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Effectiveness of Using Summer Thermal Indices to Classify and Protect Brook Trout Streams in Northern Ontario

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Abstract.—We tested five thermal indices for their ability to differentiate streams containing brook trout *Salvelinus fontinalis* from streams not containing brook trout in forested watersheds of the Precambrian Shield, northern Ontario, with the goal of identifying and protecting riparian areas of thermally sensitive trout streams during timber harvesting. Logistic regression was used to predict brook trout presence and absence, with maximum summer temperature, mean summer temperature, mean sampling temperature, mean maximum summer temperature, and thermal stability as independent variables. Brook trout streams were cooler and thermally more stable than non-brook-trout streams, but temperatures overlapped considerably between the two types of stream. Correct classification of streams ranged from 60.3% for summer temperature stability to 67.1% for maximum summer and mean sampling temperatures. The models yielded correct predictions more often for brook trout absence (~80%) than for brook trout presence (≤50%) because streams with temperatures above lethal limits clearly precluded brook trout presence, whereas cooler temperatures merely indicated thermal suitability. In cooler streams, other factors, such as suitable spawning and rearing habitat and migration barriers, likely contributed to variation in brook trout presence. The specific prediction probabilities of the models could be used to assign management protection levels or identify additional sampling requirements necessary for determining brook trout distributions in streams with suitable temperatures.

Timber harvesting can detrimentally affect stream habitat, water quality, and salmonid populations (Chamberlin et al. 1991; Binkley and Brown 1993), particularly when conducted in riparian areas (Heifetz et al. 1986). Specifically, removal of riparian vegetation can directly increase summer water temperatures to levels that are unsuitable for salmonids (Brown and Krygier 1970; Feller 1981; Barton et al. 1985). Thermal effects can be chronic, persisting for up to 20 years or more after timber harvesting, until a riparian overstory redevelops (Hostetler 1991; Hicks et al. 1991).

Riparian buffer strips have ameliorated some negative effects of forestry practices in North America (e.g., Brown and Krygier 1970; Rishel et al. 1982; Barton et al. 1985). Because brook trout *Salvelinus fontinalis* may be particularly vulnerable to stream temperature increases (Coutant 1977) that result from timber harvesting in riparian areas (Barton et al. 1985), the Ontario Ministry of Natural Resources (OMNR) developed timber management guidelines requiring forestry operators to leave undisturbed reserves of riparian buffer strips adjacent to streams containing brook trout populations (Ontario Ministry of Natural Resources 1988). Buffer-strip dimensions used in Ontario vary depending on the slopes of riparian areas adjacent to the stream and are based, in part, on the work of Trimble and Sartz (1957) in New Hampshire. Originally designed to reduce sediment loadings from logging roads (Trimble and Sartz 1957), these buffer strips also provide shade that helps maintain cooler stream temperatures in summer (Barton et al. 1985).

Under the OMNR guidelines, fisheries biologists are responsible for identifying brook trout

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streams that require riparian protection. However, detailed information on resident brook trout distributions in streams of the Precambrian Shield, northern Ontario, is lacking because much of the region is remote and roadless, thus hindering surveys of aquatic resources. Logistic and fiscal constraints preclude the large-scale surveys required to accurately assess brook trout distributions. As a result, trout habitat may be jeopardized because precise implementation of the OMNR timber management guidelines is often extremely difficult.

Summer stream temperature is the most important single factor influencing brook trout distributions (MacCrimmon and Campbell 1969) and may be useful for discriminating brook trout streams, which need protection, from non-brook-trout streams. Brook trout often inhabit streams receiving groundwater discharge (Threinen and Poff 1963; Portt et al. 1989), which reduces summer stream temperatures and provides suitable thermal conditions. The maximum temperatures previously used to identify brook trout streams range from 19°C (Creaser 1930) to 24°C (Ricker 1934). In southern Ontario, Barton et al. (1985) observed that streams with weekly maximum stream temperatures of 22°C or lower harbored self-sustaining brook trout populations, whereas warmer streams had marginal or no brook trout populations. Brook trout prefer temperatures at or below 20°C (Creaser 1930; Cherry et al. 1977; Peterson et al. 1979) and avoid warmer temperatures (Gibson 1966; Cunjak et al. 1993).

Our objectives were to (1) assess the thermal characteristics of first- and second-order streams of the Precambrian Shield in northern Ontario and (2) evaluate the effectiveness of five summer stream temperature indices for discriminating brook trout streams from non-brook-trout streams in this geographic region.

Methods

Study streams were situated in the Lake Superior watershed west and south of Lake Nipigon and west of the Nipigon River. Northern Ontario has a continental climate, with warm summers (mean July temperature, about 16.9°C) and cold winters (mean January temperature, about −17.2°C; Environment Canada climate station, Thunder Bay, Ontario, unpublished data); temperatures are somewhat moderated near Lake Superior. Annual precipitation ranges from 685 to 831 mm, of which 75% falls as rain. Northern Ontario is typical of the Precambrian Shield in that most of the area comprises thin glacial till over igneous and metamorphic bedrock. However, thicker terminal moraines and glaciofluvial deposits are common in localized areas.

Seventy-three first-order and second-order streams from an approximately 30,000-km^2 area of northern Ontario were studied in 1993 (45 streams) and 1994 (28 streams). Mean wetted widths of streams ranged from 0.76 to 7.21 m, and mean watershed areas ranged from 1.6 to 29,391 km^2. Brook trout presence or absence in each stream was determined from three electrofishing passes through one 60-m reach per stream, conducted with a Smith-Root, Inc. backpack electrofishing unit (model 12 or 15B). Sampling occurred in mid-July to August, when summer thermal conditions are most limiting to brook trout. Stream temperatures were measured in each stream with a Taylor maximum–minimum thermometer. Thermometers were randomly placed within each site, except that deep, low-velocity pools were avoided to eliminate the possible effects of thermal stratification (Matthews et al. 1994; Nielsen et al. 1994). From late June to early September in both years, maximum, minimum, and ambient sampling temperatures were recorded to the nearest 1.0°C every other week from the maximum–minimum thermometers, which were then reset. Maximum–minimum thermometer accuracy was verified at each biweekly temperature reading with a Fisher precision thermometer or a calibrated Flett Research, Ltd. digital thermometer, each accurate to within 0.1°C.

Five thermal indices were calculated based on the biweekly temperature measurements: (1) maximum summer temperature, (2) mean maximum summer temperature, (3) mean summer temperature, (4) summer temperature stability, and (5) mean sampling temperature. The first four indices were calculated from temperatures recorded with the maximum–minimum thermometers, and mean sampling temperatures were calculated from temperatures recorded biweekly with the Fisher precision thermometer or the Flett Research, Ltd. digital thermometer. The maximum summer temperature of each stream was the single highest maximum biweekly temperature recorded. The mean maximum temperature of each stream was calculated as the sum of all maximum biweekly temperatures recorded at a site, divided by the total number of site visits. The mean summer temperature was actually the mean mid-range summer temperature and was calculated as the sum of the biweekly mid-range temperatures (i.e., (maximum temperature + minimum temperature)/2) divided by the total number of site visits. Summer temperature stability was calculated as the sum of the differences between biweekly maximum and minimum temperatures divided by the number of site visits. The mean sampling temperature of each stream was calculated as the sum of the temperatures collected at the time of sampling, divided by the number of site visits.

Because streams were studied in 2 years (1993 and 1994) and climatic conditions can influence stream temperatures (Smith 1972), climatic and stream temperature variability was assessed between years. Data from the Environment Canada climate station in Thunder Bay, Ontario, were used to evaluate variation in air temperature between 1993 and 1994 and to were compared normal (i.e., mean) climatic conditions. To directly assess annual variation in stream temperatures caused by annual differences in air temperature, 10 reference streams were monitored during both years, and temperatures were compared between years by use of paired *t*-tests. Differences in each thermal index between brook trout streams and non-brook-trout streams were compared with *t*-tests. The significance level (α) was set at 0.05.

The ability of each of the five thermal indices to predict brook trout presence and absence was evaluated by logistic regression, which is suitable for analyses with a binary response variable (Cox and Snell 1989; Manly 1994). Regression coefficients were estimated with the maximum likelihood method (Hosmer and Lemeshow 1989). Logistic regression uses the function

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

where π is the probability of brook trout presence, e is the inverse natural logarithm of 1, and

$$u = k + m_1 x_1,$$

with k being the regression constant, m_1 the regression coefficient, and x_1 the value of the independent variable.

The -2 log-likelihood statistic was used to test the significance of each model. This statistic measures the deviation of observed values from the model and is analogous to residual sums of squares in linear regression (Hosmer and Lemeshow 1989). Reductions in the value of -2 log-likelihood indicate improved model fit. The significance of -2 log-likelihood is assessed with a chi-square test, and P values less than or equal to 0.05 indicate

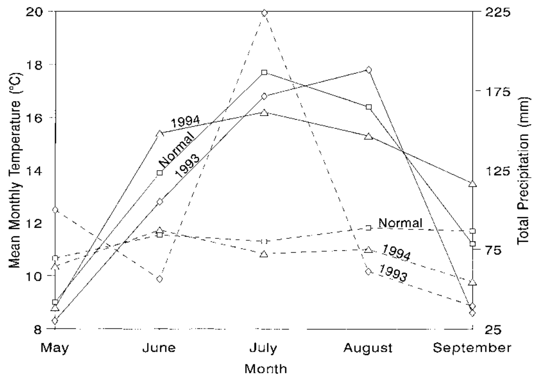


FIGURE 1.—Normal (average) mean monthly air temperatures (left scale; solid lines) and total monthly precipitation (right scale; broken lines) for May to September 1993–1994. Data were recorded at the Environment Canada climate station in Thunder Bay, Ontario.

that the regression coefficient differs significantly from zero (Hosmer and Lemeshow 1989).

To assess correct classification rates, we compared predicted probabilities of brook trout presence and absence that were calculated from the models with observed brook trout presence and absence. Brook trout were predicted as present if predicted probabilities were 0.50 or greater and absent if predicted probabilities were less than 0.50. The kappa statistic was used to determine whether the classifications of brook trout presence and absence produced by the 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). Classifications were considered significant at P values less than or equal to 0.05.

Results

Summer air temperatures and precipitation were similar between the 1993 and 1994 sampling years and were similar to the mean climatic conditions for the region (Figure 1). June and September temperatures were cooler in 1993 than in 1994, whereas July and August temperatures were cooler in 1994 than in 1993. In July and August, when trout sampling occurred, the mean monthly temperatures in both 1993 and 1994 were within 2.0°C of mean daily temperatures for those months. Precipitation was also similar between years (i.e., comparable to average conditions) except in July 1993, when 224 mm of rain fell (141.1 mm greater than normal). Maximum temperatures of some of

TABLE 1.—Comparison (*t*-tests) of differences in mean maximum and mean summer temperatures between 1993 and 1994 for 10 reference streams in northern Ontario. Significance was determined at *P* values less than 0.05.

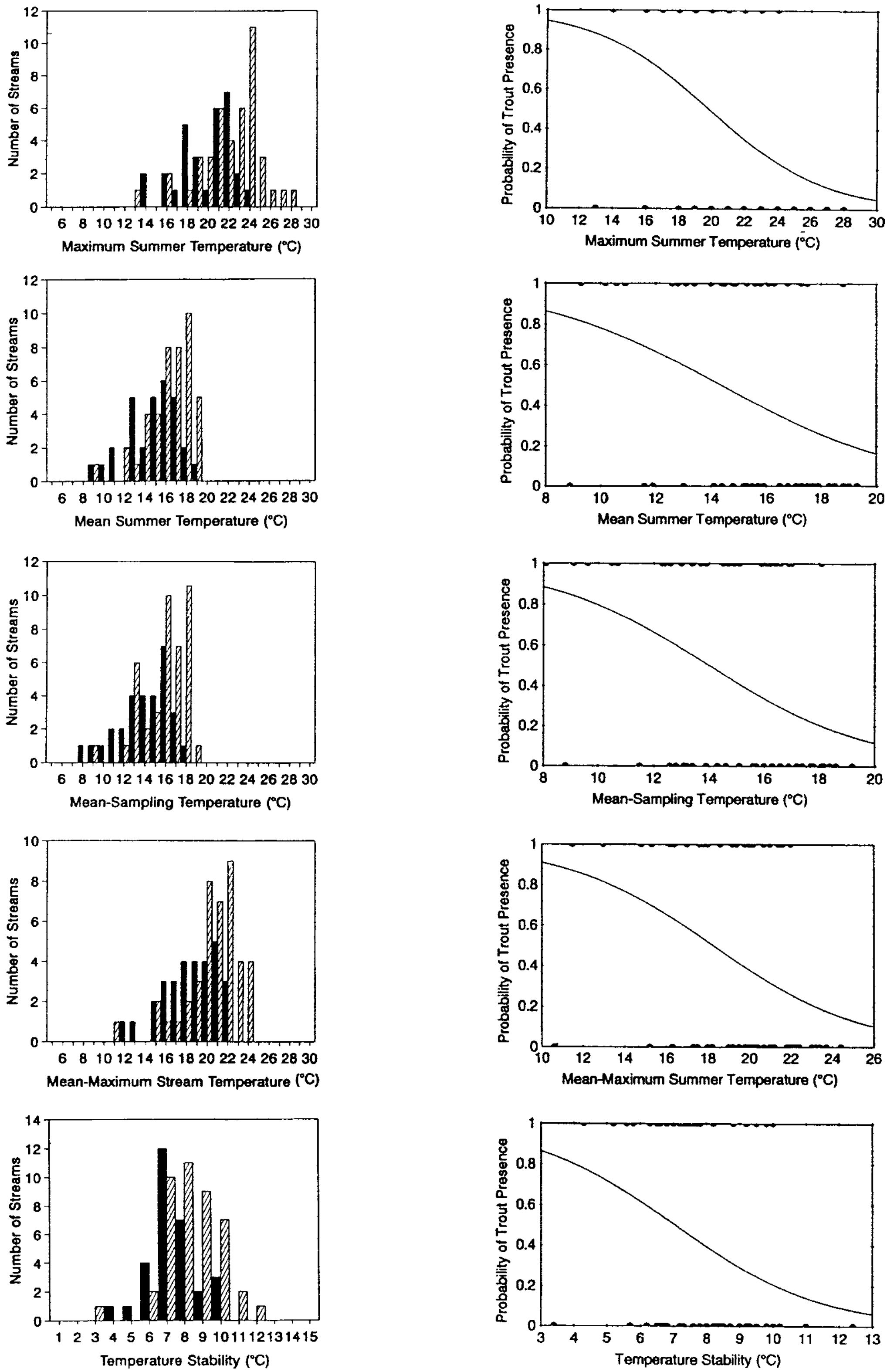
Site	Brook trout presence (1) or absence (0)	1993	1994	*t*	*P*
Mean maximum summer temperature (°C)					
Asterick	1	16.8	16.0	1.5667	0.1682
Buzzer 1	0	19.6	19.0	0.8018	0.4552
East Welch	0	16.6	17.6	−1.2700	0.2398
Max	0	17.6	16.2	1.6733	0.1328
McConnell 1	0	21.3	21.3	0.000	1.000
North Current 1	1	20.8	21.6	−1.2649	0.2415
North Current 5	1	20.2	18.4	2.0125	0.0794
Pearl 1	0	21.0	21.0	0.0000	1.0000
Savigny	0	20.6	20.6	0.0000	1.0000
West Current	1	19.2	19.2	0.0000	1.0000
Mean summer temperature (°C)					
Asterick	1	14.25	12.25	4.3818	0.0047*
Buzzer 1	0	15.50	14.70	1.0643	0.3183
East Welch	0	13.20	13.60	−0.6532	0.5319*
Max	0	14.10	12.20	4.9058	0.0012*
McConnell 1	0	17.33	15.67	1.4142	0.2302
North Current 1	1	17.17	17.50	−0.5000	0.6533
North Current 5	1	17.00	14.38	3.0851	0.0215*
Pearl 1	0	18.00	17.50	0.6124	0.5734
Savigny	0	17.40	16.80	0.9204	0.3843
West Current	1	15.50	15.40	0.1612	0.8767

the 10 reference streams varied between 1993 and 1994, but as a whole, did not appear to be influenced by the slight differences in climatic conditions that occurred between years (Table 1). Though the mean maximum temperatures of four reference streams were higher in 1993 than in 1994, two were lower, and four were the same, none differed significantly between years (Table 1). Similarly, only 3 of 10 streams had mean summer water temperatures that were significantly cooler in 1994 than in 1993. Among all study streams (i.e., brook trout and non-brook-trout combined), mean maximum temperatures were approximately 1.5°C cooler than maximum temperatures, and mean temperatures were approximately 5–6°C cooler than maximum temperatures (Table 2). Mean sampling temperatures were 0.8°C and 0.4°C lower than the mean summer temperatures of brook trout and non-brook-trout streams, respectively.

Brook trout were captured in 30 of 73 streams. For both years, the 30 streams containing brook trout were significantly cooler and thermally more stable than the 43 streams without brook trout (Table 2). Maximum, mean maximum, mean, and mean sampling temperatures were significantly cooler (2°C) in brook trout streams than in non-brook-trout streams (Table 2). Temperatures in brook trout streams were also more stable (i.e., 1°C temperature range) than those in non-brook-

TABLE 2.—Comparison of five stream temperature indices between brook trout and non-brook-trout streams ($n = 73$) in northern Ontario based on *t*-tests. Values are means ± SEs. Significance was determined at *P* values less than 0.05.

Thermal index	Trout streams ($n = 30$)	Non-trout streams ($n = 43$)	*t*	*P*
Maximum summer temperature (°C)	19.8 ± 0.48	22.1 ± 0.45	3.4711	0.0009
Mean maximum summer temperature (°C)	18.4 ± 0.48	20.5 ± 0.41	3.1691	0.0023
Mean summer temperature (°C)	14.8 ± 0.44	16.3 ± 0.33	2.8133	0.0063
Summer temperature stability (°C)	7.4 ± 0.24	8.3 (0.25)	2.7613	0.0073
Mean sampling temperature (°C)	14.04 ± 0.463	15.94 ± 0.338	3.4029	0.0011



Number of Streams
Maximum Summer Temperature (°C)
Probability of Trout Presence
Maximum Summer Temperature (°C)
Number of Streams
Mean Summer Temperature (°C)
Probability of Trout Presence
Mean Summer Temperature (°C)
Number of Streams
Mean-Sampling Temperature (°C)
Probability of Trout Presence
Mean-Sampling Temperature (°C)
Number of Streams
Mean-Maximum Stream Temperature (°C)
Probability of Trout Presence
Mean-Maximum Summer Temperature (°C)
Number of Streams
Temperature Stability (°C)
Probability of Trout Presence
Temperature Stability (°C)

trout streams. However, despite these differences, the distribution of stream temperatures overlapped considerably between brook trout and non-brook-trout streams. For example, maximum temperatures in brook trout streams ranged from 14°C to 24°C, while those in non-brook-trout streams ranged from 13°C to 28°C (Figure 2). The greatest degree of overlap in maximum temperatures occurred near the upper preferred thermal limit of brook trout (20°C), with nearly equal numbers of brook trout streams (17) and non-brook-trout streams (16) having maximum temperatures between 19°C and 22°C. Similar trends were also evident for each of the other thermal indices (Figure 2).

Brook trout presence and absence was significantly related to the five thermal indices (Figure 2; Table 3) because brook trout streams were generally cooler and thermally more stable than non-brook-trout streams. However, stream temperature indices classified trout presence and absence correctly in only 44 (60.3%) to 49 (67.1%) of the 73 streams, depending on the index used (Table 3). Maximum temperature provided the best fit in predicting brook trout presence and absence (i.e., lowest −2 log-likelihood), albeit only marginally better than the other four thermal indices. All temperature models were better predictors of brook trout absence than presence. Absence was correctly predicted in 34–36 of 43 streams (79.1–83.7%), whereas brook trout presence was correctly predicted in only 10–15 of 30 streams (33.3–50.0%).

Discussion

Despite significant relations in the ability of the thermal indices to predict brook trout presence and absence, no single index accurately distinguished brook trout streams from non-brook-trout streams in northern Ontario. Of the five thermal indices used, mean sampling temperature (i.e., ambient temperature) is the easiest to measure and therefore might be the likeliest choice among biologists for determining thermal suitability of streams for brook trout in northern Ontario. The logistic regression model based on this index had as high an overall correct classification rate as the models using maximum summer temperature and mean maximum summer temperature. Yet, though it was the best predictor of trout presence, this index unfortunately still misclassified 15 of the 30 trout streams and had a lower classification rate at predicting absence than did the other indices. Therefore, if only ambient stream temperatures were used to classify streams based upon spot surveys during timber management planning, clearly a large number of trout streams in northern Ontario would not be identified.

In general, thermal indices yielded correct classification predictions more often for brook trout absence (approximately 80%) than for brook trout presence (≤50%). While temperature plays a role in structuring brook trout distributions in northern Ontario (i.e., the models were significant), this uneven classification success rate indicates that other factors also influence brook trout distribution. The higher rates attained in predicting non-brook-trout streams (i.e., absence) occurs because high stream temperatures preclude brook trout survival once a thermal threshold level is attained. Many previous studies have indicated that brook trout prefer colder streams (≤20°C) (Creaser 1930; Cherry et al. 1977; Peterson et al. 1979) and avoid warmer temperatures (Gibson 1966; Cunjak et al. 1993), thus making temperature an excellent candidate variable to index trout populations for timber harvest planning purposes. Our study concurs with previous research findings that brook trout are absent from streams where maximum temperatures exceed 24°C (Barton et al. 1985). Because of the lethality of these higher temperatures, trout absence is nearly certain, thus producing more accurate prediction rates. Conversely, at lower temperatures, trout presence and absence are less clearly discriminated, because cooler stream temperatures do not themselves ensure brook trout presence. Rather, temperature is only one prerequisite of many for brook trout survival and persistence. Other factors, such as the lack of adequate spawning and rearing habitat, the influence of other species, stochastic climatic catastrophes (e.g., drought), and migration barriers may prevent

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FIGURE 2.—Frequency distributions of five summer thermal indices for brook trout (solid bars) and non-brook-trout streams (crosshatched bars) of the Precambrian Shield in northern Ontario (left panels) and probabilities of brook trout presence in northern Ontario streams relative to the respective thermal indices (right panels). Probabilities were calculated by means of logistic regression. Maximum summer, mean maximum, and mean sampling temperatures were considered significant at P values less than or equal to 0.05.

TABLE 3.—Results of logistic regression analyses, correct classification rates, and kappa statistics of the five temperature indices predicting brook trout presence and absence in 73 northern Ontario streams.

Variable in model	−2 log-likelihood	*P*	Presence (%) (*n* = 30)	Absence (%) (*n* = 43)	Overall (%) (*n* = 73)	Kappa	*P*
Maximum summer temperature (°C)	87.665	0.0008	13 (43.3)	36 (83.7)	49 (67.1)	0.285	<0.025
Mean maximum summer temperature (°C)	89.414	0.0021	14 (46.7)	35 (81.4)	49 (67.1)	0.292	<0.010
Mean summer temperature (°C)	91.363	0.0061	10 (33.3)	36 (83.7)	46 (63.0)	0.182	>0.050
Summer temperature stability (°C)	91.347	0.0061	10 (33.3)	34 (79.1)	44 (60.3)	0.131	>0.050
Mean sampling temperature (°C)	88.176	0.0011	15 (50)	34 (79.1)	49 (67.1)	0.300	<0.010

brook trout from colonizing and persisting in some thermally suitable streams. Moreover, catastrophic climatic events may have greater consequences for streams located close to thermal thresholds, as episodic climatic conditions that increase temperatures could cause local extirpations (Rahel and Nibblelink 1999), whereas cooler streams situated away from thermal thresholds are more thermally buffered and less subject to perturbation. When microclimates of streams are altered during timber harvesting in riparian areas, thermally marginal streams are more likely to lose trout populations (Barton et al. 1985).

Classification of natural systems based on a single continuous variable, such as temperature, can be problematic because stream thermal conditions lie along a temperature continuum that makes precise classification difficult. The overlap in temperatures near the thermal tolerances of brook trout was one source of error in the models. The low classification success rate in our study resulted from temperatures of warmer brook trout streams overlapping with those of many non-brook-trout streams, particularly the cooler ones. For example, nearly equal numbers of brook trout and non-brook-trout streams had maximum temperatures between 19°C and 22°C. As a result, our logistic regression analyses indicated that the probability of predicting brook trout presence at 20°C dropped to less than 50%. In this case, the consequence of employing maximum temperature as a predictor is that brook trout were actually present in 17 streams predicted as non-brook-trout streams by this model.

Stream temperatures are generally protected by riparian buffer strips (Binkley and Brown 1993), although summer stream temperatures have also increased following timber harvest operations that maintained buffer strips (Aubertin and Patric 1974; Hewlett and Fortson 1982; Rishel et al. 1982). In studies demonstrating the effectiveness of riparian buffers, maximum summer water temperature increased from 1.2°C to 6.0°C and persisted for up to 6 years. Similar temperature increases in some of the brook trout streams we studied in northern Ontario would likely raise temperatures above lethal limits (i.e., ~24–25°C), thereby causing local extirpations. Meisner (1990) simulated loss of thermal habitat for brook trout due to increased climatic warming in southern Ontario streams. An estimated 30–42% reduction in summer thermal habitat for brook trout occurred in two streams when mean annual air temperatures increased by 4.1–4.8°C. Large-scale timber harvesting in riparian areas across northern Ontario could create similar thermal effects on brook trout streams. Barton et al. (1985) demonstrated that stream temperatures in clearcuts increase linearly with distance from buffered areas. They found that stream sections with no forested riparian buffer could increase in temperature by more than 7°C at sites over 6 km beyond buffered riparian areas.

In studies demonstrating increased stream temperatures despite application of buffer strips, indirect hydrologic processes during timber harvest in areas outside the riparian zone may have occurred. For instance, deforestation of groundwater recharge areas in upland sections of watersheds inhibits water infiltration (Lee 1980), thereby reducing groundwater storage and transmission to streams and, in turn, reducing the thermal buffering capacity of those systems. Groundwater effects are especially prevalent when soils are disturbed and compacted by the heavy machinery used in modern forestry and silvicultural practices (Chamberlin et al. 1991). In addition to increased stream temperatures following deforestation of recharge zones, streamflows can also be drastically altered; small streams may become intermittent (Kostadinov and Mitrovic 1994) or experience chronic reductions in summer base flow (Hicks et al. 1991). Moreover, increased stream temperatures may alter the connectivity of metapopulations and affect the ability of brook trout to recolonize streams where they are extirpated. Thus, the brook trout carrying capacity in some streams may be reduced or eliminated, and long-term sustainability may be jeopardized. Relations between timber harvesting in upland areas of watersheds, stream groundwater discharge, and thermal suitability need further investigation, particularly in light of the marginal nature of these streams.

Brook trout in our study area existed in streams with temperatures above thermal preferenda and even those with temperatures near the upper lethal limit. Perhaps some of these brook trout may have adapted to slightly warmer temperatures, or perhaps the warmer brook trout streams contained pockets of suitable thermal microhabitat created by localized groundwater discharge that were undetected in our sampling. Brook trout in warmer streams probably rely on cooler temperatures near localized groundwater discharge areas during periods when streams reach maximum temperatures (Gibson 1966; Bowlby and Roff 1986; Cunjak et al. 1993). Groundwater discharge refugia can be 5.0–7.5°C cooler than the ambient stream temperature (Gibson 1966; Bilby 1984; McCrae and Edwards 1994). If similar coolwater refugia exist in northern Ontario streams, then even the warmest brook trout streams in our study (i.e., maximum temperature = 24°C) might still sustain some fish until cooler seasonal temperatures prevail in the fall. Because of the local nature of groundwater discharge (i.e., seeps), these streams would probably not be identified via thermal indices unless temperature was measured near the groundwater discharge areas. From a modeling standpoint, such a situation increases the error in predicting trout presence and absence. From a practical standpoint, locating thermal refugia for the purpose of broadly applying the OMNR timber management guidelines would be prohibitive.

Several alternate approaches that might increase the applicability of thermal indices are possible. The first approach is to use only the absence portion of the classification to identify non-brook-trout streams and then either to protect all remaining streams (i.e., those identified as potentially containing brook trout) or collect fish data from those streams. A second approach would be to use the best presence model in combination with the best absence model. A third approach would be to assign an acceptable probability level error rate for predicting presence and absence of trout. Used in this context, temperature can be a screening variable to identify streams with suitable thermal conditions for brook trout. Biologists could assign a probability of trout presence (or suitability) to streams based on the temperatures of the streams and then determine the probability of misclassification for different management activities. Perhaps, at some predetermined sensitivity level that entails an unacceptable misclassification risk, additional sampling could be warranted or additional protection could be conferred outright.

The results of our study indicate that summer temperature measurements collected at random points in streams would be insufficient to identify brook trout streams requiring protection from timber harvest operations, unless applied within the context of a more comprehensive sampling and analysis program. Our research clearly identifies that many brook trout streams in northern Ontario approach the upper thermal limits of brook trout physiology, thereby underscoring the need to identify and protect streams and their watersheds from forestry or other land use practices that result in elevated stream temperatures. Implementation of riparian buffer strips on brook trout streams aids in this effort, but may not be sufficient to protect many marginal streams from the indirect hydrologic effects of timber harvesting in the watershed. Forested groundwater recharge areas in northern Ontario may require maintenance of undisturbed reserves of standing forests in watersheds to protect brook trout habitat.

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