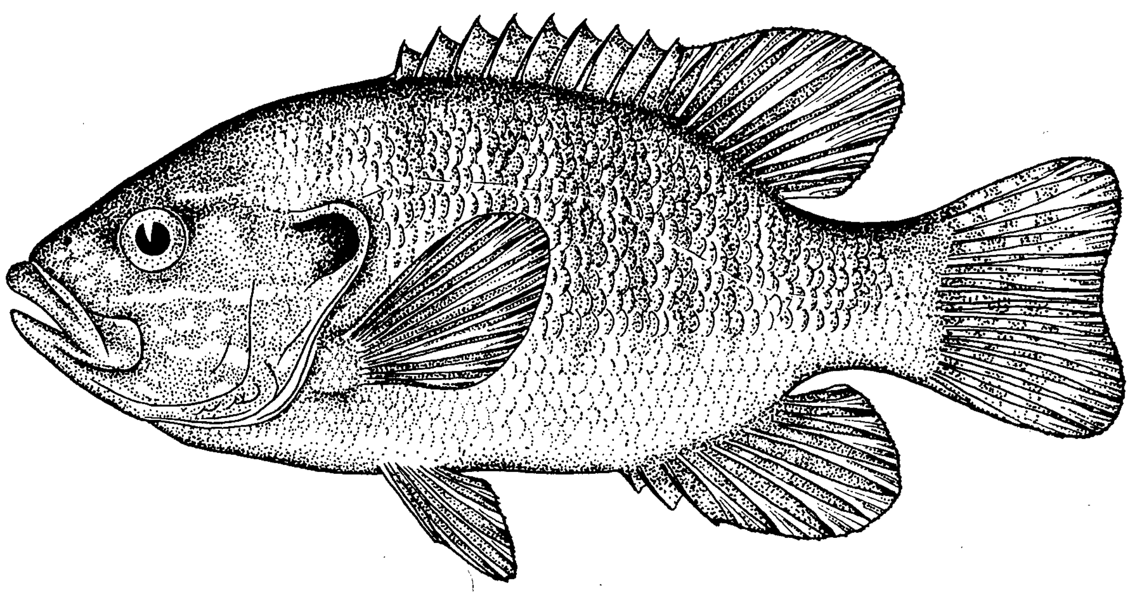
Biological Services Program
and
Division of Ecological Services

FWS/OBS-82/10.15
JULY 1982

HABITAT SUITABILITY INDEX MODELS: GREEN SUNFISH



Fish and Wildlife Service

U.S. Department of the Interior

The Biological Services Program was established within the U.S. Fish and Wildlife Service to supply scientific information and methodologies on key environmental issues that impact fish and wildlife resources and their supporting ecosystems. The mission of the program is as follows:

- To strengthen the Fish and Wildlife Service in its role as a primary source of information on national fish and wildlife resources, particularly in respect to environmental impact assessment.
- To gather, analyze, and present information that will aid decisionmakers in the identification and resolution of problems associated with major changes in land and water use.
- To provide better ecological information and evaluation for Department of the Interior development programs, such as those relating to energy development.

Information developed by the Biological Services Program is intended for use in the planning and decisionmaking process to prevent or minimize the impact of development on fish and wildlife. Research activities and technical assistance services are based on an analysis of the issues, a determination of the decisionmakers involved and their information needs, and an evaluation of the state of the art to identify information gaps and to determine priorities. This is a strategy that will ensure that the products produced and disseminated are timely and useful.

Projects have been initiated in the following areas: coal extraction and conversion; power plants; geothermal, mineral and oil shale development; water resource analysis, including stream alterations and western water allocation; coastal ecosystems and Outer Continental Shelf development; and systems inventory, including National Wetland Inventory, habitat classification and analysis, and information transfer.

The Biological Services Program consists of the Office of Biological Services in Washington, D.C., which is responsible for overall planning and management; National Teams, which provide the Program's central scientific and technical expertise and arrange for contracting biological services studies with states, universities, consulting firms, and others; Regional Staffs, who provide a link to problems at the operating level; and staffs at certain Fish and Wildlife Service research facilities, who conduct in-house research studies.

This model is designed to be used by the Division of Ecological Services in conjunction with the Habitat Evaluation Procedures.

FWS/OBS-82/10.15
July 1982

HABITAT SUITABILITY INDEX MODELS: GREEN SUNFISH

by

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This report should be cited as:

Stuber, R. J., G. Gebhart, and O. E. Maughan. 1982. Habitat suitability index models: Green sunfish. U.S. Dept. Int. Fish Wildl. Serv. FWS/OBS-82/10.15. 28 pp.

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.

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
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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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ACKNOWLEDGMENTS

We would like to thank John Magnuson, (University of Wisconsin, Madison), and Richard Applegate (South Dakota Cooperative Fishery Research Unit) for reviewing the manuscript. Their review contributions are gratefully acknowledged, but the authors accept full responsibility for the contents of the document. Word processing was provided by Dora Ibarra and Carolyn Gulzow. The cover of this document was illustrated by Jennifer Shoemaker.

GREEN SUNFISH (*Lepomis cyanellus*)

HABITAT USE INFORMATION

General

The green sunfish (*Lepomis cyanellus*) is native from the Great Lakes region south to Mexico (Eddy 1957) and has been introduced both east of the Appalachian Mountains (Raney 1965) and west of the Rocky Mountains (Wright 1951). The species is established in nearly every suitable habitat in the Western United States (McKechnie and Tharratt 1966) and is nearly ubiquitous within its native range (Trautman 1957; Cross 1967). Green sunfish hybridize with longear (*L. megalotis*), orangespotted (*L. humilis*), and redbreast (*L. auritus*) sunfishes, bluegill (*L. macrochirus*), and pumpkinseed (*L. gibbosus*) (Scott and Crossman 1973).

Age, Growth, and Food

The maximum age, length, and weight of green sunfish is about 10 years, 276 mm, and 408 g, respectively (Carlander 1977). Age at maturity ranges from 1 to 3 years, depending on geographic locale (Hubbs and Cooper 1935; Sprugel 1955; Durham 1957). Males and females mature at minimum lengths of 45 (Sprugel 1955) and 66 mm (Cross 1951), respectively.

Adult green sunfish feed principally on insects, crayfish (Mullan and Applegate 1970; Etnier 1971; Applegate et al. 1976), and fish (Biggins and Ziebell 1967; Mullan and Applegate 1968, 1970). Terrestrial and aquatic insects appear to be the most important food items (Cross 1951; Maupin et al. 1954; McDonald and Dotson 1960). Fry initially eat zooplankton (Siewert 1973) and subsequently eat aquatic insects, fish eggs, and entomostraca as they grow larger (Applegate et al. 1976). The juvenile diet is similar to that of the adult (Mullan and Applegate 1968, 1970). Growth is usually faster in downstream river areas, where population densities are lower, than in upstream areas (Finnell 1955; Hoffman 1955; Jenkins and Finnell 1957; Purkett 1958).

Reproduction

Spawning has been noted at temperatures between 19 and 31° C (Hunter 1963), with initial spawning usually occurring at 20 to 22° C (Swingle 1952; Lawrence 1957; Pflieger 1963). The male clears a nest area of about 30 cm in diameter (Carson 1968) and guards the nest (Hankinson 1919). Green sunfish nest at a depth of 4 to 35 cm (Hunter 1963; Carson 1968) on a firm substrate (Childers 1967) of gravel or sand (Hankinson 1919; Hunter 1963) near rocks, logs, and vegetation (Hunter 1963).

Specific Habitat Requirements

Green sunfish typically inhabit pool areas of streams (Brown 1960; Minckley 1963; Harlan and Speaker 1969), and optimal riverine habitat consists of at least 50% pool area. Species abundance is positively correlated with percent vegetative cover (Moyle and Nichols 1973). Forshage and Carter (1974) attributed reductions in game fish populations, which included green sunfish, to reductions in sheltered areas consisting of logs, brush, and gravel. More than 80% cover is assumed to be suboptimal, because it provides too much protection for green sunfish prey. Green sunfish have been found at a wide range of gradients, varying from 0.2 to 5.7 m/km (Cross 1954; Funk 1975a); however, they are most abundant at lower (≤ 2 m/km) gradients (Trautman 1957; Funk 1975b). They prefer small to medium-sized (< 30 m width) streams (Trautman 1957; Cross 1967; Moyle and Nichols 1973).

Green sunfish also thrive in lacustrine environments. Optimal habitat consists of fertile lakes, ponds, and reservoirs with extensive (≥ 20% of lacustrine surface area) littoral areas (Scott and Crossman 1973). Optimal cover within littoral areas is similar to riverine criteria. Jenkins (1976) reported a significant positive correlation between TDS levels of 100 to 350 ppm and sportfish (which included sunfishes) standing crop.

Water quality criteria for green sunfish in both riverine and lacustrine environments are outlined as follows. High species abundance is positively correlated with moderate (25-100 JTU) turbidities (Trautman 1957; Cross 1967; Moyle and Nichols 1973), although the species occurs in both clear and turbid water (Jenkins and Finnell 1957). Dissolved oxygen (D.O.) requirements are presumably similar to those of the bluegill sunfish. Thus, optimal D.O. levels are > 5 mg/l (Petit 1973), and lethal levels are ≤ 1.5 mg/l (Moore 1942). Using Stroud's (1967) criteria for freshwater fish, optimal pH range is from 6.5 to 8.5. Assuming green sunfish exhibit similar responses to pH levels as do bluegill, mortality may occur at pH levels ≤ 4.0 or ≥ 10.35 (Trama 1954; Calabrese 1969; Ultsch 1978). If green sunfish have salinity tolerances similar to those of bluegill, optimal salinities are < 3.6 ppt (Tebo and McCoy 1964), and green sunfish will not tolerate salinities > 5.6 ppt (Kilby 1955).

Adult. The temperature preference for adult green sunfish is 28.2° C and, when possible, they avoid temperatures above 31° C or below 26° C (Beitinger et al. 1975). Green sunfish have been found in the field at temperatures as high as 36° C (Sigler and Miller 1963; Proffitt and Benda 1971). Growth and food conversion efficiency increased as temperature increased from 13.2 to 28° C (Jude 1973).

Adults are found in low current velocity areas (Gerking 1945; Brown 1960; Minckley 1963; Summerfelt 1967; Harlan and Speaker 1969; Moyle and Nichols 1973). Based on catch data, preferred current velocities are ≤ 10 cm/sec, but adults will tolerate velocities up to 25 cm/sec (Kallemyn and Novotny 1977; Hardin and Bovee 1978).

Embryo. Optimal temperature for spawning and subsequent development ranges from 20 to 27° C (Childers 1967). Spawning will not occur below 19° C or above 31° C (Hunter 1963). Optimal spawning substrate corresponds to a predominance (≥ 50%) of sand and gravel (Hankinson 1919; Hunter 1963; Childers 1967). Green sunfish spawn at depths of 4 to 35 cm (Hunter 1963; Carson 1968); consequently, reservoir drawdown should not exceed 1 m during spawning to ensure optimal embryo development and survival. Probability of use curves developed by Hardin and Bovee (1978) illustrate that optimal current velocity is ≤ 10 cm/sec, and embryos probably will not tolerate velocities > 15 cm/sec.

Fry. Optimal temperatures for fry range from 18 to 26° C (Siewert 1973; Coutant 1977; Hardin and Bovee 1978). The range of tolerance for bluegill fry is 10 to 36° C (Banner and Van Arman 1972), and it is assumed that green sunfish fry tolerances are similar. Optimal current velocities are ≤ 5 cm/sec, and fry avoid areas with velocities exceeding 8 cm/sec (Kallemyn and Novotny 1977; Hardin and Bovee 1978).

Juvenile. Specific requirements for juveniles are assumed to be the same as those for the adult life stage.

HABITAT SUITABILITY INDEX (HSI) MODELS

Model Applicability

Geographic area. The models are applicable throughout the native and introduced range of the green sunfish in North America. The standard of comparison for each individual variable suitability index is the optimal 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 North where temperature related variables do not reach the optimal values that occur in the South.

Season. The models provide a rating for a body of water based on its ability to support a reproducing population of green sunfish during all seasons of the year.

Cover types. The models are applicable in riverine, lacustrine, palustrine, and estuarine habitats, 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 species to live and reproduce. No attempt has been made to establish a minimum habitat size for green sunfish.

Verification level. The acceptable output of these green sunfish models is to produce an index between 0 and 1 which the authors believe has a positive relationship to carrying capacity. Acceptance was based on model predictions using sample data sets. These sample data sets and their relationship to model verification are discussed in greater detail following presentation of the model.

Model Description - Riverine

Riverine green sunfish habitat is assumed to be composed of food and cover, water quality, and reproduction components. Variables that have been shown to affect growth, survival, distribution, or abundance were placed in the appropriate life requisite component (Fig. 1). Variables that did not appear to be related to a specific life requisite component were placed in the "other" component.

Information describing cause and effect relationships of variables and components in determining habitat suitability was lacking. We assumed that high values for one life requisite or variable would compensate for lower values of another life requisite, except when values for a variable approached levels that had clearly demonstrated negative impacts on growth or survival.

Food and cover component. Percent bottom cover (V_1) is assumed to be important because bottom cover provides habitat for aquatic insects, crayfish, and small fish which are the predominant food items of green sunfish. Bottom cover also provides resting areas with low current velocities and protection from predation. Species abundance has been positively correlated with percent cover. Percent pools (V_2) is included to quantify the amount of habitat actually used by the species. Food and cover have been aggregated into one component because the fish have a tendency to feed near cover.

Water quality component. The water quality component is limited to dissolved oxygen (V_4), turbidity (V_5), pH (V_6), temperature (V_7, V_8), and salinity (V_{18}) measurements. The salinity measurement is optional. These parameters have been shown to affect growth or survival. Variables related to temperature and oxygen were assumed to be limiting when they reach near-lethal levels. Toxic substances were not considered in this model.

Reproduction component. Temperature for spawning (V_9) describes water quality conditions that affect embryonic development. Substrate (V_{10}) is important in determining spawning success. Current velocity (V_{12}) within pools during spawning is important because developing eggs will not survive in areas with velocities > 15 cm/sec.

Other component. The variables which are in the other component also describe habitat suitability for the green sunfish, but are not specifically related to life requisite components already presented. Stream gradient (V_3) is included because green sunfish are most abundant in streams with lower gradients (≤ 2 m/km). Current velocity (V_{11}, V_{13}) is important because green sunfish prefer low velocity areas. Stream width (V_{14}) further describes preferred habitat because small to medium-sized streams (< 30 m width) are most suitable.

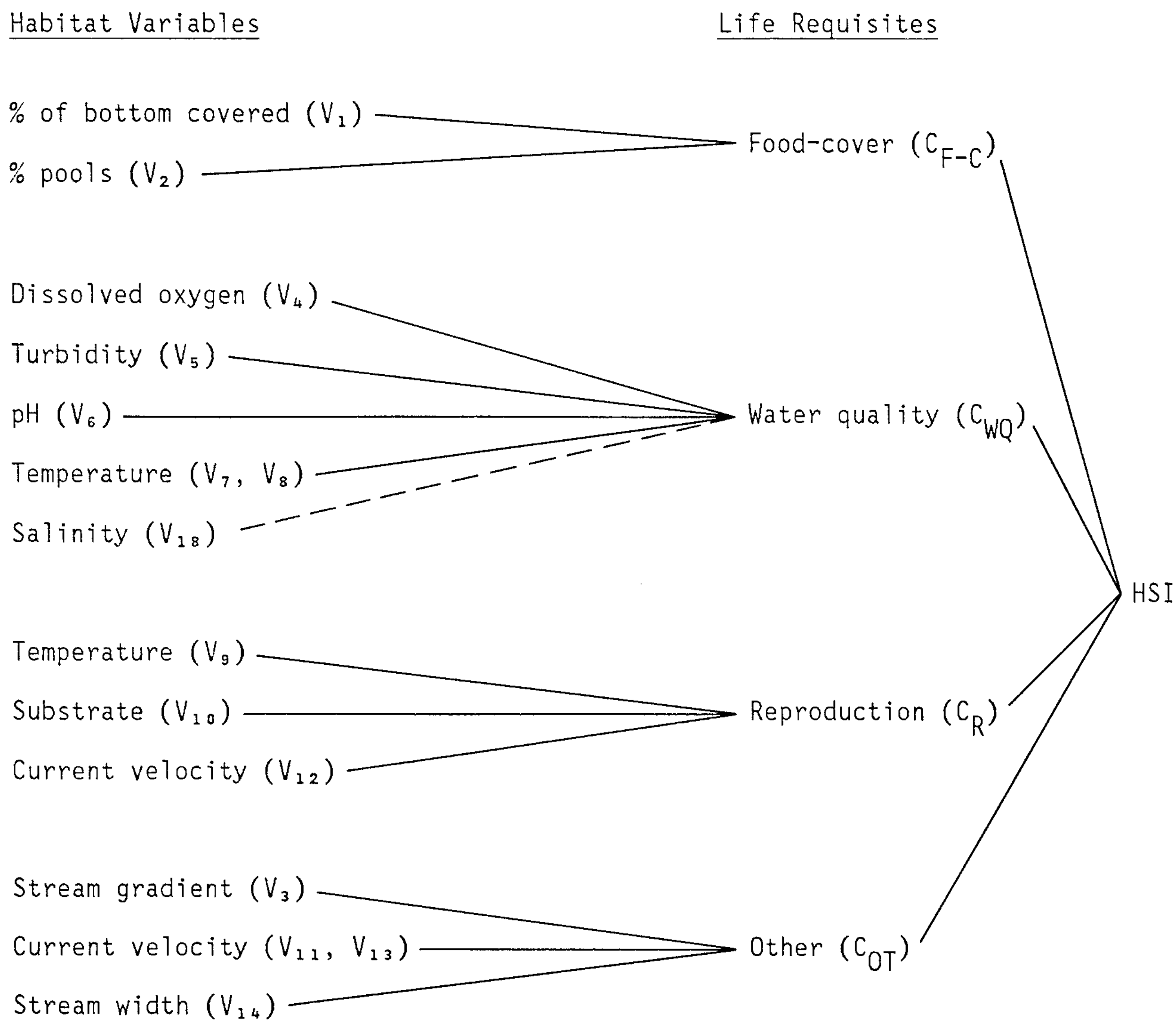


Figure 1. Tree diagram illustrating relationship of habitat variables and life requisites in the riverine model for green sunfish. The dashed line indicates an optional variable.

Model Description - Lacustrine

Lacustrine habitat suitability was assumed to be determined by the same life requisite components as riverine habitat suitability (Fig. 2). Little information was available to determine how variables combine to determine habitat suitability. We assumed that compensation for one life requisite value by another life requisite value occurs except when values for a variable approach levels that have clearly demonstrated negative impacts on growth or survival.

Food component. Average TDS (V_{15}) is included because the TDS is a measure of lacustrine productivity. There is a positive correlation between sunfish standing crops and TDS levels, presumably due to the greater amount of food organisms produced at higher TDS levels.

Cover component. Percent bottom cover (V_1) is included because species abundance is positively correlated with percent cover. Bottom cover provides resting areas and protection from predation. Percent littoral area (V_{16}) quantifies the amount of cover habitat.

Water quality component. Same explanation as presented in the riverine model description.

Reproduction component. Temperature for spawning (V_9) describes water quality conditions that affect embryonic development. Substrate (V_{10}) is important in determining spawning success. Reservoir drawdown (V_{17}) is included because optimal embryo development and survival are dependent on stable water levels during spawning.

Suitability Index (SI) Graphs for Model Variables

This section contains suitability index graphs for the 18 variables described above and equations that quantify assumptions for combining selected variable indices into a species HSI with the component approach. The "R" pertains to riverine habitat variables, and the "L" refers to lacustrine habitat variables.

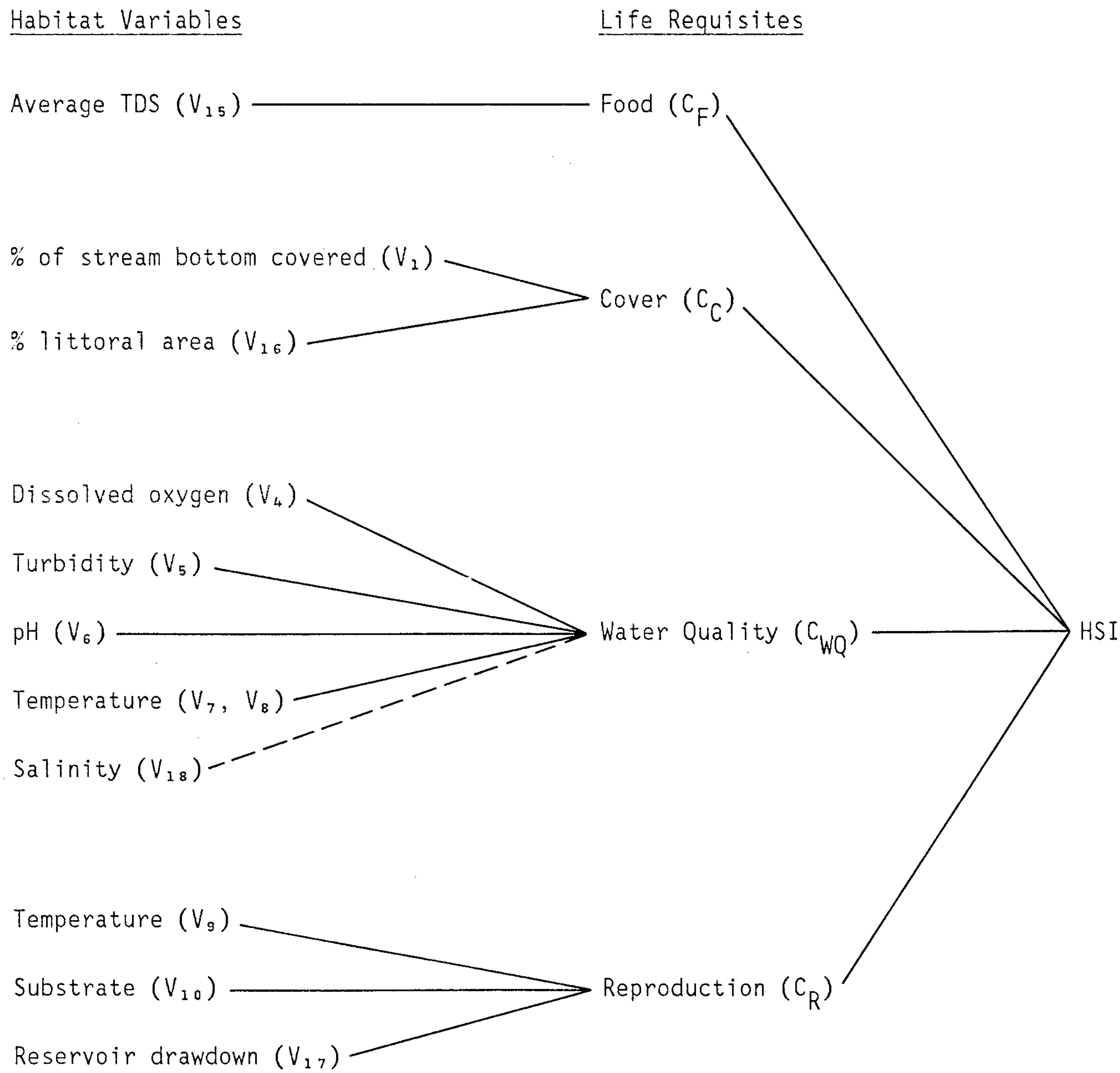
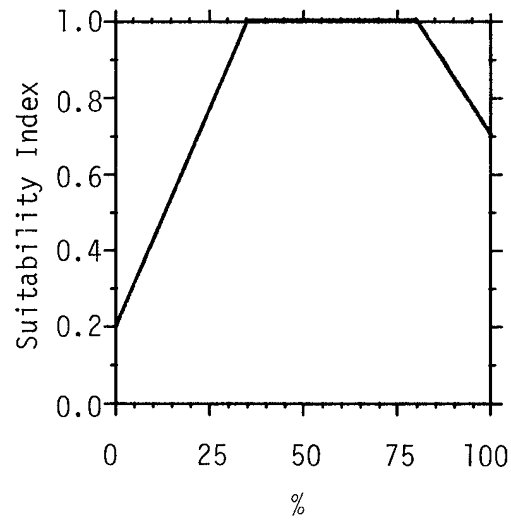
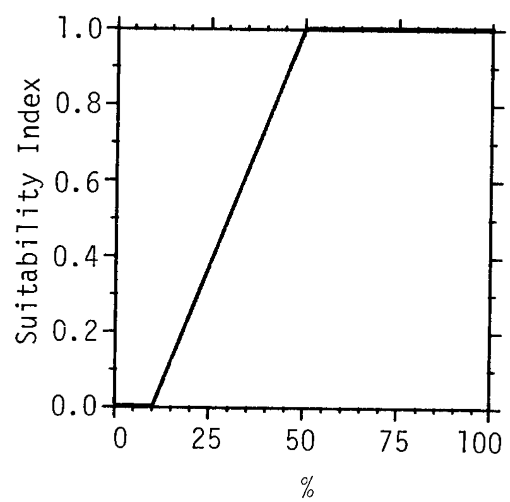
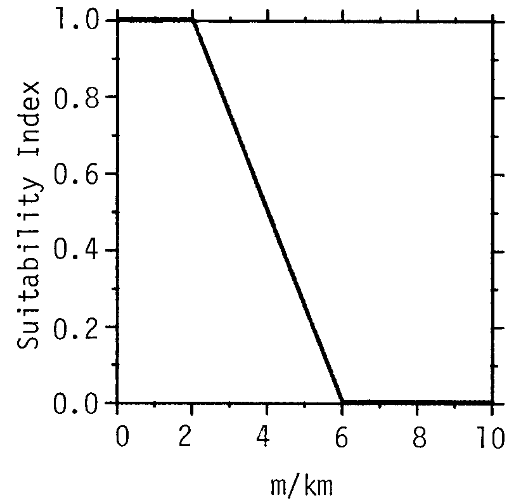
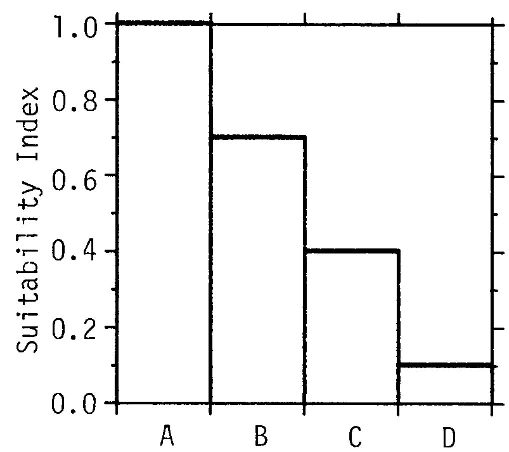
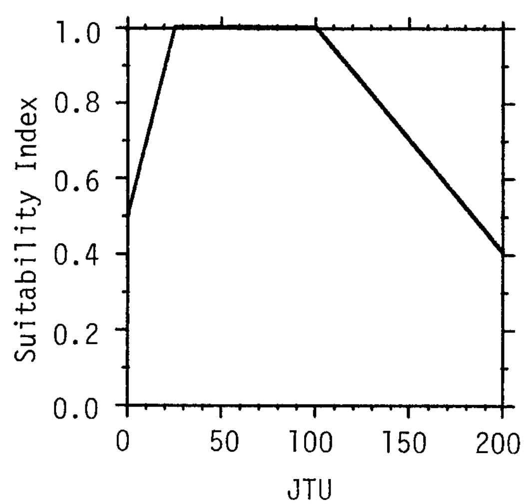


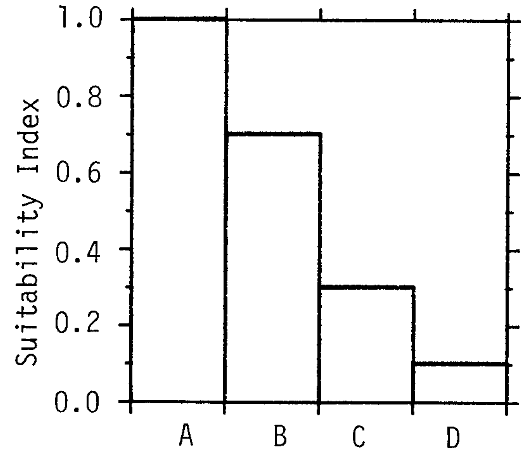
Figure 2. Tree diagram illustrating relationship of habitat variables and life requisites in the lacustrine model for green sunfish. The dashed line indicates an optional variable.

Habitat	Variable		Suitability Graph
R,L	V_1	Percent of the bottom of pools or littoral areas covered with vegetation, rocks, or debris during summer.	
R	V_2	Percent pool area during average summer flow.	

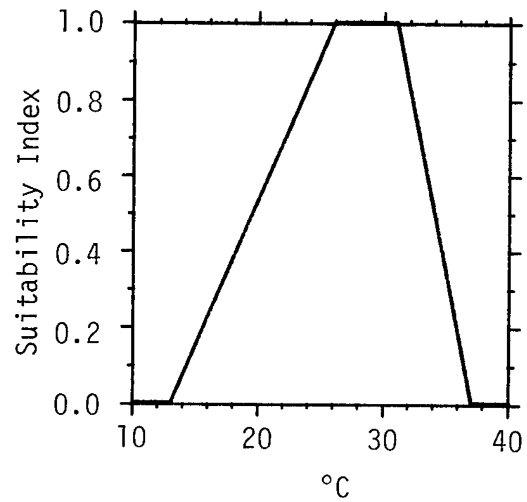
R	V_3	Stream gradient within representative reach.	
R,L	V_4	Minimum dissolved oxygen levels during summer. A) Usually > 5 mg/l B) Usually 4-5 mg/l C) Usually 2-4 mg/l D) Frequently ≤ 2 mg/l Note: Lacustrine D.O. levels refer to littoral areas.	
R,L	V_5	Maximum monthly average turbidity within pools or littoral areas during the summer.	

R,L V_6 pH range during summer growing season.

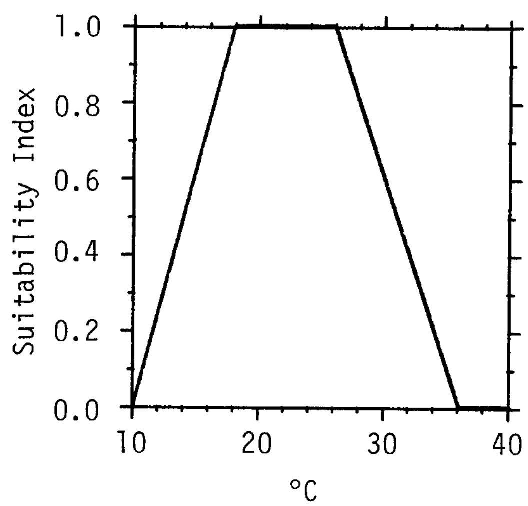
A) 6.5-8.5
B) 5.0-6.5 or 8.5-9.0
C) 4.0-5.0 or 9.0-10.0
D) < 4.0 or > 10.0



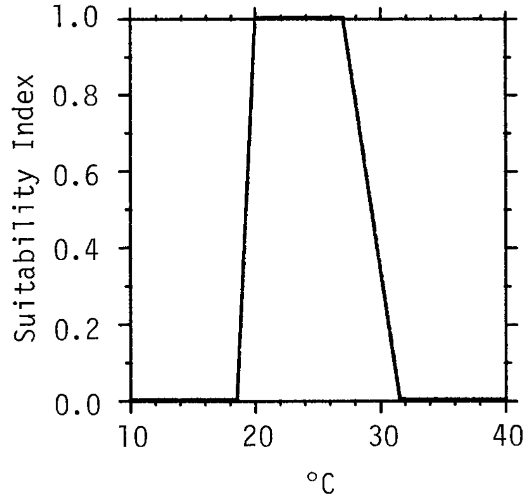
R,L V_7 Maximum midsummer temperature within pools or littoral areas (Adult, Juvenile).



R,L V_8 Maximum midsummer temperature within pools or littoral areas (Fry).

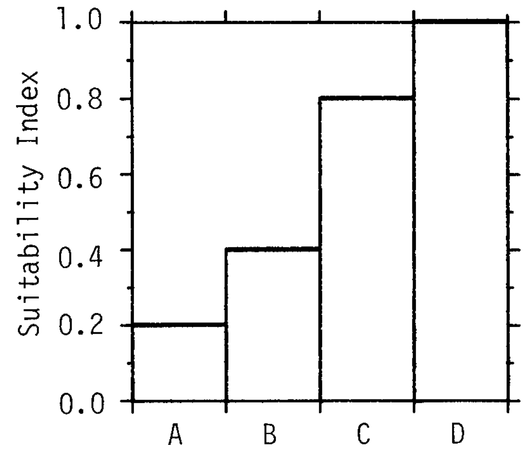


R,L V_9 Maximum temperature within pools or littoral areas during spawning (June-July) (Embryo).

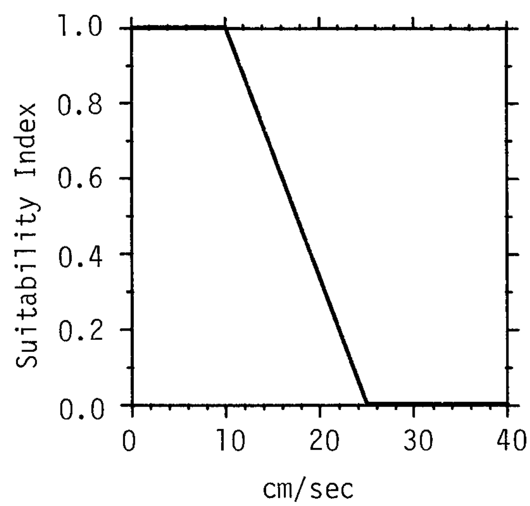


R,L V_{10} Substrate composition within pools or littoral areas for spawning (Embryo).

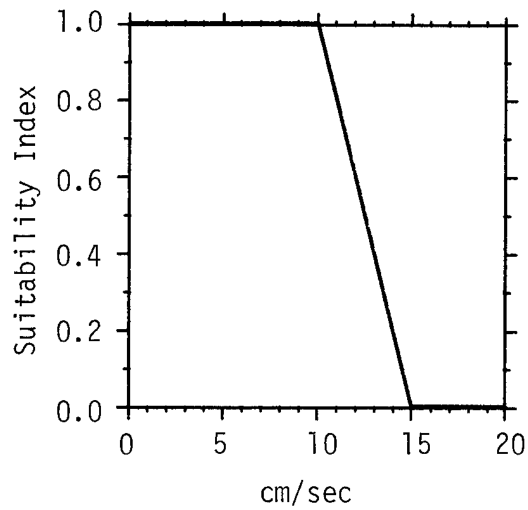
A) Boulder (> 20 cm) and bedrock predominate (≥ 50%).
B) Cobble (5-20 cm) predominates.
C) Silt and sand (≤ 0.2 cm) predominate.
D) Pebbles and gravel (0.2-5.0 cm) predominate.



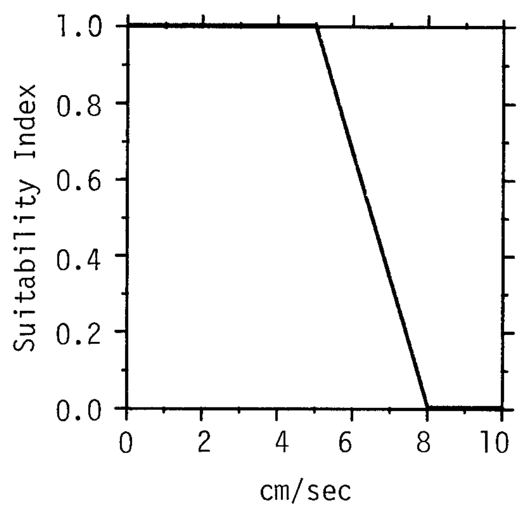
R V_{11} Average current velocity within pools during average summer flow (Adult, Juvenile).



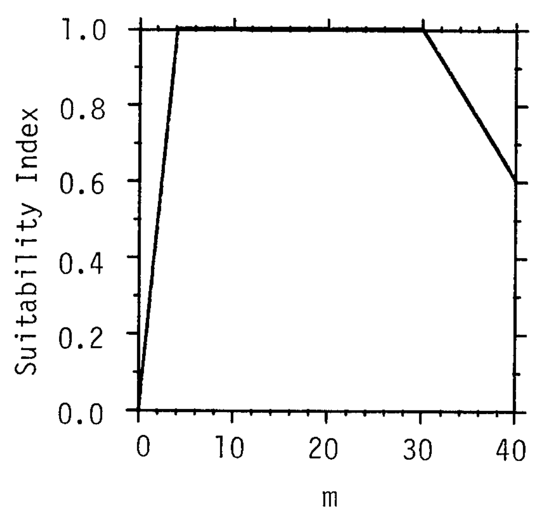
R V_{12} Average current velocity within pools during spawning (June-July) (Embryo).



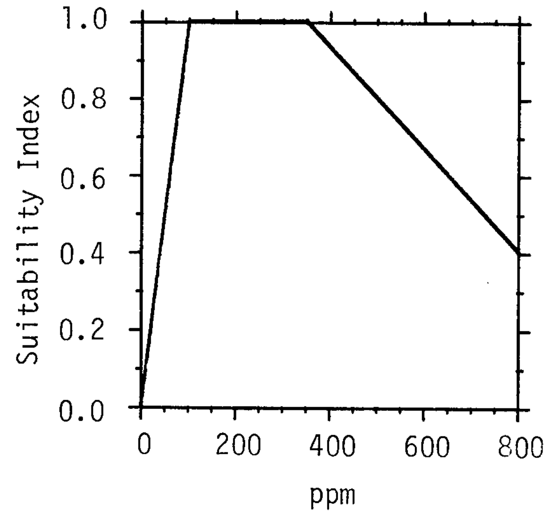
R V_{13} Average current velocity within pools during average summer flow (Fry).



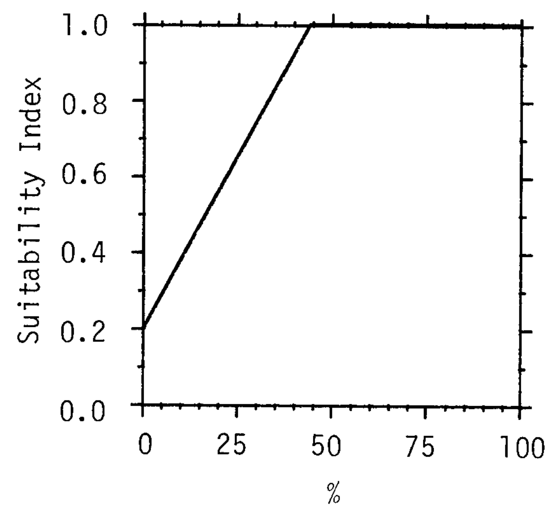
R V_{14} Average stream width within representative reach.



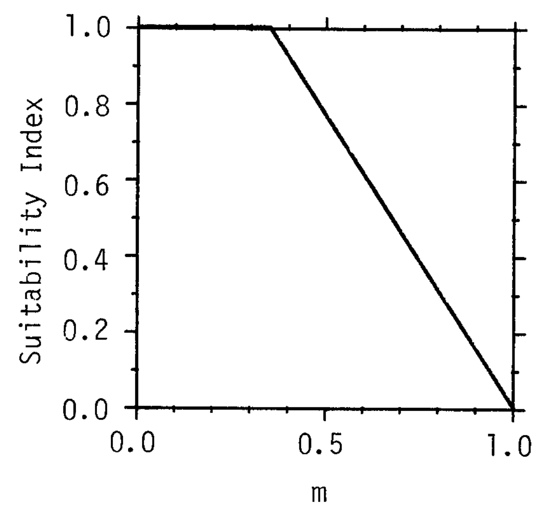
L V$_{15}$ Average TDS level during growing season when the carbonate-bicarbonate ionic concentration > sulfate-chloride ionic concentration. If the sulfate-chloride ionic concentration > than the carbonate-bicarbonate ionic concentration, the SI rating should be lowered by 0.2. SI cannot be < 0.



L V$_{16}$ Percent littoral area at summer water levels.

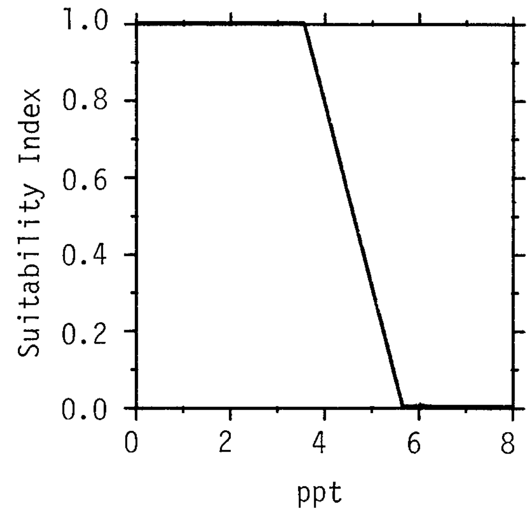


L V$_{17}$ Reservoir drawdown during spawning (Embryo).



R,L V_{18} Maximum monthly average salinity during growing season (Optional).

Note: V_{18} can be omitted if salinity is not considered to be a potential problem within the study area.



Riverine Model

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

Food and Cover ($C_{F/C}$).

$$C_{F/C} = (V_1 \times V_2)^{1/2}$$

Water Quality (C_{WQ}).

$$C_{WQ} = \frac{2V_4 + V_5 + V_6 + V_7 + V_8 + V_{18}}{7}$$

If V_4, V_7, or $V_8 \leq 0.4$, C_{WQ} equals the lowest of the following: V_4; V_7; V_8; or the above equation.

Note: If V_{18} (optional salinity variable) is omitted,

$$C_{WQ} = \frac{2V_4 + V_5 + V_6 + V_7 + V_8}{6}$$

Reproduction (C_R).

$$C_R = (V_9 \times V_{10} \times V_{12})^{1/3}$$

Other (C_{OT}).

$$C_{OT} = \frac{V_3 + \frac{V_{11} + V_{13}}{2} + 1/2\ V_{14}}{2.5}$$

HSI determination.

$$HSI = (C_{F,C} \times C_{WQ} \times C_R \times C_{OT})^{1/4}$$

If C_{WQ} is ≤ 0.4, the HSI equals the lowest of the following: C_{WQ} or the above equation.

Lacustrine Model

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

Food (C_F).

$$C_F = V_{15}$$

Cover (C_C).

$$C_C = (V_1 \times V_{16})^{1/2}$$

Water Quality (C_{WQ}).

$$C_{WQ} = \frac{2V_4 + V_5 + V_6 + V_7 + V_8 + V_{18}}{7}$$

If V_4, V_7, or $V_8 \leq 0.4$, C_{WQ} equals the lowest of the following: V_4; V_7; V_8; or the above equation.

Note: If V_{18} (optional salinity variable) is omitted,

$$C_{WQ} = \frac{2V_4 + V_5 + V_6 + V_7 + V_8}{6}$$

Reproduction (C_R).

$$C_R = (V_9 \times V_{10} \times V_{17})^{1/3}$$

Note: V_{17} should be omitted if the lacustrine environment is a natural lake or pond. Thus,

$$C_R = (V_9 \times V_{10})^{1/2}$$

HSI determination.

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

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

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

Table 1. Data sources and assumptions for green sunfish suitability indices.

	Variable and Source	Assumption
V_1	Minckley 1963 Moyle and Nichols 1973 Forshage and Carter 1974	Vegetation, rocks, and debris have similar value as cover objects. The average percent (35%) bottom covered by vegetation in areas where green sunfish were collected in streams is an optimal value for cover.
V_2	Brown 1960 Minckley 1963 Summerfelt 1967 Harlan and Speaker 1969 Moyle and Nichols 1973	Green sunfish typically inhabit pool areas of streams, and optimal habitat consists of at least 50% pool area.
V_3	Trautman 1957 Funk 1975a, b	Species abundance is greatest in lower (≤ 2 m/km) gradient streams.
V_4	Moore 1942 (BG) Petit 1973 (BG)	Dissolved oxygen requirements are presumably similar to those of the bluegill. D.O. levels that are near-lethal are unsuitable, and levels that result in avoidance are suboptimal.
V_5	Jenkins and Finnell 1957 Trautman 1957 Cross 1967 Moyle and Nichols 1973	Moderate (25-100 JTU) turbidities correlated with high species abundance are optimum.
V_6	Trama 1954 (BG) Stroud 1967 (freshwater fish) Calabrese 1969 (BG)	Optimal pH range is presumably the same as that for all freshwater fish. Levels that impair growth or reproduction are suboptimal, and levels that lead to death are unsuitable.
V_7	Sigler and Miller 1963 Proffitt and Benda 1971 Jude 1973 Beitinger et al. 1975 Cherry et al. 1975 Jones and Irwin 1975 Carlander 1977	Optimal temperatures for adults and juveniles are those where growth and food conversion efficiency are maximal.

Table 1. (continued).

Variable	and Source	Assumption
V_8	Hunter 1963 Pflieger 1963 Sigler and Miller 1963 Proffitt and Benda 1971 Banner and Van Arman 1972 (BG) Jude 1973 Beitinger et al. 1975 Cherry et al. 1975 Jones and Irwin 1975	The same assumption as for V_7 applies to green sunfish fry.
V_9	Swingle 1952 Lawrence 1957 Salyer 1958 Hunter 1963 Pflieger 1963 Kaya and Hasler 1972 Kaya 1973a,b	Optimal temperature for embryonic development are those at which survival is highest. Temperatures that result in little or no survival are unsuitable.
V_{10}	Hankinson 1919 Hunter 1963	The substrate within which the greatest survival of eggs takes place is considered optimum.
V_{11}	Gerking 1945 Minckley 1963 Harlan and Speaker 1969 Jones 1970 Moyle and Nichols 1973 Kallemyn and Novotny 1977 Hardin and Bovee 1978	Velocities that are commonly inhabitated by green sunfish are optimal.
V_{12}	Hardin and Bovee 1978	Low velocities during spawning increase the survival of eggs. Higher velocities (> 15 cm/sec) are unsuitable because survival is very low.
V_{13}	Kallemyn and Novotny 1977 Hardin and Bovee 1978	The same assumption as for V_{11} applies to fry and juvenile green sunfish.
V_{14}	Trautman 1957 Minckley 1963 Cross 1967 Moyle and Nichols 1973	The size of stream commonly inhabitated by green sunfish is the optimum.

Table 1. (concluded).

Variable and Source		Assumption
V_{15}	Jenkins 1976	Total dissolved solids (TDS) levels correlated with high standing crops of sportfish are optimum; levels correlated with lower standing crops are suboptimum. The data used to develop this curve are primarily from southeastern reservoirs.
V_{16}	Moyle and Nichols 1973	The average percent of bottom covered by rooted vegetation where green sunfish were collected (35%) is the optimal percent. The optimal percent of littoral area is that percent that can result in 35% of the bottom of total lake covered by vegetation, when there is 80% cover in any given area.
V_{17}	Hunter 1963 Carson 1968	Stable water levels during spawning ensure optimal survival of eggs. Decreasing water levels are suboptimal to unsuitable.
V_{18}	Kilby 1955 (BG) Tebo and McCoy 1964 (BG)	Salinity levels where green sunfish are most abundant are optimal. Levels that reduce growth are suboptimal to unsuitable.

Key: BG - bluegill data; other citations are green sunfish data.

Sample data sets from which HSI's have been generated using the riverine HSI equations are in Table 2. Similar sets using the lacustrine HSI equations are in Table 3. These data sets are not actual field measurements, but represent combinations of variable values that could occur in a riverine or lacustrine habitat. The HSI's calculated from the data rank the sites in the order that we believe represents the carrying capacity in riverine and lacustrine habitats with the listed characteristics. The relationship of the model-generated index to other indices of carrying capacity, such as production or standing crop, is unknown.

Table 2. Sample data sets using riverine HSI model.

Variable		Data set 1 Data	SI	Data set 2 Data	SI	Data set 3 Data	SI
% bottom cover	V_1	4	0.3	12	0.5	50	1.0
% pool area	V_2	20	0.2	30	0.5	50	1.0
Stream gradient (m/km)	V_3	9	0.0	1.0 m/km	1.0	0.6	1.0
Dissolved O_2 (mg/l)	V_4	7.2	1.0	6.0	1.0	4.5	0.7
Maximum turbidity (JTU)	V_5	10	0.7	75	1.0	10	0.7
pH range	V_6	7.0-7.4	1.0	7.9-8.2	1.0	7.5-7.8	1.0
Maximum temperature (° C) (adult, juvenile)	V_7	17	0.3	25	0.9	27	1.0
Maximum temperature (° C) (fry)	V_8	16	0.7	24	1.0	27	0.9
Maximum temperature (° C) (embryo)	V_9	13	0.0	21	1.0	24	1.0
Substrate composition	V_{10}	Cobble	0.4	Silt, sand	0.8	Gravel, sand	1.0
Average current velocity (cm/sec) (adult, juvenile)	V_{11}	22	0.2	6	1.0	5	1.0
Average current velocity (cm/sec) (embryo)	V_{12}	20	0.0	6	1.0	8	1.0
Average current velocity (cm/sec) (fry)	V_{13}	20	0.0	6	0.6	5	1.0

Table 2 (concluded).

Variable		Data set 1		Data set 2		Data set 3	
		Data	SI	Data	SI	Data	SI
Average stream width (m)	V_{14}	15	1.0	50	0.6	20	1.0
Maximum salinity (ppt)	V_{18}	1.0	1.0	4.5	0.6	1.5	1.0
<u>Component SI</u>							
$C_{F,C}$ =			0.24		0.50		1.00
C_{WQ} =			0.30[a]		0.93		0.83
C_R =			0.00		0.93		1.00
C_{OT} =			0.24		0.84		1.00
HSI =			0.00		0.78		0.95

[a] $C_{WQ} = 0.30$ because $V_7 = 0.30$

Table 3. Sample data sets using lacustrine HSI model.

Variable		Data set 1		Data set 2		Data set 3	
		Data	SI	Data	SI	Data	SI
% bottom cover	V_1	5	0.3	0	0.2	70	1.0
Dissolved O_2 (mg/l)	V_4	5.4	1.0	5.5	1.0	6.5	1.0
Maximum turbidity (JTU)	V_5	5	0.6	50	1.0	25	1.0
pH range	V_6	5.9-6.8	0.7	7.8-8.9	0.7	7.0-7.8	1.0
Maximum temperature (° C) (adult, juvenile)	V_7	24	0.8	27	1.0	26	1.0
Maximum temperature (°C) (fry)	V_8	24	1.0	27	0.9	26	1.0
Maximum temperature (° C) (embryo)	V_9	19.5	0.5	24	1.0	23	1.0
Substrate composition	V_{10}	Cobble	0.4	Silt, sand	0.8	Silt, sand	0.8
Average TDS (ppm)	V_{15}	30	0.2	800	0.4	150	1.0
% littoral area	V_{16}	21	0.6	31	0.8	50	1.0
Reservoir drawdown (m) (embryo)	V_{17}	0.8	0.3	0.6	0.6	--	--
Maximum salinity (ppt)	V_{18}	1.0	1.0	5.2	0.2	2.5	1.0
Component SI							
C_F =			0.20		0.40		1.00
C_C =			0.42		0.40		1.00
C_{WQ} =			0.85		0.83		1.00
C_R =			0.39		0.78		0.89
HSI =			0.39[a]		0.57		0.97

[a]HSI = 0.39 because C_R = 0.39

Interpreting Model Outputs

The green sunfish HSI determined by use of these models will not necessarily represent the population of green sunfish in the study area. Habitats with an HSI of 0 may contain some green sunfish; habitats with a high HSI may contain few. This is because the population of a study area of a stream does not totally depend on the ability of that area to meet all life requisite requirements of the species, as is assumed by the model. Models which are good representations of green sunfish habitat should be positively correlated to the long term average population levels in riverine and lacustrine environments where green sunfish population levels are due primarily to habitat related factors. However, this assumption has not been tested. The proper interpretation of the HSI is one of comparison. If two riverine or lacustrine habitats have different HSI's, the one with the higher HSI should have the potential to support more green sunfish than the one with the lower HSI, given that the model assumptions have not been violated.

ADDITIONAL HABITAT SUITABILITY INDEX MODELS

Model 1

Optimal riverine habitat for green sunfish is characterized by the following conditions, assuming that water quality is adequate: warm (> 20° C), stable summer water temperatures; sand and small gravel substrate in at least 50% of the stream; at least 50% of surface area in pools at average summer flow; at least 50% of the stream surface area has instream cover (such as vegetation, logs, or debris); and current velocities are < 10 cm/sec at average summer flow.

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

Model 2

Optimal lacustrine habitat for green sunfish is characterized by the following conditions, assuming that water quality is adequate: warm (> 20° C), stable summer water temperatures; fertile lakes, reservoirs, and ponds (TDS levels of 100 to 350 ppm); extensive littoral areas (≥ 20% of surface area); and moderate turbidities (25 to 100 JTU).

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

Model 3

The regression models for sunfish standing crop in reservoirs presented by Aggus and Morais (1979) can used to calculate the HSI.

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50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. FWS/OBS-82/10.15	2.	3. Recipient's Accession No.

4. Title and Subtitle
Habitat Suitability Index Models: Green sunfish

5. Report Date July 1982

6.

7. Author(s)
Robert J. Stuber, Glen Gebhart and O. Eugene Maughan

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Habitat Evaluation Procedures Group
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Fort Collins, Colorado 80526

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C)
(G)

12. Sponsoring Organization Name and Address
Western Energy and Land Use Team
Office of Biological Services
Fish and Wildlife Service
U.S. Department of the Interior
Washington, DC 20240

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This is one of a series of publications that provide information on the habitat requirements of selected fish and wildlife species. Literature describing the relationship between habitat variables related to life requisites and habitat suitability for the Green sunfish (Lepomis cyanellus) are synthesized. These data are subsequently used to develop Habitat Suitability (HSI) models. The HSI models are designed to provide information that can be used in impact assessment and habitat management.

17. Document Analysis a. Descriptors

Animal behavior
Animal ecology
Fishes
Habitability
Mathematical models

b. Identifiers/Open-Ended Terms

Green sunfish
Lepomis cyanellus
Habitat suitability
Habitat preference
Habitat management
Habitat Suitability Index models
Habitat requirements
Species-habitat relationships
Impact assessment

c. COSATI Field/Group

18. Availability Statement
RELEASE UNLIMITED

19. Security Class (This Report) UNCLASSIFIED

20. Security Class (This Page) UNCLASSIFIED

21. No. of Pages ii - v + 28 pp

22. Price

(See ANSI-Z39.18)

See Instructions on Reverse

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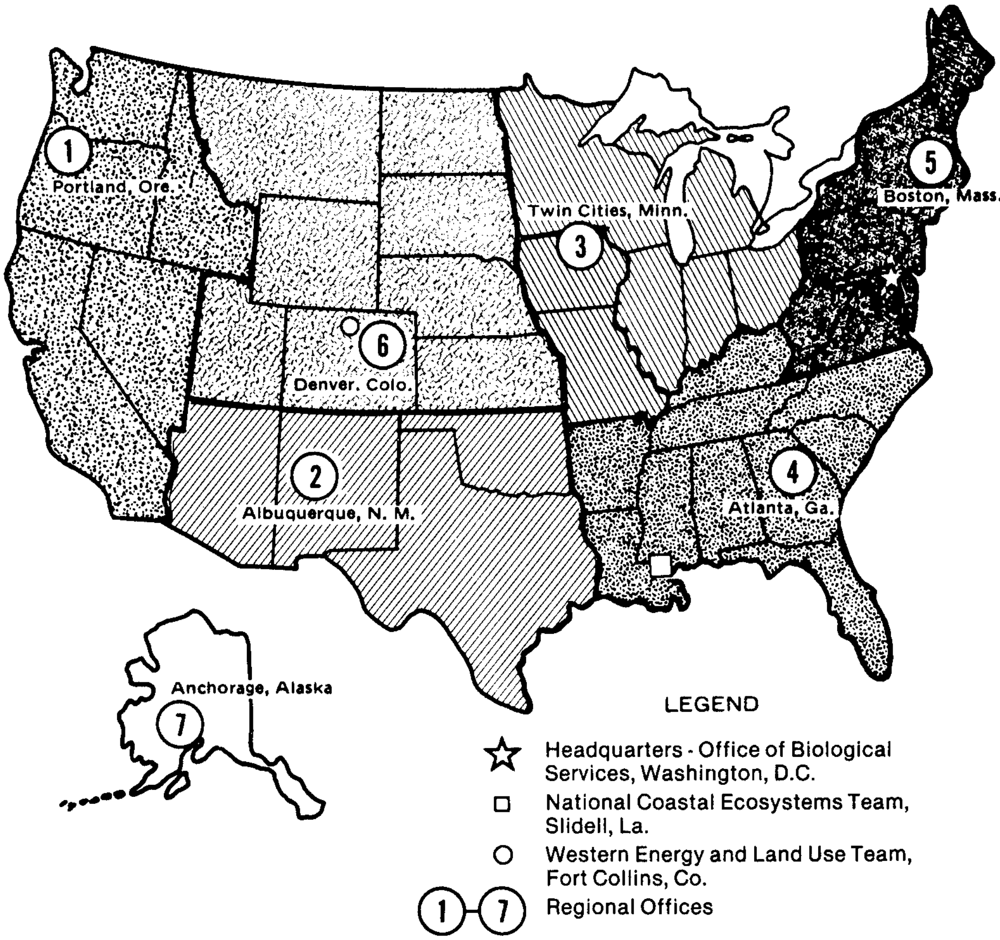

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Federal Correctional Institution, Ray Brook, NY