Factors That Predict Brook Trout Distribution, Thermal Habitat, and Abundance in Northwestern Ontario Streams

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Graduate Program in Biology

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Submitted to Lakehead University

in partial fulfilment of the requirements for a M.Sc. Degree

2 May 1995

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ISBN 0-612-09231-3

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Abstract

Predictive models were developed to improve the understanding of stream-resident brook trout (*Salvelinus fontinalis*) populations and habitat in northwestern Ontario, and to facilitate protection of stream-resident brook trout from the adverse impacts of timber harvest. Geology-based models correctly predicted trout presence/absence in 75%-80% of streams studied in 1993. However, correct prediction rates declined to 50%-65% when these models were transferred to independent data collected in 1992 and 1994. Combining data from all years produced models that correctly predicted trout presence/absence in 70%-80% of streams. Univariate geology models were best at predicting trout presence (up to 85% correct predictions). One-third of the trout streams data had maximum summer temperatures ≥22°C, and thus are considered marginal. Using the combined data, models with geology and climate variables explained up to 24% of the variation associated with stream temperatures. Stream temperatures were negatively related to brook trout abundance in the combined data. Stability of stream temperatures accounted for 25% of the variation in trout biomass (kg/ha). These models could be used by fisheries managers to implement current guidelines protecting brook trout habitat from the effects of timber harvest.

Introduction

Fisheries managers in Ontario are authorized under the federal Fisheries Act to protect brook trout (*Salvelinus fontinalis*) populations and the coldwater habitat they occupy from the adverse impacts of forest management and other land-use practices (OMNR 1988). Since brook trout is a coldwater species, increased summer temperatures resulting from stream-side (riparian) forest harvest may be the most critical impact affecting brook trout populations. For example, Barton et al. (1985) observed significantly warmer maximum summer temperatures in southern Ontario streams with reduced riparian vegetation. The removal of riparian forest stands from an Oregon salmonid stream increased annual maximum temperatures by 16°C, increased July mean-maximum temperatures by 8°C , and resulted in daily temperature fluctuations of up to 19°C (Brown and Krygier 1970). Maximum stream temperatures increased by >10°C in June and July and by 7°C in August following complete clear-cutting of a Pennsylvania watershed (Rishel et al. 1982). Brown et al. (1971) investigated six clear-cut watersheds in Oregon, and observed maximum stream temperature increases ranging from 2°C to 8°C following harvest. Maximum temperatures of a British Columbia stream increased by 5°C following complete watershed clear-cutting (Feller 1981).

While most studies only monitored the short-term (i.e. <5 years) effects of riparian forest removal, the warming influence may be chronic. Feller (1981) reported the persistence of warmer summer stream temperatures for a minimum of seven years after clear-cutting. The summer thermal regimes of several Oregon streams had not recovered to pre-logging levels 20 years after forest removal (Hostetler 1991).

Removal of riparian forest stands alters other habitat parameters important to brook trout survival. Hicks et al. (1991) reported reductions in summer base-flows that persisted for >20 years following clear-cutting in Oregon. Barton et al. (1985) observed a positive relationship between concentrations of fine particulate matter and depleted riparian vegetation. Dose and Roper (1994) observed chronic habitat deterioration in several salmonid streams in Oregon following timber harvest. Heifetz et al. (1986) reported that clear-cuts along stream banks in Alaska significantly reduced the pool habitat and overhead cover that were crucial overwintering areas for juvenile coho salmon (*Oncorhynchus kisutch*). In their review of numerous deforestation studies, Binkley and Brown (1993) summarized the adverse impacts of riparian forest removal on numerous water quality parameters (i.e. concentrations of dissolved oxygen, phosphate, nitrate, and suspended sediments).

Establishment of undisturbed stream-side reserves of standing forests (buffer-strips) can often ameliorate the negative influence of forestry practices (Brown and Krygier 1970; Brown et al. 1971; Rishel et al. 1982; Barton et al. 1985; Heifetz et al. 1986). Consequently, the Ontario Ministry of Natural Resources (OMNR) has developed timber management guidelines requiring forestry operators to leave undisturbed buffer-strips adjacent to lakes and streams containing brook trout populations (OMNR 1988) (Appendix 1). The dimensions (i.e. widths) of buffer-strips are dependent on the slope of the land that lies adjacent to streams, and are based on the work of Trimble and Sartz (1957) in New Hampshire. Originally, those buffer-strips were designed to reduce sediment loadings from logging roads (Trimble and Sartz 1957), however, they also maintain shade cover that protects stream temperatures.

In Ontario, local fisheries managers have the responsibility of identifying brook trout streams requiring riparian protection during the timber management planning process (OMNR 1988). In northwestern Ontario (NWO) however, the detailed distribution of stream resident brook trout and the majority of other stream fishes is generally not known. Therefore, an improved understanding of brook trout distribution is essential to accurately implement timber management guidelines. Since, current monetary and man-power constraints, and limited road access to much of NWO preclude the establishment of large-scale aquatic surveys to determine brook trout distribution, the development of predictive models could assist fisheries managers in protecting trout streams.

Numerous predictive models have been used to evaluate fish distribution on a variety of spatial scales. These models have used as predictor variables: 1) habitat features (Beauchamp et al. 1992; Bozek and Hubert 1992; Lyons 1992a), 2) seasonal movements (Elliot 1986), 3) watershed characteristics (Beauchamp et al. 1992; Nelson et al. 1992; Bozek and Hubert 1992), and 4) geological features (Lyons 1992a; Nelson et al. 1992). The critical difference between these previously mentioned studies and the situation in NWO is that the distribution of the species of interest was known prior to describing the relation between fish distribution and the independent variables, whereas in NWO, the development of predictive models is needed to determine brook trout distribution. Understanding habitat variables that limit brook trout distribution, and environmental conditions that produce suitable habitat is essential for developing predictive models.

Temperature

Water temperature is the most important single factor limiting brook trout distribution (MacCrimmon and Campbell 1969). Cool maximum summer temperatures are vital to stream resident brook trout populations (Brasch et al. 1973; Scott and Crossman 1973). Barton et al. (1985) observed that maximum summer temperature was the most critical variable distinguishing trout streams from non-trout streams in southern Ontario. Laboratory investigations have reported upper lethal temperatures of 23.4-25.3°C (Fry et al. 1946), 24°C (Cherry et al. 1975), and 26.2-27.8°C (Grande and Andersen 1991) for juvenile brook trout. Field studies have reported that wild brook trout can survive in streams that reach water temperatures of 24°C (Meisner 1990), and some consider this to be the maximum temperature limiting brook trout distribution (Ricker 1934; Meisner 1990). However, in southern Ontario, Barton et al. (1985) observed that self-sustaining trout populations were only found in streams with maximum temperature ≤22°C, whereas warmer streams harboured marginal or no trout populations. Also, Creaser (1930) suggested 19°C as the maximum stream temperature for the development of a self-sustaining brook trout population. While there is some inconsistency regarding the maximum temperature of a healthy brook trout stream, there is general agreement concerning preferred brook trout temperature. Numerous studies (both field and laboratory) have reported preferred temperatures of ≤20°C (Creaser 1930; Ferguson 1958; Cherry et al. 1975; Cherry et al. 1977; Coutant 1977; Peterson 1979), and the avoidance of warmer temperatures (Gibson 1966; Power 1980; Cunjak et al. 1993). In lakes, brook trout move to the deeper, cooler waters of the thermocline (Ferguson 1958), but stream resident populations rely on localized coolwater refugia during prolonged warm periods (Gibson 1966; Bowlby and Roff 1986; Cunjak et al. 1993).

Groundwater

Thermal characteristics of streams are partially influenced by groundwater discharge (Hynes 1970; Ward 1985). The importance of groundwater discharge in maintaining cool stream temperatures that lie within the physiological tolerances of brook trout is well understood (Creaser 1930; Threinen and Puff 1963; Meisner et al. 1988; Meisner 1990; McCrae and Edwards 1994). If groundwater is not sufficient to maintain total stream temperatures below 20°C, then trout use cooler, localized groundwater discharge areas (Gibson 1966; Bowlby and Roff 1986; Cunjak et al. 1993). A groundwater discharge refugium used by brook trout in the Miramichi River, New Brunswick was 5°C cooler than the main river (Gibson 1966). In Thrash Creek, Washington, Bilby (1984) observed temperatures approximately 5°C cooler near groundwater discharge areas relative to the ambient stream temperature. Groundwater-fed channels in Halley Creek, Wisconsin were up to approximately 7.5°C cooler than the main stream channel (McCrae and Edwards 1994).

Groundwater discharge is also critical throughout the life-history of stream-resident brook trout. Spawning often occurs in redds constructed on or near groundwater upwellings (Benson 1953; Hale and Hilden 1969; Webster and Eiriksdottir 1976; Johnson and Webster 1977; Witzel and MacCrimmon 1983) which protect developing eggs and larvae from the potentially lethal effects of siltation and ice formation, thus increasing survival-to-emergence (Hale and Hilden 1969). In fact, groundwater can be more important than substrate composition at determining redd sites selected by spawning brook trout (Webster and Eiriksdottir 1976). Increased groundwater discharge may be positively related to the carrying capacity of trout streams. Elevated young-of-the-year (YOY) abundance (Latta 1965), and trout biomass (Bowlby and Roff 1986) were attributed to the proximity of groundwater discharge. In winter, isolated warmwater refugia near groundwater discharge areas are important to young and adult brook trout survival (Cunjak and Power 1986). Additionally, episodic pH depressions associated with spring snow-melt can chronically effect preemergent brook trout growth and survival (Kwain and Rose 1985; Hutchison et al. 1989). Acidic conditions may be diluted and/or neutralized by groundwater discharge through redds (Johnson and Webster 1977; Curry et al. 1991; Snucins et al. 1992).

Groundwater hydrology is also important to other salmonids. Sowden and Power (1985) reported that survival of preemergent rainbow trout (*Oncorhynchus mykiss*) was positively related to groundwater velocity through spawning redds. Hansen (1975) observed that larval brown trout (*Salmo trutta*) emerged earlier from redds constructed over groundwater upwellings. Lorenz and Eiler (1989) suggested that groundwater upwellings may expand the spawning habitat available to sockeye salmon (*O. nerka*) by permitting successful reproduction in areas with lower current velocity and greater composition of fine material in the substrate. Cunjak et al. (1993) reported greater densities of YOY and age 1^{+} Atlantic salmon (*S. salar*) in stream reaches where groundwater comprised a greater proportion of the flow. On the west coast, the improvement and development of new Pacific salmon spawning areas over groundwater discharge zones may have increased adult chum salmon (*O. keta*) production (Bonnell 1991; Cowan 1991).

Geology

Groundwater hydrology and temperature are influenced by regional geology (Freeze and Cherry 1979). Geologic formations that permit water infiltration and groundwater storage are termed aquifers, while formations that are not conducive to infiltration and storage are aquitards (Freeze and Cherry 1979). Aquifers develop in both bedrock and glacial (surficial) features. Some sedimentary bedrocks such as sandstone, limestone, and dolomite form large aquifers in many areas of the world, while impermeable igneous and metamorphic formations tend to form aquitards (Freeze and Cherry 1979). In surficial deposits, well-sorted materials such as sand and gravel form aquifers since they are porous, (i.e. allowing the infiltration of water), and permeable (i.e. the pores are interconnected), allowing the movement of groundwater towards a discharge area (Freeze and Cherry 1979). In contrast, fine and compacted particles such as clay form aquitards due to reduced porosity and permeability.

Aquifers are also characterized by transmissivity which is the measure of an aquifer's water-transmitting ability (units are length^2/time; e.g. m^2/s) (Freeze and Cherry 1979; Robson 1989). Transmissivity is positively correlated to the hydraulic conductivity and thickness of the aquifer (Freeze and Cherry 1979; Robson 1989). Hydraulic conductivity is the linear rate of groundwater flow (cm/s) through an aquifer, and is proportional to porosity and permeability . Theoretically, hydraulic conductivity may be so high (e.g. subterranean channels) that groundwater flow could exhibit hydrologic extremes similar to surface run-off. In such cases, groundwater flow is of little value to brook trout.

Groundwater thermal characteristics are influenced by the depth of the water-table below the ground surface. Shallow groundwater temperatures are influenced by, and fluctuate with, air temperatures (Mathess 1982). Thermal fluctuations are negatively correlated with water-table depth (Mathess 1982). Below a specified depth, known as the neutral zone, seasonal fluctuations are eliminated and groundwater temperatures remain constant (Meisner et al. 1988).

The bedrock in NWO is primarily composed of igneous and metamorphic rocks (Ayres et al. 1970), which generally exhibit low permeabilities and form aquitards (Freeze and Cherry 1979). Therefore, the surficial geologic features deposited following the retreat of the Wisconsinin glaciers (Zoltai 1965) strongly influences distribution of NWO aquifers. The hydraulic conductivity of surficial aquifers in NWO probably permit the long-term storage of groundwater (Freeze and Cherry 1979; Dean et al. 1991a), which produces the stable hydrologic and thermal conditions brook trout prefer. The depth of the neutral zone at 40-60°N latitude (which encompasses NWO) has been estimated at 17.7m below the ground surface (Meisner et al. 1988). The estimated temperature of groundwater up to 100m in depth is 1-2°C warmer than the mean annual air temperature (Freeze and Cherry 1979), and Miesner et al. (1988) estimated annual groundwater temperatures 10-20m below the ground surface in NWO at 2.2-5.5°C.

Linkages Between Geology, Groundwater, Temperature, and Brook Trout

There may be a functional link between the distribution of brook trout in NWO and the deposition of surficial features following the retreat of previous glacial events. Surficial geology influences groundwater hydrology, which in turn provides the thermal habitat required by stream resident brook trout. Thus geology could be useful for identifying brook trout streams. Many studies have discussed mechanisms that link trout distribution in North America to geology. For example, Nelson et al. (1992) reported that cutthroat trout (*O. clarki henshawi*) and brook trout distribution within the Humboldt River drainage in northeastern Nevada were strongly related to geologic districts. Although they did not directly investigate groundwater, Nelson et al. (1992) observed that brook trout were found only in glaciated areas. Brook trout distribution in southern Ontario streams is related to surficial geologic deposits conducive to groundwater transmission (Portt et al. 1989). Threinen and Puff (1963) mapped known brook trout distribution in Wisconsin on a geological template, and also revealed that brook trout distribution was strongly correlated to glacial features conducive to groundwater transmission. A similar distribution pattern is evident for stream-resident brook trout in the southern peninsula of Michigan (Hendrickson and Doonan 1972). Dean et al. (1991a) in a comprehensive paper, discussed the influence of bedrock geology, surficial geology, and climatology on groundwater hydrology, and brook trout habitat and distribution in NWO. Dean et al. (1991b) presented a 'Geofisheries' algorithm based on subjective ratings of the three environmental variables. The Geofisheries algorithm produced a model for predicting thermal habitat suitability and brook trout distribution in NWO.

Objectives

The objectives of this study were: 1) to develop and validate models predicting the distribution of brook trout in the Lake Superior drainage of NWO using surficial geology, biogeography, climate and stream temperatures, 2) to assess the relation between geology and stream temperatures, and 3) to develop and test models predicting brook trout abundance using summer thermal conditions.

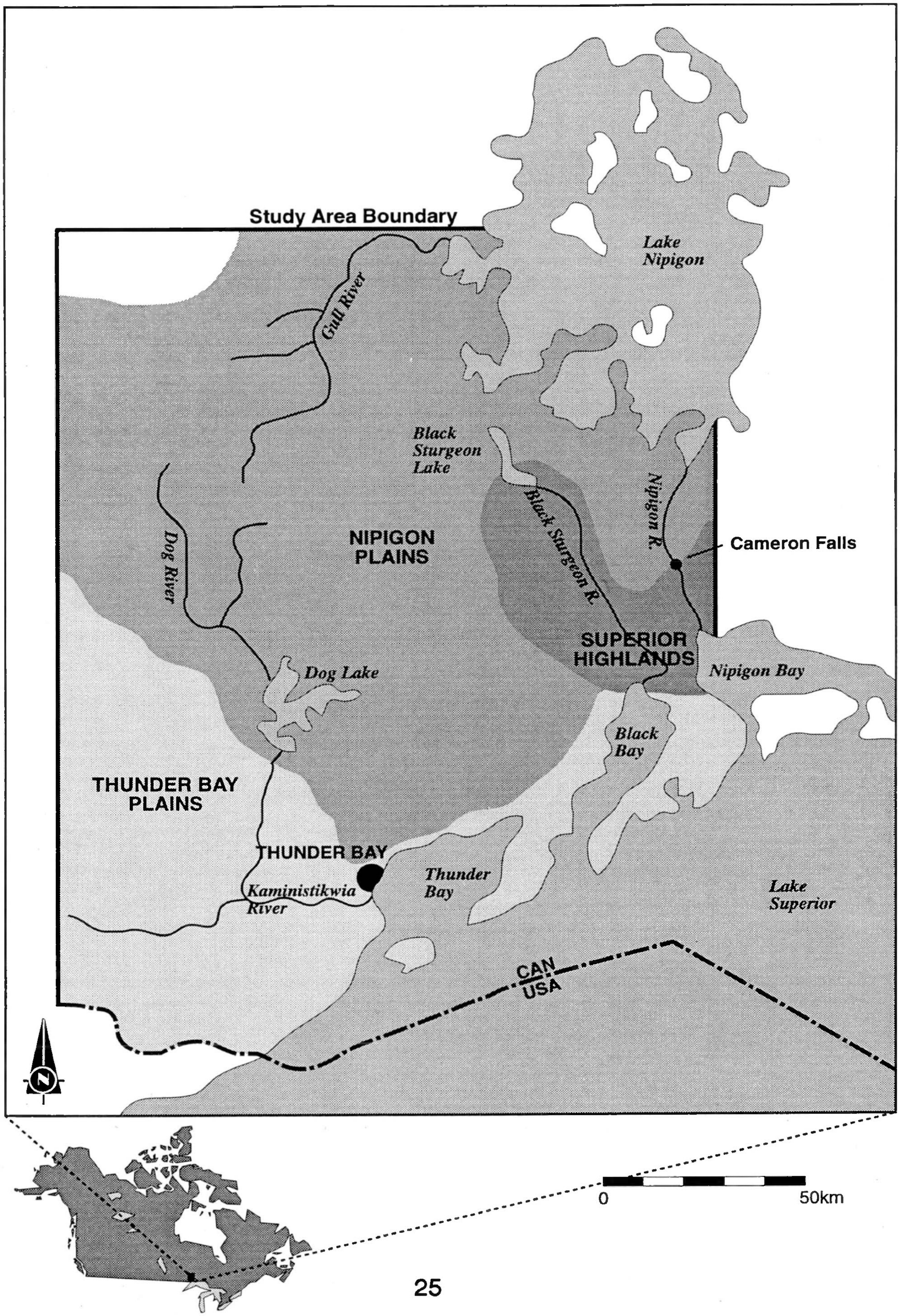
Brook trout distribution models could be used to identify trout habitat during timber management planning, and allow the implementation of protective guidelines. By assessing the relation between geology and stream temperatures, the influence that geology has on groundwater transmission and thermal habitat suitability for brook trout can be evaluated. Models predicting brook trout abundance can determine the sensitivity of trout standing stocks to the warming effects of deforestation. Fisheries managers could use all the mentioned models to implement current guidelines and develop improved protective guidelines for forest management planning.

Study Area

The study area encompassed approximately 30,000 km^2 of northwestern Ontario, and was bounded by: 1) the Kaministikwia/Dog River watershed and the Gull River watershed to the west, 2) the Gull River watershed to the north, 3) the Nipigon River watershed to the east, and 4) Lake Superior, and the Canada/U.S. border to the south (Figure 1). All study streams are direct or indirect (via Lake Nipigon) tributaries of Lake Superior. The streams lie within three ecoregions : the Nipigon Plains, the Thunder Bay Plains, and the Superior Highlands (Wickware and Rubec 1989).

Most of the study area lies within the Nipigon Plains ecoregion. Granodiorite is the dominant bedrock formation in the western portion of this ecoregion, while diabase dominates near Lake Nipigon. The principal surficial landforms are ground moraines and sandy glaciolacustrine plains. Surface relief consists of rolling and undulating hills with elevation ranging from 305-587m (Wickware and Rubec 1989). The Thunder Bay Plains ecoregion, located in the southwest portion of the study area and along the north shore of Lake Superior, is comprised of diabase, greywacke, and shale bedrock formations. In this area, thin ground moraine and glaciolacustrine clay are the dominant surficial features. The terrain is generally rolling with frequent steep cliffs and elevation ranges from 183-633m (Wickware and Rubec 1989). The Superior Highlands ecoregion comprises a narrow corridor within the study area lying between Black Sturgeon Lake and Black Bay of Lake Superior. Bedrock here

Figure 1. Map of study area showing ecoregion boundaries as presented by Wickware and Rubec (1989).


Study Area Boundary
Lake Nipigon
Gull River
Black Sturgeon Lake
Black Sturgeon R.
Nipigon R.
Cameron Falls
NIPIGON PLAINS
Dog River
SUPERIOR HIGHLANDS
Nipigon Bay
Dog Lake
Black Bay
THUNDER BAY PLAINS
THUNDER BAY
Thunder Bay
Kaministikwia River
Lake Superior
CAN
USA
N
0
50km

is comprised of conglomerate and greywacke sedimentary rocks and diabase and granodiorite igneous rocks. Ground moraine, and terminal moraines are the prominent surficial features. The relief is generally rolling and undulating with elevations ranging from 344-593m (Wickware and Rubec 1989).

The climate of the area becomes cooler in a northeast direction (Kemp 1993). The annual mean air temperature in Thunder Bay is 2.4°C, while in Cameron Falls it is 1.8°C (Figure 1). Total annual precipitation in Thunder Bay is 703.5mm (546.8mm rainfall, 156.7mm snowfall), while total annual precipitation in Cameron Falls is 831.4mm (598.8mm rainfall, 232.6mm snowfall)(Ontario Climate Centre, Environment Canada, unpublished data).

Brook trout recolonized NWO from refugia located in the Mississippi River headwaters, and possibly from the northeastern U.S. following retreat of the Wisconsinin glaciers (Bailey and Smith 1981; Underhill 1986). Stephenson and Momot (1994) suggested that recolonization occurred during the earliest stages of deglaciation (≈9,500-10,000 years before present). At this time, elevated water levels and drainage patterns permitted access to the interior of NWO via Lake Superior and glacial Lake Kelvin (located in the basin of current Lake Nipigon) (Prest 1970; Bailey and Smith 1981). Brook trout distribution became increasingly restrictive as the climate warmed and meltwaters receded. Excluding the Hudson Bay drainage, northwestern Ontario currently delimits the western edge of native brook trout distribution in Canada (MacCrimmon and Campbell 1969; Scott and Crossman 1973).

Methods

The objective of this study was to develop models predicting brook trout distribution, thermal habitat, and abundance for NWO streams and assess the models transferability to other regions in NWO. To accomplish this, two data sets from distinct geographic locations were used. The first data set consisted of 45 streams studied in 1993, and was used to develop predictive models. The second data set consisted of 34 streams studied in 1992 or 1994, and was used to validate the best models developed from the 1993 data. Stream temperatures were not available from the streams studied in 1992, therefore, models with stream temperature as either independent or dependent variables were validated with 28 streams studied in 1994. To develop and validate models predicting brook trout abundance, only streams that contained brook trout were used.

Although all streams were located within the same study area (Figure 1), the geographic location of the 1993 streams was significantly different than the 1992/1994 streams. The 1993 streams were distributed further west (Kolmogorov-Smirnoff test: D=0.4693, P=0.0004), further south (Kolmogorov-Smirnoff test: D=0.5641, P=0.0001), and further from Lake Nipigon (Kolmogorov-Smirnoff test: D=0.5719, P=0.0001) than the 1992/1994 streams. Furthermore, the 1993 streams were located in different ecoregions relative to the 1992/1994 streams (Chi-square test: X^2=23.641, P=0.0001). The 1993 streams were primarily located in the Thunder Bay Plains and Nipigon Plains, while the 1992/1994 streams were mainly in the Nipigon Plains and the Superior Highlands.

Study Stream Selection Criteria

Study reaches on streams were selected to elucidate relations between surficial geology, brook trout distribution, and summer thermal conditions in NWO streams. First- and second-order streams (Hynes 1970) draining small watersheds (<60km^2) and dominated in surface area by one type of surficial deposit were selected for this study. These streams were chosen to maximize the influence of a particular surficial deposit on stream conditions. To highlight the relationship between geology, groundwater, and brook trout, approximately two-thirds of the streams selected contained surficial deposits in the watershed that were expected to be conducive to groundwater transmission. Reaches downstream of large lakes (>1km^2 surface area) were avoided in order to eliminate potential thermal effects masking the influence of surficial geologic deposits. Streams with small lakes (<1km^2 surface area) were permitted if a suitable study site was located ≥2km downstream of the lake. To maximize sample size, streams with reasonable road access were selected. Because of limited information regarding fish distributions in NWO, no prior knowledge of species composition influenced stream selection.

Stream order and watershed boundaries were determined from 1:50,000 scale topographic maps. A Planix 7 electronic planimeter was used to measure watershed areas (km^2). Surficial geology was determined with 1:100,000 scale Northern Ontario Engineering Geology Terrain Study (NOEGTS) maps (Mollard and Mollard 1979a,b,c,d,e,f). Road access to streams was verified using topographic maps, and maps provided by the Thunder Bay District and Nipigon District offices of the OMNR, and forestry companies.

The surface area of all surficial deposits in each watershed was measured using a Planix 7 electronic planimeter. In watersheds having more than one surficial deposit, additional surface area measurements included:

1) the total area of all deposits adjacent to the stream,

2) the area of the deposit containing the study reach,

3) the area of the largest deposit in surface area adjacent to the stream, and

4) the individual areas of all other deposits adjacent to the stream.

Field Data Collection

<u>Brook Trout Presence/Absence and Abundance</u>

Study reaches were inventoried in 1993 and 1994 to determine brook trout presence/absence, and abundance. Only brook trout presence/absence data were available from the 1992 streams. Study reach lengths were measured to the nearest meter, and the upstream and downstream ends of the reaches were marked on the right bank (facing upstream) with wooden stakes. Both ends of the reaches were located at transition boundaries between habitat types (e.g. riffle, run, or pool) (Hawkins et al. 1993). The 1993 and 1994 study reaches were approximately 60m long and included ≥3 riffle/pool sequences (Lyons 1992b). The 1992 study reaches were approximately 100m long, and also included ≥3 riffle/pool sequences.

Brook trout populations and standing stocks were estimated using a three-pass depletion/removal method (Zippin 1958). However, if no fish were captured or seen during the first two passes, the third pass was not completed. Conversely, if the brook trout capture rate did not decrease during the first three passes, a fourth pass was usually performed. Trout populations and standing stocks were not estimated for Gull 3 Creek and Poshkokagan Creek. Only one depletion pass was performed in Gull 3 Creek and trout were caught by angling in Poshkokagan Creek.

Fish sampling was conducted in mid- and late-July and August by two trained persons using either a Model-12 (battery-powered) or Model-15B (generator-powered) Smith-Root backpack electrofisher. One person carried the electrofisher and operated the anode pole and a dip-net. The second person handled a dip-net and carried a 22.7 l bucket for holding all fish captured during the current pass.

The electrofisher output parameters (voltage, pulse width, pulse frequency) were adjusted to compensate for differing stream water conductivities. Electrofishers were initially set at 0 volts, 2ms pulse width, and 60Hz pulse frequency. Voltage was increased in increments of 100 volts until either: 1) fish in the stream were visibly affected by the electrical current, or 2) a rapidly repeating tone was evident from the audio output voltage indicator (Smith-Root Inc. 1988, 1992). If neither condition occurred and the maximum 1,100 volts was reached, then pulse width and pulse frequency were increased until satisfactory results were achieved.

To ensure study reach closure for population estimates (White et al. 1982), 5mm mesh blocking seine nets were set across stream widths at the upstream and downstream ends and secured to the substrate with large rocks. At the end of each pass, fish were transferred for later processing to porous buckets stabilized within the stream, and outside the study reach.

Following the last depletion pass, fish from each pass were counted and sampled separately. Total length (TL) and fork length (FL) of all fish were measured to the nearest millimetre. Large trout (≥100mm FL) were weighed individually (to the nearest gram) with Pesola spring-scales or a Sartorius PT-1200 electronic scale. Total weights of all small trout (<100mm FL) in each pass were measured together. Non-trout fish were first separated by species and pass, and then all individuals in each group were weighed together.

Trout abundance was estimated with the POPEST basic program which uses a maximum-likelihood estimator (Platts et al. 1983). Four parameters of brook trout abundance were calculated:

1) trout number per kilometre of stream,

3) trout number per hectare of stream,

2) trout biomass (kg) per kilometre of stream, and

4) trout biomass (kg) per hectare of stream.

Temperature Monitoring

Stream temperatures were monitored biweekly during daylight through the summers of 1993 and 1994 to assess the relation between stream summer thermal conditions and: 1) brook trout distribution, 2) watershed geology, and 3) brook trout abundance. Temperature data were not available for the 1992 streams.

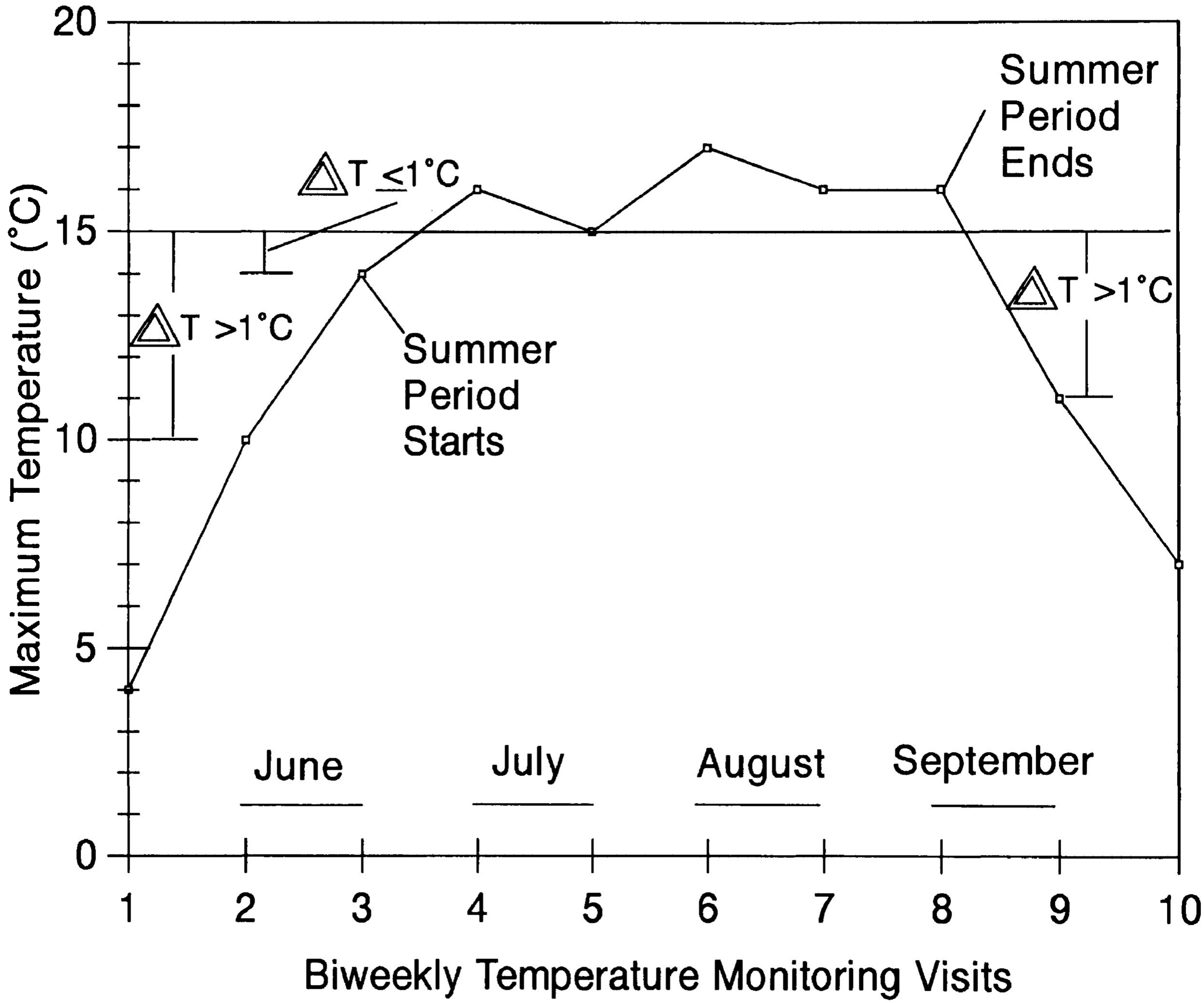
Calibrated Taylor maximum/minimum thermometers were secured inside neutral grey-coloured protective cases of ABS piping (30cm long x 7.62cm inside diameter) to avoid heat reflectance or absorbtion. Thermometers were completely submerged in riffle or run habitats of each study reach during May and early June of 1993 and 1994. Deep, low-velocity pool habitats were not sampled to avoid possible effects of thermal stratification (Matthews et al. 1994; Nielsen et al. 1994). Thermometers were secured in the stream by inserting a steel rod that was driven into the substrate through holes drilled in the ABS cases. As stream-flows decreased, some thermometers were moved to deeper areas of identical temperature (confirmed with a Flett Research Ltd. digital thermometer, accurate to ±0.1°C), usually within 3m of the original location. Stream temperatures recorded in this study reflected the general temperature of the study reaches rather than any potential thermal influences of localized groundwater discharge points. However, the general temperatures are a product of factors (including groundwater) that influence thermal conditions (Ward 1985).

From May to October of both years (1993 and 1994), maximum, minimum, and actual sampling temperatures were read and recorded biweekly from the maximum/minimum thermometers (to the nearest 1.0°C) and thermometers were reset. Temperatures were monitored on similar dates each year. Maximum/minimum thermometer accuracy was verified at each temperature reading with a Fisher precision thermometer or calibrated Flett Research Ltd. digital thermometer, each accurate to ±0.1°C.

A critical summer thermal period was standardized among streams to facilitate comparative temperature analyses. The summer thermal period was defined as all dates in July and August (the warmest months in NWO) plus contiguous dates in June and September when maximum stream temperatures were within 1°C of the coolest maximum temperature recorded in July or August (Figure 2). Streams having the most restrictive summer thermal periods in each year were used to define the summer period for all streams in that year. The summer period in 1993 included six biweekly temperature recordings. It began in the third week of June and ended in the first week of September. The summer period in 1994 included five biweekly temperature recordings. It began in the first week of July and ended in the first week of September.

Four thermal indices were calculated and used in the analyses:

Figure 2. Schematic illustration of the method used to determine the summer thermal period using the maximum temperatures of a hypothetical stream recorded during biweekly temperature monitoring visits. The summer thermal period includes all monitoring visits during July and August (visits 4-7 inclusive) plus visits in June and September when maximum temperatures were ≤1°C less than the coolest maximum temperature recorded during July or August. In this example, the coolest maximum temperature in July or August was 15°C (the horizontal line) recorded at visit 5. Therefore, monitoring visits in June and September would be included in the summer thermal period if maximum temperatures were ≥14°C. Therefore, the summer thermal period of this hypothetical stream began at monitoring visit 3 (maximum temperature = 14°C) and ended at monitoring visit 8 (maximum temperature = 16°C). Monitoring visits 2 (10°C) and 9 (11°) were excluded from the summer thermal period since the maximum temperatures recorded were >1°C less than 15°C.



Maximum Temperature (°C)
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
Biweekly Temperature Monitoring Visits
June
July
August
September
ΔT ≤1°C
ΔT >1°C
ΔT >1°C
Summer Period Starts
Summer Period Ends

1) maximum summer temperature,

2) mean-maximum summer temperature,

3) mean summer temperature, and

4) summer thermal stability.

Maximum summer temperature of each stream was the single highest maximum temperature recorded during the summer thermal period. The mean-maximum temperatures (MEANMAX) were calculated as the sum of all maximum temperatures recorded during the summer period divided by the number of temperature recording visits (n) during the summer period, ie:

$$MEANMAX(°C) = \frac{\Sigma maximums}{n}$$

The mean summer temperature (SUMMMEAN) used in this study was actually the mean-median temperature. It was calculated as the sum of the median temperatures recorded at each visit (i.e. [maximum + minimum]/2) during the summer period divided by n, ie:

$$SUMMMEAN(°C) = \frac{\Sigma[(maximum + minimum)/2]}{n}$$

Summer thermal stability (SUMMSTAB) was calculated as the sum of the differences between the maximum and minimum temperature recorded at each visit during the summer period, divided by n, ie:

$$SUMMSTAB(°C)=\frac{\Sigma(maximum-minimum)}{n}$$

Three methods were used to evaluate annual and geographical differences in stream temperatures. First, thermal indices measured from the 1993 streams were compared to those measured in 1994 with t-tests using the TTEST procedure of SAS (SAS Institute 1988). These analyses were conducted for all streams, for trout streams, and for non-trout streams. Between year differences were considered significant at $P \leq 0.05$. Second, the mean-maximum summer temperatures, and the mean summer temperatures of 10 reference streams monitored in both years were calculated based on temperature recordings from dates that coincided with the shorter summer period defined in 1994. These thermal indices for each stream were compared between years using the TTEST procedure of SAS (SAS Institute 1988). Third, since climatic conditions have a large impact on stream temperatures (Smith 1972), summer climatic conditions each year were examined for any differences that may have caused annual stream temperature variation. Climatic conditions were assessed using data from the Thunder Bay and Cameron Falls climate stations (Ontario Climate Centre, Environment Canada, unpublished data).

To assess thermal differences between trout and non trout streams each year, thermal indices were compared using the TTEST procedure of SAS (SAS Institute 1988).

For all t-test analyses, if the assumptions of normality and equal variance were not met then the Wilcoxon Rank-Sum test in the NPAR1WAY procedure of SAS (SAS Institute 1988) was used for thermal comparisons.

Modelling Brook Trout Presence/Absence

Models predicting brook trout presence/absence were developed using the 1993 data, and were validated using independent data collected in 1992 and 1994. A second model development procedure was conducted using the combined data from all years.

Variables predicting brook trout distribution were analyzed with logistic regression using the LOGISTIC procedure of SAS (SAS Institute 1990). Logistic regression was used since the response variable (brook trout presence/absence) was binary (Cox and Snell 1989), and logistic regression is the preferred analysis for distinguishing between two classes (e.g. presence or absence) when some or all of the independent variables are binary or categorical (Press and Wilson 1978; Prager and Fabrizio 1990). Regression coefficients were estimated using the maximum-likelihood method (SAS Institute 1990; Hosmer and Lemeshow 1989). Logistic regression uses the function:

$$\pi = \frac{e^u}{1+e^u}$$

where: π = the probability of brook trout presence

e = the inverse natural logarithm of 1

$u = k + m_1x_1 + m_2x_2 + ... + m_ix_j$

where: k = the regression constant

m_i = the regression coefficients

x_j = the values of the independent variables.

The -2 log likelihood statistic was used to test significance of each model. This statistic measures the deviation of observed values from the model (analogous to residual sums-of-squares in linear regression) (Hosmer and Lemeshow 1989). With constant sample size, lower values of -2 log likelihood indicate improved model fit. The significance of -2 log likelihood is assessed with a chi-square test, and $P \leq 0.05$ indicates that at least one of the regression coefficients are significantly different from zero (Hosmer and Lemeshow 1989). The Wald chi-square statistic was used to test the significance of regression coefficients in each model (SAS Institute 1990). Models were considered statistically significant if all regression coefficients were significantly ($P \leq 0.05$) different from zero.

Predicted probabilities of brook trout presence/absence were calculated from the best models and compared to brook trout presence/absence observed during model development and model validation to assess correct prediction (i.e. classification) rates. If predicted probabilities were ≥ 0.50, then brook trout were predicted present. Conversely, if predicted probabilities were <0.50 then brook trout were predicted absent. The Kappa statistic was used to determine whether the classification of trout presence/absence produced by the best logistic regression models were significantly better than chance classifications (Titus et al. 1984). The value of Kappa expresses the proportion of streams correctly classified by a given model after the effect of chance correct classification is removed (Beauchamp et al. 1992). A $P \leq 0.05$ indicates that trout presence/absence classification by a given model was significantly better than expected by chance.

Predicting Brook Trout Presence/Absence - Model Development I

Four model types were developed using the 1993 data to predict brook trout distribution: 1) Geology models, 2) Biogeographic/Climatic models, 3) Thermal models, and 4) Combined models which used combinations of variables from the first three model types.

GEOLOGY MODELS

The surficial geologic deposits used to develop predictive models were identified with the Northern Ontario Engineering Geology Terrain Study

(NOEGTS) maps (Mollard and Mollard 1979a,b,c,d,e,f) (Appendix 2). Limited quantitative information regarding the characteristics of surficial geology aquifers in NWO is available. Therefore, to evaluate the best method of quantifying surficial geologic deposits, four methods were employed and tested in models predicting brook trout presence/absence in NWO: 1) Geofisheries (Dean et al. 1991b), 2) Modified Geofisheries, 3) Objective, and 4) Dichotomous. All numeric ratings of surficial geologic deposits reflected the ability of deposits to transmit groundwater. Both the quantity (i.e. volume) and quality (i.e. temperature) of groundwater were approximated by the ratings. The subjective Geofisheries ratings (Dean et al. 1991b) were used in the assessment of the Geofisheries model. These ratings were also the basis of the Modified Geofisheries models, and the Geofisheries-derived Dichotomous models. Objective dimensional characteristics of surficial deposits were used to assess the Objective models and Objective Dichotomous models.

1) Geofisheries Model

The Geofisheries model was developed by Dean et al. (1991a,b) to predict brook trout distribution in NWO, however, this model was never empirically validated. The Geofisheries model is based on subjective numerical ratings of geologic and climatologic variables relative to their suitability to predict groundwater hydrology and thus brook trout distribution (Dean et al. 1991a,b). Variables in the model rate the following:

1) bedrock geology structures (BEDROCK) determined from Ayres et al. (1970) (Table 1),

2) surficial deposits in a stream's watershed lying within 1km of the stream (SURFACE) as determined from NOEGTS maps (Mollard and Mollard 1979a,b,c,d,e,f) (Table 2), and

3) climate zones (CLIMZONE) (Figure 3, Table 3).

For each study stream, a Geofisheries score (GEOFISH) was calculated using the following formula from Dean et al. (1991b):

$$GEOFISH=\frac{BEDROCK+(3xSURFACE)}{2}xCLIMZONE$$

Surficial geology features are separated by boundaries on the NOEGTS maps. Often within a single boundary, several surficial deposits are listed in order of their dominance, and such landforms are termed complex terrain units (Figure 4) (Gartner et al. 1981). The first deposit listed in a complex terrain unit is the dominant deposit (as determined by surface area) and usually comprises >50% of the surface area. Subordinate deposits can comprise 10-50% of the surface area (Figure 4) (Gartner et al. 1981). To calculate the Geofisheries score (GEOFISH), the highest rated surficial deposit within a complex terrain unit (Table 3) is used regardless of dominance (Dean et al. 1991b).

Table 1. Subjective Geofisheries ratings of bedrock types in the Superior and Southern provinces (Dean et al. 1991b). Rating variability is due to location and the presence or absence of dykes or faults.

Bedrock Type	Rating
	Superior Province
Migmatic Metasediments	1-3.5
Metasediments	3 or 3.5
Felsic to Intermediate Metavolcanics	3.5 or 4
Late Felsic Igneous	4.5 or 5
Mafic Metavolcanics	3 or 3.5
Ultramafic	4 or 4.5
Early Felsic Igneous	2.5-3.5
	Southern Province
Early Felsic Igneous and Migmatic Metasediments	3 or 4.5
Metasediments	2.75 or 3
Late Felsic Igneous	5 or 5.5
Mafic metavolcanics	3 or 3.5
Ultramafic	4.5 or 5
Early Felsic Igneous	3-4.5
Carbonatite Alkalic	6.5
Late Mafic Igneous	5 or 5.5
Felsic Metavolcanics	4 or 4.5
Animikie	5.5-6
Keweenawan	5.75-6.25

Table 2. Subjective Geofisheries ratings of surficial deposits (SURFACE) and Northern Ontario Engineering Geology Terrain Study (NOEGTS) map codes for the deposits (Dean et al. 1991b). Rating variability is due to location.

Surficial Deposit	NOEGTS Code	Rating
Ground Moraine	MG	2.0
DeGeer/Hummocky Moraine	MH	7.0
End Moraine	ME	8.0
Interlobate Moraine	ME	8.5
Small Esker	GE	6.5
Large Esker	GE	7.5
Kame Field	GK	7.5
Outwash	GO	7.0
Valley Train	GO	9.0
Delta	GD or LD	9.0
Glaciolacustrine Plain	LP	1.5 or 2.0
Raised Beach	LB	7.0
Alluvial Plain	AP	7.5
Organic Terrain with Sand, Gravel, or Moraine (Fen)	eg. pOT(sgME)	9.5
Organic Terrain with Bedrock or Glaciolacustrine Plain (Bog)	eg. pOT(cLP)	0.0-6.0
Spillway in Sand or Organics	graphic symbol	10.0
Spillway in Bedrock or Ground Moraine	graphic symbol	9.5
Spillway in Clay or Silt	graphic symbol	6.0
Eolian	graphic symbol	7.5
Drumlin Field	graphic symbol	7.5

Figure 3. Map of study area showing climate zone boundaries defined by Dean et al. (1991b).

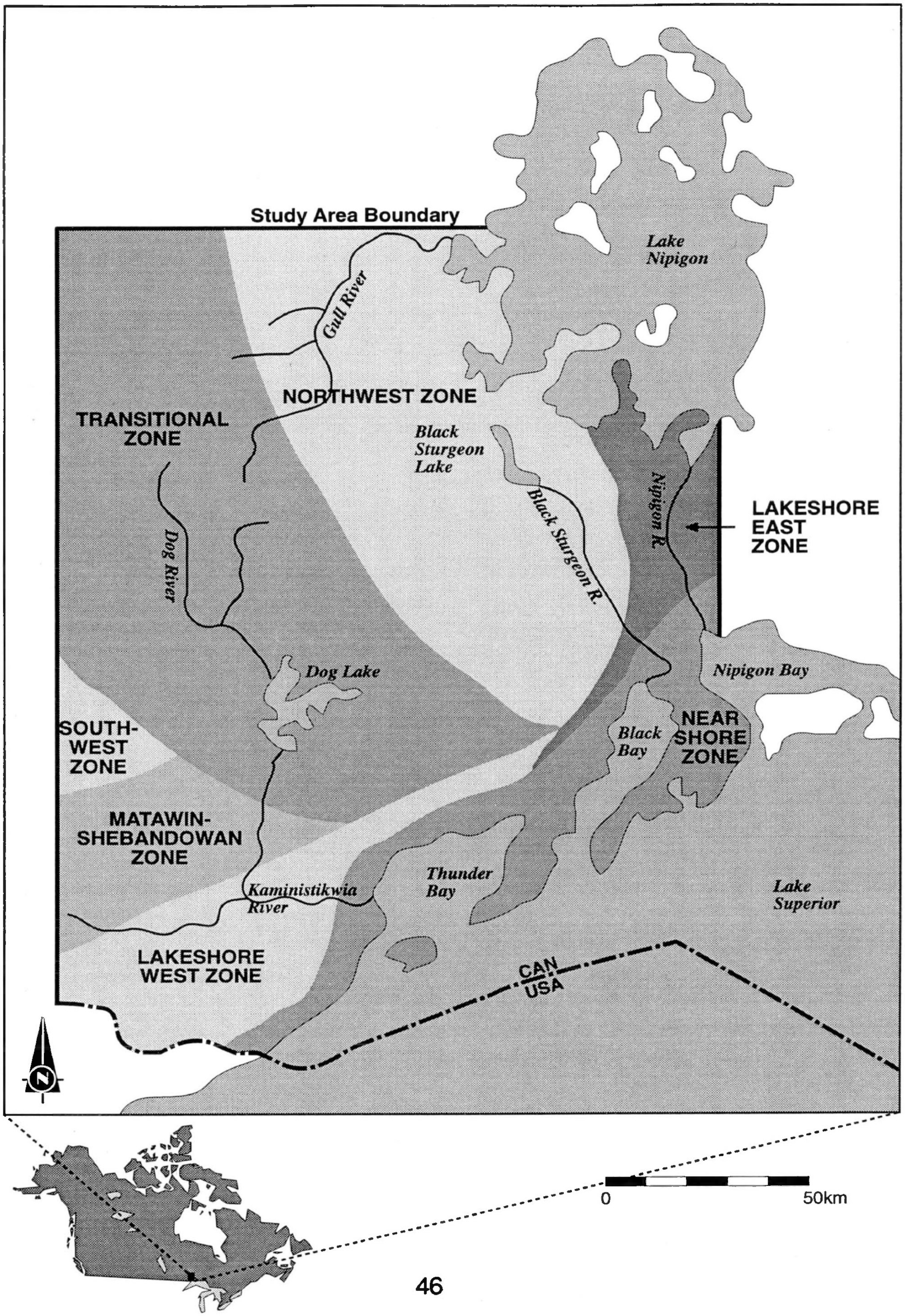
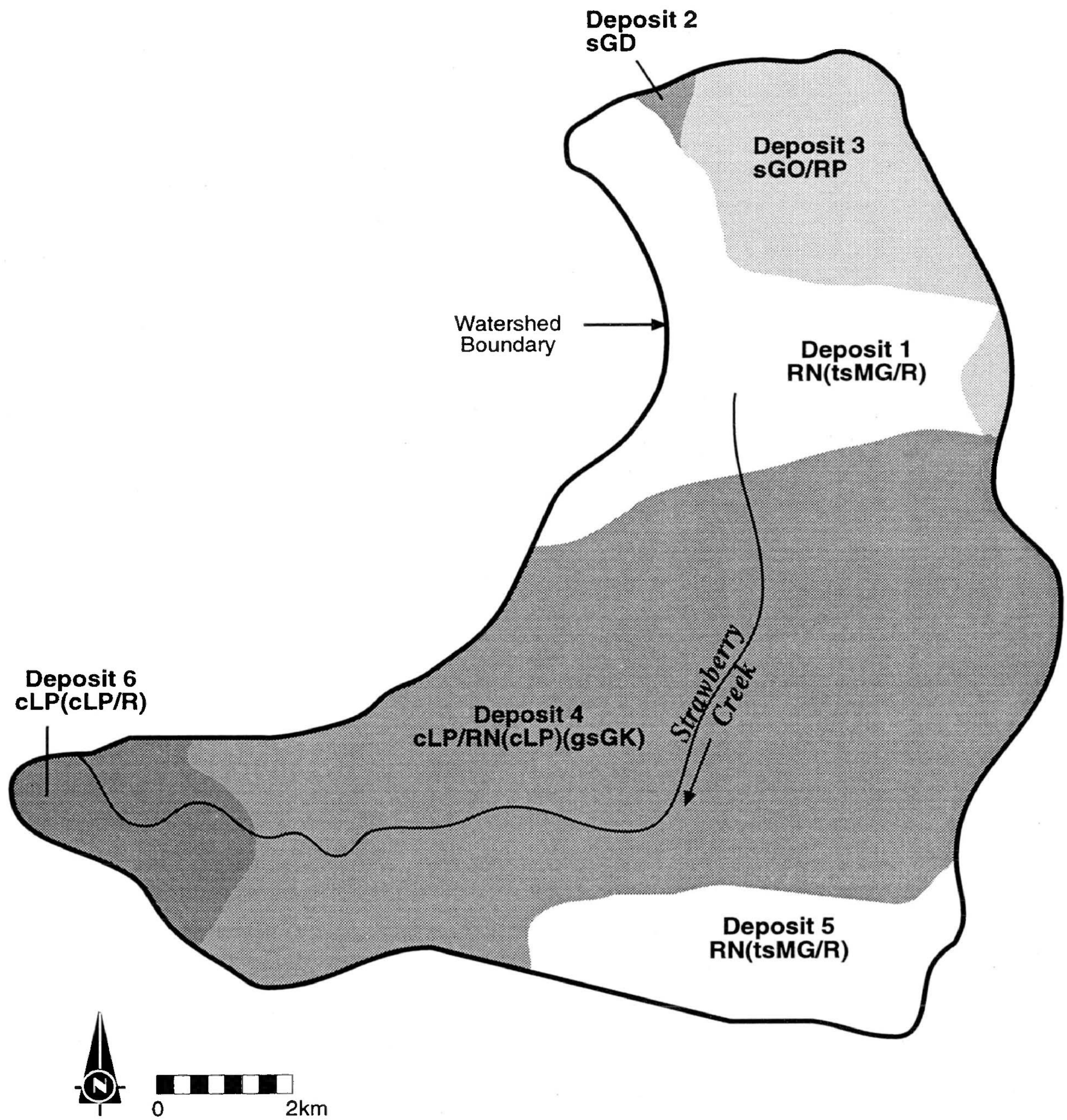

Study Area Boundary
Lake Nipigon
Gull River
NORTHWEST ZONE
TRANSITIONAL ZONE
Black Sturgeon Lake
Nipigon R.
Black Sturgeon R.
LAKESHORE EAST ZONE
Dog River
Dog Lake
Nipigon Bay
SOUTH-WEST ZONE
Black Bay
NEAR SHORE ZONE
MATAWIN-SHEBANDOWAN ZONE
Thunder Bay
Kaministikwia River
Lake Superior
LAKESHORE WEST ZONE
CAN
USA
N
0
50km

Table 3. Subjective Geofisheries ratings of climate zones (Dean et al. 1991b).

Climate Zone	Rating
Southwest	0.0
Matawin-Shebandowan	0.9
Transition	0.9
Northwest	1.0
Lake Shore West	1.2
Lake Shore East	1.2
Near Shore	1.4

Figure 4. Strawberry Creek (a 1993 site) showing the various surficial deposits within the watershed (Mollard and Mollard 1981b). More than one deposit type is listed in deposits 1,4,5, and 6, therefore, these deposits are termed complex terrain units. The dominant deposits (>50% of the surface area) are listed first, and the subordinate deposits (≤50% of the surface area) are in parentheses. Deposit 4 is a complex terrain unit consisting of 3 deposit types. In deposit 4, the highest rated deposit type is the kame (GK, rating = 7.5). The dominant deposit type is the clay glaciolacustrine plain overlying bedrock (cLP/RN) which is rated 1.5. The dominant and first subordinate deposit types (cLP/RN and cLP) are rated the same by Geofisheries, therefore, the rating for the highest rated deposit type among the dominant and first subordinate is 1.5.


Deposit 2
sGD
Deposit 3
sGO/RP
Watershed
Boundary
Deposit 1
RN(tsMG/R)
Deposit 6
cLP(cLP/R)
Deposit 4
cLP/RN(cLP)(gsGK)
Strawberry
Creek
Deposit 5
RN(tsMG/R)
N
0
2km

The components of the Geofisheries model (BEDROCK, SURFACE, CLIMZONE) were tested in univariate and multivariate logistic regression models to assess their ability to predict brook trout presence/absence (Table 4). Because the Geofisheries model uses an index value derived from the product of subjective geological and climatological ratings (Dean et al. 1991b), the variance associated with each variable (Tables 1, 2, 3) is masked in such a model (i.e. the associated variance and the interaction effects of the independent variables are not reliably represented by an additive model). Multiple regression analysis is the accepted method for evaluating the variance, and assessing interaction effects of more than one independent variable on a dependent variable (Jaccard et al. 1990; see Rempel and Colby 1991).

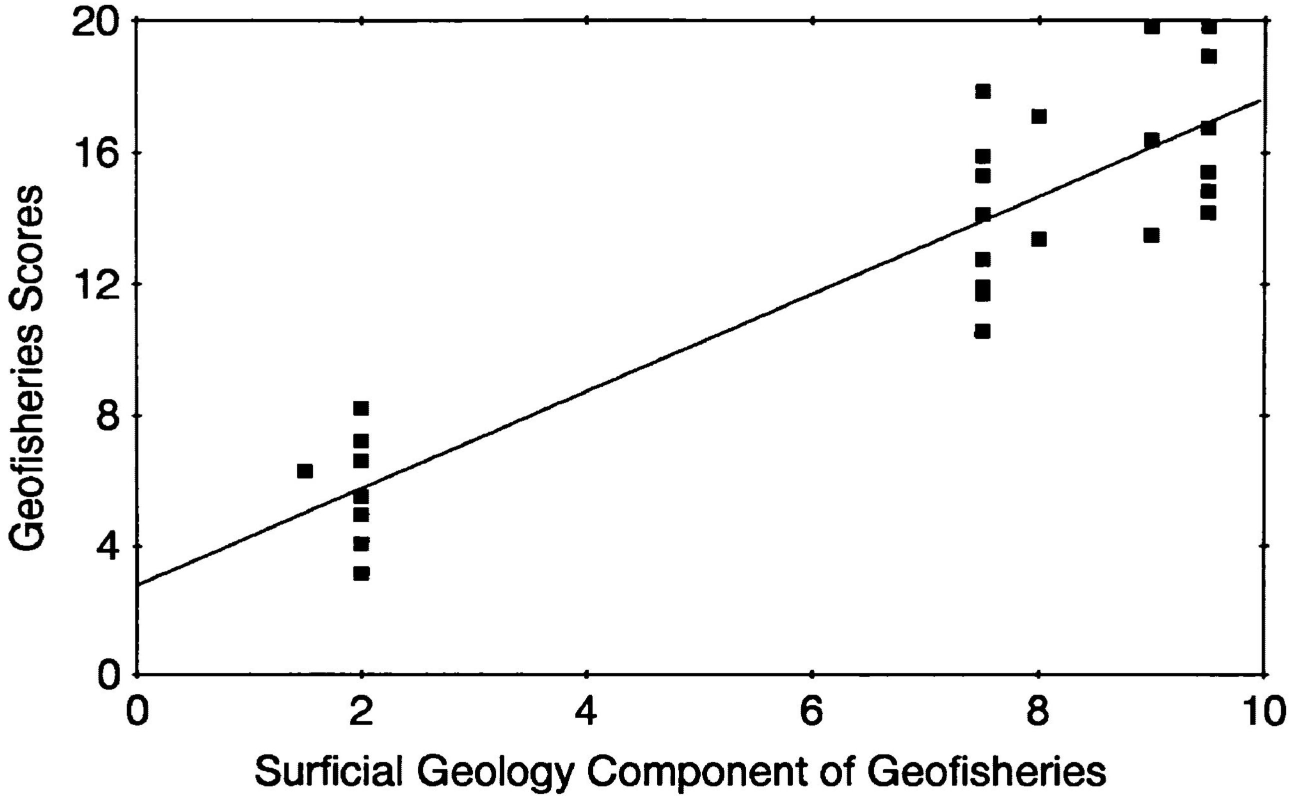
2) Modified Geofisheries Models

Results from the analyses testing the components of Geofisheries in univariate and multivariate logistic regression models revealed that the surficial geology component of the model (SURFACE) was the only variable significantly related to brook trout presence/absence (Table 4). Furthermore, the Geofisheries model (GEOFISH) was highly correlated to SURFACE (r^2=0.8599, P=0.0001) (Figure 5), thus the surficial geology component was driving the Geofisheries model. Therefore, Modified Geofisheries models predicting brook trout presence/absence were developed based on Geofisheries' ratings of surficial deposits (Table 2).

Table 4. Results of logistic regression analyses testing the surficial geology (SURFACE), bedrock geology (BEDROCK), and climate zone (CLIMZONE) components of the Geofisheries models in univariate and multivariate models predicting brook trout presence/absence.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	Constant	-2 log Likelihood	P
SURFACE	0.4472	0.0068	-3.6975	45.192	0.0005
BEDROCK	-0.0783	0.7240	-0.3644	57.162	0.7244
CLIMZONE	1.5962	0.4252	-2.4059	56.648	0.4242
SURFACE	0.4475	0.0067	-3.7739	57.286	0.0024
BEDROCK	0.0182	0.9477			
SURFACE	0.5199	0.0053	-8.4371	42.647	0.0007
CLIMZONE	3.9392	0.1241			
BEDROCK	-0.1362	0.5593	-2.1809	56.307	0.6128
CLIMZONE	1.9191	0.3574			
SURFACE	0.5234	0.0057	-8.6158	42.635	0.0021
BEDROCK	0.0331	0.9110			
CLIMZONE	3.9538	0.1240			

Figure 5. Relation between Geofisheries scores (Dean et al. 1991b) and the surficial component of the Geofisheries model (GEOFISH = 2.777 + 1.487(SURFACE); r^2 = 0.8599 and P=0.0001).



20
16
12
8
4
0
Geofisheries Scores
0
2
4
6
8
10
Surficial Geology Component of Geofisheries

A total of 54 Modified Geofisheries variables were developed based on the surficial deposits that were adjacent to the study streams (Table 5). The modifications were conducted in three steps:

Step 1. The ratings of surficial deposits comprising various portions of the watershed were tested:

1) the rating of the deposit within which the study reach was located,

2) the rating of the largest deposit in surface area within the watershed, that was adjacent to the stream (Figure 6), and

3) the weighted mean rating of all deposits adjacent to the stream (Figure 6).

Step 2. Sensitivity analyses tested different ratings of sandy glaciolacustrine plains and fens. Glaciolacustrine plains are primarily comprised of either clay or sand (Mollard and Mollard 1979a,b,c,d,e,f) which have distinct hydraulic conductivities influencing groundwater hydrology. However, Geofisheries rates all glaciolacustrine plains identically despite the hydrologic differences (Dean et al. 1991b) (Table 2). The Geofisheries rating of 1.5 or 2.0, and a higher rating of 7.8 for sandy glaciolacustrine plains were tested. A rating of 7.8 was chosen since that was the mean of the other highly rated deposits (see Table 2). The rating for clay glaciolacustrine plains (1.5 or 2.0) was not changed.

Table 5. Three iteration steps conducted to produce 54 Modified Geofisheries variables rating surficial geologic deposits. The variables were tested for their ability to predict brook trout presence/absence in northwestern Ontario streams.

Variable Name	Step 1	Step 2		Step 3
	Site Deposit (S), Largest Deposit (L) or Weighted Mean Rating (WM)	Rating for Sandy Glaciolacustrine Plains	Rating for Fens	Using the Highest Rated Deposit (H), the Dominant Deposit (D), or the Highest Rated Deposit Among the Dominant and First Subordinate Deposits (H12) for a Complex Terrain Unit
SITEAH	S	1.5	9.5	H
SITEAD	S	1.5	9.5	D
SITEAH12	S	1.5	9.5	H12
SITEBH	S	1.5	5	H
SITEBD	S	1.5	5	D
SITEBH12	S	1.5	5	H12
SITECH	S	1.5	Bog	H
SITECD	S	1.5	Bog	D
SITECH12	S	1.5	Bog	H12
SITEDH	S	7.8	9.5	H
SITEDD	S	7.8	9.5	D
SITEDH12	S	7.8	9.5	H12
SITEEH	S	7.8	5	H
SITEED	S	7.8	5	D
SITEEH12	S	7.8	5	H12
SITEFH	S	7.8	Bog	H

Table 5 (continued). Three iteration steps conducted to produce 54 Modified Geofisheries variables rating surficial geologic deposits. The variables were tested for their ability to predict brook trout presence/absence in northwestern Ontario streams.

Variable Name	Step 1	Step 2		Step 3
	Site Deposit (S), Largest Deposit (L) or Weighted Mean Rating (WM)	Rating for Sandy Glaciolacustrine Plains	Rating for Fens	Using the Highest Rated Deposit (H), the Dominant Deposit (D), or the Highest Rated Deposit Among the Dominant and First Subordinate Deposits (H12) for a Complex Terrain Unit
SITEFD	S	7.8	Bog	D
SITEFH12	S	7.8	Bog	H12
LARGAH	L	1.5	9.5	H
LARGAD	L	1.5	9.5	D
LARGAH12	L	1.5	9.5	H12
LARGBH	L	1.5	5	H
LARGBD	L	1.5	5	D
LARGBH12	L	1.5	5	H12
LARGCH	L	1.5	Bog	H
LARGCD	L	1.5	Bog	D
LARGCH12	L	1.5	Bog	H12
LARGDH	L	7.8	9.5	H
LARGDD	L	7.8	9.5	D
LARGDH12	L	7.8	9.5	H12
LARGEH	L	7.8	5	H
LARGED	L	7.8	5	D

Table 5 (continued). Three iteration steps conducted to produce 54 Modified Geofisheries variables rating surficial geologic deposits. The variables were tested for their ability to predict brook trout presence/absence in northwestern Ontario streams.

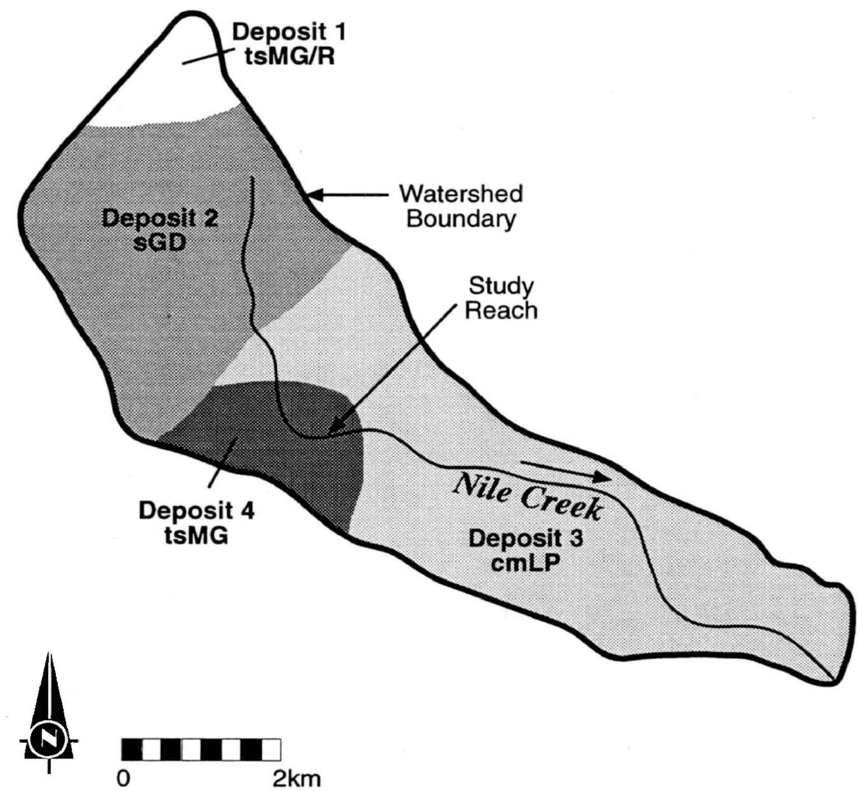
Variable Name	Step 1	Step 2		Step 3
	Site Deposit (S), Largest Deposit (L) or Weighted Mean Rating (WM)	Rating for Sandy Glaciolacustrine Plains	Rating for Fens	Using the Highest Rated Deposit (H), the Dominant Deposit (D), or the Highest Rated Deposit Among the Dominant and First Subordinate Deposits (H12) for a Complex Terrain Unit
LARGEH12	L	7.8	5	H12
LARGFH	L	7.8	Bog	H
LARGFD	L	7.8	Bog	D
LARGFH12	L	7.8	Bog	H12
MEANAH	WM	1.5	9.5	H
MEANAD	WM	1.5	9.5	D
MEANAH12	WM	1.5	9.5	H12
MEANBH	WM	1.5	5	H
MEANBD	WM	1.5	5	D
MEANBH12	WM	1.5	5	H12
MEANCH	WM	1.5	Bog	H
MEANCD	WM	1.5	Bog	D
MEANCH12	WM	1.5	Bog	H12
MEANDH	WM	7.8	9.5	H
MEANDD	WM	7.8	9.5	D
MEANDH12	WM	7.8	9.5	H12

Table 5 (continued). Three iteration steps conducted to produce 54 Modified Geofisheries variables rating surficial geologic deposits. The variables were tested for their ability to predict brook trout presence/absence in northwestern Ontario streams.

Variable Name	Step 1	Step 2		Step 3
	Site Deposit (S), Largest Deposit (L) or Weighted Mean Rating (WM)	Rating for Sandy Glaciolacustrine Plains	Rating for Fens	Using the Highest Rated Deposit (H), the Dominant Deposit (D), or the Highest Rated Deposit Among the Dominant and First Subordinate Deposits (H12) for a Complex Terrain Unit
MEANEH	WM	7.8	5	H
MEANED	WM	7.8	5	D
MEANEH12	WM	7.8	5	H12
MEANFH	WM	7.8	Bog	H
MEANFD	WM	7.8	Bog	D
MEANFH12	WM	7.8	Bog	H12

Figure 6. Demonstration of the method used to calculate the Modified Geofisheries ratings of: 1) the deposit containing the study reach, 2) the largest deposit in surface area adjacent to the stream, and 3) the weighted mean rating. The map is of Nile Creek (a 1993 study site) showing the location of the study reach and the surficial geologic deposits within the watershed (Mollard and Mollard 1979a). Deposits 2,3, and 4 are adjacent to (i.e. abutting) the stream. If an adjacent deposit extends downstream of the study reach (e.g. Deposits 3 and 4), then only the portion (surface area) of the deposit that is upstream of the study reach and adjacent to the stream is considered in the calculation of ratings. The total area of deposits adjacent to Nile Cr. (TOTAREA) is 2.129km^2. Deposit 4 (tsMG) is the site deposit since it contains the study reach. The surface area of Deposit 4 is 0.459km^2, which comprises 21.56% of TOTAREA. Deposit 2 (sGD) is the largest deposit in surface area (1.487km^2) that is adjacent to the stream, comprising 69.85% of TOTAREA. The surface area of Deposit 3 (cmLP) (the third adjacent deposit) is 0.183km^2 which comprises 8.59% of TOTAREA. The Modified Geofisheries rating of the site deposit (tsMG) for Nile Creek is 2.0. The Modified Geofisheries rating of the largest deposit adjacent (sGD) for Nile Creek is 9.0. The weighted mean rating for all deposits adjacent to Nile Creek is:

$$(2.0 \times 0.2156) + (9.0 \times 0.6985) + (1.5 \times 0.0859) = 6.847.$$


Deposit 1
tsMG/R
Watershed
Boundary
Deposit 2
sGD
Study
Reach
Nile Creek
Deposit 4
tsMG
Deposit 3
cmLP
0
2km

Sensitivity analyses also tested different ratings for fens. Fens were defined by Dean et al. (1991a) as wetlands comprised primarily of peat that are overlying or are adjacent to sand/gravel deposits. Therefore, fens are indicators of groundwater discharge rather than actual groundwater transmitting deposits. Fens were rated highly (9.5) by Geofisheries (Dean et al. 1991b). In addition to the Geofisheries rating, a moderate rating of 5.0 was tested. It was felt that groundwater discharging into fens may be exposed to the extremes of ambient temperature prior to reaching the stream channel thus hindering the cooling influence of direct groundwater discharge. Fens were also tested using a rating equivalent to the Geofisheries rating for bogs (0.0-6.0 depending on the stream's location) (Table 2), since all wetlands may impact thermal habitat and brook trout distribution similarly.

Step 3. Three other modifications of surficial deposit ratings tested the contribution of the various deposits comprising a complex terrain unit (Figure 4) to explaining brook trout presence/absence. First, the Geofisheries method of using the highest rated deposit was tested. Second, the rating of the dominant deposit (surface area) was tested since it may have the greatest influence on thermal habitat. Third, the highest rated deposit among the dominant and first subordinate deposits was also tested. The first subordinate deposit may comprise up to 50% of the surface area of a complex terrain unit (Gartner et al. 1980), and thus substantially impact thermal habitat.

3) Objective Geology Models

Since, the Geofisheries model (Dean et al. 1991b) employs subjective ratings of surficial geologic deposits, models using variables based on objective characteristics of the deposits adjacent to the study streams were also tested as predictors of brook trout presence/absence. Objective characteristics included in the models were: 1) deposit thickness, 2) hydraulic conductivity of the materials comprising the deposits, and 3) deposit volume. Since these characteristics do not apply to wetlands (i.e. fens or bogs), contrary to Geofisheries, the objective geology models rated surficial deposits associated with wetlands (i.e. deposits adjacent to or underlying wetlands) rather than rate the wetlands themselves.

Deposit thicknesses measured in meters were calculated from the estimated thickness values of the deposits listed by Zoltai (1963; 1965) (Table 6). Three variables based on deposit thickness were tested:

1) thickness of the deposit containing the study reach, (SITETHIC),
2) thickness of the largest deposit in surface area adjacent to the stream, (LARGTHIC), and
3) weighted mean thickness of all adjacent deposits (MEANTHIC).

Models based on hydraulic conductivity of the material in each deposit were developed and tested for their ability to predict brook trout

Table 6. Thickness of surficial deposits in northwestern Ontario estimated by Zoltai (1965).

Surficial Deposit	Thickness (m)
Ground Moraine	1.7
Hummocky Moraine	6.1
End and Interlobate Moraines	25.3
Outwash	9.1
Delta	15.2
Kame Fields	22.9
Kame/Outwash Complex	16.0
Clay Glaciolacustrine Plain	3.0
Sandy Glaciolacustrine Plain	12.2

presence/absence. Freeze and Cherry (1979) compiled a table of hydraulic conductivities (measured in cm/s) for a number of materials based on several empirical studies. Ratings for these values were standardized (Table 7) using the formula:

10-(-log of the median hydraulic conductivity value).

The variables tested using the hydraulic conductivity ratings were:

1) the hydraulic conductivity rating of the deposit containing the study reach (SITEHYCO),

2) the hydraulic conductivity rating of the largest deposit in surface area adjacent to the stream (LARGHYCO), and

3) a weighted mean hydraulic conductivity rating of all adjacent deposits (MEANHYCO).

Three variables representing the volume of surficial deposits were tested for their ability to predict brook trout presence/absence:

1) the volume of the deposit containing the study reach (SITEVOL):
SITEVOL= (thickness of the deposit containing the study reach) x (area of the deposit containing the study reach),

2) the volume of the largest deposit adjacent to the stream (LARGVOL):
LARGVOL= (thickness of the largest deposit) x (area of the largest

Table 7. Hydraulic conductivity ratings of surficial materials in northwestern Ontario, and the Northern Ontario Engineering Geology Terrain Study (NOEGTS) codes for the materials. Ratings were calculated as: 10-[-log of the median hydraulic conductivity values] as listed in Freeze and Cherry (1979).

Material	NOEGTS Code	Hydraulic Conductivity Rating
Gravel	g	10.7
Sand	s	8.3
Gravel/Sand	gs	9.7
Silt or Loess	m	5.3
Silty Sand	ms	7.0
Till	t	2.9
Till/Sand /Gravel	tsg	8.3
Till/Sand	ts	6.3
Till/Silt	tm	4.7
Clay	c	1.6
Clay/Silt	cm	3.3
Clay/Till	tc	2.8
Unfractured Bedrock	RR, RN, RL, RP	0.3
Fractured Bedrock	RR, RN, RL, RP	6.0

deposit), and

3) the weighted mean volume of all deposits adjacent to the stream (MEANVOL):

MEANVOL= (weighted mean thickness of all adjacent deposits) x (total area of all adjacent deposits).

Variables that were indices of surficial deposit transmissivity were calculated:

1) the transmissivity of the deposit containing the study reach (SITETRAN):

SITETRAN= (thickness of the deposit containing the study reach) x (hydraulic conductivity of the deposit containing the study reach),

2) the transmissivity of the largest deposit adjacent to the stream (LARGTRAN):

LARGTRAN = (thickness of the largest deposit) x (hydraulic conductivity of the largest deposit), and

3) the weighted mean transmissivity of all deposits adjacent to the stream (MEANTRAN):

MEANTRAN= (weighted mean thickness of all adjacent deposits) x (weighted mean hydraulic conductivity of all adjacent deposits).

Each of the transmissivity variables were very highly correlated with the corresponding deposit thickness variable (r^2 values approximately 0.98), therefore, the transmissivity variables were considered redundant and not tested.

In addition to these univariate models, numerous multivariate models using combinations of the objective geology variables were also tested for their ability to predict brook trout presence/absence. The rate of groundwater flow (volume/time) is dependent upon the hydraulic conductivity of the porous material travelled through, and the size of the deposit comprised by the material (Freeze and Cherry 1979). Therefore, in bivariate models predicting trout presence/absence, hydraulic conductivity variables were paired with their corresponding variable that reflected surficial deposit size (either thickness, area, or volume). The components of the three deposit volume variables (deposit thickness and deposit area) were also tested as bivariate models.

4) Dichotomous Geology Models

Two methods were implemented to rate surficial deposits on a dichotomous basis (i.e. good or poor). Variables derived from these ratings were then used in models that were tested for their ability to predict brook trout presence/absence. In the first method, dichotomous ratings were derived from the Geofisheries ratings of surficial deposits (Table 2). Good deposits (rated 1) were those that Geofisheries rated ≥6, and poor deposits (rated 0) were rated <6. Three steps (similar to those taken in the 'Modified Geofisheries Models' section) were taken to develop 36 Geofisheries-derived dichotomous ratings (Table 8):

Table 8. Three iteration steps conducted to produce 36 Geofisheries-derived dichotomous variables rating surficial geologic deposits. The variables were tested for their ability to predict brook trout presence/absence in northwestern Ontario streams.

Variable Name	Step 1	Step 2		Step 3
	Largest Deposit (L) or Weighted Mean Rating (WM)	Rating for Sandy Glaciolacustrine Plains	Rating for Fens	Using the Highest Rated Deposit (H), the Dominant Deposit (D), or the Highest Rated Deposit Among the Dominant and First Subordinate Deposits (H12) for a Complex Terrain Unit
GPAH	L	0	1	H
GPAD	L	0	1	D
GPAH12	L	0	1	H12
GPBH	L	0	0.5	H
GPBD	L	0	0.5	D
GPBH12	L	0	0.5	H12
GPCH	L	0	0	H
GPCD	L	0	0	D
GPCH12	L	0	0	H12
GPDH	L	1	1	H
GPDD	L	1	1	D
GPDH12	L	1	1	H12
GPEH	L	1	0.5	H
GPED	L	1	0.5	D
GPEH12	L	1	0.5	H12
GPFH	L	1	0	H

Table 8 (continued). Three iteration steps conducted to produce 36 Geofisheries-derived dichotomous variables rating surficial geologic deposits. The variables were tested for their ability to predict brook trout presence/absence in northwestern Ontario streams.

Variable Name	Step 1	Step 2		Step 3
	Largest Deposit (L) or Weighted Mean Rating (WM)	Rating for Sandy Glaciolacustrine Plains	Rating for Fens	Using the Highest Rated Deposit (H), the Dominant Deposit (D), or the Highest Rated Deposit Among the Dominant and First Subordinate Deposits (H12) for a Complex Terrain Unit
GPFD	L	1	0	D
GPFH12	L	1	0	H12
GPGH	WM	0	1	H
GPGD	WM	0	1	D
GPGH12	WM	0	1	H12
GPHH	WM	0	0.5	H
GPHD	WM	0	0.5	D
GPHH12	WM	0	0.5	H12
GPIH	WM	0	0	H
GPID	WM	0	0	D
GPIH12	WM	0	0	H12
GPJH	WM	1	1	H
GPJD	WM	1	1	D
GPJH12	WM	1	1	H12
GPKH	WM	1	0.5	H
GPKD	WM	1	0.5	D

Table 8 (continued). Three iteration steps conducted to produce 36 Geofisheries-derived dichotomous variables rating surficial geologic deposits. The variables were tested for their ability to predict brook trout presence/absence in northwestern Ontario streams.

Variable Name	Step 1	Step 2		Step 3
	Largest Deposit (L) or Weighted Mean Rating (WM)	Rating for Sandy Glaciolacustrine Plains	Rating for Fens	Using the Highest Rated Deposit (H), the Dominant Deposit (D), or the Highest Rated Deposit Among the Dominant and First Subordinate Deposits (H12) for a Complex Terrain Unit
GPKH12	WM	1	0.5	H12
GPLH	WM	1	0	H
GPLD	WM	1	0	D
GPLH12	WM	1	0	H12

Step 1. Ratings of surficial deposits comprising various portions of the watershed were tested:

1) the dichotomous rating of the largest deposit in surface area adjacent to the stream, and

2) a weighted mean dichotomous rating of all deposits adjacent to the stream.

Step 2. Sensitivity analyses were conducted to test different ratings for sandy glaciolacustrine plains and fens. Glaciolacustrine plains are primarily comprised of either clay or sand (Mollard and Mollard 1979a,b,c,d,e,f) which have distinct hydraulic conductivities influencing groundwater hydrology. However, Geofisheries rates all glaciolacustrine plains lowly despite the hydrologic differences (Dean et al. 1991b) (Table 2). Sandy glaciolacustrine plains were tested as good (i.e. 1) and poor (i.e. 0) rated deposits.

Sensitivity analyses also tested different ratings for fens. Fens were defined by Dean et al. (1991a) as wetlands comprised primarily of peat that are overlying or are adjacent to sand/gravel deposits. Therefore, fens are indicators of groundwater discharge rather than actual groundwater transmitting deposits. A good rating (i.e. 1) for fens was tested since fens were rated highly by Geofisheries (Dean et al. 1991b). In addition, a moderate rating (i.e. 0.5) was tested. It was felt that groundwater discharging into fens may be exposed to the extremes of ambient temperature prior to reaching the stream channel thus hindering the cooling influence of direct groundwater discharge. Fens were also tested using a low rating (i.e. 0) since Geofisheries rates other wetlands poorly and all wetlands may have similar effects on thermal stream habitat and brook trout distribution.

Step 3. The dichotomous rating of various deposits comprising a complex terrain unit were tested. The highest rated deposit, the dominant deposit, and the highest rated deposit among the dominant and first subordinate deposits of a complex terrain unit were all tested.

The second dichotomous method of rating surficial deposits employed objective characteristics of surficial deposits. Groundwater transmission is dependent on deposit thickness and material hydraulic conductivity, therefore, reasonably thick deposits with high hydraulic conductivities were considered good, and thin, low conductivity deposits were poor. The good deposits were defined as those greater than 6m thick (Table 6) and having hydraulic conductivities greater than 6.0 (Table 7) since these were the respective median values of deposit thickness and hydraulic conductivity observed for the streams studied in 1993. Similar to 'Objective Geology Models', the objective dichotomous method of rating surficial deposits differed from the Geofisheries-derived dichotomous method by rating surficial deposits that were associated with wetlands (i.e. fens or bogs) rather than rating the wetlands themselves.

The two objective dichotomous ratings tested for their ability to predict brook trout presence/absence were:

1) the objective dichotomous rating of the largest deposit in surface area adjacent to the stream (GPOBJLAR), and

2) a weighted mean objective dichotomous rating of all deposits adjacent to the stream (GPOBJMEA).

BIOGEOGRAPHIC/CLIMATIC MODELS

Biogeographic influences and climatic conditions in NWO may have some bearing on brook trout distribution, therefore, models employing biogeographic/climatic indices were tested. Measurements from maps were used to identify location of all the study streams. The locations represented: 1) the influence of post-glacial brook trout recolonization into NWO, 2) current biogeographic factors, and 3) the climatic gradient across the region. Several of the variables may reflect the influence of both biogeography and climate. The biogeographic/climatic variables used to predict brook trout presence/absence were:

1) the ecoregion (Wickware and Rubec 1989) in which the study streams were located (ECOREGIO); Thunder Bay Plains=1, Nipigon Plains=2, Thunder Bay Plains/Nipigon Plains boundary=3, Superior Highlands=4, Thunder Bay Plains/Superior Highlands boundary=5, Nipigon Plains/Superior Highlands boundary=6 (Figure 1),

2) the shortest straight-line distance (km) the streams were from Lake Superior (DISTLSUP),

3) the shortest straight-line distance (km) the streams were from Lake Nipigon (DISTLNIP),

4) the shortest straight-line distance (km) the streams were from the large lake (Lake Superior or Lake Nipigon) they drained (DISTLGLK),

5) the drainage in which the streams were located (DRAINAGE) (Lake Superior=1, Lake Nipigon=2),

6) the shortest straight-line distance (km) the streams were from a major end or interlobate moraine (DISTMOR),

7) the degrees west longitude of each stream (DEGWEST),

8) the degrees north latitude of each stream (DEGNORTH), and

9) the presence or absence of a migration barrier between the study streams and a potentially recolonizing population of brook trout (FALLS). Migration barriers were defined as the symbol for falls on the 1:50,000 scale topographic maps, or a stream indicated by the topographic maps as ceasing surface flow prior to reaching a downstream system. Lake Superior, Lake Nipigon, or large (>3rd order) rivers known to support brook trout were defined as having a potential recolonizing brook trout population.

The biogeography/climate variables were tested in univariate, and all possible multivariate logistic regression models for their ability to predict brook trout presence/absence.

THERMAL MODELS

Four summer thermal condition variables were tested in univariate logistic regression models for their ability to predict brook trout presence/absence:

1) maximum summer temperature, (MAX),

2) mean-maximum summer temperature, (MEANMAX),

3) mean summer temperature, (SUMMMEAN), and

4) summer thermal stability, (SUMMSTAB).

Data for these thermal models were obtained from the biweekly temperature monitoring previously described.

COMBINED MODELS

In addition to the various univariate and multivariate geology, biogeographic/climatic, and thermal models described above that were tested for their ability to predict brook trout presence/absence, the best of these models were combined and tested in multivariate logistic regression models predicting brook trout presence/absence. First, geology variables were combined with biogeographic/climatic variables. Second geology variables were combined with thermal variables. And third, geology variables were combined with biogeographic/climatic and thermal variables.

Predicting Brook Trout Presence/Absence - Model Validation

Two methods of validation were conducted of the 1993 models predicting brook trout presence/absence. First, new data collected from the 1992/1994 study streams were used in the best 1993 models (Geology, Biogeographic/Climatic, Thermal, and Combined) to calculate predicted probabilities of brook trout presence/absence. If probabilities were ≥ 0.5, then brook trout presence was predicted. The predicted probabilities were then compared to observed trout presence/absence in the 1992/1994 data, and rates of correct prediction were compared among models. To assess if the 1993 models classified the 1994 streams better than expected by chance, Kappa statistics were calculated for each model validated.

For the second method of model validation, relations between brook trout presence/absence in the 1992/1994 data and the identical variables from the best 1993 models were assessed using logistic regression. Consistency of model and regression coefficient significance was compared between data sets.

Since stream temperatures were not available for the streams studied in 1992, thermal models and combined models containing thermal variables were validated with only 28 sites studied in 1994.

Predicting Brook Trout Presence/Absence - Model Development II

Data from all years (1992, 1993, 1994) were combined into one data set (the combined data) in order to develop more general models predicting brook trout distribution in NWO. All four types of predictive models (Geology, Biogeographic/Climatic, Thermal, and Combined) were developed from this data set using logistic regression analyses similar to those used in Model Development I. The significance of each model and regression coefficient, and correct classification rates of these models were assessed.

Models that included thermal variables were developed from the 73 streams that had summer temperature data collected. Models that did not include thermal variables were developed from all 79 sites.

Assessing Relations Between Summer Stream Thermal Conditions, Geology and Climate

Groundwater and climatic conditions influence stream temperatures (Smith 1972; Ward 1985) and thus, thermal suitability for brook trout. Therefore, the relation between stream summer thermal conditions, and geology and climatic variables was tested to assess the influence of groundwater and climate on thermal suitability of NWO streams. Since the streams studied in 1993 were geographically distinct streams from the streams studied in 1992/1994 these relations were assessed using the combined data to account for the climatic gradient across the study area.

These relations were assessed by developing linear models with all-subsets linear regression using the RSQUARE option of the REG procedure in SAS (SAS Institute 1988). The RSQUARE option considers all possible combinations of independent variables in models up to a specified size (i.e. number of independent variables). Models containing up to seven independent variables were considered. The output lists a specified number of models of each size in order of descending coefficients of determination. For these analyses, the best 30 models were considered. Models were considered significant if regression coefficients were significantly (i.e. $P \leq 0.05$) different from zero.

All sub-sets linear regression tests models that contain all possible combinations of the independent variables. Models that contained more than one type of the four types of geology variables (i.e. Geofisheries, Modified Geofisheries, Objective, Dichotomous) were disregarded as redundant since the various types of geology variables are independent measurements of the same characteristics rather than measurements of distinct characteristics. However, models that contained more than one geology variable of a single type were accepted if the independent variables were intuitively expected to independently contribute to the variance associated with summer thermal conditions. For example, models containing a Modified Geofisheries variable and an Objective variable that both rated the largest deposit adjacent to the stream would be considered redundant. However, a model containing the rating for the thickness of the largest deposit and the hydraulic conductivity of the largest deposit would be accepted since each is an independent characteristic of the deposit.

Modelling Brook Trout Abundance

Predicting Brook Trout Abundance - Model Development I

To assess the potential impacts of stream warming resulting from timber harvest operations on brook trout abundance, models predicting abundance were developed using the four thermal indices. Models were developed using the 1993 brook trout streams to predict the four indices of trout abundance:

1) trout number per kilometre of stream, (NPERKM),
2) trout number per hectare of stream, (NPERHA),
3) trout biomass (kg) per kilometre of stream, (KGPERKM), and
4) trout biomass per hectare of stream , (KGPERHA).

The independent variables used in these models were the four thermal indices derived from the 1993 biweekly stream temperature monitoring:

1) maximum summer temperature, (MAX),
2) mean-maximum summer temperature, (MEANMAX),
3) mean summer temperature, (SUMMMEAN), and
4) summer thermal stability, (SUMMSTAB).

Models were analyzed with linear regression using the REG procedure of

SAS version 6.04 (SAS Institute 1988). Models were considered significant if all regression coefficients were significantly (i.e. $P \leq 0.05$) different from zero.

Predicting Brook Trout Abundance - Model Validation

Two validation methods were conducted of the 1993 thermal models predicting brook trout abundance. First, new thermal data collected from the 1994 brook trout streams were used in the best 1993 models to calculate predicted brook trout abundances. The correlations between predicted brook trout abundances and observed trout abundances in 1994 were analyzed with linear regression. The 1993 models were considered transferable to the 1994 trout streams if regression coefficients were near positive one, and significantly (i.e. $P \leq 0.05$) greater than zero, and coefficients of determination were high (near 1.0).

A second validation of the ability of the four thermal indices to predict brook trout abundance was conducted. The relation between stream temperatures and trout abundances of the 1994 streams was assessed using linear regression. These new models were compared with those from 1993 to assess consistency of regression coefficient significance.

Predicting Brook Trout Abundance - Model Development - II

In order to develop more general models predicting brook trout abundance, the 1993 and 1994 trout streams were combined into one data set.

The four thermal variables were then tested for their ability to predict trout abundance using linear regression. Models were considered significant if all regression coefficients were significantly different (i.e. $P \leq 0.05$) from zero.

Results

Field Data

<u>Brook Trout Presence/Absence and Abundance</u>

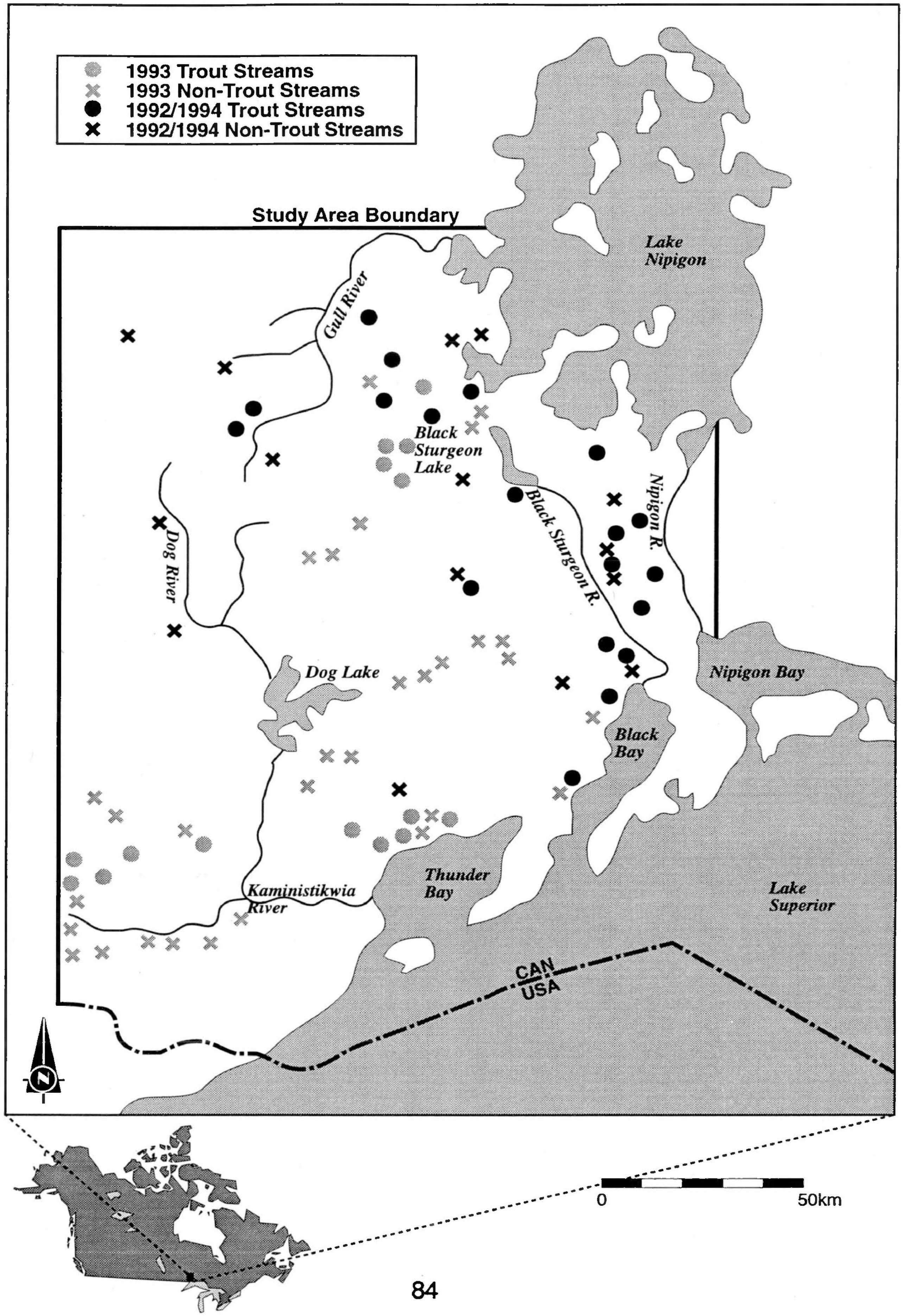
Brook trout were captured in 15 of the 45 streams studied in 1993 (Table 9, Figure 7, Appendix 3). Trout abundance estimates in two streams (Asterisk Creek and Lime 2 Creek) were not considered accurate since a decreasing trend of trout capture was not attained, and a fourth pass was not completed. The density of brook trout in the other 13 streams ranged from 33 to 4254 trout/km (mean=780 ±312.4), and from 128 to 22599 trout/ha (mean=3645 ±1652.0). Brook trout biomass ranged from 1.978 to 30.758 kg/km (mean=8.3 ±2.27), and from 4.833 to 88.136 kg/ha (mean=36.2 ±8.22).

Sixteen of 29 streams studied in 1994 contained brook trout, and three of five 1992 streams had brook trout (Table 9, Figure 7). Brook trout density in the 14 streams studied in 1994 that had population estimates calculated ranged from 14 to 742 trout/km (mean=255 ±86.3), and from 54 to 2115 trout/ha (mean=897 ±282.0). Brook trout biomass ranged from 0.2 to 10.5 kg/km (mean=4.0 ±0.89), and 1.1-34.8 (mean=14.7 ±3.18) kg/ha. Brook trout

Table 9. Results of t-tests comparing mean values of the four brook trout abundance indices between years. Abundance estimates are for northwestern Ontario trout streams studied in 1993 and 1994. Values are considered significantly different (*) at $P \leq 0.05$.

Abundance	Trout Streams			
Variable	1993 (n=13)	1994 (n=14)	t	P
Brook trout density (number/km)	780 ±312.4	255 ±86.3	1.6129	0.1280
Brook trout density (number/ha)	3645 ±1652.0	897 ±282.0	1.6396	0.1256
Brook trout biomass (kg/km)	8.4 ±2.27	4.0 ±0.89	1.7714	0.0960
Brook trout biomass (kg/ha)	36.2 ±8.22	14.7 ±3.18	2.4439	0.0269*

Figure 7. Map of the study area showing the locations of trout and non-trout streams studied in 1992, 1993, and 1994.


1993 Trout Streams
1993 Non-Trout Streams
1992/1994 Trout Streams
1992/1994 Non-Trout Streams
Study Area Boundary
Lake Nipigon
Gull River
Black Sturgeon Lake
Dog River
Black Sturgeon R.
Nipigon R.
Dog Lake
Nipigon Bay
Black Bay
Thunder Bay
Kaministikwia River
Lake Superior
CAN
USA
0
50km

biomass (i.e. kg/ha) was significantly greater in the 1993 streams relative to the 1994 streams (Table 9). Rainbow trout (*Oncorhychus mykiss*) were also captured in two of the brook trout streams (Clay Hill Cr. and Coldwater 1 Cr.), and abundances are presented in Table 10.

Stream Temperatures

Temperatures of the 1993 streams were significantly warmer than the 1994 streams (Table 11, Appendix 4). The t-tests analyses revealed that maximum summer temperature (t=3.9982, P=0.0002), mean-maximum summer temperature (t=2.8445, P=0.0058), and summer mean temperature (t=3.8753, P=0.0002) were significantly different between years. However, summer thermal stability was not significantly different between years (t=-0.8282, P=0.4103).

Thermal differences between years was primarily due to non-trout streams. The 1993 non-trout streams had warmer maximum summer temperatures (t=2.7618, P=0.0140), and mean summer temperatures (t=2.8912, P=0.0109) than the 1994 non-trout streams. Thermal conditions of trout streams were not significantly different between years.

There were virtually no between-year temperature differences for the 10 sites monitored both years (Table 12). Mean-maximum temperatures were not significantly different between years for all 10 sites. Summer mean temperatures were significantly different for only three streams. Asterisk Creek (t=4.3818, P=0.0047), Max Creek (t=4.9058, P=0.0012), and North Current 5

Table 10. Abundance estimates of rainbow trout in two northwestern Ontario streams studied in 1994.

Abundance Variable	Stream	
	Clay Hill	Coldwater 1
Rainbow trout density (number/km)	1039	271
Rainbow trout density (number/ha)	3264	549
Rainbow trout biomass (kg/km)	1.9	3.6
Rainbow trout biomass (kg/ha)	5.2	7.3

Table 11. Results of t-tests comparing mean values of the four thermal indices between years. Thermal indices are based on bi-weekly temperature measurements of northwestern Ontario streams studied in 1993 and 1994. Values are significantly different (*) at $P \leq 0.05$.

Thermal Variable	Stream Temperatures 1993 (mean ±se)	Stream Temperatures 1994 (mean ±se)	t	P
Maximum Summer Temperature (°C)	22.2 ±0.39	19.5 ±0.57	3.9982	0.0002*
Mean-maximum Summer Temperature (°C)	20.3 ±0.37	18.5 ±0.59	2.8445	0.0058*
Mean Summer Temperature (°C)	16.4 ±0.31	14.4 ±0.44	3.8753	0.0002*
Summer Thermal Stability (°C)	7.8 ±0.21	8.1 ±0.35	-0.8282	0.4103

Table 12. Results of t-tests comparing the mean-maximum and mean summer temperatures of the 10 northwestern Ontario streams monitored in both years (1993 and 1994) of the study. Values are significantly different (*) at P≤0.05.

Site	1993	1994	t	P
Mean-Maximum Summer Temperature (°C)				
Asterick	16.8	16.0	1.5667	0.1682
Buzzer 1	19.6	19.0	0.8018	0.4552
East Welch	16.6	17.6	-1.2700	0.2398
Max	17.6	16.2	1.6733	0.1328
McConnell 1	21.3	21.3	0.0000	1.0000
North Current 1	20.8	21.6	-1.2649	0.2415
North Current 5	20.2	18.4	2.0125	0.0794
Pearl 1	21.0	21.0	0.0000	1.0000
Savigny	20.6	20.6	0.0000	1.0000
West Current	19.2	19.2	0.0000	1.0000
Mean Summer Temperature (°C)				
Asterick	14.25	12.25	4.3818	0.0047*
Buzzer 1	15.50	14.70	1.0643	0.3183
East Welch	13.20	13.60	-0.6532	0.5319
Max	14.10	12.20	4.9058	0.0012*
McConnell 1	17.33	15.67	1.4142	0.2302
North Current 1	17.17	17.50	-0.5000	0.6533
North Current 5	17.00	14.38	3.0851	0.0215*
Pearl 1	18.00	17.50	0.6124	0.5734
Savigny	17.40	16.80	0.9204	0.3843
West Current	15.50	15.40	0.1612	0.8767

Creek (t=3.0851, P=0.0215) were warmer in 1993.

Summer climatic conditions in 1993 and 1994 were similar (Table 13). July temperatures were similar both years at the Environment Canada climate stations in Thunder Bay and Cameron Falls. However, substantially more rain fell in 1993 relative to 1994. August temperatures were warmer in 1993 at both climate stations, but precipitation levels were similar between years. At the Thunder Bay station, July 1994 experienced considerably more total hours of bright sunshine relative to 1993. Total hours of bright sunshine in August were comparable between years. Bright sunshine data were not available from the Cameron Falls station.

T-test analyses indicated that brook trout streams studied in 1993 were significantly cooler (maximum summer temperature: t=3.3554, P=0.0017; mean-maximum summer temperature: t=3.1207, P=0.0032; summer mean temperature: t=2.2156, P=0.0119) and thermally more stable (summer thermal stability: T=2.7694, P=0.0083) than non-trout streams. Thermal conditions between trout and non-trout streams were not significantly different in 1994.

Modelling Brook Trout Presence/Absence

<u>Predicting Brook Trout Presence/Absence - Model Development I</u>

The results of all logistic regression analyses performed with the 1993 data are presented in Appendix 6.

Table 13. Climatic conditions recorded at the Thunder Bay and Cameron Falls stations during the summers of 1993 and 1994 (source: Environment Canada, Ontario Climate Centre, unpublished data).

Climatic	July		August	
Condition	1993	1994	1993	1994
		Thunder Bay Station		
Mean Monthly Temperature (°C)	16.8	16.2	17.8	15.3
Precipitation (mm)	224.0	72.2	61.1	75.0
Bright Sunshine (hrs)	189.4	252.2	252.1	228.0
		Cameron Falls Station		
Mean Monthly Temperature (°C)	16.0	15.9	17.0	14.6
Precipitation (mm)	144.6	116.4	85.1	84.2
Bright Sunshine (hrs)	na	na	na	na

GEOLOGY MODELS

Brook trout presence/absence in 1993 was significantly related to characteristics of surficial geologic deposits (Table 14). In general, the probability of trout presence was greater in streams that flowed through deposits conducive to groundwater transmission.

1)Geofisheries Model

The Geofisheries model (GEOFISH) (Dean et al. 1991b) was significant and positively related to brook trout presence in the 1993 data (Table 14, Figure 8). The logistic regression model developed from the Geofisheries variable was:

1)

$$\pi=\frac{e^{-4.8668+0.3236(GEOFISH)}}{1+e^{-4.8668+0.3236(GEOFISH)}}$$

This model correctly predicted trout presence/absence in 36 of 45 streams (80.0%). Brook trout presence was correctly predicted in 11 of 15 streams (73.3%), and trout absence was correctly predicted in 25 of 30 streams (83.3%). The value of the Kappa statistic indicated that the Geofisheries model predicted brook trout presence/absence 55.7% better than expected by chance.

Of the three components of Geofisheries (surficial geology, bedrock geology, climate zones), only surficial geology was significantly related to brook

Table 14. Results of logistic regression analyses, correct classification rates, and Kappa statistics of the best models predicting brook trout presence/absence in northwestern Ontario streams studied in 1993. See Appendix 5 for a detailed description of variables.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	Constant	-2 log likelihood	P	Correct Classification Rates: Presence (%) n=15	Absence (%) n=30	Overall(%) n=45	Kappa	P
Geology Models										
1) Geofisheries Models										
GEOFISH	0.3236	0.0029	-4.8668	41.974	0.0001	11 (73.3)	25 (83.3)	36 (80.0)	0.557	<0.0005
SURFACE	0.4472	0.0068	3.6975	45.192	0.0005	8 (53.3)	26 (86.7)	34 (75.6)	0.421	<0.0100
2) Modified Geofisheries Models										
LARGDH12	0.5420	0.0013	-3.8250	39.903	0.0001	12 (80.0)	21 (70.0)	33 (73.3)	0.455	<0.0050
LARGEH12	0.5734	0.0009	-3.8603	39.463	0.0001	13 (86.7)	22 (73.3)	35 (77.8)	0.545	<0.0005
3) Objective Geology Models										
LARGTHIC	0.1523	0.0035	-2.0792	45.950	0.0008	8 (53.3)	27 (90.0)	35 (77.8)	0.464	<0.0050
LARGHYCO	0.3736	0.0138	-3.2382	48.597	0.0032	6 (40.0)	27 (90.0)	33 (73.3)	0.333	<0.0250
4) Dichotomous Geology Models										
GPEH12	3.3416	0.0009	-3.0445	39.502	0.0001	13 (86.7)	22 (73.3)	35 (77.8)	0.545	<0.0005
GPKH12	3.7144	0.0012	-2.9316	40.022	0.0001	10 (66.7)	24 (80.0)	34 (75.6)	0.459	<0.0050
GPOBJLAR	3.4864	0.0017	-3.0445	38.925	0.0001	14 (93.3)	21 (70.0)	35 (77.8)	0.559	<0.0005

Table 14 (continued). Results of logistic regression analyses, correct classification rates, and Kappa statistics of the best models predicting brook trout presence/absence in northwestern Ontario streams studied in 1993. See Appendix 5 for a detailed description of variables.

						Correct Classification Rates				
Variable(s) in Model	Regression Coefficient	Wald Chi-square P	Constant	-2 log likelihood	P	Presence (%) n=15	Absence (%) n=30	Overall(%) n=45	Kappa	P
				Geology Models						
				4) Dichotomous Geology Models (continued)						
GPOBJMEA	3.7366	0.0013	-3.0393	39.438	0.0001	12 (80.0)	24 (80.0)	36 (80.0)	0.571	<0.0005
				Biogeographic/Climate Models						
FALLS	-1.7383	0.0392	-0.2076	51.948	0.0209	0 (00.0)	30 (100)	30 (66.7)	0.000	1.0000
FALLS	-3.1126	0.0049	-2523.7	39.919	0.0016	9 (60.0)	26 (86.7)	35 (77.8)	0.483	<0.0050
DEGWEST	28.6046	0.0174								
DISTLSUP	-0.2757	0.0199								
DISTLNIP	-0.2461	0.0162								
				Thermal Models						
MAX	-0.4707	0.0089	9.3607	47.088	0.0014	4 (26.7)	28 (93.3)	32 (71.1)	0.235	>0.0500

Table 14 (continued). Results of logistic regression analyses, correct classification rates, and Kappa statistics of the best models predicting brook trout presence/absence in northwestern Ontario streams studied in 1993. See Appendix 5 for a detailed description of variables.

						Correct Classification Rates				
Variable(s) in Model	Regression Coefficient	Wald Chi-square P	Constant	-2 log likelihood	P	Presence (%) n=15	Absence (%) n=30	Overall(%) n=45	Kappa	P
Combined Models										
1) Geology and Biogeographic/climate Variables										
SURFACE	0.5738	0.0028	-3.7447	35.789	0.0001	12 (80.0)	25 (83.3)	37 (82.2)	0.613	<0.0005
FALLS	-2.6563	0.0071								
LARGDH12	0.7268	0.0007	-4.0593	29.634	0.0001	13 (86.7)	27 (90.0)	40 (88.9)	0.754	<0.0005
FALLS	-3.1482	0.0055								
LARGEH12	0.6225	0.0006	-3.4423	33.203	0.0001	12 (80.0)	27 (90.0)	39 (86.7)	0.700	<0.0005
FALLS	-2.3136	0.0240								
LARGTHIC	0.1614	0.0045	-1.6036	40.917	0.0003	8 (53.3)	27 (90.0)	35 (77.8)	0.526	<0.0050
FALLS	-1.9540	0.0465								
LARGHYCO	0.4815	0.0050	-3.2141	39.575	0.0001	10 (66.7)	27 (90.0)	37 (82.2)	0.586	<0.0050
FALLS	-2.4632	0.0107								
GPEH12	3.5039	0.0007	-2.2512	34.025	0.0001	12 (80.0)	27 (90.0)	39 (86.7)	0.700	<0.0005
FALLS	-2.1272	0.0325								

Table 14 (continued). Results of logistic regression analyses, correct classification rates, and Kappa statistics of the best models predicting brook trout presence/absence in northwestern Ontario streams studied in 1993. See Appendix 5 for a detailed description of variables.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	Constant	-2 log likelihood	P	Correct Classification Rates: Presence (%) n=15	Absence (%) n=30	Overall(%) n=45	Kappa	P
Combined Models										
1) Geology and Biogeographic/climate Variables (continued)										
GPKH12	3.7495	0.0010	-2.3393	35.262	0.0001	12 (80.0)	27 (90.0)	39 (86.7)	0.700	<0.0005
FALLS	-1.9432	0.0449								
GPOBJLAR	4.0213	0.0008	-2.6157	31.311	0.0001	12 (80.0)	27 (90.0)	39 (86.7)	0.700	<0.0005
FALLS	-2.5352	0.0133								
GPOBJMEA	4.0030	0.0009	-2.5152	33.491	0.0001	12 (80.0)	27 (90.0)	39 (86.7)	0.700	<0.0005
FALLS	-2.2130	0.0269								
2) Geology and Thermal Variables										
GEOFISH	0.3059	0.0060	5.8449	34.852	0.0001	11 (73.3)	25 (83.3)	36 (80.0)	0.557	<0.0005
MAX	-0.4826	0.0316								
SURFACE	0.4409	0.0142	6.8037	37.776	0.0001	11 (73.3)	26 (86.7)	37 (82.2)	0.600	<0.0005
MAX	-0.4791	0.0251								

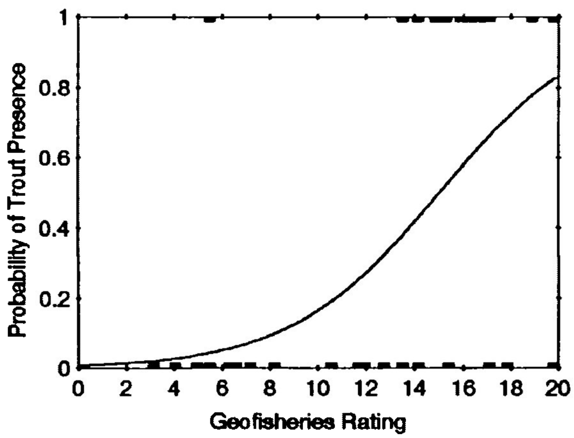
Table 14 (continued). Results of logistic regression analyses, correct classification rates, and Kappa statistics of the best models predicting brook trout presence/absence in northwestern Ontario streams studied in 1993. See Appendix 5 for a detailed description of variables.

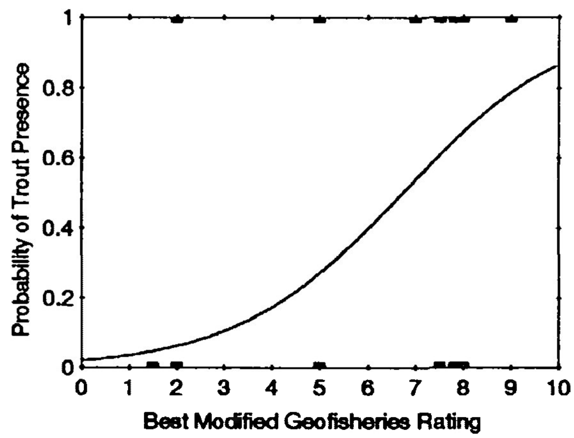
Variable(s) in Model	Regression Coefficient	Wald Chi-square P	Constant	-2 log likelihood	P	Correct Classification Rates: Presence (%) n=15	Absence (%) n=30	Overall(%) n=45	Kappa	P
Combined Models										
2) Geology and Thermal Variables (continued)										
LARGDH12	0.6509	0.0041	10.1667	30.553	0.0001	11 (73.3)	27 (90.0)	38 (84.4)	0.644	<0.0005
MAX	-0.6697	0.0229								
LARGEH12	0.5788	0.0023	7.3598	32.684	0.0001	13 (86.7)	27 (90.0)	40 (88.9)	0.754	<0.0005
MAX	-0.5114	0.0334								
LARGTHIC	0.1562	0.0036	9.6458	36.383	0.0001	10 (66.7)	26 (86.7)	36 (80.0)	0.542	<0.0010
MAX	-0.5417	0.0122								
LARGHYCO	0.3964	0.0234	7.1251	39.629	0.0001	9 (60.0)	27 (90.0)	36 (80.0)	0.526	<0.0050
MAX	-0.4789	0.0162								
GPEH12	3.2904	0.0021	8.0554	32.806	0.0001	13 (86.7)	26 (86.7)	39 (86.7)	0.710	<0.0005
MAX	-0.4919	0.0359								
GPKH12	3.6992	0.0024	8.3940	32.880	0.0001	11 (73.3)	26 (86.7)	37 (82.2)	0.600	<0.0005
MAX	-0.5152	0.0367								

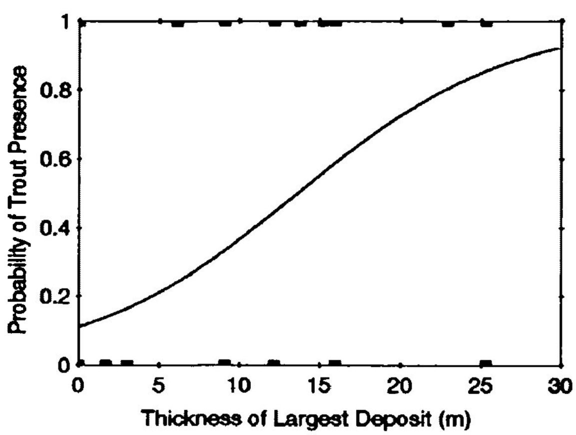
Table 14 (continued). Results of logistic regression analyses, correct classification rates, and Kappa statistics of the best models predicting brook trout presence/absence in northwestern Ontario streams studied in 1993. See Appendix 5 for a detailed description of variables.

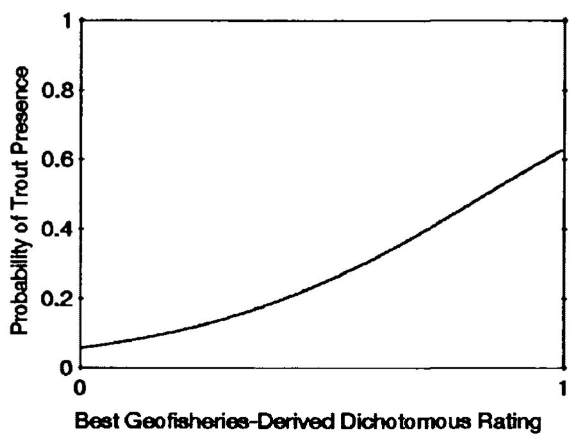
Variable(s) in Model	Regression Coefficient	Wald Chi-square P	Constant	-2 log likelihood	P	Correct Classification Rates: Presence (%) n=15	Absence (%) n=30	Overall(%) n=45	Kappa	P
Combined Models										
2) Geology and Thermal Variables (continued)										
GPOBJLAR	3.7887	0.0032	9.6173	30.735	0.0001	11 (73.3)	28 (93.3)	39 (86.7)	0.690	<0.0005
MAX	-0.5855	0.0282								
GPOBJMEA	4.1264	0.0029	9.9858	30.959	0.0001	11 (73.3)	26 (86.7)	37 (82.2)	0.600	<0.0005
MAX	-0.6059	0.0308								
3) Geology, Biogeographic/climate, and Thermal Variables										
LARGHYCO	0.4680	0.0123	5.9107	33.183	0.0001	12 (80.0)	26 (86.7)	38 (84.4)	0.656	<0.0005
FALLS	-2.5821	0.0259								
MAX	-0.4156	0.0319								
GPOBJMEA	4.6614	0.0030	10.0240	25.673	0.0001	12 (80.0)	27 (90.0)	39 (86.7)	0.700	<0.0005
FALLS	-2.6044	0.0439								
MAX	-0.5951	0.0370								

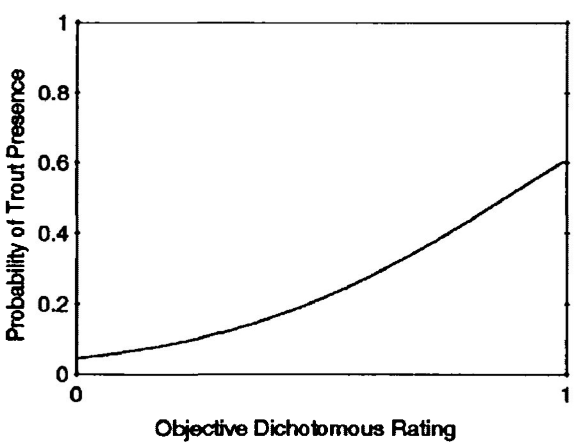
Figure 8. Probabilities of brook trout presence, in northwestern Ontario streams studied during 1993, relative to the best models derived from the various methods used to rate surficial geologic deposits based on their ability to transmit groundwater. The rating methods used were: 1) Geofisheries (Dean et al. 1991b), 2) Modified Geofisheries rating, 3) Objective rating (e.g. deposit thickness), and 4) Dichotomous rating (Geofisheries-derived and Objective). Observed brook trout presence/absence are given for the former three rating methods. Probabilities were calculated using logistic regression.


Probability of Trout Presence
0
0.2
0.4
0.6
0.8
1
0 2 4 6 8 10 12 14 16 18 20
Geofisheries Rating


Probability of Trout Presence
0
0.2
0.4
0.6
0.8
1
0 1 2 3 4 5 6 7 8 9 10
Best Modified Geofisheries Rating


Probability of Trout Presence
0
0.2
0.4
0.6
0.8
1
0 5 10 15 20 25 30
Thickness of Largest Deposit (m)


Probability of Trout Presence
0
0.2
0.4
0.6
0.8
1
0 1
Best Geofisheries-Derived Dichotomous Rating


Probability of Trout Presence
0
0.2
0.4
0.6
0.8
1
0 1
Objective Dichotomous Rating

trout presence/absence (Table 14). However, the surficial geology component did not perform as well as the complete Geofisheries model. The model correctly predicted brook trout presence/absence in 34 of 45 streams (75.6%). Brook trout presence was correctly predicted in 8 of 15 streams (53.3%), and trout absence was correctly predicted in 26 of 30 streams (86.7%). The value of the Kappa statistic indicated that the surficial component predicted brook trout presence/absence 42.1% better than expected by chance.

2) Modified Geofisheries Model

Most of the Modified Geofisheries models (i.e. 48 of 54) were significantly related to brook trout presence/absence in the 1993 data (Appendix 6). Brook trout distribution was best predicted by the Modified Geofisheries model (LARGEH12) that employed: 1) the rating of the largest deposit adjacent to the stream, 2) a high rating for sandy glaciolacustrine deposits, and a moderate rating for fens, and 3) the highest rated feature among the dominant and first subordinate deposits in the case of complex terrain units (Table 14, Figure 8). The logistic regression equation for this model was:

2)

$$\pi = \frac{e^{-3.8603+0.5734(LARGEH12)}}{1+e^{-3.8603+0.5734(LARGEH12)}}$$

This model correctly predicted brook trout presence/absence in 35 of 45 streams (77.8%). Brook trout presence was correctly predicted in 13 of 15 streams (86.7%), and trout absence was correctly predicted in 22 of 30 streams (73.3%). The value of the Kappa statistic indicated that this model predicted brook trout presence/absence 54.5% better than expected by chance.

Results of the 54 Modified Geofisheries iterations indicated that brook trout presence/absence was best predicted by models that employed the largest adjacent surficial deposit (Appendix 6). Weighted mean ratings of all adjacent surficial deposits were marginally less successful, and ratings of surficial deposits containing the study reach were least successful. Models using a high rating (7.8) for sandy glaciolacustrine plains performed better than models with a low rating (1.5 or 2.0). A moderate rating (5.0) for fens produced only marginally improved models relative to either a high (9.5) rating or a rating equivalent to bogs (0.0 to 6.0). The highest rated deposit among the dominant and first subordinate deposits of a complex terrain unit performed better than the rating of the overall highest rated deposit, or the dominant deposit.

3) Objective Geology Models

Most of the univariate objective geology models were significantly related to brook trout presence/absence in the 1993 data (Appendix 6). Brook trout presence/absence was most related to the thickness of the largest surficial deposit adjacent to the stream (LARGTHIC) (Table 14, Figure 8). The logistic regression equation of this model was:

3)

$$\pi = \frac{e^{-2.0792+0.1523(LARGTHIC)}}{1+e^{-2.0792+0.1523(LARGTHIC)}}$$

This model correctly predicted brook trout presence/absence in 35 of 45 streams (77.8%). Brook trout presence was correctly predicted in 8 of 15 streams (53.3%), and trout absence was correctly predicted in 27 of 30 streams (90.0%). The value of the Kappa statistic indicated that this model predicted brook trout presence/absence 46.4% better than expected by chance.

Multivariate objective geology models, which reflected multiple dimensions of surficial deposits, produced only marginally improved fits to the data relative to univariate models (i.e. the values of the -2 log likelihood statistic were slightly lower) (Appendix 6). All of these models were not considered significant since one or more of the independent variables were not significantly contributing to the variation associated with brook trout presence/absence.

4) Dichotomous Models

All 36 of the dichotomous models (i.e. good/poor) derived from the Geofisheries ratings of surficial features were significantly related to brook trout distribution in the 1993 data (Appendix 6). Brook trout distribution was best predicted by the Geofisheries-derived dichotomous model (GPEH12) that employed: 1) the rating of the largest deposit adjacent to the stream, 2) a high rating for sandy glaciolacustrine deposits (1.0), and a moderate rating for fens

(0.5), and 3) the highest rated feature among the dominant and first subordinate deposits in the case of complex terrain units (GPEH12) (Table 14, Figure 8). The logistic regression equation of this model was:

4)
$$\pi=\frac{e^{-3.0445+3.4864(GPEH12)}}{1+e^{-3.0445+3.4864(GPEH12)}}$$

This model correctly predicted brook trout presence/absence in 35 of 45 streams (77.8%). Brook trout presence was correctly predicted in 13 of 15 streams (86.7%), and trout absence was correctly predicted in 22 of 30 streams (73.3%). The value of the Kappa statistic indicated that this model predicted brook trout presence/absence 54.5% better than expected by chance.

In contrast to the Geofisheries-derived dichotomous ratings, two dichotomous models used ratings incorporating objective characteristics of surficial deposits (thickness and hydraulic conductivity), and rated the deposits associated with wetlands (fens or bogs) rather than rate the wetlands themselves. Brook trout presence\absence was significantly related to both models. The objective dichotomous model rating the largest deposit adjacent to the stream (GPOBJLAR) had a marginally better fit to the 1993 trout presence/absence data (i.e. -2 log likelihood was lower) than the weighted mean dichotomous model (Table 14, Figure 8). The logistic regression equation of this model was:

5)

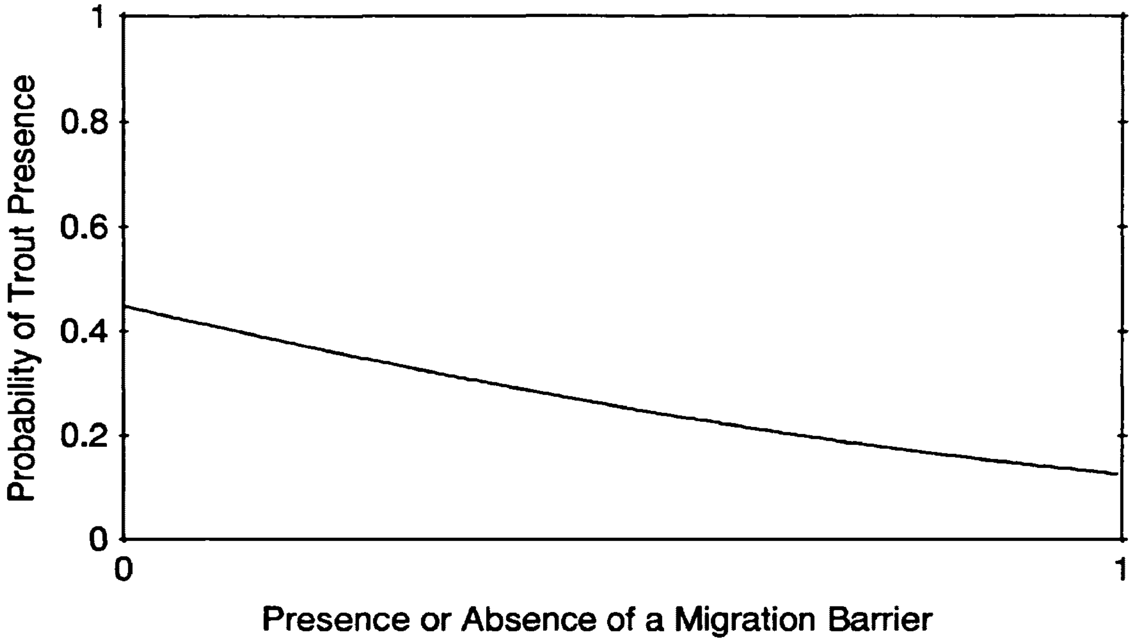
$$\pi=\frac{e^{-3.0445+3.4864(GPOBJLAR)}}{1+e^{-3.0445+3.4864(GPOBJLAR)}}$$

This model correctly predicted brook trout presence/absence in 35 of 45 streams (77.8%). Of all models developed from the 1993 data, brook trout presence was best predicted by this model (14 of 15 streams, 93.3%). Trout absence was correctly predicted in 22 of 30 streams (73.3%). The value of the Kappa statistic indicated that this model predicted brook trout presence/absence 55.9% better than expected by chance. However, the objective dichotomous model that used the weighted mean rating of all deposits adjacent to the stream (GPOBJMEA) predicted trout overall presence/absence better (36 of 45 streams, 80.0%), and had a higher value for Kappa (0.571).

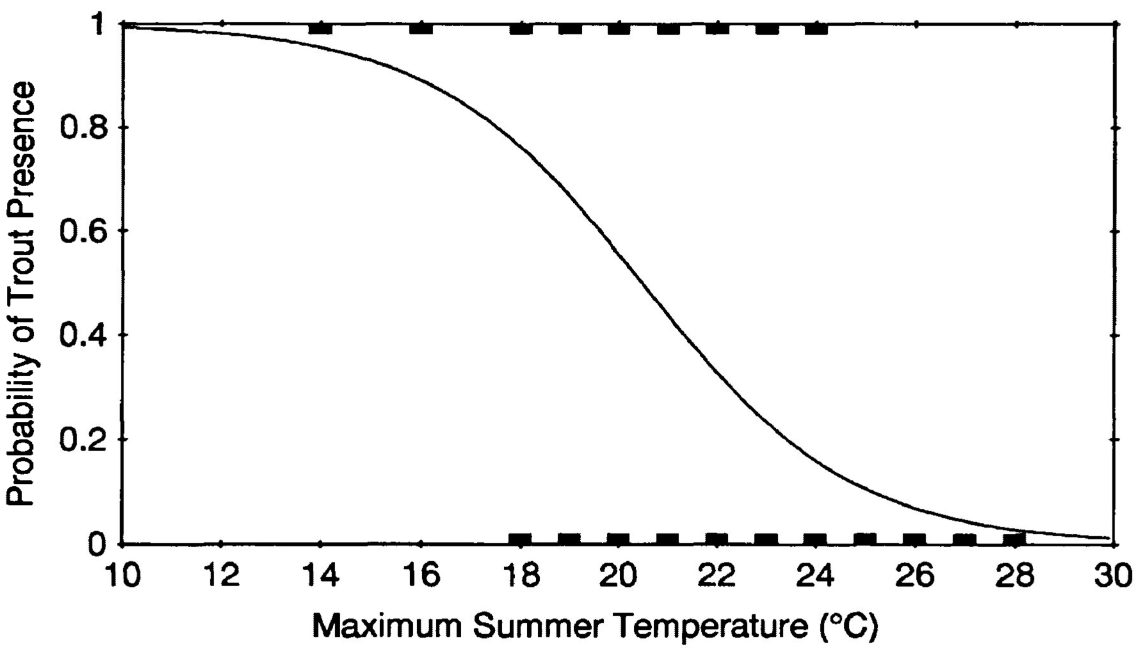
BIOGEOGRAPHY/CLIMATIC MODELS

Brook trout distribution in the 1993 data was not significantly related to most variables that represented biogeographic or climatic factors in NWO (Appendix 6). Only the presence or absence of a migration barrier between the study site and a potentially recolonizing brook trout population (FALLS) had a significant influence on trout distribution (Table 14, Figure 9), indicating that trout were more likely in streams that did not have a barrier. The logistic regression equation of this model was:

Figure 9. Probabilities of brook trout presence, in northwestern Ontario streams studied during 1993, relative to the presence or absence of a barrier falls (upper graph) and relative to maximum summer stream temperature (°C)(lower graph). Observed brook trout presence/absence are given for the latter model. Probabilities were calculated using logistic regression.



Probability of Trout Presence
1
0.8
0.6
0.4
0.2
0
0
1
Presence or Absence of a Migration Barrier



Probability of Trout Presence
1
0.8
0.6
0.4
0.2
0
10
12
14
16
18
20
22
24
26
28
30
Maximum Summer Temperature (°C)

6)

$$\pi=\frac{e^{-0.2076-1.7383(FALLS)}}{1+e^{-0.2076-1.7383(FALLS)}}$$

This model correctly predicted brook trout presence/absence in 30 of 45 streams (66.7%). However, this model predicted absence for all 45 streams. Although this model was significant, the Kappa value of zero indicated that the model showed no improvement over chance correct classifications of trout presence/absence.

The one significant multivariate biogeographic/climatic model indicated that brook trout streams in the 1993 data were more likely found without a migration barrier (FALLS), near Lake Superior (DISTLSUP) and Lake Nipigon (DISTLNIP), and further west (DEGWEST) (Table 14). The logistic regression equation of this model was:

7)

$$\pi=\frac{e^{-2523.7-3.1126(FALLS)+28.6046(DEGWEST)-0.2757(DISTLSUP)-0.2461(DISTLNIP)}}{1+e^{-2523.7-3.1126(FALLS)+28.6046(DEGWEST)-0.2757(DISTLSUP)-0.2461(DISTLNIP)}}$$

This model correctly predicted brook trout presence/absence in 35 of 45 streams (77.8%). Brook trout presence was correctly predicted in 9 of 15 streams (60.0%), and trout absence was correctly predicted in 26 of 30 streams (86.7%). The value of the Kappa statistic indicated that this model predicted brook trout presence/absence 48.3% better than expected by chance.

THERMAL MODELS

The significant relation between brook trout presence/absence and the four thermal variables indicated that trout streams in 1993 were cooler and thermally more stable than non-trout streams (Appendix 6). Maximum summer temperature was the best thermal variable discriminating between trout and non-trout streams (Table 14, Figure 9). The logistic regression equation of the maximum summer temperature model (MAX) was:

8)
$$\pi=\frac{e^{9.6307-0.4707(MAX)}}{1+e^{9.6307-0.4707(MAX)}}$$

This model correctly predicted brook trout presence/absence in 32 of 45 streams (71.1%). Brook trout presence was correctly predicted in 4 of 15 streams (26.7%), and trout absence was correctly predicted in 28 of 30 streams (93.3%). The value of the Kappa statistic (0.235) indicated that this model did not predict brook trout presence/absence significantly better than expected by chance.

COMBINED MODELS

Brook trout presence/absence in 1993 was significantly related to most models that combined geology variables with the presence or absence of a migration barrier (Appendix 6). Brook trout were more likely found in streams without a migration barrier and flowing through surficial deposits conducive to groundwater transmission. The model that best fit the data combined the presence or absence of a migration barrier (FALLS) with the Modified Geofisheries rating (LARGDH12) employing: 1) the rating of the largest deposit adjacent to the stream, 2) a high rating for sandy glaciolacustrine deposits, and a high rating for fens, and 3) the highest rated feature among the dominant and first subordinate deposits in the case of complex terrain units (Table 14, Figure 10). The logistic regression equation of this model was:

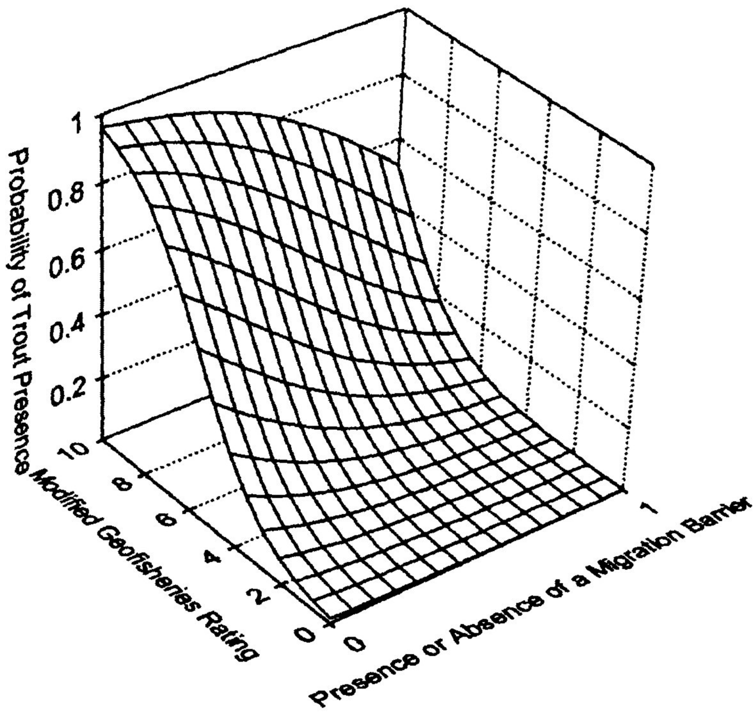
9)
$$\pi = \frac{e^{-4.0593+0.7268(LARGDH12)-3.1482(FALLS)}}{1+e^{-4.0593+0.7268(LARGDH12)-3.1482(FALLS)}}$$

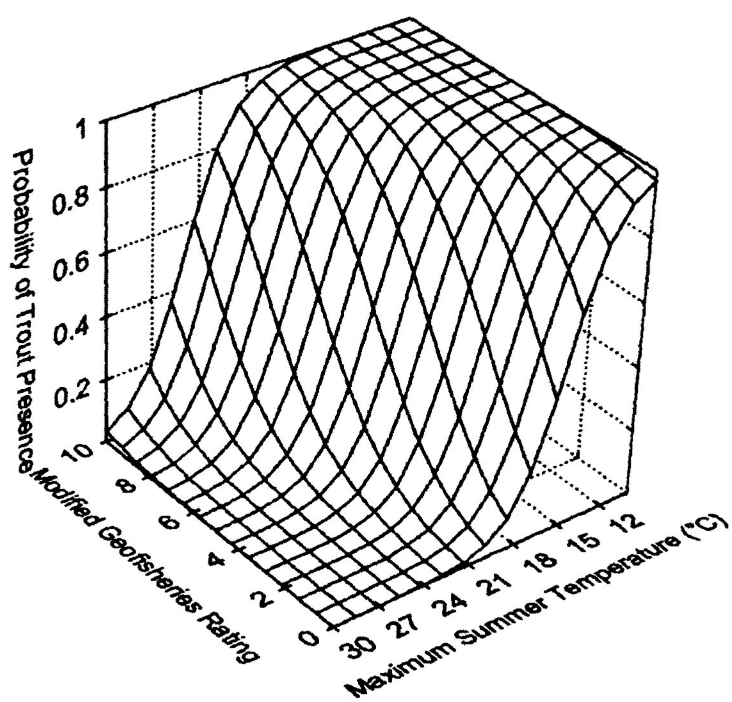
This model correctly predicted brook trout presence/absence in 40 of 45 streams (88.9%). Brook trout presence was correctly predicted in 13 of 15 streams (86.7%), and trout absence was correctly predicted in 27 of 30 streams (90.0%). The value of the Kappa statistic indicated that this model predicted brook trout presence/absence 75.4% better than expected by chance.

No models combining geology variables with the other biogeographic/climate variables were significant (Appendix 6).

All models that combined geology variables with maximum summer temperature were significantly related to brook trout distribution in 1993 (Appendix 6). Brook trout were more likely found in cooler streams flowing through surficial deposits conducive to groundwater transmission. The model

Figure 10. Probabilities of brook trout presence, in northwestern Ontario streams studied during 1993, relative to the best Modified Geofisheries rating of surficial geologic deposits combined with: 1) the presence or absence of a migration barrier (upper graph), and 2) maximum summer stream temperature (°C) (lower graph). Probabilities were calculated using logistic regression.


1
0.8
0.6
0.4
0.2
0
Probability of Trout Presence
10
8
6
4
2
0
Modified Geofisheries Rating
0
1
Presence or Absence of a Migration Barrier


1
0.8
0.6
0.4
0.2
0
Probability of Trout Presence
10
8
6
4
2
0
Modified Geofisheries Rating
30
27
24
21
18
15
12
Maximum Summer Temperature (°C)

that best fit the data combined maximum summer temperature (MAX) with the Modified Geofisheries (LARGDH12) rating employing: 1) the rating of the largest deposit adjacent to the stream, 2) a high rating for sandy glaciolacustrine deposits, and a high rating for fens, and 3) the highest rated feature among the dominant and first subordinate deposits in the case of complex terrain units (Table 14, Figure 9). The logistic regression equation of this models was:

10)

$$\pi = \frac{e^{10.1667+0.6509(LARGDH12)-0.6697(MAX)}}{1+e^{10.1667+0.6509(LARGDH12)-0.6697(MAX)}}$$

This model correctly predicted brook trout presence/absence in 38 of 45 streams (84.4%). Brook trout presence was correctly predicted in 11 of 15 streams (73.3%), and trout absence was correctly predicted in 27 of 30 streams (90.0%). The value of the Kappa statistic indicated that this model predicted brook trout presence/absence 64.4% better than expected by chance. However, a different model produced better correct prediction rates. This second model combined maximum summer temperature (MAX) with the Modified Geofisheries variable (LARGEH12) that employed: 1) the largest deposit adjacent to the stream, 2) a high rating for sandy glaciolacustrine deposits, and a moderate rating for fens, and 3) the highest rated feature among the dominant and first subordinate deposits in the case of complex terrain units. This second geology/thermal model correctly predicted brook trout presence/absence in 40 of 45 streams (88.9%). Brook trout presence was correctly predicted in 13 of 15 streams (86.7%), and trout absence was correctly predicted in 27 of 30 streams (90.0%). The value of the Kappa statistic indicated that this model predicted brook trout presence/absence 75.4% better than expected by chance.

Models that combined geology variables with the presence or absence of a migration barrier (FALLS) and maximum summer temperature (MAX) best fit the 1993 brook trout presence/absence data (Appendix 6). These models indicated that brook trout were found in cool streams, without a migration barrier, flowing through surficial geologic deposits conducive to groundwater transmission. In many of these models however, either FALLS or MAX were not significant (however, the P-values for all regression coefficients were <0.1). The model with the best fit and significant at P≤0.05 included the weighted mean Objective Dichotomous rating of surficial deposits (GPOBJMEA), the presence or absence of a migration barrier (FALLS), and maximum summer temperature (MAX). The logistic regression equation of this model was:

11)

$$\pi=\frac{e^{10.0240+4.6614(GPOBJMEA)-2.6044(FALLS)-0.5951(MAX)}}{1+e^{10.0240+4.6614(GPOBJMEA)-2.6044(FALLS)-0.5951(MAX)}}$$

This model correctly predicted brook trout presence/absence in 39 of 45 streams (86.7%). Brook trout presence was correctly predicted in 12 of 15 streams (80.0%), and trout absence was correctly predicted in 27 of 30 streams (90.0%). The value of the Kappa statistic indicated that this model predicted brook trout presence/absence 70.0% better than expected by chance.

Predicting Brook Trout Presence/Absence - Model Validation

Only four logistic regression models developed using the 1993 data correctly classified brook trout presence/absence in the 1992/1994 data significantly better than would be expected by chance (Table 15). The 1993 model including the objective dichotomous geology variable (GPOBJMEA) using the weighted mean rating of all surficial deposits adjacent to the stream had the best correct classification rate. This model correctly predicted brook trout presence/absence in the 1992/1994 data for 23 of 34 streams (67.6%). Brook trout presence was correctly predicted in 14 of 19 streams (73.7%), and trout absence was correctly predicted in 9 of 15 streams (60.0%). The value of the Kappa statistic indicated that this model predicted brook trout presence/absence 33.9% better than expected by chance.

The other three models with significant Kappa statistics included: 1) the Geofisheries model (GEOFISH) (Dean et al. 1991b), 2) the model combining the thickness of the largest deposit adjacent to the stream (LARGTHIC) with the presence or absence of a migration barrier (FALLS), and 3) the model that combined the hydraulic conductivity of the largest deposit adjacent to the stream (LARGHYCO) with the presence or absence of a migration barrier

Table 15. Validation results of the best models developed in 1993 predicting brook trout presence/absence for northwestern Ontario streams studied in 1992 and 1994. Models with maximum summer temperature (MAX) were validated with 28 streams (15 trout present, 13 trout absent). All other models were validated with 34 streams (19 trout present, 15 trout absent). See Appendix 5 for detailed description of variables.

Variable(s) in	Correct Classification Rates				
Model	Presence (%)	Absence (%)	Overall (%)	Kappa	P
		Geology Models			
		1) Geofisheries Models			
GEOFISH	11 (57.9)	11 (73.3)	22 (64.7)	0.304	<0.0500
SURFACE	11 (57.9)	7 (46.7)	18 (52.9)	0.046	>0.1000
		2) Modified Geofisheries Models			
LARGDH12	13 (68.4)	8 (53.3)	21 (61.8)	0.219	>0.1000
LARGEH12	12 (63.2)	9 (60.0)	21 (61.8)	0.284	>0.0500
		3) Objective Geology Models			
LARGTHIC	4 (21.1)	15 (100.0)	19 (55.9)	0.190	>0.1000
LARGHYCO	5 (26.3)	15 (100.0)	20 (58.8)	0.240	>0.0500
		4) Dichotomous Geology Models			
GPEH12	12 (63.2)	9 (60.0)	21 (61.8)	0.284	>0.0500
GPKH12	11 (57.9)	9 (60.0)	20 (58.8)	0.176	>0.1000
GPOBJLAR	15 (78.9)	7 (46.7)	22 (64.7)	0.264	>0.0500
GPOBJMEA	14 (73.7)	9 (60.0)	23 (67.6)	0.339	<0.0500
		Biogeographic/Climatic Models			
FALLS	0 (00.0)	15 (100.0)	15 (44.1)	0.000	1.0000
FALLS DEGWEST DISTLSUP DISTLNIP	4 (21.0)	11 (73.3)	15 (44.1)	-0.052	1.0000

Table 15 (continued). Validation results of the best models developed in 1993 predicting brook trout presence/absence for northwestern Ontario streams studied in 1992 and 1994. Models with maximum summer temperature (MAX) were validated with 28 streams (15 trout present, 13 trout absent). All other models were validated with 34 streams (19 trout present, 15 trout absent). See Appendix 5 for detailed description of variables.

Variable(s) in Model	Correct Classification Rates Presence (%)	Absence (%)	Overall (%)	Kappa	P
Thermal Models					
MAX	9 (60.0)	8 (61.6)	17 (60.7)	0.214	>0.1000
Combined Models 1) Geology and Biogeographic/climate Models					
SURFACE FALLS	12 (63.2)	6 (40.0)	18 (52.9)	0.032	>0.1000
LARGDH12 FALLS	12 (63.2)	9 (60.0)	21 (61.8)	0.230	>0.0500
LARGEH12 FALLS	10 (52.6)	10 (66.7)	20 (58.8)	0.188	>0.1000
LARGTHIC FALLS	10 (52.6)	12 (80.0)	22 (64.7)	0.313	<0.0500
LARGHYCO FALLS	12 (63.2)	10 (66.7)	22 (64.7)	0.294	<0.0500
GPEH12 FALLS	9 (47.3)	10 (66.7)	19 (55.8)	0.136	>0.1000
GPKH12 FALLS	10 (52.6)	9 (60.0)	19 (55.8)	0.124	>0.1000
GPOBJLAR FALLS	12 (63.2)	9 (60.0)	21 (61.8)	0.230	>0.0500
GPOBJMEA FALLS	12 (63.2)	9 (60.0)	21 (61.8)	0.230	>0.0500

Table 15 (continued). Validation results of the best models developed in 1993 predicting brook trout presence/absence for northwestern Ontario streams studied in 1992 and 1994. Models with maximum summer temperature (MAX) were validated with 28 streams (15 trout present, 13 trout absent). All other models were validated with 34 streams (19 trout present, 15 trout absent). See Appendix 5 for detailed description of variables.

Variable(s) in	Correct Classification Rates				
Model	Presence (%)	Absence (%)	Overall (%)	Kappa	P
		Combined Models			
		2) Geology and Thermal Models			
GEOFISH MAX	10 (66.7)	8 (61.6)	18 (64.3)	0.282	>0.0500
SURFACE MAX	9 (60.0)	5 (38.5)	14 (50.0)	-0.016	1.0000
LARGDH12 MAX	10 (66.7)	5 (38.5)	15 (53.6)	0.052	>0.1000
LARGEH12 MAX	11 (73.3)	6 (46.2)	17 (60.7)	0.198	>0.1000
LARGTHIC MAX	10 (66.7)	7 (53.8)	17 (60.7)	0.250	>0.0500
LARGHYCO MAX	12 (80.0)	4 (30.8)	16 (57.1)	0.111	>0.1000
GPEH12 MAX	11 (73.3)	7 (53.8)	18 (64.3)	0.275	>0.0500
GPKH12 MAX	11 (73.3)	5 (38.5)	16 (57.1)	0.120	>0.1000
GPOBJLAR MAX	11 (73.3)	5 (38.5)	16 (57.1)	0.120	>0.1000
GPOBJMEA MAX	11 (73.3)	5 (38.5)	16 (57.1)	0.120	>0.1000

Table 15 (continued). Validation results of the best models developed in 1993 predicting brook trout presence/absence for northwestern Ontario streams studied in 1992 and 1994. Models with maximum summer temperature (MAX) were validated with 28 streams (15 trout present, 13 trout absent). All other models were validated with 34 streams (19 trout present, 15 trout absent). See Appendix 5 for detailed description of variables.

Variable(s) in	Correct Classification Rates				
Model	Presence (%)	Absence (%)	Overall (%)	Kappa	P
Combined Models					
3) Geology, Biogeographic/climate, and Thermal Models					
LARGHYCO FALLS MAX	13 (86.7)	5 (38.5)	18 (64.3)	0.259	>0.0500
GPOBJMEA FALLS MAX	11 (73.3)	6 (46.2)	17 (60.7)	0.198	>0.1000

(FALLS) (Table 15). These three models correctly predicted brook trout presence/absence in 22 of 34 streams (64.7%). The values of Kappa indicated that the prediction rates of these models were ≈30% better than expected by chance.

Some models developed in 1993 were better than those mentioned above at predicting either brook trout presence or absence in the 1992/1994 streams. The model that best classified trout presence in the 1992/1994 data included the objective dichotomous geology rating (GPOBJLAR) of the largest deposit adjacent to the stream (Table 15). This model correctly predicted presence in 15 of 19 streams (78.9%). However, this model correctly predicted absence for only 7 of 15 streams (46.7%), and the value of Kappa was not significant. The best model predicting trout absence was the presence or absence of a migration barrier (FALLS), which correctly predicted absence in 15 of 15 (100%) streams. However, this model predicted trout absence for all 1992/1994 streams, and Kappa was not significant.

Contrary to the results from the 1993 data, logistic regression revealed that brook trout presence/absence in the 1992/1994 data was significantly related to only one model. This model included the thickness of the largest surficial deposit adjacent to the 1992/1994 streams (LARGTHIC) (Table 16, Figure 11). The logistic regression equation of this models was:

Table 16. Validation results of logistic regression analyses using variables from the best models developed in 1993 to predict brook trout presence/absence using data collected from northwestern Ontario streams studied in 1992 and 1994. Models with maximum summer temperature (MAX) were validated with 28 streams (15 trout present, 13 trout absent). All other models were validated with 34 streams (19 trout present, 15 trout absent). See Appendix 5 for detailed description of variables.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	Constant	-2 log Likelihood	P
		Geology Models			
		1) Geofisheries Models			
GEOFISH	0.0646	0.3455	-0.6390	45.751	0.3398
SURFACE	0.0338	0.7627	-0.0090	46.571	0.7629
		2) Modified Geofisheries Models			
LARGDH12	0.1884	0.1237	-0.8995	44.177	0.1149
LARGEH12	0.2466	0.0776	-1.1066	43.350	0.0687
		3) Objective Geology Models			
LARGTHIC	0.1529	0.0285	-0.9872	40.712	0.0147
LARGHYCO	0.2848	0.0970	-1.8080	43.142	0.0606
		4) Dichotomous Geology Models			
		i) Geofisheries Derived			
GPEH12	1.2289	0.1231	-0.4920	44.182	0.1153
GPKH12	1.3245	0.1244	-0.5470	44.192	0.1160
		ii) Objective			
GPOBJLAR	1.1892	0.1201	-0.5596	44.141	0.1123
GPOBJMEA	1.2990	0.1028	-0.5964	43.867	0.0945
		Biogeography/Climate Models			
FALLS	0.2877	0.7496	0.2877	46.561	0.7498

Table 16 (continued). Validation results of logistic regression analyses using variables from the best models developed in 1993 to predict brook trout presence/absence using data collected from northwestern Ontario streams studied in 1992 and 1994. Models with maximum summer temperature (MAX) were validated with 28 streams (15 trout present, 13 trout absent). All other models were validated with 34 streams (19 trout present, 15 trout absent). See Appendix 5 for detailed description of variables.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	Constant	-2 log Likelihood	P
	Biogeography/Climate Models (continued)				
FALLS	3.3109	0.0659	-295.5	36.199	0.0333
DEGWEST	3.4090	0.2166			
DISTLSUP	-0.0989	0.0445			
DISTLNIP	-0.0941	0.0324			
	Thermal Models				
MAX	-0.1198	0.3718	2.4893	37.842	0.3619
	Combined Models				
	1) Geology and Biogeographic/Climate Models				
GEOFISH	0.0698	0.3213	-0.6213	45.551	0.5737
FALLS	-0.4099	0.6543			
LARGDH12	0.1991	0.1106	-0.8692	43.870	0.2475
FALLS	-0.5218	0.5795			
LARGEH12	0.2586	0.0695	-1.0723	43.025	0.1623
FALLS	-0.5409	0.5694			
LARGTHIC	0.1574	0.0276	-0.9262	40.453	0.0448
FALLS	-0.4896	0.6113			
LARGHYCO	0.2906	0.0893	-1.7613	42.895	0.1521
FALLS	-0.4579	0.6195			
GPEH12	1.3124	0.1082	-0.4410	43.840	0.2439
FALLS	-0.5546	0.5593			

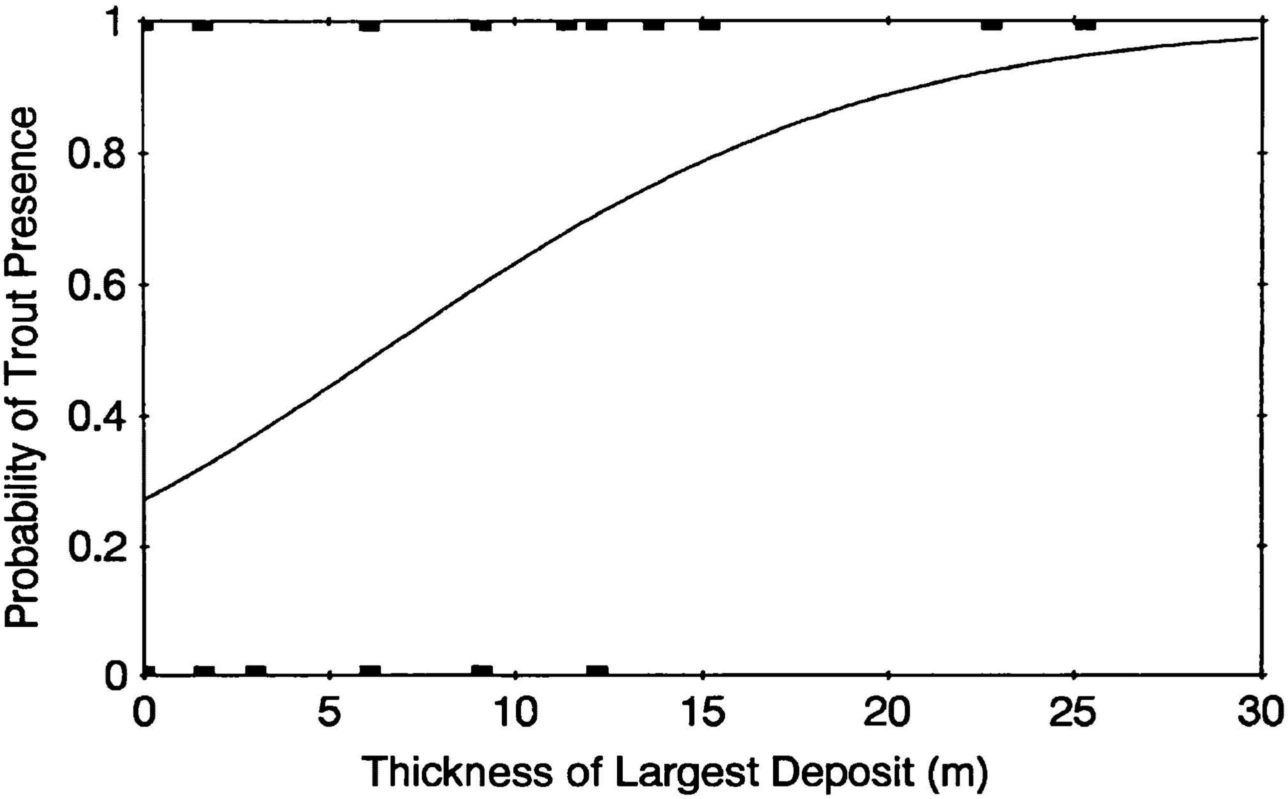
Table 16 (continued). Validation results of logistic regression analyses using variables from the best models developed in 1993 to predict brook trout presence/absence using data collected from northwestern Ontario streams studied in 1992 and 1994. Models with maximum summer temperature (MAX) were validated with 28 streams (15 trout present, 13 trout absent). All other models were validated with 34 streams (19 trout present, 15 trout absent). See Appendix 5 for detailed description of variables.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	Constant	-2 log Likelihood	P
Combined Models					
1) Geology and Biogeographic/Climate Models (continued)					
GPKH12	1.3846	0.1131	-0.4934	43.922	0.2541
FALLS	-0.4867	0.6033			
GPOBJLAR	1.2704	0.1049	-0.5128	43.790	0.2378
FALLS	-0.5607	0.5536			
GPOBJMEA	1.3396	0.0958	-0.5395	43.636	0.2202
FALLS	-0.4500	0.6303			
2) Geology and Thermal Models					
GEOFISH	0.0089	0.9072	2.2882	37.828	0.6554
MAX	-0.1157	0.4048			
LARGDH12	0.0588	0.6703	1.7530	37.661	0.6029
MAX	-0.1006	0.4736			
LARGEH12	0.0997	0.5208	1.4401	37.429	0.5367
MAX	-0.0940	0.4987			
LARGTHIC	0.1082	0.1335	0.2105	35.266	0.1820
MAX	-0.0499	0.7248			
LARGHYCO	0.1848	0.3426	-0.0008	36.852	0.4023
MAX	-0.0622	0.6696			
GPEH12	0.4749	0.5914	1.8346	37.544	0.5713
MAX	-0.1011	0.4627			

Table 16 (continued). Validation results of logistic regression analyses using variables from the best models developed in 1993 to predict brook trout presence/absence using data collected from northwestern Ontario streams studied in 1992 and 1994. Models with maximum summer temperature (MAX) were validated with 28 streams (15 trout present, 13 trout absent). All other models were validated with 34 streams (19 trout present, 15 trout absent). See Appendix 5 for detailed description of variables.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	Constant	-2 log Likelihood	P
		Combined Models			
		2) Geology and Thermal Models (continued)			
GPKH12	0.5077	0.5919	1.8554	37.554	0.5715
MAX	-0.1033	0.4505			
GPOBJLAR	0.3619	0.6737	1.9106	37.665	0.6041
MAX	-0.1029	0.4593			
GPOBJMEA	0.5062	0.5720	1.6706	37.523	0.5626
MAX	-0.0950	0.4972			
		3) Geology, Biogeographic/Climate, and Thermal Models			
LARGHYCO	0.2301	0.2480	-1.1475	35.145	0.3172
FALLS	-1.5671	0.2212			
MAX	-0.0090	0.9535			
GPOBJMEA	0.6220	0.4991	1.0993	36.173	0.4752
FALLS	-1.3792	0.2749			
MAX	-0.0601	0.6774			

Figure 11. Probabilities of brook trout presence, in northwestern Ontario streams studied during 1994, relative to the thickness of the largest surficial geologic deposit adjacent to the stream. Observed brook trout presence/absence are also given. Probabilities were calculated using logistic regression.


Probability of Trout Presence
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
Thickness of Largest Deposit (m)

12)

$$\pi = \frac{e^{-0.9872+0.1529(LARGTHIC)}}{1+e^{-0.9872+0.1529(LARGTHIC)}}$$

Predicting Brook Trout Presence/Absence - Model Development II

Since the models developed with the 1993 data did not perform well on the 1992/1994 data (Tables 15 and 16), additional models were developed by combining data from all three years (1992, 1993, 1994) to develop more general models predicting brook trout distribution in NWO (Appendix 7). Most models were developed from 79 streams (trout present at 34 sites, and trout absent at 45 sites). However, models containing thermal variables were developed from only 73 streams (trout present at 30 streams, and trout absent at 43 streams) having temperature data.

GEOLOGY MODELS

Brook trout presence/absence in the combined data was significantly related to characteristics of surficial geologic deposits. Trout streams were more likely found flowing through deposits conducive to groundwater transmission.

1) Geofisheries Model

The Geofisheries model (GEOFISH) (Dean et al. 1991b) was significant (P=0.0002) and positively related to brook trout presence in the combined data set (Table 17, Figure 12). The logistic regression model developed from the Geofisheries variable was:

13)
$$\pi=\frac{e^{-2.5944+0.1797(GEOFISH)}}{1+e^{-2.5944+0.1797(GEOFISH)}}$$

This model correctly predicted trout presence/absence in 58 of 79 streams (73.4%). Brook trout presence was correctly predicted in 24 of 34 streams (70.6%), and trout absence was correctly predicted in 34 of 45 streams (75.6%). The value of the Kappa statistic indicated that the Geofisheries model predicted brook trout presence/absence 46.0% better than expected by chance.

2) Modified Geofisheries Model

The Modified Geofisheries models were significantly related to brook trout presence/absence in the combined data (Appendix 7). Brook trout presence/absence was best fit by the Modified Geofisheries (LARGEH12) model that employed: 1) the rating of the largest deposit adjacent to the stream, 2) a high rating for sandy glaciolacustrine deposits, and a moderate rating for fens, and 3) the highest rated feature among the dominant and first

Table 17. Results of logistic regression analyses, correct classification rates, and Kappa statistics of the best models predicting brook trout presence/absence in northwestern Ontario streams studied in 1992, 1993, and 1994. See Appendix 5 for a detailed description of variables.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	Constant	-2 log Likelihood	P	Correct Classification Rates: Presence (%)	Absence (%)	Overall(%)	Kappa	P
Geology Models										
1) Geofisheries Models										
GEOFISH	0.1797	0.0010	-2.5944	94.539	0.0002	24 (70.6)	34 (75.6)	58 (73.4)	0.460	<0.0005
SURFACE	0.2300	0.0054	-1.8299	99.064	0.0028	21 (61.8)	28 (62.2)	49 (62.0)	0.236	<0.0250
2) Modified Geofisheries Models										
LARGDH12	0.3584	0.0001	-2.3294	89.216	0.0001	29 (85.3)	27 (60.0)	56 (70.9)	0.433	<0.0005
LARGEH12	0.4064	0.0001	-2.4448	87.766	0.0001	25 (73.5)	31 (68.9)	56 (70.9)	0.417	<0.0005
3) Objective Geology Models										
LARGTHIC	0.1500	0.0004	-1.5469	91.128	0.0001	22 (64.7)	37 (82.2)	59 (74.4)	0.476	<0.0005
LARGHYCO	0.3514	0.0018	-2.7161	94.282	0.0002	26 (76.5)	29 (64.4)	55 (69.6)	0.398	<0.0005
4) Dichotomous Models										
GPEH12	2.2303	0.0001	-1.5776	89.669	0.0001	25 (73.5)	31 (68.9)	56 (70.9)	0.417	<0.0005
GPKH12	2.4482	0.0001	-1.6835	89.973	0.0001	25 (73.5)	29 (64.4)	54 (68.4)	0.370	<0.0005
GPOBJLAR	2.2568	0.0001	-1.7228	88.674	0.0001	29 (85.3)	28 (62.2)	57 (72.2)	0.456	<0.0005
GPOBJMEA	2.4137	0.0001	-1.7501	88.826	0.0001	26 (76.5)	29 (64.4)	55 (69.6)	0.398	<0.0005

Table 17 (continued). Results of logistic regression analyses, correct classification rates, and Kappa statistics of the best models predicting brook trout presence/absence in northwestern Ontario streams studied in 1992, 1993, and 1994. See Appendix 5 for a detailed description of variables.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	Constant	-2 log Likelihood	P	Correct Classification Rates Presence (%)	Absence (%)	Overall(%)	Kappa	P
				Biogeographic/Climatic Models						
FALLS	-1.2589	0.0282	0.0351	102.583	0.0202	29 (85.3)	17 (37.8)	46 (58.2)	0.213	<0.0250
DRAINAGE	1.2246	0.0302	103.5	94.605	0.0039	19 (55.9)	32 (71.1)	51 (64.6)	0.272	<0.0100
DEGWEST	-1.1739	0.0299								
DISTMOR	-0.0604	0.0241								
				Thermal Models						
MAX	-0.2914	0.0026	5.7743	87.665	0.0008	13 (43.3)	37 (86.0)	50 (68.5)	0.311	<0.0100
				Combined Models						
				1) Geology and Biogeographic/Climatic Models						
GEOFISH	0.1737	0.0013	-2.1903	90.162	0.0001	24 (70.6)	32 (71.1)	56 (70.9)	0.413	<0.0005
FALLS	-1.2021	0.0453								
SURFACE	0.2767	0.0017	-1.7157	90.935	0.0002	24 (70.6)	32 (71.1)	56 (70.9)	0.413	<0.0005
FALLS	-1.6488	0.0077								

Table 17 (continued). Results of logistic regression analyses, correct classification rates, and Kappa statistics of the best models predicting brook trout presence/absence in northwestern Ontario streams studied in 1992, 1993, and 1994. See Appendix 5 for a detailed description of variables.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	Constant	-2 log Likelihood	P	Correct Classification Rates Presence (%)	Absence (%)	Overall(%)	Kappa	P
				Combined Models						
				1) Geology and Biogeographic/Climatic Models (continued)						
LARGDH12	0.4059	0.0001	-2.1578	81.315	0.0001	24 (70.6)	35 (77.8)	59 (74.7)	0.484	<0.0005
FALLS	-1.7488	0.0086								
LARGEH12	0.4328	0.0001	-2.1807	81.405	0.0001	23 (67.6)	37 (82.2)	60 (75.9)	0.504	<0.0005
FALLS	-1.5559	0.0172								
LARGTHIC	0.1563	0.0004	-1.2337	85.739	0.0001	22 (64.7)	37 (82.2)	59 (74.7)	0.476	<0.0005
FALLS	-1.3968	0.0290								
LARGHYCO	0.3935	0.0008	-2.5704	86.371	0.0001	22 (64.7)	37 (82.2)	59 (74.7)	0.476	<0.0005
FALLS	-1.6396	0.0084								
GPEH12	2.3781	0.0001	-1.2684	83.410	0.0001	21 (61.8)	37 (82.2)	58 (73.4)	0.448	<0.0005
FALLS	-1.5243	0.0181								
GPKH12	2.5194	0.0001	-1.3537	84.543	0.0001	23 (67.6)	36 (80.0)	59 (74.7)	0.480	<0.0005
FALLS	-1.3963	0.0267								

Table 17 (continued). Results of logistic regression analyses, correct classification rates, and Kappa statistics of the best models predicting brook trout presence/absence in northwestern Ontario streams studied in 1992, 1993, and 1994. See Appendix 5 for a detailed description of variables.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	Constant	-2 log Likelihood	P	Correct Classification Rates: Presence (%)	Absence (%)	Overall(%)	Kappa	P
Combined Models										
1) Geology and Biogeographic/Climatic Models (continued)										
GPOBJLAR	2.4800	0.0001	-1.4379	81.485	0.0001	26 (76.5)	36 (80.0)	62 (78.5)	0.563	<0.0005
FALLS	-1.6420	0.0115								
GPOBJMEA	2.4969	0.0001	-1.4192	83.185	0.0001	24 (70.6)	36 (80.0)	60 (75.9)	0.508	<0.0005
FALLS	-1.4320	0.0239								
GEOFISH	0.1914	0.0011	-4.8225	84.277	0.0001	25 (73.5)	35 (77.8)	60 (75.9)	0.511	<0.0005
DRAINAGE	2.9408	0.0049								
DISTLSUP	-0.0409	0.0125								
SURFACE	0.2877	0.0026	-4.2239	86.668	0.0001	22 (64.7)	34 (75.6)	56 (70.9)	0.404	<0.0005
DRAINAGE	3.1495	0.0035								
DISTLSUP	-0.0488	0.0042								
LARGDH12	0.3536	0.0004	-3.6302	82.459	0.0001	23 (67.6)	32 (71.1)	55 (69.6)	0.385	<0.0005
DRAINAGE	2.2725	0.0326								
DISTLSUP	-0.0379	0.0210								

Table 17 (continued). Results of logistic regression analyses, correct classification rates, and Kappa statistics of the best models predicting brook trout presence/absence in northwestern Ontario streams studied in 1992, 1993, and 1994. See Appendix 5 for a detailed description of variables.

Variable(s) in	Regression	Wald Chi-square				Correct Classification Rates				
Model	Coefficient	P	Constant	-2 log Likelihood	P	Presence (%)	Absence (%)	Overall(%)	Kappa	P
Combined Models										
1) Geology and Biogeographic/Climatic Models (continued)										
LARGEH12	0.4166	0.0001	-4.0766	79.604	0.0001	26 (76.4)	32 (71.1)	58 (73.4)	0.467	<0.0005
DRAINAGE	2.5065	0.0148								
DISTLSUP	-0.0399	0.0144								
LARGTHIC	0.1404	0.0007	-3.4861	82.905	0.0001	24 (70.6)	36 (80.0)	60 (75.9)	0.508	<0.0005
DRAINAGE	2.6985	0.0103								
DISTLSUP	-0.0358	0.0301								
LARGHYCO	0.3456	0.0019	-4.2237	84.876	0.0001	21 (61.8)	32 (71.1)	53 (67.1)	0.329	<0.0050
DRAINAGE	2.5701	0.0109								
DISTLSUP	-0.4090	0.0100								
GPEH12	2.3177	0.0002	-3.3064	80.933	0.0001	24 (70.6)	34 (75.6)	58 (73.4)	0.460	<0.0005
DRAINAGE	2.6144	0.0110								
DISTLSUP	-0.0407	0.0124								
GPKH12	2.4371	0.0004	-3.2887	82.275	0.0001	22 (64.7)	34 (75.6)	56 (70.9)	0.404	<0.0005
DRAINAGE	2.4445	0.0148								
DISTLSUP	-0.0368	0.0188								

Table 17 (continued). Results of logistic regression analyses, correct classification rates, and Kappa statistics of the best models predicting brook trout presence/absence in northwestern Ontario streams studied in 1992, 1993, and 1994. See Appendix 5 for a detailed description of variables.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	Constant	-2 log Likelihood	P	Correct Classification Rates: Presence (%)	Absence (%)	Overall(%)	Kappa	P
Combined Models										
1) Geology and Biogeographic/Climatic Models (continued)										
GPOBJLAR	2.2760	0.0003	-3.1189	81.251	0.0001	22 (64.7)	32 (71.1)	54 (68.4)	0.357	<0.0010
DRAINAGE	2.3644	0.0247								
DISTLSUP	-0.0396	0.0164								
GPOBJMEA	2.3348	0.0003	-3.1472	82.253	0.0001	22 (64.7)	34 (75.6)	56 (70.9)	0.404	<0.0005
DRAINAGE	2.2889	0.0265								
DISTLSUP	-0.0356	0.0253								
SURFACE	0.2127	0.0147	-0.2842	91.365	0.0008	17 (50.0)	35 (77.8)	52 (65.8)	0.285	<0.0100
DISTMOR	-0.0581	0.0411								
DISTLNIP	-0.0126	0.0325								
LARGTHIC	0.1589	0.0003	0.1009	80.488	0.0001	24 (70.6)	38 (84.4)	62 (78.5)	0.556	<0.0005
DISTMOR	-0.0786	0.0143								
DISTLNIP	-0.0147	0.0241								
LARGDH12	0.4208	0.0001	133.0	78.707	0.0001	25 (73.5)	33 (73.3)	58 (73.4)	0.464	<0.0005
DEGWEST	-1.5140	0.0210								
DISTMOR	-0.0694	0.0245								

Table 17 (continued). Results of logistic regression analyses, correct classification rates, and Kappa statistics of the best models predicting brook trout presence/absence in northwestern Ontario streams studied in 1992, 1993, and 1994. See Appendix 5 for a detailed description of variables.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	Constant	-2 log Likelihood	P	Correct Classification Rates: Presence (%)	Absence (%)	Overall(%)	Kappa	P
Combined Models										
1) Geology and Biogeographic/Climatic Models (continued)										
GPOBJLAR	2.5563	0.0001	126.3	79.103	0.0001	25 (73.5)	34 (75.6)	59 (74.7)	0.487	<0.0005
DEGWEST	-1.4305	0.0264								
DISTMOR	-0.0662	0.0291								
GPOBJMEA	2.6078	0.0001	110.9	80.414	0.0001	23 (67.6)	33 (73.3)	56 (70.9)	0.408	<0.0005
DEGWEST	-1.2575	0.0431								
DISTMOR	-0.0634	0.0335								
LARGDH12	0.3844	0.0003	-3.6931	77.326	0.0001	25 (73.5)	36 (80.0)	61 (77.2)	0.535	<0.0005
DRAINAGE	2.8293	0.0193								
DISTMOR	-0.0699	0.0335								
DISTLSUP	-0.0425	0.0212								
LARGEH12	0.4416	0.0001	-4.0564	74.910	0.0001	26 (76.5)	37 (82.2)	63 (79.7)	0.587	<0.0005
DRAINAGE	2.9694	0.0104								
DISTMOR	-0.0652	0.0402								
DISTLSUP	-0.0430	0.0167								

Table 17 (continued). Results of logistic regression analyses, correct classification rates, and Kappa statistics of the best models predicting brook trout presence/absence in northwestern Ontario streams studied in 1992, 1993, and 1994. See Appendix 5 for a detailed description of variables.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	Constant	-2 log Likelihood	P	Correct Classification Rates Presence (%)	Absence (%)	Overall(%)	Kappa	P
Combined Models										
1) Geology and Biogeographic/Climatic Models (continued)										
LARGTHIC	0.1615	0.0003	-3.5668	76.630	0.0001	21 (61.8)	36 (80.0)	57 (72.2)	0.424	<0.0005
DRAINAGE	3.3061	0.0075								
DISTMOR	-0.0780	0.0206								
DISTLSUP	-0.0396	0.0332								
LARGHYCO	0.3713	0.0010	-4.0836	79.273	0.0001	24 (70.6)	35 (77.8)	59 (74.7)	0.484	<0.0005
DRAINAGE	2.8961	0.0108								
DISTMOR	-0.0655	0.0291								
DISTLSUP	-0.0426	0.0147								
GPEH12	2.4469	0.0002	-3.2240	76.517	0.0001	25 (73.5)	37 (82.2)	62 (78.5)	0.560	<0.0005
DRAINAGE	3.0565	0.0080								
DISTMOR	-0.0631	0.0463								
DISTLSUP	-0.0439	0.0144								
GPKH12	2.6118	0.0003	-3.1966	77.458	0.0001	24 (70.6)	35 (77.8)	59 (74.7)	0.484	<0.0005
DRAINAGE	2.8564	0.0105								
DISTMOR	-0.0647	0.0382								
DISTLSUP	-0.0392	0.0225								

Table 17 (continued). Results of logistic regression analyses, correct classification rates, and Kappa statistics of the best models predicting brook trout presence/absence in northwestern Ontario streams studied in 1992, 1993, and 1994. See Appendix 5 for a detailed description of variables.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	Constant	-2 log Likelihood	P	Correct Classification Rates: Presence (%)	Absence (%)	Overall(%)	Kappa	P
Combined Models										
1) Geology and Biogeographic/Climatic Models (continued)										
GPOBJLAR	2.4549	0.0002	-3.1101	76.403	0.0001	26 (76.5)	36 (80.0)	62 (78.5)	0.563	<0.0005
DRAINAGE	2.9156	0.0148								
DISTMOR	-0.0658	0.0380								
DISTLSUP	-0.0444	0.0166								
GPOBJMEA	2.4965	0.0003	-3.0962	77.548	0.0001	24 (70.6)	36 (80.0)	60 (75.9)	0.508	<0.0005
DRAINAGE	2.7493	0.0170								
DISTMOR	-0.0637	0.0411								
DISTLSUP	-0.0386	0.0275								
LARGTHIC	0.1681	0.0003	-2.2516	77.689	0.0001	20 (58.8)	36 (80.0)	59 (74.7)	0.424	<0.0005
FALLS	-1.3429	0.0429								
DRAINAGE	1.2180	0.0485								
DISTMOR	-0.0704	0.0322								

Table 17 (continued). Results of logistic regression analyses, correct classification rates, and Kappa statistics of the best models predicting brook trout presence/absence in northwestern Ontario streams studied in 1992, 1993, and 1994. See Appendix 5 for a detailed description of variables.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	Constant	-2 log Likelihood	P	Correct Classification Rates: Presence (%)	Absence (%)	Overall(%)	Kappa	P
Combined Models										
2) Geology and Thermal Models										
GEOFISH	0.1340	0.0177	3.1447	81.415	0.0002	17 (56.7)	36 (83.7)	53 (72.6)	0.416	<0.0005
MAX	-0.2477	0.0151								
LARGDH12	0.2815	0.0040	2.9176	78.441	0.0001	18 (60.0)	32 (74.4)	50 (68.5)	0.346	<0.0050
MAX	-0.2321	0.0202								
LARGEH12	0.3248	0.0025	2.8140	77.407	0.0001	21 (70.0)	35 (81.4)	56 (76.7)	0.517	<0.0005
MAX	-0.2327	0.0206								
LARGTHIC	0.1245	0.0023	4.0933	76.626	0.0001	19 (63.3)	35 (81.4)	54 (74.0)	0.454	<0.0005
MAX	-0.2648	0.0096								
LARGHYCO	0.2830	0.0206	2.5772	80.960	0.0001	20 (66.7)	34 (79.1)	54 (74.0)	0.460	<0.0005
MAX	-0.2341	0.0178								
GPEH12	1.8332	0.0028	3.6017	77.753	0.0001	24 (80.0)	27 (62.8)	51 (69.9)	0.407	<0.0005
MAX	-0.2395	0.0163								

Table 17 (continued). Results of logistic regression analyses, correct classification rates, and Kappa statistics of the best models predicting brook trout presence/absence in northwestern Ontario streams studied in 1992, 1993, and 1994. See Appendix 5 for a detailed description of variables.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	Constant	-2 log Likelihood	P	Correct Classification Rates: Presence (%)	Absence (%)	Overall(%)	Kappa	P
				Combined Models						
				2) Geology and Thermal Models (continued)						
GPKH12	1.9909	0.0034	3.5716	77.996	0.0001	20 (66.7)	35 (81.4)	55 (75.3)	0.486	<0.0005
MAX	-0.2420	0.0149								
GPOBJLAR	1.7962	0.0031	3.4425	77.785	0.0001	22 (73.3)	33 (76.7)	55 (75.3)	0.496	<0.0005
MAX	-0.2352	0.0181								
GPOBJMEA	1.9199	0.0033	3.3425	77.920	0.0001	20 (66.7)	34 (79.1)	54 (74.0)	0.460	<0.0005
MAX	-0.2317	0.0205								
				3) Geology, Biogeographic/Climatic and Thermal Models						
GEOFISH	0.1285	0.0229	2.9387	76.535	0.0001	22 (73.3)	33 (76.7)	55 (75.3)	0.496	<0.0005
FALLS	-1.5107	0.0401								
MAX	-0.2185	0.0349								
SURFACE	0.2067	0.0300	3.0236	77.116	0.0001	22 (73.3)	34 (79.1)	56 (76.7)	0.521	<0.0005
FALLS	-1.8951	0.0123								
MAX	-0.2053	0.0483								

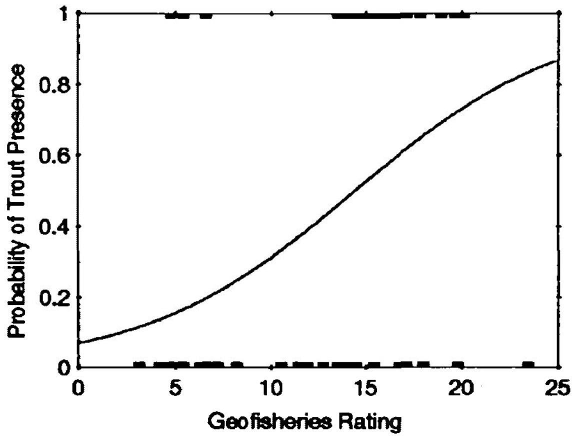
Table 17 (continued). Results of logistic regression analyses, correct classification rates, and Kappa statistics of the best models predicting brook trout presence/absence in northwestern Ontario streams studied in 1992, 1993, and 1994. See Appendix 5 for a detailed description of variables.

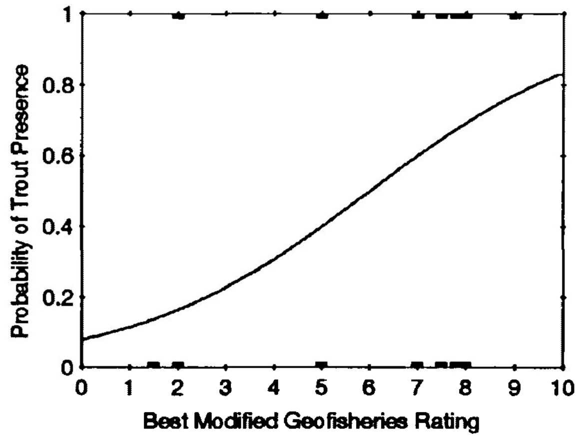
Combined Models

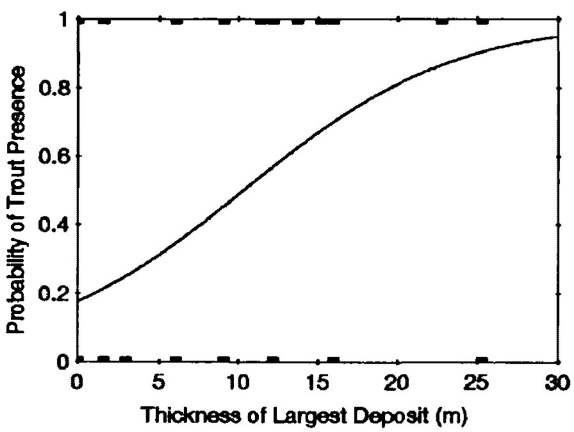
3) Geology, Biogeographic/Climatic and Thermal Models (continued)

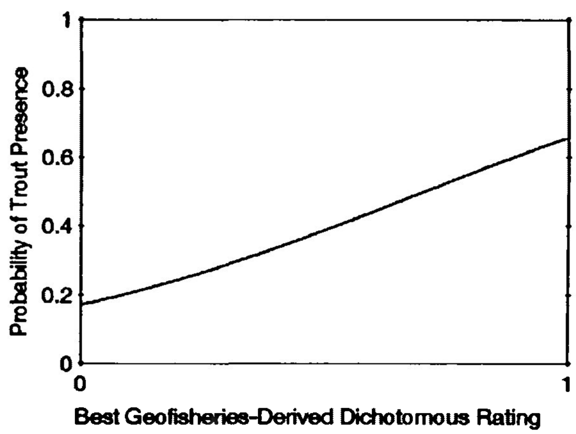
Variable(s) in Model	Regression Coefficient	Wald Chi-square P	Constant	-2 log Likelihood	P	Correct Classification Rates: Presence (%)	Absence (%)	Overall(%)	Kappa	P
LARGTHIC	0.1338	0.0021	3.5344	70.848	0.0001	22 (73.3)	35 (81.4)	57 (78.1)	0.547	<0.0005
FALLS	-1.7638	0.0273								
MAX	-0.2239	0.0308								
SURFACE	0.2110	0.0333	1.2421	76.907	0.0002	21 (70.0)	35 (81.4)	56 (76.7)	0.517	<0.0005
DRAINAGE	2.3918	0.0363								
DISTLSUP	-0.0453	0.0131								
MAX	-0.2007	0.0475								

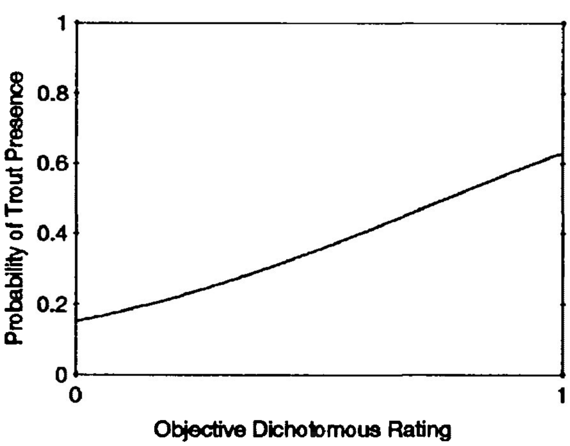
Figure 12. Probabilities of brook trout presence, in northwestern Ontario streams studied during 1992, 1993, and 1994 relative to the various methods used to rate surficial geologic deposits based on their ability to transmit groundwater. The rating methods used were: 1) Geofisheries (Dean et al. 1991b), 2) Modified Geofisheries, 3) Objective (e.g. deposit thickness), and 4) Dichotomous (Geofisheries-derived and Objective). Observed brook trout presence/absence are given for the former three rating methods. Probabilities were calculated using logistic regression.


Probability of Trout Presence
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20
25
Geofisheries Rating


Probability of Trout Presence
0
0.2
0.4
0.6
0.8
1
0
1
2
3
4
5
6
7
8
9
10
Best Modified Geofisheries Rating


Probability of Trout Presence
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20
25
30
Thickness of Largest Deposit (m)


Probability of Trout Presence
0
0.2
0.4
0.6
0.8
1
0
1
Best Geofisheries-Derived Dichotomous Rating


Probability of Trout Presence
0
0.2
0.4
0.6
0.8
1
0
1
Objective Dichotomous Rating

subordinate deposits in the case of complex terrain units (Table 17, Figure 12). The logistic regression equation for this model was:

14)

$$\pi=\frac{e^{-2.4448+0.4064(LARGEH12)}}{1+e^{-2.4448+0.4064(LARGEH12)}}$$

This model correctly predicted trout presence/absence in 56 of 79 streams (70.9%). Brook trout presence was correctly predicted in 25 of 34 streams (73.5%), and trout absence was correctly predicted in 31 of 45 streams (68.9%). The value of the Kappa statistic indicated that this model predicted brook trout presence/absence 41.7% better than expected by chance. However, a second Modified Geofisheries model (LARGDH12) had higher correct trout presence prediction rate (29 of 34 streams), and Kappa statistic (Kappa=0.433). This model employed: 1) the rating of the largest deposit adjacent to the stream, 2) a high rating for sandy glaciolacustrine deposits, and a high rating for fens, and 3) the highest rated feature among the dominant and first subordinate deposits in the case of complex terrain units (Table 17).

3) Objective Geology Models

Most of the objective geology models were significantly related to brook trout presence/absence in the combined data (Appendix 7). The model best able to predict trout distribution used the thickness of the largest deposit adjacent to the stream (LARGTHIC) (Table 17, Figure 12). The logistic regression equation of this model was:

15)
$$\pi=\frac{e^{-1.5469+0.1500(LARGTHIC)}}{1+e^{-1.5469+0.1500(LARGTHIC)}}$$

This model correctly predicted brook trout presence/absence in 59 of 79 streams (74.7%). Brook trout presence was correctly predicted in 22 of 34 streams (64.7%), and trout absence was correctly predicted in 37 of 45 streams (82.2%). The value of the Kappa statistic indicated that this model predicted brook trout presence/absence 47.6% better than expected by chance.

4) Dichotomous Models

The dichotomous models (i.e. good/poor) derived from the Geofisheries ratings of surficial features were significantly related to brook trout distribution in the combined data (Appendix 7). Brook trout distribution was best predicted by the Geofisheries derived model (GPEH12) that employed: 1) the rating of the largest deposit adjacent to the stream, 2) a high rating for sandy glaciolacustrine deposits (1.0), and a moderate rating for fens(0.5), and 3) the highest rated feature among the dominant and first subordinate deposits in the case of complex terrain units (Table 17, Figure 12). The logistic regression equation of this model was:

16)

$$\pi = \frac{e^{-1.5776+2.2303(GPEH12)}}{1+e^{-1.5776+2.2303(GPEH12)}}$$

This model correctly predicted brook trout presence/absence in 56 of 79 streams (70.9%). Brook trout presence was correctly predicted in 25 of 34 streams (73.5%), and trout absence was correctly predicted in 31 of 45 streams (68.9%). The value of the Kappa statistic indicated that this model predicted brook trout presence/absence 41.7% better than expected by chance.

Both objective dichotomous models were significantly related to brook trout presence\absence in the combined data (Table 17). The model rating the largest deposit adjacent to the stream (GPOBJLAR) had a marginally better fit to the data (Figure 12). The logistic regression equation of this model was:

17)

$$\pi = \frac{e^{-1.7228+2.2568(GPOBJLAR)}}{1+e^{-1.7228+2.2568(GPOBJLAR)}}$$

This model correctly predicted brook trout presence/absence in 57 of 79 streams (72.2%). Trout presence was correctly predicted in 29 of 34 streams (85.3%), and trout absence was correctly predicted in 28 of 45 streams (62.2%). The value of the Kappa statistic indicated that this model predicted brook trout presence/absence 45.6% better than expected by chance.

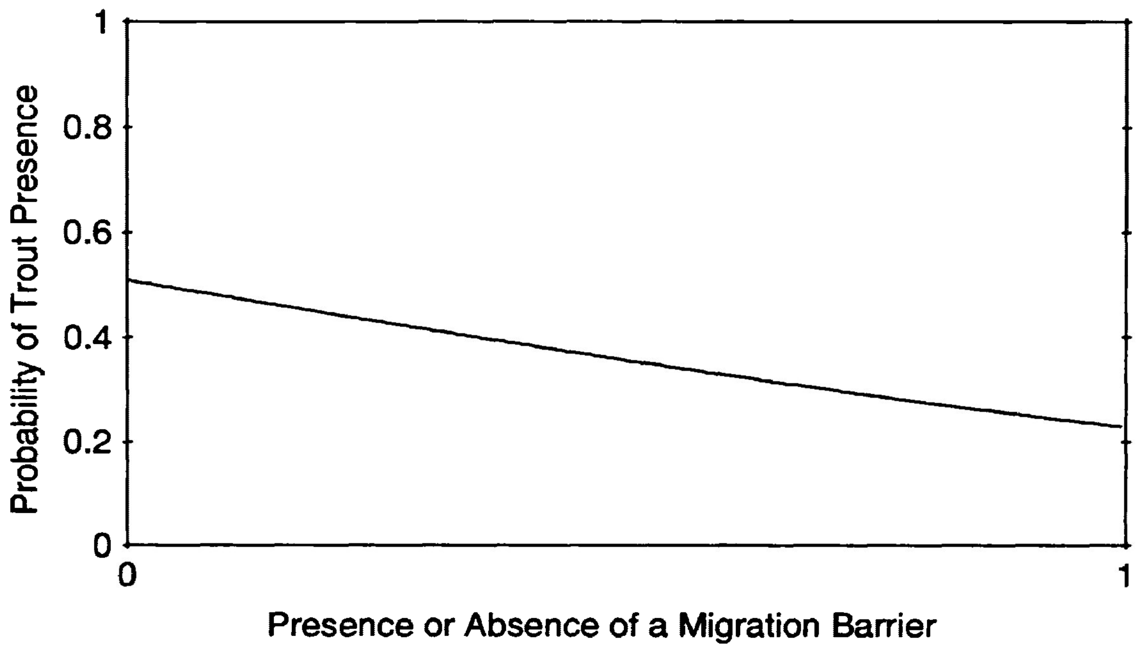
BIOGEOGRAPHY/CLIMATIC MODELS

Brook trout distribution was related to several more biogeographic/climate models (univariate and multivariate) in the combined data than in the 1993 data (Appendix 7). The two significant univariate models included biogeographic variables. The first indicated that trout distribution was related to the presence or absence of a barrier falls between the site and a potentially recolonizing brook trout population (FALLS). The second indicated that trout were more likely found closer to the large lake (Lake Superior or Lake Nipigon) into which they flowed (DISTLGLK). The correlation between these two variables was assessed with logistic regression since the presence or absence of a migration barrier is binary. The analysis revealed that a migration barrier on a stream was more likely found further from the large lake into which the stream flowed (-2 log likelihood=81.186, P=0.0005). Both variables are likely indicators of a migration barrier because the probability of the presence of a migration barrier increases with length of stream (i.e. increasing distance upstream). Therefore, the influence of the presence or absence of a migration barrier (FALLS) was considered more important (Table 17, Figure 13). The logistic regression equation of this model was:

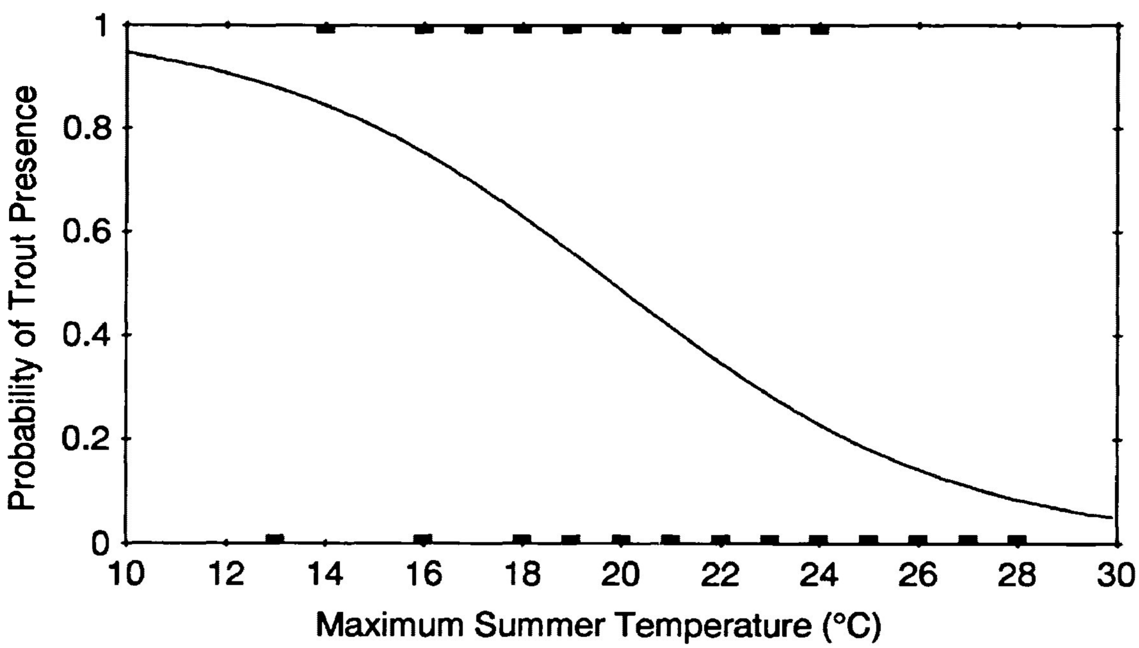
18)

$$\pi = \frac{e^{0.0351-1.2589(FALLS)}}{1+e^{0.0351-1.2589(FALLS)}}$$

Figure 13. Probabilities of brook trout presence, in northwestern Ontario streams studied during 1992, 1993, and 1994 relative to the presence or absence of a barrier falls (upper graph) and maximum summer stream temperature (°C) (lower graph). Observed brook trout presence/absence are given for the latter model. Probabilities were calculated using logistic regression.



1
0.8
0.6
0.4
0.2
0
Probability of Trout Presence
0
1
Presence or Absence of a Migration Barrier



1
0.8
0.6
0.4
0.2
0
Probability of Trout Presence
10
12
14
16
18
20
22
24
26
28
30
Maximum Summer Temperature (°C)

This model correctly predicted brook trout presence/absence in 46 of 79 streams (58.2%). Brook trout presence was correctly predicted in 29 of 34 streams (85.3), and trout absence was correctly predicted in 17 of 45 streams (37.8%). The Kappa value indicated that this model predicted trout presence/absence 21.3% better than expected by chance.

Brook trout presence/absence in the combined data was related to several multivariate biogeographic/climatic models (Appendix 7). The best of these models included: 1) the drainage in which the streams were located (DRAINAGE) (either Lake Superior or Lake Nipigon), 2) the degrees west longitude of each stream (DEGWEST), and 3) the distance (km) the streams were from a major moraine (DISTMOR). The model indicated that brook trout streams were more likely found in the Lake Nipigon drainage, in the eastern portion of the study area, and closer to major moraines. The logistic regression equation of this model was:

19)

$$\pi=\frac{e^{103.5+1.2246(DRAINAGE)-1.1739(DEGWEST)-0.0604(DISTMOR)}}{1+e^{103.5+1.2246(DRAINAGE)-1.1739(DEGWEST)-0.604(DISTMOR)}}$$

This model correctly predicted brook trout presence/absence in 51 of 79 streams (64.6%). Brook trout presence was correctly predicted in 19 of 34 streams (55.9%), and trout absence was correctly predicted in 32 of 45 streams (71.1%). The Kappa value indicated that this model predicted trout presence/absence 27.2% better than expected by chance.

THERMAL MODELS

Brook trout streams were negatively related to the four thermal variables in the combined data, suggesting that trout streams were cooler and more stable than non-trout streams (Appendix 7). Maximum summer temperature (MAX) was the best thermal variable discriminating between trout and non-trout streams (Table 17, Figure 13). The logistic regression equation of the maximum summer temperature model was:

20)
$$\pi = \frac{e^{5.7743-0.2914(MAX)}}{1+e^{5.7743-0..2914(MAX)}}$$

This model correctly predicted brook trout presence/absence in 50 of 73 streams (68.5%). Brook trout presence was correctly predicted in 13 of 30 streams (43.3%), and trout absence was correctly predicted in 37 of 43 streams (86.0%). The value of the Kappa statistic indicated that this model predicted brook trout presence/absence 31.1% better than expected by chance.

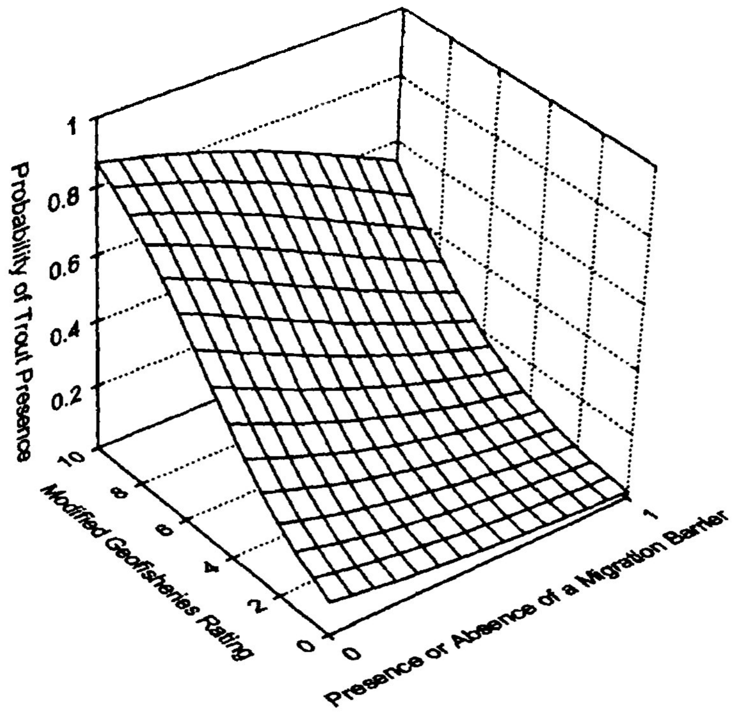
COMBINED MODELS

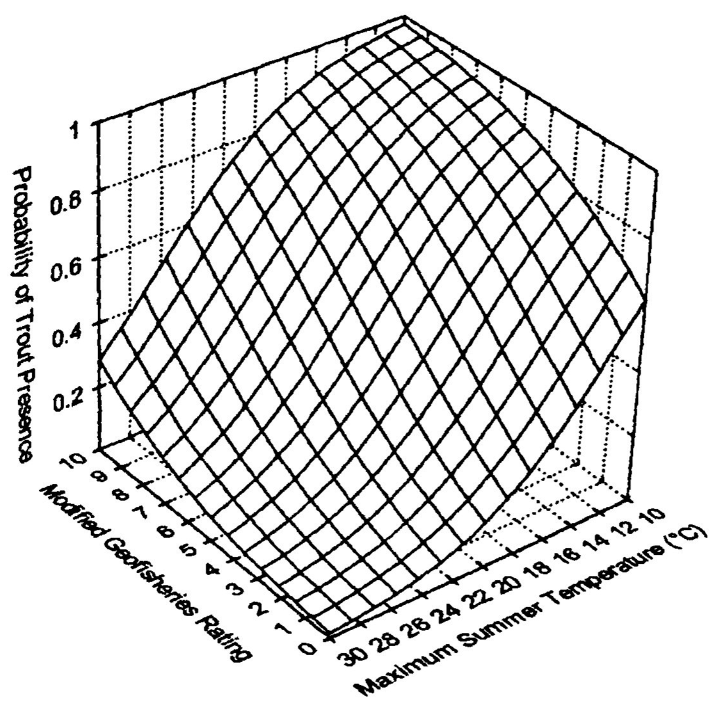
Brook trout presence/absence in the combined data was significantly related to several models that combined geology variables with biogeographic/climatic variables (Table 17, Appendix 7). Several models combining geology with the presence or absence of a barrier falls were significant, suggesting that trout were more likely found in streams flowing through geologic deposits conducive to groundwater transmission, and not having a migration barrier. The best of these models combined the barrier falls variable (FALLS) with the Modified Geofisheries variable (LARGDH12) that employed: 1) the rating of the largest deposit adjacent to the stream, 2) a high rating for sandy glaciolacustrine deposits, and a high rating for fens, and 3) the highest rated feature among the dominant and first subordinate deposits in the case of complex terrain units (Table 17, Figure 14). The logistic regression equation of this model was:

21)
$$\pi = \frac{e^{-2.1578+0.4059(LARGDH12)-1.7488(FALLS)}}{1+e^{-2.1578+0.4059(LARGDH12)-1.7488(FALLS)}}$$

This model correctly predicted brook trout presence/absence in 59 of 79 streams (74.7%). Brook trout presence was correctly predicted in 24 of 34 streams (70.6%), and trout absence was correctly predicted in 35 of 45 streams (77.8%). The value of the Kappa statistic indicated that this model predicted brook trout presence/absence 48.4% better than expected by chance. The model that combined the presence or absence of a migration barrier (FALLS) with the Modified Geofisheries variable (LARGEH12) that employed: 1) the rating of the largest deposit adjacent to the stream, 2) a high rating for sandy glaciolacustrine deposits, and a moderate rating for fens, and 3) the highest

Figure 14. Probabilities of brook trout presence, in northwestern Ontario streams studied during 1992, 1993, and 1994 relative to the best Modified Geofisheries rating of surficial geologic deposits combined with: 1) the presence or absence of a migration barrier (upper graph), and 2) maximum summer stream temperature (°C) (lower graph). Probabilities were calculated using logistic regression.


Probability of Trout Presence
1
0.8
0.6
0.4
0.2
10
8
6
4
2
0
Modified Geofisheries Rating
0
1
Presence or Absence of a Migration Barrier


Probability of Trout Presence
1
0.8
0.6
0.4
0.2
10 9 8 7 6 5 4 3 2 1 0
Modified Geofisheries Rating
30 28 26 24 22 20 18 16 14 12 10
Maximum Summer Temperature (°C)

rated feature among the dominant and first subordinate deposits in the case of complex terrain units had a higher overall correct prediction rate (60 of 79 sites) and Kappa value (0.504).

The best models predicting brook trout presence/absence in the combined data combined geology variables with: 1) the drainage in which the streams were located (DRAINAGE), 2) the distance the streams were from a major moraine (DISTMOR), and 3) the distance the streams were from Lake Superior (DISTLSUP) (Table 17). These models indicated that trout were more likely found in streams flowing through geologic deposits that were conducive to groundwater transmission, in the Lake Nipigon drainage, and closer to major moraines and Lake Superior. The best of these models combined DRAINAGE, DISTMOR, DISTLSUP with the Modified Geofisheries variable (LARGEH12) that employed: 1) the rating of the largest deposit adjacent to the stream, 2) a high rating for sandy glaciolacustrine deposits, and a moderate rating for fens, and 3) the highest rated feature among the dominant and first subordinate deposits in the case of complex terrain units (Table 14). The logistic regression equation of this model was:

22)
$$\pi=\frac{e^{-4.0564+0.4416(LARGEH12)+2.9694(DRAINAGE)-0.0652(DISTMOR)-0.0430(DISTLSUP)}}{1+e^{-4.0564+0.4416(LARGEH12)+2.9694(DRAINAGE)-0.0652(DISTMOR)-0.0430(DISTLSUP)}}$$

This model correctly predicted brook trout presence/absence in 63 of 79 streams (79.7%). Brook trout presence was correctly predicted in 26 of 34 streams (76.5%), and trout absence was correctly predicted in 37 of 45 streams (82.2%). The value of the Kappa statistic indicated that this model predicted brook trout presence/absence 58.7% better than expected by chance.

Brook trout presence/absence in the combined data set was significantly related to models that combined geology variables with maximum summer temperature (MAX) (Table 17). These models indicated that brook trout were more likely found in cool streams that flowed through surficial deposits conducive to groundwater transmission. The best of these models combined maximum summer temperature with the Modified Geofisheries variable (LARGEH12) that employed: 1) the rating of the largest deposit adjacent to the stream, 2) a high rating for sandy glaciolacustrine deposits, and a moderate rating for fens, and 3) the highest rated feature among the dominant and first subordinate deposits in the case of complex terrain units (Figure 14). The logistic regression equation of this model was:

23)
$$\pi = \frac{e^{2.8140+0.3248(LARGEH12)-0.2327(MAX)}}{1+e^{2.8140+0.3248(LARGDH12)-0.2327(MAX)}}$$

This model correctly predicted brook trout presence/absence in 56 of 73 streams (76.7%). Brook trout presence was correctly predicted in 21 of 30 streams (70.0%), and trout absence was correctly predicted in 35 of 43 streams

(81.4%). The value of the Kappa statistic indicated that this model predicted brook trout presence/absence 51.7% better than expected by chance.

Brook trout presence/absence in the combined data was significantly related to three models that combined geology variables with the presence or absence of a migration barrier (FALLS) and maximum summer temperature (MAX) (Table 17). The best of these models combined the thickness of the largest deposit adjacent to the stream (LARGTHIC) with FALLS and MAX. The logistic regression equation of this models was:

24)

$$\pi = \frac{e^{3.5344+0.1338(LARGTHIC)-1.7638(FALLS)-0.2239(MAX)}}{1+e^{3.5344+0.1338(LARGTHIC)-1.7638(FALLS)-0.2239(MAX)}}$$

This model correctly predicted brook trout presence/absence in 57 of 73 streams (78.1%). Brook trout presence was correctly predicted in 22 of 30 streams (73.3%), and trout absence was correctly predicted in 35 of 43 streams (81.4%). The value of the Kappa statistic indicated that this model predicted brook trout presence/absence 54.7% better than expected by chance.

Relation Between Summer Stream Thermal Conditions, Geology, and Climate

Using the combined data (1993 and 1994), geology variables and climatic variables were able to account for significant proportions of the variance associated with all four thermal variables. Maximum summer temperature, mean-maximum summer temperature, and mean summer temperature were most related to the surficial deposit that contained the study reach (Table 18). The best univariate geology model used the Modified Geofisheries variable (SITEFH12) employing: 1) the rating of the deposit containing the study reach, 2) a high rating for sandy glaciolacustrine deposits, and a low rating for fens, and 3) the highest rated feature among the dominant and first subordinate deposits in the case of complex terrain units. This variable explained 12.64% to 15.77% of the variance associated with the thermal variables.

In contrast, summer thermal stability was most related to the largest deposit adjacent to the stream (Table 18). The univariate geology model that best predicted thermal stability was the Modified Geofisheries variable (LARGFH12) that employed: 1) the rating of the largest deposit adjacent to the stream, 2) a high rating for sandy glaciolacustrine deposits, and a low rating for fens, and 3) the highest rated feature among the dominant and first subordinate deposits in the case of complex terrain units. This model explained 15.30% of the variance associated with the summer thermal stability.

The Modified Geofisheries variables (SITEFH12 and LARGFH12) that best fit the temperature data both used a low rating for fens (i.e. 0.0-6.0). This indicates that fens have a warming influence on stream temperatures.

Stream temperature (i.e. maximum, mean-maximum, and mean summer

Table 18. Linear regression results of the best significant models predicting thermal conditions of northwestern Ontario streams studied in 1993 and 1994. Relations are considered significant at P≤0.05. See Appendix 5 for a detailed description of variables.

Dependent Variable	Variable(s) in Model	Regression Coefficient	P	Constant	r^2	P
Maximum Summer Temperature (°C)			**Geology Models**			
			1) Geofisheries Model			
	GEOFISH	-0.1738	0.0106	23.3088	0.0885	0.0106
			2) Modified Geofisheries Model			
	SITEFH12	-0.4131	0.0005	23.1385	0.1577	0.0005
			3) Objective Geology Model			
	LARGHYCO	-0.3252	0.0072	23.3260	0.0972	0.0072
			4) Dichotomous Geology Model			
	GPEH12	-1.7670	0.0167	22.1221	0.0780	0.0167
			Biogeographic/Climatic Model			
	DISTLNIP	0.0225	0.0025	19.5746	0.1214	0.0025
			Combined Model			
	SITEFH12	-0.3464	0.0030	21.5838	0.2259	0.0001
	DISTLNIP	0.0174	0.0154			

Table 18 (continued). Linear regression results of the best significant models predicting thermal conditions of northwestern Ontario streams studied in 1993 and 1994. Relations are considered significant at $P \leq 0.05$. See Appendix 5 for a detailed description of variables.

Dependent Variable	Variable(s) in Model	Regression Coefficient	P	Constant	r^2	P
Mean-maximum Summer Temperature (°C)		**Geology Models**				
		1) Geofisheries Model				
	SURFACE	-0.2457	0.0185	21.1876	0.0757	0.0185
		2) Modified Geofisheries Model				
	SITEFH12	-0.3844	0.0006	21.4513	0.1553	0.0006
		3) Objective Geology Model				
	LARGHYCO	-0.3464	0.0021	21.9159	0.1256	0.0021
		4) Dichotomous Geology Model				
	GPEH12	-1.7714	0.0103	20.5737	0.0764	0.0103
		Biogeographic/Climatic Model				
	DISTLNIP	0.0230	0.0009	17.9919	0.1437	0.0009
		Combined Model				
	SITEFH12	-0.3140	0.0037	19.8134	0.2414	0.0001
	DISTLNIP	0.0183	0.0063			

Table 18 (continued). Linear regression results of the best significant models predicting thermal conditions of northwestern Ontario streams studied in 1993 and 1994. Relations are considered significant at P≤0.05. See Appendix 5 for a detailed description of variables.

Dependent Variable	Variable(s) in Model	Regression Coefficient	P	Constant	r^2	P
Mean Summer Temperature (°C)		**Geology Models**				
		1) Geofisheries Model				
	GEOFISH	-0.0893	0.0113	16.9018	0.0740	0.0113
		2) Modified Geofisheries Model				
	SITEFH12	-0.2891	0.0200	17.0378	0.1264	0.0020
		3) Objective Geology Model				
	LARGHYCO	-0.2651	0.0050	17.4170	0.1058	0.0050
		4) Dichotomous Geology Model				
	GPEH12	-1.2370	0.0328	16.3266	0.0626	0.0328
		Biogeographic/Climatic Model				
	DISTLNIP	0.0213	0.0002	14.1457	0.1785	0.0002
		Combined Model				
	SITEFH12	-0.2196	0.0137	15.4198	0.2473	0.0001
	DISTLNIP	0.0181	0.0013			

Table 18 (continued). Linear regression results of the best significant models predicting thermal conditions of northwestern Ontario streams studied in 1993 and 1994. Relations are considered significant at $P \leq 0.05$. See Appendix 5 for a detailed description of variables.

Dependent Variable	Variable(s) in Model	Regression Coefficient	P	Constant	r^2	P
Summer Thermal Stability (°C)		**Geology Models**				
		1) Geofisheries Model				
	SURFACE	-0.1980	0.0231	8.5159	0.0706	0.0231
		2) Modified Geofisheries Model				
	LARGFH12	-0.2045	0.0006	8.8871	0.1530	0.0006
		3) Objective Geology Model				
	LARGHYCO	-0.1572	0.0126	8.9727	0.0716	0.0126
		4) Dichotomous Geology Model				
	GPEH12	-1.0373	0.0064	8.4884	0.1000	0.0064
		Biogeographic/Climatic Model				
	DISTLGLK	0.0237	0.0118	7.2725	0.0859	0.0118
		Combined Model				
	LARGFH12	-0.1843	0.0017	8.2620	0.2068	0.0003
	DISTLGLK	0.0190	0.0327			

temperature) were weakly related to the distance the streams were from Lake Nipigon (DISTLNIP) (Table 18), indicating that stream temperatures were warmer further from Lake Nipigon (Table 18). This variable explained 12.14% to 17.85% of the variation associated with stream temperatures. Thermal stability was very weakly related to the distance the streams were from the large lake (Lake Superior or Lake Nipigon) into which they flowed (DISTLGLK). Stream temperatures were more stable closer to either Lake Superior or Lake Nipigon. This model explained 8.59% of the variation associated with thermal stability.

The best models predicting stream temperatures (i.e. maximum, mean-maximum, and mean summer temperature) combined the distance the streams were from Lake Nipigon (DISTLNIP) with the Modified Geofisheries variable (SITEFH12) that employed: 1) the rating of the deposit containing the study reach, 2) a high rating for sandy glaciolacustrine deposits, and a low rating for fens, and 3) the highest rated feature among the dominant and first subordinate deposits in the case of complex terrain units (Table 18). Temperatures were cooler in streams that were near Lake Nipigon and flowed through geologic deposits that were conducive to groundwater transmission. These variables accounted for ≈24% of the variation associated with stream temperatures.

Summer thermal stability was best predicted by the model that combined the distance the streams were from the large lake into which they flowed (DISTLGLK) and the Modified Geofisheries variable (LARGFH12) that employed: 1) the rating of the largest deposit adjacent to the stream, 2) a high rating for sandy glaciolacustrine deposits, and a low rating for fens, and 3) the highest rated feature among the dominant and first subordinate deposits in the case of complex terrain units (Table 18). This models accounted for 20.68% of the variance associated with summer thermal stability.

Modelling Brook Trout Abundance

Predicting Brook Trout Abundance - Model Development I

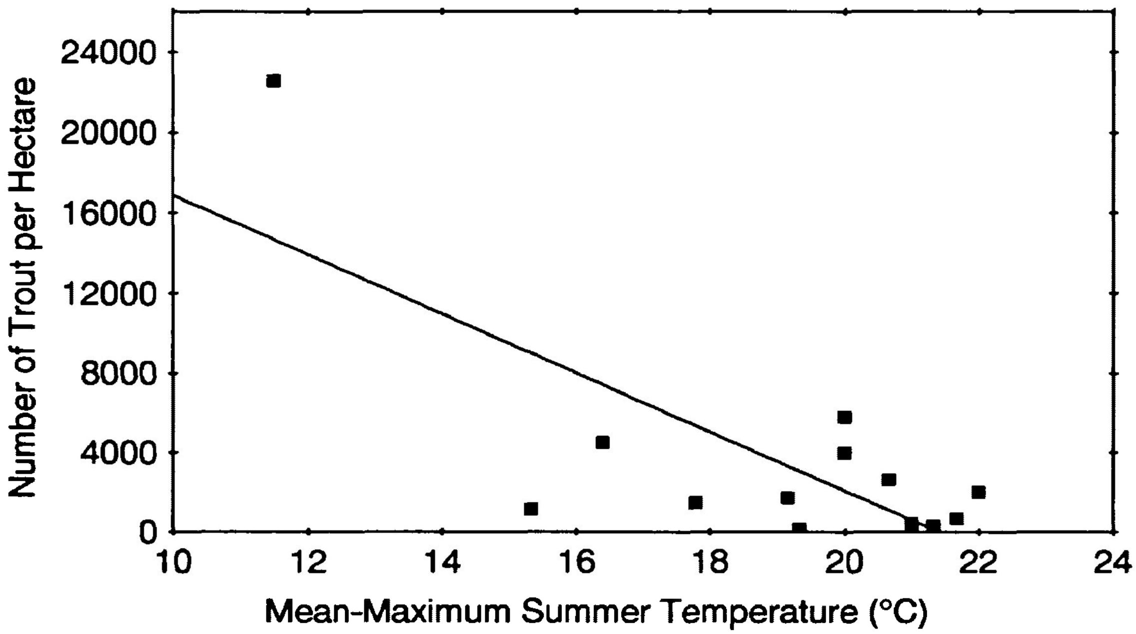
Brook trout were captured in 15 of the 45 streams studied in 1993 (Table 9, Appendix 3). Accurate population estimates were not possible in two of the streams (Asterisk Creek, and Lime 2 Creek), therefore, only 13 trout streams were used in these analyses.

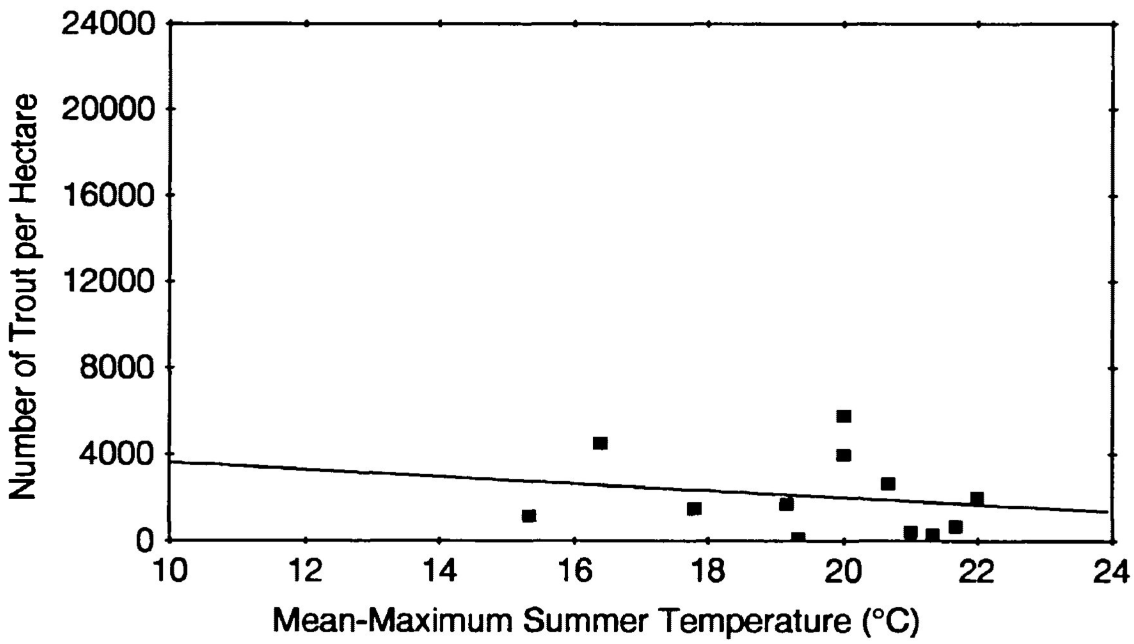
Brook trout density in 1993 (i.e. number of trout/km, and number of trout/ha) was significantly related to summer thermal conditions (Table 19). Trout densities were greater in cooler streams, and thermally stable streams. These models accounted for 40.85% to 55.92% of the variation in number of trout/ha, and 37.12% to 51.52% of the variation in number of trout/km. Mean-maximum summer temperature was consistently the best thermal variable predicting density. The best model was the relation between mean-maximum summer temperature (MEANMAX) and number of trout/ha (NPERHA) (Figure 15). The equation of this model was:

Table 19. Relations between brook trout abundance variables and thermal conditions of northwestern Ontario streams studied in 1993. Relations are considered significant at P≤0.05.

Variable in Model	Dependent Variable	Regression Coefficient	P	Constant	r^2
Maximum Summer Temperature (°C)	Brook trout density (trout/km)	-258.3360	0.0129	6086	0.4437
	Brook trout density (trout/ha)	-1444.5076	0.0072	33313	0.4962
	Brook trout biomass (kg/km)	-0.5290	0.5395	19.2256	0.3520
	Brook trout biomass (kg/ha)	-3.6601	0.2290	111.4120	0.1286
Mean-maximum Summer Temperature (°C)	Brook trout density (trout/km)	-269.1137	0.0057	5876	0.5152
	Brook trout density (trout/ha)	-1482.4811	0.0033	31721	0.5592
	Brook trout biomass (kg/km)	-0.0277	0.7411	13.6080	0.0103
	Brook trout biomass (kg/ha)	-2.5702	0.3901	84.9143	0.0678
Mean Summer Temperature (°C)	Brook trout density (trout/km)	-248.2409	0.0271	4578	0.3712
	Brook trout density (trout/ha)	-1376.9907	0.0187	24717	0.4085
	Brook trout biomass (kg/km)	-0.0660	0.9424	9.3704	0.0005
	Brook trout biomass (kg/ha)	-1.5302	0.6419	59.6551	0.0204
Summer Thermal Stability (°C)	Brook trout density (trout/km)	-513.9670	0.0145	4525	0.4328
	Brook trout density (trout/ha)	-2767.3005	0.0123	23811	0.4487
	Brook trout biomass (kg/km)	-1.9714	0.2455	22.7260	0.1204
	Brook trout biomass (kg/ha)	-11.3130	0.0514	118.6779	0.3026

Figure 15. Relation between estimated numbers of brook trout per hectare and mean-maximum summer temperature (°C) of northwestern Ontario streams studied during 1993. Analyses were conducted with Nile 2 Creek which was an outlier (upper graph) and without Nile 2 Creek (lower graph).


Number of Trout per Hectare
24000
20000
16000
12000
8000
4000
0
10
12
14
16
18
20
22
24
Mean-Maximum Summer Temperature (°C)


Number of Trout per Hectare
24000
20000
16000
12000
8000
4000
0
10
12
14
16
18
20
22
24
Mean-Maximum Summer Temperature (°C)

25)

$$NPERHA = 31721 - 1482.4811(MEANMAX)$$

The density estimates of Nile 2 Creek appeared to have a disproportionate influence on the regression (Figure 15), and z-scores (Tabachnick and Fidell 1989) indicated that trout density estimates from Nile 2 Creek were outliers (number of trout/ha.: z=3.1822; number of trout/km.: z=3.0840). The analyses run without the density estimates for Nile 2 Creek indicated no significant relation between trout density and stream temperature indices (e.g. number of trout/ha regressed against mean-maximum summer temperature: r^2=0.0348, P=0.5616; Figure 15). Since no significant models predicting trout abundance were developed after the outlier was removed, model validation was not conducted.

Predicting Brook Trout Abundance - Model Development II

Using combined data from 1993 and 1994 linear regression revealed that brook trout density (i.e. number of trout/km, and number of trout/ha) was significantly related to summer thermal conditions. Trout densities were greater in cooler, thermally stable streams (Table 20). These models accounted for 16.13% to 30.39% of the variation in number of trout/ha, and 15.46% to 33.22% of the variation in number of trout/km. Summer thermal stability was consistently the best thermal variable predicting both density indices. The best model was the relation between summer thermal stability (SUMMSTAB) and

Table 20. Relations between brook trout abundance variables and thermal conditions of northwestern Ontario streams studied in 1993 and 1994. Relations are considered significant at P≤0.05.

Variable in Model	Dependent Variable	Regression Coefficient	P	Constant	r^2
Maximum Summer Temperature (°C)	Brook trout density (trout/km)	-122.1412	0.0407	2928	0.1570
	Brook trout density (trout/ha)	-659.1637	0.0316	15282	0.1717
	Brook trout biomass (kg/km)	-0.0187	0.9687	6.4894	0.0001
	Brook trout biomass (kg/ha)	-0.5426	0.7637	35.8150	0.0037
Mean-maximum Summer Temperature (°C)	Brook trout density (trout/km)	-148.1313	0.0107	3246	0.2336
	Brook trout density (trout/ha)	-775.5569	0.0094	16560	0.2404
	Brook trout biomass (kg/km)	-0.0546	0.9081	7.1283	0.0005
	Brook trout biomass (kg/ha)	-0.6000	0.7381	36.1567	0.0046
Mean Summer Temperature (°C)	Brook trout density (trout/km)	-134.4464	0.0425	2492	0.1546
	Brook trout density (trout/ha)	-708.8065	0.0378	12680	0.1613
	Brook trout biomass (kg/km)	0.1845	0.7261	3.3967	0.0050
	Brook trout biomass (kg/ha)	0.4961	0.8044	17.7434	0.0025
Summer Thermal Stability (°C)	Brook trout density (trout/km)	-387.8186	0.0017	3405	0.3322
	Brook trout density (trout/ha)	-1996.8580	0.0017	17140	0.3039
	Brook trout biomass (kg/km)	-1.9798	0.0472	20.9118	0.1485
	Brook trout biomass (kg/ha)	-9.7532	0.0080	97.9346	0.2495

number of trout/km (NPERKM) (Figure 16). The equation of this model was:

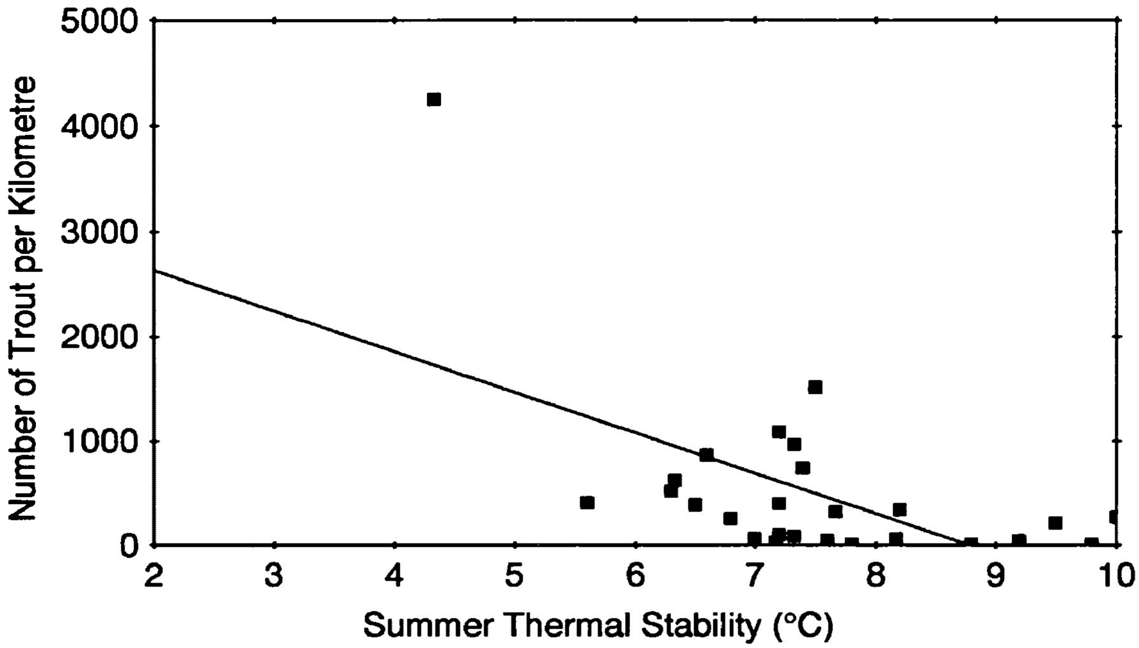
26) $$NPERKM = 3405.7 - 387.8186(SUMMSTAB)$$

The density estimates of Nile 2 Creek appeared to have a disproportionate influence on the regression (Figure 16), and z-scores (Tabachnick and Fidell 1989) indicated that trout density estimates from Nile 2 Creek were outliers (number of trout/ha.: z=4.6890; number of trout/km.: z=4.4481). The analyses run without the density estimates for Nile 2 Creek indicated no significant relation between trout density and stream temperature indices (e.g. number of trout/km regressed against summer thermal stability: r^2=0.1083, P=0.1007; Figure 16).

Trout biomass increased with greater stability of stream temperatures (Table 20, Figure 17). Summer thermal stability (SUMMSTAB) was most related to kg of trout/ha (KGPERHA), and accounted for 24.95% of the variation. The equation of this model was:

27) $$KGPERHA = 97.9 - 9.7532(SUMMSTAB)$$

Figure 16. Relation between estimated numbers of brook trout per hectare and summer thermal stability (°C) of northwestern Ontario streams studied during 1993 and 1994. Analyses were conducted with Nile 2 Creek which was an outlier (upper graph) and without Nile 2 Creek (lower graph).


5000
4000
3000
2000
1000
0
Number of Trout per Kilometre
2
3
4
5
6
7
8
9
10
Summer Thermal Stability (°C)

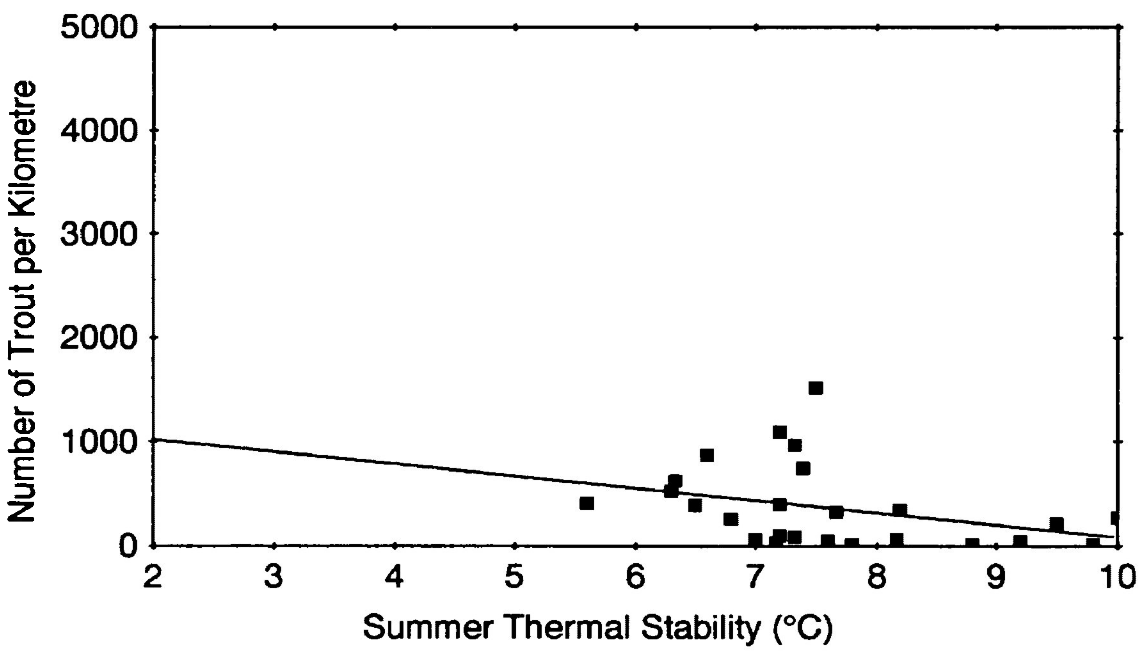
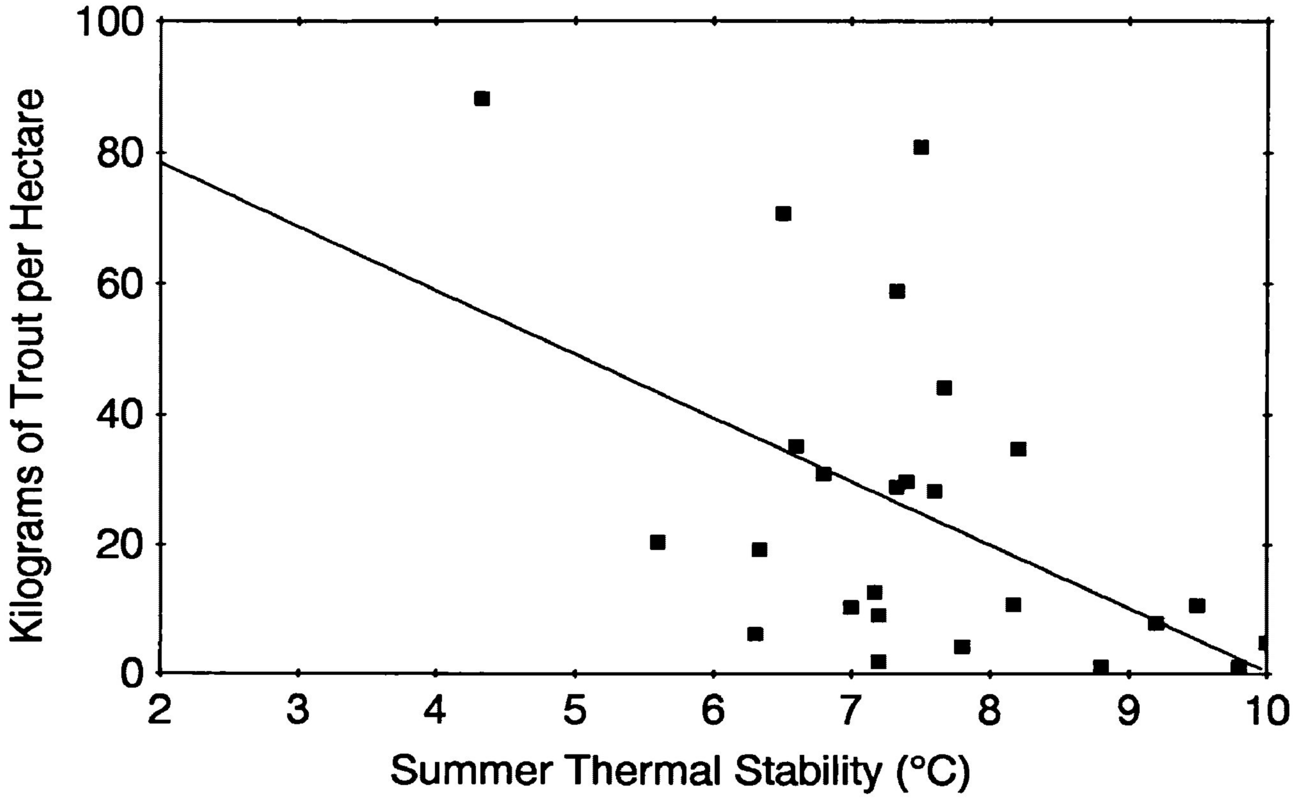

5000
4000
3000
2000
1000
0
Number of Trout per Kilometre
2
3
4
5
6
7
8
9
10
Summer Thermal Stability (°C)

Figure 17. Relation between estimated biomass (kg) of brook trout per hectare and summer thermal stability (°C) of northwestern Ontario streams studied during 1993 and 1994.



100
80
60
40
20
0
2
3
4
5
6
7
8
9
10
Kilograms of Trout per Hectare
Summer Thermal Stability (°C)

Discussion

Brook Trout Distribution

The Ontario Ministry of Natural Resources (OMNR) has recently implemented guidelines for protecting fish habitat from effects of timber harvesting (OMNR 1988)(Appendix 1). The guidelines require that undisturbed riparian buffer-strips be left along streams containing brook trout populations. Similar practices have protected stream temperatures and habitat from otherwise devastating impacts of timber harvest elsewhere in North America (Brown and Krygier 1970; Rishel et al. 1982; Barton et al. 1985; Heifetz et al. 1986). During timber management planning, fisheries managers are responsible for identifying brook trout streams to permit the implementation of the protective guidelines. However, in northwestern Ontario (NWO), the detailed distribution of brook trout is not well understood. Most streams have not been surveyed in part because road access to much of NWO is not possible until after timber harvest has occurred. In this study, models predicting brook trout distribution in NWO were developed for first- and second-order streams. These models could be used during timber management planning to identify brook trout streams requiring riparian protection.

Watershed surficial geology was used as the basis for these predictive models. Geology influences groundwater hydrology which in turn provides the thermal habitat required by stream resident brook trout. Other studies have demonstrated the relation between geology and brook trout distribution. In southern Ontario, brook trout distribution is strongly related to sand and gravel surficial deposits conducive to groundwater transmission (Portt et al. 1989). Threinen and Puff (1963) also observed that brook trout distribution in Wisconsin was related to groundwater yielding surficial geologic deposits such as end moraines, alluvium, and sandy outwash. They also reported that brook trout were absent from streams flowing through areas dominated by thin ground moraine and clay glaciolacustrine plains. Similarly, Hendrickson and Doonan (1972) reported that the best trout streams displaying stable hydrologic and thermal regimes in the southern peninsula of Michigan were found in groundwater transmitting surficial deposits. Nelson et al. (1992) reported that brook trout and cutthroat trout distributions in northeastern Nevada were highly correlated with the sedimentary geologic district of their study area. While Nelson et al. (1992) did not specifically study groundwater, it may have influenced their results since many sedimentary formations are conducive to groundwater transmission (Freeze and Cherry 1979).

The importance of surficial geology to brook trout distribution in this study is evident in models developed from the combined data. Regardless of the method used to quantify surficial geology (i.e. Geofisheries, Modified Geofisheries, Objective, and Dichotomous), univariate geology models were significantly related to brook trout presence/absence. The best of these models had correct classification rates of 70% to 75% which were 40% to 48% better than expected by chance. These results indicate that these models would be useful for identifying brook trout streams in NWO during timber management planning.

Several drainages in this study that contained study streams having both good and poor geology study streams further demonstrate the importance of surficial geology to brook trout distribution. For example, in the eight study streams located within the Whitefish River drainage (a large tributary of the Kaministikwia River), brook trout were captured in the three streams with highly rated geologic deposits, and were not captured in five streams with low rated deposits. Similar trout presence/absence results were observed in Nile Creek (1 high-rated stream, 1 low-rated stream), Pearl River (1 high, 1 low), Coldwater Creek (1 high, 1 low), and McConnell Creek (2 high, 1 low).

Combining geology variables with biogeographic, climatic, and/or stream temperature variables in multivariate models provided better fits to the combined data relative to univariate geology models. The improvement was primarily due to better trout absence predictions which were ≈10% higher in combined multivariate models. However, to implement timber harvest guidelines in NWO that protect brook trout habitat, models that are best able to predict brook trout presence are the most valuable. Univariate surficial geology models were consistently best at predicting trout presence. They predicted presence up to ≈10% better than combined multivariate models. Furthermore, the model using the objective dichotomous rating of the largest surficial geologic deposit adjacent to the study streams (i.e. GPOBJLAR) was consistently the best at predicting brook trout presence. This model correctly predicted brook trout presence in 29 of the 34 total trout streams studied (14 of the 15 1993 trout streams, 15 of the 19 1992/1994 trout streams).

In addition to accurately predicting brook trout presence, the objective dichotomous model (GPOBJLAR) may be preferred for other reasons. First, the simplicity of the dichotomous rating scheme facilitates data management and brook trout suitability assessments since streams can be classified as suitable or unsuitable. Second, the value of using categorical ratings to represent the groundwater transmissivity of surficial deposits (i.e. Geofisheries, Modified Geofisheries, and Objective rating schemes) is limited until greatly improved quantitative data regarding the characteristics of surficial aquifers (i.e. thickness and hydraulic conductivity) in NWO is available. The dichotomous rating system only attempts to discriminate between deposits that are and are not conducive to groundwater transmission (i.e. good or poor). The other three rating systems attempt to quantify relative degrees of groundwater transmissivity among all deposit types, thus giving the false impression that the characteristics of surficial aquifers in NWO are well understood. One of the problems associated with dichotomizing data is the loss of more detailed information, however, such information is not yet available for surficial aquifers in NWO. Third, in contrast to Geofisheries, the objective dichotomous model rates surficial deposits that are associated with wetlands (i.e. fens and bogs) rather than directly rating wetlands. This eliminates ambiguity associated with the influence of wetlands on stream thermal habitat and maintains geology as the model's focus. Also, the Geofisheries model uses subjective values to rate surficial deposits (Dean et al. 1991b), and by definition, the Modified Geofisheries and Geofisheries-derived dichotomous ratings were also subjective. Although these ratings were highly related to brook trout presence/absence, the appropriateness of using subjective variables is questionable.

The objective dichotomous model is conservative since it tends to over-predict brook trout presence. This model predicted trout presence in nine streams studied in 1993 and eight streams studied in 1994 where trout were not captured. Several reasons may account for trout absence in these streams. First and most importantly, absence is much more difficult to confirm than presence. It is conceivable that the 'true' correct prediction rates of the dichotomous geology model is higher than reported, but not achieved in this study due to inadequate fish sampling methodology (i.e. a single 60m reach in each stream may not have been adequate for all streams). Since most of the study reaches were reasonably close to roads, angling pressure may have locally eliminated trout since brook trout populations are highly susceptible to collapse resulting from angling (McFadden 1961; Power 1980). Although study reaches in this study were selected to represent all habitat types in each stream, this may not have been accomplished and improved habitat and trout may have been located outside of the study reach. These scenarios seem particularly plausible in streams that flow through good geologic deposits with suitable thermal conditions (e.g. mean-maximum summer temperature≈20°C or less), but brook trout were not captured. There were four such streams studied in 1993 (East Asterisk 1 Creek, Max Creek, Rockstone Creek, and Savigny Creek) and seven such streams studied in 1994 (Chief 1 Creek, Eileen Creek, Grew Creek, Kabitotikwia Creek, Larson 2 Creek, Little Squaw Creek, and Mooseland Creek). More intensive sampling of streams where trout were not captured in the study reach may have improved correct prediction rates, however, sample size likely would have been sacrificed.

Second, variability associated with the dimensions of surficial deposits may have influenced trout absence from highly-rated streams. The actual thickness of surficial deposits could not be determined from the NOEGTS maps which depict only spatial characteristics of the land surface. Deposit characteristics (i.e. thickness and hydraulic conductivity) could only be qualitatively evaluated by observing gravel pits near the study streams or observing the composition of the stream bank. Consequently, the actual dimensions of many of the highly rated surficial deposits may not have been conducive to groundwater transmission, and brook trout presence. Also, streams may not actually flow through the surficial deposit depicted on the NOEGTS maps since streams cut incised channels that may reach stratigraphic layers below the surficial deposit.

Third, some non-trout streams flowing through highly rated geologic deposits may have been located in groundwater recharge zones, and thus were not influenced by groundwater discharge. Groundwater moves from high elevation recharge zones, downward to discharge zones where groundwater is intercepted by surface-flow (e.g. streams) (Freeze and Cherry 1979). Groundwater in the recharge zone moves downward away from the land surface, and the water-table is usually at considerable depth and not available to interception by surface-flow (Freeze and Cherry 1979). Consequently, perennial stream-flows in recharge areas are maintained by surface-flows subjected to the extremes of ambient temperature and usually not thermally suitable for brook trout. This was probably the case for at least three streams studied in 1993 (Moraine Creek, Springlet Creek, and Yea Creek) that were located on an end moraine. The summer base-flow of these streams was probably maintained by surface-flow as indicated by the warm temperatures: Moraine Creek: maximum=24°C, mean-maximum=22°C; Springlet Creek: maximum=24°C, mean-maximum=22°C; Yea Creek: maximum=24°C, mean-maximum=21.3°C. Furthermore, streams in recharge zones are often intermittent since they lose water to subsurface-flow (Freeze and Cherry 1979). This may account for two dewatered streams in this study that flowed through high-rated geologic deposits (end moraine and sandy glaciolacustrine plain). Streams currently in recharge areas may become trout streams in the future as they continue to cut downward through the surficial deposit and eventually intercept the water-table.

Surficial geology models were less effective at predicting brook trout presence/absence in the 1994 streams relative to the 1993 streams. In 1994, correct classification rates for the best models were only a 30% improvement over chance classifications, and several models were not significantly better than chance. In particular, trout were absent in eight streams studied in 1994 that flowed through highly rated deposits, seven of which had mean-maximum summer temperature ≤20°C. However, abundance estimates in several 1994 trout streams were very low, and ≤4 trout were caught in eight of 15 (53.3%) trout streams. These results indicate that particularly in 1994, a single 60m study reach may not have been sufficient to determine trout presence/absence since trout may have been disjunctly distributed in several streams, and less vulnerable to capture.

The difference in geographic location of the streams studied in 1994 relative to those in 1993 may also have influenced the transferability of the models developed in 1993. The 1994 streams were located further northeast and were significantly cooler than the 1993 streams. These temperature differences occurred despite similar temperatures both years for the 10 reference sites. These results coincide with cooler summer climatic conditions in the northeast portion of the study area (Kemp 1993). The cooler conditions may allow summer temperatures of some surface-flow dominated streams to remain within tolerable levels for brook trout. Consequently, in some northeast streams, the dependence of surficial geology to provide suitable summer thermal conditions is somewhat lessened. This phenomenon may be associated with three poor geology trout streams studied in 1994 that were located in the northeast portion of the study area. Mean-maximum summer temperatures of these streams were <20°C, yet they were entirely in poor geologic deposits (ground moraine, and clay glaciolacustrine plain).

An annual water budget gradient across the study area may further enhance the suitability of northeastern streams for brook trout. Water surplus (and deficit) is defined as the difference between precipitation and potential evapotranspiration. The northeastern portion of the study area experiences an annual water surplus of >200mm, while areas to the southwest experience an annual surplus of <200mm (Kemp 1993). Furthermore, the southwest portion of the study area is subjected to occasional water deficits (Department of Energy Mines and Resources 1974). Therefore, in the northeast, more water is available for groundwater recharge (and discharge) which provides more stable trout habitat during extreme conditions (i.e. mid-summer and winter).

The influence of the climatic gradient on brook trout distribution across the study area may be represented in several significant models developed with the combined data. Many models indicated that the probability of brook trout presence increased 1) further east, 2) in the Lake Nipigon drainage, and 3) closer to Lake Nipigon. These three variables suggest that brook trout are more prevalent in the northeast. Also, several multivariate models indicated that trout presence was positively related to the proximity to Lake Superior.

This may reflect cooler summer conditions close to Lake Superior (Kemp 1993). The proximity to Lake Superior and Lake Nipigon may also have a biogeographic influence. Brook trout from these waterbodies are accessible to quickly recolonize small streams that may have experienced local extirpations.

The climatic gradient may have influenced the quality of trout stream thermal habitat in 1993. Several of the 1993 trout streams which are located in the southwest portion of the study area, were thermally marginal. Brook trout thermal preferences (i.e. maximum temperature ≤20°C, Cherry et al. 1975) were exceeded in 11 (73%) of 15 streams. Furthermore, seven (47%) trout streams had maximum temperatures ≥22°C, the temperature used by Barton et al. (1985) to distinguish marginal trout streams in southern Ontario. In contrast, only five (33%) of 15 trout streams studied in 1994 exceeded 20°C, and only three (20%) exceeded 22°C. These temperature differences occurred despite similar temperatures both years for the 10 reference sites.

Marginal thermal conditions in the southwest portion of the study area may have influenced the significant relation between trout presence/absence and migration barriers observed in the 1993 streams. Brook trout populations in marginal streams probably rely on groundwater discharge points for coolwater refugia when streams become too warm (Gibson 1966). Thermal refugia are often sparse, and comprise only a minor portion (i.e. surface area and volume) of streams (Bilby 1984; Nielsen et al. 1994). Therefore, marginal trout streams are especially susceptible to catastrophic events that may eliminate refugia causing local trout extirpations. Migration barriers then preclude the recolonization of depopulated stream reaches upstream of the barrier. For instance, many phenomena may cause local extirpations. Nelson et al. (1992) reported that streams in Nevada which historically contained brook trout and cutthroat trout were devoid of trout during their study. They attributed these losses to habitat deterioration and drought conditions resulting from human activity. Minshall et al. (1989) observed stream fish kills during the 1988 fires in Yellowstone Park. Bozek and Young (1994) reported fish kills in burnt watersheds two years after the Yellowstone fires which they attributed to increased suspended solid concentrations following summer rainstorms. Also, stream warming that follows timber harvest operations (Hall and Lantz 1969; Brown and Krygier 1970; Hewlett and Fortson 1982) can increase temperatures above brook trout lethal limits (Fry et al. 1946; Cherry et al. 1975; Grande and Andersen 1991) resulting in fish kills. Northwestern Ontario experienced successive warm and dry summers during the mid-1980's (drought), and vast areas of NWO have been altered by wild- and prescribed-fires, and extensive deforestation. Any or all of these disturbances can cause fish kills particularly in the marginal southwestern portion of the study area.

The thermal delineation used by the OMNR timber management guidelines to distinguish trout (i.e. coldwater streams vs. coolwater and warmwater streams; OMNR 1988) would not be sufficient to protect brook trout habitat in NWO. The best thermal model predicting trout presence/absence in this study used maximum summer temperature. Although this model was significantly related to trout distribution, it predicted trout absence for >50% of the streams that contained trout. As mentioned earlier, several trout streams in this study were thermally marginal, and trout populations probably rely on localized groundwater discharge areas during warm periods. Therefore, the importance of temperature in determining brook trout distribution may have been partially masked in this study by the method used to measure temperature. Temperatures were recorded from random points in each stream and likely missed localized coolwater refugia that probably were more important than overall stream temperature in determining brook trout distribution.

Stream Temperatures

Surficial geology had a minor yet significant influence on stream temperatures in this study. Temperatures were cooler, more stable, and thus more favourable for brook trout in streams flowing through deposits conducive to groundwater transmission. These results were expected since groundwater cools temperatures and ameliorates thermal fluctuations (Ward 1985). The small amount of variation in stream temperatures accounted for by geology (i.e. ≈12-16%) reiterates the previously discussed idea that the influence of groundwater in several streams was localized and not completely detected by the randomly placed thermometers used to measure temperature in this study. Since groundwater discharge was not sufficient to cool entire streams, suitable thermal habitat available for brook trout in most NWO stream is restricted during the summer. More of the variation in stream temperatures was explained (≈24%) in models that combined geology variables with variables reflecting the climatic differences in the study area, reiterating the cooler conditions in the northeast portion of the study area.

Numerous factors not investigated in this study undoubtedly influenced stream temperatures. Ward (1985) suggested that three general factors control a stream's thermal regime: 1) insolation, 2) climate, and 3) hydrology. The predictive models developed in this study only indirectly accounted for the latter two factors, and insolation was not represented. Variables influencing insolation include: channel form, riparian vegetation, and topography (e.g. gradient, aspect) (Ward 1985). Models accurately predicting stream temperature based on insolar effects have been developed (e.g. Brown 1969), but the detailed measurements required for them (e.g. aspect, elevation, stream discharge, water velocity, riparian vegetation, thermal conductivity of the substrate, net radiation, air temperature, wind speed, barometric pressure, and humidity) are beyond the scope of this project. Furthermore, small streams (like those in this study) are extremely sensitive to variation in any of the variables that control temperature (Brown 1969; Smith 1972; Chamberlin et al. 1991). Since the streams in this study varied widely in these temperature-regulating variables, the modest amount of variation explained by the predictive models is not surprising.

Brook Trout Abundance

Estimates of brook trout abundance for most streams in NWO are on the lower end of the range observed for allopatric brook trout populations elsewhere in North America. Biomass estimates for all trout streams in this study ranged from 1.130 to 88.136 kg/ha with a mean of 24.600 kg/ha. Six (22%) of 27 streams had biomasses <5kg/ha, three (11%) were between 5-10kg/ha, six (22%) had 10-20kg/ha, seven (26%) had 20-40kg/ha, and five (19%) had >40kg/ha. Bowlby and Roff (1986) reported biomass estimates for seven southern Ontario allopatric brook trout populations. Their biomasses were comparable to this study, but wider ranging: 0.5-143.9 kg/ha, and only two of their streams had <5kg/ha. Other low biomass estimates for allopatric brook trout populations have been reported within the species' natural range. Biomass estimates in Quebec streams ranged from 12.1 to 53.3kg/ha (O'Connor and Power 1976). Waters et al. (1990) reported a biomass of 34.5 kg/ha for an allopatric brook trout population in a Minnesota stream. Cooper and Scherer (1967) reported biomasses of 4.368 and 23.083 kg/ha in two Pennsylvania streams. Neves and Pardue (1983) reported estimates of 10.6, 11.8, and 3.4 kg/ha in three Appalachian Mountain streams in Virginia. Higher biomass estimates for allopatric populations have been reported in the Rocky Mountains (outside brook trout's natural range). Biomasses of two Colorado populations were >100kg/ha (Scarnecchia and Bergersen 1987). Binns and Eiserman (1979) reported allopatric brook trout biomasses in Wyoming streams that ranged from 34-192 kg/ha. Winkle et al. (1990) studied allopatric brook trout populations in Wyoming beaver ponds and reported biomasses of 5-312 kg/ha.

The influence of stream thermal conditions on brook trout abundance was manifested only in the combined data set. Brook trout biomass was greater in streams that were thermally stable. This relation stresses the need to protect brook trout streams from the adverse impacts of deforestation. Stream temperatures and temperature fluctuations can drastically increase following the removal of riparian vegetation (Brown and Krygier 1970; Rishel et al. 1982; Barton et al. 1985; Li et al. 1994). In NWO, such impacts would have catastrophic effects on brook trout populations. For example, impacts causing summer temperature fluctuations to increase by only 1°C could theoretically decrease brook trout biomass by ≈10kg/ha. This consequence of stream warming agrees with Li et al. (1994) who reported lower rainbow trout density in an Oregon stream after riparian vegetation was removed.

Other investigators have described the influence of stream temperature on trout abundance. Maximum and mean-maximum summer temperature were negatively related to trout biomass, accounting for approximately 20% of the variation in southern Ontario streams (Bowlby and Roff 1986). Also, mean-maximum summer temperature was a significant variable in multivariate models explaining 56% and 62% of the variation associated with trout biomass (Bowlby and Roff 1986). Binns and Eiserman (1979) reported that maximum summer temperature accounted for 28% of the variation in trout biomass in Wyoming streams. They also used maximum summer temperature in multivariate models that explained 95% and 97% of the variation associated with trout biomass. Hendrickson and Doonan (1972) found that mean annual maximum stream temperature accounted for 63% of the variation associated with trout biomass in the southern peninsula of Michigan.

The small amount of variation in trout biomass accounted for by temperature in this study indicates that other factors also influence trout abundance in NWO. Most of NWO is comprised of igneous and metamorphic bedrock indicating that streams have characteristically low alkalinity, soft water (Hynes 1970). However, it is well understood that salmonid biomass is directly related to stream alkalinity (Cooper and Scherer 1967; Bowlby and Roff 1986; Scarnecchia and Bergersen 1987; Fausch et al. 1988; Waters et al. 1990), and soft-water streams are unproductive (Cooper and Scherer 1967; Whitworth and Strange 1983; Neves and Pardue 1983; Waters et al. 1990). In contrast, hard-water, high alkalinity streams are usually associated with limestone bedrock formations (Hynes 1970). The only three biomass estimates in this study that were >70kg/ha were in streams (Nile 2 Creek, North 6 Creek, Pitch Creek) flowing through the relatively limestone rich Aminikie bedrock formation (Ayres et al. 1970) in the southwest portion of the study area.

Physical stream habitat is probably another important determinant of trout abundance in NWO. Bowlby and Roff (1986) reported that the abundance of pools and overhead cover were proportional to trout biomass in southern Ontario streams. Substrate diversity which increased the habitat available to juvenile trout was positively related to total trout biomass in Colorado streams (Scarnecchia and Bergersen 1987). Several habitat variables that were significantly related to trout biomass in Wyoming included: annual stream flow variation, % cover, % eroded banks, substrate composition, water velocity, and stream width (Binns and Eiserman 1979).

Summary and Recommendations

The surficial geology models were good predictors of brook trout presence/absence in first- and second-order NWO streams. These models may be used during timber management planning to identify brook trout streams requiring riparian protection. Furthermore, the objective dichotomous geology model (GPOBJLAR) is recommended because of the simplicity of the rating system and the ability of this model to accurately predict brook trout presence. However, it is recommended that this model, and any others that may be used, be validated with an independent data set comprised of streams from the area where employed. The unsuccessful transfer of models developed in 1993 to the geographically close 1992/1994 streams emphasize the importance of such a validation. The models developed from the combined data should be more transferable to other areas of NWO since they are more general than those from 1993 (i.e. developed from 79 sites compared to 45 sites). Multivariate models combining variable types (e.g. geology, biogeographic/climatic, thermal) developed from the combined data set should be used with caution. They had lower correct trout presence prediction rates, which could result in fewer trout streams receiving protection.

In timber management planning, using only temperature to classify streams, as the OMNR timber management guidelines do, would not be sufficient to protect brook trout populations. Since many trout streams in NWO are thermally marginal, a temperature dichotomy is not apparent to distinguish trout streams from non-trout streams. The maximum summer temperature model predicted trout absence for more than half of the streams that contained trout. If only stream temperature were considered, protective guidelines would often not be implemented, and the majority of NWO trout streams would be subjected to the potentially devastating impacts of riparian forest removal.

These models were developed to conserve brook trout streams under the assumption that riparian buffer-strips provide adequate protection from the impacts of forest harvest in NWO. However, the effectiveness of buffer-strips to protect first- and second-order streams in NWO has not been evaluated. Such an evaluation program needs to be implemented. In addition, the strong relation between brook trout distribution and geology indicates that brook trout populations and stream habitat are intrinsicly linked to characteristics of the watershed. Land-use activities such as timber harvest that deteriorate watershed integrity will likely also adversely impact habitat quality in streams.

Impact assessment on small streams, in particular, is required. Such systems are likely to be more sensitive to watershed disturbances relative to larger rivers and lakes since the ratio of land/water ecotone:volume is several-fold larger. In concordance, Brown (1969), Smith (1972), and Chamberlin et al. (1991) state that small streams are very responsive to watershed alterations causing increased temperatures.

The impacts of timber harvest in groundwater recharge zones on brook trout populations and habitat in NWO needs investigation. Hydrologic impacts of such timber harvest may reduce or eliminate suitable brook trout habitat in many NWO streams. Deforestation in groundwater recharge areas inhibits water infiltration, thus reducing groundwater storage and transmission to streams, and increasing surface run-off (Lee 1980). This is especially true when soils are extensively disturbed and compacted by heavy machinery used in modern forestry and silvicultural operations (Chamberlin et al. 1991). Consequently, maximum stream temperatures increase (Aubertin and Patric 1974; Hewlett and Fortson 1982; Rishel et al. 1982; Harr and Fredicksen 1988), small streams intermittently dry (Kostadinov and Mitrovic 1994) or experience chronic base-flow reductions (Hicks et al. 1991), and peak-flows increase causing greater erosion and habitat deterioration (Chamberlin et al. 1991; Dose and Roper 1994).

One of the indirect impacts of timber operations is improved access for anglers to brook trout populations. To protect the low abundances observed in

NWO brook trout populations, it would be useful for fisheries managers to evaluate annual production and size and age characteristics of stream brook trout populations so that more accurate angler harvest guidelines can be implemented. McFadden (1961) reported that angling success for brook trout in Wisconsin was relatively independent of stock density. Consequently, Power (1980) suggested that this made smaller stocks (like those in this study) more susceptible to collapse by angling.

It is recommended that improved models predicting brook trout abundance be developed. The utility of such models was well demonstrated by Binns and Eiserman (1979). They used their models to predict potential losses of salmonid biomass in the western U.S. resulting from a variety of land and water management programs. They also predicted biomass gains from habitat restoration projects. Such predictions provided resource managers with potential consequences of management programs upon which to base their decisions.

A consistent theme in this study is the marginal nature of brook trout populations and habitat in NWO indicating that stream resident brook trout and the coldwater habitat they require are fragile. The low trout abundance estimates indicates that these populations may have a limited ability to recover their numbers following disturbance (e.g. deforestation, and angling). In addition, the marginal habitat of several trout streams and the sensitivity of small streams to disturbances stresses the need for responsible land-use management. Protecting brook trout populations and habitat should be a priority for resource managers in NWO. The conservation of self-sustaining brook trout populations and coldwater streams in NWO should be considered a challenge to our ingenuity and commitment to sustainability.

Acknowledgements

This project was funded by the Fish Habitat/Comparative Aquatic Effects Program of the Ontario Ministry of Natural Resources.

This project was not possible without the enthusiasm, perseverance, and advice of Michael Bozek. The guidance provided by Walter Momot was greatly appreciated. Murray Lankester, Brian Phillips, and William Latta critically reviewed an earlier draft and improved this paper.

I thank Diisa King, Kenneth MacIntosh, and Darren McCormick for their advice and tireless assistance in the field. Additional field assistance was provided by Michael Bozek, Stephen Cambly, Jeff Black, Dennis Muzzin, Nick Dryorub, Al Kalas, Joe Miller, Michael Friday, James Rusak, Todd Hurdon, Michael McCarthy, and Sarah Jaward. I also thank Terry Marshall for his assistance.

Finally, I thank Paula Hyslop. Her field assistance, support, patience, and occasional reminders to 'keep my eye on the prize' have been inspirational and immensely appreciated.

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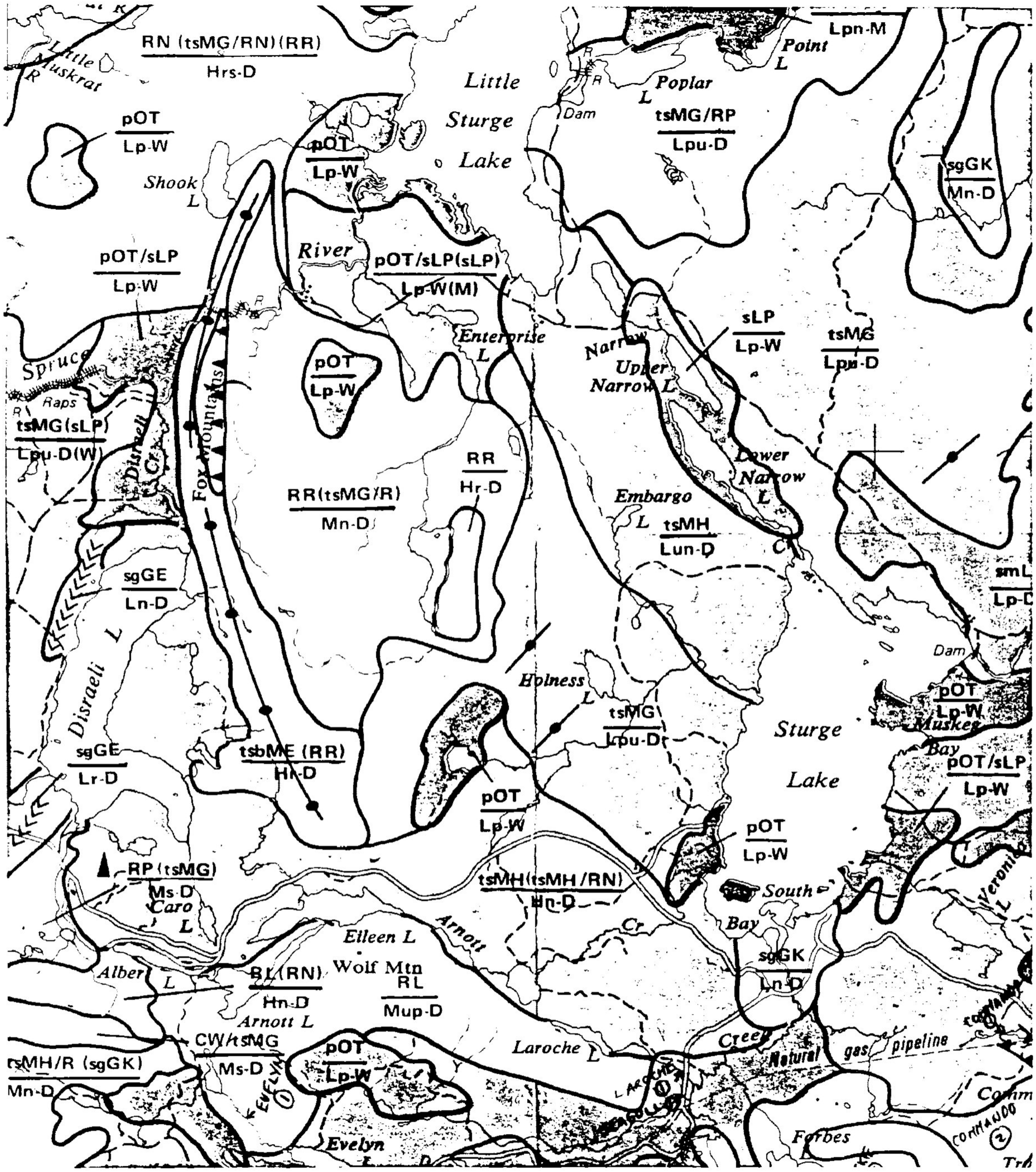
Appendix 1. Summary of Ontario Ministry of Natural Resources timber management guidelines for the protection of fish habitat (OMNR 1988).

			Modifications to Timber Management Operations Within Areas of Concern			
Fish Habitat	Slope	Width of Area of Concern	Roads	Landings	Harvesting Options	Mechanical Site Preparation
Lake Trout Lakes, Self-Sustaining Brook Trout Lakes, Aurora Trout Lakes	0 - 15%	30m	No	No	No Harvesting.	No
	16 - 30%	50m			Selection cutting on a restricted basis; avoid damaging banks, keep debris away, avoid erosion.	
	31 - 45%	70m				
	46 - 60%	90m				
Other Lakes	0 - 15%	30m	No	No	No Harvesting.	Restricted, minimize exposure of mineral soil; orient furrows at right angles to slope
	16 - 30%	50m			Selection cutting on a restricted basis.	
	31 - 45%	70m				
	46 - 60%	90m			Shelterwood or limited clearcutting; do not cut near critical fish habitats or roads.	
Coldwater Streams	0 - 15%	30m	Stream Crossing Only		Same as for Lake Trout Lakes; maintain shade on both sides	No
	16 - 30%	50m				
	31 - 45%	70m				
	46 - 60%	90m				
Coolwater and Warmwater Streams	0 - 15%	30m	Stream Crossing Only		Same as for Other Lakes; no shelterwood cutting upstream of critical fish habitats.	Same as for Other Lakes.
	16 - 30%	50m				
	31 - 45%	70m				
	46 - 60%	90m				

Appendix 2. A portion of a Northern Ontario Engineering Geology Terrain Study Map (Mollard and Mollard 1979d).



Appendix 3. Population estimates and 95% confidence limits, abundance estimates, and fork lengths of brook trout in northwestern Ontario streams studied in 1993 and 1994. Streams with inaccurate population estimates are indicated with an *, and were not used in the linear modelling in this study. Population of Gull 3 Creek was not estimated since only one depletion pass was conducted.

Stream	Population Estimate and 95% Confidence Limits (Upper, Lower)	Number/km	Number/ha	Kilograms/km	Kilograms/ha	Mean Fork Length (mm) ±se
1993 Streams						
Asterisk*	409 (17, 17213)	6292	11198	161.7	287.8	108.8 ±11.04
Boulder	35 (34, 39)	522	1500	2.1	6.2	70.3 ±1.83
Cedar	5 (5,7)	89	417	6.2	28.9	176.8 ±12.11
Lime 1	4 (4,5)	65	306	2.3	10.7	122.0 ±18.81
Lime 2*	24 (7, 190)	375	820	6.0	13.1	98.3 ±12.49
Lime 10	15 (15, 16)	217	1166	2.0	10.6	88.0 ±7.42
McIntyre	2 (2,3)	33	128	3.3	12.7	202.0 ±23.00
McVicar	54 (45, 69)	870	4508	6.8	35.2	73.2 ±4.51
Nile 2	234 (57, 933)	4254	22599	16.6	88.1	52.6 ±3.26
North 6	100 (57, 176)	1515	3983	30.8	80.9	96.8 ±6.50
North Current 1	58 (47, 76)	626	2641	4.6	19.3	76.0 ±3.71
North Current 5	69 (59, 83)	967	5775	9.9	58.9	86.1 ±3.94
Pitch	32 (29, 38)	390	1998	13.8	70.7	124.6 ±10.14
Serpent	15 (15, 17)	272	662	2.0	4.8	78.7 ±2.07
West Current	23 (21, 28)	323	1705	8.4	44.2	118.9 ±5.86

Appendix 3 (continued). Population estimates and 95% confidence estimates, abundance estimates, and fork lengths of brook trout in northwestern Ontario streams studied in 1993 and 1994. Streams with inaccurate population estimates are indicated with an *, and were not used in the linear modelling in this study. Population of Gull 3 Creek was not estimated since only one depletion pass was conducted.

Stream	Population Estimate and 95% Confidence Limits (Upper, Lower)	Number/km	Number/ha	Kilograms/km	Kilograms/ha	Mean Fork Length (mm) ±se
			1994 Streams			
Brophy	19 (13, 39)	260	878	9.2	30.9	128.2 ±9.84
Clay Hill	4 (4, 4)	51	161	1.2	3.9	122.5 ±5.52
Coldwater 1	19 (17, 25)	129	260	2.5	5.0	101.5 ±13.77
Driftstone	7 (7, 9)	104	320	4.4	13.6	150.1 ±8.05
Frazer	3 (3, 3)	49	200	7.0	28.2	219.7 ±29.58
Gull 2	1 (1 ,1)	14	73	0.8	4.3	175.0 ±0.00
Gull 3	na	na	na	na	na	91.5 ±8.77
Jam	3 (3, 3)	43	198	1.7	7.9	142.0 ±13.50
Larson 1	1 (1, 1)	14	56	0.3	1.1	115.0 ±0.00
Larson 3	2 (2,3)	31	258	0.2	1.9	78.5 ±19.50
McCann	46 (38, 61)	742	2102	10.5	29.7	87.82 ±6.87
McConnell 3	4 (4,4)	66	238	2.9	10.4	147.75 ±14.69
Pearl 2	22 (13, 55)	338	2115	5.6	34.7	95.62 ±10.45
Seagull	30 (27, 37)	411	1839	4.5	20.3	85.3 ±5.82
Stillwater	1 (1, 1)	14	54	0.3	1.1	115.0 ±0.00

Appendix 4. Summer temperature indices of northwestern Ontario streams studied in 1993 and 1994.

Stream	Maximum Summer Temperature (°C)	Mean-Maximum Summer Temperature (°C)	Mean Summer Temperature (°C)	Summer Thermal Stability (°C)
		1993 Streams		
Asterick	19	17.0	14.5	5.2
Beaver	26	23.0	18.2	9.2
Boulder	22	17.8	14.8	6.3
Buzzer 1	22	19.5	15.3	8.3
Buzzer 2	24	20.7	16.5	8.3
Cedar	22	21.0	17.3	7.3
East Asterick 1	23	20.0	15.9	8.2
East Asterick 2	21	19.3	15.7	7.3
East Welch	18	16.3	13.0	6.7
Lime 1	23	21.3	17.3	8.2
Lime 2	22	19.8	16.9	5.8
Lime 10	16	15.3	10.6	9.5
Little Whitefish	24	23.2	18.4	9.5
Max	20	17.3	14.1	6.7
McCauley	22	19.8	15.8	8.2
McConnell	24	22.2	17.5	9.3
McIntyre	21	19.3	15.8	7.2
McVicar	18	16.4	13.1	6.6
McWhinney	19	17.5	14.4	6.2
Moraine	24	22.0	17.3	9.3

Appendix 4 (continued). Summer temperature indices of northwestern Ontario streams studied in 1993 and 1994.

Stream	Maximum Summer Temperature (°C)	Mean-Maximum Summer Temperature (°C)	Mean Summer Temperature (°C)	Summer Thermal Stability (°C)
1993 Streams (continued)				
North Current 1	22	20.7	17.5	6.3
North Current 3	23	21.0	17.3	7.3
North Current 5	21	20.0	16.3	7.3
Nile 2	14	11.5	9.3	4.3
Nile 3	21	21.0	16.0	10.0
North 3	21	20.3	16.0	8.7
North 6	21	20.0	16.3	7.5
Northwest Pine	24	22.3	18.3	8.0
Oliver	24	23.7	19.0	9.3
One Island 1	28	23.3	18.8	9.0
One Island 2	24	21.8	17.6	8.3
Pearl	23	21.8	18.5	6.6
Pitch	23	22.0	18.8	6.5
Rockstone	21	19.7	16.8	5.7
Savigny	23	20.3	17.1	6.5
Serpent	24	21.7	16.7	10.0
Silver	23	21.8	17.9	7.8
Silver Fall	23	21.8	17.7	8.4
Sitch	24	21.2	17.2	8.0
Springlet 2	24	22.0	18.3	7.3

Appendix 4 (continued). Summer temperature indices of northwestern Ontario streams studied in 1993 and 1994.

Stream	Maximum Summer Temperature (°C)	Mean-Maximum Summer Temperature (°C)	Mean Summer Temperature (°C)	Summer Thermal Stability (°C)
1993 Streams (continued)				
Strawberry	25	23.8	19.3	9.0
West Current	20	19.2	15.3	7.7
Weigand	22	20.7	16.4	8.5
Wolf	27	23.8	18.5	11.0
Yea	24	21.3	16.7	9.3
1994 Streams				
Brophy	19	17.8	14.4	6.8
Chief 1	16	15.2	11.6	7.2
Chief 2	25	23.4	18.3	10.2
Clay Hill	17	16.4	12.8	7.2
Coldwater 1	18	16.2	12.6	7.2
Coldwater 3	25	24.4	18.2	12.4
Driftstone	19	17.6	14.0	7.2
Eileen	19	18.2	14.8	6.8
Empey	24	22.4	17.3	10.2
Frazer	21	19.4	15.6	7.6
Grew	21	20.2	15.2	10.0
Gull 2	16	14.8	10.9	7.8

Appendix 4 (continued). Summer temperature indices of northwestern Ontario streams studied in 1993 and 1994.

Stream	Maximum Summer Temperature (°C)	Mean-Maximum Summer Temperature (°C)	Mean Summer Temperature (°C)	Summer Thermal Stability (°C)
		1994 Streams (continued)		
Gull 3	18	17.0	13.1	7.8
Jam	22	21.4	16.8	9.2
Kabitotiwia	20	19.0	14.1	9.8
Larson 1	21	20.2	15.8	8.8
Larson 2	16	15.2	11.9	6.6
Larson 3	18	17.0	13.4	7.2
Larson 4	13	10.6	8.9	3.4
Little Squaw	19	18.0	14.2	7.6
Magee	20	19.2	15.3	7.8
McCann	21	18.6	14.9	7.4
McConnell 3	18	18.0	14.5	7.0
Mooseland	21	20.4	15.5	9.8
Pearl 2	22	21.6	17.5	8.2
Seagull	14	13.0	10.2	5.6
Stillwater	22	21.0	16.1	9.8
Taman	22	21.2	15.7	11.0

Appendix 5. Names and descriptions of variables used in this study.

Variable	Description
Geology Variables	
1) Geofisheries Variables	
GEOFISH	Geofisheries rating (Dean et al. 1991) of stream suitability for brook trout.
SURFACE	Surficial geology component of the Geofisheries rating.
BEDROCK	Bedrock geology component of the Geofisheries rating.
CLIMZONE	Climate zone component of the Geofisheries rating.
2) Modified Geofisheries Variables	
i) Rating of surficial deposit containing the study reach	
SITEAH	Rating of 1.5 for sandy glaciolacustrine plains, rating of 9.5 for fens, using the highest rated deposit of a complex terrain unit.
SITEAD	Rating of 1.5 for sandy glaciolacustrine plains, rating of 9.5 for fens, using the dominant deposit of a complex terrain unit.
SITEAH12	Rating of 1.5 for sandy glaciolacustrine plains, rating of 9.5 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
SITEBH	Rating of 1.5 for sandy glaciolacustrine plains, rating of 5.0 for fens, using the highest rated deposit of a complex terrain unit.
SITEBD	Rating of 1.5 for sandy glaciolacustrine plains, rating of 5.0 for fens, using the dominant deposit of a complex terrain unit.
SITEBH12	Rating of 1.5 for sandy glaciolacustrine plains, rating of 5.0 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
SITECH	Rating of 1.5 for sandy glaciolacustrine plains, a bog rating for fens, using the highest rated deposit of a complex terrain unit.
SITECD	Rating of 1.5 for sandy glaciolacustrine plains, a bog rating fens, using the dominant deposit of a complex terrain unit.
SITECH12	Rating of 1.5 for sandy glaciolacustrine plains, a bog rating for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
SITEDH	Rating of 7.8 for sandy glaciolacustrine plains, rating of 9.5 for fens, using the highest rated deposit of a complex terrain unit.
SITEDD	Rating of 7.8 for sandy glaciolacustrine plains, rating of 9.5 for fens, using the dominant deposit of a complex terrain unit.

Appendix 5 (continued). Names and descriptions of variables used in this study.

Variable	Description
	2) Modified Geofisheries Variables
	i) Rating of surficial deposit containing the study reach (continued)
SITEDH12	Rating of 7.8 for sandy glaciolacustrine plains, rating of 9.5 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
SITEEH	Rating of 7.8 for sandy glaciolacustrine plains, rating of 5.0 for fens, using the highest rated deposit of a complex terrain unit.
SITEED	Rating of 7.8 for sandy glaciolacustrine plains, rating of 5.0 for fens, using the dominant deposit of a complex terrain unit.
SITEEH12	Rating of 7.8 for sandy glaciolacustrine plains, rating of 5.0 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
SITEFH	Rating of 7.8 for sandy glaciolacustrine plains, a bog rating for fens, using the highest rated deposit of a complex terrain unit.
SITEFD	Rating of 7.8 for sandy glaciolacustrine plains, a bog rating for fens, using the dominant deposit of a complex terrain unit.
SITEFH12	Rating of 7.8 for sandy glaciolacustrine plains, a bog rating for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
	ii) Rating of the largest surficial deposit adjacent to the stream
LARGAH	Rating of 1.5 for sandy glaciolacustrine plains, rating of 9.5 for fens, using the highest rated deposit of a complex terrain unit.
LARGAD	Rating of 1.5 for sandy glaciolacustrine plains, rating of 9.5 for fens, using the dominant deposit of a complex terrain unit.
LARGAH12	Rating of 1.5 for sandy glaciolacustrine plains, rating of 9.5 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
LARGBH	Rating of 1.5 for sandy glaciolacustrine plains, rating of 5.0 for fens, using the highest rated deposit of a complex terrain unit.
LARGBD	Rating of 1.5 for sandy glaciolacustrine plains, rating of 5.0 for fens, using the dominant deposit of a complex terrain unit.
LARGBH12	Rating of 1.5 for sandy glaciolacustrine plains, rating of 5.0 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
LARGCH	Rating of 1.5 for sandy glaciolacustrine plains, a bog rating for fens, using the highest rated deposit of a complex terrain unit.

Appendix 5 (continued). Names and descriptions of variables used in this study.

Variable	Description
	2) Modified Geofisheries Variables
	ii) Rating of the largest surficial deposit adjacent to the stream (continued)
LARGCD	Rating of 1.5 for sandy glaciolacustrine plains, a bog rating fens, using the dominant deposit of a complex terrain unit.
LARGCH12	Rating of 1.5 for sandy glaciolacustrine plains, a bog rating for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
LARGDH	Rating of 7.8 for sandy glaciolacustrine plains, rating of 9.5 for fens, using the highest rated deposit of a complex terrain unit.
LARGDD	Rating of 7.8 for sandy glaciolacustrine plains, rating of 9.5 for fens, using the dominant deposit of a complex terrain unit.
LARGDH12	Rating of 7.8 for sandy glaciolacustrine plains, rating of 9.5 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
LARGEH	Rating of 7.8 for sandy glaciolacustrine plains, rating of 5.0 for fens, using the highest rated deposit of a complex terrain unit.
LARGED	Rating of 7.8 for sandy glaciolacustrine plains, rating of 5.0 for fens, using the dominant deposit of a complex terrain unit.
LARGEH12	Rating of 7.8 for sandy glaciolacustrine plains, rating of 5.0 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
LARGFH	Rating of 7.8 for sandy glaciolacustrine plains, a bog rating for fens, using the highest rated deposit of a complex terrain unit.
LARGFD	Rating of 7.8 for sandy glaciolacustrine plains, a bog rating for fens, using the dominant deposit of a complex terrain unit.
LARGFH12	Rating of 7.8 for sandy glaciolacustrine plains, a bog rating for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
	iii) Weighted mean rating of all surficial deposits adjacent to the stream
MEANAH	Rating of 1.5 for sandy glaciolacustrine plains, rating of 9.5 for fens, using the highest rated deposit of a complex terrain unit.
MEANAD	Rating of 1.5 for sandy glaciolacustrine plains, rating of 9.5 for fens, using the dominant deposit of a complex terrain unit.
MEANAH12	Rating of 1.5 for sandy glaciolacustrine plains, rating of 9.5 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.

Appendix 5 (continued). Names and descriptions of variables used in this study.

Variable	Description
	2) Modified Geofisheries Variables
	iii) Weighted mean rating of all surficial deposits adjacent to the stream (continued)
MEANBH	Rating of 1.5 for sandy glaciolacustrine plains, rating of 5.0 for fens, using the highest rated deposit of a complex terrain unit.
MEANBD	Rating of 1.5 for sandy glaciolacustrine plains, rating of 5.0 for fens, using the dominant deposit of a complex terrain unit.
MEANBH12	Rating of 1.5 for sandy glaciolacustrine plains, rating of 5.0 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
MEANCH	Rating of 1.5 for sandy glaciolacustrine plains, a bog rating for fens, using the highest rated deposit of a complex terrain unit.
MEANCD	Rating of 1.5 for sandy glaciolacustrine plains, a bog rating fens, using the dominant deposit of a complex terrain unit.
MEANCH12	Rating of 1.5 for sandy glaciolacustrine plains, a bog rating for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
MEANDH	Rating of 7.8 for sandy glaciolacustrine plains, rating of 9.5 for fens, using the highest rated deposit of a complex terrain unit.
MEANDD	Rating of 7.8 for sandy glaciolacustrine plains, rating of 9.5 for fens, using the dominant deposit of a complex terrain unit.
MEANDH12	Rating of 7.8 for sandy glaciolacustrine plains, rating of 9.5 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
MEANEH	Rating of 7.8 for sandy glaciolacustrine plains, rating of 5.0 for fens, using the highest rated deposit of a complex terrain unit.
MEANED	Rating of 7.8 for sandy glaciolacustrine plains, rating of 5.0 for fens, using the dominant deposit of a complex terrain unit.
MEANEH12	Rating of 7.8 for sandy glaciolacustrine plains, rating of 5.0 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
MEANFH	Rating of 7.8 for sandy glaciolacustrine plains, a bog rating for fens, using the highest rated deposit of a complex terrain unit.
MEANFD	Rating of 7.8 for sandy glaciolacustrine plains, a bog rating for fens, using the dominant deposit of a complex terrain unit.
MEANFH12	Rating of 7.8 for sandy glaciolacustrine plains, a bog rating for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.

Appendix 5 (continued). Names and descriptions of variables used in this study.

Variable	Description
	3) Objective Geology Variables
SITETHIC	Thickness (m) of the deposit containing the study reach
LARGTHIC	Thickness (m) of the largest deposit adjacent to the stream
MEANTHIC	Weighted mean thickness (m) of all deposits adjacent to the stream
SITEHYCO	Hydraulic conductivity of the deposit containing the study reach
LARGHYCO	Hydraulic conductivity of the largest deposit adjacent to the stream
MEANHYCO	Weighted mean hydraulic conductivity of all deposits adjacent to the stream
SITEVOL	Volume of the deposit containing the study reach
LARGVOL	Volume of the largest deposit adjacent to the stream
MEANVOL	Weighted mean volume of all deposits adjacent to the stream
SITEAREA	Area (km^2) of the surficial deposit containing the study reach
LARGAREA	Area (km^2) of the largest surficial deposit adjacent to the stream
ADJAREA	Area (km^2) of all surficial deposits adjacent to the stream
	4) Dichotomous Geology Variables
	i)Geofisheries Derived
	i) Rating of the largest surficial deposit adjacent to the stream
GPAH	Rating of 0.0 for sandy glaciolacustrine plains, rating of 1.0 for fens, using the highest rated deposit of a complex terrain unit.
GPAD	Rating of 0.0 for sandy glaciolacustrine plains, rating of 1.0 for fens, using the dominant deposit of a complex terrain unit.
GPAH12	Rating of 0.0 for sandy glaciolacustrine plains, rating of 1.0 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
GPBH	Rating of 0.0 for sandy glaciolacustrine plains, rating of 0.5 for fens, using the highest rated deposit of a complex terrain unit.
GPBD	Rating of 0.0 for sandy glaciolacustrine plains, rating of 0.5 for fens, using the dominant deposit of a complex terrain unit.
GPBH12	Rating of 0.0 for sandy glaciolacustrine plains, rating of 0.5 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.

Appendix 5 (continued). Names and descriptions of variables used in this study.

Variable	Description
	4) Dichotomous Geology Variables
	i)Geofisheries Derived
	i) Rating of the largest surficial deposit adjacent to the stream (continued)
GPCH	Rating of 0.0 for sandy glaciolacustrine plains, rating of 0.0 for fens, using the highest rated deposit of a complex terrain unit.
GPCD	Rating of 0.0 for sandy glaciolacustrine plains, rating of 0.0 for fens, using the dominant deposit of a complex terrain unit.
GPCH12	Rating of 0.0 for sandy glaciolacustrine plains, rating of 0.0 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
GPDH	Rating of 1.0 for sandy glaciolacustrine plains, rating of 1.0 for fens, using the highest rated deposit of a complex terrain unit.
GPDD	Rating of 1.0 for sandy glaciolacustrine plains, rating of 1.0 for fens, using the dominant deposit of a complex terrain unit.
GPDH12	Rating of 1.0 for sandy glaciolacustrine plains, rating of 1.0 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
GPEH	Rating of 1.0 for sandy glaciolacustrine plains, rating of 0.5 for fens, using the highest rated deposit of a complex terrain unit.
GPED	Rating of 1.0 for sandy glaciolacustrine plains, rating of 0.5 for fens, using the dominant deposit of a complex terrain unit.
GPEH12	Rating of 1.0 for sandy glaciolacustrine plains, rating of 0.5 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
GPFH	Rating of 1.0 for sandy glaciolacustrine plains, rating of 0.0 for fens, using the highest rated deposit of a complex terrain unit.
GPFD	Rating of 1.0 for sandy glaciolacustrine plains, rating of 0.0 for fens, using the dominant deposit of a complex terrain unit.
GPFH12	Rating of 1.0 for sandy glaciolacustrine plains, rating of 0.0 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
	ii) Weighted mean rating of all surficial deposits adjacent to the stream
GPGH	Rating of 0.0 for sandy glaciolacustrine plains, rating of 1.0 for fens, using the highest rated deposit of a complex terrain unit.
GPGD	Rating of 0.0 for sandy glaciolacustrine plains, rating of 1.0 for fens, using the dominant deposit of a complex terrain unit.

Appendix 5 (continued). Names and descriptions of variables used in this study.

Variable	Description
	4) Dichotomous Geology Variables
	i)Geofisheries Derived
	ii) Weighted mean rating of all surficial deposits adjacent to the stream (continued)
GPGH12	Rating of 0.0 for sandy glaciolacustrine plains, rating of 1.0 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
GPHH	Rating of 0.0 for sandy glaciolacustrine plains, rating of 0.5 for fens, using the highest rated deposit of a complex terrain unit.
GPHD	Rating of 0.0 for sandy glaciolacustrine plains, rating of 0.5 for fens, using the dominant deposit of a complex terrain unit.
GPH12	Rating of 0.0 for sandy glaciolacustrine plains, rating of 0.5 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
GPIH	Rating of 0.0 for sandy glaciolacustrine plains, rating of 0.0 for fens, using the highest rated deposit of a complex terrain unit.
GPID	Rating of 0.0 for sandy glaciolacustrine plains, rating of 0.0 for fens, using the dominant deposit of a complex terrain unit.
GPIH12	Rating of 0.0 for sandy glaciolacustrine plains, rating of 0.0 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
GPJH	Rating of 1.0 for sandy glaciolacustrine plains, rating of 1.0 for fens, using the highest rated deposit of a complex terrain unit.
GPJD	Rating of 1.0 for sandy glaciolacustrine plains, rating of 1.0 for fens, using the dominant deposit of a complex terrain unit.
GPJH12	Rating of 1.0 for sandy glaciolacustrine plains, rating of 1.0 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
GPKH	Rating of 1.0 for sandy glaciolacustrine plains, rating of 0.5 for fens, using the highest rated deposit of a complex terrain unit.
GPKD	Rating of 1.0 for sandy glaciolacustrine plains, rating of 0.5 for fens, using the dominant deposit of a complex terrain unit.
GPKH12	Rating of 1.0 for sandy glaciolacustrine plains, rating of 0.5 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
GPLH	Rating of 1.0 for sandy glaciolacustrine plains, rating of 0.0 for fens, using the highest rated deposit of a complex terrain unit.
GPLD	Rating of 1.0 for sandy glaciolacustrine plains, rating of 0.0 for fens, using the dominant deposit of a complex terrain unit.

Appendix 5 (continued). Names and descriptions of variables used in this study.

Variable	Description
4) Dichotomous Geology Variables	
i)Geofisheries Derived	
ii) Weighted mean rating of all surficial deposits adjacent to the stream (continued)	
GPLH12	Rating of 1.0 for sandy glaciolacustrine plains, rating of 0.0 for fens, using the highest rated among the dominant and first subordinate deposits of a complex terrain unit.
4) Dichotomous Geology Variables	
ii) Objective	
GPOBJLAR	Rating of the largest deposit adjacent to the stream
GPOBJMEA	Weighted mean rating of all deposits adjacent to the stream
Biogeographic/Climate Variables	
ECOREGIO	The ecoregio in which the streams were located
DISTLSUP	The shortest straight-line distance (km) the streams were from Lake Superior
DISTLNIP	The shortest straight-line distance (km) the streams were from Lake Nipigon
DISTLGLK	The shortest straight-line distance (km) the streams were from the large lake (Lake Superior or Lake Nipigon) to which they flowed
DRAINAGE	The drainage in which the sites were located (either Lake Superior or Lake Nipigon)
DISTMOR	The shortest straight-line distance (km) the streams were from a major end or interlobate moraine
DEGWEST	The degrees west longitude of each site
DEGNORTH	The degrees north laditude of each site
FALLS	The presence or absence of a migration barrier between the stream and a potentially recolonizing population of brook trout
Thermal Variables	
MAX	Maximum summer stream temperature (°C)
MEANMAX	Mean-maximum summer stream temperature (°C)
SUMMMEAN	Mean summer stream temperature (°C)
SUMMSTAB	Summer thermal stability (°C)

Appendix 5 (continued). Names and descriptions of variables used in this study.

Variable	Description
Brook Trout Abundance Variables	
NPERKM	Number of trout per kilometre of stream
NPERHA	Number of trout per hectare of stream
KGPERKM	Trout biomass (kg) per kilometre of stream
KGPERHA	Trout biomass (kg) per hectare of stream

Appendix 6. Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
Geology Models				
1) Geofisheries Models				
GEOFISH	0.3236	0.0029	41.974	0.0001
SURFACE	0.4472	0.0068	45.192	0.0005
BEDROCK	-0.0783	0.7240	57.162	0.7244
CLIMZONE	1.5962	0.4252	56.648	0.4242
SURFACE	0.4475	0.0067	57.286	0.0024
BEDROCK	0.0182	0.9477		
SURFACE	0.5199	0.0053	42.647	0.0007
CLIMZONE	3.9392	0.1241		
BEDROCK	-0.1362	0.5593	56.307	0.6128
CLIMZONE	1.9191	0.3574		
SURFACE	0.5234	0.0057	42.635	0.0021
BEDROCK	0.0331	0.9110		
CLIMZONE	3.9538	0.1240		
1) Modified Geofisheries Models				
SITEAH	0.2720	0.0199	51.302	0.0144
SITEAD	0.2148	0.0566	53.537	0.0528
SITEAH12	0.2931	0.0126	50.370	0.0085
SITEBH	0.2891	0.0197	51.331	0.0147
SITEBD	0.2383	0.0545	53.479	0.0510
SITEBH12	0.3161	0.0118	50.274	0.0081
SITECH	0.2497	0.0323	52.416	0.0273
SITECD	0.2104	0.0810	54.191	0.0785
SITECH12	0.2756	0.0197	51.466	0.0197
SITEDH	0.3048	0.0132	50.145	0.0075
SITEDD	0.1854	0.0929	54.403	0.0895

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
1) Modified Geofisheries Models (continued)				
SITEDH12	0.3238	0.0085	49.192	0.0044
SITEEH	0.3202	0.0131	50.213	0.0078
SITEED	0.2004	0.0961	54.467	0.0931
SITEEH12	0.3444	0.0080	49.141	0.0043
SITEFH	0.2729	0.0220	51.519	0.0163
SITEFD	0.1741	0.1371	55.060	0.1357
SITEFH12	0.2963	0.0136	50.552	0.0095
LARGAH	0.3688	0.0033	46.807	0.0012
LARGAD	0.2523	0.0249	51.985	0.0213
LARGAH12	0.3895	0.0020	45.622	0.0006
LARGBH	0.3949	0.0029	46.590	0.0011
LARGBD	0.2836	0.0222	51.752	0.0187
LARGBH12	0.4224	0.0016	45.210	0.0005
LARGCH	0.3420	0.0050	48.290	0.0027
LARGCD	0.2548	0.0345	52.625	0.0309
LARGCH12	0.3685	0.0028	47.023	0.0014
LARGDH	0.5295	0.0020	41.136	0.0001
LARGDD	0.2638	0.0176	51.273	0.0142
LARGDH12	0.5420	0.0013	39.903	0.0001
LARGEH	0.5528	0.0015	40.921	0.0001
LARGED	0.2902	0.0161	51.099	0.0121
LARGEH12	0.5734	0.0009	39.463	0.0001
LARGFH	0.4492	0.0017	43.792	0.0002
LARGFD	0.2592	0.0256	52.066	0.0223
LARGFH12	0.4707	0.0010	42.430	0.0001
MEANAH	0.3852	0.0051	47.908	0.0022
MEANAD	0.3143	0.0199	51.430	0.0155
MEANAH12	0.4140	0.0030	46.592	0.0011
MEANBH	0.4387	0.0039	47.076	0.0014
MEANBD	0.3519	0.0182	51.251	0.0182
MEANBH12	0.4791	0.0021	45.455	0.0006
MEANCH	0.4229	0.0043	47.673	0.0019

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
1) Modified Geofisheries Models (continued)				
MEANCD	0.3487	0.0225	51.667	0.0178
MEANCH12	0.4667	0.0022	46.012	0.0008
MEANDH	0.5186	0.0024	43.350	0.0002
MEANDD	0.3102	0.0175	51.159	0.0133
MEANDH12	0.5421	0.0015	41.955	0.0001
MEANEH	0.5903	0.0021	42.200	0.0001
MEANED	0.3384	0.0170	51.099	0.0129
MEANEH12	0.6267	0.0014	40.477	0.0001
MEANFH	0.5396	0.0017	43.362	0.0002
MEANFD	0.3296	0.0214	51.588	0.0214
MEANFH12	0.5777	0.0010	41.616	0.0001
3) Objective Geology Models				
SITETHIC	0.0949	0.0405	52.694	0.0321
LARGTHIC	0.1523	0.0035	45.950	0.0008
MEANTHIC	0.1406	0.0096	49.066	0.0096
SITEHYCO	0.2355	0.0740	53.302	0.0459
LARGHYCO	0.3752	0.0112	48.042	0.0024
MEANHYCO	0.4438	0.0109	47.517	0.0018
SITEVOL	0.0000000069	0.3017	56.102	0.2765
LARGVOL	0.0000000136	0.0748	53.078	0.0402
MEANVOL	0.0000000116	0.0076	48.382	0.0028
SITETHIC	0.0642	0.2589	51.955	0.0695
SITEHYCO	0.1292	0.4051		
LARGTHIC	0.1074	0.1158	45.160	0.0023
LARGHYCO	0.1614	0.3864		

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
3) Objective Geology Models (continued)				
MEANTHIC	0.0565	0.4439	46.905	0.0056
MEANHYCO	0.3147	0.1712		
SITETHIC	0.1061	0.0335	51.825	0.0652
SITEAREA	-0.1537	0.2867		
LARGTHIC	0.1543	0.0034	45.856	0.0033
LARGAREA	-0.0377	0.7617		
MEANAREA	0.1392	0.0113	49.038	0.0162
ADJAREA	0.0155	0.8659		
SITEHYCO	0.2343	0.0799	53.089	0.1226
SITEAREA	-0.0631	0.6496		
LARGHYCO	0.3792	0.0102	47.852	0.0089
LARGAREA	0.0542	0.6627		
MEANHYCO	0.4368	0.0098	47.004	0.0059
ADJAREA	0.0718	0.4697		
SITEVOL	0.00000000236	0.7272	53.178	0.1282
SITEHYCO	0.2180	0.1179		
LARGVOL	0.00000000575	0.4225	47.891	0.0091
LARGHYCO	0.3228	0.0438		
MEANVOL	0.00000000710	0.1585	45.949	0.0035
MEANHYCO	0.2762	0.1560		

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
3) Objective Geology Models (continued)				
SITETHIC	0.0796	0.2087	51.406	0.1176
SITEHYCO	0.1033	0.5257		
SITEAREA	-0.1360	0.3706		
LARGTHIC	0.1153	0.1080	45.329	0.0075
LARGHYCO	0.1389	0.4776		
LARGAREA	-0.0118	0.9295		
MEANTHIC	0.0527	0.4950	47.001	0.0163
MEANHYCO	0.3168	0.1811		
ADJAREA	0.0541	0.6026		
4) Dichotomous Geology Models				
i)Geofisheries Derived				
GPAH	2.2336	0.0032	46.767	0.0012
GPAD	1.5198	0.0276	52.239	0.0247
GPAH12	2.3979	0.0018	45.267	0.0005
GPBH	2.2363	0.0033	47.023	0.0140
GPBD	1.5852	0.0286	52.285	0.0253
GPBH12	2.4212	0.0017	45.446	0.0006
GPCH	2.0232	0.0047	48.189	0.0026
GPCD	1.4759	0.0384	52.855	0.0353
GPCH12	2.2012	0.0024	46.709	0.0011
GPDH	3.3322	0.0026	40.642	0.0001
GPDD	1.5950	0.0192	51.499	0.0161
GPDH12	3.4864	0.0017	38.925	0.0001

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
4) Dichotomous Geology Models (continued)				
i)Geofisheries Derived				
GPEH	3.1668	0.0015	41.300	0.0001
GPED	1.6416	0.0202	51.593	0.0170
GPEH12	3.3416	0.0009	39.502	0.0001
GPFH	2.7191	0.0015	43.357	0.0002
GPFD	1.5198	0.0276	52.239	0.0247
GPFH12	2.8834	0.0009	41.678	0.0001
GPGH	2.4250	0.0041	47.327	0.0016
GPGD	1.8852	0.0221	51.687	0.0180
GPGH12	2.6518	0.0021	45.626	0.0006
GPHH	2.5333	0.0039	47.135	0.0014
GPHD	2.0048	0.0215	51.608	0.0172
GPH12	2.7991	0.0019	45.280	0.0005
GPIH	2.4781	0.0041	47.506	0.0018
GPID	2.0008	0.0248	51.877	0.0200
GPIH12	2.7597	0.0020	45.612	0.0006
GPJH	3.3558	0.0022	42.250	0.0001
GPJD	1.8602	0.0195	51.405	0.0153
GPJH12	3.5825	0.0013	40.333	0.0001
GPKH	3.4427	0.0019	42.107	0.0001
GPKD	1.9432	0.0197	51.405	0.0153
GPKH12	3.7144	0.0012	40.022	0.0001
GPLH	3.2240	0.0016	42.927	0.0002
GPLD	1.9109	0.0230	51.737	0.0185
GPLH12	3.4960	0.0009	40.835	0.0001
ii) Objective				
GPOBJLAR	3.4864	0.0017	38.925	0.0001
GPOBJMEA	3.7366	0.0013	39.438	0.0001

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
Biogeographic/Climate Models				
ECOREGIO	0.3102	0.5207	56.873	0.5201
FALLS	-1.7383	0.0392	51.948	0.0209
DISTLGLK	-0.0209	0.3179	56.244	0.3074
DRAINAGE	1.1787	0.1244	54.906	0.1229
DEGWEST	0.4584	0.5971	57.004	0.5955
DISTMOR	-0.0412	0.1349	54.647	0.1043
DISTLSUP	0.0077	0.5615	56.949	0.5612
DISTLNIP	-0.0018	0.7947	57.219	0.7948
FALLS	-3.1126	0.0049	39.919	0.0016
DEGWEST	28.6046	0.0174		
DISTLSUP	-0.2757	0.0199		
DISTLNIP	-0.2461	0.0162		
Thermal Models				
MAX	-0.4707	0.0089	47.088	0.0014
MEAN	-0.4426	0.0120	48.546	0.0031
SUMMMEAN	-0.4250	0.0270	50.886	0.0114
SUMMSTAB	-0.6806	0.0157	50.034	0.0071
Combined Models				
1) Geology and Biogeographic/Climate Models				
GEOFISH	0.2878	0.0038	39.041	0.0001
FALLS	-1.4773	0.1062		
SURFACE	0.5738	0.0028	35.789	0.0001
FALLS	-2.6563	0.0071		
LARGAH12	0.6060	0.0006	33.910	0.0001
FALLS	-3.4210	0.0052		

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
1) Geology and Biogeographic/Climate Models (continued)				
LARGBH12	0.5321	0.0009	36.929	0.0001
FALLS	-2.6292	0.0135		
LARGCH12	0.4353	0.0025	40.457	0.0002
FALLS	-2.2583	0.0246		
LARGDH12	0.7268	0.0007	29.634	0.0001
FALLS	-3.1482	0.0055		
LARGEH12	0.6225	0.0006	33.203	0.0001
FALLS	-2.3136	0.0240		
LARGFH12	0.5031	0.0012	37.387	0.0001
FALLS	-2.0269	0.0408		
MEANAH12	0.6049	0.0011	36.305	0.0001
FALLS	-3.0619	0.0074		
MEANBH12	0.5905	0.0013	37.615	0.0001
FALLS	-2.4898	0.0148		
MEANCH12	0.5230	0.0021	39.803	0.0002
FALLS	-2.1597	0.0271		
MEANDH12	0.6785	0.0010	33.470	0.0001
FALLS	-2.7413	0.0108		
MEANEH12	0.6564	0.0011	34.933	0.0001
FALLS	2.0999	0.0322		
MEANFH12	0.5745	0.0013	37.415	0.0001
FALLS	-1.8166	0.0585		

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
1) Geology and Biogeographic/Climate Models (continued)				
SITEDH12	0.3759	0.0062	42.868	0.0007
FALLS	-2.1272	0.0259		
SITEEH12	0.3407	0.0115	44.647	0.0018
FALLS	-1.7342	0.0534		
SITEFH12	0.2773	0.0278	46.704	0.0050
FALLS	-1.5920	0.0716		
LARGTHIC	0.1614	0.0045	40.917	0.0003
FALLS	-1.9540	0.0465		
MEANTHIC	0.1580	0.0094	43.284	0.0009
FALLS	-2.0527	0.0335		
SITETHIC	0.0917	0.0585	48.071	0.0100
FALLS	-1.7028	0.0522		
LARGHYCO	0.4815	0.0050	39.575	0.0001
FALLS	-2.4632	0.0107		
MEANHYCO	0.5345	0.0057	39.976	0.0002
FALLS	-2.2906	0.0149		
SITEHYCO	0.2751	0.0501	47.134	0.0062
FALLS	-1.9451	0.0268		
MEANVOL	0.0000000108	0.0153	44.869	0.0020
FALLS	-1.5645	0.0852		

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
1) Geology and Biogeographic/Climate Models (continued)				
GPEH12	3.5039	0.0007	34.025	0.0001
FALLS	-2.1272	0.0325		
GPKH12	3.7495	0.0010	35.262	0.0001
FALLS	-1.9432	0.0449		
GPFENDOM	4.0213	0.0008	31.311	0.0001
FALLS	-2.5352	0.0133		
GPFENMEA	4.0030	0.0009	33.491	0.0001
FALLS	-2.2130	0.0269		
GEOFISH	0.3778	0.0035	35.391	0.0001
DRAINAGE	3.1874	0.0286		
DISTMOR	-0.0599	0.2132		
SURFACE	0.6233	0.0140	36.953	0.0001
DRAINAGE	3.5748	0.0343		
DISTMOR		0.0888		
LARGDH12	0.6015	0.0030	33.889	0.0001
DRAINAGE	2.1123	0.0878		
DISTMOR	-0.0954	0.0435		
LARGEH12	0.5671	0.0020	35.243	0.0001
DRAINAGE	1.6226	0.1664		
DISTMOR	-0.0801	0.0779		

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
1) Geology and Biogeographic/Climate Models (continued)				
LARGFH12	0.4527	0.0031	38.511	0.0003
DRAINAGE	1.4605	0.1820		
DISTMOR	-0.0727	0.0910		
MEANDH12	0.6338	0.0038	35.342	0.0001
DRAINAGE	2.1563	0.0841		
DISTMOR	-0.1011	0.0364		
MEANEH12	0.6718	0.0032	35.178	0.0001
DRAINAGE	1.8745	0.1283		
DISTMOR	-0.0914	0.0533		
MEANFH12	0.5811	0.0027	37.147	0.0002
DRAINAGE	1.6435	0.1553		
DISTMOR	-0.0808	0.0720		
LARGTHIC	0.1892	0.0038	37.401	0.0002
DRAINAGE	2.5593	0.0290		
DISTMOR	-0.1055	0.0318		
MEANTHIC	0.1979	0.0060	39.271	0.0004
DRAINAGE	2.8293	0.0211		
DISTMOR	-0.1100	0.0254		
LARGHYCO	0.3456	0.0190	42.654	0.0022
DRAINAGE	1.3958	0.1540		
DISTMOR	0.0711	0.0525		
MEANHYCO	0.4315	0.0172	41.896	0.0015
DRAINAGE	1.4156	0.1433		
DISTMOR	-0.0725	0.0470		

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
1) Geology and Biogeographic/Climate Models (continued)				
GPEH12	3.2330	0.0019	35.668	0.0001
DRAINAGE	1.5151	0.1966		
DISTMOR	-0.0771	0.0891		
GPKH12	3.8028	0.0025	35.329	0.0001
DRAINAGE	1.7216	0.1594		
DISTMOR	-0.0858	0.0651		
GPOBJLAR	3.5519	0.0026	34.171	0.0001
DRAINAGE	1.7907	0.1411		
DISTMOR	-0.0857	0.0645		
GPOBJMEA	4.0003	0.0027	34.157	0.0001
DRAINAGE	1.9781	0.1156		
DISTMOR	-0.0903	0.0548		
GEOFISH	0.3073	0.0232	31.797	0.0001
FALLS	-2.2008	0.0635		
DEGWEST	22.5645	0.0862		
DISTLSUP	-0.2102	0.1094		
DISTLNIP	-0.2042	0.0749		
SURFACE	0.6470	0.0311	29.178	0.0001
FALLS	-3.6294	0.0058		
DEGWEST	24.1364	0.0683		
DISTLSUP	-0.2243	0.0911		
DISTLNIP	-0.2180	0.0651		

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
1) Geology and Biogeographic/Climate Models (continued)				
LARGDH12	0.8704	0.0055	22.405	0.0001
FALLS	-4.9420	0.0112		
DEGWEST	24.9439	0.0900		
DISTLSUP	-0.2301	0.1251		
DISTLNIP	-0.1926	0.1252		
LARGEH12	0.6709	0.0082	27.291	0.0001
FALLS	-3.6643	0.0136		
DEGWEST	19.9931	0.1227		
DISTLSUP	-0.1783	0.1818		
DISTLNIP	-0.1532	0.1757		
LARGFH12	0.4776	0.0135	31.626	0.0001
FALLS	-3.1415	0.0150		
DEGWEST	20.2082	0.1020		
DISTLSUP	-0.1858	0.1423		
DISTLNIP	-0.1620	0.1331		
MEANDH12	0.7918	0.0048	25.492	0.0001
FALLS	-4.1829	0.0105		
DEGWEST	26.3392	0.0715		
DISTLSUP	-0.2440	0.1005		
DISTLNIP	-0.2082	0.0957		
MEANEH12	0.7793	0.0073	27.218	0.0001
FALLS	-3.4908	0.0160		
DEGWEST	23.0484	0.0895		
DISTLSUP	-0.2035	0.1407		
DISTLNIP	-0.1762	0.1313		

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
1) Geology and Biogeographic/Climate Models (continued)				
MEANFH12	0.6315	0.0097	30.163	0.0001
FALLS	-3.0027	0.0212		
DEGWEST	21.4464	0.0939		
DISTLSUP	-0.1893	0.1489		
DISTLNIP	-0.1666	0.1347		
LARGTHIC	0.2108	0.0151	29.949	0.0001
FALLS	-3.2695	0.0151		
DEGWEST	32.2171	0.0177		
DISTLSUP	-0.3145	0.0232		
DISTLNIP	-0.2735	0.0187		
MEANTHIC	0.2291	0.0135	30.987	0.0001
FALLS	-3.3048	0.0117		
DEGWEST	34.1110	0.0149		
DISTLSUP	-0.3283	0.0208		
DISTLNIP	-0.2891	0.0163		
LARGHYCO	0.5096	0.0210	31.073	0.0001
FALLS	-4.1498	0.0056		
DEGWEST	24.1700	0.0508		
DISTLSUP	-0.2266	0.0716		
DISTLNIP	-0.1927	0.0705		
MEANHYCO	0.5856	0.0177	30.916	0.0001
FALLS	-3.9873	0.0077		
DEGWEST	25.7771	0.0445		
DISTLSUP	-0.2425	0.0591		
DISTLNIP	-0.2060	0.0598		

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
1) Geology and Biogeographic/Climate Models (continued)				
GPEH12	3.5994	0.0111	29.090	0.0001
FALLS	-3.1966	0.0166		
DEGWEST	17.0511	0.1764		
DISTLSUP	-0.1507	0.2500		
DISTLNIP	-0.1304	0.2418		
GPKH12	4.1477	0.0082	28.693	0.0001
FALLS	-3.0750	0.0211		
DEGWEST	20.1638	0.1241		
DISTLSUP	-0.1775	0.1863		
DISTLNIP	-0.1547	0.1747		
GPOBJLAR	4.4598	0.0088	25.893	0.0001
FALLS	-3.8052	0.0126		
DEGWEST	18.1115	0.1671		
DISTLSUP	-0.1601	0.2371		
DISTLNIP	-0.1359	0.2363		
GPOBJMEA	4.4767	0.0050	26.699	0.0001
FALLS	-3.3749	0.0191		
DEGWEST	21.8922	0.1086		
DISTLSUP	-0.1967	0.1571		
DISTLNIP	-0.1704	0.1474		
2) Geology and Thermal Variables				
GEOFISH	0.3059	0.0060	34.852	0.0001
MAX	-0.4826	0.0316		
SURFACE	0.4409	0.0142	37.776	0.0001
MAX	-0.4791	0.0251		

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
2) Geology and Thermal Variables (continued)				
LARGAH12	0.4377	0.0043	36.350	0.0001
MAX	-0.5723	0.0154		
LARGBH12	0.4221	0.0052	37.698	0.0001
MAX	-0.4887	0.0218		
LARGCH12	0.3437	0.0124	40.143	0.0002
MAX	-0.4457	0.0258		
LARGDH12	0.6509	0.0041	30.553	0.0001
MAX	-0.6697	0.0229		
LARGEH12	0.5788	0.0023	32.684	0.0001
MAX	-0.5114	0.0334		
LARGFH12	0.4530	0.0040	36.276	0.0001
MAX	-0.4499	0.0371		
MEANAH12	0.4325	0.0071	38.074	0.0001
MAX	-0.5217	0.0189		
MEANBH12	0.4771	0.0065	37.878	0.0001
MAX	-0.4931	0.0236		
MEANCH12	0.4375	0.0088	39.113	0.0001
MAX	-0.4579	0.0277		
MEANDH12	0.5862	0.0035	33.542	0.0001
MAX	-0.5770	0.0260		
MEANEH12	0.5788	0.0023	32.684	0.0001
MAX	-0.5114	0.0334		

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
2) Geology and Thermal Variables (continued)				
MEANFH12	0.5540	0.0032	35.214	0.0001
MAX	-0.4779	0.0391		
SITEDH12	0.3955	0.0126	38.819	0.0001
MAX	-0.5388	0.0093		
SITEEH12	0.3584	0.0174	40.373	0.0002
MAX	-0.4725	0.0125		
SITEFH12	0.2806	0.0394	42.436	0.0006
MAX	-0.4413	0.0154		
LARGTHIC	0.1562	0.0036	36.383	0.0001
MAX	-0.5417	0.0122		
MEANTHIC	0.1558	0.0079	38.566	0.0001
MAX	-0.5537	0.0099		
SITETHIC	0.1080	0.0339	42.185	0.0005
MAX	-0.5036	0.0080		
LARGHYCO	0.3964	0.0234	39.629	0.0001
MAX	-0.4789	0.0162		
MEANHYCO	0.4992	0.0172	38.355	0.0001
MAX	-0.5117	0.0154		
SITEHYCO	0.3836	0.0401	41.002	0.0003
MAX	-0.5611	0.0047		
MEANVOL	0.0000000145	0.0063	36.593	0.0001
MAX	-0.5718	0.0068		

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
2) Geology and Thermal Variables (continued)				
GPEH12	3.2904	0.0021	32.806	0.0001
MAX	-0.4919	0.0359		
GPKH12	3.6992	0.0024	32.880	0.0001
MAX	-0.5152	0.0367		
GPFENDOM	3.7887	0.0032	30.735	0.0001
MAX	-0.5855	0.0282		
GPFENMEA	4.1264	0.0029	30.959	0.0001
MAX	-0.6059	0.0308		
GEOFISH	0.3196	0.0047	35.115	0.0001
MEAN	-0.4886	0.0337		
SURFACE	0.4470	0.0127	38.741	0.0001
MEAN	-0.4695	0.0325		
LARGAH12	0.3918	0.0057	39.100	0.0001
MEAN	-0.4777	0.0281		
LARGBH12	0.3916	0.0068	40.041	0.0002
MEAN	-0.4202	0.0417		
LARGCH12	0.3229	0.0153	42.156	0.0005
MEAN	-0.3908	0.0462		

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
2) Geology and Thermal Variables (continued)				
LARGDH12	0.5523	0.0041	34.501	0.0001
MEAN	-0.4758	0.0472		
LARGEH12	0.5310	0.0031	35.740	0.0001
MEAN	-0.3833	0.0818		
LARGFH12	0.4206	0.0053	38.841	0.0001
MEAN	-0.3533	0.0840		
MEANAH12	0.3921	0.0094	40.617	0.0002
MEAN	-0.4329	0.0353		
MEANBH12	0.4391	0.0084	40.311	0.0002
MEAN	-0.4078	0.0463		
MEANCH12	0.4095	0.0112	41.290	0.0003
MEAN	-0.3849	0.0527		
MEANDH12	0.5153	0.0043	36.955	0.0001
MEAN	-0.4163	0.0568		
MEANEH12	0.5708	0.0039	36.529	0.0001
MEAN	-0.3756	0.0829		
MEANFH12	0.5127	0.0043	38.007	0.0001
MEAN	-0.3508	0.0909		
SITEDH12	0.3499	0.0163	41.451	0.0004
MEAN	-0.4432	0.0169		
SITEEH12	0.3324	0.0216	42.536	0.0006
MEAN	-0.3994	0.0227		

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
2) Geology and Thermal Variables (continued)				
SITEFH12	0.2639	0.0462	44.312	0.0015
MEAN	-0.3813	0.0269		
LARGTHIC	0.1553	0.0037	37.981	0.0001
MEAN	-0.5152	0.0168		
MEANTHIC	0.1521	0.0095	40.330	0.0002
MEAN	-0.5107	0.0143		
SITETHIC	0.1067	0.0344	43.660	0.0011
MEAN	-0.4744	0.0122		
LARGHYCO	0.3590	0.0335	42.254	0.0005
MEAN	-0.4130	0.0335		
MEANHYCO	0.4692	0.0244	40.888	0.0003
MEAN	-0.4413	0.0295		
SITEHYCO	0.3365	0.0657	43.751	0.0012
MEAN	-0.4871	0.0087		
MEANVOL	0.0000000137	0.0061	38.467	0.0001
MEAN	-0.5226	0.0097		
GPEH12	3.0220	0.0030	35.885	0.0001
MEAN	-0.3628	0.0912		

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
2) Geology and Thermal Variables (continued)				
GPKH12	3.3807	0.0036	36.083	0.0001
MEAN	-0.3612	0.0872		
GPOBJLAR	3.3262	0.0040	34.430	0.0001
MEAN	-0.4157	0.0686		
GPOBJMEA	3.6061	0.0034	34.645	0.0001
MEAN	-0.4097	0.0679		
GEOFISH	0.3316	0.0039	36.239	0.0001
SUMMMEAN	-0.4917	0.0507		
SURFACE	0.4402	0.0104	40.513	0.0002
SUMMMEAN	-0.4333	0.0633		
LARGAH12	0.3878	0.0044	40.998	0.0003
SUMMMEAN	-0.4545	0.0635		
LARGBH12	0.4137	0.0042	41.077	0.0003
SUMMMEAN	-0.0436	0.0751		
LARGCH12	0.3492	0.0081	43.035	0.0008
SUMMMEAN	-0.4060	0.0767		
LARGDH12	0.5425	0.0027	36.000	0.0001
SUMMMEAN	-0.4448	0.0881		
LARGEH12	0.5587	0.0021	36.221	0.0001
SUMMMEAN	-0.4086	0.1120		
LARGFH12	0.4469	0.0028	39.259	0.0001
SUMMMEAM	-0.3756	0.1105		

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
2) Geology and Thermal Variables (continued)				
MEANAH12	0.3936	0.0069	42.309	0.0006
SUMMMEAN	-0.4113	0.0727		
MEANBH12	0.4564	0.0054	41.520	0.0004
SUMMMEAN	-0.4085	0.0839		
MEANCH12	0.4383	0.0063	42.207	0.0005
SUMMMEAN	-0.3970	0.0860		
MEANDH12	0.5151	0.0030	38.368	0.0001
SUMMMEAN	-0.3874	0.0998		
MEANEH12	0.5903	0.0027	37.363	0.0001
SUMMMEAN	-0.3742	0.1226		
MEANFH12	0.5399	0.0025	38.577	0.0001
SUMMMEAN	-0.3623	0.1224		
SITEDH12	0.3369	0.0140	43.616	0.0011
SUMMMEAN	-0.4308	0.0330		
SITEEH12	0.3426	0.0153	44.075	0.0014
SUMMMEAN	-0.4070	0.0389		
SITEFH12	0.2810	0.0290	45.689	0.0030
SUMMMEAN	-0.3875	0.0433		
LARGTHIC	0.1629	0.0027	39.136	0.0001
SUMMMEAN	-0.5334	0.0286		
MEANTHIC	0.1551	0.0077	42.100	0.0005
SUMMMEAN	-0.5065	0.0271		

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
2) Geology and Thermal Variables (continued)				
SITETHIC	0.1061	0.0322	45.860	0.0033
SUMMMEAN	-0.4617	0.0238		
LARGHYCO	0.3726	0.0244	43.660	0.0011
SUMMMEAN	-0.4090	0.0655		
MEANHYCO	0.4729	0.0191	42.414	0.0006
SUMMMEAN	-0.4383	0.0537		
SITEHYCO	0.3210	0.0603	45.897	0.0034
SUMMMEAN	-0.5002	0.0176		
MEANVOL	0.0000000142	0.0038	39.586	0.0001
SUMMMEAN	-0.5559	0.0136		
GPEH12	3.1899	0.0019	36.316	0.0001
SUMMMEAN	-0.3881	0.1196		
GPKH12	3.5149	0.0024	36.824	0.0001
SUMMMEAN	-0.3678	0.1192		
GPOBJLAR	3.4010	0.0029	35.359	0.0001
SUMMMEAN	-0.4174	0.1069		
GPOBJMEA	3.6289	0.0024	35.822	0.0001
SUMMMEAN	-0.3955	0.1033		

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
2) Geology and Thermal Variables (continued)				
GEOFISH	0.2851	0.0077	39.086	0.0001
SUMMSTAB	-0.4804	0.1086		
SURFACE	0.4146	0.0150	41.124	0.0003
SUMMSTAB	-0.5624	0.0616		
LARGAH12	0.3691	0.0059	41.254	0.0003
SUMMSTAB	-0.5915	0.0489		
LARGBH12	0.3614	0.0097	42.607	0.0006
SUMMSTAB	-0.4699	0.1197		
LARGCH12	0.2996	0.0238	44.679	0.0018
SUMMSTAB	-0.4512	0.1376		
LARGDH12	0.5213	0.0037	36.683	0.0001
SUMMSTAB	-0.5434	0.0903		
LARGEH12	0.5103	0.0039	38.259	0.0001
SUMMSTAB	-0.3454	0.2856		
LARGFH12	0.4104	0.0071	41.281	0.0003
SUMMSTAB	-0.3381	0.2947		
MEANAH12	0.3914	0.0090	42.159	0.0005
SUMMSTAB	-0.5793	0.0048		
MEANBH12	0.4241	0.0094	42.268	0.0005
SUMMSTAB	-0.5011	0.0887		
MEANCH12	0.3923	0.0144	43.465	0.0010
SUMMSTAB	-0.4607	0.1236		

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
2) Geology and Thermal Variables (continued)				
MEANDH12	0.5261	0.0046	38.308	0.0001
SUMMSTAB	-0.5560	0.0733		
MEANEH12	0.5688	0.0045	38.324	0.0001
SUMMSTAB	-0.4368	0.1612		
MEANFH12	0.5092	0.0053	40.029	0.0002
SUMMSTAB	-0.3874	0.2221		
SITEDH12	0.3664	0.0112	42.036	0.0005
SUMMSTAB	-0.7584	0.0162		
SITEEH12	0.3226	0.0192	43.864	0.0012
SUMMSTAB	-0.6419	0.0327		
SITEFH12	0.2564	0.0462	45.813	0.0032
SUMMSTAB	-0.6035	0.0409		
LARGTHIC	0.1295	0.0118	42.442	0.0006
SUMMSTAB	-0.5318	0.0783		
MEANTHIC	0.1240	0.0232	44.230	0.0015
SUMMSTAB	-0.5990	0.0423		
SITETHIC	0.0965	0.0494	45.836	0.0033
SUMMSTAB	-0.7011	0.0178		
LARGHYCO	0.3182	0.0367	44.375	0.0016
SUMMSTAB	-0.5213	0.0753		
MEANHYCO	0.4112	0.0274	43.317	0.0009
SUMMSTAB	-0.5466	0.0583		

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
2) Geology and Thermal Variables (continued)				
SITEHYCO	0.2505	0.0868	46.443	0.0044
SUMMSTAB	-0.6874	0.0172		
MEANVOL	0.0000000103	0.0257	44.054	0.0013
SUMMSTAB	-0.5747	0.0513		
GPEH12	2.9569	0.0040	38.237	0.0001
SUMMSTAB	-0.3477	0.2748		
GPKH12	3.3786	0.0041	37.835	0.0001
SUMMSTAB	-0.4347	0.1569		
GPOBJLAR	3.2034	0.0044	36.655	0.0001
SUMMSTAB	-0.4455	0.1510		
GPOBJMEA	3.6499	0.0041	36.184	0.0001
SUMMSTAB	-0.5262	0.0885		
3) Geology and Biogeographic/Climate and Thermal Variables				
GEOFISH	0.2746	0.0077	32.380	0.0001
MAX	-0.4574	0.0318		
FALLS	-1.6098	0.1437		

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
3) Geology and Biogeographic/Climate and Thermal Variables				
SURFACE	0.5571	0.0069	30.369	0.0001
MAX	-0.4301	0.0518		
FALLS	-2.7695	0.0182		
LARGDH12	0.8185	0.0044	23.112	0.0001
MAX	-0.6156	0.0753		
FALLS	-3.2239	0.0182		
LARGEH12	0.5967	0.0023	28.368	0.0001
MAX	-0.4405	0.0756		
FALLS	-2.3405	0.0624		
LARGFH12	0.4641	0.0052	32.473	0.0001
MAX	-0.4033	0.0641		
FALLS	-2.0984	0.0798		
MEANDH12	0.7933	0.0036	25.884	0.0001
MAX	-0.5852	0.0383		
FALLS	-3.2974	0.0196		
MEANEH12	0.6712	0.0032	28.749	0.0001
MAX	-0.4956	0.0498		
FALLS	-2.3835	0.0575		
MEANFH12	0.5628	0.0047	31.557	0.0001
MAX	-0.4544	0.0489		
FALLS	-2.0616	0.0849		
LARGTHIC	0.1635	0.0062	32.504	0.0001
MAX	-0.4925	0.0192		
FALLS	-2.1314	0.0796		

Appendix 6 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log Likelihood	P
3) Geology and Biogeographic/Climate and Thermal Variables (continued)				
MEANTHIC	0.1825	0.0099	33.534	0.0001
MAX	-0.5321	0.0126		
FALLS	-2.3667	0.0508		
LARGHYCO	0.4680	0.0123	33.183	0.0001
MAX	-0.4156	0.0319		
FALLS	-2.5821	0.0259		
MEANHYCO	0.5949	0.0098	31.882	0.0001
MAX	-0.4827	0.0168		
FALLS	-2.5961	0.0251		
GPEH12	3.4296	0.0022	28.530	0.0001
MAX	-0.4452	0.0582		
FALLS	-2.3090	0.0633		
GPKH12	3.9263	0.0029	28.515	0.0001
MAX	-0.5094	0.0384		
FALLS	-2.3290	0.0641		
GPOBJLAR	4.1890	0.0021	25.086	0.0001
FALLS	-2.7109	0.0359		
MAX	-0.5153	0.0572		
GPOBJMEA	4.6614	0.0030	25.673	0.0001
FALLS	-2.6044	0.0439		
MAX	-0.5951	0.0370		

Appendix 7. Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
Geology Models				
1) Geofisheries Models				
GEOFISH	0.1797	0.0010	94.539	0.0002
SURFACE	0.2300	0.0054	99.064	0.0028
BEDROCK	0.1447	0.3848	107.213	0.3809
CLIMZONE	2.2123	0.1447	105.805	0.1402
SURFACE	0.2304	0.0054	98.324	0.0080
BEDROCK	0.1535	0.3945		
SURFACE	0.3144	0.0013	92.562	0.0004
CLIMZONE	4.5046	0.0163		
BEDROCK	0.1103	0.5578	105.459	0.2834
CLIMZONE	2.0370	0.1888		
SURFACE	0.3136	0.0014	92.394	0.0014
BEDROCK	0.0776	0.6832		
CLIMZONE	4.3821	0.0209		
2) Modified Geofisheries Models				
LARGDH12	0.3584	0.0001	89.216	0.0001
LARGEH12	0.4064	0.0001	87.766	0.0001
LARGFH12	0.3260	0.0002	91.863	0.0001
MEANDH12	0.3927	0.0001	89.116	0.0001
MEANEH12	0.4291	0.0001	89.445	0.0001
MEANFH12	0.3704	0.0003	92.837	0.0001
SITEDH12	0.2242	0.0065	100.147	0.0049
SITEEH12	0.2441	0.0046	99.331	0.0033
SITEFH12	0.2278	0.0062	100.004	0.0047

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
4) Objective Geology Models (continued)				
LARGTHIC	0.1500	0.0004	91.128	0.0001
MEANTHIC	0.1398	0.0010	94.410	0.0002
SITETHIC	0.0978	0.0074	99.767	0.0042
LARGHYCO	0.3514	0.0018	94.282	0.0002
MEANHYCO	0.3939	0.0018	94.467	0.0002
SITEHYCO	0.1789	0.0589	104.009	0.0463
MEANVOL	0.00000001010	0.0035	96.869	0.0009
SITEVOL	0.00000000777	0.1964	106.054	0.1651
3) Dichotomous Geology Models				
i) Geofisheries Derived				
GPEH12	2.2303	0.0001	89.669	0.0001
GPKH12	2.4482	0.0001	89.973	0.0001
ii) Objective				
GPOBJLAR	2.2568	0.0001	88.674	0.0001
GPOBJMEA	2.4137	0.0001	88.826	0.0001
Biogeography/Climate Models (P<0.1 ONLY)				
FALLS	-1.2589	0.0282	102.583	0.0202
DISTLGLK	-0.0300	0.0294	102.454	0.0187
DISTMOR	-0.0445	0.0558	103.749	0.0397
DISTLNIP	-0.0091	0.0737	104.613	0.0655
DRAINAGE	0.9067	0.0773	104.792	0.0741
DEGWEST	-0.8950	0.0784	104.753	0.0724

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
Biogeography/Climate Models (continued) (P<0.1 ONLY)				
DRAINAGE	2.7746	0.0045	97.582	0.0055
DISTLSUP	-0.0363	0.0149		
DISTMOR	-0.0595	0.0207	97.993	0.0068
DISTLNIP	-0.0124	0.0212		
FALLS	-1.3088	0.0262	99.226	0.0126
DRAINAGE	0.9682	0.0714		
DEGWEST	-1.0352	0.0472	99.593	0.0151
DISTMOR	-0.0513	0.0378		
DRAINAGE	1.0745	0.0478	99.653	0.0155
DISTMOR	-0.0520	0.0388		
ECOREGIO	0.4604	0.0865	100.676	0.0259
DISTMOR	-0.0487	0.0440		
DRAINAGE	1.0185	0.0534	100.907	0.0291
DEGWEST	-1.0152	0.0550		
DRAINAGE	1.2246	0.0302	94.605	0.0039
DEGWEST	-1.1739	0.0299		
DISTMOR	-0.0604	0.0244		
DRAINAGE	2.9143	0.0054	93.681	0.0025
DISTMOR	-0.0504	0.0653		
DISTLSUP	-0.0351	0.0258		
FALLS	-1.1954	0.0479	95.351	0.0055
DRAINAGE	1.1331	0.0446		
DISTMOR	-0.0490	0.0673		

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
Thermal Models				
MAX	-0.2914	0.0026	87.665	0.0008
MEAN	-0.2819	0.0053	89.414	0.0021
SUMMMEAN	-0.2920	0.0107	91.363	0.0061
SUMMSTAB	-0.4547	0.0019	91.347	0.0061
Combined Models				
1) Geology and Biogeographic/Climate Models (P<0.05 Only)				
GEOFISH	0.1737	0.0013	90.162	0.0001
FALLS	-1.2021	0.0453		
SURFACE	0.2767	0.0017	90.935	0.0002
FALLS	-1.6488	0.0077		
LARGDH12	0.4059	0.0001	81.315	0.0001
FALLS	-1.7488	0.0086		
LARGEH12	0.4328	0.0001	81.405	0.0001
FALLS	-1.5559	0.0172		
LARGFH12	0.3387	0.0002	86.553	0.0001
FALLS	-1.3930	0.0288		
MEANDH12	0.4253	0.0001	82.290	0.0001
FALLS	-1.5952	0.0138		
MEANEH12	0.4478	0.0001	83.638	0.0001
FALLS	-1.4512	0.0222		
MEANFH12	0.3795	0.0003	87.652	0.0001
FALLS	-1.3499	0.0306		

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
1) Geology and Biogeographic/Climate Models (continued) ($P<0.05$ Only)				
SITEDH12	0.2364	0.0060	94.436	0.0011
FALLS	-1.3575	0.0253		
SITEEH12	0.2441	0.0064	94.621	0.0013
FALLS	-1.2380	0.0387		
LARGTHIC	0.1563	0.0004	85.739	0.0001
FALLS	-1.3968	0.0290		
MEANTHIC	0.1469	0.0010	88.782	0.0001
FALLS	-1.4041	0.0258		
SITETHIC	0.0975	0.0096	94.906	0.0014
FALLS	-1.2504	0.0366		
LARGHYCO	0.3935	0.0008	86.371	0.0001
FALLS	-1.6396	0.0084		
MEANHYCO	0.4375	0.0009	87.008	0.0001
FALLS	-1.5824	0.0102		
SITEHYCO	0.2076	0.0383	97.720	0.0059
FALLS	-1.3990	0.0183		
LARGVOL	0.00000001580	0.0115	93.944	0.0009
FALLS	-1.3329	0.0341		
MEANVOL	0.00000001070	0.0024	90.432	0.0002
FALLS	-1.5362	0.0198		

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
1) Geology and Biogeographic/Climate Models (continued) (P<0.05 Only)				
GPEH12	2.3781	0.0001	83.410	0.0001
FALLS	-1.5243	0.0181		
GPKH12	2.5194	0.0001	84.543	0.0001
FALLS	-1.3963	0.0267		
GPOBJLAR	2.4800	0.0001	81.485	0.0001
FALLS	-1.6420	0.0115		
GPOBJMEA	2.4969	0.0001	83.185	0.0001
FALLS	-1.4320	0.0239		
GEOFISH	0.1777	0.0013	89.883	0.0001
DISTLGLK	-0.0296	0.0446		
SURFACE	0.2784	0.0020	90.946	0.0002
DISTLGLK	-0.0394	0.0103		
LARGDH12	0.3867	0.0001	82.646	0.0001
DISTLGLK	0.0384	0.0208		
MEANDH12	0.4170	0.0001	83.033	0.0001
DISTLGLK	-0.0362	0.0251		
SITEDH12	0.2170	0.0103	95.448	0.0019
DISTLGLK	-0.0284	0.0453		
LARGHYCO	0.3800	0.0008	86.572	0.0001
DISTLGLK	-0.0385	0.0128		
MEANHYCO	0.4360	0.0009	86.887	0.0001
DISTLGLK	-0.0380	0.0134		

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
1) Geology and Biogeographic/Climate Models (continued) (P<0.05 Only)				
SITEHYCO	0.1988	0.0408	97.755	0.0060
DISTLGLK	-0.0323	0.0211		
GPOBJLAR	2.3674	0.0001	82.907	0.0001
DISTLGLK	-0.0352	0.0282		
GPOBJMEA	2.4851	0.0001	83.710	0.0001
DISTLGLK	-0.0326	0.0359		
LARGDH12	0.3713	0.0001	84.767	0.0001
DISTMOR	-0.5440	0.0492		
MEANDH12	0.4096	0.0001	84.605	0.0001
DISTMOR	-0.0549	0.0468		
LARGTHIC	0.1584	0.0003	86.225	0.0001
DISTMOR	-0.0581	0.0428		
MEANTHIC	0.1442	0.0008	89.859	0.0001
DISTMOR	-0.0538	0.0493		
LARGHYCO	0.3662	0.0009	88.422	0.0001
DISTMOR	-0.0564	0.0266		
MEANHYCO	0.4095	0.0011	88.934	0.0001
DISTMOR	-0.0542	0.0304		

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
1) Geology and Biogeographic/Climate Models (continued) ($P<0.05$ Only)				
SITEHYCO	0.2090	0.0306	98.479	0.0086
DISTMOR	-0.0508	0.0289		
LARGVOL	0.000000001690	0.0090	94.218	0.0010
DISTMOR	-0.0536	0.0463		
GEOFISH	0.1927	0.0007	90.294	0.0001
DEGWEST	-1.1585	0.0465		
SURFACE	0.2851	0.0020	92.985	0.0006
DEGWEST	-1.3839	0.0195		
LARGDH12	0.3879	0.0001	84.798	0.0001
DEGWEST	-1.2360	0.0435		
MEANVOL	0.000000001090	0.0024	92.414	0.0004
DEGWEST	-1.1294	0.0401		
GEOFISH	0.1914	0.0011	84.277	0.0001
DRAINAGE	2.9408	0.0049		
DISTLSUP	-0.0409	0.0125		
SURFACE	0.2877	0.0026	86.668	0.0001
DRAINAGE	3.1495	0.0035		
DISTLSUP	-0.0488	0.0042		
LARGDH12	0.3536	0.0004	82.459	0.0001
DRAINAGE	2.2725	0.0326		
DISTLSUP	-0.0379	0.0210		

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
1) Geology and Biogeographic/Climate Models (continued) ($P<0.05$ Only)				
LARGEH12	0.4166	0.0001	79.604	0.0001
DRAINAGE	2.5065	0.0148		
DISTLSUP	-0.0399	0.0144		
LARGFH12	0.3516	0.0002	81.618	0.0001
DRAINAGE	2.9054	0.0047		
DISTLSUP	-0.0422	0.0096		
MEANDH12	0.3882	0.0004	82.366	0.0001
DRAINAGE	2.2664	0.0319		
DISTLSUP	-0.0375	0.0209		
MEANEH12	0.4244	0.0004	82.028	0.0001
DRAINAGE	2.4033	0.0167		
DISTLSUP	-0.0361	0.0212		
MEANFH12	0.3856	0.0005	83.587	0.0001
DRAINAGE	2.7241	0.0058		
DISTLSUP	-0.0369	0.0168		
SITEDH12	0.1929	0.0262	92.444	0.0014
DRAINAGE	2.4195	0.0139		
DISTLSUP	-0.0335	0.0253		
SITEEH12	0.2053	0.0242	92.306	0.0013
DRAINAGE	2.3174	0.0184		
DISTLSUP	-0.0327	0.0283		
SITEFH12	0.1848	0.0372	93.125	0.0019
DRAINAGE	2.2917	0.0196		
DISTLSUP	-0.0322	0.0298		

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
1) Geology and Biogeographic/Climate Models (continued) (P<0.05 Only)				
LARGTHIC	0.1404	0.0007	82.905	0.0001
DRAINAGE	2.6985	0.0103		
DISTLSUP	-0.0358	0.0301		
MEANTHIC	0.1351	0.0018	85.707	0.0001
DRAINAGE	2.7117	0.0080		
DISTLSUP	-0.0348	0.0300		
SITETHIC	0.0860	0.0190	91.575	0.0009
DRAINAGE	2.5422	0.0097		
DISTLSUP	-0.0315	0.0385		
LARGHYCO	0.3456	0.0019	84.876	0.0001
DRAINAGE	2.5701	0.0109		
DISTLSUP	-0.4090	0.0100		
MEANHYCO	0.4063	0.0020	84.748	0.0001
DRAINAGE	2.6096	0.0098		
DISTLSUP	-0.0417	0.0088		
LARGVOL	0.00000001540	0.0209	90.395	0.0005
DRAINAGE	2.5862	0.0094		
DISTLSUP	-0.0367	0.0182		
MEANVOL	0.00000001070	0.0032	86.465	0.0001
DRAINAGE	2.8511	0.0069		
DISTLSUP	-0.0463	0.0074		

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
1) Geology and Biogeographic/Climate Models (continued) (P<0.05 Only)				
GPEH12	2.3177	0.0002	80.933	0.0001
DRAINAGE	2.6144	0.0110		
DISTLSUP	-0.0407	0.0124		
GPKH12	2.4371	0.0004	82.275	0.0001
DRAINAGE	2.4445	0.0148		
DISTLSUP	-0.0368	0.0188		
GPOBJLAR	2.2760	0.0003	81.251	0.0001
DRAINAGE	2.3644	0.0247		
DISTLSUP	-0.0396	0.0164		
GPOBJMEA	2.3348	0.0003	82.253	0.0001
DRAINAGE	2.2889	0.0265		
DISTLSUP	-0.0356	0.0253		
SURFACE	0.2127	0.0147	91.365	0.0008
DISTMOR	-0.0581	0.0411		
DISTLNIP	-0.0126	0.0325		
LARGTHIC	0.1589	0.0003	80.488	0.0001
DISTMOR	-0.0786	0.0143		
DISTLNIP	-0.0147	0.0241		
MEANTHIC	0.1476	0.0009	84.309	0.0001
DISTMOR	-0.0752	0.0162		
DISTLNIP	-0.0140	0.0259		

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
1) Geology and Biogeographic/Climate Models (continued) (P<0.05 Only)				
SITETHIC	0.0946	0.0114	90.946	0.0007
DISTMOR	-0.0619	0.0238		
DISTLNIP	-0.0124	0.0342		
LARGVOL	0.00000001600	0.0133	89.695	0.0004
DISTMOR	-0.0698	0.0188		
DISTLNIP	-0.0118	0.0402		
MEANVOL	0.00000001080	0.0039	87.114	0.0001
DISTMOR	-0.0706	0.0198		
DISTLNIP	-0.0103	0.0303		
LARGDH12	0.4208	0.0001	78.707	0.0001
DEGWEST	-1.5140	0.0210		
DISTMOR	-0.0694	0.0245		
MEANDH12	0.4419	0.0001	79.784	0.0001
DEGWEST	-1.3169	0.0358		
DISTMOR	-0.0673	0.0257		
MEANVOL	0.00000001150	0.0019	86.722	0.0001
DEGWEST	-1.2834	0.0229		
DISTMOR	-0.0631	0.0334		
GPOBJLAR	2.5563	0.0001	79.103	0.0001
DEGWEST	-1.4305	0.0264		
DISTMOR	-0.0662	0.0291		

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
1) Geology and Biogeographic/Climate Models (continued) ($P<0.05$ Only)				
GPOBJMEA	2.6078	0.0001	80.414	0.0001
DEGWEST	-1.2575	0.0431		
DISTMOR	-0.0634	0.0335		
MEANTHIC	0.1512	0.0006	85.072	0.0001
DRAINAGE	1.2647	0.0344		
DISTMOR	-0.0683	0.0225		
SITETHIC	0.1020	0.0066	91.458	0.0009
DRAINAGE	1.1672	0.0415		
DISTMOR	-0.0564	0.0367		
MEANVOL	0.00000001150	0.0018	87.759	0.0002
ECOREGIO	0.5880	0.0383		
DISTMOR	-0.0593	0.0396		
LARGTHIC	0.1625	0.0003	77.041	0.0001
DRAINAGE	1.4416	0.0247		
DEGWEST	-1.4023	0.0304		
DISTMOR	-0.0856	0.0108		
MEANTHIC	0.1547	0.0008	80.616	0.0001
DRAINAGE	1.5046	0.0185		
DEGWEST	-1.2619	0.0417		
DISTMOR	-0.0828	0.0116		
LARGDH12	0.3844	0.0003	77.326	0.0001
DRAINAGE	2.8293	0.0193		
DISTMOR	-0.0699	0.0335		
DISTLSUP	-0.0425	0.0212		

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
1) Geology and Biogeographic/Climate Models (continued) (P<0.05 Only)				
LARGEH12	0.4416	0.0001	74.910	0.0001
DRAINAGE	2.9694	0.0104		
DISTMOR	-0.0652	0.0402		
DISTLSUP	-0.0430	0.0167		
LARGFH12	0.3739	0.0002	77.201	0.0001
DRAINAGE	3.2614	0.0037		
DISTMOR	-0.0630	0.0458		
DISTLSUP	-0.0439	0.0125		
MEANDH12	0.4237	0.0003	77.163	0.0001
DRAINAGE	2.8206	0.0186		
DISTMOR	-0.0676	0.0319		
DISTLNIP	-0.0417	0.0221		
MEANEH12	0.4579	0.0003	76.988	0.0001
DRAINAGE	2.8340	0.0116		
DISTMOR	-0.0664	0.0342		
DISTLSUP	-0.0384	0.0256		
MEANFH12	0.4166	0.0004	78.714	0.0001
DRAINAGE	3.0683	0.0045		
DISTMOR	-0.0652	0.0373		
DISTLSUP	-0.0379	0.0225		
LARGTHIC	0.1615	0.0003	76.630	0.0001
DRAINAGE	3.3061	0.0075		
DISTMOR	-0.0780	0.0206		
DISTLSUP	-0.0396	0.0332		

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
1) Geology and Biogeographic/Climate Models (continued) (P<0.05 Only)				
MEANTHIC	0.1558	0.0008	79.644	0.0001
DRAINAGE	3.2956	0.0058		
DISTMOR	-0.0738	0.0222		
DISTLSUP	-0.0381	0.0339		
LARGHYCO	0.3713	0.0010	79.273	0.0001
DRAINAGE	2.8961	0.0108		
DISTMOR	-0.0655	0.0291		
DISTLSUP	-0.0426	0.0147		
MEANHYCO	0.4318	0.0015	79.611	0.0001
DRAINAGE	2.9132	0.0098		
DISTMOR	-0.0619	0.0351		
DISTLSUP	-0.0430	0.0137		
LARGVOL	0.000000001610	0.0128	85.328	0.0001
DRAINAGE	2.9257	0.0087		
DISTMOR	-0.0638	0.0389		
DISTLSUP	-0.0367	0.0278		
GPEH12	2.4469	0.0002	76.517	0.0001
DRAINAGE	3.0565	0.0080		
DISTMOR	-0.0631	0.0463		
DISTLSUP	-0.0439	0.0144		

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
1) Geology and Biogeographic/Climate Models (continued) (P<0.05 Only)				
GPKH12	2.6118	0.0003	77.458	0.0001
DRAINAGE	2.8564	0.0105		
DISTMOR	-0.0647	0.0382		
DISTLSUP	-0.0392	0.0225		
GPOBJLAR	2.4549	0.0002	76.403	0.0001
DRAINAGE	2.9156	0.0148		
DISTMOR	-0.0658	0.0380		
DISTLSUP	-0.0444	0.0166		
GPOBJMEA	2.4965	0.0003	77.548	0.0001
DRAINAGE	2.7493	0.0170		
DISTMOR	-0.0637	0.0411		
DISTLSUP	-0.0386	0.0275		
LARGTHIC	0.1681	0.0003	77.689	0.0001
FALLS	-1.3429	0.0429		
DRAINAGE	1.2180	0.0485		
DISTMOR	-0.0704	0.0322		
MEANTHIC	0.1598	0.0007	80.518	0.0001
FALLS	-1.3350	0.0421		
DRAINAGE	1.3054	0.0333		
DISTMOR	-0.0650	0.0392		
2) Geology and Thermal Models (P<0.05 Only)				
GEOFISH	0.1340	0.0177	81.415	0.0002
MAX	-0.2477	0.0151		
LARGDH12	0.2815	0.0040	78.441	0.0001
MAX	-0.2321	0.0202		

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
2) Geology and Thermal Models (continued) (P<0.05 Only)				
LARGEH12	0.3248	0.0025	77.407	0.0001
MAX	-0.2327	0.0206		
LARGFH12	0.2528	0.0065	79.806	0.0001
MAX	-0.2511	0.0125		
MEANDH12	0.2972	0.0056	79.145	0.0001
MAX	-0.2256	0.0246		
MEANEH12	0.3450	0.0035	78.040	0.0001
MAX	-0.2344	0.0192		
MEANFH12	0.3112	0.0047	78.983	0.0001
MAX	-0.2550	0.0111		
LARGTHIC	0.1245	0.0023	76.626	0.0001
MAX	-0.2648	0.0096		
MEANTHIC	0.1122	0.0071	79.623	0.0001
MAX	-0.2677	0.0079		
LARGHYCO	0.2830	0.0206	80.960	0.0001
MAX	-0.2341	0.0178		
MEANHYCO	0.2996	0.0241	81.399	0.0001
MAX	-0.2379	0.0164		
MEANVOL	0.00000000907	0.0154	80.874	0.0001
MAX	-0.3125	0.0020		
GPEH12	1.8332	0.0028	77.753	0.0001
MAX	-0.2395	0.0163		

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
2) Geology and Thermal Models (continued) (P<0.05 Only)				
GPKH12	1.9909	0.0034	77.996	0.0001
MAX	-0.2420	0.0149		
GPOBJLAR	1.7962	0.0031	77.785	0.0001
MAX	-0.2352	0.0181		
GPOBJMEA	1.9199	0.0033	77.920	0.0001
MAX	-0.2317	0.0205		
GEOFISH	0.1397	0.0129	82.446	0.0003
MEAN	-0.2405	0.0249		
LARGDH12	0.2837	0.0036	79.932	0.0001
MEAN	-0.2140	0.0403		
LARGEH12	0.3248	0.0023	79.025	0.0001
MEAN	-0.2118	0.0436		
LARGFH12	0.2500	0.0067	81.615	0.0002
MEAN	-0.2302	0.0278		
MEANDH12	0.3025	0.0047	80.508	0.0001
MEAN	-0.2065	0.0469		
MEANEH12	0.3473	0.0032	79.587	0.0001
MEAN	-0.2140	0.0388		
MEANFH12	0.3079	0.0048	80.791	0.0001
MEAN	-0.2338	0.0244		
LARGTHIC	0.1258	0.0022	78.110	0.0001
MEAN	-0.2509	0.0180		

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
2) Geology and Thermal Models (continued) (P<0.05 Only)				
MEANTHIC	0.1141	0.0068	81.060	0.0001
MEAN	-0.2545	0.0147		
LARGHYCO	0.2842	0.0203	82.690	0.0003
MEAN	-0.2160	0.0394		
MEANHYCO	0.3066	0.0223	82.963	0.0004
MEAN	-0.2216	0.0331		
MEANVOL	0.00000000847	0.0207	83.326	0.0004
MEAN	-0.2892	0.0052		
GPEH12	1.8288	0.0026	79.409	0.0001
MEAN	-0.2195	0.0345		
GPKH12	1.9986	0.0033	79.597	0.0001
MEAN	-0.2224	0.0303		
GPOBJLAR	1.8048	0.0028	79.322	0.0001
MEAN	-0.2169	0.0364		
GPOBJMEA	1.9416	0.0029	79.374	0.0001
MEAN	-0.2121	0.0398		
GEOFISH	0.1467	0.0088	83.517	0.0005
SUMMMEAN	-0.2492	0.0398		
LARGFH12	0.2672	0.0034	82.098	0.0002
SUMMMEAN	-0.2570	0.0341		
MEANFH12	0.3258	0.0027	81.405	0.0002
SUMMMEAN	-0.2587	0.0314		

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
2) Geology and Thermal Models (continued) (P<0.05 Only)				
LARGTHIC	0.1313	0.0013	78.792	0.0001
SUMMMEAN	-0.2774	0.0233		
MEANTHIC	0.1194	0.0044	82.016	0.0002
SUMMMEAN	-0.2755	0.0211		
LARGVOL	0.00000001270	0.0441	86.226	0.0018
SUMMMEAN	-0.2951	0.0114		
MEANVOL	0.00000009210	0.0119	84.085	0.0006
SUMMMEAN	-0.3268	0.0064		
GPEH12	1.9026	0.0016	80.160	0.0001
SUMMMEAN	-0.2363	0.0498		
GPKH12	2.0584	0.0021	80.569	0.0001
SUMMMEAN	-0.2349	0.0481		
SURFACE	0.1805	0.0389	86.721	0.0023
SUMMSTAB	-0.4162	0.0258		
LARGDH12	0.3092	0.0015	79.538	0.0001
SUMMSTAB	-0.4084	0.0334		
MEANDH12	0.3340	0.0018	79.939	0.0001
SUMMSTAB	-0.3986	0.0354		
MEANHYCO	0.3237	0.0141	83.708	0.0005
SUMMSTAB	-0.3715	0.0463		

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
2) Geology and Thermal Models (continued) (P<0.05 Only)				
GPOBJLAR	1.8907	0.0016	79.805	0.0001
SUMMSTAB	-0.3779	0.0463		
GPOBJMEA	2.0600	0.0015	79.630	0.0001
SUMMSTAB	-0.3790	0.0449		
3) Geology and Biogeographic/Climate and Thermal Models (P<0.05 Only)				
GEOFISH	0.1285	0.0229	76.535	0.0001
FALLS	-1.5107	0.0401		
MAX	-0.2185	0.0349		
SURFACE	0.2067	0.0300	77.116	0.0001
FALLS	-1.8951	0.0123		
MAX	-0.2053	0.0483		
LARGFH12	0.2595	0.0077	74.603	0.0001
FALLS	-1.6432	0.0350		
MAX	-0.2086	0.0402		
MEANFH12	0.3162	0.0056	73.837	0.0001
FALLS	-1.6159	0.0351		
MAX	-0.2164	0.0333		
LARGTHIC	0.1338	0.0021	70.848	0.0001
FALLS	-1.7638	0.0273		
MAX	-0.2239	0.0308		
MEANTHIC	0.1214	0.0071	73.859	0.0001
FALLS	-1.6913	0.0271		
MAX	-0.2321	0.0237		

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
3) Geology and Biogeographic/Climate and Thermal Models (continued) (P<0.05 Only)				
LARGVOL	0.00000001200	0.0403	77.745	0.0001
FALLS	-1.6383	0.0320		
MAX	-0.2610	0.0090		
MEANVOL	0.00000000907	0.0227	76.137	0.0001
FALLS	-4.1993	0.0432		
MAX	-0.2844	0.0058		
GPKH12	2.0379	0.0035	72.665	0.0001
FALLS	-1.6214	0.0316		
MAX	-0.2043	0.0451		
GEOFISH	0.1327	0.0181	77.146	0.0001
FALLS	-1.5566	0.0335		
MEAN	-0.2118	0.0470		
LARGTHIC	0.1350	0.0023	71.724	0.0001
FALLS	-1.8375	0.0335		
MEAN	-0.2087	0.0464		
MEANTHIC	0.1254	0.0064	74.664	0.0001
FALLS	-1.7678	0.0210		
MEAN	-0.2197	0.0342		
LARGVOL	0.00000001170	0.0444	79.109	0.0002
FALLS	-1.7006	0.0253		
MEAN	-0.2463	0.0158		
MEANVOL	0.00000000845	0.0300	77.911	0.0001
FALLS	-1.5743	0.0321		
MEAN	-0.2603	0.0117		

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
3) Geology and Biogeographic/Climate and Thermal Models (continued) (P<0.05 Only)				
MEANTHIC	0.1283	0.0046	75.106	0.0001
FALLS	-1.8016	0.0171		
SUMMMEAN	-0.2464	0.0414		
LARGVOL	0.000000001250	0.0317	79.612	0.0002
FALLS	-1.7419	0.0207		
SUMMMEAN	-0.2763	0.0202		
MEANVOL	0.000000000911	0.0200	78.253	0.0001
FALLS	-1.6095	0.0270		
SUMMMEAN	-0.3005	0.0131		
LARGHYCO	0.2879	0.0145	77.858	0.0001
DISTMOR	-0.0536	0.0433		
MEAN	-0.2242	0.0461		
MEANHYCO	0.3138	0.0170	78.215	0.0001
DISTMOR	-0.0527	0.0447		
MEAN	-0.2285	0.0400		
LARGVOL	0.000000001250	0.0385	80.316	0.0003
DISTMOR	-0.0555	0.0471		
MEAN	-0.2873	0.0082		
LARGTHIC	0.1391	0.0012	74.136	0.0001
DISTMOR	-0.0583	0.0471		
SUMMMEAN	-0.2968	0.0209		

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
MEANTHIC	0.1267	0.0037	77.347	0.0001
DISTMOR	-0.0565	0.0471		
SUMMMEAN	-0.2962	0.0185		
LARGVOL	0.00000001360	0.0245	81.105	0.0005
DISTMOR	-0.0579	0.0422		
SUMMMEAN	-0.3160	0.0098		
MEANVOL	0.00000001010	0.0107	79.275	0.0002
DISTMOR	-0.0565	0.0471		
SUMMMEAN	-0.3459	0.0057		
SURFACE	0.2110	0.0333	76.907	0.0002
DRAINAGE	2.3918	0.0363		
DISTLSUP	-0.0453	0.0131		
MAX	-0.2007	0.0475		
MEANFH12	0.3336	0.0048	73.138	0.0001
DRAINAGE	2.0685	0.0495		
DISTLSUP	-0.0377	0.0290		
MAX	-0.2081	0.0378		
LARGTHIC	0.1438	0.0016	67.211	0.0001
DRAINAGE	2.7703	0.0330		
DISTMOR	-0.0636	0.0644		
DISTLSUP	-0.0412	0.0402		
MAX	-0.2101	0.0421		

Appendix 7 (continued). Results of logistic regression analyses for models predicting brook trout presence/absence in northwestern Ontario streams studied during 1993 and 1994.

Variable(s) in Model	Regression Coefficient	Wald Chi-square P	-2 log likelihood	P
3) Geology and Biogeographic/Climate and Thermal Models (continued) (P<0.05 Only)				
MEANTHIC	0.1336	0.0054	70.472	0.0001
DRAINAGE	2.6747	0.0312		
DISTMOR	-0.0617	0.0642		
DISTLSUP	-0.0374	0.0484		
MAX	-0.2135	0.0362		