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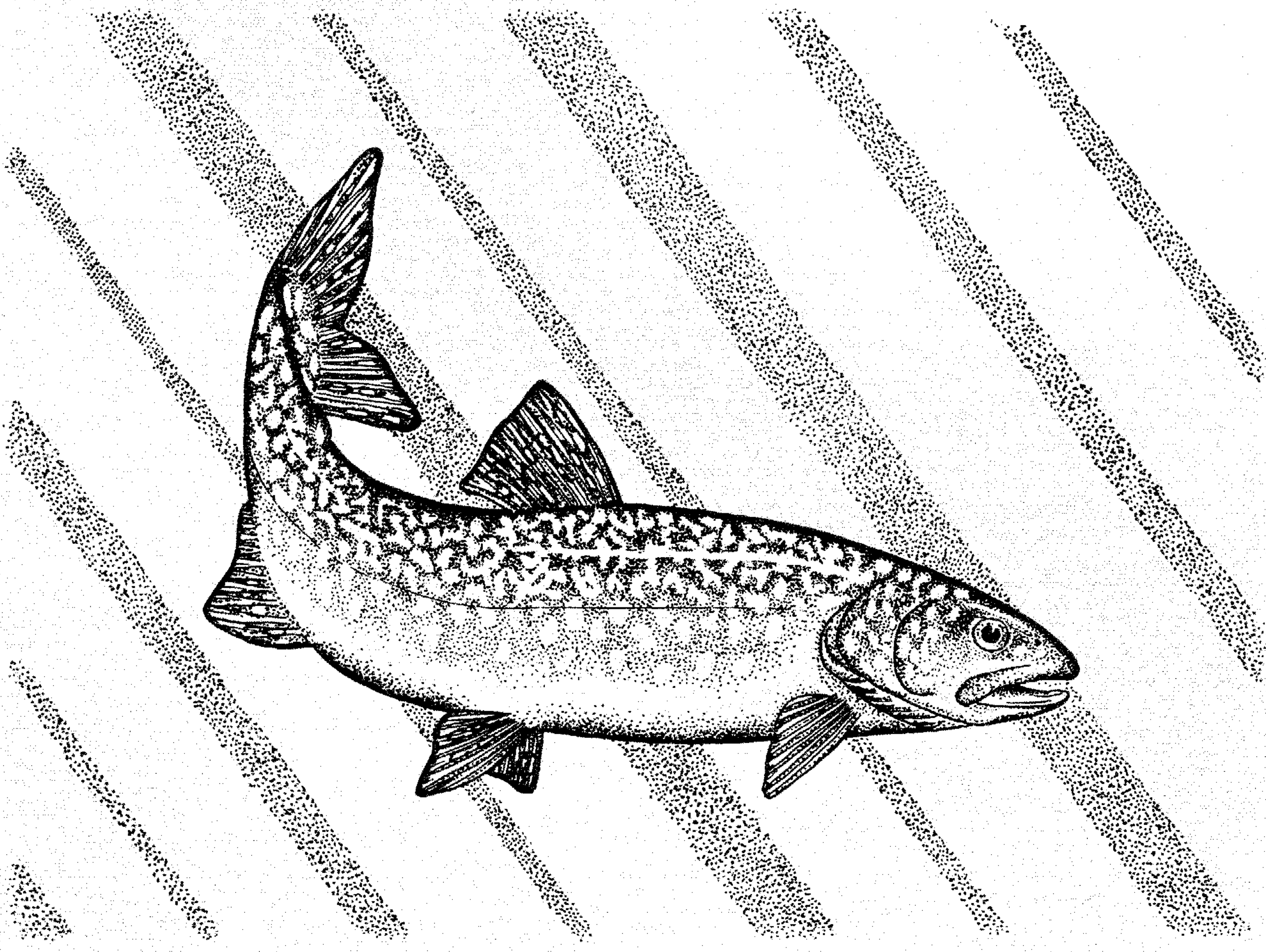
HABITAT SUITABILITY INDEX MODELS: LAKE TROUT (EXCLUSIVE OF THE GREAT LAKES)



Fish and Wildlife Service

Department of the Interior

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HABITAT SUITABILITY INDEX MODELS: LAKE TROUT (EXCLUSIVE OF THE GREAT LAKES)

by

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PREFACE

The Habitat Suitability Index (HSI) models presented in this publication aid in identifying important habitat variables. Facts, ideas, and concepts obtained from the research literature and expert reviews are synthesized into HSI models, which are scaled to produce an index between 0 (unsuitable habitat) and 1 (optimal habitat). The models are hypotheses of species-habitat relationships, and model users should recognize that the degree of veracity of the HSI model and assumptions will vary according to geographical area and the extent of the data base for individual variables. After clear study objectives have been set, the HSI model building techniques presented in U.S. Fish and Wildlife Service (1981)[1] and the general guidelines for modifying HSI models and estimating model variables presented in Terrell et al. (1982)[2] may be useful for simplifying and applying the models to specific impact assessment problems. Simplified models should be tested with independent data sets, if possible. A statistically-derived model that is an alternative to using Suitability Indices to calculate an HSI is referenced in the text.

Model reliability is likely to vary in different geographical areas and situations. The U.S. Fish and Wildlife Service encourages model users to provide comments, suggestions, and test results that may help us increase the utility and effectiveness of this habitat-based approach to impact assessment. Please send comments to:

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Western Energy and Land Use Team
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2627 Redwing Road
Ft. Collins, CO 80526-2899

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[1]U.S. Fish and Wildlife Service. 1981. Standards for the development of habitat suitability index models. 103 ESM. U.S. Fish Wildl. Serv., Div. Ecol. Serv. n.p.

[2]Terrell, J. W., T. E. McMahon, P. D. Inskip, R. F. Raleigh, and K. L. Williamson (1982). Habitat suitability index models: Appendix A. Guidelines for riverine and lacustrine applications of fish HSI models with the Habitat Evaluation Procedures. U.S. Fish Wildl. Serv. FWS/OBS-82/10.A. 54 pp.

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LAKE TROUT (*Salvelinus namaycush*)

HABITAT USE INFORMATION

General

The lake trout is an important commercial and sport fish in North America. In the Central Rocky Mountain region, lake trout are commonly referred to as "mackinaw". There is good evidence that lake trout should be called "lake charr" (Morton 1980). No subspecies of lake trout is presently recognized (Robins et al. 1980). The species, however, has extreme variability throughout its range, making it difficult to draw general conclusions about its biology (Martin and Olver 1980).

Native lake trout are confined to northern North America, with their distribution in the United States limited to the Great Lakes drainage and parts of northern New England, New York, Wisconsin, Minnesota, Montana, and Alaska (Carlander 1969; Martin and Olver 1980). In Canada, native lake trout occur in all provinces and territories, except Prince Edward Island, insular Newfoundland, portions of the prairie provinces, and coastal British Columbia. Lake trout have been introduced into California, Nevada, Colorado, Washington, Oregon, Idaho, Utah, Wyoming, Massachusetts, Connecticut, Argentina, Peru, Bolivia, Finland, Sweden, Switzerland, France, and New Zealand (Martin and Olver 1980). For the most part, lake trout are confined to fresh water, though they may enter brackish water in the far northern part of their range.

Morphometric and meristic data indicate that the distribution of native lake trout resulted from migrations originating from at least three and likely five unglaciated refugia following the Wisconsin Glaciation (Khan and Qadri 1971; Martin and Olver 1980). Genetic differences present in these various historical population stocks may partially account for the great biological variability observed in this species.

Lake trout are highly mobile, with individuals making horizontal and vertical movements in response to various physical, chemical, and biological factors (Martin and Olver 1980). While few data exist on the movement of young lake trout, it appears that fry move from the spawning areas within a month after hatching and travel to the deeper waters of the lake. This may be to avoid higher light intensities or predation (Martin and Olver 1980). Sometime during the first 22 weeks after hatch, the alevins fill their swimbladders with a trip to the surface. Young-of-the-year and older lake trout tend to remain in the deeper waters of lakes.

Individual lake trout may occur wherever water temperatures are favorable. For example, Johnson (1975) reported that the youngest trout in Great Bear Lake used a variety of habitats, including rocky shore lines, inflowing streams, and deep waters. In inland lakes, the vertical movement of lake trout appeared to be dependent primarily upon water temperature (Martin and Olver 1980). Dahlberg (1981) reported that temperature was the most important factor controlling the depth distribution of lake trout in Lake Cayuga, New York.

While lake trout tend to be nomadic, some individuals, particularly those from planted stock, appear sedentary (Martin and Olver 1980). For comparison, one individual tagged in Lake Superior travelled 306 km in 19 days (Eschmeyer et al. 1953). In contrast, other lake trout planted in Lake Superior were found after 3 years to be most abundant at distances of 3.2 to 6.4 km from the planting area (Pycha et al. 1965). All size groups of native lake trout in Great Bear Lake appeared to have some members that move and some that do not; Johnson (1975) reported that the movement of individuals ranged from 32 km in one year to no measurable movement for 5 to 6 years.

Walch (1980) used radio tags to investigate the movement of 34 lake trout in Twin Lakes, Colorado. He reported that average movement ranged from 1.1 m/min in fall to 1.6 m/min in summer. During the spring, summer, and fall, movements were significantly greater between 0830 and 1130 than between 2230 and 0500. In the fall, afternoon movements were significantly greater than at night. Home ranges were largest during the spring and fall, and most individuals were found within 3 m of the reservoir bottom. Movement was primarily limited to waters less than 12° C.

Age, Growth, and Food

Maximum age and size. The oldest lake trout reported from the United States was a 28-year-old hatchery fish in Minnesota (Carlander 1969). Rawson (1961) reported 36-year-old lake trout from Lac la Ronge, Saskatchewan. Being long lived, lake trout can reach substantial sizes. Capture records for individual lake trout include: (1) 54.4 kg from Lake Huron; (2) 46.3 kg from Lake Athabaska, Saskatchewan; (3) 39.9 kg from Lake Michigan; (4) 30.16 kg from Great Slave Lake; (5) 28.5 kg from Lake Superior (the sport-catch record); and (6) 11.34 kg from Twin Lakes, Colorado (Sigler and Miller 1963; Carlander 1969; Everhart and Seaman 1971).

Growth. Lake trout fry are about 23 mm total length at time of hatching (Carlander 1969). Growth rates for lake trout vary by year, season, lake area, strain, age, types and densities of food resources available, stock densities (intraspecific competition), and other factors (Martin and Olver 1980).

Weight of lake trout appears to increase at a rate greater than the cube of the length; length-weight relationships and condition factors are generally similar in both sexes (Carlander 1969). In lakes where alewives are the primary source of food, lake trout growth tends to slow with the onset of sexual maturity (age 5 to 7); where larger forage fish species (e.g., ciscoes and suckers) are the primary food, a slowing of growth is not apparent

(Carlander 1969). Growth tends to be slower in the northern part of the range. Lake trout feeding on fish grow faster than those feeding on plankton (Martin 1966). Griest (1977) noted that lake trout reaching legally catchable size (≥ 381 mm) in Twin Lakes, Colorado were usually 4 years old.

Ages of lake trout at first spawning are related to growth rates. Where growth is slow, maturity may not be achieved until 13 to 17 years; in contrast, when growth is rapid, males can mature at age 5 and females at age 6 to 8 (Carlander 1969). In general, males mature one year earlier than females (Martin and Olver 1980). However, when slower growth is caused by plankton feeding, maturity may be reached at a younger age, for example, at age 4 in some Algonquin Park lakes (Martin 1966).

Food. General surveys of the literature suggest that lake trout will tend to feed primarily on the most abundant food available, whether zooplankton, insects, or fish. Salamanders, shrews, and yellow warblers have been found in the stomachs of lake trout (Carlander 1969). Overall, zooplankton and dipteran larvae and pupae are the principal foods of young lake trout; however, even 38 mm individuals may eat small fish (Carlander 1969). *Mysis* tends to be an important food source in many lakes for all sizes of lake trout, and growth rates have been increased through the introduction of *Mysis relicta* (Grabowski and Ahern 1982). Larger lake trout generally feed predominantly on fish (Carlander 1969; Frantz and Cordone 1970; Warner 1972; Johnson 1975; Griest 1977; Martin and Olver 1980). However, in many lakes, lake trout continue to feed on zooplankton throughout their lives (Martin 1966; Carlander 1969; Martin and Olver 1980). In Lake Tahoe, crayfish are an important food for lake trout larger than about 380 mm (Frantz and Cordone 1970; Flint and Goldman 1975).

Feeding generally decreases prior to spawning in the fall. Feeding rates tend to remain low during the winter before increasing to maximum in the spring and summer (Carlander 1969; Frantz and Cordone 1970).

Reproduction

Factors affecting reproduction are the same as those affecting growth (Martin and Olver 1980). After reaching sexual maturity, it is not uncommon for lake trout to spawn intermittently (Carlander 1969; Martin and Olver 1980). For example, in Great Bear Lake, lake trout may spawn every third year; whereas in Great Slave Lake spawning may occur every year. Reasons for the intermittent spawning behavior appear to include latitude, temperature, and photoperiod (Martin and Olver 1980).

Spawning periods vary among lake trout population stocks: for example, (1) September to November in the Great Lakes; (2) September to December in New York; (3) October to December in New Hampshire; (4) mid-October to mid-November in Maine; (5) mid-September in Great Slave Lake; and (6) mid-August to early September in Great Bear Lake (Carlander 1969; Johnson 1975). Stocks from different sources may spawn during different periods when planted into the same lake (Griest 1977).

Several reports suggest that declining water temperatures and photoperiod coupled with strong on-shore winds are necessary factors triggering spawning (Carlander 1969; Martin and Olver 1980). Most spawning activity occurs between dusk and 2300 (Carlander 1969; Martin and Olver 1980). Lake trout usually spawn in lakes, rarely in streams.

The average number of eggs in a female lake trout range from 628 to 1710 per kilogram of total weight (Carlander 1969). Average size female lake trout from Jackson Lake, Wyoming, yield as many as 6000 eggs (Baxter and Simon 1970). Hatching time for eggs increases with decreasing temperatures (Embody 1934; Carlander 1969): 50 days at 10° C; 100 to 117 at 5° C; and 141 to 156 at 2 to 2.5° C.

Specific Habitat Requirements

Lakes containing populations of lake trout have been described as "larger, of higher altitude, deeper, clearer, colder, better oxygenated, more acidic, softer, and lower in total alkalinity, buffering capacity, total dissolved solids and morphoedaphic index values" than waters without lake trout (Martin and Olver 1980). In an analysis of 2500 Ontario lakes, lake trout lakes were distinguished by: (1) mean depths > 6 m; (2) total dissolved solids concentrations < 50 mg/l; (3) average hypolimnetic oxygen concentrations ≥ 6 mg/l; and (4) metric morphoedaphic index values (Ryder 1965) < 6 (Johnson et al. 1977).

Temperature is a critical factor influencing lake trout. During field studies, lake trout are rarely found at water temperatures > 10 to 12° C (e.g., Rawson 1961; Eschmeyer 1964; Johnson 1975; Walch 1980). Carlander (1969) suggested that lake trout can be found at water temperatures ranging between 4 to 18° C during the summer.

Laboratory studies suggest that 12° C is the preferred temperature of adult lake trout, but this preferendum may range between 8 and 15° C (Johnson 1975). For yearling lake trout the preferred temperature was reported as 11.7° C (McCauley and Tait 1970). The preferred temperature for fingerling lake trout was reported as 10.8° C; while that for fry ranged between 9.0 and 10.0° C (Peterson et al. 1979). The upper lethal temperature for adult lake trout was reported to be 23.5° C (Gibson and Fry 1954). Temperature appears to be a stimulus for spawning, though the critical temperature varies between 4.5 and 14° C for different lakes (Rawson 1961; Carlander 1969; DeRoche 1969; Johnson 1975).

For the most part, spawning is limited to lakes, but some spawning has been reported to occur in tributary streams of Lake Superior and in rivers in tundra areas of Canada and Alaska (Loftus 1957; McPhail and Lindsey 1970; Lawrie and Rahrer 1973). In general the beds of the spawning rivers consist of larger boulders intermixed with coarse gravel.

Spawning depths in lakes have been reported to range from 15 cm to over 55 m (Merriman 1939; Carlander 1969; DeRoche 1969; Johnson 1975). For successful spawning in reservoirs it is important that spawning depths remain below drawn-down levels to prevent exposure of eggs (Bergersen and Maiolie 1981).

Lake trout may spawn on a variety of surfaces: clay bottoms in southern Lake Michigan; silt, hardpan clay, marl, and gravel in Green Lake, Wisconsin; and stone bottoms in Lake Superior (Carlander 1969). For most inland lakes spawning occurs primarily on rubble 2.5 cm or larger in diameter (Merriman 1939; Hacker 1956; DeRoche 1969; Martin and Olver 1980). DeRoche (1969) observed lake trout selecting angular rubble over smooth rubble as spawning substrate. Martin (1956) reported spawning areas of lakes in Algonquin Park, Ontario to be free of mud, sand, and detritus. Lake trout have been observed cleaning debris, silt, algae, and slime out of spawning areas prior to spawning (Merriman 1939; DeRoche and Bond 1955; Carlander 1969). Spawning areas for lake trout can be improved by dumping angular rock into lakes (e.g., Hacker 1956).

Dissolved oxygen concentrations of < 6 mg/l have been reported to adversely affect lake trout embryo development and survival at 7 and 10° C (Carlson and Siefert 1974). Garside (1959) suggested that, if oxygen concentrations decrease below 40% of the air saturation at 3° C (about 5.5 mg/l oxygen), lake trout embryos will be subjected to stress and deformities will result. These reports agree with the observation that lake trout tended to be absent from Ontario lakes when average hypolimnetic oxygen concentrations were < 6 mg/l (Johnson et al. 1977).

HABITAT SUITABILITY INDEX (HSI) MODELS

Model Applicability

Geographical area. The models provided are applicable throughout North America except for the Great Lakes. The standard of comparison for each individual variable suitability index is the optimal value of the variable that occurs anywhere within this region. Therefore, the models will never provide an HSI of 1.0 when optimal temperatures, forage fish species, or satisfactory spawning substrate are lacking.

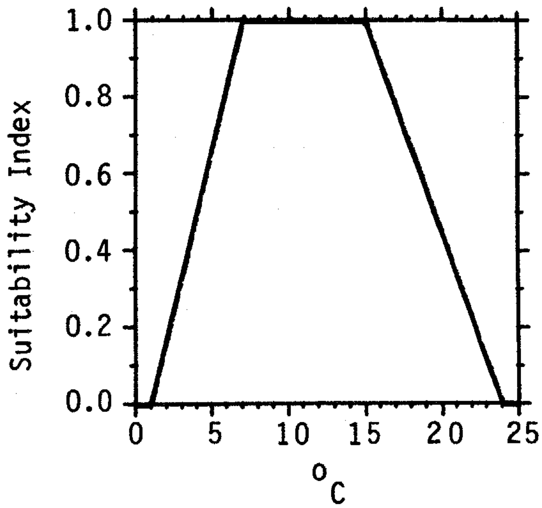
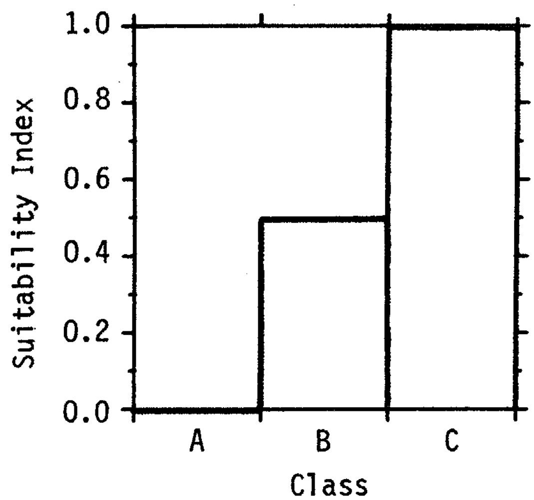
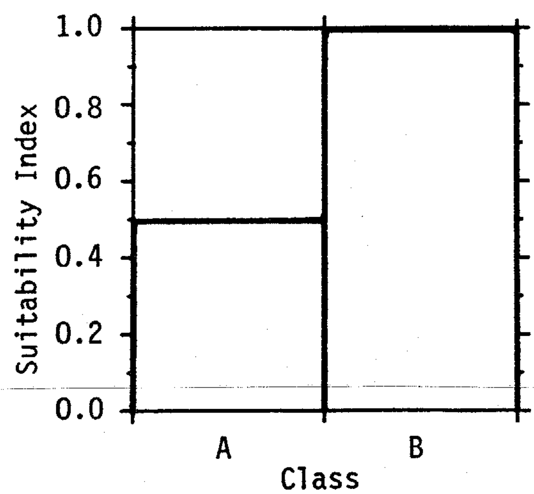
Lake types. The models were developed for oligotrophic (mean metric MEI ≤ 6, see Ryder 1965) lakes and reservoirs, having mean depths greater than 6 m. The Great Lakes are excluded.

Model Descriptions

Models were developed for (1) stocked lake trout populations, (2) naturally reproducing lake trout populations in lakes, and (3) naturally reproducing lake trout populations in reservoirs. The models were based on different combinations of five habitat variables.

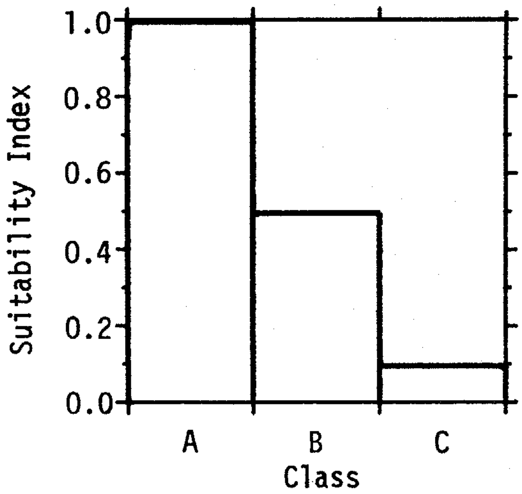
Suitability Index (SI) Graphs for Model Variables

This section contains suitability index graphs for the five variables described below. These graphs are followed by equations for combining selected variable indices, using the component approach, to provide HSI's for stocked lake trout populations in lakes and reservoirs, reproducing populations in lakes, and reproducing populations in reservoirs.

Variable		Suitability graph
V_1	Mean maximum temperature in hypolimnion or deeper half of water body.	
V_2	Minimum oxygen concentration in hypolimnion or deeper. A. O_2 min < 6 mg/l B. O_2 ≥ 6 mg/l or ≤ 8 mg/l C. O_2 > 8 mg/l	
V_3	Availability of forage fish species. A. Absent B. Present	

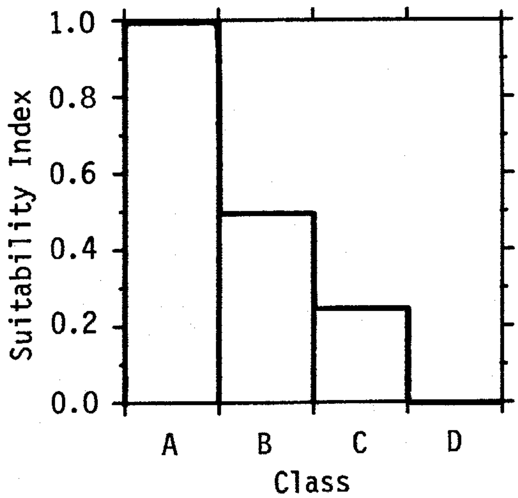
V_4 Type and size of available spawning substrate.

A. Patches of cobble (2 to 30 cm diameter) on lake bottom between 0.5 and 50 m deep.
B. Other substrate available that offers eggs and larvae protection from predation.
C. Substrate lacking protective cover for eggs and larvae.



V_5 Annual reservoir drawdown during incubation.

A. ≤ 0.15 m
B. > 0.15 m, but drawdown exposes < 10% of cobble substrate available for spawning.
C. Drawdown exposes 10 to 90% of cobble substrate available for spawning.
D. Drawdown exposes 100% of cobble substrate.



Development of Suitability Index Graphs: Rationale and Assumptions

The preceding suitability index graphs should be regarded as tentative and open to modification. The prospective user should understand that the graphs reflect the authors' selective integration of information from the literature, personal experience, and reviewers' comments. The following discussion documents the rationale for constructing the graphs. While there is information on preferred and unsuitable conditions for lake trout, little information exists on intermediate conditions. The models are offered as a starting point, with the hope that refinements will be made as additional information becomes available, including results from model testing.

Mean maximum temperature in hypolimnion (V_1). Lake trout prefer water of 10 to 12° C (Rawson 1961; Eschmeyer 1964; Johnson 1975; Walch 1980), but are abundant in lakes where the water temperature is between 7 and 15° C (Everhart and Seaman 1971; Johnson 1975). Carlander's (1969) review suggested that lake trout are found between 4 and 18° C during the summer. The fish can survive temperatures up to 23.5° C (Gibson and Fry 1954). It is assumed that a maximum summer water temperature of 7 to 15° C is optimum. Above 15° C productivity drops until the upper maximum lethal temperature of 23.5° C is reached. Below 7° C productivity drops due to reduced metabolic rates and depressed community productivity.

Minimum oxygen concentration in hypolimnion (V_2). Dissolved oxygen concentrations of less than 6 mg/l have been shown to depress embryo survival (Garside 1959; Carlson and Siefert 1974) and to be associated with the absence of lake trout in Ontario lakes (Johnson et al. 1977). Therefore, it is assumed that a dissolved oxygen level of 6 mg/l in the hypolimnion of a lake is the absolute minimum required for lake trout survival, but populations subjected to 6 mg/l for extended periods during the growing season would be severely stressed, likely resulting in extensive population mortality and probable population failure.

Presence of forage fish (V_3). Lake trout feed heavily on zooplankton throughout their lives in lakes with little or no fish forage (Martin 1966; Carlander 1969; Martin and Olver 1980). When forage fish are present, lake trout feed predominantly on them (Carlander 1969; Frantz and Cordone 1970; Warner 1972; Johnson 1975; Griest 1977). Lake trout that feed on fish grow faster than those feeding on plankton (Carlander 1969). It is assumed that the productivity of a lake trout population is increased when forage fish are available.

Spawning substrate (V_4). Lake trout can spawn over a variety of substrates (Carlander 1969), but they prefer rubble 2.5 cm or larger in diameter (Merriman 1939; Hacker 1966; DeRoche 1969; Martin and Olver 1980). Spawning areas tend to be free of silt or detritus (Martin 1956). Lake trout have been observed to clean spawning areas of silt and debris prior to spawning (Merriman 1939; DeRoche and Bond 1955). It is assumed that clean rubble (2.5 to 30 cm diameter) is the optimum spawning substrate. Other substrates can produce young if suitable protection from predation is available. Substrates of silt, clay, or marl are generally unsuitable for successful reproduction.

Reservoir drawdown during incubation (V_5). Spawning depths range from 15 cm to > 55 m (Merriman 1939; Carlander 1969; DeRoche 1969; Johnson 1975). Exposure of eggs during incubation prevent their survival (Bergersen and Maiolie 1981). It is assumed that if lake trout spawn in a reservoir they will be impacted by the degree to which the reservoir level fluctuates over this spawning substrate. Where ice is very thick, the values of the suitability index may have to be adjusted to account for habitat exclusion due to ice formation.

HSI Model for Stocked Lake Trout Populations

This model consists of three variables: mean maximum water temperature; minimum oxygen concentration; and presence of forage fish.

$$HSI = V_1 \times V_2 \times V_3$$

HSI Model for Reproducing Lake Trout Populations in Lakes

This model consists of four variables: mean maximum water temperature; minimum oxygen concentration; presence of forage fish; and available spawning substrate.

$$HSI = V_1 \times V_2 \times V_3 \times V_4$$

HSI Model for Reproducing Lake Trout Populations in Reservoirs

This model consists of five variables: mean maximum water temperature; minimum oxygen concentration; presence of forage fish; available spawning substrate; and relative degree of reservoir drawdown.

$$HSI = V_1 \times V_2 \times V_3 \times V_4 \times V_5$$

Interpreting Model Outputs

These lake trout HSI models have not been verified as having a direct relationship to carrying capacity. Although relationships clearly exist between carrying capacities or productivities of lake trout and temperatures and forage fish in the habitat area, insufficient information exists to define these relationships. Therefore, SI's determined for V_1 and V_3 may reflect relative, rather than absolute, differences for populations.

Criteria used for V_4 reflect a "best guess" synthesis of available information. They may be inappropriate for some lakes or reservoirs. Additional data are necessary to refine this predictor. The importance of V_5 can be reduced by the use of deep spawning strains of lake trout when stocking reservoirs.

We believe the models should be able to predict the presence or absence of lake trout as a result of variables V_1, V_2, and V_5. These three variables involve maximum temperature, minimum dissolved oxygen, and maximum exposure of spawning areas that can be encountered by a lake trout population.

ADDITIONAL HABITAT MODELS

Aggus and Bivin (1982) used angler harvest as an indicator of habitat suitability and developed a regression equation relating harvest to reservoir habitat variables for six impoundments in the conterminous United States:

$$\text{Harvest of lake trout} = 1.826 - 0.8714 \log_{10} (\text{outlet depth})$$

Units are kg/ha (harvest) and midline depth of principal outlet in feet below listed surface elevation of reservoir. The authors discuss procedures for converting measured or predicted harvest values to HSI's and present cautionary material concerning model use and interpretation.

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The Habitat Suitability Index (HSI) models for Lake Trout (Salvelinus namaycush) presented in this publication aid in identifying important habitat variables. Facts, ideas, and concepts obtained from the research literature and expert reviews are synthesized into subjective HSI models, which are scaled to produce an index between 0 (unsuitable habitat) and 1 (optimal habitat).

The models are hypotheses of species-habitat relationships, and model users should recognize that the degree of verocity of the HSI model, SI graphs, and assumptions will vary according to geographical area and the extent of the data base for individual variables.

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