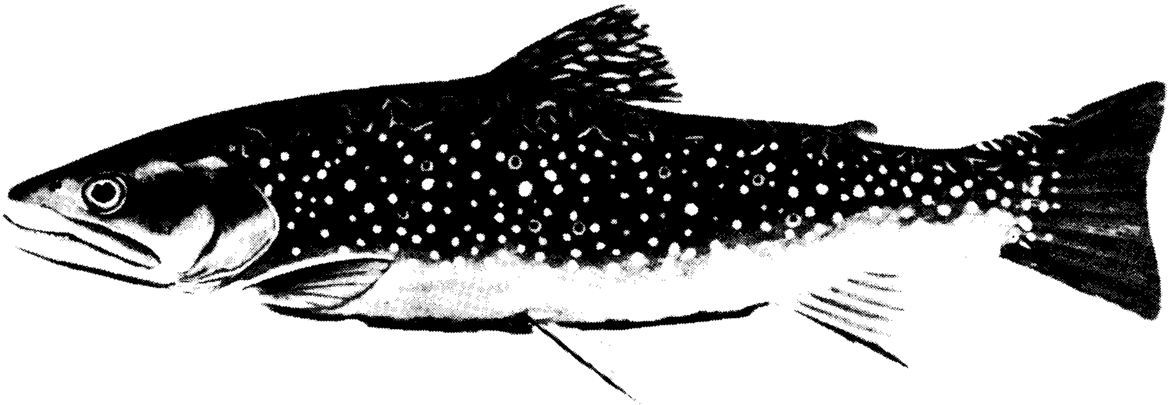
Biological Services Program
and
Division of Ecological Services

FWS/OBS-82/10.24
SEPTEMBER 1982

HABITAT SUITABILITY INDEX MODELS: BROOK TROUT



h and Wildlife Service

. Department of the Interior

FWS/OBS-82/10.24
September 1982

HABITAT SUITABILITY INDEX MODELS: BROOK TROUT

by

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

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

This report should be cited as:

Raleigh, R. F. 1982. Habitat suitability index models: Brook trout. U.S. Dept. Int., Fish Wildl. Serv. FWS/OBS-82/10.24. 42 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 Terrell et al. (in press)[1]. A discussion of HSI model building techniques, including the component approach, is presented in U.S. Fish and Wildlife Service (1981).[2]

The HSI models presented herein are complex hypotheses of species-habitat relationships, not statements of proven cause and effect relationships. Results of model performance tests, when available, are referenced; however, models that have demonstrated reliability in specific situations may prove

---

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

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

unreliable in others. For this reason, the U.S. Fish and Wildlife Service encourages model users to send comments and suggestions that might help us increase the utility and effectiveness of this habitat-based approach to fish and wildlife planning. Please send comments to:

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

CONTENTS

Page

PREFACE iii
ACKNOWLEDGMENTS vi

HABITAT USE INFORMATION 1
    General 1
    Age, Growth, and Food 2
    Reproduction 2
    Migratory and Anadromy 2
    Specific Habitat Requirements 3
HABITAT SUITABILITY INDEX (HSI) MODELS 8
    Model Applicability 10
    Model Description - Riverine 10
    Suitability Index (SI) Graphs for Model Variables 12
    Riverine Model 24
    Lacustrine Model 28
    Interpreting Model Outputs 29
ADDITIONAL HABITAT MODELS 30
    Model 1 30
    Model 2 34
    Model 3 34

REFERENCES 34

ACKNOWLEDGMENTS

Tom Weshe, University of Wyoming; Robert Behnke, Colorado State University; Allan Binns, Wyoming Game and Fish Department; and Fred Eiserman, ETSI Pipeline Project provided a comprehensive review and many helpful comments and suggestions on the manuscript. Charles Haines, Colorado Division of Wildlife, and Joan Trial, Maine Cooperative Fishery Unit, completed a literature review to develop the report. Charles Solomon also reviewed the manuscript, provided comments, and prepared the final manuscript for publication. Cathy Short conducted the editorial review, and word processing was provided by Dora Ibarra and Carolyn Gulzow. The cover illustration is from Freshwater Fishes of Canada, Bulletin 184, Fisheries Research Board of Canada, by W. B. Scott and E. J. Crossman.

BROOK TROUT (Salvelinus fontinalis)

HABITAT USE INFORMATION

General

The native range of brook trout (Salvelinus fontinalis Mitchill) originally covered the eastern two-fifths of Canada northward to the Arctic Circle, the New England States, and southward through Pennsylvania, along the crest of the Appalachian Mountains to northeastern Georgia. Western limits included Manitoba southward through the Great Lake States. Reductions in the original range have resulted from environmental changes, such as pollution, siltation, and stream warming due to deforestation (MacCrimmon and Campbell 1969).

Since the late 19th century, brook trout have been introduced into 20 additional States and have sustaining populations in 14 States (MacCrimmon and Campbell 1969). Introductions have not been attempted in most of the central plains and the southern States.

Brook trout can be separated into two basic ecological forms: a short-lived (3-4 years), small (200-250 mm) form, typical of small, cold stream and lake habitats and a long-lived (8-10 years), large (4-6 kg), predaceous form associated with large lakes, rivers, and estuaries. The smaller, short-lived form is typically found south of the Great Lakes region and south of northern New England, while the larger form is located in the northern portion of its native range (Behnke 1980). Although no subspecies designation has been recognized for these two forms, they respond as two different species to environmental interactions influencing life history (Flick and Webster 1976; Flick 1977).

Brook trout can be hybridized artificially with lake trout (to produce a fertile hybrid called splake trout) and with rainbow trout (Buss and Wright 1957). In rare cases, natural hybrids occur between brook trout and brown trout (Salmo trutta); the hybrid is termed tiger trout (Behnke 1980). Behnke (1980) also collected brook trout and bull trout (Salvelinus confluentis) hybrids in the upper Klamath Lake basin, Oregon. Brook trout appear to be sensitive to introductions of brown and rainbow trout and are usually displaced by them. However, brook trout have displaced cutthroat trout and grayling in headwaters and tributaries of western streams (Webster 1975).

Age, Growth, and Food

Brook trout appear to be opportunistic sight feeders, utilizing both bottom-dwelling and drifting aquatic macroinvertebrates and terrestrial insects (Needham 1930; Dineen 1951; Wiseman 1951; Benson 1953; Reed and Bear 1966). Such feeding habits make them particularly susceptible to even moderate turbidity levels, which can reduce their ability to locate food (Bachman 1958; Herbert et al. 1961a, 1961b; Tebo 1975). Drifting forms may be selected over benthic forms when they are available (Hunt 1966). The choice of particular drift organisms is apparently either a function of seasonal availability and/or the overall availability of terrestrial forms in a particular situation. Between age groups, there may be a tendency for selection of food items based on size. In Idaho, age group 0 trout selected smaller drifting organisms (Diptera and Ephemeroptera) with less variation than did older trout, while age group I trout seemed to prefer larger Trichoptera larvae (Griffith 1974). Fish are an important food item in lake populations (Webster 1975).

Reproduction

Age at sexual maturity varies among populations, with males usually maturing before females (Mullen 1958). Male brook trout may mature as early as age 0+ (Buss and McCreary 1960; Hunt 1966). In Wisconsin (Lawrence Creek), the smallest mature male was approximately 8.9 cm (3.5 inches) long (McFadden 1961).

Spawning typically occurs in the fall and has been described by several authors (Greeley 1932; Hazzard 1932; Smith 1941; Brasch et al. 1958, Needham 1961). Spawning may begin as early as late summer in the northern part of the range and early winter in the southern part of the range (Sigler and Miller 1963). The spawning behavior of brook trout is very similar to that of rainbow and cutthroat trout (Smith 1941). In streams and ponds, areas of ground water upwelling appear to be highly preferred (Webster and Eiriksdottier 1976; Carline and Brynildson 1977) and to override substrate size as a site selection factor (Mullen 1958; Everhart 1966). Brook trout can be highly successful spawners in lentic environments in upwelling areas of springs (Webster 1975). Spawning occurs at temperatures ranging from 4.5-10° C (White 1930; Hazzard 1932; McAfee 1966). The fertilized ova are deposited in redds excavated by the female in the stream gravels (Smith 1947). Spawning success is reduced as the amount of fine sediments is increased and the intergravel oxygen concentration is diminished (McFadden 1961; Peters 1965; Harshbarger 1975).

Migration and Anadromy

With the exception of the sea-run New England populations, brook trout migrations are generally limited to movements into headwater streams or tributaries for spawning (Brasch et al. 1958) or relatively short seasonal migrations to avoid temperature extremes (Powers 1929; Scott and Crossman 1973). Some brook trout may spend their entire lives, including spawning periods, within a restricted stream area, as opposed to more migratory salmonids (McFadden et al. 1967). However, some movement upstream or downstream may occur due to space-related aggressive behavior following emergence from the redd (Hunt 1965).

Some coastal populations of brook trout may move into salt water from coastal streams of eastern Canada and northeastern United States. Sea-run individuals caught in salt water may differ in appearance, form, and coloration from trout that have never or have not recently been in salt water (Smith and Saunders 1958). Not all brook trout in the same stream will necessarily move to sea. In a study by White (1940), 79% of the brook trout going to sea were age 2, and the rest were age 3. Smith and Saunders (1958) stated that age 1 brook trout also migrated to the sea.

Smith and Saunders (1958) reported brook trout going to sea on Prince Edward Island during spring and early summer and during fall and early winter. Movement was observed in every month of the year, although very few fish were observed migrating during midwinter and midsummer. Smith and Saunders (1958) observed that approximately half of the brook trout migrating to salt water returned to freshwater within a month. As temperatures decline in freshwater, brook trout tend to spend more time in saltwater, and some may overwinter in saltwater (Smith and Saunders 1958).

Specific Habitat Requirements

Brook trout are the most generalized and adaptable of all *Salvelinus* species. They inhabit small headwater streams, large rivers, ponds, and large lakes in inland and coastal areas. Typical brook trout habitat conditions are those associated with a cold temperate climate, cool spring-fed ground water, and moderate precipitation (MacCrimmon and Campbell 1969). Warm water temperatures appear to be the single most important factor limiting brook trout distribution and production (Creaser 1930; Mullen 1958; McCormick et al. 1972). In a comparative distribution study between brook and brown trout from headwater tributaries of the South Platte River, Colorado, Vincent and Miller (1969) found that, as the elevation increased and the streams became smaller and colder, brook trout became more abundant.

Optimal brook trout riverine habitat is characterized by clear, cold spring-fed water; a silt-free rocky substrate in riffle-run areas; an approximate 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. Brook trout south of Canada tend to occupy headwater stream areas, especially when rainbow and brown trout are present in the same river system (Webster 1975). They tend to inhabit large rivers in the northern portion of their native range (Behnke 1980).

Optimal lacustrine habitat is characterized as clear, cold lakes and ponds that are typically oligotrophic. Brook trout are typically stream spawners, but spawning commonly occurs in gravels surrounding spring upwelling areas of lakes and ponds.

Cover is recognized as one of the basic and 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) found that the amount of cover present was important in determining the number of trout in sections of a Montana stream. Cover for trout consists of areas of low stream bottom visibility, suitable water depths (> 15 cm), and low current velocity (< 15 cm/s) (Wesche 1980). Cover can be provided by overhanging vegetation, submerged vegetation, undercut banks, instream objects (stumps, logs, roots, and large rocks), rocky substrate, depth, and water surface turbulence (Giger 1973). In a study to determine the amount of shade utilized by brook, rainbow, and brown trout, Butler and Hawthorne (1968) reported that rainbow trout showed the lowest preference for shade produced by artificial surface cover. Brown trout showed the highest use of shade while brook trout were intermediate between brown and rainbow trout. Brook trout in two Michigan streams showed a strong preference for overhead cover along the stream margin (Enk 1977). The major limiting factor for brook trout in these streams was bank cover.

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 50-75% midday 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 ≥ 55% 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 Wesche 1974; Binns and Eiserman 1979; Wesche 1980).

Hunt (1976) listed average depth, water volume, average depth of pools, amount of pool area, and amount of overhanging bank cover as the most important parameters relating to brook trout carrying capacity in Lawrence Creek, Wisconsin. The main use of summer cover is probably for predator avoidance and resting. Salmonids occupy different habitat areas in the winter 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). Everest (1969) suggested that some salmonid population levels were regulated by the availability of suitable overwintering areas. Winter hiding behavior in salmonids is triggered by low temperatures (Chapman and Bjornn 1969; Everest 1969; Bustard and Narver 1975a,b). Bustard and Narver (1975a) indicated that, as water temperatures dropped to 4-8° C, feeding was reduced in young salmonids and most were found within or near cover; few were more than 1 m from potential cover. Everest (1969) found juvenile rainbows 15-30 cm deep in the substrate, which was often covered by 5-10 cm of anchor ice. Lewis (1969) reported that adult rainbow trout tended to move into deeper water during winter. The major advantages in seeking winter cover are prevention of physical damage from ice scouring (Hartman 1965; Chapman and Bjornn 1969) and conservation of energy (Chapman and Bjornn 1969; Everest 1969). A cover area ≥ 25% for adults and ≥ 15% for juveniles of the entire stream habitat appears adequate for most brook trout populations.

Optimum turbidity values for brook trout growth are approximately 0-30 JTU's, with a range of 0-130 JTU's (adapted from Sykora et al. 1972). An accelerated rate of sediment deposition in streams may reduce local brook trout production because of the adverse effects on production of food organisms, smothering of eggs and embryos in the redd, and loss of escape and overwintering habitat.

Brook trout appear to be more tolerant than other trout species to low pH (Dunson and Martin 1973; Webster 1975). Laboratory studies indicate that brook trout are tolerant of pH values of 3.5-9.8 (Daye and Garside 1975). Brook trout fingerlings in Pennsylvania inhabited a bog stream with a pH less than 4.75 and occassionally dropping to 4.0-4.2 (Dunson and Martin 1973). Parsons (1968) reported brook trout inhabiting a stream in Missouri with a pH of 4.1-4.2. Creaser (1930) believed that brook trout tolerated pH ranges greater than the range of most natural waters (4.1-9.5). Menendez (1976) demonstrated that continued exposure to a pH below 6.5 resulted in decreased hatching and growth in brook trout. The selection of spawning sites may be associated with the pH of upwelling water; neutral or alkaline waters (pH 6.7 and 8) were selected by brook trout held at pH levels of 4.0, 4.5, and 5.0 (Menendez 1976). The optimal pH range for brook trout appears to be 6.5-8.0, with a tolerance range of 4.0-9.5.

Brook trout occur in waters with a wide range of alkalinity and specific conductance, although high alkalinity and high specific conductance usually increase brook trout production (Cooper and Scherer 1967). Brook trout populations in the Smoky Mountains, North Carolina, are becoming increasingly restricted to low alkalinity headwater streams, apparently due to competition from introduced rainbow trout (*Salmo gairdneri*), and are frequently in poor condition (Lennon 1967). The small size of the trout in the headwater areas has been attributed to the infertility of the water, which has been linked to low total alkalinities (10 ppm or less) and TDS values less than 20 ppm. TDS values in the Smoky Mountains are lower than values from similar streams in Shenandoah National Park, Virginia, and the White Mountains National Forest, New Hampshire, where trout populations appear to be more robust.

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 1971; 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 40-60% pool area) appears to provide an optimum mix of trout food producing and rearing areas (Needham 1940). In riffle areas, the presence of fines (> 10%) reduces the production of invertebrate fauna (based on Cordone and Kelly 1961; Platts 1974).

Adult. The reported upper and lower temperature limits for adult brook trout vary; this may reflect local and regional population acclimation differences. Bean (1909) reported that brook trout will not live and thrive in temperatures warmer than 20° C. McAfee (1966) indicated that brook trout usually do poorly in streams where water temperature exceeds 20° C for extended periods. Brasch et. al (1958) reported that brook trout exposed to temperatures of 25° C for more than a few hours did not survive. Embody (1921) observed brook trout living in temperatures of 24-27° C for short durations and recommended 23.8° C as the maximum tolerable limit. Kendall (1924) agreed that 23.9° C represented the limit of even temporary endurance, but stated that the optimum temperature should not exceed 15.6° C. Hynes (1970) stated that brook trout can withstand temperatures from 0-25.3° C, but acclimation is necessary. The upper tolerable limit is raised by approximately 1° for every 7° rise in acclimation temperature up to 18° C, where it levels off at the absolute limit of 25.3° C. Fish kept at 24° C and above cannot tolerate temperatures as low as 0° C. Seasonal temperature cycles from summer highs to winter lows provide the necessary acclimation period needed to tolerate annual temperature extremes. The overall temperature range of 0-24° C was observed by MacCrimmon and Campbell (1969.

The above upper and lower tolerance limits probably do not reflect the range of temperatures that is most conducive to good growth. Baldwin (1951) cites an optimum growth rate at 14° C. He further contends that 11-16° C is best suited for overall welfare, while trout exist at a relative disadvantage in terms of activity and growth at higher and lower, albeit tolerable, temperatures. Mullen (1958) gave the optimum temperature range for activity and feeding for brook trout as between 12.8° C and 19° C. We assume that the temperature range for brook trout is 0-24° C, with an optimal range for growth and survival of 11-16° C.

Brook trout normally require high oxygen concentrations with optimum conditions at dissolved oxygen concentrations near saturation and temperatures above 15° C. Local or temporal variations should not decrease to less than 5 mg/l (Mills 1971). Dissolved oxygen requirements vary with age of fish, water temperature, water velocity, activity level, and concentration of substances in the water (McKee and Wolf 1963). As temperatures increase, the dissolved oxygen saturation level in the water decreases, while the dissolved oxygen requirements of the fish increases. As a result, an increase in temperature resulting in a decrease in dissolved oxygen can be detrimental to the fish. Optimum oxygen levels for brook 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. In the summer (temperatures ≥ 10° C), cutthroat trout generally avoid water with dissolved oxygen levels of less than 5 mg/l (Trojnar 1972; Sekulich 1974). Fry (1951) stated that the lowest dissolved oxygen concentrations where brook trout can exist is 0.9 ppm at 10° C and 1.6-1.8 ppm at 20° C. Embody (1927) contends that the dissolved oxygen concentration should not be less than 3 cc per liter (4.3 ppm).

Elson (1939) reported that brook trout prefer moderate flows. Griffith (1972) reported that focal point velocities for adult brook trout in Idaho ranged from 7-11 cm/sec, with a maximum of 25 cm/sec. In a Wyoming study, 95% of all brook trout observed were associated with point velocities of less than 15 cm/sec (Wesche 1974).

The carrying capacity of adult brook trout in streams is dependent, at least in part, on cover provided by pools, undercut banks, submerged brush and logs, large rocks, and overhanging vegetation (Saunders and Smith 1955, 1962; Elwood and Waters 1969; O'Connor and Power 1976). Enk (1977) reported that the biomass and number of brook trout ≥ 150 mm in size were significantly correlated with bank cover in two Michigan streams. Wesche (1980) reported that cover for adult trout should be located in stream areas with water depths ≥ 15 cm and velocities of < 15 cm/sec. We assume that an area ≥ 25% of the total stream area occupied by brook trout will provide adequate cover.

Embryo. —Temperatures in the range of 4.5-11.5° C have been reported as optimum for egg incubation (MacCrimmon and Campbell 1969). Length of egg incubation is about 45 days at 10° C, 165 days at 2.8° C (Brasch et al. 1958), and 28 days at 14.8° C (Embody 1934). Brook trout eggs develop slightly faster than brown trout eggs at 2° C or colder, but the reverse is true at 3° C or above (Smith 1947). We assume that the range of acceptable temperatures for brook trout embryos is similar to that for cutthroat trout (Salmo clarki).

Dissolved oxygen concentrations should not fall below 50% saturation in the redd for embryo development (Harshbarger 1975). We assume that oxygen requirements for embryos are similar to those of adults. Peters (1965) observed high mortality rates when water velocity in the redd was reduced. Water velocity is important in flushing out fines in the redds. Because brook trout can successfully spawn in spawning areas of lakes, velocity is not necessary for successful spawning as long as oxygen levels are high and the redd is free of silt. Spawning velocities for brook trout range from 1 cm/sec (Smith 1973) to 92 cm/sec (Thompson 1972; Hooper 1973). Spawning velocities measured for brook trout in Wyoming ranged from 3-34 cm/sec (Reiser and Wesche 1977).

Reiser and Wesche (1977) stated that optimum substrate size for brook trout embryos ranges from 0.34-5.05 cm. Duff (1980) reported a range of suitable spawning gravel size of 3-8 cm in diameter for trout. Most workers agree that both water velocity and dissolved oxygen in the intergravel environment determine the adequacy of the substrate for the hatching and survival of salmonid embryos and fry. Increases in sediment that alter gravel permeability reduces velocities and intergravel dissolved oxygen availability to the embryo and results in smothering of eggs (Tebo 1975). In a California study, brook trout survival was lower as the volume of materials less than 2.5 mm in diameter increased (Burns 1970). In a 30% sand and 70% gravel mixture, only 28% of implanted steelhead embryos hatched; of those that hatched, only 74%

emerged (Bjornn 1971; Phillips et al. 1975). We assume that suitable spawning gravel conditions include gravels 3-8 cm in size (depending on size of spawners) with ≤ 5% fines.

Fry. McCormick et al. (1972) cited temperature as an important limiting factor of growth and distribution of young brook trout. Fry emerge from gravel redds from January to April, depending on the local temperature regime (Brasch et al. 1958). Temperatures from 9.8-15.4° C were considered suitable, with 12.4-15.4° C optimum; temperatures greater than 18° C were considered detrimental. The optimum temperature for brook trout fry, in a laboratory study, was between 8-12°C (Peterson et al. 1979). Upper lethal temperatures are between 21 and 25.8° C (Brett 1940), possibly a reflection of different acclimatization temperatures. Latta (1969) reported that upwelling ground water was an important consideration for the well-being of fry in streams; Carline and Brynildson (1977) reported the same situation for fry in spring ponds. Menendez (1976) found that fry survival increased as pH increased from 5 to 6.5. Griffith (1972) reported that focal point velocities for brook trout fry in Idaho ranged from 8-10 cm/sec, with a maximum of 16 cm/sec. Because brook trout fry occupy the same stream reaches as adults, we assume that temperature and dissolved oxygen requirements for brook trout fry are similar to those for adults.

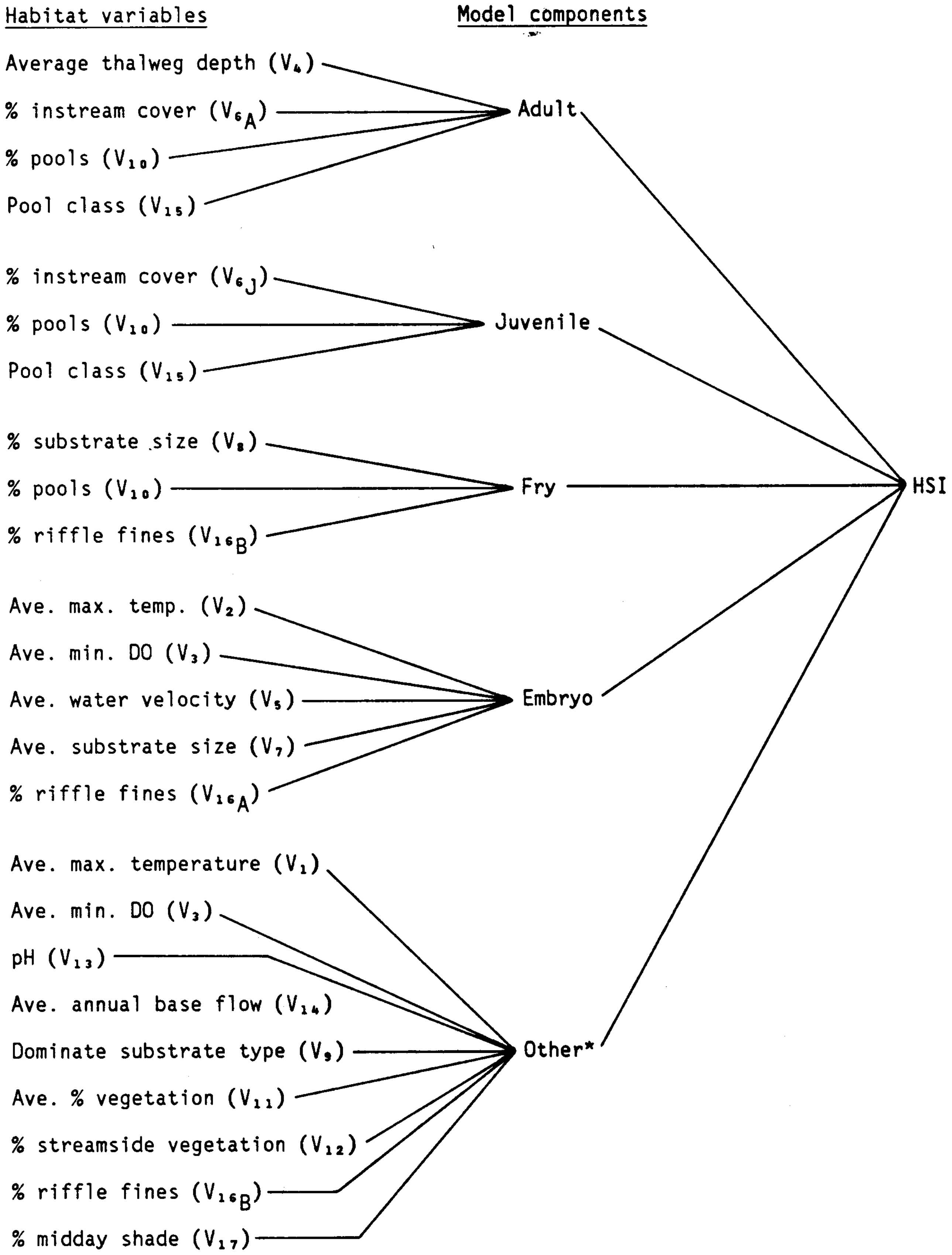
Trout fry usually overwinter in shallow areas of low velocity, with rubble being the principal cover (Everest 1969; Bustard and Narver 1975a). Optimum size of substrate used as winter cover by steelhead fry and small juveniles ranges from 10-40 cm in diameter (Hartman 1965; Everest 1969). A relatively silt-free area of substrate of this size class (10-40 cm), ≥ 10% of the total habitat, will probably provide adequate cover for brook trout fry and small juveniles. The use of smaller diameter rocks for winter cover may result in increased mortality due to shifting of the substrate (Bustard and Narver 1975a).

Juvenile. Davis (1961) stated that temperatures of 11-14° C are optimum for fingerling growth. Griffith (1972) reported focal point velocities for juvenile brook trout that ranged from 8.0-9.0 cm/sec, with a maximum of 24 cm/sec. We assume that temperature and dissolved oxygen requirements for juvenile brook trout are similar to those for adults.

Wesche (1980) reported that brook trout fry and small juveniles < 15 cm long were associated more with instream cover objects (rubble substrate) than overhead stream bank cover. An area of cover ≥ 15% of the total stream area appears adequate for juvenile brook trout.

HABITAT SUITABILITY INDEX (HSI) MODELS

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



*Variables that affect all life stages.

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

Model Applicability

Geographic area. The following model is applicable over the entire range of brook trout distribution. Where differences in habitat requirements have been identified for different races of brook 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 brook 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 contiguous habitat that is required for a species to live and reproduce. Because brook trout 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 brook trout model is for it to produce an index between 0 and 1 that the authors and other biologists familiar with brook 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 author to simulate high, medium, and low quality brook trout habitat and model review by biologists familiar with brook trout ecology.

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 brook 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, percent instream cover, is included because standing crops of adult trout have been shown to be correlated with the amount of cover available. Percent 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, percent instream cover; V_{10}, percent pools; and V_{15}, pool class are included in the juvenile component for the same reasons listed above for the adult component. Juvenile brook trout use these essential stream features for escape cover, winter cover, and resting areas.

Fry component. Variable V_8, percent 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}, percent 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 affect 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 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 type (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 brook 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 reduces 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. 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.

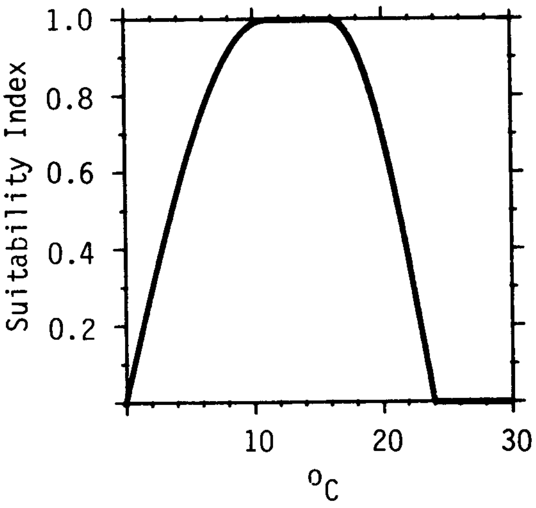
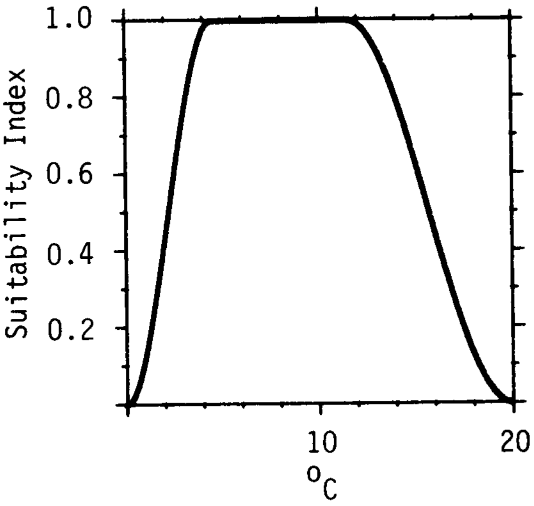
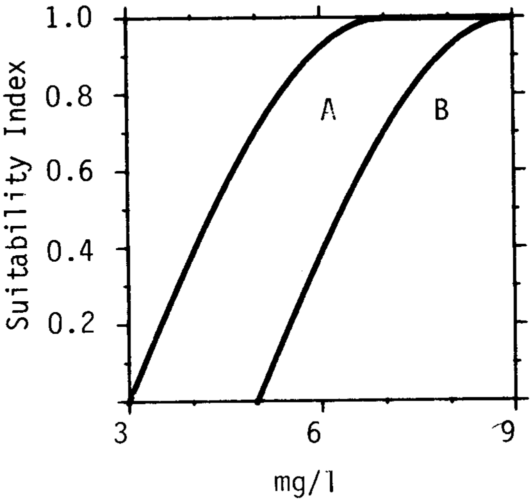
Variables V_{11}, V_{12}, and V_{17} are optional variables to be used only when needed and appropriate. Average percent vegetation for nutrient supply, V_{11}, should be used only on small (< 50 m wide) streams with summer temperatures > 10° C. Percent streamside vegetation, V_{12}, is included because streamside vegetation is an important means of controlling soil erosion, a major source of fines in streams. Variable V_{17}, percent midday shade, is included because the amount of shade can affect water temperature and photosynthesis in streams. Variables V_{11}, V_{12}, and V_{17} are used primarily for streams $\leq$ 50 m wide with temperature, photosynthesis, or erosion problems or when changes in the riparian vegetation is 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 brook trout HSI scores are included.

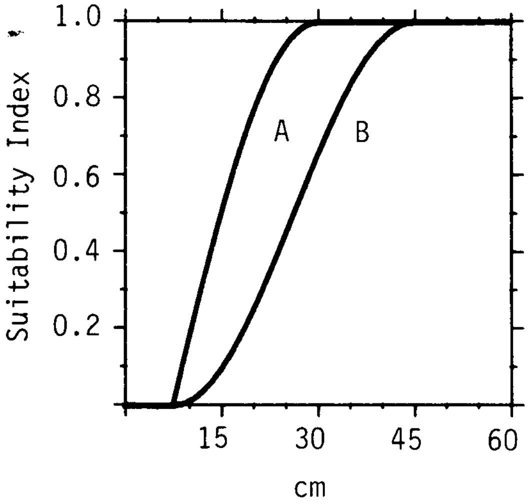
The graphs were constructed by quantifying information on the effect of each habitat variable on the growth, survival, or biomass of brook trout. The curves were built on the assumption that increments of growth, survival, or biomass originally plotted on the y-axis of the graph could be directly converted into an index of suitability from 0.0 to 1.0 for the species; 0.0 indicates unsuitable conditions and 1.0 indicates optimum 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 a different variable suitability relationship.

The habitat measurements and SI graph construction are based on the premise that extreme, rather than average, values of a variable 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.

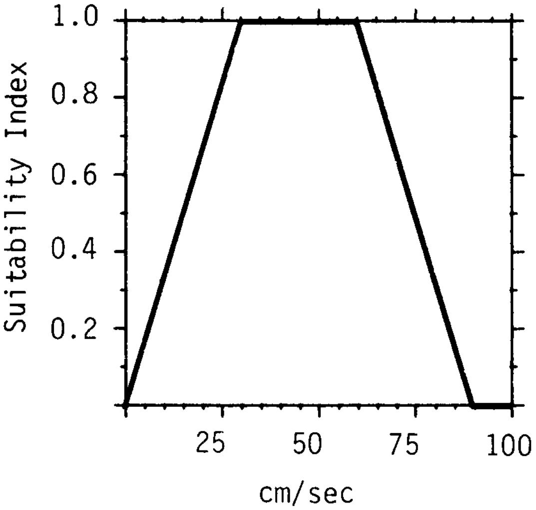
Habitat	Variable		Suitability graph
R,L	V_1	Average maximum water temperature (°C) during the warmest period of the year (adult, juvenile, and fry). For lacustrine habitats, use temperature strata nearest optimum in dissolved oxygen zones of > 3 mg/l.	
R	V_2	Average maximum water temperature (°C) during 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 optimum 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 = stream width ≤ 5 m
B = stream width > 5 m

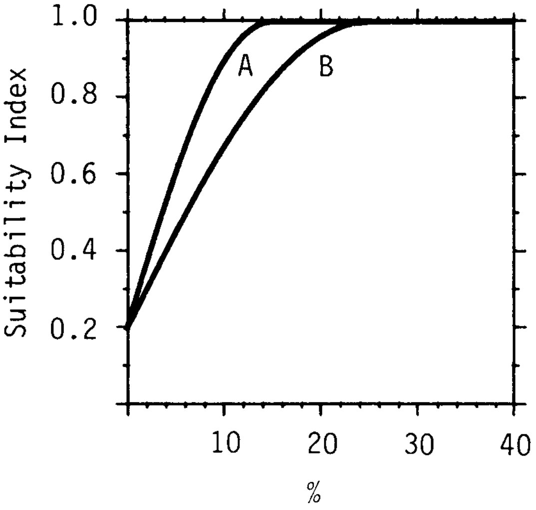


R V_5 Average velocity (cm/sec) over spawning areas during embryo development.



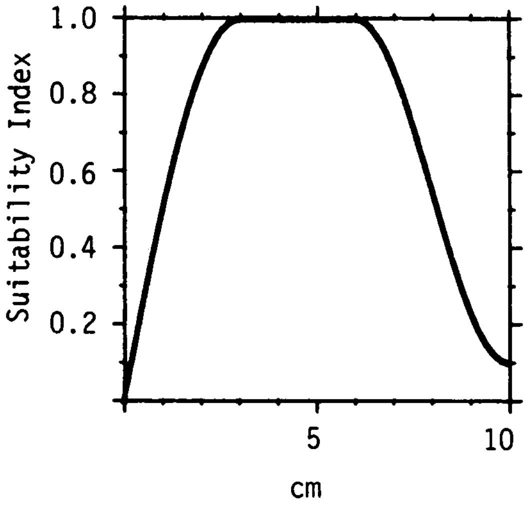
R V_6 Percent instream cover during the late growing season low water period at depths ≥ 15 cm and velocities < 15 cm/sec.

A = Juveniles
B = Adults

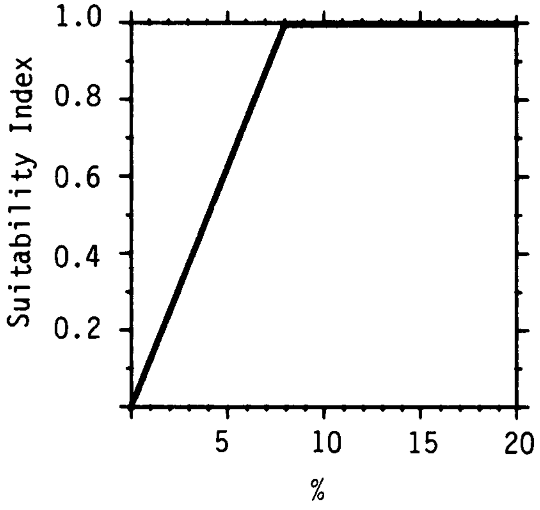


R V_7 Average size of substrate between 0.3-8 cm diameter in spawning areas, preferably during the spawning period.

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 the sample contains an area equal to 5% of the total brook trout habitat being evaluated.

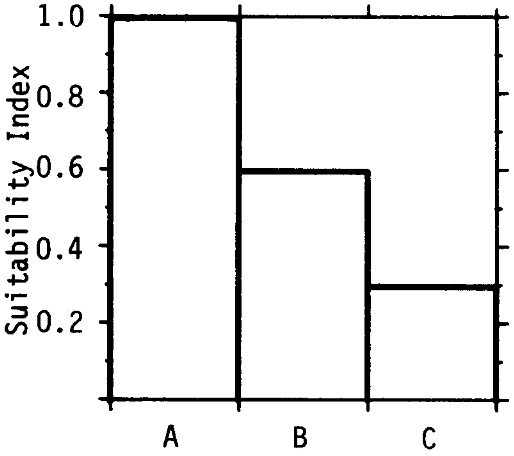


R V_8 Percent substrate size class (10-40 cm) used for winter and escape cover by fry and small juveniles.

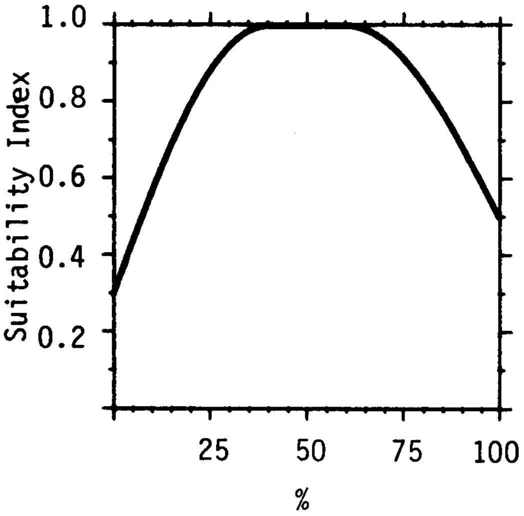


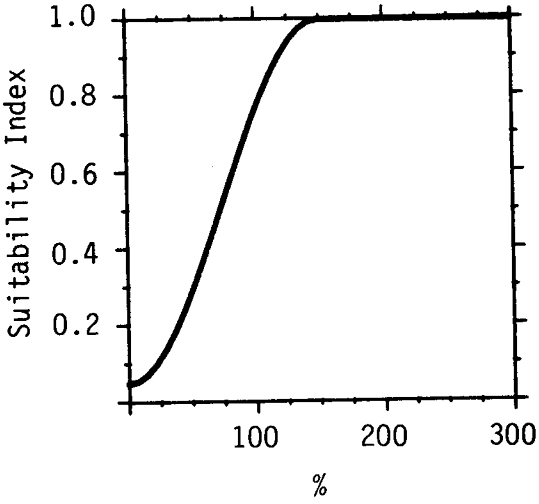
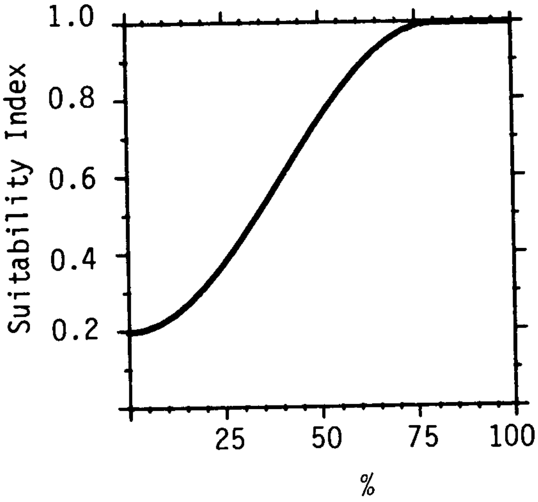
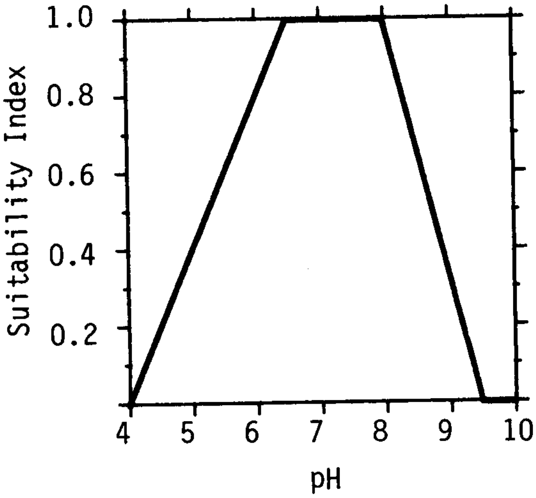
R V_9 Dominant (≥ 50%) substrate type in riffle-run areas for food production.

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%).

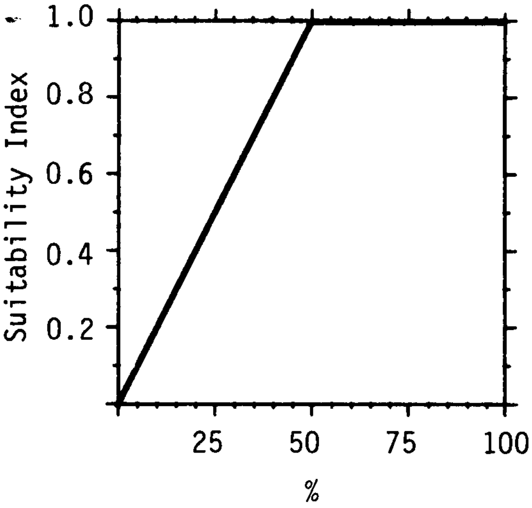


R V_{10} Percent pools during the late growing season low water period.



R	V_{11} Optional	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 with the best combination of dissolved oxygen and temperature.	

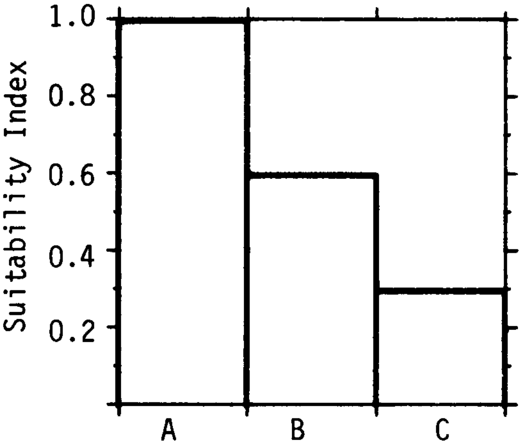
R V_{14} Average annual base flow regime during the late summer or winter low flow period as a percent of the average annual daily flow.



R V_{15} Pool class rating during the late growing season low flow period (Aug-Oct). The rating is based on the percent of the area containing pools of the three classes described below.

A) ≥ 30% of the area is comprised of first-class pools.
B) ≥ 10% but < 30% first-class pools or ≥ 50% second-class pools.
C) < 10% first-class pools and < 50% second-class pools.

(See pool class descriptions below)



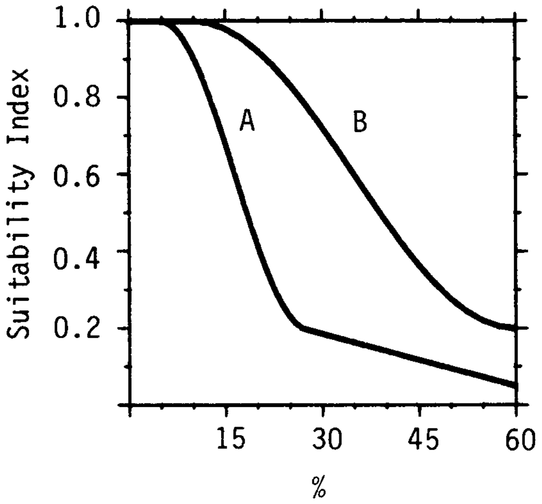
A) First-class pool: Large and deep. Pool depth and size are sufficient to provide a low velocity resting area for several adult trout. More than 30% of the pool bottom is obscured due to depth, surface turbulence, or the presence of structures, e.g., logs, debris piles, boulders, or overhanging banks 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 obscured 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.

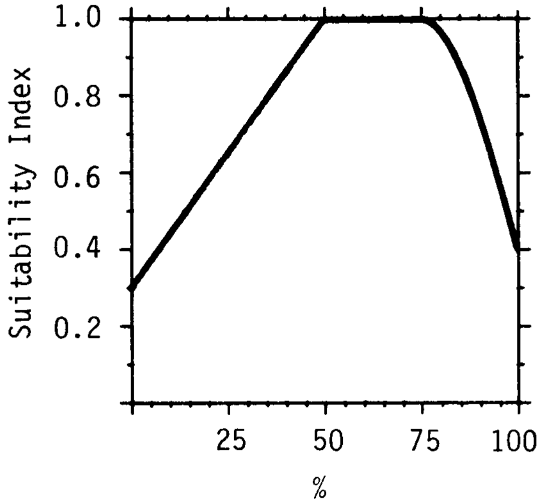
C) Third-class pool: Small or shallow or both. Pool depth and size are sufficient to provide a low velocity resting area for one to very few adult trout. Cover, if present, is in the form of shade, surface turbulence, or very limited structures. Typical third-class pools are wide, shallow pool areas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

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 (< 16° C max. temp.), unproductive streams.



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

Table 1. Data sources for brook trout suitability indices.

Variable and source		Assumption
V_1	Bean 1909 Embody 1921 Kendall 1924 Baldwin 1951 Brasch et al. 1958 Mullen 1958 Davis 1961 McAfee 1966 MacCrimmon & Campbell 1969 Hynes 1970	Average maximum daily temperatures have a greater effect on trout growth and survival than minimum temperature.
V_2	Embody 1934 Smith 1947 Brasch et al. 1958 MacCrimmon & Campbell 1969	The average maximum daily water temperature during embryo development related to the highest survival of embryos and normal development is optimum.
V_3	Embody 1927 Fry 1951 Doudoroff & Shumway 1970 Mills 1971 Trojnav 1972 Sekulich 1974 Harshbarger 1975	The average minimum daily dissolved oxygen level during embryo development and the late growing season that is related to the greatest growth and survival of brook trout and trout embryos is optimum. Levels 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 Reiser and Wesche 1977	The average velocity over the spawning areas affects the dissolved oxygen concentration and the manner in which waste products are removed from the developing embryos. Average velocities that result in the highest survival of embryos are optimum. Velocities 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 ≥ 15 cm deep and velocities ≤ 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 optimum cover conditions for trout streams are reached at < 50% of the total area.
V_7	Bjornn 1971 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 brook 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. Brook trout 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 ≥ 0.5 m^2 1,000 x 0.5 ≥ 500 m^2

Table 1 (continued).

Variable and source		Assumption
		6. There are 10,000 m² per hectare $\frac{500}{10,000} = 5\%$ of total area
V_8	Hartman 1965 Everest 1969 Bustard and Narver 1975a	The substrate size range selected for escape and winter cover by brook trout fry and small juveniles is assumed to be optimum.
V_9	Pennak and Van Gerpen 1947 Hynes 1970	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	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 1971 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 optimum and suboptimum 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}	Creaser 1930 Parsons 1968 Dunson & Martin 1973 Daye & Garside 1975 Webster 1975 Menendez 1976	The average annual maximum or minimum pH levels related to high survival of trout are optimum.

Table 1 (concluded).

Variable and source		Assumption
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.
V_{15}	Needham 1940 Lewis 1969 Hunt 1976	Pool classes associated with the highest standing crops of trout are optimum.
V_{16}	Cordone & Kelly 1961 Bjornn 1969 Sykora et al. 1972 Platts 1974 Phillips et al. 1975	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 that is shaded that is associated with optimum 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 brook trout.

The suitability curves are a compilation of published and unpublished information on brook trout. Information from other life stages or species or expert opinion was used to formulate curves when data for a particular habitat parameter or life stage were insufficient. Data are not sufficient at this time to refine the habitat suitability curves that accompany this narrative to reflect subspecific or regional differences. Local knowledge should be used to regionalize the suitability curves if that information will yield a more precise suitability index score. Additional information on this species that can be used to improve and regionalize the suitability curves should be forwarded to the Habitat Evaluation Group, U.S.D.I. Fish and Wildlife Service, 2625 Redwing Road, Fort Collins, CO 80526.

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_6; 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 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, 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, 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 between 0.3-8.0 cm;
3. The percent 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 follows:

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

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

Select the best V_s scores until all sites are included, or until brook trout habitat has been included, whichever comes first.

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

where A_i = the area of each spawning site in m² (ΣA_i cannot exceed 5% of the total brook trout 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 brook trout habitat being evaluated has been included, whichever occurs first.

D. Derive C_E

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

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_{11}, V_{12} and V_{17} are optional and, therefore, can be omitted.

HSI determination. HSI scores can 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 the HSI. This method should be used to determine the 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, the HSI = the lowest component value; if C_A is < the equation value, the HSI = C_A.

   where N = the number of components in the equation.

   Solve the equation for the number of components 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, in which case the 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, the 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, C_{OQ} = the value of the lowest variable.

B. Calculate the 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.

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

where N = the number of components and subcomponents inside the parentheses or, if the model components or subcomponents have unequal weights, $N = \Sigma$ of weights selected.

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

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

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

where N = the number of components and subcomponents in the equation or, if the model components or subcomponents have unequal weights, $N = \Sigma$ of weights selected.

Or, if C_A is ≤ 0.4, the $HSI' = C_A$

2) If C_{OQ} is < HSI', HSI = the HSI' $\times [1 - (HSI' - C_{OQ})]$; if $C_{OQ} \geq HSI'$, the 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 can be used to evaluate brook 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, C_{WQ} = the lowest SI score for V_1 or V_3.

Note: Lacustrine brook trout can spawn in spring upwelling areas of lacustrine habitats but will utilize tributary streams for spawning and embryo development when available and suitable. If the embryo life stage riverine habitat is included in the evaluation, use the embryo component steps and equations in the riverine model above, except that the area of spawning gravel needed is only about 1% 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, the 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. The HSI models, in their present form, are not intended to reliably 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 brook trout. If the model is correctly structured, a high HSI score for a habitat indicates near optimum regional conditions for brook trout for those factors included in the model, intermediate HSI scores indicate average habitat conditions, and low HSI scores indicate poor habitat conditions. An HSI of 0 does not necessarily mean that the species is not present; it does indicate that the habitat is very poor and that the species is likely to be scarce or absent.

Brook trout tend to occupy riverine habitats where very few other fish species are present. They are usually competitively excluded by other salmonid species, except cutthroat. Thus, disease, interspecific competition, and predation usually have little affect on the model. When the brook trout model is applied to brook trout streams with similar water quality and lengths 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 author to represent high, intermediate, and low habitat suitabilities are in Table 2, along with the SI's and HSI's generated by the brook trout riverine model. The model outputs calculated from the sample data sets (Tables 3 and 4) reflect what I believe carrying capacity trends would be in riverine habitats with the listed characteristics.

The models also have been reviewed by biologists familiar with brook trout ecology; therefore, the model meets the previously specified acceptance level.

ADDITIONAL HABITAT MODELS

Model 1

Optimum riverine brook trout habitat is characterized by:

1. Clear, cold water with an average maximum summer temperature of < 22° C;
2. Approximately a 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;
7. A relatively silt-free rocky substrate in riffle-run areas; and
8. Relatively good water quality (e.g., DO and pH).

$$HSI = \frac{\text{number of attributes present}}{8}$$

Table 2. Sample data sets using the riverine brook 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	0.6	16	0.4
Min. dissolved O_2 (mg/l)	V_3	9	1.0	5	0.7	6	0.4
Ave. depth (cm)	V_4	25	0.9	17	0.6	17	0.6
Ave. velocity (cm/s)	V_5	30	1.0	20	0.7	20	0.7
% cover	V_6	20	A 0.9 J 1.0	10	A 0.7 J 0.9	10	A 0.7 J 0.9
Ave. gravel size (cm)	V_7	4	1.0	3	1.0	2.5	1.0
% substrate 10-40 cm in diameter	V_8	15	1.0	6	0.7	6	0.7
Dom. substrate class	V_9	A	1.0	B	0.6	B	0.6
% pools	V_{10}	55	1.0	15	0.7	10	0.6
% Alloch. vegetation	V_{11}	225	1.0	175	1.0	200	1.0
% bank vegetation	V_{12}	95	1.0	40	0.6	35	0.5
Max. pH	V_{13}	7.1	1.0	7.2	1.0	7.2	1.0
% ann. base flow	V_{14}	39	0.8	30	0.6	25	0.5

Table 2. (concluded).

Variable		Data set 1		Data set 2		Data set 3	
		Data	SI	Data	SI	Data	SI
Pool class	V_{15}	A	1.0	B	0.6	C	0.3
% fines (A)	V_{16}	5	1.0	20	0.4	20	0.4
% fines (B)	V_{16}	20	0.9	35	0.6	35	0.6
% shade	V_{17}	60	1.0	60	1.0	60	1.0

Table 3. Equal component value method.

Variable	Data set 1		Data set 2		Data set 3	
	Data	SI	Data	SI	Data	SI
Component						
C_A		0.95		0.65		0.56
C_J		1.00		0.73		0.30
C_F		0.97		0.67		0.62
C_E		1.00		0.60		0.40
C_O		0.97		0.79		0.74
Species HSI		0.98		0.68		0.50

Table 4. Unequal component value method.

Variable	Data set 1		Data set 2		Data set 3	
	Data	SI	Data	SI	Data	SI
Component						
C_A		0.95		0.65		0.56
C_J		1.0		0.73		0.30
C_F		0.97		0.67		0.62
C_E		1.00		0.60		0.40
C_{OF}		0.97		0.80		0.80
C_{OQ}		1.00		0.81		0.40
Species HSI						
Noncompensatory		0.98		0.56		0.12
Compensatory		0.98		0.69		0.51

Model 2

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

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

Model 3

Optimum lacustrine brook trout 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. Presence of spring upwelling areas or access to riverine spawning tributaries.

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

REFERENCES

Anonymous. 1979. Managing riparian ecosystems (zones) for fish and wildlife in eastern Oregon and eastern Washington. Prep. by the Riparian Habitat Subcommittee of the Oregon/Washington Interagency Wildl. Conf. 44 pp.

Bachman, R. W. 1958. The ecology of four north Idaho trout streams with reference to the influence of forest road construction. M.S. Thesis, Univ. of Idaho, Moscow. 97 pp.

Baldwin, N. S. 1951. A preliminary study of brook trout food consumption and growth at different temperatures. Res. Council Ontario, 5th Tech. Session. 18 pp.

Bean, T. H. 1909. Examination of streams and lakes. 14th Ann. Rep. N.Y. State Forest, Fish and Game Comm., 1908. Pp. 215-217.

Behnke, R. J. 1980. A systematic review of the genus Salvelinus. Pages 441-480 in E. J. Balon, ed. Charr Monograph. The Hague: Junk Publ.

Benson, N. G. 1953. Seasonal fluctuations in the feeding of brook trout in the Pigeon River, Michigan. Trans. Am. Fish. Soc. 83:76-83.

Binns, N. A. 1979. A habitat quality index for Wyoming trout streams. Wyom. Game and Fish Dept. Fish. Res. Rep. 2. 75 pp.

Binns, N. A., and F.M. Eiserman. 1976. Environmental index of trout streams. Job 70 75-01-7101. Administrative files, Wyoming Game and Fish Dept. Cheyenne. 10 pp.

Binns, N. A., and F. M. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. Trans. Am. Fish. Soc. 108:215-228.

Bjornn, T. C. 1971. Trout and salmon movements in two Idaho streams as related to temperature, food, stream flow, cover, and population density. Am. Fish. Soc. Trans. 100(3):423-438.

Boussu, M. F. 1954. Relationship between trout populations and cover on a small stream. J. Wildl. Manage. 18(2):229-239.

Brasch, J., J. McFadden, and S. Kmiotek. 1958. Brook trout. Life history, ecology, and management. Wisc. Dept. Nat. Resour. Publ. 226. 15 pp.

Brett, J. R. 1940. Tempering versus acclimation in the planting of speckled trout. Trans. Am. Fish. Soc. 70:397-403.

Burns, J. W. 1970. Spawning bed sedimentation studies in northern California streams. California Fish Game 56(4):253-270.

Buss, K., and R. McCreary. 1960. A comparison of egg production of hatchery reared brook, brown, and rainbow trout. Prog. Fish-Cult. 22(1):7-10.

Buss, K., and J. E. Wright. 1957. Results of species hybridization within the family Salmonidae. Prog. Fish-Cult. 18(4):149-158.

Bustard, D. R., and D. W. Narver. 1975a. Aspects of the winter ecology of juvenile coho salmon (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri). J. Fish. Res. Board Can. 32(3):667-680.

______________. 1975b. Preferences of juvenile coho salmon (Oncorhynchus kisutch) and cutthroat trout (Salmo clarki) relative to simulated alteration of winter habitat. J. Fish. Res. Board Can. 32(3):681-687.

Butler, R. L., and V. M. Hawthorne. 1968. The reactions of dominant trout to changes in overhead artifical cover. Trans. Am. Fish. Soc. 97(1):37-41.

Carline, R. F., and O. M. Brynildson. 1977. Effects of hydraulic dredging on the ecology of native trout populations in Wisconsin spring ponds. Dept. Nat. Resourc. Madison, WI. Tech. Bull. 98. 40 pp.

Chapman, D. W. 1971. The relative contribution of aquatic and terrestrial primary producers to the trophic relation of stream organisms. Univ. of Pittsburg, Pymatuning Lab. of Ecol. Spec. Publ. 4:116-130.

Chapman, D. W., and T. C. Bjornn. 1969. Distribution of salmonids in streams, with special reference to food and feeding. Pages 153-176 in T. G. Northcote, ed. Symposium on salmon and trout in streams. H.R. MacMillian Lec. in Fish. Univ. British Columbia, Vancouver.

Cooper, E. L., and R. C. Scherer. 1967. Annual production of brook trout (Salvelinus fontinalis) in fertile and infertile streams of Pennsylvania. Pa. Acad. Sci. Proc. 41:65-70.

Cordone, A. J., and D. W. Kelly. 1961. The influences of inorganic sediments on the aquatic life of streams. California Fish Game 47(1):189-228.

Creaser, C. W. 1930. Relative importance of hydrogen-ion concentration, temperature, dissolved oxygen, and carbon-dioxide tension, on habitat selection by brook trout. Ecology 11(2):246-262.

Davis, H. S. 1961. Culture and diseases of game fishes. Univ. Calif. Press, Berkeley and Los Angeles, CA. 332 pp.

Daye, P. G., and E. T. Garside. 1975. Lethal levels of pH for brook trout, Salvelinus fontinalis. Can. J. Zool. 53(5):639-641.

Delisle, G. E., and B. E. Eliason. 1961. Effects on fish and wildlife resources of proposed water development on Middle Fork Feather River. State of Calif.-Dept. of Fish and Game Water Projects Rep. 19 pp.

Dineen, C. F. 1951. A comparative study of the food habits of Cottus bairdi and associated species of Salmonidae. Am. Midl. Nat. 46:640-645.

Doudoroff, P., and D. L. Shumway. 1970. Dissolved oxygen requirements of freshwater fishes. Food and Agriculture Organization of the United Nations, Rome. Fish. Tech. Paper 86. 291 pp.

Duff, D. A. 1980. Livestock grazing impacts on aquatic habitat in Big Creek, Utah. Paper presented at Livestock and Wildlife Fisheries Workshop. May 3-5, 1977. Reno, NV. U.S.D.I., Bur. Land Manage., Utah State Office. 36 pp.

Duff, D. A., and J. Cooper. 1976. Techniques for conducting stream habitat surveys on National Resource Lands. U.S.D.I., Bur. Land Manage. Tech. Note 283. 72 pp.

Dunson, W. A., and R. R. Martin. 1973. Survival of brook trout in a bog-derived acidity gradient. Ecology 54(6):1370-1376.

Elser, A. A. 1968. Fish populations of a trout stream in relation to major habitat zones and channel alterations. Trans. Am. Fish. Soc. 97(4):389-397

Elson, P. F. 1939. Effects of current on the movement of trout. J. Fish. Res. Board Can. 4(5):491-499.

Elwood, J. W., and T. F. Waters. 1969. Effects of floods on food consumption and production rates of a stream brook trout population. Trans. Am. Fish. Soc. 98(2):253-262.

Embody, G. C. 1921. Concerning high water temperatures and trout. Trans. Am. Fish. Soc. 51:58-64.

__________. 1927. An outline of stream study and the development of a stocking policy. Contrib. Agric. Lab., Cornell Univ. 54 pp.

__________. 1934. Relation of temperature to the incubation periods of eggs of four species of trout. Trans. Am. Fish. Soc. 64:281-291.

Enk, M. D. 1977. Instream overhead bank cover and trout abundance in two Michigan streams. M.S. Thesis, Mich. State Univ., E. Lansing. 127 pp.

Everest, F. H. 1969. Habitat selection and spatial interaction of juvenile chinook salmon and steelhead trout in two Idaho streams. Ph.D. Diss., Univ. Idaho, Moscow. 77 pp.

Everhart, W. H. 1966. Fishes of Maine. 3rd ed. Maine Dept. Inland Fish and Game. Augusta, ME. 96 pp.

Flick, W. A. 1977. Some observations, age, growth, food habits and vulnerability of large brook trout (Salvelinus fontinalis) from four Canadian Lakes. Nature Canada 104(4):353-359.

Flick, W. A., and D. A. Webster. 1976. Production of wild, domestic, and interstrain hybrids of brook trout (Salvelinus fontinalis) in natural ponds. J. Fish. Res. Board Can. 33(7):1525-1539.

Fry, F. E. 1951. Some environmental relations of the speckled trout (Salveinus fontinalis). Northeast Atlantic Fish Conf. Proc. 14 pp. (Mimeo.).

Garside, E. T. 1966. Effects of oxygen in relation to temperature on the development of embryos of brook trout and rainbow trout. J. Fish. Res. Board Can. 23(8):1121-1134.

Giger, R. D. 1973. Streamflow requirements of salmonids. AFS-62-1. Oregon Wildlife Comm., Portland. 117 pp.

Greeley, J. R. 1932. The spawning habits of brook, brown, and rainbow trout, and the problem of egg predators. Trans. Am. Fish. Soc. 62:239-247.

Griffith, J. S. 1972. Comparative behavior and habitat utilization of brook trout (Salvelinus fontinalis) and cutthroat trout (Salmo clarki) in small streams in Northern Idaho. J. Fish. Res. Board Can. 29(3):265-273.

__________ 1974. Utilization of invertebrate drift by brook trout (Salvalinus fontinalis) and cutthroat trout (Salmo clarki) in small streams in Idaho. Trans. Am. Fish. Soc. 103(3):440-447.

Harshbarger, T. J. 1975. Factors affecting regional trout stream productivity. Pages 11-27 in U.S.D.A. For. Serv. Proc. Southeastern trout resource: ecology and management symposium. Southeastern Forest Exp. Stn., Asheville, NC. 145 pp.

Hartman, G. F. 1965. The role of behavior in the ecology and interaction of underyearling Coho salmon (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri). J. Fish. Res. Board Can. 22(4):1035-1081.

Hazzard, A. S. 1932. Some phases in the life history of the eastern brook trout, Salvelinus fontinalis, Mitchill. Trans. Am. Fish. Soc. 62:344-350.

Herbert, D. W. M., and J. C. Merkens. 1961. The effect of suspended mineral solids on the survival of trout. Int. J. Air and Water Poll. 5:46-55.

Hooper, D. R. 1973. Evaluation of the effects of flow on trout stream ecology. Dept. Eng. Res., Pacific Gas and Electric Co. Emeryville, CA. 97 pp.

Hunt, R. L. 1965. Dispersal of wild brook trout during their first summer of life. Trans. Am. Fish. Soc. 94(2):186-188.

__________. 1966. Production and angler harvest of wild brook trout in Lawrence Creek, Wisconsin. Wisc. Div. Conserv., Madison. Tech. Bull. 35. 52 pp.

__________. 1971. Responses of a brook trout population to habitat development in Lawrence Creek. Dept. Nat. Resourc., Madison, WI. Tech. Bull. 48. 35 pp.

__________. 1976. In-stream improvement of trout habitat. Pages 26-31 in Stream management of Salmonids. Trout Magazine, Pub. by Trout Unlimited, 4260 East Evans, Denver, CO. 31 pp.

Hunter, J. W. 1973. A discussion of game fish in the State of Washington as related to water requirements. Rep. from Fish Manage. Div., Wash. State Dept. Game, to Wash. State Dept. Ecol. 66 pp.

Hynes, H. B. N. 1970. The ecology of running waters. Univ. Toronto Press, Canada. 555 pp.

Kendall, W. C. 1924. The status of fish culture in our inland public waters and the role of investigation in the maintenance of fish resources. Roosevelt Wild Life Bull. 2(3):205-351.

Latta, W. C. 1969. Some factors affecting survival of young-of-the-year brook trout (Salvelinus fontinalis, Mitchill) in streams. Pages 229-240 in T. G. Northcoat, ed. The H. P. McMillon Lecture in Fisheries Senes. The Univ. Brit. Columbia Press. Vancouver, B.C. Feb. 22-24, 1968. 388 pp.

Lennon, R. E. 1967. Brook trout of Great Smoky Mountains National Park. Bur. Sport. Fish. and Wildl. Tech. Paper 15. 18 pp.

Lewis, S. L. 1969. Physical factors influencing fish populations in pools of a trout stream. Trans. Am. Fish. Soc. 98(1):14-19.

MacCrimmon, H. R., and J. C. Campbell. 1969. World distribution of brook trout, Salvelinus fontinalis. J. Fish. Res. Board Can. 26:1699-1725.

McAfee, W. R. 1966. Eastern brook trout. Pages 242-260 in A. Calhoun, ed. Inland fisheries management. Calif. Dept. Fish Game.

McCormick, J. H., K. E. F. Hokansen, and B. R. Jones. 1972. Effects of temperature on growth and survival of young brook trout, Salvelinus fontinalis. J. Fish. Res. Board Can. 29:1107-1112.

McFadden, J. T. 1961. A population study of the brook trout, Salvelinus fontinalis. Wildl. Monogr. 7. 73 pp.

McFadden, J. T., G. R. Alexander, and D. S. Shetter. 1967. Numerical changes and population regulation in brook trout, Salvelinus fontinalis. J. Fish. Res. Board Can. 24:1425-1459.

McKee, J. E., and H.W. Wolf. 1963. Water quality criteria. State Water Control Board. Sacramento, CA. Pub. 3A. 548 pp.

Menendez, R. 1976. Chronic effects of reduced pH on brook trout (Salvelinus fontinalis). J. Fish. Res. Board Can. 33(1)118-123.

Mills, D. 1971. Salmon and trout; a resource, its ecology, conservation and management. St. Martains Press, N.Y. 351 pp.

Mullen, J. W. 1958. A compendium of the life history and ecology of the eastern brook trout, Salvelinus fontinalis Mitchill. Mass. Div. Fish Game, Fish. Bull. 23. 37 pp.

Needham, P. R. 1930. Studies on the seasonal food of brook trout. Trans. Am. Fish. Soc. 60:73-86.

__________. 1940. Trout streams. Comstock Publ. Co., Ithaca, NY. 233 pp.

__________. 1961. Observations on the natural spawning of eastern brook trout. California Fish Game 47(1):27-40.

O'Connor, J. F., and G. Power. 1976. Production by brook trout in the Matamek watershed, Quebec. J. Fish Res. Board Can. 33(1):118-123.

Parsons, J. D. 1968. The effects of acid strip-mine effluents on the ecology of a stream. Arch. Hydrobiol. 65:25-50.

Pennak, R. W., and E. D. VanGerpen. 1947. Bottom fauna production and physical nature of the substrate in a northern Colorado trout stream. Ecology 28(1):42-48.

Peters, J. C. 1965. The effects of stream sedimentation on trout embryo survival. Seminar on Biol. Problems in Water Poll. U.S. Dept. Health. Education and Welfare, Public Health Service, Cincinnati, OH. 1962. Pp. 275-279.

Peterson, R. H., A. M. Sutterlin, and J. L. Metcalfe. 1979. Temperature preference of several species of *Salmo* and *Salvelinus* and some of their hybrids. J. Fish. Res. Board Can. 36:1137-1140.

Phillips, R. W., R. L. Lantz, E. W. Claire, and J. R. Moring. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Trans. Am. Fish. Soc. 3:461-466.

Platts, W. S. 1974. Geomorphic and aquatic conditions influencing salmonids and stream classification with application to ecosystem classification. U.S.D.A., For. Serv., SEAM Publ., Billings, MT. 199 pp.

Powers, E. B. 1929. Fresh water studies I. Ecology 10:97-111.

Rabe, F. W. 1967. The transplantation of brook trout in an alpine lake. Prog. Fish-Cult. 29(1):53-55.

Raleigh, R. F., and D. A. Duff. (in press). Trout stream habitat improvement: ecology and management. *in* W. King, ed. Proc. Wild Trout Symposium II. Yellowstone Park, WY.

Reed, E. B., and G. Bear. 1966. Benthic animals and foods eaten by brook trout in Archuleta Creek, Colorado. Hydrobiol. 27:227-237.

Reiser, D. W., and T. A. Wesche. 1977. Determination of physical and hydraulic preferences of brown and brook trout in the selection of spawning locations. Water Resources Res. Inst., Univ. Wyo., Laramie. Water Res. Series 64. 100 pp.

Rupp, R. S. 1953. The eastern brook trout, *Salvelinus fontinalis* (Mitchill) at Sunkhaze Stream, Maine. M.S. Thesis, Univ. Maine, Orono. 96 pp.

Sabean, B. 1976. The effects of shade removal on stream temperature in Nova Scotia. Nova Scotia Dept. of Lands and Forests, Cat/76118/100. 32 pp.

Saunders, J. W., and M. W. Smith. 1955. Standing crop of trout in a small Prince Edward Island stream. Can. Fish Cult. 17:32-39.

__________. 1962. Physical alterations of stream habitat to improve brook trout production. Trans. Am. Fish. Soc. 91(2):185-188.

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

Sekulich, P. T. 1974. Role of the Snake River cutthroat trout (*Salmo clarki* subsp.) in fishery management. M.S. Thesis, Colo. State Univ., Ft. Collins, CO. 102 pp.

Sigler, W. F. and R. R. Miller. 1963. Fishes of Utah. Utah Dept. Fish Game, Salt Lake City. 203 pp.

Smith, A. K. 1973. Development and application of spawning velocity and depth criteria for Oregon salmonids. Trans. Am. Fish. Soc. 2:312-316.

Smith, M. W., and J. W. Saunders. 1958. Movements of brook trout, *Salvelinus fontinalis* between and within fresh and salt water. J. Fish. Res. Board Can. 15(6):1403-1449.

Smith, O. R. 1941. The spawning habits of cutthroat and eastern brook trouts. J. Wildl. Manage. 5(4):461-471.

__________. 1947. Returns from natural spawning of cutthroat trout and eastern brook trout. Trans. Am. Fish. Soc. 74:281-296.

Sykora, J., E. Smith, and M. Synak. 1972. Effect of lime neutralized iron hydroxide suspensions on juvenile brook trout (*Salvelinus fontinalis*, Mitchill). Water Res. 6:935-950.

__________. 1975. Review of selected parameters of trout stream quality. Pages 20-32 *in* Symposium on trout habitat research and management proceedings. U.S.D.A., For. Serv., Southeastern For. Exp. Stn., Asheville, NC. 110 pp.

Thompson, K. 1972. Determining stream flows for fish life. Pages 31-50 *in* Proc. Instream flow requirement workshop, Pacific Northwest River Basin Commission, Vancouver, WA. Pp. 31-50.

Trojnar, J. R. 1972. Ecological evaluation of two sympatric strains of cutthroat trout. M.S. Thesis, Colo. State Univ., Ft. Collins, CO. 59 pp.

Vincent, R. E., and W. H. Miller. 1969. Altitudinal distribution of brown trout and other fishes in a headwater tributary of the South Platte River, Colorado. Ecology 50(3):464-466.

Webster, D. (Ed.) 1975. Proceedings of brook trout seminar. Wisc. Dept. Nat. Resour., Univ. Wisc. 16 pp.

Webster, D., and Eiriksdottier. 1976. Upwelling water as a factor influencing choice of spawning sites by brook trout (*Salvelinus fontinalis*). Trans. Am. Fish. Soc. 75:257-266.

Wesche, T. A. 1973. Parametic determination of minimum streamflow for trout. Water Resour. Series 37. Water Resour. Res. Inst., Univ. of Wyom., Laramie, WY. 102 pp.

Wesche, T. A. 1974. Evaluation of trout cover in smaller streams. Proc. Western Assoc. Game and Fish Commissioners. 54:286-294.

__________. 1980. The WRRI trout cover rating method: developments and application. Water Resour. Res. Inst., Water Resour. Ser. 78. 46 pp.

White, H. C. 1930. Some observations on the eastern brook trout (_Salvelinus fontinalis_) of Prince Edward Island. Trans. Am. Fish. Soc. 60:101-108.

__________. 1940. Life history of sea-running brook trout (_Salvelinus fontinalis_) of Moser River, N.S. J. Fish. Res. Board Can. 5(2):176-186.

Wiseman, J. S. 1951. A quantitative analysis of foods eaten by eastern brook trout. Wyo. Wildl. 15:12-17.

50272-101

REPORT DOCUMENTATION PAGE

1. REPORT NO. FWS/OBS-82/10.24

2.

3. Recipient's Accession No.

4. Title and Subtitle
Habitat Suitability Index Models: Brook Trout

5. Report Date
September 1982

6.

7. Author(s)
Robert F. Raleigh

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Habitat Evaluation Procedures Group
U.S. Fish and Wildlife Service
Western Energy and Land Use Team
Drake Creekside Building One
2625 Redwing Road
Fort Collins, CO 80526

10. Project/Task/Work Unit No.

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

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

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

Literature describing the habitat preferences of the brook trout (Salvelinus fontinalis) is reviewed, and the relationships between habitat variables and life requisites are synthesized into a Habitat Suitability Index (HSI) model. HSI models are designed for use with the Habitat Evaluation Procedures (HEP) in impact assessment and habitat management activities.

17. Document Analysis a. Descriptors
Animal behavior
Aquatic biology
Habitability
Habit
Fishes
Trout

b. Identifiers/Open-Ended Terms
Brook trout
Salvelinus fontinalis
Habitat Suitability Index (HSI)
Habitat Evaluation Procedures (HEP)
Impact assessment
Habitat management

c. COSATI Field/Group

18. Availability Statement
RELEASE UNLIMITED

19. Security Class (This Report)
UNCLASSIFIED

20. Security Class (This Page)
UNCLASSIFIED

21. No. of Pages
ii - vi +42pp

22. Price

(See ANSI–Z39.13)

See Instructions on Reverse

OPTIONAL FORM 272 (4-7
(Formerly NTIS–35)
Department of Commerce

☆U.S. GOVERNMENT PRINTING OFFICE:1982—580-621 / 421