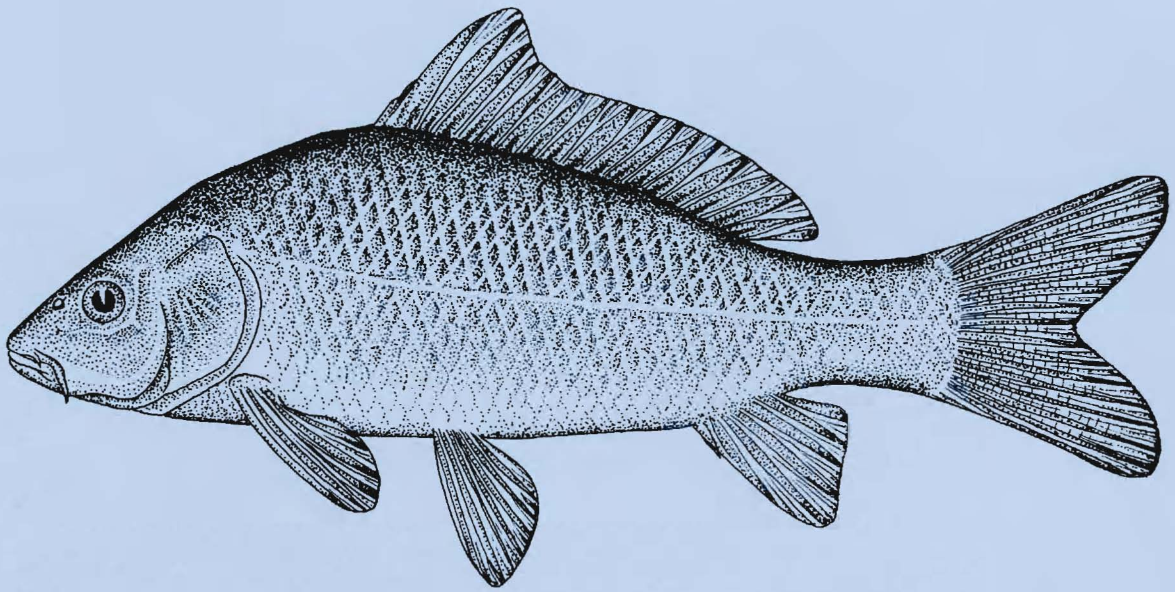
Biological Services Program
and
Division of Ecological Services

FWS/OBS-82/10.12
JULY 1982

HABITAT SUITABILITY INDEX MODELS: COMMON CARP



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.

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PREFACE

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

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 Appendix A. A description of various methods used to develop an HSI model is provided in U.S. Fish Wildlife Service (1981)[1].

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 U.S. Fish and Wildlife Service encourages model users to convey comments and suggestions that may help us increase the utility and effectiveness of this habitat-based approach to fish and wildlife planning. Please send comments to:

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U.S. Fish and Wildlife Service
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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. Dept. Int. Fish Wildl. Serv., Div. Ecol. Serv., Washington, DC. n.p.

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COMMON CARP (*Cyprinus carpio*)

HABITAT USE INFORMATION

General

The common carp (*Cyprinus carpio*) is a native of Asia. It is now found on every continent except Antarctica (Jester 1974) and in all 48 contiguous States (Sigler 1958). The northern limit to carp distribution appears to be the 18° C isotherm (Keleher 1956). The common carp hybridizes in nature with the goldfish (*Carassius auratus*) (Bardach et al. 1972; Smith 1979).

Age, Growth, and Food

Fast growing males may mature at age I (Bardach et al. 1972) but most mature at ages II to IV in temperate climates (Carlander 1969). Females generally mature between ages III and V (Carlander 1969). The maximum weight reported for an adult was 37.4 kg in South Africa (Sigler and Miller 1963) and 42.1 kg in North America (Jester 1974).

The adults are opportunistic feeders which are able to utilize any available food source (Moen 1953; Sigler 1958; Rehder 1959; Effendie 1968; Perry 1970; Sanchez 1970). Fry initially feed on zooplankton (Gill 1907; Alikunhi 1958; Filatov 1972; Persons 1979), but feed on phytoplankton when zooplankton density is low (Alikunhi 1958; Vaas and Vaas-van Oven 1959; Panov et al. 1973). As the young fish grow, they feed on littoral fauna and later on bottom fauna, taking in worms and larvae of aquatic insects as well as vegetable food, such as seeds, algae, and detritus (Vaas and Vaas-van Oven 1959).

Reproduction

The carp generally spawns in spring, but, in warmer, southern climates, spawning can occur from March to June, and, in cooler, northern climates, from May to June (McCrimmon 1968). Females with recently spent ovaries have been observed from March to October (Jester 1974), and ripe males have been observed during most of the summer months in the temperate zone (Swee and McCrimmon 1966; Sanchez 1970; Mauck and Summerfelt 1971; Padilla 1972). This indicates that the species may spawn over a prolonged period of time in warmer environments (McCrimmon 1968).

In reservoirs, rising water levels may provide access to terrestrial vegetation, which is good substrate for spawning (June 1977). In Lake Oahe, peak spawning occurred during the 4 or 5 days when water levels fluctuated only slightly (< 7 cm) or increased rapidly following a level period (June 1977). Fluctuating reservoir waters may be detrimental to carp populations (Benson 1977; June 1977).

Adults congregate and deposit their adhesive eggs on aquatic or submerged terrestrial vegetation or any other object the eggs will adhere to (Sigler 1958; McCrimmon 1968). Spawning over areas of dense vegetation will increase reproductive success (June 1977).

Specific Habitat Requirements

In both riverine and lacustrine habitats, carp prefer enriched, relatively shallow, warm, sluggish, and well-vegetated waters with a mud or silt substrate (Harlan and Speaker 1956; Sigler 1958; Swee and McCrimmon 1966; McCrimmon 1968; Pflieger 1975). Adults spend summer and early autumn in shallow areas of dense vegetation (May and Gloss 1979) and, as temperatures drop, the fish move into deeper waters for the winter (Adams and Hankinson 1928; Huntington and Hill 1956; Jester et al. 1969; Sanchez 1970; Jester 1974).

The species prefers areas of slow current. In the Missouri River, common carp occurred in pools and chutes (≤ 60 cm/sec) and in the main channel borders (60-120 cm/sec) (Schmulbach et al. 1975), but were most abundant in marshes and backwaters (≤ 20 cm/sec) (Kallemeyn and Novotny 1977). Deep pools with abundant cover, including logs, brush, and other objects, provide feeding and resting areas in swift rivers (Pflieger 1975). Although occasionally found in high gradient streams, the species is more common in low to moderate gradient streams. In high gradient streams, carp occur in warm backwaters and in organically polluted sections (Sigler 1958; Pflieger 1975).

Carp also thrive in reservoirs, lakes, bayous, estuaries, farm ponds, and sewage lagoons (Trautman 1957; Sigler 1958; Vaas and Vaas-van Oven 1959; Bardach et al. 1972; Pflieger 1975). In lacustrine habitats, adults are usually found in association with abundant vegetation (Sigler 1955, 1958). Waters with a diversity of both shallow and deep areas represent optimum habitat.

Reservoir storage ratio (SR) (ratio of mean reservoir water volume to annual discharge volume) may also affect habitat suitability. It has been reported that standing crops peak at storage ratios less than 0.4 and at about 1.5 and decline above 2.0 (Jenkins 1976).

Common carp are extremely tolerant of turbidity as long as food production is not limiting (Forbes and Richardson 1909; Sigler 1955; Trautman 1957; Sigler 1958; McCrimmon 1968). The species can tolerate turbidities far above those usually found in nature (Sigler 1955; Burns 1966; McCrimmon 1968). Feeding and spawning activities over silty bottoms increase turbidity. Turbidity levels > 200 JTU and Secchi disc visibilities < 8 cm are common at spawning sites (Jester 1974).

Optimum growth of freshwater fish in general occurs at pH levels of 6.8-7.5 (European Inland Fisheries Advisory Commission 1969). Growth is reduced at a pH < 6.0, probably due to a reduced food supply (Committee on

Water Quality Criteria 1972). A pH of < 5.0 is reported as harmful to carp (European Inland Fisheries Advisory Commission 1969). The pH levels of the Bear River Migratory waterfowl refuge, an excellent carp habitat, range around 8.1 (Sigler, personal communication). Carp are common in New Mexico reservoirs having a pH in the 8.5 to 8.7 range (Jester 1974), but a pH of 10.5 is lethal (European Inland Fisheries Advisory Commission 1969). Fluctuating pH values and the presence of toxic substances will affect the pH tolerances of the species but are not considered here.

Adult. High production is strongly correlated with warm, midsummer (July and August) water temperatures, as well as the number of days with temperatures > 20° C (Backiel and Stegman 1968). In Lake Powell, large numbers were collected at temperatures from 18-27° C (May and Gloss 1979). Sigler (personal communication) observed, at the Bear River marshes, that, when the temperature exceeded 26° C in the flats, carp moved into deeper, cooler water. A range of 20-28° C is optimum for growth under laboratory conditions (Huet 1970), and temperatures < 13° C and ≥ 30° C cause the growth rate to decrease (Gribanov et al. 1968). The upper lethal temperature for adults is ≥ 34.5° C (Meuwis and Huets 1957; McCrimmon 1968), and feeding ceases at 5° C (Huet 1970).

Adults are very tolerant of low dissolved oxygen (DO) levels, a condition common in warm, fertile waters (Sigler 1955, 1958; McCrimmon 1968). Adults will also feed in the oxygen-depleted hypolimnion (< 2 mg/l D.O.) (Hover 1976). Adults can gulp surface air when the DO is ≤ 0.5 mg/l (Yashouv 1956). Respiration is elevated at 3-5 mg/l DO (13-23° C) (Itazawa 1971; Davis 1975). The DO should remain at least 6-7 mg/l for good growth (Huet 1970).

Common carp may occupy brackish or saline waters (McCrimmon 1968), but production is low in these areas (Bardach et al. 1972). In Israel, the species is grown in ponds at salinities of 0.1-5.0 ppt. Yields decrease at 2.0-3.0 ppt, although food production may also be limiting at this level (Soller et al. 1965; Mark 1966). A salinity level of 7.2 ppt is lethal after 36 days in lab aquaria (Soller et al. 1965). Although the species is tolerant of saline conditions, a rapid change from fresh to salt water can be lethal to carp (Sigler 1958).

Embryo. Preferred spawning areas are over aquatic or inundated terrestrial vegetation at depths of < 0.5 m, but spawning has also been observed over vegetation in water up to 1.8 m deep (McCrimmon 1968). Moderately warm water temperatures are a primary environmental stimulus for spawning (McCrimmon 1968), and spawning temperatures are in the range of 18° to 23° C (Sigler 1958; Swee and McCrimmon 1966; Bardach et al. 1972; Jester 1974). The species generally will not spawn in waters with an average summer temperature < 18° C (Huet 1970); spawning activity decreases at temperatures > 26° C and stops at 28° C (Berg 1949; Swee and McCrimmon 1966; Ignatieva 1976; Jones et al. 1978). Temperatures < 11° C can increase embryo mortality (Makino and Osima 1943; Swee and McCrimmon 1966).

Eggs are tolerant of fluctuating oxygen levels, and some may survive short exposures to DO levels as low as 1.2 mg/l (25° C). Percentage hatching increases with increasing DO content. At 3 mg/l DO, 40% of the embryos hatched; at 6 mg/l, 65% hatched; and at 9 mg/l, 92% hatched (Kaur and Toor 1978).

Fry. After hatching, the fry remain in shallow (< 2 m), warm, fertile, sluggish waters for 2 to 8 weeks (Sigler 1958). Vegetation and turbidity provide cover and protection from predators, as well as a good environment for food production.

Larvae are more tolerant of temperature extremes than embryos. The low temperature threshold for larvae is ≤ 7° C (Tatarko 1970). Larval common carp can survive and continue to feed at 36° C, but most will die at 38° C (Black 1953; Meuwis and Huets 1957; Tatarko 1970). Preferred temperature for fry was reported to be 27° C (Askerov 1975), and the optimum growth was at 30° C (Adelman 1977).

Lower lethal oxygen levels for fry in the laboratory are < 1.6 mg/l at 21-22° C (Doudoroff and Shumway 1970; Askerov 1975). Larvae die at salinities greater than 4 ppt, but growth slows before this level (Askerov 1975).

Juvenile. Juveniles are most common in the same habitat as the fry (Sigler 1958). Optimum growth of juveniles occurs from 28-30° C (Adelman 1977). Temperature preferences of juveniles in the laboratory and in thermal effluents have been reported to be between 27° C and 33.5° C (Pitt et al. 1956; Neill and Magnuson 1974; Askerov 1975; Coutant 1977). Daily food consumption was greatest at 23-27° C (Backiel and Stegman 1968). Temperatures ≥ 38° C are lethal for juveniles (Meuwis and Huet 1957).

The lower lethal oxygen level for juveniles is < 1.0 mg/l (< 20° C) (Privolnev 1954; Downing and Merkens 1957; Doudoroff and Shumway 1970). The growth rate of juveniles begins to decrease at approximately 2.1 mg/l at 20-23° C (Chiba 1965). Optimal DO levels are assumed to be ≥ 6 mg/l, as with adults. Salinities greater than 6 ppt were reported to be lethal to juveniles (Askerov 1975).

HABITAT SUITABILITY INDEX (HSI) MODELS

Model Applicability

Geographic area. The model is applicable wherever common carp occur in the 48 contiguous States. The standard of comparison for each individual variable suitability index is the optimum value of the variable that occurs anywhere within this region. Therefore, the model will never provide an HSI of 1.0 when applied to water bodies in the northern States where temperature related variables do not reach the optimum values found in the southern States.

Season. The model provides a rating for a riverine or lacustrine habitat based on its ability to support all life stages of carp through all seasons of the year. The model will provide an HSI of 0.0 if any reproduction related variable indicates that the species is not able to reproduce in the habitat being evaluated.

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

Minimum habitat area. Minimum habitat area is defined as the minimum area of contiguous suitable habitat that is required for a population to live and reproduce. No attempt has been made to establish a minimum habitat size for survival and growth of a carp population.

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

Model Description - Riverine

Carp habitat quality analysis is based on basic components consisting of food, cover, water quality, and reproduction requirements. Variables that have been shown to affect growth, survival, abundance, or other measures of well-being of carp are placed in the appropriate component (Figs. 1 and 2).

Food component. Percent vegetative cover (V_1) is included because areas with abundant vegetation provide habitat for various food organisms. In addition, the amount of vegetation reflects the general productivity of the habitat, and carp are opportunistic feeders on vegetation and detritus, as well as animal matter. Percent pools, backwaters, and marsh areas (V_3) is included because this variable quantifies the amount of area available for production of food for the species.

Cover component. Percent vegetative cover (V_1) is included because the species frequents areas of vegetation as adults in summer and fall. Dense vegetation is also required by fry and juveniles for cover. Percent pools, backwaters, and marsh areas (V_3) quantifies the amount of habitat available for cover. Percent cover in pools (V_2) is included because adults spend the winter in these areas and require cover.

Water quality component. Average turbidity (V_6) is important because high levels may limit food production and reduce growth rates. Temperature (V_7 and V_9) and dissolved oxygen (V_{12}) affect growth, survival, and feeding. pH (V_{14}) is included because a certain pH range is necessary for survival and reproduction. Salinity (V_{11}) is included as an optional variable; carp can be very tolerant of high salinity levels, and salinity is not considered to be a problem in most areas where the species is found.

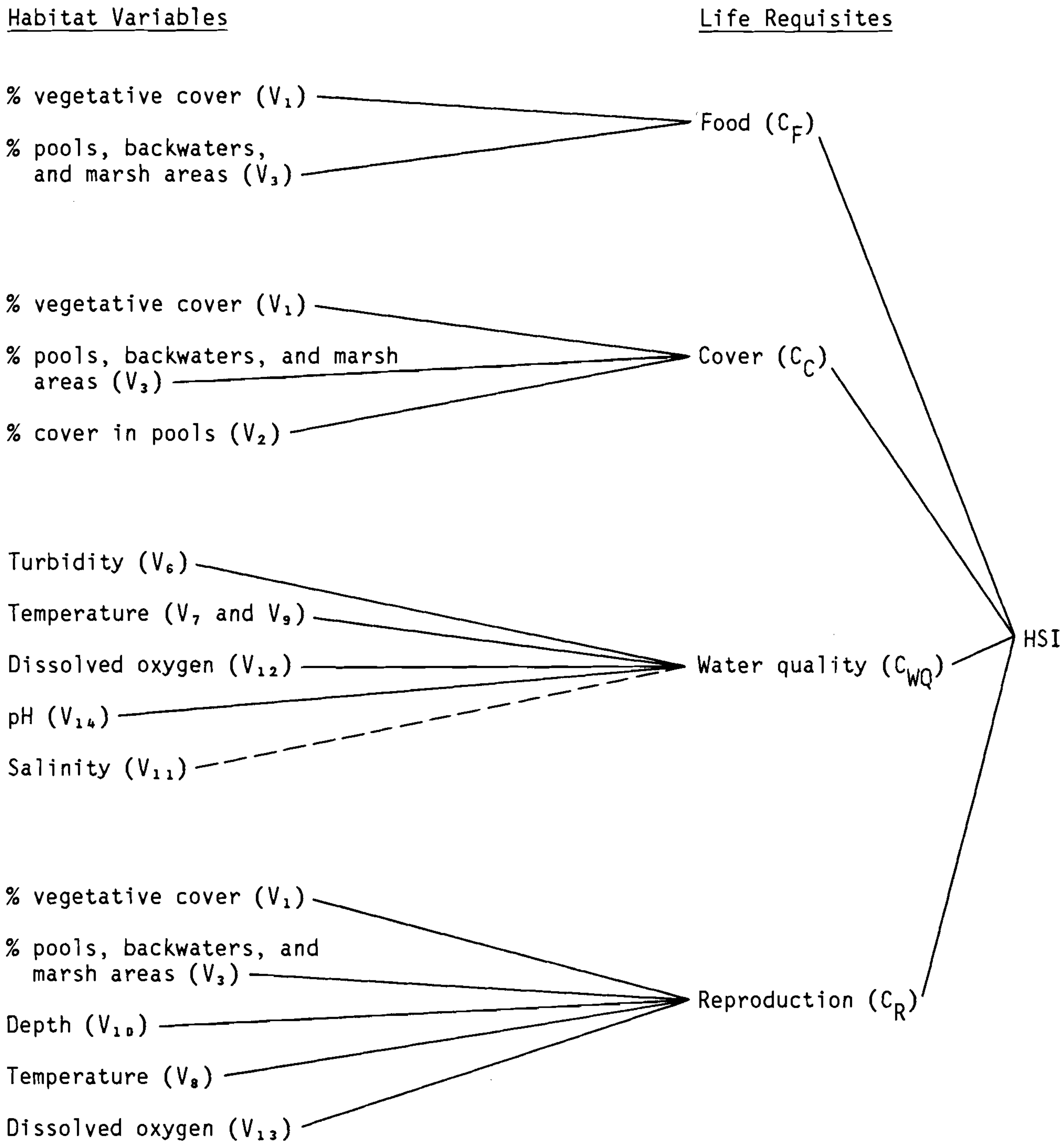


Figure 1. Tree diagram illustrating relationships of habitat variables and life requisites in the riverine model for the carp. Dashed line indicates optional variable in the model.

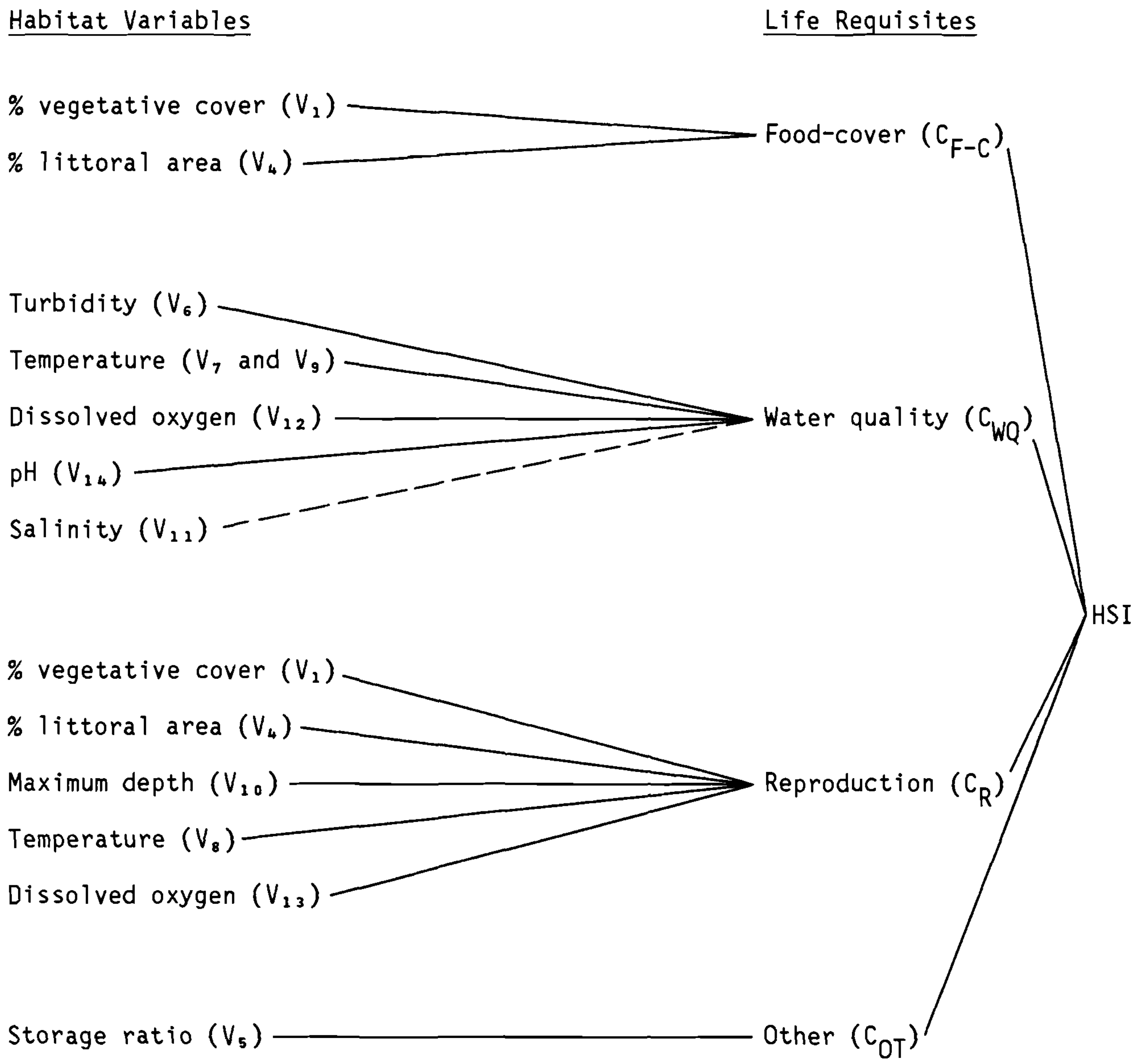


Figure 2. Tree diagram illustrating relationship of habitat variables and life requisites in the lacustrine model for the carp. Dashed line indicates optional variable in the model.

Reproduction component. Percent vegetative cover (V_1) is important because preferred spawning substrate is vegetation. Percent pools, backwaters, and marsh areas (V_3) are included because this variable quantifies the amount of spawning habitat. Maximum depth for spawning (V_{10}) is included because carp primarily spawn in shallow waters. Temperature (V_8) and dissolved oxygen (V_{13}) are important water quality variables that can affect embryo survival and development. Temperature is also a primary stimulus for spawning.

Model Description - Lacustrine

Food-cover component. Food and cover have been aggregated into one component because the variables within this component describe both food and cover suitability. Percent vegetative cover (V_1) is included because areas with abundant cover provide habitat for various food organisms. Carp are opportunistic feeders, and the amount of vegetation will reflect the general productivity in feeding areas. Vegetation is also used for cover for all life stages. Percent littoral area (V_4) quantifies the amount of area available for food and cover.

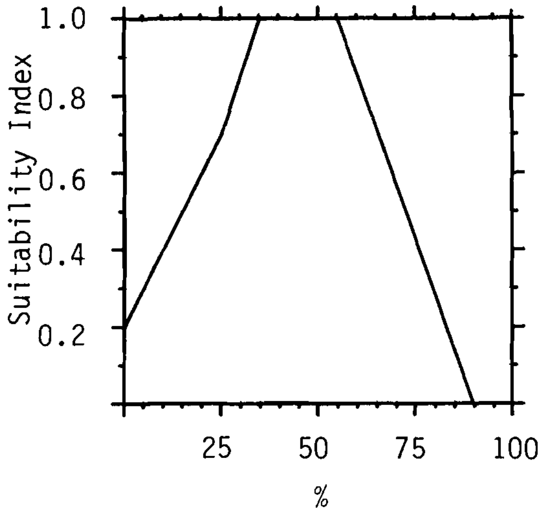
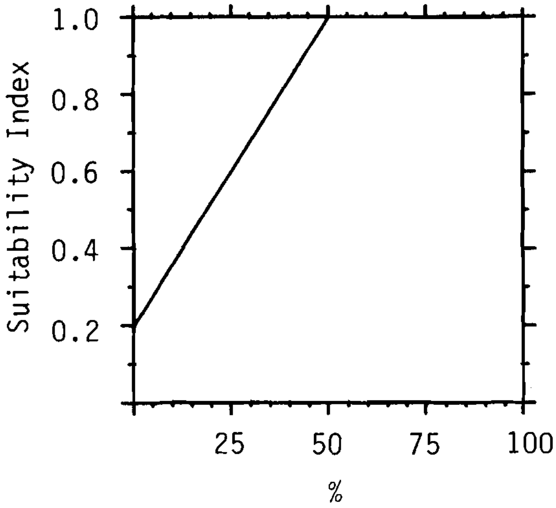
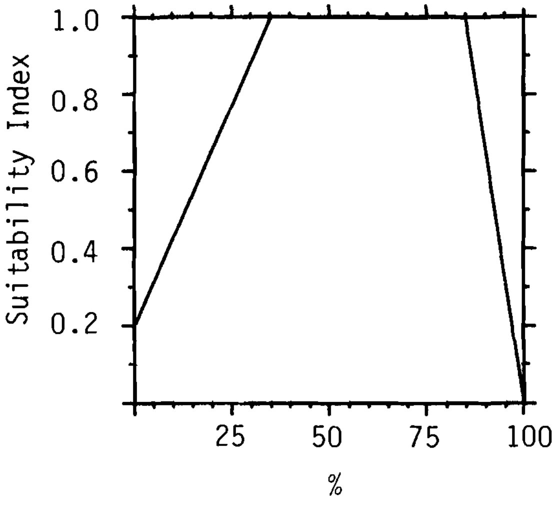
Water quality component. See riverine water quality component.

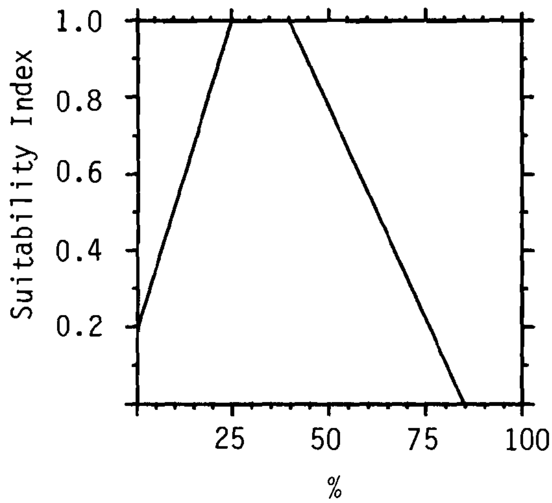
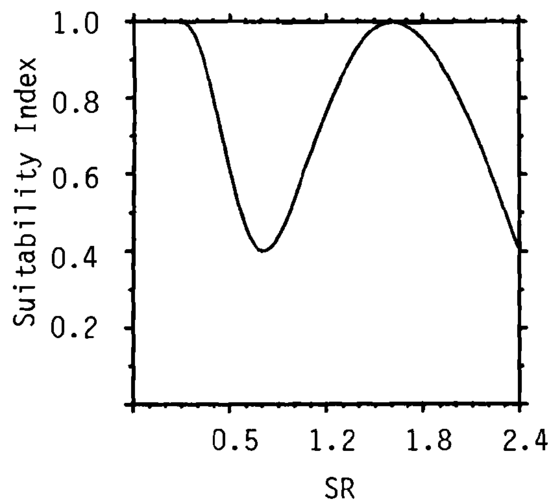
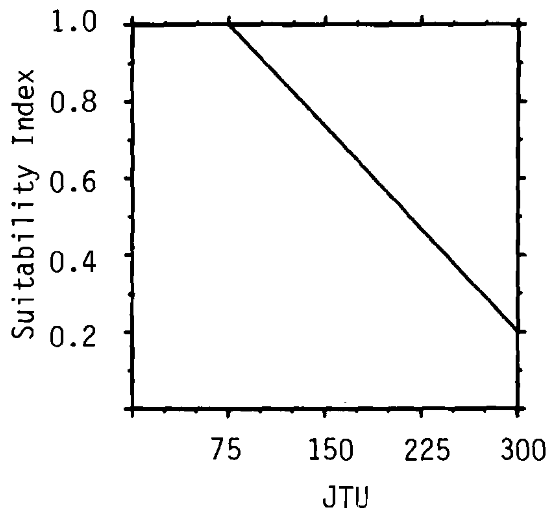
Reproduction component. Percent vegetative cover (V_1) is important since preferred spawning substrate is vegetation. Percent littoral area (V_4) quantifies the amount of spawning habitat available. Maximum depth (V_{10}) is important because successful spawning primarily occurs in shallow water. Temperature (V_8) and dissolved oxygen (V_{13}) are included since their levels can affect embryo survival and development. Temperature is also a primary stimulus for spawning.

Other component. The variable in the other component is one that aids in describing habitat suitability for carp, yet is not specifically related to life requisite components already presented. Storage ratio (SR) (V_5) is important because standing crop of carp has been correlated with storage ratio.

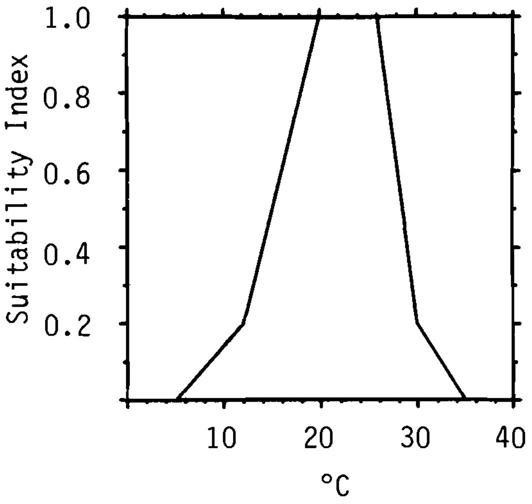
Suitability Index (SI) Graphs for Model Variables

This section contains suitability index graphs for the 14 variables described above. The "R" pertains to riverine habitat variables, and the "L" refers to lacustrine habitat variables.

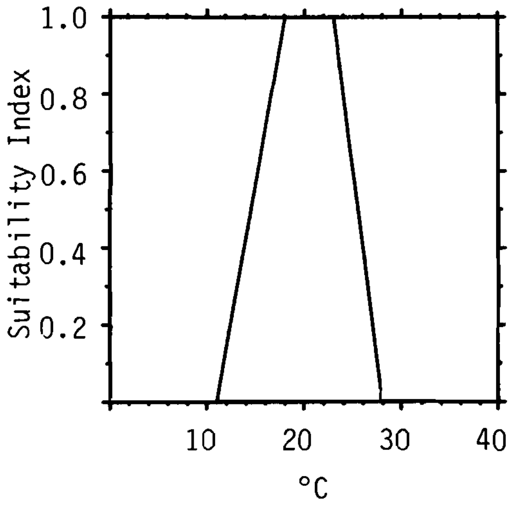
Habitat	Variable		Suitability Graph
R,L	V_1	Percent vegetative cover in shallow areas during spring and summer.	
R	V_2	Percent cover in pools (e.g., logs, brush, submerged objects, and depth).	
R	V_3	Percent pools, back-waters, and marsh areas during average summer flow.	

L	V_4	Percent littoral area during spring and summer.	
L	V_5	Storage ratio.	
R,L	V_6	Maximum monthly average turbidity during average summer flow or summer stratification.	

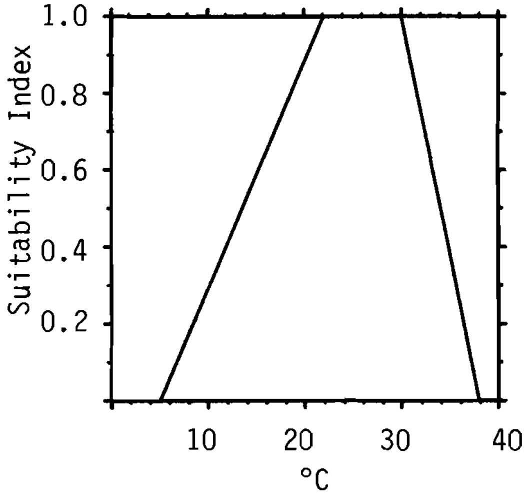
R,L V$_7$ Maximum midsummer water temperature (adult).



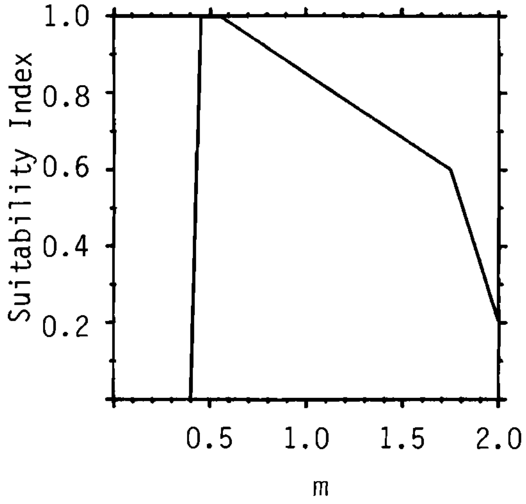
R,L V$_8$ Average water temperatures during spawning within specified areas (embryo).



R,L V$_9$ Maximum midsummer water temperature within pools, backwaters, or littoral areas (juvenile and fry).

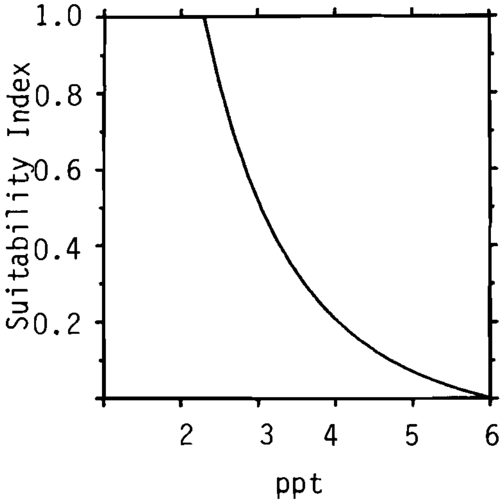


R,L V_{10} Maximum depth of littoral (L) or pools, marshes, and backwaters (R) during spawning.

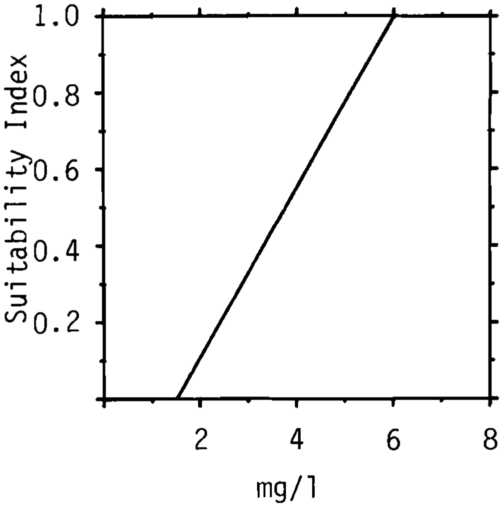


R,L V_{11} Maximum salinity.

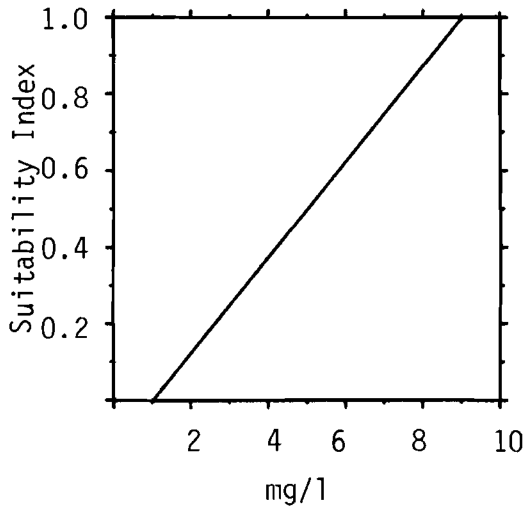
Note: Optional variable. V_{11} should be used in the model only if salinity is considered to be a potential problem within the study area.



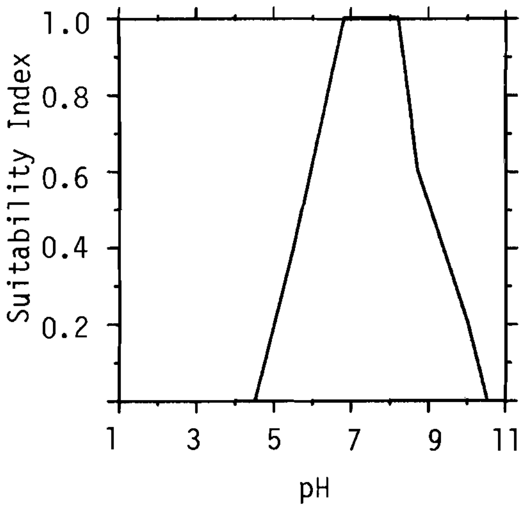
R,L V_{12} Minimum dissolved oxygen levels during midsummer (fry, juvenile, and adult).



R,L V_{13} Minimum dissolved oxygen levels within specified areas during spawning (March-June) (embryo).



R,L V_{14} pH levels during the year.



Riverine Model

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

Food (C_F)

$$C_F = (V_1 \times V_3)^{1/2}$$

Cover (C_C)

$$C_C = (V_1 \times V_2 \times V_3)^{1/3}$$

Water Quality (C_{WQ})

$$C_{WQ} = \frac{V_6 + 2[(V_7 \times V_9)^{1/2}] + 2V_{12} + V_{14}}{6}$$

If $(V_7 \times V_9)^{1/2}$ or $V_{12} \leq 0.4$, C_{WQ} equals the lowest of the following: $(V_7 \times V_9)^{1/2}$; V_{12}; or the above equation. If either V_7 or V_9 is ≤ 0.4, then $(V_7 \times V_9)^{1/2}$ equals the lowest rating.

Note: If V_{11} (optional salinity variable) is added,

$$C_{WQ} = \frac{V_6 + 2[(V_7 \times V_9)^{1/2}] + 2V_{12} + V_{14} + V_{11}}{7}$$

Reproduction (C_R)

$$C_R = (V_1 \times V_3 \times V_8 \times V_{10} \times V_{13})^{1/5}$$

HSI determination

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

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

Lacustrine Model

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

Food-Cover (C_{F-C})

$$C_{F-C} = \frac{V_1 + V_4}{2}$$

Water Quality (C_{WQ})

$$C_{WQ} = \frac{V_6 + 2[(V_7 \times V_9)^{1/2}] + 2V_{12} + V_{14}}{6}$$

If $(V_7 \times V_9)^{1/2}$ or $V_{12} \leq 0.4$, C_{WQ} equals the lowest of the following: $(V_7 \times V_9)^{1/2}$; V_{12}; or the above equation. If either V_7 or V_9 is ≤ 0.4, then $(V_7 \times V_9)^{1/2}$ equals the lowest rating

Note: V_{11} (optional salinity variable) may be added here, as for the riverine water quality component.

Reproduction (C_R)

$$C_R = (V_1 \times V_4 \times V_{10} \times V_8 \times V_{13})^{1/5}$$

Other (C_{OT})

$$C_{OT} = V_5$$

HSI determination

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

If C_{WQ} or C_R is ≤ 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.

Sample data sets for the above riverine and lacustrine HSI models are listed in Tables 2 and 3. The data sets are not actual field measurements, but represent combinations that could occur in a riverine or lacustrine habitat. The HSI's calculated from the data reflect what the carrying capacity trends would be in riverine and lacustrine habitats with the listed characteristics. Thus, the model meets the acceptable goal of producing an index between 0 and 1 which is believed to have a positive relationship to the spawning success of adults and carrying capacity of fry, juvenile, and adult common carp.

Interpreting Model Outputs

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

ADDITIONAL HABITAT MODELS

Model 1

Optimal riverine common carp habitat is characterized by the following conditions, assuming the water quality is adequate: warm waters ($\geq 20°$ C during the growing season, approximately mid-June through August); low gradient rivers (≤ 1.5 m/km); shallow vegetated marshland available for spawning habitat; structural features, such as logs and brush, for cover in pools; 50% or greater of river area in pools and/or off-channel areas; and fertile conditions.

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

Table 1. Data sources for common carp suitability indices.

Variable and source		Assumption
V_1	McCrimmon 1968 May and Gloss 1979	The percentage of vegetative cover associated with high numbers of fish is optimum. The percentage associated with low numbers is suboptimum.
V_2	Pflieger 1975	The percent cover that is associated with areas where the species is most often found in rivers is optimum.
V_3	Kallemeyn and Novotny 1977	Because the species is most abundant in off-channel and pool areas, it is assumed that a high percentage of these areas must exist for habitat to be optimum.
V_4	Sigler 1955; 1958 McCrimmon 1968	Because common carp are associated with shallow vegetated areas, it is assumed that a littoral region must exist for habitat to be adequate. Because carp retreat to deeper waters during winter, too much littoral area is suboptimum.
V_5	Jenkins 1976	The storage ratios associated with high standing crops are optimum.
V_6	Burns 1966 McCrimmon 1968 Jester 1974	Even though adults may tolerate high turbidities, populations may be limited by the effects of turbidity on eggs and fry. Therefore, the levels which are associated with high abundance are optimum. Levels associated with reduced populations are suboptimum.
V_7	Meuwis and Heuts 1957 Backiel and Stegman 1968 Gribanov et al. 1968 McCrimmon 1968 Huet 1970 May and Gloss 1979	Temperatures associated with maximum numbers of fish are optimum. Those associated with reduced growth rates are suboptimum. Lethal temperatures are unsuitable.
V_8	Makino and Osima 1943 Swee and McCrimmon 1966 Huet 1970 Jester 1974 Ignatieva 1976	Temperatures where survival is highest and normal development occurs are optimum. Temperatures associated with lower survival rates are suboptimum. Temperatures causing death are unsuitable.

Table 1. (concluded).

Variable and source		Assumption
V_9	Meuwis and Heuts 1957 Backiel and Stegman 1968 Tatarko 1970 Askerov 1975 Adelman 1977	Temperatures associated with high growth rates are optimum. Temperature preferences near thermal effluents are not considered to necessarily reflect natural conditions. Temperatures causing death are unsuitable.
V_{10}	McCrimmon 1968 Jester 1974	Spawning depths preferred by the species are optimum. Deeper areas are adequate but suboptimum.
V_{11}	Soller et al. 1965 Mark 1966 Bardach et al. 1972	Salinity levels where growth rates are highest are optimum. Levels which are tolerated but where production is low are suboptimum to unsuitable for all life stages.
V_{12}	Chiba 1965 Doudoroff and Shumway 1970 Huet 1970 Itazawa 1971 Askerov 1975 Davis 1975	Levels of DO associated with abundant numbers are optimum. Levels that may be tolerated but reduce growth are suboptimum. Lethal levels or levels where adults must gulp surface air are unsuitable.
V_{13}	Kaur and Toor 1978	DO levels that are associated with maximum hatching and high survival are optimum. Levels where the percent of hatching decreases are suboptimum. Levels where none hatch are unsuitable.
V_{14}	European Inland Fisheries Advisory Commission 1969 Committee on Water Quality Criteria 1972	pH levels that promote high growth rates are optimum. pH levels where growth is reduced or reproduction is adversely affected are suboptimum. Levels that cause death are unsuitable.

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
% vegetative cover	V_1	20	0.6	50	1.0	5	0.3
% cover in pools	V_2	25	0.6	75	1.0	45	0.9
% pools, backwaters, and marsh areas	V_3	25	0.7	60	1.0	95	0.6
Turbidity (JTU)	V_6	80	0.9	100	0.8	225	0.4
Temperature (adult) (° C)	V_7	20	1.0	18	0.8	28	0.5
Temperature (embryo) (° C)	V_8	23	0.9	20	1.0	24	0.8
Temperature (juvenile, fry) (° C)	V_9	26	1.0	30	1.0	34	0.5
Depth in pools, marshes, and backwaters during spawning (m)	V_{10}	0.5	1.0	1.2	0.8	2.0	0.2
Salinity (optional) (ppt)	V_{11}	2.0	1.0	1.5	1.0	2.0	1.0
Dissolved oxygen (fry, juvenile, adult) (mg/l)	V_{12}	5	0.8	6	1.0	4	0.6
Dissolved oxygen (embryo) (mg/l)	V_{13}	6.3	0.7	7.3	0.8	5.5	0.6
pH	V_{14}	7	1.0	7.5	1.0	6	0.4

Table 2. (concluded).

Variable	Data set 1 Data	SI	Data set 2 Data	SI	Data set 3 Data	SI
Component SI						
C_F =		0.65		1.00		0.42
C_C =		0.63		1.00		0.55
C_{WQ} =		0.91		0.93		0.50
C_R =		0.77		0.91		0.44
HSI =		0.73		0.96		0.47

Note: C_{WQ} does not include salinity variable (V_{11}).

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
% vegetative cover	V_1	20	0.6	50	1.0	35	0.8
% littoral	V_4	15	0.7	40	1.0	10	0.5
Storage ratio	V_5	0.7	0.4	1.5	1.0	2.1	0.6
Turbidity (JTU)	V_6	80	0.9	150	0.7	75	1.0
Temperature (adult) (° C)	V_7	18	0.8	19	0.9	20	1.0
Temperature (embryo) (° C)	V_8	12	0.5	19	1.0	22	0.8
Temperature (juvenile, fry) (° C)	V_9	18	0.7	20	0.8	25	1.0
Depth of littoral during spawing (m)	V_{10}	0.5	1.0	0.8	0.9	1.8	0.6
Salinity (optional) (ppt)	V_{11}	2.0	1.0	1.0	1.0	1.5	1.0
Dissolved oxygen (fry, juvenile, adult) (mg/l)	V_{12}	4	0.6	5	0.8	3	0.4
Dissolved oxygen (embryo) (mg/l)	V_{13}	4	0.4	8	0.9	4	0.4
pH	V_{14}	7	1.0	6	0.4	6	0.4

Table 3. (concluded).

Variable	Data set 1		Data set 2		Data set 3	
	Data	SI	Data	SI	Data	SI
Component SI						
$C_{F/C}$ =		0.65		1.00		0.65
C_{WQ} =		0.77		0.73		0.70
C_R =		0.61		0.96		0.60
C_{OT} =		0.70		1.00		0.60
HSI =		0.68		0.91		0.64

Note: C_{WQ} does not include salinity variable (V_{11}).

Model 2

Optimal lacustrine common carp habitat is characterized by the following conditions: fertile conditions; warm waters ($\geq 20°$ from mid-June through August); aquatic or inundated vegetation for spawning in spring and early summer; deeper waters for overwintering; and at least 25% littoral area.

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

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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 Common carp (*Cyprinus carpio*) 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
Carp
Fishes
Habitability
Mathematical models

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Common carp
Cyprinus carpio
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Habitat preference
Habitat management
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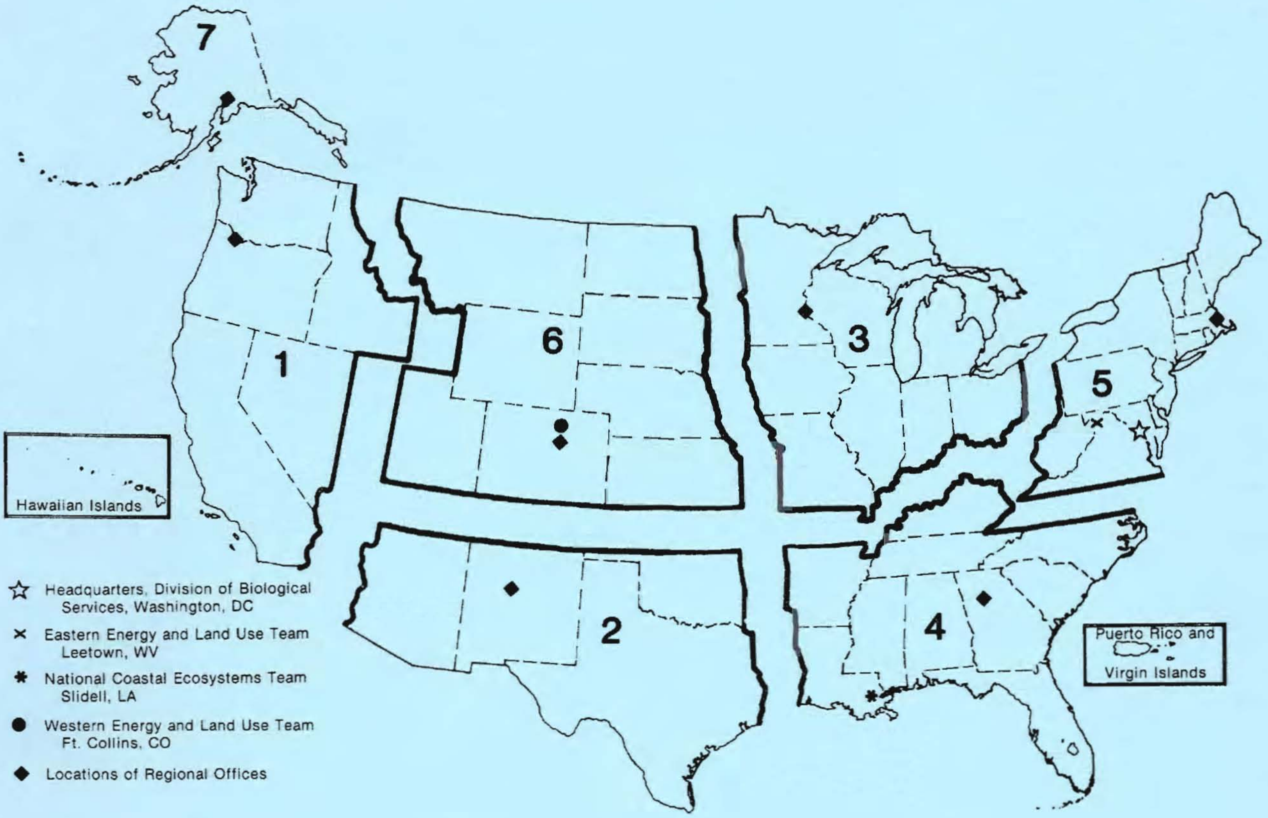

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