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Department of Fisheries and Oceans
Science Branch
P.O. Box 5667
St. John's, Newfoundland
A1C 5X1

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The Copper Lake Buffer Zone Study: Pre-Harvest Conditions of the Aquatic Habitat

by

K.D. Clarke, D.A. Scruton, L.J. Cole, J.H. McCarthy[1],
J.M. Greene[1], I. Bell[2] and L.J. Moores[3]

Department of Fisheries and Oceans
Science Branch
P.O. Box 5667
St. John's, Newfoundland
A1C 5X1

[1] Department of Biology, Memorial University of Newfoundland
[2] Newfoundland Department of Environment and Labour - Water Resources Management Division
[3] Newfoundland Department of Forest Resources and Agrifoods - Newfoundland Forestry Service

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Abstract/Résumé

Clarke, K.D., D.A. Scruton, L.J. Cole, J.H. McCarthy, J.M. Green, I. Bell, and L.J. Moores. 1997. The Copper Lake Buffer Zone Study: Pre-Harvest Conditions of the Aquatic Habitat. Can. Tech. Rep. Fish. Aquat. Sci. No. 2181: vii + 66 p.

The Copper Lake Buffer Zone Study is a multi-agency and multi-disciplinary research study that was conceived to conduct region-specific research on the benefit of providing buffer strips in riparian zones to protect fish and wildlife resources and water quality in insular Newfoundland. The study is designed to quantify environmental perturbations arising from forest harvesting operations and investigate the ability to ameliorate these perturbations through the provision of an unharvested leave strip of varying widths along riparian zones. This report, the second from the project, outlines the physical and biotic conditions in the watershed before forest harvesting. The report includes a general description of the study area and survey streams before the onset of forest harvest operations including descriptions of hydrology, water quality, stream temperatures, fine sediment in the streams and large woody debris dynamics. Also, presented is population information on stream benthic macroinvertebrates as well as brook trout populations from both the lotic and lentic habitats including two of the major standing water bodies in the watershed (Copper Lake and Jim's Lake). Detailed study of the movement of brook trout between the lakes and streams of the watershed and within the streams, has also been conducted. This information collectively constitutes the pre-harvest baseline data for the project and will provide the basis for comparison in the post harvesting years of the study.

Clarke, K.D., D.A. Scruton, L.J. Cole, J.H. McCarthy, J.M. Green, I. Bell, and L.J. Moores. 1997. Étude de la zone-tampon de Copper lake: Conditions de l'habitat aquatique antérieures à l'exploitation. Rapp. Techn. Can. Sciences halieutiques et aquatiques no. 2181: vii + 66 p.

L'étude de de la zone-tampon de Copper Lake regroupe de nombreaux organisms et disciplines et a été conçue dans le but d'examiner, pour la région particulaire, l'advantage de prévoir des zones-tampons le long des rives pour protéger les ressources halieutiques et fauniques, ainsi que la qualité de l'eau a Terre-Neuve. L'étude vise à quantifer les perturbations environnementales qui découlent de l'exploitation forestière et à examiner la capacité de les atténuer au moyen d'une zone de non-exploitation de largeurs variables le long des rives. Ce rapport, le deuxième du project, donne les grandes lignes des conditions physiques et biotiques du bassin hydrographique avant l'exploitation. Il comprend une description générale de la zone étudiée et des cours d'eau avant le début d'activités forestières, ansi que le l'hydologie, de la qualité de l'eau, des températures dans le cours d'eau, des sédiments fins et des gros rebuts de bois. En outre, on y présente de l'information sur les macroinvertébrés benthiques et les populations d'ombles de fontaine pour les habitats biotiques et benthiques, y comprise deux des grands plans d'eau du bassin hydrographique (Copper Lake et Jim's Lake). On a également effectué des recherches détaillées sur les mouvements des ombles de fontaine entre les lacs et les ruisseaux du bassin et dans les ruisseaux eux-mêmes. L'ensemble de cette information constitue la base de données antérieures à l'exploitation du projet et servira à établir des comparaisons au cours de la partie postérieure à l'exploitation de l'étude.

1.0 Preface

Intensive forest harvesting activities have been ongoing since the early 1900's in Newfoundland and much of the merchantable timber in the province is associated with riparian zones. Therefor the potential for interactions between fish and wildlife resources and forestry practices is high. Current environmental protection guidelines for timber resource management in Newfoundland and Labrador are based on 'best available information'. They require the maintenance of a no harvest 20 m buffer zone along all water bodies that appear on a 1:50,000 scale topographic map. In special cases only (e.g. main branch of scheduled salmon rivers; protected water supply areas; pesticide application areas; areas of significance for wildlife) wider "no harvest" buffer zones are established. The practice of maintaining a protective "no harvest" buffer zone along all water bodies has been introduced in other jurisdictions and local resource agencies argue that a similar practice should be mandatory in Newfoundland.

The Copper Lake Buffer Zone Study was thus conceived to conduct region-specific research on the benefit of providing buffer strips in riparian zones to protect fish and wildlife resources and water quality. The study was designed to quantify environmental perturbations to fish and wildlife habitats arising from forest harvesting operations and to investigate the ability to ameliorate these perturbations through the provision of an unharvested leave strip. This study was initiated under the auspices of the Western Newfoundland Model Forest Program and is multi-agency and multi-disciplinary in nature such that the interests and mandates of various resource management agencies can be addressed in a common framework. This approach will also facilitate integration of study results to evaluate the relative tradeoffs and benefits for resource protection associated with forest harvesting activities and the provision of riparian buffer zones.

The main objective of this, the second technical report developed from the project, is to document the pre-harvesting conditions of the aquatic habitats in the Copper Lake watershed. Thus this report, does not include in-depth discussions of individual observations, as these will be the topics of specific papers, but instead includes a general description of the environmental features (i.e. temperature, sedimentation, water quality and large organic debris) and biological populations (i.e. benthic invertebrates and brook trout) within the watershed before forest harvesting. This information will serve as the baseline data against which the effects of forest harvesting within the watershed, under experimental buffer strip sizes, can be evaluated.

2.0 Introduction

Riparian zones represent an ecotone between aquatic and forest ecosystems and thus support a large diversity of plant and animal life. This complexity creates a highly productive system that is both important as an economic and recreational zone and highly susceptible to external disturbances. These unique features have been the driving force behind the extensive study of forestry-fishery interactions in these areas over the past 30 years (e.g. Krygier and Hall 1970, Salo and Cundy 1987, Hartman and Scrivener 1990).

Most studies of this nature conducted in North America, have been based in the Pacific Northwest (Krygier and Hall 1971, Beschta 1978, Bilby and Ward 1989, Hartman and Scrivener 1990, Fausch and Northcote 1991, Ralph et al. 1993) with a few originating in the Eastern United States (Bilby and Likens 1980, Bilby 1981, Flebbe and Dolloff 1995). The present study is being conducted in the boreal forest of Eastern Canada, namely insular Newfoundland, were there is a complete lack of published material on this subject. The fish/wildlife fauna, climate, forest and bio-physiography conditions are different in these areas, with the eastern Canadian boreal forest generally having shallow erodible soils and a lower species diversity.

These differences are more pronounced in Newfoundland where many important salmonid nursery streams are part of small headwater systems. Much of Newfoundland's harvestable wood lies within these small watersheds increasing the potential for interactions between the forestry and fishery resources. This type of habitat however, has received little attention in the study of forest-fishery interactions to date. Thus, a multi-disciplinary research project, namely the Copper Lake Buffer Zone Study (Scruton et al. 1995), was initiated in a small headwater ecosystem in Newfoundland, Canada to address the ability to ameliorate the effects of forest harvesting through the provision of an unharvested riparian leave strip (buffer zone).

The major objective of this research project is to determine the benefits for the protection of productive capacity of habitats (and fishes) associated with maintaining an unharvested strip of timber along the riparian zones of fluvial salmonid habitat. This will involve contrasting habitat attributes, fish populations, water quantity and quality, and invertebrate communities in stream reaches characterized by: i) no buffer strip (harvesting to the stream edge), ii) harvesting under proposed buffer strip widths (currently, a 20 m strip); iii) harvesting with a strip width of 100 m (as proposed for protection of wildlife species); and iv) no cutting ('control' reaches). The second objective of this research project will be to develop a set of criteria and/or indices to permit an evaluation of sensitivity of fish habitats to the effects of forest harvesting. This may include developing habitat based models, possibly employing habitat suitability indices, that could then be used to evaluate fisheries, forestry, and wildlife values in a framework supporting integrated resource management.

3.0 Materials and Methods

3.1 Study Area

The Copper Lake watershed is a small headwater system (13.5 km^2) located approximately 17 km southeast of Corner Brook, Newfoundland, Canada (Scruton et al. 1995). Within the Copper Lake drainage basin, there are 5 primary (or headwater) tributaries (labeled T1-1 through T1-5) (Figure 1). The tributary numbering scheme followed DFO conventions for hierarchal structure in a drainage basin (Scruton et al. 1992). The outlet of Copper Lake (T1) draining into Corner Brook Lake is a second order (2^0) stream. Survey results from 1993 have identified 3 primary tributaries (T1-1, T1-2, and T1-3) and the second order stream (T1) as containing suitable fish and wildlife habitats and these streams have been selected for study according to the experimental design as described in Scruton et al. (1995).

The watershed is located 350-650 meters above sea level and has an average annual rainfall of 1186 mm. Streams in the watershed have moderate to high gradients ranging from 2.5 to 23.8%. Soils are predominantly moderate to coarse glacial tills derived from intensely deformed and highly metamorphosed rocks (Kennedy 1981) which have a relatively large moisture content. This coupled with the steep hill side slopes creates an increased potential for erodibilty within the watershed (van Kesteren 1992).

The vegetation of the area is typical of the Western Newfoundland Ecoregion (Damman 1983) and is largely composed of mature and over mature balsam fir (*Abies balsam*) with interspersed black spruce (*Picea mariana*) and white birch (*Betula lutea*). A more detailed description of the study area, including maps and project design, is provided in Scruton et al. (1995).

3.2 Stream Surveys

An in-depth stream survey was undertaken in June and October, 1993, of all candidate tributaries following protocols set out in Scruton et al. (1992). Surveys included (i) width/depth transects; (ii) velocity estimates; (iii) typing of substrate; (iv) habitat classification; (v) estimates of cover types including instream vegetation, riparian vegetation, and canopy cover; (vi) assessment of bank height, flood height, bank stability assessment, etc.; recorded for every 100 m stretch, or more frequently as determined by changes in habitat type. Habitat type followed Allen (1951) as modified by Gibson et al. (1987) for application to insular Newfoundland salmonid habitat. Photographs of every section were taken and catalogued. The stream survey data were georeferenced using a hand held Geographical Positioning System (GPS). Helicopter reconnaissance of the area was also completed, with photographs and video taken, to document canopy cover, stream gradient, location of standing water, etc.

3.3 Lake Bathymetry

Depth measurements were collected in June, 1994 to help evaluate the quantity and quality of lentic brook trout habitat in Copper Lake and Jim's Lake (Figure 1). A subsequent set of depth measurements were collected in the small lake which bisects T1-1 during June 1996, here after referred to as Lloyd's Gully. A depth sounder (Model eagle IIA) was used to outline the topography by conducting a number of transects across the lakes in a small motor boat at constant speed and recording depths at 5 sec intervals. These depths were later entered into a SPANS-GIS environment and detailed bathymetric maps were developed for each lake, Figures 2, 3 and 4 for Copper Lake, Jim's Lake and Lloyd's Gully, respectively. An initial analysis of the available littoral area for brook trout production was conducted by calculating the proportion of each lake that was under a depth of 10.0 m. The 10.0 m depth is an arbitrary number which was selected after a literature review and discussion with experts. The applicability of this depth criteria for defining the littoral zone will be tested in the future.

3.4 Hydrology and Water Quality

Hydrology measurements have been collected on the outlet of Copper Lake (T1) starting in May 1994 and continuing throughout the course of the study using an automated hydrometric monitoring station. This station is operated by the Inland Waters Branch of Environment Canada. Discharge measurements collected at this station were averaged on a monthly basis and plotted from the start of the project to the end of 1995 to evaluate the discharge characteristics of the watershed before forest harvesting.

Water samples were collected on a monthly basis starting in November 1993 (Scruton et al. 1995), with more frequent samples being collected opportunistically. A list of the water quality parameters analyzed is presented in Table (1). Methods followed those outlined by Franson et al. 1985, with metals being analyzed by atomic absorption, nutrients and anions by a Technicon Autoanalyzer and descriptive parameters by a variety of benchtop equipments.

3.5 Stream Temperatures

Stream temperature data were collected using Hugrun Seamon underwater temperature recorders (Type A, -2^{0}C to +38^{0}C range, 0.1^{0}C accuracy). Eight (8) thermographs were deployed in the watershed on July 12 and 13, 1993 with an additional two units being added to the sampling regime on October 16, 1993 (Scruton et al. 1995). Thermographs were collected, downloaded and redeployed in October 1993 (8 units), May 1994, October 1994, May 1995 and October 1995. Thermographs were set to record temperature hourly and data was averaged on a daily and monthly basis. Diel and monthly temperature fluctuations were calculated and an analysis of temperature regimes as they relate to published stress limits on brook trout (Lynch et al. 1984) was conducted for each stream. An initial quantification of thermal brook trout habitat has been conducted, the highlights of which is presented here, for a more detailed analysis refer to Scruton et al. (1997).

3.6 Sediment Sampling

Fine particulate sediment accumulation was monitored using modified Whitlock-Vibert boxes (14 cm by 6.4 cm by 8.9 cm deep, with 3.5 by 13 mm openings) as described by Wesche et al. (1989). These boxes (typically used for egg incubation) were filled with cleaned gravel (approximately 25 mm dia.) and a strip of duct tape added to the bottom of the boxes to prevent loss of accumulated fines. Sediment boxes were initially deployed in the candidate streams in July 1993 (Scruton et al. 1995) and were collected in October 1993, May 1994, October 1994, May 1995 and October 1995. The sediment traps were lifted to the surface being careful not to lose the accumulated fine sediment, transferred to plastic collection bags and new traps redeployed at each sampling date. Samples were wet sieved dried at 70 °C for 24 hours and weighed in each of 4 size fractions (<1.40, <0.85, <0.50, <0.09 mm diameter). Confidence intervals used to compare the stream reaches were estimated by randomization with replacement techniques. The methods employed and their ability to discern expected changes in sediment accumulation is discussed in Clarke and Scruton (1997).

An evaluation of road construction and a small (< 20 ha) clear cut on sediment accumulation has been conducted (Clarke et al. 1997a). The highlights of these results will be presented here as they are considered part of the baseline data. This will allow for separate evaluations of road construction, clear cutting and their compounding effects. Road construction bisected T1 in 1993 and T1-1 in the summer of 1994. A limited clear cut was conducted on the upper part of T1-1L which constituted 9% of the stream's watershed (Clarke et al. 1997a). Sediment accumulation as collected by the methods outlined above were compared before and after each of these perturbations.

3.7 Large Woody Debris (LWD)

Evaluation of changes in LWD is conducted through a series of annual LWD surveys in the study streams T1, T1-1L and T1-3, the first of which was conducted in August 1994. These surveys were conducted by walking the stream sections and measuring the length, diameter and noting the orientation to flow of any LWD in the stream channel. These measurements were later converted to a volume for each stream section and an average volume per 30 m of stream length, both in the channel and submerged, was calculated to allow comparison between streams and over time. An initial analysis of LWD and brook trout densities in these streams has been conducted (Clarke et al. 1997b), the highlights of which are outlined in this report.

3.8 Benthic Invertebrates

Pre-harvested benthic invertebrate abundance and community composition were evaluated by deploying artificial substrates in five locations on each of T1, T1-1L, T1-3L and T1-3U (Scruton et al. 1995). These substrates are deployed in May of each year and are allowed to colonize throughout the summer period, being harvested in October. Each substrate consisted of a plastic dish tray filled with cobble size substrate from the adjacent stream bed (Ryan et al. 1985). Specimens collected were sorted, counted and identified to genus where possible, using keys in Merritt and Cummins (1984). Taxonomic lists were developed for each study stream and the average abundance for the major orders were compared between stream reaches. The confidence intervals for average abundance were estimated using randomization with replacement techniques (Edgington 1987). Results from the 1994 field season are presented, those from 1995 were not analyzed at the time of publication.

3.9 Brook Trout Population Analysis

3.9.1 Stream Surveys

Electrofishing surveys were conducted in three sub-tributaries of Copper Lake (T1-1L, T1-3L) and in the stream between Copper Lake and Corner Brook Lake (T1) in August 1993. These surveys were repeated in August 1994 and 1995 with an additional site being added to the sampling regime at T1-3U (Scruton et al. 1995).

Brook trout population estimates were determined by electrofishing using the fixed effort (successive) removal method. Each station was cordoned off with barrier nets to prevent immigration/emigration to/from the study site. Successive sweeps (runs) at each site were made using a backpack electrofisher, with a minimum of four sweeps per site. Electrofishing equipment (Smith-Root Type 12 model) and methods are described in detail in Scruton and Gibson (1995). Population estimates were calculated for all age classes using the Microfish 3.0 program developed by the U.S. Fish and Wildlife Service (Van Deventer and Platts 1989), employing a maximum likelihood (ML) estimator (Burnham formula, Van Deventer and Platts 1983).

All fish were anaesthetized, measured for length (nearest mm), weighed (only fish greater than 0+ in age) using a portable electronic balance (to the nearest gram), and fish 1+ and greater in age had a scale sample collected. Length-weight regressions were calculated for each tributary and these regressions were used to calculate weights from lengths for fish that were not weighed (primarily 0+ or young-of-the-year [YOY]).

Scale samples collected were mounted on glass slides and read using a Bausch & Lomb microprojector at 46X magnification. Number of annuli (total age estimates) and measurement of the radius of each annuli were determined for back calculation of fish growth (Nickerson et al. 1980). These calculations were made for each tributary by cohort using the software program developed by Weisberg (1989).

3.9.2 Lake Surveys

A brook trout population estimate was conducted for Copper Lake in June, 1994 and for both Copper Lake and Jim's Lake in June 1995. Fyke nets were deployed in Copper Lake at five locations in both years and fishing continued for approximately ten days (Scruton et al. 1995). Estimates of Jim's Lake were conducted by fishing four fyke nets for a duration of eight nights. Fish caught during these estimates where marked with an anal fin clip and released, length, weight and scale samples were collected for analysis. The population estimate was calculated by the Schnabel multiple markrecapture method outlined in Ricker (1975). This part of the study will be expanded in the future to include Lloyd's Gully.

3.10 Movement/Migration Studies

A detailed study of brook trout movement within the Copper Lake watershed was conducted from early June to mid October of 1994 and 1995 (McCarthy 1997, McCarthy et al. 1997a). Movement indices as outlined in Bergersen and Keefe (1976) were developed for brook trout in T1-1L, T1-3U in 1994 with T1-3L being added to the sampling regime in 1995. Movement was monitored by the use of modified counting fences on each stream (Scruton et al. 1995, McCarthy et al. 1997a). Brook trout were tagged with individually number Floy tags during electrofishing and fyke net surveys, subsequent fish were captured throughout the summer by angling (McCarthy 1997, McCarthy et al. 1997a). The indices developed were compared with a variety of habitat features, which were expected to change as a result of forest harvesting, within each stream. A subsequent movement study was conducted in August, 1995 with 19 of the larger brook trout using radio telemetry techniques (McCarthy et al. 1997b).

4.0 Results and Discussion

4.1 Stream Surveys

The stream sections surveyed are identified in Figure 1. In total, 49 sections were surveyed in detail on tributaries T1 (14 sections), T1-1L (6 sections), T1-2 (10 sections - lower, 3 sections - upper), and T1-3 (4 sections - lower, 13 sections -upper). A summary of the characteristics observed in each stream is provided below.

Tributary T1, the main outlet of Copper Lake flowing downstream to Corner Brook lake, was surveyed for the entire length of 1399 m. A total of 14 sections were surveyed totaling 117.3 habitat units (1 unit = 100 m^2). The habitat in this stretch of river was characterized as 66% riffle and 31% rapids. Mean wetted widths (m), channel widths (m), and depth (cm) were 8.85, 11.1, and 13.0, respectively. Mean substrate composition for the reach, as percentages, includes bedrock (2), large boulder (20), small boulder (36), rubble (21), cobble (12), pebble (5), gravels (3), and fines (1). It is noteworthy that there is no pool habitat in this reach. Twelve (12) of the sections included canopy cover for a total of 28% of the reach. Obstructions noted in this reach included a falls at section 3 of 1.5 meters in height (deemed passable to adult brook trout).

Tributary T1-1L was surveyed for a total length of 527 m to a set of major impassable falls at the end of section 5 (Lloyd's Gully; Figure 1). Over this length, a total of 5 sections were surveyed totaling 17.78 habitat units. This stretch of river was characterized as having 90% riffle with 10% steady habitat. Mean wetted widths (m), channel widths (m), and depth (cm) were 3.4, 6.3, and 6.0 respectively, reflecting the relatively smaller drainage basin of this tributary. Mean substrate composition for the reach, as percentages, included bedrock (5), large boulder (4), small boulder (17), rubble (26), cobble (32), pebble (14), gravels (3), and fines (0); reflecting the smaller nature of substrate material relative to T1 indicative of the differences in hydrologic and geomorphological control. Again, pool habitat was completely absent in this stretch. All five (5) sections included canopy cover for a total of 45% for the reach.

Tributary T1-2 was surveyed for a total length of 1295 m to an extremely steep stretch above section 13 and this was divided into lower (sections 1 - 10) and upper (sections 11 to 13) reaches. Over this length, the 13 sections totaled 45.1 habitat units (34.0 units - lower, 11.1 units - upper). The lower river was characterized as having 68% riffle with 30% other habitat while the upper reach was 98% riffle habitat. Mean wetted widths (m), channel widths (m), and depth (cm) are 3.5, 6.1, and 9.0, respectively, similar in character to T1-1L. Mean substrate composition for the reach, as percentages, included bedrock (25), large boulder (6), small boulder (26), rubble (25), cobble (14), pebble (2), gravels (1), and fines (0). Pool habitat was completely absent on this tributary as well. Nine (9) sections included canopy cover for a total of 54% for the entire stream reach. The survey identified a total of 6 obstructions over this 1.3 kilometer stretch including a 1.0 m debris/log jam (section 1), a 7.0 m falls (section 6), a chute (section 7), a 9.0 m falls (section 8), and 2 falls (10 and 1.5 m) at the end of section 9. Three (3) of the 4 falls identified are likely impassable to adult brook trout.

Tributary T1-3 was surveyed for a total length of 1595 m, divided into lower (sections 1 - 4) and upper (sections 5 to 17). Over this length, the 17 sections totaled 76.7 habitat units (39.1 units - lower, 37.6 units - upper). The lower reach was characterized as having 75% riffle with 25% steady habitat while the upper reach was 70% riffle with 17% run, 8% steady, and 3% rapid habitats. Mean wetted widths (m), channel widths (m), and depth (cm) were 4.0, 5.8, and 9.0, respectively. Mean substrate composition for the reach, as percentages, included bedrock (3), large boulder (7), small boulder (21), rubble (24), cobble (15), pebble (15), gravels (13), and fines (3). Generally, the upper reach was characterized as contained higher proportions of the finer substrates (pebbles, gravels fines). Pool habitat was completely absent on this tributary as well. Eleven (11) sections included canopy cover for a total of 26% for the entire stream reach, with a higher percentage of canopy cover in the lower section (72%). The survey identified a total of 3 obstructions over this 1.6 kilometer stretch including two debris/log jams (section 4 and 6) and a 5.0 m falls (section 8).

There are a number of standing water bodies in the study area including Copper Lake. On tributary T1-1, there were 4 lakes identified, totaling 15.2 hectares. All of these lakes except Lloyd's Gully (4.4 ha) were above the fluvial habitat surveyed. On tributary T1-2, there were 6 small lakes identified totaling 6.5 hectares, 4 of these were above the fluvial habitat to be studied. Tributary T1-3 contained 7 lakes totaling 30.0 hectares including Jim's Lake (17.5 ha) between the upper and lower reaches. The other lakes on this tributary were above the habitat surveyed. Copper Lake, the major standing water body in the study area is 82.4 ha.

4.2 Lake Bathymetry

Copper Lake is located in a valley with steep slopes which continue into the lake creating a sharp drop-off from the shore that results in a large proportion of the lake being relatively deep (Figure 2). The average depth in June, 1994 was 19.96 m with a maximum depth of 45.43 m. Only 2.6% or 2.12 ha of the lake area has a depth less than 10.0 m (defined as the littoral zone). This bathymetric profile suggests that there is relatively little littoral area in the lake suitable for brook trout production, which are visual benthic/surface predators.

Jim's Lake located in the middle of tributary T1-3 is also located in a valley with a steep slope on one side which continues into the lake. The opposite side of Jim's Lake however, has a moderate slope and the depth profile is more gradual on this side of the lake (Figure 3). The average depth in June 1994 was 9.43 m with a maximum depth of 24.39 m. Fifty-two percent (9.1 ha) of the lake was less than 10.0 m in depth suggesting that a higher proportion of this lake is suitable for brook trout production.

Lloyd's Gully which is a small lake bisecting T1-1 is located on a small plateau (Figure 1). The lake is relatively uniform in depth, average depth 5.94 m in June 1996 (Figure 4). The maximum depth at this time was 28.05 m and 77% (3.4 ha) of the lake had a depth less than 10.0 m.

4.3 Hydrology and Water Quality

Copper Lake watershed had a mean annual flow (MAF) of 0.473 m^3s^{-1} during 1995, the first full year of hydrological monitoring. The monthly flows observed in 1994 were of a similar magnitude to those of 1995 (Figure 5) so we have assumed that the MAF recorded in 1995 is typical for the watershed. From this MAF and the total watershed area (13.5 km^2) it is possible to estimate the MAFs for the individual tributaries within the watershed. T1-1, T1-2, and T1-3 have drainage basins of 2.022, 1.926, and 3.593 km^2, which calculate into estimated MAFs of 0.071, 0.067, and 0.126 m^3s^{-1}, respectively. The seasonal distribution of runoff for the Copper Lake watershed was typical of a river located on the west coast of Newfoundland (Newfoundland and Labrador Department of Environment and Lands - Water Resources Division 1992) displaying two peak flow periods (Figure 5). The greatest period of runoff was observed in spring (May and June) and is associated with snow melt. The second peak in runoff is associated with rainfall in the fall and was approximately half the magnitude of the spring runoff . Low flow periods were in the summer months, July through early September, associated with low rainfall and winter, January through March, when precipitation is accumulated as snow. The Copper Lake watershed being a headwater system with no upstream standing water storage was quick to react to extreme rainfall events. This attribute was highlighted during a rain storm in early June, 1995. The daily discharge on June 7, 1995, before the storm, was 0.631 m^3 s^{-1} this had increased to 5.89 m^3 s^{-1} the next day and 6.62 m^3 s^{-1} on the ninth both of which were during the storm. The high flows receded just as quickly being 2.43 m^3 s^{-1} on the tenth and 0.655 m^3 s^{-1} on the eleventh which was similar to the flow observed before the storm.

The streams being monitored in the Copper Lake watershed were similar in water quality characteristics (Table 1). These streams are acidic (average pH ranging from 5.70 - 6.26), soft (average $CaCO_3$ concentrations ranging from 2.7 - 4.8 mg/L), and oligotrophic (average NO_3 and total phosphorus concentrations 0.013 - 0.043 mg/L and 0.01 - 0.02 mg/L, respectively). Total Dissolved Solids (TDS) were similar in the study streams (15.1 - 17.8 mg/L) with chloride, sulfate and carbonate constituting the major anions and sodium, calcium, magnesium, and potassium constituting the major cations (Table 1). Metal concentrations were generally low to below detection in the study streams with iron, manganese, aluminum having the highest concentrations and, occasionally, copper and zinc in detectable quantities (Table 1).

An important water quality parameter in this study will be turbidity as an indicator of suspended sediment load. Average turbidity measurements for the period from November 24, 1993 to November 3, 1996 indicate a low level of natural sedimentation in the study streams with average turbidity ranging from 0.34 - 3.83 NTU and Total Suspended Solids (TSS) averaging 2.1 to 18.1 mg/L (Table 1). An exception to this general trend in turbidity measurements was observed in T1-1L which had a small clear cut on its upper portion before the summer of 1995. This clear cut compounded by an intense rain storm in June 1995 created the upper limits of TSS and turbidity observed in T1-1L (Table 1). This extreme observation thus biased the average turbidity measurement for the stream reach over the course of the study. Measurements collected before the perturbation were similar in T1-1L to those observed in the other streams (Scruton et al. 1995). This will be closely monitored in the future to evaluate the relative effect intense storms have on the turbidity of harvested and non-harvested streams.

4.4 Stream Temperatures

The pre-harvested temperature regimes of the study streams had a distinct seasonal pattern with peak water temperatures being observed in July and August of each year (see example; Figure 6). During the summer months daily mean temperatures rarely exceeded 20 °C which is considered stressful for brook trout (Fry 1951, Raleigh 1982). The daily mean temperatures in the summer were generally within the optimum temperature range for brook trout growth, which is between 11-16 °C (Fry 1951, Raleigh 1982). The daily maximum temperatures however, did go above 20 °C on a regular basis in all the study streams (Figure 6). This observation differs from previous studies where pre-harvested temperatures generally were lower (Feller 1981, Lynch et al. 1984, Brownlee et al. 1988). This is due to the small, shallow nature of the streams and suggests that these streams may be more sensitive to changes in water temperature resulting from forestry practices than those studied on mainland North America.

Brook trout eggs can be killed by temperatures exceeding 12.2 °C (Fry 1951, Raleigh 1982), therefore the spawning season (September - November) is a temperature sensitive period. Temperatures during the spawning period in 1993, 1994 and 1995 (pre-harvested) were below 10 °C in all the study streams, indicating good temperature conditions for brook trout egg survival.

Quick changes in temperature can also be stressful to aquatic organisms and a diel fluctuation of 6 °C per day has been suggested to be stressful for brook trout (Lynch et al. 1984). The diel temperature fluctuations exceeded this stress limit on a regular basis in the study streams during the summer months (see example; Figure 7), several of the streams had monthly averages ranging from 4-6 °C/day. These diel fluctuations are high when compared to those reported from studies conducted on mainland North America, where a pre-harvested diel temperature fluctuation of 2-3° C has been observed to be the norm (Feller 1981, Lynch et al. 1984, Brownlee et al. 1988). This can also be related to the shallow, low flow nature of these streams and the large changes in air temperature owing to the relatively high elevation of these streams.

An analysis of the suitability of the study streams for brook trout production in relation to their thermal habitat has been conducted (Scruton et al. 1997). It was found that these small headwater streams were high quality thermal habitats with calculated HSIs ranging from 0.72 to 0.82 for streams with complete thermal records (Scruton et al. 1997). The unharvested streams supply a cooling effect from the upper to lower reaches (Figure 8). This was due to the shading provided by the intact riparian vegetation. The lakes also played a role in thermal regulation as they warmed the water passing through them in the latter parts of the summer (Figure 8). These results, will assist in understanding thermal regulation in the watershed and will provide confidence for post harvest comparison. This will assist in the determination of the effectiveness of the varius buffer widths in protecting brook trout thermal habitat.

The small clear cut conducted on the upper part of T1-1L prior to the field season of 1995 allowed for the first of these comparisons. The harvesting was observed to alter the thermal conditions in the stream (Scruton et al 1997). The daily mean and maximum temperatures as well as the diel fluctuations were observed to increase in the harvested stream. These changes did not, however, result in a significant change in the thermal HSI. A more in-depth analysis of the effect this limited cut had on the thermal habitat of brook trout is discussed in Scruton et al. (1997).

4.5 Sediment Sampling

The average fine particulate sediment by particle size for the first five sampling dates (October 1993, June and October 1994, 1995) is presented in Table 2. The first sampling date was designed to evaluate the effect of a road crossing on the sediment yield in the 2° stream T1, with T1L being the affected stream reach and T1U and T1-1L acting as control reaches. The total average sediment yield was significantly higher in T1L while the control reaches had similar sediment yields (Figure 9).

Sampling effort was increased in the second year of the study to include at least one stream reach in each of the proposed buffer zone treatments (Scruton et al. 1995). The effect of a road crossing on sediment yield was again evaluated by placing sediment samplers above and below the crossing in T1-1L, which allowed for a test of the T1 experience in the previous year, as no base line data was collected in T1 before the road crossing. The total average particulate sediment yield was significantly higher in T1-1L (below the road) than T1-1U in the June 1994 (Figure 9), this result was similar to observations for T1 in October 1993. T1 still had an elevated sediment yield in June

1994 but it was not significantly different than that of T1-1L. T1-1U and T1-3U had similar sediment yields in June 1994 which was significantly higher than that observed for T1-3L (Figure 9). The October 1994 sampling date revealed a similar pattern to that observed in June 1994 with T1 and T1-1L having significantly higher total sediment yields than the other stream reaches but not being significantly different from each other (Figure 9).

In June 1995, after limited forest harvesting, the sediment deposited in T1-1L was significantly higher than all the other streams. The accumulation observed in T1 was still elevated as compared to the other streams but was not as high as that observed in T1-1L (Figure 9). The sediment accumulation had returned to normal levels in T1 by October 1995 while that observed in T1-1L was still significantly higher than that observed in all the other streams reaches (Figure 9). The road crossing and limited clear cut have confounded these results and may have combined to increase sediment accumulation in T1-1L as compared to T1 and the other streams.

Sediment accumulation was greater after the spring freshet ('June') than that observed for the summer low flow period ('October') (Figure 9). Seasonal differences in sediment accumulation for the undisturbed stream reaches T1-1U, T1-3L and T1-3U were 10.2, 2.1 and 7.2 respectively in 1994. The smallest decrease from the June to October sample was observed in T1-3L (2.1), which was due to consistently lower sediment accumulation throughout the monitoring period. A similar pattern was observed in 1995 although the seasonal difference observed in T1 was much higher than that of 1994 indicating that sediment accumulation in this stream may have returned to 'normal' by October 1995 (Figure 9). Seasonal patterns of sediment accumulation at the road crossings were similar to the other stream reaches, but the magnitude of decrease from June to October was lower, 3.3 and 4.0, for T1 and T1-1L respectively; in 1994 (Figure 9) and 2.6 in 1995 for T1-1L (Figure 9). Thus, the increased sediment accumulation over the summer may be of more importance to the biological populations in these habitats because it does not occur in the natural environment, while increased sediment after spring run off is a natural occurrence. Also, this is the most important time for growth and development for biological populations utilizing these habitats.

There was very little inter-annual variation observed in sediment accumulation between corresponding sampling dates in the unperturbed streams (Figure 9). This observation persisted in spite of a large hydrological event in early June of 1995. In the perturbed streams no difference was observed in the June samples for T1 while that of T1-1L was significantly higher in 1995 which appears to be due to the limited clear cutting on that stream reach (Figure 9). When comparing the 'October' samples we observed a significant reduction in sediment yield in T1 and a significant increase in T1-1L from 1994 to 1995 (Figure 9). This suggests that the limited clear cut has increased the sediment accumulation on T1-1L and the total accumulation for this stream is due to a combination of the road crossing and the clear cut.

4.6 Large Woody Debris (LWD) Survey

The frequency of LWD (#/30 m) averaged over the two year period was highest in the 2° stream T1 followed by T1-3U, T1-1L and T1-3L, respectively (Figure 10). There was no trend observed between stream size and frequency of LWD as has been the case with studies conducted on the west coast of North America (Bilby and Ward 1989, Robinson and Beschta 1990b, Bilby and Ward 1991) and the observation of the highest frequency in the largest stream is in direct contradiction to the findings of these studies. The lack of a relationship between LWD and stream size may, in part, be a function of the narrow range in widths in the study streams or the limited sample size (i.e. one 2° stream).

Changes in LWD frequency between 1994 to 1995 were most pronounced in T1-3L and T1-3U with a 3.4 and 1.7 fold increase respectively (Figure 10), both of which were significant ($p < 0.05$). In contrast, T1-1L, the other 1° stream, had a significant ($p < 0.05$) 1.5 fold decrease in the numbers of LWD from 1994 to 1995 (Figure 10). A decrease in numbers was also observed in the 2° stream (T1), however, the 1.9 fold change was not significant ($p < 0.05$) (Figure 10). It appears the natural trend for the smaller streams in the watershed was an increase in LWD number from 1994 to 1995. This increase was likely related to a severe rainstorm in the watershed in early June of 1995 (see hydrology above). Estimated discharge at T1-1L (McCarthy 1997) was 3584 m^3s^1, or about 896 times the mean annual discharge, and approximately a 176 fold increase in seasonal discharge levels before this storm event. The difference observed between the other 1° streams, T1-3U and T1-3L, and T1-1L was most likely due to harvesting of the top 200 m, without a riparian buffer strip. This removal of trees meant that T1-1L did not have a source of LWD to draw from in 1995, and the high water levels caused by the rainstorm event reduced the frequency of LWD by flushing the channel.

T1-3U had the highest observed volume of LWD per 30 m of stream in both 1994 and 1995 followed by T1, T1-1L and T1-3L, respectively (Figure 11). There was no discernable trend between LWD volume in the stream channel and stream size.

The LWD volume per 30 m of stream between 1994 and 1995 decreased 2.0 and 2.4 fold in T1 and T1-1L, respectively (Figure 11), both of which were significant ($p < 0.05$). These decreases correspond to decreases in number of LWD observed in these streams over the same period. Volumes in T1-3U and T1-3L did not change significantly from 1994 to 1995, however, T1-3U demonstrated an increase in volume corresponding to an increase in number. The only stream to have differing trends in numbers and volume from 1994 to 1995, T1-3L, demonstrated an increase in numbers (Figure 10) while volume remained the same (Figure 11). These observations suggest the larger LWD's observed in T1-3L in 1994 were flushed from the stream channel, presumably during the rainstorm of June 1995, and replaced by smaller LWD's with greater frequency in 1995. Consequently, all streams except T1-3U, were observed to have a pronounced flushing of LWD from the stream channel due to the hydrological peaks related to the June, 1995 rainstorm.

Observations of submerged LWD volume did follow a continuum based on stream size where the widest stream was observed to have the most submerged LWD on average with the smaller streams having less submerged LWD (Figure 12). All streams in the Copper Lake watershed were observed to have a reduction in the volume of submerged LWD from 1994 to 1995 with the exception of T1-3L. The reduction in submerged volume observed in T1 and T1-1L were 17.0 and 14.3 fold, respectively, indicative of relative rates of flushing of LWD observed in these streams due to the high water flows in June 1995 and the forest harvesting in T1-1L.

The orientation of LWD within the streams was calculated on a percentage basis to discern any trends within the watershed and to make a preliminary comparison of these trends with observations from the west coast of North America. Smaller 1° streams had more LWD placed perpendicular to the stream flow (32-53%) than did the 2° stream T1 (24-26%) (Figure 13) and this is likely related to relative difference in stream energy and the ability to dislocate LWD during hydrological events. These observations are similar to those noted by Bilby and Ward (1989) in Washington streams but differ from observations in Southeast Alaska by Robinson and Beschta (1990b). Little change in LWD orientation was observed from 1994 to 1995 except in T1-3L were the large number of perpendicular LWD's were replaced (or displaced) by/to LWD's directed downstream relative to the flow.

An analysis of these LWD dynamics and their relationship to the brook trout populations observed in these streams has been conducted (Clarke et al. 1997). It was found that both LWD numbers and volume was negatively correlated to brook trout density. This unusual observation was hypothesized to be due to either the population structure in these small streams and/or their role as spawning and incubation areas. Refer to Clarke et al. (1997) for a more thorough discussion of these observations.

4.7 Benthic Invertebrate Populations

The lotic benthic community in the Copper Lake watershed was composed of organisms that have widespread distributions, similar to most freshwater benthic communities in Newfoundland (Larson and Colbo 1983). The community was dominated by Ephemeroptera and Trichoptera with Plecoptera and Diptera occurring in moderate abundances. The pre-harvested Ephemeroptera community consisted of three abundant families, Ephemerellidae, Leptophlbiidae and Heptageniidae while the majority of the Plecoptera were from the family, Perlidae. The pre-harvested Trichoptera community was composed of genera from 7 families with the most abundant of these being variable between streams and sampling sites within streams. The Hydropsychidae, Hydroptilidae, Lepidostomatidae and Leptoceridae all have been observed in relative abundance in isolated pockets in the pre-harvested streams with the Hydropsychidae being the most common.

The pre-harvested abundances of the major benthic invertebrate orders are presented in Figure (14). The study streams T1-1L and T1-3U had similar ephemeropteran abundances which were significantly lower ($p<0.05$) than those observed for T1 and T1-3L. The abundances of the other three major benthic orders were observed to have similar patterns with the study streams T1, T1-1L and T1-3L generally having significantly lower abundances than T1-3U (except for Trichoptera which was not significant). Data collected during the 1995 field season was not analyzed at the time of publication.

4.8 Brook Trout Population Analysis

4.8.1 Stream Surveys:

Fluvial brook trout populations were investigated in tributaries T1, T1-1L, and T1-3L during August 1993 with an additional tributary, T1-3U, being added to the sampling regime in 1994. Details on the characteristics of each electrofishing station are provided in Table (3). The majority of the stations were established in 100% riffle type habitats except station 4 and 12 which were comprised of riffle (69%, 75%, respectively) and steady (31%, 25%, respectively), station 10 which was 100% steady and station 11 which was comprised of run (60%) and riffle (40%) habitats. Most stations were dominated by small boulder/rubble/cobble substrate and 6 of 12 stations were characterized by 40% or greater canopy cover. Station areas ranged from 1.24 units to 3.43 units (1 unit=100m^2).

Brook trout population estimates for the electrofishing stations during August 1993, 1994 and 1995 are presented in Tables 4, 5 and 6, respectively. Densities ranged from 15.58 (station 4) to 72.61 (station 1) per unit during August 1993, from 7.53 (station 6) to 125.14 (station 11) per unit during August 1994 and from 2.40 (station 6) to 96.24 (station 12) per unit during August 1995. Total populations were highest in T1-3L (stations 1, 2 and 3), ranging from 44.45 to 72.61 per unit (x=56.88) during August 1993 while the lowest densities, ranging from 15.58 to 19.64 per unit ($\bar{x}$ = 17.66) were observed in T1-1L (stations 4, 5 and 6). The same general trend was observed in 1994 and 1995 with the exception of the new stream reach, T1-3U (stations 10, 11 and 12), which had the highest densities. These trends are outlined graphically in Figure 15. The population estimates were similar in tributaries T1 and T1-3L with some inter annual variation, while those of T1-1L were approximately 2 fold lower and those of T1-3U were approximately 2-fold higher. Densities declined significantly in both T1-1L and T1-3L ($p < 0.05$) from 1993 to 1994 while those of T1 remained unchanged.

The age-class distributions were similar in the streams over the first three years of this study with the young of the year (YOY) and 1+ being the dominate age class observed (Figure 16). There was a declining trend from YOY through to the older fish in the population in all the streams except T1-1L were the numbers of YOY fish were lower than expected. This distribution indicates that these small streams are heavily utilized as nursery areas by brook trout. The maximum age observed over the two years was 5+ suggesting a short lifespan is the norm for brook trout in the Copper Lake watershed.

Size frequency distributions for the streams over the course of the study are presented in Figure 17, with fork lengths ranging from 33-263 mm. These distributions were similar within streams over the three years with the exception of T1 were the average fork length observed was higher in 1993 than 1994 and 1995 (Figure 17). The distributions are heavily skewed towards the lower end of the scale again indicating the role of the lotic habitat as primarily nursery area. The relatively low maximum length (263 mm) suggests that growth rates in the area are low when compared to other insular Newfoundland populations (Ryan and Kerekes 1988).

Length-weight regressions were developed for trout captured in each stream during the first three sampling years to compare the condition of fish, 1+ and greater in age, between streams and years. The plots of these regressions are presented in Figure 18 for 1993, Figure 19 for 1994 and Figure 20 for 1995 with the summary statistics in Table 7. The regression line developed from fish captured in T1 during 1993 was significantly different ($p<0.05$) than those developed for the other two tributaries, T1-1L and T1-3L (Table 7). This difference is due to a larger slope in the line developed for T1 trout, suggesting a better growth rate for T1 trout as compared to those sampled in the other two tributaries which had very similar length-weight characteristics (Table 7).

The regressions for trout in T1-3U and T1 were similar in both slope and intercept in 1994 (Table 7) while the trout in T1-1L had a significantly lower slope and those sampled from T1-3L had a significantly higher slope. If we compare the three streams that were sampled in both years on an annual basis the slopes of the lines were significantly ($p<0.05$) higher in 1994 as compared to 1993 for trout sampled in tributaries T1 and T1-3L but no change was observed in T1-1L (Table 7). This observation suggests that conditions for trout growth in the Copper Lake watershed were improved in 1994 as compared to 1993 but the improvement of conditions in T1-1L were held in check by some environmental variable unique to this stream. This stream (T1-1L) was crossed by road construction during the early summer of 1994 increasing sedimentation (see above), which is one plausible explanation for the different length-weight characteristics observed.

The length-weight regressions were again similar in T1 and T1-3U in 1995 (Table 7). These streams had significantly higher slopes than the other two streams, T1-1L and T1-3L, which were similar to each other. The regression statistics were similar in T1, T1-1L and T1-3U in the first three years of the study (1994 and 1995 for T1-3U). Those observed in T1-3L were lower in 1995 than 1994 but were similar to those observed in this river in 1993 (Table 7). The general trend in 1995 was for lower slopes on average but T1-3L had the only significant change while T1-1L did not change significantly. These statistics will be monitored in the post harvest years to discern any changes in growth rate due to the harvesting practices.

Summary statistics and biomass estimates by electrofishing station for the pre-harvested streams are presented in Tables 7, 8 and 9 for 1993, 1994 and 1995 respectively. The average biomass by stream reach was the lowest in T1-1L in all three years with a decline being observed in each subsequent year (Figure 21). T1-3U had the highest average biomass observed of the streams in both years it was sampled but there was a decline in 1995 from 1994 (Figure 21). In general, average biomass declined in 1994 from 1993 levels except in T1-3L where there was no change. There was a subsequent decline in 1995 except in T1 were there was a slight increase. The only streams to have a consistent trend in average biomass over the first three years were T1-1L and T1-3U. T1-1L has been affected by a road crossing and a limited clear cut and it will be of interest to see if the downward trend in biomass continues in this streams or if it rebounds.

4.8.2 Copper Lake Survey:

A total of 529 brook trout were captured in Copper Lake during the population estimate of

1994 with a total of 53 recaptures. This resulted in a final multiple estimate of 2662 brook trout or a density of 32.3 ha^{-1} (Table 11). In 1995, 343 brook trout were marked in Copper Lake with 19 recaptures and 696 brook trout were marked in Jim's Lake with 138 recaptures (Table 12). The population estimates were thus 2880 and 2043 for Copper Lake and Jim's Lake, respectively, corresponding to density estimates of 34.95 ha^{-1} and 116.74 ha^{-1}. The density estimates observed in Copper Lake are at the low end of estimates observed in other lakes of insular Newfoundland while the Jim's Lake estimate was relatively high (Knoechel and Ryan 1994). These estimates will be expanded, to include Lloyd's Gully, in subsequent years.

The age distribution of trout in Copper lake during 1994 was dominated by the 2+ and 3+ fish (Figure 22) with the maximum age observed of 5+. This age distribution when viewed in light of the age distribution observed in the streams suggests that trout in this watershed utilize the stream habitat during their first and second year of life and then move into the lake to continue their growth and development after the second year returning to the stream to reproduce. This observation is a generalization and individual fish would be expected to vary their behavior in respect to their movement to and from the stream habitats. These differences may well be correlated to environmental variables, one of which may be changes induced by forest harvesting practices. This is the basis for a graduate research project being conducted by J. McCarthy of Memorial University of Newfoundland on the movement/migration of brook trout within the Copper Lake watershed (see below). Also, a telemetry project conducted in the summer of 1995 revealed that some brook trout spawned in the lakes, so it would be reasonable to expect some juvenile rearing occurred in the lakes as well (see below).

Fork length ranged from 82-382 mm in Copper Lake during 1994 with an average of 160 mm and a median of 158 mm (Figure 23). The most common size classes were between 120-200 mm which correspond to the 2 and 3 year old fish. These observation again highlight the small slow growing nature of the brook trout population in this watershed.

A length-weight regression was developed for trout sampled in Copper Lake during the population estimate of 1994 and is presented in Figure (24). This regression will be used to compare the growth and condition of the fish in Copper Lake just after spring breakup through time and between lakes. The length, weight and age data for the lakes sampled in 1995, Copper Lake and Jim's Lake, was still being analyzed and verified at the time of publication

4.9 Movement/Migration Studies

The results of the movement/migration studies conducted in 1994 and 1995 by J.H. McCarthy under the supervision of J.M. Greene, Memorial University of Newfoundland, have been analyzed and discussed in a M. Sc. Thesis (McCarthy 1997). The project was repeated during the 1996 field season, after harvesting, and will become a part of the post harvesting analysis. In general, there was no significant ($p < 0.05$) difference in the movement index calculated for the brook trout populations in T1-1L and T1-3U within years (Figure 25). There was a decline in the calculated index from 1994 to 1995 observed in both streams. This decline was significantly different in T1-1L but the indices were not different between streams (Figure 25). The significant reduction in the overall movement of trout in T1-1L in 1995 was hypothesized to be the result of the limited clear cut that occurred on this stream before the field season of 1995. A more in-depth look at the movement patterns within these streams revealed that there was in fact observable differences in the direction of movement from 1994 to 1995 in T1-1L. The proportion of brook trout moving from the upper reaches of T1-1L declined in 1995 and there were significantly more fish leaving the stream and moving into the lake (McCarthy et al 1997a). The most notable difference in habitat parameters measured in T1-1L from 1994 to 1995 was the increase in sedimentation (see above; Clarke et al. 1997a). It was therefore hypothesized that the brook trout were actively avoiding the high levels of sediment in T1-1L by moving into the lake (McCarthy et al. 1997a). The initial results from this project are an indication of what we may expect to see in relation to brook trout movement after the cutting plan has been completed.

A telemetry project was conducted within the Copper Lake watershed form August 10 to October 7, 1995 to evaluate the range size of the larger (>100 g) brook trout (McCarthy et al. 1997b). Movements were variable but 88% of the fish exhibited a range that was less than one third their 'home' lake. Of the 19 trout tagged with surgically implanted radio transmitters, 3 moved into tributary streams to spawn. There was no movement between lakes and several of the trout were observed to be located over potential lacustrine spawning areas (Figure 26). This was later confirmed by the observation of redds at these locations. A more through discussion of the results of this project are outlined in McCarthy et al. (1997b).

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Table 1: Average and range (in brackets) of water quality parameters in the pre-harvested streams of the Copper Lake watershed (24 Novmber 1993 - 3 November 1996).

Water Quality Parameter	Stream Reach T1	T1-1L	T1-2	T1-3L	T1-3U	T1-5
Iron (mg/L)	0.04 (0.005 - 0.14)	1.78 (0.023 - 42.0)	0.26 (0.02 - 4.0)	0.15 (0.005 - 0.97)	0.21 (0.03 - 0.76)	0.14 (0.03 - 0.46)
Colour (TCU)	36 (30 - 46)	62 (43 - 91)	41 (24 - 82)	44 (34 - 69)	51 (25 - 84)	39 (18 - 73)
Spec.Cond. (µS)	19.1 (15.7 - 24.7)	18.5 (13.3 - 25.8)	22.8 (12.1 - 33.0)	19.3 (15.0 - 24.3)	22.0 (12.8 - 31.1)	21.9 (11.9 - 21.9)
Hardness (mg/L CaCO)	2.7 (2.1 - 3.4)	3.2 (1.5 - 13.3)	4.8 (2.0 - 4.8)	2.7 (1.6 - 3.9)	3.1 (1.2 - 4.9)	3.0 (1.6 - 4.5)
Calcium (mg/L)	0.58 (0.30 - 0.76)	0.64 (0.04 - 1.32)	1.30 (0.05 - 2.62)	0.55 (0.19 - 1.02)	0.65 (0.1 - 1.29)	0.57 (0.21 - 1.0)
Copper (mg/L)	0.0028 (0.0025 - 0.01)	0.0038 (0.0025 - 0.02)	0.0032 (0.0025 - 0.02)	0.0025 (0.0025 - 0.0025)	0.0025 (0.0025 - 0.0025)	0.0025 (0.0025 - 0.0025)
Nitrate (mg/L)	0.038 (0.002 - 0.055)	0.014 (0.002 - 0.058)	0.043 (0.002 - 0.172)	0.016 (0.002 - 0.047)	0.013 (0.002 - 0.055)	0.023 (0.002 - 0.069)
Turbidity (NTU)	0.34 (0.06 - 0.84)	40.22 (0.03 - 1060.0)	3.83 (0.04 - 84.8)	0.64 (0.1 - 8.87)	0.60 (0.11 - 2.63)	0.59 (0.05 - 5.1)
Zinc (mg/L)	0.0030 (0.0025 - 0.01)	0.0090 (0.0025 - 0.12)	0.0043 (0.0025 - 0.03)	0.0025 (0.0025 - 0.0025)	0.0025 (0.0025 - 0.0025)	0.0029 (0.0025 - 0.01)
pH	6.08 (5.62 - 6.84)	5.70 (5.08 - 6.53)	6.26 (5.35 - 6.89)	5.92 (5.25 - 6.66)	5.92 (5.12 - 6.9)	6.08 (5.42 - 6.7)
Magnesium (mg/L)	0.30 (0.16 - 0.41)	0.39 (0.11 - 3.22)	0.38 (0.16 - 0.79)	0.32 (0.21 - 0.45)	0.36 (0.12 - 0.48)	0.40 (0.2 - 0.53)
Cadmium (mg/L)	0.0003 (0.0003 - 0.0003)	0.0003 (0.0003 - 0.0003)	0.0003 (0.0003 - 0.0003)	0.0003 (0.0003 - 0.0003)	0.0003 (0.0003 - 0.0003)	0.0003 (0.0003 - 0.0003)
Total Phosphorus (mg/L)	0.01 (0.01 - 0.05)	0.02 (0.01 - 0.11)	0.01 (0.01 - 0.02)	0.01 (0.01 - 0.04)	0.01 (0.01 - 0.04)	0.02 (0.01 - 0.16)
Manganese (mg/L)	0.0056 (0.0025 - 0.04)	0.0241 (0.0025 - 0.42)	0.0201 (0.0025 - 0.2)	0.0097 (0.0025 - 0.07)	0.0127 (0.0025 - 0.11)	0.0081 (0.0025 - 0.0081)
Lead (mg/L)	0.0007 (0.0005 - 0.003)	0.0009 (0.0005 - 0.008)	0.0006 (0.0005 - 0.002)	0.0006 (0.0005 - 0.002)	0.0005 (0.0005 - 0.001)	0.0007 (0.0005 - 0.003)
Chloride (mg/L)	2.8 (1.8 - 3.8)	2.7 (1.8 - 4.9)	2.8 (1.3 - 4.8)	2.7 (1.9 - 4.4)	2.9 (1.7 - 4.5)	2.9 (1.6 - 3.6)
Sodium (mg/L)	1.83 (1.39 - 3.88)	1.68 (1.32 - 2.43)	1.85 (1.16 - 2.5)	1.84 (1.41 - 3.32)	2.01 (1.16 - 3.57)	2.04 (1.08 - 2.47)
Potassium (mg/L)	0.25 (0.16 - 0.35)	0.42 (0.15 - 4.9)	0.29 (0.19 - 0.83)	0.27 (0.17 - 0.46)	0.29 (0.20 - 0.36)	0.27 (0.21 - 0.42)
Aluminum (mg/L)	0.11 (0.05 - 0.18)	3.32 (0.025 - 86.0)	0.57 (0.025 - 11.0)	0.00 (0.06 - 1.13)	0.16 (0.07 - 0.47)	0.20 (0.09 - 1.03)
Ammonia (mg/L)	0.01 (0.01 - 0.06)	0.02 (0.01 - 0.1)	0.01 (0.01 - 0.06)	0.01 (0.01 - 0.09)	0.02 (0.01 - 0.09)	0.01 (0.01 - 0.04)
Nitrite (mg/L)	0.0014 (0.0005 - 0.19)	0.0012 (0.0005 - 0.007)	0.0008 (0.0001 - 0.003)	0.0008 (0.0005 - 0.002)	0.0010 (0.0005 - 0.005)	0.0007 (0.0005 - 0.002)
Sulfate (mg/L)	3.3 (2.3 - 5.1)	4.4 (2.5 - 8.5)	3.9 (2.3 - 6.2)	3.7 (2.0 - 5.8)	4.6 (2.2 - 11.0)	4.2 (2.8 - 6.5)
TDS (mg/L)	15.5 (13.0 - 19.0)	15.1 (11.0 - 19.0)	17.8 (11.0 - 25.0)	15.9 (12.0 - 20.0)	17.6 (11.0 - 25.0)	17.4 (11.0 - 23.0)
TSS (mg/L)	2.1 (2.0 - 4.0)	78.6 (2.0 - 2050.0)	18.1 (2.0 - 389.0)	2.9 (2.0 - 26.0)	3.1 (2.0 - 26.0)	2.8 (2.0 - 15.0)
TOC (mg/L)	3.2 (1.3 - 4.6)	4.2 (1.5 - 6.9)	3.7 (2.2 - 6.0)	3.8 (1.4 - 5.1)	4.1 (2.2 - 6.4)	3.4 (1.0 - 5.2)

TDS = Total Dissolved Solids
TSS = Total Suspended Solids
TOC = Total Organic Carbon

Table 2: Average fine particulate sediment (g) collected by Whitlock-Vibert during the four pre-harvested sampling dates (October 1993, June and October 1994 and 1995)

Stream Reach	Sampling Date	Particle Size (mm)					Number of Traps
		0.09	0.5	0.85	1.4	Total	
T1L	Oct 93	1.92	2.71	4.22	16.79	25.65	14
T1U	Oct 93	0.62	0.98	2.47	12.37	16.44	14
T1-1L	Oct 93	0.50	0.64	1.79	12.73	15.66	15
T1	June 94	3.77	4.60	6.13	18.40	32.90	14
T1-1L	June 94	5.90	3.35	4.03	12.37	25.64	9
T1-1U	June 94	0.43	0.53	1.15	5.40	7.51	8
T1-3L	June 94	0.23	0.09	0.19	1.94	2.45	11
T1-3U	June 94	0.82	1.15	2.34	7.25	11.56	11
T1	Oct 94	1.02	1.53	2.45	4.96	9.96	14
T1-1L	Oct 94	2.55	0.43	0.62	2.80	6.41	15
T1-1U	Oct 94	0.10	0.04	0.08	0.52	0.74	14
T1-3L	Oct 94	0.33	0.11	0.09	0.66	1.18	14
T1-3U	Oct 94	0.31	0.14	0.18	0.97	1.59	15
T1	June 95	1.59	2.79	5.72	19.29	29.4	15
T1-1L	June 95	9.46	7.54	14.97	34.95	55.04	15
T1-1U	June 95	1.48	1.56	2.49	6.14	11.67	10
T1-3L	June 95	0.25	0.19	0.26	1.17	1.87	14
T1-3U	June 95	2.62	2.97	4.96	9.53	20.07	11
T1	Oct 95	0.22	0.04	0.05	0.26	0.55	14
T1-1L	Oct 95	10.93	3.79	3.81	7.92	26.45	12
T1-1U	Oct 95	0.26	0.08	0.12	0.71	1.15	9
T1-3L	Oct 95	0.2	0.05	0.05	0.13	0.43	10
T1-3U	Oct 95	2.9	0.65	0.73	1.06	2.31	12

Table 3: Copper Lake electrofishing station descriptions.

Station	Location	Length (m)	Width (m)	Area (m^2)	Mean Depth(cm)	Habitat Type	Cover Type (%)			
							Overhang	Instream(debris)	Instream(Vege)	Canopy
1	T1-3 (L)	75	4.53	340	8.14	100% Riffle	15	3	81	75
2	T1-3 (L)	50	4.47	223.33	9.34	100% Riffle	10	7	87	100
3	T1-3 (L)	38	3.27	124.13	13.35	100% Riffle	15	35	95	40
4	T1-1	100	2.78	278.33	9.64	69% Riffle 31% Steady	30	5	65	15
5	T1-1	100	2.58	258.33	10.82	100% Riffle	5	2	86	75
6	T1-1	95	2.52	239.08	9.02	100% Riffle	30	10	75	50
7	T1	60	4.97	298	18.68	97% Riffle	5	0	10	1
8	T1	60	4.87	292	14.72	97% Riffle	5	0	10	1
9	T1	50	4.87	243.33	21.34	100% Riffle	10	5	40	90
10	T1-3 (U)	100	3.43	343.33	15.76	75% Riffle 25% Steady	0	0	30	0
11	T1-3 (U)	70	2.5	175	17.53	100% Steady	0	0	5	0
12	T1-3 (U)	70	2.17	151.67	17.25	60% Run 40% Riffle	2	0	60	1

Station	Location	Substrate Distributions (%)								
		Bedrock	Lg.Boulder	Sm.Boulder	Rubble	Cobble	Pebble	Gravel	Sand	Mud,etc.
1	T1-3(L)	0	2	15	30	45	5	3	0	0
2	T1-3(L)	0	6	28	28	22	8	8	0	0
3	T1-3(L)	0	25	35	25	10	5	0	0	0
4	T1-1A	0	3	17	25	48	5	2	0	0
5	T1-1B	0	2	18	25	35	30	0	0	0
6	T1-1C	0	8	17	30	25	15	5	0	0
7	T1 X	0	10	60	10	50	3	8	2	0
8	T1 Y	2	10	60	10	5	3	8	2	0
9	T1 Z	0	5	45	25	15	5	5	0	0
10	T1-3 (U)	5	5	30	20	20	7	15	10	0
11	T1-3 (U)	0	0	6	2	6	12	62	12	0
12	T1-3 (U)	0	1	10	25	9	40	10	5	0

Table 4: Brook trout population estimates for electrofishing stations, August, 1993.

Station	Number	Population	Estimated CI		P.E.	Estimated CI/100 m²	
Year Class	Caught	Estimate	Lower	Upper	/100 m²	Lower	Upper
Station 1							
YOY	148	151	148	156	50.76	49.75	52.44
1+	41	41	41	41	13.78	13.78	13.78
2+	14	14	14	14	4.71	4.71	4.71
3+	10	10	10	10	3.36	3.36	3.36
4+	1	1	-	-	0.34	-	-
ALL FISH	214	216	214	219	72.61	71.93	73.61
Station 2							
YOY	58	58	58	59	25.03	25.03	25.46
1+	33	33	33	34	14.24	14.24	14.67
2+	7	7	-	-	3.02	-	-
3+	4	4	-	-	1.73	-	-
ALL FISH	102	103	102	105	44.45	44.02	45.32
Station 3							
YOY	29	30	29	33	21.72	21.00	23.90
1+	31	31	31	32	22.45	22.45	23.17
2+	11	11	11	11	7.97	7.97	7.97
3+	3	3	-	-	2.17	-	-
ALL FISH	74	74	74	75	53.58	53.58	54.31
Station 4							
YOY	23	23	23	24	8.96	8.96	9.35
1+	15	15	15	15	5.84	5.84	5.84
2+	2	2	2	4	0.78	0.78	1.56
ALL FISH	40	40	40	41	15.58	15.58	15.97
Station 5							
YOY	3	3	-	-	2.13	-	-
1+	18	18	18	18	12.79	12.79	12.79
2+	4	4	-	-	2.84	-	-
ALL FISH	25	25	25	25	17.77	17.77	17.77
Station 6							
YOY	6	6	6	6	4.71	4.71	4.71
1+	18	18	18	18	14.14	14.14	14.14
2+	1	1	-	-	0.79	-	-
ALL FISH	25	25	25	25	19.64	19.64	19.64

Table 4 (continued)

Station Year Class	Number Caught	Population Estimate	Estimated CI Lower	 Upper	P.E. /100 m2	Estimated CI/100 m2 Lower	 Upper
Station 7							
YOY	39	40	39	43	12.66	12.34	13.61
1+	32	34	32	39	10.76	10.13	12.34
2+	18	18	18	19	5.70	5.70	6.01
3+	22	22	22	22	6.96	6.96	6.96
4+	3	3	3	5	0.95	0.95	1.58
ALL FISH	114	117	114	122	37.03	36.08	38.61
Station 8							
YOY	36	36	36	37	13.24	13.24	13.60
1+	33	33	33	34	12.13	12.13	12.50
2+	23	23	23	24	8.46	8.46	8.82
3+	24	24	24	24	8.82	8.82	8.82
4+	5	5	5	5	1.84	1.84	1.84
ALL FISH	121	123	121	126	45.22	44.49	46.32
Station 9							
YOY	34	35	34	38	15.44	15.00	16.76
1+	24	24	24	25	10.59	10.59	11.03
2+	18	18	18	20	7.94	7.94	8.82
3+	8	8	8	8	3.53	3.53	3.53
4+	5	5	-	-	2.21	-	-
ALL FISH	89	91	89	95	40.14	39.26	41.91

Note: Year classes with no C. I. given had all fish caught on the first sweep.

Table 5: Brook trout population estimates for electrofishing stations, August, 1994.

Station Year Class	Number Caught	Population Estimate	Estimated C.I. Lower	Estimated C.I. Upper	P.E. 100/M2	Estimated C.I./100m2 Lower	Estimated C.I./100m2 Upper
Station 1							
YOY	76	77	76	80.3	22.65	22.35	23.62
1+	36	37	36	40.6	10.88	10.59	11.94
2+	14	14	14	14.4	4.12	4.12	4.24
3+	10	10	10	10.1	2.94	2.94	2.97
Total	136	139	136	143.5	40.88	40.00	42.21
Station 2							
YOY	59	59	59	60.85	26.42	27.25	27.25
1+	22	22	22	23.5	9.85	10.52	10.52
2+	11	11	11	11.6	4.93	5.19	5.19
3+	7	7	7	8.5	3.13	3.81	3.81
Total	99	100	99	102.9	44.78	46.08	46.08
Station 3							
YOY	27	28	27	31.78	22.56	21.75	25.60
1+	21	21	21	22.6	16.92	16.92	18.21
2+	18	18	18	18.4	14.50	14.50	14.82
3+	3	3	-	-	2.42	0.00	0.00
Total	69	70	69	72.99	56.39	55.59	58.80
Station 4							
YOY	9	9	9	11.8	3.23	3.23	4.24
1+	11	11	11	11.9	3.95	3.95	4.28
2+	5	5	5	5	1.80	1.80	1.80
3+	1	1	-	-	0.36	0.00	0.00
Total	26	26	26	27.7	9.34	9.34	9.95
Station 5							
YOY	8	8	8	9.3	3.10	3.10	3.60
1+	12	12	12	12.5	4.65	4.65	4.84
2+	11	11	11	11.8	4.26	4.26	4.57
3+	2	2	2	4.4	0.77	0.77	1.70
Total	33	33	33	34.3	12.77	12.77	13.28
Station 6							
YOY	0	0	0	0	0.00	0.00	0.00
1+	8	8	8	9.8	3.35	3.35	4.10
2+	10	10	10	10.2	4.18	4.18	4.27
Total	18	18	18	19.1	7.53	7.53	7.99
Station 7							
YOY	28	28	28	29.9	9.40	9.40	10.03
1+	23	24	23	28	8.05	7.72	9.40
2+	26	26	26	28.3	8.72	8.72	9.50
3+	4	4	4	4.8	1.34	1.34	1.61
Total	81	84	81	89.4	28.19	27.18	30.00

Table 5 (continued)

Station 8							
YOY	48	50	48	54.9	17.12	16.44	18.80
1+	19	19	19	20.4	6.51	6.51	6.99
2+	19	21	19	27.2	7.19	6.51	9.32
3+	15	15	15	15.8	5.14	5.14	5.41
4+	1	1	-	-	0.34	0.00	0.00
Total	102	107	102	113.8	36.64	34.93	38.97
Station 9							
YOY	92	99	92	107.85	40.69	37.81	44.32
1+	24	25	24	28.8	10.27	9.86	11.84
2+	15	15	15	17.3	6.16	6.16	7.11
3+	17	17	17	17.6	6.99	6.99	7.23
Total	148	157	148	166.45	64.52	60.82	68.41
Station 10							
YOY	149	164	149.9	178.1	47.77	43.66	51.87
1+	76	76	76	77.2	22.14	22.14	22.49
2+	45	45	45	45.4	13.11	13.11	13.22
3+	35	35	35	35.1	10.19	10.19	10.22
4+	10	10	-	-	2.91	0	0
5+	1	1	-	-	0.29	0	0
Total	322	316	316	328	92.04	92.04	95.53
Station 11							
YOY	140	150	140	160.4	85.71	80.00	91.66
1+	51	51	51	52.3	29.14	29.14	29.89
2+	19	19	19	19.6	10.86	10.86	11.20
3+	2	2	-	-	1.14	0.00	0.00
5+	1	1	-	-	0.57	0.00	0.00
Total	213	220	213	227	125.71	121.71	129.71
Station 12							
YOY	79	81	79	85.2	53.41	52.09	56.17
1+	40	40	40	41.1	26.37	26.37	27.10
2+	19	19	19	19.4	12.53	12.53	12.79
3+	6	6	6	6.1	3.96	3.96	4.02
4+	8	8	-	-	5.27	0.00	0.00
5+	2	2	-	-	1.32	0.00	0.00
Total	154	155	154	158	102.20	101.54	104.17

Note: Year classes with no C.I. given had all fish caught on the first sweep.

Table 6: Brook trout population estimates for electrofishing stations, August, 1995

Station Year Class	Number Caught	Population Estimate	Estimated C.I. Lower	Estimated C.I. Upper	P.E. 100/M2	Estimated C.I./100m2 Lower	Estimated C.I./100m2 Upper
Station 1							
YOY	93	94	93	96.7	30.64	30.32	31.52
1+	51	51	51	52.8	16.63	16.63	17.21
2+	13	13	13	13.7	4.24	4.24	4.47
3+	12	12	-	-	3.91	0.00	0.00
4+	2	2	-	-	-	-	-
Total	171	172	171	174.98	56.07	55.75	57.04
Station 2							
YOY	76	77	76	79.8	31.32	30.92	32.46
1+	27	27	27	27.7	10.98	10.98	11.27
2+	6	6	6	6.4	2.44	2.44	2.60
3+	3	3	-	-	-	-	-
Total	112	113	112	115.6	45.97	45.56	47.02
Station 3							
YOY	2	2	2	4.4	0.85	0.81	1.79
1+	17	17	17	17.8	6.92	6.92	7.24
2+	5	5	5	6.1	2.03	2.03	2.48
3+	1	1	-	-	-	-	-
Total	25	25	25	27.34	21.22	21.22	23.21
Station 4							
YOY	15	15	15	15.96	6.00	6.00	6.38
1+	15	15	15	15.1	6.00	6.00	6.04
2+	10	10	10	10.5	4.00	4.00	4.20
3+	2	2	-	-	0.80	0	0
Total	42	42	42	42.61	16.80	16.80	17.04
Station 5							
YOY	5	5	5	6.2	1.67	1.67	2.07
1+	5	5	5	6.2	1.67	1.67	2.07
2+	10	10	10	10.5	3.33	3.33	3.50
Total	20	20	20	21.24	6.67	6.67	7.08
Station 6							
YOY	0	0	0	0	0.00	0.00	0.00
1+	0	0	-	-	0	0	0
2+	6	6	-	-	2.06	0	0
3+	1	1	-	-	0.34	0	0
Total	7	7	7	-	2.40	2.40	0
Station 7							
YOY	14	14	14	16.2	4.28	4.28	4.95
1+	23	23	23	24.4	7.03	7.03	7.46
2+	32	32	32	32.2	9.79	9.79	9.85
3+	8	8	8	9.7	2.45	2.45	2.97
4+	2	2	2	4.4	0.61	0.61	1.35
Total	80	81	80	84.13	24.77	24.46	25.73
Station 8							
YOY	19	21	19	27.1	7.37	6.67	9.51
1+	18	18	18	19.2	6.32	6.32	6.74
2+	18	18	18	19.6	6.32	6.32	6.88
3+	14	14	14	14.6	4.91	4.91	5.12
4+	5	5	-	-	1.75	0	0
Total	74	75	74	78.31	26.32	25.96	27.48

Table 6 (continued)

Station 9							
YOY	23	26	23	34	6.47	5.72	8.46
1+	33	35	33	40	8.71	8.21	9.95
2+	16	17	16	21.5	4.23	3.98	5.35
3+	23	23	23	24.8	5.72	5.72	6.17
4+	4	4	4	4.8	1.00	1.00	1.19
Total	99	107	99	116.78	26.62	24.63	29.05
Station 10							
YOY	179	185	179	191.8	46.06	44.56	47.75
1+	91	91	91	92.1	22.66	22.66	22.93
2+	39	39	39	39.2	9.71	9.71	9.76
3+	19	19	-	-	4.73	0	0
4+	3	3	3	3.5	0.75	0.75	0.87
Total	331	334	331	338.37	83.15	82.41	84.24
Station 11							
YOY	99	117	99	136.5	42.86	36.26	50.00
1+	64	64	64	64.8	23.44	23.44	23.74
2+	25	25	25	26.3	9.16	9.16	9.63
3+	8	8	8	8.5	2.93	2.93	3.11
4+	1	1	-	-	0.37	0	0
Total	197	205	197	213.23	75.09	72.16	78.11
Station 12							
YOY	46	48	46	52.9	36.09	34.59	39.77
1+	50	50	50	50.8	37.59	37.59	38.20
2+	19	19	19	19.4	14.29	14.29	14.59
3+	9	9	-	-	6.77	0	0
4+	3	3	-	-	2.26	0	0
Total	127	128	127	130.6	96.24	95.49	98.20

Note: Year classes with no C. I. given had all fish caught on the first sweep.

Table 7: Length:weight regression summary statistics for brook trout sampled by electrofishing during pre-harvested conditions in the Copper Lake watershed.

Stream	Measurement	Year	Co-efficient	95 % C.I.		R-sq
T1	Slope	1993	3.01	2.96	3.07	0.99
	Intercept		-4.02	-4.12	-3.91	
T1	Slope	1994	3.10	3.03	3.17	0.99
	Intercept		-4.19	-4.33	-4.04	
T1	Slope	1995	3.04	2.98	3.09	0.99
	Intercept		-4.05	-4.17	-3.94	
T1-1L	Slope	1993	2.89	2.73	3.04	0.98
	Intercept		-3.71	-4.00	-3.41	
T1-1L	Slope	1994	2.93	2.75	3.10	0.97
	Intercept		-3.86	-4.22	-3.50	
T1-1L	Slope	1995	2.93	2.82	3.05	0.99
	Intercept		-3.82	-4.05	-3.59	
T1-3L	Slope	1993	2.89	2.81	2.97	0.99
	Intercept		-3.72	-3.87	-3.56	
T1-3L	Slope	1994	3.18	3.07	3.29	0.98
	Intercept		-4.34	-4.56	-4.11	
T1-3L	Slope	1995	2.91	2.82	3.00	0.98
	Intercept		-3.77	-3.95	-3.59	
T1-3U	Slope	1994	3.09	3.04	3.15	0.99
	Intercept		-4.19	-4.30	-4.08	
T1-3U	Slope	1995	3.05	2.98	3.12	0.98
	Intercept		-4.08	-4.21	-3.95	

Table 8: Summary statistics and biomass estimates for brook trout by electrofishing station, August, 1993.

Station Year class	Number Caught	Population Estimate	Mean Fork Length (mm)	Mean Weight (g)	Condition Factor (K)	Area (m2)	Biomass g/100m²
Station 1							
yoy	148	151	50	1.6	1.27	297.5	81.2
1+	41	41	89	8.0	1.15	297.5	110.3
2+	14	14	130	23.9	1.08	297.5	112.5
3+	10	10	164	47.3	1.07	297.5	159.0
4+	1	1	215	96.0	0.97	297.5	32.3
ALL FISH	214	216		10.6		297.5	495.2
Station 2							
yoy	58	58	55	2.2	1.32	231.7	55.1
1+	33	33	90	9.0	1.21	231.7	128.2
2+	7	7	128	25.9	1.25	231.7	78.2
3+	4	4	157	45.5	1.18	231.7	78.5
ALL FISH	102	103		10.4		231.7	340.1
Station 3							
yoy	29	30	53	2.0	1.31	138.1	43.4
1+	31	31	93	9.9	1.22	138.1	222.2
2+	11	11	133	28.6	1.21	138.1	227.8
3+	3	3	173	63.0	1.22	138.1	136.9
ALL FISH	74	74		26.9		138.1	630.3
Station 4							
yoy	23	23	59	2.7	1.33	256.7	24.2
1+	15	15	92	9.9	1.29	256.7	57.8
2+	2	2	147	37.0	1.16	256.7	28.8
ALL FISH	40	40		9.0		256.7	110.9
Station 5							
yoy	3	3	72	4.7	1.24	140.7	10.0
1+	18	18	93	9.5	1.17	140.7	121.5
2+	4	4	137	30.3	1.19	140.7	86.1
ALL FISH	25	25		12.2		140.7	217.7
Station 6							
yoy	6	6	74	5.0	1.23	127.3	23.6
1+	18	18	89	8.0	1.15	127.3	113.1
2+	1	1	152	42.0	1.20	127.3	33.0
ALL FISH	25	25		8.6		127.3	169.7

Table 8 (continued)

Station 7							
yoy	39	40	45	1.1	1.23	316	13.9
1+	32	34	84	6.5	1.10	316	69.9
2+	18	18	131	22.2	0.99	316	126.5
3+	22	22	169	50.9	1.06	316	354.4
4+	3	3	230	127.7	1.05	316	121.2
ALL FISH	114	117		20.9		316	685.9
Station 8							
yoy	36	36	47	1.2	1.12	272	15.9
1+	33	33	81	5.6	1.04	272	67.9
2+	23	23	130	23.6	1.09	272	199.6
3+	24	24	171	52.8	1.07	272	465.9
4+	5	5	214	108.2	1.10	272	198.9
ALL FISH	121	123		22.9		272	948.2
Station 9							
yoy	34	35	47	1.3	1.23	226.7	20.1
1+	24	24	87	7.7	1.16	226.7	81.5
2+	18	18	112	14.7	1.04	226.7	116.7
3+	8	8	151	36.4	1.05	226.7	128.5
4+	5	5	190	68.2	0.99	226.7	150.4
ALL FISH	89	91		14.7		226.7	497.2

Note: YOY mean weight calculated from total weight of all YOY divided by N

Table 9: Summary statistics and biomass estimates for brook trout by electrofishin station, August, 1994.

Station Year Class	Number Caught	Population Estimate	Mean Fork Length(mm)	Mean Weight (g)	Condition Factor (K)	Area (m2)	Biomass g/100 m2
Station 1							
YOY	76	77	54	1.04	0.66	340	23.55
1+	36	37	91	7.97	1.06	340	86.73
2+	14	14	125	22.71	1.16	340	93.51
3+	10	10	155	43.5	1.17	340	127.94
Total	136	139		9.1		340	372.03
Station 2							
YOY	59	59	54	1.61	1.02	223.33	42.53
1+	22	22	94	8.23	0.99	223.33	81.07
2+	11	11	129	23	1.07	223.33	113.29
3+	7	7	159	46.71	1.16	223.33	146.41
Total	99	100		8.6		223.33	385.08
Station 3							
YOY	27	28	51	1.39	1.05	124.13	31.35
1+	21	21	98	10.05	1.07	124.13	170.02
2+	18	18	129	26.22	1.22	124.13	380.21
3+	3	3	159	49	1.22	124.13	118.42
Total	69	70		12.6		124.13	710.55
Station 4							
YOY	9	9	51	1.16	0.87	278.33	3.75
1+	11	11	92	7.82	1.00	278.33	30.91
2+	5	5	117	14.2	0.89	278.33	25.51
3+	1	1	162	34	0.80	278.33	12.22
Total	26	26		7.7		278.33	71.93
Station 5							
YOY	8	8	53	1.2	0.81	258.33	3.72
1+	12	12	98	10.07	1.07	258.33	46.78
2+	11	11	127	21.09	1.03	258.33	89.80
3+	2	2	154	31	0.85	258.33	24.00
Total	33	33		13.7		258.33	175.01
Station 6							
YOY	-	-	-	-	-	-	-
1+	8	8	100	10	1.00	239.08	33.46
2+	10	10	122	18.9	1.04	239.08	79.05
Total	18	18		14.9		239.08	112.18
Station 7							
YOY	28	28	47	1.14	1.10	298	10.71
1+	23	24	87	6.61	1.00	298	53.23
2+	26	26	116	16.81	1.08	298	146.66
3+	4	4	141	31	1.11	298	41.61
Total	81	84		9.4		298	264.97

Table 9 (continued)

Station 8							
YOY	48	50	48	1.13	1.02	292	19.35
1+	19	19	85	6.74	1.10	292	43.86
2+	19	21	112	15.32	1.09	292	110.18
3+	15	15	163	51	1.18	292	261.99
4+	1	1	205	104	1.21	292	35.62
Total	102	107		13.2		292	483.70
Station 9							
YOY	92	99	45	0.86	0.94	243.33	34.99
1+	24	25	85	6.17	1.00	243.33	63.39
2+	15	15	113	15.72	1.09	243.33	96.91
3+	17	17	156	42.94	1.13	243.33	300.00
Total	148	157		8.1		243.33	522.62
Station 10							
YOY	149	164	43	0.74	0.93	343.33	35.35
1+	76	76	82	5.5	1.00	343.33	121.75
2+	45	45	118	18.07	1.10	343.33	236.84
3+	35	35	170	54.8	1.12	343.33	558.65
4+	10	10	196	81.9	1.09	343.33	238.55
5+	1	1	263	182	1.00	343.33	53.01
Total	305	311		13.6		343.33	1231.93
Station 11							
YOY	140	150	40	0.62	0.97	175	53.14
1+	51	51	82	5.49	1.00	175	159.99
2+	19	19	111	14.05	1.03	175	152.54
3+	2	2	161	46.5	1.11	175	53.14
5+	1	1	198	72	0.93	175	41.14
Total	213	219		3.7		175	463.03
Station 12							
YOY	79	81	40	0.5	0.78	151.67	26.70
1+	40	40	79	5.25	1.06	151.67	138.46
2+	19	19	112	15.05	1.07	151.67	188.53
3+	6	6	164	49.5	1.12	151.67	195.82
4+	8	8	188	64.37	0.97	151.67	339.53
5+	2	2	213	101	1.05	151.67	133.18
Total	154	155		10.4		151.67	1062.83

Note: YOY mean weight calculated from total weight of all YOY divided by N

Table 10: Summary statistics and biomass estimates for brook trout by electrofishing station, August, 1995.

Station Year Class	Number Caught	Population Estimate	Mean Fork Length(mm)	Mean Weight (g)	Condition Factor (K)	Area (m2)	Biomass g/100 m2
Station 1							
YOY	93	94	50	1.41	1.13	306.75	43.21
1+	51	51	89	8.07	1.14	306.75	134.17
2+	13	13	119	19.31	1.15	306.75	81.84
3+	12	12	160	47.33	1.16	306.75	185.15
4+	2	2	188	75	1.13	306.75	48.90
Total	171	172		8.78		306.75	492.31
Station 2							
YOY	76	77	50	1.52	1.22	245.83	47.61
1+	27	27	87	7.89	1.20	245.83	86.66
2+	6	6	139	29	1.08	245.83	70.78
3+	3	3	164	45.67	1.04	245.83	55.73
Total	112	113		5.67		245.83	260.63
Station 3							
YOY	2	2	53	1	0.67	117.8	1.70
1+	17	17	87	8.22	1.25	117.8	118.62
2+	5	5	134	30.4	1.26	117.8	129.03
3+	1	1	148	37	1.14	117.8	31.41
Total	25	25		13.23		117.8	280.77
Station 4							
YOY	15	15	51	1.47	1.11	250	8.82
1+	15	15	88	7.47	1.10	250	44.82
2+	10	10	118	18.2	1.11	250	72.80
3+	2	2	150	34.5	1.02	250	27.60
Total	42	42		9.17		250	154.06
Station 5							
YOY	5	5	57	2.2	1.19	300	3.67
1+	5	5	88	8.2	1.20	300	13.67
2+	10	10	131	25.2	1.12	300	84.00
Total	20	20		15.2		300	101.33
Station 6							
YOY	0	0	-	-	-	-	-
1+	0	0		-	-	-	-
2+	6	6	123	22.33	0.69	291.33	45.99
3+	1	1	148	37		291.33	
Total	7	7		24.43		291.33	58.70
Station 7							
YOY	14	14	41	0.63	0.91	327	2.70
1+	23	23	81	5.52	1.04	327	38.83
2+	32	32	115	16.72	1.10	327	163.62
3+	8	8	158	44.5	1.13	327	108.87
4+	2	2	202	81.5	0.99	327	
Total	80	81		14.69		327	363.88

Table 10 (continued)

Station 8							
YOY	19	21	40	0.73	1.14	285	5.38
1+	18	18	79	5.78	1.17	285	36.51
2+	18	18	124	21.44	1.12	285	135.41
3+	14	14	157	44.5	1.15	285	218.60
4+	5	5	182	64.2	1.06	285	112.63
Total	74	75		19.32		285	508.42
Station 9							
YOY	23	26	42	0.85	1.15	402	5.50
1+	33	35	82	5.7	1.03	402	49.63
2+	16	17	123	20.19	1.08	402	85.38
3+	23	23	169	54.35	1.13	402	310.96
4+	4	4	179	66.5	1.16	402	
Total	99	107		19.45		402	517.70
Station 10							
YOY	179	185	39	0.62	1.05	401.67	28.56
1+	91	91	78	5.42	1.14	401.67	122.79
2+	39	39	107	13.38	1.09	401.67	129.91
3+	19	19	151	40.32	1.17	401.67	190.72
4+	3	3	201	97.67	1.20	401.67	72.95
Total	331	334		6.55		401.67	544.65
Station 11							
YOY	99	117	36	0.41	0.88	273	17.57
1+	64	64	78	5.56	1.17	273	130.34
2+	25	25	104	12.84	1.14	273	117.58
3+	8	8	148	35.113	1.08	273	102.90
4+	1	1	191	69	0.99	273	25.27
Total	197	205		5.24		273	393.48
Station 12							
YOY	46	48	38	0.45	0.82	133	16.24
1+	50	50	75	4.06	0.96	133	152.63
2+	19	19	104	11.89	1.06	133	169.86
3+	9	9	149	37.44	1.13	133	253.35
4+	3	3	179	65	1.13	133	146.62
Total	127	128		7.68		133	739.13

Note: YOY mean weight calculated from total weight of all YOY divided by N

Table 11: Population estimate for brook trout in Copper Lake during June, 1994.

Date t	Marked M	Caught C	Recapture R	Mt--1 C	Mt-1(C)/R Daily Estimate	Σ (M t-1)x(C)	Σ R	Σ (Mt-1(C)/(R) Multiple Estimate
15	23	23	0	-	-	-	-	-
16	100	77	0	1,771	-	-	-	-
17	121	23	2	2,300	1,150	4,071	2	2,036
18	165	47	3	5,687	1,896	9,758	5	1,952
19	217	53	1	8,745	8,745	18,503	6	3,084
20	293	82	6	17,794	2,966	36,297	12	3,025
21	395	112	10	32,816	3,282	69,113	22	3,142
22	441	57	11	22,515	2,047	91,628	33	2,777
23	509	81	13	35,721	2,748	127,249	46	2,769
24	529	27	7	13,743	1,963	141,092	53	2,662

Table 12: Population estimate for brook trout in Copper Lake (A) and Jim's Lake (B) during June, 1995.

(A)

Date t	Marked M	Caught C	Recapture R	Mt--1 C	Mt-1(C)/R Daily Estimate	Σ (M t-1)x(C)	Σ R	Σ (Mt-1(C)/(R) Multiple Estimate
15	87	29	0	1682	-	-		
16	109	23	1	2001	2001	3683	1	3683
17	152	43	0	4687	-	8370	1	8370
18	186	34	2	5168	2584	13538	3	4513
19	195	10	1	1860	1860	15398	4	3850
20	289	101	7	19695	2814	35093	11	3190
21	314	29	4	8381	2095	43474	15	2898
22	329	18	3	5652	1884	49126	18	2729
23	343	17	1	5593	5593	54719	19	2880

(B)

Date t	Marked M	Caught C	Recapture R	Mt--1 C	Mt-1(C)/R Daily Estimate	Σ (M t-1)x(C)	Σ R	Σ (Mt-1(C)/(R) Multiple Estimate
15	183	93	0	8370	-	8370	0	-
16	270	91	4	16653	4163	25023	4	6256
17	329	65	6	17550	2925	42573	10	4257
18	411	103	21	33887	1614	76460	31	2466
19	493	95	13	39045	3003	115505	44	2625
20	569	109	33	53737	1628	169242	77	2198
21	636	103	36	58607	1628	227849	113	2016
22	696	85	25	54060	2162	281909	138	2043

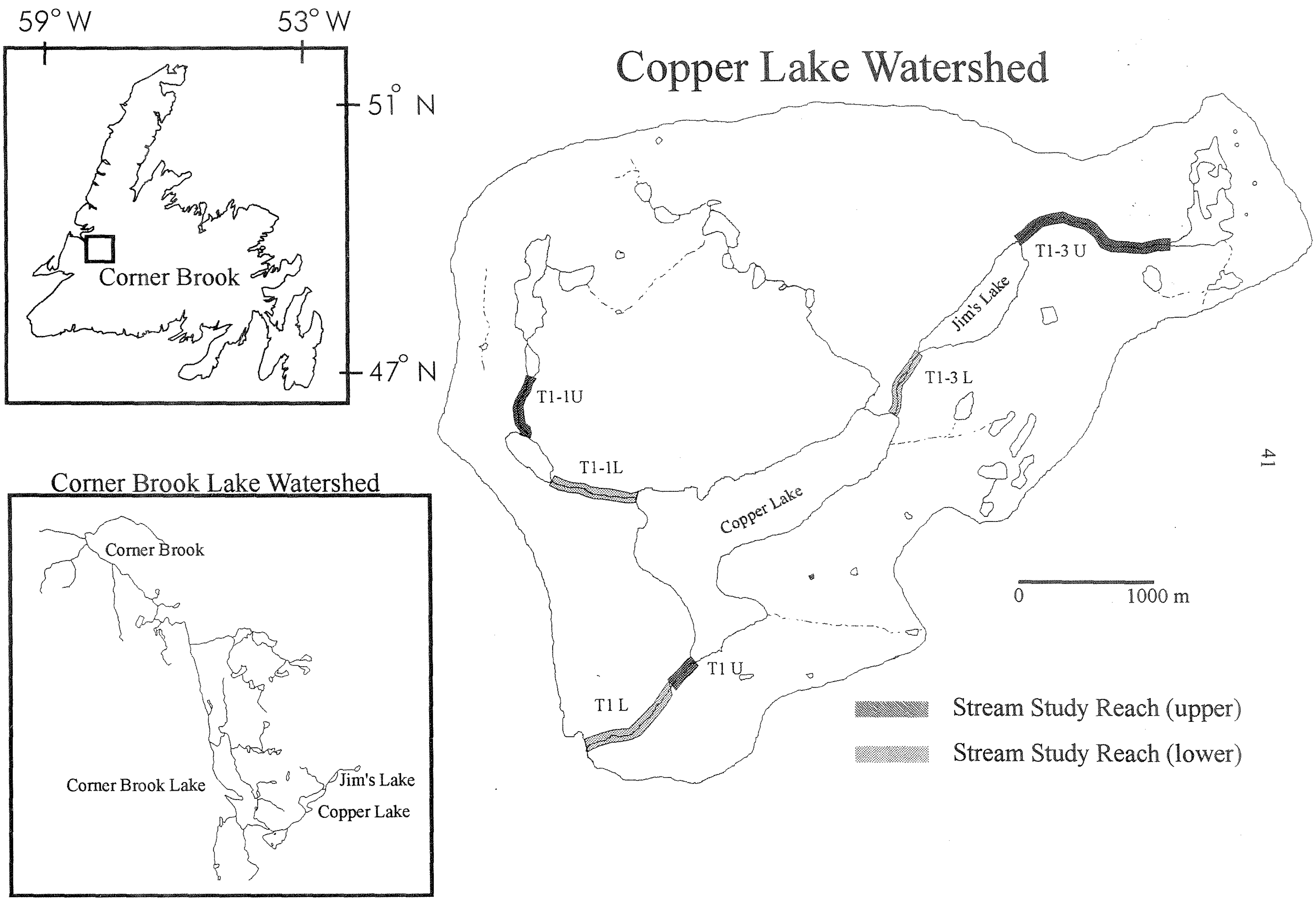


Figure 1: Location of the Copper Lake watershed with stream sections highlighted.

Figure 2: Bathymetry profile of Copper Lake, contours are in 5 meter intervals.

Figure 3: Bathymetry profile of Jim's Lake, contours are in 5 meter intervals.

Figure 4: Bathymetry profile of Lloyd's Gully, contours are in 5 meter intervals.

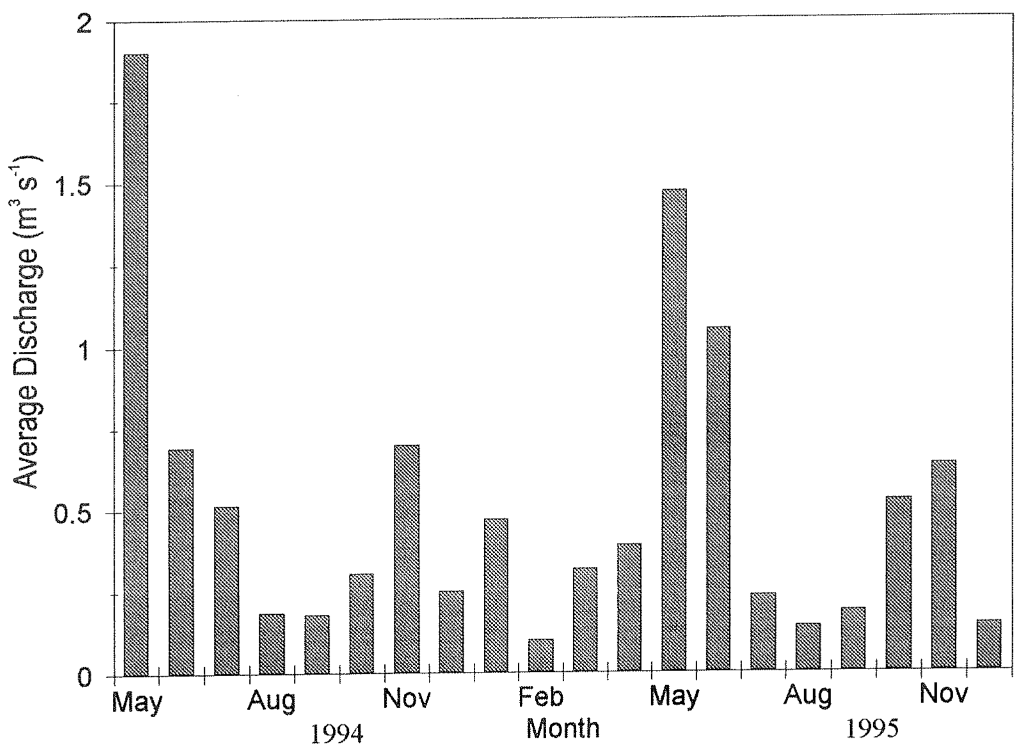


Figure 5: Average monthly discharge from the Copper Lake Watershed from May, 1994 to December, 1995

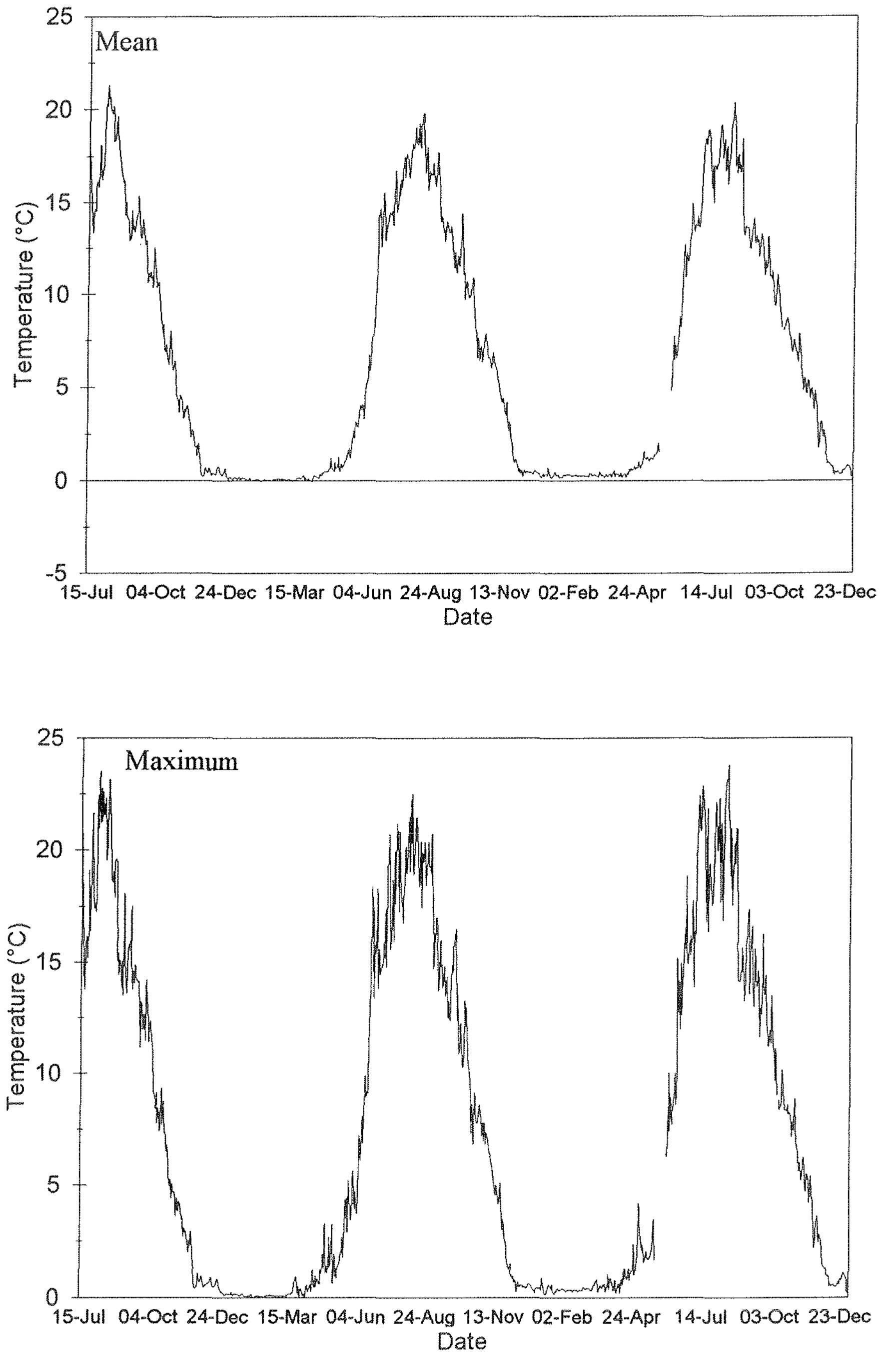


Figure 6: Temperature regime of T1-3 (lower B) from 15 July, 1993 to 31 December, 1995. Top panel is the daily mean; Bottom panel is the daily maximum.

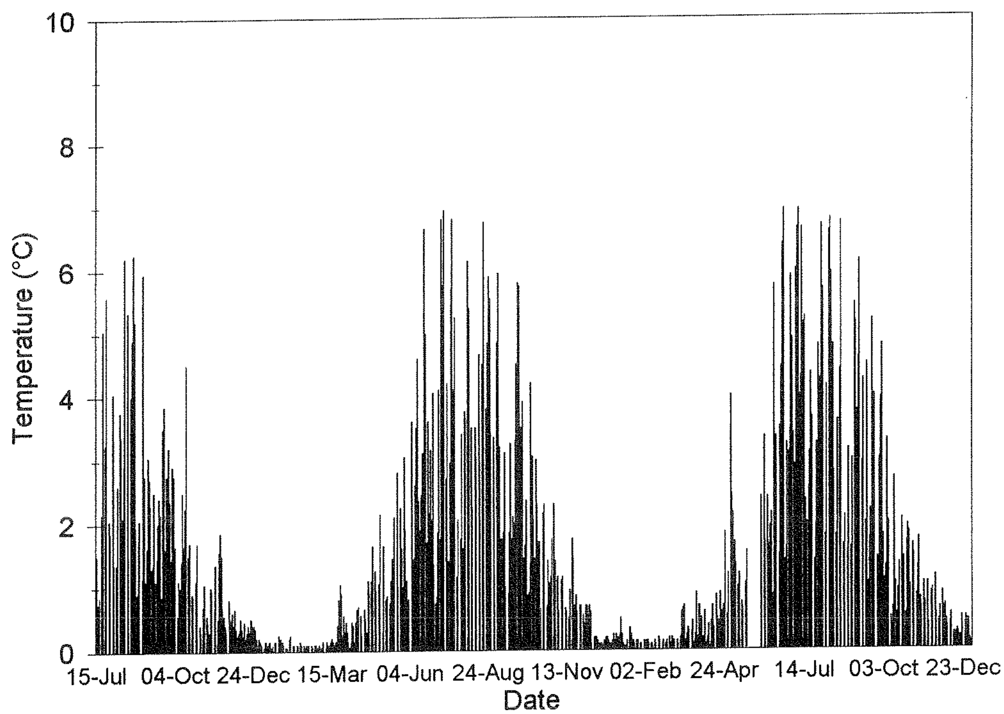
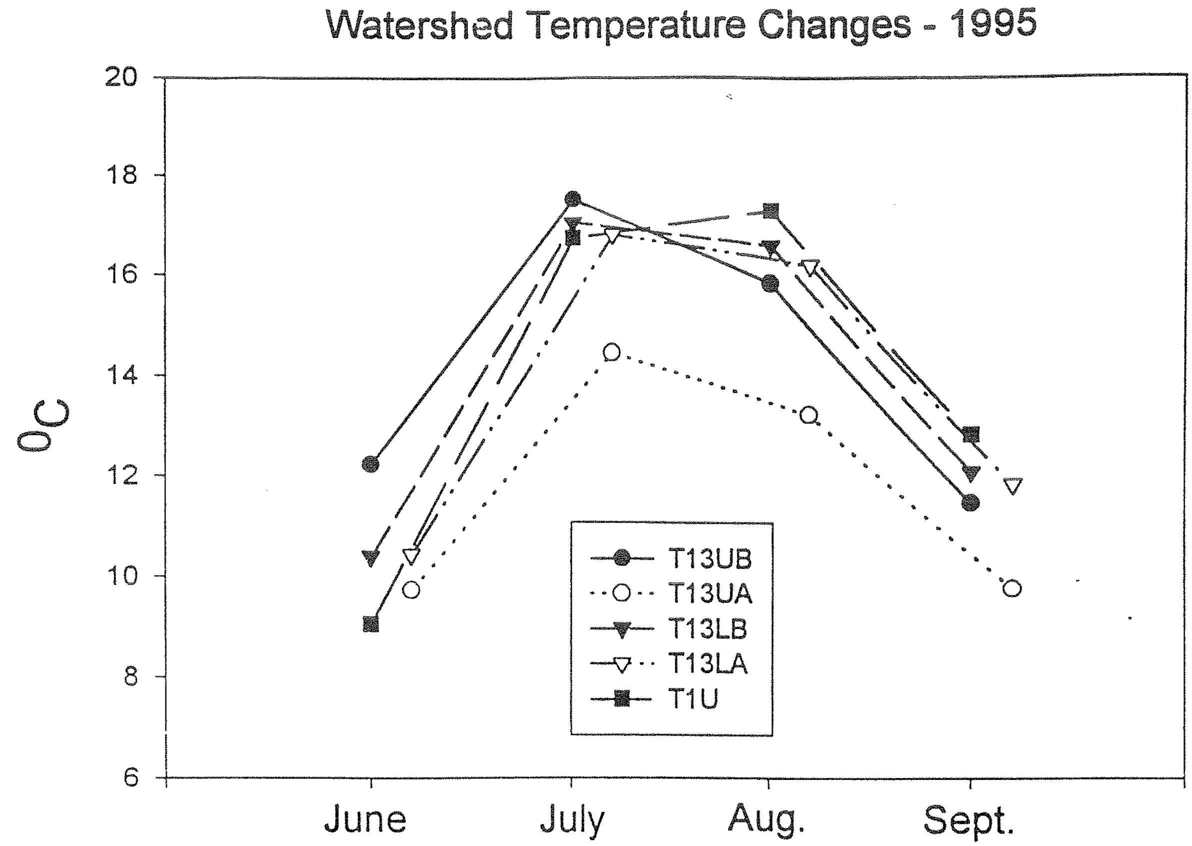


Figure 7: Daily temperature fluctuation observed in T1-3 (Lower B) from 15 July, 1993 to 31 December, 1995.



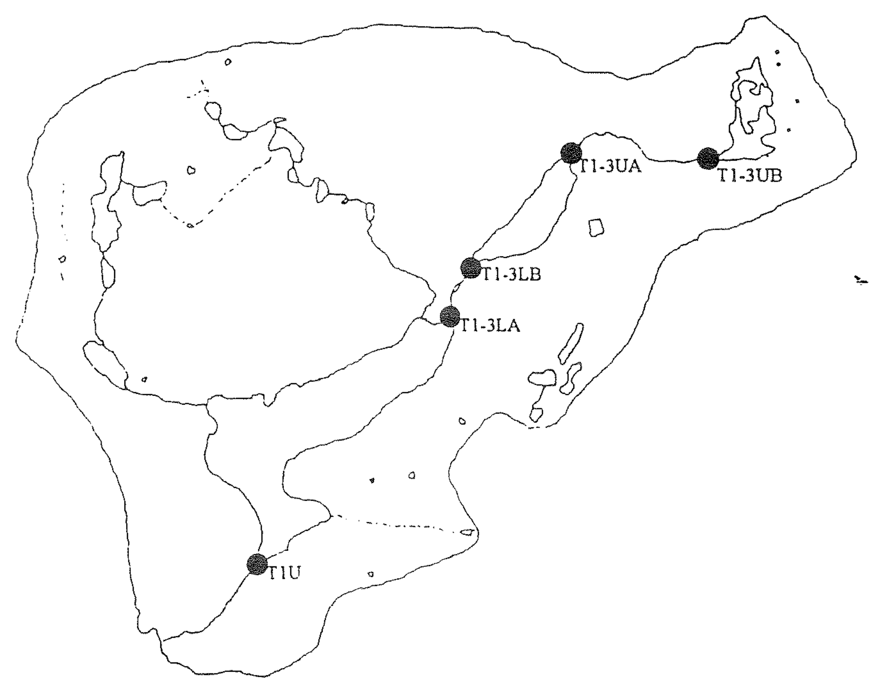


Figure 7: Mean monthly summer temperature dynamics from the top of the watershed (T1-3UB to the lower portions (T1U).

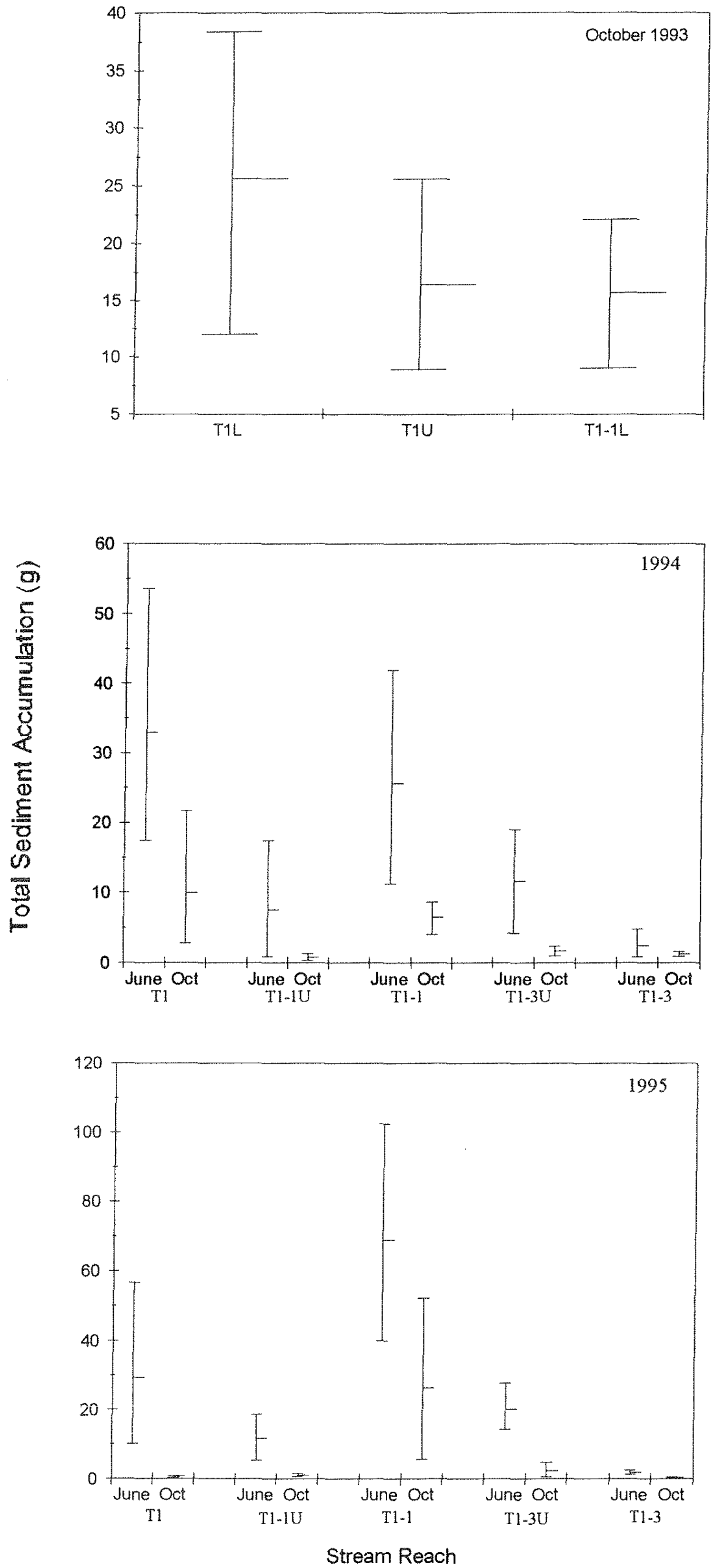


Figure 9: Total fine particulate sediment accumulation collected in the Whitlock Viebert boxes during the first three years of study (1993-1995). Vertical bars are 95% confidence intervals of the mean.

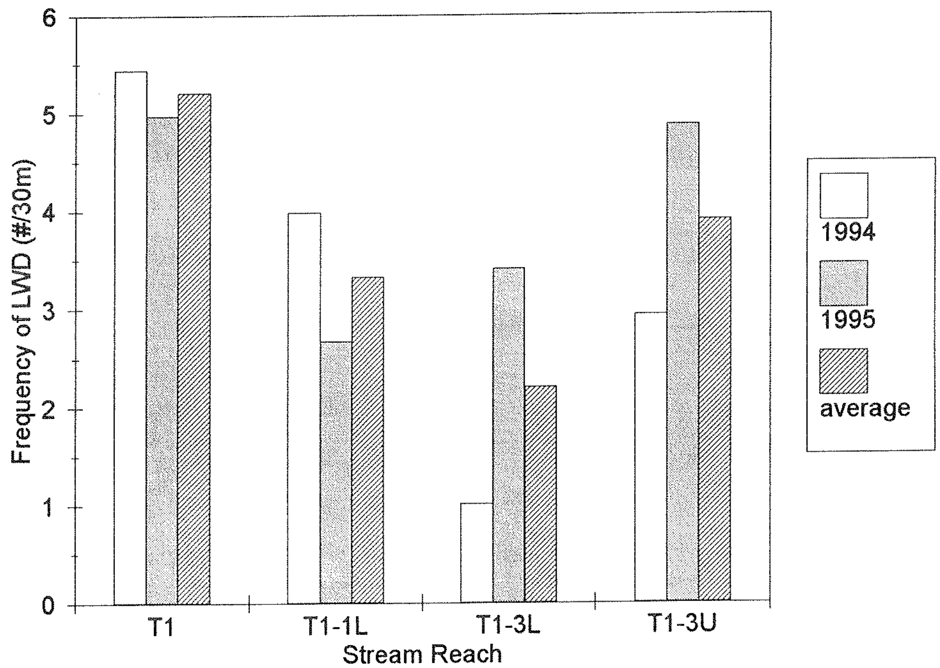


Figure 10: Frequency of LWD surveyed in the study streams in 1994 and 1995.

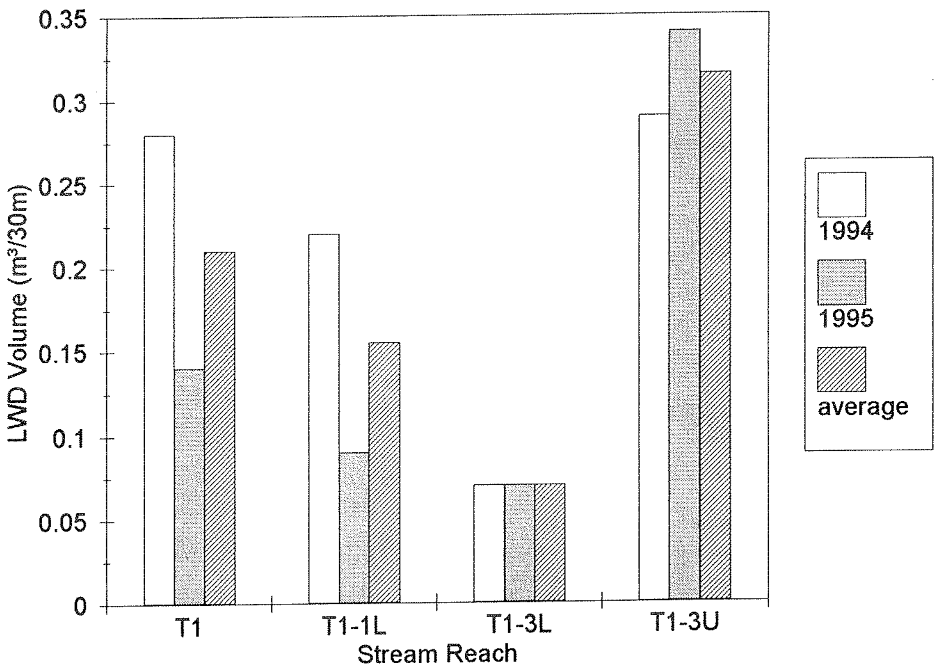


Figure 11: LWD volume in the study streams during 1994 and 1995.

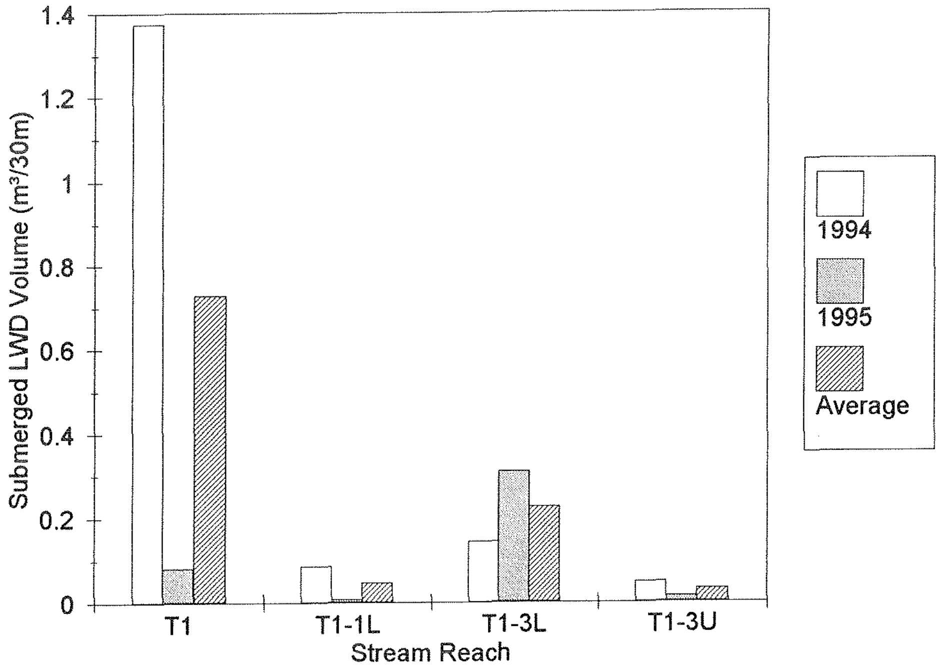


Figure 12: Submerged LWD volume in the study streams during 1994 and 1995.

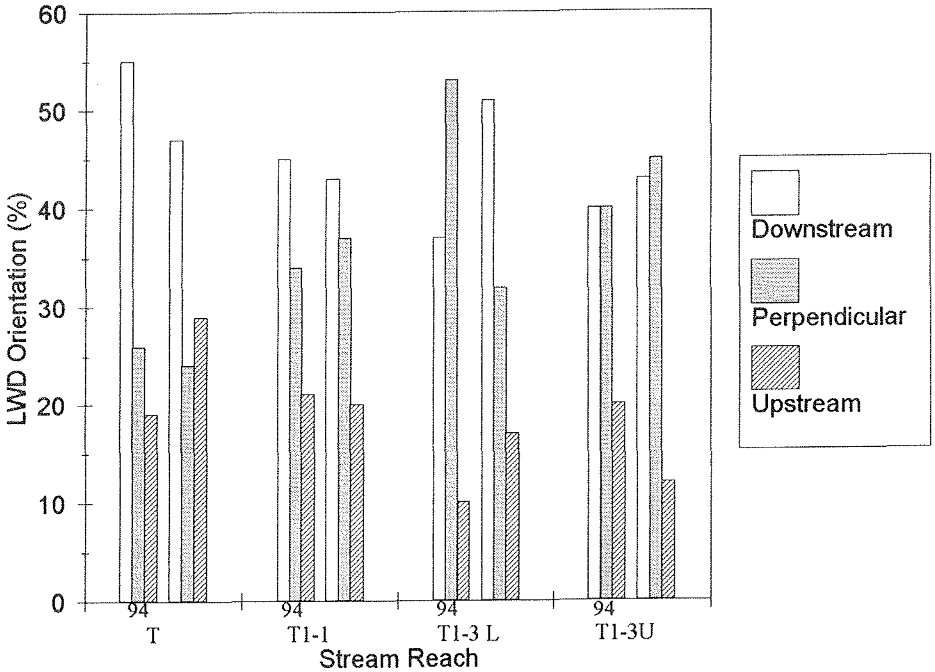


Figure 13: Orientation to the flow of LWD surveyed in 1994 and 1995.

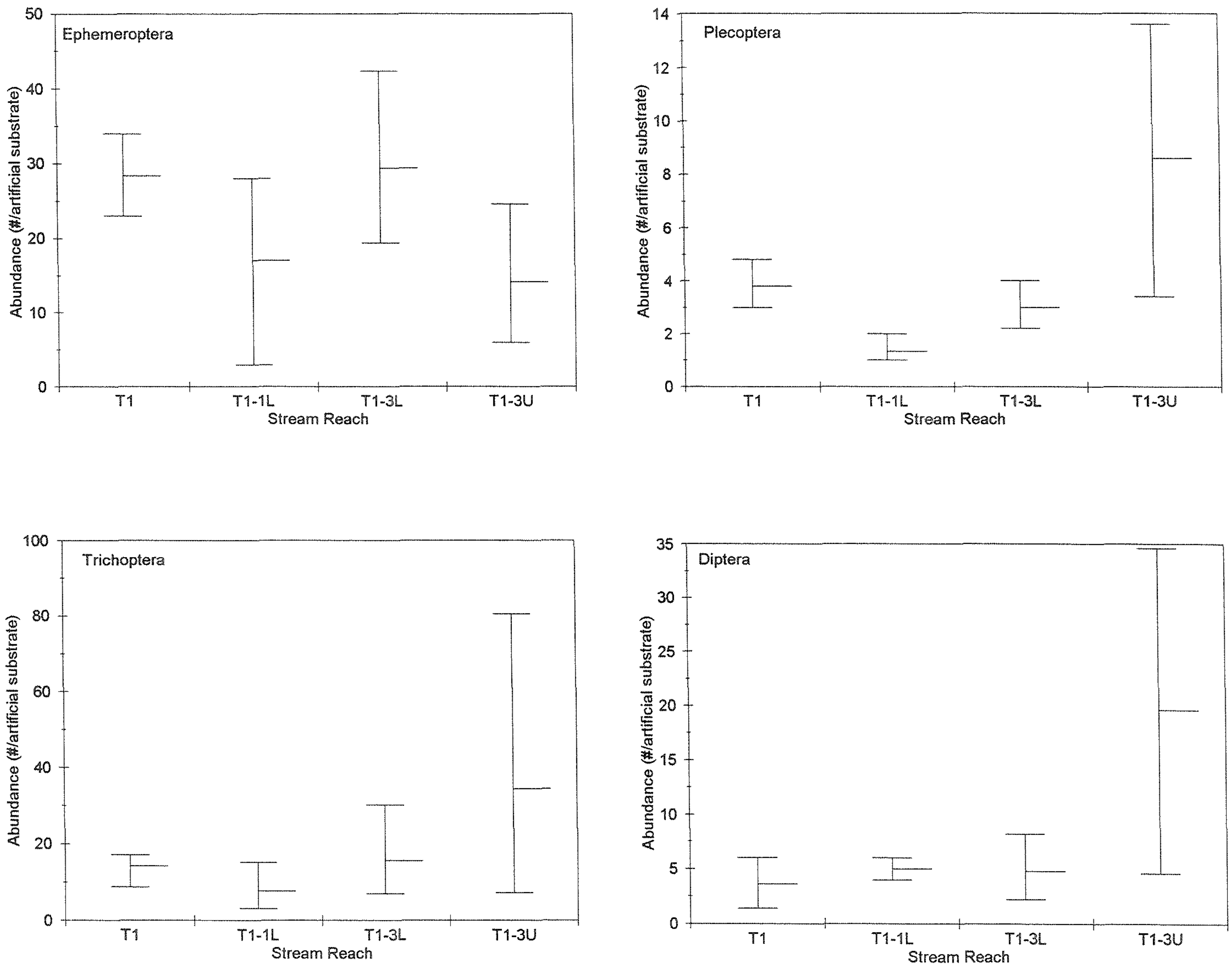


Figure 14: Pre-harvested abundances of the major benthic macroinvertebrate taxa in the study streams.

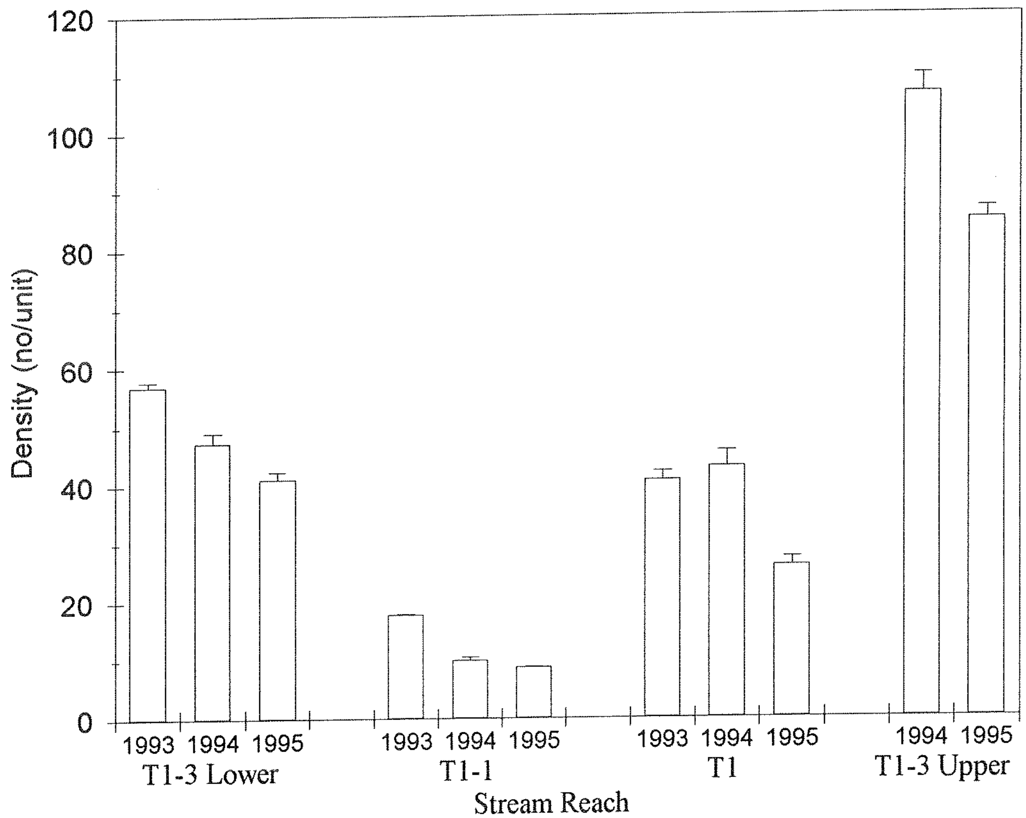


Figure 15: Lotic pre-harvested brook trout densities with 95% C.I.

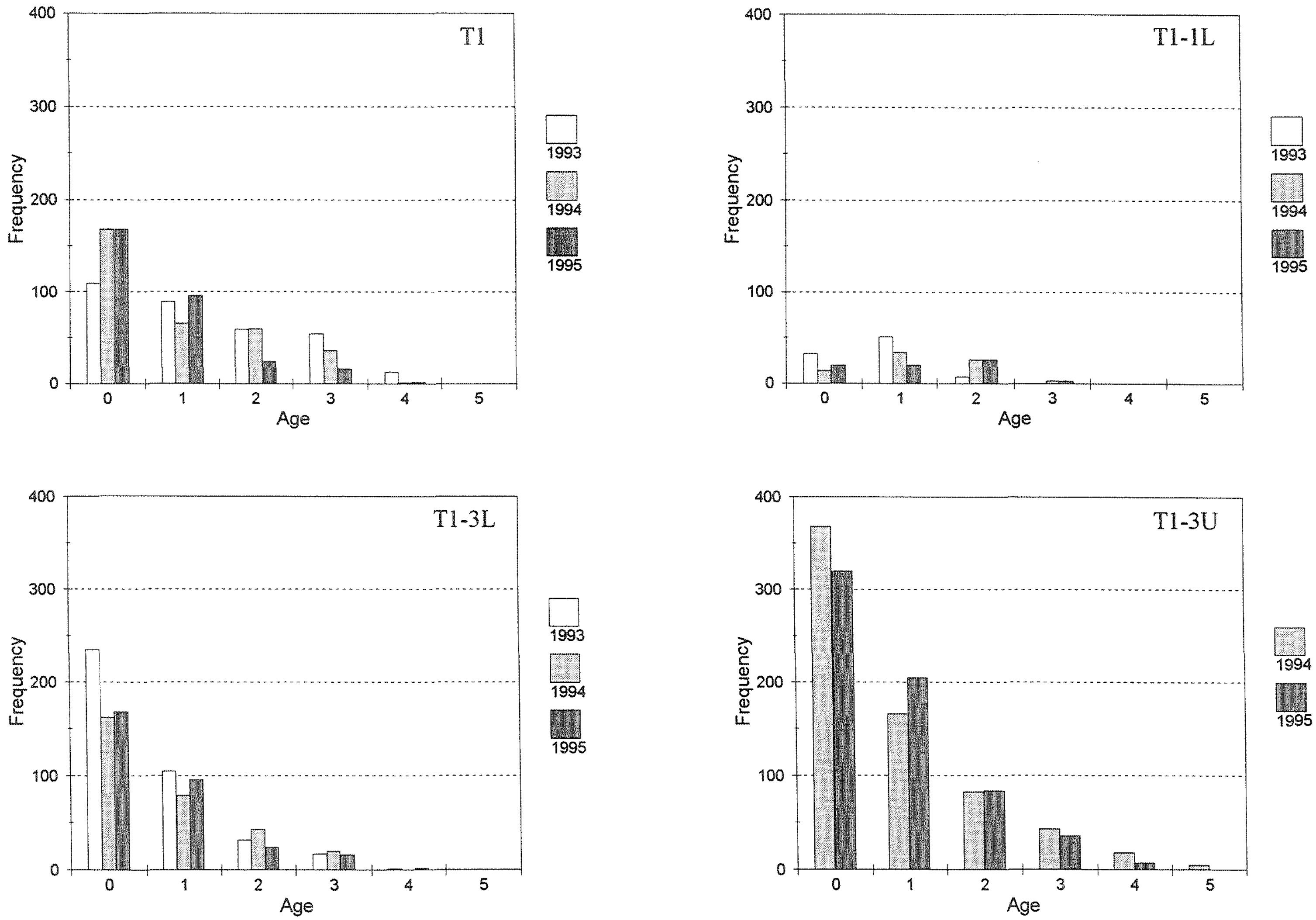


Figure 16: Age-class distributions of brook trout in the streams of the Copper Lake watershed.

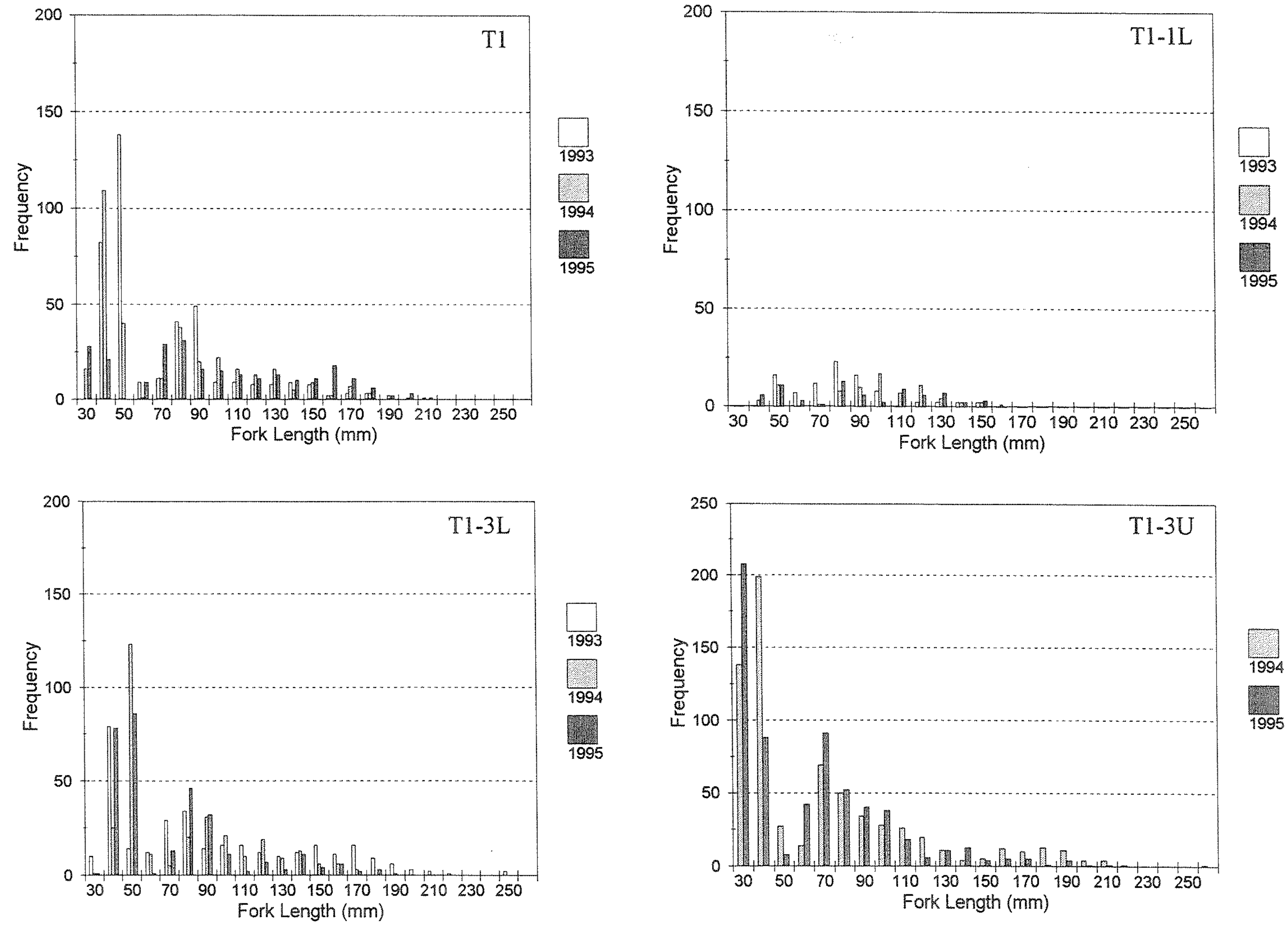


Figure 17: Length frequency distributions of brook trout sampled in the stream reaches.

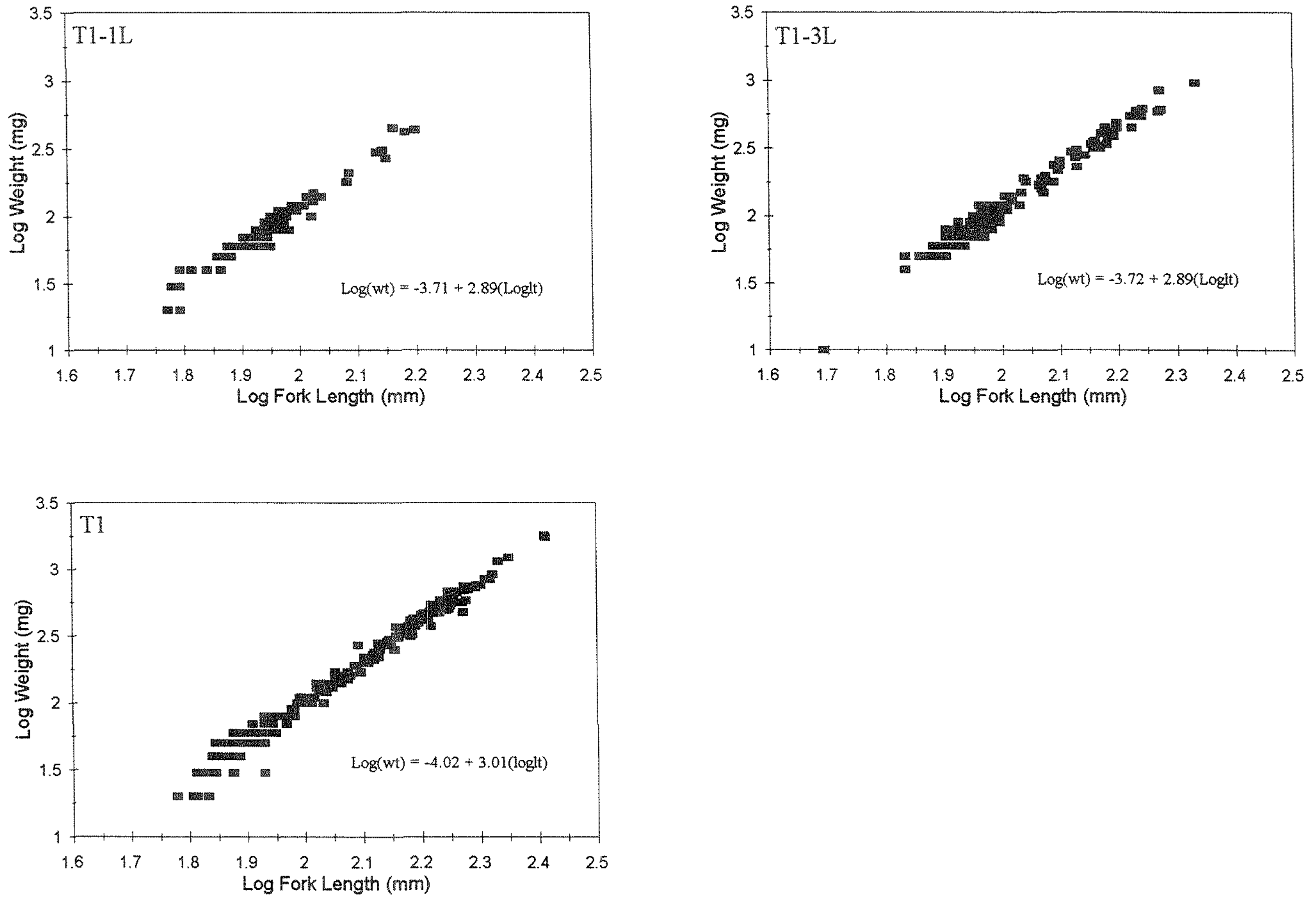


Figure 18: Length-weight regressions for brook trout sampled in each stream reach during August, 1993.

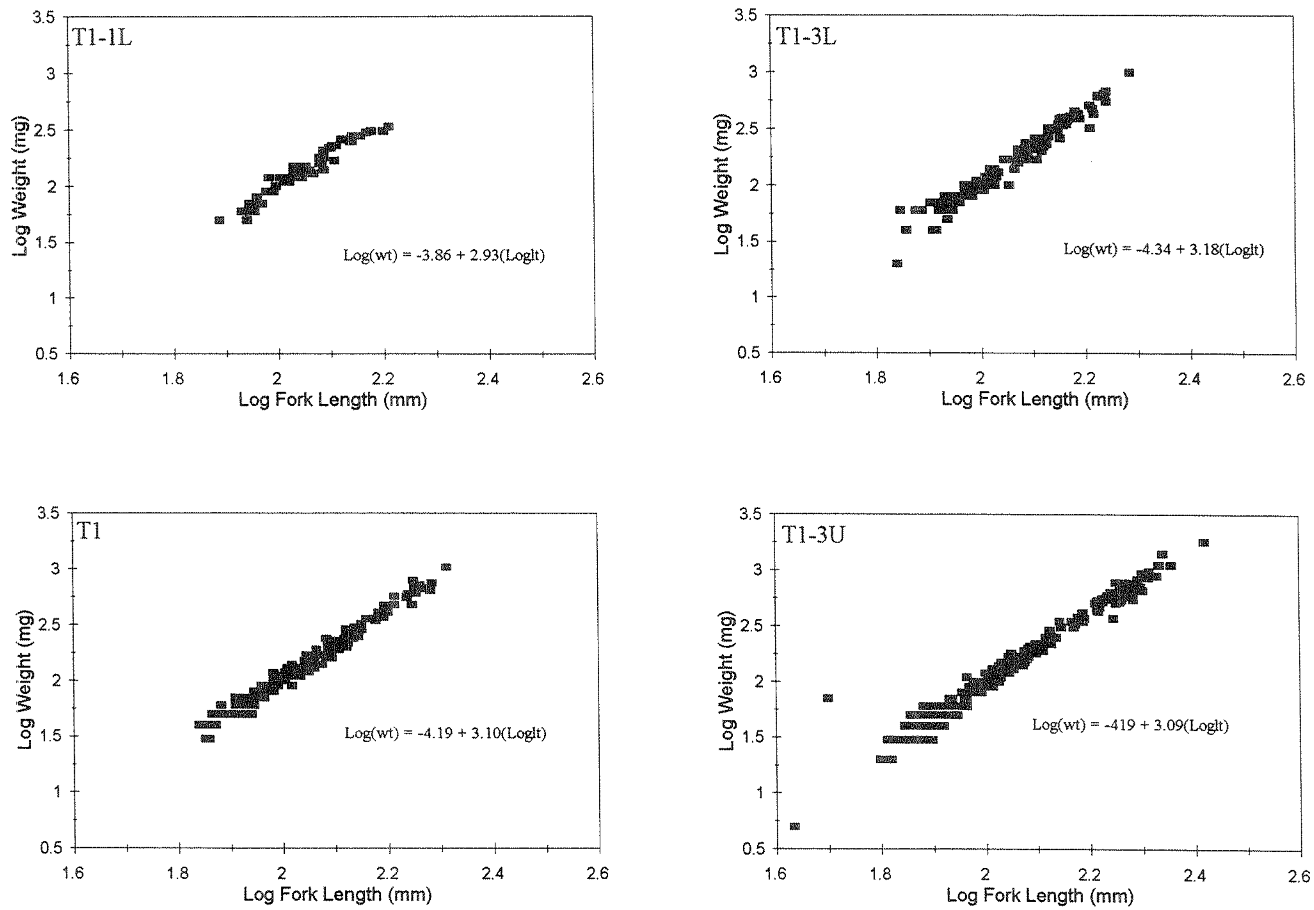


Figure 19: Length : Weight regressions for brook trouut sampled in each stream reach during August, 1994.

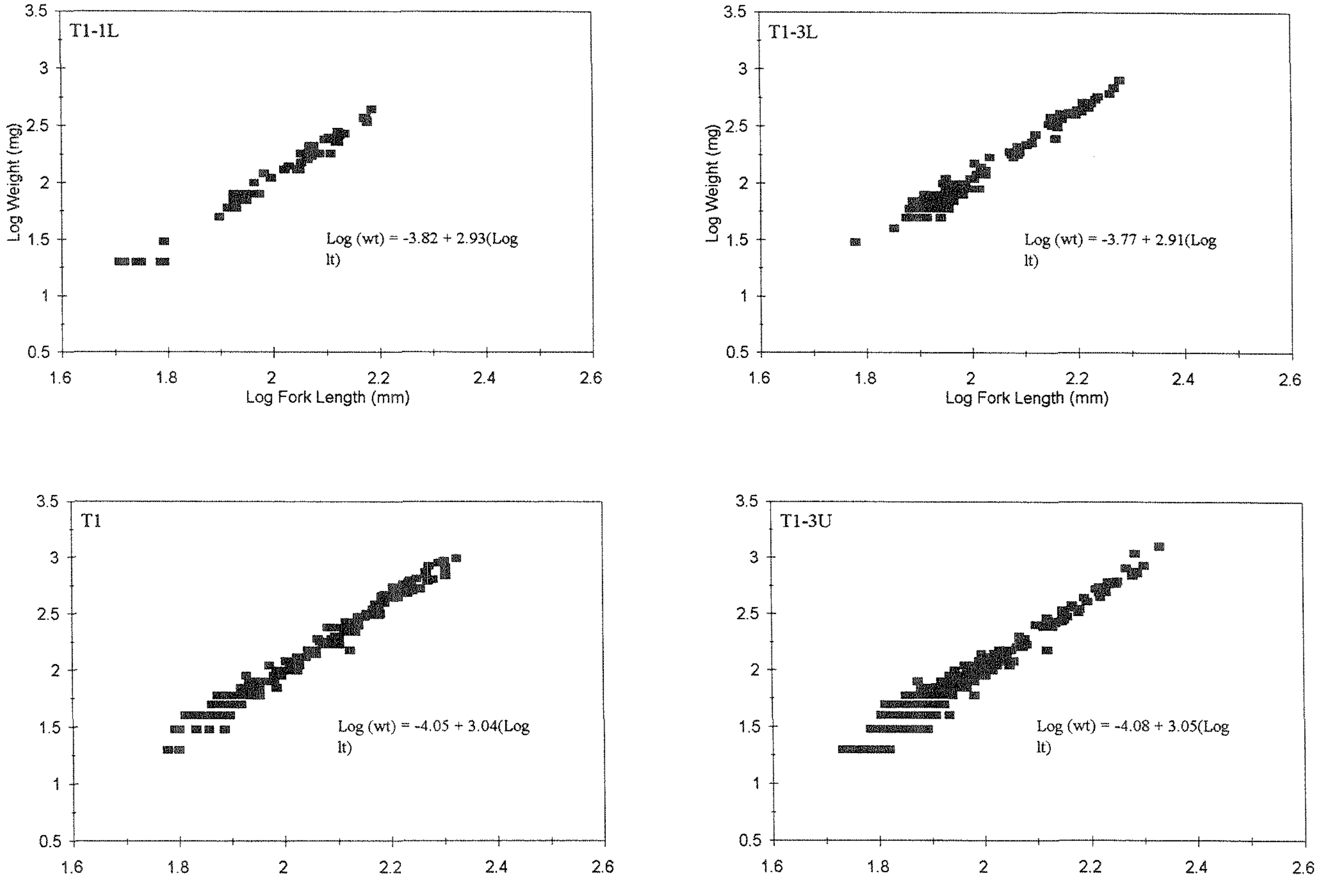


Figure 20: Length-weight regressions for brook trout sampled in each stream reach during August 1995.

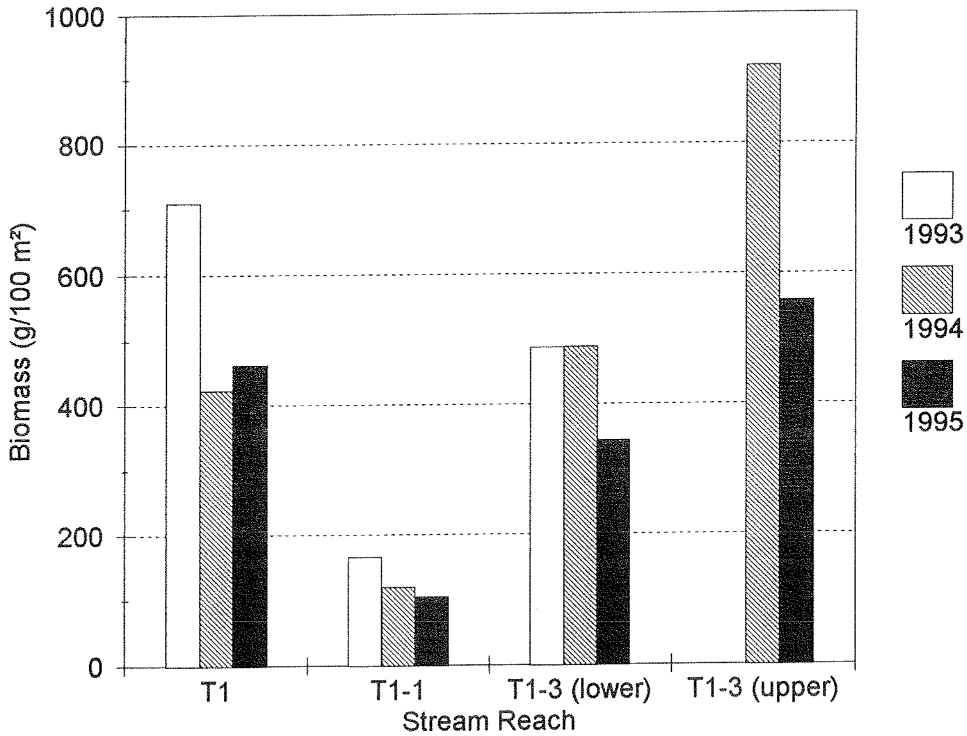


Figure 21: Average biomass estimates for each stream reach during the first three years (1993 - 1995) of electrofishing.

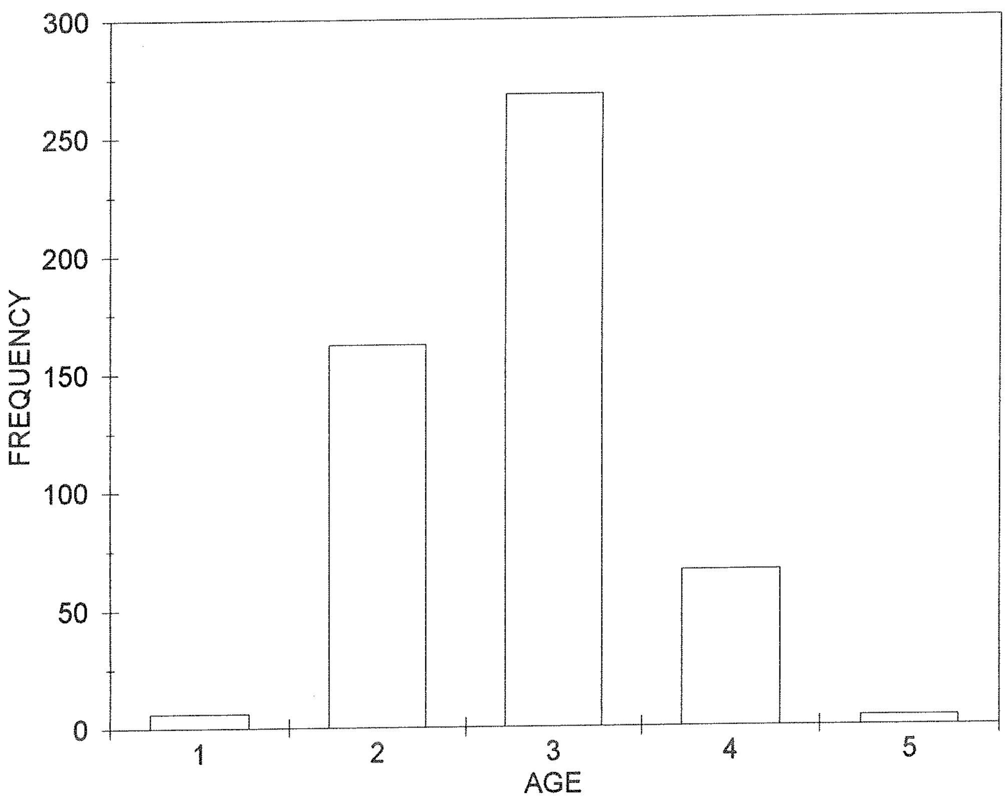


Figure 22: Age-class distribution of brook trout sampled from Copper Lake in June 1994.

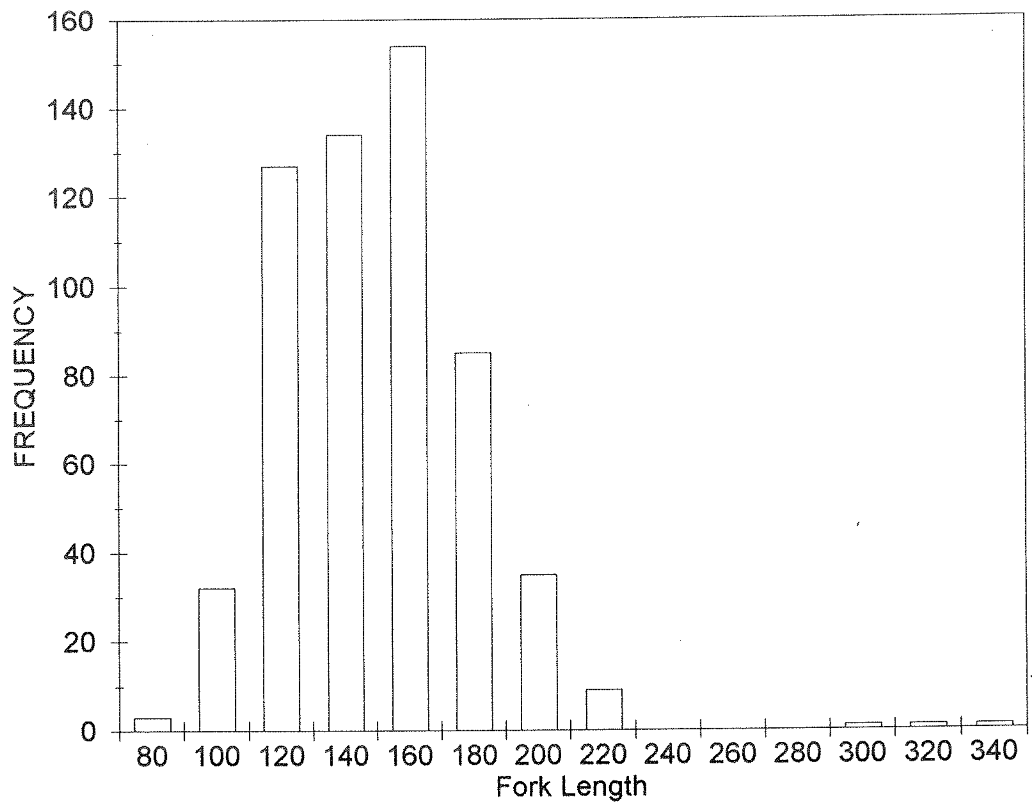


Figure 23: Size frequency distribution of brook trout sampled from Copper Lake, June 199

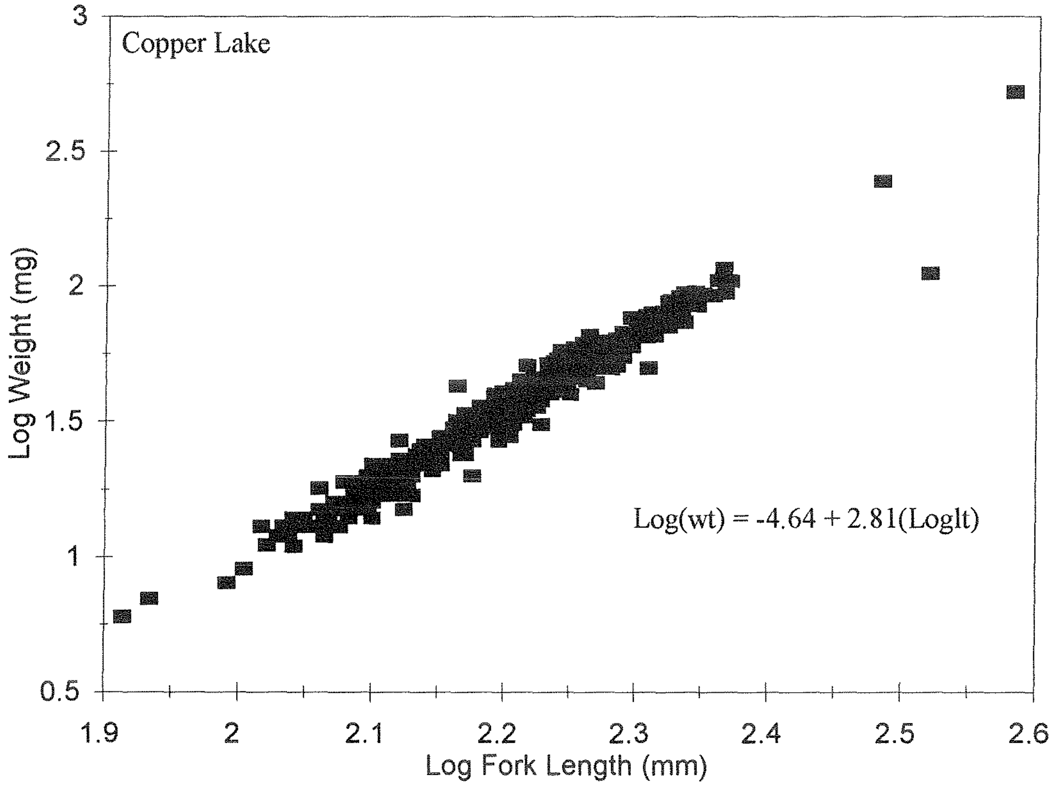


Figure 24: Length-weight regression for brook trout sampled from Copper Lake in June 1994.

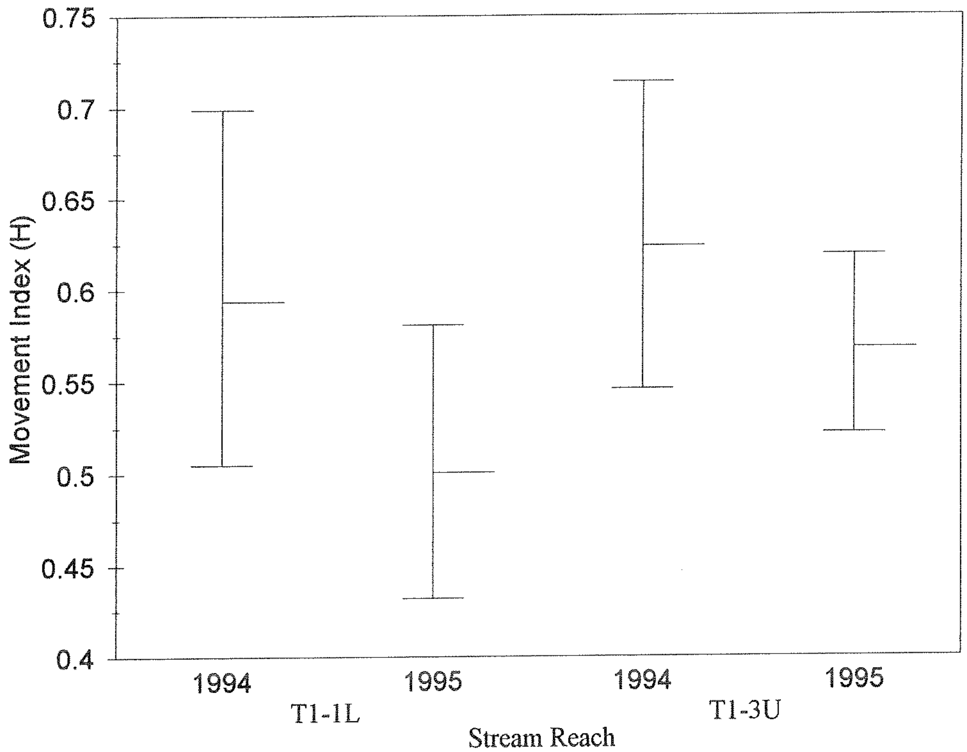


Figure 25: Movement indices calculated for brook trout in T1-1L and T1-3U in 1994 and 1995.

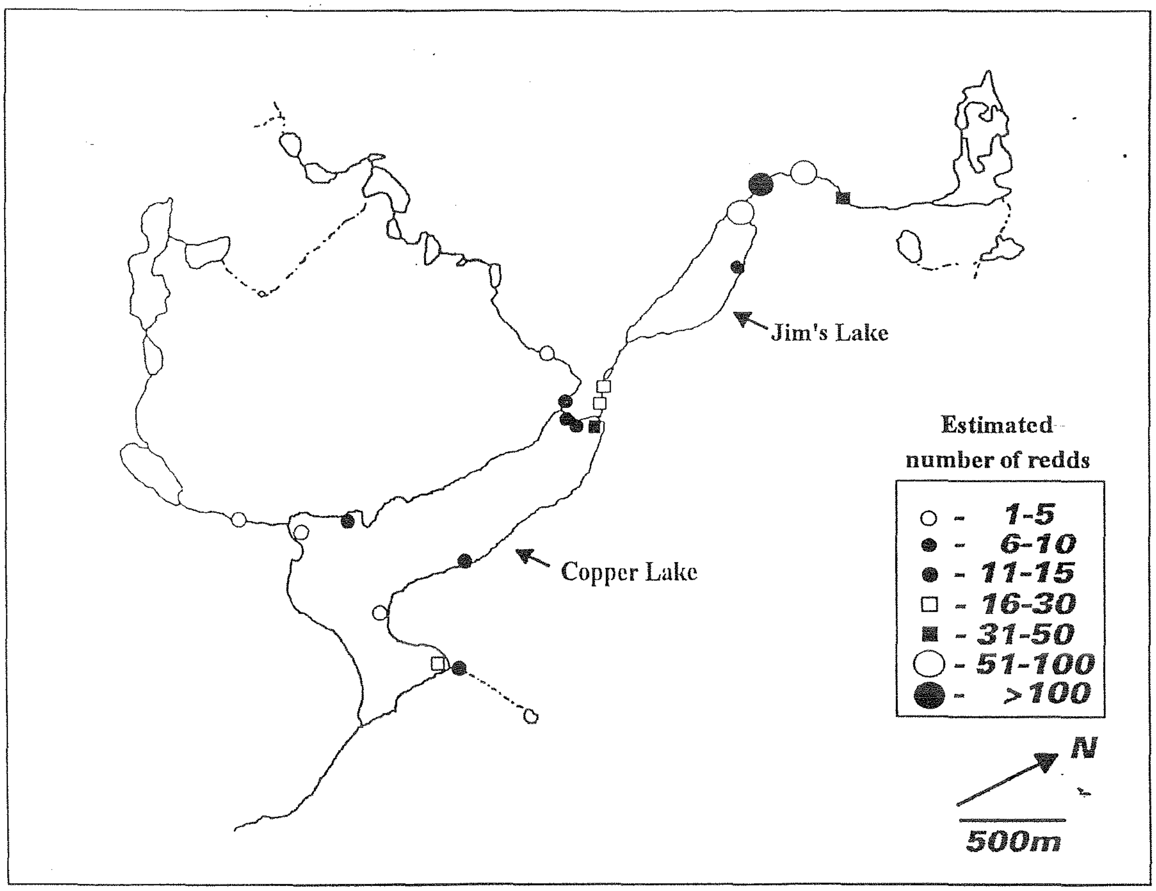


Figure 26: Location and estimated number of lacustrine and fluvial redds in the study area.