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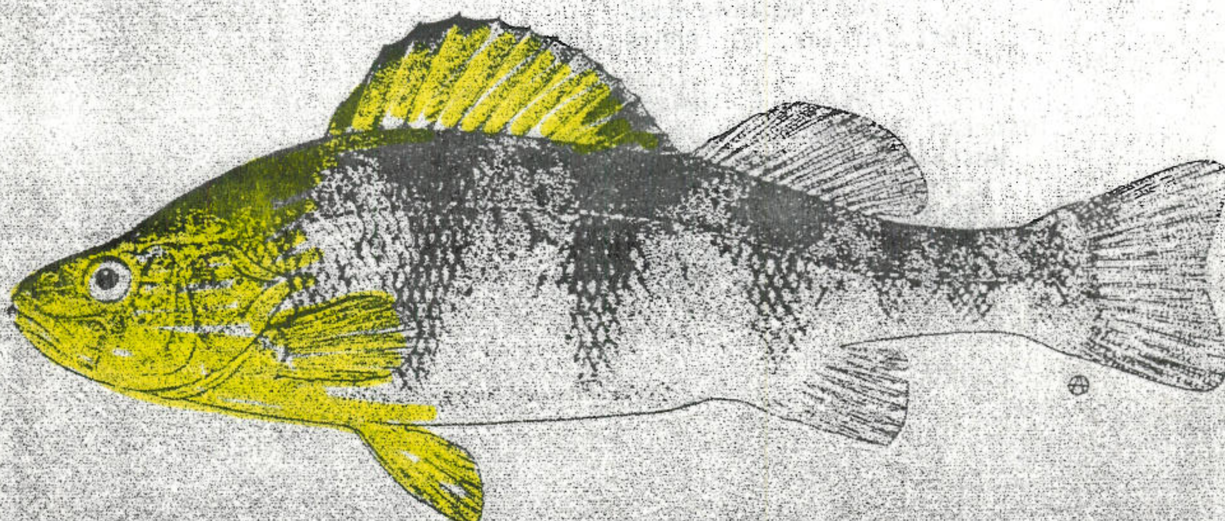
HABITAT SUITABILITY INFORMATION: YELLOW PERCH



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December 1983

HABITAT SUITABILITY INFORMATION: YELLOW PERCH

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 yellow perch habitat.

Use of the models presented in this publication for impact assessment requires the setting of clear study objectives, and the selection of the correct model variables to meet those objectives. Methods for reducing model complexity and recommended measurement techniques for model variables are presented in Terrell et al. (1982).[1] A discussion of HSI model building technologies is presented in U.S. Fish and Wildlife Service (1981).[2]

The HSI models presented herein are 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 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. Fish Wildl. Serv. FWS/OBS-82/10.A. 54 pp.

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

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ACKNOWLEDGMENTS

We would like to thank J. P. Clugston, J. L. Forney, and J. L. Oliver for reviewing the manuscript. They provided many helpful comments, but the reader should not assume that they endorse the models presented in this manuscript. J. P. Clugston and J. L. Oliver also provided unpublished data on habitat conditions in Lakes Keowee and Jocassee. C. J. Short provided editorial assistance. Word processing was provided by C. J. Gulzow and D. E. Ibarra. K. Twomey assisted in finalizing the manuscript. Cover art is from Freshwater Fishes of Canada 1973, Bulletin 184, Fisheries Research Board of Canada by W. B. Scott and E. J. Crossman.

YELLOW PERCH (Perca flavescens)

HABITAT USE INFORMATION

General

The native distribution of yellow perch (Perca flavescens) extends from Nova Scotia south to Georgia and west to the Mississippi, and in Canada, across Ontario, central Manitoba, and Saskatchewan to Great Slave Lake (Scott and Crossman 1973; Collette and Banarescu 1977). The range has been extended by introductions to include areas in the United States south to Florida and Alabama (Clugston et al. 1978), most States west of the Mississippi to the Pacific coast, and as far north as British Columbia (Scott and Crossman 1973; Collette and Banarescu 1977).

Age, Growth, and Food

In Canadian and northern United States waters, female yellow perch mature at 3-4 years of age, one year later than males (Herman et al. 1964; Scott and Crossman 1973). Maximum age is usually 9-10 years. Few fish live longer than 5 years in southern reservoirs (Clugston et al. 1978).

Yellow perch larvae (6 mm) feed on copepod nauplii, cyclopoid copepods and cladocerans (Siefert 1972; Kelso and Ward 1977) including Diaptomus and Diaphanosoma (Oliver, in press). Fry survival, and ultimately year-class strength, are dependent on a plentiful supply of zooplankton at the onset of feeding (Kelso and Ward 1977). Turbidity may lower visibility of prey and restrict zooplankton to upper water strata, where they are unavailable to feeding young (El-Zarka 1959). After becoming bottom dwelling in the littoral areas, juveniles feed on amphipods, ostracods, and chironomid larvae. Larger yellow perch (> 120 mm) prey on aquatic insects, fish, and crayfish (Ward and Robinson 1974; Kelso and Ward 1977). Collette et al. (1977) concluded that the composition of the diet is determined more by the relative availability of different prey types than by preference for certain prey types.

Reproduction

Yellow perch begin spawning migrations from deep water into tributaries, lake shallows, or low velocity areas of rivers from April to June when water temperatures reach 7-13° C (Harrington 1947; Wells 1968; Scott and Crossman 1973). Photoperiod (Hergenrader 1969), rising water temperatures (Amundrud et al. 1974), and/or completion of maturation (Hokanson 1977) may trigger spawning. Adults must be exposed to an extended period of cold water temperatures to ensure ripening of eggs. A winter minimum temperature of 10° C is near the upper limit for maturation of gonads (Hokanson 1977).

The female releases a gelatinous, semi-bouyant string of eggs near aquatic or inundated terrestrial vegetation. Rocks, sand, or gravel may be used if submerged vegetation is not available (Herman et al. 1964; Mansueti 1964; Scott and Crossman 1973; Clady and Hutchinson 1975). There is no parental care (Hergenrader 1969; Scott and Crossman 1973).

Year-class strength is positively correlated with the rate of warming during incubation and hatching (Hartman 1972; Eschenroder 1977). Rising water levels during spawning season in Missouri River reservoirs led to large year classes due to increased inundation of terrestrial vegetation (Nelson and Walburg 1977).

Specific Habitat Requirements

Yellow perch are frequently associated with shoreline (littoral) areas in lakes and reservoirs where there are moderate amounts of vegetation present (Herman et al. 1964; Ward and Robinson 1974; Kitchell et al. 1977; Helfman 1979). These areas provide both cover and spawning habitat. Suitable riverine habitat resembles the lacustrine habitat; i.e., pools and slack water areas with moderate amounts of vegetation (> 20% of area) (Coots 1956; Kitchell et al. 1977).

Several laboratory and field studies have examined winter dissolved oxygen (D.O.) requirements of yellow perch and determined that levels from 0.2 to 1.5 mg/l are lethal (Moore 1942; Cooper and Washburn 1949; Magnuson and Karlen 1970). At a summer temperature of 26° C, D.O. concentrations below 3.1 mg/l were lethal (Moore 1942). Because these studies were of a short duration (< 5 days), we concluded that a D.O. level of 5 mg/l would be the lower optimum limit.

Yellow perch are found in brackish water at river mouths [up to 13 ppt in Chesapeake Bay (Hildebrand and Schroeder 1928)] and in Manitoba lakes with salinities as high as 10.3 ppt (Driver and Garside 1966). However, they require freshwater for spawning (Scott and Crossman 1973).

In general, yellow perch are most common in clear water and numbers decrease with increasing turbidity (Scott and Crossman 1973; Nelson and Walburg 1977). Yellow perch are found in Ontario lakes with a pH range from approximately 3.9 to 9.5 (Johnson et al. 1977). Yellow perch are relatively tolerant of low pH (Rahel 1983) but reproductive success is reduced in lakes with pH < 5.5 (Ryan and Harvey 1979). Using Stroud's (1967) criteria for freshwater fish, it is assumed that the optimum pH ranges from 6.5-8.5.

Adult. Preferred temperatures of adult perch during the growing season are between 17.6° C and 25.0° C (Ferguson 1958; McCauley and Read 1973) with 19 to 24° C being optimum (Scott and Crossman 1973). Growth is initiated at 6 to 10° C (Nakashima and Leggett 1978; Hokanson 1977). The upper lethal summer temperature is 32.3° C (Ferguson 1958).

Yellow perch adults can be found in moderate currents (Muncy 1962; Manion 1977) but prefer sluggish currents or slack water habitat (Coots 1956; Kitchell et al. 1977), particularly during spawning (Harrington 1947).

Embryo. Yellow perch egg strands are broadcast in water depths of 1.0 to 3.7 m (Harrington 1947; Herman et al. 1964; Benson 1973; Clady and Hutchinson 1975). Minimum winter water temperatures (4-10° C) should be maintained for 145-175 days to allow for normal gonadal development of adults so that viable gametes will be produced (Hokanson 1977; Jones et al. 1977). Hokanson and Kleiner (1973) reported that 7-20° C was the temperature range for embryo incubation and hatching. Temperatures of 10° C, increasing 1°/day to 20° C, are optimum for embryo development.

Spawning occurs in low (< 5 cm/s) current velocities (Harrington 1947). Velocities above 25 cm/s have been found to fragment egg strands in the Klamath River, California (Coots 1956).

A moderate amount of vegetation in littoral areas (either aquatic or flooded terrestrial) is important for spawning (Clady and Hutchinson 1975) and cover (Helfman 1979). Reduction in water levels during spawning may lead to dessication of eggs (Benson 1973). Drawdown of mainstem Missouri River reservoirs resulted in the elimination of inundated terrestrial vegetation used for spawning and a corresponding decrease in perch abundance (Beckman and Elrod 1971; Nelson and Walburg 1977). Hatching success may be higher in areas of sparse aquatic vegetation than in areas of very dense vegetation (Forney, pers. comm.).

Fry. Perch fry are susceptible to a number of environmental factors which affect year-class strength. Fry tolerate temperatures from 3.0 to 28.0° C, but they are inactive below 5.3° C, and survival is better at 20° C than at 10° C (Hokanson 1977). Young fry (before swim bladder formation) have a tendency to move to warm water areas (Ross et al. 1977).

Fry move to open water during the first two months of life. Larvae (< 9.5 mm) are unable to maintain position in current velocities greater than 2.5 cm/s (Houde 1969). Clady (1976) determined that larval survival and wind velocity are inversely related.

Juvenile. Habitat requirements of juvenile perch are similar to those of adults. Temperatures selected in summer months are in the range of 20-23° C (McCauley and Read 1973). This range is slightly higher than that for adults, and juveniles can be expected to inhabit slightly shallower water. The ultimate upper incipient lethal temperature for yellow perch is between 29.2 and 35° C (Hokanson 1977).

HABITAT SUITABILITY INDEX (HSI) MODELS

Model Applicability

Geographic area. The models provided are designed to be applicable throughout the 48 contiguous United States. The standard of comparison for each variable is the optimum value of the variable that occurs anywhere within this region. Therefore, the models will never provide an HSI of 1.0 when applied to bodies of water in the far southern portions of this region where temperature-related variables do not reach the optimum values found in the northern portion of the region.

Season. The models provide a rating for a body of water based on its ability to support a reproducing population of yellow perch throughout the year.

Cover types. The models are applicable to riverine, lacustrine, and palustrine habitats, as described by Cowardin et al. (1979).

Verification level. The models provided in this section represent our interpretation of how some specific environmental factors determine potential carrying capacity for yellow perch. The reservoir version of the model ranked the habitat suitability of one pair of reservoirs in similar order as harvest data while producing low but equal rankings to a pair of reservoirs with low standing crops. We interpret this to mean that some of the model variables were important in determining carrying capacity for yellow perch in the selected reservoirs. The sample size is too small to determine what degree of accuracy we have obtained in our model. The riverine version of the model has not been field tested nor applied to field data. We assume that some of the riverine model variables will also be important in determining carrying capacity of riverine habitat for yellow perch.

Model Description - Riverine

The structure of the riverine HSI model for yellow perch is represented in Figure 1.

Food/cover component. Percent pool and backwater area (V_2) was included because yellow perch abundance varies with the amount of pools and backwaters present. We also assumed V_2 would be an important measure of food availability to yellow perch in rivers since these areas are habitat for forage species utilized by yellow perch. Percent cover in pool and backwater areas (V_3) was included in this component because abundance of perch varies directly with amount of cover present. Cover consisting of brush, debris, standing timber, or vegetation should also tend to increase abundance of forage items.

Water quality component. The water quality component is limited to temperature (V_4), dissolved oxygen (V_6), and pH (V_8) because these parameters are commonly measured and have been shown to affect abundance, growth, or survival. Toxic substances were not considered in this model.

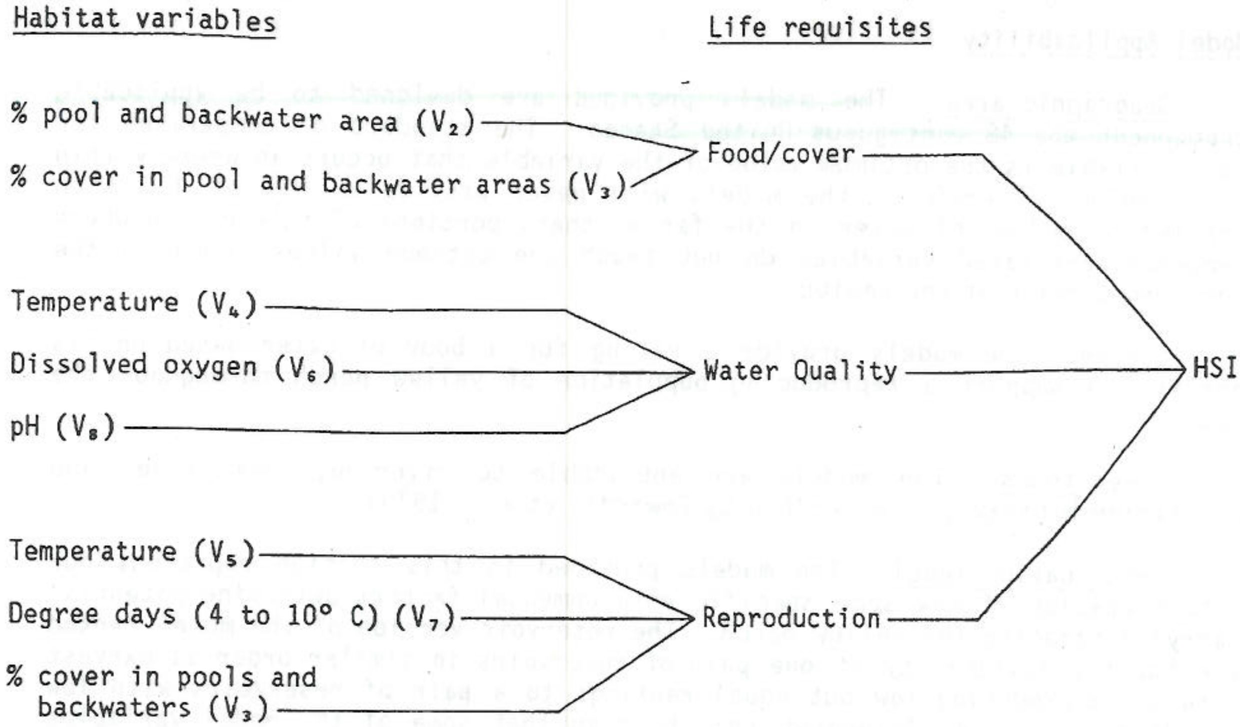


Figure 1. Tree diagram illustrating relationships between model variables, components (life requisites) and HSI for the riverine yellow perch model.

Reproduction component. The temperature during embryonic development (V_5) is critical to reproductive success. Gonadal development also depends on the duration of low winter temperatures. This is accounted for by V_7, water temperature degree days when the water is between 4 and 10° C. Area of aquatic vegetation (V_3) is included because perch spawn on aquatic vegetation if it is available.

HSI determination. We assumed that the most limiting factor (i.e., lowest SI score) defines the carrying capacity for yellow perch; thus, the HSI equals the minimum value of suitability indices V_2, V_3, V_4, V_5, V_6, V_7, or V_8.

Model Description - Lacustrine

The structure of the lacustrine HSI model for yellow perch is represented in Figure 2.

Food/cover component. Percent of littoral area (V_1) and percent cover in littoral area (V_3) were included because abundance of yellow perch has been shown to vary with the percent of littoral area and with the percent of cover within the littoral zone. These variables also provide a measure of the habitat available for the insects and small fish used as forage by yellow perch.

Water quality component. This includes the same variables (V_4, V_6, and V_8) as presented in the riverine model description.

Reproduction component. Percent cover in littoral area (V_3) was included because yellow perch deposit eggs in shallow areas with cover. Temperature (V_5) was included because it affects spawning and embryo development. Degree days between 4 and 10° C (V_7) was included because it affects the ability of perch to produce viable gametes.

Other component. Trophic status (V_9) was included because abundance of yellow perch has often been related to trophic conditions present in a water body.

HSI determination. We assumed that the most limiting factor (i.e., lowest SI score) defines the carrying capacity for yellow perch; thus, the HSI equals the minimum value of suitability indices V_1, V_3, V_4, V_5, V_6, V_7, V_8, or V_9.

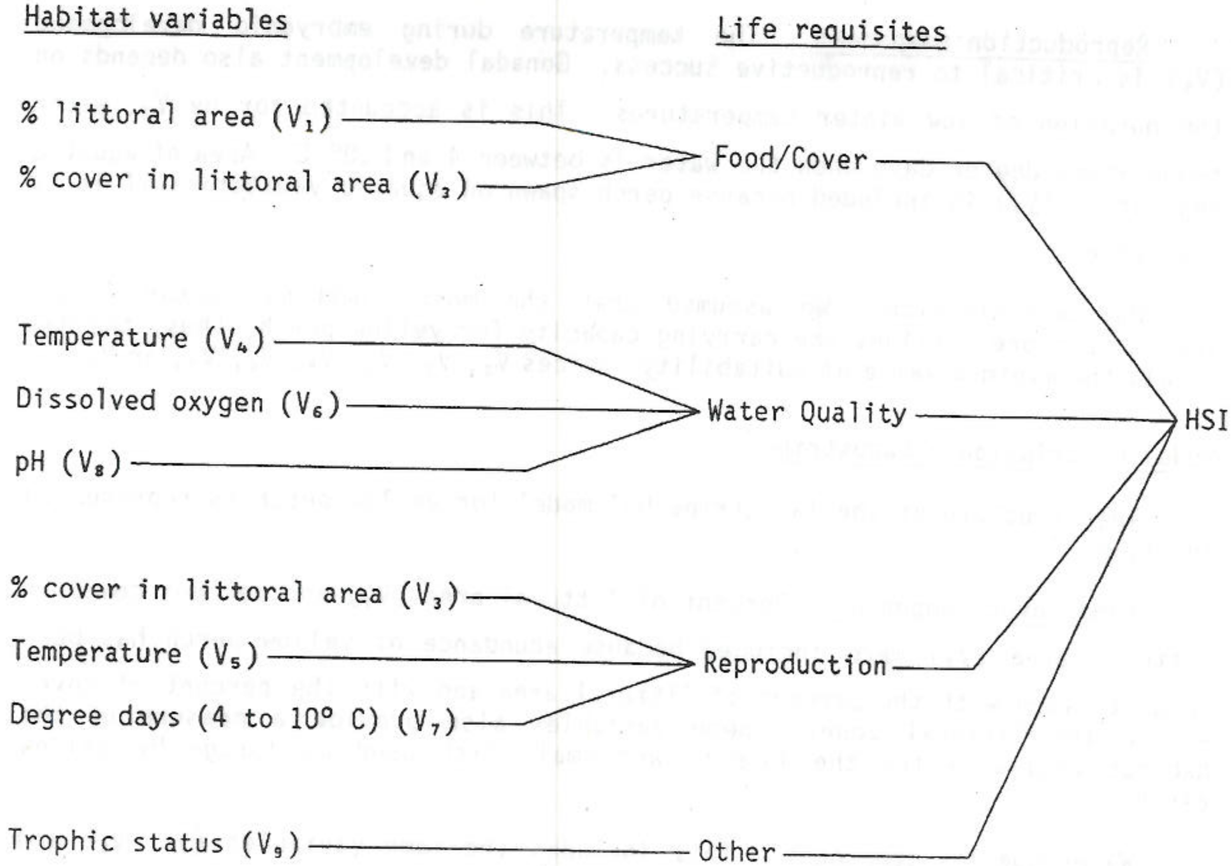
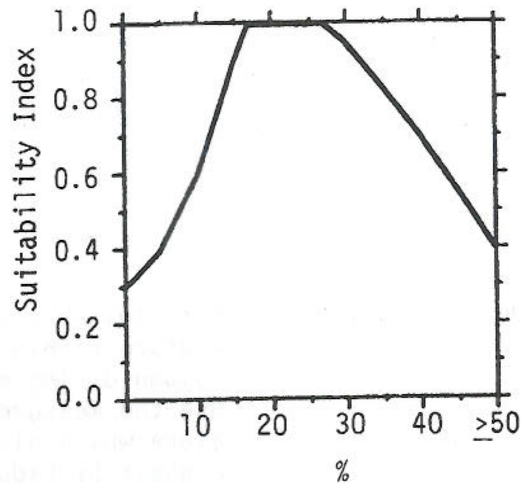
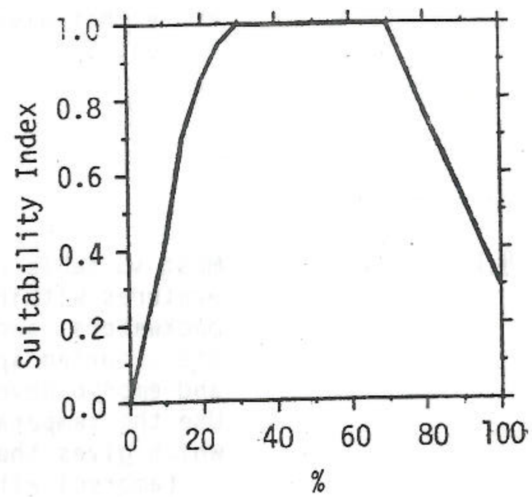
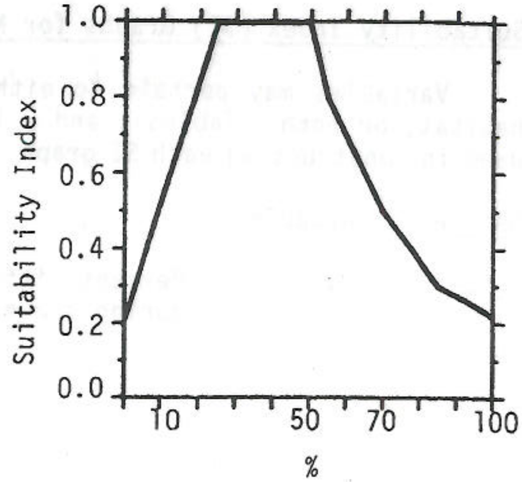
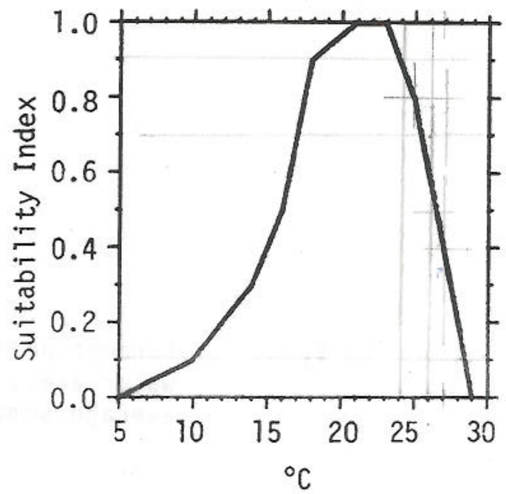
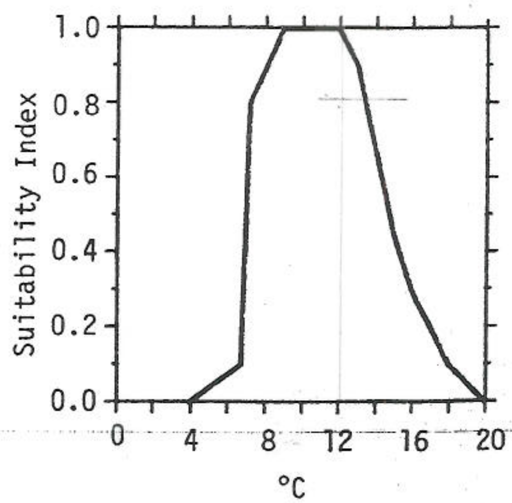


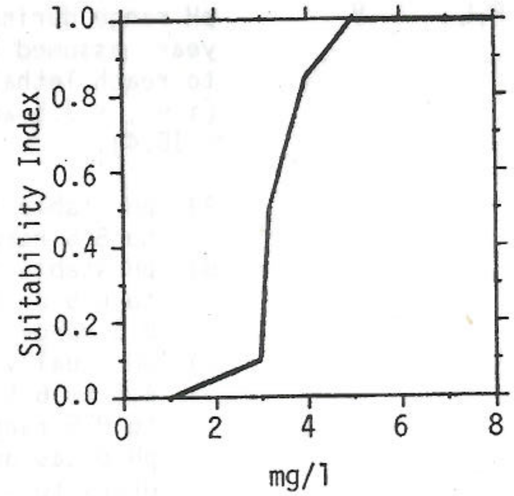
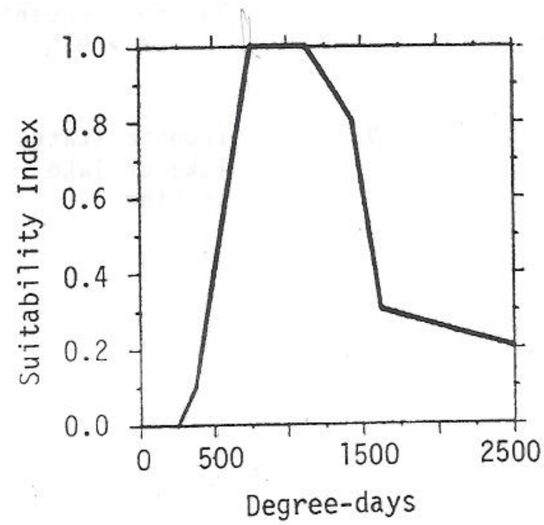
Figure 2. Tree diagram illustrating relationships between model variables, components (life requisites) and HSI for the lacustrine yellow perch model.

Suitability Index (SI) Graphs for Model Variables

Variables may pertain to either a riverine (R) habitat, a lacustrine (L) habitat, or both. Tables 1 and 2 list the information sources and assumptions used in constructing each SI graph.

Habitat	Variable		Suitability Graph
L	V_1	Percent littoral area during summer.	
R	V_2	Percent pool and backwater areas during average summer flow.	

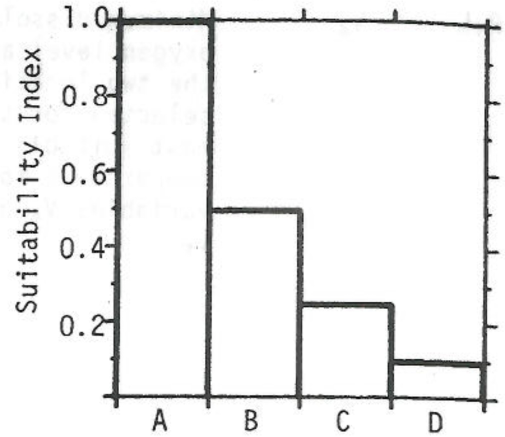
R,L	V_3	Percent cover (e.g., vegetation, brush, debris, or standing timber) during summer within pools, backwater areas (R), and littoral areas (L).	
R,L	V_4	Most suitable water temperature within the water column during midsummer. Use the measured temperature which gives the highest SI (adult, juvenile, fry). To estimate, determine a temperature profile, and select the temperature that gives the highest SI.	
R,L	V_5	Most suitable water temperatures within pools, backwaters, and littoral areas during spawning and embryo development. Use the temperature which gives the highest SI (embryo) within the above locations.	

R,L	V_6	Minimum dissolved oxygen level at the two locations selected for the most suitable temperature for variables V_4 and V_5.	
R,L	V_7	Degree-days (between 4 and 10° C) from October 30 to April 1. Calculate by multiplying water temperatures in the range of 4-10° C by number of days that are in this temperature range (e.g., 160 days of water temperature of 8° C = 1,080 degree-days = SI of 1.0). *(1,280)*	

R,L V_8

pH range during the year, assumed never to reach lethal levels (i.e., < 3.5 and > 10.4).

A) pH stable in 6.5 to 8.5 range
B) pH stable in 5.5 to 6.5 or 8.5 to 9.5 range
C) pH usually in the 4.5 to 6.5 or 8.5 to 9.5 range, but pH occasionally drops to < 4.5 or increases to > 9.5
D) pH frequently < 4.5 or > 9.5



L V_9

Trophic status of lake or lake section.

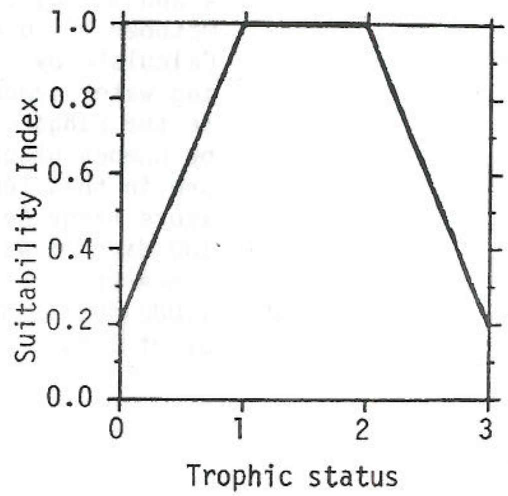


Table 1 provides a list of parameters which can be used to classify a water body by trophic status. Leach et al. (1977) provided values for each parameter corresponding to a trophic status. These values were based on data collected from lakes in Northwestern Ontario and may not adequately describe trophic status in other geographical areas. We believe that the class boundaries for each parameter corresponding to trophic status should be developed by the model user to reflect the conditions in his or her particular study location. Parameter tropic status data must be subjectively evaluated to determine the tropic status rating for the lake.

Table 1. Trophic status criteria. (Adapted from Leach et al. 1977).

Parameter	Trophic Status 0-1 (oligotrophic)	1-2 (mesotrophic)	2-3 (eutrophic)
Primary production rate	low	moderate	high
Organic matter in sediments	low	moderate	high
Hypolimnetic O_2 loss	low	moderate	high
Nutrient loading rates (phosphorus, nitrogen)	low	moderate	high
Morphoedaphic index (MEI - metric)	< 6.0	6 to 7.2	> 7.2
Transparency (Secchi depth)	high (> 6 m)	moderate (1 to 6 m)	low (< 1 m)

Table 2. Sources of information and assumptions for construction of the suitability index graphs. In construction of the graphs, "excellent" habitat for yellow perch was assumed to correspond to an SI of 0.8 to 1.0, "good" to an SI of 0.5 to 0.7, "fair" to an SI of 0.2 to 0.4, and "poor" to an SI of 0.0 to 0.1.

Variable	Assumptions and sources
V_1	Yellow perch of all sizes are abundant in the littoral zone of lakes (Wells 1968; Helfman 1979) and reservoirs (Beckman and Elrod 1971; Nelson and Walburg 1977). Kitchell et al. (1977) stated that extensive littoral and shoreline areas are optimum for percids. We interpret "extensive" to mean approximately 1/4 of total lake area. We selected 35% as the upper limit for excellent conditions to reflect the need for deeper water for summer (or winter) refugia (e.g., Ferguson 1958). We deemed > 40% littoral area good-fair since only moderate biomass levels of yellow perch are found in lakes with very extensive littoral area (Carlander 1977; Forney pers. comm.). The percent littoral area selected as the minimum for excellent habitat suitability was near 15% based on the observations of Forney (pers. comm.) who found that high perch biomass occurs in New York lakes with < 20% littoral zone. Because even a deep reservoir, such as Jocassee (Table 3) with only 5% littoral area contained perch, the ascending portion of the SI graph begins at a value greater than 0.
V_2	Yellow perch are most abundant in pools and backwaters of rivers (Coots 1956; Kitchell et al. 1977) and utilize these habitats for spawning (Harrington 1947), but little specific information was available to relate percentages of these areas present to habitat quality for yellow perch. We have developed the SI curve based on the assumption that the riverine habitat categories described by Kitchell et al. (1977) as optimum percid habitat (moderate current, mixed substrate) would contain at least 25% pools and backwaters. We also assumed that very high percent pools was a condition commonly associated with very low gradient streams more characteristic of centrarchid habitat. Kitchell et al. (1977) noted that the littoral areas occupied by perch in lakes were similar to pool habitat in rivers. Given the generality of the data, we constructed a very broad SI graph. The ascending limb starts at 0 since perch are not collected in areas of faster current (Coots 1956). Conversely, a very high percentage of pool area was assumed to provide only fair habitat because conditions present in very low gradient streams would likely be suboptimum for perch (e.g., unsuitable temperatures and D.O.; Kitchell et al. 1977).

Table 2. (continued)

Variable	Assumptions and sources
V_3	Yellow perch utilize aquatic vegetation, brush, and other underwater structure as spawning substrate (Harrington 1947; Muncy 1962; Beckman and Elrod 1971; Scott and Crossman 1973; Kitchell et al. 1977; Nelson and Walburg 1977) and as cover (Helfman 1977). In Missouri River reservoirs, perch year-class strength was positively correlated to the amount of newly-inundated terrestrial vegetation present during spawning (June 1976; Nelson and Walburg 1977). We assumed that at least 25% vegetative cover would be necessary for optimum habitat suitability. Areas with large percentages of vegetation were considered suboptimum because they would likely lack the deeper water used as summer (or winter) refugia. We assumed percent cover of < 20% good-fair habitat suitability. June (1976) found that spawning success of yellow perch in Lake Oahe declined greatly when submerged brush and vegetation was unavailable. Forney (pers. comm.) reported that significant yellow perch populations develop in shallow New York lakes with only sparse (~ 15%) vegetative cover.
V_4	We assumed summer temperatures that correspond to optimum growth [23° C (Schneider 1973), 22° C (Huh et al. 1976)], preference [18 to 24° C depending on age (Ferguson 1958; McCauley and Read 1973)], and classified by Hokanson (1977) as the physiological optimum for yellow perch (24.7° C) as excellent. Lethal temperatures [29.2 to 33° C (Hokanson 1977)] were deemed poor. The descending limb of the graph is based on the seasonal temperature envelope for yellow perch presented by Hokanson (1977) wherein ≤ 5% of stream stations with midsummer water temperatures of ≤ 15° C contained perch. The most suitable temperature within the water column is used to develop a rating because fish can select temperatures closest to their preferred temperature.
V_5	Successful reproduction of yellow perch depends on rising temperatures during spawning and early life stages (Hokanson 1977). Temperatures corresponding to peak spawning [e.g., 9° C (Harrington 1947); 7.2 to 11.1° C (Herman et al. 1964); 7.2 to 12.8° C (Coots 1966); 10° C (Clugston et al. 1978)] and highest gamete viability [8 to 11° C (Jones et al. 1977 cited in Hokanson (1977)] of yellow perch were considered excellent. We assumed that temperatures less than the lower TL_{50} (6.8° C) or greater than the upper TL_{50} (19.9° C) (Hokanson and Kleiner 1974) for perch embryos were poor.

Table 2. (continued)

Variable	Assumptions and sources
V_6	D.O. levels ≥ 5.0 were considered optimum based on the optimum D.O. criteria for Canadian freshwater fish (excluding salmonids) developed by Davis (1975). We considered D.O. levels < 3.0 as poor since Kitchell et al. (1977) defined > 2-4 mg/l as the minimum D.O. concentration suitable for spawning by percids and since Carlson et al. (1980) reported a significant decrease in growth in yellow perch at a D.O. concentration of 2 mg/l.
V_7	This SI graph is based on information found in Jones et al. (1977) and Hokanson (1977) demonstrating that yellow perch require winter minimum temperatures < 10° C for proper gonad maturation. They found that optimum conditions for maturation occurred when fish were exposed to water temperatures ≤ 6° C for 185 days from October 30. We then assumed that a chill duration of 740 (4° C times 185 days) to 1,110 (6° C times 185 days) degree-days would provide optimum habitat quality for gonad maturation and subsequent spawning for yellow perch. We considered a chill duration of 360 degree-days to be near the lower limit for gonad maturation because limited viable spawnings occurred in yellow perch held at a minimum of 12° C except for 45 days at 8° C. We considered > 2,000 degree-days to be fair to poor habitat quality since only a small percentage of perch reared at 10° C for 200 or 240 days spawned successfully.
V_8	pH levels in the range of 6.5 to 8.5 were considered optimum according to the pH criteria considered optimum for growth and survival of freshwater fish populations (Stroud 1967). Yellow perch are relatively tolerant to low pH. Rahel (1983) found that perch from naturally acidic (pH 4.5) bog lakes in Wisconsin could survive at pH 3.2. However, Ryan and Harvey (1979) found that abundance of age 0 perch was greatly reduced in Ontario lakes with pH levels < 5.5. Runn et al. (1977, cited by Ryan and Harvey 1979) found a much reduced egg hatchability in another, similar perch species, the Eurasian perch (<u>Perca fluviatilis</u>), at pH < 5.5. Thus, we deemed pH levels < 5.5 as <u>fair-poor</u>. We considered pH > 9.5 as poor because a pH value ≥ 10.4 is lethal to yellow perch (Rahel 1983) and growth and survival of freshwater fish populations decreases at pH > 9.5 (Stroud 1967).

Table 2. (concluded)

Variable	Assumptions and sources
V_9	Yellow perch are most abundant in waters classifed as mesotrophic, i.e., waters with moderate fertility and moderate turbidity (Herman et al. 1964; Kitchell et al. 1977; Leach et al. 1977; Thorpe 1977) and hence we considered mesotrophic conditions to be excellent. Perch populations decline with increasing turbidity (decreasing transparency) and decreasing amounts of aquatic vegetation accompanying eutrophication (Scott and Crossman 1973; Kitchell et al. 1977; Leach et al. 1977; Nelson and Walburg 1977). Perch also are less abundant in clear, deep, unproductive lakes or lake sections (Nakashima and Leggett 1975; Kitchell et al. 1977). We provide broad guidelines of trophic status by adapting the classification system of Leach et al. (1977). We assumed that very eutrophic or very oligotrophic water bodies would be less suitable as habitat for yellow perch.

Application of Lacustrine Model to Reservoir Sites

The lacustrine model correctly ranked two eastern Colorado reservoirs (Stalker and Chatfield) with very different perch densities, as reflected by sport harvest estimates (Tables 3 and 4). When applied to two South Carolina reservoirs (Jocassee and Keowee) with low perch standing crops (Clugston et al. 1978), the model rated both as having equally low habitat suitability for yellow perch (Tables 5 and 6).

Interpreting Model Outputs

The models described above are generalized descriptions of habitat requirements for yellow perch and, as such, the outputs of either model are not expected to discriminate among different habitats with a high resolution at this stage of development. Each model variable is considered to be able to limit carrying capacity for yellow perch. The suitability index graphs are based on easily measurable responses, such as growth or survival, and may not accurately depict the relationship to carrying capacity. The model assumes that each model variable can limit perch production, but this has not been tested. A major potential weakness in the models is that while model variables may be necessary in determining suitability of habitat for yellow perch, they may not be sufficient. Species interactions and other factors may determine carrying capacity to a greater degree than the variables included in the models (e.g., Forney 1971, 1974). The model must be viewed as conceptual and very subjective. Any attempt to use the model as a predictive model should be preceded by testing the model in areas of known carrying capacity where habitat conditions are similar to the area of proposed model application. This testing should help determine which, if any, model variables are predictors of carrying capacity in the proposed area of model application. For example, MEI values ranked the pair of South Carolina reservoirs (Tables 4 and 5) in the same order as the standing crop data while the complete model rated both reservoirs as having the same HSI.

We recommend interpreting model outputs as indicators (or predictors) of excellent (0.8 to 1.0), good (0.5 to 0.7), fair (0.2 to 0.4), or poor (0.0 to 0.1) habitat for yellow perch. If two areas have different HSI's, the one with the higher HSI is assumed to have the potential to support more yellow perch. Given the limited (four reservoirs) usage the model has had, the assumption must be considered virtually untested. Model variables may be useful for developing revised models that incorporate site-specific factors affecting habitat suitability for yellow perch. Helfman (1979) noted the ecological plasticity and varying habitat preferences of perch in different studies. Users of the model should be cautious of such differences when using habitat use data from one part of the country to evaluate habitats in another area.

Table 3. Environmental data for Chatfield Reservoir, Colorado.

Variable		Data	SI
V_1	Percent littoral area	13%	0.8
V_3	Percent cover	60%	0.7
V_4	H_2O temperature (summer)	20° C	1.0
V_5	H_2O temperature (embryo)	11° C	1.0
V_6	D.O.	7.2 mg/l	1.0
V_7	Degree Days	1460	0.8
V_8	pH	7.8-8.3	1.0
V_9	Trophic status	Mesotrophic[a]	1.0

[a]Mesotrophic classification and SI determined on basis of secchi depth transparency (~ 3.0 to 4.0m).

HSI = lowest SI score = 0.7.

Measured population level of yellow perch = sport harvest of 20.6 kg/ha.

Table 4. Environmental data for Stalker Lake, Colorado.

Variable		Data	SI
V_1	Percent littoral area	30%	1.0
V_3	Percent cover	80%	0.4
V_4	H_2O temperature (summer)	22° C	1.0
V_5	H_2O temperature (embryo)	13° C	0.9
V_6	D.O.	8.5 mg/l	1.0
V_7	Degree days	1587	0.3
V_8	pH	8.7-9.0	0.5
V_9	Trophic status	Mesotrophic/Eutrophic[a]	0.7

[a]Classification and SI determined on basis of organic matter in sediments (moderately high), and secchi transparency (~ 2 m). We selected an SI from the rating curve that was between the mesotrophic optimum and the lower eutrophic rating to reflect the intermediate nature of the variable values.

HSI = lowest SI score = 0.3.

Measured population level of yellow perch = sport harvest of < 0.1 kg/ha.

Table 5. Environmental data for Jocassee Reservoir, South Carolina.

Variable		Data	SI
V_1	Percent littoral area	5%	0.4
V_3	Percent cover	80%	0.4
V_4	H_2O temperature (summer)	20° C	1.0
V_5	H_2O temperature (embryo)	9.6° C	1.0
V_6	D.O.	8.2 mg/l	1.0
V_7	Degree days	2346	0.2
V_8	pH	5.6-6.9	0.5
V_9	Trophic status	Oligotrophic[a]	0.2

[a]Oligotrophic classification and SI determined on basis of MEI. TDS was 18 mg/l and mean depth, 46.0 m (Clugston et al. 1978; Clugston pers. comm.). Thus, $MEI = \frac{18}{46} = .39$

HSI = lowest SI score = 0.2.

Measured population level of yellow perch = Mean standing crop of 0.5 kg/ha.

Table 6. Environmental data for Keowee Reservoir, South Carolina.

Variable		Data	SI
V_1	Percent littoral area	10%	0.6
V_3	Percent cover	10%	0.5
V_4	H_2O temperature (summer)	20° C	1.0
V_5	H_2O temperature (embryo)	12.8° C	1.0
V_6	D.O.	6.4 mg/l	1.0
V_7	Degree days	2672	0.2
V_8	pH	5.7-7.0	0.5
V_9	Trophic status	Oligotrophic[a]	0.3

[a]Oligotrophic classification and SI determined on basis of MEI. TDS was 20 mg/l and mean depth 15.8 m (Clugston et al. 1978; Clugston pers. comm.). Thus, MEI = $\frac{20}{15.8}$ = 1.27

HSI = lowest SI score = 0.2.

Measured population level of yellow perch = Mean standing crop of 1.6 kg/ha.

ADDITIONAL HABITAT MODELS

Model 1

Optimum riverine habitat for yellow perch is characterized by the following conditions, assuming water quality is adequate: deep pools (deeper than average river depth) and slack water areas (25 to 75% of river area) with moderate amounts of vegetation (25 to 50% of pool and backwater area), with low to moderate turbidities (< 100 JTU); low velocities (≤ 10 cm/sec); and warm (20 to 28° C) summer temperatures.

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

Model 2

Optimum lacustrine habitat for yellow perch is characterized by the following conditions, assuming water quality is adequate: a littoral area 20 to 30% of the total lake or reservoir area; 25 to 50% of the littoral area vegetated; warm (20 to 28° C) surface water temperature in summer; and low to moderate turbidities (< 100 JTU).

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

Model 3

Use the yellow perch HSI model for planned cool and coldwater reservoirs developed by McConnell et al. (1982).

Model 4

Aggus and Bivin (1982) used angler harvest as a measure of habitat suitability and developed a regression equation relating harvest to reservoir habitat variables for 37 reservoirs in the conterminous United States:

$$\log_{10} (\text{harvest of yellow perch}) = 3.7117 - 0.0142 (\text{growing season}) - 0.7530 \log_{10} (\text{outlet depth}).$$

$$R^2 = 0.38.$$

Units for the above equation are kg/ha (harvest), days (growing season), and feet below a specified elevation (outlet depth). These authors present a summary of reservoir harvest data and discuss procedures for converting measured or predicted harvest values to HSI's.

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 estimating 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. Estimation of monthly flows that minimize habitat reductions for species and life stages of interest;

2. Habitat Time Series. Estimation 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. Estimation 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 a species preference for hydraulic-related parameters (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 to 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 for use with IFIM. 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 by which the curve is generated 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 (category one) curve 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 to 1.0 m). Unpublished data and expert opinion can also be used to develop these curves. Occasionally, the reference also contains information on the optimum or preferred condition within the limits of tolerance (e.g., juveniles are found at water depths of 0.3 to 1.0 m, but are most common at depths from 0.4 to 0.6 m). 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 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 IFIM curve development efforts.

The fourth category of curves is still largely conceptual. One type of curve 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

Investigators who wish to do an IFIM analysis of yellow perch habitat should study the available SI curves (Table 7) carefully and determine if they reflect yellow perch habitat utilization in the study area of interest. SI curves for spawning velocity, depth, and substrate utilization (Fig. 3) are category one. Yellow perch seem to prefer aquatic or submerged terrestrial vegetation for spawning substrate, but will utilize rocks, gravel, or sand when vegetation is absent. Therefore, an investigator may want to modify the SI curve for spawning substrate (Fig. 3) into a much broader curve.

Assuming that habitat requirements for egg incubation are similar to those for spawning, SI curves for spawning (Fig. 3) may be used for IFIM analysis of egg incubation habitat. The SI curve for egg incubation substrate should be modified as it was for analysis of spawning habitat.

Table 7. Availability of curves for IFIM analysis of yellow perch habitat.

	Velocity[a]	Depth[a]	Substrate[a,c]	Temperature[a]	Cover[a]
Spawning	Use SI curve, Figure 3.	Use SI curve, Figure 3.	Use SI = 1.0[b] for submerged vegetation and SI curve, Figure 3.	Use SI curve for V_5.	No curve available.
Egg incubation	Use SI curve, Figure 3.	Use SI curve, Figure 3.	Use SI = 1.0[b] for submerged vegetation and SI curve, Figure 3.	Use SI curve for V_5.	No curve available.
Fry	Use SI curve, Figure 4.	Use SI curve, Figure 4.	Use SI curve, Figure 4.	Use SI curve for V_4.	No curve available.
Juvenile	Use SI curve, Figure 5.	Use SI curve, Figure 5.	Use SI curve, Figure 5.	Use SI curve for V_4.	Use SI curve for V_3.
Adult	Use SI curve, Figure 6.	Use SI curve, Figure 6.	Use SI curve, Figure 6.	Use SI curve for V_4.	Use SI curve for V_3.

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

[b] Use SI = 1.0 if the habitat variable is optimal; but if the habitat variable is less than optimal, the user must determine, by judgement, what is the most appropriate SI value.

[c] 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)

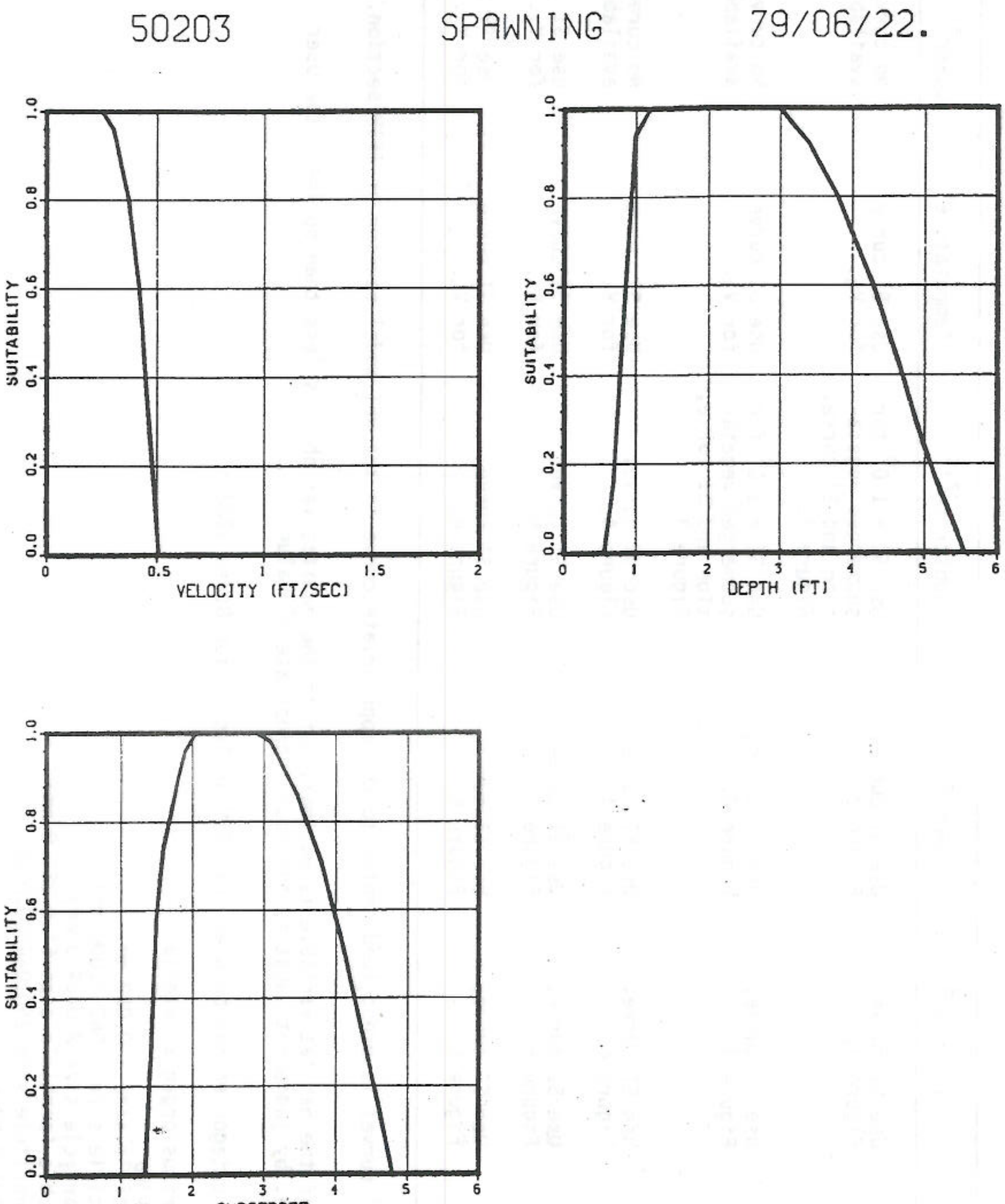


Figure 3. Category one SI curves for yellow perch spawning habitat (Coots 1966; Scott and Crossman 1973).

The SI curves for adults, juveniles, and fry (Figs. 4-6) are category two, and were generated from frequency analyses of raw data collected from the Missouri River (Kallemeyn and Novotny unpubl. data). Each of four stations was sampled for 4 days every 4 weeks from 29 March to 4 November 1976. Three stations were unchannelized sections of river located on the South Dakota/ Nebraska border, one below Fort Randall Dam and two below Gavins Point Dam. The fourth station was on a channelized section of river on the Iowa/Nebraska border below Sioux City. Sampling gear included gill nets, trammel nets, hoop nets, seines, a drop trap, an electroshocker, and plankton nets. A total of 787 fry, 400 juveniles, and 70 adult yellow perch were collected and used in the frequency analyses.

Habitat types identified in the unchannelized sections of the Missouri River included main channel, main channel border, sandbar, chute, backwater, pool, and marsh; those in channelized sections of the river included main channel, spur dike, notched spur dike, notched wing dike, revetment, and notched revetment. During the study channel, widths ranged 300 to 1,500 m ($\bar{x}$ = 640 to 760 m), depths ranged 0.0 to 8.0 m ($\bar{x}$ < 2.0 m), daily mean discharges ranged from 872 to 1,104 m^3/second ($\bar{x}$ ~ 1,015 m^3/second), surface velocities ranged from 0.0 to 2.1 m/second, the gradient was approximately 0.2 m/km, surface water temperatures ranged from 3.5 to 27.5° C, turbidity ranged from 2.3 to 33.0 JTU's, and conductivity ranged from 550 to 780 µmhos/ cm. The substrate consisted primarily of sand; silt was dominant in backwater and marsh areas.

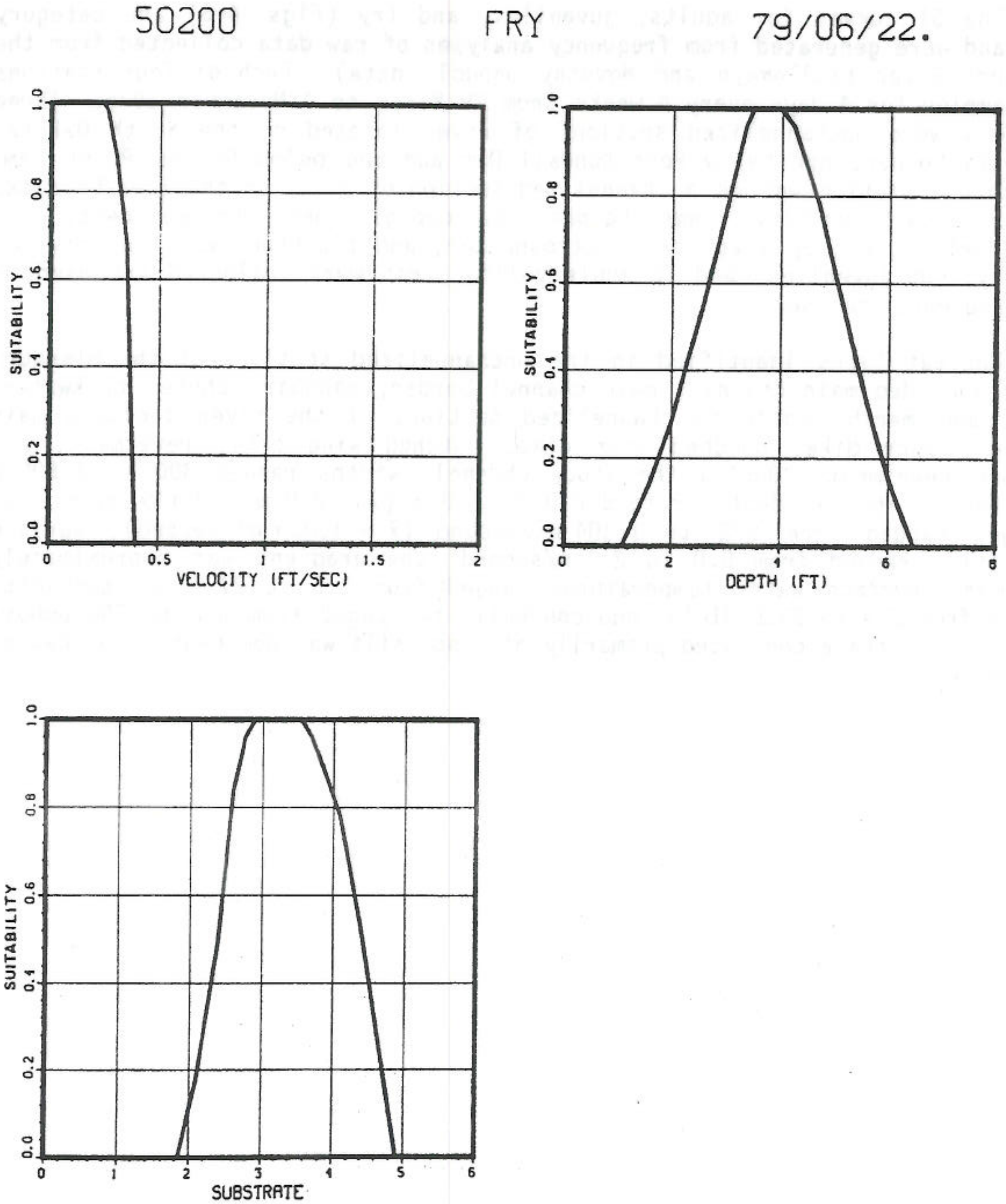


Figure 4. Category two SI curves for yellow perch fry (Kallemeyn and Novotny unpubl. data).

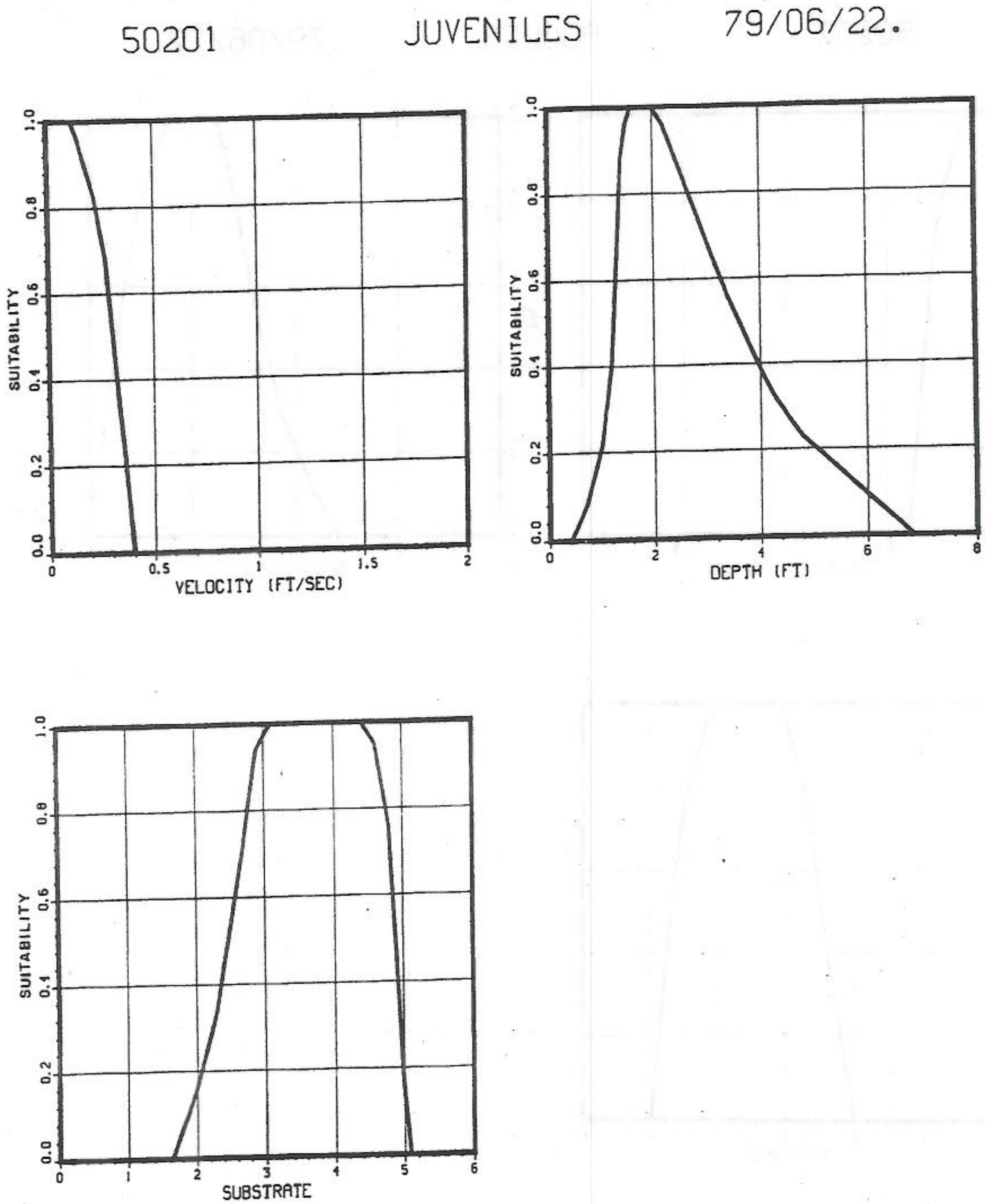


Figure 5. Category two SI curves for yellow perch juveniles (Kallemeyn and Novotny unpubl. data).

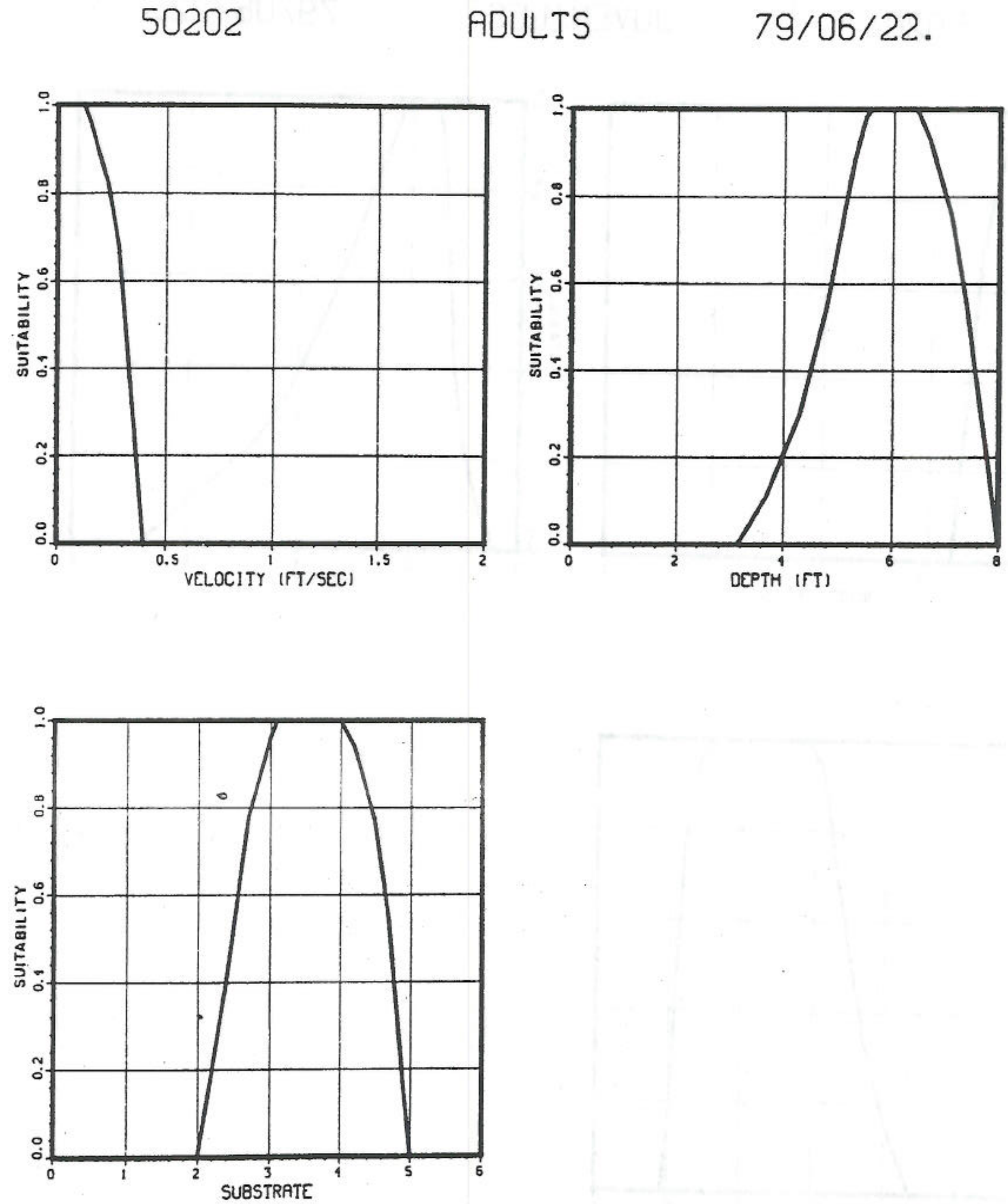


Figure 6. Category two SI curves for yellow perch adults (Kallemeyn and Novotny unpubl. data).

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