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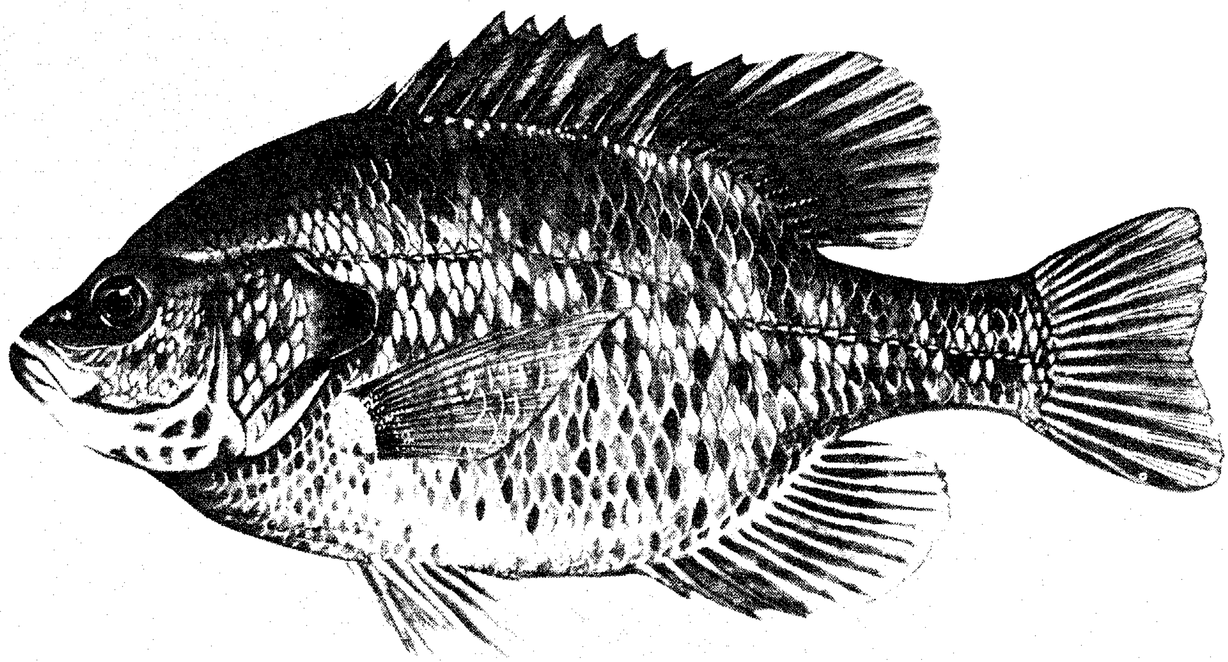
HABITAT SUITABILITY INDEX MODELS AND INSTREAM FLOW SUITABILITY CURVES: REDEAR SUNFISH



Fish and Wildlife Service

U.S. Department of the Interior

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HABITAT SUITABILITY INDEX MODELS AND INSTREAM FLOW SUITABILITY CURVES: REDEAR SUNFISH

by

Kathleen A. Twomey
Wyoming Cooperative Fishery Unit
University of Wyoming
Laramie, WY 82071

Glen Gebhart
O. Eugene Maughan
Oklahoma Cooperative Fishery Research Unit
Oklahoma State University
Stillwater, OK 74074

and

Patrick C. Nelson
Instream Flow and Aquatic Systems Group
Western Energy and Land Use Team
U.S. Fish and Wildlife Service
Drake Creekside Building One
2627 Redwing Road
Fort Collins, CO 80526-2899

Western Energy and Land Use Team
Division of Biological Services
~~Research and Development~~
Fish and Wildlife Service
U.S. Department of the Interior
Washington, DC 20240

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PREFACE

The Habitat Suitability Index (HSI) models presented in this publication aid in identifying important habitat variables. Facts, ideas, and concepts obtained from the research literature and expert reviews are synthesized and presented in a format that can be used for impact assessment. The models are hypotheses of species-habitat relationships, and model users should recognize that the degree of veracity of the HSI model, SI graphs, and assumptions will vary according to geographical area and the extent of the data base for individual variables. After clear study objectives have been set, the HSI model building techniques presented in U.S. Fish and Wildlife Service (1981)[1] and the general guidelines for modifying HSI models and estimating model variables presented in Terrell et al. (1982)[2] may be useful for simplifying and applying the models to specific impact assessment problems. Simplified models should be tested with independent data sets, if possible. Statistically-derived models that are an alternative to using Suitability Indices to calculate an HSI are referenced in the text.

A brief discussion of the appropriateness of using selected Suitability Index (SI) curves from HSI models as a component of the Instream Flow Incremental Methodology (IFIM) is provided. Additional SI curves, developed specifically for analysis of redear sunfish habitat with IFIM, also are presented.

Model reliability is likely to vary in different geographical areas and situations. The U.S. Fish and Wildlife Service encourages model users to provide comments, suggestions, and test results that may help us increase the utility and effectiveness of this habitat-based approach to impact assessment. Please send comments to:

Habitat Evaluations Procedures Group or
Instream Flow and Aquatic Systems Group
Western Energy and Land Use Team
U.S. Fish and Wildlife Service
2627 Redwing Road
Fort Collins, CO 80526-2899

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

[2]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.

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REDEAR SUNFISH (<u>Lepomis microlophus</u>)

HABITAT USE INFORMATION

<u>General</u>

The redear sunfish (<u>Lepomis microlophus</u>), commonly referred to as the shellcracker, is native from the Mississippi River in Missouri and southern Indiana to North Carolina, south through Florida, and west to eastern Texas (Cole 1951; Trautman 1957; Hubbs and Lagler 1964; Wilbur 1969; Pflieger 1975). The species has been successfully introduced into Arizona, California, and southern Michigan and stocked into new waters in Oklahoma, Missouri, Ohio, Indiana, and Illinois (Cole 1951; Beland 1953; Jenkins 1955; Trautman 1957; Lopinot 1961; Hubbs and Lagler 1964; Wilbur 1969).

<u>Age, Growth, and Food</u>

Redear sunfish have been reported to mature at Age I (Schoffman 1939; Lopinot 1961; Dineen 1968) at an average length of 12.7 cm in Florida (Wilbur 1969). Attainment of sexual maturity is probably a function of size more than age. In most natural situations, redear mature at Age II (Krumholz 1950; Wilbur 1969). When redear matured less than Age I, this occurred in newly stocked waters that contained only the one redear age class. Age I and less redear probably do not reproduce when living with older age classes (Cole 1951; Dineen 1968; Wilbur 1969). Maximum reported age, length, and weight are 8 years, 35.5 cm, and 1.3 kg, respectively (Carlander 1977).

Redear growth is usually slower in riverine environments than in lacustrine environments (Jenkins et al. 1955). Growth is significantly better in waters with low turbidities (< 25 ppm) (Jenkins et al. 1955; Buck 1956a).

Redear sunfish primarily feed on the bottom and seldom feed on surface insects (Chable 1947; Swingle and Smith 1947; Cole 1951). Newly hatched redear feed on green algae and microcrustaceans (Lopinot 1961; Emig 1966). McClane (1955) found 16 to 30 mm redear consumed principally copepods, cladocerans, and amphipods; Wilbur (1969) reported that redear (30 to 69 mm) feed primarily on copepods. The major food items most often reported for larger redear include midge larvae, snails, mayfly larvae, and dragonfly naiads (Chable 1947; Parks 1949; Cole 1951; McClane 1955; Carothers and Allison 1968). Foods of secondary importance include copepods, cladocerans, ostracods, water boatman, small clams, and freshwater prawns (Huish 1957; Wilbur 1969; Pasch 1975).

Reproduction

Redear sunfish display great variation in spawning season. Within most of their range, redear sunfish usually begin to spawn in May to June, and may continue to spawn until September (Schoffman 1939; Dineen 1968; Pflieger 1975). Redear may spawn sparingly during the summer and heavily in the early fall (Swingle 1949). In Florida redear sunfish begin to spawn in late February or early March and continue to spawn intermittently until October 1 (Clugston 1966). In the northern reaches of their distribution (Michigan, Illinois, and Indiana), nesting begins in May to July and generally does not extend into late summer (Krumholz 1950; Cole 1951; Childers 1967).

The eggs are laid in saucer-shaped nests, fanned free of debris (Gresham 1965; Wilbur 1969). Redear tend to be community spawners, often with nests only a few inches from each other (McClane 1955; Clugston 1966; Emig 1966; Pflieger 1975). Nests have been found at water depths from approximately 5 to 10 cm (Swingle and Smith 1947; Gresham 1965; Emig 1966) to 4 to 6 m (Wilbur 1969). Gresham (1965) and Clugston (1966) reported that nests were usually at water depths of 45 to 90 cm. McClane (1955) reported that spawning most often occurred at depths of 91 to 122 cm in the St. Johns River; Swingle and Smith (1947) reported that nests in ponds were most often at water depths of at least 183 cm.

Redear use a wide range of spawning habitats and nesting substrates. Nests have been reported on substrates of sand, sandy-clay, mud, limestone, shells, and gravel with no vegetation (McClane 1955; Emig 1966; Wilbur 1969), often in locations exposed to the sun (Childers 1967). Nests are often within or along the edge of water lilies, Pancium, Chara, Vallesneria, and fallen trees and old pilings in Florida (McClane 1955; Wilbur 1969).

After the eggs are fertilized, the male remains above the nest guarding and fanning the eggs until they hatch, which takes 6 to 10 days, depending on the water temperature. An alpha-threshold temperature necessary for 50% hatching is reported as 18.3° C (Childers 1967). The highest percent of normal fry resulted at an incubation temperature of 23.6° C in an experimental temperature range of 22.3 to 28.6° C (Childers 1967). It is assumed that optimum temperatures for successful incubation and subsequent hatching are 21 to 24° C, based on field observations by Swingle (1949), Cole (1951), Lopinot (1961, 1972), Clugston (1966), and Wilbur (1969), although Clugston (1966) reported that spawning occurred at temperatures as high as 32.2° C. After hatching, the fry remain on the nest for about a week (Lopinot 1961). There appears to be little difference, if any, in the spawning requirements of redear in lacustrine and riverine environments.

Specific Habitat Requirements

Redear sunfish prefer warm, large lakes, bayous, marshes, and reservoirs with vegetated shallow areas and clear water (Chable 1947; Cole 1951; Finnell et al. 1956; Lopinot 1961). In riverine habitats, redear sunfish prefer large, clear, low gradient streams and rivers with sluggish currents and some aquatic vegetation. Redear sunfish prefer habitats with no noticeable currents (McClane 1955; Trautman 1957; Pflieger 1975). Bailey et al. (1954) reported that redear occurred in areas with no to moderate current velocities (0 to approximately 10 cm/sec). In streams, redear are more likely to be in protected bays and overflow pools than in the main stream channel (Chable 1947; McClane 1955; Pflieger 1975; Smith 1979).

Redear sunfish appear to prefer riverine pools with aquatic vegetation (Smith 1979) and do best in lacustrine waters with at least some vegetation (Trautman 1957; Pflieger 1975). The redear is also known to congregate around brush, stumps, and logs (Trautman 1957; Lopinot 1961). Redear adults typically occur in deeper, open waters and only move shoreward to spawn (Chable 1947; Cole 1951; McClane 1955; Lopinot 1961; Wilbur 1969), although Wilbur (1969) reported that greater densities of redear occurred in the peripheral deep water areas near submergent vegetation. Wilbur (1969) concluded that, except during spawning season, emergent vegetation was of lesser importance to redear than open water areas. Vegetation enhances redear habitat by providing cover and substrate for food (Chable 1947). Centrarchids appear to reach their greatest abundance in lakes where large numbers of invertebrates are associated with vegetation (Chable 1947; Wilbur 1969; Colle and Shireman 1980).

The condition of redear is influenced by the amount of vegetation in Florida (Colle and Shireman 1980). Redear sunfish are influenced to a greater extent by the amount of vegetation in the water column than by the percent bottom cover. Colle and Shireman (1980) indicated that habitats with moderate levels of Hydrilla result in improved condition and growth for redear sunfish > 100 mm. However, if plants occupy the entire water column, a marked reduction in both growth and condition of redear occurs. Redear sunfish were of average or above average condition when Hydrilla covered up to 78% of the bottom and surface matting was present in 23% of the lake. Lower condition factors were evident when 95% of the lake bottom was covered and 80% of the surface was matted. When the water column is full of Hydrilla, the Hydrilla probably becomes a physical constraint on foraging efficiency by eliminating the foraging gradient between open water and submersed macrophytes.

Redear sunfish grew faster and reproduced more abundantly in average turbidities of ≤ 25 ppm (Buck 1956b). Although redear sunfish were reported to reproduce and young redear were recovered in a pond with a high turbidity (174 ppm) in one study, the critical level for successful reproduction and growth over time is probably between 75 and 100 ppm (Buck 1956b). Although redear prefer clear waters, redear sunfish seem to be more tolerant of turbidity than bass or bluegills (Buck 1956b; Smith 1979).

Redear sunfish are usually outnumbered by other centrarchid species when they occur in the same freshwaters; but in marshes and brackish waters, redear generally have larger standing crops than the other centrarchids present (Horel 1967; Dineen 1968; Wilbur 1969). Redear are probably the most salinity-tolerant species of all the centrarchids and survive without apparent discomfort in brackish water (Bailey et al. 1954; Wilbur 1969). Redear are found living in the tidewater of the Escambia River, Florida, where salinities ranged up to 24.4 ppt (Bailey et al. 1954). Bailey et al. (1954) classified redear sunfish as facultative invaders of brackish water. They frequently invade, probably for a considerable time, into water of low salinity (i.e., at least 4.5 ppt). Redear occur at salinities from 2.6 to 6.7 ppt in Louisiana

(Geagan 1962) and at salinities up to 12.3 ppt in Florida gulf coast marshes, although 90% of the redear collected in this survey were from water with a salinity of less than 5 ppt (Kilby 1955).

The highest standing crops of warmwater sport fishes (including sunfishes) occur in waters of moderate alkalinity of 100 to 350 ppm (Jenkins 1976). The following environmental variables have a positive effect on redear standing crop: increased mean depth; increased storage ratio (lower water exchange rate); and longer growing season (Jenkins 1968, 1970). Water level fluctuations and shore development have a negative effect on redear standing crop. A positive association between length of growing season (number of frost-free days) and sunfish standing crop was reported by Jenkins and Morais (1971). No sunfishes were harvested in reservoirs with growing seasons of less than 140 days. Annual harvest rates increase most rapidly when the growing season is 180 to 240 days long; therefore, it is assumed that optimal growing season for redear is > 180 days.

There is little information on the dissolved oxygen (D.O.) requirements of redear sunfish, but it is assumed that their D.O. needs are similar to those of bluegills. The first external sign of stress in bluegills occurs when oxygen levels drop to 5 mg/l; at 3 mg/l D.O., bluegills begin to intermittently swim to the surface; and, at 1 mg/l D.O., feeding ceases (Petit 1973). The critical level of dissolved oxygen for bluegills is 0.75 to 1.50 mg/l at 25° C and 2.0 mg/l at 35° C (Moss and Scott 1961). A pH range of approximately 6.7 to 8.6, with an extreme range of 6.3 to 9.0 is thought to safely support a good mixed fish fauna (McKee and Wolf 1963). Thus, it is assumed redear populations would be unaffected by these pH ranges.

Adult. The best growth for redear was reported to occur at temperatures of 23.9° C by Rounsefell and Everhart (1953), but Leidy and Jenkins (1977) reported the optimum or preferred temperature for growth of bluegills, smallmouth bass, and largemouth bass to be 27° C. At acclimation temperatures of 16° C, 21° C, and 26° C the redear sunfish selected temperatures at 22° C, 23° C, and 28° C, respectively (Hill et al. 1975). From this information the author assumes optimal temperatures for redear growth range from 24 to 27° C. Cole (1951) reported that bacterial fin rot and fungus attacked redear sunfish almost continuously in aquaria once temperatures fall below 14.4° C. Below 6.6° C, redear were inactive and did not feed. It is assumed that redear growth ceases when temperatures fall below 10° C, as is true for bluegills (Anderson 1958). A lower lethal temperature of 6.5° C was determined in reservoirs by Leidy and Jenkins (1977). Redear sunfish are susceptible to rapid temperature changes (Swingle 1949; Rounsefell and Everhart 1953).

Embryo. Embryonic development is inhibited by turbidity levels > 175 ppm, and optimum turbidity levels are < 25 ppm (Buck 1956a). It is assumed that current velocities of < 1 cm/sec for embryos are preferred because redear sunfish inhabiting streams move shoreward into coves and bays to spawn (McClane 1955) and aeration of the eggs is provided by the guarding male. Redear sunfish nest from several centimeters to 6 m in depth; therefore, reservoir drawdowns > 6 m would probably destroy all nests. To ensure optimum survival, reservoir drawdown should probably not occur during the spring and early summer.

Fry. Young redear sunfish are most often found among the submergent vegetation in the littoral zone (McClane 1955; Wilbur 1969). Temperature, turbidity, and velocity criteria for redear fry are assumed to be similar to those for the embryo life stage.

Juvenile. Juvenile habitat requirements are assumed to be similar to those of adult redear sunfish.

HABITAT SUITABILITY INDEX (HSI) MODELS

Model Applicability

Geographic area. This model is applicable throughout North American waters within the native and introduced range of redear sunfish. The standard of comparison for each individual variable is the optimum value that occurs anywhere within this geographic range.

Season. The model provides an index for a riverine and lacustrine habitat based on the habitats ability to support all life stages of redear sunfish throughout the year.

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

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

Verification level. The model represents an interpretation of how selected environmental factors limit potential carrying capacity for redear sunfish. The acceptance level of the lacustrine and riverine models is that it produce an index between 0 and 1 that the authors believe have a positive relationship to carrying capacity for redear sunfish. This model has not been subjected to field testing or application.

Model Description

Riverine and lacustrine Habitat Suitability Index (HSI) models are presented. These models condense the preceding observations into a set of measurable habitat variables. The models are structured to produce an index of redear sunfish habitat quality between 0.0 (unsuitable) and 1.0 (optimum). A positive relationship between HSI and carrying capacity is assumed but has not been demonstrated. Habitat variables believed to be important in limiting distribution, abundance, or survival of redear sunfish are included in the models. An assumed functional relationship between each habitat variable and habitat suitability is represented in a variable suitability index (SI) graph. The model is likely to provide the most accurate description of carrying capacity when all of the variables have extreme SI values; i.e., either near optimum or near unsuitable.

Redear sunfish habitat quality is represented by food, cover, water quality, and reproduction components. Component ratings were derived from individual variable suitability indices (Figs. 1 and 2). Reasons for placing individual variables in specific components and assumed variable interactions are described below.

Model Description - Riverine

The structure of the riverine HSI model for redear sunfish is illustrated in Figure 1.

Food component. Bottom and surface vegetation (V_1) are part of the food component because redear sunfish condition and growth are positively influenced by a moderate level of vegetation that supports a large number of invertebrates. Too much vegetation can decrease foraging efficiency by redear and have a negative influence on growth and condition.

Cover component. Percentage of habitat > 2 m (depth) (V_{11}) is included in the cover component because redear sunfish adults and juveniles usually occur in the deeper waters of rivers and only come shoreward or utilize shallow littoral areas for spawning.

Water quality component. Dissolved oxygen (V_2), turbidity (V_4), temperature for adults/juveniles (V_5), and pH (V_8) are included in the water quality component because they affect growth, survival, and/or distribution of redear sunfish. Salinity (V_3) is in the water quality component because redear sunfish are probably the most salinity-tolerant centrarchid. They are often found in brackish marshes and tidewaters, where they generally occur in greater standing crops than other centrarchids. This variable should only be considered in areas where salinity is a factor.

Reproduction component. Temperature for spawning and incubation (V_6) is included in the reproduction component because it influences spawning time, incubation length, and hatching success. Redear sunfish are also susceptible to rapid temperature changes. Velocity (V_9) is considered part of the reproduction component because nests are built in waters with no to very slow water currents, and adult males guard the nest and aerate the eggs for a time. Therefore, flowing waters are not needed for aeration and high velocities would prevent nest construction or limit the time that the males attend the nest. Although it is not critical for nesting substrate, bottom and surface vegetation (V_1) are part of this component because they provide cover for fry, substrate for green algae and microcrustaceans on which fry feed, and nests often are located along the edges of vegetation or within its rhizomes.

Model Description - Lacustrine

The structure of the lacustrine HSI model for redear sunfish is illustrated in Figure 2.

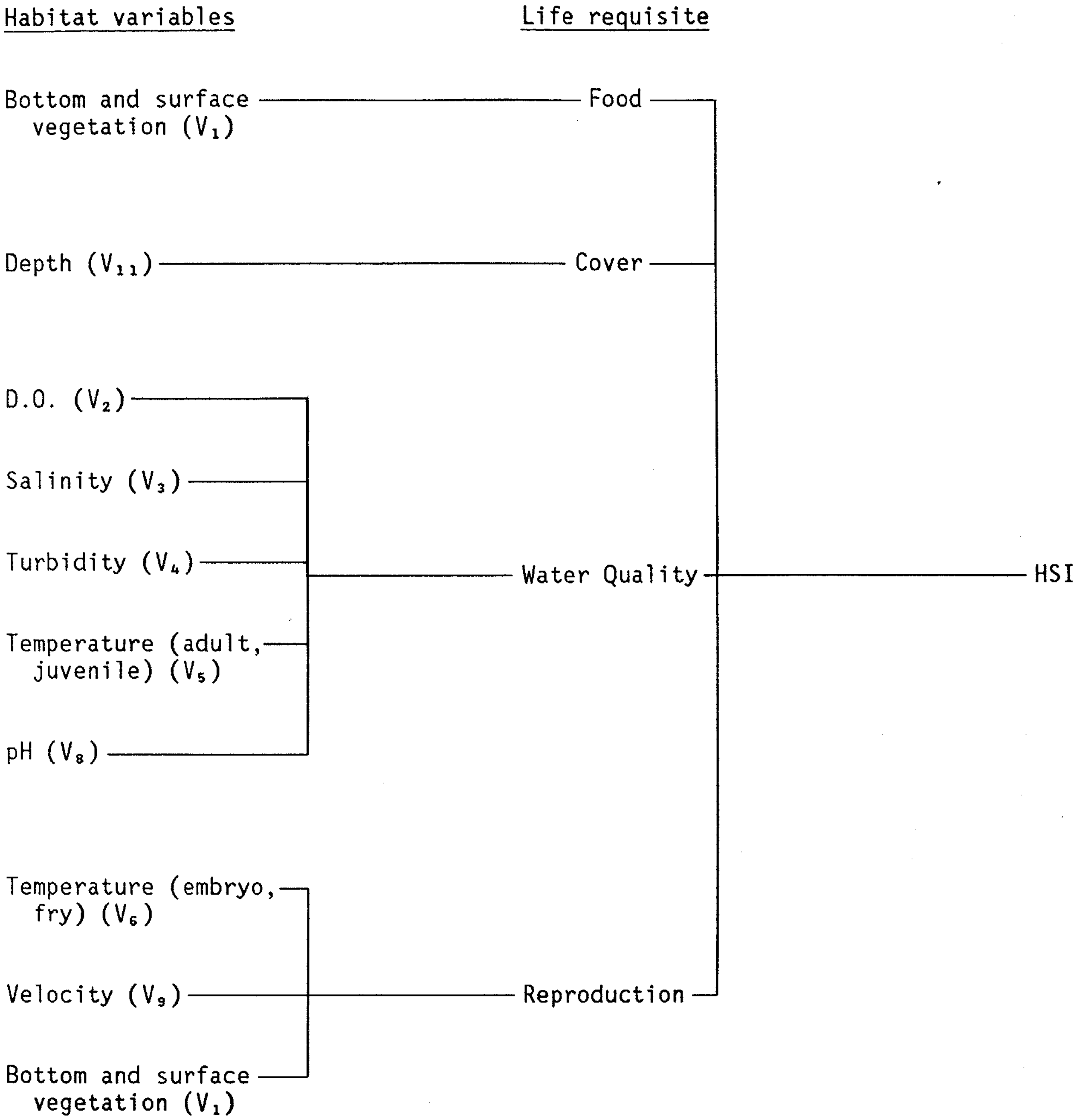


Figure 1. Tree diagram illustrating relationships between model variables, model components, and HSI for redear sunfish riverine environments.

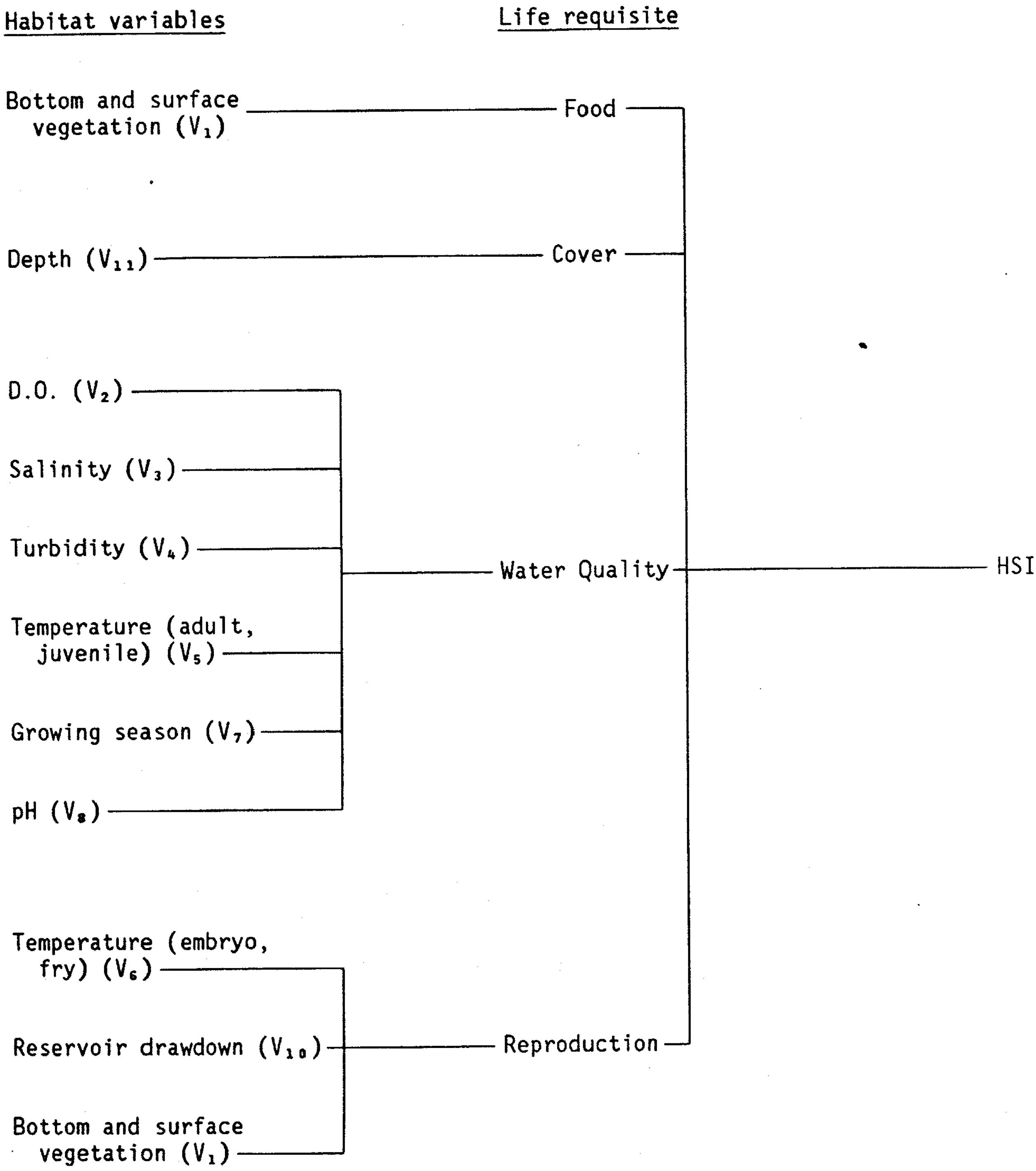


Figure 2. Tree diagram illustrating relationships between model variables, model components, and HSI for redear sunfish lacustrine environments.

Food component. Only bottom and surface vegetation (V_1) are included in this component. As in the riverine model, moderate vegetation positively influences redear growth and condition because it supports an invertebrate population important as a food source.

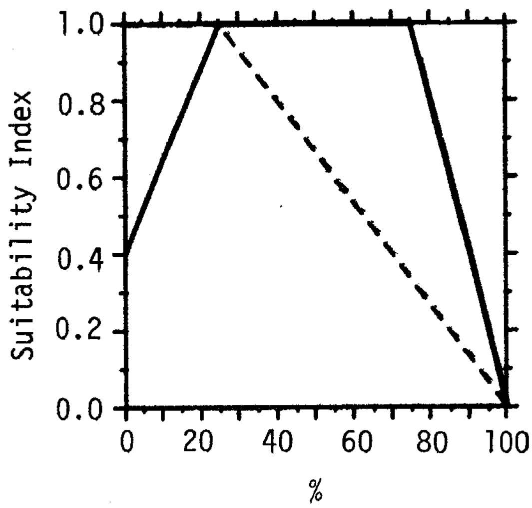
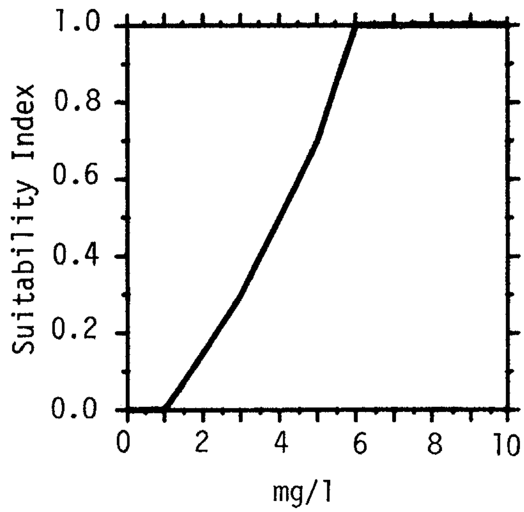
Cover component. Percentage of habitat > 2 m (depth) (V_{11}) is important as cover because adult and juvenile redear sunfish prefer deeper water and only move shoreward for spawning.

Water quality component. Dissolved oxygen (V_2), turbidity (V_4), temperature for adults/juveniles (V_5), and pH (V_8) are included in the water quality component because they influence growth, survival, and distribution of redear sunfish. Salinity (V_3) can be important to water quality in some areas; however, redear sunfish are relatively salinity-tolerant and occur in brackish marshes and lakes. Growing season (V_7) is included in this component because redear growth and standing crop are positively correlated to length of growing season (number of frost-free days).

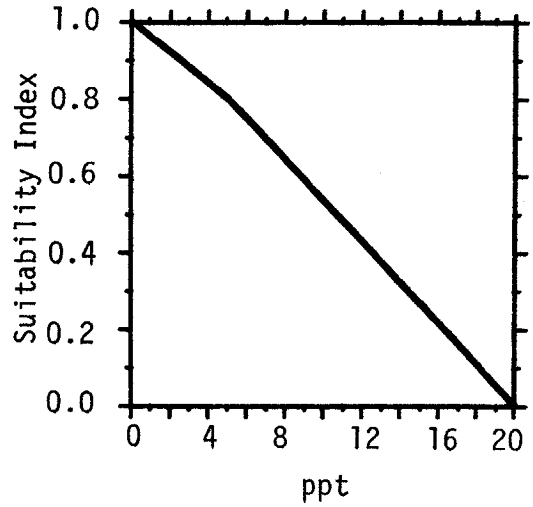
Reproduction component. As in the riverine model, temperature for embryo/fry (V_6) is important in the reproduction component because it influences spawning time, incubation length, and hatching success. Reservoir drawdown (V_{10}) can negatively affect reproductive success when spawning occurs in shallow water and nests and eggs become exposed when water levels drop. Redear sunfish spawn in coves, bays, and shorelines at depths < 6 m. Bottom and surface vegetation (V_1) offer protection for fry, a substrate for food, and nests often are located near or within vegetation.

Suitability Indices of Selected Variables

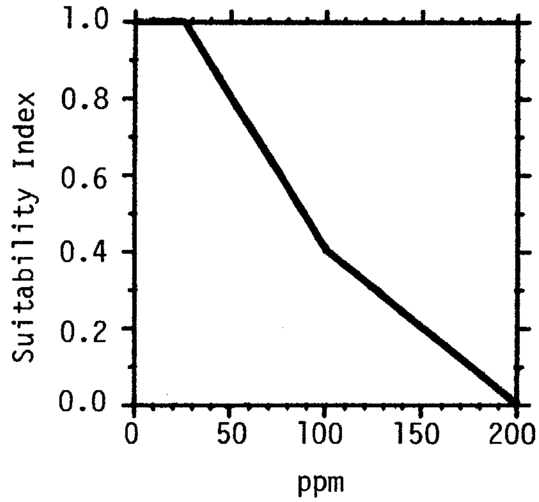
Suitability indices for selected variables are given below. The "R" for riverine and "L" for lacustrine under the heading "habitat" describe the type of habitat where the variable should be measured. Sources of data used to develop the suitability indices are listed in Table 1.

Habitat	Variable		Suitability graph
R,L	V_1	Percent area vegetated within riverine pools or lacustrine habitat during summer. A. Bottom cover —— B. Surface matting --- $\frac{A + B}{2} = V_1$	
R,L	V_2	Minimum dissolved oxygen concentration during summer.	

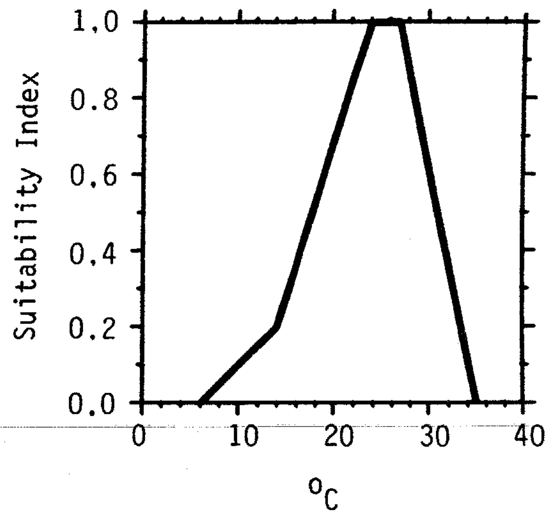
R,L V_3 Maximum salinity during average summer flow or summer water levels.

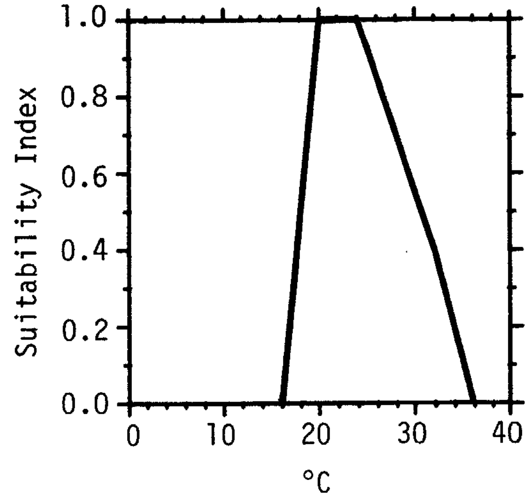
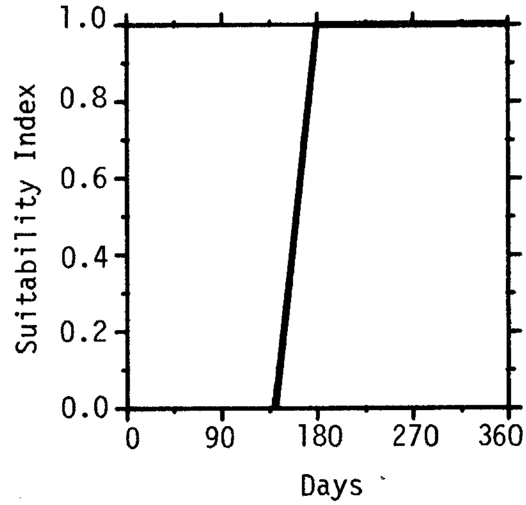
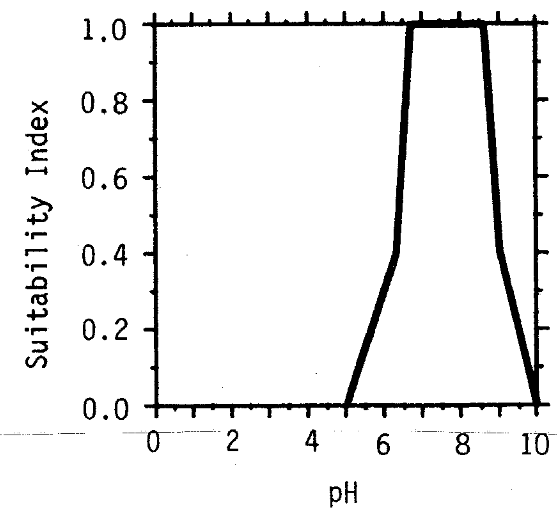


R,L V_4 Maximum monthly average turbidity during spring and summer.

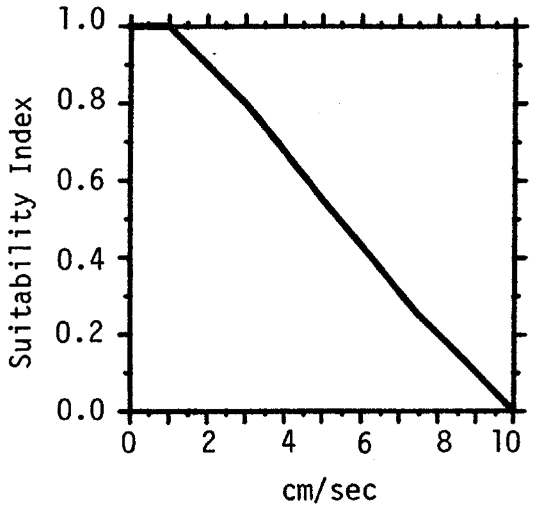


R,L V_5 Maximum average summer riverine pool or lacustrine water temperature (adult, juvenile).

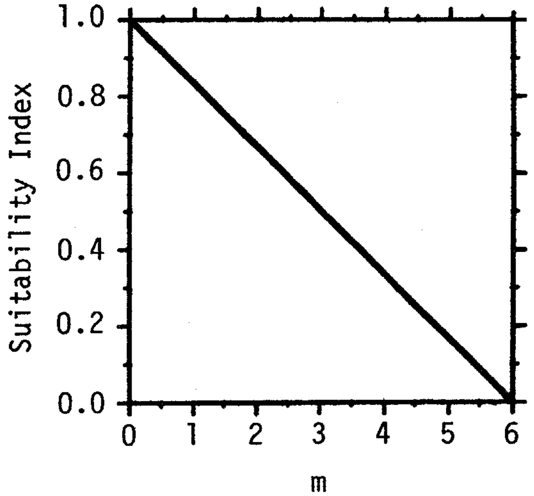


R,L	V_6	Average of mean weekly water temperature within pools and littoral areas during spawning (embryo, fry).	
L	V_7	Average length of frost-free season.	
R,L	V_8	Least suitable pH during year.	

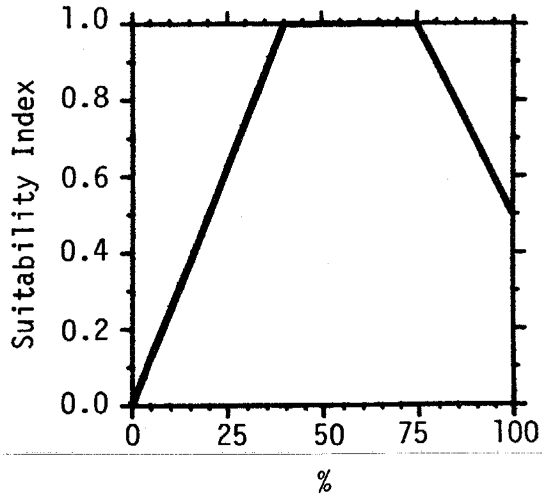
R V_9 Average current velocity (at 0.6 depth) during year.



L V_{10} Reservoir drawdown during spawning season at a particular locale. Use only if applicable to water body.



R,L V_{11} Percent riverine or lacustrine area > 2 m depth (adult, juvenile).



Riverine Model

This model describes life requisite requirements separately and consists of four components: Food; Cover; Water Quality; and Reproduction.

(1) Food (C_F).

$$C_F = V_1$$

(2) Cover (C_C).

$$C_C = V_{11}$$

(3) Water Quality (C_{WQ}).

$$C_{WQ} = \text{the lowest of } V_2, V_3, V_4, V_5, \text{ or } V_8$$

(4) Reproduction (C_R).

$$C_R = \text{the lowest of } V_1, V_6, \text{ or } V_9$$

(5) HSI determination.

$$HSI = \text{the lowest of } C_F, C_C, C_{WQ}, \text{ or } C_R$$

Sources of data and a synopsis of the assumptions made in developing the suitability indices used in this model are presented in Table 1.

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

Variable	Assumptions and sources
V_1	Redear sunfish appear to prefer riverine pools and lacustrine waters with at least some vegetation (Trautman 1957; Pflieger 1975). Although nesting sites can vary, nests often are located within or along the margin of vegetation. Vegetation offers cover and a substrate base for food for young fry, which are most often found among submergent vegetation in the littoral zone (McClane 1955; Wilbur 1969). Vegetation enhances adult redear sunfish habitat by providing cover and substrate for food (Chable 1947). The condition of redear is influenced by the level of vegetation and that the greatest effect on condition is from vegetation in the water column [Colle and Shireman (1980)]. Moderate levels of vegetation improve the growth and condition of redear, but a reduction in growth and condition occurs when vegetation growth is heavy, especially when plant density in the water column is high. High vegetation densities probably restrict foraging efficiencies (Colle and Shireman 1980). Because vegetation is not absolutely necessary for redear survival, no submergent, bottom cover vegetation is considered fair habitat and 25% to 75% is considered optimum. The bottom cover enhances invertebrate productivity and provides cover for young redear. Emergent, surface matting, vegetation is optimum when it occupies 0 to 25% of the water column. It is assumed that habitat quality declines as more of the water column is occupied by vegetation. It also is assumed that the combination of vegetation types should be considered when determining optimum vegetation conditions.
V_2	No specific information for dissolved oxygen requirements for redear sunfish were located in the literature, but it is assumed that bluegill D.O. information is applicable to redear. Dissolved oxygen levels of ≥ 6 mg/l are considered optimum. Dissolved oxygen levels of 5 mg/l are considered good, although the first external signs of stress in bluegills appears at this D.O. level, and D.O. levels of 3 mg/l make the habitat only fair because bluegills begin to intermittently swim to the surface (Petit 1973). Petit (1973) reported that bluegill feeding ceased at D.O. levels of 1 mg/l, and Moss and Scott (1961) reported critical levels of D.O. beginning at 2 mg/l, depending on temperature; thus, D.O. $<$ 2 mg/l indicates poor habitat.

Table 1. (continued).

Variable	Assumptions and sources
V_3	Redear sunfish are probably the most salinity-tolerant of all the centrarchids and are able to survive without apparent discomfort in brackish water (Bailey et al. 1954; Horel 1967; Wilbur 1969). Bailey et al. (1954) classified redear as facultative invaders of brackish water. They frequently invade water of low salinity (i.e., ≤ 4.5 ppt) for a considerable time. Because most redear are collected in salinities ≤ 5 ppt (Bailey et al. 1954; Kilby 1955; Geagan 1962), this level of salinity is considered excellent. Although redear sunfish occur where salinities range up to 24.4 ppt (Bailey et al. 1954), salinities > 16 ppt are assumed poor.
V_4	Redear sunfish usually occur in clear water (< 25 ppm) (Chable 1947; Cole 1951; McClane 1955; Pflieger 1975) and grow faster and reproduce more abundantly at turbidities ≤ 25 ppm (Jenkins et al. 1955; Buck 1956a;b). Therefore, turbidities ≤ 25 ppm are assumed to be optimum. Successful reproduction and fry survival have been reported at turbidities as high as 174 ppm, but embryonic development is inhibited at turbidities > 174 ppm (Buck 1956a). Therefore, this turbidity level is considered poor. The critical levels for successful reproduction and growth over time are probably between 75 to 100 ppm (Buck 1956b), which constitute good to fair habitat.
V_5	Temperatures of 24 to 27° C are considered optimum for growth of adult and juvenile redear sunfish (Emig 1966). Temperatures of 14° C and below are assumed to represent poor habitat because of the increasing disease problems (Cole 1951) and at temperatures < 10° C redear sunfish growth ceases (Anderson 1958). No specific information is available, but it is assumed that temperatures of ≥ 34° C are poor.
V_6	Based on field observations by Swingle (1949), Cole (1951), Lopinot (1961, 1972), Clugston (1966), and Wilbur (1969), optimum temperatures for successful incubation and hatching are 21 to 24° C. Childers (1967) reported that 50% hatching occurs at 18.3° C, which is assumed to correspond to good to fair habitat. Clugston (1966) reported successful spawning at temperatures as high as 32° C, which are assumed to be fair. However, habitat quality is assumed to decline rapidly at these high spawning and hatching temperatures. Rapid temperature changes decrease habitat quality, because redear sunfish are susceptible to rapid fluctuations in temperature (Swingle 1949; Rounsefell and Everhart 1953).

Table 1. (continued).

Variable	Assumptions and sources
V_7	Jenkins (1968, 1970) and Jenkins and Morais (1971) reported that longer growing seasons were positively correlated with redear sunfish standing crop. Because no sunfishes were harvested in reservoirs with growing seasons < 140 days, habitats with this short a growing season are considered poor (Jenkins and Morais 1971). Annual harvest rates increase most rapidly with growing seasons between 180 to 240 days; therefore, it is assumed that growing seasons > 180 days are optimum.
V_8	The pH range not directly lethal to fish is 5 to 9, and there is a gradual deterioration in habitat as the pH values become either higher or lower than the normal range (European Inland Fisheries Advisory Commission 1969). Productivity of aquatic ecosystems is reduced below a pH of 5.0, which also diminishes habitat quality (European Inland Fisheries Advisory Commission 1969). A pH range of 6.7 to 8.6 is considered optimum and a pH range of 6.3 to 9.0 is fair in supporting a good mixed fish fauna, including redear sunfish (McKee and Wolf 1963).
V_9	Redear sunfish most commonly occur in low gradient streams with sluggish currents (Chable 1947; Pflieger 1975; Smith 1979). Redear sunfish occur more often in protected bays and overflow pools, than in main stream channels (McClane 1955). Bailey et al. (1954) reported that redear sunfish occurred in waters of no to moderate currents. It is assumed that currents < 1 cm/sec are optimum and that currents > 8 cm/sec are poor.
V_{10}	Redear sunfish move to shallow waters to build nests and spawn. The nests are located at water depths from 5 to 10 cm (Swingle and Smith 1947; Gresham 1965; Emig 1966) to 4 to 6 m (Wilbur 1969). Nests were reported most often at depths of 45 to 90 cm by Gresham (1965) and Clugston (1966), 91 to 122 cm by McClane (1955), and 183 cm by Swingle and Smith (1947). Because most nests are built at < 200 cm (2 m) depth during spawning season, it is assumed that no reservoir drawdowns is the optimum condition to protect nests and that increasing water drawdowns endanger an increasing number of nests. Drawdowns ≥ 5 m are considered poor.

Table 1. (concluded).

Variable	Assumptions and sources
V_{11}	Redear sunfish adult and juveniles most commonly inhabit deep waters and move shoreward into shallow coves, bays, and littoral areas only to spawn (Cole 1951; McClane 1955; Lopinot 1961). It is assumed that water depths of at least 2 m or greater should occur over 40% to 75% of lakes or riverine pools for optimum habitat. If habitats have ≤ 10% of their area > 2 m, the habitat is considered poor; if 100% of the area is > 2 m, the habitat is considered good to fair, depending on the accessibility and quality of nesting areas in shoreward areas.

Lacustrine Model

This model utilizes the life requisite approach and consists of four components: Food; Cover; Water Quality; and Reproduction.

(1) Food (C_F).

$$C_F = V_1$$

(2) Cover (C_C).

$$C_C = V_{11}$$

(3) Water Quality (C_{WQ}).

C_{WQ} = the lowest of V_2, V_3, V_4, V_5, V_7, or V_8

(4) Reproduction (C_R).

C_R = the lowest of V_1, V_6, or V_{10}

(5) HSI determination.

HSI = the lowest of C_F, C_C, C_{WQ}, or C_R

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

Interpreting Model Outputs

The models described above are generalized descriptions of habitat requirements for redear sunfish and are unlikely to discriminate among different habitat with a high level of accuracy or precision at this stage of development. Each model variable is considered to have some effect on carrying capacity for redear sunfish, and the suitability index graphs depict this assumed effect. However, the graphs are derived from a series of untested assumptions and have unknown accuracy in depicting habitat suitability for redear sunfish. The model assumes that each model component alone can limit redear sunfish production, but this has not been tested. A major weakness of the models is that, while model variables may be necessary to determine the suitability of habitat for redear sunfish, they may not be sufficient. Therefore, high HSI's may be associated with low or zero standing crops, as well as high standing crops.

Model outputs should be interpreted 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 redear sunfish. The output of the models provided should be most useful in comparing different habitats. If two study areas have different HSI's, the one with the higher HSI is expected to have the potential to support a larger redear sunfish population. The models also provide the basic framework for incorporating new model hypotheses or other site-specific factors that affect habitat suitability for redear sunfish. Users should recognize that carrying capacity is a concept and not a measurable response for which one can build a falsifiable predictive model. Users conducting impact assessments requiring major model improvements and testing should concentrate on building a falsifiable model. The model should use a clearly documented chain of logic to predict a measurable response (e.g., growth, standing crop) that is acceptable for judging a selected impact.

ADDITIONAL HABITAT SUITABILITY INDEX MODELS

Model 1

Optimal riverine habitat for redear sunfish is characterized by the following conditions, assuming that the water quality is adequate: large, low gradient (0.5 m/km) streams with warm water temperatures (> 20° C); sluggish current velocities (≤ 3 cm/sec); low turbidities (< 25 ppm); and an abundance of aquatic vegetation in protected areas of the stream (25 to 75% of area).

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

Model 2

Optimal lacustrine habitat for redear sunfish is characterized by the following conditions, assuming that the water quality is adequate: fertile lakes, reservoirs, and marshes with 25 to 75% vegetated littoral areas; 40 to 75% of the area > 2 m deep; warm water temperatures (> 20° C); low turbidities (< 25 ppm); and stable water levels.

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

Model 3

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

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

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. (1984), is one component of IFIM that can be used by investigators interested in determining the amount of available instream habitat for a fish species as a function of streamflow. The output generated by PHABSIM can be used for several IFIM habitat display and interpretation techniques, including:

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

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

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

Suitability Index Graphs as Used in IFIM

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

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

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

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

Category three curves are derived from utilization curves which have been corrected for environmental bias and therefore represent preference of the species. To generate a preference curve, one must simultaneously collect habitat utilization data and habitat availability data from the same area. Habitat availability should reflect the relative amount of different habitat types in the same proportions as they exist throughout in the stream-study area. A curve is then developed for the habitat frequency distribution in the same way as for fish utilization observations, and the equation coefficients of the availability curve are subtracted from the equation coefficients of the the utilization curve, resulting in preference curve coefficients. Theoretically, category three curves should be unconditionally transferable to any stream, although this has not been validated. At present, very few category three curves exist because most habitat utilization data sets are without concomitant habitat availability data sets. In the future, the need to collect habitat availability data will be impressed upon investigators.

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

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

For an IFIM analysis of riverine habitat, an investigator may wish to utilize the curves available in this publication; modify the curves based on new or additional information; or collect field data to generate new curves. For example, if an investigator has information that spawning habitat utilization in his study stream is different from that represented by the SI curves, he may want to modify the existing SI curves or collect data to generate new curves. Once the curves to be used are decided upon, then the curve coordinates are used to build a computer file (FISHFIL) which becomes a necessary component of PHABSIM analyses (Milhous et al. 1984).

Availability of Graphs for Use in IFIM

All the SI curves available for the IFIM analysis of redear sunfish riverine physical microhabitat are category one (Table 2), and can be found in the HSI model section of this report (sources and assumptions in Table 1). Some of the curves may require modification before use in the PHABSIM model.

Redear sunfish generally spawn sometime between February and October, depending on locale, and spawning duration may range from 1 to 8 months (Carlander 1977). The SI curves for spawning habitat should be used for the defined spawning period within the selected study area. Egg incubation generally requires 1 to 2 days (Ibid) and, therefore, egg incubation curves should be used for the defined spawning period. Fry are defined as individuals less than 1.0 inches in length, and fry curves should be used for the period from 3 days after the beginning to 3 months after the end of spawning. Juveniles are defined to range in length from 1.0 to 6.0 inches; and sexually mature adults are generally greater than 6.0 inches in length. Juvenile and adult habitat is required year-round.

The SI curves for velocity and percent cover suitability (V_9; V_1) are meant to be used for all life stages of redear sunfish. The SI curve for spawning, egg incubation, and fry temperature suitability (V_6) above 20° C is identical to that for juveniles and adults (V_5). Curve coordinates can be taken from the curves for entry into FISHFIL. Any curves which are thought not to represent circumstances found at a given site may be modified for IFIM applications. No curves are available for depth or substrate suitability for any of the life stages, and will have to be generated by the investigator before a complete IFIM analysis can be undertaken.

Table 2. Availability of SI curves for the IFIM analyses of redear sunfish habitat.

	Velocity[a]	Depth	Substrate	Temperature[a]	Cover[a]
Spawning	Use SI curve for V_9.	No curve available.	No curve available.	Use SI curve for V_6.	Use SI curve for V_1.
Egg incubation	Use SI curve for V_9.	No curve available.	No curve available.	Use SI curve for V_6.	Use SI curve for V_1.
Fry	Use SI curve for V_9.	No curve available.	No curve available.	Use SI curve for V_6.	Use SI curve for V_1.
Juvenile	Use SI curve for V_9.	No curve available.	No curve available.	Use SI curve for V_5.	Use SI curve for V_1.
Adult	Use SI curve for V_9.	No curve available.	No curve available.	Use SI curve for V_5.	Use SI curve for V_1.

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

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Wyoming Cooperative Fishery Unit
University of Wyoming
Laramie, WY 82071

Instream Flow and Aquatic Systems Group
Western Energy and Land Use Team
U.S. Fish and Wildlife Service
2627 Redwing Road
Ft. Collins, CO 80526-2899

Oklahoma Coop. Fishery Research Unit, Oklahoma State Univ., Stillwater, OK 74074

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16. Abstract (Limit: 200 words)

The habitat suitability index (HSI) models presented in this publication aid in identifying important habitat variables for the redear sunfish (Lepomis microlophus). Information obtained from the research literature and expert reviews are synthesized into models which present hypotheses of species-habitat relationships.

A brief discussion of using selected Suitability Index (SI) curves from HSI models as a component of the Instream Flow Incremental Methodology (IFIM) is provided. Additional SI curves, specifically designed for analysis of Redear sunfish habitat with IFIM, are also presented.

17. Document Analysis a. Descriptors

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