
0.009	0.05
0.010	0.80
0.039	0.80
0.040	1.00
0.078	1.00
0.079	0.90
0.156	0.90
0.157	0.50
0.629	0.50
0.630	0.05
100.000	0.05

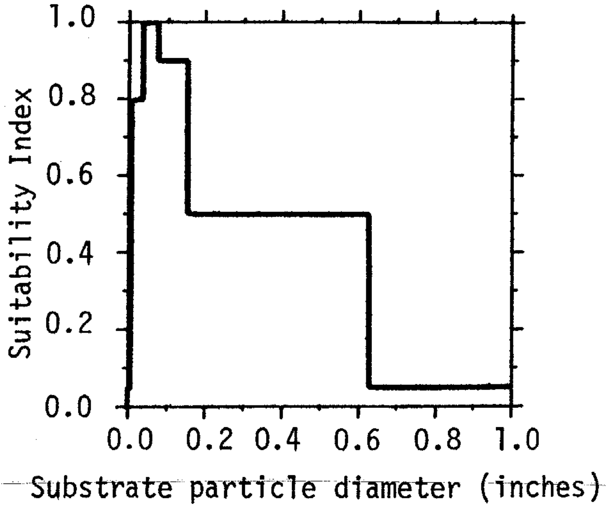


Figure 5. SI curves for white sucker egg incubation velocity, depth, substrate, cover, and temperature.

Cover is assumed not to be important for white sucker egg incubation. No curve is necessary.

Coordinates

x	y
0.0	0.0
41.0	0.0
48.0	0.8
53.0	0.9
59.0	1.0
63.0	0.8
69.0	0.7
75.0	0.0
100.0	0.0

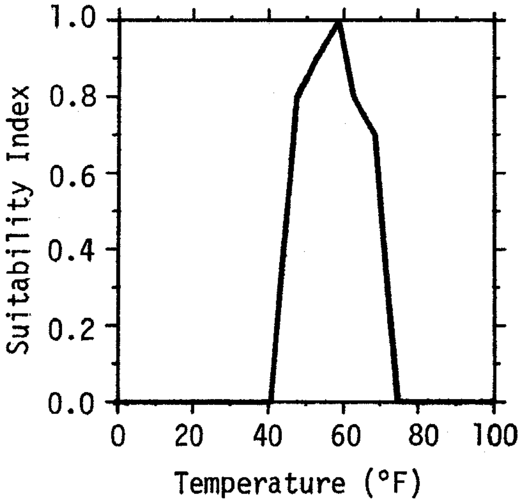
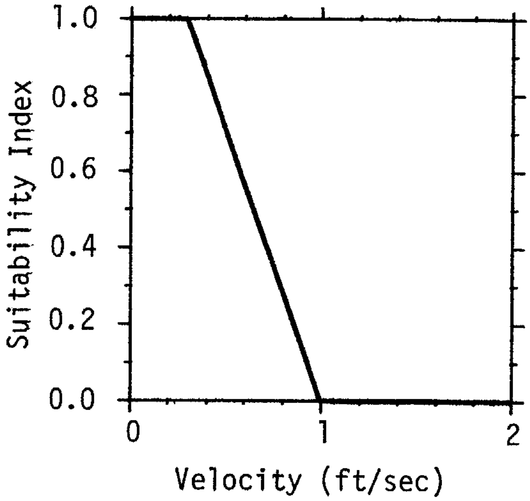


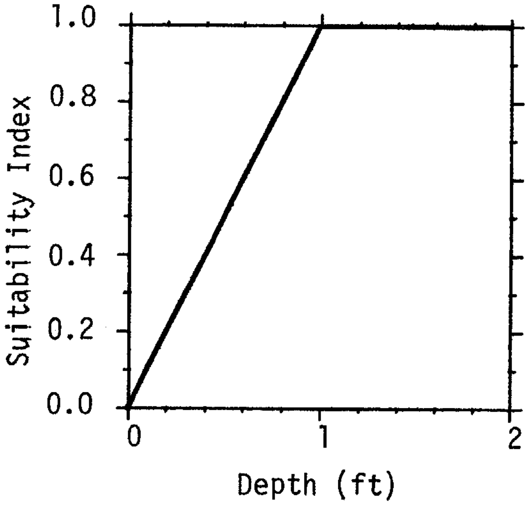
Figure 5. (concluded).

Coordinates

x	y
0.0	1.0
0.3	1.0
1.0	0.0
100.0	0.0



x	y
0.0	0.0
1.0	1.0
100.0	1.0



x	y
0.0	1.0
100.0	1.0

Based on assumption that all substrate types are suitable.

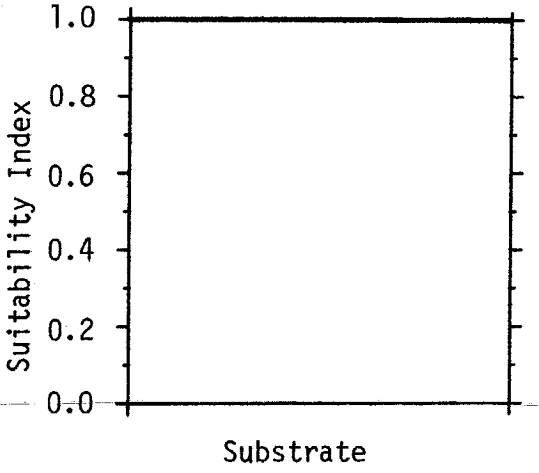
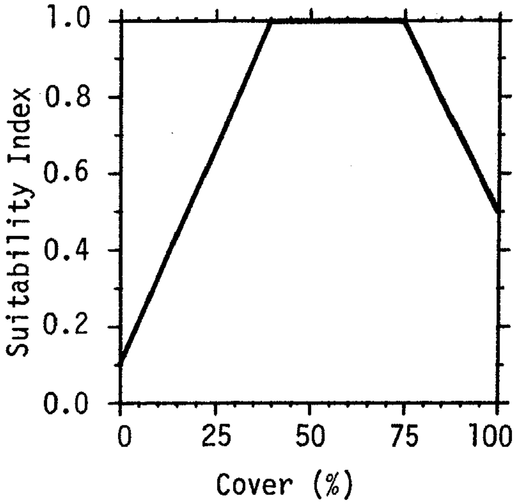


Figure 6. SI curves for white sucker fry velocity, depth, substrate, cover, and temperature.

Coordinates

x	y
0.0	0.1
40.0	1.0
75.0	1.0
100.0	0.5



x	y
0.0	0.00
50.0	0.00
59.4	0.47
63.0	0.66
69.4	0.81
75.4	0.88
80.4	1.00
85.5	0.00
100.0	0.00

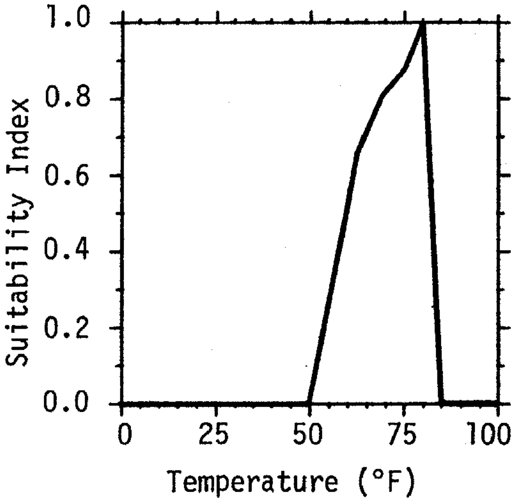


Figure 6. (concluded).

Coordinates

x	y
0.00	0.0
0.16	0.7
0.33	1.0
0.49	1.0
0.66	0.7
1.31	0.0
100.00	0.0

x	y
0.0	0.0
0.5	0.0
2.3	1.0
3.3	1.0
9.8	0.5
16.4	0.0
100.0	0.0

x	y
0.0	1.0
100.0	1.0

Based on assumption that all substrate types are suitable.

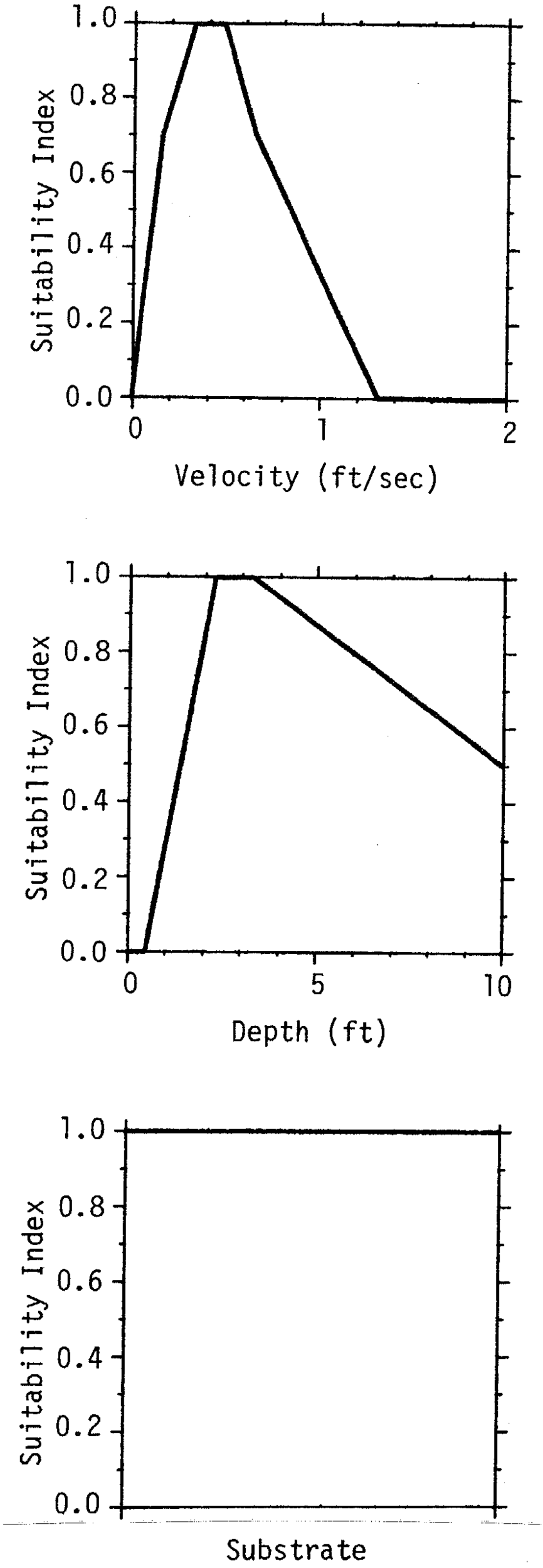
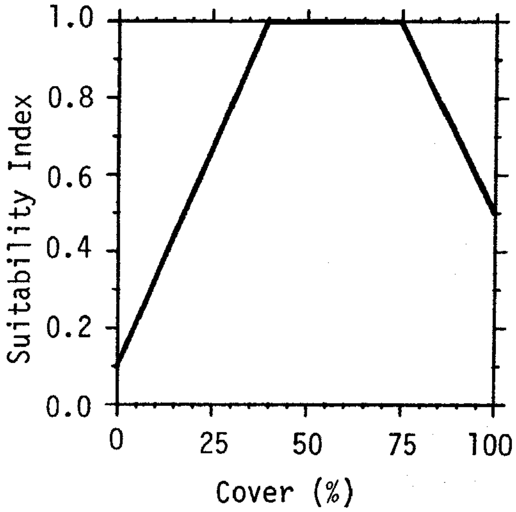


Figure 7. SI curves for white sucker juvenile velocity, depth, substrate, cover, and temperature.

Coordinates

x	y
0.0	0.1
40.0	1.0
75.0	1.0
100.0	0.5



x	y
0.0	0.0
33.8	0.0
57.2	0.8
66.2	1.0
75.2	1.0
93.2	0.0
100.0	0.0

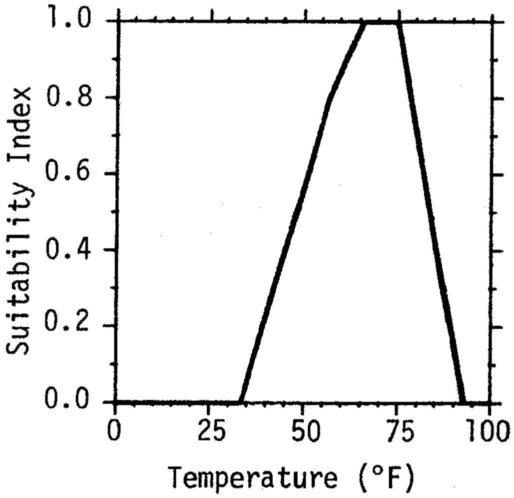
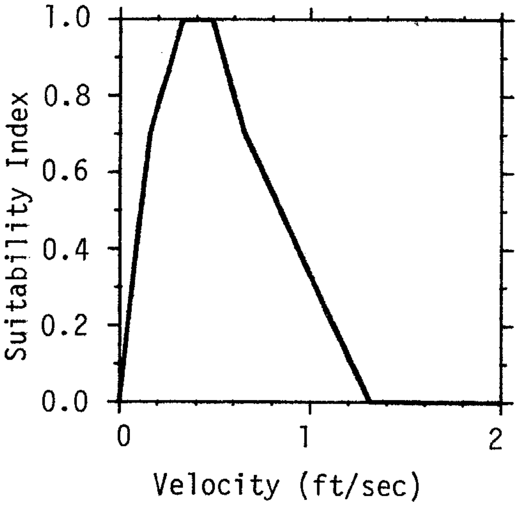


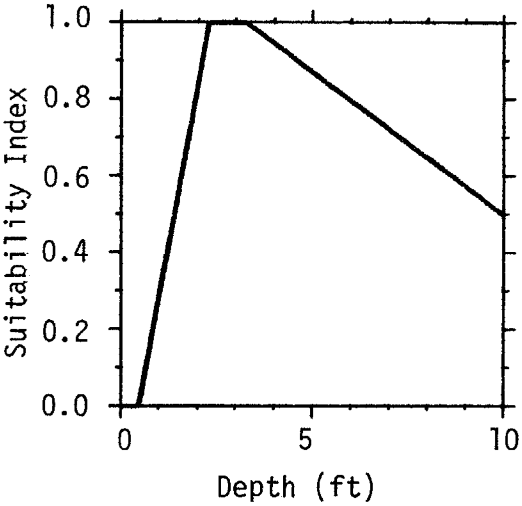
Figure 7. (concluded).

Coordinates

x	y
0.00	0.0
0.16	0.7
0.33	1.0
0.49	1.0
0.66	0.7
1.31	0.0
100.00	0.0



x	y
0.0	0.0
0.5	0.0
2.3	1.0
3.3	1.0
9.8	0.5
16.4	0.0
100.0	0.0



x	y
0.0	1.0
100.0	1.0

Based on assumption that all substrate types are suitable.

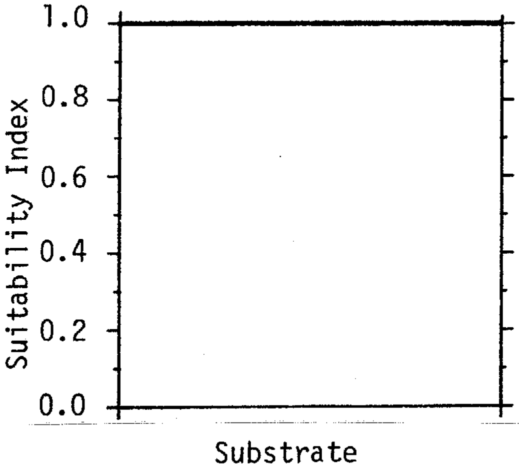
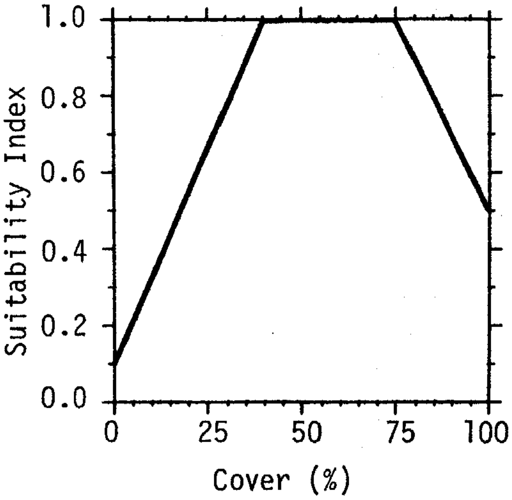


Figure 8. SI curves for white sucker adult velocity, depth, substrate, cover, and temperature.

Coordinates

x	y
0.0	0.1
40.0	1.0
75.0	1.0
100.0	0.5



x	y
0.0	0.0
33.8	0.0
57.2	0.8
66.2	1.0
75.2	1.0
93.2	0.0
100.0	0.0

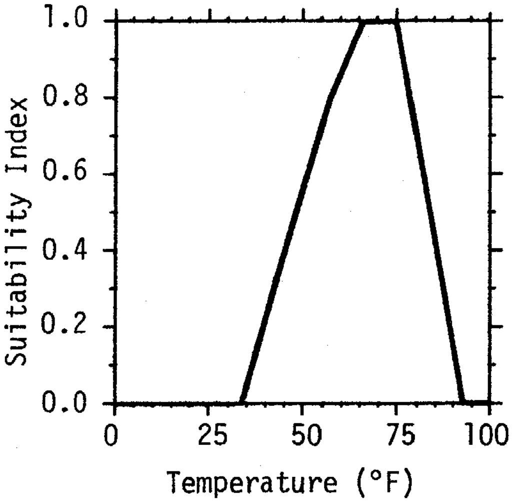


Figure 8. (concluded).

SI curves for spawning (Fig. 4) were taken from the HSI model section (V_6, V_7, V_8, V_{12}). Assumptions and sources used in developing the curves are in Table 1.

Egg incubation. For IFIM analyses of white sucker egg incubation habitat, use curves for the time period from the beginning of spawning to 14 days beyond the end of spawning. All SI curves for egg incubation (Fig. 5) were taken from the HSI model section (V_7, V_8, V_{12}) except for the temperature curve, which was taken from McCormick et al. (1977). See Table 1 for assumptions and information sources.

Fry. For IFIM analyses of white sucker fry habitat, curves should be used for the time period beginning with the end of spawning, and ending approximately 2 months after spawning, at which time fry become juveniles (at lengths of 0.7 to 0.9 inches, when their mouths become ventral). Very little information was found concerning fry habitat requirements. The SI curve for fry depth (Fig. 6) was derived from observations of fry inhabiting the upper 6 inches of the water column (Stewart 1926), and the assumption that a maximum depth does not exist. The SI curve for fry velocity was based entirely on professional guesswork, and the assumption that free-swimming fry can tolerate only the lowest of velocities because of their small size. The SI curve for fry substrate resulted from the assumption that substrate type is unimportant to fry after their emergence from the gravel. The SI curve for fry cover was taken from the HSI model section (V_9), and the assumption that the cover requirements for fry are the same as for juveniles and adults. The SI curve for fry temperature was taken from McCormick et al. (1977).

Juvenile. For IFIM analyses of white sucker juvenile habitat, curves should be used for individuals 1.0 to 9.9 inches in length, or from age two months to age at sexual maturity (usually ages III to VIII; Carlander 1969). SI curves were taken from the HSI model section (V_4, V_9, V_{13}, V_{16}), except for the substrate curve. Juveniles and adults have been observed over all forms of substrate ranging from sludge to rock (Thompson and Hunt 1930; Shurrager 1932). See Table 1 for all other assumptions and information sources.

Adult. For IFIM analyses of white sucker adult habitat, all curves are the same as for juveniles, and assumptions are outlined in Table 1. Adults are considered to be sexually mature at lengths ≥ 10 inches.

REFERENCES

Aggus, L. R., and D. I. Morais. 1979. Habitat suitability index equations for reservoirs based on standing crop of fish. Natl. Reservoir Res. Prog. Unpubl. Rept. to U.S. Fish Wildl. Serv., Habitat Eval. Proc. Group, Ft. Collins, CO. 120 pp.

Beamish, R. J. 1972. Lethal pH for the white suckers, Catostomus commersonii (Lacepede). Trans. Am. Fish. Soc. 101(2):355-358.

____________. 1973. Determination of age and growth of populations of white sucker (Catostomus commersoni) exhibiting a wide range in size at maturity. J. Fish. Res. Board Can. 30(5):607-616.

____________. 1974. Growth and survival of white sucker (Catostomus commersonii) in acidified lake. J. Fish. Res. Board Can. 31(1):49-54.

Bovee, K. D. 1982. A guide to stream habitat analysis using the Instream Flow Incremental Methodology. Instream Flow Information Paper 12. U.S. Fish Wildl. Serv. FWS/OBS-82/16. 248 pp.

Brett, J. R. 1944. Some lethal temperature relations of Algonquin Park fishes. Publ. Ontario Fish. Res. Lab. 63:1-49.

Campbell, R. S. 1935. A study of the common sucker, Catostomus commersoni (Lacepede), of Waskesiu Lake. M.A. Thesis, Univ. Sask., Saskatoon. 48 pp.

Carlander, K. D. 1969. Handbook of freshwater fishery biology. Vol. 1. Life history data on freshwater fishes of the United States and Canada, exclusive of the Perciformes. Iowa State Univ. Press, Ames, IA. 752 pp.

Cummins, K. W. 1962. An evaluation of some techniques for the collection and analysis of benthic samples with special emphasis on lotic waters. Am. Midl. Nat. 67(2):477-504.

Cummins, K. W., and G. H. Lauff. 1969. The influence of substrate particle size on the microdistribtion of stream macrobenthos. Hydrobiologia 34:145-181.

Curry, K. D. 1979. Use of a Wabash River tributary for sucker (Catostomidae) reproduction. Ph.D. Dissertation, Purdue Univ., Lafayette, IN. 96 pp.

Dence, W. A. 1948. Life history, ecology, and habits of the dwarf sucker, Catostomus commersonnii utawana Mather, at the Huntington Wildlife Station. Roosevelt Wildl. Bull. 8(4):81-150.

Dunson, W. A., and D. R. Martin. 1973. Survival of brook trout in a bog-derived acidity gradient. Ecology 54(6):1370-1376.

European Inland Fisheries Advisory Commission. Working Party on Water Quality Criteria for European Freshwater Fish. 1969. Report of extreme pH values and inland fisheries. Water Res. 3(8):593-611.

Forbes, S. A., and R. E. Richardson. 1920. The fishes of Illinois. Ill. Nat. Hist. Surv. pp. 85-86.

Fuiman, L. A. 1978. Descriptions and comparisons of northeastern catostomid fish larvae. M.S. Thesis, Cornell Univ., Ithaca, NY. 110 pp.

Geen, G. H., T. G. Northcote, G. F. Hartman, and C. C. Lindsey. 1966. Life histories of two species of catostomid fishes in Sixteenmile Lake, British Columbia, with particular reference to inlet stream spawning. J. Fish. Res. Board Can. 23(11):1761-1788.

Hayes, M. L. 1956. Life history studies of two species of suckers in Shadow Mountain Reservoir, Grand County, Colorado. M.S. Thesis, Colorado A&M College, Ft. Collins. 126 pp.

Hocutt, C. H., and J. R. Stauffer. 1975. Influence of gradient on the distribution of fishes in Conowingo Creek, Maryland and Pennsylvania. Chesapeake Sci. 16(2):143-147.

Horak, D. L., and H. A. Tanner. 1964. The use of vertical gill nets in studying fish depth distribution, Horsetooth Reservoir, Colorado. Trans. Am. Fish. Soc. 93(2):137-145.

Krieger, D. A. 1980. Life histories of catostomids in Twin Lakes, Colorado, in relation to a pumped-storage powerplant. M.S. Thesis, Colorado State Univ., Ft. Collins. 116 pp.

Lalancette, L. M. 1977. Feeding in white suckers (*Catostomus commersoni*) from Gamelin Lake, Quebec, over a twelve month period. Naturaliste Canadien 104(4):369-376.

Marcy, B. C., Jr. 1976. Planktonic fish eggs and larvae of the Lower Connecticut River and the effects of the Connecticut Yankee Plant including entrainment. Pages 115-139 *in* D. Merriman and L. M. Thorpe, eds. The Connecticut River ecological study, the impact of a nuclear power plant. Am. Fish. Soc. Monogr. 1. 252 pp.

McConnell, W. J., E. P. Bergersen, and K. L. Williamson. 1982. Habitat suitability index models: A low effort system for planned coolwater and coldwater reservoirs. U.S. Fish Wildl. Serv. FWS/OBS-82/10.3. 47 pp.

McCormick, J. H., B. R. Jones, and K. E. F. Hokanson. 1977. White sucker (*Catostomus commersoni*) embryo development, and early growth and survival at different temperatures. J. Fish Res. Board Can. 34(7):1019-1025.

Milhous, R. T. Unpub. (1982). Working paper on the application of the Physical Habitat Simulation System to water management - the use of the PHABSIM system for incubation-spawning analysis. U.S. Fish Wildl. Serv. 21 pp.

Milhous, R. T., D. L. Wegner, and T. Waddle. 1981. User's guide to the Physical Habitat Simulation System. Instream Flow Information Paper 11. U.S. Fish Wildl. Serv. FWS/OBS-81/43. 273 pp.

Minckley, W. L. 1963. The ecology of a spring stream, Doe Run, Meade Co., Kentucky. Wildl. Monogr. 11:3-124.

Muth, R. T. 1983. Personal communication. Fish Wildl. Dept., Colo. State Univ., Ft. Collins. Phone conversation, October 20.

Nelson, J. S. 1968. Hybridization and isolating mechanisms between Catostomus commersoni and C. macrocheilus (Pisces:Catostomidae). J. Fish. Res. Board Can. 25(1):101-150.

Nurnberger, P. K. 1928. A list of the plant and animal food of some fishes of Jay Cooke Park. Trans. Am. Fish. Soc. 58:175-177.

Olson, D. E. 1963. Role of the white sucker in Minnesota waters. Proc. Minnesota Acad. Sci. 31(1):63-73.

Pflieger, W. L. 1971. A distributional study of Missouri fishes. Mus. Nat. Hist., Univ. Kansas, Publ. 20(3):225-570.

______________. 1975. The fishes of Missouri. Missouri Dept. Conserv., Jefferson City. 343 pp.

Propst, D. L. 1982a. Performance of creek chub and white sucker habitat models in central Colorado. Unpubl. Rpt. to U.S. Fish Wildl. Serv., Habitat Eval. Proc. Group, Ft. Collins, CO. 120 pp.

______________. 1982b. Warmwater fishes of the Platte River basin, Colorado; distribution, ecology, and community dynamics. Ph.D. Dissertation, Colorado State Univ., Ft. Collins. 284 pp.

Raney, E. C. 1943. Unusual spawning habitat for the common white sucker Catostomus c. commersonii. Copeia (1943) 4:256.

Raney, E. C., and D. A. Webster. 1942. The spring migration of the common white sucker, Catostomus c. commersonnii (Lacepede), in Skaneateles Lake Inlet, New York. Copeia 1942(3):139-148.

Reighard, J. E. 1913. An ecological reconnaissance of the fishes of Douglas Lake, Cheboygan County, Michigan, in midsummer. Bull. U.S. Bur. Fish. XXXIII:215-249.

Reutter, J. M., and C. E. Herdendorf. 1976. Thermal discharge from a nuclear power plant: predicted effects on Lake Erie fish. Ohio J. Sci. 76(1):39-45.

Reynolds, W. W., and M. E. Casterlin. 1978. Behavioral thermoregulation and diel activity in white sucker (Catostomus commersoni). Comp. Biochem. Physiol. A. Comp. Physiol. 59(3):261-262.

Scherer, R. C. 1965. Dynamics of stream populations of the white sucker, Catostomus commersoni Lacepede. Ph.D. Dissertation. Pennsylvania State Univ., University Park. 53 pp.

Schneberger, E. 1977. The white sucker, its life history, ecology, and management. Dept. Nat. Res., Madision, WI. 18 pp.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can. Bull. 184. 966 pp.

Shurrager, S. 1932. An ecological study of the fishes of the Hocking River. Ohio Biol. Survey Bull. 28; 5(5):377-401.

Siefert, R. E. 1972. The first food of larval yellow perch, white sucker, bluegill, emerald shiner, and rainbow smelt. Trans. Am. Fish. Soc. 101:219-225.

Siefert, R. E., and W. A. Spoor. 1974. Effects of reduced oxygen on embryos and larvae of the white sucker, coho salmon, brook trout and walleye. Pages 487-495 *in* J. H. S. Blaxter, ed. The early life history of fish. Springer-Verlag, NY.

Spoor, W. A. 1938. Age and growth of the sucker, *Catostomus commersoni* (Lacepede), in Muskellunge Lake, Vilas County, Wisconsin. Trans. Wisc. Acad. Sci. Art and Letters 31:457-505.

Stewart, N. H. 1926. Development, growth, and food habits of the white suckers, *Catostomus commersonii* Lesueur. Bull. U.S. Bur. Fish. 42:147-184.

Symons, P. E. K. 1976. Behavior and growth of juvenile Atlantic salmon (*Salmo salar*) and three competitors at two stream velocities. J. Fish. Res. Board Can. 33(2):2766-2773.

Thompson, D. H., and F. D. Hunt. 1930. The fishes of Champaign County. A study of the distribution and abundance of fishes in small streams. Illinois Div. Nat. Hist. Survey Bull., Vol. 19. 71 pp.

Trojnar, J. R. 1977. Egg and larval survival of white sucker (*Catostomus commersoni*) at low pH. J. Fish. Res. Board Can. 34(2):262-266.

Walton, B. D. 1980. The reproductive biology, early life history and growth of white suckers, *Catostomus commersoni*, and longnose suckers, *C. catostomus*, in the Willow Creek-Chain Lakes System, Alberta. Alberta Dept. Energy Nat. Resour. Fish Res. Rep. 23.

Werner, R. G. 1979. Homing mechanism of spawning white suckers in Wolf Lake, New York. New York Fish and Game J. 26(1):48-58.

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The habitat suitability index (HSI models presented in this publication aid in identifying important habitat variables for the white sucker (Catostomus commersoni), a freshwater species found in lacustrine and riverine environments. Information obtained from the research literature and expert reviews are synthesized into models which present hypotheses of species/habitat relationships.

A brief discussion of suitability index (SI) curves as used in the Instream Flow Incremental Methodology (IFIM), and a discussion of SI curves available for the IFIM analysis of white sucker habitat are also included.

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