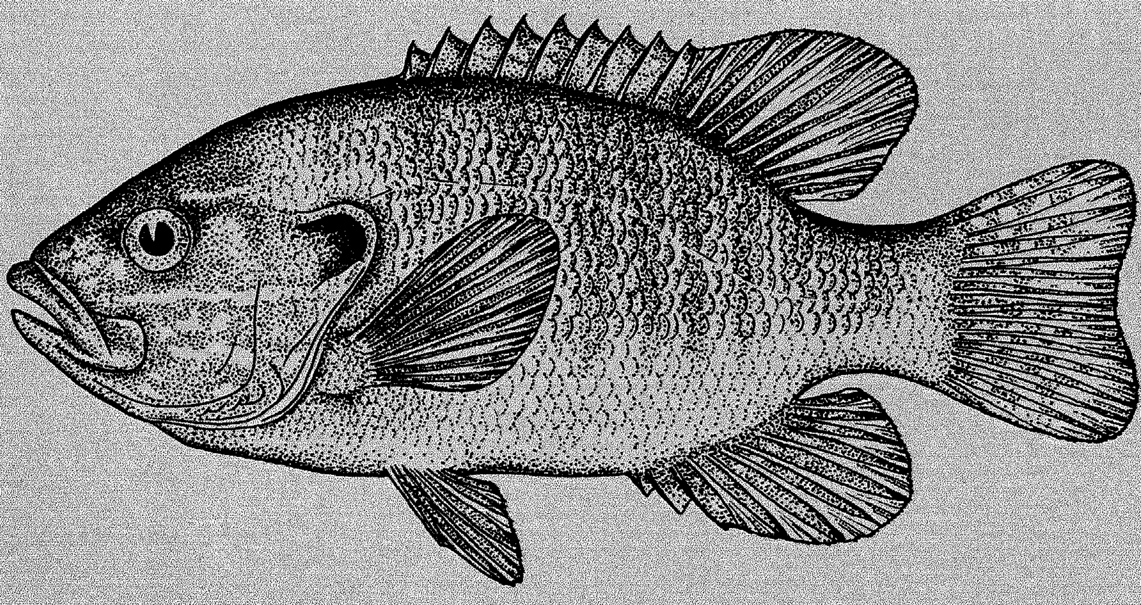
Biological Services Program
and
Division of Ecological Services

FWS/OBS-82/10.15
JULY 1982

HABITAT SUITABILITY INDEX MODELS: GREEN SUNFISH



Fish and Wildlife Service

U.S. Department of the Interior

FWS/OBS-82/10.15
July 1982

HABITAT SUITABILITY INDEX MODELS: GREEN SUNFISH

by

Robert J. Stuber
Habitat Evaluation Procedures Group
Western Energy and Land Use Team
U.S. Fish and Wildlife Service
Drake Creekside Building One
2625 Redwing Road
Fort Collins, CO 80526

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

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

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 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 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 can 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.

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

The HSI models presented herein are complex hypotheses of species-habitat relationships, not statements of proven cause and effect relationships. Results of model performance tests, when available, are referenced; however, models that have demonstrated reliability in specific situations may prove unreliable in others. For this reason, the FWS encourages model users to send comments and suggestions that might help us increase the utility and effectiveness of this habitat-based approach to fish and wildlife planning. Please send comments to:

Habitat Evaluation Procedures
Western Energy and Land Use Team
U.S. Fish and Wildlife Service
2625 Redwing Road
Ft. Collins, CO 80526

---

[1]Terrell, J. W., T. E. McMahon, P. D. Inskip, R. F. Raleigh, and K. W. Williamson (in press). Habitat Suitability Index models: Appendix A. Guidelines for riverine and lacustrine applications of fish HSI models with the Habitat Evaluation Procedures. U.S. Fish and Wildl. Serv. FWS/OBS 82/10.A.

[2]U.S. Fish and Wildlife Service. 1981. Standards for the development of Habitat Suitability Index models. 103 ESM. U.S. Fish and Wildl. Serv. Div. Ecol. Serv. n.p.

CONTENTS

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 ($\leq$ 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.

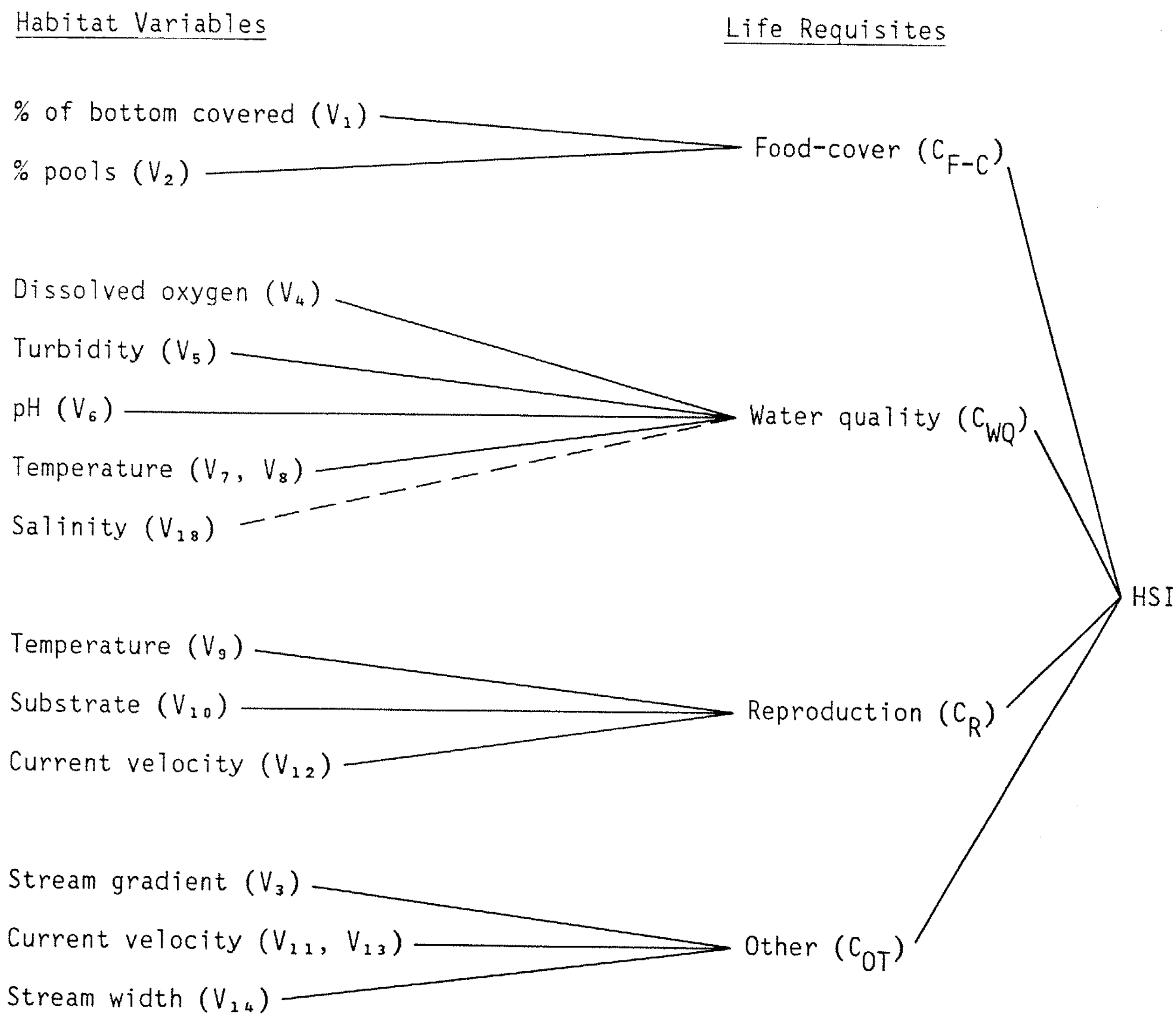


Figure 1. Tree diagram illustrating relationship of habitat variables and life requisites in the riverine model for green sunfish. The dashed line indicates an optional variable.

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.

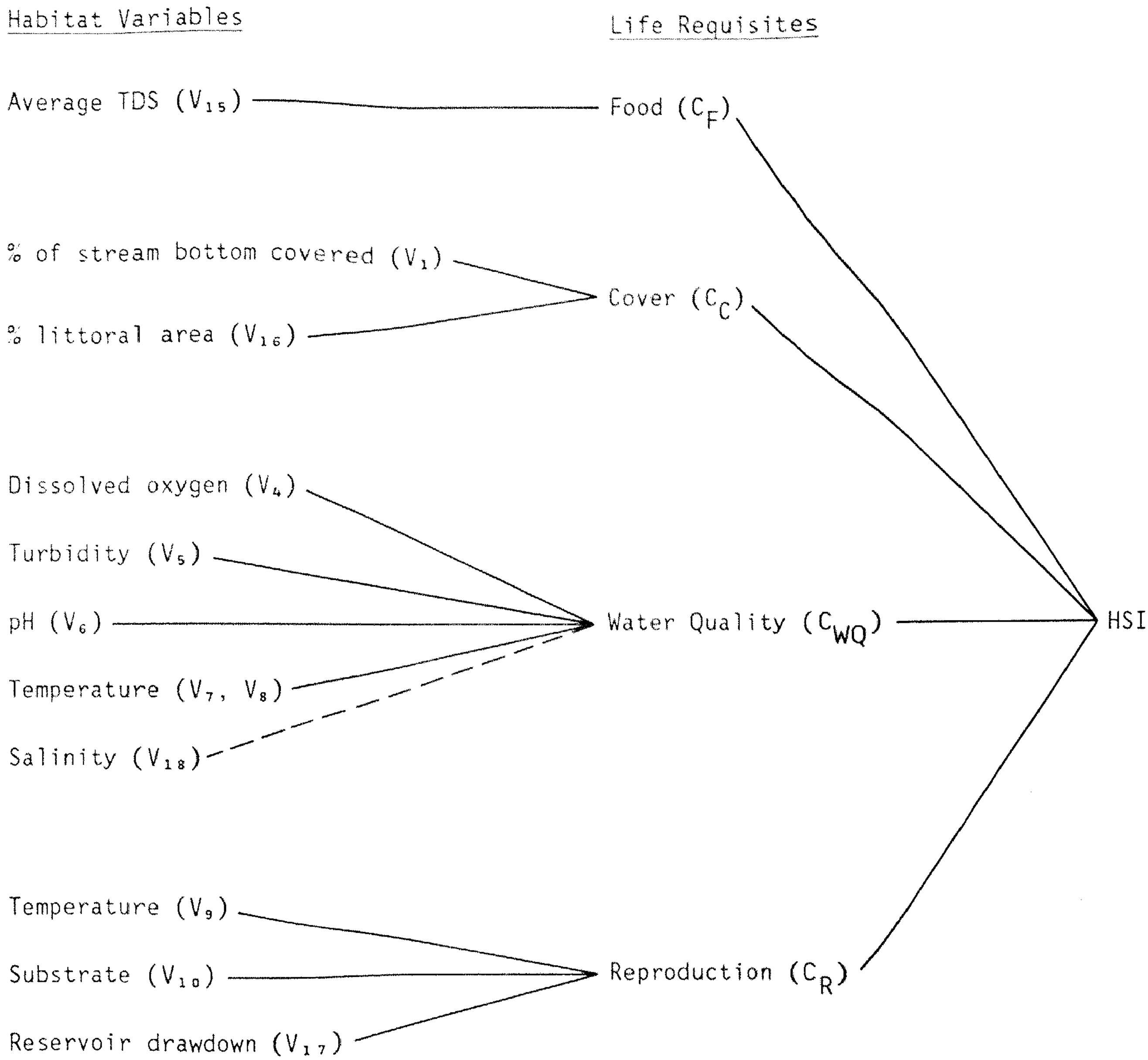
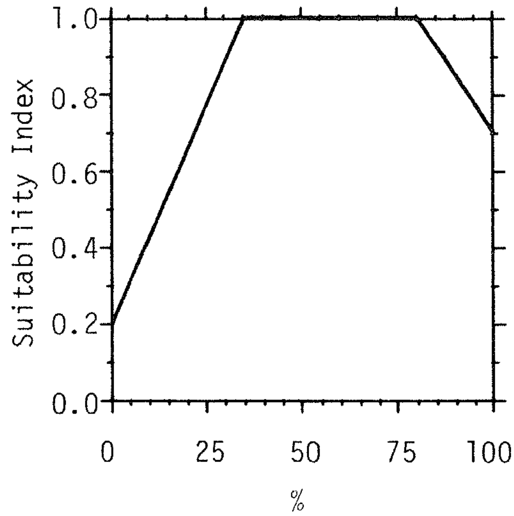
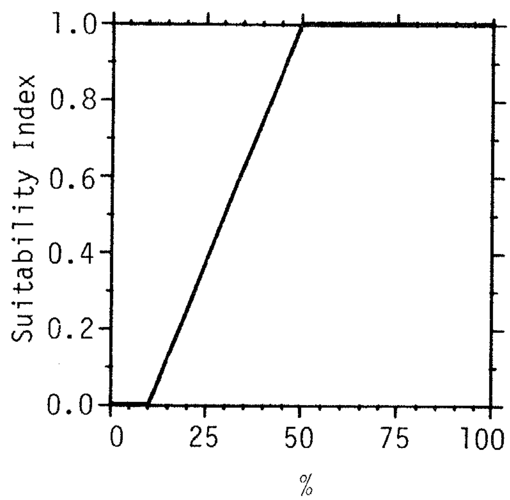
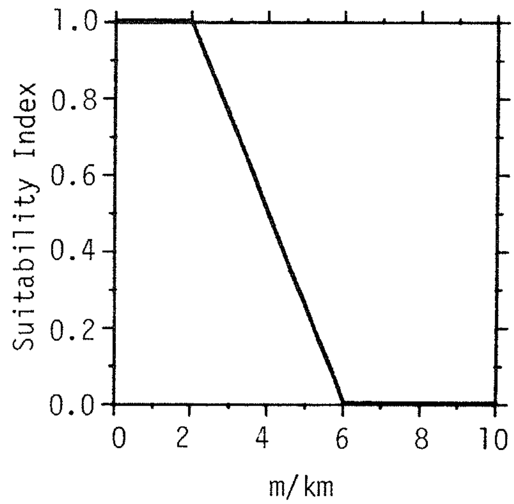


Figure 2. Tree diagram illustrating relationship of habitat variables and life requisites in the lacustrine model for green sunfish. The dashed line indicates an optional variable.

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.	

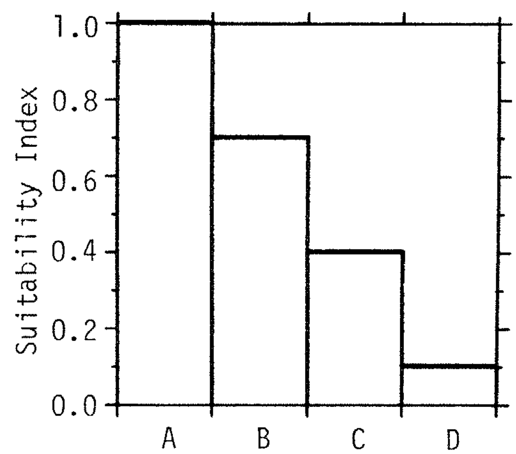
R V_3 Stream gradient within representative reach.



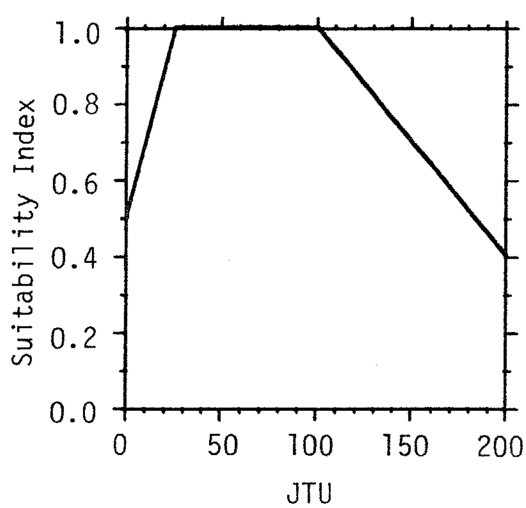
R,L V_4 Minimum dissolved oxygen levels during summer.

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.

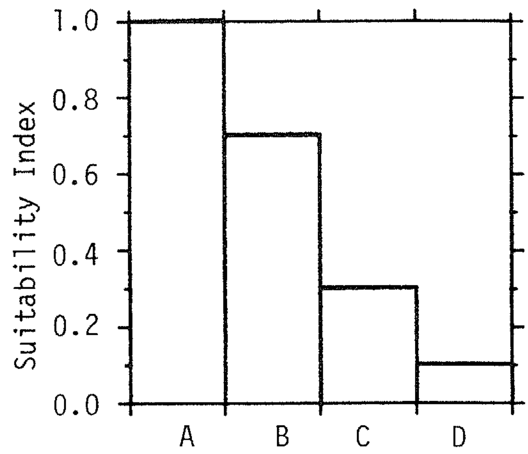


R,L V_5 Maximum monthly average turbidity within pools or littoral areas during the summer.

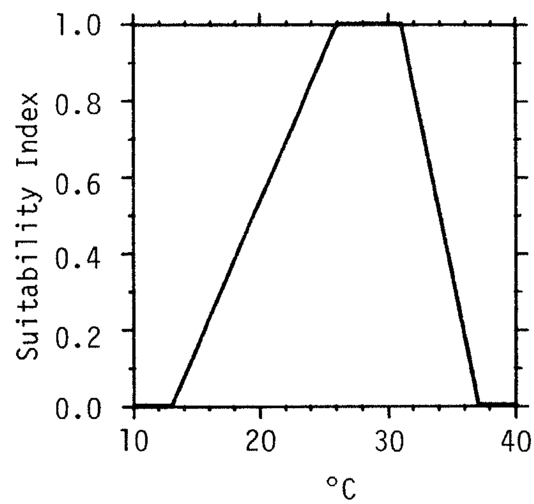


R,L V_6 pH range during summer growing season.

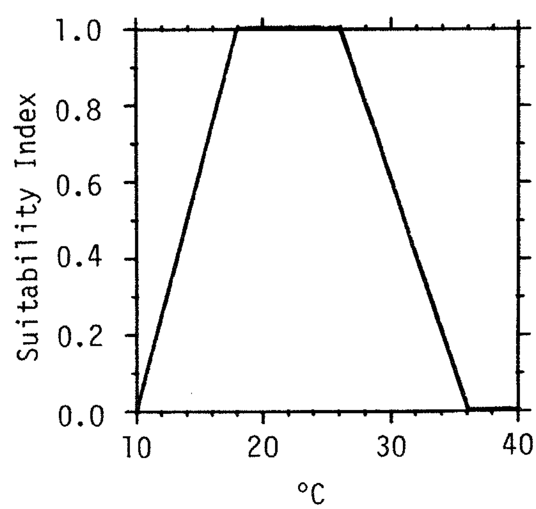
A) 6.5-8.5
B) 5.0-6.5 or 8.5-9.0
C) 4.0-5.0 or 9.0-10.0
D) < 4.0 or > 10.0



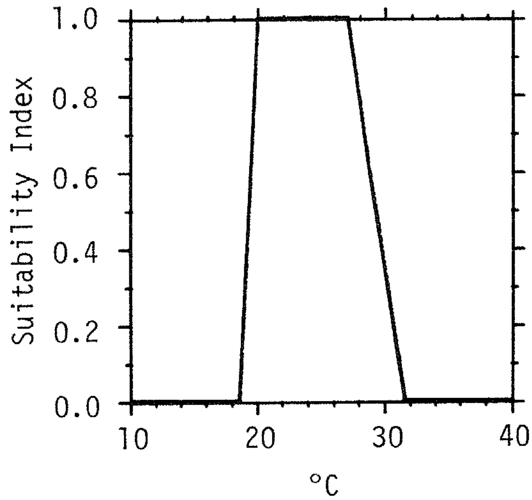
R,L V_7 Maximum midsummer temperature within pools or littoral areas (Adult, Juvenile).



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

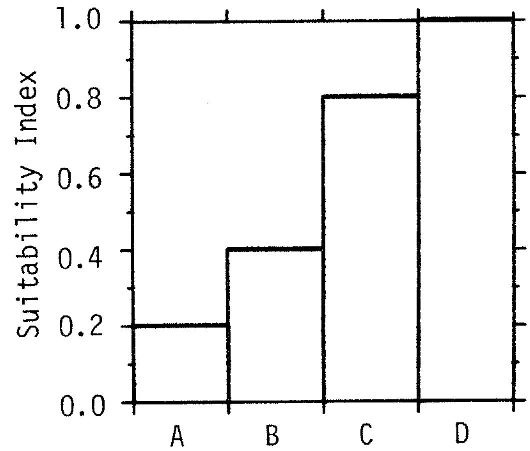


R,L V_9 Maximum temperature within pools or littoral areas during spawning (June-July) (Embryo).

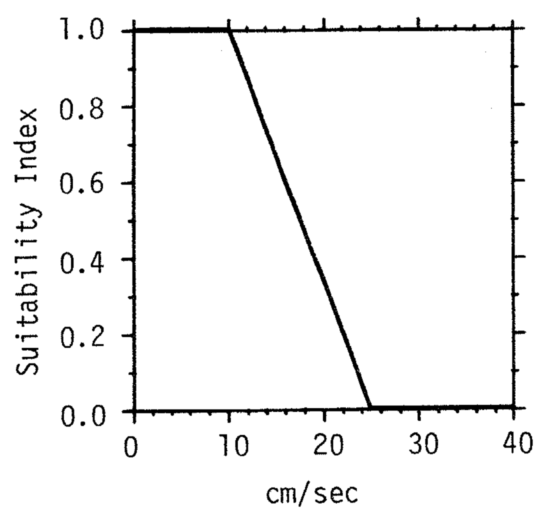


R,L V_{10} Substrate composition within pools or littoral areas for spawning (Embryo).

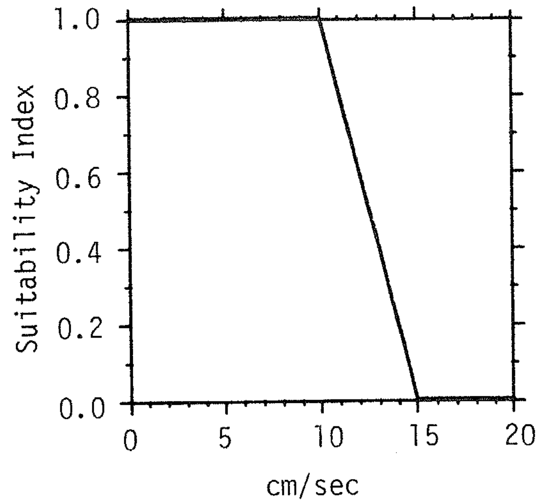
A) Boulder (> 20 cm) and bedrock predominate (≥ 50%).
B) Cobble (5-20 cm) predominates.
C) Silt and sand (≤ 0.2 cm) predominate.
D) Pebbles and gravel (0.2-5.0 cm) predominate.



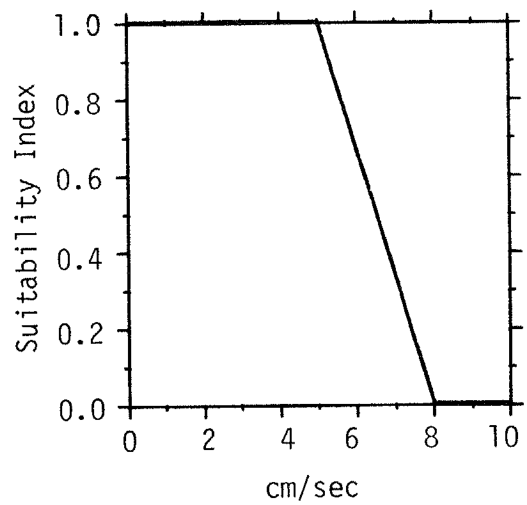
R V_{11} Average current velocity within pools during average summer flow (Adult, Juvenile).



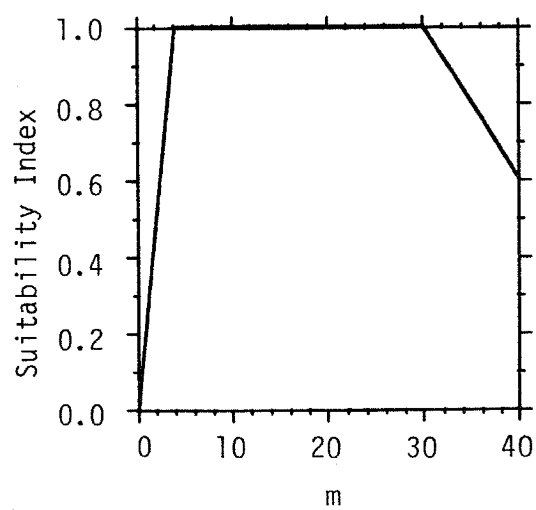
R V_{12} Average current velocity within pools during spawning (June-July) (Embryo).

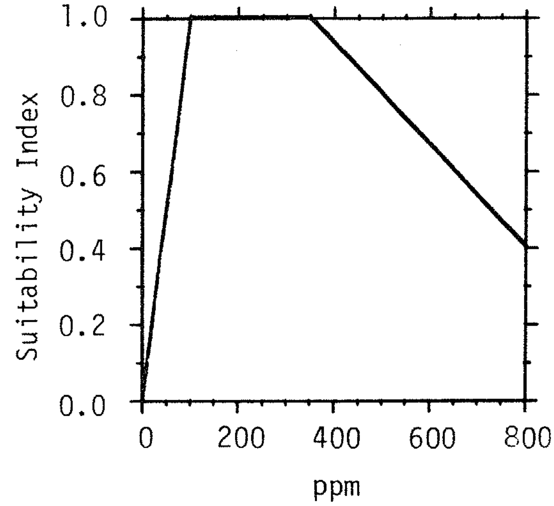
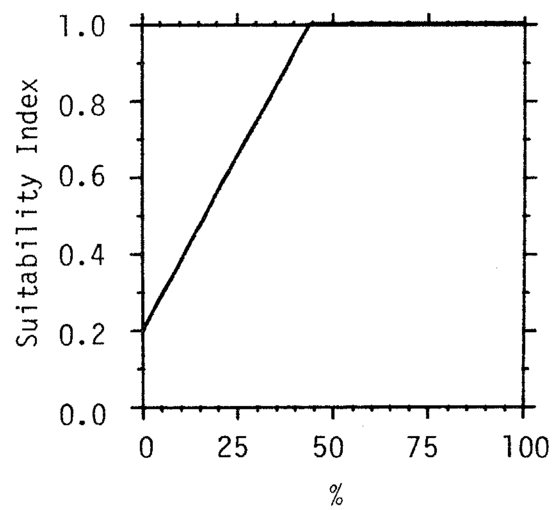
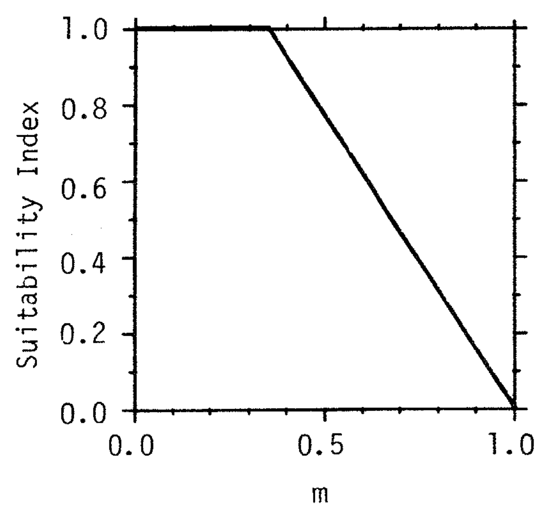


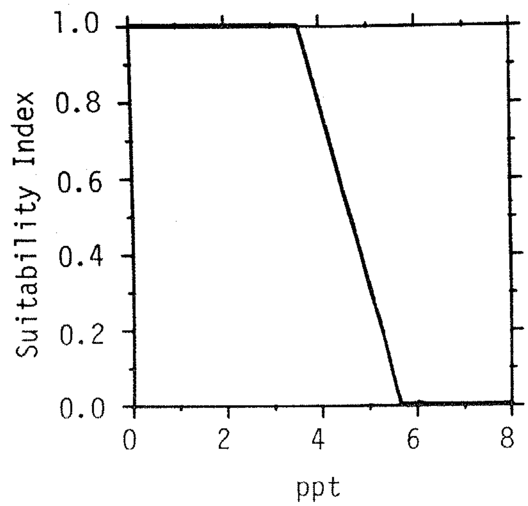
R V_{13} Average current velocity within pools during average summer flow (Fry).



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,

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

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}).

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

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,

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

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 ($\leq$ 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 set 2		Data set 3	
		Data	SI	Data	SI	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}	19	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	SI	Data set 2 Data	SI	Data set 3 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.

REFERENCES

Aggus, L. R., and D. I. Morais. 1979. Habitat suitability index equations for reservoirs based on standing crop of fish. Natl. Reservoir Res. Proj., Rep. to U.S. Dept. Int. Fish Wildl. Serv. Hab. Eval. Program, Ft. Collins, Colorado. 120 pp.

Applegate, R. L, J. W. Mullan, and D. I. Morais. 1976. Food and growth of six centrarchids from shoreline areas of Bull Shoals Reservoir. Proc. Southeastern Assoc. Game and Fish Commissioners 20:469-482.

Banner, A. and J. A. Van Arman. 1972. Thermal effects on eggs, larvae, and juveniles of bluegill sunfish. U.S. Environmental Protection Agency, Duluth, MN. Report EPA-R3-73-041.

Beitinger, T. L., J. J. Magnuson, W. H. Neill, and W. R. Shaffer. 1975. Behavioral thermoregulation and activity patterns in the green sunfish, Lepomis cyanellus. Anim. Behav. 23:222-229.

Biggins, R. G., and C. D. Ziebell. 1967. Feeding patterns of four common centrarchid fishes. Arizona Coop. Fish. Res. Unit, Res. Rep. Ser. 67-1. 19 pp.

Brown, E. H., Jr. 1960. Little Miami River headwater-stream investigations. Ohio Dept. Nat. Resour. Columbus, OH. 143 pp.

Calabrese, A. 1969. Effects of acids and alkalies on survival of bluegills and largemouth bass. U.S. Dept. Int. Bur. Sport Fish. Wildl., Tech. Pap. 42:2-10.

Carlander, K. D. 1977. Handbook of freshwater fishery biology, Vol. 2. Iowa State Univ. Press, Ames. 431 pp.

Carson, J. B. 1968. The green sunfish. Underwater Nat. 5(1):29. (Cited by Carlander 1977).

Cherry, D. S., K. L. Dickson, and J. Cairns, Jr. 1975. Temperatures selected and avoided by fish at various acclimation temperatures. J. Fish. Res. Board Can. 32:484-491.

Childers, W. F. 1967. Hybridization of four species of sunfishes (Centrarchidae). Ill. Nat. Hist. Surv. Bull. 29:159-214.

Cross, F. 1951. Early limnological and fish population conditions of Canton Reservoir, Oklahoma, with special reference to carp, channel catfish, largemouth bass, green sunfish and bluegill and fishery management recommendations. Ph.D. Thesis. Oklahoma Agric. Mech. Coll., Stillwater, OK. 92 pp.

_____________. 1954. Fishes of Cedar Creek and the South Fork of the Cottonwood River, Chase County, Kansas. Trans. Kans. Acad. Sci. 57:303-314.

_____________. 1967. Handbook of fishes of Kansas. Univ. Kansas Mus. Nat. Hist. Misc. Publ. 45. 357 pp.

Coutant, C. C. 1977. Compilation of temperature preference data. J. Fish. Res. Board Can. 34(5):739-746.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Dept. Int. Fish Wildl. Serv., FWS/OBS-79/31. 103 pp.

Durham, L. 1957. Green sunfish, bluegill, largemouth bass. Summaries for Handb. Biol. Data. 20 pp. (Cited by Carlander 1977).

Eddy, S. 1957. How to know the freshwater fishes. Wm. C. Brown Co. Dubuque, IA. 253 pp.

Etnier, D. A. 1971. Food of three species of sunfishes (Lepomis, Centrarchidae) and their hybrids in three Minnesota lakes. Trans. Am. Fish. Soc. 100:124-128.

Finnell, J. C. 1955. Growth of fishes in cutoff lakes and streams of the Little River System, McCurtain County, Oklahoma. Proc. Oklahoma Acad. Sci. 36:61-66.

Forshage, A., and N. E. Carter. 1974. Effects of gravel dredging on the Brazos River. Proc. Southeastern Assoc. Game and Fish Commissioners 27:695-709.

Funk, J. L. 1975a. The fishery of Black River, Missouri, 1947-1957. Missouri Dept. Conserv. Aquatic Ser. 12. 22 pp.

_______________. 1975b. The fishery of Gasconade River, Missouri, 1947-1957. Missouri Dept. Conserv. Aquatic Ser. 13. 26 pp.

Gerking, S. D. 1945. The distribution of the fishes of Indiana. Invest. Indiana Lakes Streams 3(1):1-137.

Hankinson, T. L. 1919. Notes of life histories of Illinois fish. Trans. Illinois Acad. Sci. 12:132-150.

Hardin, T., and K. Bovee. 1978. The green sunfish. U.S. Dept. Int. Fish Wildl. Serv., Instream Flow Group, Fort Collins, CO. Unpublished data.

Harlan, J. R., and E. B. Speaker. 1969. Iowa fish and fishing. Iowa Conserv. Comm., Des Moines, IA. 365 pp.

Hoffman, J. M. 1955. Age and growth of the green sunfish, Lepomis cyanellus Rafinesque, in the Niangua Arm of the Lake of the Ozarks. M.S. Thesis. Univ. Missouri, Columbia, MO.

Hubbs, C. L., and G. P. Cooper. 1935. Age and growth of the longeared and the green sunfishes in Michigan. Pap. Michigan Acad. Sci. Arts Lett. 20:669-696.

Hunter, J. R. 1963. The reproductive behavior of the green sunfish, Lepomis cyanellus. Zoologica 48:13-24.

Jenkins, R. M. 1976. Prediction of fish production in Oklahoma reservoirs on the basis of environmental variables. Ann. Oklahoma Acad. Sc. 5:11-20.

Jenkins, R. M., and J. C. Finnell. 1957. The fishery resources of the Verdigris River in Oklahoma. Oklahoma Fish. Res. Lab. Rep. 59. 46 pp.

Jones, A. R. 1970. Inventory and classification of streams in the Licking River drainage. Kentucky Fish Bull. 53. 62 pp.

Jones, T. C., and W. H. Irwin. 1975. Temperature preferences by two species of fish and the influence of temperature on fish distribution. Proc. Southeastern Assoc. Game and Fish Commissioners 16:323-333.

Jude, D. J. 1973. Sublethal effects of ammonia and cadmium on growth of green sunfish. Ph.D. Thesis, Michigan State University, East Lansing, MI. 193 pp.

Kallemyn, L. W., and J. F. Novotny. 1977. Fish and fish food organisms in various habitats of the Missouri River in South Dakota, Nebraska, and Iowa. U.S. Dept. Int. Fish Wildl. Serv. FWS/OBS-77/25. 100 pp.

Kaya, C. M. 1973a. Effects of temperature and photoperiod on seasonal regression of gonads of green sunfish, Lepomis cyanellus. Copeia 1973:369-373.

____________. 1973b. Effects of temperature on responses of the gonads of green sunfish (Lepomis cyanellus) to treatment with carp pituitaries and testosterone proprionate. J. Fish. Res. Board Can. 30:905-912.

Kaya, C. M., and A. D. Hasler. 1972. Photoperiod and temperature effects on the gonads of green sunfish, Lepomis cyanellus (Rafinesque), during the quiescent, winter phase of its annual sexual cycle. Trans. Am. Fish. Soc. 101:270-275.

Kilby, J. D. 1955. The fishes of two gulf coast marsh areas of Florida. Tulane Stud. Zool. 2:175-247.

Lawrence, J. M. 1957. Life history and ecology of centrarchid fishes. Data for Handbook Biol. Data. 9 pp.

Maupin, J. K., J. R. Wells, Jr., and C. Leist. 1954. A preliminary survey of food habits of the fish and physico-chemical conditions of three stripmine lakes. Trans. Kans. Acad. Sci. 57:164-171.

McDonald, D. B., and P. A. Dotson. 1960. Fishery investigations of the Glen Canyon and Flaming Gorge impoundment areas. Utah Dept. Fish Game Inf. Bull. 60-63. 70 pp.

McKechnie, R. J., and R. C. Tharratt. 1966. Green sunfish. Pages 399-401 in A. Calhoun, ed. Inland fisheries management. California Dept. Fish Game.

Minckley, W. L. 1963. The ecology of a spring stream, Doe Run, Meade County, Kentucky. Wildl. Monog. 11. 124 pp.

Moore, W. G. 1942. Field studies on the oxygen requirements of certain fresh-water fishes. Ecology 23:319-329.

Moyle, P. B., and R. D. Nichols. 1973. Ecology of some native and introduced fishes of the Sierra Nevada foothills in central California. Copeia 1973:478-490.

Mullan, J. W., and R. L. Applegate. 1968. Centrarchid food habits in a new and old reservoir during and following bass spawning. Proc. Southeastern Assoc. Game and Fish Commissioners 21:332-342.

Mullan, J. W., and R. L. Applegate. 1970. Food habits of five centrarchids during filling of Beaver Reservoir, 1965-66. U.S. Bur. Sport Fish Wildl. Tech. Paper 50. 16 pp.

Petit, G. D. 1973. Effects of dissolved oxygen on survival and behavior of selected fishes of western Lake Erie. Ohio Biol. Surv. Bull. 4(4):1-76.

Pflieger, W. L. 1963. Spawning and survival of smallmouth bass and associated species in small Ozark streams. Missouri Dept. Conserv., D-J Proj. F-1-R-12, Plan 10, Job 2. 21 pp.

Proffitt, M. A., and R. S. Benda. 1971. Growth and movement of fishes, and distribution on invertebrates, related to a heated discharge into the White River at Petersburg, Indiana. Indiana Univ. Water Resour. Dept. Invest. 5., Bloomington, IN. 94 pp.

Purkett, C. A., Jr. 1958. Growth rates of Missouri stream fishes. Final Rep., Fed. Aid to Fish Restoration Proj. F-1-R. Ser. 1. 46 pp.

Raney, E. C. 1965. Some pan fishes of New York--rock bass, crappies and other sunfishes. New York State Conserv. Dept. Inf. Leafl. D-47:10-16.

Salyer, J. T. 1958. Factors associated with the decline of the largemouth bass, Micropterus salmoides (Lacepede), in San Vicente Reservoir, San Diego County, California. M.A. Thesis, San Diego State Coll. San Diego, CA. 103 pp. (Cited by Carlander 1977).

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

Siewert, H. F. 1973. Thermal effects on biological production in nutrient rich ponds. Univ. Wisc. Water Resour. Cent. Tech. Compl. Rep. A-020 and A-032. 23 pp. (Cited by Carlander 1977).

Sigler, W. F., and R. R. Miller. 1963. Fishes of Utah. Utah State Dept. Fish Game. 203 pp. (Cited by McKechnie and Tharratt 1966).

Sprugel, G., Jr. 1955. The growth of green sunfish (Lepomis cyanellus) in Little Wall Lake, Iowa. Iowa State Coll. J. Sci. 29:707-719.

Stroud, R. H. 1967. Water quality criteria to protect aquatic life: a summary. Am. Fish. Soc. Spec. Publ. 4:33-37.

Summerfelt, R. C. 1967. Fishes of the Smokey Hill River, Kansas. Trans. Kansas Acad. Sci. 70:102-139.

Swingle, H. S. 1952. Pounds of fish per acre in central Alabama power reservoirs. Pounds of fish per acre in Alabama rivers. Temperatures of surface water of ponds at Auburn, Alabama when the first young fish hatch in the spring. Data for Handbook Biol. Data. (Cited by Carlander 1977).

Tebo, L. B., and E. G. McCoy. 1964. Effects of seawater concentration on the reproduction of largemouth bass and bluegills. Prog. Fish-Cult. 26(3):99-106.

Trama, F. 1954. The pH tolerance of the common bluegill (Lepomis macrochirus Rafinesque). Notulae Nat. 256:1-13.

Trautman, M. B. 1957. The fishes of Ohio. Ohio State Univ. Press., Columbus, OH. 683 pp.

Ultsch, G. R. 1978. Oxygen consumption as a function of pH in three species of freshwater fishes. Copeia 1978:272-279.

Wright, Y. E. 1951. Age and growth of the green sunfish, Lepomis cyanellus Rafinesque, in northern Utah. M.S. Thesis, Utah State Agric. Coll., Logan, UT. 22 pp. (Cited by Carlander 1977).

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
Western Energy and Land Use Team
U.S. Fish and Wildlife Service
Drake Creekside Building One
2625 Redwing Road
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

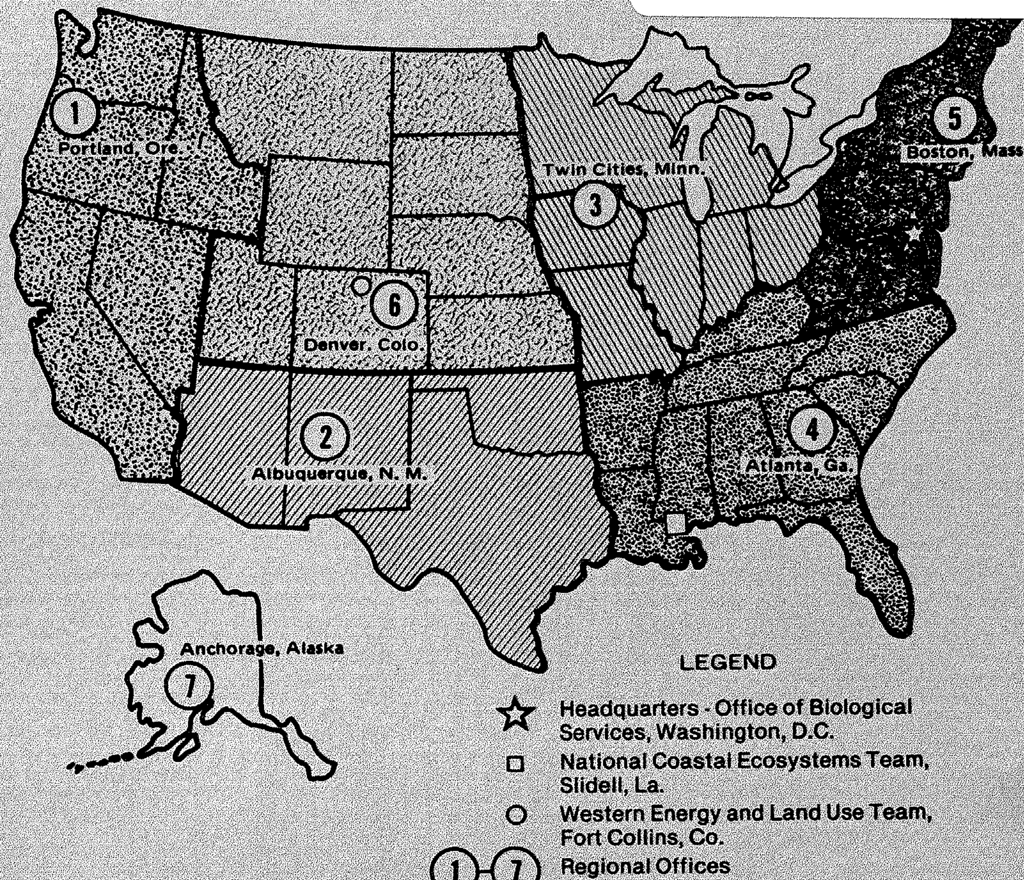
22. Price

(See ANSI-Z39.18)

See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

U.S. GOVERNMENT PRINTING OFFICE: 1982-580-610/410



U.S. FISH AND WILDLIFE SERVICE REGIONAL OFFICES

REGION 1
Regional Director
U.S. Fish and Wildlife Service
Lloyd Five Hundred Building, Suite 1692
500 N.E. Multnomah Street
Portland, Oregon 97232

REGION 2
Regional Director
U.S. Fish and Wildlife Service
P.O. Box 1306
Albuquerque, New Mexico 87103

REGION 3
Regional Director
U.S. Fish and Wildlife Service
Federal Building, Fort Snelling
Twin Cities, Minnesota 55111

REGION 4
Regional Director
U.S. Fish and Wildlife Service
Richard B. Russell Building
75 Spring Street, S.W.
Atlanta, Georgia 30303

REGION 5
Regional Director
U.S. Fish and Wildlife Service
One Gateway Center
Newton Corner, Massachusetts 02158

REGION 6
Regional Director
U.S. Fish and Wildlife Service
P.O. Box 25486
Denver Federal Center
Denver, Colorado 80225

REGION 7
Regional Director
U.S. Fish and Wildlife Service
1011 E. Tudor Road
Anchorage, Alaska 99503

DEPARTMENT OF THE INTERIOR
U.S. FISH AND WILDLIFE SERVICE

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.