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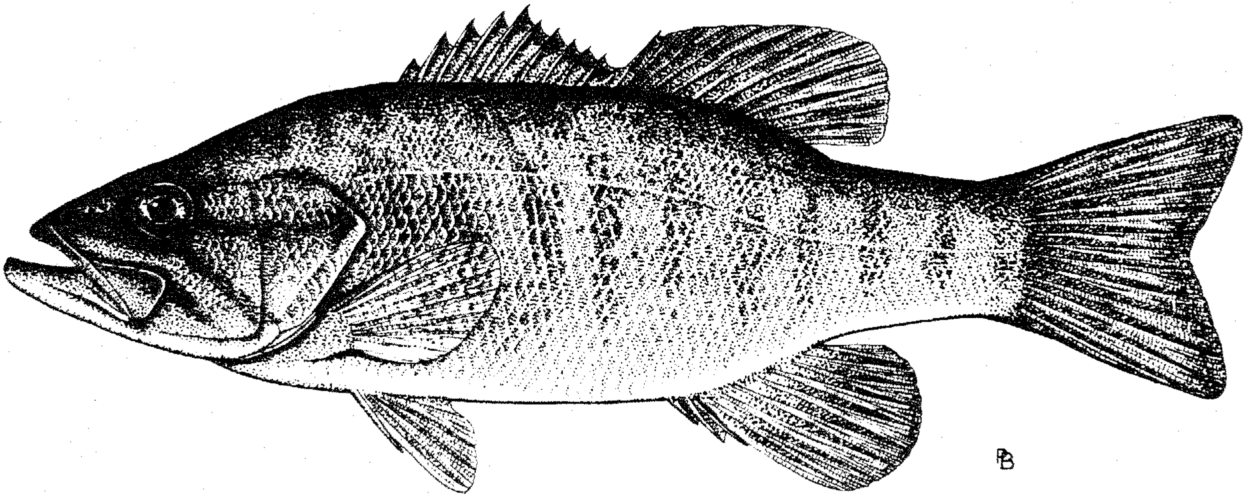
HABITAT SUITABILITY INFORMATION: SMALLMOUTH BASS



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September 1983

HABITAT SUITABILITY INFORMATION: SMALLMOUTH BASS

by

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PREFACE

The habitat use information and Habitat Suitability Index (HSI) models presented in this document are an aid for impact assessment and habitat management activities. Literature concerning a species' habitat requirements and preferences is reviewed and then synthesized into subjective HSI models, which are scaled to produce an index between 0 (unsuitable habitat) and 1 (optimal habitat). Assumptions used to transform habitat use information into these mathematical models are noted, and guidelines for model application are described. Any models found in the literature which may also be used to calculate an HSI are cited, and simplified HSI models, based on what the authors believe to be the most important habitat characteristics for this species, are presented. 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 smallmouth bass habitat.

Use of the habitat information presented in this publication for impact assessment requires the setting of clear study objectives. Methods for reducing HSI model complexity and recommended measurement techniques for model variables are presented in Terrell et al. (1982).[1] A discussion of HSI model building techniques 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. The models have not been tested against field data. For this reason, the U.S. Fish and Wildlife Service 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. Dept. Int., 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. Dept. Int., Fish Wildl. Serv., Div. Ecol. Serv. n.p.

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FIGURES

ACKNOWLEDGMENTS

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SMALLMOUTH BASS (Micropterus dolomieui)

HABITAT USE INFORMATION

General

The original range of the smallmouth bass (Micropterus dolomieui) extended from the Great Lakes south to northern Georgia and Alabama, east to the Appalachian range, and west to eastern Oklahoma (MacCrimmon and Robbins 1975; Lee et al. 1980). The species has been widely introduced outside of this range in the Northeast and areas west of the Mississippi drainage (Lee et al. 1980). Two subspecies are recognized: (1) the northern smallmouth (M. d. dolomieui) of the Great Lakes and adjacent regions (Hubbs and Bailey 1940); and (2) the Neosho smallmouth (M. d. velox) of northwestern Arkansas, northeastern Oklahoma, and southwestern Missouri (Hubbs and Bailey 1940; Ramsey 1975).

Age, Growth, and Food

Age at sexual maturity of smallmouth bass varies throughout its range and is related to latitude and to the growth rate of local populations (Robbins and MacCrimmon 1974). Males and females mature at age II in the South and at age VI in the North (Fraser 1955; Harlan and Speaker 1969; Turner and MacCrimmon 1970). In the central part of the range, males usually mature at age III-IV (about 25 cm), and females usually mature at age IV or V (30 cm) (Stone et al. 1954; Webster 1954; Fraser 1955; Latta 1963; Pflieger 1975).

Although a 15-year old smallmouth bass has been recorded (Scott and Crossman 1973), fish older than 7 years are uncommon (Robbins and MacCrimmon 1974). Adults are usually 20-56 cm long. The largest recorded smallmouth bass was a 5.4 kg, 68.6 cm long fish from Kentucky (Anonymous 1972).

The diet of smallmouth bass changes from small to large food items as the fish grow. Fry feed on microcrustaceans (Beeman 1924; Applegate et al. 1967). Juvenile smallmouth bass eat larger insects, crayfish, and fish (Doan 1940; Webster 1954). Adults primarily feed on fish and crayfish in both lakes and streams (Tester 1932; Doan 1940; Tate 1949; Webster 1954; Reynolds 1965). The diet is influenced by abundance (Paragamian 1973) and availability of prey (Coble 1975).

Reproduction

Smallmouth bass spawn in spring, usually mid-April to July (Watson 1955; Henderson and Foster 1957; Harlan and Speaker 1969; Turner and MacCrimmon 1970; Smitherman and Ramsey 1972; Neves 1975; Pflieger 1975), depending on geographical location and water temperature. Cleary (1956) observed a 45 day post-nesting period for smallmouth spawning in Iowa streams.

Smallmouth bass spawn on rocky lake shoals, river shallows, or backwaters or move into creeks or tributaries to spawn (Harrison 1954; Webster 1954; Cleary 1956; Sanderson 1958; Harlan and Speaker 1969; Coble 1975; Clancey 1980). Smallmouth bass spawned in warm sloughs or backwater areas bordering the Columbia River (Montgomery et al. 1980). The species requires a clean stone, rock, or gravel substrate for spawning (Robbins and MacCrimmon 1974). Studies show that the habitat condition during spawning is the most important factor for year class strength in smallmouth bass (Clancey 1980).

Nest building and spawning occur when the water temperature is 12.8-21.0° C (Turner and MacCrimmon 1970; Scott and Crossman 1973; Shuter et al. 1980), but most activity occurs at or above 15° C (Henderson and Foster 1957; Latta 1963; Harlan and Speaker 1969; Coble 1975; Shuter et al. 1980).

Specific Habitat Requirements

Optimum riverine habitat is characterized by cool, clear, midorder streams > 10.5 m wide (Carlander 1977) with abundant shade and cover (Larimore et al. 1952) and deep pools, moderate current, and a gravel or rubble substrate (Sanderson 1958; Robbins and MacCrimmon 1974; Coble 1975; Pflieger 1975). Streams with gradients of 0.75-4.70 m/km, that provide alternating pools and riffles, support the largest stream populations of smallmouth bass (Trautman 1942; Hallam 1959; Robbins and MacCrimmon 1974; Coble 1975; Funk and Pflieger 1975). Standing crop is generally largest in pools deeper than 1.2 m (Robbins and MacCrimmon 1974; Paragamian 1979; Clancey 1980).

Growth of smallmouth bass is faster in lakes and reservoirs than in rivers (Robbins and MacCrimmon 1974). Optimum lacustrine habitat is characterized by large, clear lakes and reservoirs with an average depth greater than 9 m with rocky shoals (Turner and MacCrimmon 1970; Coble 1975; Miller 1975; Pflieger 1975). Large concentrations of smallmouth bass occurred over a broken rock and boulder substrate with a large amount of interstitial space in the Tongue River Reservoir in Montana (Penkal and Gregory 1980). No bass were found over a rounded rock substrate or sand in the Snake River (Munther 1970). Although smallmouth are able to live in small ponds (Bennett 1965; Buck and Thoits 1970; Coble 1975), populations are more successful in larger lakes and reservoirs (Jenkins 1975). Smallmouth are found almost exclusively in the epilimnion during summer stratification in northeastern Wisconsin and Ontario (Hile and Juday 1941; Turner and MacCrimmon 1970), yet frequent depths up to 12 m in all seasons in northern New York (Webster 1954).

Smallmouth bass exhibit strong, cover-seeking behavior and prefer protection from light in all life stages (Coble 1975; Miller 1975). Deep, dark quiet water is used for cover (Coble 1975), but bass use all forms of submerged cover, such as boulders, rocks, stumps, root-masses, trees, and crevices, without apparent preference for any one type (Larimore et al. 1952; Hubert and Lackey 1980).

Smallmouth occur at pH levels of 5.7 (Clady 1977) to 9 (Paragamian 1979), although optimum pH is 7.9-8.1 (Funk and Pflieger 1975). Butler (1972) found that smallmouth bass cover-seeking behavior was reduced at pH levels < 6, and the lower lethal pH level was 3.

Smallmouth bass populations are more productive in clearer, less fertile reservoirs several years after impoundment that have low total dissolved solids (TDS = 100-350 ppm) (Jenkins 1975, 1976).

Smallmouth require more than 6 ppm dissolved oxygen (D.O.) for optimal growth (Bulkley 1975). Production rates are reduced by 10% when the amount of oxygen is lowered to 3 ppm at 15° C; production rates are reduced by 20% if oxygen is lowered to 4 ppm at 20° C (Bulkley 1975). Smallmouth bass frequently die at DO concentrations approaching 1 ppm at 20-25° C (Burdick et al. 1954; Bulkley 1975).

Smallmouth bass apparently can tolerate periodic turbidity (Webster 1954; Cleary 1956), although excessive turbidity and siltation will reduce a population (Coutant 1975). Hubert and Lackey (1980) reported a typical smallmouth bass habitat to have very low turbidity, usually ≤ 25 JTU, and almost never > 75 JTU (except under flood conditions when turbidity is sometimes as high as 250 JTU).

Adult. In streams, adults occupy pools or deep areas behind rocks where there is no perceptible current (Keating 1970; Munther 1970; Funk and Pflieger 1975; Pflieger 1975). Adults are often near the edge of the current during the day (Cleary 1956; Munther 1970). Movement of adults in streams is restricted during a single season to a single pool (Funk 1957; Brown 1961; Fajen 1962; Munther 1970; Montgomery et al. 1980).

In lakes and reservoirs, adults most often use cooler areas, such as dropoffs, that are away from vegetation and in water < 12 m deep (Scott and Crossman 1973; Coble 1975). In a Tennessee River reservoir, adults were frequently in water > 10 m deep during the summer (Hubert and Lackey 1980). Seasonal mean current velocity in bass habitats during the study varied from 10.9 to 32.0 cm/sec.

Temperatures may be the most important single factor limiting distribution of smallmouth bass (Robbins and MacCrimmon 1974; Coutant 1975). Faster growth rates of adult smallmouth bass are generally associated with higher summer temperatures (Doan 1940; Brown 1961; Forney 1972). Faster growth rates occur in southern reservoirs, resulting in earlier death than in northern regions (Coutant 1975). In the summer, bass inhabit warmer shoreline areas of large lakes in the North and deeper, cooler waters in the South (Coutant 1975). Growth does not begin until water temperatures reach 10-14° C (Coble 1975). Field data indicate that adults prefer temperatures of about 21-27° C in the summer (Clancey 1980). Smallmouth bass have been reported "sunning" themselves in pools with water temperatures of about 26.7° C in summer (Munther 1970).

Temperature preferences of smallmouth bass vary considerably depending on the acclimation temperature (Ferguson 1958; Cherry et al. 1975; Coutant 1975). Smallmouth bass acclimated at 2.2-30.0° C selected temperatures of 20-32° C in laboratory tests (Mathur et al. 1981). Adult bass in the laboratory preferred temperatures of 28° C (Ferguson 1958; Bennett 1965) to 31° C (Barans and Tubb 1973; Coutant 1975). Optimum growth rates in the lab occurred at temperatures from 26-29° C (Peek 1965; Shuter et al. 1980; Wrenn 1980). Upper lethal temperatures for adults were above 32.3° C (Coble 1975).

When temperatures drop to 15-20° C, adults seek deep, dark areas (Webster 1954; Munther 1970). At about 10° C, bass become inactive and seek shelter (Coble 1975; Shuter et al. 1980). At 6-7° C, most smallmouth bass are beneath the rock substrate, with few remaining on top (Munther 1970). The lower lethal temperature is near freezing (Coble 1975). Bass will congregate around warm springs in winter when available (Coutant 1975).

Embryo. Nests are usually in water from 0.3-0.9 m deep (Coble 1975), but may be built in water up to 7 m deep (Mraz 1964; Robbins and MacCrimmon 1974). Nests are commonly in gravel or broken rock (Latta 1963; Mraz 1964); near boulders, logs, or other cover (Scott and Crossman 1973); in shallows or backwaters of streams (Clancey 1980); or in protected bays or shoals in lakes (Robbins and MacCrimmon 1974). Nests are also made over bedrock, rootlets in silt, or sand, but these substrates are less commonly used (Cleary 1956; Latta 1963; Scott and Crossman 1973). Nests are usually in areas of quiet water (Pflieger 1975) or very slow current (Robbins and MacCrimmon 1974).

Embryos develop normally at temperatures from 13-25° C (Webster 1954; Coble 1975). Extreme fluctuations in temperature cause embryo mortality from acute thermal shock (Webster 1954; Montgomery et al. 1980) or will cause males, the caretakers, to leave the nest unprotected from predators and/or fungus may grow (Cleary 1956; Watt 1959). There may be another spawning period if there is a sudden drop in temperature during the first attempt.

In a laboratory study, 42% of the embryos survived more than 14 days at 4.4 ppm dissolved oxygen and 20° C; none survived at D.O. levels < 2.5 ppm (Siefert et al. 1974). It is assumed that D.O. levels > 6 ppm are necessary for maximum embryo survival (Bulkley 1975).

Large fluctuations in water level can affect reproductive success (Pflieger 1975; Montgomery et al. 1980). Ideal spawning conditions include one or more substantial rises in water level a week or two prior to bass nesting (Pflieger 1975) and relatively stable water levels while nesting is in progress (Watson 1955; Pflieger 1975). Rising water may flush nest areas with cold water, causing nest desertion and halting embryo development (Watt 1959; Montgomery et al. 1980). Falling water levels may drive guarding males off, limit water circulation around eggs, and increase predation, resulting in lower reproductive success (Neves 1975; Montgomery et al. 1980).

Fry. Smallmouth bass fry grow faster at higher temperatures (Shuter et al. 1980). The optimum temperature range for growth in the laboratory was 25-29° C (Munther 1970; Shuter et al. 1980). Fry inhabit areas with near optimum temperatures in summer (Coutant 1975), using calm, shallow, marginal areas with rocks and vegetation (Paragamian 1973; Coble 1975). Growth of fry ceases at 35° C (Shuter et al. 1980), and the upper lethal temperature is about 38° C (Larimore and Duever 1968).

Activity levels of fry drop at 20° C (Coble 1975), and swimming is greatly reduced at 10° C (Larimore and Duever 1968; Pflieger 1975). Fry seek rocky shelters in littoral or shore areas when the water is 7° C (Webster 1954; Keast 1968). The lower lethal temperature for fry is about 4° C (Larimore and Duever 1968). There is generally high winter mortality of fry, especially in northern areas; size of the fish and the length of hibernation determines their survival (Oliver et al. 1979; Shuter et al. 1980).

Fry seem to be especially vulnerable to flood conditions and fluctuating water levels (Larimore 1975). A rapid drop in water level may trap them in areas where they will become dessicated (Montgomery et al. 1980). A stream rise of only a few inches may displace advanced fry newly risen from the nest (Webster 1954). Most fry remain in shallow water (Doan 1940; Forney 1972), although some may be found at depths of 4.6.-6.1 m (Stone et al. 1954; Forney 1972). Fry 20-25 mm in length cannot maintain themselves in current velocities > 200 mm/sec (Larimore and Duever 1968). An increase in turbulence during flood conditions creates conditions with which smallmouth fry appear unable to cope (Webster 1954). Fry cannot tolerate and are displaced at high turbidities (2,000 JTU) combined with an increase in water velocity, but they will not be displaced at moderate turbidities (250 JTU) (Larimore 1975). Low water temperatures during flood conditions will reduce fry swimming ability (Larimore and Duever 1968).

Fry cease feeding at dissolved oxygen levels < 1 ppm (Bulkley 1975), and survival is low at levels < 2.5 ppm (Siefert et al. 1974). Levels > 6 ppm are considered optimum.

Juvenile. Juveniles spend most of their time in quiet water near or under a dark shelter, such as brush or rocks (Reynolds 1965; Paragamian 1973, 1979). Juvenile and adult smallmouth bass both prefer low velocity water near a current, but juveniles are often found in slightly shallower water than adults.

In laboratory studies, juveniles preferred temperatures of about 28° C (Coutant 1975) to 31° C (Barans and Tubb 1973). Maximum growth occurred at 25-29° C (Horning and Pearson 1973; Cherry et al. 1975; Shuter et al. 1980; Wrenn 1980). The upper lethal temperature for juveniles is about 35° C (Cherry et al. 1975). Activity is reduced below 20° C (Coble 1975) and little growth occurs below 16° C (Horning and Pearson 1973). Juveniles seek shelter in the crevices and fissures of the rock substrate at very low temperatures (below 7.8° C) (Munther 1970), and the lower lethal temperature occurs near freezing (Horning and Pearson 1973).

HABITAT SUITABILITY INDEX (HSI) MODELS

Model Applicability

Geographic area. The model is applicable throughout the native and introduced range of smallmouth bass in North America. The standard of comparison for each individual variable suitability index is the optimum value of the variable that occurs anywhere within the native and introduced range of the species. For example, the model may never provide an HSI of 1.0 when applied to water bodies in northern areas where temperature related variables do not reach the optimum values of more southern locations.

Season. The model provides a rating for a water body based on its ability to support a reproducing population of smallmouth bass through all seasons of the year. The model will provide an HSI of 0.0 if the Suitability Index (SI) for any reproduction related variable indicates that the species is not able to reproduce in the habitat being evaluated.

Cover types. The model is applicable in riverine and lacustrine habitats as described by Cowardin et al. (1979).

Minimum habitat area. Minimum habitat area is defined as the minimum area of contiguous habitat that is required for a species to live and reproduce. No attempt has been made to establish a minimum habitat size for smallmouth bass.

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

Model Description - Riverine

The analysis of the quality of smallmouth bass habitat is based on an evaluation of the ability of the habitat to meet the requirements for food, cover, water quality, and reproduction. Habitat variables that affect growth, survival, abundance, or other measures of well-being of smallmouth bass are placed in the appropriate model component (Figs. 1 and 2).

Food component. Substrate type (V_1) is assumed to be important in relation to food production. Crayfish are a large part of the adult diet, and they usually live on rocky substrates. Some studies have indicated that the preference of smallmouth bass for a certain substrate is related to food production. Percent pools (V_2) is included because smallmouth bass occupy pools almost exclusively in rivers. Percent cover (V_5) is included because cover, such as stumps, trees, boulders, and crevices, is related to the production of adult food (crayfish and small fish).

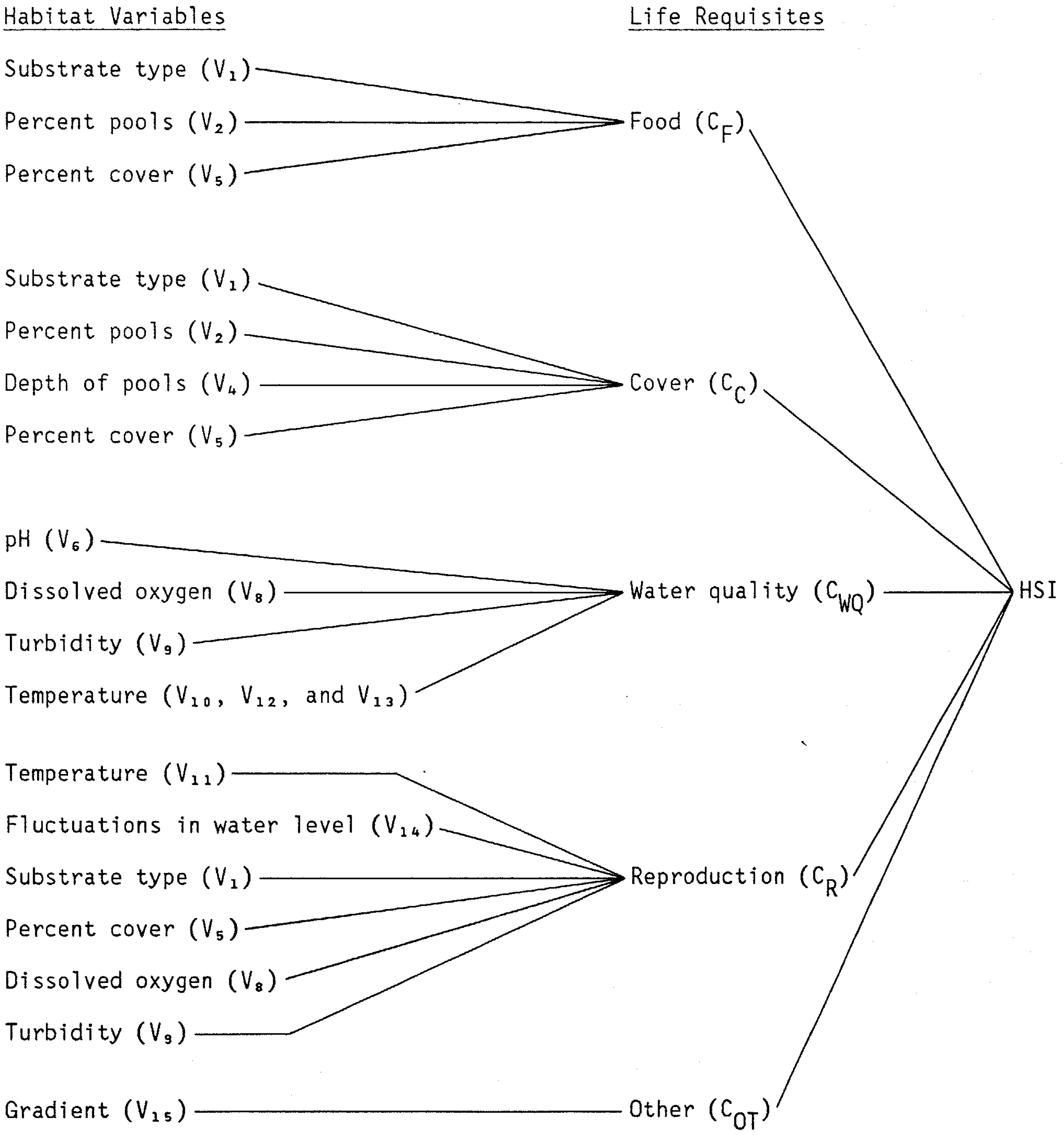


Figure 1. Tree diagram illustrating relationships of habitat variables and life requisites in the riverine model for the smallmouth bass.

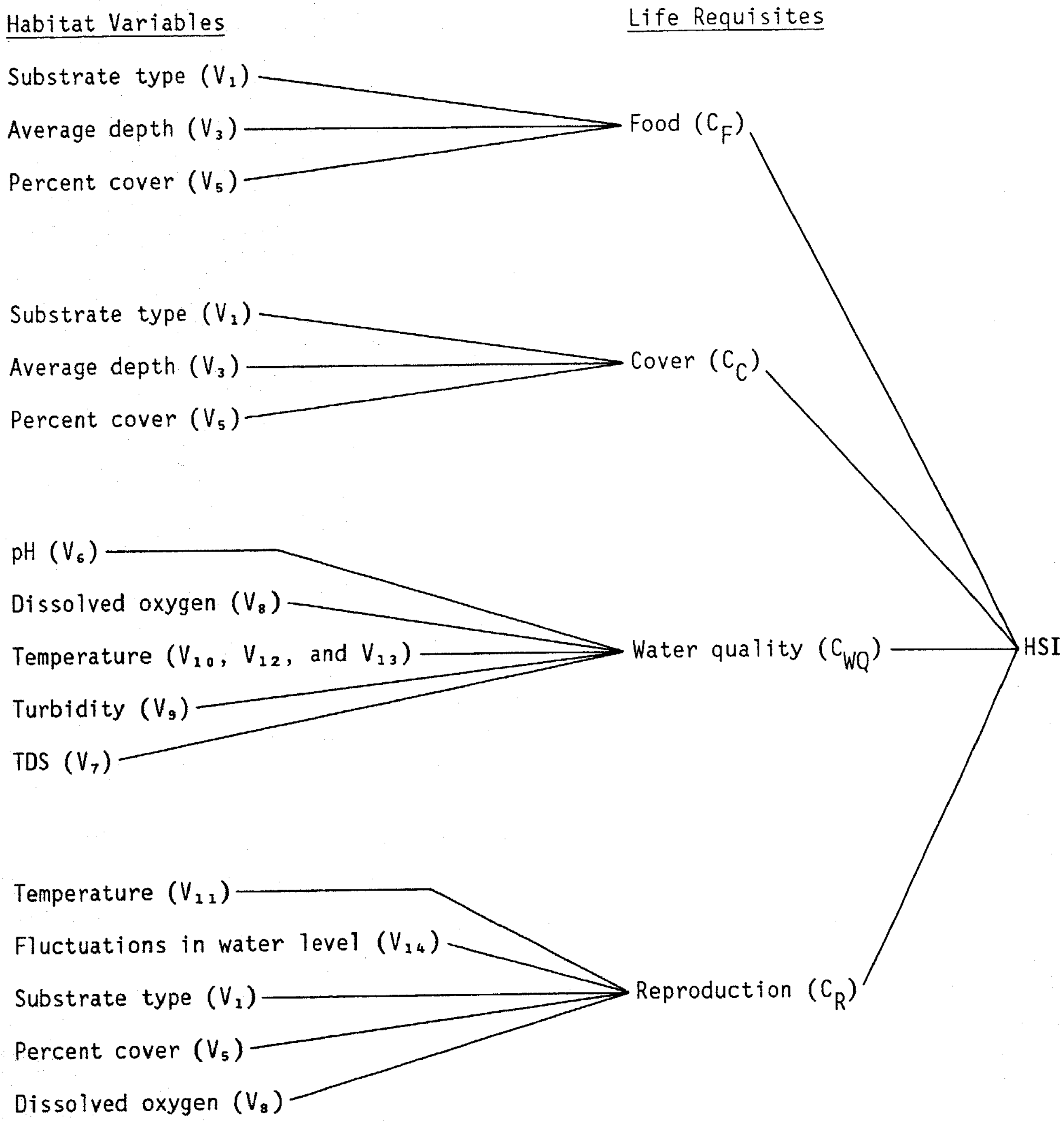


Figure 2. Tree diagram illustrating relationships of habitat variables and life requisites in the lacustrine model for the smallmouth bass.

Cover component. Substrate type (V_1) is important because smallmouth bass prefer a broken rock substrate with crevices and fissures they may use for shelter. Percent pools (V_2) is important because pools are the primary habitat of smallmouth bass. Depth (V_4) of pools affects their quality as cover. Cover is also provided by stumps, trees, boulders, and crevices (V_5).

Water quality component. The water quality component includes pH (V_6), dissolved oxygen (V_8), turbidity (V_9), and temperature (V_{10}, V_{12}, and V_{13}). These parameters affect growth or survival. Interactions with toxic substances are not considered in this model.

Reproduction component. Temperature (V_{11}) is a critical variable in the reproduction component because temperature fluctuations can disrupt spawning. Acute changes in water level (V_{14}) can affect reproductive success. Substrate type (V_1) is important because smallmouth bass only spawn over certain types of substrate. Percent cover (V_5) is included in this component because bass usually nest near some form of cover. Dissolved oxygen level (V_8) is critical for normal embryo development. Excess turbidity (V_9) reduces survivability in streams.

Other component. The other component helps describe habitat suitability for smallmouth bass but contains variables not related to a specific life requisite component. Stream gradient (V_{15}) is included because in riverine environments smallmouth bass usually occur in midorder streams of moderate gradient (but can occur in all stream sizes up to the St. Lawrence River). Gradient is also an important factor related to the formation of pools and riffles.

Model Description - Lacustrine

Food component. Substrate type (V_1) is assumed to be important in terms of food production, because smallmouth bass preference for a rocky substrate appears to be related to production of crayfish and forage fish. Average depth (V_3) is important because smallmouth bass forage in areas of a certain depth. Percent cover (V_5) is included because cover contributes to the production of crayfish and small forage fish.

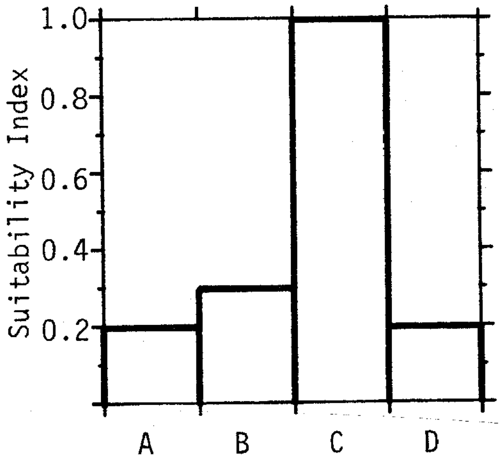
Cover component. Substrate type (V_1) is important because smallmouth bass prefer a broken rock substrate with crevices and fissures they may use for shelter. Depth (V_3) is important because deep, dark, quiet areas are used as cover. Cover in the form of stumps, trees, boulders, and crevices (V_5) is utilized whenever available.

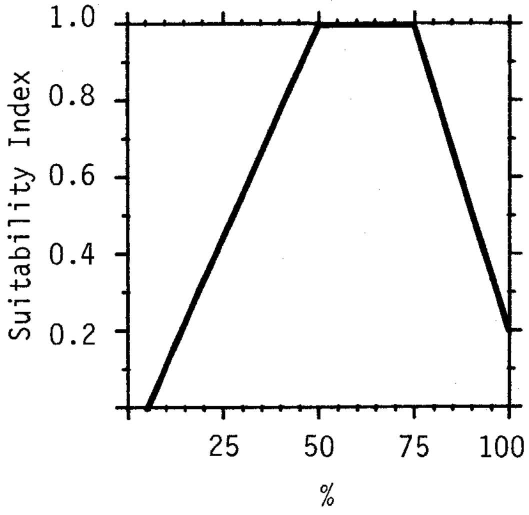
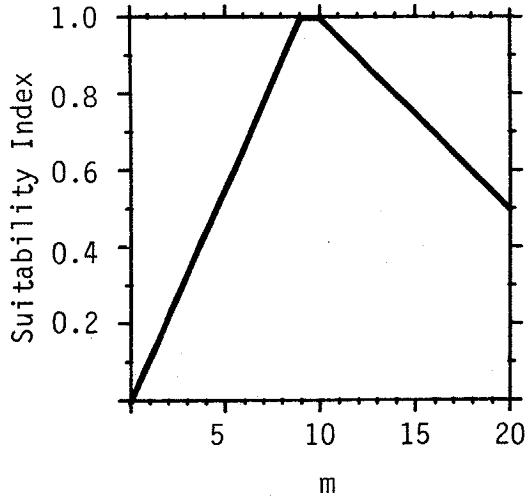
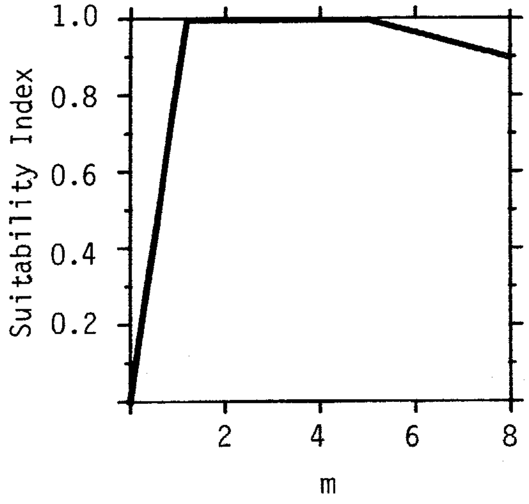
Water quality component. The water quality component includes pH (V_6), dissolved oxygen (V_8), temperature (V_{10}, V_{12}, and V_{13}), and turbidity (V_9). These variables effect growth and survival. Total dissolved solids (TDS) (V_7) is included because smallmouth bass standing crop is correlated with TDS levels.

Reproduction component. Temperature (V_{11}) is a critical variable in the reproduction component because temperature fluctuations can disrupt spawning. Fluctuations in water level (V_{14}) can adversely affect reproductive success. Substrate type (V_1) is important because smallmouth bass spawn over a specific type of substrate. Percent cover (V_5) is included because bass usually nest near some form of cover. Dissolved oxygen level (V_8) is critical for normal embryo development.

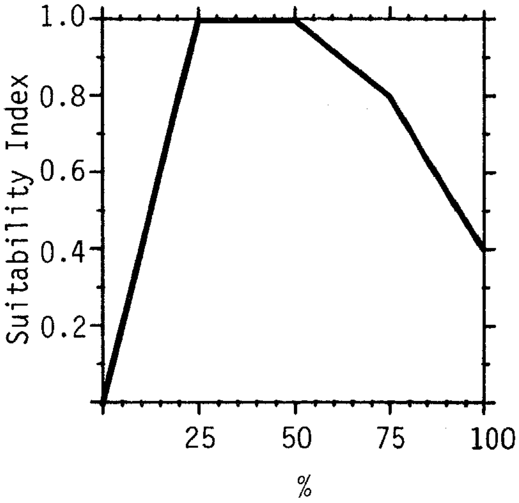
Suitability Index (SI) Graphs for Model Variables

This section contains suitability index graphs for the 15 variables described above and equations for combining the suitability indices for these variable indices into a species HSI using the component approach. Variables may pertain to either a riverine (R) habitat, a lacustrine (L) habitat, or both.

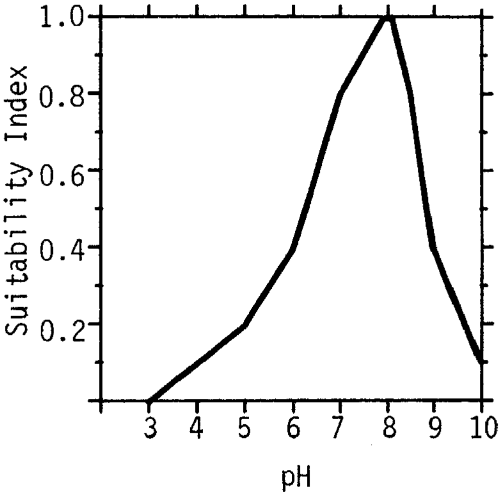
Habitat	Variable		Suitability Graph
R,L	V_1	Dominant substrate type within pool, backwater (R), or shoal area (L). A. Silt and sand (< 0.2 cm) and/or rooted vegetation B. Pebble (0.2-1.5 cm) C. Gravel, broken rock (1.6-2.0 cm), and boulder with adequate interstitial space D. Bedrock	

R	V_2	Percent pools.	
L	V_3	Average depth of lake or reservoir during midsummer.	
R	V_4	Average depth of pools during midsummer.	

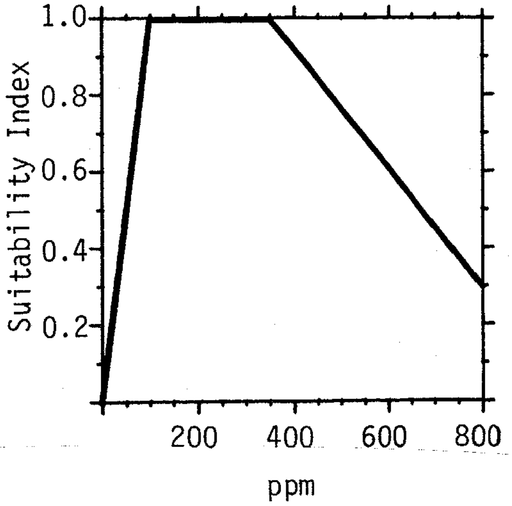
R,L V_5 Percent cover in the form of boulders, stumps, dead trees, and crevices (adults) or vegetation and rocks (fry).

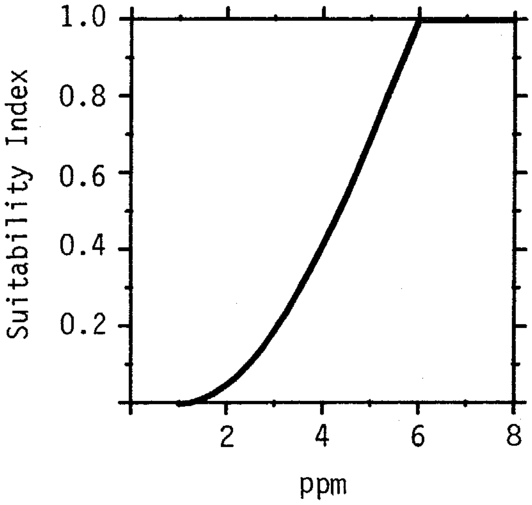
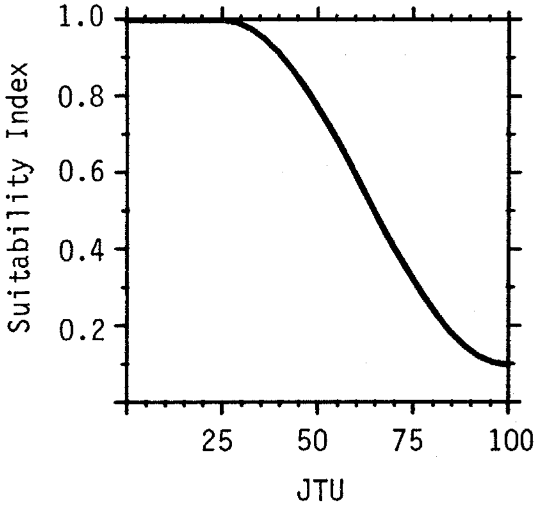
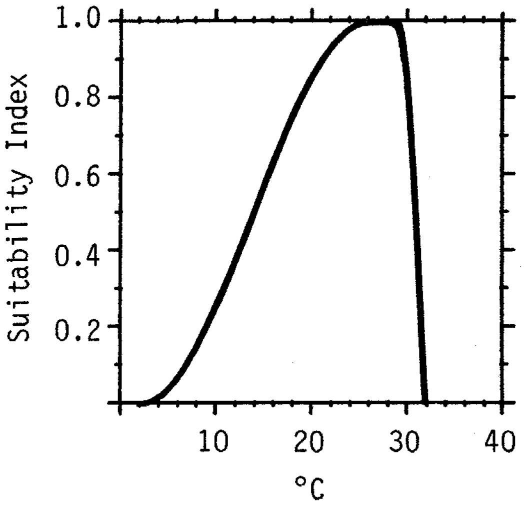


R,L V_6 Average pH level during the year.

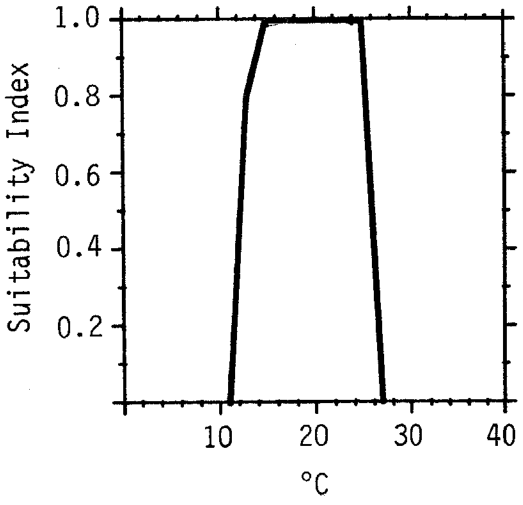


L V_7 Average TDS level during the growing season (May to October).

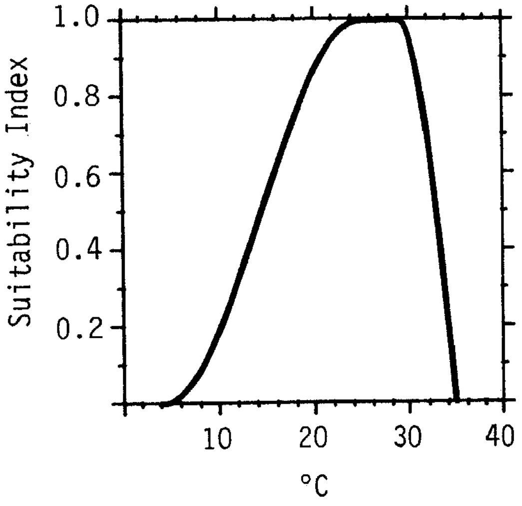


R,L	V_8	Minimum dissolved oxygen level throughout the year.	
R,L	V_9	Maximum monthly average turbidity level during the summer.	
R,L	V_{10}	Water temperature in selected habitat during the growing season (May to October) (adults).	

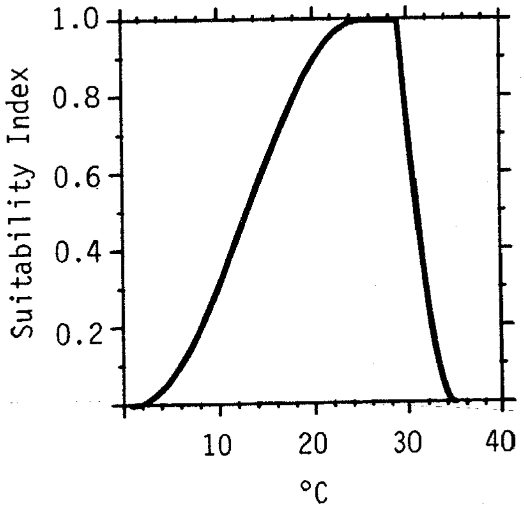
R,L V_{11} Water temperature in selected habitat during spawning and for 45 days afterwards (embryo).

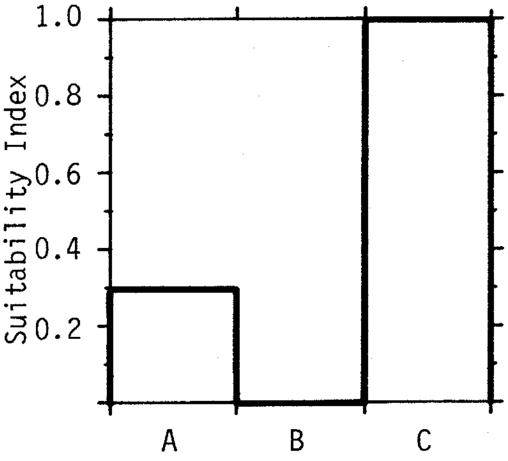
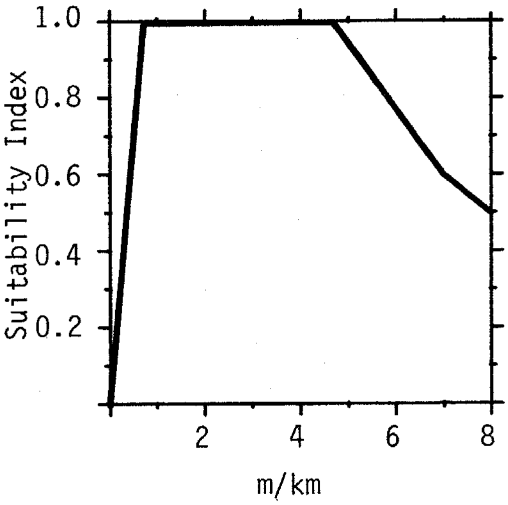


R,L V_{12} Water temperature in selected habitat during the growing season (May to October) (fry).



R,L V_{13} Water temperature in selected habitat during the growing season (May to October) (juvenile).



R,L	V_{14}	Water level fluctuations during spawning and for 45 days after spawning. A. Rapid rise during spawning (1-2 m) B. Rapid fall during spawning or afterwards (.5-1 m) C. Slow rise previous to spawning (.5-1 m) with stable levels during spawning and afterwards	
R	V_{15}	Stream gradient within representative reach.	

Riverine Model

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

Food (C_F).

$$C_F = (V_1 \times V_2 \times V_5)^{1/3}$$

Cover (C_C).

$$C_C = \frac{V_1 + V_2 + V_4 + V_5}{4}$$

Water Quality (C_{WQ}).

$$C_{WQ} = \frac{V_6 + V_8 + V_9 + 2\,[(V_{10} \times V_{12} \times V_{13})^{1/3}]}{5}$$

Except, if V_{10}, V_{12}, or V_{13} is ≤ 0.6, then C_{WQ} equals the lowest of V_{10}, V_{12}, V_{13} or the above equation where the lowest of V_{10}, V_{12}, or V_{13} is substituted for $(V_{10} \times V_{12} \times V_{13})^{1/3}$ in the equation.

Reproduction (C_R).

$$C_R = (V_{11}^2 \times V_{14} \times V_1 \times V_5 \times V_8 \times V_9)^{1/7}$$

Other (C_{OT}).

$$C_{OT} = V_{15}$$

HSI determination

$$HSI = (C_F \times C_C \times C_{WQ} \times C_R \times C_{OT})^{1/5}$$

Or, if C_{WQ} or C_R is ≤ 0.6, the HSI equals the lowest of the following:

C_{WQ}; C_R; or the above equation.

Sources of data and assumptions made in developing the suitability indices are presented in Table 1.

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

Lacustrine Model

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

Food (C_F).

$$C_F = (V_1 \times V_3 \times V_5)^{1/3}$$

Cover (C_C).

$$C_C = \frac{V_1 + V_3 + V_5}{3}$$

Table 1. Data sources for smallmouth bass suitability indices.

	Variable and source	Assumption
V_1	Harrison 1954 Webster 1954 Cleary 1956 Sanderson 1958 Latta 1963 Mraz 1964 Harlan and Speaker 1969 Scott and Crossman 1973 Robbins and MacCrimmon 1974 Coble 1975 Miller 1975 Pflieger 1975 Clancey 1980 Penkal and Gregory 1980	The type of substrate associated with high numbers of smallmouth bass is optimum. The substrate must produce adequate food and be suitable for spawning.
V_2	Trautman 1942 Funk 1957 Sanderson 1958 Brown 1961 Fajen 1962 Keating 1970 Munther 1970 Robbins and MacCrimmon 1974 Coble 1975 Funk and Pflieger 1975 Pflieger 1975 Paragamian 1979 Clancey 1980 Montgomery et al. 1980	Pools have the highest standing crop of smallmouth bass in streams. Conditions must exist for an adequate percentage of pools (vs. riffles) for the habitat to be optimum.
V_3	Turner and MacCrimmon 1970 Coble 1975 Miller 1975 Pflieger 1975	Mean depths associated with large populations of smallmouth bass are optimum.
V_4	Robbins and MacCrimmon 1974 Paragamian 1979 Clancey 1980	Pool depths associated with greater numbers of smallmouth bass are optimum.

Table 1 (continued)

	Variable and source	Assumption
V_5	Coble 1975 Miller 1975 Hubert and Lackey 1980	The strong cover-seeking behavior of smallmouth bass indicates that adequate cover must be present for the habitat to be optimum.
V_6	Butler 1972 Funk and Pflieger 1975 Paragamian 1979	pH levels that contribute to high growth rate and production of smallmouth bass are optimum.
V_7	Jenkins 1975, 1976	TDS levels associated with good production of smallmouth bass are optimum.
V_8	Burdick et al. 1954 Bulkley 1975	Dissolved oxygen levels that ensure the maximum growth rate are optimum.
V_9	Webster 1954 Cleary 1956 Coutant 1975 Hubert and Lackey 1980	Turbidity levels that do not interfere with growth and reproduction are suitable. Levels associated with high numbers of smallmouth bass are optimum.
V_{10}	Doan 1940 Webster 1954 Ferguson 1958 Brown 1961 Bennett 1965 Munther 1970 Forney 1972 Barans and Tubb 1973 Robbins and MacCrimmon 1974 Cherry et al. 1975 Coble 1975 Coutant 1975 Clancey 1980 Shuter et al. 1980 Wren 1980 Mathur et al. 1981	Temperatures that result in maximum growth rates are optimum. Temperatures that result in slow growth have low suitability. Lethal temperatures are unsuitable.

Table 1 (concluded)

	Variable and source	Assumption
V_{11}	Webster 1954 Henderson and Foster 1957 Watt 1959 Latta 1963 Harlan and Speaker 1969 Turner and MacCrimmon 1970 Scott and Crossman 1973 Coble 1975 Montgomery et al. 1980 Shuter et al. 1980	Optimum temperatures for embryos are where spawning or male nest guarding is not disrupted, and development is normal.
V_{12}	Webster 1954 Keast 1968 Larimore and Duever 1968 Munther 1970 Coble 1975 Coutant 1975 Pflieger 1975 Oliver et al. 1979 Shuter et al. 1980	Abundant numbers of fry are found in areas with the optimum temperature. Maximum growth occurs at optimum temperatures. Temperatures that slow growth and activity have lower suitability. Lethal temperatures are unsuitable.
V_{13}	Reynolds 1965 Munther 1970 Barans and Tubb 1973 Horning and Pearson 1973 Cherry et al. 1975 Coutant 1975 Shuter et al. 1980 Wrenn 1980	Temperatures that promote high growth rates are optimum. Temperatures where growth and activity slows are suboptimum, and lethal temperatures are unsuitable.
V_{14}	Watson 1955 Neves 1975 Pflieger 1975 Montgomery et al. 1980	Rising water conditions associated with successful spawning are optimum. Fluctuating conditions associated with nest desertion, no embryo development, and lower reproductive success are unsuitable.
V_{15}	Trautman 1942 Hallam 1959 Robbins and MacCrimmon 1974 Coble 1975 Funk and Pflieger 1975	Stream gradients associated with the largest populations of smallmouth bass are optimum.

Table 2. Sample data sets using riverine HSI model.

Variable		Data set 1		Data set 2		Data set 3	
		Data	SI	Data	SI	Data	SI
Substrate type	V_1	gravel, cobble	1.0	pebble	0.3	gravel, cobble	1.0
% pools	V_2	40	0.8	85	0.6	50	1.0
Average depth (m)	V_4	2	1.0	8	0.9	4	1.0
% cover	V_5	80	0.7	80	0.7	50	1.0
pH	V_6	7	0.8	9	0.4	8	1.0
Dissolved oxygen (ppm)	V_8	6	1.0	4	0.4	8	1.0
Turbidity (JTU)	V_9	45	0.8	60	0.6	10	1.0
Temperature (° C) (adult)	V_{10}	22	0.9	30	0.8	28	1.0
Temperature (° C) (embryo)	V_{11}	15	1.0	12	0.6	20	1.0
Temperature (° C) (fry)	V_{12}	19	0.8	13	0.4	24	1.0
Temperature (° C) (juvenile)	V_{13}	16	0.7	11	0.4	28	1.0
Water level fluctuations (m)	V_{14}	slow rise	1.0	rapid rise	0.3	slow rise	1.0
Gradient (m/km)	V_{15}	2	1.0	0.5	0.6	3	1.0

Table 2 (concluded)

Variable	Data set 1		Data set 2		Data set 3	
	Data	SI	Data	SI	Data	SI
Component SI						
C_F =		0.82		0.50		1.00
C_C =		0.88		0.63		1.00
C_{WQ} =		0.84		0.40		1.00
C_R =		0.92		0.47		1.00
C_{OT} =		1.00		0.60		1.00
HSI =		0.89		0.40		1.00

Water Quality (C_{WQ}).

$$C_{WQ} = \frac{V_6 + V_7 + V_8 + V_9 + 2[(V_{10} \times V_{12} \times V_{13})^{1/3}]}{6}$$

Except, if V_{10}, V_{12}, or V_{13} is ≤ 0.6, C_{WQ} equals the lowest of V_{10}, V_{12}, or V_{13} or the above equation where the lowest of V_{10}, V_{12}, or V_{13} is substituted for $(V_{10} \times V_{12} \times V_{13})^{1/3}$ in the equation.

Reproduction (C_R)

$$C_R = (V_{11}^2 \times V_{14} \times V_1 \times V_5 \times V_8)^{1/6}$$

HSI determination.

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

Or, if C_{WQ} or C_R is ≤ 0.6, the HSI equals the lowest of the following: C_{WQ}; C_R; or the above equation.

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

Table 3. Sample data sets using lacustrine HSI model.

Variable		Data set 1		Data set 2		Data set 3	
		Data	SI	Data	SI	Data	SI
Substrate	V_1	gravel, cobble	1.0	pebble	0.3	gravel, cobble	1.0
Depth (m)	V_3	7	0.8	5	0.5	10	1.0
% cover	V_5	80	0.7	80	0.7	50	1.0
pH	V_6	7	0.8	9	0.4	8	1.0
TDS (ppm)	V_7	200	1.0	600	0.6	200	1.0
Dissolved oxygen (ppm)	V_8	6	1.0	4	0.4	8	1.0
Turbidity (JTU)	V_9	45	0.8	60	0.6	10	1.0
Temperature (° C) (adult)	V_{10}	22	0.9	30	0.8	28	1.0
Temperature (° C) (embryo)	V_{11}	15	1.0	12	0.6	20	1.0
Temperature (° C) (fry)	V_{12}	19	0.8	13	0.4	24	1.0
Temperature (° C) (juvenile)	V_{13}	16	0.7	11	0.4	28	1.0
Water level fluctuations (m)	V_{14}	slow rise	1.0	rapid rise	0.3	slow rise	1.0
Component SI							
C_F =			0.82		0.47		1.0
C_C =			0.83		0.50		1.0
C_{WQ} =			0.87		0.47		1.0
C_R =			0.94		0.67		1.0
HSI =			0.86		0.47		1.0

Interpreting Model Outputs

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

The sample data sets are not actual field measurements, but represent combinations of variable values that could occur in a riverine or lacustrine habitat. The HSI's calculated from the data rank the sites in the order that we believe represents the carrying capacity in habitats with the listed characteristics. The relationship of the model-generated index to measurable indices of carrying capacity, such as production or standing crop, is unknown. The model must be viewed as conceptual. Any attempt to use the model, or model components, as predictive tools should be preceded by the evaluation of the model with actual field measurements to better define which, if any, model variables are important habitat descriptors in the proposed area of model application.

ADDITIONAL HABITAT MODELS

Model 1

Optimum riverine habitat for smallmouth bass is characterized by the following conditions: clear (≤ 25 JTU) water; second order stream with a gradient between 0.75 and 4.7 m/km; at least 25% pools; at least 25% cover and/or > 1 m depth in the pools; warm (21-29° C) summer temperatures; and gravel, rubble, or boulder substrate.

$$\text{HSI} = \frac{\text{number of above criteria present}}{6}$$

Model 2

Optimum lacustrine habitat for smallmouth bass is characterized by the following conditions: lakes and reservoirs with warm (21-29° C) strata available during midsummer; abundant cover and/or depth available; gravel, rubble, or boulder substrate or rocky shoals; and clear ($\leq$ 25 JTU) water.

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

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 pelagic species that only shows preferences for velocity and temperature will have very broad curves for depth, substrate, and cover). Instream Flow Information Papers 11 (Milhous et al. 1981) and 12 (Bovee 1982) should be reviewed carefully before using any curves for a PHABSIM analysis. SI curves used with the IFIM that are generated from empirical microhabitat data are quite similar in appearance to the more generalized literature-based SI curves developed in many HSI models (Armour et al. 1983). These two types of SI curves are interchangeable, in some cases, after conversion to the same units of measurement (English, metric, or codes). SI curve validity is dependent on the quality and quantity of information used to generate the curve. The curves used need to accurately reflect the conditions and assumptions inherent in the model(s) used to aggregate the curve-generated SI values into a measure of habitat suitability. If the necessary curves are unavailable or if available curves are inadequate (i.e., built on different assumptions), a new set of curves should be generated (data collection and analyses techniques for curve generation will be included in a forthcoming Instream Flow Information Paper).

There are several ways to develop SI curves. The method selected depends on the habitat model that will be used and the available database for the species. The validity of the curve is not obvious and, therefore, the method used to generate the curve and the quality of the database are very important. Care also must be taken to choose the habitat model most appropriate for the specific study or evaluation; the choice of models will determine the type of SI curves that will be used. For example, in an HSI model, a SI curve for velocity usually reflects suitability of average channel (stream) velocity (i.e., a macrohabitat descriptor); in an IFIM analysis, SI curves for velocity are assumed to represent suitability of the velocity at the point in the stream occupied by a fish (i.e., a microhabitat descriptor) (Armour et al. 1983).

A system with standard terminology has been developed for classifying SI curve sets and describing the database used to construct the curves in IFIM applications. The classification is not intended to define the quality of the data or the accuracy of the curves. There are four categories in the classification. A literature-based curve (category one) has a generalized description or summary of habitat preferences from the literature as its database. This type of curve usually is based on information in published references on the upper and lower limits of a variable for a species (e.g., juveniles are usually found at water depths of 0.3-1.0 m). Unpublished data and expert opinion also can be used to develop these curves. Occasionally, the reference also contains information on the optimal or preferred condition within the limits of tolerance (e.g., juveniles are found at water depths of 0.3-1.0 m, but are most common at depths from 0.4-0.6 m). Most of the SI curves presently available for use with the IFIM, and virtually all of the SI curves published in the HSI series for depth, velocity, and substrate, are category one curves.

Utilization curves (category two) are based on a frequency analysis of fish observations in the stream environment with the habitat variables measured at each sighting (see Instream Flow Information Paper 3 (Bovee and Cochnauer 1977) and Instream Flow Information Paper 12 (Bovee 1982:173-196). These curves are designated as utilization curves because they depict the habitat conditions a fish will use within a specific range of available conditions. Because of the way the data are collected for utilization curves, the resulting function represents the probability of occurrence of a particular environmental condition, given the presence of a fish of a particular species, P(E|F). Utilization curves are generally more precise for IFIM applications than literature-based curves because they are based on specific measurements of habitat characteristics where the fish may actually occur. However, utilization curves may not be transferable to streams that differ substantially in size and complexity from the streams where the data were obtained.

A preference curve (category three) is a utilization curve that has been corrected for environmental bias. For example, if 50% of the fish are found in pools over 1.0 m deep, but only 10% of the stream has such pools, the fish are actively selecting that type of habitat. Preference curves approximate the function of the probability of occurrence of a fish, given a set of environmental conditions:

$$P(F|E) \approx \frac{P(E|F)}{P(E)}$$

Only a limited number of experimental data sets have been compiled into IFIM preference curves. The development of these curves should be the goal of all new curve development efforts.

The fourth category of curves is still largely conceptual. One type under consideration is a cover-conditioned, or season-conditioned, preference curve set. Such a curve set would consist of different depth-velocity preference curves as a function or condition of the type of cover present or the time of year. No fourth category curves have been developed at this time.

The advantage of category three and four curves is the significant improvement in precision and confidence in the curves when applied to streams similar to the streams where the original data were obtained. The degree of increased accuracy and transferability obtainable when applying these curves to dissimilar streams is unknown. In theory, the curves should be widely transferable to any stream in which the range of environmental conditions is within the range of conditions found in the streams from which the curves were developed.

Availability of Graphs for Use in IFIM

Curve sets for smallmouth bass range from category one (literature-based) for some life stages to category three for others. There is a considerable range in the quality of the database for the different sets of curves.

The spawning, incubation, and fry curves are all category one curves. Two curve sets have been developed for spawning and incubation because there is some evidence that smallmouth spawn in shallower water if visibility is reduced (Breder 1936) and that survival of embryos is affected by silt deposition on the nests during the incubation period. The velocity curve for incubation in turbid water goes to zero utilization at zero velocity, as a function of siltation potential. At about 0.5 ft/sec (15 cm/sec), silt sized material should remain in suspension, based on the Hjulstrom curve (Fig. 3). The databases used to develop both the spawning and incubation curves are fair, at best, for the depth and substrate variables. The velocity curves do not have an empirical database; they were estimated by applying a variety of hydraulic formulae to the investigators' descriptions of the streams (Breder 1936; Pflieger 1966; Funk 1977).

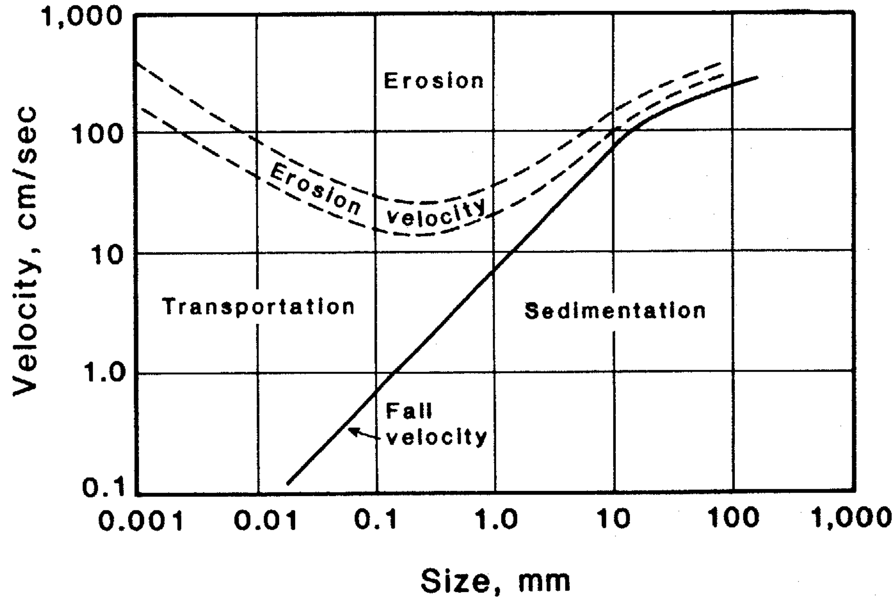


Figure 3. Hjulstrom curves of erosion and deposition for uniform materials. Erosion velocity shown as a band (Morisawa 1968).

The spawning velocity curves (20100 and 20115) (Figs. 4 and 5), probably overrate the utility of velocities over 1.0 ft/sec (30 cm/sec). A more reasonable spawning velocity function might be described by the fry curve (20100) (Fig. 4). The spawning and incubation curve sets should be evaluated by local experts before use because they are based on a very limited database.

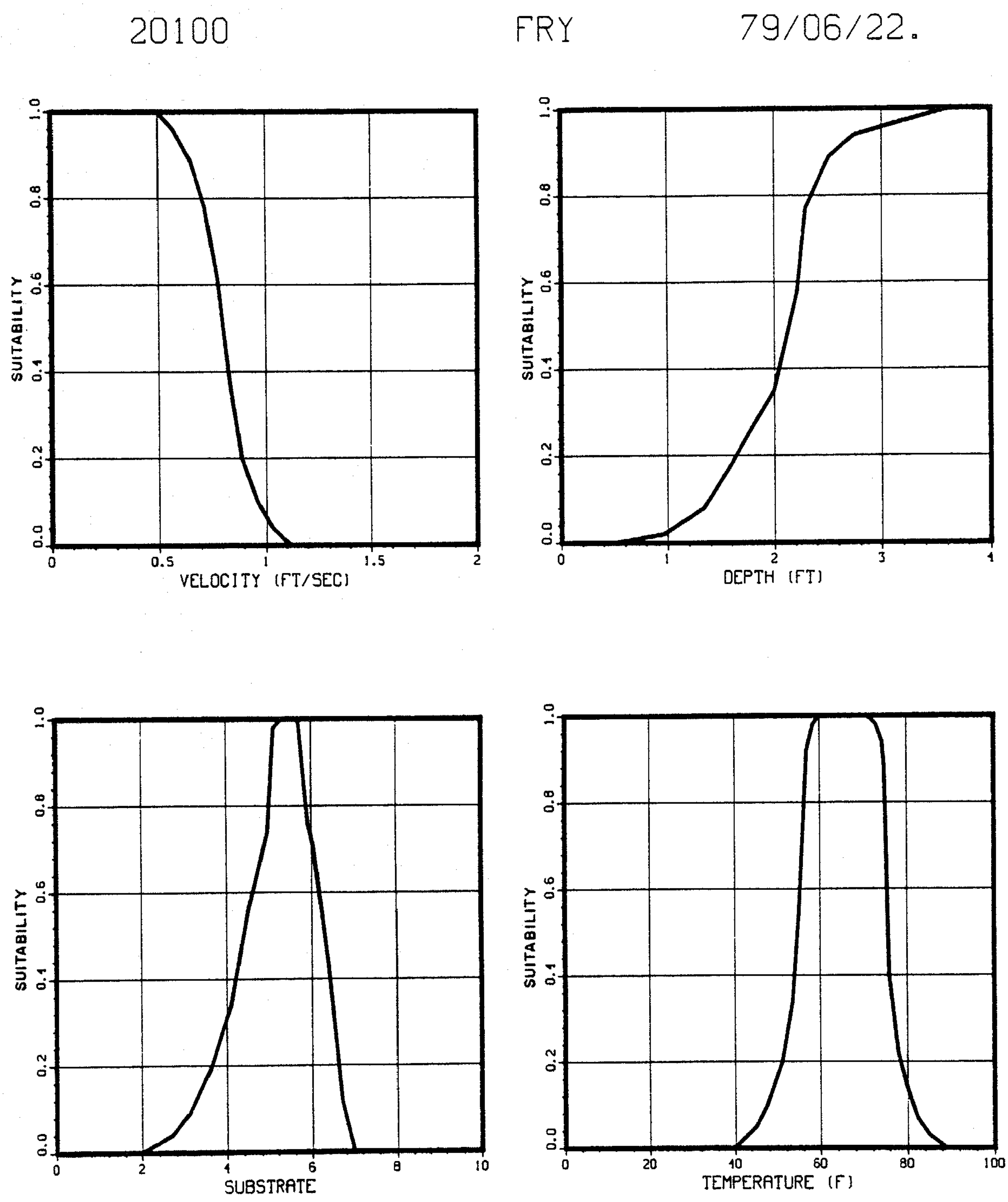


Figure 4. Category one SI curves for velocity, depth, substrate, and temperature for smallmouth bass fry.

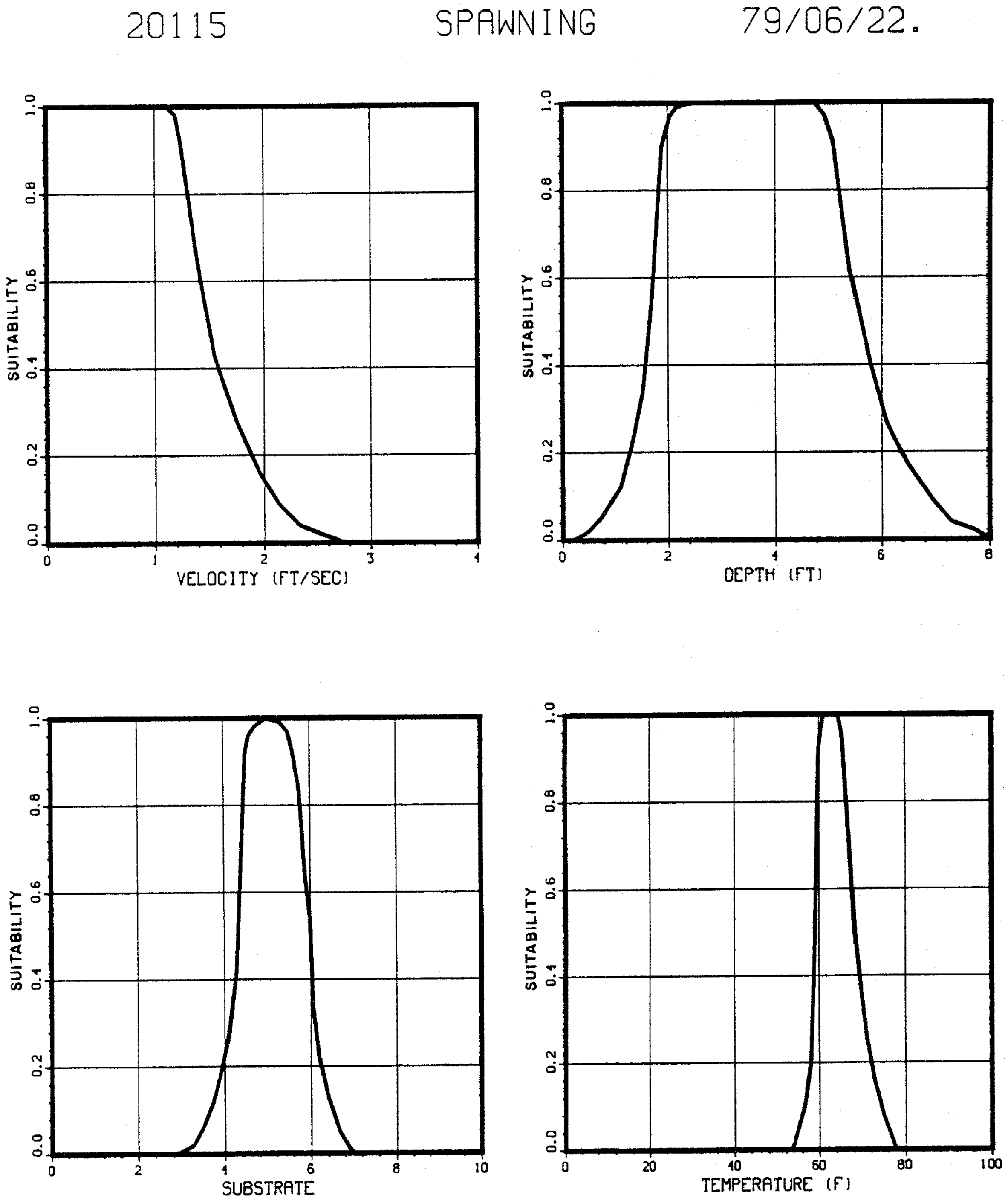


Figure 5. Category one SI curves for velocity, depth, substrate, and temperature for smallmouth bass spawning.

The fry curves, although category one, are of higher quality than the spawning and incubation curves. The velocity curve is the result of swimming performance tests under laboratory conditions (Larimore and Duever 1968). A preference (category three) curve of velocities actually selected by young bass in the wild would undoubtedly be more compressed toward lower velocities than the velocity curve shown. The results of the swimming performance tests indicate that smallmouth fry are capable of maintaining position, without tiring, in velocities up to 0.5 ft/sec (15 cm/sec). However, based on the juvenile and adult velocity curves, it is unlikely that young fish would voluntarily select velocities much over 0.5 ft/sec. The depth curves are based on a fry mortality study in a lake (Neves 1975). One of the primary mortality factors in lakes is wave action, which is most severe at depths of less than 2 ft (60 cm). Most bass streams rarely experience the kind of wave action that develops in lakes, so it is reasonable to suggest a greater utilization of shallow water than curve 20100 (Fig. 4) shows.

The juvenile and adult curve sets have been recently updated. These are category three (preference) curves based on data collected during 1978 by Don Orth and O. E. Maughan of the Oklahoma Cooperative Fisheries Research Unit, Sillwater, Oklahoma (Orth 1981; Orth and Maughan 1982). Data were collected year-round, but only spring and summer observations were used for these curves resulting in a fairly small database of 55 adult and 40 juvenile observations. Despite the small database, the utilization functions derived were well-defined.

There may be several biases incorporated in the adult and juvenile databases. First, the subject stream appears to be restricted in the amount of preferred smallmouth bass habitat available. Specifically, very little water over 3 ft (90 cm) deep is evident in the database. Glover Creek may also lack the variety desired in a stream used for criteria development. Another potential source of bias is the sampling technique. Electrofishing was used for virtually all the smallmouth bass observations. Smallmouth are extremely sensitive to electrical fields and often stay just ahead of the sampler. Unless great care is taken during collection, data biases may result by "herding" the fish ahead of the shocker. One obvious outlying data point (an adult in 2 inches of water at a velocity of 2 ft/sec) was discarded from the data set. The remainder of the data were assumed to be free of "fright" bias. A third source of bias may be the result of the way habitat availability was calculated. The database did not contain independent, random samples of the environment. However, numerous species besides smallmouth bass were collected from a wide variety of habitat types. Data from all fish collections were used to describe the habitat availability function.

Despite potential biases, the category three depth and velocity curves (20101 and 20102) (Figs. 6 and 7) nearly replicate the category two curves, which were based on utilization data from Idaho (Cochnauer 1977). Only the juvenile depth curve changed significantly (the older curve peaked at 1.3 ft, instead of 2.4 ft).

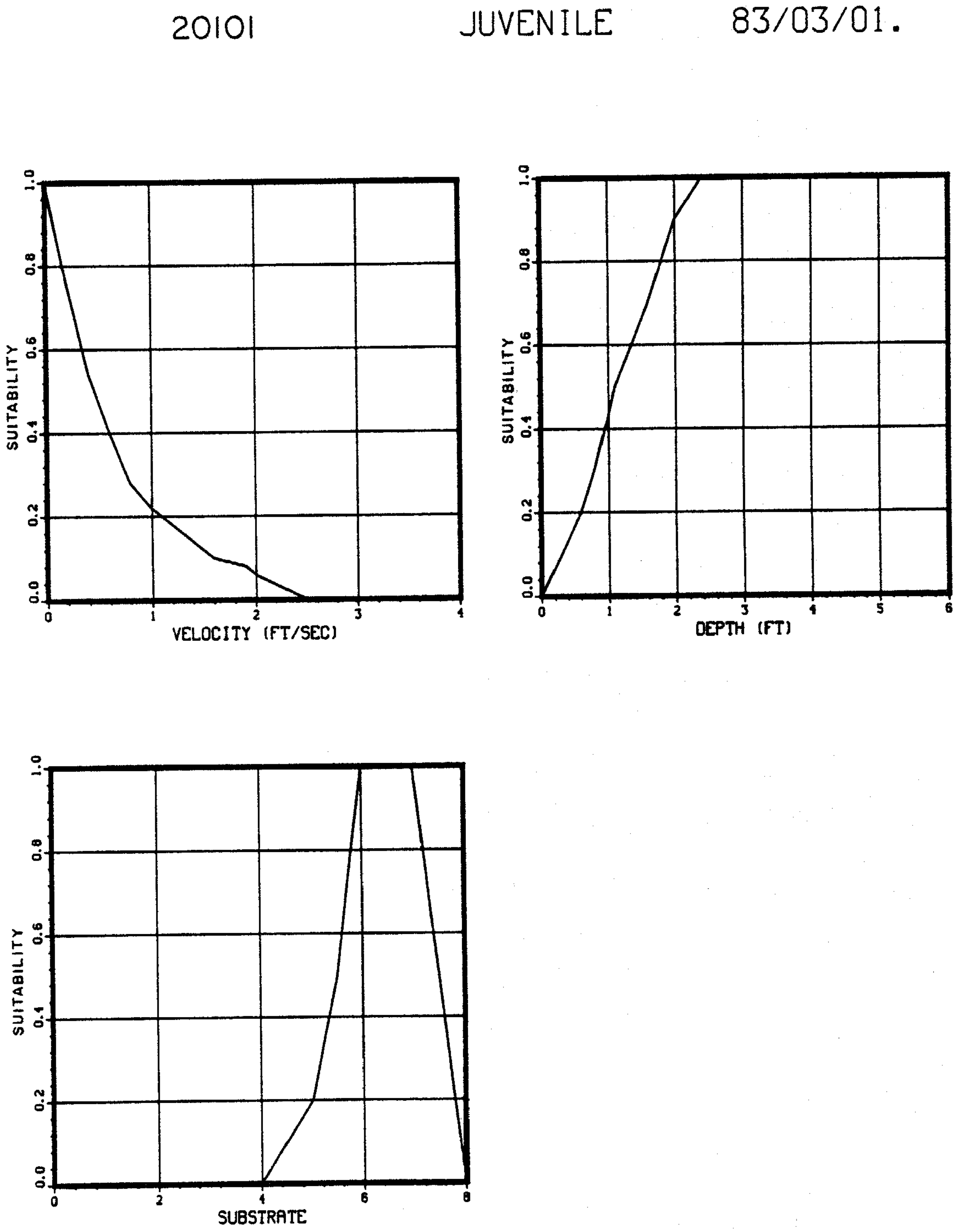


Figure 6. Category three SI curves for velocity, depth, and substrate for juvenile smallmouth bass.

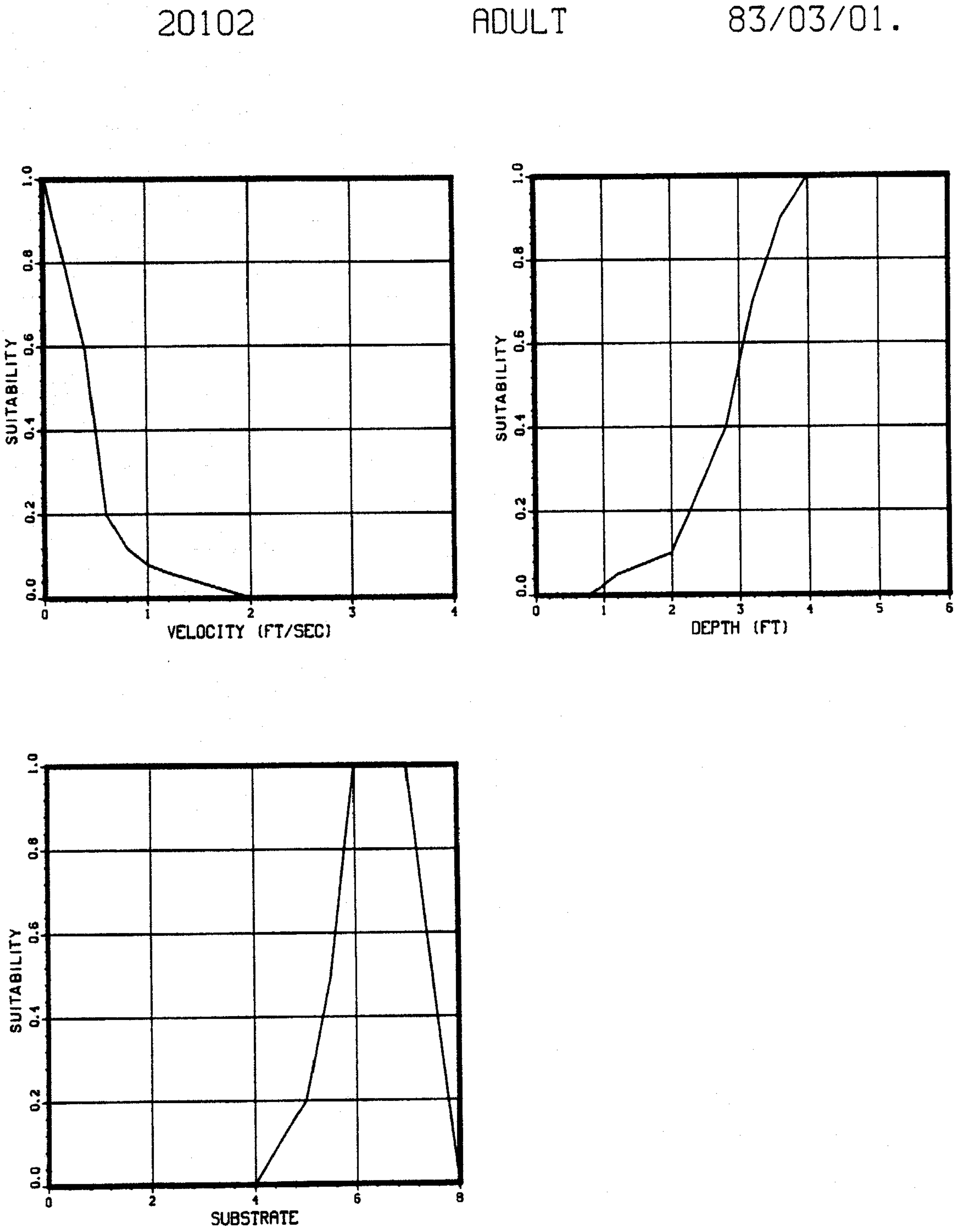


Figure 7. Category three SI curves for velocity, depth, and substrate for adult smallmouth bass.

The category three substrate curves for both adults and juveniles are very different from the category two curves. The Oklahoma data indicate an unmistakable preference for cobble/boulder substrate material. In fact, the fish observations were so clumped in these two categories, it was impossible to fit a curve to the data. These data probably reflect a very high affinity for instream cover objects, rather than an actual substrate preference. Therefore, substrate codes 0-5 on curve sets 20101 and 20102 (Figs. 6 and 7), may really represent "no cover" with a preference of about 0.2 (material smaller than gravel, code 5, was not represented in the samples). Substrate codes 6 and 7 (cobble and boulder, respectively) may actually represent the preference of bass for instream cover objects.

The IFG has not compiled any data regarding the utilization of various cover types by smallmouth bass. The only information currently available for cover usage is contained in the HSI model (see page 12, habitat variable V_5). Unfortunately, the cover curve shown in the HSI model is not in a format that can be easily entered into PHABSIM. Figures 8 and 9 are transformations of the same data contained in the cover curve from the HSI model. The cover code used in Figures 8 and 9 is given in Table 4. "Adult" cover refers to boulders, stumps, dead trees, and crevices and "fry" cover, to vegetation and rocks, consistent with the HSI cover curve. Note that Figures 8 and 9 have as a minimum suitability, 0.2, instead of 0.0, as shown on the HSI model curve. This adjustment was made to reflect the data provided by Orth (1981).

The user should be aware that this cover code has been devised specifically for the smallmouth bass. The code should be modified, replaced, or expanded if species in addition to the smallmouth are to be analyzed with PHABSIM. Preferably, the cover code should describe a cover function (such as light reduction or breaking the current) rather than referring to a specific cover type (e.g., stumps) unless the type makes a difference to the fish. The cover code should also provide minimal criteria as to the effective sizes of pertinent cover types (e.g., how big is a rock?). A complete description of cover codes and options for use in PHABSIM is given in Bovee (1982).

The depth and velocity curves for juveniles and adults show signs of convergence (as more data are obtained, the curves do not change shape very much). The original set of curves were category two (utilization) curves from the Payette River in Idaho. The category three curves are from Glover Creek in Oklahoma. The two sets of curves are very similar, despite the significantly different streams from which they were derived.

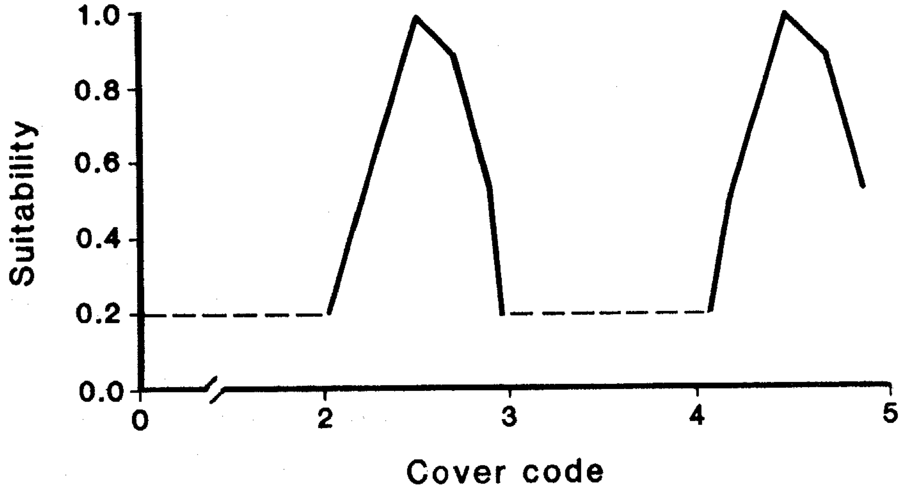


Figure 8. Cover utilization curve for adult and juvenile smallmouth bass.

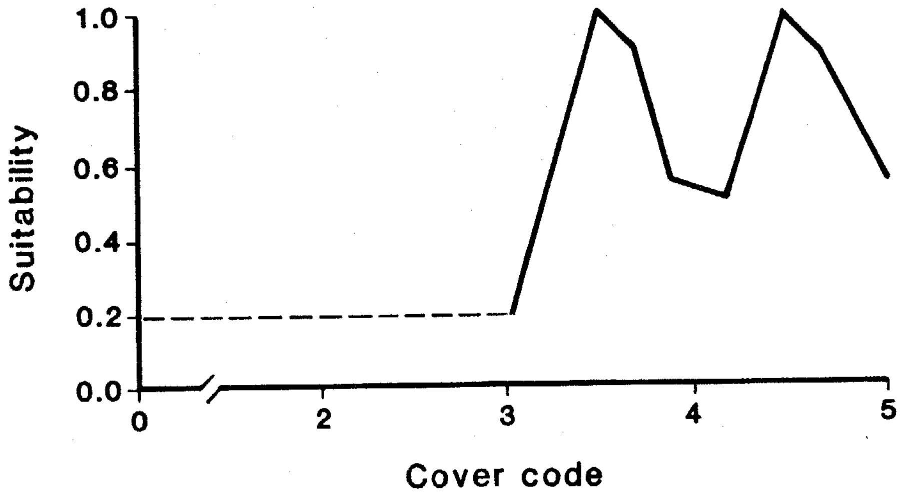


Figure 9. Cover utilization curve for young-of-the-year smallmouth bass.

Table 4. Key to cover code for transformed HSI model cover curves shown in Figures 8 and 9.

Code	Cover	Code	Cover
1.0-1.9	No cover	3.7	50-75% fry cover
2.2	< 25% adult cover	3.9	75-100% fry cover
2.5	25-50% adult cover	4.2	< 25% adult and fry
2.7	50-75% adult cover	4.5	25-50% adult and fry
2.9	75-100% adult cover	4.7	50-75% adult and fry
3.2	< 25% fry cover	4.9	75-100% adult and fry
3.5	25-50% fry cover		

There are several precautions to accepting these curve sets as "universal" smallmouth bass curves: (1) neither the Idaho nor the Oklahoma data sets contained the recommended number of observations (150); (2) there is some evidence that Glover Creek (Oklahoma) was well below carrying capacity when the fish observations were made; (3) both streams appear to be lacking certain types of habitat (especially pools over 4 ft deep, and combinations of deep, fast water); and, (4) electrofishing was used to make the fish collections. Any or all of these factors can introduce error into the curves. The fact that some curves show convergence may, in fact, be a reflection of the same errors being made in both studies. Additional suitability curves also follow (20105, 20110, 20111) (Figs. 10, 11, and 12).

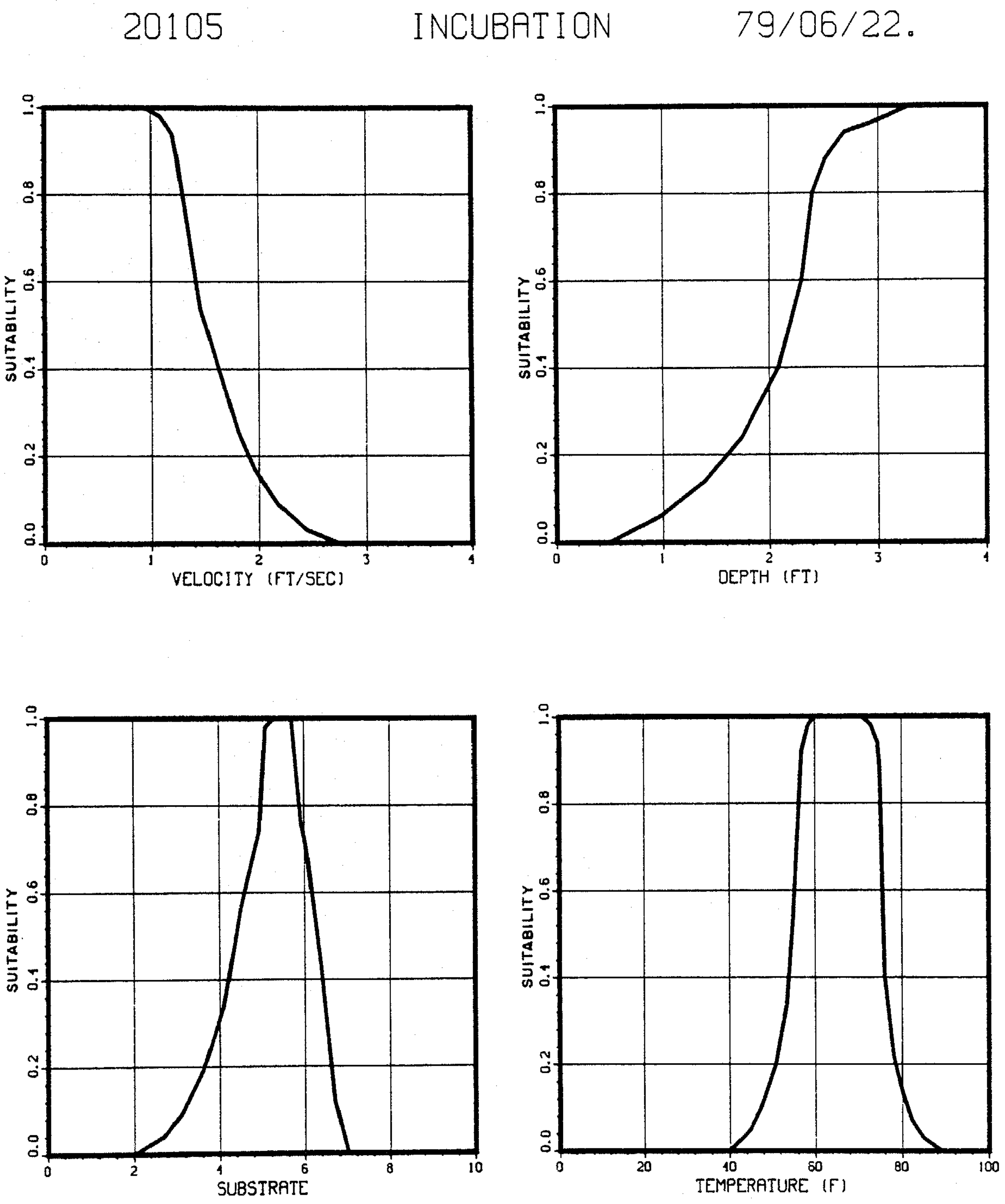


Figure 10. Category one SI curves for velocity, depth, substrate, and temperature for incubation of smallmouth bass.

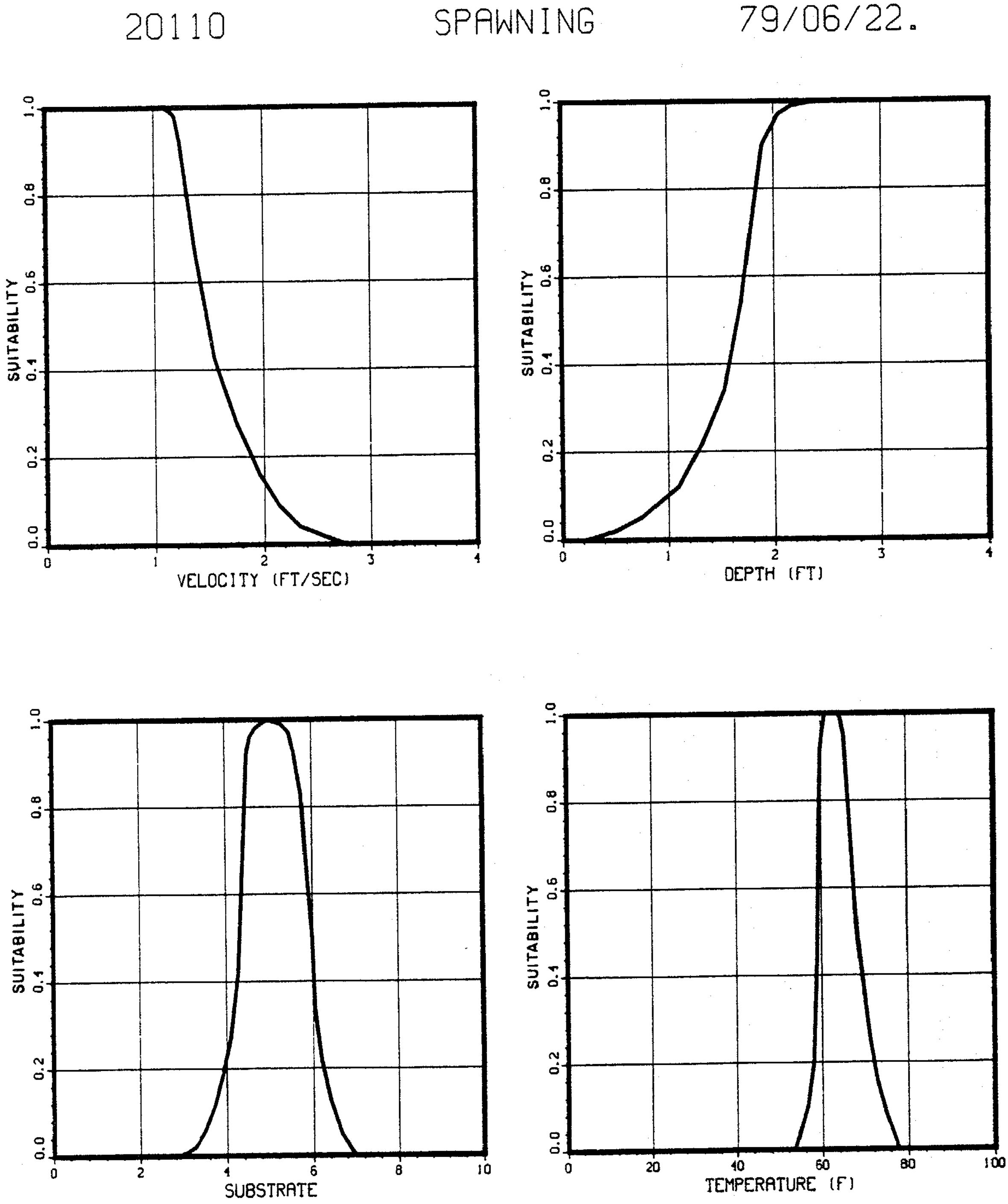


Figure 11. Category one SI curves for velocity, depth, substrate, and temperature for spawning of smallmouth bass.

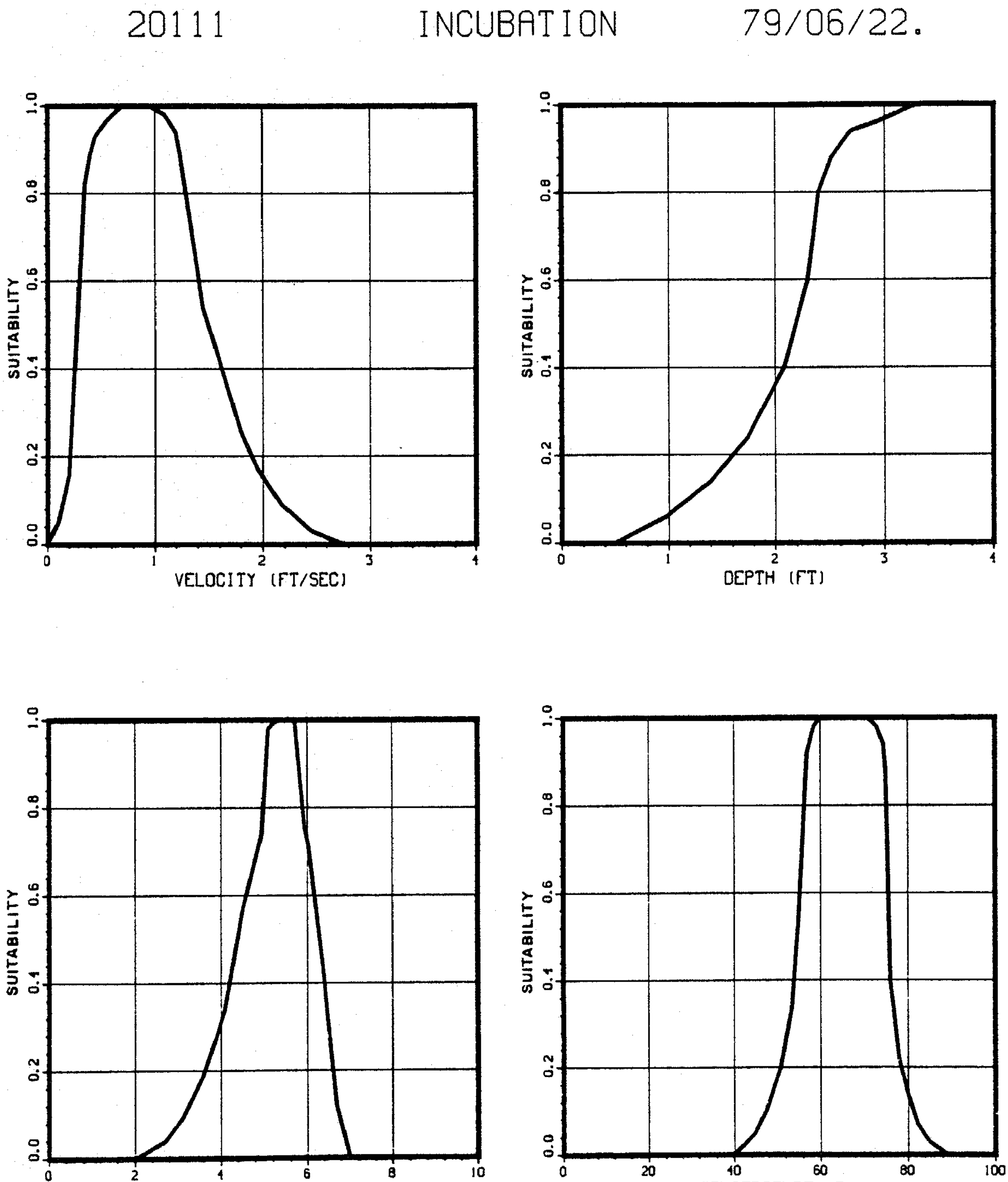


Figure 12. Category one SI curves for velocity, depth, substrate, and temperature for incubation of smallmouth bass.

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16\. Abstract (Limit: 200 words)

A review and synthesis of existing information were used to develop riverine and lacustrine habitat models for Smallmouth bass (Micropterus dolomieui), a freshwater species. The models are scaled to produce an index of habitat suitability between 0 (unsuitable habitat) and 1 (optimally suitable habitat) for freshwater areas of the continental United States. Habitat suitability indexes (HSI's) are designed for use with Habitat Evaluation Procedures previously developed by the U.S. Fish and Wildlife Service.

Also included are discussions of Suitability Index (SI) curves as used in the Instream Flow Incremental Methodology (IFIM) and SI curves available for an IFIM analysis of Smallmouth bass habitat.

17\. Document Analysis a. Descriptors

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