Population indices of brook trout (*Salvelinus fontinalis*), Atlantic salmon (*Salmo salar*), and salmonid competitors in relation to summer water temperature and habitat parameters in 100 streams in Nova Scotia

J.L. MacMillan, D. Caissie, T.J. Marshall, and L. Hinks

Department of Fisheries and Oceans
Gulf Region
Oceans and Science Branch
Diadromous Fish Section
P.O. Box 5030, Moncton, NB, E1C 9B6

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Population indices of brook trout (*Salvelinus fontinalis*), Atlantic salmon (*Salmo salar*), and salmonid competitors in relation to summer water temperature and habitat parameters in 100 streams in Nova Scotia

by

J. L. MacMillan[1] D. Caissie[2] T.J. Marshall[1] L. Hinks [3]

Department of Fisheries and Oceans
Gulf Region, Oceans and Science Branch
Diadromous Fish Section
P.O. Box 5030, Moncton, NB, E1C 9B6

[1.] **Nova Scotia Department of Fisheries and Aquaculture, Inland Fisheries Division, Pictou, NS, B0K 1H0.**
[2.] **Fisheries and Oceans, Diadromous Fish Section, Moncton, NB, E1C 9B6.**
[3.] **Atlantic Salmon Federation, Box 359, Chester, NS, B0J 1J0.**

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ABSTRACT

MacMillan, J.L., D. Caissie, T.J. Marshall, and L. Hinks. 2008. Population indices of brook trout (*Salvelinus fontinalis*), Atlantic salmon (*Salmo salar*), and salmonid competitors in relation to summer water temperature and habitat parameters in 100 streams in Nova Scotia. Can. Tech. Rep. Fish. Aquat. Sci. 2819: 41p.

Many Nova Scotia streams warm to stressful levels for brook trout (Salvelinus fontinalis) and Atlantic salmon (Salmo salar) in summer. A total of 100 streams were classified into three categories based on the mean summer water temperature and known thermal preferences for brook trout. Mean summer water temperatures were <16.5^{o}C for cool streams, between 16.4 and 19^{o}C for intermediate streams, and >18.9^{o}C for warm streams. Studied streams were electrofished to determine potential influences of thermal conditions on salmonids during the summer.

Juvenile salmon population densities ranged from zero to 65 fish/100m^2 and were not greatly influenced by water temperature. Brook trout population densities ranged from zero to 332 fish/100m^2 and were strongly influenced by mean summer water temperature. Notably, the mean population density of brook trout was 58 fish/100m^2 in 33 cool water streams, 14 fish/100m^2 in 33 intermediate streams, and 2 fish/100m^2 in 34 warm water streams. Stream habitat parameters including habitat type, substrate, cover, and water depth were not correlated with salmonid densities. However, warm water streams were wider, more acidic, and less conductive compared to cool water streams. Non-salmonid species sampled that were considered to be competitors on trout included: yellow perch (*Perca flavescens*), smallmouth bass (*Micropterus dolomieu*), chain pickerel (*Esox niger*), American eel (*Anquilla rostrata*), white sucker (*Catostomus commersoni*), brown bullhead (*Ameiurus nebulosus*). One or more competitor species were present in 39% of cool water streams, 64% of intermediate streams, and 85% of warm water streams.

Regional differences in water quality parameters are related to surficial geology. Most cool water streams were circumneutral (6 < pH < 8), conductive, inhabited by few fish species, and important summer habitat for brook trout. The thermal nature of rivers is an important consideration in the development of management strategies to improve and sustain the trout fishery in Nova Scotia.

RÉSUMÉ

MacMillan, J.L., D. Caissie, T.J. Marshall, and L. Hinks. 2008. Population indices of brook trout (*Salvelinus fontinalis*), Atlantic salmon (*Salmo salar*), and salmonid competitors in relation to summer water temperature and habitat parameters in 100 streams in Nova Scotia. Can. Tech. Rep. Fish. Aquat. Sci. 2819: 41p.

Plusieurs rivières de la Nouvelle-Écosse ont des températures de l'eau élevée en été et celles-ci peuvent atteindre un niveau critique pour les populations d'omble de fontaine (*Salvelinus fontinalis*) et du saumon de l'Atlantique (*Salmo salar*). Un total de 100 cours d'eau a été classifié en trois catégories basées sur la température moyenne estivale et la préférence thermique de l'omble de fontaine, soit les cours d'eau froids <16.5^oC, intermédiaires (16.4 à 19^oC) et les cours d'eau chauds >18.9^oC. Une pêche à l'électricité a été effectuée sur les cours d'eau étudiés durant la période estivale afin de déterminer l'influence potentiel de la température sur les salmonidés.

Les populations juvéniles de salmonidés variaient entre zéro et 65 poisson/100m^2 et celles-ci n'étaient pas grandement influencées par la température de l'eau. Les populations d'omble de fontaine variaient entre zéro et 332 poisson/100m^2 et celles-ci étaient grandement influencées par la température moyenne de l'eau. Notamment, la population moyenne d'omble de fontaine étaient de 58 poisson/100m^2 dans 33 cours d'eau froids, 14 poisson/100m^2 dans 33 cours d'eau intermédiaires et 2 poisson/100m^2 dans 34 cours d'eau chauds. Les paramètres de l'habitat du poisson des cours d'eau, incluant le type d'habitat, le substrat, le couvert et la profondeur d'eau, n'étaient pas corrélés avec les densités des salmonidés. Par contre, les cours d'eau chauds étaient plus larges, plus acidifiés, avec une conductivité spécifique plus faibles comparativement aux cours d'eau froids. Les espèces non salmonidés échantillonnées aussi considérées comme des concurrents à l'omble de fontaine inclus: la perchaude (*Perca flavescens*), l'achigan à petite bouche (*Micropterus dolomieu*), le brochet maillé (*Esox niger*), l'anguille d'Amérique (*Anquilla rostrata*), le meunier noir (*Catostomus commersoni*), et la barbotte brune (*Ameiurus nebulosus*). Les non salmonidés compétiteurs aux salmonidés étaient presents dans 39% des cours d'eau froids, 64% des cours d'eau intermediaries et 85% des cours d'eau chauds.

Les différences régionales dans les paramètres de qualité de l'eau sont surtout liées à la géologie de surface. La plus part des cours d'eau froids étaient circumneutre (6 < pH < 8), avec une forte conductivité, peu habité par les espèces de poissons et important pour l'omble de fontaine. La nature thermique des rivières est alors une considération importante au développement d'une gestion stratégique dans le but d'améliorer et soutenir une pêcherie halieutique en Nouvelle-Écosse.

1.0 INTRODUCTION

Brook trout and Atlantic salmon are important species to the Nova Scotian sport fishery that was worth approximately $53 million to the provincial economy and had supported the participation of about 51,000 licensed anglers in 2005 (DFO 2007). Decline in the annual catch of brook trout and Atlantic salmon may reflect a change in the sport fishery. Habitat loss, introduced species and over-exploitation are commonly cited for changing the sport fishery resource. Understanding the factors that control significant species is essential to resource management (Kohler and Hubert 1999). Brook trout and Atlantic salmon are members of the salmonid family, and require cool water habitat in order to survive (Power 1980, Cherry et al. 1977). Brook trout are one of the most sensitive salmonids to warm water, and tend to avoid temperatures greater than 20^{o}C, whereas brown trout (Salmo trutta) and Atlantic salmon are slightly more tolerant of warmer waters (Garside 1973). In response to thermal stress from warm water, brook trout will migrate to cooler waters (Elson 1942, Gibson 1966, Baird and Krueger 2003, Biro 1998).

Climate changes and land use practices have increased water temperatures, and decreased flow rates and water levels (Schindler 2001). Habitat degradation was related to warmer water, fewer salmonids, and increased stream size on the River Philip, Nova Scotia (Kanno and MacMillan 2004). Currently, many Nova Scotia stream systems warm to temperatures that are considered to be seasonally unsuitable for salmonids and future warming of fresh waters by only 2^{o}C could result in a significant loss of cool water habitat. For example, a total of 312 streams in Nova Scotia were classified into three thermal categories: cool (ideal for brook trout), intermediate (marginal), and warm (unsuitable for brook trout) (MacMillan et al. 2005). Salmonid population and habitat data were collected from 100 stream sites that were previously assessed through the Nova Scotia water temperature-monitoring program.

Besides the River Philip study by Kanno and MacMillan (2004), few related studies in Nova Scotia have looked at the relationship between water temperature and fish presence and habitat parameters (Miles 1986, Cameron and Gray 1979, Sabean 1976, Alexander et al. 1986). Therefore, the purpose of this study was to identify stream habitat parameters that are factors limiting production of salmonids in Nova Scotia. The Nova Scotia stream classification system was based on the assumption that cool water sites are more important to Atlantic salmon and brook trout populations during warm low flow conditions in summer.

2.0 MATERIALS AND METHODS

Fish habitats and populations were assessed for 100 streams on 23 river systems in Nova Scotia during the summers from 2002 to 2005 (Figure 1). Surveyed river systems were selected to represent different habitat conditions within the province's river systems from each of the six Recreational Fishing Areas (RFAs). The streams were formerly categorized based on mean summer water temperature using Vemco™ mini data loggers from 15 June through to 5 September, as described in MacMillan et al. (2005). The number of stream study sites and mean summer temperatures was used to determine their category: cool (< 16.5°C), intermediate (16.5 - 18.9°C), and warm (≥19.0°C) sites. Mean summer water temperature was assessed between 2000 and 2002 and up to five years prior to provide detailed assessments of fish habitats and populations. Twenty-two volunteer organizations participated in the collection of habitat parameters and fish population indices (Table 1). Water temperature at the time of sampling, specific conductivity and acidity (pH) was measured using a YSI 63 pH meter at each site.

Habitat survey measurements of stream length and wetted stream width were recorded to the nearest tenth of a meter at each study site. Two cross channel habitat transects were located between the upstream end and the mid-section of the study site and two transects were located between the mid-section and the downstream end (for a total of four transects). Transects were approximately equal distances apart in order to sample different habitat types within the electrofishing site. Stream width was recorded at each transect. Surface area for each site was estimated from the mean stream width and the total stream length.

Water depth, substrate and cover were recorded at three points along each of the four transects for a total of twelve points at each site electrofished. Water depths were recorded with a meter stick to the nearest centimeter. The substrate (fines, gravel, cobble, boulder, or bedrock) was recorded at the point where the meter stick intersected with the stream bottom. The fine substrate classification included sand and silt with a diameter less than one centimeter. Gravel included substrate that ranged from 1cm to 10cm in diameter. Cobble ranged from 10cm to 25cm and boulder was larger than 25cm in diameter. Bedrock or hardpan were sections that contained relatively large flat rock substrate.

Fish cover included instream cover, overhanging vegetation and canopy cover. Cover type was recorded at each point where water depth and substrate were recorded. More than one cover type could be recorded at a transect point. Instream cover included aquatic vegetation, logs or branches that could provide hiding sites for fish. Vegetation was classified as overhanging if present within one meter above the surface of the water where the transect point was located. Overhanging vegetation included leaves, branches of trees and grasses. Canopy vegetation was located higher than one meter above the surface of the water and included the leaves and branches of trees.

Habitat types such as riffles, runs, and flats, were identified at each of the three points along each transect line dependent on water velocity, substrate, and depth of water. Riffles and runs displayed faster flowing waters often with a broken surface. Riffles were characterized as shallow and fast flowing water with a velocity greater than 0.3 m/s where gravel, cobble or boulder was partially exposed above the water surface. Runs were characterized as fast moving water with a velocity of >0.3 m/s over substrate that was not exposed to the air. Flats were slow moving (<0.3 m/s) or still water appearing flat on the surface.

Fish populations were assessed using a Smith-Root model 12 electrofisher. Electrofishing was conducted using a voltage range from 100 to 800 V and a frequency of 60 Hz. In this study, a one sweep electrofishing method or rapid assessment technique was used to estimate fish populations as described by Kruse et al. (1998). Using the one sweep (or single pass) method increased the number of sites where population estimates could be obtained. The single pass method utilized in the present study was selected based on results of eighty trout population estimates where the removal method (Zippin 1958) was used by the Inland Fisheries Division of the Nova Scotia Department of Fisheries and Aquaculture. Regression analysis to determine the relationship between the number of trout caught in the first electrofishing sweep and the total population estimate was defined as $y = 1.98x$, $r^2=0.834$, $p<0.001$, where x = number of fish caught in a single sweep and y= population estimate. From this equation the number of trout caught in the first sweep represented close to 50% of the total trout population estimate in the site. Although, Kruse et al. (1998) reported a higher r^2 (0.94) for the one sweep method and total fish density comparisons, the coefficient of determination used in our study (r^2 = 0.83) was nonetheless useful in providing an index of density for comparison among sites and thermal categories. The linear relationship for brook trout was used to estimate the population density of different fish species or families.

The absence of barrier nets used in the one sweep method was not believed to have a significant impact on fish escapement because of the water depth and size of the streams sampled. The sampled sites were on average 0.18 m (std = 0.06 m) in depth, 53 m (std = 21 m) long, 4.5 m (std = 2.3 m) wide, and 247 m^2 (std = 161 m^2) in surface area. The electrofishing start point was located at the downstream end of the site. Electrofishing was conducted by slowly moving upstream and shocking in a zigzag movement across the stream channel to sample the entire surface area of the site. Dip nets were used by at least one individual at each site. The individuals involved in the electrofishing sample were careful not to disturb the site prior to electrofishing. Dip netting was conducted in a consistent manner by following the electrofisher probe to minimize escapement of fish. Captured fish were placed in a bucket of water, retained for sampling and released back into the electrofishing site. Salmonids were measured to the nearest millimeter and were weighted to the nearest gram. Non-salmonid species were identified and released. Brook trout biomass (grams per 100 m^2) estimates were calculated for electrofishing sites from the weight-length relationship ($W=0.008*L^{3.12}$, w=weight in g, L=length in cm) from a subsample of the measurements taken on brook trout sampled. Brook trout biomass per 100 m^2 was used as a population index.

Fish were identified to species and included: brook trout, Atlantic salmon, brown trout, yellow perch, smallmouth bass, chain pickerel, white perch, American eel , white sucker, brown bullhead, banded killifish *Fundulus diaphanus,* and gaspereau *Alosa pseudoharengus.* The five species of stickleback in Nova Scotia were reported as Gasterosteidae and included, fourspine stickleback *Apeltes quadracus,* brook stickleback *Culaea inconstans,* threespine stickleback *Gasterosteus aculeatus,* blackspotted stickleback *Gasterosteus wheatlandi,* and ninespine stickleback Pungitius pungitius. All minnows and chub were reported as Cyprinidae. Nova Scotia Cyprinidae included northern redbelly dace *Phoxinus eos,* lake chub *Couesius plumbeus,* golden shiner *Notemigonus crysoleucas,* common shiner, *Luxilus cornutus,* blacknose shiner *Notropis heterolepis,* blacknose dace *Rhinichthys atratulus*, creek chub *Semotilus atromaculatus,* fallfish *Semotilus corporalis,* and pearl dace *Margariscus margarita*. The number of species or family per 100m^2 was used as a population index. Non- salmonid species that are considered to be important competitors of trout include: white sucker (Flick and Webster 1992), yellow perch (Fraser 1978), American eel (Hayes and Livingstone 1955), smallmouth bass, and chain pickerel (Smith 1952), Brown bullhead have been reported to prey on the eggs of lake trout *Salvelinus namaycush* (Martin 1957), and, therefore were also categorized as a competitor of trout in our study. The proportion of non-salmonid competitors was determined for each thermal category.

Relationships among fish population densities, pH, conductivity, stream width, substrate, cover, and habitat type in each thermal category were assessed. To study the statistical differences between both physical and biological parameters of different thermal categories, a one-way analysis of variance (ANOVA) was carried out. Duncan's multiple range (DMR) test was used to discriminate significant differences among parameters. This test evaluates the statistical significance of ranges in the sorted sample for each pair of means.

3.0 RESULTS

Electrofishing site habitat parameters relating to temperature, width, depth, substrate, cover, and habitat type, were recorded from 100 stream sites on 23 river systems in Nova Scotia (Appendix A). The number of stream study sites and mean summer temperatures in each category were 33 cool (< 16.5°C), 33 intermediate (16.5 - 18.9°C), and 34 warm (≥18.9°C) sites. The mean values of each habitat parameter were determined for streams in each of the three thermal categories and compared. Mean water temperature for streams in each category was 14°C in cool, 17°C in intermediate, and 21°C in warm. The number of days when the mean summer water temperature was greater than 20°C was 0.3 for cool streams, 6 for intermediate streams, and 54 for warm streams (Table 2).

Streams with cool or intermediate mean summer temperatures were generally associated with narrower stream widths. Only one stream from both the cool stream category and intermediate stream category had a stream width greater than six meters, in comparison; fourteen warm category streams had a width greater than six meters (Figure 2). Mean stream width was 3.5 m for cool streams, which was similar to the 3.9 m for intermediate streams, however, warm sites showed significantly ($p < 0.0001$) wider stream width at 6.0 m. Figure 2 also showed a significant linear trend ($p < 0.001$) showing wider streams having warmer temperatures, although the explained variability was only 23% ($R^2 = 0.23$). The greater stream size as defined by stream width also showed a greater stream depth, although the depth of warm sites was significantly different than that of cool sites but not for intermediate sites ($p = 0.018$). Mean depth was 0.16 m in cool streams, 0.17 m in intermediate streams, and 0.20 m in warm streams.

Stream pH decreased as water temperature increased. For instance, mean pH was 7.1 in the cool category, 6.8 in the intermediate category, and 6.2 in the warm water category (Table 2). The pH of warm sites was significantly lower than for other sites ($p < 0.0001$). The cool water category included streams that were acidic or neutral, and all were greater than a 6.3 pH level. The intermediate thermal category contained six streams with pH below 6.3. The warm water category included the most acidic streams in the survey with eight streams below the lowest 5.5 pH level of streams in the intermediate category (Figure 3). This figure shows a significant decreasing trend of pH with mean summer water temperature ($p < 0.001$; $R^2 = 0.26$).

Mean specific conductivity was greater in cool water streams compared to intermediate or warm water streams. Mean specific conductivity was 224 μS in 26 cool streams, 180 μS in 23 intermediate streams, and 66 μS in 26 warm streams (Table 2). The exclusion of an outlier value of 1357 from Big Brook, River Denys reduced the mean specific conductivity value to 127 μS for intermediate sites which still represents an intermediate value.

The mean percentage of different substrate types demonstrated little variation among the three thermal categories (Table 2) and all substrate categories showed no significant relation with cool, intermediate and warm temperature sites. Gravel and cobble percentage ranged from 29% to 34% and were the most abundant substrate types in each of the three thermal categories (Figure 4). The percentage of bedrock substrate was found to be the least abundant and was close to one percent in all thermal categories sampled. The mean percentage of fine substrate was 20% in cool sites, 12% in intermediate sites, and 17% in warm sites.

The mean percentage of different cover types demonstrated little variation among the three thermal categories (Figure 5). Canopy was the most abundant cover type among all of the thermal categories. Mean percentage of canopy cover was 40% in cool water streams, 47% in intermediate water streams, and 33% in warm water streams. The percentage of overhang was greater in cool (37%) streams compared to warm (27%) streams and the percentage of instream cover was greater in warm (31%) streams compared to cool (20%) streams. Overhanging vegetation was slightly different between cool and intermediate sites ($p = 0.05$); however, both were similar to warm temperature sites. The "no cover" habitat category may be related to the amount of shade and solar radiation that can result in warming and instream growth of aquatic vegetation. The percentage of no cover habitat in cool water streams was slightly less than in both intermediate and warm water sites but all showed no statistical differences (Table 2).

The most abundant habitat type in all thermal categories was flats, followed by run, then riffle (Figure 6). The mean percentage of flat habitat type was very similar in cool (56%) streams and in warm (58%) streams. The mean percentage of riffle habitat type was 12% in cool streams, 3% in intermediate streams, and 11% in warm streams. The mean percentage of riffles and runs was similar in cool and warm water streams (Table 2).

The mean population density for brook trout was 24 fish per $100m^2$ and ranged from 0 to 332 fish per $100m^2$. The mean biomass density for brook trout was 448 g per $100m^2$ and ranged from 0 to 6756 g per $100m^2$ (Appendix B). Streams with large population densities of brook trout tended to be found in the cool water category (Figure 7). Mean brook trout biomass was 1126 g per $100m^2$ in cool streams, 214 g per $100m^2$ in intermediate streams, and 16 g per $100m^2$ in warm streams (Table 3). Mean brook trout biomass was significantly higher in cool water temperature sites ($p<0.0001$) compared to other sites, whereas biomass in both intermediate and warm temperature sites were not significantly different. The greatest brook trout population densities were located in streams that had a width of less than six meters. Brook trout tended to be absent or in very small numbers in streams with widths greater than six meters which is reflective of warmer temperature sites (Figure 8). The greatest brook trout population densities were located in streams with a pH level of greater than 6.3 (Figure 9).

The mean population density for Atlantic salmon was 6 fish per $100m^2$ and ranged from 0 to 65 fish per $100m^2$ (Appendix B). No relationship was apparent between Atlantic salmon density and stream width (Figure 10). Atlantic salmon were absent in acidic streams that were less than 5.5 on the pH scale (Figure 11). The mean number of Atlantic salmon juveniles per $100m^2$ in each thermal category was 9.1 in the cool water category, 4.6 in the intermediate category, and 4.3 in the warm category and showed no significant differences between thermal categories (Table 3). The mean number of brown trout per $100m^2$ in each thermal category was 7.5 in cool streams, 0.2 in intermediate streams, and 0.3 in warm streams. Brown trout were only found in 8 streams and the large population density from Rochford Brook (148 trout per $100m^2$), a cool water stream in Cornwallis River, resulted in a relatively high mean in the cool water category compared to other thermal categories.

Non-salmonid competitors of trout that were captured in electrofishing sites included; white sucker, yellow perch, American eel, smallmouth bass, brown bullhead, and chain pickerel (Appendix B). The presence of competitors was related to summer water temperature in the electrofishing sites. White sucker were located in each of the thermal categories and were more abundant in intermediate and warm water categories but no significant differences among categories. American eel were present in all thermal categories and the number of American eel at 10.9 per $100m^2$, was significantly greater ($p = 0.0005$) in the warm water category than both the cool and intermediate water categories. Brown bullhead catfish and yellow perch were only detected in intermediate and warm water categories. Smallmouth bass and chain pickerel were only detected in the warm water sites. The proportion of sites with competitors was 0.39 in the cool water category, 0.64 in the intermediate category and 0.85 in the warm category (Table 3). Captured fish that were not considered to be competitors of salmonids included stickleback, gaspereau, banded killifish, and cyprinids. Stickleback and cyprinids were found in sites in each thermal category. Gaspereau and killifish were found in sites in the warm water category.

4.0 DISCUSSION

Brook trout population density was strongly related to water temperature. Streams that had a summer mean water temperature of 19°C and warmer had either very few or no brook trout. Nova Scotia streams are sensitive to warming. For example, a 2°C increase in summer mean water temperature could result in a 50% loss of cool water stream habitats and a dramatic increase in warm water habitats (MacMillan et al. 2005). Future warming could further reduce cool water habitats as air temperatures in the Maritime Provinces could increase by 4-6°C over the next 50-100 years (Parks Canada 1999). For this reason, the identification, protection, and restoration of cool water habitats are important initiatives to improve and sustain the trout fishery in Nova Scotia.

The consequences of climate warming on salmonid habitat could be severe and may result in significant changes to the behaviour and distribution of cold-water fishes (Schindler 2001). As main branches of rivers tend to warm earlier and to a greater extent than tributaries, the large densities of trout detected in some cool water sites may reflect the use of thermal refugia by brook trout. A recent multi-year telemetry tracking study demonstrated extensive usage of small spring seeps by brook trout in a warm water acid stressed system in Kejimkujic National Park, Nova Scotia. Spring seeps were much cooler and less acidic compared to surface waters (Corbett et al. 2008). Behavioural thermoregulation allows fish to avoid harmful temperatures but can result in large numbers of fish moving into small areas (Biro 1998, Cunjak et al. 1993, Fry 1951, Gibson 1966, Elson 1942, Huntsman 1945). Also, fish in space-limited refugia are more susceptible to exploitation, disease, predation, and competition (Coutant 1987).

Book trout are generally considered to be poor competitors to many other fish species (Flick and Webster 1992, Hayes and Livingstone 1955). Competitors of brook trout in Nova Scotia include: white perch, yellow perch, smallmouth bass, chain pickerel, white sucker, American eel, and brown bullhead. The greatest percentage of sites

(85%) with competitors was found in the warm water category and the smallest percentage of sites (39%) with competitors was found in the cool water category. Habitat disturbance and increased water temperatures were associated with the presence of more tolerant species in River Philip, Nova Scotia (Kanno and MacMillan 2004). Most of the fish considered as important competitors of trout prefer warmer water, and, as a result, warming will most likely increase the habitat for some competitor populations (Eaton and Scheller 1996).

When compared to other habitat parameters such as cover, water depth, and stream bottom type, water temperature appeared to be the most important factor separating trout streams from non-trout streams (Stoneman and Jones 2000). Fines, silt, and sand are considered deleterious to salmonid reproduction and production and these findings are well documented (Waters 1995). For instance, suspended sediments can damage gills and hamper respiration and reduce feeding success. Stream sedimentation can smother eggs in spawning sites, in-fill deep holding areas for larger salmonids, and reduce insect production (DFO 2000b). Saunders and Smith (1965) detected a decrease in brook trout densities in Ellerslie Brook, Prince Edward Island, after nearby road construction resulted in heavy stream sedimentation. Impact of sedimentation is beyond the scope of the present study, although substrate type was monitored at every site. In our study, substrate type was not related to brook trout abundance; in fact, some of the largest densities of brook trout were recorded from sites that had the largest amounts of sediment in agriculturally impacted sites in Annapolis Valley. Groundwater rich streams of Annapolis Valley tend to be alkaline, conductive and productive (Brylinsky and Pindham 2001, Miles 1986). High alkalinity has been correlated with productivity and abundance of trout (Almodovar et al. 2006) and, in some cases, may compensate for some of the impacts of sedimentation in cool lotic habitats.

Many productive trout rivers in Nova Scotia are supplied with abundant groundwater resources from circumneutral ($6 < pH < 8$) cool springs that help to stabilize fluctuations in flow and temperature. Groundwater quality and quantity is related to regional differences in geology and hydrology. The underlying geology in much of Annapolis Valley and Northern Nova Scotia is comprised of sedimentary rock and includes siltstone, sandstone, glacial till, limestone and gypsum deposits. The overlying soils tend to be porous and groundwater contributions to stream flow tend to be relatively large (Davis and Brown 1996). Most of the streams in this region are less prone to acidic problems, more conductive, and cooler compared to streams in Southwest and Eastern Nova Scotia. Brook trout and Atlantic salmon were absent in many steams in the Southern uplands. The geology of this region is dominated by shallow soils that cover poorly-weathered igneous rock and much of the stream flow is dependant on surface runoff (Davis and Brown 1996). The rocky nature of this landscape results in less groundwater recharge, low productivity, conductivity, and alkalinity in many rivers, and, as a result, provides very little natural buffering capacity against acid precipitation (Watt et al. 1983, Farmer et al. 1980). Acidification of Nova Scotia waters has been correlated with heavy industrialization in the early to mid 1900s (Ginn et al. 2007). Atlantic salmon have been extirpated from many acidified systems and streams that flow from interspersed pockets of limestone rich soils and drumlins provide refugia to remnant salmonid populations (DFO 2000a, DFO 2003). Although brook trout can inhabit acidic streams ($pH < 5.0$) and are more resilient than other salmonids to acidity, as reviewed by Power (1980), low alkalinity and acidity can reduce survival of brook trout eggs and young (Petty et al. 2005). The absence of cold-water and low pH streams (e.g., $pH < 6.3$) sampled did not allow for the differentiation of the impact of cool-water from acidic conditions. Regional differences may relate to the apparent scarcity of cool acidic streams in Nova Scotia.

The distribution of Atlantic salmon was not related to the thermal nature of streams in our study. Summer thermal conditions in many Nova Scotian rivers are potentially more favourable for Atlantic salmon because of their tolerance to warmer conditions compared to brook trout; however, thermal death of salmon and trout has been reported in 1938 and 1939 in Nova Scotia rivers (Huntsman 1945). July and August air temperatures of 1938 and 1939 were two of the warmest on record over the past 135 years (1871-2005) of a summer warming trend (MacMillan and Madden 2007).

A major factor affecting juvenile Atlantic salmon population densities could be differences in recruitment among rivers surveyed. Atlantic salmon have been at critically low levels of abundance or extirpated in many Inner Bay of Fundy Rivers in New Brunswick and Nova Scotia, and as a result this stock has been listed as endangered (DFO 2003). In many cases, low abundance of juvenile Atlantic salmon may be related to limited recruitment rather than habitat conditions in fresh water (Amiro 1998a and 1998b).

Most cool water streams were circumneutral, conductive, inhabited by few fish species, and important habitat for brook trout. The thermal nature of rivers should be an important consideration in the development of management strategies to improve and sustain the trout fishery in Nova Scotia.

5.0 ACKNOWLEGEMENTS

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Table1. Organizations and volunteers involved in the Nova Scotia Salmonid Population Assessment Project, 2002-05**.**

Contact	Organization	River	County
Billy Stevens	Cape Breton Sportfishing Advisory Council	Middle	Victoria
Jack MacKillop	Cape Breton Sportfishing Advisory Council	Baddeck	Victoria
Mary MacNeil	L.Ainslie and Margaree River Hertiage Association	Margaree	Inverness
John King	Stewards of River Denys Watershed Association	River Denys	Inverness
Bill Carpin	St. Mary's River Association	St. Mary's	Guysborough
Bill Cardiff	Pictou County Rivers Association	East & West Pictou	Pictou
Brooke Cook	Bluenose Coastal Action Foundation	Mushamush	Lunenburg
Carol Randall	LaHave River Salmon Association	LaHave	Lunenburg
Garth Trider	LaHave Trout Association	Upper LaHave	Lunenburg
Doug Bell	Petite Riviere Association	Petite Riviere	Lunenburg
Paul Smith	NS Fed Anglers and Hunters / Shel Co. Fish and Game	Roseway	Shelburne
Richard Swaine	NS Fed Anglers and Hunters / Shel Co. Fish and Game	Clyde	Shelburne
Charles Trask	Tusket River Environmenatl Protection Association	Tusket	Yarmouth
Roland Smith	Annapolis Fly Fishers	Nictaux	Annapolis
Stephan Hawbolt	Clean Annapolis River Project	Annapolis	Annapolis
Doug Warner	Habitant River Trout Association	Habitant & Pereaux	Kings
Mike Brylinsky	Estuarine Center Biology Department Acadia University	Habitant	Kings
Peter Bagnall/Derrick Fritz	Friends of Cornwallis River	Cornwallis	Kings
Danny Ripley	Cumberland County River Enhancement Association	Philip & Wallace	Cumberland
Walter Regan	Sackville River Association	Sackville	Halifax
Darrel Brown	Wildlife Habitat Advocates	Avon & Kennetcook	Hants
Chris van Slyke	Nine Mile River Association	Nine Mile River	Hants

Table 2. Mean habitat characteristics in each thermal category from 100 electrofished stream sites from 2002 - 2005 in Nova Scotia.

	Thermal category °C		
	Cool	Intermediate	Warm
	<16.5	16.5-18.9	>18.9
Thermal classification characteristics			
Number of sites	33	33	34
Summer 15 Jun - 5 Sep °C	13.9	17.4	20.8
Number of days >20°C	0.3	6.1	54
Electrofishing site charateristics			
Temperature time of sampling	16	18	21
Width in meters	3.5	3.9	6.0
Length in meters	44	62	55
Area in square meters	162	247	330
Depth in meters	0.16	0.17	0.20
pH	7.1	6.8	6.2
Conductivity µS *	224	180	66
Substrate percentage			
Fines	20	12	17
Gravel	31	32	29
Cobble	33	34	30
Boulder	17	23	25
Bedrock	1	1	1
Cover percentage			
Instream	20	22	31
Canopy	40	47	33
Overhang	37	23	27
No Cover	19	29	27
Habitat type percentage			
Riffle	12	3	11
Run	30	17	29
Flat	56	79	58

* Conductivity was recorded from 26 cool sites, 23 intermediate sites, and 26 warm sites

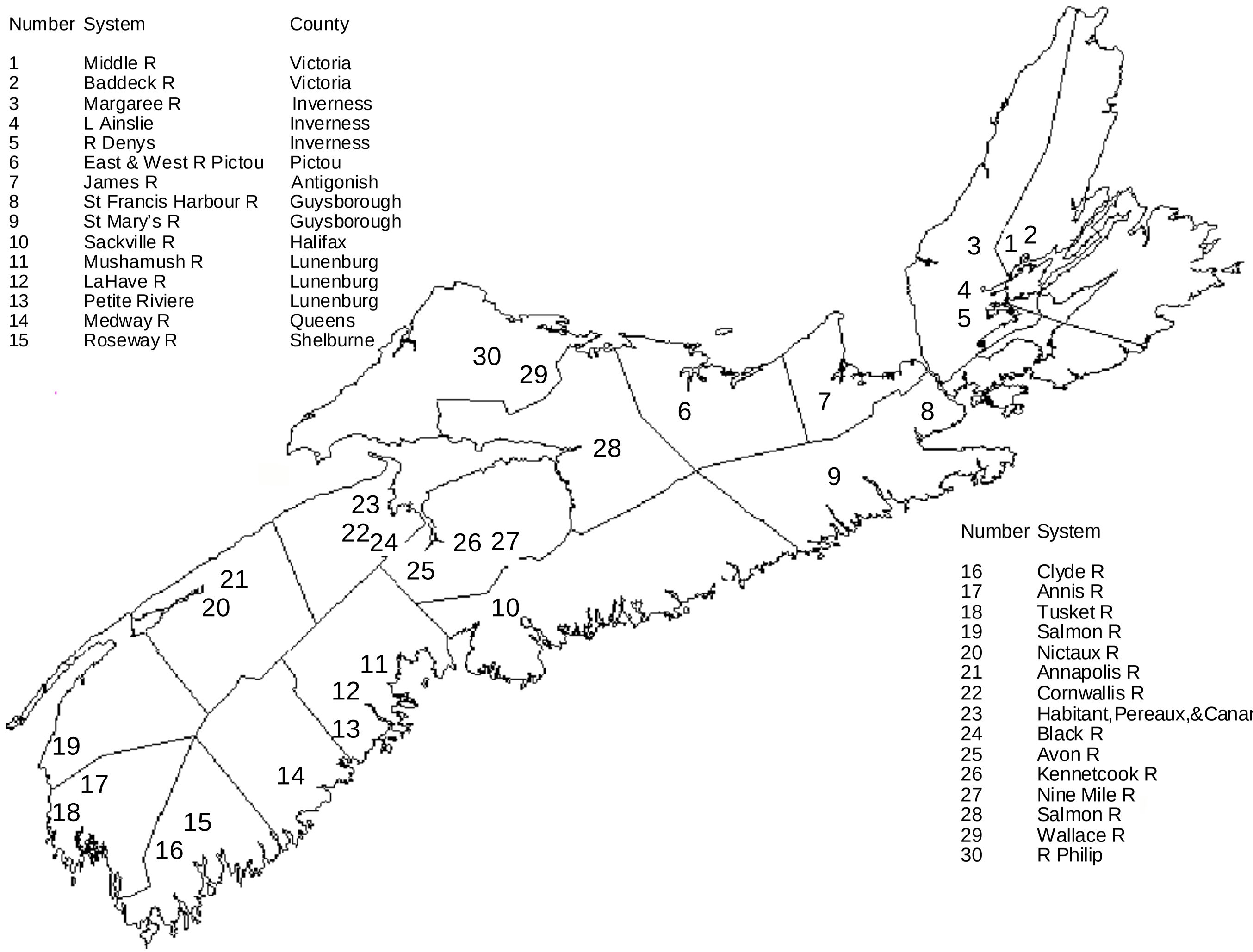
Table 3. Mean fish population densities in each thermal category from 100 electrofished stream sites from 2002-05 in Nova Scotia.

		Thermal category °C		
		Cool	Intermediate	Warm
		<16.5	16.5-18.9	>18.9
Thermal classification characteristics				
Number of sites		33	33	34
Summer 15 Jun - 5 Sep °C		13.9	17.4	20.8
Number of days >20°C		0.3	6.1	54
Fish per 100m^2				
Brook trout	grams	1126	214	16
	number	58	14	1.7
Atlantic salmon		9.1	4.6	4.3
Brown trout		7.5	0.2	0.3
White sucker		0.5	3.7	3.0
American eel		2.0	0.8	10.9
Yellow perch		0	0.4	0.2
Brown bullhead		0	0.06	0.03
Smallmouth bass		0	0	0.03
Chain pickerel		0	0	0.03
Gaspereau		0	0	1.3
Stickleback		0.2	0.2	0.1
Killifish		0	0.03	1.1
Cyprinids		2.7	4.7	6.2
[A]Proportion of sites with competitors		0.39	0.64	0.85

[A]Salmonid competitors: white sucker, yellow perch, American eel, smallmouth bass, brown bullhead, chain pickerel

Legend

Number	System	County
1	Middle R	Victoria
2	Baddeck R	Victoria
3	Margaree R	Inverness
4	L Ainslie	Inverness
5	R Denys	Inverness
6	East & West R Pictou	Pictou
7	James R	Antigonish
8	St Francis Harbour R	Guysborough
9	St Mary's R	Guysborough
10	Sackville R	Halifax
11	Mushamush R	Lunenburg
12	LaHave R	Lunenburg
13	Petite Riviere	Lunenburg
14	Medway R	Queens
15	Roseway R	Shelburne



Number	System	County
16	Clyde R	Shelburne
17	Annis R	Yarmouth
18	Tusket R	Yarmouth
19	Salmon R	Digby
20	Nictaux R	Annapolis
21	Annapolis R	Annapolis
22	Cornwallis R	Kings
23	Habitant, Pereaux, & Canard R	Kings
24	Black R	Kings
25	Avon R	Hants
26	Kennetcook R	Hants
27	Nine Mile R	Hants
28	Salmon R	Colchester
29	Wallace R	Cumberland
30	R Philip	Cumberland

Figure 1. Location of river system in the Nova Scotia habitat monitoring project, 2002-05.

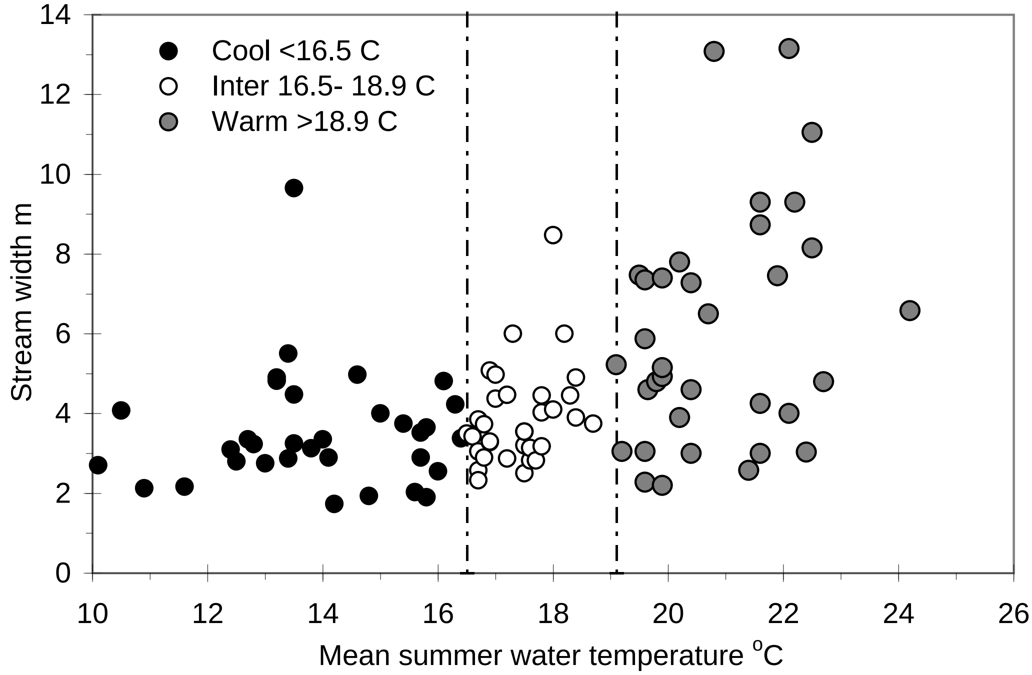


Figure 2. Stream width and mean summer temperature of 100 electrofished stream sites, Nova Scotia, 2002-05

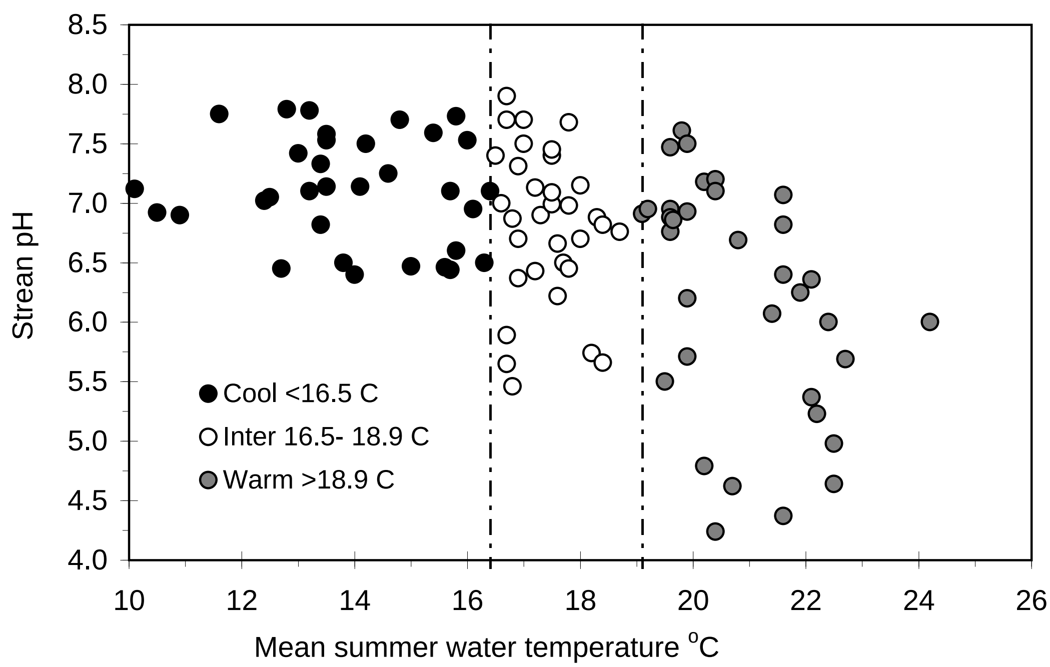


Figure 3. Stream pH and mean summer temperature of 100 electrofished stream sites, Nova Scotia, 2002-05

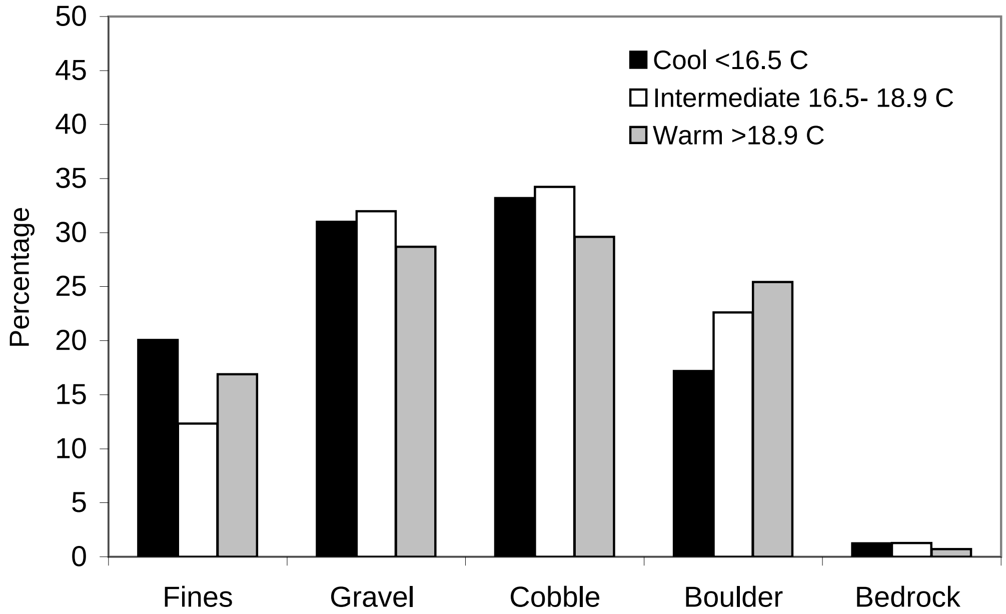


Figure 4. Mean percentage of substrate type in each thermal category from 100 electrofished stream sites, Nova Scotia, 2002-05.

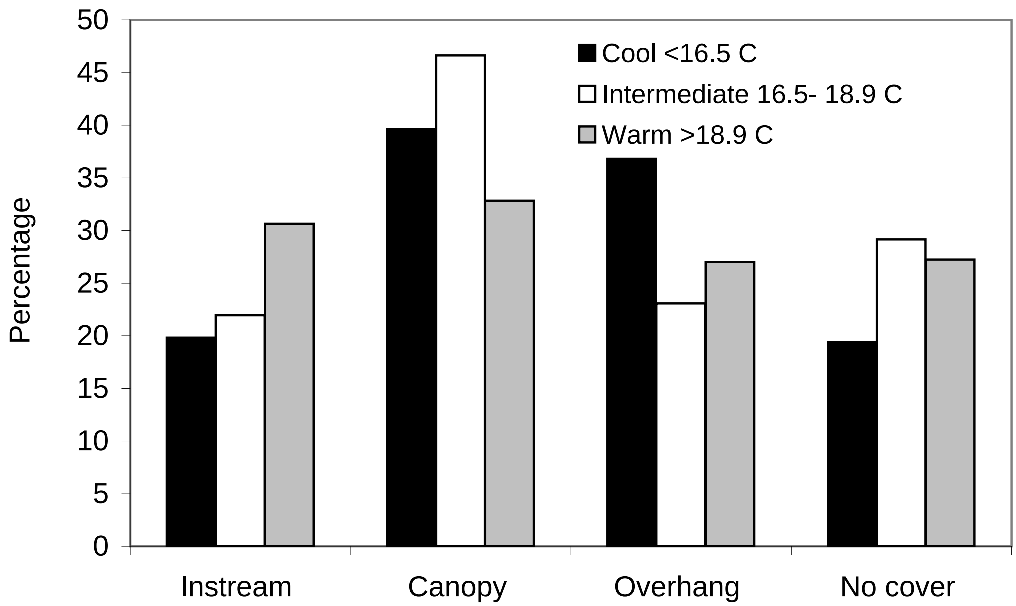


Figure 5. Mean percentage of each cover type in each thermal category from 100 electrofished stream sites, Nova Scotia, 2002-05.

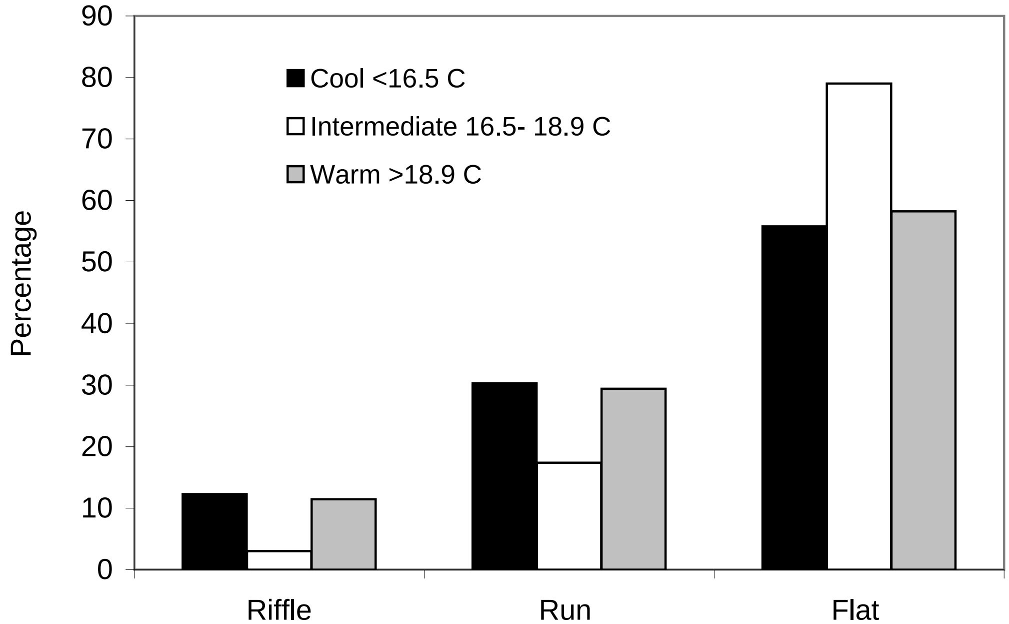


Figure 6. Mean percentage of habitat types in each thermal category from 100 electrofished stream sites, Nova Scotia, 2002-05.

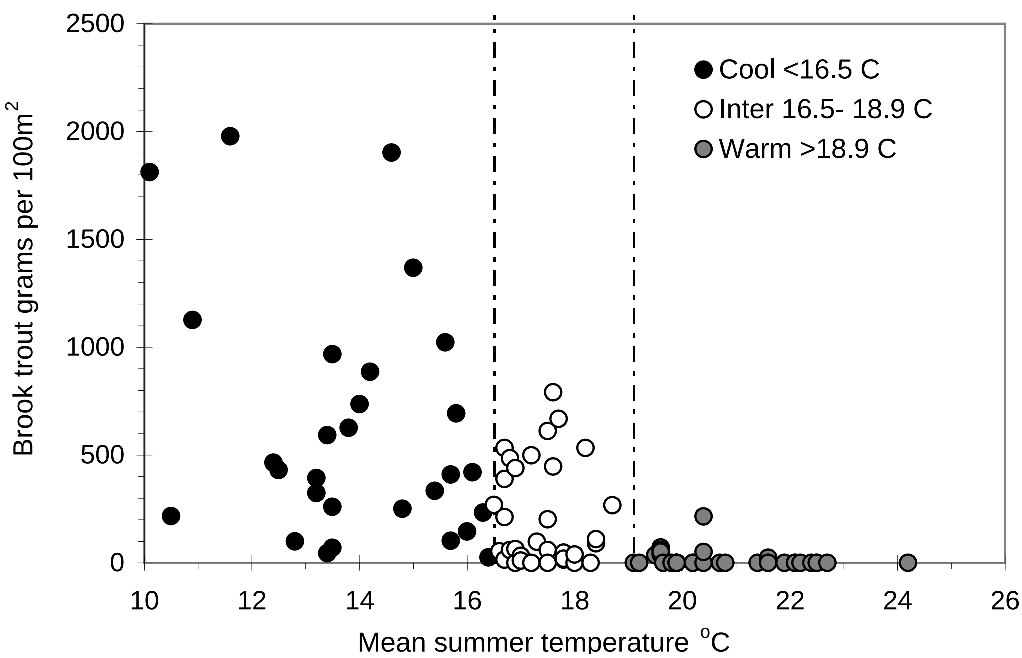


Figure 7. Population density of brook trout and mean summer temperature of 100 electrofished stream sites, Nova Scotia, 2002-05

* four data points in the cool water category (6756, 4776, 3862 and 3841 brook trout grams per 100m2) are outside the upper range of y - axis.

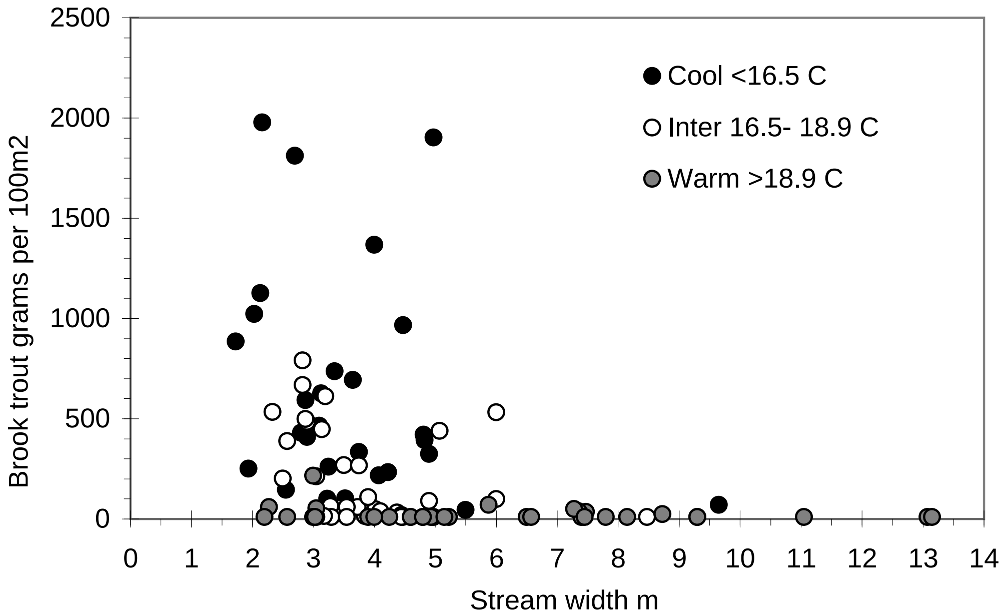


Figure 8. Population density of brook trout and mean stream width of 100 electrofished stream sites in each thermal category, Nova Scotia, 2002-05.
(Note: four data points in the cool water category (6756, 4776, 3862 and 3841 brook trout grams per 100m2) are outside the upper range of y - axis.)

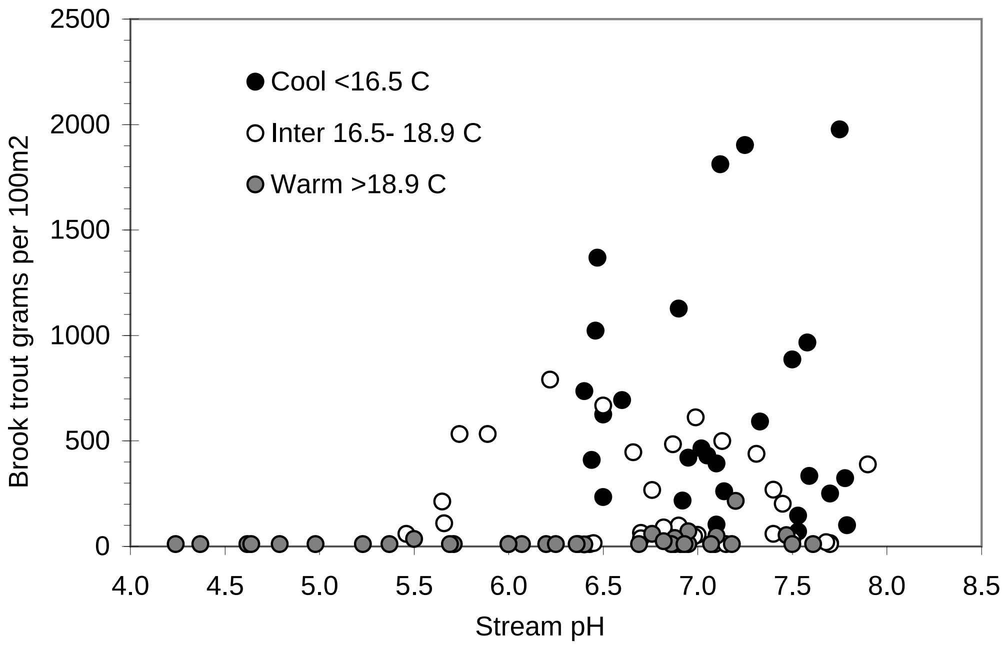


Figure 9. Population density of brook trout and stream pH of 100 electrofished stream sites, Nova Scotia, 2002-05
(Note: four data points in the cool water category (6756, 4776, 3862 and 3841 brook trout grams per 100m2) are outside the upper range of y - axis.)

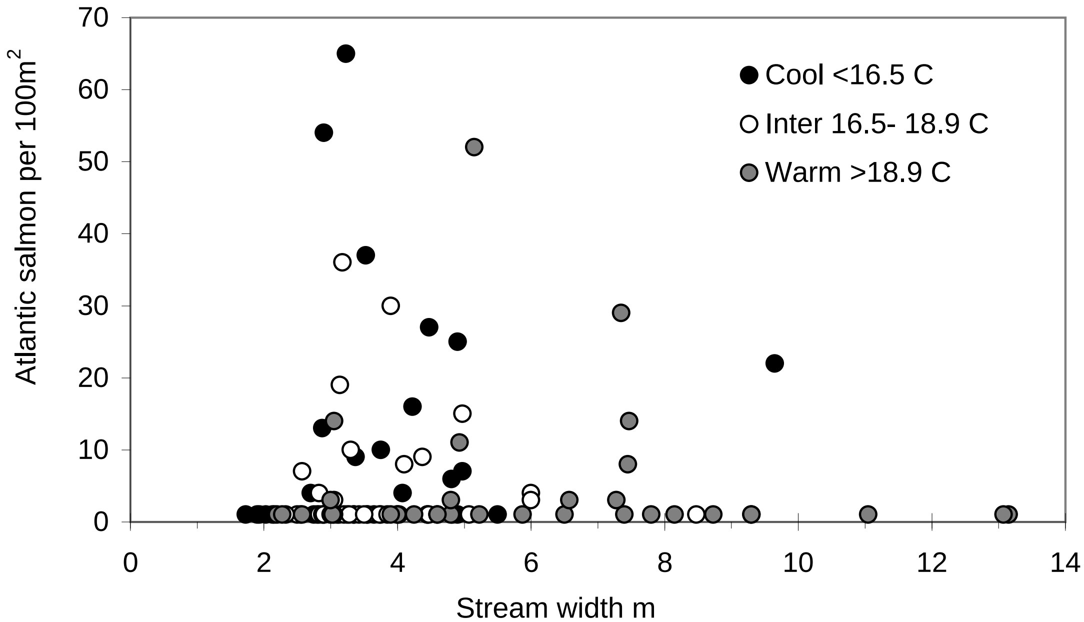


Figure 10. Population density of Atlantic salmon and mean stream width of 100 electrofished stream sites in each thermal category, Nova Scotia, 2002-05.

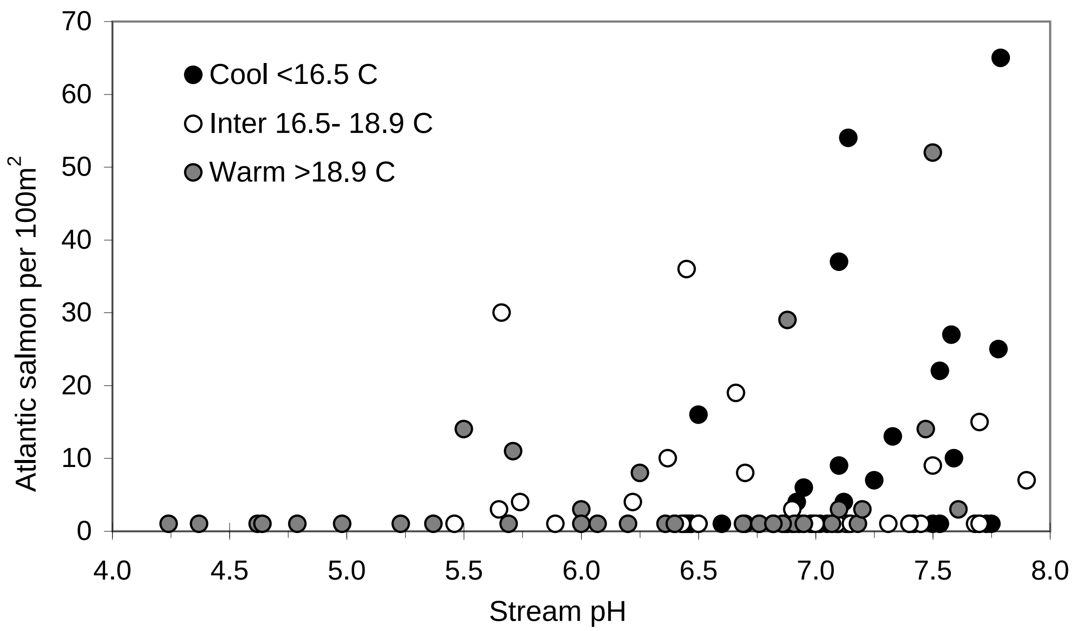


Figure 11. Population density of Atlantic salmon and stream pH of 100 electrofished stream sites in each thermal category, Nova Scotia, 2002-05.

Appendix A. Thermal category and habitat characteristics from 100 electrofished stream sites from 2000 - 2005 in Nova Scotia.

System (Thermal classification characteristics)	Site	Year	Latitude Longitude	Summer 15Jun- 5Sep average	Warmest daily average	Number of days >20°C	Rank[A]	Year (Electrofishing site charateristics)	Date	Temp°C time of sampling	Width[B] m	Length m	Area m^2	Depth m	pH	Specific conductivity uS	Substrate %[C] F	G	Co	B	Be	Cover %[D] In	Ca	O	Habitat type %[E] NC	Ri	Ru	F
Annapolis	Bloody Creek	2000	4449 6518	19.6	27.7	30	warm	2002	20/Aug	21	5.9	65	382	0.25	7.0	61	0	33	58	8	0	0	8	17	75	0	33	67
	McGee Brook	2001	4501 6451	14.2	15.5	0	cool	2002	20/Aug	19	1.7	14	24	0.23	7.5	223	8	17	25	17	33	0	0	100	0	0	0	100
	Paradise Brook	2000	4452 6512	18.4	24.5	12	inter	2002	20/Aug	20	4.9	65	319	0.16	6.8	249	0	50	50	0	0	0	83	0	17	0	0	100
	Patterson Brook	2001	4502 6449	15.8	19.3	0	cool	2002	20/Aug	16	1.9	25	48	0.27	7.7	249	58	0	0	42	0	25	0	92	8	8	8	83
	Round Hill River	2000	4446 6524	19.9	27.5	34	warm	2002	20/Aug	22	7.4	98	722	0.13	6.9	59	0	0	100	0	0	0	33	8	58	0	58	42
	Wiswall River	2000	4458 6500	17.5	21.5	2	inter	2002	20/Aug	22	3.2	43	138	0.10	7.0	39	50	42	8	0	0	42	58	25	83	0	33	67
Annis	Gardners Mills	2000	4402 6558	22.2	24.3	79	warm	2003	29/Jul	22	9.3	37	346	0.25	5.2	49	8	33	33	25	0	83	0	8	0	0	42	58
	Norwood Fire Station	2000	4404 6601	22.1	24.0	79	warm	2003	29/Jul	21	4.0	34	136	0.18	5.4	55	17	17	42	25	0	42	42	75	0	0	17	83
	Big Brazil Lake outflow	2000	4401 6600	21.4	22.6	79	warm	2005	5/Jul	25	2.6	46	119	0.25	6.1	62	83	0	17	0	0	0	67	25	33	0	17	83
	Saunders Road	2000	4356 6600	22.1	24.7	77	warm	2005	4/Jul	22	13.2	59	772	0.36	6.4	na	0	8	67	25	0	0	75	33	25	0	42	58
Avon	Allen Brook	2000	4458 6410	19.9	23.2	43	warm	2005	13/Jul	16	2.2	52	114	0.20	6.2	na	67	67	0	17	0	75	0	50	8	0	50	50
	LeBreau Creek	2000	4458 6409	21.6	26.3	58	warm	2005	13/Jul	18	3.0	36	108	0.30	6.4	na	0	0	8	92	0	0	0	75	25	0	25	75
	Mill Brook	2000	4449 6416	17.7	20.9	2	inter	2005	13/Jul	15	2.8	67	190	0.20	6.5	65	0	33	25	42	0	67	58	42	8	0	0	100
Baddeck	Adelaide Brook	2001	4609 6048	14.1	17.3	0	cool	2003	18/Aug	17	2.9	42	122	0.11	7.1	343	0	67	33	0	0	25	17	58	0	0	50	50
	Harris Brook	2001	4607 6050	14.6	16.5	0	cool	2003	18/Aug	16	5.0	54	270	0.10	7.3	290	25	67	0	8	0	8	17	50	25	0	17	84
	MacRae Brook	2001	4610 6047	10.5	12.3	0	cool	2003	18/Aug	12	4.1	81	330	0.17	6.9	557	0	17	25	58	0	67	8	25	0	83	0	16
	Mill Brook	2002	4612 6044	13.4	16.9	0	cool	2003	18/Aug	15	2.9	48	138	0.08	7.3	65	17	0	75	8	0	0	33	25	58	33	25	42
	Morgans Brook	2001	4608 6046	19.6	23.0	46	warm	2003	18/Aug	20	7.4	82	604	0.11	6.9	146	17	0	58	25	0	17	0	17	66	0	50	50
Clyde	Bloody Creek	2001	4343 6532	20.7	22.4	74	warm	2005	6/Jul	20	6.5	47	306	0.17	4.6	31	100	0	0	0	0	33	0	0	67	0	0	100
	Lyles Hill Brook	2001	4342 6532	20.4	25.0	49	warm	2005	6/Jul	16	4.6	42	191	0.24	4.2	46	0	0	50	50	0	0	50	42	33	0	50	50
Cornwallis	Brandywine Brook	2001	4505 6435	17.5	20.8	3	inter	2002	21/Aug	18	3.6	42	149	0.32	7.4	293	50	50	0	0	0	0	75	8	17	0	0	100
	Sharpe Brook	2001	4503 6438	13.2	15.0	0	cool	2002	21/Aug	15	4.8	31	149	0.13	7.1	41	0	42	58	0	0	0	100	0	0	33	33	33
	Spidle Brook	2001	4504 6436	13.5	15.9	0	cool	2002	21/Aug	14	3.3	47	152	0.16	7.1	113	8	50	42	0	0	0	42	17	42	25	50	25
	Tupper Brook	2001	4503 6434	17.2	21.7	5	inter	2002	21/Aug	17	2.9	83	239	0.19	7.1	187	0	92	8	0	0	0	100	0	0	0	0	100
	Rochford Brook	2001	4503 6440	13.8	16.8	0	cool	2005	27/Jul	13	3.1	48	149	0.19	6.5	144	25	50	0	25	0	58	25	67	0	0	50	50
Habitant	Pereaux River	2001	4511 6424	11.6	13.8	0	cool	2002	21/Aug	14	2.2	15	32	0.09	7.8	428	100	0	0	0	0	8	92	33	0	0	42	58
	Sleepy Hollow Brook	2001	4509 6429	14.8	18.7	0	cool	2002	21/Aug	16	1.9	21	40	0.09	7.7	398	92	85	0	0	0	25	50	75	0	0	25	75
	Upper Habitant	2002	4509 6430	13.0	15.6	0	cool	2002	21/Aug	14	2.8	22	61	0.15	7.4	554	100	0	0	0	0	0	75	25	8	0	8	92
Kennetcook	Birch Brook	2001	4506 6349	17.8	20.0	0	inter	2002	22/Aug	17	4.0	82	328	0.11	7.0	na	0	0	92	8	0	0	58	0	42	17	33	50
	Hanna Brook	2001	4512 6339	17.5	21.6	8	inter	2002	22/Aug	19	3.6	34	120	0.18	7.1	119	8	8	67	16	0	8	25	58	33	0	0	100
	Rines Brook	2001	4509 6345	20.2	24.1	46	warm	2002	22/Aug	17	3.9	38	149	0.27	7.2	107	0	67	33	0	0	0	33	0	67	17	25	58
	Upper Kennetcook	2001	4514 6337	16.6	20.4	1	inter	2002	22/Aug	17	3.4	40	136	0.13	7.0	349	0	42	80	8	0	0	58	17	25	0	17	83
La Have	Ash Brook	2002	4428 6449	16.7	22.6	8	inter	2002	28/Aug	18	3.1	58	175	0.18	5.7	19	8	25	33	17	17	0	100	25	0	0	8	92
	Cooks Brook	2002	4425 6433	17.8	22.7	11	inter	2002	28/Aug	15	3.2	49	156	0.08	6.5	123	17	25	25	33	0	33	75	25	0	0	25	75
	Rhyno Lake outflow	2000	4425 6444	24.2	28.8	82	warm	2002	28/Aug	26	6.6	86	567	0.17	6.0	18	0	58	0	42	0	75	0	17	25	42	8	50
	Varner Brook	2002	4433 6445	17.6	20.4	6	inter	2002	28/Aug	15	2.8	74	209	0.19	6.2	59	0	0	17	83	0	25	67	33	8	0	0	100

Appendix A. Thermal category and habitat characteristics from 100 electrofished stream sites from 2000 - 2005 in Nova Scotia (continued).

Thermal classification characteristics								Electrofishing site charateristics																				
System	Site	Year	Latitude	Summer	Warmest	Number	[A]Rank	Year	Date	Temp°C	[B]Width	Length	Area	Depth	pH	Specific	[C]Substrate %					[D]Cover %			[E]Habitat type			
			Longitude	15Jun- 5Sep	daily	of days				time of						conductivity											%	
				average	average	>20°C				sampling	m	m	m^2	m		uS	F	G	Co	B	Be	In	Ca	O	NC	Ri	Ru	F
Margaree	Dan MacDonalds Brook	2001	4606 6113	17.5	21.8	6	inter	2002	14/Aug	21	2.5	30	75	0.10	7.5	135	0	42	33	25	0	0	67	8	17	17	0	83
	Johnson Brook	2001	4606 6108	12.7	15.2	0	cool	2002	14/Aug	13	3.4	35	117	0.20	6.5	220	0	42	50	8	0	0	100	8	0	0	33	67
	MacMillan Brook	2001	4602 6107	15.0	17.6	0	cool	2002	14/Aug	16	4.0	46	184	0.13	6.5	149	0	8	83	8	0	0	83	17	8	0	42	59
	MacSweens Brook	2001	4602 6106	14.0	17.3	0	cool	2002	14/Aug	14	3.4	60	201	0.14	6.4	135	25	58	17	0	0	0	58	8	33	0	67	33
	Saddlers Brook	2001	4608 6117	18.7	21.1	6	inter	2002	14/Aug	22	3.8	30	113	0.21	6.8	514	42	25	25	8	0	33	67	17	0	0	0	100
Middle	MacDonald Brook	2000	4611 6055	10.1	11.5	0	cool	2003	19/Aug	10	2.7	51	138	0.08	7.1	93	0	0	75	25	0	42	0	42	0	17	58	25
	MacKenzie Brook	2000	4608 6058	13.5	14.9	0	cool	2003	19/Aug	14	4.5	68	304	0.20	7.6	70	0	8	33	58	0	58	17	17	0	17	50	33
	MacLeod Brook	2000	4609 6055	13.5	14.2	0	cool	2003	19/Aug	15	9.7	37	357	0.16	7.5	200	8	0	58	33	0	0	8	17	67	0	100	0
	Morrison Brook	2000	4614 6056	12.8	13.9	0	cool	2003	18/Aug	12	3.2	55	178	0.18	7.8	24	0	0	50	50	0	25	33	25	17	0	75	25
Mushamush	"main branch"	2000	4428 6424	20.8	24.8	80	warm	2002	27/Aug	20	13.1	39	510	0.26	6.7	32	0	17	25	58	0	50	0	17	33	25	42	33
	Big Mush Lake outflow	2000	4430 6432	19.1	21.2	13	warm	2002	27/Aug	23	5.2	52	273	0.12	6.9	32	8	42	50	0	0	8	75	42	25	8	33	58
	Big North Brook	2000	4432 6430	22.7	28.1	70	warm	2002	27/Aug	21	4.8	42	202	0.20	5.7	18	0	0	25	67	8	50	67	17	8	0	42	58
	Blockhouse Mill Brook	2000	4428 6425	19.2	22.3	21	warm	2002	27/Aug	21	3.1	71	216	0.10	7.0	35	0	67	25	8	0	33	67	50	0	50	0	50
	Caribou Lake outflow	2000	4431 6432	18.3	20.6	2	inter	2002	27/Aug	24	4.5	84	374	0.21	6.9	34	25	25	8	45	0	25	33	42	25	0	25	75
	Naas Brook	2000	4426 6428	19.6	23.1	34	warm	2002	27/Aug	21	2.3	45	102	0.06	6.8	33	25	67	0	8	0	67	25	50	0	42	0	58
Nine Mile	Captain MacPhee Brook	2002	4504 6340	12.4	15.2	0	cool	2004	19/Aug	17	3.1	55	169	0.23	7.0	62	8	50	17	25	0	17	33	83	0	0	17	83
	Carrigan Brook	2002	4502 6341	13.4	15.4	0	cool	2004	19/Aug	16	5.5	42	230	0.16	6.8	104	8	25	25	16	0	33	58	58	0	0	58	42
	Tributary of Nine Mile	2002	4505 6336	12.5	14.9	0	cool	2004	19/Aug	19	2.8	29	80	0.19	7.1	284	8	50	0	0	0	42	75	92	0	0	42	58
	Whittier Brook	2002	4504 6341	10.9	14.8	0	cool	2004	19/Aug	15	2.1	43	92	0.16	6.9	140	8	50	17	33	0	8	67	25	0	25	17	58
Petite	"main branch"	2001	4415 6428	21.9	25.7	73	warm	2002	28/Aug	25	7.5	41	306	0.31	6.3	44	8	0	8	92	0	100	0	0	0	58	42	0
	Wamback Mill Brook	2001	4414 6426	18.2	21.9	12	inter	2002	28/Aug	19	6.0	48	290	0.17	5.7	44	8	0	0	100	0	50	25	33	0	8	0	92
Pictou East	Archibald Brook	2000	4525 6236	17.0	21.2	7	inter	2002	13/Aug	22	4.4	93	407	0.19	7.5	na	8	42	58	0	0	0	17	17	67	0	8	92
	Cameron Brook	2000	4527 6242	17.6	21.7	10	inter	2002	13/Aug	23	3.1	73	229	0.19	6.7	na	8	20	60	13	0	0	20	40	67	33	0	67
	Little River	2002	4524 6222	15.8	19.0	0	cool	2002	13/Aug	19	3.7	35	126	0.19	6.6	na	8	33	67	0	0	17	0	42	33	0	0	100
	Mill Stream Brook	2001	4527 6238	19.6	22.6	32	warm	2002	13/Aug	23	3.1	76	232	0.13	7.5	na	8	42	58	0	0	8	92	0	0	25	25	50
	Thompson Brook	2000	4524 6227	15.7	18.7	0	cool	2002	13/Aug	19	2.9	35	102	0.20	6.4	na	8	33	25	25	0	33	0	50	25	33	0	66
	W Branch Lake outflow	2002	4522 6239	19.6	22.3	27	warm	2002	13/Aug	23	4.6	95	437	0.18	6.9	na	8	67	17	8	0	8	58	8	42	8	17	75
River Denys	Alder River	2002	4553 6114	13.2	17.0	0	cool	2002	15/Aug	17	4.9	16	78	0.18	7.8	231	8	67	25	8	0	0	0	8	100	25	17	58
	Big Brook	2002	4549 6111	18.0	23.5	16	inter	2002	15/Aug	21	8.5	71	602	0.28	7.2	1357	8	42	58	0	0	0	0	17	83	0	17	83
	Glen Brook	2002	4553 6116	15.4	20.4	2	cool	2002	15/Aug	17	3.8	50	188	0.31	7.6	674	8	33	33	16	0	0	33	42	50	42	0	58
	MacLellans Brook	2002	4551 6115	17.8	27.7	22	inter	2002	15/Aug	21	4.5	62	276	0.19	7.7	231	8	67	33	0	0	0	8	8	92	0	17	83
	McIntyre Brook	2002	4549 6110	16.9	23.0	10	inter	2002	15/Aug	18	5.1	67	340	0.24	7.3	95	8	50	42	8	0	0	33	42	50	0	0	100
River Phillip	Bulmer Brook	2001	4536 6352	16.1	19.4	0	cool	2004	12/Aug	17	4.8	83	397	0.14	7.0	31	8	29	29	4	0	4	43	14	25	7	25	43
	Tillets Brook	2001	4540 6347	21.6	27.0	58	warm	2004	12/Aug	22	8.7	80	698	0.16	6.8	83	8	8	75	8	8	17	8	25	33	33	8	58
Roseway	"main branch"	2001	4348 6521	21.6	24.5	56	warm	2003	29/Jul	26	9.3	37	346	0.23	4.4	33	8	8	33	58	0	92	17	17	0	0	50	50
	Beaver Creek	2002	4403 6527	20.2	27.7	47	warm	2003	29/Jul	23	7.8	70	546	0.23	4.8	30	8	100	0	0	0	8	8	33	43	0	25	75
	Turtle Creek	2002	4357 6522	16.8	21.7	12	inter	2003	29/Jul	20	3.7	47	176	0.18	5.5	32	8	25	8	0	0	0	0	8	92	0	0	100

Appendix A. Thermal category and habitat characteristics from 100 electrofished stream sites from 2000 - 2005 in Nova Scotia (continued).

Thermal classification characteristics							Electrofishing site charateristics																					
System	Site	Year	Latitude Longitude	Summer 15Jun- 5Sep average	Warmest daily average	Number of days >20°C	[A]Rank	Year	Date	Temp°C time of sampling	[B]Width m	Length m	Area m^2	Depth m	pH	Specific conductivity uS	[C]Substrate % F	G	Co	B	Be	[D]Cover % In	Ca	O	NC	[E]Habitat type % Ri	Ru	F
Sackville	Payzants Brook	2001	4445 6340	19.8	22.4	35	warm	2004	23/Aug	18	4.8	60	288	0.29	7.6	na	33	33	25	8	0	0	42	25	33	0	92	8
	Stratton Court Brook	2001	4447 6346	19.9	23.9	38	warm	2004	23/Aug	18	4.9	20	99	0.24	5.7	na	8	0	0	92	0	0	75	17	8	8	83	8
	Feely Lake outflow	2001	4447 6341	22.4	25.8	70	warm	2005	27/Jul	22	3.0	44	133	0.15	6.0	39	25	58	17	0	0	58	42	50	8	0	0	100
	Little Sackville River	2000	4446 6340	19.5	25.0	35	warm	2005	27/Jul	18	7.5	48	359	0.08	5.5	44	0	17	8	50	0	50	58	25	8	0	0	100
Salmon	Clifford Brook	2001	4525 6309	16.0	22.0	6	cool	2004	25/Aug	17	2.6	40	102	0.10	7.5	na	0	42	50	0	8	0	75	0	25	0	8	92
	Farnham Brook	2000	4523 6317	16.8	18.5	0	inter	2004	16/Sep	13	2.9	61	178	0.10	6.9	na	17	67	17	0	0	25	42	50	17	0	50	50
	Greenfield Brook	2000	4524 6307	15.6	18.5	0	cool	2004	25/Aug	17	2.0	41	83	0.12	6.5	na	0	0	100	0	0	25	33	8	33	58	0	25
St. Mary's	Archibald Mill Brook	2002	4516 6205	16.7	20.8	7	inter	2005	12/Jul	18	3.9	82	314	0.19	7.7	na	0	8	33	58	0	92	33	25	0	0	0	100
	Chisholm Brook	2002	4516 6225	16.3	18.1	0	cool	2005	11/Jul	15	4.2	69	290	0.16	6.5	na	0	42	25	33	0	33	42	50	42	0	25	75
	Clark Brook	2001	4516 6212	15.7	18.7	0	cool	2005	11/Jul	20	3.5	51	181	0.12	7.1	na	67	50	25	8	0	58	50	33	8	0	25	75
	Glencross Brook	2001	4516 6210	18.0	21.1	7	inter	2005	12/Jul	16	4.1	83	339	0.17	6.7	na	0	0	83	17	0	58	58	8	0	0	42	58
	Indian Man Brook	2001	4516 6213	16.4	20.7	2	cool	2005	11/Jul	20	3.4	66	224	0.16	7.1	na	0	8	33	58	0	42	42	8	33	0	33	58
	Long John Brook	2002	4518 6231	17.0	20.3	1	inter	2005	12/Jul	19	5.0	72	357	0.13	7.7	na	0	0	33	67	0	75	17	0	25	0	67	33
	MacDonald Brook	2001	4516 6214	17.3	20.5	2	inter	2005	11/Jul	19	6.0	99	592	0.20	6.9	na	33	0	67	25	0	8	50	25	25	0	8	92
	MacDonald Mill Brook	2002	4515 6216	16.9	19.2	0	inter	2005	11/Jul	18	3.3	86	282	0.12	6.7	na	0	17	33	50	0	41	45	46	0	0	50	50
	McLeod Lake Brook	2002	4516 6209	20.4	23.5	43	warm	2005	12/Jul	16	3.0	76	227	0.09	7.2	na	0	50	42	8	0	75	25	83	17	0	8	92
	Mitchell Brook	2002	4516 6221	16.5	19.0	0	inter	2005	11/Jul	15	3.5	77	271	0.09	7.4	na	0	17	8	75	0	58	100	17	0	0	33	67
	Sutherland Brook	2001	4516 6215	16.7	19.0	0	inter	2005	11/Jul	16	2.6	80	205	0.15	7.9	60	33	67	25	0	0	17	50	58	8	0	25	75
	Barren Brook	2001	4516 6217	18.4	21.4	9	inter	2003	27/Aug	15	3.9	39	152	0.24	5.7	26	0	58	33	8	0	8	33	17	43	0	83	0
	Cross Brook	2002	4517 6223	16.9	23.1	14	inter	2003	27/Aug	15	3.3	39	127	0.22	6.4	na	17	33	33	16	0	17	33	25	17	17	0	83
	Kelly Brook	2001	4516 6219	16.7	17.5	0	inter	2003	27/Aug	15	2.3	29	66	0.12	5.9	21	0	42	8	25	25	42	50	0	25	8	33	58
	Nelson Brook	2001	4518 6240	20.4	25.4	46	warm	2003	27/Aug	21	7.3	76	552	0.19	7.1	29	25	50	8	8	8	50	0	17	43	8	8	83
Tusket	Cold Stream	2001	4358 6548	22.5	23.6	83	warm	2003	29/Jul	22	8.2	58	473	0.18	4.6	31	0	25	42	33	0	17	8	17	58	8	42	50
	Big Brazil Brook	2001	4400 6600	21.6	24.7	74	warm	2005	4/Jul	25	4.3	40	170	0.37	7.1	63	100	0	0	0	0	0	50	50	8	0	0	100
	Carleton Bridge	2001	4400 6555	22.5	24.8	82	warm	2005	5/Jul	20	11.1	38	417	0.34	5.0	40	33	8	50	33	0	0	92	0	8	0	50	50
Wallace	Drennan Brook	2001	4542 6334	19.9	23.7	38	warm	2003	28/Aug	17	5.2	25	126	0.16	7.5	109	17	33	33	17	0	25	0	8	67	58	17	0
	Treen Brook	2001	4540 6339	17.2	19.2	0	inter	2004	12/Aug	21	4.5	48	215	0.19	6.4	na	33	42	25	0	0	0	0	25	75	0	0	100
Mean				17.4	20.9	20.4				18.3	4.5	53	247	0.18	6.7	153	16	31	22	22	1	24	40	29	25	9	26	64

[A] Rank Inter = intermediate [B]m= meters [C]Substrate: F=Fines (sand,clay,silt,detrirus), Co=cobble, B=boulder, Be=Bedrock, G=gravel

[D]Cover: In=instream, Ca=canopy, O=overhang, NC=no cover [E]Habitat type: Ri=riffle, Ru=run, F=flat

Appendix B. Fish population densities from 100 electrofished stream sites from 2002-05 in Nova Scotia.

Station	Site	Year	Fish per 100m^2 Brook trout grams	Brook trout Number	Atlantic salmon	Brown trout	White sucker	Yellow perch	American eel	Smallmouth bass	Brown bullhead	Chain pickerel	Gaspereau	Stickle back	Killifish	Cyprinids	[A]Number of Competitor Species
Annapolis	Bloody Creek	2002	71	2	2	0	1	0	0	0	0	0	0	0	0	2	1
	McGee Brook	2002	885	58	0	0	8	0	0	0	0	0	0	0	0	25	1
	Paradise Brook	2002	90	6	1	0	1	0	2	0	0	0	0	0	0	5	2
	Patterson Brook	2002	6756	332	0	0	0	0	2	0	0	0	0	2	0	0	1
	Round Hill River	2002	0	0	1	0	0	0	8	0	0	0	0	0	0	3	1
	Wiswall River	2002	611	23	0	0	3	0	0	0	0	0	0	0	0	0	1
Annis	Gardners Mills	2003	0	0	0	0	0	0	98	0	0	0	0	0	0	0	1
	Norwood Fire Station	2003	0	0	0	0	0	0	38	0	0	0	0	0	0	0	1
	Big Brazil Lake outflow	2005	0	0	0	0	0	0	32	0	0	0	0	0	0	0	1
	Saunders Road	2005	0	0	0	0	0	0	5	0	0	0	0	0	0	0	1
Avon	Allen Brook	2005	0	0	0	0	0	0	12	0	0	0	0	0	0	4	1
	LeBreau Creek	2005	9	2	0	0	0	0	0	0	0	0	0	0	0	4	0
	Mill Brook	2005	668	11	0	0	22	0	0	0	0	0	0	1	0	1	1
Baddeck	Adelaide Brook	2003	4776	71	54	0	0	0	0	0	0	0	0	0	0	0	0
	Harris Brook	2003	1902	38	7	0	0	0	0	0	0	0	0	0	0	0	0
	MacRae Brook	2003	217	14	4	0	0	0	0	0	0	0	0	0	0	0	0
	Mill Brook	2003	592	20	13	0	0	0	0	0	0	0	0	0	0	0	0
	Morgans Brook	2003	39	4	29	0	0	0	0	0	0	0	0	0	0	0	0
Clyde	Bloody Creek	2005	0	0	0	0	0	0	13	0	0	0	0	0	0	0	1
	Lyles Hill Brook	2005	0	1	0	0	0	0	27	0	0	0	0	0	0	0	1
Cornwallis	Brandywine Brook	2002	60	1	0	1	0	0	0	0	0	0	0	0	0	0	0
	Sharpe Brook	2002	394	41	0	9	0	0	2	0	0	0	0	0	0	0	1
	Spidle Brook	2002	260	35	0	72	0	0	0	0	0	0	0	0	0	0	0
	Tupper Brook	2002	499	63	0	0	0	0	0	0	0	0	0	0	0	0	0
	Rochford Brook	2005	626	41	0	148	0	0	8	0	0	0	0	1	0	0	1
Habitant	Pereaux River	2002	1977	81	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sleepy Hollow Brook	2002	251	135	0	0	0	0	0	0	0	0	0	0	0	0	0
	Upper Habitant	2002	3841	136	0	0	0	0	2	0	0	0	0	0	0	29	1
Kennetcook	Birch Brook	2002	47	5	0	0	6	0	0	0	0	0	0	0	0	12	1
	Hanna Brook	2002	0	0	0	0	15	0	9	0	0	0	0	0	0	18	2
	Rines Brook	2002	0	0	0	0	15	0	35	0	0	0	0	0	0	30	2
	Upper Kennetcook	2002	54	19	0	0	1	0	0	0	0	0	0	0	0	8	1
La Have	Ash Brook	2002	213	17	3	0	5	12	0	0	0	0	0	0	0	0	2
	Cooks Brook	2002	15	8	36	0	3	0	3	0	0	0	0	0	0	11	2
	Rhyno Lake outflow	2002	0	0	3	0	0	1	0	0	1	0	2	0	1	4	2
	Varner Brook	2002	790	23	4	0	17	0	0	0	0	0	0	3	0	4	1

Appendix B. Fish population densities from 100 electrofished stream sites from 2002-05 in Nova Scotia (continued).

Station	Site	Year	Fish per 100m² Brook trout grams	Number	Atlantic salmon	Brown trout	White sucker	Yellow perch	American eel	Smallmouth bass	Brown bullhead	Chain pickerel	Gaspereau	Stickle back	Killifish	Cyprinids	[A]Number of Competitor Species
Margaree	Dan MacDonalds Brook	2002	201	63	0	0	0	0	0	0	0	0	0	0	0	0	0
	Johnson Brook	2002	3862	90	0	0	0	0	0	0	0	0	0	0	0	0	0
	MacMillan Brook	2002	1368	54	0	0	0	0	0	0	0	0	0	0	0	0	0
	MacSweens Brook	2002	736	30	0	0	0	0	0	0	0	0	0	0	0	0	0
	Saddlers Brook	2002	267	12	0	0	0	0	0	0	0	0	0	0	0	0	0
Middle	MacDonald Brook	2003	1812	148	4	0	0	0	0	0	0	0	0	0	0	0	0
	MacKenzie Brook	2003	967	30	27	0	0	0	0	0	0	0	0	0	0	0	0
	MacLeod Brook	2003	70	8	22	0	0	0	0	0	0	0	0	0	0	0	0
	Morrison Brook	2003	100	11	65	0	0	0	0	0	0	0	0	0	0	0	0
Mushamush	"main branch"	2002	0	0	2	0	1	0	3	0	0	0	0	0	0	0	2
	Big Mush Lake outflow	2002	0	0	1	0	0	0	5	1	0	0	0	0	0	8	2
	Big North Brook	2002	0	0	0	0	1	0	15	0	0	0	0	0	0	3	2
	Blockhouse Mill Brook	2002	0	0	1	0	7	0	3	0	0	0	0	0	0	24	2
	Caribou Lake outflow	2002	0	0	1	0	2	0	0	0	0	0	0	0	1	5	1
	Naas Brook	2002	60	14	0	0	3	0	8	0	0	0	0	1	0	17	2
Nine Mile	Captain MacPhee Brook	2004	465	40	0	0	0	0	9	0	0	0	0	0	0	0	1
	Carrigan Brook	2004	45	8	0	0	0	0	9	0	0	0	0	1	0	0	1
	Tributary of Nine Mile	2004	430	25	0	0	2	0	0	0	0	0	0	0	0	0	1
	Whittier Brook	2004	1127	96	0	0	0	0	11	0	0	0	0	2	0	20	1
Petite	"main branch"	2002	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0
	Wamback Mill Brook	2002	533	15	4	0	1	0	0	0	0	0	0	0	0	0	1
Pictou East	Archibald Brook	2002	33	1	9	3	0	0	0	0	0	0	0	0	0	1	0
	Cameron Brook	2002	447	21	19	0	0	0	0	0	0	0	0	0	0	0	0
	Little River	2002	693	35	0	0	0	0	0	0	0	0	0	0	0	0	0
	Mill Stream Brook	2002	53	6	14	0	0	0	0	0	0	0	0	0	0	2	0
	Thompson Brook	2002	409	51	0	0	0	0	0	0	0	0	0	0	0	0	0
	W Branch Lake outflow	2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
River Denys	Alder River	2002	324	51	25	0	0	0	0	0	0	0	0	0	0	0	0
	Big Brook	2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Glen Brook	2002	334	46	10	0	0	0	0	0	0	0	0	0	0	0	0
	MacLellans Brook	2002	19	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	McIntyre Brook	2002	439	8	1	1	0	0	0	0	0	0	0	0	0	0	0
River Phillip	Bulmer Brook	2004	419	40	6	19	0	0	0	0	0	0	0	0	0	0	0
	Tillets Brook	2004	24	10	0	9	3	0	0	0	0	0	0	1	0	10	1
Roseway	"main branch"	2003	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1
	Beaver Creek	2003	0	0	0	0	0	2	4	0	0	0	0	0	0	0	2
	Turtle Creek	2003	59	3	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix B. Fish population densities from 100 electrofished stream sites from 2002-05 in Nova Scotia (continued).

			Fish per 100m^2														[A]Number of
Station	Site	Year	Brook trout		Atlantic	Brown	White	Yellow	American	Smallmouth	Brown	Chain	Gaspereau	Stickle	Killifish	Cyprinids	Competitor
			grams	Number	salmon	trout	sucker	perch	eel	bass	bullhead	pickerel		back			Species
Sackville	Payzants Brook	2004	0	0	3	0	3	0	12	0	0	0	0	0	0	3	2
	Stratton Court Brook	2004	0	0	11	0	1	0	6	0	0	0	0	0	0	1	2
	Feely Lake outflow	2005	0	0	0	0	34	0	2	0	0	0	0	0	2	23	2
	Little Sackville River	2005	35	1	14	0	4	0	7	0	0	0	0	0	0	3	2
Salmon	Clifford Brook	2004	145	17	0	0	0	0	0	0	0	0	0	0	0	0	0
	Farnham Brook	2004	485	58	0	0	0	0	3	0	0	0	0	0	0	0	1
	Greenfield Brook	2004	1022	101	0	0	0	0	7	0	0	0	0	0	0	2	1
St. Mary's	Archibald Mill Brook	2005	15	6	0	0	3	0	0	0	1	0	0	0	0	2	2
	Chisholm Brook	2005	233	9	16	0	2	0	8	0	0	0	0	0	0	1	2
	Clark Brook	2005	103	37	37	0	1	0	3	0	0	0	0	0	0	7	2
	Glencross Brook	2005	38	4	8	0	1	0	0	0	0	0	0	0	0	4	2
	Indian Man Brook	2005	25	3	9	0	3	0	6	0	0	0	0	0	0	5	2
	Long John Brook	2005	10	7	15	0	2	0	0	0	0	0	0	0	0	10	1
	MacDonald Brook	2005	98	4	3	0	2	0	0	0	0	0	0	0	0	1	1
	MacDonald Mill Brook	2005	64	11	1	0	0	0	0	0	0	0	0	1	0	0	0
	McLeod Lake Brook	2005	215	17	3	0	1	3	0	0	0	0	0	0	6	34	2
	Mitchell Brook	2005	268	14	0	0	0	0	3	0	0	0	0	0	0	0	1
	Sutherland Brook	2005	388	19	7	0	0	0	3	0	0	0	0	0	0	7	1
	Barren Brook	2003	109	3	30	0	9	0	3	0	0	0	0	0	0	8	2
	Cross Brook	2003	0	0	10	0	14	0	1	0	0	0	0	0	0	23	2
	Kelly Brook	2003	533	24	0	0	0	0	0	0	0	0	0	0	0	0	0
	Nelson Brook	2003	50	0	3	0	22	0	0	0	0	0	0	0	0	3	1
Tusket	Cold Stream	2003	0	0	0	0	0	0	23	0	0	0	42	0	0	0	1
	Big Brazil Brook	2005	0	0	0	0	0	0	13	0	0	1	0	0	0	0	2
	Carleton Bridge	2005	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Wallace	Drennan Brook	2003	0	0	52	0	5	0	0	0	0	0	0	2	30	33	1
	Treen Brook	2004	0	0	0	0	17	0	0	0	1	0	0	1	0	35	2
Mean			448	24	6.0	2.6	2.4	0.2	4.7	0.01	0.03	0.04	0.4	0.2	0.4	4.5	0.9

[A]Salmonid competitors: white sucker, yellow perch, American eel, smallmouth bass, brown bullhead, chain pickerel