BROOK TROUT (*Salvelinus fontinalis* Mitchell) MOVEMENT, HABITAT USE, AND POTENTIAL IMPACTS OF FOREST HARVESTING ACTIVITY IN THE COPPER LAKE WATERSHED, CORNER BROOK, NEWFOUNDLAND

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Brook trout (*Salvelinus fontinalis* Mitchell) movement, habitat use, and potential impacts of forest harvesting activity in the Copper Lake Watershed, Corner Brook, Newfoundland.

by

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Abstract

Seasonal movements of brook trout (*Salvelinus fontinalis* Mitchell) within a treatment and control stream in a forested area near Corner Brook, Newfoundland were determined using counting fences and tagging. Trout movement was weakly or uncorrelated with habitat parameters. Most trout moved in association with increased discharge associated with storm events. Two patterns in upstream movement were observed: 1) an apparent 'preferred' velocity range of 0.395-0.462 $m \cdot s^{-1}$ in the treatment and 0.206-0.409 $m \cdot s^{-1}$ in the control stream; and 2) an increase in upstream movement after the storm peak if the peak was greater than 0.474 and 0.421 $m \cdot s^{-1}$ in the treatment and control stream, respectively. Downstream movement in the treatment stream occurred most at lower velocity ranges and trout moved more before and after storm peaks than during the peak. Downstream movement in the control stream occurred at all velocity ranges and trout moved throughout the storms.

Increased movement out of the treatment stream was recorded in 1995 after a limited forest harvest of approximately 9.0% of the drainage basin (20% of the stream-length). Trout from the treatment stream did not appear to change their distance of migration but moved out of the treatment stream and into Copper Lake. This increase appeared to have been due to subtle changes in stream habitat.

Discharge, maximum stream temperature, mean stream depth, velocity, and temperature were not altered by forest harvesting and dissolved oxygen did not reach critical levels even after the cut. The minimum daily water temperature was affected by harvesting with a significantly higher number of days with minimum temperatures less than 11°C. In addition, total suspended sediment appeared to have been increased, however, statistical evidence is lacking.

Radio telemetry of mature trout in the lakes of the study area showed that lacustrine spawning represents a large proportion of the reproduction in certain areas of the watershed. This has rarely been documented in Newfoundland and needs to be considered in the context of effects from forest harvesting practices.

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1 **Introduction**

Although intensive forest harvesting activities have been ongoing in Newfoundland since the early 1900's, their effects on populations of freshwater fish are poorly understood here (D. Scruton pers comm). This is true despite the fact that the majority of merchantable timber in Newfoundland is associated with riparian zones and consequently, the potential for forestry - fishery interactions is very high (Scruton et al. 1995). The multi-disciplinary nature of resource management is now recognized in Newfoundland (Scruton et al. 1992b) and forest harvesting practices are being altered to give better protection to aquatic systems.

To better assess the impacts of forest harvesting practices on riparian ecosystems in Newfoundland, the Copper Lake Buffer Zone Study was undertaken in 1993 as an interdisciplinary, multi-agency research effort (Scruton et al. 1995). An important aspect of this research involves assessing the impacts of logging and road construction on fluvial and lacustrine habitats and the affect that these changes may have on brook trout (*Salvelinus fontinalis* Mitchell) behaviour and habitat use. Owing to their relatively high mobility, and their ability to avoid or exploit changes in their environment, fish can serve as initial indicators of changing conditions in aquatic habitats; furthermore, a knowledge of fish movements is often useful in identifying subtle changes in habitat which may not be readily detected by other means (Bergersen and Keefe 1976).

To understand the impact that forest harvesting practices have on brook trout populations, it is necessary to know the regular movements of these populations, and how they are influenced by natural changes in habitat. Only then can pre- and post-harvesting population characteristics (density, biomass, age-class structure, growth, survival, etc.) be assessed. In addition, an understanding of the seasonal movements may assist in explaining possible seasonal variations in the stream population estimates conducted by the department of Fisheries and Oceans (DFO). The sampling dates for estimating the stream populations over the course of the five-year buffer zone study (Scruton et al. 1995) will almost certainly vary from year to year as will the seasonal conditions during the time of sampling. For example, seasonal movements could result in fish utilizing different habitats or areas in mid-June than in early July. Population estimates conducted once each year could therefore give misleading results as to the impacts of logging activities due to regular, seasonal movements (Stauffer 1972; Thorpe 1974; Meyers et al. 1992) of the population.

This study examined the movement and habitat use of brook trout in the Copper Lake watershed, Corner Brook, Newfoundland. It compared variation in fluvial habitat parameters in harvested and unharvested catchments to determine effects on trout movements.

1.1 Objectives

The objectives were: 1) to determine brook trout movements and habitat utilization, including major spawning locations, (pre-harvesting) in selected parts of the Copper Lake watershed, 2) to determine if certain habitat parameters were correlated with trout movements, 3) to determine whether these habitat parameters were affected by forest harvesting, and 4) to determine if trout movements were affected in catchments where harvesting occurred (post-harvest).

2 Materials and Methods

2.1 Study site

The Copper Lake watershed (N 48° 49'17.5'' W 57° 46'27.0''), drains approximately 13.5 km^2 within the Corner Brook Lake watershed (Fig. 2.1). In 1993 this area was a virgin forest containing a diversity of terrestrial and aquatic habitats (Scruton et al. 1995). It was scheduled for harvest by Corner Brook Pulp and Paper Ltd. in 1994 and 1995.

The watershed is located in the Corner Brook sub-region of the Western Newfoundland Ecoregion (Damman 1983). This sub-region is characterized by heavily forested areas with rugged topography and nutrient rich soils. The geology of the Corner Brook Lake area has been described in detail by Kennedy (1981). The surface soils are dominated by glacial till having a moderate to coarse texture (ie. sand and coarse loam) (van Kesteren 1992).

The forest within the watershed is composed largely of mature (60-100 years old) and insect-killed balsam fir (*Abies balsamea* L.) with some intermixing of black spruce (*Picea mariana* Mill.). There are also areas of balsam fir - white birch (*Betula papyrifera* Marsh.) mixed stands as well as softwood and hardwood scrub, bog, and treed bog which are generally located on the fringes of large forested areas

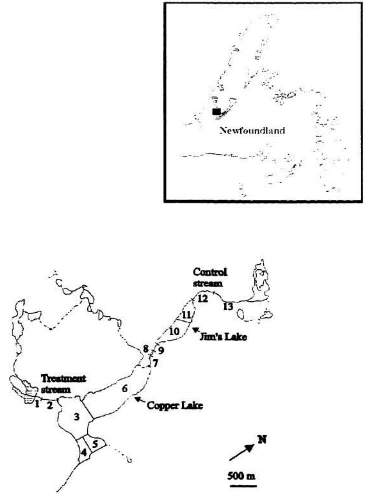


Figure 2.1 The location of the Copper Lake watershed, treatment (T1-1) and control (T1-3) streams, habitat sections (1-13), and clear-cut (shaded) within the watershed.

(Scruton et al. 1995).

The Corner Brook Lake watershed is inaccessible to anadromous fish by natural and man-made barriers. The only fish species present is brook trout.

All the streams of the Copper lake watershed were surveyed during the summer of 1993 and were described as being almost entirely composed of riffle and rapid habitat (Fig. 2.2) (Scruton et al. 1992a). Pool habitat represented less than 1% of the total stream area. The stream which drains the watershed into Corner Brook Lake also has many falls and rapids and isolates the Copper Lake system from upstream trout migration. The two lakes available to trout within the study area were Copper Lake (82.4 ha) and Jim's Lake (17.5 ha) (Fig. 2.1).

2.1.1 **Stream study sections**

The two streams monitored in this study were a control stream (T1-3) and a treatment stream (T1-1) (Fig. 2.1). The control stream was located in the northern part of the watershed where no forest harvesting or road construction occurred. It has an impassable falls 505 m upstream from its mouth. The treatment stream was in the south-eastern part of the watershed where road construction and forest

Figure 2.2 Control stream study section (# 13) composed of riffle and rapid habitat.

harvesting without any buffer strip were scheduled. It has an impassable falls 527 m upstream from its mouth. Both streams were second-order streams (based on a 1:50,000 topographical map) with average wetted widths less than 3 metres. The catchment areas of the treatment and control streams are 2.022 and 3.593 km^2 respectively.

2.1.2 **Forest harvesting and road construction**

Road construction within the watershed began in June and continued until November, 1994. In the fall of 1994, a portion of the treatment basin was clear-cut. This cut was harvested manually using chainsaws. The limbed trees were winched to the road and the limbs and debris were left on the cut. No buffer strip was left along the stream-edge. By the winter of 1994, the treatment stream had a road crossing approximately 300 m upstream from its mouth (with a 1 m cylindrical culvert installed at the crossing) and approximately 20% of its length clear-cut. This clear-cut was 1.82 ha and constituted 9.0% of the stream's drainage basin. The cut was located on the upper 100 m of the stream, below the falls (Fig. 2.1).

2.2 **Brook trout movement**

2.2.1 **Counting fences**

Counting fences were used to monitor fish movement within fluvial, and between lacustrine and fluvial, habitats. They were placed between stream sections and at the mouth of each stream. The upper and lower stream sections on the treatment stream were approximately 250 m in length while the upper and lower stream sections in the control were approximately 120 and 350 m, respectively.

The cage-portion of the fence was put into place two days before the wings were attached. This was done to assess if the cage provided shade and hence attracted trout. For all fences, no trout were found inside the cage before the wings were attached. There were 4 wings for each fence which, together crossed the entire stream above and below the cage so that both upstream and downstream migrants were directed into it (Fig. 2.3). The cage was divided internally so that upstream and downstream migrants were kept separate. The top of the cage was covered with 'chicken wire' to deter avian predators. The lower half of the cage and wings were painted dark-green with non-toxic paint to reduce the brightness of the wood and netting. Algae later covered the lower portions of these structures. The fences were usually checked each morning (Stauffer

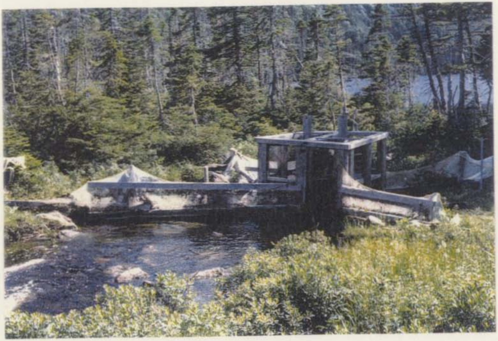


Figure 2.3 Placement and design of counting fence at the mouth of the control stream.

1972). During storm events and the spawning season, the fences were checked more frequently. Each fish larger than 6.0 cm encountered in a fence was tagged except during some storm events when maintaining the fences took precedence over tagging. Fences were in operation from at least June 11 to October 7, 1994 and 1995 except July 24-27, 1994 when they were washed out during a rainstorm.

2.2.2 **Tagging**

Individually numbered, colour-coded fingerling tags (Floy model #FTF-69) were used to tag fish. Tagging was conducted on trout caught in the counting fences, through angling with small flies and lures (barbless), by electrofishing, and in fyke nets. The tags were attached with stretchable thread inserted slightly anterior to the dorsal fin (Nielson and Johnson 1983). They were colour-coded for each initial capture location: maroon for the treatment stream, cherry for the control stream, and green for the lakes. Fourteen hundred and eighty trout were tagged between June 1994 and October 1995 (813 were tagged in 1994 and 667 were tagged in 1995).

Before tagging, fish were anaesthetized with benzocaine (40 $mg \cdot L^{-1}$ acetone) at a concentration of 8 ml per 5 litres of water (Brown 1993). The stages of anaesthetization described by McKinley et al. (1992) were used to monitor the trout. They were allowed to recover in freshwater for approximately 0.17 h and then released at the point of capture, unless they were caught in a counting fence. Fish caught in fences were released in the direction they were migrating.

2.2.3 Monthly age composition of migrant trout

The age composition of migrant trout caught in counting fences was determined on a monthly basis. Fish were aged using scales collected from the dorsal region below, and just posterior to, the dorsal fin. The scales were examined for annular rings (Cooper 1951; Lagler 1952; Ambrose 1983). They were pressed between a petri dish and a glass slide. Water was added and they were then viewed through a Bausch & Lomb (catalog # 42-63-59) scale reader at a magnification of 46X. An outline of the focal point and each annulus was recorded on paper for each scale. When possible, at least 4 separate scales were aged for each fish to give a mean annular distance from the focal point (Bagenal and Tesch 1978). Scale samples were not taken from many trout less than 6.0 cm in fork length.

A blind test was conducted on 25 randomly selected scale samples from the previously aged samples. This subsample was re-aged to determine the consistency of the scale aging methodology. Of the 25 fish re-aged, 22 were aged as they were previously and only 3 were aged differently, all by a single year. This blind test indicated that the consistency of the scale readings was high.

2.2.4 **Telemetry**

Radio transmitters were implanted into a total of 19 brook trout from Copper and Jim's lakes to monitor movement within the lakes between August 10 and October 7, 1995. Fish large enough to permit implantation of transmitters were caught in fyke nets and by angling (barbless hooks) immediately before implanting. The transmitters (Lotek model # FSM-3) had a battery-life of approximately 60 d and weighed 2.3 g in water. Only fish greater than 110 g were implanted (the majority being greater than 165 g), consequently, transmitters were always less than 2.1% of the trout's body weight. This size-class includes the largest trout found in the watershed. All transmitters were implanted between August 9 and August 24, 1995.

Transmitters were surgically implanted using the method described by McKinley et al. (1992) with the following exception: the incision for the transmitter was made on the ventral surface immediately posterior to the pelvic fins and anterior to the anus. This area provides more muscle for suturing and has less tendency to tear after the sutures are in place (S. McKinley pers comm). After surgery, fish were allowed to recover in small impoundments within the lakes for 0.25-0.5 h before being released into their home lake. In total, 10 fish from Jim's Lake and nine fish from Copper Lake were implanted.

The location (latitude and longitude) of each fish was determined daily (between 1300 and 2000 h) using a hand held receiver (Lotek model # SRX-400) and a Yagii antenna from fixed land positions around the watershed (Fig. 2.4). The minimum linear distance a fish had travelled since the last known position was then estimated. The daily point-locations were plotted on maps of the watershed to determine habitat use and range of movements for each implanted fish.

Spawning activity was monitored from September 27 to October 7, 1995, by surveying the watershed for redds. All streams were monitored by walking along stream-banks while the lakes were surveyed by boat. The maneuvering of the boat and lower visibility in the lakes made an actual count of the redds difficult. Therefore, a visual estimate of the number of redds present in each area was determined as best as conditions would allow. Redds were identified as light

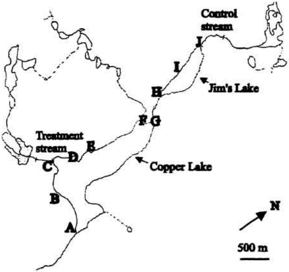


Figure 2.4. Fixed land positions (A to J) used for telemetry.

patches of substrate which had been cleaned of the surface covering of filamentous green algae and debris (Cowan and Baggs 1988). Brook trout were observed spawning and constructing redds which validated the redd description. No potential redds were dug up to assist in the redd validation. The distribution of redds was later related to the ranges and movement patterns of implanted fish.

2.3 **Stream habitats**

Certain habitat parameters (see below) were measured to determine if they were correlated with trout movement. Although many habitat parameters may be correlated with the movements of brook trout, this study focused on those which would most likely be affected by forest harvesting. All habitat parameters were measured between 1100 and 1500 h on both study streams twice a week.

2.3.1 **Transect location and use**

Six transects per stream study section were used to measure dissolved oxygen (DO), water velocity, and depth. Stream discharge and total suspended sediments (TSS) were measured in each stream at the most downstream transect only (see below). Transects were all marked on the left-hand side of the stream with a small steel post. The same transects were used in both years. Three measurements were taken at marked points on each transect for a total of 18 point-measurements per stream section. The transect-points were at approximately one-third, one-half, and two-thirds the wetted width of the stream.

2.3.2 **Staff-gauge location and use**

Because counting fences were checked daily and stream habitat parameters could only be measured on each stream twice a week, staff-gauges were used to obtain daily calculated values for stream discharge, mean velocity, and mean depth.

Staff-gauges were placed at the mouth of both study streams on June 18, 1994. They consisted of long metal poles driven deep into the substrate in the centre of each stream. The staff-gauge height was measured daily between 1100 and 1500 h with a meter stick to the nearest 0.5 cm. The height measured was the distance from the top of the staff-gauge to the surface of the water. This measure, rather than the height of water up the gauge (water depth), was used so that any shift in substrate near the base of the pole would not affect the readings. An increase in staff-gauge 'height' therefore indicates a decrease in stream water levels.

The staff-gauge height was related to stream discharge, mean water velocity, and mean water depth for each stream study section using least-square linear regressions. All equations were significant with high r^2 values (Appendix 1 to 3).

One high-water discharge measurement was omitted from the computation of the 1994 discharge regression for the treatment stream due to high water flows. If streamflow is turbulent and the current meter is not held steady, the meter can yaw, drift, and move vertically, causing under-registration by a propeller-type meter (Herschey 1978). Three very low-water discharge measurements were also omitted from the 1994 discharge relationship for the treatment stream because most of the velocity-meter blade was out of the water.

2.3.3 **Atmospheric/weather conditions**

Atmospheric/weather records were obtained from the Department of Forestry, Massey Drive, Corner Brook for the 1994-1995 field seasons. This automatic weather station is located 17 km north-west of Copper Lake. Measurements of daily rainfall (0.1 mm) and air temperature (0.1 °C) were recorded daily at 1300 h. Comparisons of mean monthly temperatures and rainfall between months within years, as well as between years, were made to determine if weather patterns between years were similar.

2.3.4 **Water velocity and depth**

Water velocity was measured with an A. Ott (model Z210) propeller-type current meter at the set transect-points. The number of blade revolutions of the meter over a 40 s time interval was counted. This number was then converted to velocity ($m \cdot s^{-1}$) using the Ott Z210 flow meter manual. Measurements were taken at 0.6 the water depth to obtain the average velocity for each transect-point (Herschey 1978, Riggs 1985).

Water depth was measured to the nearest 0.5 cm on a meter stick immediately before the velocity measurements were made. If there was no water below a transect-point, the point was recorded as dry (depth = 0.0 cm) and no other measurements were recorded.

2.3.5 **Discharge**

Discharge was calculated by measuring the water depth and velocity every 0.1 m across the wetted width of the first (most downstream) transect in each stream (Riggs 1985). Discharge was calculated as the total volume of water flowing past this transect per second ($m^3 \cdot s^{-1}$).

2.3.6 **Stream temperatures**

Hugrun thermographs (Seamon UTR-B: -2°C - +38°C ±0.1°C) were attached to the bottom of the staff-gauges at the mouth of both study streams. Water temperature was measured every hour over the course of the study (except for some battery failures). These hourly measures were used to calculate the mean, maximum, and minimum daily water temperature for each stream. Temperature measurements were also taken manually with a YSI oxygen/temperature meter (model 51A/B). These measurements were taken twice a week on each stream.

2.3.7 **Dissolved oxygen**

Dissolved oxygen (DO) was monitored with a YSI dissolved oxygen/temperature meter (model 51A/B) at the set transect-points. The meter was calibrated at two week intervals. Measurements were taken 5 cm above the substrate. If the water depth was less than 5 cm, the measurement was taken in what water was present. DO was measured to the nearest 0.1 part per million ($mg\ O_2 \cdot L^{-1}$) (Davis 1975).

Least-square linear regression equations were used to calculate a relationship between DO, mean water temperature and mean water velocity (Gordon et al. 1992). The 1995 equations, relating DO to water temperature and velocity, showed significant results with high r^2 values (Appendix 4). Water velocity was included in the DO equations because it accounted for a significant amount of the variation in DO readings (Schmitt et al. 1993).

The 1995 DO relationships were used to calculate the 1994 mean DO levels within each stream section. This was necessary due to the discovery that the DO meter had given unreliable measurements in 1994.

2.3.8 **Total suspended sediments**

A sample of water, usually one litre, was collected at the mid-point of the bottom transect of each study stream on set dates throughout each season for water quality analysis by the Provincial Department of the Environment under the direction of Ian Bell, Regional Watershed Officer, Water Resources Division, Provincial Dept. of the Environment, Corner Brook, NF.

2.4 **Statistical tests**

All statistical tests were conducted at the 0.05 level of significance. Randomized p-values were calculated for those parametric tests whose residuals did not appear normally distributed (Ryan et al. 1985). All randomization tests were replicated between 300 and 1005 times (majority 500).

2.4.1 **Correlations between habitat parameters and trout movement**

All calculated habitat values for each day the counting fences were checked were compared to both upstream and downstream trout movement through the fences using correlation analysis. Analysis was carried out using Minitab (7.0 for VAX/VMS). Correlation coefficients were tested to determine if they were significantly different from zero (Sokal and Rohlf 1981). A good correlation was arbitrarily defined as one with a coefficient value above ± 0.500.

2.4.2 **Storm events**

Staff-gauge heights were recorded and counting fences checked more frequently during storm events. This allowed a finer scale examination of the relationships between trout movement and habitat measures. Storm events were defined as a doubling in stream discharge over a relatively short time (approximately 1 h). The first measurements were made at the beginning of possible storm events (very hard rain) and then approximately every 3-4 h until stream discharge subsided. The stream discharge:staff-gauge regression was then used to calculate the storm discharge profile for each stream.

The proportions of those trout moving through the fences during various discharge levels were analyzed using chi-square tests. Due to low numbers at some discharge ranges, tests were conducted on combined range values for the treatment stream (upstream and downstream movement) and the control stream (downstream only). The proportion of fish which moved before, during, and after the storm peaks were also compared. Storms were pooled for both years due to the low frequency of events, hence comparison between years was not possible. To compare mean stream velocities during the storms, the 1995 regression equations for the lower stream sections of each stream were used since four out of the five storms occurred in 1995 and most upstream movement was from the lake into the lower stream sections. The fork lengths of trout moving at different peaks in upstream movement (associated with different discharge/velocity ranges) were compared to determine if the timing of upstream movement was size-related.

2.4.3 Comparison of pre- and post-harvest aquatic environment

Mean monthly rainfall and air temperatures were compared between years and between months within years using ANOVA. Total mean rainfall and air temperature for both field seasons were also compared between years using ANOVA.

Water velocity, depth, and discharge were compared between years using general linear model (GLM) analysis of covariance (ANCOVA) tests which compared the habitat:staff-gauge regressions. This test compares the slopes of the linear regression equations between years and hence determines if the relationship has changed.

Mean, maximum, and minimum daily water temperatures taken from the thermograph data for both study streams were compared between years using chi-square tests for the proportion of days that the daily temperatures were in one of several temperature regimes. These regimes were based on brook trout temperature preferenda (Raleigh 1982) as outlined by Scruton et al. (1996 In press):

(1) less than 11°C : LOWER; below optimum but not stressful
(2) 11 to 16°C : OPTIMUM; preferred range with good growth potential
(3) 16-21°C : UPPER; above optimum but not stressful
(4) 21-24°C : STRESS; potential stressful condition, poor growth potential, increased susceptibility to other stressors (eg., disease)
(5) above 24°C : LETHAL; potentially lethal temperatures if exposed for a period of time.

TSS samples were used to compare the amount of suspended sediment in the streams before and after forest harvesting using ANOVA.

2.4.4 **Comparison of trout movement between years**

Recaptures of floy-tagged brook trout from June 11 to October 7 in both years were used to compare movement patterns within the treatment and control stream before and after forest harvesting and road construction as well as between streams within years. Stream and lake habitat within the study area were divided into habitat-sections (Fig. 2.1), with stream study sections being separated by counting fences.

A statistical method developed by Bergersen and Keefe (1976) allows the comparison of the extent of movement of fish within a population by calculation of a measure of association (H) which relates initial marking stations to final recapture stations based on matrices of double entry (contingency tables). A sample index of movement (h) was calculated for tagged trout from both streams based on capture/recapture data. The sample measure of association between the two categories is defined as

$$h=e^{\bar{w}}$$

where

$$\bar{w}=\sum_{i=1}^{R}\sum_{j=1}^{C}\ln\left(\frac{(p_{ij})}{(p_{i\cdot})*(p_{\cdot j})}\right)^{0.5}$$

where p_{ij}, $p_{i\cdot}$, and $p_{\cdot j}$ denote the cell, row (R), and column (C) proportions, respectively.

Using a large-sample distribution, an approximate 95% confidence interval for the population $\bar{W}$ can be derived; namely:

$$\left(\bar{w}-Z_{\alpha/2}\left(\frac{\partial}{\sqrt{n}}\right),\ \bar{w}+Z_{\alpha/2}\left(\frac{\partial}{\sqrt{n}}\right)\right)$$

where $Z_{\alpha/2}$ is the $(1-\alpha/2)$ percentile of the standard normal distribution. Since the population index of movement is an increasing function of $\bar{W}$, an approximate 95% confidence interval for the population index is calculated by simply evaluating the natural logarithm exponential ($H=e^{\bar{W}}$) for the upper and lower values of the confidence interval for $\bar{W}$ (Bergersen and Keefe 1976).

The recommended test procedure is to calculate the confidence interval for $\bar{W}$, associated with each contingency table and then make one of the following two decisions: i) if the 95% confidence intervals do not overlap, then the difference between the two sample index values is significant (at the α level of significance); or ii) if the confidence intervals do overlap, perform the following approximate test of significance: calculate Z, where

$$Z=\frac{(\overline{w_1}-\overline{w_2})}{\sqrt{(\frac{\hat{\sigma}_1^2}{n_1})+(\frac{\hat{\sigma}_2^2}{n_2})}}$$

The approximate test of significance for the comparison of the sample index of movements was conducted at $p=0.05$.

The strength of association of tagged trout with their initial capture location approaches a value of 1 when the association is strong. A value of $1/\sqrt{RC}$ would indicate little or no association, where R is the number of rows in the contingency table and C is the number of columns. The number of columns for each table in this study was three. As each fish had a chance of being recaptured in every habitat section, the number of rows was 13. Hence, little or no association would give a value of 0.160.

No 1995 recaptures of fish tagged in 1994 were used in the index calculations so that seasonal time intervals were comparable. No fish was entered into the contingency table more than once so that all recapture observations were independent, i.e., only the final recapture location within each season was recorded. As a result, only tagged fish were used. Some fish passed through the counting fences without being tagged, however, they were generally smaller fish (fork length <6.0 cm) whose behaviour may have been altered if they had been tagged (Xiao 1994). Brook trout initially caught in counting fences were recorded as 'recaptures' because information about previous location and present location were known, much like a mark and subsequent recapture.

In July of 1994, damage to the counting fence which separated Jim's lake from the control stream occurred. This allowed fish to move into the stream without being caught by the fence for approximately 3-4 days. This event coincided with the time when larger fish started moving into the stream prior to spawning. Electrofishing of the stream was conducted after the damage was repaired; and since no large fish were in the stream before the storm, an estimate of the number of fish which entered the first stream section could be made. These larger fish were tagged during electrofishing so that subsequent movements could be monitored.

The index of association does not take into consideration direction of movement (Bergersen and Keefe 1976) and hence could potentially mask a change in directional behaviour of movement. This potential change may be important if there is a difference in habitat-type between upstream and downstream movement. For example, there is a difference between moving within a stream and moving between a stream and a lake.

Stream and lake study sections were grouped by habitat-type, subsequently, investigations could be made on movement patterns between different habitats (Leclerc and Power 1980). Chi-square tests were used to compare movement patterns between years. The habitat-types used in the chi-square tests were lake (lacustrine) habitat, and stream (fluvial) habitat. The combining of some study sections was necessary for statistical purposes; lake sections were combined, the stream component of the behaviour category 'stream → lake' has both movement to the lake from the upper and lower stream sections, and tagged fish which were recaptured in their initial capture location within the streams were also combined into one behaviour category, ie. 'no movement within stream'. Combining these sections, however, does not impede comparing the movement of fish between habitat-types.

2.5 **Trout population analysis**

2.5.1 **Electrofishing**

The electrofishing stations used by DFO within the treatment stream encompassed all of the stream below the road crossing (approximately 300 m), and the stations in the control stream covered approximately the first 200 m upstream from the mouth as well as 100 m around the upper counting fence (95 m downstream and 5 m upstream of the fence) (Scruton et al. 1995). These stations were used by DFO to obtain yearly stream population estimates.

Electrofishing was conducted on each station between early to mid-August once each season (Scruton et al. 1995). The timing of electrofishing for fluvial population estimates, i.e. age composition, for each stream were compared to seasonal movement patterns to determine if seasonal movement patterns would affect electrofishing population estimates. The age composition of each stream was compared between years using chi-square tests.

2.5.2 **Age-at-maturity**

Age-at-maturity was determined on samples collected from each lake during the late-summer and fall of both years. This was done to help determine if movements of younger (1+, 2+) trout during the fall could be associated with spawning and to determine if the assumption that all telemetry implanted trout were in a mature, pre-spawning condition.

Male trout were considered mature if their gonads were greater than 3 mm in width (Jones 1959). Females were considered mature if they had eggs greater than 3.5 mm in diameter (Vladykov 1956). Maturity between the sexes was first compared within each age-class and those with no significant difference between sexes were pooled. Due to the low numbers of fish sampled in some age-classes, samples were grouped as those fish below the age of 3 (0+,1+,2+) and those above the age of 3 (3+,4+) for chi-square tests to achieve reliable estimates of approximation (Ryan et al. 1985). The proportion of mature and non-mature fish for each age-class were also compared between lakes.

3 Results

3.1 Stream habitats

3.1.1 Atmospheric/weather conditions

Figure 3.1 shows mean monthly rainfall with 95% confidence limits. Mean monthly rainfall showed no significant difference between months within each year ($p=0.098$ for 1994 and $p=0.098$ for 1995) or between years within each month ($p=0.373$ for June, 0.315 for July, 0.922 for August, 0.215 for September, and 0.783 for October).

Figure 3.2 shows mean monthly air temperatures with 95% confidence limits. There was also no significant difference in mean air temperatures between years within each month ($p=0.643$ for June, 0.891 for July, 0.516 for August, 0.421 for September, and 0.137 for October). There was, however, a significant difference in air temperature between months within each year ($p=0.000$ for both years) as would be expected throughout June to October.

3.1.2 Water velocity and depth

A comparison between the slopes of the 1994 and 1995 mean water velocity:staff-gauge regressions (Appendix 2) showed that slopes were significantly different in every stream section between years (Table 3.1). Mean stream

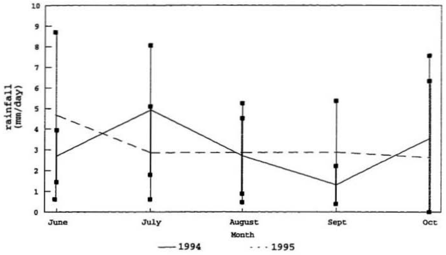


Figure 3.1 Mean monthly rainfall (mm/day) for 1994 and 1995 (with 95% CI).

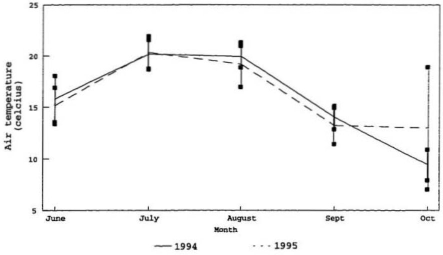


Figure 3.2 Mean monthly air temperature for 1994 and 1995 (with 95% CI).

Table 3.1. Values for GLM Ancova homogeneity of slope comparisons between years for mean water velocity (V) and depth (D) regressions within the treatment (T1-1) and control (T1-3) streams (n=46 for all comparisons).

Stream section:habitat variable 1994 vs 1995	p-value
Treatment Lower section:Mean stream velocity	0.000[1]
Treatment Upper section:Mean stream velocity	0.000[1]
Control Lower section:Mean stream velocity	0.000[1]
Control Upper section:Mean stream velocity	0.019[1]
Treatment Lower section:Mean stream depth	0.361[2]
Treatment Upper section:Mean stream depth	0.289[2]
Control Lower section:Mean stream depth	0.492[2]
Control Upper section:Mean stream depth	0.659[2]

[1] Significant

[2] Not significant

velocities at set discharges of 0.10 and 0.50 $m^3 \cdot s^{-1}$ were calculated and show the treatment stream had a lower relative mean velocity in 1995 than in 1994 compared to the control (Table 3.2). The slopes of the mean depth:staff-gauge regressions for 1994 and 1995 (Appendix 3) did not differ significantly in any stream section between years (Table 3.1).

3.1.3 **Discharge**

The slopes of the discharge:staff-gauge regression equations (Appendix 1) were not significantly different between years for either the treatment ($p=0.263$) or control stream ($p=0.075$).

3.1.4 **Stream temperature**

There was no significant difference in the proportion of days with mean daily water temperatures in each temperature range between years for the treatment or control stream ($p>0.05$) (Table 3.3). There was also no significant difference between years for maximum daily temperatures in the treatment stream ($p>0.05$), but there was a significant difference between years in the control stream ($p<0.05$) (Table 3.4). The control stream comparison for

Table 3.2. Calculated mean velocities ($m \cdot s^{-1}$) at discharges of 0.10 and 0.50 $m^3 \cdot s^{-1}$ between years for each stream study section.

Discharge ($m^3 \cdot s^{-1}$)	Year	Treatment		Control	
		lower ($m \cdot s^{-1}$)	upper ($m \cdot s^{-1}$)	lower ($m \cdot s^{-1}$)	upper ($m \cdot s^{-1}$)
0.10	1994	0.494	0.408	0.083	0.082
	1995	0.458	0.390	0.196	0.294
0.50	1994	0.847	0.702	0.426	0.455
	1995	0.485	0.408	0.361	0.487

Table 3.3. Number of days during the study with mean daily water temperature in each temperature range.

Stream & year	Temperature range				
	<11°C	11-16°C	>16-21°C	>21-24°C	>24°C
Treatment 94	12	38	22	0	0
Treatment 95	22	47	24	0	0
Control 94	23	46	8	0	0
Control 95	40	46	7	0	0

Table 3.4. Number of days during the study with maximum daily water temperature in each temperature range.

Stream & year	Temperature range			
	<16°C	16-21°C	>21-24°C	>24°C
Treatment 94	28	37	7	0
Treatment 95	51	33	9	0
Control 94	42	35	0	0
Control 95	59	27	6	0

maximum temperatures, however, had more than 20% of its cells with expected values less than 5.0 so the approximation may be invalid (Ryan et al. 1985). In the treatment stream, there was a significant difference in the proportion of days with minimum daily water temperatures in each temperature regime between years ($P<0.05$) with a larger than expected number of days having minimum temperatures less than 11°C in 1995 (Table 3.5). There was no significant difference in the proportion of days with minimum daily temperatures in each temperature regime for the control stream ($p>0.05$). The water temperature never exceeded 24°C (the upper limit for brook trout) even with the treatment stream having 20% of its streambank clear-cut in 1995.

3.1.5 **Total Suspended Sediments**

Neither the treatment stream nor the control stream had a significant difference in TSS between years ($p=0.480$ and 0.423, respectively). There was one storm event (Table 3.6) which elevated TSS levels dramatically (June 8, 1995), however, the sampling regime was too infrequent to determine if this was statistically significant. Visual observations determined that this large amount of TSS in the treatment stream was from rainwater pouring off the road's surface.

Table 3.5. Number of days during the study with minimum daily water temperature in each temperature range.

stream & year	Temperature range				
	<11°C	11-16°C	>16-21°C	>21-24°C	>24°C
Treatment 94	12	45	10	0	0
Treatment 95	35	51	7	0	0
Control 94	49	28	0	0	0
Control 95	64	29	0	0	0

Table 3.6. Total suspended sediments ($mg \cdot L^{-1}$) in samples from the treatment and control stream as analyzed by the Newfoundland Department of the Environment.

Date	Treatment ($mg \cdot L^{-1}$)	Control ($mg \cdot L^{-1}$)
21/06/94	2	--
02/08/94	2	2
02/09/94	2	2
08/09/94	2	2
20/09/94	2	2
30/09/94	2	2
02/06/95	2	2
08/06/95	2050	26
22/06/95	17	2
11/07/95	2	2
22/07/95	7	2
01/08/95	2	2
22/08/95	2	5
14/09/95	2	2
02/10/95	2	2

3.2 Trout movement

Brook trout in the treatment stream showed less overall movement than those in the control stream (Figs. 3.3-3.10). The most noticeable differences were the apparent lack of a strong spawning run in the treatment stream in both years and the increased downstream movement from the treatment stream in 1995 (Figs. 3.3, 3.4, 3.7, and 3.8). The fences in the control stream were operational earlier in 1995 which seemed to capture more downstream movement (the lower fence on the control stream was not operational until mid-June in 1994), however, the treatment stream fences were operational for similar dates in both years. Relatively little movement occurred in either stream throughout July and August.

The monthly age compositions of migrant trout for both streams are shown in Figures 3.11 - 3.14. In both streams, the trout moving in June were generally 1+ and 2+ (some 3+ in the treatment stream) moving downstream to the lakes. Notable was the increase in 2+ trout moving out of the treatment stream in the spring of 1995 (T1-1 lower fence) (Figure 3.12).

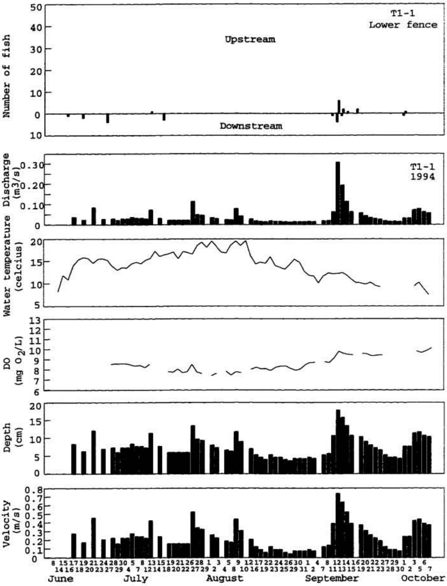


Figure 3.3 Trout movement through the lower fence, treatment stream, 1994, and associated mean daily habitat measures.

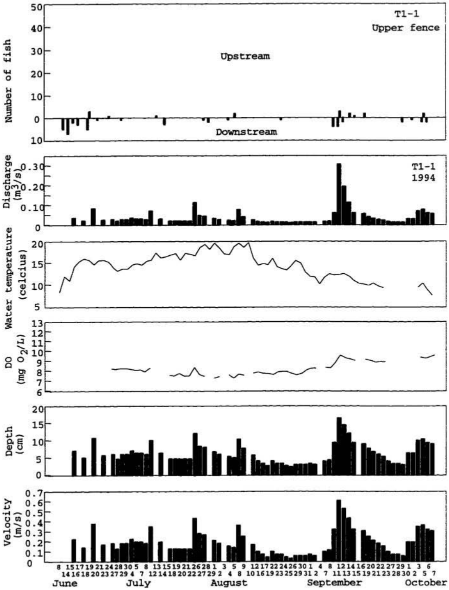


Figure 3.4 Trout movement through the upper fence, treatment stream, 1994, and associated mean daily habitat measures.

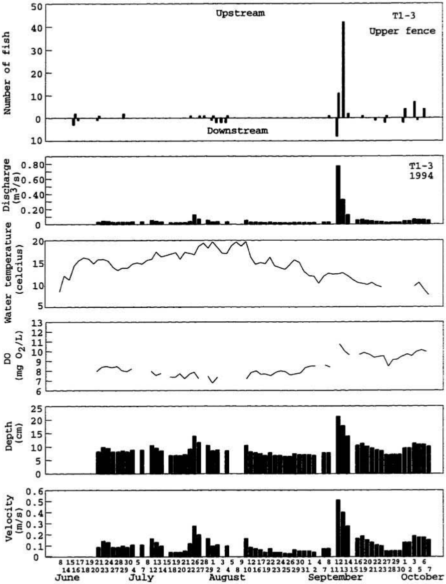


Figure 3.5 Trout movement through the lower fence, control stream, 1994, and associated mean daily habitat measures.

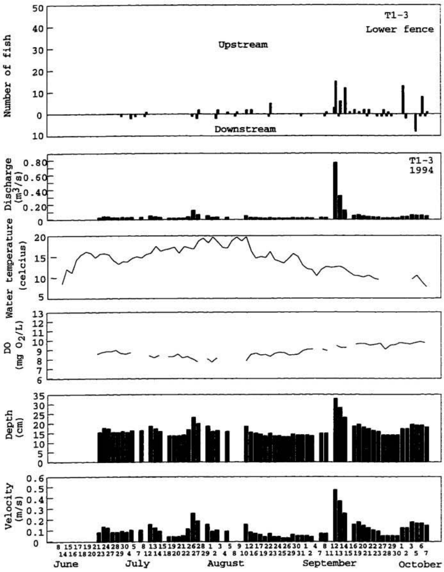


Figure 3.6 Trout movement through the upper fence, control stream, 1994, and associated mean daily habitat measures.

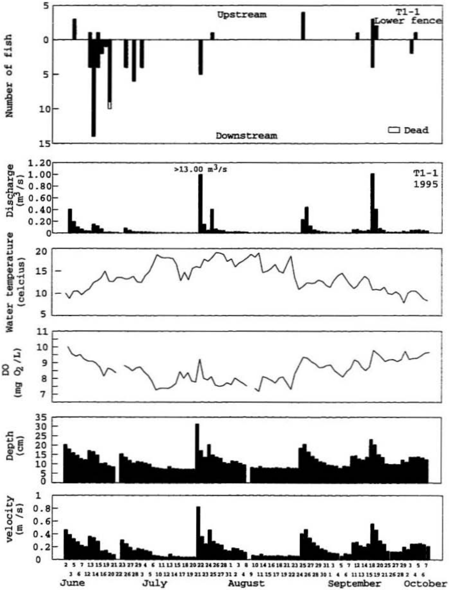


Figure 3.7 Trout movement through the lower fence, treatment stream, 1995, and associated mean daily habitat measures.

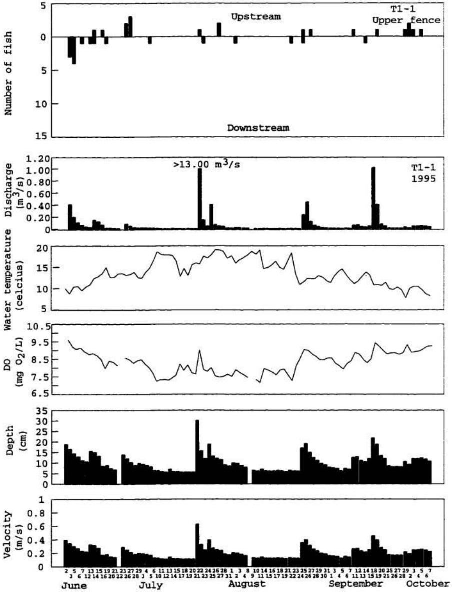


Figure 3.8 Trout movement through the upper fence, treatment stream, 1995, and associated mean daily habitat measures.

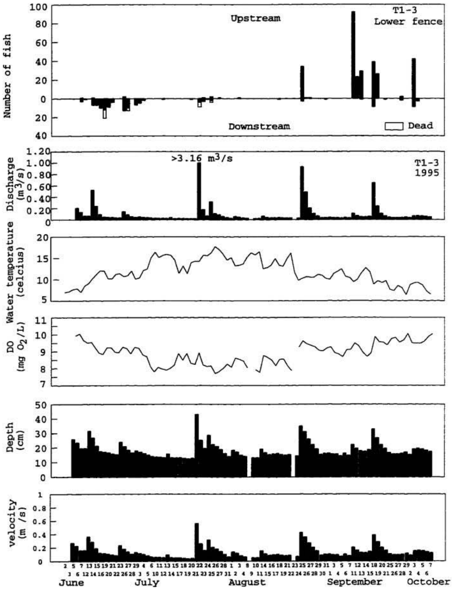


Figure 3.9 Trout movement through the lower fence, control stream, 1995, and associated mean daily habitat measures.

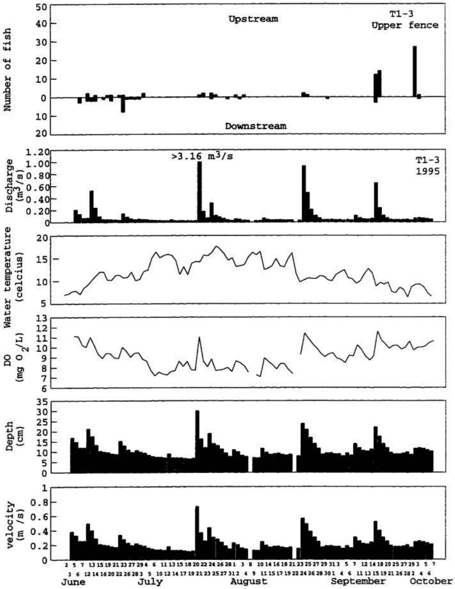


Figure 3.10 Trout movement through the upper fence, control stream, 1995, and associated mean daily habitat measures.

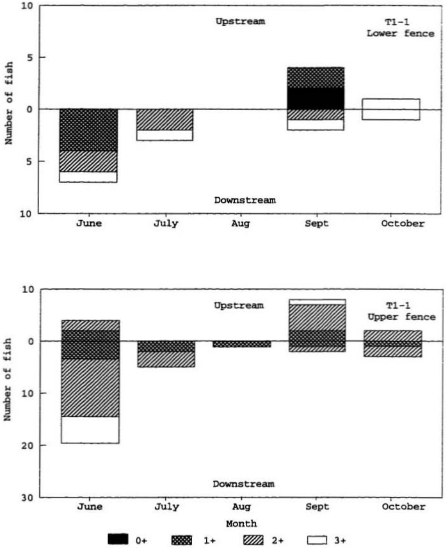
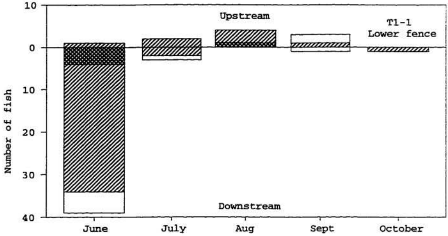


Figure 3.11 Monthly age composition of trout from both counting fences, treatment stream, 1994.



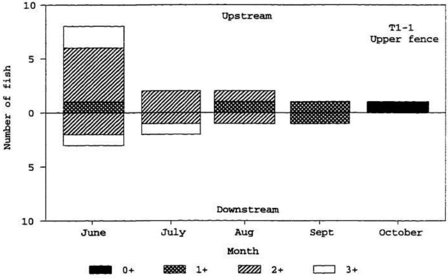
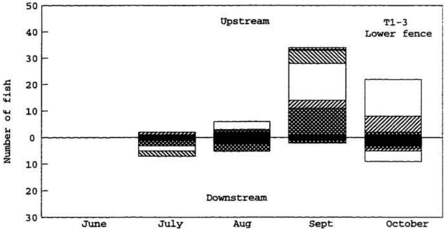


Figure 3.12 Monthly age composition of trout from both counting fences, treatment stream, 1995.



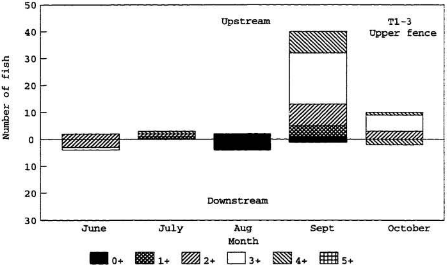


Figure 3.13 Monthly age composition of trout from both counting fences, control stream, 1994.

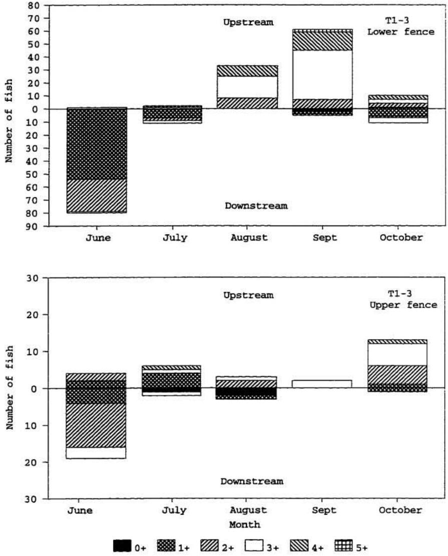


Figure 3.14 Monthly age composition of trout from both counting fences, control stream, 1995.

There was also an increase in the number of trout moving out of the control stream in the spring of 1995, however, this likely resulted from having the fences in this stream earlier in 1995 than in 1994. During July and August, movement was lower in both streams and moving fish represented all ages (except 5+) unlike the spring migrants. During September and early October, movement tended to be upstream with a higher number of mature 3+, 4+, and 5+ trout coming into the streams for spawning. The treatment stream, however, still had a high proportion of 0+, 1+, and 2+ fish moving in both directions in the fall.

There was very little movement of trout between the two lakes. Only three of the 231 recaptured fish moved between lakes. All three were initially tagged in Jim's Lake and recaptured in Copper Lake. Two were tagged in 1995 (tag numbers G938 & C832) and one in 1994 (tag number C068). The latter was recaptured in 1995. Two other fish that were tagged in Copper Lake (tag numbers G803 & G9313) were recaptured in the stream connecting the two lakes (T1-3A) near its outflow into Copper Lake.

Twenty-five fish recaptured in 1995 were tagged in the control stream in 1994. Of these, 13 were reentering the stream from Jim's Lake. The majority of these were 12.7-20.9 cm in fork length when they were initially tagged during the spawning run in 1994 and hence were probably reentering the stream to spawn in 1995. The majority of the others (recaptured in Jim's Lake) were 5.8-9.4 cm in fork length. These fish were probably non-mature and would not spawn until 1996 based on age-at-maturity results (see section 3.7).

Of the 49 tagged fish leaving the treatment stream, none were recaptured reentering that stream. Most 1994 tagged fish recaptured from the treatment stream were either leaving the stream during 1995 or in the same habitat section (by angling or electrofishing) where they were tagged in 1994.

The greatest relocation distance was approximately 4.5 km. This was a fish (C832: FL 11.9 cm) that was tagged in the control steam in 1995 and recaptured near the outflow of Copper lake (station 4).

3.2.1 Comparison of movement patterns between years

The movement of brook trout is summarized for both streams in 1994 and 1995 in Tables 3.7 and 3.8. Not all 13 habitat sections are included in the tables as sections with no recaptures were omitted. The sample index of movement (h) for the treatment and the control streams between years as well as between each other within years were not significantly different ($p>0.05$). The 95% confidence interval for the population index of movement (H) for each of the stream populations broadly overlapped (Table 3.9).

There was no significant change in movement patterns between years ($p>0.05$) in the control stream (Table 3.10), however, the treatment stream did have a significant difference in movement patterns between years ($p<0.05$) with a decrease in the proportion of fish moving downstream from the upper stream section to the lower section and an increase in downstream movement from the stream to Copper Lake (Table 3.11).

Table 3.7. Movement matrix of tagged brook trout from the treatment stream (T1-1) showing station of initial and final capture in 1994 and 1995 (1995 is in parentheses).

Station of final recapture	Station of initial capture			Totals
	1	2	3	
1	2 (1)	3 (10)	(1)	5 (12)
2	31 (2)	(2)	2 (6)	33 (10)
3	4 (3)	9 (40)	(3)	13 (46)
4	1	(1)		1 (1)
5		(1)		(1)
6				
7	1			1
Totals	39 (6)	12 (54)	2 (10)	53 (70)

Table 3.8. Movement matrix of tagged brook trout from the control stream (T1-3) showing station of initial and final capture in 1994 and 1995 (1995 is in parentheses).

Station of final recapture	Station of initial capture 11	12	13	Totals
4		(1)		(1)
10			(1)	(1)
11	1 (4)	13 (38)		14 (42)
12	103 (98)	11 (4)	11 (7)	125 (109)
13	2 (36)	13 (11)	1	16 (47)
Totals	106 (138)	37 (54)	12 (8)	155 (200)

Table 3.9. Summary of calculations ($\bar{w}$ and $\sigma^2_{\bar{w}}$), sample index of movement (h), and 95% confidence intervals for the population index of movement (H) for the treatment and control streams.

Stream (year)	$\bar{w}$	$\hat{\sigma}^2_{\bar{w}}$	$h=\iota$	95% C.I. for H
Treatment (1994)	-0.520	0.379	0.594	0.699 - 0.505
Treatment (1995)	-0.691	0.417	0.501	0.581 - 0.432
Control (1994)	-0.472	0.442	0.624	0.714 - 0.546
Control (1995)	-0.565	0.405	0.568	0.619 - 0.522

Table 3.10. Observed movement (number of fish) from the control stream (T1-3) and the calculated expected values (χ^2) for the comparison of trout movement patterns between 1994 and 1995.

movement pattern	observed 1994	expected 1994	observed 1995	expected 1995
Upper→lower stream section	11	8.72	7	9.28
Lower→upper stream section	13	11.63	11	12.38
Stream→lake	14	11.14	9	11.86
Lake→stream	105	115.77	134	123.23
No movement in stream	12	7.75	4	8.25
Totals	155	155	165	165
χ^2calc				9.3581[1]

$\chi^2_{0.05,4}$ = 9.488

[1] Not significantly different.

Table 3.11. Observed movement (number of fish) from the treatment stream (T1-1) and the calculated expected values (χ^2) for the comparison of trout movement patterns between 1994 and 1995.

movement pattern	observed 1994	expected 1994	observed 1995	expected 1995
Upper→lower stream section	31	14.57	21	18.42
Lower→upper stream section	3	5.74	10	7.26
stream→lake	15	26.50	45	33.50
Lake→stream	2	3.97	7	5.03
No movement in stream	2	2.21	3	2.79
Totals	53	53	67	67
χ^2calc				46.2283[1]

$\chi^2_{0.05,4} = 9.488$

[1] Significantly different.

3.3 **Correlations between habitat parameters and trout movement**

Correlation coefficients were not strong between trout movement and habitat measures (Tables 3.12 - 3.15) despite strong visible patterns seen in Figures 3.3 to 3.10. Stream discharge had the highest overall correlation with trout movement, especially in 1994. Water temperature dropped sharply just before the fall spawning runs in both years but was not strongly correlated with movement.

3.4 **Storm Events**

There were five storm events, one in 1994 and four in 1995 (Figs. 3.15 - 3.19) (Appendix 7). The apparent lag in the rise of the discharge at the beginning of some storms represents the time between the start of the storm and the last time the fences were checked before the storm (usually around 0900 the morning before the storm), not a lag between the start of a storm and an increase in stream discharge. In almost all storms, the first movement through the fences was downstream. The control stream had both up and downstream movement occur simultaneously at the beginning of the storm on September 15-20, 1995. It should also be noted that storm events represent the majority of trout movement

Table 3.12. Correlation coefficients between trout movements (# of fish) and habitat parameters for the treatment stream (T1-1), 1994 (down=downstream; up=upstream). Zero indicates that the correlation coefficient was not significantly different from zero.

Habitat measure	Lower fence down	Lower fence up	Upper fence down	Upper fence up	Total down	Total up
Air temp	0	0	0	0	0	-0.223
Rain fall	0	0	0	0	-0.236	0
Water temp	0	0	0	0	0	0
DO lower section	-0.242	0.320	-0.374	0.350	-0.321	0.433
DO upper section	0.286	0.377	-0.416	0.390	-0.321	0.488
Depth lower section	-0.443	0.566	-0.456	0.483	-0.442	0.627
Depth upper section	-0.443	0.566	-0.456	0.483	-0.442	0.627
Velocity lower section	-0.443	0.566	-0.456	0.483	-0.442	0.627
Velocity upper section	-0.443	0.566	0.456	0.483	-0.442	0.627
Discharge	-0.704	0.858	-0.571	0.585	-0.567	0.854

Table 3.13. Correlation coefficients between trout movements (# of fish) and habitat parameters for the control stream (T1-3), 1994 (down=downstream; up=upstream). Zero indicates that the correlation coefficient was not significantly different from zero.

Habitat measure	Lower fence down	Lower fence up	Upper fence down	Upper fence up	Total down	Total up
Air temp	0	0.310	0	0	0	0
Rain fall	0	0	0	0	0	0
Water temp	0	0	0	0	0	0
DO lower section	0	0.302	0	0	-0.235	0.224
DO upper section	0	0.488	-0.295	0.373	-0.404	0.438
Depth lower section	0	0.646	-0.525	0.611	-0.572	0.695
Depth upper section	0	0.646	-0.525	0.611	-0.572	0.695
Velocity lower section	0	0.646	-0.525	0.611	-0.572	0.695
Velocity upper section	0	0.646	-0.525	0.611	-0.572	0.695
Discharge	0.279	0.657	-0.788	0.560	-0.752	0.656

Table 3.14. Correlation coefficients between trout movements (# of fish) and habitat parameters for the treatment stream (T1-1), 1995 (down=downstream; up=upstream). Zero indicates that the correlation coefficient was not significantly different from zero.

Habitat measure	Lower fence down	Lower fence up	Upper fence down	Upper fence up	Total down	Total up
Air temp	0	-0.217	0	0	0	-0.258
Rain fall	-0.337	0.348	0	0.287	-0.306	0.434
Water temp	0	-0.214	0	0	0	-0.248
DO lower section	0	0.337	-0.230	0.232	-0.245	0.393
DO upper section	0	0.347	-0.236	0.232	-0.254	0.405
Depth lower section	-0.308	0.451	-0.280	0.328	-0.366	0.538
Depth upper section	-0.308	0.451	-0.280	0.328	-0.366	0.538
Velocity lower section	-0.308	0.451	-0.280	0.328	-0.366	0.538
Velocity upper section	-0.308	0.451	-0.280	0.328	-0.366	0.538
Discharge	-0.276	0.443	0.443	0	-0.301	0.426

Table 3.15. Correlation coefficients between trout movements (# of fish) and habitat parameters for the control stream (T1-3), 1995 (down=downstream; up=upstream). Zero indicates that the correlation coefficient was not significantly different from zero.

Habitat measure	Lower fence down	Lower fence up	Upper fence down	Upper fence up	Total down	Total up
Air temp	0.204	-0.224	0.217	0	0.225	-0.222
Rain fall	-0.366	0.247	-0.365	0.329	-0.397	0.291
Water temp	0	-0.205	0.185	0	0	-0.214
DO lower section	-0.241	0.248	-0.227	0	-0.258	0.261
DO upper section	-0.334	0.308	-0.290	0.250	-0.351	0.326
Depth lower section	-0.378	0.294	-0.289	0.253	-0.385	0.315
Depth upper section	-0.378	0.294	-0.289	0.253	-0.385	0.315
Velocity lower section	-0.378	0.294	-0.289	0.253	-0.385	0.315
Velocity upper section	-0.378	0.294	-0.289	0.253	-0.385	0.315
Discharge	-0.290	0.254	0	0	-0.280	0.267

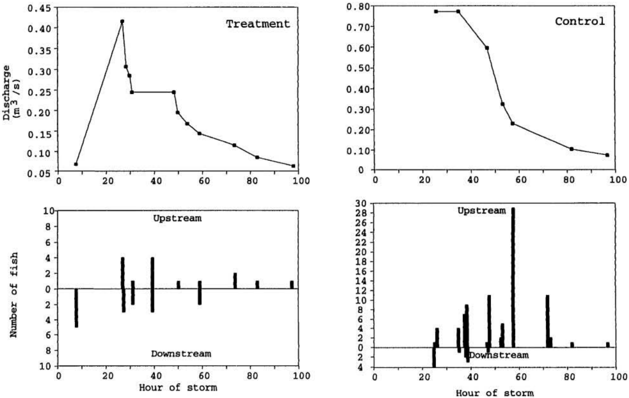


Figure 3.15 Fish movement and discharge profile of storm #1, 0900 September 11 - 1100 September 15, 1994.

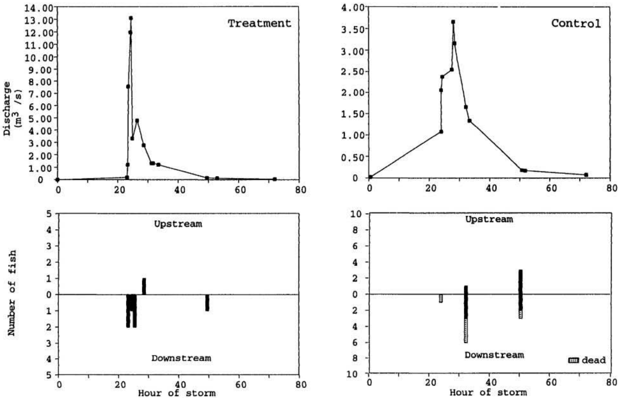


Figure 3.16 Fish movement and discharge profile of storm #2, 0900 July 21 - 0900 July 24, 1995.

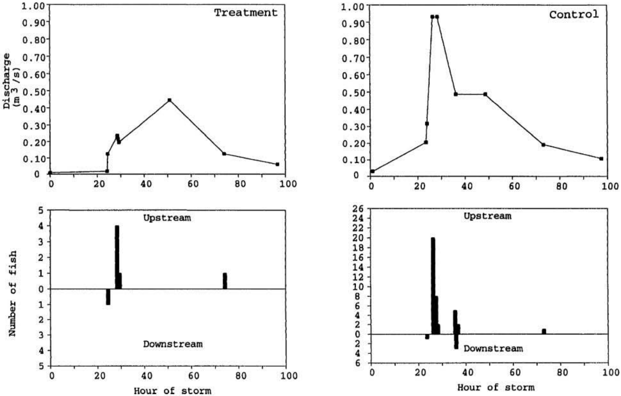


Figure 3.17 Fish movement and discharge profile of storm #3, 0900 August 24 - 1300 August 26, 1995.

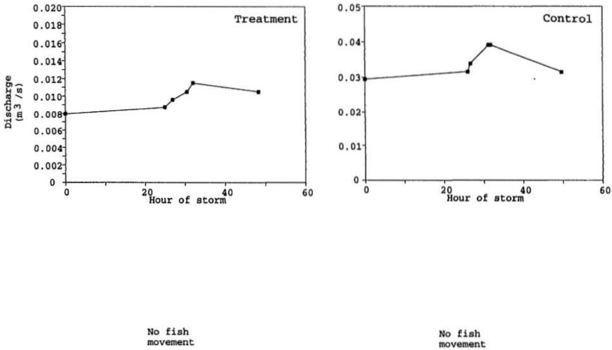


Figure 3.18 Fish movement and discharge of storm #4, 0900 September 5 - 1200 September 7, 1995.

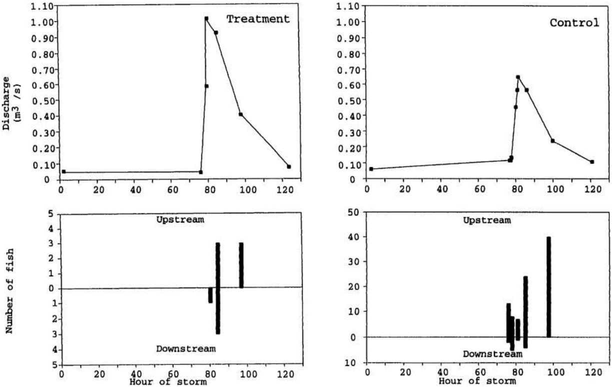


Figure 3.19 Fish movement and discharge of storm #5, 0900 September 15 - 1300 September 20, 1995.

throughout the monitored seasons.

3.4.1 **Movement with respect to storm discharge ranges**

There was a significant difference in the proportions of those fish moving upstream and downstream at different discharge ranges in the treatment stream ($p<0.05$) (Table 3.16). The peak in upstream movement occurred at 0.20-0.39 $m^3 \cdot s^{-1}$ while the peak in downstream movement was at 0.0-0.29 $m^3 \cdot s^{-1}$.

The control stream had a significant difference in the proportions of those fish moving upstream ($p<0.05$), but not downstream at different discharge ranges ($p>0.05$) (Table 3.16). There were two peaks in upstream movement in the control stream, one at 0.10-0.29 $m^3 \cdot s^{-1}$ and the other at 0.50-0.79 $m^3 \cdot s^{-1}$.

The fork lengths of trout moving upstream at the two peaks in the control stream were significantly different ($p<0.003$). The mean fork length at the lower discharge range was 16.3 cm while the length at the upper discharge range was 18.6 cm. In addition, no fish smaller than 16.0 cm moved at the higher discharge range while those moving at the lower discharge range were 5.8 to 21.5 cm in fork length.

Table 3.16. Total numbers of trout moving during each discharge range for all storms in 1994 and 1995.

Discharge $m^3 \cdot s^{-1}$	Treatment upstream	Treatment downstream	Control upstream	Control downstream
0 - 0.09	2	6	1	0
0.10 - 0.19	5	5	34	8
0.20 - 0.29	10	5	73	2
0.30 - 0.39	7	3	7	0
0.40 - 0.49	0	0	0	0
0.50 - 0.59	0	1	42	9
0.60 - 0.69	0	0	28	0
0.70 - 0.79	0	0	26	10
0.80 - 0.89	0	0	0	0
0.90 - 0.99	3	3	10	0
1.00 +	1	3	1	3

3.4.2 **Movement with respect to the storm peak**

The numbers of trout moving in relation to the storm peaks are given in Tables 3.17 and 3.18. The proportions of those fish moving before, during, and after the storm peaks were not significantly different between streams ($p>0.05$). When proportions were compared within streams there were significant differences in upstream movement in both streams ($p>0.05$), with a larger than expected proportion moving after the storm peak. There was also a significant difference in the proportions of those fish moving downstream in the treatment stream ($p>0.05$), with a lower than expected proportion moving at the peak. There was no significant difference in the proportions of those fish moving downstream in the control stream ($p<0.05$).

Table 3.17. The number of trout which moved before, during, and after the storm peaks in the treatment stream.

Movement pattern	Relationship to the storm peak		
	Before	During	After
Upstream	9	0	19
Downstream	12	1	13

Table 3.18. The number of trout which moved before, during, and after the storm peaks in the control stream.

Movement pattern	Relationship to the storm peak		
	Before	During	After
Upstream	47	25	146
Downstream	9	7	16

3.5 **Telemetry**

Only three implanted trout moved into tributary streams to spawn. All three moved into the control stream. Fourteen of the 16 surviving trout restricted their movements to areas usually less than one-third the size of their home-lake (Fig. 3.20). However, several trout utilized their entire home-lake, travelling up to 1300 m between observations (Tables 3.19 and 3.20). The largest ranges were in Copper Lake. No fish moved between lakes. The majority of fish remained around the shoals at the mouths of tributary streams or along the western side of their home lake (Fig. 3.20). Estimated distances travelled between observations are recorded in Tables 3.19 and 3.20. They varied from 0 to 600 m in Jim's Lake and 0 to 1300 m in Copper Lake.

On August 28, 1995 an implanted fish (#306) was recovered dead in a fyke net at the outflow of Copper Lake. This fish had been implanted on August 22. On September 25, another implanted fish (#185) was located in a mink (*Mustela vison)* hole approximately 5 m from the mouth of the control stream. This fish was implanted on August 18, and was tracked until September 25. One fish, implanted in Copper Lake, (#225) could not be detected with the receiver 6 days after being implanted (August 22-August 28). Either the

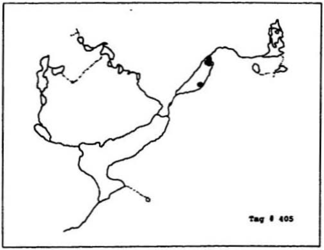
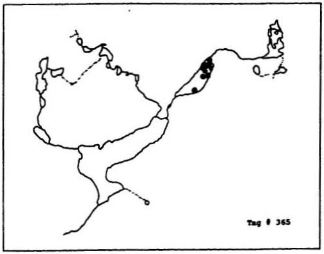


Figure 3.20 Daily telemetry locations for tagged trout, August 10 - October 7, 1995. Tag number is inside map border.



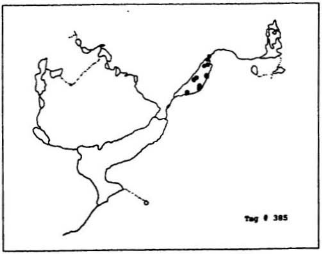
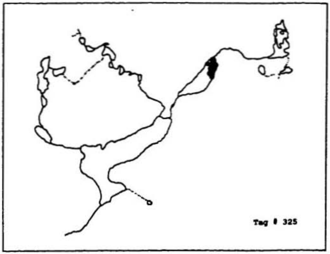


Figure 3.20 (cont.)



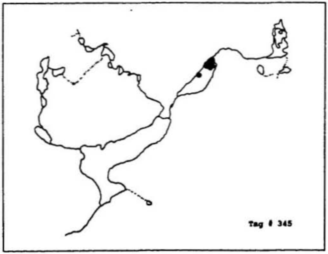
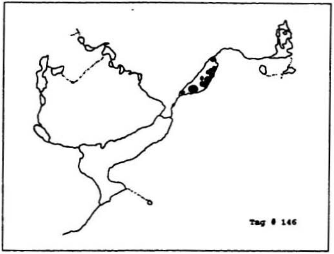


Figure 3.20 (cont.)



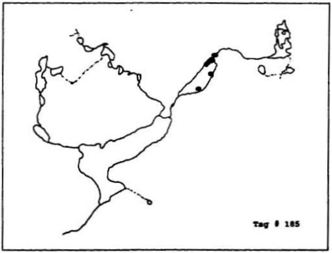


Figure 3.20 (cont.)

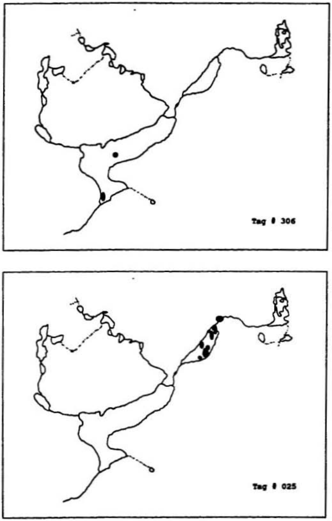
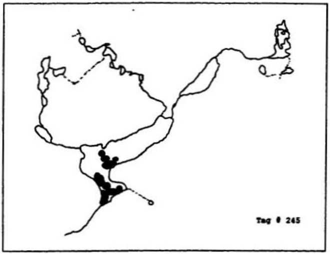


Figure 3.20 (cont.)



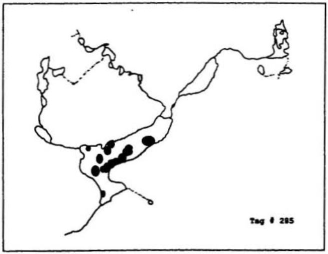
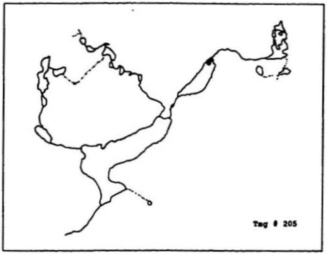


Figure 3.20 (cont.)



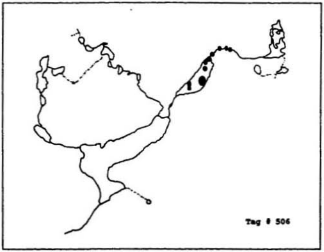
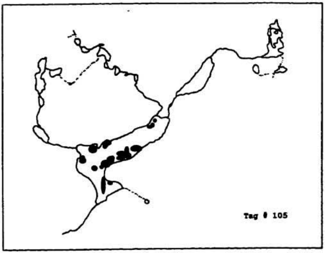


Figure 3.20 (cont.)



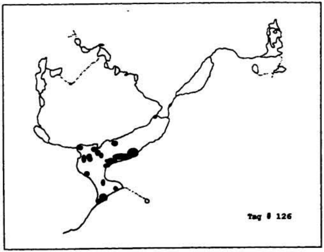


Figure 3.20 (cont.)

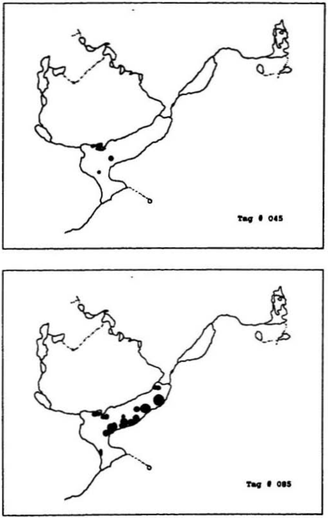


Figure 3.20 (cont.)

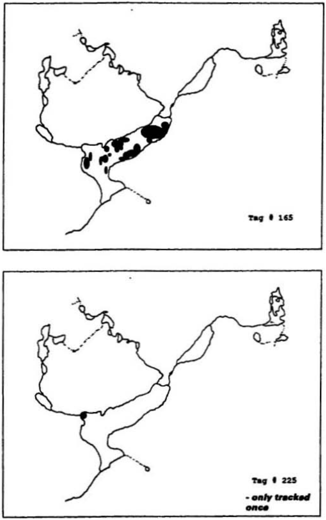


Figure 3.20 (cont.)

Table 3.19. Estimated distance (m) from the previous position for each fish tracked in Copper lake, Newfoundland. D-fish was found dead; *-no signal detected.

Date	Tag number								
m/d	045	085	105	126	165	225	245	285	306
8/11									
8/15	25	25							
8/16	150	400	550	500					
8/17	0	650	1000	500					
8/18	100	250	0	200	1000				
8/19	350	300	550	300	100				
8/21	0	0	250	700	75				
8/22	0	150	200	*	0				
8/24	25	150	25	550	850	0	800	50	800
8/28	25	250	150	100	400	*	750	350	750
8/29	25	250	100	150	500	*	25	250	D
9/3	25	50	100	100	100	*	*	400	
9/4	0	0	0	200	*	*	0	*	
9/5	0	500	200	400	0	*	100	100	
9/7	0	25	100	300	800	*	*	0	
9/11	0	400	200	500	500	*	25	100	
9/12	0	0	1250	200	150	*	800	500	
9/13	0	500	700	700	1250	*	50	600	
9/19	0	1100	*	*	1000	*	500	800	
9/20	0	1000	400	1300	450	*	0	100	
9/21	0	1000	*	500	1300	*	300	0	
9/25	150	700	400	0	*	*	700	600	
9/26	0	400	400	200	800	*	200	200	
10/2	75	450	300	900	350	*	200	300	
10/4	75	1000	300	350	200	*	300	0	
10/5	0	0	600	500	800	*	200	200	
10/6	0	100	0	550	*	*	0	0	
10/7	100	250	500	0	250	*	300	400	

Table 3.20. Estimated distance (m) from the previous position for each fish tracked in Jim's lake, Newfoundland. D-fish was found dead; *-no signal detected.

Date	Tag number									
m/d	025	146	185	205	506	325	345	365	385	405
8/11										
8/15	300				300					
8/16	450				450					
8/17	300	450			300					
8/18	0	450			150					
8/19	150	600	300	0	225					
8/21	150	0	300	0	225					
8/22	0	375	450	0	600					
8/24	0	0	0	0	0					
8/26	450	*	0	0	150	0	150	*	0	150
8/28	375	0	0	0	150	0	75	*	0	150
8/29	75	300	0	0	0	0	0	225	0	600
9/3	0	525	0	0	0	150	0	0	0	600
9/4	150	600	0	0	0	150	0	150	0	0
9/5	75	450	0	0	0	0	0	600	0	0
9/7	150	150	0	0	0	75	0	450	0	0
9/10	150	375	75	0	75	75	75	75	450	0
9/11	450	400	50	0	100	0	25	100	100	0
9/12	100	50	0	0	125	100	0	100	300	0
9/13	300	200	0	0	20	150	0	100	300	100
9/19	350	350	20	0	0	300	0	75	450	100
9/20	0	350	200	50	0	100	50	0	400	50
9/21	0	400	250	50	0	50	100	0	300	50
9/25	50	300	D	0	0	0	0	0	500	0
9/26	150	450		0	0	0	0	0	0	0
10/2	150	250		0	*	0	0	0	50	0
10/4	300	200		0	25	0	0	25	50	0
10/5	30	0		25	25	0	0	0	0	25
10/6	15	400		0	300	25	50	0	15	25
10/7	15	450		0	0	300	300	150	0	25

transmitter failed or the fish may have moved out of the Copper Lake watershed to Corner Brook Lake.

3.5.1 **Spawning Observations**

Lake spawning was recorded in 10 separate locations; eight in Copper Lake and two in Jim's Lake (Fig. 3.21). Copper Lake had an estimated 47-95 redds in tributary streams and 67-130 redds in the lake. Jim's Lake had an estimated 80-250 redds in the control stream (the only stream on Jim's Lake) and 55-110 redds in the lake.

3.6 **Electrofishing age composition**

Chi-square analysis of the age composition of the stream electrofishing surveys (Table 3.21) showed no significant difference in the treatment stream between years ($p>0.05$) and a significant difference in the control stream ($p<0.05$).

3.7 **Age-at-maturity**

There was no significant difference in the proportion of mature males and females in each age category ($p>0.05$) in either lake so sexes were pooled to compare age-at-maturity

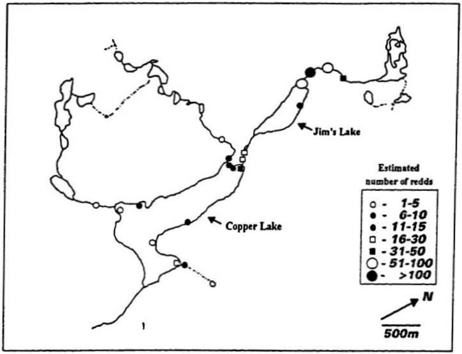


Figure 3.21 Spawning sites and estimated number of redds in the Copper Lake watershed. The legend indicates the number of redds at each site.

Table 3.21. Age composition of electrofished trout in the treatment and control stream in 1994 and 1995 (August 8-15). Percentages are in parentheses.

Age	Electrofishing age composition			
	Treatment		Control	
	1994	1995	1994	1995
0+	14 (18.2)	20 (29.0)	368 (53.9)	320 (49.1)
1+	34 (44.2)	20 (29.0)	166 (24.3)	205 (31.4)
2+	26 (33.8)	26 (37.7)	83 (12.2)	84 (12.9)
3+	3 (3.9)	3 (4.3)	43 (6.3)	36 (5.5)
4+	0 (0)	0 (0)	18 (2.64)	7 (1.07)
5+	0 (0)	0 (0)	5 (0.73)	0 (0)

between lakes (Table 3.22). When these proportions were compared, Copper Lake had a significantly higher proportion of mature fish below the age of 3 than Jim's Lake ($p<0.05$). Copper Lake had the only 3+ and 4+ trout which were non-mature.

Table 3.22. The number of mature fish found in each age-class for each lake (with its associated stream). The total number of fish sampled in each age-class are in parentheses.

	Copper Lake (# of fish)			Jim's Lake (# of fish)		
Age	Male	Female	Total	Male	Female	Total
0+	0 (0)	0 (0)	0 (0)	0 (6)	0 (4)	0 (10)
1+	1 (7)	0 (2)	1 (9)	0 (12)	0 (9)	0 (21)
2+	10 (11)	7 (8)	17 (19)	6 (10)	11 (14)	17 (24)
3+	10 (11)	8 (8)	18 (19)	8 (8)	8 (8)	38 (38)
4+	0 (1)	0 (0)	0 (1)	2 (2)	1 (1)	3 (3)

4 Discussion

4.1 Trout movement

Hunter (1991) grouped salmonid life histories into three categories: 1) salmonids that migrate from streams to larger bodies of water almost immediately after emergence from the spawning gravels (eg. some *Oncorhynchus sp.*); 2) salmonids that spend 1 or more years in freshwater, then migrate to the sea or lakes to complete their growth (includes Atlantic salmon, *Salmo salar* (Linnaeus), as well as anadromous/adfluvial races or strains of rainbow trout, *Oncorhynchus mykiss* (Walbaum), brown trout, *Salmo trutta* (Linnaeus), and brook trout); and 3) salmonids that spend their entire lives in streams. Within the Copper Lake watershed, the control stream population of brook trout are generally adfluvial. However, trout in the treatment stream tend towards category three in that they use the stream more as a permanent residence rather than just as spawning and rearing habitat.

Power (1980) found that brook trout that hatched in streams and later moved to lakes usually did so during their second or third summer when they had reached lengths of 8.0-15.0 cm. In the present study, this was generally the case as 1+ and 2+ (some 3+ in the treatment stream) trout moved downstream to the lakes in June. Movement of newly emerged salmonids to feeding areas usually occurs primarily in the spring and early summer for most stocks (Godin 1982; Näslund 1992; Curry et al. 1993). Generally, movement of young-of-the-year appeared to be limited in both streams since very few were observed moving through the fences in the spring.

During July and August, movement was low and migrants represented all ages, except 5+. These movements were possibly more in response to environmental factors such as temperature and DO and less associated with life history than those in the spring and fall. During September and October, movement tended to be upstream as mature 3+, 4+, and 5+ trout came into the streams prior to spawning. However, 0+, 1+, and 2+ fish were still moving in both directions during the fall in the treatment stream. This stream, which had less spawning habitat, had fewer young trout moving into the lake and fewer mature fish entering it to spawn.

The overall number of trout which returned to either stream in 1995, after migrating to the lakes in 1994, was very low. For the control stream, the recapture of returning tagged fish in 1996 indicated that trout tended to stay in the lakes for at least two years before returning to the stream to spawn (McCarthy Unpublished data).

The low degree of movement between lakes and the apparent one-way direction from Jim's to Copper Lake is likely due to the morphology of the stream between the two lakes. There is a small gully approximately half-way between the two lakes (400 m away from each). Upstream of the gully (towards Jim's Lake) the streambed is composed of large boulders. During the summer months, the above ground flow here is minimal and even small trout would have trouble passing through. Below the gully, there is good water flow throughout the season and the stream is much more typical of trout habitat with deep pools and fast riffles. Given these conditions, movement from Copper Lake up to Jim's Lake would be much more difficult than vice versa, even during high water.

4.1.1 **Correlations with habitat variables**

The majority of brook trout movement in Catamaran Brook, New Brunswick, occurred during elevated (storm) discharge levels (R. Cunjak pers comm.). This was also the case in the Copper Lake system. Therefore, discharge was significantly correlated to trout movement. However, there were stronger correlations between trout movement and habitat parameters during 1994 than 1995. It should also be noted that the overall range in parameter values, during times when the fences were operational, were lower in 1994. For example, the peak discharge calculated for the treatment stream in 1994 was approximately 0.42 $m^3 \cdot s^{-1}$ compared with a peak in 1995 of over 13.00 $m^3 \cdot s^{-1}$. A greater range in habitat parameters, which may include values outside a preferred range for movement, would weaken the correlation. This suggests that the relationship between trout movement and habitat variables may not be linear.

A correlation coefficient measures one type of association between two variables - linear , however, relationships between environmental variables and fish behaviour, i.e. movement, may not be linear. Green (1977) states that the use of models that assume linear, additive relations among environmental variables and animal abundance can be misleading, primarily because species tend to have optimum levels for each variable. Preferred ranges in environmental conditions may also exist for fish movement. Ranges outside these may represent levels at which fish are either unable to move, or have already moved, to avoid harsher conditions. This suggests that while some parameters may only be weakly correlated to fish movement, they may facilitate movement within preferred ranges. The storm events from this study further suggest (see below) that the relationships between brook trout movement and environmental parameters may not be linear and that preferred ranges for movement within some parameters may exist.

Dissolved oxygen was only weakly correlated to fish movement, however, movement during mid-summer may have been in response to lower DO levels which were present during low stream-flows in the warmer summer months. These mid-summer low-flows were usually less than 0.01 $m^3 \cdot s^{-1}$ which probably restricted the amount of movement trout could or would do. With increased flows during mid-summer rains (and hence increased DO), movement occurred. However, some of these trout may have been 'escaping' from stream conditions experienced prior to the increased flow.

Low DO has been shown to elicit avoidance reactions and halt migration in salmonids (Whitmore et al. 1960; Hallock et al. 1970). Sheppard (1955) found that brook trout exhibited a violent burst of activity involving all individuals in a sample when oxygen deficient water was introduced into test chambers. Davis (1975) reviewed DO requirements for aquatic organisms and developed a table of incipient DO levels for freshwater salmonids. He describes optimal levels (7.84 mg $O_2 \cdot L^{-1}$), incipient non-lethal levels (6.00 mg $O_2 \cdot L^{-1}$) when behavioural responses will occur, and lethal levels (4.16 mg $O_2 \cdot L^{-1}$) where a large portion of a fish population may be severely affected if the condition lasts beyond a few hours.

With these values in mind, it appeared that both study streams usually had DO levels above optimum when trout were moving. However, the values measured at the transect-points did reach low levels (5.81-6.81 mg $O_2 \cdot L^{-1}$) in both streams, generally in August, when water temperatures were high and flows low. In addition, the daily DO calculated for each stream section was based on the mean daily water temperature and not the maximum, hence DO levels may have reached lower levels at some point during the day.

4.1.2 **Storm events**

4.1.2.1 **Movement with respect to discharge levels**

The maximum swimming speeds of fish depend chiefly upon species, water temperature, and fish size (Crisp 1993). Several researchers have studied the swimming performance of trout at different life stages to determine their sustainable (V_{sus}) and maximum (V_{max}) swimming velocities. V_{sus} is defined here as the swimming speed a fish can maintain without incurring oxygen debt (Crisp 1993), and V_{max} is defined as that maximum swimming speed which can only be maintained briefly (a few seconds) (Bjornn & Reiser 1991; Crisp 1993).

Bjornn and Reiser (1991) suggest that V_{max} for trout is around 0.61-1.95 $m \cdot s^{-1}$ or 8-12 body lengths$\cdot$sec^{-1}. Heggenes and Traaen (1988) studied brook trout fry and found the maximum critical velocities at various temperatures was 0.17 $m \cdot s^{-1}$ @ 6-8°C; 0.19 $m \cdot s^{-1}$ @ 12-14°C; and 0.22 $m \cdot s^{-1}$ @ 19.2°C. These low maximum swimming velocities were due to the small size of fry. Ottaway and Clarke (1981) suggested that substantial proportions of trout fry populations may be dislodged by velocities less than 0.5 $m \cdot s^{-1}$. Recent work by DFO on brook trout swimming speeds suggests that fish >20 cm fork length can sustain speeds of 0.55 $m \cdot s^{-1}$ for 1 h, but can only sustain speeds of 0.85 $m \cdot s^{-1}$ for 0.33 h (D. Scruton pers comm).

These results indicate that velocities greater than 0.5 $m \cdot s^{-1}$ may be sub-optimal for upstream movement of brook trout and could cause downstream displacement, particularly for trout less than 20 cm fork length. The mean size of trout in streams of the Copper Lake watershed is less than 20 cm.

The proportions of those fish moving upstream within each discharge range showed that there were significant differences within as well as between streams. Most upstream movement occurred at stream discharges of 0.20-0.39 $m^3 \cdot s^{-1}$ in the treatment stream, while in the control stream, it occurred most at 0.10-0.29 $m^3 \cdot s^{-1}$ and 0.50-0.79 $m^3 \cdot s^{-1}$. Interestingly, velocities were similar at these discharge levels (Table 4.1). The peak upstream movement in the treatment stream corresponded to a mean velocity range of 0.395-0.462 $m \cdot s^{-1}$ and the control stream peaks were 0.206-0.309 $m \cdot s^{-1}$ and 0.363-0.409 $m \cdot s^{-1}$, respectively. This suggests that both trout populations moved in response to similar stream velocity ranges and that the majority of upstream movement during the storm events in both streams occurred below 0.5 $m \cdot s^{-1}$.

A significantly higher proportion of those trout which moved downstream in the treatment stream, moved at lower discharge levels (0.0-0.29 $m^3 \cdot s^{-1}$) than at higher discharge levels. This peak in downstream movement generally coincided with the peak in upstream movement. The proportion of those fish moving downstream in the control stream showed no significant difference between discharge levels.

The differences in 'preferred' discharge ranges were probably due to the fact that a steady (Figure 4.1) near the lower end of the control stream buffered against extremes in velocity at higher discharges. The steady had high undercut banks so that higher discharges would increase stream depth, but water velocity would rise slowly compared to the treatment stream.

Table 4.1. Calculated velocity ($m \cdot s^{-1}$) at discharge ranges when peak upstream movement occurred in both streams (1.00 $m^3 \cdot s^{-1}$ was also calculated). Maximum and minimum stream velocities were calculated from individual point-transect equations (Appendix 5).

stream	Discharge ($m^3 \cdot s^{-1}$)	Staff gauge (cm)	mean velocity ($m \cdot s^{-1}$)	maximum velocity ($m \cdot s^{-1}$)	minimum velocity ($m \cdot s^{-1}$)
T1-1	0.20	52.11	0.395	0.985	0.036
	0.39	48.59	0.462	1.03	0.036
	1.00	43.57	0.557	1.22	0.036
T1-3	0.10	47.34	0.206	0.349	0.036
	0.29	40.37	0.309	0.556	0.036
	0.50	36.68	0.363	0.667	0.036
	0.79	33.55	0.409	0.760	0.036
	1.00	32.00	0.432	0.806	0.036

Figure 4.1 Steady located near the lower end of the control stream.

4.1.2.2 **Movement with respect to storm peaks**

During storms with a peak discharge of less than 0.40-0.45 $m^3 \cdot s^{-1}$, upstream movement in the treatment stream generally occurred throughout the duration of the storm. However, the majority of upstream movement occurred after the peak, as discharge subsided, when the discharge was greater than 0.46 $m^3 \cdot s^{-1}$. The same trend was true for the control stream except that the 'threshold' peak appeared to be approximately 0.70-0.90 $m^3 \cdot s^{-1}$. There were again similarities in mean velocities between the two streams at these apparent 'threshold' discharges. The corresponding 'threshold' velocity values for treatment and control stream were 0.474 $m \cdot s^{-1}$ and 0.421 $m \cdot s^{-1}$ respectively (Table 4.2). These velocity values further suggest that 0.5 $m \cdot s^{-1}$ may be nearing the maximum velocity for upstream movement.

Most downstream movement in the treatment stream occurred either before or after the storm peak. This may represent active downstream movement at the start of a storm event to avoid increasingly harsh conditions and possibly movement by exhausted trout unable to further hold position after the storm had begun to subside. Trout in the control stream moved downstream throughout the storms, regardless of the strength of the peak. This was again probably due to

Table 4.2. Mean velocities at 'threshold' storm peaks where upstream movement shifted to after the peak.

Stream	Discharge ($m^3 \cdot s^{-1}$)	Staff-gauge (cm)	Mean velocity ($m \cdot s^{-1}$)
Treatment (T1-1)	0.40	48.59	0.462
	0.45	47.94	0.474
Control (T1-3)	0.70	34.50	0.395
	0.90	32.73	0.421

stream morphology.

The heterogeneity of stream habitat can allow refuge from extremes in water velocity (Pearsons et al. 1992; Lobón-Cerviá 1996). Immediately following an extremely large storm (80 mm rain) on June 8, 1995, when the counting fences were severely damaged, sampling (fly fishing) revealed that many trout still occupied the treatment stream. While the mean velocity of the stream at its mouth may represent some physical barrier or signal to delay upstream movement, trout holding in the stream may not experience this velocity. Examination of the minimum point-velocities in both streams in Table 4.1, show that even at high discharges some point-velocities were very low (0.036 $m \cdot s^{-1}$).

Swank et al. (1988) have shown that more rapid storm events, due to increased run-off from clear-cuts, can cause quicker and larger storm peaks. While possible changes in storm event characteristics due to the treatment clear-cut could not be determined because of the low number of events, it can be suggested that more frequent, larger storm peaks may delay upstream movement of some trout and flush others out of the streams by exceeding a velocity of 0.5 $m \cdot s^{-1}$. In addition, these possible effects on movement patterns may also be increased by increases in other factors such as suspended sediments.

If there are preferred ranges in stream velocity for trout movement, then a change in the hydrological regime of a stream may cause changes in the timing of some movement events such as out-migration of juveniles and spawning runs of mature trout. For example, in the control stream there were two velocity ranges when most trout moved upstream. Since V_{max} is dependant on fish size, only larger fish should have been able to move upstream at the higher velocity range. This was the case. There was a significant difference in mean fork length between trout moving upstream in each velocity range, with the lower range having the smaller mean fork length.

4.1.3 **Comparison of movement patterns between years**

Shetter (1968) stated that brook trout are essentially sedentary in a habitat that offers adequate cover, food, and spawning sites. The low sample index of association values may be an indication that the streams within the watershed do not provide all of these requirements, resulting in movement between habitat-types throughout the season. However, if the scale of environmental change exceeds an animals capacity to respond *in situ*, the general biological response to adversity, i.e. migration, may also come into play (Bjornn 1971; Taylor and Taylor 1977; Shirvell and Dungey 1983; Gagen et al. 1989; Thorpe 1994).

Changes in salmonid habitat within streams after forest harvesting and road construction has been studied (Hall and Lantz 1968; Burns 1972; Feller 1981; Murphy and Hall 1981; Hewlett and Forston 1982; Johnson et al. 1986). Everest and Harr (1982) and Grant et al. (1986) suggested that if the area logged is less than 25-30% of the drainage area, impacts to habitat and trout abundance may not be significant. However, even though the harvesting in the present study constituted only 9.0% of the drainage area, an increase in the proportion of fish leaving the treatment stream and entering the lake was observed. Also, a decrease in downstream movement from the upper stream section to the lower section occurred only in the treatment stream.

This decrease in downstream movement from the upper stream section was probably the result of there being fewer fish in that section after harvesting and not a behavioural response. Electrofishing surveys in 1993 and 1994 showed population estimates of 25 and 17 fish respectively in the first 100 m of the upper section of the treatment stream in August (Scruton and Daya 1994; Clarke et al. 1996b In press). In 1995, there were only 7 fish in this section of the stream, possibly a result of decreased winter survival (Johnson et al. 1986; Hicks et al. 1991) or movement downstream in the spring or winter before the fences were in place.

The low sample index of movement (h) values may also have been partially the result of using initial captures in the counting fences as recaptures. As the fences were almost always in operation, and hence provided the majority of movement information, the proportions of those fish recaptured moving out of their initial capture location was probably inflated. This would reduce the strength of association between a fish and its initial location.

The counting fences were in-operable due to high water flows for just 3-4 days of the entire 1994 field season. The number of fish entering the control stream prior to spawning, while the fence was washed out, was estimated to be 43. An accurate estimate of the number of fish moving downstream during the same storm could not be made. Observations during the 1995 season, however, which also had a storm at this time, suggested that there was probably very little downstream movement.

Fences on the treatment stream were also out for a short time (1-2 days) during the same storm. An accurate estimate of the number of fish which moved into or out of the stream could not be made. Therefore, the number of fish moving between the treatment stream and the lake may be underestimated for 1994. However, the movement patterns between years were still significantly different ($p<0.05$) even if the estimated number of fish moving to the lake was the same in 1994 and 1995.

4.2 **Possible changes in habitat**

All salmonids are products of their environment (Hunter 1991). As they evolved in areas dominated by unique vegetation and geologic characteristics, populations adapted to their individual surroundings. Some habitat changes attributed to forest harvesting from other studies include streamflow regimes (Crisp 1993), water temperatures (Gray and Edington 1969), and dissolved oxygen levels (Hall and Lantz 1968). In the present study, stream discharge, mean stream depth, and dissolved oxygen levels were not significantly affected by the treatment clear-cut. In addition, the summer low-flows in the treatment stream did not appear to be altered. Mean stream velocities did change between years. However, whether they were caused by forest harvesting could not be determined. Minimum daily water temperatures, sedimentation (Clarke et al. 1996a In press), and hence total suspended sediments, differed between years and were probably affected by the treatment clear-cut and road construction. The apparent minimal impact by harvesting on most habitat variables may be due to the fact that the cut was only 1.82 ha in size and constituted just 9.0% of the stream drainage basin and 20% of the stream-length. In addition, there may have been a possible moderating affect on some habitat parameters from the small, upstream lake.

4.2.1 **Stream temperature**

Raleigh and Chapman (1971) found that changing the temperature regime altered trout fry movement patterns, even when temperatures were not at or near lethal levels. Elliott (1994) suggested that it would be foolish to define the thermal axis simply in terms of the critical limits for survival as there are narrower limits for feeding and even narrower limits for growth. When presented with a temperature gradient, fish species usually select and occupy a temperature range at which physiological processes are optimized for growth (Elliott 1994). Ferguson (1958) showed that brook trout young-of-the-year and yearlings throughout Maine and Ontario have a final temperature preferenda of 14-16°C which is far below their lethal temperature. With this in mind, monitoring changes in stream temperature regimes due to forest harvesting only in terms of a maximum or critical temperature may be short sighted because subtle increases or decreases in temperature can bring about behavioural changes.

The minimum daily temperatures in the treatment stream, but not the control stream, were significantly different between years with an increase in the number of days in the <11°C range. This suggests that forest harvesting caused a slight decrease in minimum daily water temperatures in the treatment stream in 1995. This result would not have been detected if only maximum or critical temperatures were considered. This decrease in minimum daily temperatures may have behavioural consequences. Gibson (1978) and Baggs (1988) observed that low temperatures (around 8°C) appeared to cause brook trout to move into the substrate and Crisp (1993) stated that growth in brown trout is negligible when the water temperature is less than 4°C.

As water flows downstream its temperature tends to equilibrate with the air temperature, a process influenced by local environmental factors such as stream shading, wind, humidity, and groundwater influence (Scruton et al. 1996 In press). Harvesting and road construction may have caused changes in wind patterns and groundwater flows which would alter stream temperatures. Increases in flow as well as altered temperatures of groundwater have been associated with the removal of forest cover (Peck & Williamson 1987). An increase in colder groundwater flow could increase the number of days with a minimum water temperature below 11°C.

In addition, without the canopy provided by trees in the riparian zone to trap heat, nighttime water temperatures may cool as a result of increased heat dissipation. The pond above the treatment stream may also regulate temperature more so than the shading provided by the trees which were removed as a result of the cutting. However, the relative importance of pond outflow and groundwater was not addressed in this study.

Both clear-cutting and slashburning can increase stream summer temperatures (Feller 1981), however, in the present study there was no significant difference in the proportion of days with mean or maximum water temperatures in each temperature regime between years for either stream. The maximum daily temperature in neither stream exceeded 21-24°C, above which is considered lethal to brook trout (Raleigh 1982; Scott and Scott 1988).

4.2.2 **Total suspended sediments**

Trout living in streams with naturally high silt levels may have adapted to these conditions over time (Everest et al. 1987). Where adaptation to silt has not occurred, an increase in TSS levels may be more harmful.

The major affect of road construction and logging activities in the Copper Lake watershed appeared to be a significant increase in sedimentation in the treatment stream (Clarke et al. 1996a In press). Sediment embedded within the substrate may not cause physiological problems for free-swimming trout, but suspended sediments in the water column may. Road crossings can lead to the input of fine sediments from road surfaces which can restrict upstream movement (Hicks et al. 1991), increase physiological stress, decrease feeding, and increase the susceptibility of trout to bacterial disease (Redding et al. 1987). Due to Newfoundland's generally thin soils (Meades and Moores 1989), resident brook trout may not encounter naturally high silt levels often enough to have adapted to them (Taylor 1991). Such sublethal stress and reduced performance capacity may increase avoidance behaviour. While increases in TSS levels in the treatment stream after road construction and forest harvesting were not statistically significant, visual observations and the fact that there was increased stream-bed sedimentation (Clarke et al. 1996a In press), lead to the conclusion that TSS levels were increased in the treatment stream after forest harvesting and road construction. This was visually evident when it rained (Fig. 4.2) as silt would run off the road's surface. More frequent sampling for TSS may have confirmed this.

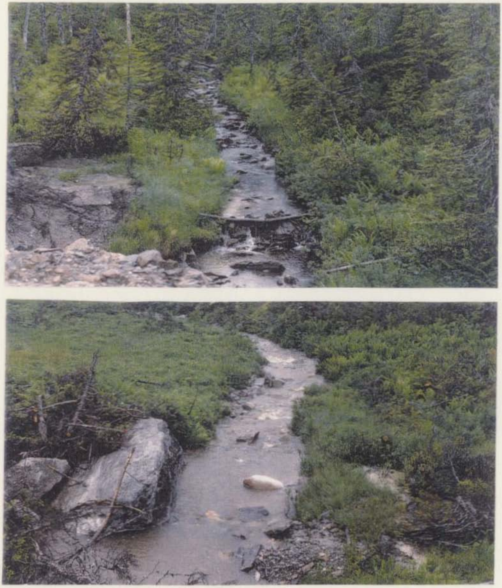


Figure 4.2 Photographs showing the increase in TSS below the road crossing in the treatment stream during rain. The top photo was taken above the road crossing and the bottom photo was taken below the road. Both were taken at the same time.

4.3 **Territory and stream holding capacity**

The electrofishing results for early August indicate there was no significant difference between years in the total proportions of fish in each age-class in the treatment stream electrofishing sites. The total numbers of fish were also very similar between years. The increase in movement out of the treatment stream to Copper Lake in 1995 may have occurred as a natural process of density-dependent regulation brought about by undetected changes in stream habitats.

Territory size is directly related to fish size, fish density, and physical characteristics of the stream (Hunter 1991; Elliott 1994). As trout grow, their territories become larger. As territories of larger, more aggressive trout increase in size, other trout are displaced (Elliott 1994). Several researchers suggest that displaced trout tend to go downstream in search of empty territories or in response to food supply (Gibson 1981; McNicol and Noakes 1981; Hunter 1991; Elliott 1994). The size of the fish remaining in the streams in June were not measured to determine if they were larger than those moving to the lake, however, dead and moribund 1+ trout which were caught going downstream in the counting fences in the spring were generally smaller (fork length) than those alive and apparently healthy 1+ trout which passed through the fences in the spring. Other studies have also suggested that lakeward movement by stream-dwelling salmonids may be under genetic control (Raleigh 1967; McCart 1967; Raleigh and Chapman 1971; Kelso et al. 1981). The precise factors controlling the downstream movement of trout to the lakes are not apparent in this study, however, evidence may suggest that territory size was involved.

Theories of density-dependant regulation of populations suggest that there is a limit to the number of residents that can inhabit a section of stream (Sinclair 1989), i.e., the holding capacity. Lack (1954) included movement as one of the 3 major factors involved in the natural regulation of animal numbers (along with reproduction and mortality). Hunt (1965) recorded increased dispersion of stream populations of brook trout at higher densities and emigration of trout in excess of the holding capacity of streams in England has been noted (Northcote 1967).

The holding capacity for brook trout in the treatment stream (within all electrofishing stations) does not appear to have changed between years. However, possible changes in stream habitats may have occurred which were undetected by the point-transect measurements. For example, the uppermost electrofishing section had 17 trout in 1994 but only 7 in 1995 (Clarke et al. 1996a In press). In addition, the fact that more 2+ trout left the treatment stream in 1995 than there were 1+ trout in all the electrofishing stations in 1994, which encompassed all of the treatment stream below the road crossing and clear-cut, implies that some of these trout must have come from upstream of the road crossing. The clear-cut surrounded all of the treatment stream above the road-crossing and hence may have had an effect on the stream immediately adjacent to it. Trout within this section of stream may have been displaced downstream (upstream movement was impossible due to the waterfall) into stream sections where trout had already established territories and were consequently forced out to the lake. Saunders and Smith (1962) found that prior residence in a stream section gave a competitive advantage over transplanted brook trout, even if those transplanted were from the same stream. Some evidence for this is the fact that many trout tagged coming down through the upper fence in the treatment stream also moved through the lower fence at the mouth of the stream, or were in the slower water just upstream of it, one to three days later.

The age compositions of the electrofished trout in the control stream were confounded by the timing of the spawning runs. In 1994, the first large run of pre-spawning trout into the control stream occurred approximately one week before electrofishing took place. In 1995, the run started approximately one week after electrofishing was completed. These dates coincided with storms which rapidly increased discharge and decreased water temperatures, factors often associated with the initiation of spawning runs (Collins 1952; Munro and Balmain 1956; Lindsey and Northcote 1963). Because of the large numbers of trout associated with the spawning runs into the control stream, the differences in the timing of the runs led to a significant difference in the age composition of electrofished trout between years.

The age composition of younger, non-migrant trout (0+, 1+, 2+) also differed significantly between years which suggests different sizes in juvenile year-classes. The number of 1+ trout in 1994 was high which led to a large number of 2+ in 1995. This may explain why a large number of 1+ left the stream in the spring of 1995, i.e. they could not compete for territories with the larger 2+ individuals.

4.4 **Telemetry**

Brook trout are considered classic fluvial spawners (Scott and Crossman 1979), however, shoal or lake spawning has been described (Witzel and MacCrimmon 1983; Fraser 1985; Chapman 1988; Schofield 1993; Curry and Noakes 1995). Lacustrine spawning of brook trout has rarely been documented in Newfoundland (Cowan and Baggs 1988) and hence its importance to the reproductive capacity of populations is unknown. This portion of the study was intended in part, to determine which of the various tributary streams in the watershed were preferred spawning habitats, however, a surprising finding was that shoals in both Copper Lake and Jim's Lake were important spawning habitat. Only three of the 16 surviving trout implanted with transmitters went into tributary streams to spawn. The others appeared to be associated with lacustrine spawning habitat near the mouths of tributary streams or along the western shores of their home lake. This behaviour was not the result of low streamflows as they were usually high and hence, access to the streams prior to spawning was not impeded. In addition, other trout were entering the streams during this time. Visual evidence also suggests that these fish were spawning on the shoals.

The western sides of the lakes are characterized by very steep slopes and limited littoral habitat (Scruton et al. 1995). Along these western shores, redds were located on small rock outcrops approximately 2 m^2. These observations indicate that brook trout are able to detect and utilize very small and isolated spawning habitats within the lakes.

The amount of lacustrine spawning in Newfoundland may vary based upon the availability of groundwater upwelling (Fraser 1985) and the level of competition for preferred spawning habitat (Cowan and Baggs 1988). In this study, Copper Lake appeared to have proportionally more redds in it than Jim's Lake. Groundwater upwelling has been strongly associated with brook trout spawning habitat (Fraser 1985; Curry and Noakes 1995; Curry et al. 1995); however, dye dispersion studies over redd sites in ponds on the Avalon Peninsula, Newfoundland, did not reveal groundwater upwelling (Cowan and Baggs 1988). Water moving over the redds as it flowed toward the pond outflow was identified. Cowan and Baggs (1988) suggested that these redds were used by brook trout which were displaced from preferred spawning areas in tributary streams. Unfortunately, the importance of groundwater to the selection of spawning sites within the Copper Lake watershed was not investigated, and the relative importance of groundwater and competition to the selection of lacustrine spawning sites remains an open question.

Based on the amount of time fish spent in one location, it appeared that Copper Lake trout were much more active during the spawning season than those in Jim's Lake. With trout density in Copper Lake being approximately one-third that of Jim's Lake (K.D. Clarke pers comm), this increased movement may have been associated with the search for mates.

In addition, some of the implanted fish in Copper Lake may not have been spawners. Only 83.3% of individuals in the size-class implanted with transmitters in Copper Lake were mature, whereas the value in Jim's Lake was 100%. This may also explain why some of the implanted fish in Copper Lake travelled large distances; they may have been non-maturing, feeding fish.

No trout were re-captured after implantation to check if the transmitters interfered with gonad maturation or spawning. However, previous studies on the effect of surgical implantation found no significant differences in exhaustion times (Mellas and Haynes 1985), maturation, mortality or growth of internally implanted and non-implanted salmonids provided that the transmitter was less than 2% of the fish's total weight (Lucas 1989). All transmitters in this study were less than 2.1% of the implanted fish's total body weight so the effects of implantation were considered minimal. Of the three fish which moved into the control stream, one was implanted on August 24 and the other two were implanted on August 11. All three fish were observed spawning which suggests that the transmitters did not impede spawning activity. In addition, two of the three trout were inspected as they went through a counting fence and were found to be in good condition with closed incisions, lost sutures, and no evidence of infection.

Meehan (1991) reviewed the many facets of salmonid spawning activity that can be adversely affected by forest harvesting activities. Some of the major factors include changes in (i) substrate composition (sedimentation), (ii) suspended sediment, (iii) hydrological regimes, and (iv) temperature profiles. Schofield (1993) stated that shoal spawning habitat may be degraded as a result of siltation due to beaver impoundment. Improper forest harvesting, which causes increased stream TSS levels, may also cause the siltation of shoals as they are located where streamflows meet the slower water of the lake and, hence, sediment would be deposited there (Swanston 1991).

The Federal Department of Fisheries and Oceans (DFO) fish habitat management policy outlines a 'no net loss' philosophy in maintaining the productive capacity of fish habitats (Fish Habitat Management Branch 1986). Integral to this is the maintenance of spawning habitat, and as such, awareness of the loss to sedimentation, due to forest harvesting activities, of potential spawning shoals should be considered in forest harvest management.

4.5 **Conclusions**

Movements of brook trout within the treatment and control streams were determined. Trout in the control stream generally moved to Jim's Lake at 1+ and 2+ years of age and returned approximately 2 years later to spawn. They may repeat spawn after their initial spawning year. Most trout in the treatment stream remained there as permanent residents. If they left the stream and moved into Copper Lake, they did not return to the stream. The older trout which entered the treatment stream in the fall were not those previously observed leaving the stream.

Trout movement was correlated to habitat parameters with most correlation coefficients being significant. However, correlations were not strong. Most trout moved in association with storm events. Two patterns in upstream movement were observed; 1) an apparent 'preferred' velocity range, similar in both streams, and 2) a shift in the timing of upstream movement during a storm based on the mean velocity at the storm peak. These patterns indicate a preferred mean stream velocity for upstream movement of 0.395-0.462 $m \cdot s^{-1}$ in the treatment and 0.206-0.409 $m \cdot s^{-1}$ in the control stream and a switch to moving upstream after the storm peak if the peak velocity was greater than 0.474 and

0.421 $m \cdot s^{-1}$ for the treatment and control stream respectively.

Downstream movement in the treatment stream occurred most at lower velocity ranges and more trout moved before and after storm peaks than during the peak. In the control stream, downstream movement occurred at all velocity ranges with trout moving downstream throughout the storms. These differences may be related to differences in stream morphology near the entrances of the streams.

Discharge, maximum water temperature, mean stream depth, velocity, and temperature were not altered in the treatment stream by the limited forest harvest. Dissolved oxygen could not be compared between years, but it did not reach critical levels even after the cut. The minimum daily water temperature was affected by harvesting. In addition, TSS may have been increased, however, statistical evidence is lacking. The apparent lack of affect on most parameters was probably due to the small size of the cut (atypical of the usual size of clear-cuts harvested in Newfoundland).

Increased movement out of the treatment stream was recorded in 1995 after the limited forest harvest within its drainage basin. Trout did not appear to change the distance of migration but changed their direction of movement and the habitat-type they occupied, i.e. they moved out of the treatment stream and into Copper Lake. This increase may have been due to subtle changes in stream habitat, undetected by the present methodologies, which decreased the holding capacity of the section of stream adjacent to the clear-cut.

Lacustrine spawning may represent a large proportion of reproduction in certain areas of the watershed. Therefore, lacustrine spawning sites need to be considered in the context of effects from forest harvesting practices.

It is important to stress that these conclusions are developed after only two years of detailed study. At this point, there is little opportunity to observe year-to-year variation in movement and habitat use. At present, conclusions are drawn from contrasting observations between the treatment and control streams. Additional study is required to determine variation in seasonal behaviour as well as to identify causal factors for observed changes. This is a problem when trying to assess the significance of any ecological change when little is known about the spatial and temporal variations in the 'baseline' from which the change occurred (Elliott 1994). With the limited number of years monitored to date, this study is only able to assess immediate results, which may not be representative of longer time series (Hall and Knight 1981). Monitoring the changes in habitats and the effects on behaviour and habitat use of trout over the coming years will help determine if this observed change in the treatment stream is persistent and/or detrimental to the population.

Further cutting regimes within the watershed are scheduled including a more extensive cut of the treatment drainage basin in 1996 and the leaving of a 20 meter no-harvest buffer strip on other treatment streams. Further research within the watershed will help determine if this required buffer size is beneficial to aquatic ecosystems in Newfoundland.

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Appendix 1. Calculated equations for discharge (D) for each stream section and year. SH = Staff-gauge height.

Location and year	equation Discharge=$10^{(a(SH)+b)}$	p-value	r^2	n
T1-1 1994	$D = 10^{((-0.0658SH)+2.58)}$	0.000[1]	92.2	21
T1-1 1995	$D = 10^{((-0.0752SH)+2.67)}$	0.000[1]	92.7	25
T1-3 1994	$D = 10^{((-0.0794SH)+3.46)}$	0.000[1]	85.1	11
T1-3 1995	$D = 10^{((-0.0625SH)+2.00)}$	0.000[1]	94.8	23

[1] Significant

Appendix 2. Calculated regression equations for mean velocity (V) for each stream section and year.

Location and year	equation $V = b + a$(staff height)	p value	r^2	n
T1-1 lower 94	V = 2.30 - 0.0332SH	0.000[1]	96.6	26
T1-1 upper 94	V = 1.91 - 0.0276SH	0.000[1]	96.5	26
T1-1 lower 95	V = 1.38 - 0.0189SH	0.000[1]	92.0	20
T1-1 upper 95	V = 1.00 - 0.0125SH	0.000[1]	81.6	20
T1-3 lower 94	V = 1.24 - 0.0206SH	0.000[1]	94.9	25
T1-3 upper 94	V = 1.34 - 0.0224SH	0.000[1]	95.6	25
T1-3 lower 95	V = 0.902 - 0.0147SH	0.000[1]	93.2	21
T1-3 upper 95	V = 1.12 - 0.0172SH	0.000[1]	84.3	21

[1] Significant

Appendix 3. Calculated regression equations for mean depth (D) for each stream section and year.

Location and year	equation D = b + a(staff height)	p-value	r^2	n
T1-1 lower 94	D = 49.6 - 0.676SH	0.000[1]	94.1	26
T1-1 upper 94	D = 48.1 - 0.671SH	0.000[1]	91.3	26
T1-1 lower 95	D = 48.4 - 0.580SH	0.000[1]	56.2	20
T1-1 upper 95	D = 47.5 - 0.590SH	0.000[1]	81.6	20
T1-3 lower 94	D = 66.7 - 0.915SH	0.000[1]	81.4	25
T1-3 upper 94	D = 46.7 - 0.689SH	0.000[1]	85.2	25
T1-3 lower 95	D = 62.6 - 0.851SH	0.000[1]	97.3	21
T1-3 upper 95	D = 45.1 - 0.656SH	0.000[1]	92.2	21

[1] Significant

Appendix 4. Calculated regression equations for mean daily dissolved oxygen (DO) based on water temperature (T) and water velocity (V) for each stream section, 1995.

Location and year	equation $DO = a+b(T)+c(V)$	p-value	r^2	n
T1-1 lower 95	DO = 11.0-0.207T+1.82V	0.000[1]	89.4	20
T1-1 upper 95	DO = 10.1-0.172T+2.56V	0.000[1]	87.9	20
T1-3 lower 95	DO = 11.3-0.218T+1.28V	0.000[1]	85.5	21
T1-3 upper 95	DO = 11.5-0.309T+5.45V	0.019[1]	39.1	21

[1] significant

Appendix 5. Regression equations for calculating water depth (cm) from staff-gauge height (cm) for individual transect points, T1-1 section 1, 1994.

equation Depth=b+a(Staff Height)	p value	r^2	transect
D= 45.5 - 0.680SH	<0.002[1]	76.1	1(Point 1)
D= 63.7 - 0.867SH	<0.002[1]	79.6	1(Point 2)
D= 28.2 - 0.424SH	0.008[1]	31.4	1(Point 3)
D= 66.6 - 0.933SH	<0.002[1]	75.3	2(Point 1)
D= 60.8 - 0.853SH	<0.002[1]	62.8	2(Point 2)
D= 21.0 - 0.308SH	0.012[1]	26.7	2(Point 3)
D= 39.6 - 0.572SH	0.014[1]	34.3	3(Point 1)
D= 61.6 - 0.882SH	<0.002[1]	62.7	3(Point 2)
D= 60.2 - 0.846SH	0.000	90.4	3(Point 3)
D= 46.1 - 0.641SH	<0.002[1]	67.2	4(Point 1)
D= 40.3 - 0.500SH	0.010[1]	27.5	4(Point 2)
D= 60.4 - 0.766SH	<0.005[1]	45.4	4(Point 3)
D= 43.5 - 0.626SH	<0.005[1]	62.8	5(Point1)
D= 54.4 - 0.710SH	<0.005[1]	57.7	5(Point 2)
D= 53.8 - 0.738SH	0.000	61.5	5(Point 3)
D= 39.3 - 0.488SH	<0.005[1]	60.2	6(Point 1)
D= 42.5 - 0.482SH	0.000	49.4	6(Point 2)
D= 57.0 - 0.704SH	<0.005[1]	61.0	6(Point 3)

[1] randomized p-value

[2] not significant

Appendix 5 (cont.). Regression equations for calculating water depth (cm) from staff-gauge height (cm) for individual transect points T1-1s2, 1994.

equation Depth=a+b(Staff Height)	p value	r^2	transect
D= 36.6 - 0.551SH	<0.005[1]	68.9	1(Point 1)
D= 48.8 - 0.653SH	<0.005[1]	88.6	1(Point 2)
D= 44.6 - 0.596SH	0.000	45.8	1(Point 3)
D= 76.5 - 1.09SH	0.000	79.6	2(Point 1)
D= 42.6 - 0.658SH	0.000	74.7	2(Point 2)
D= 46.5 - 0.688SH	<0.005[1]	51.5	2(Point 3)
D= 26.1 - 0.388SH	0.010[1]	37.4	3(Point 1)
D= 39.9 - 0.545SH	0.000	66.4	3(Point 2)
D= 52.5 - 0.749SH	<0.005[1]	53.5	3(Point 3)
D= 39.7 - 0.581SH	0.000	53.7	4(Point 1)
D= 47.2 - 0.561SH	0.000	62.1	4(Point 2)
D= 21.5 - 0.268SH	0.675[1,2]	7.5	4(Point 3)
D= 55.7 - 0.782SH	<0.005[1]	57.5	5(Point 1)
D= 59.9 - 0.713SH	0.000	83.4	5(Point 2)
D= 77.3 - 1.06SH	<0.005[1]	59.3	5(Point 3)
D= 38.9 - 0.561SH	0.000	71.2	6(Point 1)
D= 47.7 - 0.645SH	0.000	69.0	6(Point 2)
D= 46.0 - 0.628SH	0.000	61.4	6(Point 3)

[1] randomized p-value

[2] not significant

Appendix 5 (cont.). Regression equations for calculating water depth (cm) from staff-gauge height (cm) for individual transect points, T1-3s1, 1994.

equation Depth=a+b(Staff Height)	p value	r^2	transect
D= 67.7 - 0.881SH	0.000	70.1	1(Point 1)
D= 72.5 - 0.991SH	0.010[1]	37.3	1(Point 2)
D= 75.1 - 0.984SH	0.000	95.4	1(Point 3)
D= 83.0 - 1.08SH	0.061[2]	15.1	2(Point 1)
D= 61.7 - 0.825SH	0.000	95.2	2(Point 2)
D= 46.3 - 0.628SH	0.000	51.8	2(Point 3)
D= 54.9 - 0.813SH	0.000	95.4	3(Point 1)
D= 62.8 - 0.867SH	0.000	93.7	3(Point 2)
D= 62.7 - 0.866SH	<0.005[1]	71.6	3(Point 3)
D= 64.9 - 0.882SH	0.000	69.0	4(Point 1)
D= 88.3 - 1.06SH	0.000	55.8	4(Point 2)
D= 77.0 - 0.941SH	<0.005[1]	37.2	4(Point 3)
D= 70.0 - 1.14SH	0.000	97.0	5(Point 1)
D= 73.7 - 1.16SH	0.000	95.3	5(Point 2)
D= 73.5 - 1.18SH	0.000	85.6	5(Point 3)
D= 65.4 - 0.969SH	0.000	69.7	6(Point 1)
D= 34.3 - 0.185SH	0.668[1,2]	1.0	6(Point 2)
D= 67.2 - 1.02SH	0.00	93.8	6(Point 3)

[1] randomized p-value

[2] not significant

Appendix 5 (cont.). Regression equations for calculating water depth (cm) from staff-gauge height (cm) for individual transect points, T1-3s2, 1994.

equation Depth=a+b(Staff Height)	p value	r^2	transect
D= 89.9 - 1.54SH	0.000	81.2	1(Point 1)
D= 76.3 - 1.28SH	0.000	82.6	1(Point 2)
D= 82.2 - 1.35SH	0.000	84.5	1(Point 3)
D= 61.0 - 0.718SH	0.000	68.4	2(Point 1)
D= 50.4 - 0.574SH	<0.005[1]	60.8	2(Point 2)
D= 73.3 - 0.905SH	0.000	94.3	2(Point 3)
D= 44.6 - 0.691SH	0.038[1]	20.1	3(Point 1)
D= 54.3 - 0.914SH	0.000	76.9	3(Point 2)
D= 48.9 - 0.730SH	<0.005[1]	44.1	3(Point 3)
D= 20.9 - 0.369SH	0.000	65.7	4(Point 1)
D= 24.3 - 0.432SH	0.043[1]	37.1	4(Point 2)
D= 22.0 - 0.386SH	0.000	53.1	4(Point 3)
D= 35.6 - 0.591SH	0.007	29.0	5(Point 1)
D= 25.3 - 0.473SH	0.000	76.1	5(Point 2)
D= 35.7 - 0.531SH	<0.005[1]	24.7	5(Point 3)
D= 26.0 - 0.229SH	0.120[1,2]	9.5	6(Point 1)
D= 39.9 - 0.428SH	0.000	55.1	6(Point 2)
D= 37.2 - 0.388SH	0.000	49.8	6(Point 3)

[1] randomized p-value

[2] not significant

Appendix 5 (cont.). Regression equations for calculating water velocity ($m \cdot s^{-1}$) from staff-gauge height (cm) for individual transect points, T1-1s1, 1994.

equation Velocity=a+b(Staff Height)	p value	r^2	transect
V= 2.49 - 0.0364SH	0.000	81.0	1(Point 1)
V= 2.11 - 0.0264SH	<0.005[1]	33.1	1(Point 2)
V= 1.44 - 0.0190SH	0.012[1]	52.7	1(Point 3)
V= 2.65 - 0.0378SH	<0.005[1]	68.8	2(Point 1)
V= 1.96 - 0.0261SH	0.000	61.5	2(Point 2)
V= 1.11 - 0.0163SH	0.114[1,2]	30.6	2(Point 3)
V= 2.94 - 0.0454SH	<0.005[1]	80.5	3(Point 1)
V= 2.97 - 0.0428SH	0.000	78.4	3(Point 2)
V= 2.45 - 0.0351SH	0.000	80.6	3(Point 3)
V= 2.54 - 0.0360SH	<0.005[1]	61.8	4(Point 1)
V= 4.06 - 0.0614SH	0.000	84.5	4(Point 2)
V= 0.015 + 0.00110SH	0.257[1,2]	2.9	4(Point 3)
V= 2.39 - 0.0363SH	0.000	70.3	5(Point 1)
V= 2.56 - 0.0350SH	0.000	45.4	5(Point 2)
V= 2.09 - 0.0267SH	0.000	55.9	5(Point 3)
V= 2.85 - 0.0383SH	<0.005[1]	79.7	6(Point 1)
V= 1.82 - 0.0269SH	0.002	51.8	6(Point 2)
V= 2.26 - 0.0325SH	0.000	83.8	6(Point 3)

[1] randomized p-value

[2] not significant

Appendix 5 (cont.). Regression equations for calculating water velocity ($m \cdot s^{-1}$) from staff-gauge height (cm) for individual transect points, T1-1s2, 1994.

equation Velocity=a+b(Staff Height)	p value	r^2	transect
V= 1.65 - 0.0254SH	0.020[1]	41.8	1(Point 1)
V= 1.41 - 0.0190SH	0.002[1]	40.6	1(Point 2)
V= 1.04 - 0.0141SH	0.000	88.3	1(Point 3)
V= 0.114 - 0.00243SH	0.586[1,2]	1.2	2(Point 1)
V= 3.98 - 0.0606SH	0.000	80.0	2(Point 2)
V= 1.47 - 0.0191SH	0.118[1,2]	16.4	2(Point 3)
V= 2.59 - 0.0391SH	0.000	84.2	3(Point 1)
V= 1.39 - 0.0184SH	<0.005[1]	33.8	3(Point 2)
V= 2.31 - 0.0337SH	0.000	87.0	3(Point 3)
V= 1.10 - 0.0162SH	0.004[1]	43.4	4(Point 1)
V= 1.31 - 0.0178SH	0.000	77.0	4(Point 2)
V= 3.01 + 0.0488SH	0.000	90.9	4(Point 3)
V= 0.312 + 0.00077SH	0.887[2]	0.1	5(Point 1)
V= 0.582 - 0.00772SH	0.111[2]	12.2	5(Point 2)
V= 1.51 - 0.0188SH	0.018	30.2	5(Point 3)
V= 2.91 - 0.0425SH	0.000	85.0	6(Point 1)
V= 3.75 - 0.0540SH	0.000	69.0	6(Point 2)
V= 2.53 - 0.0366SH	0.000	79.1	6(Point 3)

[1] randomized p-value

[2] not significant

Appendix 5 (cont.). Regression equations for calculating water velocity ($m \cdot s^{-1}$) from staff-gauge height (cm) for individual transect points, T1-3s1, 1994.

equation Velocity=a+b(Staff Height)	p value	r^2	transect
V= 1.50 - 0.0208SH	0.071[2]	14.1	1(Point 1)
V= 0.247 - 0.00394SH	0.000	82.8	1(Point 2)
V= 1.86 - 0.0315SH	0.000	76.6	1(Point 3)
V= 1.21 - 0.0212SH	0.000	87.7	2(Point 1)
V= 1.86 - 0.0315SH	0.000	95.2	2(Point 2)
V= 1.61 - 0.0269SH	0.000	88.8	2(Point 3)
V= 1.04 - 0.0178SH	0.000	81.4	3(Point 1)
V= 1.30 - 0.0218SH	0.000	95.5	3(Point 2)
V= 1.28 - 0.0209SH	0.020[1]	34.5	3(Point 3)
V= 0.835 - 0.0153SH	0.001	98.5	4(Point 1)
V= 1.06 - 0.0183SH	0.000	79.7	4(Point 2)
V= 1.53 - 0.0260SH	<0.005[1]	94.3	4(Point 3)
V= 1.91 - 0.0322SH	0.000	90.1	5(Point 1)
V= 1.55 - 0.0239SH	<0.005[1]	71.6	5(Point 2)
V= 0.946 - 0.0131SH	<0.005[1]	48.3	5(Point 3)
V= 0.215 - 0.00307SH	0.074[1,2]	22.5	6(Point 1)
V= 1.28 - 0.0217SH	0.000	85.2	6(Point 2)
V= 0.598 - 0.0101SH	0.108[2]	63.2	6(Point 3)

[1] randomized p-value

[2] not significant

Appendix 5 (cont.). Regression equations for calculating water velocity ($m \cdot s^{-1}$) from staff-gauge height (cm) for individual transect points, T1-3s2, 1994.

equation Velocity=a+b(Staff Height)	p value	r^2	transect
V= 1.88 - 0.0292SH	0.004	34.3	1(Point 1)
V= 1.31 - 0.0187SH	0.013	23.8	1(Point 2)
V= 0.926 - 0.0130SH	0.014	23.5	1(Point 3)
NOT ENOUGH DATA (DRY)			2(Point 1)
V= 0.194 - 0.00287SH	0.000	50.2	2(Point 2)
V= 0.990 - 0.0172SH	<0.005[1]	70.6	2(Point 3)
V= 3.02 - 0.0496SH	0.000	62.4	3(Point 1)
V= 4.30 - 0.0758SH	0.000	82.4	3(Point 2)
V= 3.16 - 0.0512SH	0.000	59.9	3(Point 3)
V= 0.350 - 0.0020SH	0.931[1,2]	0.2	4(Point 1)
V= 0.969 - 0.0160SH	0.054[2]	99.3	4(Point 2)
V= 1.66 - 0.0282SH	0.002[1]	91.5	4(Point 3)
V= -0.161 + 0.00566SH	0.561[2]	2.7	5(Point 1)
V= 0.687 - 0.0126SH			5(Point 2)
V= 1.60 - 0.0276SH	0.000	82.7	5(Point 3)
V= 0.542 - 0.00981SH	0.004	99.2	6(Point 1)
V= 1.04 - 0.0192SH	0.016	96.9	6(Point 2)
V= 0.948 - 0.0175SH	0.014	97.2	6(Point 3)

[1] randomized p-value

[2] not significant

Appendix 5 (cont.). Regression equations for calculating water depth (cm) from staff-gauge height (cm) for individual transect points, T1-1s1, 1995.

equation Depth=a+b(Staff Height)	p value	r^2	transect
D= 55.2 - 0.896SH	0.005	89.1	1(Point 1)
D= 75.5 - 0.929SH	0.000	82.5	1(Point 2)
D= 80.9 - 1.01SH	0.000	92.7	1(Point 3)
D= 76.3 - 0.913SH	0.001	45.6	2(Point 1)
D= 87.5 - 1.06SH	0.000	89.5	2(Point 2)
D= 61.8 - 0.919SH	<0.005[1]	85.9	2(Point 3)
NOT ENOUGH DATA (DRY)			3(Point 1)
D= 57.0 - 0.702SH	0.000	75.7	3(Point 2)
D= 48.2 - 0.606SH	0.000	91.7	3(Point 3)
D= 71.8 - 0.943SH	0.000	94.9	4(Point 1)
D= 75.7 - 0.878SH	0.000	70.7	4(Point 2)
D= 69.0 - 0.696SH	0.017	26.5	4(Point 3)
D= 42.6 - 0.586SH	0.000	87.7	5(Point 1)
D= 62.3 - 0.746SH	0.000	80.6	5(Point 2)
D= 57.2 - 0.726SH	0.000	84.4	5(Point 3)
D= 53.2 - 0.642SH	0.000	71.6	6(Point 1)
D= 61.3 - 0.767SH	<0.005[1]	69.6	6(Point 2)
D= 53.6 - 0.712SH	0.000	90.4	6(Point 3)

[1] randomized p-value

[2] not significant

Appendix 5 (cont.). Regression equations for calculating water depth (cm) from staff-gauge height (cm) for individual transect points, T1-1s2, 1995.

equation Depth=a+b(Staff Height)	p value	r^2	transect
D= 57.2 - 0.765SH	0.000	82.7	1(Point 1)
D= 71.5 - 0.673SH	0.006[1]	36.8	1(Point 2)
D= 65.6 - 0.685SH	0.000	55.0	1(Point 3)
D= 56.8 - 0.788SH	0.000	89.1	2(Point 1)
D= 67.4 - 0.843SH	<0.005[1]	77.2	2(Point 2)
D= 68.0 - 0.931SH	0.000	92.2	2(Point 3)
D= 26.6 - 0.408SH	0.162[2]	35.0	3(Point 1)
D= 36.9 - 0.529SH	0.000	78.9	3(Point 2)
D= 36.2 - 0.438SH	0.032[1]	21.9	3(Point 3)
D= 62.4 - 0.753SH	0.000	82.6	4(Point 1)
D= 67.4 - 0.877SH	0.000	94.7	4(Point 2)
D= -3.39 + 0.061SH	0.663[2]	7.2	4(Point 3)
D= 55.8 - 0.631SH	0.007	30.9	5(Point 1)
D= 71.9 - 0.907SH	0.000	90.2	5(Point 2)
D= 64.7 - 0.859SH	0.000	80.7	5(Point 3)
D= 65.6 - 0.903SH	<0.005[1]	85.3	6(Point 1)
D= 56.6 - 0.752SH	0.000	90.3	6(Point 2)
D= 31.3 - 0.473SH	0.034[1]	63.5	6(Point 3)

[1] randomized p-value

[2] not significant

Appendix 5 (cont.). Regression equations for calculating water depth (cm) from staff-gauge height (cm) for individual transect points, T1-3s1, 1995.

equation Depth=a+b(Staff Height)	p value	r^2	transect
D= 67.6 - 0.902SH	0.000	94.7	1(Point 1)
D= 60.3 - 0.775SH	0.000	71.2	1(Point 2)
D= 72.6 - 0.948SH	0.000	98.6	1(Point 3)
D= 54.7 - 0.757SH	0.000	94.1	2(Point 1)
D= 57.0 - 0.748SH	0.000	72.3	2(Point 2)
D= 48.2 - 0.704SH	0.000	97.8	2(Point 3)
D= 54.3 - 0.813SH	0.000	94.1	3(Point 1)
D= 60.0 - 0.864SH	0.000	97.6	3(Point 2)
D= 56.9 - 0.777SH	0.000	96.7	3(Point 3)
D= 71.1 - 1.13SH	0.000	88.8	4(Point 1)
D= 80.8 - 0.961SH	0.000	67.0	4(Point 2)
D= 81.8 - 1.03SH	0.000	85.3	4(Point 3)
D= 60.1 - 0.825SH	0.000	91.0	5(Point 1)
D= 65.2 - 0.879SH	0.000	88.8	5(Point 2)
D= 60.0 - 0.800SH	0.000	80.2	5(Point 3)
D= 65.9 - 0.857SH	<0.005[1]	78.7	6(Point 1)
D= 65.3 - 0.927SH	0.000	88.9	6(Point 2)
D= 65.6 - 0.975SH	0.000	97.5	6(Point 3)

[1] randomized p-value

[2] not significant

Appendix 5 (cont.). Regression equations for calculating water depth (cm) from staff-gauge height (cm) for individual transect points, T1-3s2, 1995.

equation Depth=a+b(Staff Height)	p value	r^2	transect
D= 76.6 - 1.39SH	0.000	86.4	1(Point 1)
D= 71.7 - 1.20SH	0.000	79.5	1(Point 2)
D= 70.6 - 1.14SH	0.000	80.4	1(Point 3)
D= 57.8 - 0.750SH	<0.005[1]	63.3	2(Point 1)
D= 64.4 - 0.924SH	0.000	93.2	2(Point 2)
D= 67.3 - 0.856SH	0.000	93.3	2(Point 3)
D= 41.9 - 0.626SH	0.000	70.3	3(Point 1)
D= 37.9 - 0.698SH	0.000	96.7	3(Point 2)
D= 46.9 - 0.767SH	0.000	82.9	3(Point 3)
D= 29.1 - 0.473SH	0.000	75.4	4(Point 1)
D= 19.6 - 0.284SH	0.003	43.1	4(Point 2)
D= 48.7 - 0.826SH	0.000	75.4	4(Point 3)
NOT ENOUGH DATA (DRY)			5(Point 1)
D= 63.9 - 0.789SH	0.000	82.5	5(Point 2)
D= 76.6 - 0.897SH	0.000	73.1	5(Point 3)
D= 28.3 - 0.203SH	0.001	45.3	6(Point 1)
D= 48.4 - 0.677SH	0.000	75.9	6(Point 2)
D= 12.0 - 0.250SH	ONLY 2	POINTS	6(Point 3)

[1] randomized p-value

[2] not significant

Appendix 5 (cont.). Regression equations for calculating water velocity ($m \cdot s^{-1}$) from staff-gauge height (cm) for individual transect points, T1-1s1, 1995.

equation Velocity=a+b(Staff Height)	p value	r^2	transect
V= 1.52 - 0.0236SH	0.100[2]	53.2	1(Point 1)
V= 2.23 - 0.0304SH	0.000	90.6	1(Point 2)
V= 1.15 - 0.0151SH	0.000	71.7	1(Point 3)
V= 0.985 - 0.0136SH	0.000	67.2	2(Point 1)
V= 1.07 - 0.0148SH	0.000	73.2	2(Point 2)
V= 0.0360 - 0.00SH*	0.000	100.0	2(Point 3)
V= 0.0360 - 0.00SH*	0.000	100.0	3(Point 1)
V= 2.50 - 0.0352SH	0.000	91.5	3(Point 2)
V= 1.88 - 0.0276SH	0.000	87.5	3(Point 3)
V= 0.638 - 0.00854SH	0.001	46.3	4(Point 1)
V= 1.50 - 0.0217SH	0.003	44.9	4(Point 2)
V= -0.0472 + 0.00144SH	0.324[2]	19.3	4(Point 3)
V= 2.13 - 0.0302SH	0.000	64.8	5(Point 1)
V= 2.15 - 0.0305SH	0.000	57.4	5(Point 2)
V= 2.03 - 0.0268SH	0.000	90.5	5(Point 3)
V= 2.43 - 0.0337SH	0.000	65.1	6(Point 1)
V= 2.93 - 0.0392SH	0.000	92.3	6(Point 2)
V= 0.241 - 0.00279SH	0.058[2]	18.6	6(Point 3)

[1] randomized p-value

[2] not significant

Appendix 5 (cont.). Regression equations for calculating water velocity ($m \cdot s^{-1}$) from staff-gauge height (cm) for individual transect points, T1-1s2, 1995.

equation Velocity=a+b(Staff Height)	p value	r^2	transect
V= 0.936 - 0.0149SH	0.186[2]	38.9	1(Point 1)
V= 0.725 - 0.00972SH	0.000	62.5	1(Point 2)
V= 0.524 - 0.00716SH	0.008	31.3	1(Point 3)
V= 1.28 - 0.0135SH	0.120[2]	12.3	2(Point 1)
V= 0.622 - 0.00817SH	0.001	50.1	2(Point 2)
V= 0.307 - 0.00383SH	0.071[2]	20.1	2(Point 3)
V= 0.0251 + 0.000185SH	0.002	88.5	3(Point 1)
V= 0.788 - 0.0123SH	0.144[2]	45.2	3(Point 2)
V= 3.23 - 0.0454SH	0.000	91.8	3(Point 3)
V= 0.158 - 0.00201SH	0.209[2]	35.8	4(Point 1)
V= 1.32 - 0.0175SH	0.000	65.2	4(Point 2)
V= 0.036 + 0.00SH	ONLY 2	POINTS	4(Point 3)
V= 0.019 + 0.00158SH	0.654[2]	1.1	5(Point 1)
V= 0.561 - 0.00662SH	0.042[1]	22.9	5(Point 2)
V= 1.62 - 0.0187SH	0.008	31.6	5(Point 3)
V= 3.18 - 0.0432SH	0.001	46.7	6(Point 1)
V= 4.02 - 0.0529SH	0.000	64.9	6(Point 2)
V= 0.040 - 0.00014SH	0.906[1,2]	0.1	6(Point 3)

[1] randomized p-value

[2] not significant

Appendix 5 (cont.). Regression equations for calculating water velocity ($m \cdot s^{-1}$) from staff-gauge height (cm) for individual transect points, T1-3s1, 1995.

equation Velocity=a+b(Staff Height)	p value	r^2	transect
V= 1.02 - 0.00961SH	0.116[2]	13.1	1(Point 1)
V= 0.015 - 0.00094SH	0.828[2]	3.0	1(Point 2)
V= 1.41 - 0.0238SH	0.001	49.9	1(Point 3)
V= 0.789 - 0.0133SH	0.000	91.2	2(Point 1)
V= 1.76 - 0.0298SH	0.000	97.5	2(Point 2)
V= 1.30 - 0.0218SH	0.000	93.9	2(Point 3)
V= 0.839 - 0.0147SH	0.000	83.5	3(Point 1)
V= 1.23 - 0.0210SH	0.000	94.5	3(Point 2)
V= 1.23 - 0.0210SH	0.000	93.4	3(Point 3)
V= 0.326 - 0.00506SH	0.070[1,2]	17.9	4(Point 1)
V= 0.707 - 0.0121SH	0.000	77.9	4(Point 2)
V= 1.03 - 0.0168SH	0.000	83.0	4(Point 3)
V= 1.28 - 0.0223SH	0.000	97.5	5(Point 1)
V= 1.48 - 0.0254SH	0.000	98.0	5(Point 2)
V= 0.536 - 0.00857SH	0.000	71.0	5(Point 3)
V= 0.100 - 0.00119SH	0.032[1]	44.6	6(Point 1)
V= 1.68 - 0.0296SH	0.000	90.7	6(Point 2)
V= 0.0857 - 0.00118SH	ONLY 2	POINTS	6(Point 3)

[1] randomized p-value

[2] not significant

Appendix 5 (cont.). Regression equations for calculating water velocity ($m \cdot s^{-1}$) from staff-gauge height (cm) for individual transect points, T1-3s2, 1995.

equation Velocity=a+b(Staff Height)	p value	r^2	transect
V= 1.12 - 0.0174SH	0.133[2]	26.0	1(Point 1)
V= 0.624 - 0.00148SH	0.783[2]	0.5	1(Point 2)
V= 0.691 - 0.00676SH	0.271[2]	6.7	1(Point 3)
V= 0.0857 - 0.00118SH	ONLY 2	POINTS	2(Point 1)
V= 2.00 - 0.0371SH	0.000	98.3	2(Point 2)
V= 0.185 - 0.00270SH	0.000	78.5	2(Point 3)
V= 3.66 - 0.0611SH	0.000	88.7	3(Point 1)
V= 2.71 - 0.0486SH	0.005[1]	91.3	3(Point 2)
V= 3.05 - 0.0461SH	0.001	51.2	3(Point 3)
V= 2.63 - 0.0473SH	0.000	90.3	4(Point 1)
V= 1.66 - 0.0270SH	0.004	58.7	4(Point 2)
V= 0.100 + 0.0039SH	0.715[2]	0.9	4(Point 3)
NOT ENOUGH DATA (DRY)			5(Point 1)
V= 0.158 - 0.00229SH	0.055[2]	43.0	5(Point 2)
V= 0.194 - 0.00228SH	0.161[2]	10.6	5(Point 3)
V= 0.725 - 0.0141SH	0.129[2]	96.0	6(Point 1)
V= 0.625 - 0.0115SH	0.002	97.4	6(Point 2)
V= 0.185 - 0.00355SH	ONLY 2	POINTS	6(Point 3)

[1] randomized p-value

[2] not significant

Appendix 6. Stream transect locations for habitat measurements.

Stream Section	Transect	Lat-Long position
T1-1-S1	1	N 48° 49' 9.5'' W 57° 46' 48.9''
T1-1-S1	2	N 48° 49' 14.0'' W 57° 46' 54.0''
T1-1-S1	3	N 48° 49' 15.5'' W 57° 46' 54.6''
T1-1-S1	4	N 48° 49' 8.4'' W 57° 46' 52.2''
T1-1-S1	5	N 48° 49' 13.9'' W 57° 46' 55.0''
T1-1-S1	6	N 48° 49' 14.0'' W 57° 46' 57.3''
T1-1-S2	1	N 48° 49' 13.1'' W 57° 46' 57.3''
T1-1-S2	2	N 48° 49' 14.8'' W 57° 47' 00.1''
T1-1-S2	3	N 48° 49' 11.2'' W 57° 47' 00.8''
T1-1-S2	4	N 48° 49' 13.5'' W 57° 47' 00.3''
T1-1-S2	5	N 48° 49' 14.0'' W 57° 47' 3.4''
T1-1-S2	6	N 48° 49' 13.2'' W 57° 47' 2.5''
T1-3-S1	1	N 48° 50' 3.5'' W 57° 44' 53.4''
T1-3-S1	2	N 48° 50' 2.2'' W 57° 44' 51.6''
T1-3-S1	3	N 48° 50' 4.2'' W 57° 44' 54.9''
T1-3-S1	4	N 48° 50' 5.4'' W 57° 44' 56.6''
T1-3-S1	5	N 48° 50' 6.4'' W 57° 44' 55.0''
T1-3-S1	6	N 48° 50' 8.0'' W 57° 44' 54.1''
T1-3-S2	1	N 48° 49' 56.7'' W 57° 44' 54.9''
T1-3-S2	2	N 48° 50' 10.7'' W 57° 44' 43.6''
T1-3-S2	3	N 48° 50' 8.7'' W 57° 44' 41.2''
T1-3-S2	4	N 48° 49' 51.7'' W 57° 44' 33.2''
T1-3-S2	5	N 48° 49' 51.9'' W 57° 44' 31.5''
T1-3-S2	6	N 48° 50' 2.3'' W 57° 44' 42.0''

Appendix 7. Individual storm event data for all storm events.

			Treatment stream movement (# of fish)		Control stream movement (# of fish)	
Storm #	Duration	Rainfall (mm)	Upstream	Downstream	Upstream	Downstream
1	0900 Sept 11 - 1100 Sept 15, 1994	25.0	15	15	88	11
2	0900 July 21 - 0900 July 24,1995	34.2	1	6	4	5 + 6 dead
3	0900 Aug 21 - 1300 Aug 24, 1995	29.8	6	1	38	4
4	0900 Sept 5 - 1200 Sept 7, 1995	3.7	0	0	0	0
5	0900 Sept 15 - 1300 Sept 20, 1995	39.3	6	4	92	12