Spatial and Temporal Analysis of Brook Trout (*Salvelinus fontinalis*) Population Parameters and Dynamics throughout Nova Scotia

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Abstract

Brook trout are an important recreational fishing species in Nova Scotia. Management of this important species depends upon understanding and appreciating its population characteristics, including spatial and temporal variation in abundance (density), age and size structure, growth, survival, and its relative abundance within the stream fish community. To address these population characteristics on a large scale, the Nova Scotia Department of Fisheries and Aquaculture (NSDFA) conducted a comprehensive electrofishing survey throughout the province during the period 1989 to 1993. Three stream systems were sampled annually in each of the then current five Recreational Fishing Areas (RFAs). Additional data (Musquodoboit, St. Mary's, LaHave, and Stewiacke Rivers) were included in this analysis, provides by NSDFA and Department of Fisheries and Oceans (DFO). Water quality, electrofishing effort, fish community composition, brook trout population parameters (density and size-at-age), brook trout population dynamics (survival and recruitment, and growth) were analyzed via a variety of procedures.

Water quality of streams fall into four groups reflecting bedrock geology. pH is circum-neutral to slightly alkaline except for that area known as the Southern Uplands where it is depressed due to atmospheric acidification. RFAs 1 and 2 have greater electrofishing effort applied than those streams in RFAs 3, 4 and 5, a difference not accountable by area fished but may reflect greater complexity of habitat in some RFAs than others.

The most abundant and widespread fish species were Atlantic salmon, brook trout, white sucker and American eel. The community analysis was composed of two analyses, which produced contradictory results. When richness, diversity and evenness were treated as univariate parameters, RFAs 4 and 5 quite clearly stand out as being separated from RFA 2 in terms of these three community measures, different from RFA 3 with respect to richness and different from RFA 1 in diversity. Community composition among streams within an RFA is quite similar, except for RFAs 1 and 5. The cluster analysis suggested most of the 14 streams have similar community composition with the exception of Porcupine Brook, Kewstoke and Bailey's brooks. This is likely an incorrect inference, given the evidence above that the RFAs do indeed differ in individual aspects of their community compositions.

Precision of the Zippin estimates in this sampling program was quite good. Rigorous analysis of brook trout density was compromised by the weakness of the multiple comparison tests following the Kruskall Wallis tests. However, general features emerge from this analysis. Trout density within RFA 4 appears to be significantly less than that of the other RFAs, with RFAs 1 and 2 having greatest density and RFAs 3 and 5 intermediate. RFA 4 also has the lowest spatial variation in density, while RFAs 1 and 2 the greatest. This is suggestive that the limiting factors operating in RFA 4 are widespread and affect all brooks, while in RFAs 1 and 2 the limiting factors are operating much more on a brook-specific basis. For RFAs 1, 2, and 4 the variation expected within a brook among multiple sites is of the same order as the observed variation among brooks. For RFA 3 and 5 variation among brooks was much greater than that expected within a brook. Variation over time (inter-annual variation) within a brook is greater for RFAs 1 and 2 than for other RFAs, though there are exceptions, and this applies to each age class. Indications are that in the St. Mary's area the trout densities in the period 1989-1993 were approximately average of the long-term trend, while for the LaHave the densities were at the

high end of estimates. With the exception of RFA 3, the relative importance of spatial versus temporal variation varied with RFA and age class. Alkalinity and pH appear to offer the greatest explanatory power of relationships of trout density with environmental factors. There is very little correlation with physical habitat in these data, implying, at a provincial scale, factors most affecting trout density are chemical, rather than physical. These data may be useful to provide some indications of reasonable management targets for RFA-specific trout densities.

Trout body size was smaller in RFAs 1 and 2 than in RFA 4 for ages 0+ and 1+. This observation is intriguing as there is no evidence of density dependence effects on size (see below), and RFA 4 represents the more acidified streams and thus organisms would be expected to suffer physiological and ecological stress. This differential in size among RFAs is most pronounced in age 1+, and by age 2+ the trout in all RFAs appear to be of similar size. Variation in body size among streams within an RFA is quite low. That is, streams within an RFA are quite similar. No streams showed systematic smaller (or larger) body sizes for all age classes. There is no evidence of systematic change in body size (trends) over the 5 year period for any brook or age class evaluated. The results of size-at-age correlation with water chemistry are counter-intuitive as they all suggest inverse relationships with measures of stream productivity (pH, alkalinity, hardness, conductivity). The observed patterns shown here need to be investigated further to confirm their ecological reality.

Estimates for “survival” (change in density) indicate that they are highly variable both among years and also among RFAs. Typical survivals of age 0+ to 1+ appear to be in the range of 0.3 to 0.6 and for age 1+ to 2+, 0.15 to 0.35. The recruitment correlation of RFA 1, and absence of such a relationship in other RFAs, further emphasizes that processes occurring in RFA 1 affecting trout are different than elsewhere. Observations of individual age classes suggest age 0+ trout density is relatively similar among all five RFAs, but then the age 1+ and 2+ appear to be lost in RFAs 3 and 4 relative to the other three RFAs. This is suggestive that spawning is successful but the loss of individuals occurs between age 0+ and 1+.

It appears that growth in RFA 1 is reduced for ages 0+ to 1+ relative to other RFAs, but elevated for ages 1+ to 2+. This result is surprising as RFA 1 shows the highest trout density but no direct evidence of density dependence. Further, RFA 1 has the most appropriate water quality for growth. That it is retarded in this Area relative to other locations is unexplained. Growth showed no correlation with the environmental variables considered here.

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INTRODUCTION

Brook trout (*Salvelinus fontinalis*) are an important recreational fishing species in the Province of Nova Scotia, being the favored species targeted by anglers[1]. Management of this important species depends upon understanding and appreciating its population characteristics, including spatial and temporal variation in abundance (density), age and size structure, growth, survival, and its relative abundance within the stream fish community. Managers and biologists require an understanding of naturally occurring variation in order to separate evidence of population declines/increases from natural variability, or to assess efficacy of habitat restoration or new regulations on fish populations.

To address these population characteristics on a large scale, the Nova Scotia Department of Fisheries and Aquaculture (NSDFA) conducted a comprehensive electrofishing survey throughout the province during the period 1989 to 1993. Three stream systems were sampled annually in each of the then current five Recreational Fishing Areas (RFAs). Unfortunately, following the field sampling, the data analysis was postponed and ultimately the data filed and largely forgotten. In 2011-2012 these data have been revisited and analyzed. Though two decades have passed since the field collections, analysis of these data are highly relevant and valuable to assess spatial and temporal variation and understand those historical conditions. Appreciating the variation in density, size, survival and growth, and having baseline information on these, is particularly important now as the Province has recently begun a new 10-year study of the effectiveness of some restoration techniques. Further, understanding variation among the RFAs is important in managing at an RFA scale. Additionally, estimates of "maximum" or "high" densities, survival and growth rates may provide RFA-specific "targets" for which management may strive to manage these exploited trout populations.

There were three principal objectives to the work presented here:

1. Quantify and analyze spatial and temporal variation of brook trout densities and size-at-age in order to provide scientific information to management on how these vary across brooks, Recreational Fishing Areas, and time.
2. Determine and investigate brook trout population dynamics of survival, recruitment, growth, and potential for density dependence effects on body size.
3. Correlate observed densities and life history parameters with environmental variables.

STUDY AREA

The 1989-1993 sampling program included 14 streams throughout Nova Scotia and these are summarized in Figure 1 and Table 1 (see also Appendix 1). Effectively, the province is the study area of this program. Physical habitat characteristics (width, depth, and velocity) for each stream are provided in Figure 2.

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[1] Brook trout were ranked the number one preferred sport fish by between 23.2%-49.5% of resident anglers in sportfishing surveys of 1985, 1990, 1995, and 2000. The next most favoured species (rainbow trout, *Oncorhynchus mykiss*) was ranked at least 10% below brook trout in each year.

At the time of this sampling, the province was divided into five Recreational Fishing Areas (RFAs). Subsequent to this sampling the RFA boundaries were re-defined and six Areas established. Throughout this document reference to RFAs will be to the historical five regions as the experimental design was based on these five and so data analysis and interpretation need to be consistent with this. These five RFAs are:

- RFA 1: Cape Breton Island
- RFA 2: Cumberland, Pictou, Antigonish, part of Colchester County that is located North of highway 104
- RFA 3: Lunenburg, Halifax, Guysborough
- RFA 4: Shelburne, Queens, Yarmouth, Digby,
- RFA 5: Annapolis, Kings, Hants, and portion of Colchester County located South of highway 104

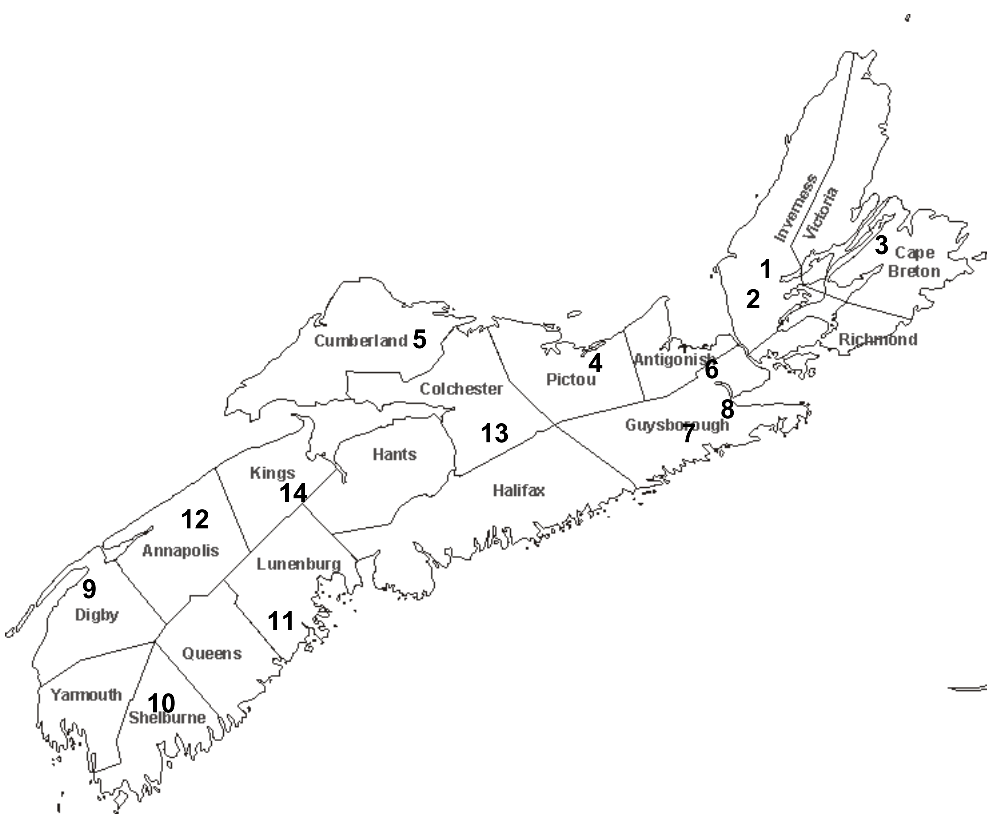

Figure 1: Locations of 14 streams sampled by NSDFA, 1989-1993 during brook trout research program. Base map from Nova Scotia Government website. Numbered sites are (1) Kewstoke Brook, (2) MacDonald's Brook, (3) Dan Morisson's Brook, (4) Bailey's Brook, (5) Bulmer Brook, (6) Hurlburt Brook, (7) Gegogin Brook, (8) St. Francis Harbour Brook, (9) Mistake River, (10) Logging Brook, (11) Wamback Mill Brook, (12) Delancey Brook, (13) South Branch, Stewiacke, and (14) Porcupine Brook. See also Table 1 for identification and further information.

Table 1: Descriptions of streams sampled by NSDFA, 1989-1993 during brook trout research program. See Appendix 1 for greater description of sites and land use.

Zone	Brook	County	River system	Lat/Long of stream mouth
1	Kewstoke Brook	Inverness	Indian River then into Skye River	45º59'33"N, 61º12'58"W
1	MacDonald's Brook	Inverness	River Inhabitants	45º42'35"N, 61º16'37"W
1	Dan Morrison's Brook	Cape Breton	Meadows Brook then into Sydney River	46º10'07"N, 60º18'29"W
2	Bailey's Brook	Pictou	Drains into Northumberland Strait (near Barney's River)	45º42'19"N, 62º16'09"W
2	Bulmer Brook	Cumberland	River Phillip	45º36'15"N, 63º52'34"W
2	Hurlburt Brook	Antigonish	Tracadie River	45º34'45"N, 61º35'05"W
3	Gegogin Brook	Guysborough	Drains into Gegogin Harbour near Liscomb	45º04'12"N, 61º58'49"W
3	St. Francis Harbour Brook	Guysborough	St. Francis Harbour River	45º29'04"N, 61º25'07"W
4	Mistake River	Digby	Sissiboo River	44º25'24"N, 65º51'30"W
4	Logging Brook	Shelburne	Roseway River	Stream not identified due to ambiguity in field notes
4	Wamback Mill Brook	Lunenburg	Petite Riviere	44º14'23"N, 64º27'46"W
5	Delancey Brook	Annapolis	Annapolis River	44º54'46"N, 65º06'08"W
5	South Branch Stewiacke	Colchester	Stewiacke River	45º12'44"N, 63º01'20"W
5	Porcupine Brook	Kings	Gasperau River	45º01'10"N, 64º23'45"W

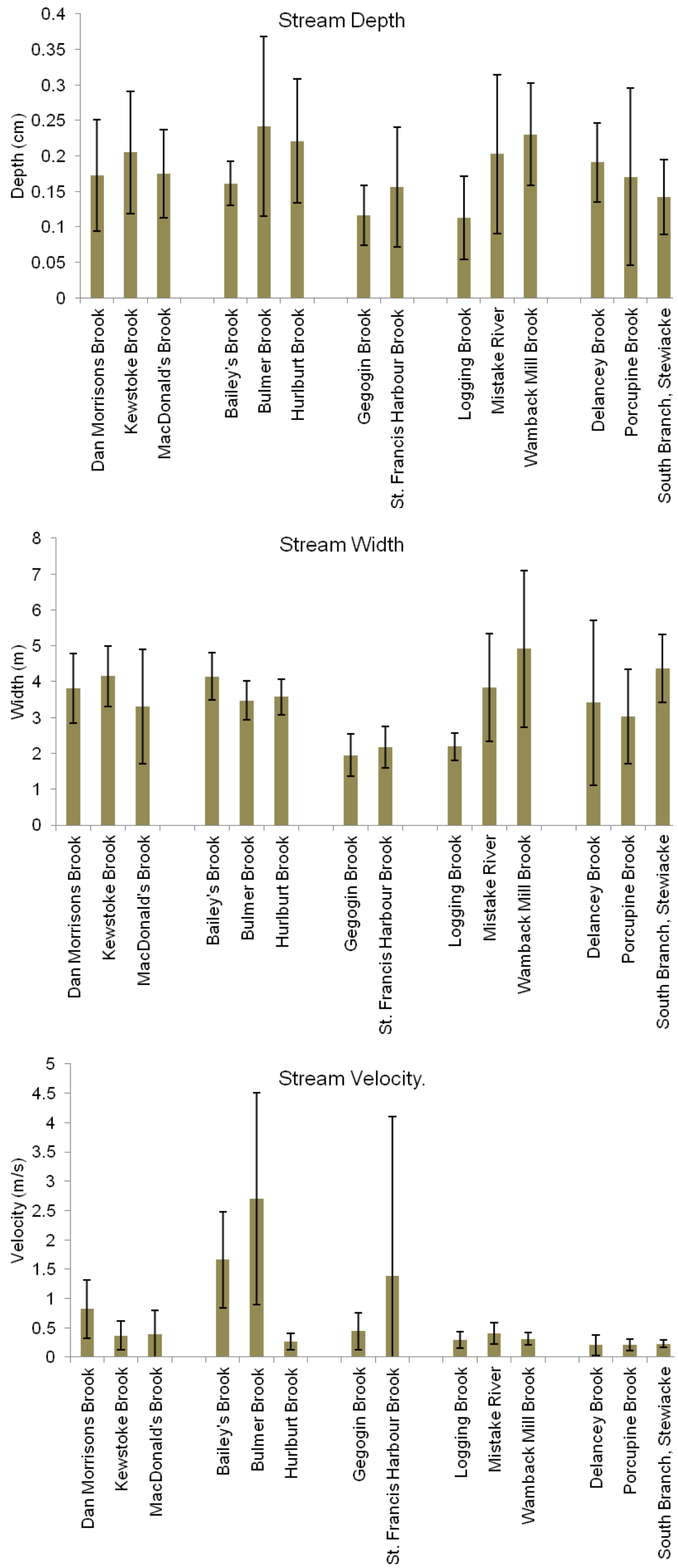

Figure 2: Mean stream depth (upper panel), width (middle panel) and velocity (lower panel) among sampled brooks 1989-1993. Error bars represent standard deviation.

METHODS

Sampling Design and Data Sources

NSDFA sampling (1989-1993)

In the original study design, 15 streams were to be sampled (3 streams in each of 5 RFAs) annually from 1989 to 1993. Originally, this would have provided data for 75 sampling events (15 streams * 5 years each). Unfortunately the data for Robinson Brook (RFA 3) have been subsequently lost, and seven streams were not sampled every year resulting in 53 sampling events on 14 streams. The seven streams with sampling omissions were:

- Bulmer Brook (RFA 2) sampling omitted 1989
- Mistake River (RFA 4) sampling omitted 1990
- Bulmer Brook (RFA 2), Wamback Mill Brook (RFA 4), and Delancey Brook, Porcupine Brook (RFA 5) sampling omitted 1991
- Kewstoke Brook (RFA 1) sampling omitted 1993

The following description of the field procedure was provided by Al McNeil (Manager, NSDFA; personal communication) who participated in these surveys.

Electrofishing was conducted by a two person experienced crew[2] using a Smith Root Model 11a backpack electrofisher. Barrier nets were placed at the upstream and downstream extent of the area sampled and a minimum of three sweeps made through the area. Captured salmonids were identified, measured for length (fork length) and scale sampled. All other species captured were identified and counted. The area sampled was estimated from measurements of length of site and mean of three widths. Stream velocity was estimated by the "floating chip" method (i.e., use of a neutrally or positively buoyant object to determine time for the current to carry an object a measured distance).

Water quality samples were collected at each site in 1989 (21 parameters), 1992 (23 parameters) and 1993 (8 parameters) (Appendix 2).

Additional Data Sources

To complement these RFA data, additional data (brook trout density estimates by size class) were provided by NSDFA from electrofishing of 24 sites in the Musquodoboit River system (RFA 3) between 1989 and 1993. These data are not directly comparable to the 14 other systems as the Musquodoboit data are for multiple sites within a single system (versus single sites per system for the other 14 brooks) and the purposes of data collection differed. However, these Musquodoboit data are viewed as valuable to assess within system variability in the time interval of the directed sampling on the other 14 streams. The data are estimated population densities by size (age) class, <6.0 cm, 6.0 to 11.9 cm, and >11.9 cm for each site and year.

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[2] A two person crew was used to ensure a consistent effort over 5 years with permanent NSDFA staff; in the first year it was decided there was no guarantee of having a third person (student) each year.

The analysis was further expanded by the use of Department of Fisheries and Oceans (DFO) electrofishing data. Data were provided by DFO, Maritimes Region. Similar data were not provided by Gulf Region DFO, despite requests and signing of data sharing agreement. Thus, only Maritimes Region DFO data are included here. DFO data consisted of electrofishing data from 91 river systems from the Inner Bay of Fundy, Southern Uplands, and eastern Cape Breton for the period 1968 to 2010. Only the LaHave River and St. Mary's River (both RFA 3) included more than 4 years of data and also data that overlapped the 1989-1993 period[3]. The Stewiacke River (RFA 5) also had long-term data (29 years) but unfortunately the data for the 1989-1993 period lacked area measurements and so densities could not be calculated.

Data Analysis

Fish Community Composition

Fish community composition was described using (*i*) species richness, (*ii*) Shannon-Weiner diversity index, (*iii*) evenness, and (*iv*) cluster analysis. Species richness (S) is simply the number of species present in a sample and was calculated for each sampling occasion (stream and year) as the sum of individual species. Shannon-Weiner Diversity Index (H') was calculated for each stream and year as:

$$H' = - \Sigma (p_i * \log(p_i))$$

where p_i = proportion of total fish captured comprised by species *i*

H' was calculated using the number of individuals per species in the sample, not by population size or density. Evenness (J') is an estimate of how evenly the observed diversity is distributed among species. That is, whether all species are present in equal abundance (J' approaches 1.0) or the community is dominated by a single (or few) species with others only present at very low abundance (J' approaching 0.0). J' is calculated using the observed H' as a proportion of maximum H' (H_{max}).

$$J' = H'/H_{max}$$

where $H_{max} = \ln(S)$

[3] Of the 91 systems in the DFO electrofishing dataset only 6 had 5 or more years of data: Kennetcook River (5 years), Economy River (9 years), Great Village River (10 years), Lahave River (29 years), Stewiacke River (29 years, and St. Mary's River (33 years). Only LaHave and St. Mary's included density data within the 1989-1993 period.

Brook Trout Population Parameters

Brook Trout Density

Density of brook trout (number/100 m^2) for each stream and year was determined by age class (age 0+, age 1+, age 2+) and for all ages combined using the Zippin method where sufficient captures per sweep allowed. Age classes based on size were assigned in the files previous to data entry and analysis; these classes are not validated or corroborated here, but accepted as they were provided. When Zippin was not applicable (i.e., insufficient captures to allow calculation), density was based on the sum of trout caught (or sum within age class, as appropriate). This must be recognized as a minimum estimate of the population, not a true estimate. There were 63 Zippin and zero non-Zippin (minimum number) estimates for all ages combined, 58 Zippin and 5 non-Zippin for age 0+, 48 Zippin and 14 non-Zippin for age 1+, and 40 Zippin and 21 non-Zippin for age 2+. Density was calculated by dividing each population estimate by the sample area, and standardizing to 100 m^2.

Brook Trout Size-at-Age

As the data in the files were not individual lengths recorded, but rather number of fish assigned to 0.5 cm length classes, calculations of summary statistics were done by treating these as frequency rather than count data. Age classes based on size were assigned in the files previous to data entry and analysis; these classes are not validated or corroborated here, but accepted as they were provided. Mean size-at-age was calculated for each stream, year and age class (ages 0+, 1+, 2+). Parametric summary statistics (mean and SD) were calculated at the brook X year level as mean size-per-age is the standard measure used in fishery science and the samples sizes (number of individual fish measured at each brook in each year) are generally large[4] and the Central Limit Theorem suggests that distributions with large sample sizes should approach normality (Sokal and Rohlf, 1969). However, the summary data (i.e., the means of brooks X years) are not normally distributed (D'Agastino and Pearson test $p<<0.001$ for each of ages 0+, 1+ and 2+) and possess heterogenous variances among RFAs for each age class (Bartlett's Test $p<<0.001$ for each of ages 0+, 1+ and 2+). Statistical tests of size-at-age are described below.

The potential of density-dependent effects on body size were assessed by regressing mean body size on density, on the premise that if density dependent effects were apparent they should show up as a decline in body size with increasing density. Three regressions were evaluated: (i) age 0+ body size against age 0+ density, (ii) age 1+ body size against age 1+ density, and (iii) age 1+ body size against age 0+ density.

[4] Mean number of age 0+ trout used in calculating mean size = 20.1 (SD = 16.1); Mean number of age 1+ trout used in calculating mean size = 14.3 (SD = 15.3); Mean number of age 2+ trout used in calculating mean size = 5.0 (SD= =5.1).

Brook Trout Population Dynamics

Survival & Recruitment

Brook trout survival estimates from age class *i* to *i+1* were derived from age class-specific density data. However, it must be emphasized that these estimates are not true survivals, as they also include movement (immigration and emigration) between years by trout. Thus, survival values >1.0 are possible, for example if there is immigration of age 2+ trout in year *t*+1 relative to age 1+ in year *t*. The data were filtered prior to calculation of survivals to exclude those values which used density estimates based only on minimum estimates (not calculated by Zippin method) as these values are not comparable with Zippin estimates. Values of zero were also excluded (2 zero values for ages 0+ to 1+, 15 zero values for age 1+ to 2+). Exclusion of zeros was based on the premise that there may have been a small number of a given age class not captured and a survival of 0 would be incorrect when the reality is that survival is unknown rather than zero.

Upon this data filtering, and using only the high-quality Zippin density estimates, survival was then calculated as a proportion of an age class in year *t* being present as the following years age class in year *t*+1. That is, survival was calculated as:

$$\text{Density (age class}_{\,i+1 \text{ in year } t+1}) \,/\, \text{Density (age class}_{\,i \text{ in year } t})$$

for age classes 0+ to 1+ and 1+ to 2+.

For recruitment methods, see *Statistical Analysis*, below.

Growth

Annual growth of trout was calculated as the increase in mean body size from one age class to the next in successive years within a single brook.

Statistical Analysis

Water Quality

To assess water quality among the 14 streams, brooks were grouped by Cluster Analysis (Euclidian distance, single linkage method) of water quality parameters using Systat 13.0. The data for cluster analysis was the mean measurement of each parameter across the three years of measurement.

Electrofishing Effort

Electrofishing effort (shocking time in seconds) was summarized over years for each site using median and the interquartile ranges (10^{th} – 90^{th} percentiles). Statistical tests among and within RFAs are presented under *Statistical Tests*, below.

Fish Community Composition

Cluster Analysis (Euclidian distance, single linkage method) using Systat 13.0, was conducted to determine groupings of fish communities. Data used were mean number of individuals per species across the five years of sampling. Estimates of S, H', and J' were subjected to statistical testing to evaluate differences within and among RFAs and these presented under *Statistical Tests*, below.

A particular interest within the fish community was whether there is an inverse correlation between Atlantic salmon (*Salmo salar*) density and brook trout density as the two salmonids are potentially competitors. To assess this, correlation analysis was conducted on Atlantic salmon and brook trout density (all ages combined for each species). Simple linear correlations were conducted (*i*) on an RFA-specific basis (using data from all brooks and years within an RFA), and (*ii*) combining all of the RFAs to increase sample size. Correlation coefficients were compared with critical values in Zar (1999) to determine significance. The Atlantic salmon density estimates had also been calculated by the Zippin method[5] and so the estimates were comparable.

Brook Trout Density

Zippin population estimates have associated uncertainty, in this case calculated as 95% confidence intervals (CI). Zippin estimates and confidence intervals were calculated for individual age classes and all ages combined from POPDN3[6] and estimates included in the files prior to data entry. Thus, the estimates were not calculated by this author. Relative precision of each estimate, analogous to a parametric Coefficient of Variation, was determined as:

$$\text{Relative precision} = (95\%\ \text{CI} / \text{Zippin estimate})*100.$$

The brook trout electrofishing data (all ages combined) were assessed for applicability of parametric statistical analysis (i.e., normal distribution and equal variances among RFAs). Bartlett's Test indicated that variances among the five RFA's are not homogenous ($p<<0.001$), and D'Angastino and Pearson tests indicated that within each RFA the data are not distributed normally ($p<<0.001$ for each RFA). Therefore, non-parametric procedures were used to test for differences in space (within and among RFAs) (see *Statistical Tests*, below).

The NSDFA electrofishing program was based on sampling one site in a brook, and is useful to evaluate variation among brooks and among RFAs but provides no indication of variation within a brook. To assess variation that may exist among multiple sites within a brook, and so understand how representative single site sampling may be, data from three other river systems were evaluated for the period 1989-1993. These systems were the Musquodoboit River, the St. Mary's River and the Stewiacke River. Data from the Musquodoboit was trout density (all ages combined) from between 2 and 6 sites in each of 6 tributaries, that from the St. Mary's was count

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[5] Of 67 samples (brook X year), 26 were zero values (no salmon captured), 36 were Zippin estimates, and 5 were non-Zippin (minimum number estimates) of Atlantic salmon.
[6] POPDN3 is standard software used to calculate Zippin population estimates from electrofishing data.

data (total number of trout, all ages, captured) at between 2 and 5 sites in each of 10 tributaries, and from the Stewiacke River also count data from between 2 and 5 sites in each of 12 tributaries. It is important to note that the number of sites sampled per tributary per year varied greatly among systems and years. To determine relative variation among sites, the median, 10^{th} percentile and 90^{th} percentiles of density or count were calculated across sites within a brook for each year. This was an estimate of variation over the sites within the brook within a single year. Relative variation among sites for each year was then calculated for each tributary as a "CV" analogue:

$$\text{“CV” analogue} = (90^{th}\ \text{percentile} - 10^{th}\ \text{percentile}) / \text{median}) * 100$$

The median, 10^{th} percentile and 90^{th} percentiles of these CV analogues over the 1989-1993 time period for each brook was then calculated, providing an overall median relative variation (%) among multiple sites within a brook. These were not subjected to statistical tests but rather presented in descriptive manner only.

Density over time was assessed at two scales. First was to place the 1989-1993 density results in the context of longer-term brook trout time series to evaluate whether this 5-year period was representative, or if these were extreme years. This was determined by assessing the mean median annual trout density (i.e., the 5-year mean of annual median estimates) in the St. Mary's and LaHave Rivers from the DFO dataset. The mean median annual trout density (trout/100 m^2) for the period of 1989-1993 was compared with percentiles of densities over the period 1966-2010 for each of the LaHave and St. Mary's Rivers for all ages combined (i.e., total trout density). The mean median densities approximating the 50^{th} percentile of the long term distribution would suggest that the period 1989-1993 is typical or representative of a longer period. The Stewiacke River was not used for this assessment as densities during the period 1989-1993 could not be calculated as sampling areas were not provided in the dataset, thus these data were counts only. The second temporal evaluation was to evaluate directed change (trends) over time within the five year sampling period. This was evaluated for each brook using density of (*i*) all age classes combined and (*ii*) age 0+ trout. Annual density of each of these classes was regressed for each of the 14 sites over the 5 year period. Second order polynomial regressions were fit to the data to assess direction of non-linear change. Regressions were conducted using Systat 13.0.

To assess whether variation in one dimension, space or time, was greater than the other, median interquartile ranges (10^{th} – 90^{th} percentiles) were calculated for each dimension. For the temporal dimension this was done by calculating the median of the 5-year interquartile range of the three brooks within an RFA (two for RFA 3). Spatially the median interquartile range was determined by calculating interquartile ranges across brooks within each RFA for each year and calculating median value across years. These medians (temporal and spatial) were then formed into a ratio (temporal/spatial) for each age class and RFA to evaluate relative magnitudes of variation. Ratios with values >1.0 indicate temporal variation exceeds spatial, values <1.0 that spatial variation is greater than temporal, values approximating 1.0 that the two source of variation are equal.

Statistical Tests

Non-Parametric Testing

For several of the variables of interest, differences among RFAs, and among sites within individual RFAs, were assessed using Kruskal Wallis non-parametric tests followed by non-parametric multiple comparison procedures (Zar, 1999). To compare streams in RFA 3 (for which there were only two streams), the Mann Whitney test was used in place of Kruskall Wallis. These tests were used for (i) electrofishing effort, (ii) fish community composition (S, H', J'), (iii) spatial density analysis, (iv) size–at-age, and (v) growth. For size-at-age and growth these tests were used only for comparisons among RFAs; testing among brooks within RFAs for size –at-age was by testing among several medians according to Zar (1999, p 200-202) and sample size for growth was too small to allow testing among brooks within an RFA.

Correlation and Regression

Recruitment is another way of examining "survival" from one age class to the next. Recruitment from age 0+ to age 1+ trout was evaluated by brook-specific correlation analysis of age 0+ density in year t with age 1+ density in year $t+1$ (generally, n=3 or 4 data pairs). This correlation could only be conducted on nine of the 14 brooks as five (Bulmer, Delancey, Mistake, Porcupine and Wamback Mill Brooks) were missing years of data and so yielded only 1 or 2 pairs of data for correlation analysis. Due to the very small sample sizes when using individual brooks (generally, n=3 or 4 data pairs) similar correlation of age 1+ and age 0+ density was conducted at the RFA scale using all brooks in an RFA (generally, n=8 or 10 data pairs). Correlation coefficients were compared with critical values in Zar (1999) to determine significance.

Temporal analysis of size-at-age and growth were conducted using linear regression analysis of stream and age class. Annual estimates of size-at-age or growth were regressed on year to evaluate directed change (trends).

Aspects of brook trout population parameters were correlated with environmental (habitat) variables to explore relationships of trout response to habitat. Simple linear correlations were conducted on:

Brook trout parameters	Environmental (habitat) factor
Density (age 0+, 1+, all ages combined)	Physical (mean width, mean depth, CV depth, velocity)
Size at age (age 0+, 1+) Growth (ages 0+ to 1+, 1+ to 2+)	Chemical (hardness, alkalinity, phosphorous, nitrogen (nitrate), conductivity, pH)

Correlations were between brook trout parameters and environmental factors at the time of sampling. Correlation coefficients were compared with critical values in Zar (1999) to determine significance.

RESULTS

Water Quality

A total of 42 water quality samples were collected (one sample at each of 14 brooks in each of three years). Cluster analysis shows the data to group into four clusters of brooks with similar water chemistry (Figure 3). Kewstoke and MacDonald's Brooks (both in RFA 1) are each separate clusters. Kewstoke Brook stands out (Figure 4) as having high concentrations of calcium, hardness, alkalinity, conductivity, and bicarbonate. MacDonald's Brook also has high values of these parameters, though not as high as Kewstoke, as well as elevated levels of sodium, sulphate and iron. The third cluster (seven streams from Porcupine Brook to Mistake River) consists of all of the RFA 3 and RFA 4 brooks and two of the RFA 5 brooks. These streams stand out as having elevated values of color and total organic carbon. Finally, the fourth cluster of five streams (Bailey's Brook to Bulmer Brook in Figure 3) contains all three streams from RFA 2, and 1 each from RFAs 1 and 4, and the parameters associated with this cluster form the baseline against which the other three clusters are compared.

pH is significantly lower (based on 95% CI) in Cluster 3 (mean=5.88; SD=0.34; 95% CI=0.25) than Cluster 4 (mean=6.98; SD=0.25; 95% CI=0.0.20). Mean pH of Kewstoke Brook over the three sample years was 7.81 (SD=0.25) and MacDonald's Brook 7.53 (SD=0.43).

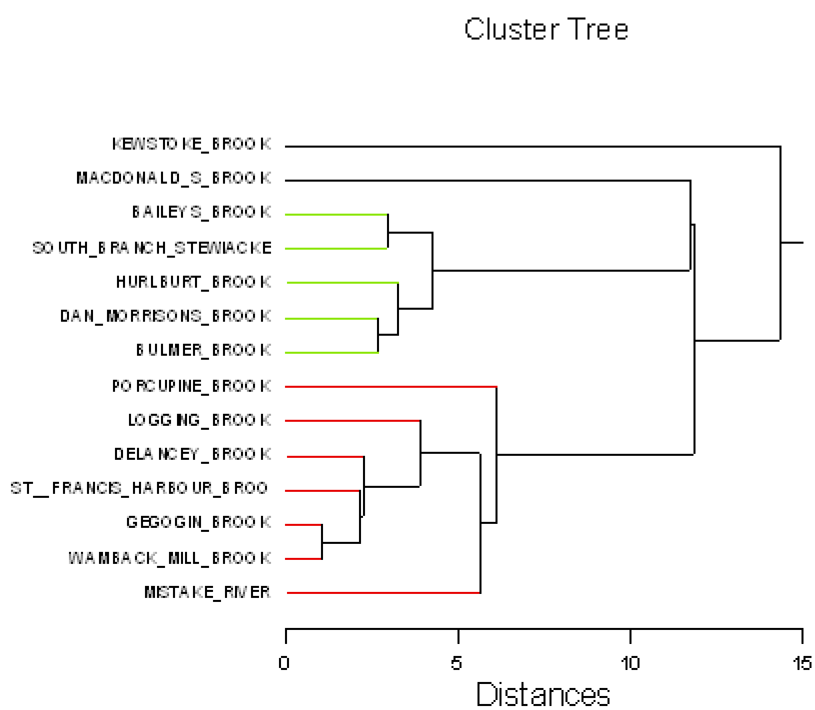

Figure 3: Cluster analysis of water quality data (all variables) of 14 streams in 5 RFAs, 1989-1993.

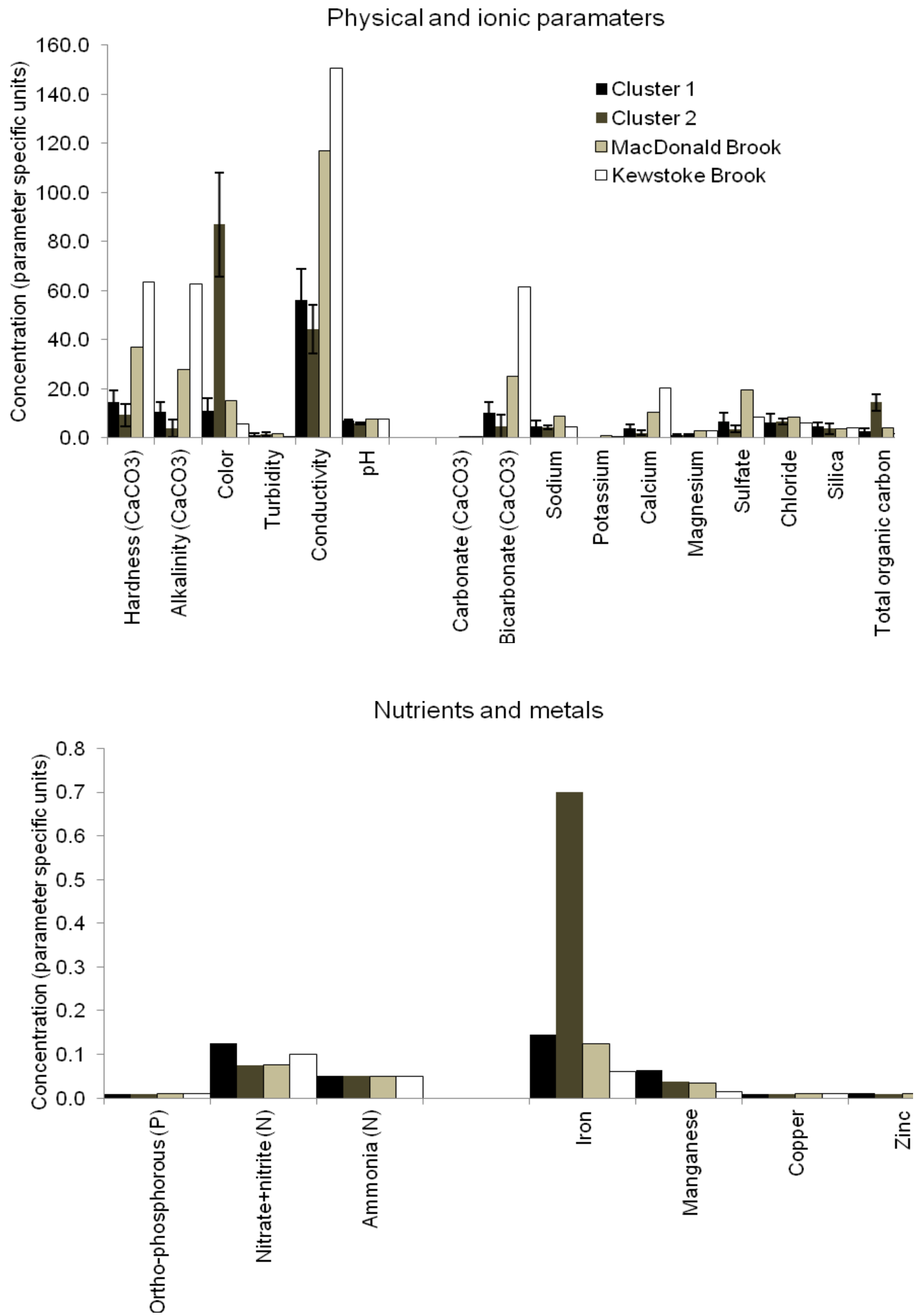

Figure 4: Summary of water quality by cluster identified in Cluster Analysis. Error bars are SD.

Electrofishing Effort

Electrofishing effort (time in seconds) is greater in RFA 1 than RFA 3 ($0.01<p<0.02$), and greater in RFA 2 than RFAs 3, 4 and 5 ($p<0.002$ for each comparison); all other comparisons at the RFA scale indicated similarity. Median effort per brook per year was between 3,759 and 4,905 seconds in RFAs 1 and 2, and between 3,025 and 3,725 in RFAs 3, 4 and 5. Comparisons among brooks within RFAs (Figure 5) indicated only in RFA 1 was there significant difference among streams ($0.002<p<0.005$), though the follow-up multiple comparison could not discriminate those which differed. It is reasonable to conclude from Figure 5 that effort in Dan Morisson's Brook was greater than Kewstoke Brook. Effort among streams within an RFA ranged from very consistent (RFA 3) with differences of median effort among brooks of 157 seconds, to consistent (RFAs 2, 4, 5; differences in median effort among brooks 340 to 636 seconds), to low consistency (RFA 1; difference in median effort among brooks 1,034 seconds). Variation among years within a stream (i.e., interquartile ranges in Figure 5) is greatest in Wamback Mill Brook and Mistake River, and least in Gegogin and St. Francis Harbour Brooks.

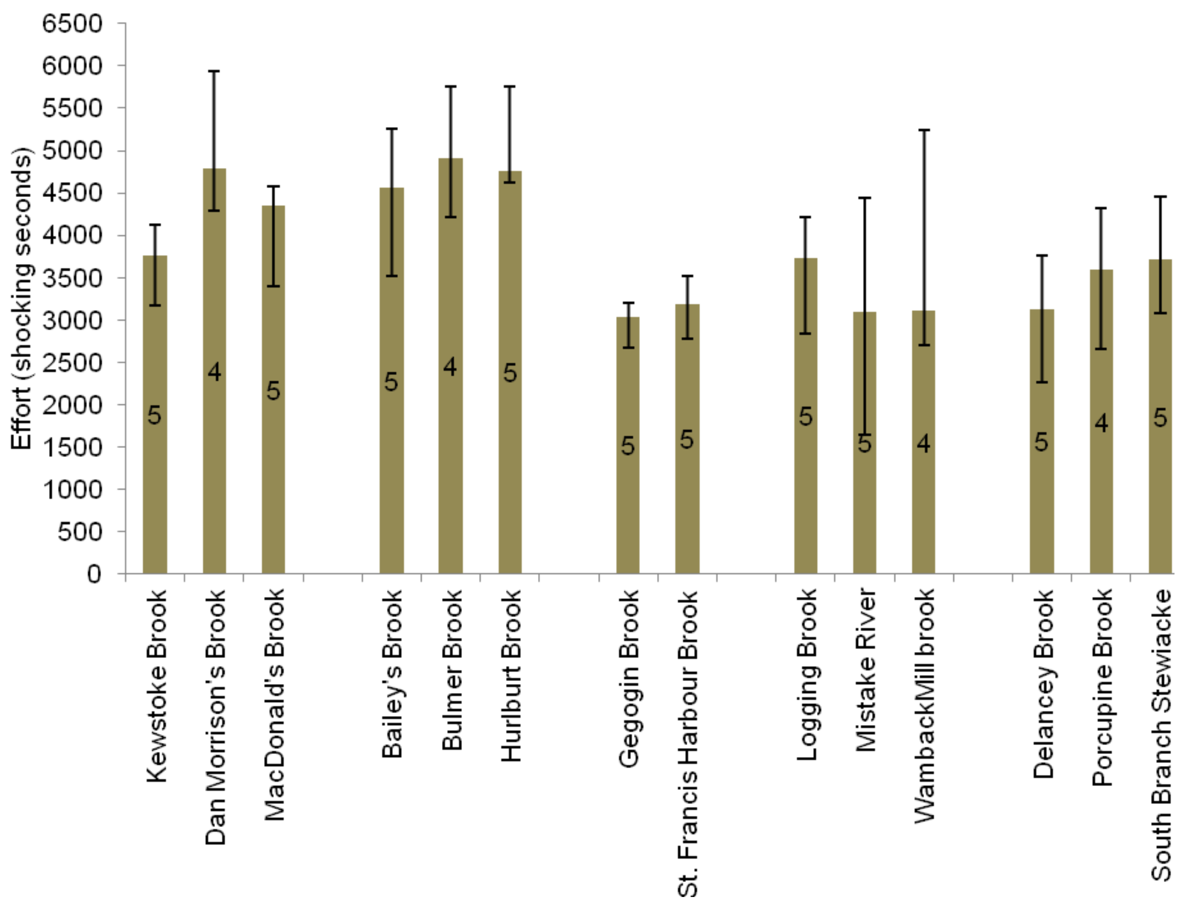

Figure 5: Median electrofishing effort (seconds) over period 1989-1993 for each of 14 sites in five RFAs. Error bars represent interquartile (10^{th} to 90^{th} percentile) range. Values in column represent number of years in sample.

<u>Fish Community Composition</u>

Species richness per sample ranged from 1 (Gegogin Brook, 1989; Delancey Brook, 1989) to 9 species (South Brook, Stewiacke, 1990, 1991, 1992) and total richness per brook over the full five years from 2 (Kewstoke Brook) to 9 species (South Brook, Stewiacke) (Figure 6). The most commonly occurring and widespread species (occurring in more than 7 of the 14 sites) were Atlantic salmon, brook trout, white sucker (*Catastomus commersoni*), and American eel (*Anguilla rostrata*) (Table 2; Figure 7); these four species account for 91.6% of all fish captured among all streams and years (salmon = 54.3%, trout = 26.3%, sucker 6.9%, eel = 4.1%).

RFA 1 has the same richness as all other RFAs, but RFAs 4 and 5 have greater richness than RFAs 2 and 3 ($0.01<p<0.05$) (Table 3). Within individual RFAs, the brooks have equal species richness in RFAs 2, 3, and 4, but in RFA 1 Kewstoke Brook has significantly ($0.02<p<0.05$) lower richness than MacDonald's and Dan Morrison's Brooks. In RFA 5 Delancey Brook has lower richness ($0.005<p<0.01$) than South Branch, Stewiacke, but both of these streams are equal to the intermediate Porcupine Brook.

Table 2: Species presence by RFA from 1989-1993 electrofishing surveys.

	RFA 1	RFA 2	RFA 3	RFA 4	RFA 5
Brook trout (*Salvelinus fontinalis*)	X	X	X	X	X
Atlantic salmon (*Salmo salar*)	X	X	X	X	X
American eel (*Anguilla rostrata*)	X	X	X	X	X
White sucker (*Catastomus commersoni*)	X	X	X	X	X
Stickleback spp. (Gasterostidae)	X	X		X	X
Lamprey (*Petromyzon marinus*)	X				X
Brown trout (*Salmo trutta*)		X			X
Yellow perch (*Perca fluviatalis*)				X	
Creek chub (*Semotilus atromaculatus*)				X	X
Blacknose shiner (*Notropis heterolepis*)				X	
Brown bullhead (*Ameuirus nebulosus*)				X	
Golden shiner (*Notemigonus crysoleucas*)					X
Common shiner (*Notropis cornutus*)					X
Lake chub (*Couesius plumbeus*)					X

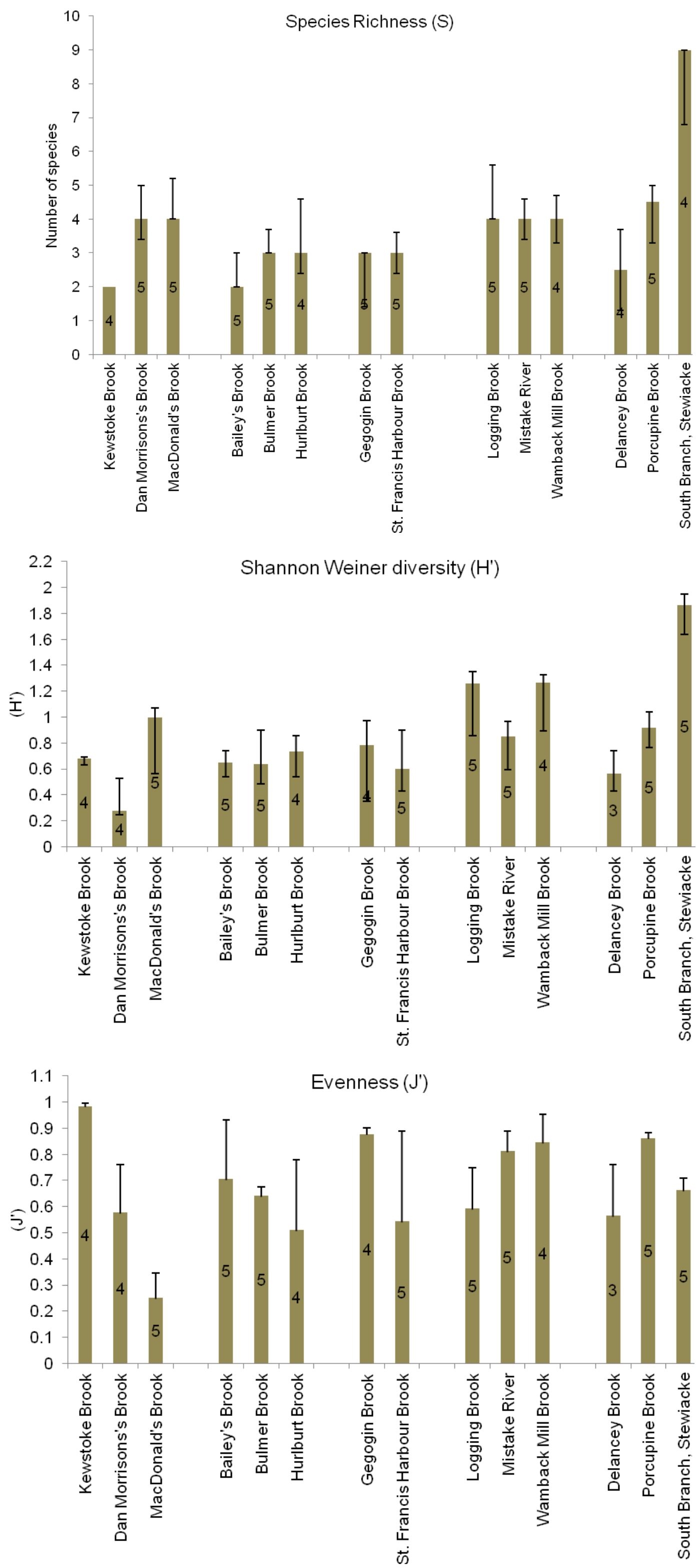

Figure 6: Median fish species richness (S), Shannon-Weiner diversity index (H'), and evenness (J') of brooks in five RFAs, 1989-1993. Error bars represent interquartile (10th to 90th percentile) range. Values in column represent number of years in sample.

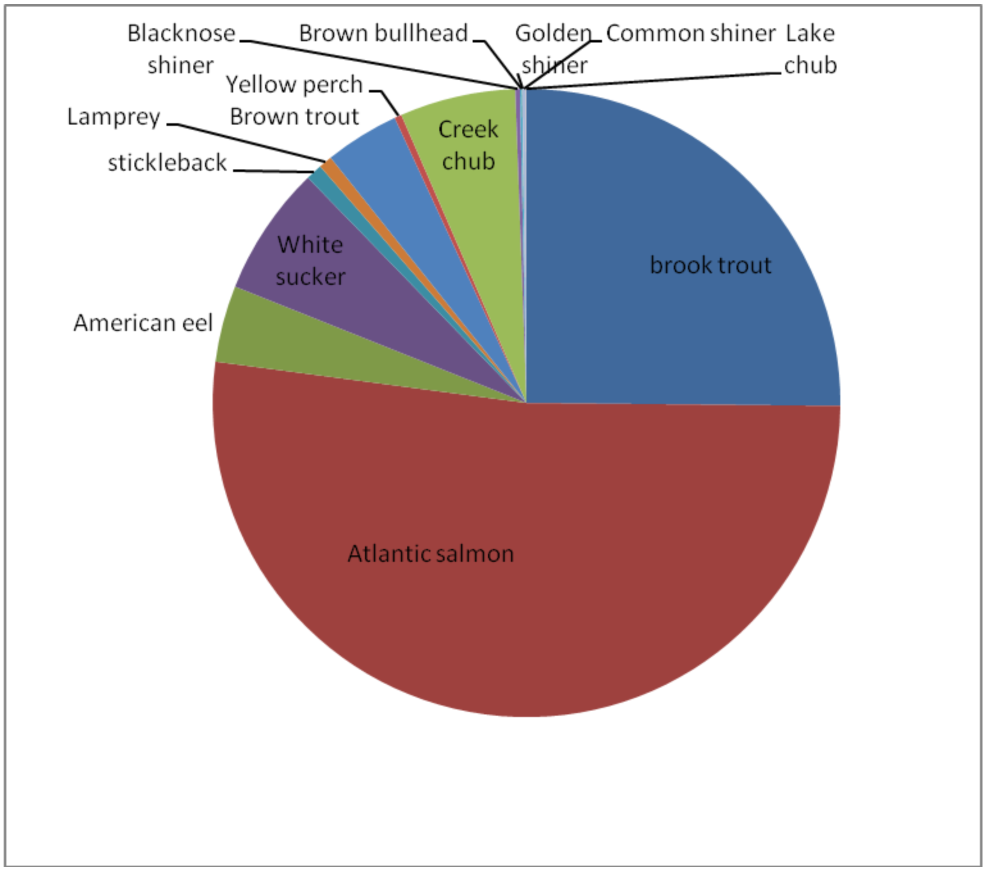

Figure 7: Relative distribution of fish species among 8,849 individual fish captured among the 14 brooks, 1989-1993.

In terms of species diversity (H'), RFAs 1, 2, and 3 are statistically similar, RFA 4 is equal to 2 and 3, and RFA 5 is equal to 3 and 4. From a practical standpoint however, RFAs 4 and 5 have considerably greater diversity than RFAs 1, 2, and 3 (i.e., double the values) (Table 3; Figure 6). The inability to discriminate among these by the statistical method is likely due to small sample size and low power. Similar to species richness, within individual RFAs, the brooks have similar diversity values for RFAs 2, 3 and 4. In RFA 1, MacDonald's Brook has greater diversity values ($0.02<p<0.05$) than Dan Morrison's Brook, but each of these are of equal diversity to Kewstoke Brook. In RFA 5 South Branch Stewiacke has greater diversity values ($0.01<p<0.02$) than Delancey Brook, but each of these are of equal diversity to Porcupine Brook.

Not all RFA's are equivalent with respect to evenness of the community. The Kruskal-Wallis test indicated some differences among RFAs ($0.025<p<0.05$), but the follow up multiple comparisons failed to detect any difference among them. Evenness of RFAs 3, 4, and 5, appear higher than RFAs 1 and 2 (Table 3; Figure 6), though this is not supported by the multiple comparisons. Among streams within RFAs the brooks have equal species evenness in RFAs 2, 3, and 4, but in RFA 1 Kewstoke Brook has significantly ($0.002<p<0.005$) greater evenness than Dan Morrison's Brook, and each are equal to MacDonald's Brook (Figure 6). In RFA 5

Delancey Brook has lower evenness ($0.02<p<0.05$) than South Branch, Stewiacke, but both of these streams are "equal" to the intermediate Porcupine Brook. South Branch and Porcupine Brooks are statistically similar ($0.05<p<0.10$) but very near the critical value of 0.05 which would then imply they are different; they appear different in Figure 6.

Table 3: Summary statistics of species richness (S), Shannon-Weiner diversity (H'), and evenness (J') for each RFA.

	RFA 1	**RFA 2**	**RFA 3**	**RFA 4**	**RFA 5**
			Richness (S')		
Mean (±SD)	3.64 (1.27)	3 (0.87)	2.7 (0.82)	4.21 (0.8)	5.23 (2.77)
n	14	14	10	14	13
Range	2 - 6	2 - 5	1 - 4	3 - 6	1 - 9
CV	0.35	0.29	0.3	0.19	0.53
Median	4	3	3	4	5
			Diversity (H')		
Mean (±SD)	0.62 (0.27)	0.67 (0.15)	0.66 (0.27)	1.15 (0.27)	1.41 (0.5)
n	14	14	13	9	9
Range	0.22 - 1.09	0.45 - 0.98	0.23 - 0.99	0.63 - 1.38	0.73 - 1.95
CV	0.44	0.23	0.4	0.23	0.35
Median	0.61	0.67	0.62	1.25	1.54
			Evenness (J')		
Mean (±SD)	0.57 (0.31)	0.66 (0.16)	0.66 (0.27)	0.79 (0.15)	0.76 (0.13)
n	14	14	9	9	9
Range	0.14 - 0.99	0.4 - 0.94	0.21 - 0.9	0.45 - 0.97	0.51 - 0.89
CV	0.54	0.24	0.41	0.19	0.17
Median	0.5	0.64	0.85	0.81	0.84

Cluster analysis (Figure 8) indicated that there are three clusters of streams with respect to fish community structure: (1) Porcupine Brook (RFA 5), (2) Kewstoke and Bailey's Brooks (RFAs 1 and 2, respectively), and (3) all other streams. Porcupine Brook showed a relatively large number of white sucker, and was the only brook to show lake chub (*Couesius plumbeus,* though only two individuals) (Figure 9). Cluster 2 was notable by only three species present (brook trout, Atlantic salmon, and American eel). Cluster 3, in contrast to Cluster 2, showed numerous species, and was separate from Porcupine Brook by lack of large numbers of white sucker.

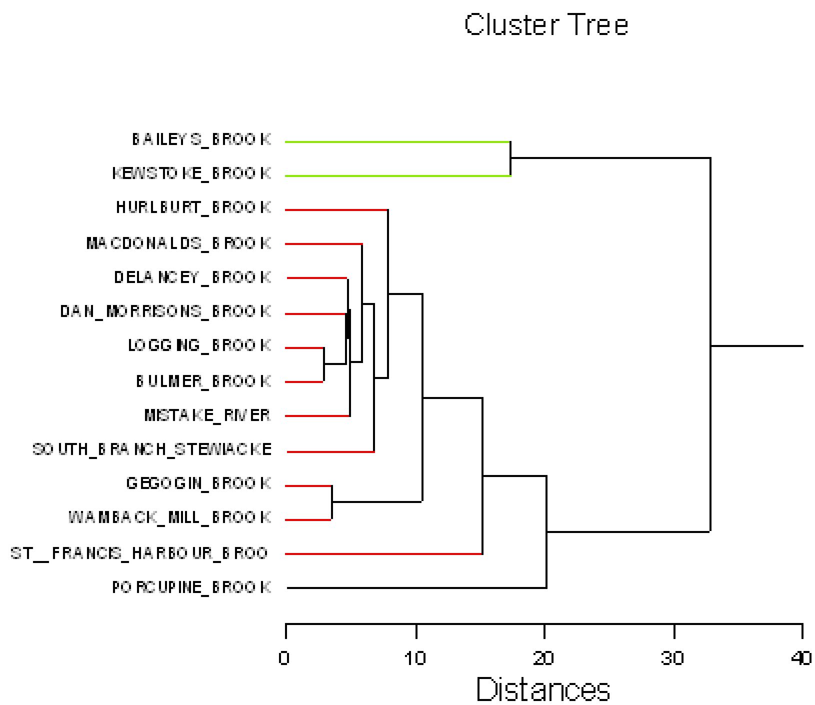

Figure 8: Cluster analysis of fish community composition (mean number of individuals averaged across years) of 14 streams in five RFAs, 1989-1993.

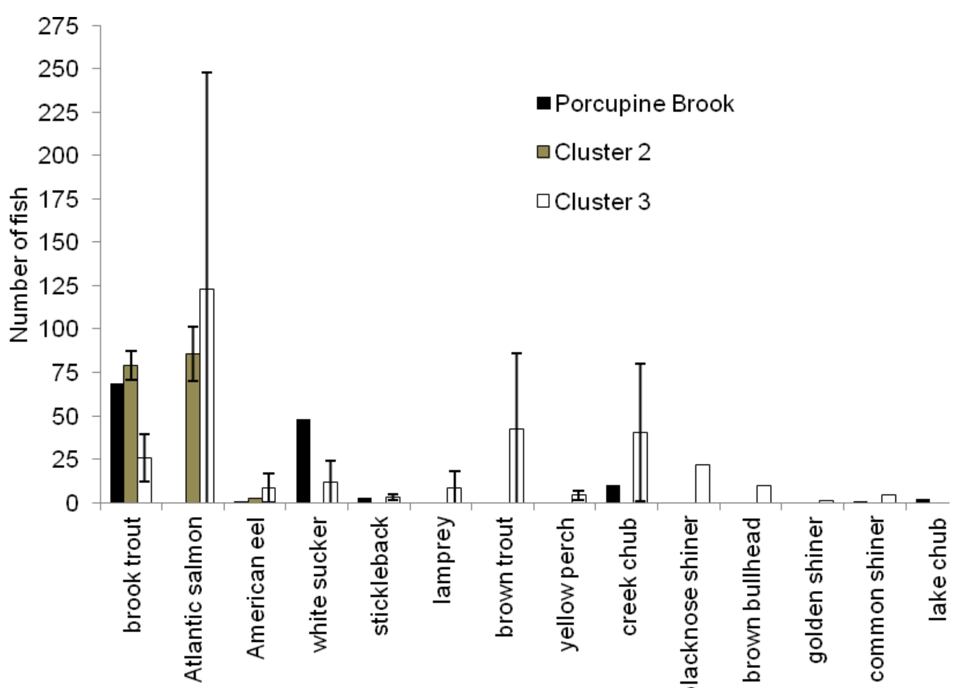

Fig 9: Mean number of fish caught by species and cluster in each year, 1989-1993. Error bars represent SD.

Atlantic salmon may exert competitive inhibition on brook trout and so these data were examined for such an effect. There is no clear relationship of trout density and salmon density ($p=0.07$; $r^2= 0.053$; $n=62$) (Figure 10). While the regression equation approaches significance, the variation explained (r^2) is extremely low, implying that salmon density likely has little to no effect on trout density. Further, the slope of the line is opposite to that of competitive inhibition (which would be a negative slope). Examining possible relationships between these two species at the RFA-scale by correlation analysis also showed no significant relationships (*r* ranged from -0.443 to 0.486[7]; $p>0.10$ for all correlations). There is no evidence that Atlantic salmon presence or abundance affects density of trout in these data.

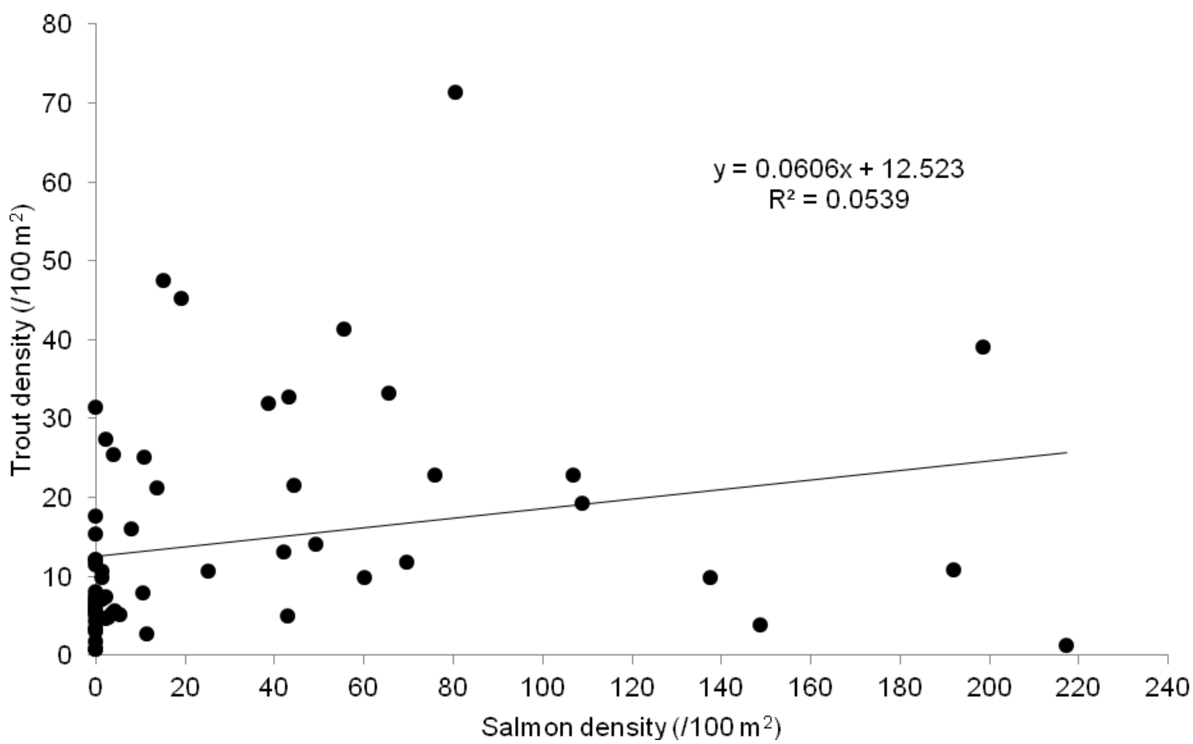

Figure 10: Relationship of brook trout density to salmon density among all streams, RFAs and years (n=62 points).

[7] For RFA 3 initial correlation with n=10 yielded a significant correlation of 0.891. Examination of the plot showed this was driven by a single data point well removed from the cluster of 9 other points. Exclusion of this outlier reduced the correlation coefficient to non-significance. Thus, this correlation is considered not significant as it is extremely affected by a single point.

Brook Trout Population Parameters

Precision of density estimates

Trout populations were estimated with greatest precision for all ages combined and least for age 2+ trout (Figure 11). Median precision for ages 0+, 1+ and all ages combined ranged between 18% and 25%. For age 2+ trout, median precision was 50%. Variation about these median (i.e., interquartile ranges) were greatest for ages 0+ and 2+. In general, the precision of these population estimates were quite good as fish sampling precision is notoriously low.

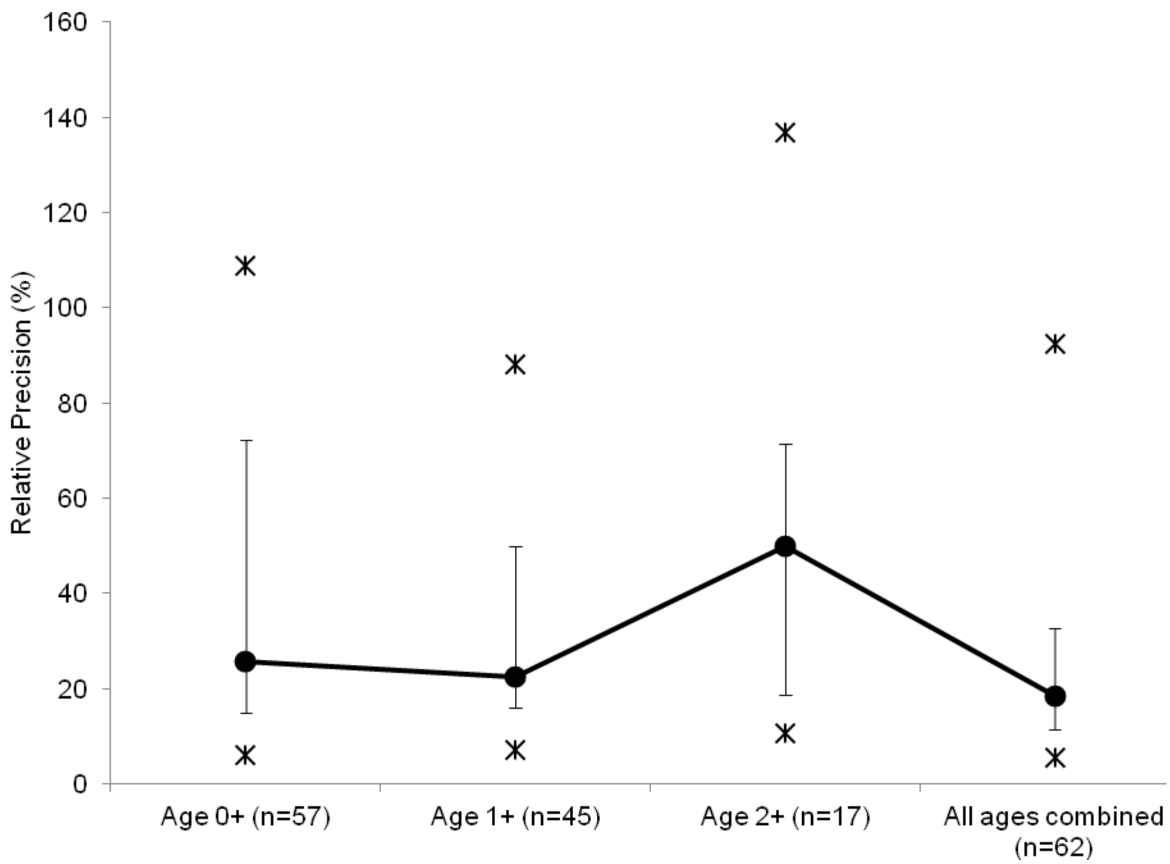

Figure 11: Median precision of electrofishing population (Zippin) estimates of brook trout in five RFAs, 1989-1993, by age class and all ages combined. Error bars represent the (25^{th} to 75^{th} percentile) interquartile range and asterisks the (10^{th} to 90^{th} percentile) interquartile range.

Density

In the following section two general forms of graphics are illustrated. The first is summary statistics (median and interquartile range) of individual RFAs. In these, the variation shown is both spatial (among brooks) and temporal (among years) combined. The second form of figures, summary statistics by brook within RFA, show variation over time for each brook. These two graphics, taken together, provide a picture of variation over space and time at two scales. The asymmetry of the error bars in Figures 12 and 14-16 indicate dispersion of the data, whether the median is near the center of the data distribution or near one of the extremes. The interquartile range of 10^{th} to 90^{th} percentile (error bars in graphics) are very conservative, representing the central 80% of the underlying distribution. The more standard typical presentation using Standard Deviation only represents 66% of the underlying distribution.

Total densities (all ages combined)

In general, RFAs 1 and 2 appear to have greater brook trout densities than the other three RFAs (Figure 12), but the high variability among streams and years within an RFA prevent statistically meaningful distinctions between RFAs, with the exception that brook trout densities of RFA 4 are less than RFAs 1 ($0.005<p<0.01$) and 2 ($p<0.001$). The other RFAs are statistically indistinguishable from each other. In RFA 1, the Kruskal-Wallis test indicated differences among streams, but this was not corroborated by the multiple comparison test as has occurred frequently in this analysis. Accepting there is a difference among streams, Kewstoke Brook is of significantly greater density than MacDonald's Brook (Figure 12). In RFA 2, Bulmer Brook has lower density than Bailey's Brook ($0.02<p<0.05$), while in RFA 3 the two brooks are equivalent. In RFA 4 Logging Brook has higher density than Mistake River ($0.02<p<0.05$), but equal to Wamback Mill Brook while the latter two systems are equivalent. Finally, in RFA 5, similar to RFA 1, the Kruskal-Wallis test indicated differences among brooks, but this was not corroborated by the multiple comparison test. Accepting there is a difference among streams, Porcupine Brook has greater density than South Branch Stewiacke.

Variation of brook trout density among streams is high in RFAs 1 and 2, low for RFAs 3 and 4, and intermediate for RFA 5 (Table 4). Stream variation is 2 to 3 times greater (or more) between RFAs 1 and 2 over RFAs 3, 4 and 5. The high variability in RFA 1 is driven by Kewstoke Brook, which in turn is largely driven by the single year of 1989 ($71.4/100m^2$). This 1989 value is estimated with good precision (25%) and so cannot be excluded as an anomalous point. Variability in RFA 2 is driven by Bulmer Brook, which has a lower median estimate than the other two RFA brooks. The variability in RFA 3 is driven by inter-year variability in St. Francis Harbour Brook rather than spatial variability between brooks. Variability in St. Francis Harbour Brook includes a 1989 estimate of $47.6\ /100m^2$, which is considerably greater than the next highest estimate ($27.4/100\ m^2$) for this brook. Interestingly, the 1989 high value is estimated with a very high degree of precision (3.4%). RFA 4 has very high consistency, albeit low values, of density for brook trout among sites.

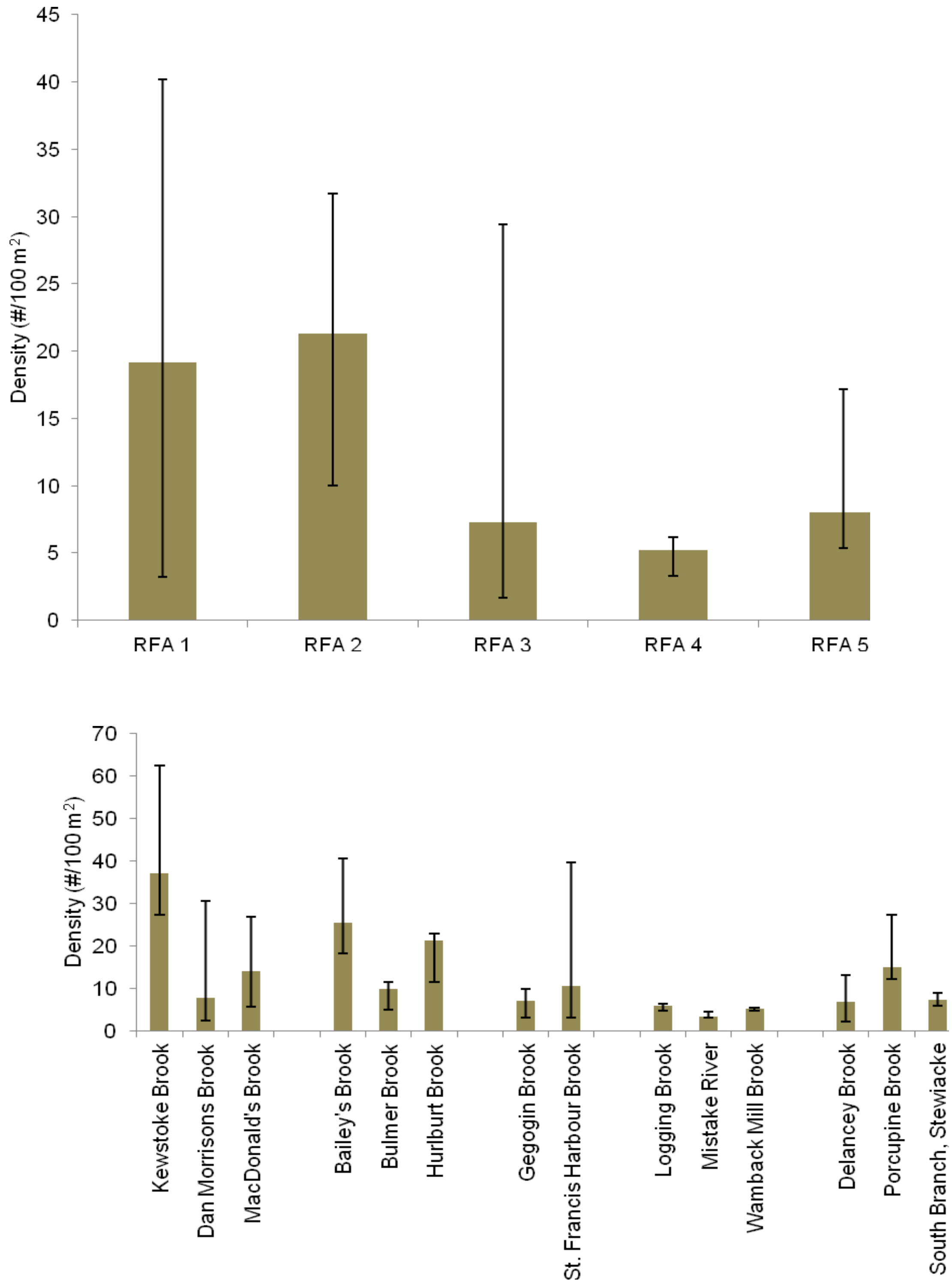

Figure 12: Median density of brook trout (all ages combined) by RFA (upper panel) and by site within RFA (lower panel). Error bars represent interquartile (10^{th} to 90^{th} percentile) range.

Table 4: Median and interquartile ranges (10^{th} – 90^{th} percentiles) of variation (number trout/100m^2) among brooks within each RFA. These values calculated by determining the range (maximum – minimum) of density values among brooks within RFA in each year, then determining median and interquartile range over the five years.

	RFA 1	RFA 2	RFA 3	RFA 4	RFA 5
			Age 0+		
Median	19.2	12.6	6.2	2.6	7.8
Interquartile range	9.16 - 30.88	5.24 - 19.76	2.8 - 11.26	1.22 - 4.24	1.2 - 14.124
			Age 1+		
Median	10.6	9.5	5.3	1.8	4.2
Interquartile range	5.44 - 24.16	5.92 - 11.84	1.14 - 20.62	1.62 - 2.66	1.64 - 8.1
			Age 2+		
Median	3	2.5	0.7	0.3	1.1
Interquartile range	1.36 - 6.26	0.54 - 5.18	0 - 4.22	0.3 - 0.7	0.28 - 2
			All ages combined		
Median	31.6	19	6.6	2.3	10.1
Interquartile range	20.54 - 46.72	12.92 - 22.1	3.78 - 34.94	1.02 - 2.9	1.68 - 23.2

The bulk of the trout density analysis is based upon sampling a single site within a brook, but there exist data (Musquodoboit, St. Mary's, and Stewiacke Rivers; see *Methods*) allowing an appreciation of variation among multiple (2 to 6) sites within a single brook. With each of the Musquodoboit and St. Mary's systems there are one or a few individual brooks that show a very high degree of variation among multiple sites within a brook (e.g., Kent Brook in Musquodoboit system, Moose River, North Nelson River and Archibald's Brook in St. Mary's system) (Figure 13). Mean median relative variation among multiple sites within a single brook are on the order of 65% to 85% (Table 5), except when Moose River included in the St. Mary's assessment in which case the variation rises appreciably. This implies that, on average, the variation relative to the median estimate, among sites within a single brook and single year, may be expected to be in this range. Therefore, the results from single site sampling may not be completely represent the entire brook but the density or count estimates may be expected to be within 65% to 85% of other unsampled sites.

Calculating a similar relative variation from the medians and interquartile range in Table 4 to assess relative variation among brooks within an RFA indicate this variation ranges from 48.3% (RFA 2) to 472% (RFA 3) with the other three RFAs showing intermediate values of 81.7% (RFA 4), 82.8 (RFA 1), and 213% (RFA 5). Thus, the variation among brooks in three RFAs is approximately similar to the variation within brooks. But for the RFAs 4 and 5, variation among brooks is much greater than expected for among sites within a brook.

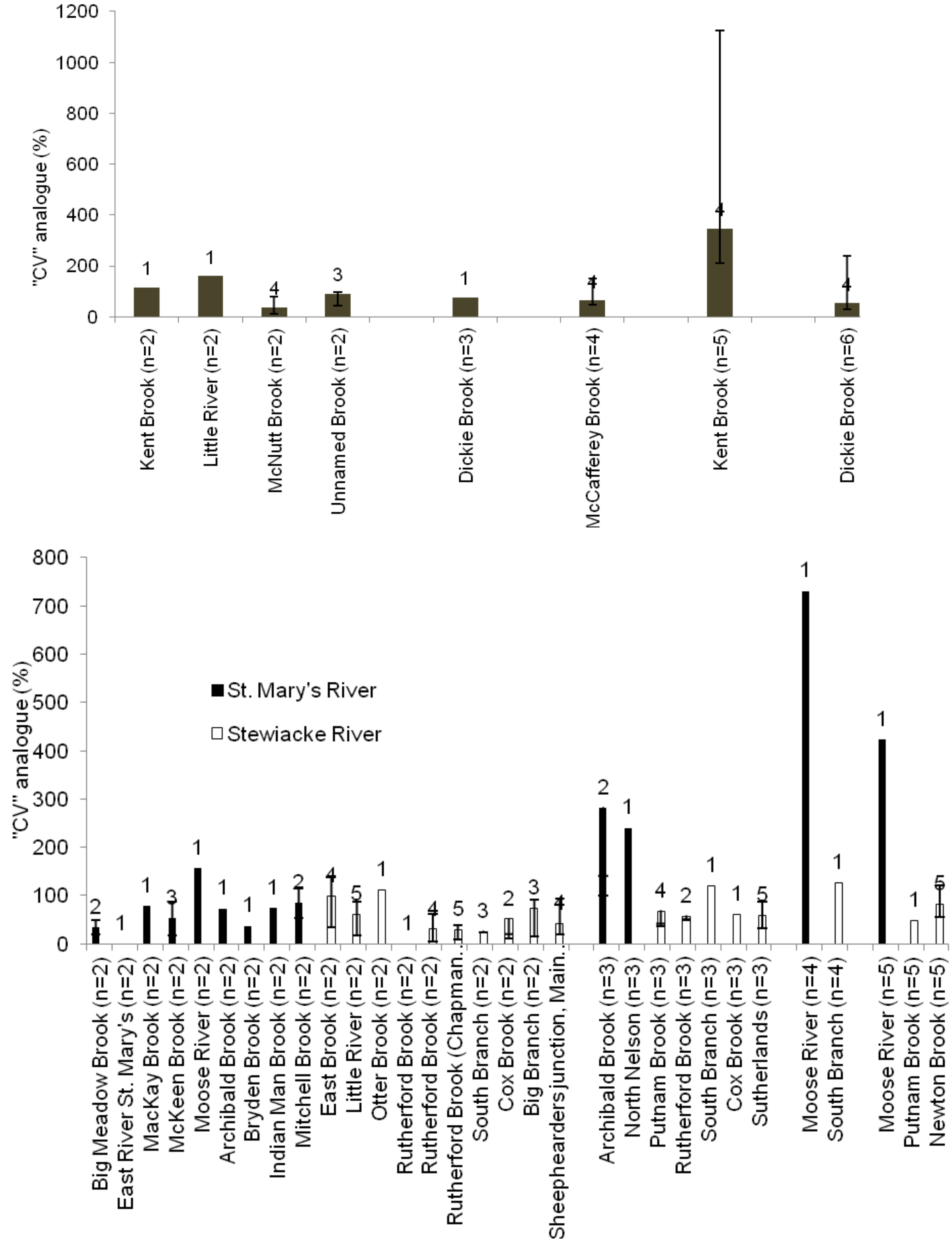

Figure 13: Median "CV" analogue within sites among streams in the Musquodoboit River (upper panel) and St. Mary's and Stewiacke Rivers (lower panel) 1989-1993. The Musquodoboit data from which these variations are calculated are density (number/100 m^2; all ages combined) and for the St. Mary's and Stewiacke are counts of trout captured (all ages combined). Error bars are

interquartile (10^{th}-90 percentile) ranges. Column values indicate number of years and values on x-axis number of sites used in calculation.

Table 5: Mean median "CV" analogues of relative variation (%) among brooks within a river system.

	mean	SD	n
Musquodoboit (all data)	86.92	70.07	8
Musquodoboit (excluding Kent Brook)	85.51	41.59	7
St. Mary's (all data)	174.38	205.86	13
St. Mary's (excluding Moose, Archibald's and North Nelson)	65.76	43.72	9
Stewiacke River (all data)	63.46	34.23	18

Density By Age Class

AGE 0+

In comparing density of age 0+ trout among RFAs, the sole significant difference was that RFA 2 is greater than RFA 4 ($p<0.001$), all others are similar (Figure 14). RFA 1 is very near statistical significance ($0.05<p<0.10$) for difference from RFA 4. The year-to-year and brook-to-brook variation is very large within a given RFA, particularly for Areas 1 and 2, which result in few significant differences. Variation of age 0+ density among streams within RFA 4 is low, within RFAs 1 and 2 is high, in RFAs 3 and 5 is intermediate (Table 4). Comparison of brooks within RFAs indicate there are significant differences among brooks (Kruskal-Wallis $p<0.002$) for each of RFAs 1, 2, 4, and 5 (Figure 14), but the multiple comparison test cannot discriminate those sites which differ from others, with the exceptions of RFA 2 where density in Bailey's Brook is greater than Bulmer's Brook and RFA 4 where Logging Brook has greater density than Wamback Mill Brook ($0.02<p<0.05$ for each). Accepting that there are differences among brooks, the reasonable inferences are that age 0+ trout density in Kewstoke Brook is greater than Dan Morisson's and, possibly, MacDonald's Brooks (RFA 1), and Porcupine Brook is greater than Delancey Brook (RFA 5). The sites within RFA 3 do not differ from each other ($p>0.20$).

Annual variation (as measured by interquartile range of brook) is greatest in RFAs 1 and 2, and less in the other RFAs (Figure 14). In particular, variation in RFA 4, Delancey Brook and South Branch, Stewiacke (RFA 5), and Bulmer Brook (RFA 2) are low (i.e., interquartile range <4 trout/100m^2 for each brook over the 5 years). The other five brooks in RFA 1 and 2 are all of high variation (interquartile range 11.4-22.5 trout/100m^2). Dan Morrison's Brook has an anomalous density value (32.4 trout/100m^2 in 1989 while the maximum value among the remaining four years is 6 trout/100 m^2) driving the high variance of 0+ trout in this brook. The other brooks with high variation are not so influenced by a single influential point but the data are more evenly distributed within the interquartile range.

AGE 1+

Similar to age 0+ density, RFA 2 had greater density than RFA 4 ($0.01<p<0.02$), but RFA 1 also differed from RFA 4 for this age class (0.02,<<0.05) (Figure 15); all others are similar. The multiple comparison tests are weak as it appears in Figure 15 that RFAs 2 and 5 both exceed RFAs 3 and 4. As with age 0+, the year-to-year and brook-to-brook variation is very large within a given RFA which preclude significant differences among RFAs. Variation of age 1+ density among streams within RFA 4 is low, within RFAs 1 and 2 is high, in RFAs 3 and 5 is intermediate (Table 4). RFA 1 has very high variation in age 1+ density (interquartile range 21.8 trout/100m^2), driven by Kewstoke Book. Comparison of streams within RFAs indicate there are significant differences among brooks (Kruskal-Wallis $p<0.001$ in each RFA) of RFAs 1, 2, and 4, but not RFAs 3 and 5 (Figure 15). Kewstoke Brook is greater than Dan Morisson's Brook in RFA 1 ($0.01<p<0.02$) and Wamback Mill Brook density is greater than Logging and Mistake Brooks in RFA 4 ($p<<0.001$). The multiple comparison test did not discriminate RFA 2 sites but it appears from Figure 15 that age 0+ trout density is greater in Bailey's Brook than Hurlburt Brook.

Annual variation of age 1+trout (as measured by interquartile range at each brook) appear quite similar among RFAs with a few brooks driving isolated greater variation (Figure 15). Variation is greatest (range of interquartile ranges from 7.6-20.8 trout/100 m^2) in Kewstoke Brook (RFA 1), Bailey's and Bulmer's Brooks (RFA 2), and St. Francis Harbour Brook (RFA 3). The other 10 streams each show variation of <6.6 trout/100 m^2 among the five years of sampling.

Dan Morrison's and MacDonald's Brooks (RFA 1), and Hurlburt Brook (RFA 2) show greatly reduced inter-annual variation by age 1+ trout relative to age 0+, (Interquartile ratio[8] of age 1+ to age 0+ <0.30). Bulmer (RFA 2), St. Francis Harbour (RFA 3), Logging (RFA 4), and Delancey Brooks (RFA 5) all show increased variation relative to age 0+ (Interquartile ratio of age 1+ to age 0+ >1.0).

AGE 2+

The Kruskal-Wallis test detected significant ($p<<0.001$) differences among RFA's for age 2+ trout density, but the follow up non-parametric multiple comparisons only identified RFA 1 as being greater than RFAs 3 and 4 ($p<0.05$ for each). However, RFA 3 is effectively zero age 2+ trout (Figure 16) so this is not particularly helpful. As with the previous ages, this analysis suffers from small sample size and large variation which preclude differences. RFAs 1 and 2 have very high variation relative to the medians, but in absolute terms all RFAs showed low variation (Table 4). Comparison of streams within RFAs indicate there are significant differences among brooks (Kruskal-Wallis $p<0.002$ in each RFA) in RFAs 1, 2, 4, and 5 (Figure

[8] The interquartile ratio is simply the interquartile range (90th percentile – 10th percentile) for the older age class divided by the interquartile range for the younger age class, for each brook. Values greater than 1.0 indicate increasing variation with age, values <1.0 indicate decreasing variation with age.

16). In RFA 4, Wamback Mill Brook has significantly greater age 2+ density then Logging Brook or Mistake River ($p<0.001$ for each comparison) and in RFA 5 density in Delancey Brook is less than South Branch, Stewiacke. Accepting that there are differences among sites in RFAs 1 and 2 not detected by the multiple comparison, the reasonable inferences are that age 2+ trout density in Kewstoke and MacDonald's Brooks are greater than Dan Morisson's Brook (RFA 1), and Bailey's and Bulmer Brooks have greater density than Hurlburt Brook (RFA 2). Gegogin Brook showed no age 2+ trout, while St. Francis Harbour Brook (both RFA 3) did. Statistical significance was approached ($0.05<p<0.10$) but it could not be concluded that they were different.

Annual variation of age 2+ trout (as measured by interquartile range at each brook) appear quite similar among RFAs with a few brooks driving isolated greater variation (Figure 16). This variation is greatest in MacDonald Brook (RFA 1), Bailey's and Bulmer's Brooks (RFA 2), St. Francis Harbour Brook (RFA 3), and Delancey Brook (RFA 5) (range of interquartile from 2.8-5.6 trout/100 m^2). The other 10 streams each show variation of <1.7 trout/100 m^2 among the five years of sampling.

Kewstoke Brook (RFA 1) shows greatly reduced inter-annual variation by age 2+ trout relative to age 1+, (interquartile ratio of age 2+ to age 1+ <0.10). MacDonald's (RFA 1) and South Branch, Stewiacke (RFA 5) show increased variation relative to age 1+(Interquartile ratio of age 2+ to age 1+ >0.80).

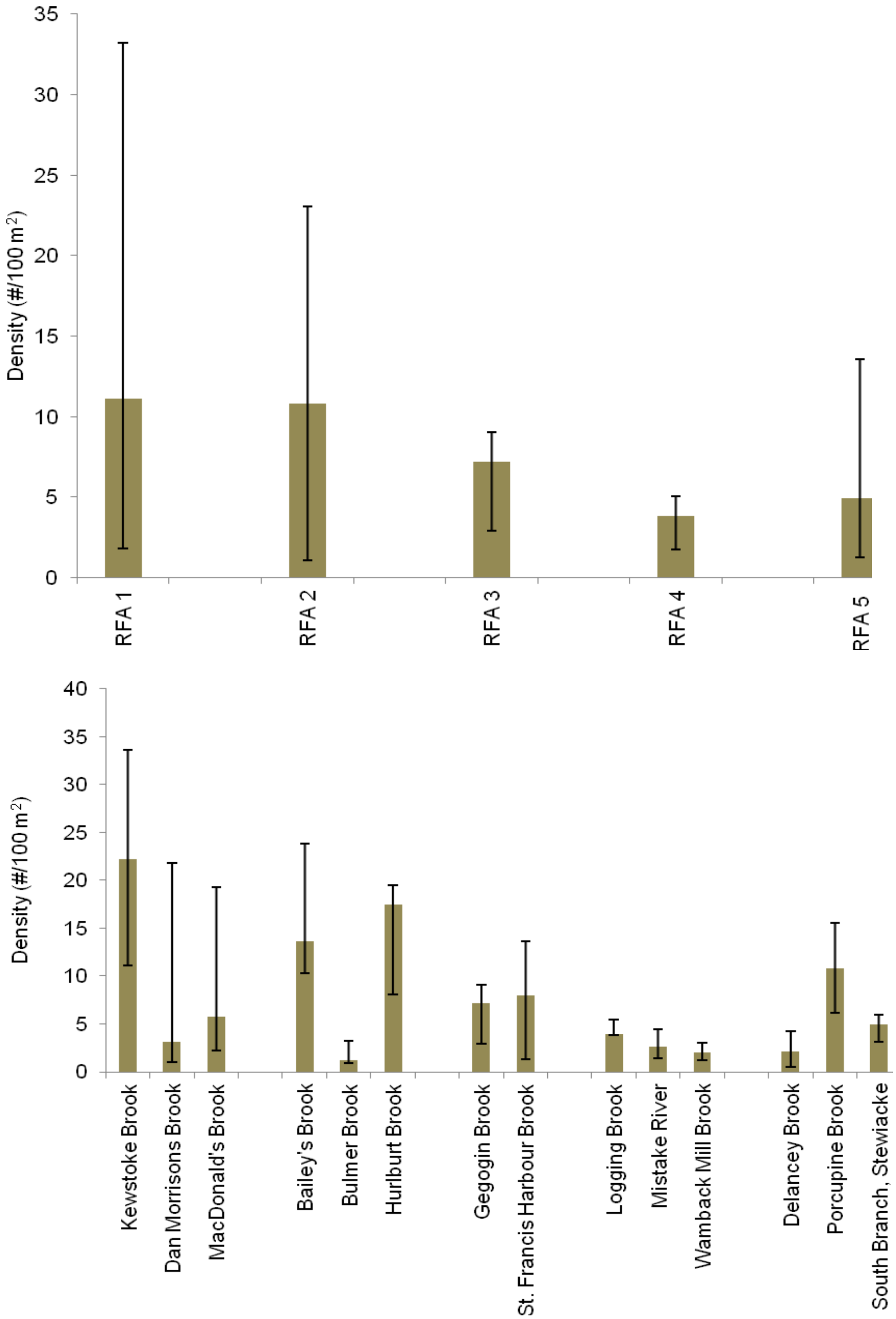

Figure 14: Median density of brook trout (age 0+) by RFA (upper panel) and by site within RFA (lower panel). Error bars represent interquartile (10^{th} to 90^{th} percentile) range.

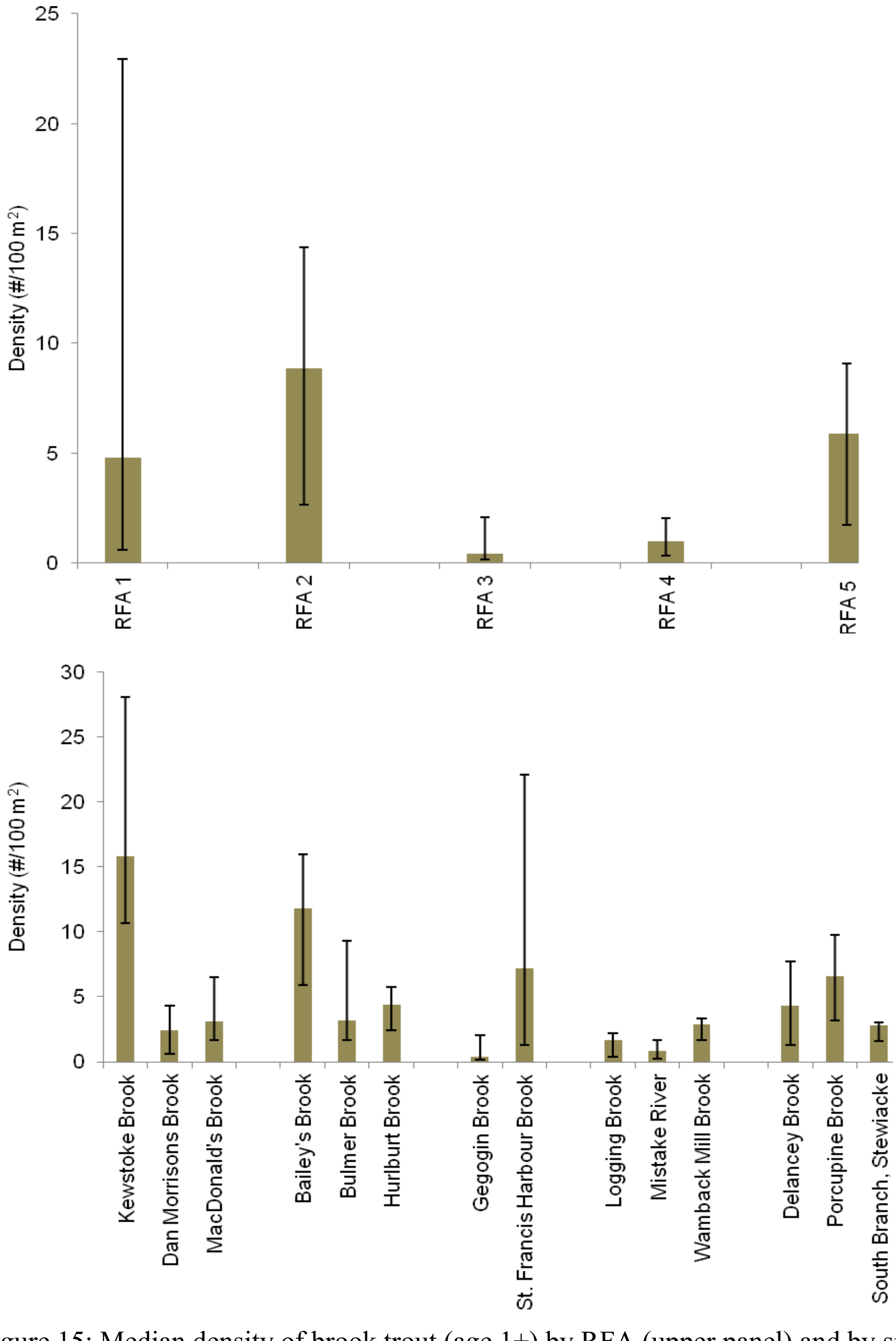

Figure 15: Median density of brook trout (age 1+) by RFA (upper panel) and by site within RFA (lower panel). Error bars represent interquartile (10th to 90th percentile) range.

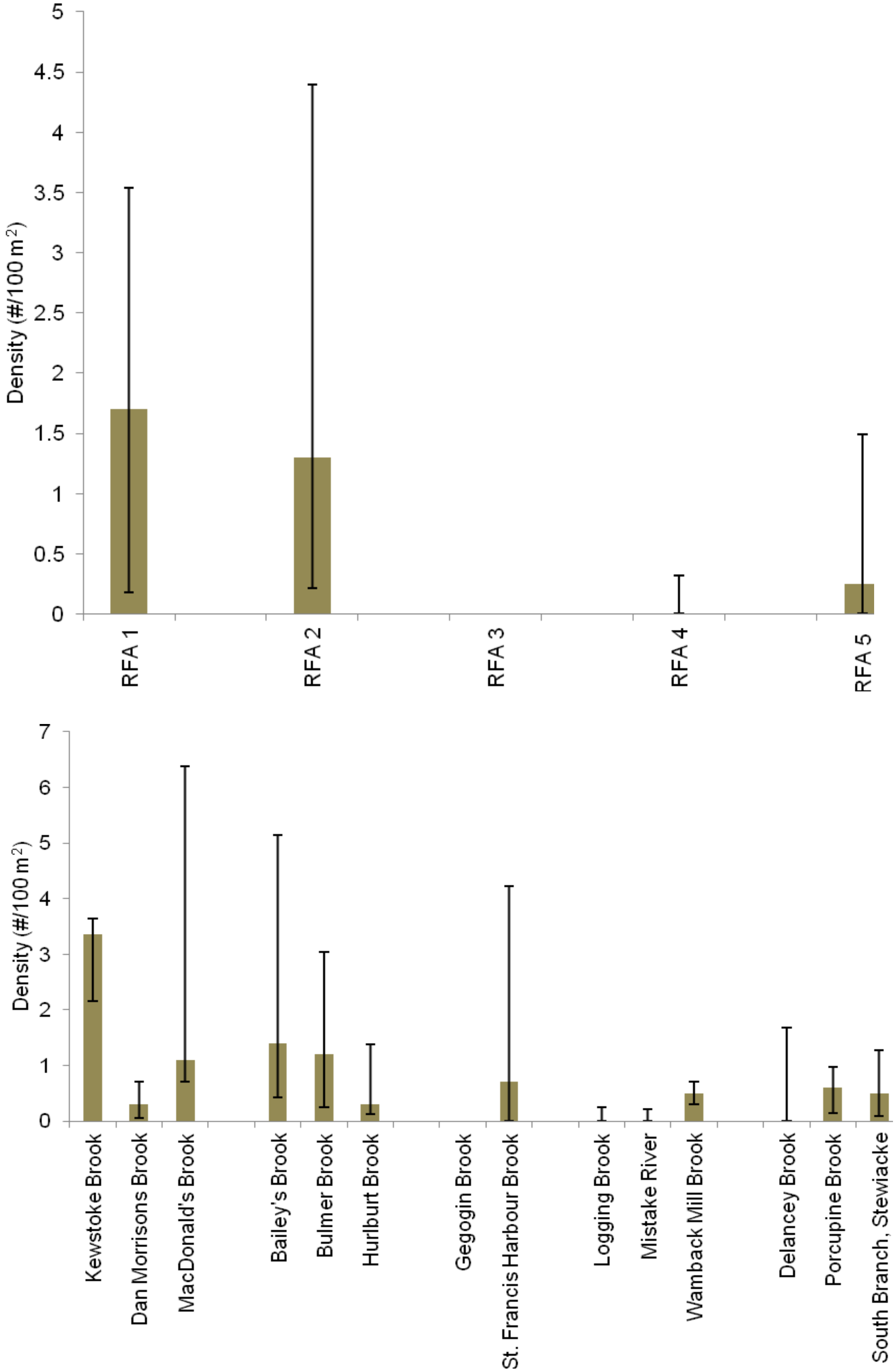

Figure 16: Median density of brook trout (age 2+) by RFA (upper panel) and by site within RFA (lower panel). Error bars represent interquartile (10^{th} to 90^{th} percentile) range.

Comparison of spatial and temporal variation

The relative dominance of temporal versus spatial variation varies by age class and RFA (Figure 17; Table 6). RFA 3 has high ratio values for each age class indicating that for these two brooks, temporal variation is greater than spatial. The other four RFAs are not as obvious in their interpretations and depend on the age class considered. Age 0+ indicates greater temporal variation than spatial in RFA 1, the reverse in RFA5 and the two dimensions are approximately equal in RFAs 2 and 4. Age 1+ shows the opposite pattern to age 0+ with temporal variation greater in RFA 5 and least in RFA 1. Age 2+ again show temporal variation less than spatial in RFA 1, while greater than spatial in RFAs 2 and 5. Thus, with the exception of RFA 3, in most streams the relative importance of temporal versus spatial variation is itself variable.

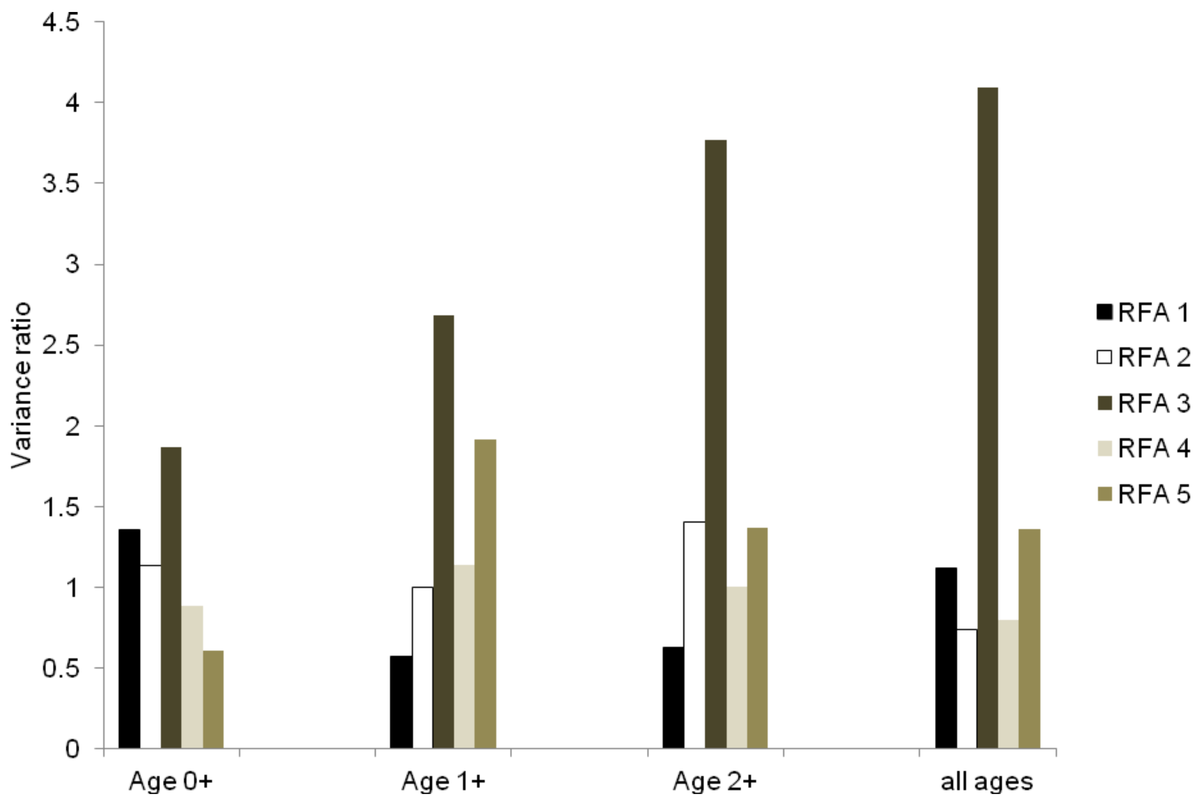

Figure 17: Variance ratio (temporal/spatial) by brook trout age class and RFA, 1989-1993.

Temporal Representativeness

The St. Mary's River (RFA 3) long-term data set indicates that the mean median annual trout density in the period 1989-1993 (0.55 trout/100 m^2; n=3; all ages combined) (Figure 18) is at the 44^{th} percentile of the annual density estimates between 1966 and 2010 (n=20 estimates). Thus, for this area of RFA 3, there is evidence that trout abundance in the 1989-1993 period is "average" compared to a long-term trend.

The LaHave River (also RFA 3) long-term data set indicates that the mean median annual trout density in the period 1989-1993 (1.57 trout/100 m^2; n=1; all ages combined) is at the 88^{th} percentile of the annual density estimates between 1966 and 2010 (n=15 estimates) (Figure 18). Thus, for this area, there is evidence that trout abundance in the 1989-1993 period is "high" compared to a long-term trend.

Table 6: Variance ratio (temporal/spatial) by brook trout age and RFA, 1989-1993.

	Age 0+	Age 1+	Age 2+	all ages
RFA 1	1.35	0.56	0.62	1.11
RFA 2	1.13	1	1.4	0.73
RFA 3	1.86	2.67	3.76	4.09
RFA 4	0.88	1.13	1	0.79
RFA 5	0.6	1.91	1.36	1.35
Mean (±95% CI)	1.16 (0.42)	1.46 (0.73)	1.63 (1.08)	1.62 (1.23)

5 year trends

Of 28 polynomial regressions (of age 0+ or total all ages combined) trout density over the 5 year period, only a single regression (MacDonald Brook, age 0+) was statistically significant at α = 0.05[9]. Two others (Delancey Brook, age 0+; MacDonald Brook, all ages combined) showed near-significance between α = 0.05 and 0.10; all others had p-values >0.13 (Dan Morrison's Brook, all ages combined). Based on an error rate (α = 0.05), from 28 regressions 1 to 2 of these would be expected to be found to be significant when they, in fact, are not. So these results fall within the realm of random chance. Additionally, when plotted the regression lines, even if not statistically significant, were inconsistent in the pattern shown (curving up, curving down or straight line). Age 0+ had 4 regressions curving down, 9 curving up and 1 straight; all ages combined had 6 regressions curving down, 7 curving up and 1 straight. Taken in total, this suggests that there is no evidence of temporal trends among these 14 brooks. However, 5 years may be too short a time period to detect changes over time for this species.

[9] Equation is: Age 0+ density(#/100 m^2) = 2.943 * X^2 + 4.88 * X + 3.474; r^2 = 0.987, p=0.013; n=5

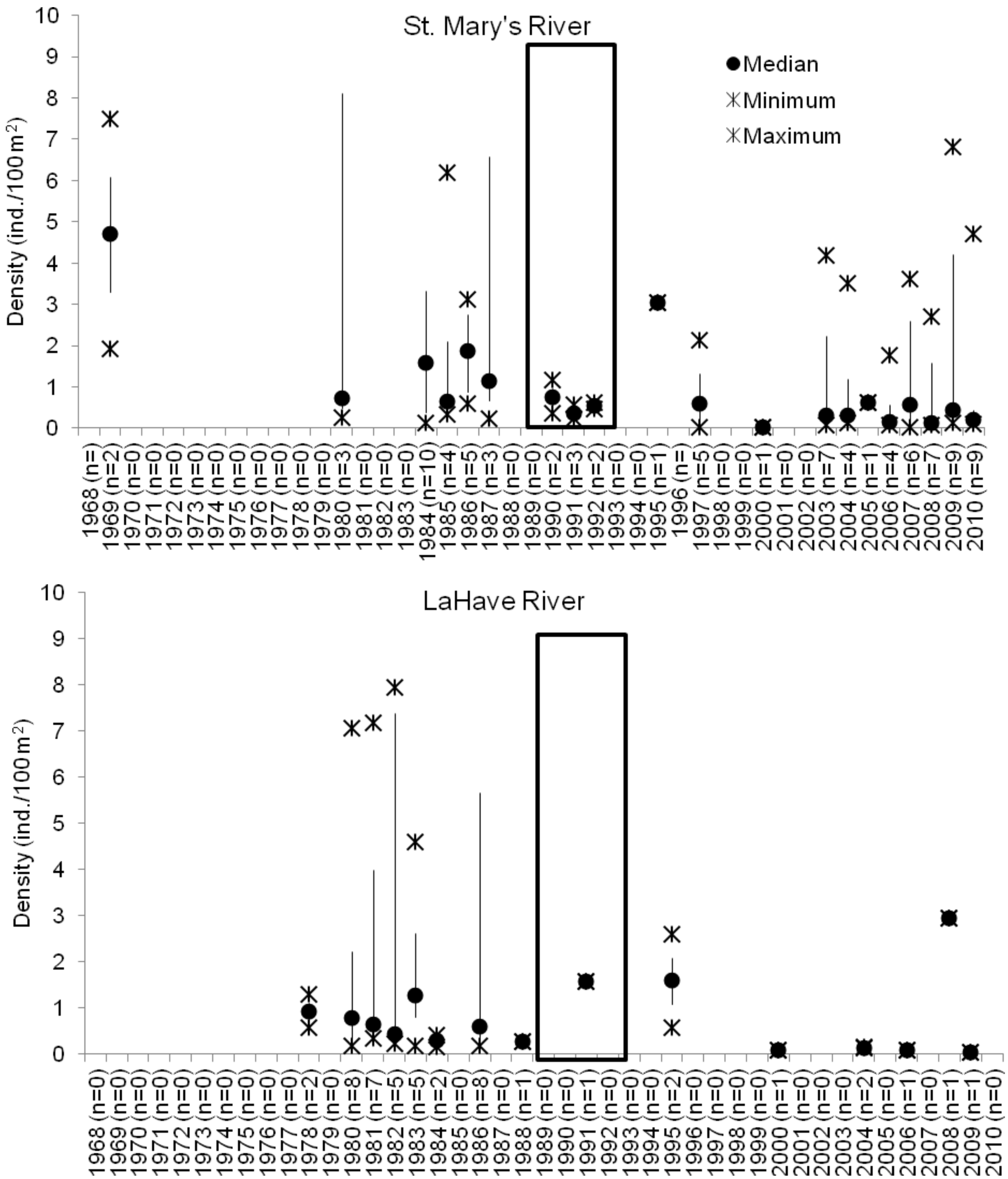

Figure 18: Median total trout density (St. Mary's and LaHave Rivers), 1966-2010. Vertical lines represent annual 25th to 75th percentile range. Asterisks represent annual minimum and maximum estimates. Box indicates 1989-1993 period of sampling.

Correlation with Environmental Factors

Variables of the physical environment were not well correlated to trout density, with only a single significant correlation; that of age 1+ density with stream velocity (*r*=0.369; n=60; r_{crit}=0.25). In terms of water chemistry, age 0+ and age 1+ densities were significantly (positively) correlated with hardness (*r*= 0.41-0.44), alkalinity (*r*= 0.46-0.55), conductivity (*r*= 0.39-0.43), and pH (*r*= 0.45-0.52). Critical *r* for these correlations (n=40) is *r*=0.30. Density of all ages combined showed stronger correlations (all >0.50) with these same environmental factors (hardness *r*=0.52, alkalinity *r*=0.68, conductivity *r*=0.51, pH *r*=0.58) (Figure 19). Regressions of densities of all ages combined against each of these factors were statistically significant, but hardness and conductivity are sensitive to an extreme point (71.4 trout/100 m^2 in Kewstoke Brook, 1989); exclusion of this point changes the regression for these two factors to non-significance[10] Alkalinity and pH remain significant after exclusion of this point, and slopes are statistically identical (based on 95% confidence intervals) with or without this point, and so are more robust and likely reflect a true relationship.

There are no correlations of density, of any age class, with the nutrients phosphorus and nitrogen. This is likely due to variation in nutrient concentrations being very small while changes in density are large.

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[10] Regression of density on hardness including 1989 Kewstoke Brook point p=0.006, r^2=0.27; exclusion of this point p=0.086, r^2=0.08. Regression of density on conductivity including 1989 Kewstoke Brook point p=0.0008, r^2=0.26; exclusion of this point p=0.064, r^2=0.09.

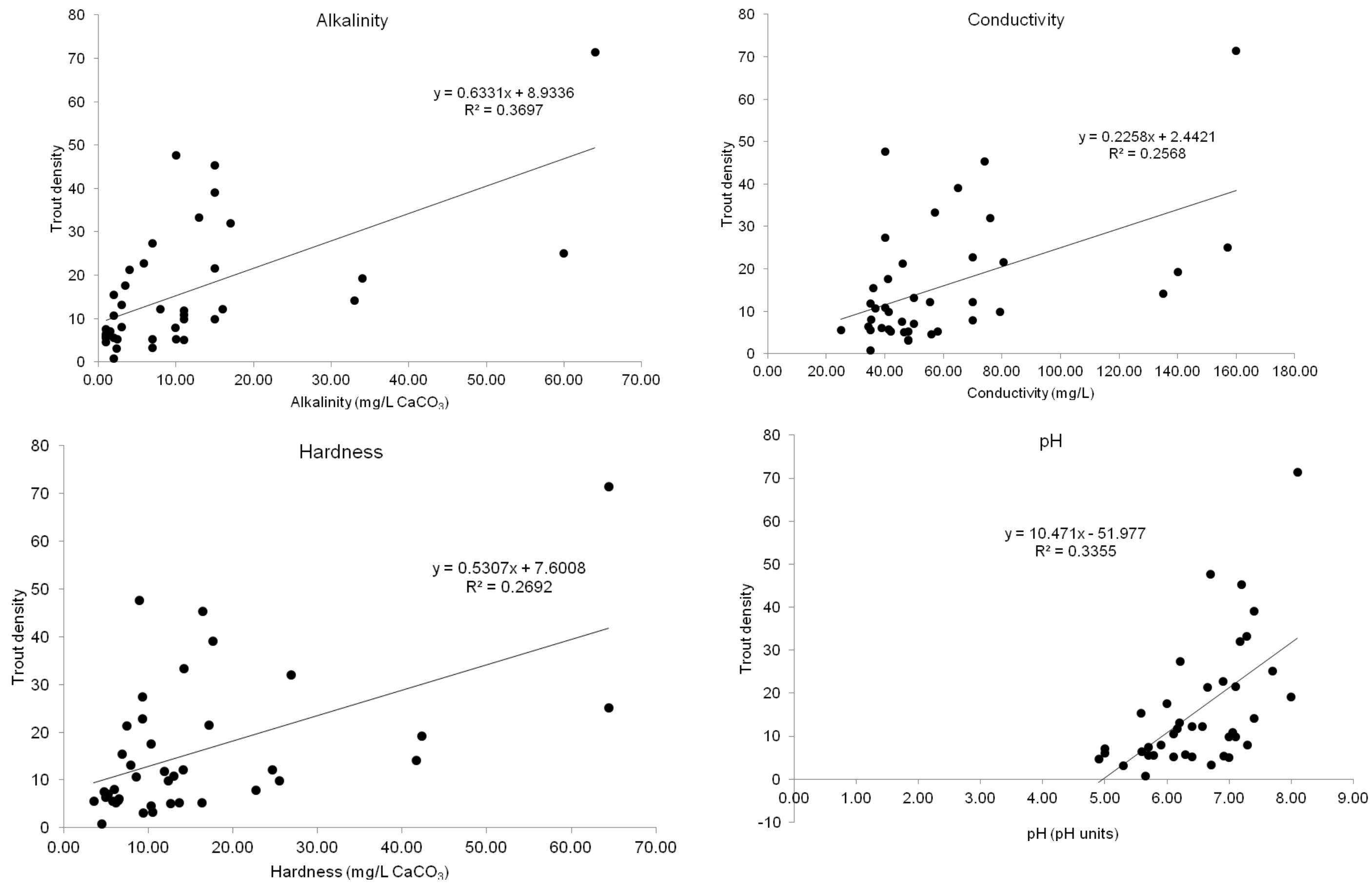

Figure 19: Relationships of brook trout density (all ages combined) with alkalinity, hardness, conductivity and pH from the 1989-1993 data collected among five RFAs.

Size-at-age

There are significant differences in age specific body size among RFAs. Age 0+ trout are smaller in RFA 1 than RFAs 3 ($p=0.01$) and 4 ($p<0.001$) and smaller in RFA 2 than RFA 4 ($0.001<p<0.002$) (Figure 20). Age 1+ trout are smaller in RFAs 1 ($p<0.001$) and 2 ($0.005>p>0.002$) than RFA 4; all other age 1+ comparisons were not significantly different. For age 2+ trout, the Kruskall-Wallis test showed a highly significant difference among the five RFAs ($p<<0.001$) but the follow up multiple comparison tests could not discriminate among the RFAs due to small sample size (i.e., low power). Visual examination of Figure 18 does not indicate any RFAs obviously different from the others.

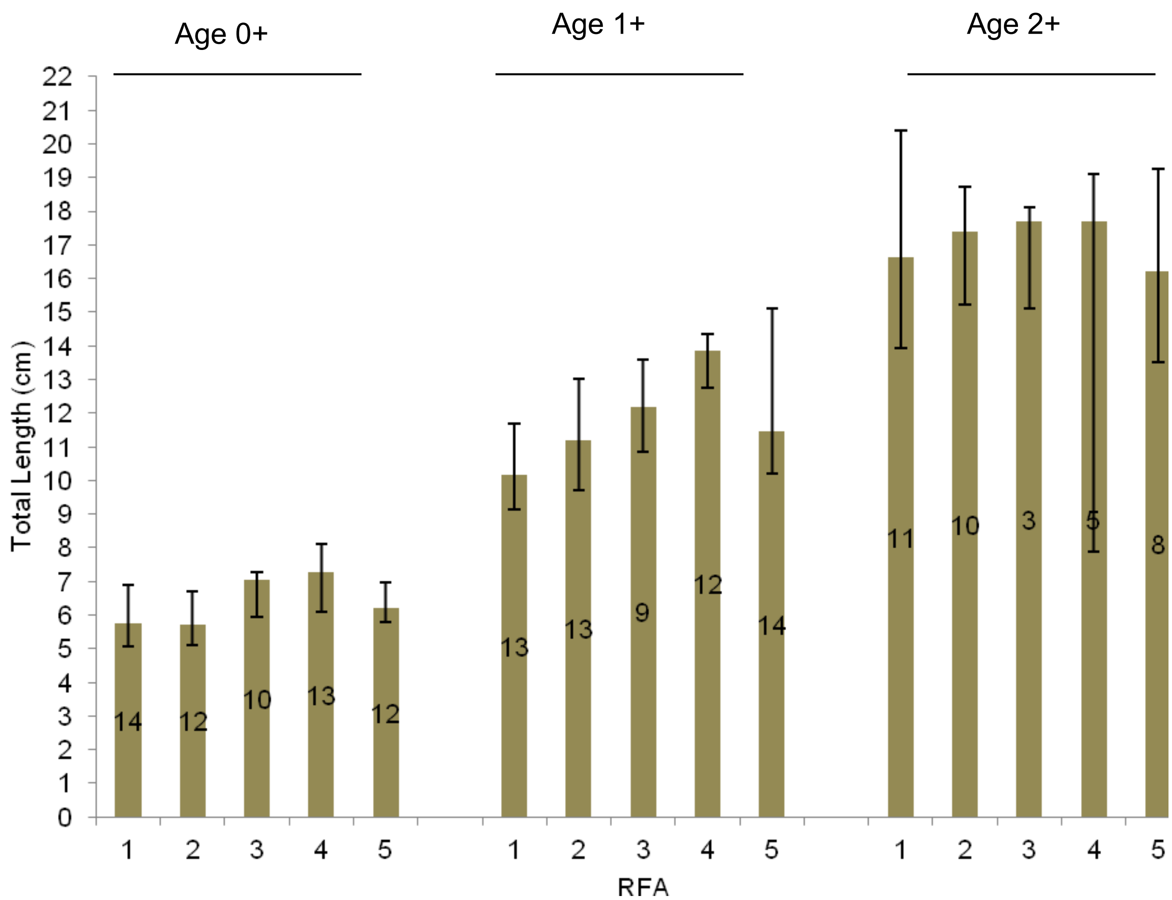

Figure 20: Median size-at-age of brook trout for three age classes among the five RFAs. Error bars represent interquartile (10^{th} to 90^{th} percentile) range. Values in column represent number of brooks X years in calculation.

Evaluating the among stream differences within an RFA, five of 13 tests (age 2+ for RFA 3 not tested as data not sufficient) showed significance indicating differences of median body size among streams within an RFA (Figure 21). These five differences were: age 0+ (in RFAs 3 and

4), age 1+ (in RFAs 1 and 2), and age 2+ (RFA 1). Of these five differences detected only two could then be further statistically discriminated by non-parametric multiple comparison; the other three were not sufficiently robust for multiple comparisons to determine differences. The two which could be statistically separated were age 0+ in RFA 3 (Gegogin Brook greater than St. Francis Harbour Brook; $p<0.05$) and age 2+ in RFA 1 (Dan Morrison and Kewstoke Brooks both greater than MacDonald's Brook ($p<0.05$)). Within RFA 4, age 0+ body size in Mistake River appears smaller than Logging and Wamback Mill Brooks, though this was not detected by the multiple comparison. Similarly, for age 1+ in RFA 1 MacDonald's Brook body size appears smaller than Kewstoke Brook and in RFA 2 median size in Hurlburt Brook appears smaller than Bailey's Brook, though, again, these are not supported by the multiple comparison.

Thirty six linear regressions (14 age 0+, 14 age 1+, 8 age 2+) of mean size-at-age over time were conducted, of which zero were significant at $\alpha=0.05$. Five of these 13 regressions had p-values between 0.05 and 0.10 (MacDonald's Brook age 0+ and age 2+, Dan Morrison's Brook age 1+, St. Francis Harbour Brook age 2+, and South Branch, Stewiacke age 2+). All other regressions had p-values >0.15. Thus, there is no evidence of trends over time. This analysis is, however, handicapped, by small sample sizes for regressions (n= 7 in 13 cases, 5 in 16 cases, and 4 in 14 cases).

To explore possible density dependence of body size, regressions of size on trout density were conducted for ages 0+ and 1+.

$$\text{Age 0+ size (cm)} = -0.0342 * \text{Age 0+ density } (/100\text{m}^2) + 6.65 \quad r^2 = 0.106;\ n=61;\ p=0.01$$
$$\text{Age 1+ size (cm)} = -0.0799 * \text{Age 1+ density } (/100\text{m}^2) + 12.37 \quad r^2 = 0.08;\ n=59;\ p=0.026$$
$$\text{Age 1+ size (cm)} = -0.0273 * \text{Age 0+ density } (/100\text{m}^2) + 11.98 \quad r^2 = 0.014;\ n=41;\ p=0.457$$

Two of the regressions, those of mean age size regressed on conspecific age class density, show statistically significant negative slopes which is consistent with density dependence. However, the variation explained (r^2) is very low (i.e., 8-11%).

Of much greater explanatory power than density to understand size-at-age, is the size of the previous age class in the prior year. Regression of age 1+ size in year $t+1$ on age 0+ size of year t, yielded:

$$\text{Age 1+ size (cm)} = 1.247 * \text{Age 0+ density } (/100\text{m}^2) + 3.84 \quad r^2 = 0.419;\ n=39;\ p<<<0.001$$

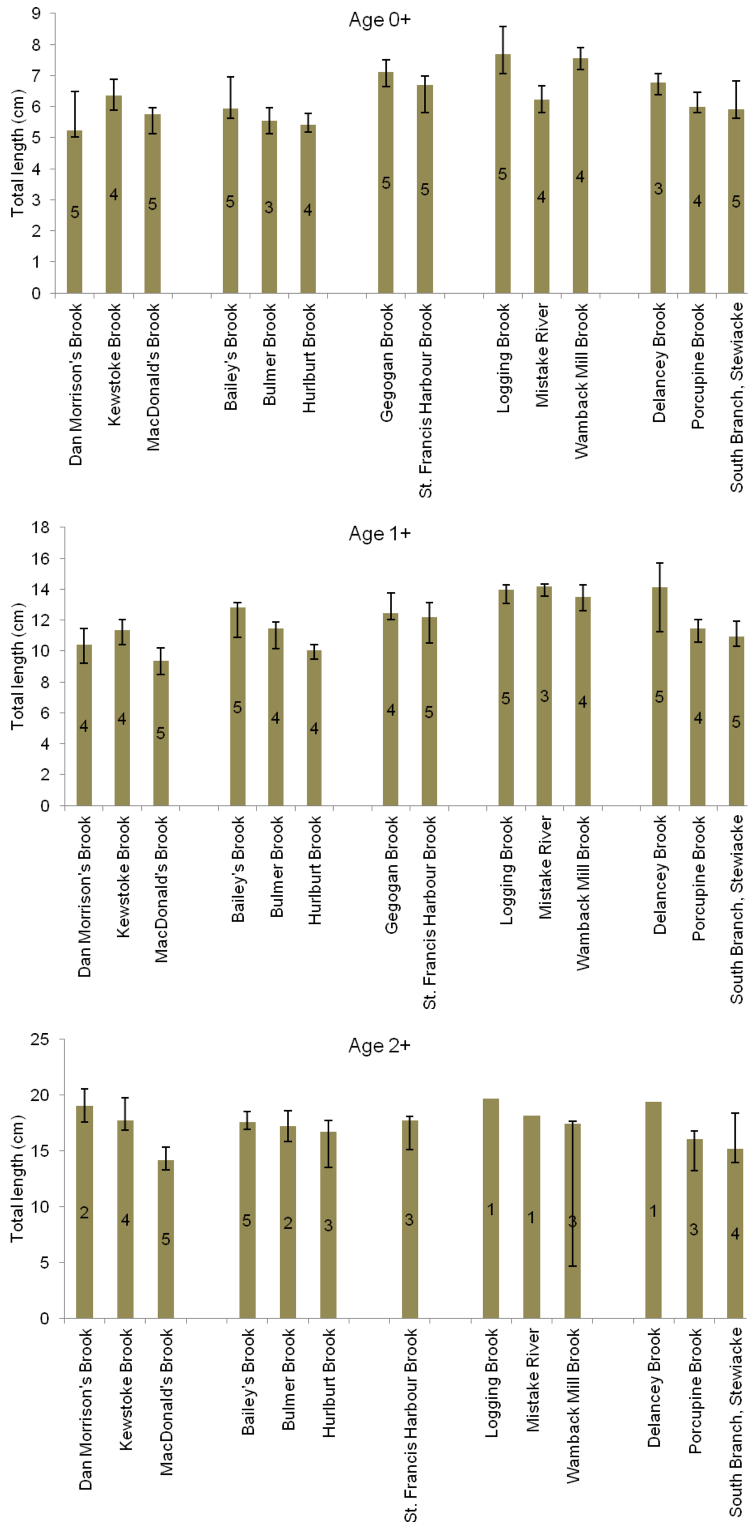

Figure 21: Median size-at age of brook trout by age class and stream within RFAs. Error bars represent interquartile (10th to 90th percentile) range. Values in column represent number of years sampled per stream.

Size-at-age for both ages 0+ and 1+ were significantly correlate with the same environmental variables, hardness (*r*= -0.35 to -0.36), alkalinity (*r*= -0.36 to -0.38), nitrate (*r*= -0.34 to -0.40), conductivity (*r*= -0.34 to -0.35), and pH (*r*= -0.64 to -0.68) (r_{crit}= 0.30; n=40). All correlations are negative indicating inverse relationships. pH shows a strongly negative correlation on size-at-age (Figure 22). Regression equations for each of these are:

Age 0+ length (cm) = -0.773 * pH + 11.327 p<<<0.001; r^2 = 0.460; n=40
Age 1+ length (cm) = -1.339 * pH + 20.60 p<<<0.001; r^2 = 0.413; n=40

The slopes of these two regressions are statistically similar, based on overlapping 95% confidence intervals.

There are no significant correlations of size-at-age with physical factors (*r* ranges from -0.248 to +0.33; r_{crit}= 0.25). Age o+ size is very near significance when correlated with velocity (*r*= -0.248)

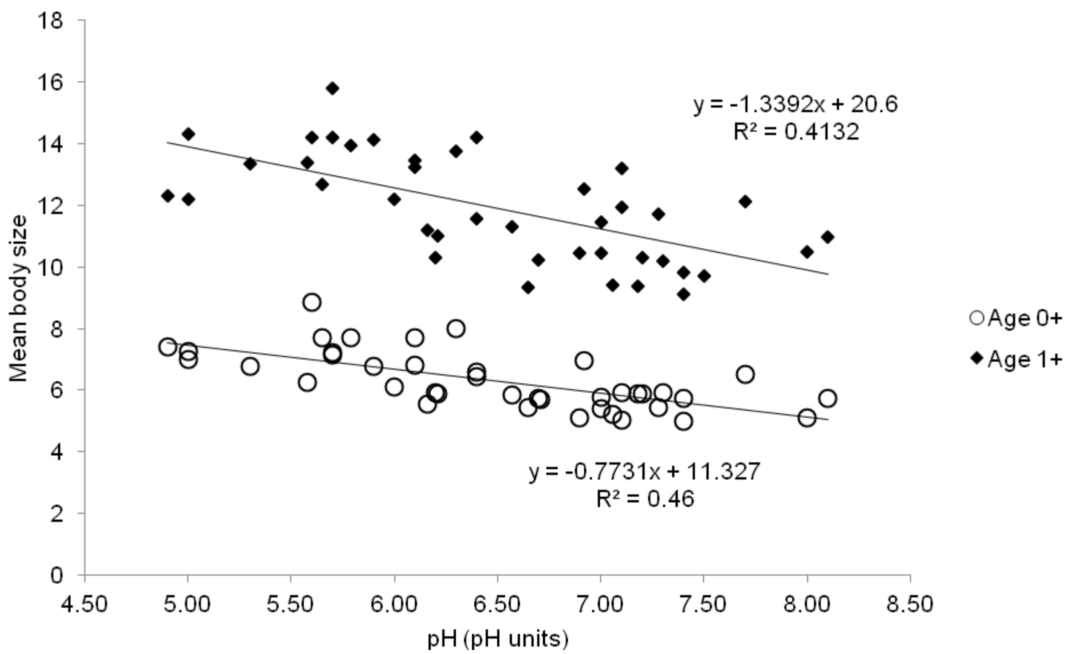

Figure 22: Relationship of mean body size for ages 0+ and 1+brook trout and pH based on 1989-1993 sampling across five RFAs

Brook Trout Population Dynamics

Survival & Recruitment

There are only a limited number of survival estimates, as this parameter requires estimates of density in year *t* and *t*+1 for successive age classes. Therefore, a missing year of sampling, or absence of a year class, or insufficient number of individuals in a year class captured to generate meaningful density estimates, precludes survival estimates for three years. There are a total of 41 survival estimates[11], 30 for ages 0+ to 1+ and 11 for ages 1+ to 2+ transitions. Calculated survival estimates ranged from 0.073 to 9.0 for age 0+ to 1+ and 0.12 to 1.42 for age 1+ 2+. Values greater than 1.0 were excluded (6 values for ages 0+ to 1+ and 1 value for ages 1+ to 2+). When these were excluded, medians over the 5 years ranged between 0.33 and 0.60 (age 0+ to 1+) and 0.17 to 0.32 (age 1+ to 2+) (Figure 23). Survivals did not differ among years (Kruskal-Wallis test, $0.05<p<0.10$ for each of age 0+ to 1+ and age 1+ to 2+). Variation in survival was considerable among brooks within a year as evidenced by the interquartile range in Figure 23. The variability among brooks within a year is greater for the age 0+ to 1+ transition (0.33-0.41) than for the ages 1+ to 2+ (0.06-0.17). A similar analysis using the Musquodoboit data (excluding values >1.0) showed similar results (Figure 24), with medians ranging between 0.21 and 0.64 (age 0+ to 1+) and 0.27 to 0.65 (age 1+ to 2+). Interquartile ranges are very large in this system, despite the sample sizes being considerable larger.

Attempts were made to analyze survival by RFA (Figure 23), but any conclusions are weak due to the very small sample sizes and that these are not true estimates of survival, but rather only changes in density. Survivals from age 0+ to 1+ appear to be highly variable, and similar among RFAs (not statistically tested). There is some indication that survival may be higher for ages 1+ to 2+ in RFA 2 over RFAs 1 and 4.

The correlation analysis for recruitment of age 0+ trout to age 1+ trout was conducted on 9 brooks with three or more data pairs, none of which yielded a statistically significant correlation. The range of correlation coefficients was -0.768 to 0.747, but the sample sizes were very small (n= 3 or 4 data pairs per brook) and critical values for statistical significance for these sample sizes are 0.997 and 0.950, respectively (Zar, 1999). The very small sample size precludes meaningful analysis of recruitment at the brook level. Similar correlations were done using data from all brooks in each RFA and so analysis was RFA scale. Only RFA 1 yielded a significant correlation ($r=0.862$; $0.001<p<0.002$). The regression equation for RFA 1 describing this recruitment is:

$$\text{Age 1+ density} = 0.433 * \text{Age 0+ density} + 1.57 \quad (p=0.0001, r^2=0.743; n=10)$$

Plots of age 1+ density against age 0+ density were visually examined for non-linearity or patterns, but none noted. Of the five RFAs, only RFA 1 indicated any form of recruitment relationship between ages 0+ and 1+ and that is described by the above equation.

Growth

There are only a limited number of growth estimates, as growth requires data of mean body size in year *t* and *t+1* for successive age classes. Therefore, a missing year of sampling, or absence of a year class, or insufficient number of individuals in a year class captured to generate

[11] In total there were 67 estimates. 41 of these were age 0+ to 1+ of which 11 were based on non-Zippin estimates and so excluded leaving 30 estimates. 26 of the 68 were age 1+ to 2+ of which 15 were based on non-Zippin estimates and so excluded leaving 11 estimates.

meaningful body size estimates, precludes growth estimates for three year. Further, to ensure reliable estimates of growth, only sites with mean body size data based on three or more fish each year are included here (22 estimates excluded due to size data based on only one fish and 3 estimates excluded due to size based on two fish). This left 43 growth estimates (30 estimates for growth of age 0+ to 1+; 12 estimates for growth of age 1+ to 2+; and 1 estimate of growth for age 2+ to ≥ 2+). Of the 14 brooks, 7 have only two growth estimates (age 0+ to 1+, Hurlburt, Logging, Wamback Mill, Delancey, and Porcupine Brooks; Age 1+ to 2+, Bailey's Brook and South Branch, Stewiacke), 4 have only 3 growth estimates (age 0+ to 1+ Kewstoke, MacDonald, and St. Francis Harbour Brooks; age 1+ to 2+ Kewstoke Brook), and 2 have 4 growth estimates (age 0+ to 1+ Bailey's Brook, South Branch, Stewiacke).

The Kruskal Wallis test indicates bare significance in differences of growth for ages 0+ to 1+ among the 5 RFAs ($0.025<p<0.05$) (Table 7). Growth from age 1+ to 2+ were not tested due to very small sample size. As with other tests, the non-parametric multiple comparison was not sufficiently sensitive to detect differences among individual RFAs. RFA 1 median age 0+ to 1+ growth is less than 4.0 cm per year while for other RFAs median annual growth ranges between 4.9 and 6.0 cm (Table 7). In contrast, growth from age 1+ to 2+ appears greater in RFA 1 than other areas.

Variation in growth among years within a site can be quite high (Figure 25). For age 0+ to 1+, the range of growth estimates for streams in which there are at least three estimates, is typically 1.4 to 2.9 cm/year. MacDonald's Brook showed lesser variation based on three estimates (range of estimates 0.88 cm/yr). For age 1+ to 2+ only one stream (Kewstoke Brook) has three estimates; in this brook the range of estimates cover 3.0 cm.

Six streams had either 3 (age 0+ to 1+ Kewstoke, MacDonald, and St. Francis Harbour Brooks; age 1+ to 2+ Kewstoke Brook) or 4 (age 0+ to 1+ Bailey's Brook and South Branch, Stewiacke) data points allowing linear regression analyses over time. None of these systems showed statistically significant change over time (i.e., all regressions were not significant, $p>0.13$ in all cases) indicating no trends over time.

Growth of either age 0+ to 1+ or 1+ to 2+ showed no significant correlation with the physical habitat variables considered here (maximum age 0+ to 1+ $r = 0.303$; $r_{crit}= 0.35$; n=30;. maximum age 1+ to 2+ r = 0.368; $r_{crit}= 0.63$; n=8). Age 1+ to 2+ growth could not be correlated with chemical variables as there were only three growth estimates for this age group coincident with water quality sampling. Age 0+ to 1+ growth (n=20; $r_{crit}= 0.42$) showed no significant correlations with water chemistry though hardness ($r = -0.409$) and conductivity ($r = -0.404$) approached significance. Correlation with pH ($r = -0.236$) is not significant.

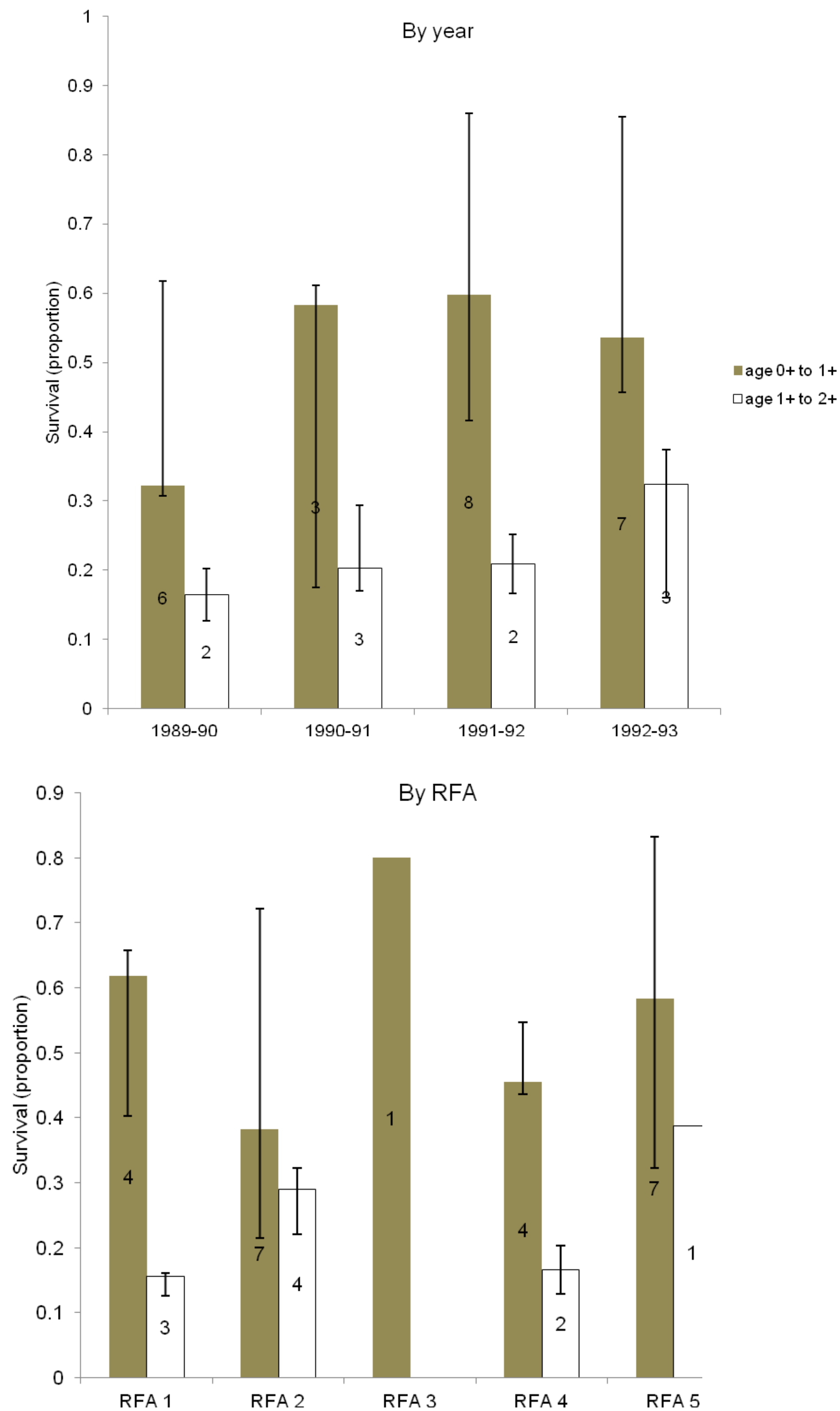

Figure 23: Median survival estimates among year classes for 1989-1993 by years (upper panel) and by RFA (lower panel). Error bars represent interquartile (10^{th} to 90^{th} percentile) range. Values in column represent number of years in sample.

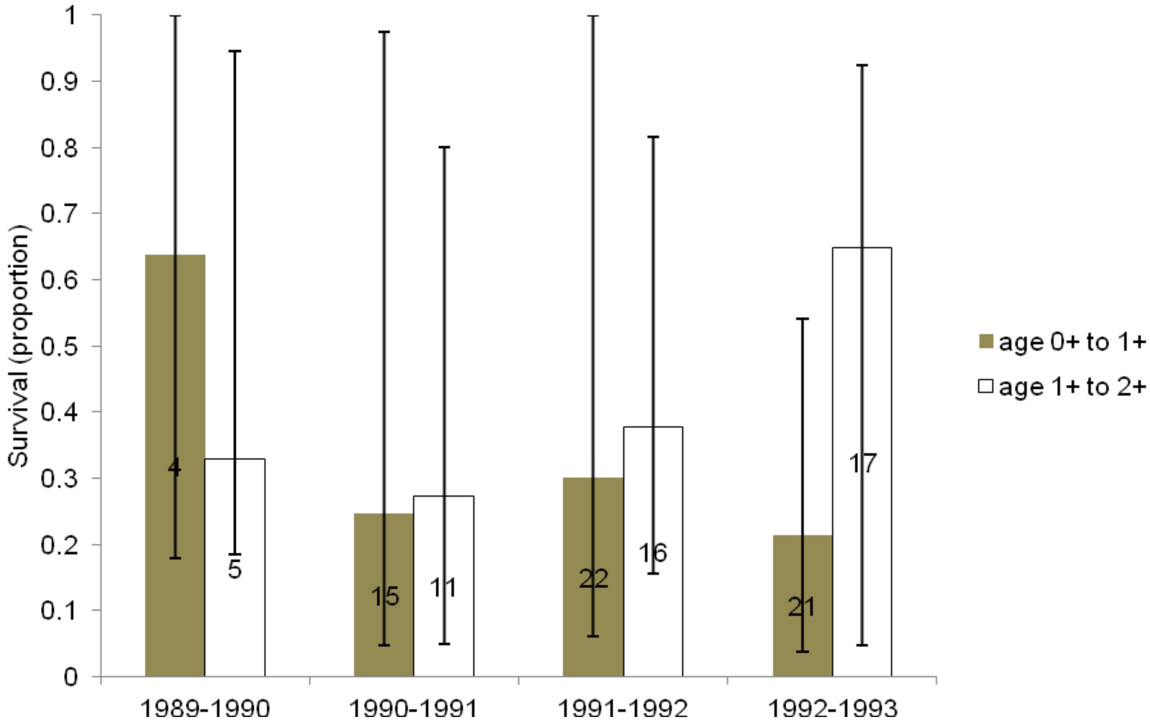

Figure 24: Median survival estimates among year classes for years 1989-1993 by years for the Musquodoboit River system. Error bars represent interquartile (10^{th} to 90^{th} percentile) range. Values in column represent number of years in sample.

Table 7: Median growth (cm/yr) between years by age class and RFA. Range is interquartile (10^{th} to 90^{th} percentile) range. Data compiled across all years.

	age 0+ to 1+	age 1+ to 2+	age 2+ to ≥2+
RFA 1	3.82 (n=7) range = 3.05-5.96	6.79 (n=4) range = 4.80-8.75	
RFA 2	6.04 (n=7) range = 4.16-6.56	4.51 (n=3) range = 3.75=5.31	0.25 (n=1)
RFA 3	5.97 (n=4) range = 4.62-6.77	5.50 (n=1)	
RFA 4	5.58 (n=4) range = 4.55-6.56	N/A (n=0)	
RFA 5	4.93 (n=8) range = 4.04-7.24	4.17 (n=4) range = 1.13-5.31	

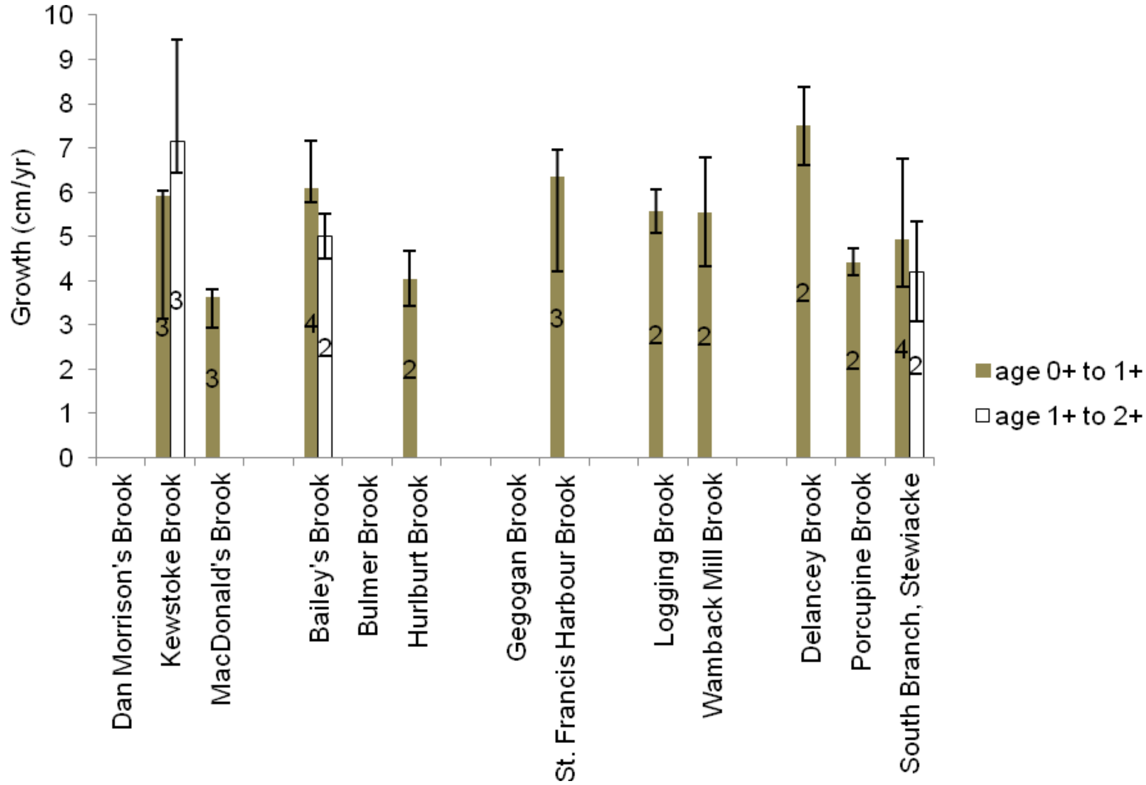

Figure 25: Brook trout annual growth among years by age class and brook. Error bars are range of estimates (minimum and maximum). Values in column represent number of growth estimates per stream.

DISCUSSION

Comments on Statistical Tests

Throughout this analysis the statistical testing has been weak (low power tests) and so conclusions must be tempered with professional judgement and "common sense". Non-parametric approaches were selected in this analysis to avoid the requirements of data normality and equality of variances (likely to be violated with small sample sizes). However, the small sample size weakens even these tests. Despite the intensive field work, and well designed experimental approach, statistically this remains a small sample size (n=10-14 sample periods per RFA, each with large spatial and temporal variation). Given the practical limitations of intensive field sampling, achieving large sample sizes for statistical analysis is challenging.

In many cases in this analysis the Kruskal-Wallis test would identify significant differences among RFAs or among brooks within an RFA, but the following multiple comparisons could not discriminate where the differences lie. Zar (1999) makes the following observation with respect to parametric procedures (ANOVA and Tukey multiple comparisons) but the concept applies to the non-parametric analysis here as well. "*It is possible for the [*null hypothesis] *to be rejected by an analysis of variance and the subsequent multiple comparison test to fail to detect differences between any pairs of means.... it reflects the fact that the analysis of variance is a more powerful test than is the multiple comparison test. Repeating the experiment with larger sample sizes would tend to result in a multiple comparison analysis more capable of locating differences among means*". (p 214). Thus, the Kruskall-Wallis tests are likely the more reliable results, with the multiple comparisons suffering from low power and so less acceptance should be placed on them.

Many of the "non-significant" tests were close to significance (i.e., $0.05<p<0.10$). The concept of $\alpha=0.05$ is an entirely arbitrary cutoff point in decision-making, and there is a large body of literature highly critical of standard statistical hypothesis testing[12] (e.g., Anderson et al., 2000; Cohen, 1994; Johnsen, 1999), with one of the arguments being the arbitrary nature of α. A certain amount of professional judgement and weight-of-evidence approach is required to interpret results such as these, rather than dogmatic acceptance of statistical results only.

Water Quality

The water quality clustering of streams shown here is explainable based upon bedrock geology. Clusters 1, 2, and 4 all lie on the Avalon Terrane of Nova Scotia while Cluster 3 streams are all on the Meguma Terrane. The Avalon Terrane is a highly complex grouping of geologies, comprised largely of sandstone, siltstone, limestone, shale, conglomerate, gypsum and coal (Anonymous, 2005). The Meguma Terrane, in contrast, is largely granite, granodiorite and schist. The separate clustering of Kewstoke and MacDonald's Brooks from all other RFA 1 and 2 streams is likely also due to bedrock geology. These two streams flow over Windsor Group

[12] Bill Thompson has compiled a list of over 400 references questioning the use of statistical hypothesis testing in science and humanities. List is available at: http://warnercnr.colostate.edu/~anderson/thompson1.html

geology (comprised of limestone, siltstone, gypsum, anhydrite, salt), while the others flow over Mabou (Bailey's Brook), Morien (Dan Morisson's Brook), Cumberland (Bulmer Brook) or Horton Groups (Hurlburt Brook) (Anonymous, 2005). These latter four Groups are comprised largely of sandstone, conglomerate, siltstone and shale. Thus, the elevated levels of hardness, alkalinity, and ionic constituents in Kewstoke and MacDonald's Brook are consistent with the geology and this is emphasized by their clear and dramatic separation from all other Avalon Terrane streams.

The pattern of pH also follows geology. The low pH of Cluster 3 is a reflection of the well-known stream and lake pH depression of the Southern Uplands by atmospheric acidification (e.g., Watt, 1987; 1997; Watt et al., 1983). Apart from these streams, all other are approximately circum-neutral or slightly alkaline.

Electrofishing Effort

RFAs 1 and 2 had greater electrofishing effort applied than those streams in RFAs 3, 4 and 5. This difference is not accountable by variation in sizes of areas fished as RFA 1 sampled sites (mean 280 m^2±95% CI 30.5 m^2) were not significantly different in size from RFA 3 sites (mean 272 m^2±95% CI 9.8 m^2). RFA 2 sites (mean 334 m^2±95% CI 42.9 m^2) were larger than RFA 3 sites, equivalent to RFA 4 (mean 293 m^2±95% CI 50.7 m^2) but smaller than RFA 5 (mean 423 m^2±95% CI 18.0 m^2). Nor were there large differences in stream width or depths among RFAs (Figure 2). It is likely that the increased electrofishing time in RFAs 1 and 2 was due to greater complexity of habitat (instream and overstream debris and vegetation) as this would increase time to fish an area. This speculation is based on the RFA 4 and 5 streams being located in largely agricultural and intensive land use landscapes while those of RFAs 1 and 2 are largely forested. This is speculation only, the true cause of the electrofishing effort differential is not known.

Fish Community Composition

The most abundant and widespread fish species were Atlantic salmon, brook trout, white sucker and American eel and this is consistent with the findings of Mitchell (2012) who examined long term (1968-2010) electrofishing data for the St. Mary's River. The community analysis was composed of two analyses, which produced contradictory results. When richness, diversity and evenness were treated as univariate parameters, RFAs 4 and 5 quite clearly stand out as being separated from RFA 2 in terms of these three community measures, different from RFA 3 with respect to richness and different from RFA 1 in diversity. Those species found in RFAs 4 and 5 not found as frequently in the other areas are brown trout (*Salmo trutta*), yellow perch (*Perca fluviatalis*), creek chub (*Semotilus atromaculatus)*, blacknose shiner (*Notropis heterolepis*), brown bullhead (*Ameuirus nebulosus*), golden shiner (*Notemigonus crysoleucas*), common shiner (*Notropis cornutus*), and lake chub (*Couesius plumbeus*). Most of these species (the cyprinids and perch) are associated more with lakes or calm waters than with streams. The streams in RFAs 4 and 5 were typically of lesser velocity than RFAs 1 and 2 (Figure 2). These may also have been easier to electrofish and so required only the observed reduced fishing effort. RFA 3 shows greater evenness than RFAs 1 and 2 and this is due to there being only 3 or 4 species in RFA 3 but a variation in richness in RFAs 1 and 2 (i.e., one system with 2 species, 2 with 3 species, 2 with 5 species and 1 with 6 species). The greater consistency in RFA 3 implies greater evenness.

Community composition among streams within an RFA is quite similar, except for RFAs 1 and 5. In RFA 1. Kewstoke Brook stands out as having only two species (salmon and trout) in approximately equal abundance which gives it a very low richness but high evenness relative to the other two brooks. In RFA 5 South Branch, Stewiacke is consistently greater across all three community measures than Delancy Brook, while Porcupine Brook is intermediate. .

In contrast to the univariate analysis, the cluster analysis suggested most of the 14 streams have similar community composition with the exception of Porcupine Brook (large number of white sucker), and Kewstoke and Bailey's Brooks (only salmon and trout in Kewstoke, salmon, trout and few eel in Bailey's). This suggests that this cluster analysis was not sensitive as the individual analyses of richness, diversity and evenness suggested significant differences among RFAs, not reflected in the cluster analysis. Interestingly, those brooks which cluster most closely together (Bulmer, Logging, Dan Morisson's, Delancey, Mistake and Hurlburt) come from four of the 5 RFAs indicating that the RFAs are indeed similar with respect to community composition. This is counter-intuitive, and likely an incorrect inference, given the evidence above that the RFAs do indeed differ in individual aspects of their community compositions. Future work to resolve this is suggested as *Recommendation #1*.

There are no obvious relationships between Atlantic salmon and brook trout density, in particular an inverse relationship, as might be expected if the two species were competing for resources. Given that throughout much of the RFAs salmonid abundance is at low levels, and highly variable in time and space, the lack of relationship between the two is not surprising. For one species to have a competitive effect on the other would require high densities and competition for a critical resource. The salmonids are at relatively low density, and are both have relatively wide habitat tolerances; these two features reduce competition to the point it is not detectable here.

<u>Brook Trout Population Parameters</u>

Precision of density estimates

Precision of the Zippin estimates in this sampling program was quite good. Bohlin et al. (1989; 1990) defined three classes of measurement precision for fish density estimates based on electrofishing relevant to decision-making. Under their scheme, using Coefficient of Variation (CV), the target precision should be: CV≤5% when the estimate is to be multiplied or divided with other estimates, or when monitoring population changes; CV 5%-10% when classifying to few quality levels (e.g., from very bad to very good); and CV ~ 20% when classifying to a very coarse scale (e.g., 'good', 'bad', 'intermediate'). Krebs (1989) is not as restrictive, suggesting population estimates can be classified by precision as ±50% (preliminary surveys where only an approximation of population size is required), ±25% (sufficient for management purposes), and ±10% (research work). Compared to these benchmarks, the 1989-1993 sampling, with the exception of the age 2+ trout which are estimated with lesser precision, would be classified as sufficient for management purposes by Krebs and useful for classifying at very coarse scale by Bohlin et al.

Density

Rigorous analysis of brook trout density was compromised by the weakness of the multiple comparison tests following the Kruskall Wallis tests, as discussed above. However, general features emerge from this analysis.

Trout density within RFA 4 appears to be significantly less than that of the other RFAs, with RFAs 1 and 2 having greatest density and RFAs 3 and 5 intermediate. RFA 4 also has the lowest spatial variation in density, while RFAs 1 and 2 the greatest. RFAs 1 and 2 represent the more classic brook trout habitat (cool water, non-acidified streams of relatively low land use impact). RFA 3 streams are slightly acidified, while those of RFA 4 are known to be highly acidified (e.g., Watt, 1987; 1997 and see pH in *Water Quality*). RFA 5 drains streams of intensive land modification (agriculture, urbanization, roads), thus the reduced densities in these RFAs are not surprising. However, it must be borne in mind that electrofishing effort was also greater in RFAs 1 and 2 than the other areas, and so the greater trout densities could be a function of significantly greater sampling effort. To examine this, total trout density for each brook and year was corrected for electrofishing effort (divided by 1,000 seconds of shocking) and the Kruskal-Wallis and multiple comparison test conducted on these data (number trout/100m^2/1,000 shocking seconds). RFA 4 had significantly lower density than RFAs 1 and 2 ($p<0.02$ for each comparison) after accounting for effort and so this is likely to be a true observation of density and not an artifact of sampling.

Spatial variation of trout density was high for RFAs 1 and 2, less so for RFAs 3 and 5 and very little for RFA 4. This is suggestive that the limiting factors operating in RFA 4 are widespread and affect all brooks, while in RFAs 1 and 2 the limiting factors are operating much more on a brook-specific basis. For example, in RFA 1 the trout density is depressed in Dan Morisson's Brook, but the same processes causing this depression are clearly not operating in Kewstoke Brook where density is high. Factors affecting trout populations in RFAs 1 and 2 are likely to be much more heterogenous than those of RFAs 3 and 4 and so individual streams may be affected but other populations do well. This suggests that trout populations in these RFAs are likely to be more resilient than the southern RFAs as not all populations are affected equally. Within RFAs 3 and 5 the processes affecting trout populations are likely more of a mix of RFA-wide and brook-specific processes, accounting for the results intermediate between RFAs 1 and 2 and 4. RFA 3 streams are nutrient-poor and slightly acidified (e.g., Mitchell 2011) while RFA 5 streams are subjected to intensive land us and may be affected by nutrient enrichment rather than deprivation. These factors likely affect trout populations, but there remain individual brook-variability within these impacted landscapes.

The estimates of variation in trout density among multiple sites within a brook, from the St. Mary's and Stewiacke Rivers data, provide a baseline against which to compare among brook variability. For RFAs 1, 2, and 4 the variation expected within a brook among multiple sites is of the same order as the observed variation among brooks. For RFA 3 and 5 variation among brooks was much greater than that expected within a brook. This is the opposite to what I have argued above. It implies that variation in density among brooks in RFAs 1, 2 and 4 is small relative to variation within a brook. For RFA 4 this is consistent with the previous inference, that large scale (RFA-scale) processes are affecting trout density, but this is inconsistent with the previous inference for RFAs 1 and 2. However, conclusions based on this must be tempered by recalling that the within-stream variation is based on three RFA 3 streams, and that estimate of variation may not be exportable to other RFAs. Further examination of existing data for within-stream variation for all RFAs is recommended (*Recommendation #2*).

Variation over time (inter-annual variation) within a brook is greater for RFAs 1 and 2 than for other RFAs, though there are exceptions (Bulmer Brook in RFA 2; St. Francis Harbour Brook in RFA 3; Porcupine Brook in RFA 5) and this applies to each age class. Notably, the large variation of age 0+ in RFAs 1 and 2 suggest that these may be due to spawning in the previous autumn and egg survival through the winter. The reduced inter-annual variation in the other RFAs implies a constancy among years, either a constant number of spawners and egg survival, or processes acting to constantly reduce a variable number of age 0+ to a low level. It is not possible from these data to determine which of these may be occurring.

Indications are that in the St. Mary's area the trout densities in the period 1989-1993 were approximately average of the long-term trend, while for the LaHave the densities were at the high end of estimates. Of course, the LaHave is based on only a single data point so care must be taken in interpretation. But if these inferences are accepted, that implies that Gegogin and St. Francis Harbour Brook densities are probably typical, while RFA 4 densities (Logging, Mistake and Wamback Mill Brooks), though the lowest found in the province wide survey, may have been elevated over average conditions during the 1989-1993 period. Unfortunately, DFO Gulf Region did not supply data and so it is not possible to assess RFAs 1 or 2, and the Stewiacke River (RFA 5) data did not allow estimation of densities during the period of interest. There is no evidence of directed change (trends) among the 14 brooks. Rather variation is likely stochastic and so represent typical inter-annual variation.

With the exception of RFA 3, the relative importance of spatial versus temporal variation varied with RFA and age class. In RFA 3 temporal variation (i.e., variation in density among years) is greater than among streams. However, given only two brooks from RFA 3 in this analysis, the conclusion may be a function of small sample size resulting in biased (limited) spatial assessment; this likely made the temporal variation appear more important. Results from the other RFAs indicate that the dimension (space or time) of greater variability, varies with age class. The contrasting pattern between ages 0+ and 1+ in RFAs 1 and 5 is interesting. It appears that RFA 1 has greater temporal variability of age 0+ and greater spatial variability of age 1+. One interpretation of this is that the streams within RFA 1 are relatively similar with respect to age 0+ density and the variation is due, at least in part, to variable spawning or egg survival among years. But then survival from age 0+ to 1+ has low temporal variability (i.e., quite similar from year-to-year) but there is variation among the brooks. Interpreting the RFA 5 pattern is the opposite of this. There is little year-to-year variation in spawning and egg survival with most of the variation occurring among brooks. RFAs 2 and 4 each have approximately equal variation over time and space.

Alkalinity and pH appear to offer the greatest explanatory power of relationships of trout density with environmental factors. This is consistent with general understanding of brook trout ecology, that at depressed pH brook trout densities decline. There is very little correlation with physical habitat (with exception of age 1+ trout and stream velocity) in these data, implying, at a provincial scale, factors most affecting trout density are chemical, rather than physical. Of course, on a site- or brook-specific basis, physical habitat can be a limiting factor, but across the broad scale water chemistry appears more important. It must be borne in mind that the analysis was done using only a limited number of environmental variables. There may very well be other physical and chemical variables that play a significant role in trout density not examined here. Further research into this would be worthwhile (*Recommendation #3*)

These data may be useful to provide some indications of reasonable management targets for RFA-specific trout densities. As a preliminary estimate for management targets, the 80th percentile of the densities within each RFA were calculated. These seem a reasonable target as these are the values which may be expected to be exceeded 20% of the time, and so are not unrealistically high, yet are well above the "average" density. These values are:

RFA 1: 35 trout (all ages combined)/100 m^2
RFA 2: 25 trout (all ages combined)/100 m^2
RFA 3: 15 trout (all ages combined)/100 m^2
RFA 1: 5 trout (all ages combined)/100 m^2
RFA 1: 15 trout (all ages combined)/100 m^2

Size at age

Trout body size was smaller in RFAs 1 and 2 than in RFA 4 for ages 0+ and 1+. This observation is intriguing as there is very little evidence of density dependence effects on size (see below), and RFA 4 represents the more acidified streams and thus organisms would be expected to suffer physiological and ecological stress. Age 0+ to 1+ growth in RFA 1 is less than other RFAs supporting this observation. To compensate, growth of age 1+ to 2+ in RFA 1 is greater than other RFAs. Consistent with this observation is that the differential in size among RFAs is most pronounced in age 1+, and by age 2+ the trout in all RFAs appear to be of similar size. One possible interpretation of this is that some of the fish assigned to age class 1+ based on length were in actuality small age 2+ fish. This would bias the size of age 1+ fish high and would be consistent with understanding of how acidified water affect trout (slower growth and so smaller size at age). This suggestion could be assessed as scales were collected during the 1989-1993 sampling and, if they have been read and the data archived, an examination of these data would allow assessment of size-at-age from an independent source than Length Frequency Analysis (*Recommendation #4*). The trout of RFA 4 may be larger than RFAs 1 and 2, and if this can be confirmed, it represents an ecological and physiological puzzle of how this occurs.

Variation in body size among streams within an RFA is quite low. That is, streams within an RFA are quite similar. Streams in RFAs 1 and 2 showed the greatest differences among streams, and 4 and 5 the least. This is consistent with the idea of greater heterogeneity in RFAs 1 and 2, and processes acting more evenly across all streams of RFAs 4 and 5. Differences in body size among streams showed non-regular occurrence. That is, no streams showed systematic smaller (or larger) body sizes for all age classes. Rather, the variation generally occurred among age 0+ and 1+ and had evened out by age 2+.

There is no evidence of systematic change in body size (trends) over the 5 year period for any brook or age class evaluated.

The relationships of mean body size on density for each of age 0+ and 1+ trout are statistically significant, but explain very little of the variation. Thus, there is very weak evidence that density affects body size. A significant relationship, however, is that age 1+ trout body size is quite well related to age 0+ body size. It appears that factors promoting larger age 0+ trout are carried forward to produce large age 1+ trout. Density however, appears to likely have a very small effect on body size. In part this is likely due to density dependence only taking effect at relatively high densities and in the presence of limiting factors. The densities observed are unlikely to invoke density dependence.

The results of size-at-age correlation with water chemistry are counter-intuitive as they all suggest inverse relationships with measures of stream productivity (pH, alkalinity, hardness, conductivity) while generally accepted stream ecology theory states body size should increase with these measures, over the range encountered here. In particular, low pH is known to result in slower growth and small size-at-age (e.g., Rodgers, 1984; Tam and Payson, 1986; Mount et al., 1988). The observed patterns shown here need to be investigated further to confirm the ecological reality of them (*Recommendation #4*).

Brook Trout Population Dynamics

Survival & Recruitment

Estimating true survival of a population, or component of a population, is very difficult to do, requiring knowledge of immigration/emigration and the fates of individual fish. As a coarse proxy, changes in population size among years is frequently used, but this must be acknowledged to not truly estimate survival, as evidenced by the frequent survival values >1.0. The estimates for "survival" (change in density) indicate that they are highly variable both among years and also among RFAs. Typical survivals of age 0+ to 1+ appear to be in the range of 0.3 to 0.6 and for age 1+ to 2+, 0.15 to 0.35. The analysis from the Musquodoboit data, using much larger sample sizes, indicates great variation among sites within years. The variation is so large (effectively 0.0 to 1.0) as to not be instructive. This further suggests that this approach to "survival" may not be particularly useful or helpful.

The recruitment correlation of RFA 1, and absence of such a relationship in other RFAs, further emphasizes that processes occurring in RFA 1 affecting trout are different than elsewhere. RFA 1 is likely affected primarily by brook scale processes, rather than RFA-level processes and it is the only area to show that temporal variation of age 0+ is more important than spatial variation. As seen here, it is also the only area to show an age 0+ to 1+ recruitment relationship. The lack of this relationship in other RFAs suggests that in those areas immigration of age 1+ into the sampling area is occurring from other areas, or that large year-to-year or brook-to-brook mortality occurs, disrupting a direct relationship among age classes.

Interestingly, when the individual age classes are observed (Figures 12-14) age 0+ trout density is relatively similar among all five RFAs, but then the age 1+ and 2+ appear to be lost in RFAs 3 and 4 relative to the other three RFAs. This is suggestive that spawning is successful but the loss of individuals occurs between age 0+ and 1+.

Growth

There are only a small number of growth estimates and so interpretation must be done with caution. It does appear that growth in RFA 1 is reduced for ages 0+ to 1+ relative to other RFAs, but elevated for ages 1+ to 2+. This result is surprising as RFA 1 shows the highest trout density but the case for density dependence is very weak. Further, RFA 1 has the most appropriate water quality for growth. That it is retarded in this Area relative to other locations is unexplained. Growth (age 0+ to 1+) in the acidified streams of RFA 4 are intermediate to RFAs 2, 3 and 5 suggesting acidification has not reduced brook trout growth. Variation in growth among years within a site can be quite high , i.e. a difference among years within a brook of up to 3.0 cm. There is no indication of directed change over time (trends) in growth for any brook analyzed.

Growth showed no correlation with the environmental variables considered here. The lack of correlation with pH is surprising given the strong correlation of size-at-age with this variable. Growth was expected to be correlated in the same way as size-at-age since they are tightly coupled.

MANAGEMENT IMPLICATIONS

This analysis has highlighted differences among RFAs with respect to fish community structure, and brook trout density, size-at-age, and growth. Given these geographic variations, the management for brook trout should also be at the RFA scale. In one sense the RFAs have arbitrary boundaries, indeed, some have changed since these data were collected, grouping large areas of streams together. From this analysis it appears this regional grouping approach is reasonable and appropriate as these areas clearly do differ from each other.

The processes affecting trout, and presumably other fish species, in streams appear to operate at different scales among the RFAs. It is inferred here, due to similarities among streams within RFAs, that processes affecting trout are acting on a regional scale in RFA 4 and at more of a brook- or river system-scale in RFAs 1 and 2. RFAs 3 and 5 show intermediate characteristics to these extremes. Thus, management within the different RFAs should accept and appreciate this; that large-scale regional policies and practices in RFA 4 may be successful, but are less likely to be so in the other RFAs. Recreational Fishing Areas 1 and 2, in particular, may require finer-scale management as the individual systems show considerable variation.

Chemical factors explain more of the response of brook trout populations to environmental conditions than physical factors. This must be interpreted with care however, as the results are in opposition to brook trout ecology dogma, and thus need to be critically evaluated and reviewed prior to decisions made based upon these findings. Further, only a handful of variables were examined to assess their influence on trout. Notably, a major potential factor, introduced fish species, was not included. Smallmouth bass (*Micropterus dolomieu*) and chain pickerel (*Esox niger*) have become much more widespread in the province since this 1989-1993 sampling, particularly in RFAs 3, 4, and 5, and these may play an important role not considered here.

Preliminary RFA-specific management targets for brook trout densities are provided. These are:

RFA 1: 35 trout (all ages combined)/100 m^2
RFA 2: 25 trout (all ages combined)/100 m^2
RFA 3: 15 trout (all ages combined)/100 m^2
RFA 1: 5 trout (all ages combined)/100 m^2
RFA 1: 15 trout (all ages combined)/100 m^2

RECOMMENDATIONS

These recommendations are not presented in order of priority, but rather order of appearance in text.

Recommendation #1: The contradiction between the univariate (richness, diversity and evenness) and multivariate (cluster analysis) approaches in analyzing community composition across RFAs is likely, in part, due to the relatively small sample size. To resolve this contradiction, a compilation of electrofishing data from across the province (NSDFA, DFO data sources) and analysis of multiple sites would be worthwhile. Such a directed project would allow highly detailed assessment of stream fish community composition over space and time. DFO Maritimes (Dr. Jamie Gibson) was working on a similar project in 2011, consulting with him will prevent overlap of analyses.

Recommendation #2: Within stream variation of trout density was not adequately assessed in this research and should be further examined and compared with spatial variation at the among-brooks level. Existing electrofishing data from DFO and NSDFA should be compiled and examined to quantitatively evaluate within-brook variation at many locations throughout Nova Scotia to understand not only that source of variation but also how it varies geographically.

Recommendation #3: The correlation analysis of trout density and environmental factors conducted here resulted in useful preliminary results. A more comprehensive modelling approach is warranted to truly understand habitat use and requirements by brook trout throughout Nova Scotia, and those factors limiting their production. This is required because of the large range of environmental conditions shown throughout the province; better understanding of habitat-trout relationships will allow more region-specific management. Such a modelling approach can use existing electrofishing and environmental sampling data, should be combined with GIS data at the watershed level (e.g., land use), and employ multivariate and non-linear techniques.

Recommendation #4: Brook trout in the acidified water of RFA 4 appear to be larger at-age, and have faster growth, than those in RFAs 1and 2. While this may be a real phenomenon, the first step should be to critically examine the size data from each RFA using the scale data to confirm ages of fish by size. If the trout from the acidified waters are indeed larger as age 0+ and 1+ ages than from other RFAs then research into what is driving this is warranted as this is counter to prevailing thought on salmonid ecology in acidified waters.

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REFERENCES

Anderson, D. R., K. P. Burnham and W. L. Thompson. 2000. Null hypothesis testing: problems, prevalence, and an alternative. Journal of Wildlife Management 64:912-923.

Anonymous. 2005. Nova Scotia geological highway map. Province of Nova Scotia and Atlantic Geoscience Society

Bohlin, T., S. Hamrin, T.G. Heggberget, G. Rasmussen, and S.J. Saltveit. 1989. Electrofishing – theory and practice with special emphasis on salmonids. Hydrobiologia. 173:9-43.

Bohlin, T., T.G. Heggberget, and C. Strange. 1990. Electric fishing for sampling and stock assessment. Chapter 5 *In*: Cowx, I., and P. Lamarque [eds.]. Fishing with electricity. Applications in freshwater fisheries management. Blackwell Scientific Publications. pp112-139.

Cohen, J. 1994. The earth is round (p<.05). American Psychologist 49:997-1003.

Johnson, D. H. 1999. The insignificance of statistical significance testing. Journal of Wildlife Management 63:763-772.

Krebs, C.J. 1989. Ecological methodology. HarperCollins Publishers.

Mitchell, S.C. 2011. Water Quality of the St. Mary's River Watershed: A detailed Analysis. St. Mary's River Association Technical Report #011.

Mitchell, S.C. 2012. Fish Communities of the St. Mary's River Watershed: An analysis of community diversity and structure. St. Mary's River Association Technical Report #014

Mount, D.R., C.G. Ingersoll, D.D. Gulley, J.D. Fernandez, T.W. LaPoint, and H.L. Bergman.1988. Effect of long-term exposure to acid, aluminum, and low calcium on adult brook trout (*Salvelinus fontinalis*). 1. Survival, growth, fecundity, and progeny survival. Canadian Journal of Fisheries and Aquatic Sciences. 45:(9) 1623-1632.

Rodgers, D.W. 1984. Ambient pH and calcium concentration as modifiers of growth and calcium dynamics of brook trout, *Salvelinus fontinalis.* Canadian Journal of Fisheries and Aquatic Sciences. 41:(12) 1774-1780.

Sokal, R.R., and F.J. Rohlf. 1969. Biometry. The principles and practice of statistics in biological research. W.H. Freeman and Comapny.

Tam, W.H., and P.D. Payson. 1986. Effects of chronic exposure to sublethal pH on growth, egg production, and ovulation in brook trout, *Salvelinus fontinalis.* Canadian Journal of Fisheries and Aquatic Sciences. 43:(2) 275-280.

Watt, W.D. 1987. A summary of the impact of acid rain on Atlantic salmon *(Salmo salar*) in Canada. Water, Air, and Soil Pollution. 35: 27-35.

Watt, W.D. 1997. The Atlantic Region Acid Rain Monitoring program in acidified Atlantic salmon rivers: trends and present status. Canadian Stock Assessment Secretariat Research Document 97/28.

Watt, W.D., C.D. Scott, and W.J. White. 1983. Evidence of acidification of some Nova Scotia rivers and its impact on Atlantic salmon, *Salmo salar*. Canadian Journal of Fisheries and Aquatic Sciences. 40: 462-473.

Zar, J.H. 1999. Biostatistical analysis. Fourth Edition. Prentice Hall. Upper Saddle River, New Jersey.

Appendix1: Descriptions of streams sampled by NSDFA, 1989-1993 during brook trout research program.

Zone	Brook	County	River system	Lat/Long of stream mouth	Site location	Land use
1	Kewstoke Brook	Inverness	Indian River then into Skye River	45°59'33"N, 61°12'58"W	Sampl site is first bridge (side road) on brook (45°59'27"N, 61°13'29"W); this is the lowr section of th brook	Forstryand roading. GoogleEarth resolution poor for this area. Upper rachs of brook into high gradient terrain.
1	MacDonald's Brook	Inverness	River Inhabitants	45°42'35"N, 61°16'37"W	Elctrofishing sit location not provided in fils	Mostof watershed forstd (mix of young and mature forsts) with some roading, but that is limitd. System looks like it should b in good condition based on forst conditions. Likly historical forestry though, so may b impacts associated with that.
1	Dan Morrison's Brook	Cape Breton	Meadows Brook then into Sydney River	46°10'07"N, 60°18'29"W	Elctrofishing site immidieatly upstream of McInnis Lake.	Largely forestd, some roading and isolatedcutblocks. Likley historical impacts but current land use looksto b largelt intact forest. Downstram, howvr,extnsiv land claring and roading.
2	Bailey's Brook	Pictou	Drains into Northumberland Strait (near Barney's River)	45°42'19"N, 62°16'09"W	Prcise sampling location on stream unknown.	Lower reaches som agriculture (moderate, not xtnsive); mid- and upper-reachs som forestry/roading (modrate –ot xtensive)
2	Bulmer Brook	Cumberland	River Phillip	45°36'15"N, 63°52'34"W	Sampl site~3-4 km upstream ofconfluncewithRiverPhillip. "mid-" or "lower" section of Bulmer Brook	Watershed almost ntirely in old forestry (large cutblocks of regenrtaing growth). A small amount of agricultur. A min (quarry?)near the conflunenc of Bulmer Brookand River Phillip. Som roading and powerline crossing. Cutblocks appar to be in advancd stage of regnerationso forestry likely historical; little sign of currnt

						forestry oprtaion in watershed. Very little “truly forested” land.
2	Hurlburt Brook	Antigonish	Tracadie River	45º34’45”N, 61º35’05”W	Sampl site inlower rach(assumd to b at road crossing connecting Highway 16 and Matti Settlemnt basd on vague dscription in fils.	Forstryand roading. Much of brook drains large cutblock. GoogleEarth resolution poor for this area.
3	Gegogin Brook	Guysborough	Drains into Gegogin Harbour near Liscomb	45º04’12”N, 61º58’49”W	Elctrofishing site location not providd in fils. Located somwhre upstream of Highway 7 (i.., in”mid-section” of brook)	Extensiv forestry and roading
3	St. Francis Harbour Brook	Guysborough	St. Francis Harbour River		Sit location is ambiguous as ther isno “St. Francis Harbour Brook” in map book and site is frquntly rferrd to infils as “St. Francis Harbour Rivr”. basd on written dscription of accss in fils brrok appars to b an unnamed tributary with confluenc at 45º29’04”N, 61º25’07”W	Historical forsrty and roading. Not barrens in watrshd.
4	Mistake River	Digby	Sissiboo River	44º25’24”N, 65º51’30”W	Estiamted site location at 44º27’43”N, 65º48’41”W. This is in lower section of Mistak River, approx 2 km south of Portrs Lake outflow.	Primarily agriculture/rsidntial. Som forestry. havily roaded.
4	Logging Brook	Shelburne	Roseway Rivr	Stream not identified due toambiguoty in nots	Stream andsit location ambiguous. No “Logging brook” in mapbook. stram not idntifid.	Stream not identified due toambiguoty in nots
4	Wamback Mill Brook	Lunenburg	Petite Riviere	44º14’23”N, 64º27’46”W	Precise locationof sampl site difficult to dtermin from fils. Appars to be vry clos to conflunc of WambackMill Brook with Ptit Riviere.	Quit wll forestd, some historical forestry (rgnration); limitd roading; no obvious agriculture.

5	Delancey Brook	Annapolis	Annapolis River	44º54’46”N, 65º06’08”W	Sitelocation ambiguous based on accss dscription in fils.	Agriculture, forestry and roading – intensive land use.
5	South Branch Stewiacke	Colchester	Stewiacke River	45º12’44”N, 63º01’20”W	Sit location is ambiguous in fils but I plac it in th lowst most section of th stram,at approxiamtlly 45º11’10”N, 63º01’41”W	Agriculture and roading
5	Porcupine Brook	Kings	Gasperau River	45º01’10”N, 64º23’45”W	Sitelocation ambiguous based on accss dscription in fils.	Largely forsted though hadwaters in agriculture.

Appendix 2: Water quality sampling schedule (parameters and years) associated with NSDFA electrofishing program, 1989-1993. X indicates parameter was sampled in that year. Water samples collected at each of the 14 streams.

	1989	1992	1993
Sodium	X	X	
Potassium	X	X	
Calcium	X	X	X
Magnesium	X	X	X
Hardness ($CaCO_3$)	X	X	X
Alkalinity ($CaCO_3$)	X	X	X
Sulfate	X	X	
Chloride	X	X	
Silica	X	X	
Ortho-phosphorous (P)	X	X	
Nitrate+nitrite (N)	X	X	
Ammonia (N)	X	X	
Iron	X	X	
Manganese	X	X	
Copper	X	X	
Zinc	X	X	
Color	X	X	
Turbidity	X	X	
Conductivity	X	X	X
pH	X	X	X
Total organic carbon	X	X	
Carbonate ($CaCO_3$)		X	X
Bicarbonate ($CaCO_3$)		X	X