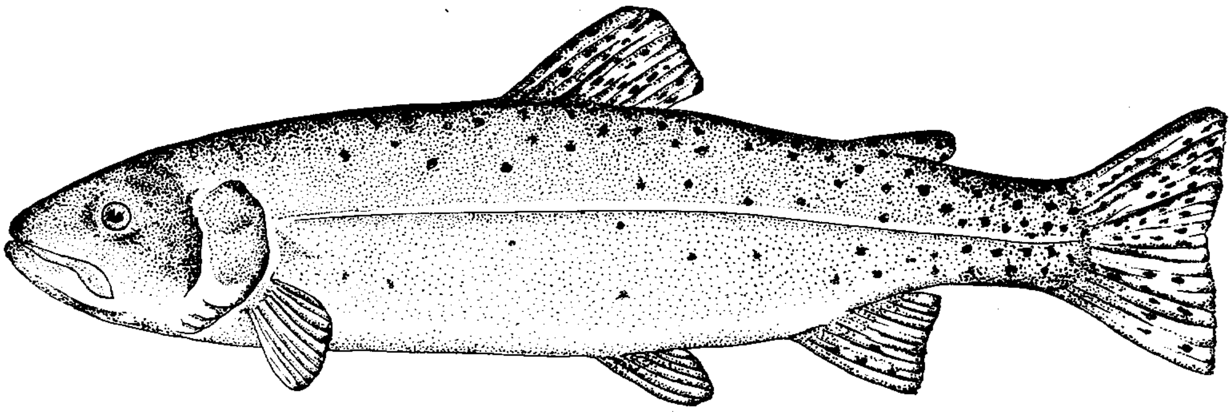
Biological Services Program

FWS/OBS-82/10.5
FEBRUARY 1982

HABITAT SUITABILITY INDEX MODELS: CUTTHROAT TROUT



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S. Department of the Interior

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February 1982

HABITAT SUITABILITY INDEX MODELS: CUTTHROAT TROUT

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This report should be cited as:

Hickman, T., and R. F. Raleigh. 1982. Habitat suitability index models: Cutthroat trout. U.S.D.I. Fish and Wildlife Service. FWS/OBS-82/10.5. 38 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 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.

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 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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CONTENTS

ACKNOWLEDGMENTS

We are indebted to Ron Anderson and Dave Meyer for their aid with early literature reviews and development work of suitability index graphs and narrative sections of the cutthroat trout summary. The manuscript was reviewed by Robert Behnke, Norman Benson, Jim Mullen, and James Johnston. Their review contributions are gratefully acknowledged, but the authors accept full responsibility for the contents of the summary. Word processing was provided by Dora Ibarra and Carolyn Gulzow. The cover of this document was illustrated by Jennifer Shoemaker.

CUTTHROAT TROUT (*Salmo clarki*)

HABITAT USE INFORMATION

General

Cutthroat trout, *Salmo clarki*, are a polytypic species consisting of several geographically distinct forms with a broad distribution and a great amount of genetic diversity (Hickman 1978; Behnke 1979). Behnke (1979) recognized 13 extant subspecies: Coastal cutthroat (S. c. *clarki*) in coastal streams from Prince William Sound, Alaska to the Eel River in California; mountain cutthroat (*S. c. alpestris*) in upper Columbia and Fraser River drainages of British Columbia; west slope cutthroat (*S. c. lewisi*) in the upper Columbia, Salmon, Clearwater, South Saskatchewan and upper Missouri drainages of Montana and Idaho; an undescribed subspecies in the Alvord basin, Oregon; Lahonton cutthroat (S. c. *henshawi*), Pauite cutthroat (*S. c. seleniris*), and an undescribed subspecies in the Humboldt River drainage of the Lahontan basin of Nevada and California; Yellowstone cutthroat (*S. c. bouvieri*) in the Yellowstone drainage of Wyoming and Montana and the Snake River drainage of Wyoming, Idaho, and Nevada; an undescribed subspecies (fine spotted) in the upper Snake River, Wyoming; Bonneville cutthroat (*S. c. utah*) in the Bonneville basin in Utah, Nevada, Idaho, and Wyoming; Colorado River cutthroat (S. *c. pleuriticus*) in the Colorado River drainage in Wyoming, Utah, New Mexico, and Colorado; greenback cutthroat (S. *c. stomias*) in the South Platte and Arkansas River systems; and Rio Grande cutthroat (*S. c. virginalis*) in the Rio Grande River drainage of Colorado and New Mexico. Many of these 13 subspecies are included on Federal or State endangered or threatened species lists.

Temperature and chemical preferences, migration, and other ecological and life history attributes vary among cutthroat subspecies (Behnke 1979). Differences in growth rate (Carlander 1969; Scott and Crossman 1973; Behnke 1979) and food preferences have also been reported (Trojnar and Behnke 1974) between some subspecies.

Age, Growth, and Food

Most male cutthroat trout mature at ages II to III, whereas females usually mature a year later (Irving 1954; Drummond and McKinney 1965; Johnston and Mercer 1977). In Washington streams that contain anadromous populations of cutthroat, which predominantly smolt at age II, less than 15% of the cutthroat returning to the river for the first time are sexually mature females (Mercer and Johnston 1978). The maximum life expectancy for coastal cutthroat is about 10 years (Johnston and Mercer 1976), whereas the maximum reported age for interior cutthroat is 7 years (Behnke 1979). Size at maturity will vary depending on environmental conditions. Cutthroat mature at a smaller size in small headwater streams (Behnke and Zarn 1976).

Trout are opportunistic feeders (Behnke and Zarn 1976), but their diet consists mainly of aquatic insects (Allen 1969; Carlander 1969; Baxter and Simon 1970; Scott and Crossman 1973; Griffith 1974). Other foods, such as zooplankton (McAfee 1966; Carlander 1969; Trojnar and Behnke 1974), terrestrial insects (Carlander 1969; Trojnar and Behnke 1974; Hickman 1977), and fish (Carlander 1969) are locally or seasonally important. Cutthroat trout usually become more piscivorous as they increase in size (McAfee 1966; Carlander 1969; Baxter and Simon 1970).

Reproduction

Cutthroat trout are stream spawners. The fertilized ova are deposited in redds constructed primarily by the female in the stream gravels (Smith 1941, 1947). Spawning begins in spring, as early as February (Behnke 1979), but can occur as late as August in colder areas (Juday 1907; Fleener 1951). The time of spawning depends on water temperature, runoff (Lea 1968), ice melt (Calhoun 1944), elevation and latitude (Behnke and Zarn 1976).

Anadromy

Coastal cutthroat are the most abundant of the thirteen recognized cutthroat subspecies and consist of both resident and anadromous populations. Both populations are usually found in the same watershed. The resident populations are frequently, but not always, segregated from the anadromous stock by some barrier to anadromy. Although resident and anadromous populations have been reported to occur in sympatry in streams and lakes, more information is needed to determine if gene flow between populations is absent (Johnston 1979).

Anadromous coastal cutthroat spend less time in saltwater than steelhead trout or salmon. Although some cutthroat overwinter in saltwater, most return to freshwater after 3 to 8 months (Johnston 1979). During this period in saltwater, the cutthroat stay close to shore and are rarely found at depths greater than 3 m. Preferred habitats in saltwater are gravel beaches vegetated above the high tide mark and gravel spits created by tidal currents. Cutthroat are rarely found in saltwater in areas with silt, mud, or solid rock substrate. Anadromous cutthroat utilize cover during upstream migration from saltwater.

Coastal cutthroat initially smolt at age II, III, or IV. Some smolt at age I, whereas others may not migrate to salt water until age VI (Jones 1974, 1975, 1976). In Washington, the smallest cutthroat entering salt water weigh from 25 to 45 gms and are 120 to 170 mm long. Physiological adaptation to salt water appears to be related to size rather than age (Johnston and Mercer 1976).

In Washington and Oregon, smolt movement to salt water begins in March, peaks in mid-May, and is completed by mid-June (Johnston and Mercer 1976). In Alaska, migration begins in April (Armstrong 1971; Jones 1974, 1975, 1976), peaks at the end of May, but may continue into August. Most seaward migrations occur at night. Re-entry into fresh water in Washington and Oregon begins in July, peaks in September and October, and lasts until the end of October (Giger 1972; Johnston and Mercer 1976). In smaller coastal streams, re-entry begins in October, peaks in December and January, and continues into March. Migrations into small stream-lake systems in Alaska begin as early as mid-May, peak in September, and last until October (Armstrong 1971; Jones 1974, 1975, 1976).

Specific Habitat Requirements

Optimal cutthroat trout riverine habitat is characterized by clear, cold water; a silt free rocky substrate in riffle-run areas; an approximately 1:1 pool-riffle ratio with areas of slow, deep water; well vegetated stream banks; abundant instream cover; and relatively stable water flow, temperature regimes, and stream banks (Raleigh and Duff 1981). Cutthroat trout tend to occupy headwater stream areas, especially when other trout species are present in the same river system (Glova and Mason 1976).

Optimal lacustrine habitat is characterized by clear, cold, deep lakes that are typically oligotrophic, but may vary in size and chemical quality, particularly in reservoir habitats. Cutthroat trout are stream spawners and require tributary streams with gravel substrate in riffle areas for reproduction to occur.

Trout literature does not clearly distinguish between feeding stations, escape cover, and winter cover requirements. Prime requisites for optimal feeding stations appear to be low water velocity and access to a plentiful food supply, e.g., energy accretion at a low energy cost. Water depth is not clearly defined as a selection factor, and overhead cover is preferred but not essential. Escape cover, however, must be nearby (Raleigh and Duff 1981). The feeding stations of dominant adult trout will include overhead cover when available. The feeding stations of subdominant adults and juveniles, however, may not always include overhead cover.

Cover is recognized as one of the essential components of trout streams. Boussu (1954) was able to increase the number and weight of trout in stream sections by adding artificial brush cover and to decrease numbers and weight by removing brush cover and undercut banks. Lewis (1969) reported that the amount of cover was important in determining the number of trout in sections of a Montana stream. Cover for adult trout consists of areas of obscure stream bottom in areas of water ≥ 15 cm deep with a low velocity of ≤ 15 cm/sec (Wesche 1980). Wesche (1980) reported that, in larger streams, the abundance of trout ≥ 15 cm in length increased with depth; most were at depths of at least 15 to 45 cm. Cover is provided by overhanging vegetation; submerged vegetation; undercut banks; instream objects, such as debris piles, logs, large rocks; and pool depth or surface turbulence (Giger 1973). A cover area of ≥ 25% of the total stream area will provide adequate cover for adult trout; a cover area of ≥ 15% is adequate for juveniles. The main use of summer cover is probably for predator avoidance and resting. In winter, salmonids occupy different habitat areas than in the summer (Hartman 1965; Everest 1969; Bustard and Narver 1975a).

In some streams, the major factor limiting salmonid densities may be the amount of adequate overwintering habitat rather than summer rearing habitat (Bustard and Narver 1975a). Winter hiding behavior in salmonids is triggered by low temperatures (Chapman and Bjornn 1969; Everest 1969; Bustard and Narver 1975a,b). Cutthroat trout were found under boulders, log jams, upturned roots, and debris when temperatures neared 4 to 8° C, depending on velocity (Bustard and Narver 1975a). Everest (1969) found juvenile rainbows 15 to 30 cm deep in the substrate, which was often covered by 5 to 10 cm of anchor ice. Lewis (1969) reported that, during winter, adult rainbow trout tended to move into deeper water (class 1 pools). Bjornn (1971) indicated that downstream movement during or preceding winter did not occur if sufficient winter cover was locally available. Trout move to winter cover to avoid physical damage from ice scouring (Hartman 1965; Chapman and Bjornn 1969) and to conserve energy (Chapman and Bjornn 1969; Everest 1969).

Headwater trout streams are relatively unproductive. Most energy inputs to the stream are in the form of allochthonous materials, such as terrestrial vegetation and terrestrial insects (Idyll 1942; Chapman 1966; Hunt 1975). Aquatic invertebrates are most abundant and diverse in riffle areas with rubble substrate and on submerged aquatic vegetation (Hynes 1970). However, optimal substrate for maintenance of a diverse invertebrate population consists of a mosaic of gravel, rubble, and boulders with rubble being dominant. The invertebrate fauna is much more abundant and diverse in riffles than in pools (Hynes 1970), but a ratio of about 1:1 of pool to riffle area (about 40 to 60% pool area) appears to provide an optimal mix of trout food producing and rearing areas. In riffle areas, the presence of fines (> 10%) reduces the production of invertebrate fauna (based on Cordone and Kelly 1961; Crouse et al. 1981).

Canopy cover is important in maintaining shade for stream temperature control and in providing allochthonous materials to the stream. Too much shade, however, can restrict primary productivity in a stream. Stream temperatures can be increased or decreased by controlling the amount of shade. About 50 to 75% mid-day shade appears optimal for most small trout streams (Anonymous 1979). Shading becomes less important as stream gradient and size increases. In addition, a well vegetated riparian area helps to control watershed erosion. In most cases, a buffer strip about 30 m deep, 80% of which is either well vegetated or has stable rocky stream banks, will provide adequate erosion control and maintain undercut stream banks characteristic of good trout habitat. The presence of fines in riffle-run areas can adversely affect embryo survival, food production and cover for juveniles.

There is a definite relationship between the annual flow regime and the quality of trout habitat. The most critical period is typically the base flow (lowest flows of late summer to winter). A base flow ≥ 50% of the average annual daily flow is considered excellent, a base flow of 25 to 50% is considered fair, and a base flow of < 25% is considered poor for maintaining quality trout habitat (adapted from Binns and Eiserman 1979; Wesche 1980).

Of 66 streams sampled in British Columbia, those containing cutthroat trout had a pH of 6.0 to 8.8 (Hartman and Gill 1968). Thirteen streams in Wyoming containing populations of Colorado River cutthroat trout had pH levels of 7.1 to 8.3 (Binns 1977). Sekulich (1974) reported that the pH in three reservoirs containing cutthroat trout ranged from 7.8 to 8.5. Platts (1974) analyzed three streams in Idaho with cutthroat trout where the pH ranged from 7.3 to 7.9 and total dissolved solids ranged from 41 to 63 mg/l. Some isolated populations of cutthroat trout in the Great Basin area have developed a unique tolerance for high pH, alkalinity, total dissolved solids, and temperature conditions. The Lahontan basin cutthroat trout persist in Pyramid and Walker Lakes, Nevada, where total dissolved solids exceed 5,000 mg/l and 10,000 mg/l, respectively (Behnke and Zarn 1976). The largest cutthroat trout ever recorded came from Pyramid Lake, which has a pH range between 9.0 and 9.5. The Lahontan basin cutthroat also lives in alkaline waters, such as Walker Lake, Nevada (alkalinity of 2,900 mg/l). These conditions are probably lethal to other cutthroat trouts (Behnke and Zarn 1976). Precise pH tolerance and optimal ranges for cutthroat trout are not well documented. Most cutthroat populations can probably tolerate a pH range of 5 to 9.5, with an optimal range of 6.5 to 8. The Lahontan basin cutthroat appear to have developed a tolerance to higher pH conditions, with regional pH tolerance and optimal ranges of 5 to 10 and 6.5 to 8.5, respectively.

Bachmann (1958) reported that, at turbidities above 35 ppm, cutthroat trout stopped feeding and moved to cover. Turbidities of less than 25 JTU and total dissolved solids from 38 to 544 mg/l characterized 13 Wyoming streams containing cutthroat trout (Binns 1977).

Adult. Dissolved oxygen requirements vary with species, age, prior acclimation temperature, water velocity, activity level, and concentration of substances in the water (McKee and Wolf 1963). As temperature increases, the dissolved oxygen saturation level in the water decreases while the dissolved oxygen requirements for the fish increases. As a result, an increase in temperature resulting in a decrease in dissolved oxygen can be detrimental to the fish. Optimal oxygen levels for cutthroat trout are not well documented, but appear to be > 7 mg/l at temperatures ≤ 15° C and ≥ 9 mg/l at temperatures > 15° C. Doudoroff and Shumway (1970) demonstrated that swimming speed and growth rates for salmonids declined with decreasing dissolved oxygen levels. At temperatures ≥ 15° C, cutthroat trout generally avoid water with dissolved oxygen levels of less than 5 mg/l (Trojnar 1972; Sekulich 1974).

Cutthroat trout usually do not persist in waters where maximum temperatures consistently exceed 22° C, although they may be able to withstand brief periods of water temperature as high as 26° C if considerable nightime cooling takes place (Behnke and Zarn 1976). The Humboldt River cutthroat trout in the Lahontan basin, however, occupy waters where temperatures may reach a summer maximum of 25° C (Behnke 1979). Needham and Jones (1959) reported cutthroat trout actively feeding at 0° C. Bell (1973) reported a preferred temperature range of 9 to 12° C for cutthroat trout. Dwyer and Kramer (1975) reported the greatest scope for activity in cutthroat trout occurred at 15° C when tested at 5° C increments. We assume that scope for activity is a better measure of optimal temperature than temperature preference tests and have selected 12-15° C as an optimal temperature range for cutthroat trout.

Focal point velocities for adult cutthroat trout on territorial stations in Idaho streams were primarily between 10 and 14 cm/sec, with a maximum of 22 cm/sec (Griffith 1972).

Embryo. Incubation time varies inversely with temperature. Eggs usually hatch within 28 to 40 days (Cope 1957), but may take as long as 49 days (Scott and Crossman 1973). Bell (1973) reported that cutthroat trout spawning temperatures ranged from 6 to 17° C. The optimal temperature for embryo incubation is approximately 10° C (Snyder and Tanner 1960). Calhoun (1966) reported increased mortalities of rainbow embryos at temperatures < 7° C and normal development at temperatures ≤ 12° C. Hooper (1973) and Thompson (1972) reported spawning velocities ranging from 31 to 92 cm/sec, while Hunter (1973) reported the range as 11 to 40 cm/sec. Average water column velocities for embryo development apparently range from 11 to 92 cm/sec. We assume that optimal velocities range from 30 to 60 cm/sec. The combined effects of temperature, dissolved oxygen levels, water velocity, and gravel permeability are important for successful incubation (Coble 1961). In a 30% sand and 70% gravel mixture, only 28% of implanted steelhead embryos hatched; of the 28% that hatched, only 74% emerged (Bjornn 1969; Phillips et al. 1975). We assume that these same results would be true for the closely related cutthroat trout. We further assume that optimal spawning gravel conditions include ≤ 5% fines, and that ≥ 30% fines will cause low survival of embryos and emerging yolk-sac fry. Suitable incubation substrate is gravel 0.3 to 8 cm in diameter (Duff 1980). Optimal substrate size will depend on size of spawners, but we assume it will average 1.5 to 6.0 cm in diameter. Doudoroff and Shumway (1970) reported that salmonids incubated at low dissolved oxygen levels were weak and small with slower development and more abnormalities. Dissolved oxygen requirements for cutthroat trout embryos are probably similar to the requirements for adults.

Fry. Cutthroat trout remain in the gravel for about two weeks after hatching (Scott and Crossman 1973) and emerge 45 to 75 days after egg fertilization, depending on water temperature (Calhoun 1944; Lea 1968). When moving from natal gravels to rearing areas, cutthroat trout fry exhibit three distinctly different genetically controlled patterns: 1) downstream to a larger river or lake; 2) upstream from an outlet river to a lake; or 3) local dispersion within a common spawning and rearing area to areas of low velocity and cover (Raleigh and Chapman 1971). Fry of lake resident fish may either move into the lake from natal streams during the first growing season or overwinter in the spawning stream and move into the lake during subsequent growing seasons (Raleigh 1971; Raleigh and Chapman 1971). Salmo clarki lewisi average two growing seasons, but may spend 1 to 4 years in the stream before migrating to the lake (Roscoe 1974).

Fry residing in streams prefer shallower water and slower velocities than other life stages (Miller 1957; Horner and Bjornn 1976). Fry utilize velocities of less than 30 cm/sec, but less than 8.0 cm/sec are preferred (Griffith 1972; Horner and Bjornn 1976). Fry survival decreases with increased velocity after optimal velocity has been reached (Bulkley and Benson 1962; Drummond and McKinney 1965). A pool area of 40% to 60% of the total stream area is assumed to provide optimal fry habitat. Cover in the form of aquatic vegetation, debris piles, and the interstitial spaces between rocks is critical. Griffith (1972) states that younger trout live in shallower water and stay closer to escape cover than do older trout. Few fry are found more than 1 m from cover. As the young cutthroat grow, they move to deeper, faster water. Everest (1969) suggested that one reason for this movement was the need for cover, which is provided by increased water depth, surface turbulence, and larger substrate.

Trout fry usually overwinter in shallow areas of low velocity near the stream margin, with rubble being the principle cover (Bustard and Narver 1975a). Optimal size of substrate used as winter cover by steelhead fry and small juveniles ranges from 10 to 40 cm in diameter (Hartman 1965; Everest 1969). An area of substrate of this size class (10-40 cm) of ≥ 10% of the total habitat will probably provide adequate cover for cutthroat fry and small juveniles. The use of smaller diameter rocks (gravel) for winter cover may result in increased mortality due to greater shifting of the substrate (Bustard and Narver 1975a). The presence of fines (≥ 10%) in the riffle-run areas impairs the value of the area as cover for fry and small juveniles.

Juvenile. Juvenile cutthroat trout in streams are most often found in water depths of 45 to 75 cm and velocities of 25 to 50 cm/sec (Nickelson unpublished data). Griffith (1972) reported focal point velocities for juvenile cutthroat in Idaho of between 10 and 12 cm/sec, with a maximum velocity of 22 cm/sec. Metabolic rates are highest between 11 and 21° C with an apparent optimal temperature of 15° C (Dwyer and Kramer 1975) .

Bustard and Narver (1975b) demonstrated that juvenile cutthroat trout used rubble and overhanging banks as cover. The juveniles also showed a preference for clean, as opposed to silted, rubble for cover. Common types of cover for juvenile trout are upturned roots, logs, debris piles, overhanging banks, and small boulders (Bustard and Narver 1975a). Young salmonids occupy different habitats in winter than in summer, with log jams and rubble important as winter cover. Wesche (1980) observed that larger cutthroat trout (> 15 cm long) tended to use streamside cover (overhanging banks and vegetation) more often than instream substrate objects, while juveniles (≤ 15 cm) preferred instream substrate cover.

HABITAT SUITABILITY INDEX (HSI) MODELS

Figure 1 depicts the theoretical relationships among model variables, components, and HSI for the cutthroat trout model.

Model Applicability

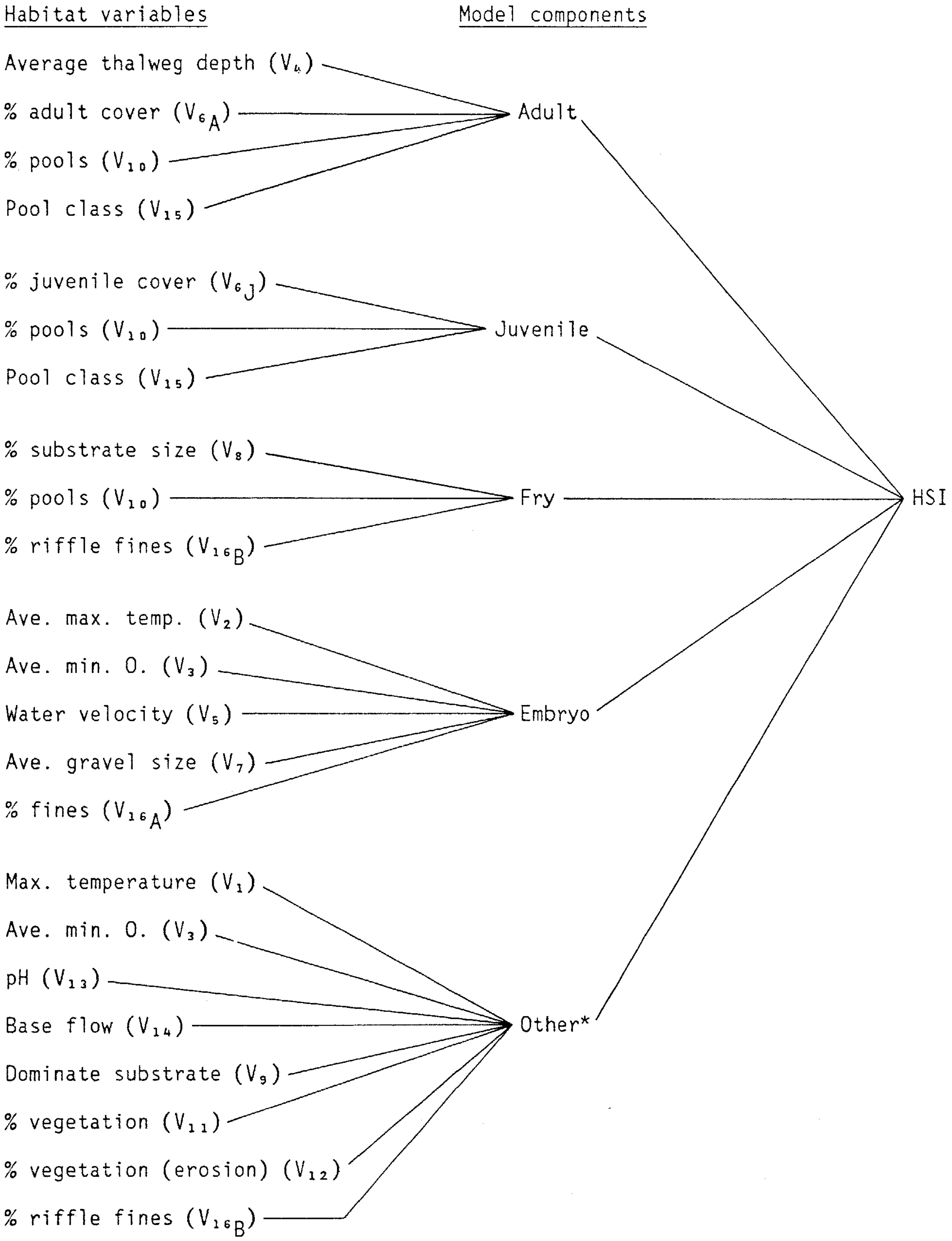
Geographic area. The following model is applicable over the entire range of cutthroat trout distribution. Where differences in habitat requirements have been identified for different races of cutthroat trout, suitability index graphs have been constructed to reflect these differences. For this reason, care must be excercised in use of the individual graphs and equations.

Season. The model rates the freshwater habitat of cutthroat trout for all seasons of the year.

Cover types. The model is applicable to freshwater riverine or lacustrine habitats.

Minimum habitat area. Minimum habitat area is the minimum area of continuous habitat that is required for a species to live and reproduce. Since cutthroat can move considerable distances to spawn or locate suitable summer or winter rearing habitat, no attempt has been made to define a minimum habitat size for the species.

Verification level. An acceptable level of performance for this cutthroat trout model is for it to produce an index between 0 and 1 that the authors and other biologists familiar with cutthroat trout ecology believe is positively correlated with the carrying capacity of the habitat. Model verification consisted of testing the model outputs from sample data sets developed by the authors to simulate high, medium, and low quality cutthroat trout habitat.



*Variables that affect all life stages.

Figure 1. Diagram illustrating the relationships among model variables, components, and HSI.

Model Description - Riverine

The riverine HSI model consists of five components, adult (C_A), Juvenile (C_J), Fry (C_F), Embryo (C_E), and Other (C_O). Each life stage component contains variables specifically related to that component. The component C_O contains variables related to water quality and food supply that affect all life stages of cutthroat trout.

The model utilizes a modified limiting factor procedure. This procedure assumes that model variables and components with suitability indices in the average to good range, > 0.4 to < 1.0, can be compensated for by higher suitability indices of other related model variables and components. However, variables and components with suitabilities ≤ 0.4 cannot be compensated for, and thus become limiting factors on habitat suitability.

Adult component. Variable V_6, percentage of instream cover, is included because standing crops of adult trout have been shown to be correlated with the amount of cover available. Percentage of pools (V_{10}) is included because pools provide cover and resting areas for adult trout. Variable V_{10} also quantifies the amount of pool habitat that is needed. Variable V_{15}, pool class, is included because pools differ in the amount and quality of escape cover, winter cover, and resting areas that they provide. Average thalweg depth (V_4) is included because average water depth affects the amount and quality of pools and instream cover available to adult trout and migratory access to spawning and rearing areas.

Juvenile component. Variables V_6, percentage of instream cover; V_{10}, percentage of pools; and V_{15}, pool class are included in the juvenile component for the same reasons listed above for the adult component. Juvenile cutthroat trout use these essential stream features for escape cover, winter cover, and resting areas.

Fry component. Variable V_8, substrate size class, is included because trout fry utilize substrate as escape cover and winter cover. Variable V_{10}, percent pools, is included because fry use the shallow, slow water areas of pools and backwaters as resting and feeding stations. Variable V_{16}, % fines, is included because the percent fines affects the ability of the fry to utilize the rubble substrate for cover.

Embryo component. It is assumed that habitat suitability for trout embryos depends primarily on water temperature, V_2; dissolved oxygen content, V_3; water velocity, V_5; spawning gravel size, V_7; and percent fines, V_{16}. Water velocity, V_5; gravel size, V_7; and percent fines, V_{16}, are interrelated factors that have been shown to effect the transport of dissolved oxygen to the embryo and the removal of the waste products of metabolism from the embryo.

These functions have been shown to be vital to the survival of trout embryos. In addition, the presence of too many fines in the redds will block movement of the fry from the incubating gravels to the stream.

Other component. This component contains model variables for two subcomponents, water quality and food supply, that affect all life stages. The subcomponent water quality contains four variables, maximum temperature (V_1), minimum dissolved oxygen (V_3), pH (V_{13}), and base flow (V_{14}). All four variables have been demonstrated to affect the growth and survival of all life stages except embryo, whose water quality requirements are included with the embryo component. The subcomponent food supply contains three variables, substrate size (V_9), percent vegetation (V_{11}), and percent fines (V_{16}). Dominant substrate type (V_9) is included because the abundance of aquatic insects, an important food item for cutthroat trout, is correlated with substrate type. Variable V_{16}, percent fines in riffle-run and spawning areas, is included because the presence of excessive fines in riffle-run areas will reduce the production of aquatic insects. Variable V_{11} is included because allochthonous materials are an important source of nutrients to cold, unproductive trout streams. The waterflow of all streams fluctuate on an annual seasonal cycle. It has been demonstrated that a correlation exists between the average annual daily streamflow and the annual low base flow period in maintaining desirable stream habitat features for all life stages. Variable V_{14} is included to quantify the relationship between annual water flow fluctuations and trout habitat suitability.

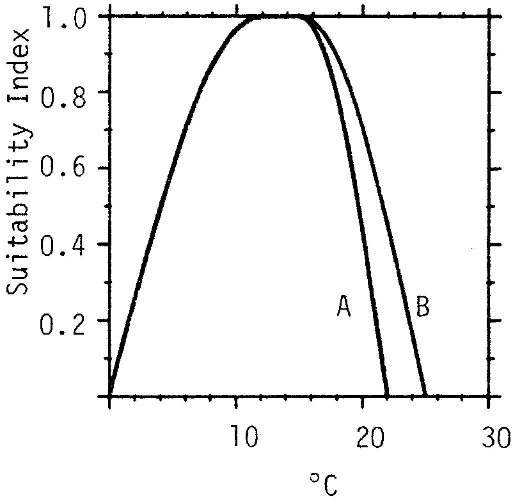
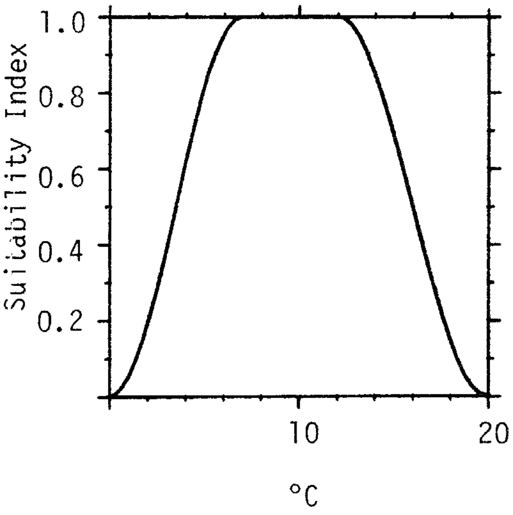
Variables V_{12} and V_{17} are optional variables to be used only when needed and appropriate. Percentage of streamside vegetation, V_{12}, is an important means of controlling soil erosion, a major source of fines in streams. Variable V_{17}, percentage of mid-day shade, is included because studies have shown that the amount of shade can affect water temperature and photosynthesis in streams. Variables V_{12} and V_{17} are used primarily for streams ≤ 50 m wide with temperature, photosynthesis, or erosion problems or when changes in the riparian vegetation are part of a potential project plan.

Suitability Index (SI) Graphs for Model Variables

This section contains suitability index graphs for 17 model variables. Equations and instructions for combining groups of variable SI scores into component scores and component scores into cutthroat trout HSI scores are included.

The graphs were constructed by quantifying information on the effect of each habitat variable on the growth, survival, or biomass of cutthroat trout. The curves were built on the assumption that increments of growth, survival, or biomass originally plotted on the y-axis of the graph could be directly converted into an index of suitability from 0 to 1.0 for the species; 0 indicates unsuitable conditions and 1.0 indicates optimal conditions. Graph trend lines represent the author's best estimate of suitability for the various levels of each variable presented. The graphs have been reviewed by biologists familiar with the ecology of the species, but obviously some degree of SI variability exists. The user is encouraged to vary the shape of the graphs when existing regional information indicates that the variable suitability relationship is different.

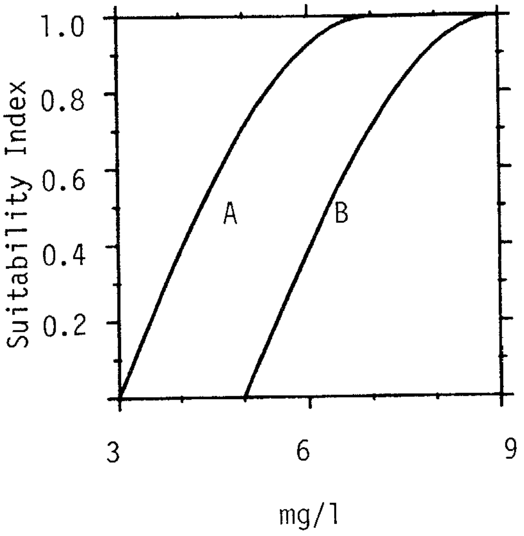
The habitat measurements and SI graph construction are based on the premise that it is the extreme, rather than the average, values of a variable that most often limit the carrying capacity of a habitat. Thus, measurement of extreme conditions, e.g., maximum temperatures and minimum dissolved oxygen levels, are often the data used with the graphs to derive the SI values for the model. The letters R and L in the habitat column identify variables used to evaluate riverine (R) or lacustrine (L) habitats.

Habitat	Variable		Suitability Graph
R,L	(V_1)	Average maximum water temperature (°C) during the warmest period of the year (adult, juvenile, and fry). For lacustrine habitats, use temperature strata nearest optimal in dissolved oxygen zones of > 3 mg/l. A = General B = Lahontan Basin	
R	(V_2)	Average maximum water temperature (°C) during embryo development.	

R,L (V_3) Average minimum dissolved oxygen (mg/l) during the late growing season low water period and during embryo development (adult, juvenile, fry, and embryo).

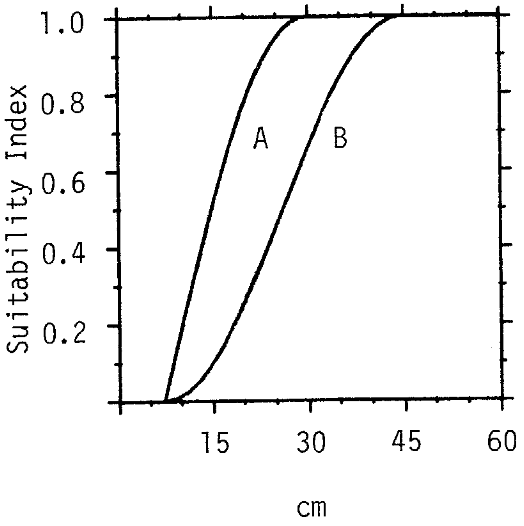
For lacustrine habitats, use the dissolved oxygen readings in temperature zones nearest to optimal where dissolved oxygen is > 3 mg/l.

A = ≤ 15° C
B = > 15° C

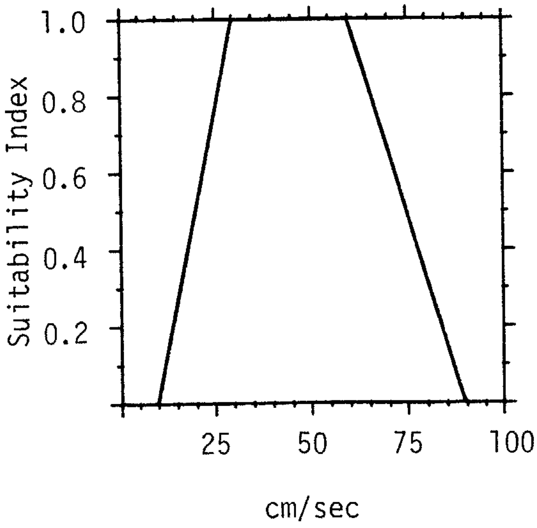


R (V_4) Average thalweg depth (cm) during the late growing season low water period.

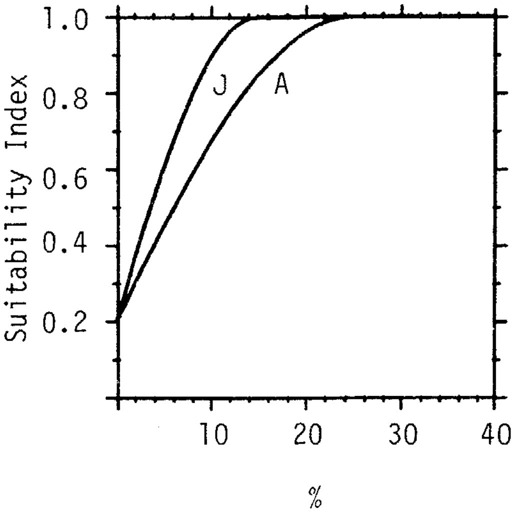
A = ≤ 5 m stream width
B = > 5 m stream width



R (V_5) Average velocity (cm/sec) over spawning areas during embryo development.

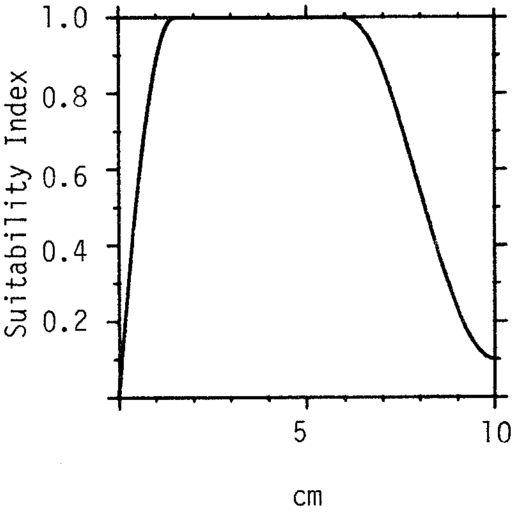


R (V_6) Percent cover during the late growing season low water period at depths ≥ 15 cm and velocities < 15 cm/sec.
J = Juveniles
A = Adults

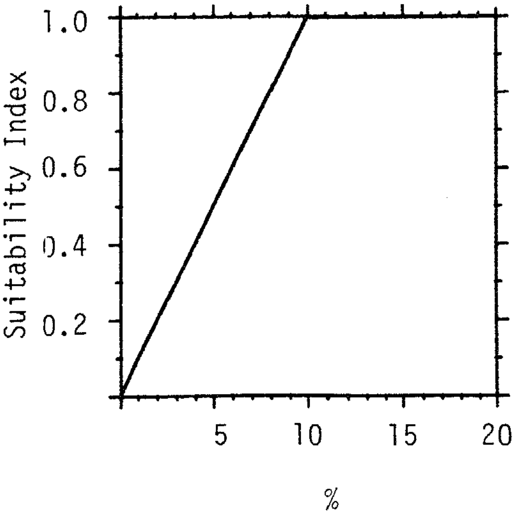


R (V_7) Average size of substrate between 0.3-8 cm diameter in spawning areas, preferably during the spawning period.

To derive an average value for use with graph V_7, include areas containing the best spawning substrate sampled until all potential spawning sites are included or until the sample contains an area equal to 5% of the total cutthroat habitat being evaluated.



R (V_8) Percent substrate size class (10-40 cm) used for winter and escape cover by fry and small juveniles.

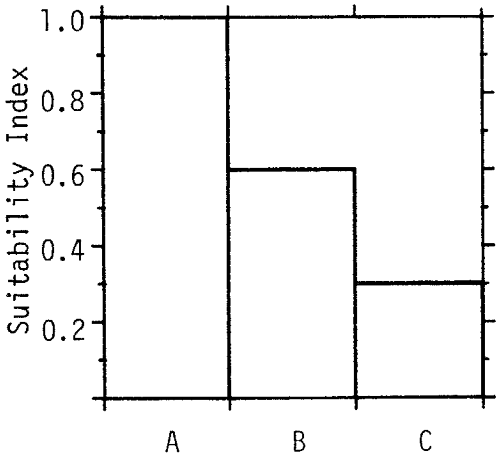


R (V_9) Dominant (≥ 50%) substrate type in riffle-run areas for food production.

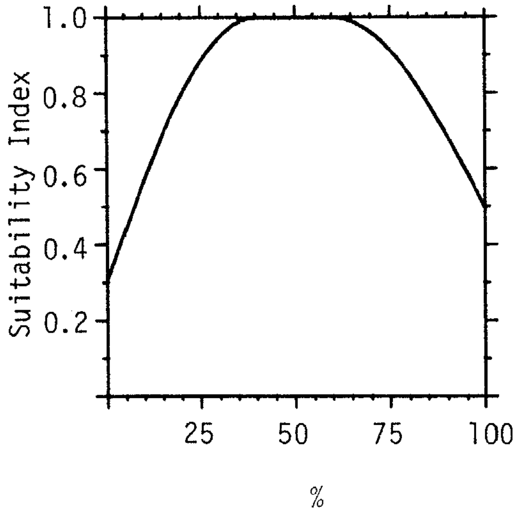
A) Rubble or small boulders or aquatic vegetation in spring areas dominant with limited amounts of gravel, large boulders, or bedrock.

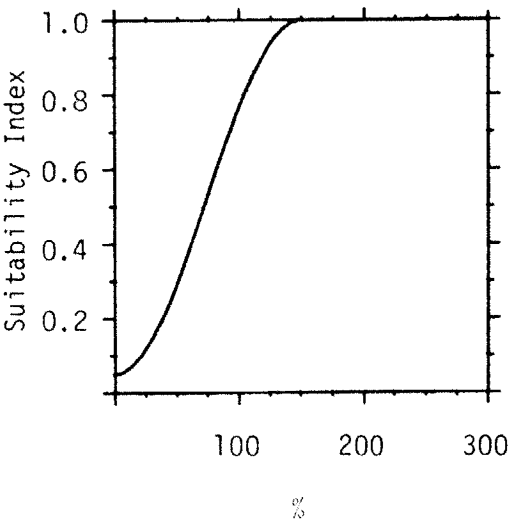
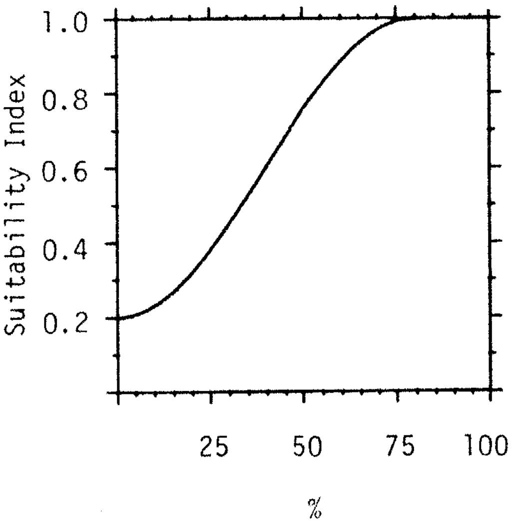
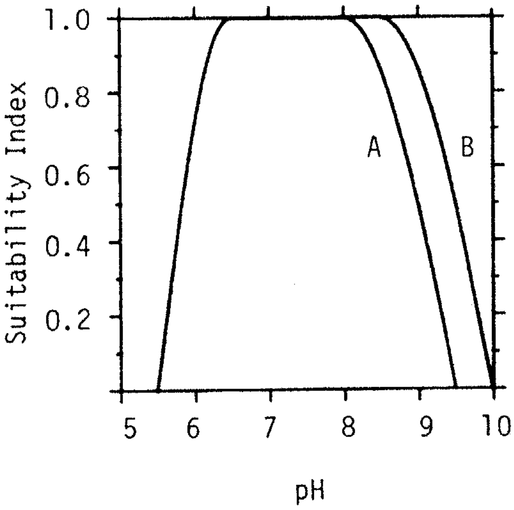
B) Rubble, gravel, boulders, and fines occur in approximately equal amounts or gravel is dominant. Aquatic vegetation may or may not be present.

C) Fines, bedrock, or large boulders are dominant. Rubble and gravel are insignificant (≤ 25%).

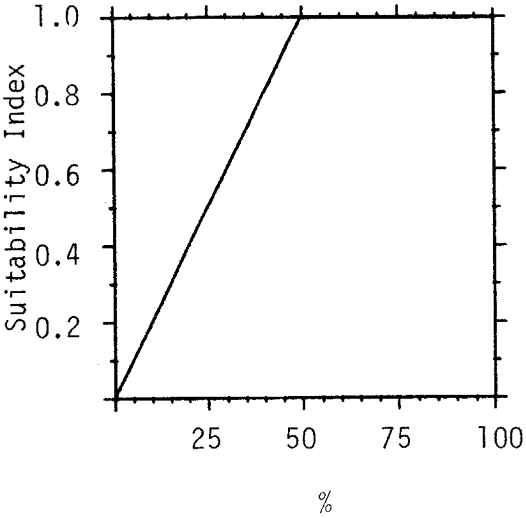


R (V_{10}) Percent pools during the late growing season low water period.



R	(V_{11})	Average percent vegetation (trees, shrubs, and grasses-forbs) along the streambank during the summer for allochthonous input. Vegetation Index = 2 (% shrubs) + 1.5 (% grasses) + (% trees) + 0 (% bareground). (For streams ≤ 50 m wide)	
R	(V_{12}) (Optional)	Average percent rooted vegetation and stable rocky ground cover along the streambank during the summer (erosion control).	
R,L	(V_{13})	Annual maximal or minimal pH. Use the measurement with the lowest SI value. For lacustrine habitats, measure pH in the zone of the best combination of dissolved oxygen and temperature. A = General B = Lahontan Basin	

R (V_{14}) Average annual base flow regime during the late summer or winter low flow period as a percentage of the average annual daily flow.



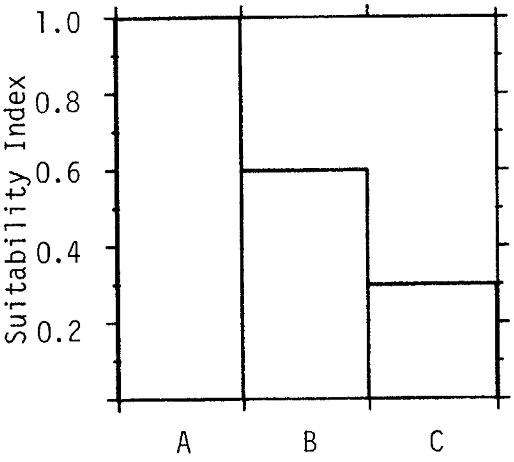
R (V_{15}) Pool class rating during the late growing season low flow period. The rating is based on the % of the area containing pools of 3 classes as described below.

A) ≥ 30% of the area is comprised of 1st-class pools.

B) ≥ 10%-< 30% 1st-class pools or ≥ 50% 2nd-class pools.

C) < 10% 1st-class pools and < 50% 2nd-class pools.

(See pool class descriptions below)



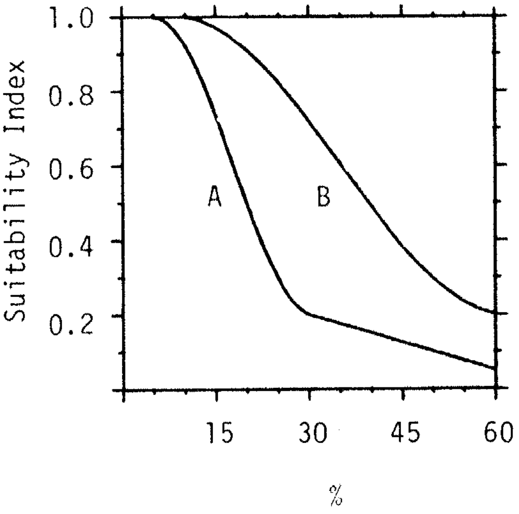
A) First-class pool: Large and deep. Pool depth and size are sufficient to provide a low velocity resting area for several adult trout. More than 30% of the pool bottom is obscure due to depth, surface turbulence, or the presence of structures, e.g., logs, debris piles, boulders, or overhanging banks and vegetation. Or, the greatest pool depth is ≥ 1.5 m in streams ≤ 5 m wide or ≥ 2 m deep in streams > 5 m wide.

B) Second-class pool: Moderate size and depth. Pool depth and size are sufficient to provide a low velocity resting area for a few adult trout. From 5 to 30% of the bottom is obscure due to surface turbulence, depth, or the presence of structures. Typical second class pools are large eddies behind boulders and low velocity, moderately deep areas beneath overhanging banks and vegetation.

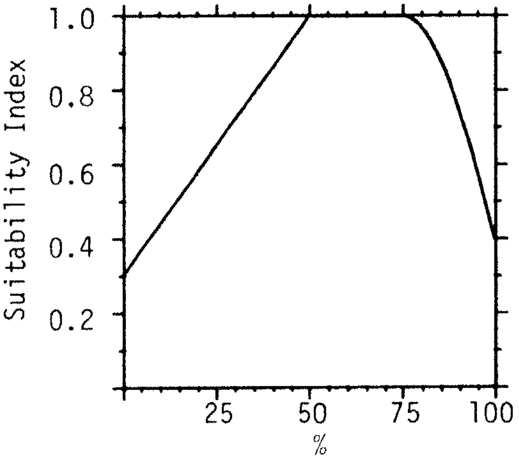
C) Third-class pool: Small or shallow or both. Pool depth and size are sufficient to provide a low velocity resting area for one to very few adult trout. Cover, if present, is in the form of shade, surface turbulence, or very limited structure. Typical third-class pools are wide, shallow pool areas of streams or small eddies behind boulders. Virtually the entire bottom area is discernable.

R (V$_{16}$) Percent fines (< 3 mm) in riffle-run and in spawning areas during average summer flows.

A = Spawning
B = Riffle-run



R (V$_{17}$) (Optional) Percent of stream area shaded between 1000 and 1400 hrs (for streams ≤ 50 m wide). Do not use on cold (<18°C) unproductive streams.



References to sources of data and the assumptions used to construct the above suitability index graphs for cutthroat trout HSI models are presented in Table 1.

Table 1. Data sources for cutthroat trout suitability indices.

	Variable and source	Assumption
V_1	Needham and Jones 1959 Bell 1973 Behnke and Zarn 1976 Behnke 1979 Dwyer and Kramer 1975	Average maximal daily water temperatures have a greater effect on trout growth and survival than minimal temperatures. The maximal temperature related with the greatest scope for activity is optimum.
V_2	Snyder and Tanner 1960 Bell 1973 Calhoun 1966	The average maximal daily water temperature during the embryo development period related to the highest survival and normal development of the embryo is optimum. Those temperatures that reduce survival are suboptimum.
V_3	Doudoroff and Shumway 1970 Trojnar 1972 Sekulich 1974	The average minimal daily dissolved oxygen level during embryo development and the late growing season that is related to the greatest growth and survival of cutthroat trout and trout embryos is optimal. Those that reduce survival and growth are suboptimum.
V_4	Delisle and Eliason 1961 Estimated by authors	The average thalweg depths that provide the best combination of pools, instream cover, and instream movement of adult trout is optimum.
V_5	Thompson 1972 Hooper 1973 Hunter 1973	The average velocities over spawning areas affect the suitability with which dissolved oxygen and waste products are carried to and from the developing embryos. Average velocities which result in the highest survival of embryos are optimum. Those that result in reduced survival are suboptimum.

Table 1 (continued)

Variable and source	Assumption
V_6 Boussu 1954 Elser 1968 Lewis 1969	Trout standing crops are correlated with the amount of usable cover present. Usable cover is associated with water $\geq$ 15 cm deep and velocities $\leq$ 15 cm/sec. These conditions are associated more with pool than riffle conditions. The best ratio of habitat conditions is about 50% pool to 50% riffle areas. Not all of a pool's area provides usable cover. Thus, it is assumed that optimal cover conditions for trout streams can be reached at $<$ 50% of the total area.
V_7 Bjornn 1969 Phillips et al. 1975 Duff 1980	The average size of spawning gravel that is correlated with the best water exchange rates, proper redd construction, and highest fry survival is assumed to be optimum for average sized cutthroat trout. The percentage of total spawning area needed to support a good trout population was calculated from the following assumptions: 1. Excellent riverine trout habitat will support about 500 kg/hectare. 2. Spawners comprise about 80% of the weight of the population. 500 kg x 80% = 400 kg of spawners. 3. Cutthroat adults average about 0.2 kg each $\frac{400\text{ kg}}{0.2\text{ kg}}$ = 2,000 adult spawners 4. There are two adults per redd $\frac{2{,}000}{2}$ = 1,000 pairs 5. Each redd covers $\geq$ 0.5 m^2 1,000 x 0.5 = 500 m^2 per hectare 6. There are 10,000 m^2 per hectare $\frac{500}{10{,}000}$ = 5% of total area

Table 1 (continued)

Variable	and source	Assumption
V_8	Hartman 1965 Everest 1969 Bustard and Narver 1975a, b	The substrate size range selected for escape and winter cover by cutthroat fry and small juveniles is assumed to be optimum.
V_9	Pennak and Van Gerpen 1947 Hynes 1970 Binns and Eiserman 1979	The dominant substrate type containing the greatest numbers of aquatic insects is assumed to be optimum for insect production.
V_{10}	Needham 1940 Elser 1968 Hunt 1971 Horner and Bjornn 1976	The percent pools during late summer low flows that is associated with the greatest trout abundance is optimum.
V_{11}	Idyll 1942 Delisle and Eliason 1961 Chapman 1966 Hunt 1975	The average percent vegetation along the streambank is related to the amount of allochthanous materials deposited annually in the stream. Shrubs are the best source of allochthanous materials, followed by grasses and forbs, and then trees. The vegetational index is a reasonable approximation of optimal and suboptimal conditions for most trout stream habitats.
V_{12}	Anonymous 1979 Raleigh and Duff 1981	The average percent rooted vegetation and rocky ground cover that provides adequate erosion control to the stream is optimum.
V_{13}	Hartman and Gill 1968 Platts 1974 Sekulich 1974 Behnke and Zarn 1976 Binns 1977	The average annual maximal or minimal pH levels related to high survival of trout are optimum.
V_{14}	Binns 1979 Adapted from Duff and Cooper 1976	Flow variations affect the amount and quality of pools, instream cover, and water quality. Average annual base flows associated with the highest standing crops are optimum.

Table 1 (concluded)

Variable	and source	Assumption
V_{15}	Lewis 1969 Raleigh (in press)	Pool classes associated with the highest standing crops of trout are optimum.
V_{16}	Bjornn 1969 Cordone and Kelly 1961 Platts 1974 McCuddin 1977 Crouse et al. 1981	The percent fines associated with the highest standing crops of food organisms, embryos, and fry in each designated area is optimum.
V_{17}	Sabean 1976, 1977 Anonymous 1979	The percent of stream area shaded that is associated with optimal water temperatures and photosynthesis rates is optimum.

The above references include data from studies on related salmonid species. This information has been selectively used to supplement, verify, or complete data gaps on the habitat requirements of cutthroat trout.

Riverine Model

This model uses a life stage approach with five components: adult, juvenile, fry, embryo, and other.

Adult (C_A). C_A variables: V_4, V_5, V_{10}, and V_{15}

Case 1: where V_6 is $> (V_{10} \times V_{15})^{1/2}$

$$C_A = [V_4 \times V_6 (V_{10} \times V_{15})^{1/2}]^{1/3}$$

Case 2: where V_6 is $\leq (V_{10} \times V_{15})^{1/2}$

$$C_A = [V_4 (V_{10} \times V_{15})^{1/2}]^{1/2}$$

If V_4 or $(V_{10} \times V_{15})^{1/2}$ is ≤ 0.4 in either equation, then C_A = the lowest factor score.

Juvenile (C_J). C_J variables: V_6, V_{10}, and V_{15}

$$C_J = \frac{V_6 + V_{10} + V_{15}}{3}$$

or, if any variable is ≤ 0.4, then C_J = the lowest variable score.

Fry (C_F). C_F variables: V_8, V_{10}, and V_{16}

$$C_F = [V_{10} (V_8 \times V_{16})^{1/2}]^{1/2}$$

or, if V_{10} or $(V_8 \times V_{16})^{1/2}$ is ≤ 0.4, then C_F = the lowest factor score.

Embryo (C_E). C_E variables: V_2, V_3, V_5, V_7, and V_{16}

Steps:

A. A potential spawning site is an ≥ 0.5 m² area of gravel 0.3-8.0 cm in size covered by flowing water ≥ 15 cm deep. At each spawning site sampled, record:

1. The average water velocity over the site;
2. The average size of all gravel 0.3-8.0 cm;
3. The percentage of fines < 0.3 cm in the gravel; and
4. The total area in m² of each site.

B. Derive a spawning site suitability index (V_s) for each site by combining V_5, V_7, and V_{16} values for each site.

$$V_s = (V_5 \times V_7 \times V_{16})^{1/3}$$

C. Derive a weighted average ($\bar{V}_s$) for all sites included in the sample.

Select the best V_s scores until all sites are included, or until a total spawning area equal to, but not exceeding, 5% of the total cutthroat trout habitat has been included, whichever comes first.

$$\bar{V}_s = \frac{\sum_{i=1}^{n} A_i \, V_{si}}{\text{total habitat area}} / 0.05 \text{ (output cannot > 1.0)}$$

where: A_i = the area of each spawning site in m², but ΣA_i cannot exceed 5% of the total cutthroat habitat.

V_{si} = the individual SI scores from the best spawning areas until all spawning sites have been included or until SI's from an area equal to 5% of the total cutthroat habitat being evaluated has been included, whichever occurs first.

D. Derive C_E

C_E = the lowest score of V_2, V_3, or $\bar{V}_s$

Other (C_O). C_O variables: V_1, V_3, V_9, V_{11}, V_{12}, V_{13}, V_{14}, V_{16}, and V_{17}

$$C_O = \left[\frac{(V_9 \times V_{16})^{1/2} + V_{11}}{2} \times (V_1 \times V_3 \times V_{12} \times V_{13} \times V_{14} \times V_{17})^{1/N}\right]^{1/2}$$

where: N = the number of variables within the parentheses. Note that variables V_{12} and V_{17} are optional and, therefore, may be omitted (see page 18).

HSI determination. HSI scores may be derived for a single life stage, a combination of two or more life stages, or all life stages combined. In all cases, except for the embryo component (C_E), an HSI is obtained by combining one or more life stage component scores with the other component (C_O) score.

1. Equal Component Value Method. The equal component value method assumes that each component exerts equal influence in determining HSI. This method should be used to determine HSI unless information exists that individual components should be weighted differently. Components: C_A, C_J, C_F, C_E, and C_O

   $$HSI = (C_A \times C_J \times C_F \times C_E \times C_O)^{1/N}$$

   or, if any component is ≤ 0.4, then HSI = the lowest component value, or if C_A is < the equation value, then HSI = C_A.

   where: N = the number of components in the equation.

   Solve the equation for the number of components to be included in the evaluation. There will be a minimum of two, one or more life stage components and the component (C_O), unless only the embryo life stage (C_E) is being evaluated; then HSI = C_E.

2. Unequal Component Value Method. This method also uses a life stage approach with five components: adult (C_A), juvenile (C_J), fry (C_F), embryo (C_E), and other (C_O). However, the C_O component is divided into two subcomponents, food (C_{OF}) and water quality (C_{OQ}). It is assumed that the C_{OF} subcomponent can either increase or decrease the suitability of

the habitat by its effect on growth at each life stage except embryo. The C_{OQ} subcomponent is assumed to exert an influence equal to the combined influence of all other model components in determining habitat suitability. The method also assumes that water quality is excellent, $C_{OQ} = 1$. When C_{OQ} is < 1, HSI is decreased. In addition, when a basis for weighting exists, model component and subcomponent weights can be increased by multiplying each index value by multipliers > 1. Model weighting procedures must be documented.

Components and subcomponents: C_A, C_J, C_F, C_E, C_{OF}, and C_{OQ}

Steps:

A. Calculate the subcomponents (C_{OF} and C_{OQ}) of C_O

$$C_{OF} = \frac{(V_9 \times V_{16})^{1/2} + V_{11}}{2}$$

$$C_{OQ} = (V_1 \times V_3 \times V_{13} \times V_{14})^{1/4}$$

or, if any variable is ≤ 0.4, then C_{OQ} = the value of the lowest variable.

B. Calculate HSI by either the noncompensatory or the compensatory option.

Noncompensatory option. This option assumes that degraded water quality conditions cannot be compensated for by good physical habitat conditions. This assumption is most likely true for small streams (≤ 5 m wide) and for persistent degraded water quality conditions.

$$HSI = (C_A \times C_J \times C_F \times C_E \times C_{OF})^{1/N} \times C_{OQ}$$

or, if any component is ≤ 0.4, then HSI = the lowest component value x C_{OQ}.

where: N = the number of components and subcomponents inside the parentheses or, if the model components or subcomponents have unequal weights, then N = Σ of weights selected.

If only the embryo component is being evaluated, then $HSI = C_E \times C_{OQ}$.

Compensatory option. This method assumes that moderately degraded water quality conditions can be partially compensated for by good physical habitat conditions. This assumption is useful for large rivers (≥ 50 m wide) and for temporary, or short term, poor water quality conditions.

1) $HSI' = (C_A \times C_J \times C_F \times C_E \times C_{OF})^{1/N}$

or, if C_A is ≤ 0.4, then $HSI' = C_A$

where: N = the number of components and subcomponents in the equation, or if the model components or subcomponents have unequal weights, then N = Σ of weights selected.

2) If C_{OQ} is < HSI' , then $HSI = HSI' \times [1 - (HSI' - C_{OQ})]$; if no
HSI = HSI'.

3) If only the embryo component is being evaluated, follow the procedure in step 2, substituting C_E for HSI'.

Lacustrine Model

The following model is available to evaluate cutthroat trout lacustrine habitat. The lacustrine model consists of two components: water quality and reproduction.

Water Quality (C_{WQ}). C_{WQ} variables: V_1, V_3, and V_{13}

$$C_{WQ} = (V_1 \times V_3 \times V_{13})^{1/3}$$

or, if the SI scores for V_1 or V_3 are ≤ 0.4, then C_{WQ} = the lowest SI score for V_1 or V_3.

Note: Lacustrine cutthroat require a tributary stream for spawning and embryo development. If the embryo life stage habitat is to be included in the evaluation, use the embryo component steps and equations in the riveri model above, except that the area of spawning gravel needed is only about of the total surface area of the lacustrine habitat.

Embryo (C_E). C_E variables: V_2, V_3, V_5, V_7, and V_{16}

$$\bar{V}_s = \frac{\sum_{i=1}^{n} A_i V_{si}}{\text{total habitat area}} / 0.01 \text{ (output cannot } > 1.0)$$

HSI determination.

$$HSI = (C_{WQ} \times C_E)^{1/2}$$

If only the lacustrine habitat is evaluated, then $HSI = C_{WQ}$.

Interpreting Model Outputs

Model HSI scores for individual life stages, composite life stages, or for the species are a relative indicator of habitat suitability for the evaluation element. The HSI models, in their present form, are not intended to consistently predict standing crops of fishes throughout the United States. Standing crop limiting factors, such as interspecific competition, predation, disease, water nutrient levels, and length of growing season, are not included in the aquatic HSI models. The models contain physical habitat variables important in maintaining viable populations of cutthroat trout. If the model is correctly structured, a high HSI score for a habitat would indicate near optimal regional conditions for cutthroat trout for those factors included in the model, intermediate HSI scores would indicate average habitat conditions, and low HSI scores would indicate poor habitat conditions. An HSI of 0 does not always mean that the species is not present. An HSI of 0 means that the habitat is very poor and the species will be scarce or absent.

Cutthroat trout tend to occupy riverine habitats with very few other fish species present. They are usually competitively excluded by other trout species. Thus, factors of disease, interspecific competition, and predation usually will have little effect on the model. When the cutthroat trout model is applied to cutthroat trout streams with similar water quality and length of growing season, it should be possible to calibrate the model output to reflect size of standing crops within some reasonable confidence limits. This possibility, however, has not been tested with the present model.

Sample data sets selected by the authors to represent high, intermediate, and low habitat suitabilities are given in Table 2, along with the SI's and HSI's generated by the cutthroat trout riverine model. The model outputs calculated from the sample data sets (Tables 3 and 4) reflect what the authors believe carrying capacity trends would be in riverine habitats with the listed characteristics; thus, the model meets the specified acceptance level.

Table 2. Sample data sets using the riverine cutthroat trout HSI model.

		Data set 1		Data set 2		Data set 3	
Variable		Data	SI	Data	SI	Data	SI
Max. temperature (°C)	V_1	14	1.0	15	1.0	16	1.0
Max. temperature (°C)	V_2	12	1.0	15	0.66	17	0.4
Min. dissolved O_2 (mg/l)	V_3	9	1.0	7	0.73	6	0.42
Ave. depth (cm)	V_4	25	0.9	18	0.6	18	0.6
Ave. velocity (cm/s)	V_5	30	1.0	25	0.7	20	0.57
% cover	V_6	20	A 0.95 J 1.0	10	A 0.65 J 0.92	10	A 0.65 J 0.92
Ave. gravel size (cm)	V_7	4	1.0	3	1.0	2.5	1.0
Dom. substrate size (cm)	V_8	15	1.0	8	0.7	8	0.7
Dom. substrate class	V_9	A	1.0	B	0.6	B	0.6
% pools	V_{10}	55	1.0	15	0.65	10	0.46
% Alloch. vegetation	V_{11}	225	1.0	175	1.0	200	1.0
% bank vegetation	V_{12}	95	1.0	50	0.6	40	0.5
Max. pH	V_{13}	7.1	1.0	7.2	1.0	7.2	1.0
% Ann. base flow	V_{14}	37	0.8	30	0.6	25	0.5
Pool class	V_{15}	A	1.0	B	0.6	C	0.3
% fines (A)	V_{16}	5	1.0	20	0.5	20	0.5
% fines (B)	V_{16}	15	0.9	30	0.6	30	0.6
% shade	V_{17}	60	1.0	60	1.0	60	1.0

Table 3. Average value method.

Variable	Data set 1		Data set 2		Data set 3	
	Data	SI	Data	SI	Data	SI
Component						
C_A		0.95		0.62		0.37
C_J		1.00		0.77		0.37
C_F		0.97		0.65		0.55
C_E		1.00		0.66		0.40
C_O		0.96		0.78		0.40
Species HSI		0.98		0.70		0.37

Table 4. Average value, probability method.

Variable	Data set 1		Data set 2		Data set 3	
	Data	SI	Data	SI	Data	SI
Component						
C_A		0.95		0.62		0.37
C_J		1.0		0.77		0.37
C_F		0.97		0.65		0.55
C_E		1.00		0.66		0.40
C_{OF}		0.97		0.80		0.80
C_{OQ}		0.96		0.80		0.67
Species HSI						
Noncompensatory		0.94		0.56		0.25
Compensatory		0.96		0.70		0.37

ADDITIONAL HABITAT MODELS

Model 1

Optimal riverine cutthroat trout habitat is characterized by:

1. Clear cold water with an average maximum summer temperature of < 22° C;
2. An approximate 1:1 pool-riffle ratio;
3. Well vegetated, stable stream banks;
4. ≥ 25% of stream area providing cover;
5. Relatively stable water flow regime, < 50% annual fluctuation from average annual daily flow;
6. Relatively stable summer temperature regime, averaging about 13° C ± 4° C; and
7. A relatively silt free rocky substrate in riffle-run areas.

$$HSI = \frac{\text{number of attributes present}}{7}$$

Model 2

A riverine trout habitat model by Binns and Eiserman (1979). Transpose the model output of pounds per acre to an index of 0-1.

$$HSI = \frac{\text{model output of pounds per acre}}{\text{regional optimal pounds per acre}}$$

Model 3

Optimal lacustrine cutthroat habitat is characterized by:

1. Clear, cold water with an average summer midepilimnion temperature of < 22° C;
2. A midepilimnion pH of 6.5 to 8.5;
3. Dissolved oxygen content of epilimnion of ≥ 8 mg/l; and

4. Access to riverine spawning tributaries.

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

Model 4

A low effort system for predicting habitat suitability of planned cool water and cold water reservoirs as habitat for individual fish species by McConnell et al. (1982).

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50272 -101

REPORT DOCUMENTATION PAGE

1. REPORT NO. FWS/OBS-82/10.5

2.

3. Recipient's Accession No.

4. Title and Subtitle

Habitat Suitability Index Models: Cutthroat trout

5. Report Date February 1982

6.

7. Author(s)

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8. Performing Organization Rept. No.

9. Performing Organization Name and Address

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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 Widlife Service
U.S. Department of Interior
Washington, D.C. 20240

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

Cutthroat trout (Salmo clarki) characteristics are described, including distribution, age, growth, food, reproduction and anadromy. A detailed literature review of specific habitat requirements is also included. 17 habitat variables are then evaluated and quantified in suitability index graphs. These data are subsequently synthesized into Habitat Suitability Index (HSI) models for the cutthroat trout.

This is one in a series of publications developed to provide information on the habitat requirements of selected fish and wildlife species. HSI models are designed to provide information for use in impact assessment and habitat management activities. The HSI technique is a corollary to the U.S. Fish and Wildlife Service's Habitat Evaluation Procedures.

17. Document Analysis a. Descriptors

Habitability
Fishes

b. Identifiers/Open-Ended Terms

Habitat
Habitat Suitability Index
Cutthroat trout
Salmo clarki

c. COSATI Field/Group

18. Availability Statement

Unlimited

19. Security Class (This Report) Unclassified

20. Security Class (This Page) Unclassified

21. No. of Pages 38

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—578-127/189 REGION No. 8