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THE NEWFOUNDLAND SMALL STREAM BUFFER STUDY PHASE I: IMPACTS OF CURRENT FOREST HARVESTING PRACTICES ON STREAM HABITAT AND BIOTA

R.C. Decker, D.A. Scruton, J.D. Meade, K.D. Clarke and L.J. Cole

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

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R.C. Decker, D.A. Scruton, J.D. Meade, K.D. Clarke and L.J. Cole

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

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The Newfoundland Small Stream Buffer Study Phase 1 was initiated and carried out by the Department of Fisheries and Oceans, Canada on the island of Newfoundland. Similar research was conducted in New Brunswick and British Columbia. The objective was to study the impacts of forest harvesting on salmonids and their habitat. Twelve stream reaches from 3 different watersheds subjected to forest harvesting were sampled during the summer of 2000. Salmonids studied were brook trout (*Salvelinus fontinalis*) and Atlantic salmon (*Salmo salar*). Other variables measured during this study included sedimentation rates, temperature regime, benthic invertebrate community composition, riparian buffer composition, stream habitat characteristics, and large woody debris. These results were then analyzed and related to the different forestry treatments. These treatments included a control stream (no cutting), treatment #1 stream reach (recent cutting, 20 m riparian buffer) and treatment #2 and treatment #3 (older cut areas, less than 20 m riparian buffer). In the control and treatment #1 reaches results from the sediment sampling, benthic invertebrate sampling, and temperature data were mixed. In one watershed forest harvesting did significantly increase the amount of sediment entering the treatment #1 reach while the other 2 watersheds did not yield any significant increase in sedimentation after cutting. Benthic invertebrates were significantly less abundant in treatment #1 reaches than in control stream reaches. Treatment #1 reach was significantly warmer than the control in one watershed while there was no significant difference in another watershed. Brook trout in treatment #1 reaches were larger than brook trout in control reaches while in treatment #2 and treatment #3 streams they were significantly smaller than those in control and treatment #1 stream reaches. Atlantic salmon size relationships were opposite to brook trout; the smallest salmon inhabiting control streams and the largest in streams impacted by older harvest events (treatment #3).

Résumé

Decker, R.C., Scruton, D.A., Meade, J.A., Clarke, K.D., and Cole, L.J. 2003. The Newfoundland small stream bufer study Phase I: Impacts of current forest harvesting practices on stream habitat and Biota. Can. Tech. Rep. Fish. Aquat. Sci. 2449: ix: + 77 p.

Le ministère des Pêches et des Océans du Canada a réalisé sur l'île de Terre-Neuve la phase 1 de l'étude sur les bandes de protection de petits cours d'eau de Terre-Neuve. Des recherches semblables ont été menées au Nouveau-Brunswick et en Colombie-Britannique. L'étude avait pour objectif d'examiner les effets de l'exploitation forestière sur les salmonidés et leur habitat. À l'été 2000, nous avons échantillonné 12 tronçons de cours d'eau situés dans trois bassins versants différents touchés par l'exploitation forestière. Nous avons étudié deux espèces de salmonidés, soit la truite mouchetée (*Salvelinus fontinalis*) et le saumon atlantique (*Salmo salar*), et avons mesuré des variables comme le taux de sédimentation, le régime de température, la composition de la communauté d'invertébrés benthiques, la composition de la bande de protection riveraine, les caractéristiques des habitats lotiques et les gros débris ligneux. Nous avons ensuite analysé les résultats en relation avec les différents traitements forestiers. En plus de cours d'eau témoins (aucune coupe), les traitements étaient les suivants : traitement n° 1 (coupe récente avec bande de protection riveraine large de 20 m) ainsi que traitements n° 2 et n° 3 (coupes plus vieilles avec bandes de protection riveraine de moins de 20 m). Dans les cours d'eau témoins et les tronçons soumis au traitement n° 1, l'échantillonnage des sédiments, l'échantillonnage des invertébrés benthiques et la prise de température ont donné des résultats variables. Dans un des bassins versants, l'exploitation forestière a entraîné une augmentation significative de l'apport de sédiments au tronçon soumis au traitement n° 1, mais pas dans les deux autres bassins versants. L'abondance des invertébrés benthiques était significativement moins élevée dans les tronçons soumis au traitement n° 1 que dans les tronçons témoins. Dans un bassin versant, l'eau était significativement plus chaude dans le tronçon soumis au traitement n° 1 que dans le tronçon témoin, alors qu'aucune différence significative n'a été observée dans un autre bassin versant. La taille des truites mouchetés était plus grande dans les tronçons soumis au traitement n° 1 que dans les tronçons témoins, tandis qu'elle était plus petite dans les tronçons soumis aux traitements n° 2 et n° 3 que dans les tronçons témoins et ceux soumis au traitement n° 1. La taille du saumon atlantique présentait une tendance contraire à celle de la truite mouchetée : les plus petits saumons habitaient les cours d'eau témoin, et les plus gros, les cours d'eau touchés par les coupes plus vieilles (traitement n° 3).

1.0 Introduction

Intensive forest harvesting has been ongoing on the island of Newfoundland since the early 1900's (Clarke et al. 1997). Three pulp and paper mills currently operating in Newfoundland are placing an increasing demand on forested areas. The method of forest removal on the island has traditionally been clear-cutting which is the most invasive and destructive method (WNMF 2002). Clear-cutting has been proven to adversely affect the local and regional environment especially aquatic systems such as small streams and ponds (Stone and Wallace 1998; Lynch and Corbat 1990; Binkley and Brown 1993). The aquatic community structure of streams is particularly sensitive to changes that occur to the adjacent terrestrial environment.

Some of the major stream issues associated with forest harvesting include increased sedimentation/siltation, changes to the thermal regime, changes to woody debris inputs and lowered amounts of large woody debris (LWD) (Rot et al. 2000; Brosofske et al. 1997; Scruton et al. 1997). Currently there are provincial guidelines in place to protect streams from these adverse effects. Retaining adequate riparian buffers is perhaps the most crucial guideline imposed by the government. A buffer is a strip of riparian habitat adjacent to the stream which is untouched during forest harvest (Scruton et al. 1995). In Newfoundland, a stream requiring a riparian buffer is any flowing body of water that is represented on a 1:50,000 topographic map (Clarke et al. 1997). There are some exceptions to this recommendation. For example, when a slope exceeds 30%, then the recommended 20 m buffer width is an additional 1.5 times the slope in percent. Therefore, a riparian buffer with a slope of 45% should measure 88 m (Table 1). Also, depending on the land-use activity (i.e. pesticide storage, fuel storage, etc.) buffer width may be up to 100 m to limit potential aquatic interactions (Table 2). Another factor influencing buffer width is wildlife management, for example, in an area frequented by black bears a buffer may be required to be 50 m wide (WNMF 2002).

The island of Newfoundland has a limited freshwater fish fauna dominated by salmonids (Goose et al. 1998). Currently extensive forest harvesting in many watersheds raises concern about potential impacts on salmonid populations. The species of interest in this study are brook trout (*Salvelinus fontinalis*) and Atlantic salmon (*Salmo salar*). Brook trout are common to nearly all streams on the island of Newfoundland and can be used to compare stress in the aquatic environment (Marschall and Crowder 1996). For a salmonid population to be sustainable it requires adequate stream flow, cover, substrate, cool temperatures, dissolved oxygen, water clarity and food. All of these parameters can be altered by forest harvesting (Scruton et al. 1997). In fact changes to any one of these parameters may have a significant impact on the age-structure, population size, and ability of salmonids to maintain populations within the stream (Gosse et al. 1998; Scruton et al. 1997).

The Newfoundland Small Stream Buffer Study Phase I is the first year of a three year project which investigates salmonid populations and habitat to determine the effectiveness of current riparian buffer guidelines. The aim of this project is to obtain regional specific data for the island of Newfoundland, Canada. This project borrows from the design of an earlier study, the Copper Lake Buffer Zone Study (Clarke et al. 1997), which evaluated the effectiveness of stream buffers at protecting salmonid populations, habitat and water quality. There have been numerous studies conducted in western Canada and the United States but these cannot be used to predict fish and wildlife interactions for Newfoundland because of different biophysical conditions (Clarke et al. 1998). For example, recent (~10,000 years) glaciation has resulted in stream morphology with variable relief patterns within a basin and the island's fauna and flora are still impoverished compared to the mainland areas of Canada (Larson and Colbo 1983).

The Newfoundland Small Stream Buffer Study Phase I is a component of a larger national project initiated by the Department of Fisheries and Oceans (DFO), with similar research being conducted in British Columbia and New Brunswick. The objective of this larger study is to: a) provide information for managing land-use impacts on streams to protect fish habitat; and, b) to evaluate the effectiveness of managed riparian buffers in mitigating the effects of forestry operations on small streams.

2.0 Methods and Materials

2.1 Study Area

Three watersheds, Corner Brook Lake, Indian Bay and Gander River, were selected for Phase I of the Newfoundland Small Stream Buffer Study (Fig. 1). In each of these watersheds, four stream reaches were examined. One of these four reaches was used as a control stream bordered by an uncut mature forest. One reach, treatment #1, was within a recently harvested area (<5 years) with a 20 m riparian buffer adjacent to the stream. Treatment #2 and #3 reaches were within older harvested areas (8–20 years) and bordered by limited riparian buffers (0–20 m). All measurements were made working upstream, therefore the endpoint of a reach was upstream of the start location. Global Positioning System (GPS) coordinates were obtained at 25 m intervals along the stream and those from the beginning (0 m) and the end of each reach in the Corner Brook Lake, Indian Bay and Gander River Watersheds are presented in Table 3-5, respectively.

2.1.1 Corner Brook Lake Watershed Study Site

Four stream reaches were chosen in this watershed. All measurements were taken from July 13 to July 18, 2000. The Corner Brook Lake control (CB-C) and treatment #1 (CB-1) stream reaches were sections of the same tributary and CB-C reach was upstream in an area not impacted by forest harvesting. CB-1 was downstream of the control, flowing through a harvested area with a 20 m riparian buffer.

CB-C flowed out of a small pond and emptied into a large meandering steady. This reach was 102 m in length with a wetted width between 4 and 6 m. No forest harvesting is scheduled adjacent to this stream until 2003.

CB-1 reach was approximately 750 m downstream of the control. This reach was 160 m long and 5-8 m in width. Harvesting occurred adjacent to this stream in 1996 and a 20 m riparian buffer remained uncut.

The second treatment reach was on different tributary than CB-C and CB-1. This stream reach flowed from a pond that had been dammed by beavers. CB-2 was 460 m long and the wetted width varied from 2 m to 6 m. Forest harvesting near this stream occurred in 1989 and only a limited buffer (0-12 m) remained.

The third treatment was also in a different stream from the previous three reaches. CB-3 began at a confluence and ended at the mouth a pond. In the headwaters, there was evidence of a dam or bridge structure that had been destroyed, possibly by ice flow. Several long timbers were still embedded along the upper portion of this reach suggesting it had been channellized for log transport during early forest harvest operations. CB-3 was approximately 270 m long and the wetted width ranged from 4 to 8 m. The substrate was extremely light in colour due to excessive amounts of marl ($CaCO_{3\,(s)}$). Marl occurs when the demand for CO_2 for photosynthesis is high in hard water ponds, resulting in precipitation of calcium carbonate (Horne and Goldman 1994). Forest harvesting adjacent to this stream occurred from 1987-88 and there was no evidence to signify a buffer had been retained.

2.1.2 Indian Bay Watershed Study Site

Sampling in this watershed was conducted from August 1 to August 8, 2000. Three of the study reaches; control (IB-C), treatment #1 (IB-1) and treatment #2 (IB-2) were located in the Indian Bay watershed while treatment #3 reach (IB-3) was a stream in the Gander Lake watershed. Two different watersheds were used because unusually hot-dry weather caused most small streams to be too warm for electrofishing (Scruton and Gibson 1995). The reaches used for IB-C and IB-1 were the same tributary in a section where there was no forest harvesting (control) and a section impacted by recent harvesting downstream (treatment #1), as described for CB-C and CB-1.

IB-C was 377 m long and 3-5 m wide. Both upstream and downstream of the reach, the stream widened into a large steady flowing through a fen.

The first treatment reach in this watershed, IB-1 was 232 m long and width varied between 1 m and 3 m. There had been recent harvesting adjacent to the stream in 1994-95 and a 20 m riparian buffer remained intact.

Treatment #2 reach, IB-2, flowed from a large steady into a pond. This reach was approximately 247 m long and width ranged from 3 to 9 m. The initial 50 m of the stream consisted of cascades and small waterfalls that may limit salmonid passage during periods of low flow. This stream reach included a stream crossing 60 m upstream from the start location (0 m). Harvesting occurred in 1994 and there was no riparian buffer bordering this reach.

IB-3 was in the Gander Lake watershed adjacent to the Indian Bay region, in close proximity to the other 3 reaches. This stream reach was 192 m long and averaged 6-8 m in width. The reach started downstream where it divided into 2 separate streams and ended upstream at the entrance to a large deep pool.

2.1.3 Gander River Watershed Study Site

Sampling of study reaches in this watershed was conducted from August 23 to August 28, 2000. All four reaches were in the Gander River watershed, with the control (GR-C) and treatment #1 (GR-1) on the same tributary with the control in an uncut area and the treatment #1 reach downstream in a harvested area.

GR-C was 370 m long and 2-6 m wide. This reach began downstream of the entrance to a widening steady and ended upstream where two smaller order streams converged.

Treatment # 1 reach, GR-1, was 325 m in length and 4 to 6 m wide. The reach began at the entrance to a long steady. Harvest adjacent to this stream occurred in 1995 with a 20 m riparian buffer intact and stream banks were dominated by thick alder growth.

GR-2 was 372 m long and 1-4 m wide. This reach started when the stream divided into two smaller streams and the upstream endpoint (372 m) occurred when the stream flowed into a bog. Forest harvesting occurred in 1995 and no riparian buffer was retained. A bridge crossed over the stream at approximately 55 m upstream from the start of the sample reach.

The final treatment reach for the Gander River watershed, GR-3, was longer and wider than any of the others because the area lacked smaller, more suitable streams. The study reach was 548 m long and averaged between 10 m and 12 m in width. The end of the reach (548 m endpoint) was the outlet from a small pond while the start was downstream where the stream meandered and widens. Both banks had been cut in 1994-95 and riparian buffers remained intact. The right buffer (upstream view) was 30-50 m wide and the left buffer varied between 20–30 m wide. A bridge was constructed across the stream 400 m upstream and a small pool formed immediately beneath.

2.2 Stream Surveys

Detailed stream surveys were conducted on all reaches. Each survey measured width/depth transects, stream velocity, substrate percentages (i.e. bedrock, large boulders (>1 m), small boulders (0.25-1 m), cobble (3-15 cm) and sand/silt/clay), pool characteristics, stream habitat classification, GPS coordinates, stream gradient, and canopy cover within the stream (Scruton et al. 1992). Detailed stream surveys were recorded at 50 m intervals for each reach. Average surface stream velocity (3 trials per each 50 m section) was calculated using an orange hockey ball. The ball was timed as it flowed over a 10 m section of the stream. Flow rate of the stream was calculated as metres per second (m/s). If present obstructions were also recorded, an obstruction is anything that would limit or prevent the passage of salmonids including falls, rapids, log jams, and areas of high velocity (Scruton et al. 1992). Substrate percentages were estimated in each 50 m section and substrate size classification is provided in Table 6. Pools were also recorded when present and measurements made included maximum length, width and depth. Stream gradient was determined using an inclinometer and stream canopy cover was determined by using a spherical densiometer (Platts et al. 1987). GPS readings were taken every 25 m to help locate and map the stream on a 1:50,000 topographic map. Appendix A provides an example of stream survey sheets used in this study.

2.3 Hydrological Measurement

A thalweg profile was used to obtain a flow pattern for each sampled reach. Thalweg measures the path of maximum water depth indicating the area maximum discharge in a channel (Hamilton and Bergersen 1984), which normally follows a meandering pattern back and forth across the channel. Thalweg determines the area of maximum flow in a stream and is useful in detecting ideal habitat for salmonids such as riffle, pools and undercut banks. The stream interval used in this project was 5 m except for the section which was electrofished where the interval was reduced to 2 m. This was done to get a more accurate hydrological map of the stream habitat electrofished. Appendix B provides an example of the Thalweg survey sheet for this study.

2.4 Large Woody Debris (LWD)

Large woody debris (LWD) analysis was conducted on all sampled reaches (n=12). LWD was considered to be any piece of wood with a base diameter greater than 8cm in, or providing shade to, the stream. The following data were collected for each piece of LWD: length, diameter at base, middle and top, length of wood submerged, tree species, branches/bark/needles/leaves present or absent, and orientation within the stream. Where possible LWD was classified either as spruce, balsam fir or birch. White spruce and black spruce were combined as spruce during sampling. LWD that could not be identified due to severe decomposition was labelled as unknown. Orientation was determined by using upstream as 0° and measuring clockwise 360° to the direction of the

LWD (Fig. 2). These initial size measurements were subsequently calculated as volume per 100 m. Appendix C provides an example of LWD survey sheets.

2.5 Buffer Composition

Buffer composition was determined at the midpoint of the 50 m section (25 m) of each stream reach. At this point a 5 m wide X 20 m deep section of the buffer was flagged off on both banks of the stream. Species composition was calculated and categorized as either adult trees (>10cm diameter at breast height-dbh), poles (<10cm dbh) or percent regeneration (saplings) within these plots. Ground cover (% shade provided by vegetation) ground was calculated using a spherical densiometer at both 15cm and 1 m height above the ground (Platts et al. 1987). Other parameters measured were forest floor cover (i.e. percent shrubs, moss, grasses percentages) and percent of trees blown down. In harvested areas the width of the remaining buffer was measured. A factor analysis was used to find any significant correlations between the following buffer parameters: percent cover; number of poles; number of mature trees; percent regeneration; percent shrubs; percent moss; percent grasses; percent alders. Appendix D provides an example of the Buffer Composition survey sheets used in this study.

2.6 Stream Temperatures

Vemco Ltd. electronic thermographs (Minilog 8-bit, -4 to 20°C, 0.1°C accuracy) were placed at the upstream and downstream endpoints of all control and treatment #1 reaches. These thermographs measured and stored the water temperature every hour for the duration that the thermographs were submerged, approximately eleven months (July/August 2000 to June 2001). Temperature data, as with sediment and benthic invertebrate data, was only collected from the control and treatment #1 reaches because these were used for the long-term component of this study.

2.7 Sediment Sampling

Modified Whitlock-Vibert boxes were used to quantify the amount of sedimentation within each sample stream (Clarke and Scruton 1997, Wesche et al. 1989). These boxes are approximately 14 cm X 6.4 cm X 8.9 cm with 3 mm openings and are typically used for egg incubation. Boxes were filled with cleaned cobble size rocks and anchored in the stream where they are used to estimate sedimentation rates. Three sediment traps were placed along every 1/5 interval of each reach (i.e.15 sediment traps per sampled reach). Sediment traps were placed only in the control and treatment # 1 stream reaches in each watershed, as a long-term study component. Boxes were deployed in July and August 2000 and collected in June 2001. Sediment traps were in Corner Brook streams for approximately eleven months and in Indian Bay and Gander River watersheds for ten months. Collection of the sediment traps involved lifting to the surface of the stream and carefully placing each in plastic bags such that none of the accumulated sediment was lost. New traps were then deployed and to be collected in 2002. The collected sediments were then wet sieved, dried at 70°C and then weighed in each of the four sediment fractions (<0.09, 0.09-0.50, 0.50-0.85, 0.85–1.40 mm diameter) (Clarke et al. 1997).

2.8 Benthic Invertebrates

Artificial substrates were deployed to evaluate invertebrate abundance and community composition of each control and treatment #1 stream reaches. Artificial substrates were deployed in July and August 2000 and collected in June 2001. Artificial substrates consisted of a plastic dish tub drilled with holes and filled with cobble-sized substrate from the adjacent streambed. One artificial substrate was placed along every 1/5 interval of the sampled reach (i.e. each control and treatment #1 stream reach had 5 artificial substrates). Specimens collected were sorted, counted and identified after Merritt and Cummins (1996). Taxonomic lists were made for each sampled stream reach and average abundance for each major orders were compared between stream reaches.

2.9 Salmonid Studies

Salmonid populations were assessed at each site by electrofishing for approximately 500 seconds. Data recorded included fork length (mm), weight (g) and age to obtain a qualitative assessment of populations. Species captured and sampled in this study were brook trout (*S. fontinalis*) and Atlantic salmon (*Salmo salar*). All captured salmonids were placed in a low concentration benzocaine bath to anaesthetize them (Scruton and Gibson 1995) and these fish were then measured for fork length and weight. A scale sample for age determination was removed from an area below the dorsal fin. Subsequently all salmonids were released unharmed to the stream reach from which they came.

2.10 Statistical Analysis

A combination of parametric and non-parametric tests was employed to analyse the data. A non-parametric Mann-Whitney U-test tested for any significant difference in LWD orientation between control and treatment #1 reaches. A one-way analysis of variance (ANOVA) was used to determine if there was any relationship between number of brook trout and amount of LWD present in a stream. A factor analysis was used to find relationships and correlations from many of the measured parameters for the buffer data. Average monthly temperature, mean daily temperature and maximum daily temperature were examined using a paired t-test to find any significant difference between the control and treatment #1 reaches in each watershed. A paired t-test was also used to find any significant difference in sediment accumulation between the control and treatment #1 reaches for each watershed. A pair t-test was also used to find if there was any significant difference in benthic invertebrate abundance between control and harvested treatment #1 reaches. A G-test was used to find if benthic invertebrate orders followed the same pattern of abundance between the control and treatment #1 reaches.

An analysis of covariance (ANCOVA) was used to determine if length and weight of salmonids were influenced by age and forest harvesting technique; the null hypothesis (H_0) tested was that salmonid size and age structure were not influenced by forest harvest practices. An ANCOVA measured homogeneity of slopes of the response variable (salmonid size) and explanatory variables (age and forestry treatment) for significance (Sokal and Rohlf 1995). A one-way ANOVA between salmonid age and treatment was performed prior to the ANCOVA and if the result was significant than an interaction between the age and forestry treatment was included as age was related to harvesting. If the one-way ANOVA was not significant then the interaction was not included in the ANCOVA because age and harvesting were not related. The level of significance for all tests was $p = 0.05$ and if residuals from any tests were not normal the data was randomized (up to 500 times) to increase reliability of the p-value (Sokal and Rohlf 1995).

3.0 Results

3.1 Stream Surveys

3.1.1 General Findings

Collectively, each reach was similar in respect to stream habitat type, size (except GR-3), substrate, and flow characteristics. Riffle habitat dominated all 12 reaches averaging 60% or more of the entire reach. Riffle habitat is defined as shallow water (<25 cm) with moderate current with broken surface usually over gravel, cobble and small boulder substrate (Scruton et al 1992). The other habitat types, such as pools, rapids, cascades, or steadies occupied the remaining 40% or less of each of the remaining reaches. Dominant substrate class within each reach were small boulders (0.25-1.0 m) and cobble (3–25 cm), with variations at each site. Mean channel widths, wetted widths and depths varied between streams. A summary of the stream characteristics observed for all reaches in each watershed is provided below.

3.1.2 Corner Brook Lake Watershed Study Site

Stream habitat for CB-C consisted of 98% riffle and 2% rapids. Mean (±S.D.) channel width, wetted width and depth were 9.8 m (±3.4), 9.0 m (±3.3) and 14.0cm (±2.9), respectively. There was less than 1% overhanging riparian vegetation consisting primarily of softwood, shrubs and grasses. Bank stability was good and there were no obstructions within the stream reach. Canopy cover for the stream reach averaged 7.95%, therefore 92.1% of solar radiation was able to reach the surface of the stream.

CB-1 stream habitat was 100% riffle. A riparian buffer of 20-30 m bordered this stream and beyond the buffer was a large clear-cut area. Mean (±S.D.) channel width, wetted width and depth were 6.9 m (±1.4), 6.4 m (±1.1) and 16.6cm (±6.9), respectively. CB-1 banks were stable and no obstructions were present. Riparian vegetation was composed of softwoods, shrubs and grasses with some hardwood present. There was less than 1% overhanging riparian vegetation along the entire sampled section. Mean canopy cover provided to this stream reach was 15.77%.

CB-2 stream habitat type was dominated by 88% riffle. The remainder was composed of 3% run, 4% pool, 4% rapids and 1% cascades. The cascades were relatively small (~4 m long) with an incline of 16° and were not considered an obstruction for salmonids. Mean (±S.D.) channel width, wetted width and depth were 6.3 m (±1.0), 4.6 m (±1.3) and 15.7cm (±4.8), respectively. No riparian buffer remained adjacent to this stream. Riparian vegetation was 72% alders with approximately 20% softwood interspersed. Ferns and grasses were also present within the riparian habitat. Mean canopy cover for the entire stream reach was 13.12% therefore 86.9% of solar radiation was able to reach the stream's surface. Dense overhanging alders provided the majority of cover, or shade, to this sampled stream reach.

Riffle habitat composed 96% of CB-3 reach along with 2% rapids and 2% pool habitat. No riparian buffer remained adjacent to this stream reach. Mean (±S.D.) channel width, wetted width and depth were 5.5 m (±1.4), 4.8 m (±1.5) and 9.4cm (±3.2), respectively. The substrate in this stream reach had a whitish-gray colour and marl was found along slower sections. This suggested a high amount of calcium carbonate ($CaCO_3$) within the stream. There was very little overhanging riparian vegetation (2.5%) and it was predominantly grasses and shrubs. There was only 10.5% softwood along this reach. There was less than 2% canopy cover provided by the riparian habitat, therefore 98% of solar radiation was able to reach the stream surface. Figure 3 illustrates the slopes for each of the four reaches within this watershed, each reach had a similar gradient.

3.1.3 Indian Bay Watershed Study Site

IB-C reach consisted of 80% riffle, 15% steady and 5% pool. Mean (±S.D.) channel width, wetted width and depth were 5.3 m (±1.1), 4.0 m (±0.9) and 11.2cm (±5.2), respectively. Only 1.5% of riparian vegetation was overhanging consisting of grasses and alders as the dominant vegetation types occupying 24% and 66%, respectively. The riparian habitat consisted of 20% softwood and only provided 7.11% average canopy cover.

IB-1 consisted of 82% riffle, 14% steady, and 4% pool. Mean (± S.D.) channel width, wetted width and depth were 7.2 m (±2.9), 5.2 m (±2.8) and 9.9cm (±9.4), respectively. Softwoods, shrubs, and alders were evenly distributed within the riparian habitat however mosses and grasses were the dominant vegetation types, 38% and 18%, respectively. Hardwoods were absent from the riparian habitat. There was less than 1% overhanging riparian vegetation, therefore only 1.5% shade was provided to the stream.

Midway along IB-3 reach there was a large, boggy steady which composed 38% of the habitat. The remaining 62% consisted of riffle (60%) and cascades (2%). These cascades were considered a potential barrier to salmonid passage during periods of extremely low flows. Mean (±S.D.) channel width, wetted width and depth were 6.9 m (±2.7), 5.2 m (±3.0) and 18.1cm (±13.0), respectively. Riparian habitat bordering this reach included softwood, shrubs, alders, grasses and bog. Overhanging riparian vegetation was present, occurring along 3% of the stream and mean canopy cover was 7.34%.

The habitat type of IB-3 was 100% riffle. Mean (±S.D.) channel width, wetted width and depth were 11.4 m (±3.5), 9.7 m (±3.6) and 17.2cm (±11.2), respectively. Alders (80%) dominated the riparian vegetation. Overhanging alders covered 6.5% of the reach although canopy cover along the reach was less than 1% in the absence of mature trees. Slopes for each of the sampled stream reaches within this watershed are graphically illustrated in Figure 4. IB-1 and IB-2 had steeper gradients then did IB-C and IB-3 but this did not cause significant differences in stream habitat or substrate composition.

3.1.4 Gander River Watershed Study Site

Stream habitat for GR-C was dominated by riffle (93%), while the remaining 7% consisted of three small pools at different locations along the reach. Mean (±S.D.) channel width, wetted width and depth were 5.0 m (±1.8), 4.1 m (±1.4) and 23.5cm (±6.1), respectively. Substrate composition differed from other reaches with dominant size classes consisting of gravel and sand rather than small boulders and cobble. Alders (78%) and grasses (22%) were the major vegetation types within the riparian zone. This dense alder growth led to 29% overhanging riparian vegetation which provided 39% shade, therefore only 61% of solar radiation was able to reach the surface of the stream.

GR-1 stream habitat was composed of 73.5% riffle, 16% steady, and 10.5% pool. Mean (±S.D.) channel width, wetted width and depth were 8.8 m (±1.7), 6.1 m (±2.0) and 22.8cm (±11.6), respectively. Substrate composition was also dominated by gravel, sand and fines. Alders, grasses and shrubs were the predominant vegetation types with softwood composing only 4% of the riparian habitat. Overhanging riparian vegetation occurred along 26% of the stream although there was only 4.5% average canopy cover at the center of the stream.

Stream reach GR-2 consisted of 96.5% riffle habitat and 3.5% pool habitat. Mean (± S.D.) channel width, wetted width and depth were 5.0 m (±1.1), 4.1 m (±1.1) and 16.5cm (±5.5), respectively. Riparian habitat consisted primarily of alders (68%) and grasses (26%) whereas softwoods and hardwoods composed only 5% and 1% of the area, respectively. Fifteen percent of the reach was shaded by overhanging riparian vegetation and the canopy cover at the surface of the stream was 21%.

GR-3 was the longest of the reaches and consisted of 98.6% riffle habitat and 1.4% pool habitat. The pool was produced by the construction of a bridge and therefore can be considered man-made. Mean (±S.D.) channel width, wetted width and depth were 9.6 m (±1.7), 7.8 m (±1.8) and 17.8cm (±4.5), respectively. Alders and grasses were the dominant vegetation along the stream banks but beyond both banks there was a 30 m buffer zone that consisted primarily of large softwoods. Only 2.5% of the reach was shaded by overhanging riparian vegetation. Mean canopy cover for this stream reach was 3.7%, therefore 96.3% of solar radiation was able to reach the water's surface. Figure 5 illustrates the slope of each reach within this watershed. GR-2 had a steeper gradient than did the other three reaches but this difference did cause any significant changes in stream habitat and substrate composition.

Average velocity for all 12 study streams is presented in Figure 6. Table 7 shows the average substrate composition for each of the 12 reaches.

3.2 Hydrological Measurements

The thalweg profile obtained from all 12 reaches revealed the maximum flow follows a meandering pattern (Fig. 7–18). Narrower flow meanders in the center of the stream occurred in narrower, faster sections of the stream reach. Bends in the stream were also noticeable on the thalweg profile because the maximum flow nears the stream bank. This may result in deeper pools or undercut banks along the outside edge of a bend in the stream.

3.3 Large Woody Debris (LWD)

The volume of LWD varied among the control and treatment stream reaches (Fig. 19). There were two stream reaches devoid of LWD in the Gander Lake watershed (GR-C and GR-1). The frequency of large woody debris (LWD/100 m) varied from 0 pieces to 17 pieces per 100 m.

The LWD consisted of 12 sampled reaches combined there was 21.6% spruce, 48.0% balsam fir, and 7.4% birch, and 23% unknown. On average, control reaches contained 7.33 pieces of LWD whereas 20.22 pieces of LWD were present in treatment reaches. In the 3 control streams, 72.8% of the LWD was labelled as unknown and 27.2% was identified as spruce. The major tree species recorded in the 9 treatment stream reaches was balsam fir and spruce at 53.3% and 20.9%, respectively.

Orientation of LWD was very similar between the control and treatment reaches. Divided into four orientation classes, 0-90°, 91-180°, 181-270°, 271-360°, the average amount of LWD in each orientation class for control reaches were 22.7%, 36.4%, 27.3%, and 13.6%, respectively. The treatment reaches followed a similar pattern to the control with the 91-180° orientation having the greatest percentage of LWD and the 271-360° having the least percentage. The average percentages for each class were 25.3%, 42.3%, 24.2%, and 8.2%, respectively. A Mann-Whitney test showed that there was no significant difference ($p = 1.00$) between the control and treatment reaches in regards to orientation of LWD.

3.4 Buffer Composition

The three control reaches had riparian buffer plot composition consistent with an old growth forest, therefore softwoods such as spruce, balsam fir, and larch were present. In all control buffers, the number of evergreen poles (<10cm dbh) was equal to or greater than the number of mature trees. Over-mature trees or dead snags were also present within the control buffers. Shrubs and alders were limited to areas along the stream banks that were often flooded during periods of peak flow. GR-C buffers were dominated by approximately 12-14 m of alders but beyond this there was a mature forested area. The slope of this buffer plot was <1° therefore this area of alders may be flooded during periods of peak flow. Other common characteristics of buffer plots along the control streams include 25-40% softwood saplings (regeneration), few blowdowns (Table 8), moss growth over forest floor, and moderate canopy cover (Fig. 20).

Remaining riparian buffer plots adjacent to treatment #1 reaches were similar to the control buffers within each watershed. Some buffers deviated from 20 m by 2-3 m, both wider and narrower, because the cut did not following the meandering of the stream. The major difference noted between control reaches and treatment reaches was that mature trees were blown down along the edge of the harvested area. There was no significant difference between the number of blown down trees (#/100 m^2) between the control and treatment reaches however downed trees in treatment buffers were usually localized near the edge of the buffer (Table 8).

With the exception of GR-3, stream buffers along the treatment #2 and #3 reaches differed from the control and treatment #1 reaches. The area adjacent to GR-3 stream reach was harvested in 1995 and a 20 m riparian buffer remained. The buffer composition of GR-3 was similar to that of the control and treatment #1 reaches. The remainder of the reaches, CB-2, CB-3, IB-2, IB-3, GR-2, were harvested prior to 1995 therefore limited riparian border remained uncut. The buffer composition of these reaches were consistent with alders present at a higher percentage and fewer mature and immature trees present than in control and treatment #1 buffers. Blowdowns, if present, were often older and decaying. Higher ground cover was found in buffers dominated by dense alder growth than in those buffers dominated by mature forest (Figure 20). With the exception of CB-2 and GR-1, no other reaches had slopes exceeding 30% (17°), therefore did not require buffers larger than 20 m. Although these two reaches had slopes ranging from 35° to 60°, riparian buffer width on GR-2 was 18 m and CB-2 had no buffer.

The factor analysis revealed the highest correlation within buffers was between mature trees, poles, moss cover (%) and regeneration (%) (Fig. 21). Percent cover was equally related to percent alders and mature trees since both provide adequate shade to the forest floor. Also a linear regression revealed that there was negative relationship ($p = 0.000$) between the amount of moss and alders and between the amount of moss and grasses. When the amount of moss was high the amount of alders and grasses were lower and vice versa (Fig. 22). Regeneration (softwood saplings) was not significantly correlated with any of the other measured parameters ($p > 0.05$).

3.5 Stream Temperatures

Temperature data was only obtained from the control and treatment #1 reach in each of the watersheds. Table 9 presents the temperature data as monthly averages and monthly temperature ranges. The four thermographs from the Corner Brook streams did not record temperatures for the entire duration of the project due to malfunctions unknown. Thermographs collected in June of 2001 were replaced for collection in June 2002.

In the Indian Bay watershed the stream temperatures were slightly higher in IB-1 than in IB-C during August, May and June (Fig. 23). During the winter months the temperatures in the IB-1 stream were slightly cooler and the ranges were smaller than IB-C (Table 9). A paired t-test on the monthly averages revealed that there was no significant difference in temperatures between the two stream reaches ($p = 0.785$). Stream temperatures in GR-1 were, on average, warmer all 10 months than GR-C (Fig. 24), the monthly temperature ranges were also greater than GR-C (Table 9). A paired t-test performed on these stream reaches revealed that GR-1 was significantly warmer than GR-C ($p = 0.001$). The warmest water was recorded in IB-C where temperatures reached a peak of 27.9°C during the month of August.

The number of days the mean and maximum daily temperatures (°C) were within a particular temperature range are presented in Table 10 and 11, respectively. The temperature range 0 – 4.9°C dominated. A paired t-test revealed that there was no significant difference between the number of days the mean daily temperature was within each class between IB-C and IB-1 ($p = 0.904$) and GR-C and GR-1 ($p = 0.993$). A t-test also showed there was no significant relationship between the maximum daily temperatures in each of the control and treatment #1 stream reaches in the Indian Bay ($p = 0.996$) and Gander River ($p = 0.926$) watersheds.

3.6 Sediment Accumulation

Ninety sediment traps were deployed only in the control and treatment # 1 reaches of each watershed. Eighty-six sediment traps from were subsequently collected and analysed in the summer of 2001. The four traps not recovered were possibly lost due to peak flows or ice scour. Total accumulated sediment is presented as average weight per size class per one sediment trap in Figure 25. The total accumulation per trap for all 6 reaches (3 control and 3 treatment # 1) ranged from 0.65 g to 5.64 g.

In the Corner Brook Lake watershed a paired t-test revealed a significant increase ($p = 0.035$) in sediment from the control to the treatment # 1 reach (Fig. 25). The average total sediment accumulation per trap in CB-C was 1.41g whereas the average in CB-1 was 5.64g. There were no stream crossings present on either CB-C or CB-1 that could increase sedimentation.

In the Indian Bay watershed, IB-C had a greater sediment accumulation than IB-1. The total accumulation per trap for IB-C was 1.05g and the average accumulation per trap in IB-1 was 0.65 g. The largest difference occurred in the 0.85<1.40 mm mesh size where there was a difference of 0.27 g per trap (Fig. 25). A paired t-test revealed that the difference between the two reaches was not significant ($p = 0.121$). Stream crossings were not present on either of these reaches.

Sediment accumulation in the Gander River watershed followed a similar pattern to the Corner Brook Lake watershed. Greater accumulation occurred in the treatment #1 than in the control reach with the exception of the <1.40 mm mesh size. The average sediment accumulation per trap in the GR-C was 1.89 g while in GR-1 it was 3.46 g (Fig. 25). The sediment accumulation in GR-1 was not significantly different from GR-C ($p = 0.069$). GR-1 was influenced by a road crossing located 22 m downstream of the endpoint resulting in 12 of 15 traps deployed downstream of the road and bridge structure.

3.7 Benthic Invertebrates

Thirty artificial substrates were deployed in the summer of 2000 and only 17 were recovered, 10 from control and 7 from treatment reaches. Similar to the sediment traps, lost artificial substrates were possibly swept away by peak flows or ice movements. Benthic invertebrates were identified, when possible, as far as genus but were presented at the Order level because of variability at genus and family levels between watersheds. Each stream community was dominated by Orders Ephemeroptera, Trichoptera, and Diptera, while Plecoptera were also present in lesser amounts (Fig. 26). Family Chironomidae (midges) are a member of Order Diptera but are not included with the Diptera in Figure 26 because they are not considered true flies. Average chironomid abundance (#/artificial substrate ±S.E.) within control reaches was 70.40 (±8.67) and average abundance within treatment reaches was 47.57 (±8.77). Order Odonata was also present in some reaches and average abundance for controls was 0.80 (±0.33) compared to 0.29 (±0.29) for treatments.

The dominant families present from Order Ephemeroptera were Heptageniidae, Ephemeridae, Ephemerellidae, Baetidae and Leptophlebiidae with Heptageniidae being the most common. Order Trichoptera was dominated by families Hydropsychidae, Limnephilidae, Hydroptilidae and Polycentropodidae. Three other families were present but only in small abundances and in different watersheds. Family Perlidae was the most abundant family within Order Plecoptera while families Perlodidae and Leuctridae were present less frequently. With the exception of the Chironomidae, family Simuliidae was the most abundant of the Diptera while families Tipulidae and Culicidae were moderately abundant in most reaches.

There was a greater abundance of all benthic invertebrate Orders in control reaches than harvested treatment reaches (Fig. 26). The data were replicated 500 times (normality) and a statistical t-test revealed that abundances in the control reaches were significantly greater ($p < 0.05$) then the abundance in the treatment #1 reaches. A G-test showed that there was no significant difference with the proportion of each Order (Ephemeroptera, Tricoptera, Plecoptera and Diptera) between control reaches and treatment reaches. Therefore, the benthic invertebrates present in the harvested treatment reaches were proportionately less abundant than in the control reaches.

3.8 Salmonid Studies

3.8.1 General Findings

The number of salmonids captured varied per reach, ranging from 13 in CB-C to 133 in GR-3. In total 654 salmonids were captured and sampled, of these 311 were older than 1 year and 343 were young of the year (YOY). The total number of brook trout (1-4 years of age), YOY brook trout (<1 year), juvenile Atlantic salmon or parr (1-4 years), and YOY Atlantic salmon (<1 year) were 216, 210, 95, and 133, respectively. Brook trout were present in all reaches whereas Atlantic salmon were captured in only 4 of the reaches; IB-C, IB-1, IB-3, and GR-3.

3.8.2 Brook Trout

In total 216 brook trout (1 year +) were captured and sampled. In the 12 reaches, the number of brook trout ranged from 1 in IB-C to 41 in CB-3. The stream length, number of brook trout sampled and number of brook trout/100 m for each reach is presented in Table 12. The number of brook trout sampled was greatest in streams influenced by logging in the Corner Brook Lake and Indian Bay watersheds while the opposite occurred in the Gander River watershed (Table 12). YOY captures ranged from 77 in IB-2 to none in other reaches. Age of sampled brook trout ranged from YOY (0) to age 4.

The average weight (g) of brook trout in all three watersheds provided the same general trend. Average weight in the treatment #1 reaches was slightly higher than in the control reaches. After this initial increase, there was a decline in treatment #2 and #3 reaches (Fig. 27). The same trend was evident with fork length (mm) with a slight increase in length from the control to the treatment #1 reaches and then a decrease in treatment #2 and #3 reaches (Fig. 28). Similar trends were expected with length and weight because the two are positively correlated. No trends were evident with the length and weight of YOY.

Analysis of covariance (ANCOVA) was employed to examine the influenced of treatments on brook trout size. Brook trout age and different forestry treatments are considered the explanatory variables for the trends found in the average brook trout size. A one-way ANOVA revealed that brook trout age is a response to treatment ($p = 0.000$) therefore an interaction term between age and treatment was present in the ANCOVA. The ANCOVA revealed that trends in brook trout length ($p = 0.023$) and weight ($p = 0.000$) can be explained by the different forestry treatments. The residuals were normally distributed therefore replication was not required.

Also, a one-way ANOVA revealed that there was no significant relationship ($p = 0.304$) between the number of brook trout/100 m against the volume of LWD(m^3)/100 m within a reach. In streams where YOY were present there was no significant relationship ($p = 0.960$) using a one-way ANOVA between YOY/100 m and LWD(m^3)/100 m.

3.8.3 Atlantic Salmon

Atlantic salmon parr were sampled from 3 reaches in the Indian Bay watershed and from 1 stream reach in the Gander River watershed. The number sampled ranged from 7 in IB-C to 48 in IB-1. The reach length, average fork length, weight and number per 100 m are in Table 13. The number of salmon YOY per stream varied from none in stream reaches to 100 in GR-3. Statistical and graphical analysis for Atlantic salmon could not be performed for the Gander River watershed because salmon were present in only one reach therefore comparisons for the watershed could not be made.

Salmon were present in the Indian Bay watershed in 3 of 4 reaches (IB-C, IB-1 and IB-3) therefore a comparison was possible. A clear trend was evident with the average length and weight in this watershed. IB-C had the smallest salmon and there was a significant size increase from IB-1 to IB-3 (Fig. 29). The largest salmon were in the stream bordered by oldest cut area and the smallest were in the non-harvested areas; this is opposite to brook trout results found from the 3 sampled watersheds.

The influence of the different treatments on size of Atlantic salmon was tested using an analysis of covariance (ANCOVA). The null hypothesis (H_0) tested was salmon size and age structure was not influenced by forest harvest practices. In contrast to the brook trout results, a one-way ANOVA revealed that age of the Atlantic salmon was not related to treatment ($p = 0.701$) therefore no interaction term between age and treatment was present in the ANCOVA (Sokal and Rohlf 1995). The ANCOVA revealed that the increase in salmon length ($p = 0.001$) and weight ($p = 0.000$) was related to the different forestry treatments. The residuals were not normally distributed from the original data therefore replication of 300 times was required.

4.0 Discussion

4.1 Stream Surveys

The habitat for the 12 reaches was dominated by riffle with small boulders and cobble as the dominant substrate composition. Salmonids use pools and coarse substrate as protective habitat from avian and mammalian predators (Sooley et al. 1998). Cobble and small boulders are often the rearing grounds for young of the year salmonids because of the shaded and protected habitat provided (Gosse et al. 1998). All 12 reaches appear to be good salmonid habitat based on substrate and habitat characteristics. Cobble and gravel size substrate used as spawning beds by salmonids can easily be destroyed by excess sedimentation and siltation from forest harvesting and road construction (Clarke et al. 1998).

Bisson et al (1992) noted that overhanging riparian vegetation along the edge of a stream also provides salmonids with shaded and protected habitat. Results from the Newfoundland Small Stream Buffer Study Phase 1 show little overhanging vegetation within any of the 12 reaches. Overhanging vegetation is also related to the amount of canopy cover provided by riparian vegetation. Canopy cover also provides shade to streams. Solar radiation reaching the surface of a stream can change productivity and temperature. Solar radiation reaching the surface of the 12 reaches used for this study ranged from 61% to 99%. Some authors have noted that loss of canopy cover can have both positive and negative impacts (Berg 1995; Binkley and Brown 1993). Unshaded sections of streams allow increased solar radiation to reach the stream bottom which increases autochthonous production thereby improving salmonid habitat (Bilby and Bisson 1992; Culp and Davies 1983). The major negative impact of forestry and canopy openings is the increase in water temperature.

Stream velocity varied between each of the 12 reaches with one notable distinction. The four stream reaches in the Indian Bay watershed had significantly lower velocities than the other 8 reaches (Fig. 6). The Indian Bay watershed was sampled during the first week of August in an extremely hot, dry period which reduced discharge. Salmonids tend to take refuge in pools created around boulders, beneath undercut banks, and in deeper steady areas within the stream and ponds during periods of low flow (Platts and Nelson 1988).

4.2 Hydrological Measurements

The thalweg profile revealed there was no difference in flow pattern between control and treatment reaches. The meandering flow patterns are consistent with all natural streams. Ideal habitat for brook trout and Atlantic salmon are the pools and undercut banks created at bends in the stream when the maximum flow scours the outside bank (Aadlund 1996; Burton 1997). Fast flowing, riffle habitat is also good for salmonids habitat as this type of habitat is rich in oxygen and food resources. These areas with broken surface water are able to absorb oxygen from the atmosphere and are more productive than pools or steadies (Horne and Goldman 1994). Forestry activities can impact many of parameters that influence flow pattern such as LWD, increasing peak flow and destabilizing stream banks (Aadlund 1996; Lisle 1986).

4.3 Large Woody Debris (LWD)

There was no significant relationship between the amount of LWD and the number of brook trout or Atlantic salmon. LWD may be considered detrimental to salmonids if it acts as a barrier to movement but it may still have an important function in the morphology of Newfoundland streams (i.e. low-head barriers). This is in contrast to most studies that show LWD is positively correlated with the population of salmonids. In Newfoundland streams, however, Clarke et al (1998) found that the amount of LWD present in a stream negatively impacted the number of brook trout and YOY inhabiting the stream.

LWD primarily enters a stream via windthrow, mass wasting and snow and ice loading (Rot et al. 2000; Hairston-Strang and Adams 1998; Bilby and Ward 1991). The amount and orientation of the LWD is a dynamic factor within streams because it has the potential to change during high winds, periods of high and low flow, and losses from erosion and decay. Greatest inputs of LWD into a stream system occur directly after a harvest event when there is greater exposure to wind (Hartman et al. 1996). LWD larger than 8cm helps form and maintain habitat units such as pools (Flebbe and Dolloff 1995) and is large enough to remain stable under normal flow conditions within the small streams sampled for this study. LWD aids in pool production because it promotes hydraulic scouring which produces pools and it also retains fine sediments that could potentially fill salmonid spawning grounds (White 1996; Ralph et al. 1994). Removal of LWD source in a stream by forest harvesting may reduce the diversity of habitat types present therefore leading to a less productive system.

4.4 Buffer Composition

The composition of buffer plots varied between the different harvest treatments for each stream. Control reaches were natural, untouched systems and therefore the wooded areas adjacent to these streams were consistent with Newfoundland's boreal forest climax community. The climax community in Newfoundland consists of black spruce (*Picea mariana*) and balsam fir (*Abies balsamea*) (Hosie 1990). There is a moderate percentage of ground cover and the forest floor was dominated by moss. This dense canopy limits the amount of light reaching the forest floor and hence there is little warming of groundwater. The old growth forest provides shade to the stream and is a source of LWD greater than 8 cm dbh.

Treatment # 1 reaches, bordered with 20 m riparian buffers, were similar to the undisturbed buffers adjacent to the controls with one major exception. Along the boundary line between the riparian buffer and the clear-cut area there was an increased number of windfalls (Table 8). This occurs because there is increased exposure to wind for trees along the edge of the buffer. The trees fall in the direction of the prevailing winds and often cause the collapse of neighbouring trees (Richards et al. 1996; Murphy et al. 1986).

Limited buffers, if any, bordered the treatment # 2 and # 3 reaches (with the exception of GR-3). These buffers consisted primarily of dense alder growth. This occurred because the area was disturbed by forest harvest, the soil stability was likely lost and much of the fine soil, along with the nutrients, may have been washed into the stream by snowmelt and precipitation. Once the soil is disturbed and devoid of nutrients it is very difficult for hardwood or coniferous species to recolonize the area. Alders invade the area because they are nitrogen fixers and replenish the nitrogen within the soil (Barnes et al. 1998). Alders are also able to withstand inundation by peak flows. Subsequently, boreal forest succession can continue as the hardwoods invade the area followed by the climax community conifers. In Newfoundland this process can take up to 100 years whereas in more temperate areas 40 years may be enough time for the area to return to climax state (Barnes et al. 1998; Hosie 1990). Regeneration and growth of trees is a slow process due to Newfoundland's short growing season and unfavourable winters therefore growth of saplings into mature trees is a slow process (Hosie, 1990).

4.5 Stream Temperatures

Change to a stream's thermal regime can significantly impact the aquatic community (Hartman et al. 1996). Other studies have shown that streams in harvested areas have higher water temperatures than those not influenced by forest removal (Scruton et al. 1998a; Brosofske et al. 1997; Holtby 1988; Beschta et al. 1987). Two main mechanisms that can increase stream temperature are loss of canopy cover and input of warm groundwater. The first occurs when the forest canopy is opened due to harvesting, allowing increased amounts of solar radiation to reach the stream surface (Garman and Moring 1991). Increased sunlight leads to increased water temperatures. The second mechanism occurs when the forest floor is exposed to excess sunlight after a clear-cut event. The soil warms causing heating of the water percolating down thereby elevating groundwater temperature. Thus warmed groundwater enters and consequently increases stream water temperature (Barton et al. 1985).

Increased stream temperature can be harmful to fish when it causes increased respiration and reduces the amount of dissolved oxygen (Bérube and Lévèsque 1998). Water temperature above 22°C is considered stressful for salmonids and long periods of exposure to high water temperatures may lead to death or habitat abandonment (Gosse et al. 1998; Clarke et al. 1997). Developing eggs require cooler water temperatures (3.5–9.0°C) to ensure hatching success (Scruton et al. 2000). None of the monthly average temperatures from the reaches were above 22°C but there were numerous days when the daily mean and maximum temperatures were within the 20.0–24.9°C and 25°C +

temperature range (Tables 10 and 11). Summer high temperatures in the IB-C and IB-1 were 27.9°C and 27.6°C, respectively.

The slight differences in temperature between the control and treatment # 1 reaches may have occurred because of the experimental design with both control and treatment # 1 reaches being portions of the same stream. There may not have been enough distance between the two reaches to allow the water to warm significantly or the 20 m riparian buffers may ameliorate major thermal changes influenced by forest harvesting. During the winter months when stream temperatures fall to –0.1°C, brook trout move to deeper areas such as steadies or they move into ponds and lakes within the watershed. Cold water temperatures in Newfoundland persist for 5 months, December to April. Some studies of stream temperatures revealed that those influenced by forest harvesting have quicker warming and cooling fluctuations than streams not impacted by cutting (Scruton et al. 1998a). This did not occur in the reaches during the summer of 2000; with temperature decline and increase being relatively uniform between control and treatment # 1 reaches (Fig. 23 and 24).

4.6 Sediment Accumulation

Previous studies in Newfoundland and mainland North America have demonstrated that streams impacted by adjacent forest harvesting receive more sediment input from terrestrial sources than streams not influenced by cutting (Berkman and Rabeni 1987; Clarke et al. 1998; Wesche et al. 1989). Sediment analysis from control and treatment # 1 reaches revealed mixed results. In the Corner Brook Lake watershed sediment accumulation was significantly greater in the treatment #1 reach than in the control. Sediment accumulation in the Gander River watershed was greater in the treatment #1 reach although results were not significant (Fig. 25). The 20 m riparian buffers have not completely protected these streams from excess sediment runoff from the clear-cut area. In the Indian Bay watershed there was slightly more sediment accumulation in the control stream.

While forest harvesting and road construction are the main causes of excess sedimentation (McCubbin et al. 1990) they may not be the only causes within these watersheds. The geomorphology of the stream and its banks may create greater inputs of sediments during periods of peak flow and runoff (Berkman and Rabeni 1987). The experimental design did not measure the pre-harvest sedimentation rates and therefore the extent of sedimentation cannot be directly related to the cutting events.

4.7 Benthic Invertebrates

The lotic benthic community of the sampled reaches consisted of organisms that have widespread distribution within freshwater systems in Newfoundland (Larson and Colbo 1983). These benthic invertebrates are sensitive to the land-use practices occurring adjacent to a stream (Brown et al. 1997). Benthic invertebrate abundances are related to stream velocities, substrate size, and woody debris all of which can be changed by forest harvesting (Gurtz and Wallace 1984). Previous studies from elsewhere have shown that clear-cutting can both increase (Kedzierski and Smock 2001) or decrease (Colbo et al. 1997; Gurtz and Wallace 1984) benthic invertebrate abundances. Increases can occur because of the increase of nutrients that enter the stream via runoff. In Newfoundland Colbo et al (1997) found that disturbances such as clear-cutting reduced both benthic invertebrate abundances and diversity in Newfoundland streams. Results from this study have shown that abundances are lower in reaches influenced by cutting while diversity does not significantly change. It is possible that 20 m riparian buffers protect invertebrate diversity although abundances are lowered after a harvesting event. Davies and Nelson (1994) found that smaller riparian buffers lead to lowered benthic invertebrate abundance and diversity. Chironomids were the most abundant family present at both the control and treatment reaches. Chironomids become a major portion of fish diet after a clear-cut event because the have the highest abundance of any other benthic invertebrate family (Garman and Moring 1993). This occurs because chironomids have a short generation time therefore can respond quickly to any changes caused by forest harvesting (Newbold et al. 1980).

4.8 Salmonid Studies

The Newfoundland Small Stream Buffer Study Phase 1 was not a quantitative assessment of salmonid populations but rather a qualitative assessment of salmonid size and habitat. The data did indicate differences in both brook trout and Atlantic salmon size between each of the stream treatments. Elsewhere in North America studies have shown forest harvesting has a negative impact on stream habitat and salmonids (Berube and Levesque 1998; Rosenfeld et al. 2000; Sullivan et al. 1986).

Streams in Newfoundland usually have low nutrient concentrations and low primary production and consequently brook trout growth is slow (Clarke and Scruton 1998). The largest brook trout inhabited treatment #1 reaches while the smallest brook trout were sampled in the treatment #2 and #3 (Fig. 27, Fig. 28). These results are consistent with Rosenfeld et al (2000). The initial increase in brook trout size from the control to the treatment #1 reaches possibly occurred because there was an increase in the amount of nutrients that entered the stream from the adjacent terrestrial environment. This input increases both the productivity of the entire aquatic system and the growth rate of the brook trout (Connolly and Hall 1999). However, when the majority of the nutrients have been washed from the soil or the soil becomes stable again there can be a decrease in stream productivity, leading to decreases in the growth rates of salmonids. This was observed in the treatment #2 and #3 reaches. Brook trout in the controls were, on average, larger than those in the treatment #2 and #3 reaches which may have been related to lack of disturbance of the adjacent terrestrial environment.

Atlantic salmon were absent from 8 of the reaches possibly because the sampled streams were small headwater streams long distances from the ocean. The greater distance from the ocean leads to the greater possibility of impassable obstructions, such as falls, which limits the distance spawning salmon can move upstream. When present, Atlantic salmon size followed the same increasing trend as brook trout between the control and treatment #1 reach although the increasing trend continued with the largest Atlantic salmon inhabiting IB-3 (Fig. 29). Within the Indian Bay watershed the smallest brook trout were captured and sampled within this reach, IB-3.

Forest harvesting can be either beneficial or detrimental to salmonids depending on the nature of the habitat alteration. Removal of mature trees can be beneficial because it opens the canopy, allows more light therefore increases primary productivity and potentially the growth of salmonids (Bérube and Lévèsque 1998; Thedinga et al. 1989). Removal of mature trees can also be harmful because it leads to increases in the water temperature to stressful levels for salmonids, increases sedimentation and siltation into the stream, and removes the LWD sources which provides potentially favourable habitat for salmonids (Rosenfeld et al. 2000; Grant et al. 1986; Sullivan et al. 1986). In this study, there was excess sediment accumulation in two watersheds impacted by harvesting but no significant differences between treatments. Temperature data showed no significant difference between the control and treatment #1 reach in the Indian Bay watershed but the treatment #1 reach in the Gander River watershed was significantly warmer than the control. There were significant differences in salmonid size between the different forestry treatments.

In the Pacific Northwest it has been determined that forest harvesting in the same area in less than 80-year intervals does not allow the aquatic community to fully recover from the negative effects of the previous harvest (Connolly and Hall 1999). Due to Newfoundland's unfavorable growing climate this recovery period may be significantly longer. Many studies from mainland North America have shown that clear-cutting is a non-point source of pollution within adjacent streams because it causes severe changes to hydrology, sedimentation, LWD inputs, solar radiation, and the thermal regime (Lynch and Corbat 1990). A combination of, or all of these variables have had some impact on the salmonids inhabiting streams on the island of Newfoundland. This study sampled all of these parameters in relation to the quality of brook trout and Atlantic salmon inhabiting the reaches. It was important to sample an uncut control area because brook trout and other salmonids tend to use undisturbed areas as refuge from the habitat alterations caused by forest harvesting (McCarthy et al. 1998). Small streams (<10 m wide) were used in this study because they are more affected by land-use management practices than larger streams (Garman and Moring 1993). Larger streams can better absorb stresses than can smaller, shallower streams.

5.0 Conclusion

Historical forest harvesting in the sampled watersheds may have had a negative impact on the growth of brook trout in small streams. Brook trout sizes were consistently smaller in streams influenced by older clear-cuts than in areas not impacted by forest harvesting. The increase in brook trout size after a harvesting event may have been related to an increased nutrients and debris in the stream from the neighbouring terrestrial system. However, this result is short-term due to stabilization of the terrestrial system. This may have led to a decrease in brook trout size a few years after forest harvesting, as seen in the older clear-cut areas in this study. Unfortunately analysis on Atlantic salmon was conducted only in the Indian Bay watershed because it was the only watershed with salmon present in multiple treatments. In the Indian Bay watershed Atlantic salmon were largest in the treatment #3 reach which was cut in 1987 and not buffered. Atlantic salmon were larger as the cut event was older but the sample size was too small to make any conclusions regarding impacts of forest harvesting. There seems to be an increase in the amount of sediment that enters streams after forest harvesting events however it was only significant in one watershed. Changes to the thermal regime and the amount of LWD in these study streams did not produce any significant patterns yet these variables may show trends after the three-year duration of the project. Further regional specific data is required to ensure a relationship between salmonids and forest harvesting on the island of Newfoundland is evident. Further sampling, under this study (Phase II and III) in different watersheds in the summers of 2001 and 2002 will increase the amount of data available on Newfoundland's small streams and hopefully will help strengthen some of the relationships between aquatic habitat and biota and forest harvesting.

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Table 1. Recommended minimum buffer strips to protect fish habitat during forest cutting activities. Buffer strip width is equal to 20m plus 1.5 times the slope in percent where the slope exceeds 30% (reproduced from Scruton et al. 1997).

Slope (%)	**Slope (°)**	**Width (m) of Buffer**
0	0	20
15	8	20
30	17	65
45	24	88
60	31	110

Table 2. A summary of recommended minimum riparian buffer strips for various forestry-related activities (reproduced from Scruton et al. 1997).

Activity	**Recommended Buffer Width (m)**
Fuelling/Servicing	30 m
Fuel Storage	100 m
Landings	20 m (+1.5 x % slope where > 30%)
Skid Trails	20 m (+1.5 x % slope where > 30%)
Roads	20 m (+1.5 x % slope where > 30%)
Barrow Pits	100 m
Drainage	30 m
Pesticide Storage, Mixing	100 m (temporary storage)
Herbicide Application	44+ m
Insecticide Application	400m from freshwater, 1.6 km from coastal areas
Silviculture	20 m (+1.5 x % slope where > 30%)
Camps/Maintenance Buildings	100 m
Primary Processing Facility	100 m
Slash Placement	30 m
Controlled Burns	20 m (+1.5 x % slope where > 30%)

Table 3. The GPS coordinates for the bottom (0 m) and top (endpoint) of each sampled stream reach in the Corner Brook Lake watershed.

	CB-C	**CB-1**	**CB-2**	**CB-3**
Bottom of sample section	N: 48°53.218` W: 57°42.650`	N: 48°52.811` W: 57°42.359`	N: 48°47.277` W: 57°50.837'	N: 48°53.842` W: 57°53.122`
Top of sample section	N: 48°53.256` W: 57°42.703`	N: 48°52.888` W: 57°42.387`	N: 48°47.055` W: 57°50.847`	N: 48°53.766` W: 57°53.305`

Table 4. The GPS coordinates for the bottom (0 m) and top (endpoint) of each sampled stream reach in the Indian Bay watershed.

	IB-C	**IB-1**	**IB-2**	**IB-3**
Bottom of sample section	N: 49°03.733` W: 54°23.602`	N: 49°03.045` W: 54°23.303`	N: 49°02.888` W: 54°24.680`	N: 48°57.906` W: 54°30.270`
Top of sample section	N: 49°03.931` W: 54°23.612'	N: 49°03.106` W: 54°23.435`	N: 49°02.910` W: 54°24.832'	N: 48°57.895` W: 54°30.422`

Table 5. The GPS coordinates for the bottom (0 m) and top (endpoint) of each sampled stream reach in the Gander River watershed.

	GR-C	**GR-1**	**GR-2**	**GR-3**
Bottom of sample section	N: 49°04.755` W: 54°47.479`	N: 49°05.630` W: 54°46.668`	N: 49°06.390` W: 54°39.534'	N: 49°09.904` W: 54°43.416`
Top of sample section	N: 49°04.789` W: 54°47.564`	N: 49°05.500` W: 54°46.785`	N: 49°06.539` W: 54°39.650`	N: 49°09.695` W: 54°43.631`

Table 6. Substrate size classification used during the stream surveys (modified from Scruton et al. 1992).

Substrate Class	**Substrate Size (diameter)**
Bedrock	N/A
Large Boulders	> 1 m
Small Boulders	0.25 – 1 m
Cobble	3 – 25 cm
Gravel	0.2 – 3 cm
Sand/Silt/Clay	< 20 mm

Table 7. The average substrate percentage (± standard deviation) for each of the 12 sampled reaches.

Stream Reach	Bedrock	Large Boulders	Small Boulders	Cobble	Gravel	Sand	Mud/Clay/ Silt
CB-C	0	3.00 (± 2.83)	70.00 (± 0.00)	20.00 (± 7.07)	7.00 (± 4.24)	0	0
CB-1	0	1.67 (± 0.58)	46.67 (± 5.77)	43.33 (± 5.77)	5.67 (± 1.16)	2.67 (±0.33)	0
CB-2	4.44 (± 8.82)	2.67 (± 3.04)	33.89 (± 8.58)	44.89 (±11.62)	8.11 (± 4.68)	1.56 (± 1.59)	0
CB-3	4.33 (± 5.72)	1.33 (± 1.03)	20.83 (± 13.20)	44.17 (± 4.92)	24.17 (±16.56)	1.33 (± 0.82)	3.00 (± 2.61)
IB-C	0.38 (± 1.06)	0.75 (± 0.46)	39.63 (± 6.30)	47.75 (± 5.65)	6.25 (± 2.32)	2.13 (± 0.35)	2.88 (± 1.73)
IB-1	12.40 (±16.07)	6.00 (± 5.83)	37.00 (± 9.08)	37.00 (±10.95)	5.40 (± 0.89)	0.40 (± 0.55)	1.60 (± 1.14)
IB-2	33.40 (±30.20)	0.80 (± 0.84)	13.00 (± 5.70)	46.00 (±28.20)	4.20 (± 1.64)	0.20 (± 0.45)	2.40 (± 0.89)
IB-3	0	1.75 (± 2.22)	17.50 (± 12.58)	55.00 (±12.91)	13.00 (± 6.27)	9.25 (± 7.89)	3.50 (± 1.29)
GL-C	0	0.57 (± 0.79)	9.43 (± 10.33)	9.43 (±11.52)	38.57 (±21.93)	36.14 (±24.58)	5.86 (± 0.56)
GL-1	2.17 (± 3.49)	0.33 (± 0.82)	5.50 (± 5.65)	7.67 (± 6.25)	43.83 (±23.63)	18.33 (± 8.16)	22.17 (± 16.38)
GL-2	9.57 (±13.46)	1.86 (± 1.46)	28.29 (± 13.12)	30.00 (±10.41)	21.43 (±24.10)	3.86 (± 3.13)	4.29 (± 2.81)
GL-3	0.18 (± 0.60)	1.00 (± 0.89)	17.55 (± 12.21)	58.18 (±11.02)	15.64 (± 8.91)	3.18 (± 1.66)	4.36 (± 1.75)

Table 8. Summary of windfalls within sampled riparian buffers adjacent to study stream reaches.

Stream Reach	Buffer Type	# of Windfalls	Area (m^2) of buffer sampled	Location in buffer	# of windfalls/ $100m^2$
CB-C	Not Cut	9	400	Within	2.3
CB-1	Riparian (20 m+)	18	600	Edge	3.0
CB-2	Limited (0–12m)	44	1800	Edge; Within	2.4
CB-3	Limited (0–20 m)	3	1200	Edge	0.3
IB-C	Not Cut	20	1600	Within	1.3
IB-1	Riparian (20 m+)	35	1000	Edge; Within	3.5
IB-2	Limited (0–20 m)	20	1000	Edge	2.0
IB-3	No Buffer (0 m)	1	800	Within	0.1
GL-C	Not Cut	2	1400	Within	0.1
GL-1	Riparian (20 m+)	2	1200	Edge	0.2
GL-2	Limited (16 m+)	41	1400	Edge; Within	2.9
GL-3	Limited (16 m+)	97	2200	Edge; Within	4.4

Table 9. The mean monthly temperatures and monthly ranges (°C) for the control streams and treatment # 1 stream reaches in the Indian Bay watershed and Gander Lake watershed.

	IB-C	IB-1	GL-C	GL-1
August	19.40 (14.2–27.9)	19.92 (14.8–27.6)	15.68 (11.7–20.9)	16.56 (12.9–21.6)
September	14.86 (8.0–21.2)	14.55 (7.2–20.6)	12.30 (6.1–19.4)	13.00 (6.0–19.6)
October	8.22 (4.6–15.0)	8.00 (4.1–13.2)	6.99 (3.0–12.8)	7.22 (3.2–13.2)
November	4.32 (0.6–6.6)	4.18 (0.3–7.5)	3.86 (-0.1–8.1)	4.16 (0.3–8.2)
December	0.38 (0.0–1.4)	0.12 (0.0–1.1)	0.01 (-0.1–0.3)	0.18 (0.1–1.0)
January	0.10 (-0.1–1.0)	0.00 (0.0–0.0)	-0.04 (-0.1–0.0)	0.10 (0.1–0.1)
February	-0.10 (0.0–0.1)	0.00 (0.0–0.0)	-0.1 (-0.1–0.0)	0.10 (0.1–0.1)
March	0.46 (-0.1–3.6)	0.02 (0.0–0.6)	-0.1 (-0.1–0.0)	0.08 (-0.1–0.1)
April	1.02 (0.0–5.0)	0.87 (0.0–3.8)	0.04 (-0.1–2.7)	0.16 (-0.1–3.8)
May	6.47 (0.1–18.6)	7.04 (0.0–18.3)	7.18 (-0.1–18.2)	7.64 (-0.1–19.2)
June	14.51 (10.2–21.1)	14.68 (11.0– 18.3)	12.28 (8.7–17.9)	12.96 (9.4–18.9)

Table 10. The number of days the mean daily water temperature (°C) was within each temperature range for each of the thermographs.

	Temperature Range (°C)							Total Days
	< 0.0	0-4.9	5-9.9	10-14.9	15-19.9	20-24.9	25 +	
IB-C Bottom	4	169	56	33	36	12	0	310
IB-C Top	26	148	54	34	30	17	1	310
IB-1 Bottom	0	174	59	28	33	13	0	307
IB-1 Top	0	174	58	27	34	15	0	308
GR-C Bottom	143	35	63	39	9	0	0	289
GR-C Top	151	30	61	37	10	0	0	289
GR-1 Bottom	146	30	62	36	14	0	0	288
GR-1 Top	1	173	63	36	15	0	0	288

Table 11. The number of days the maximum daily water temperature (°C) was within each temperature range for each of the thermographs.

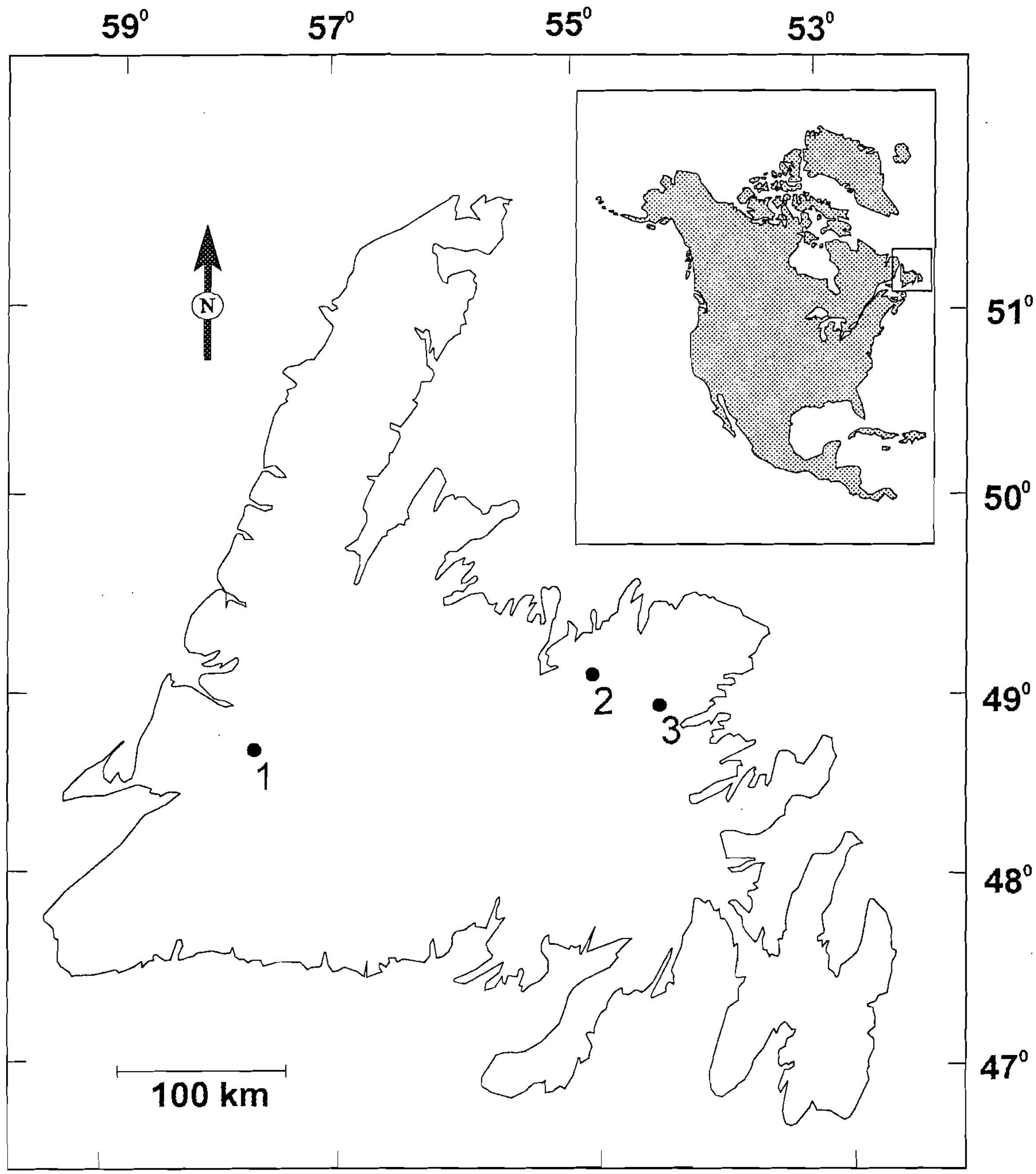
	Temperature Range (°C)							Total Days
	< 0.0	0-4.9	5-9.9	10-14.9	15-19.9	20-24.9	25 +	
IB-C Bottom	0	166	53	27	33	23	8	310
IB-C Top	1	167	51	26	33	21	11	310
IB-1 Bottom	0	165	56	31	33	18	4	307
IB-1 Top	0	165	55	31	33	18	6	308
GR-C Bottom	87	79	60	37	25	1	0	289
GR-C Top	142	25	60	35	25	2	0	289
GR-1 Bottom	128	38	62	24	32	4	0	288
GR-1 Top	0	165	60	30	29	4	0	288

Table 12. Average brook trout length (mm), weight (g), ranges and number per stream for each reach.

Stream Reach	Length (mm)	Weight (g)	N	#/100 m
CB-C (102m)	157.4 (143–190)	54.6 (33–83)	5	4.9
CB-1 (160m)	153.6 (112–197)	56.9 (17–115)	16	10.0
CB-2 (460m)	125.4 (76–198)	30.6 (7–100)	24	5.2
CB-3 (290m)	93.9 (70–134)	9.4 (4–27)	41	15.2
IB-C (377m)	89 (n/a)	8 (n/a)	1	0.2
IB-1 (232m)	115 (n/a)	14 (n/a)	1	0.4
IB-2 (247m)	92.5 (64–124)	9.6 (3–22)	19	7.7
IB-3 (192m)	75.56 (60–142)	7.1 (2–38)	23	12.0
GL-C (370m)	118.3 (4–49)	20.4 (5–75)	34	9.2
GL-1 (325m)	143.1 (89–205)	31.7 (8–85)	21	6.5
GL-2 (372m)	135.8 (90–195)	30.8 (7–87)	20	5.4
GL-3 (578m)	85.4 (63–114)	7.5 (3–16)	11	2.0

Table 13. Average Atlantic salmon length (mm), weight (g), ranges and number per stream for each reach.

Stream	Length (mm)	Weight (g)	N	#/100 m
IB-C (377m)	85.9 (72–100)	7.1 (3–12)	7	1.8
IB-1 (232m)	122.3 (67–159)	18.3 (11–71)	48	20.7
IB-3 (192m)	121.7 (93–181)	25.2 (11–71)	18	7.3
GR-3 (578m)	92.1 (72–137)	11.1 (4–33)	22	11.4



1) Corner Brook Lake Watershed; Western Newfoundland

2) Gander River Watershed; Central Newfoundland

3) Indian Bay Watershed; Central Newfoundland

Figure 1. The three study watersheds influenced by forest harvesting sampled for the Newfoundland Small Stream Buffer Study Phase I.

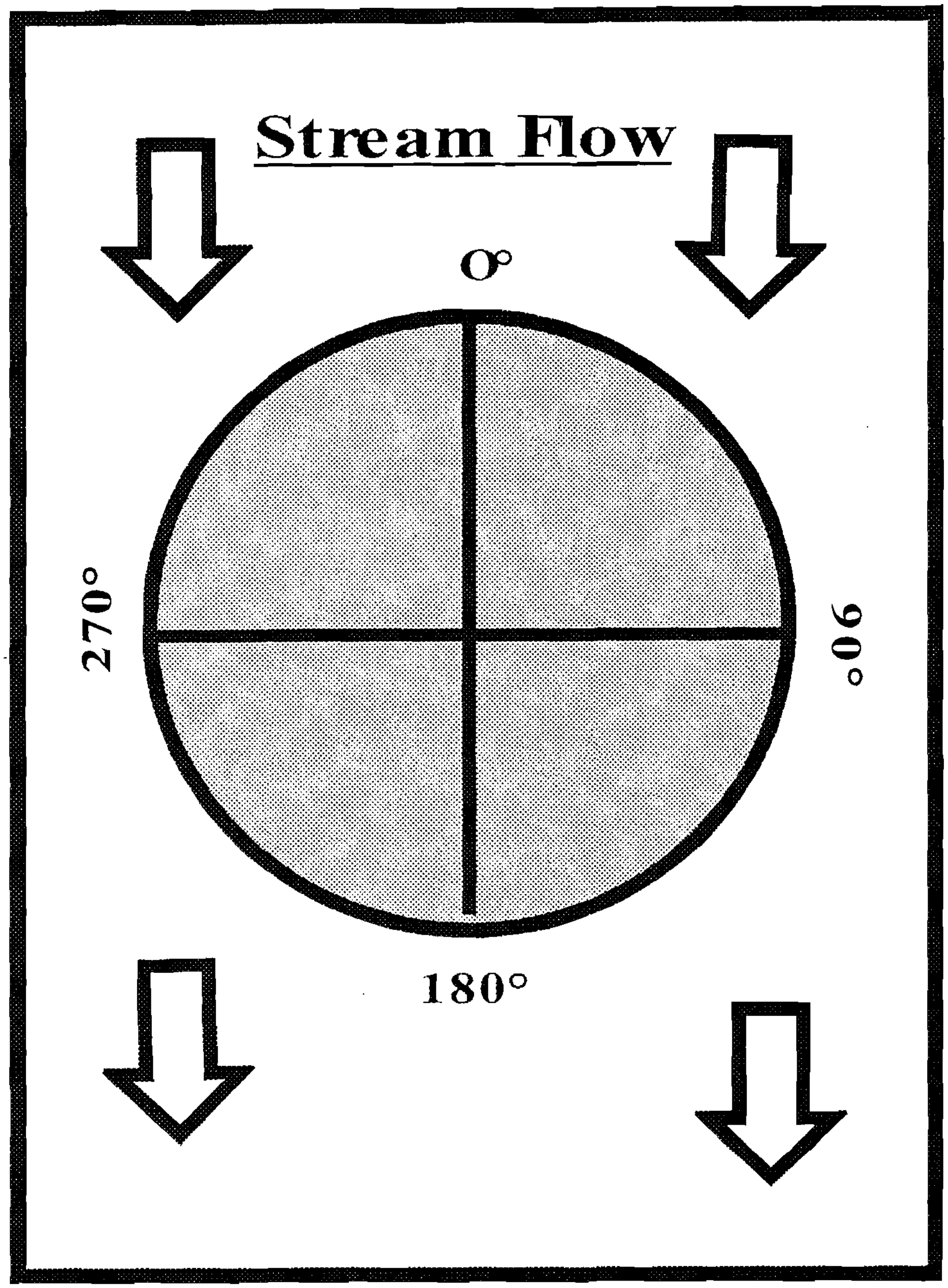


Figure 2. LWD orientation in relation to stream flow, degree measurement taken from base to top of LWD.

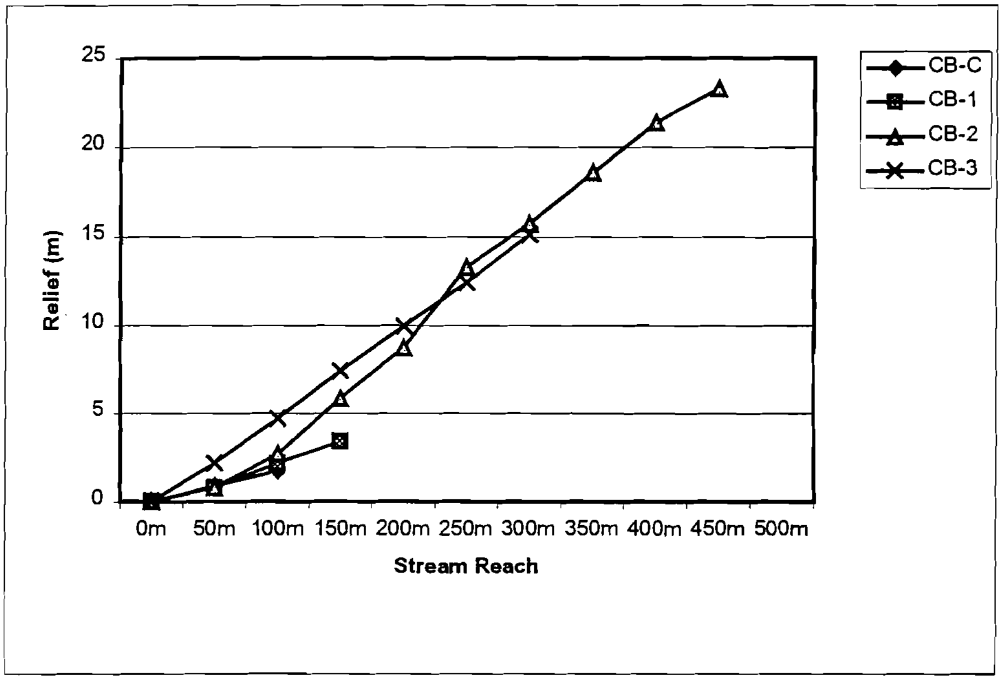


Figure 3. Total stream gradients (taken every 50m) for each of the sampled stream sections in the Corner Brook Lake watershed.

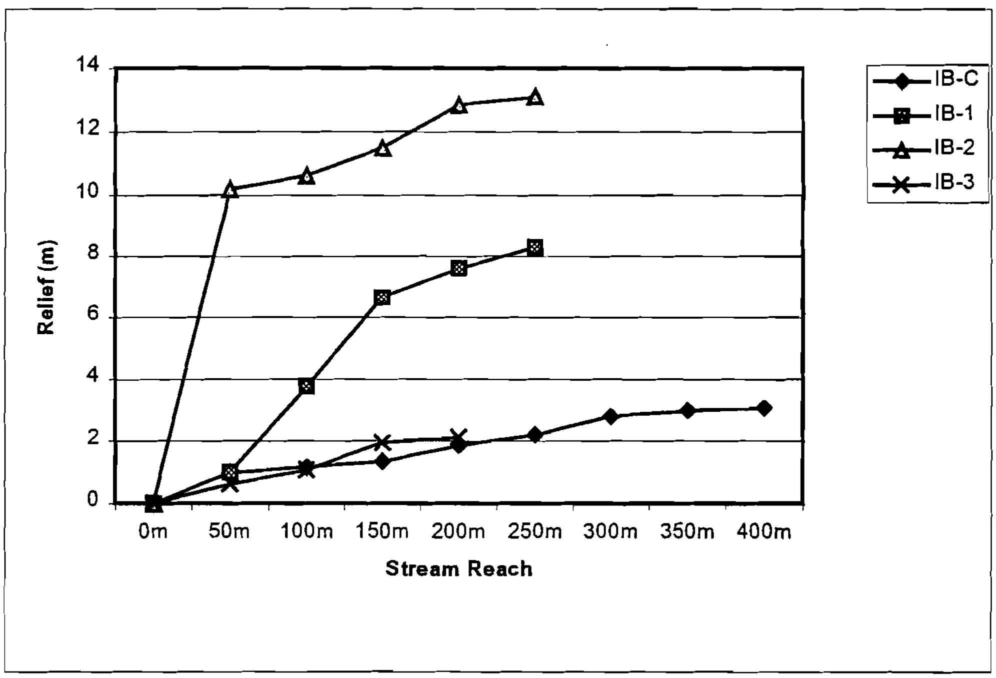


Figure 4. Total stream gradients (taken every 50m) for each of the sampled stream sections in the Indian Bay watershed.

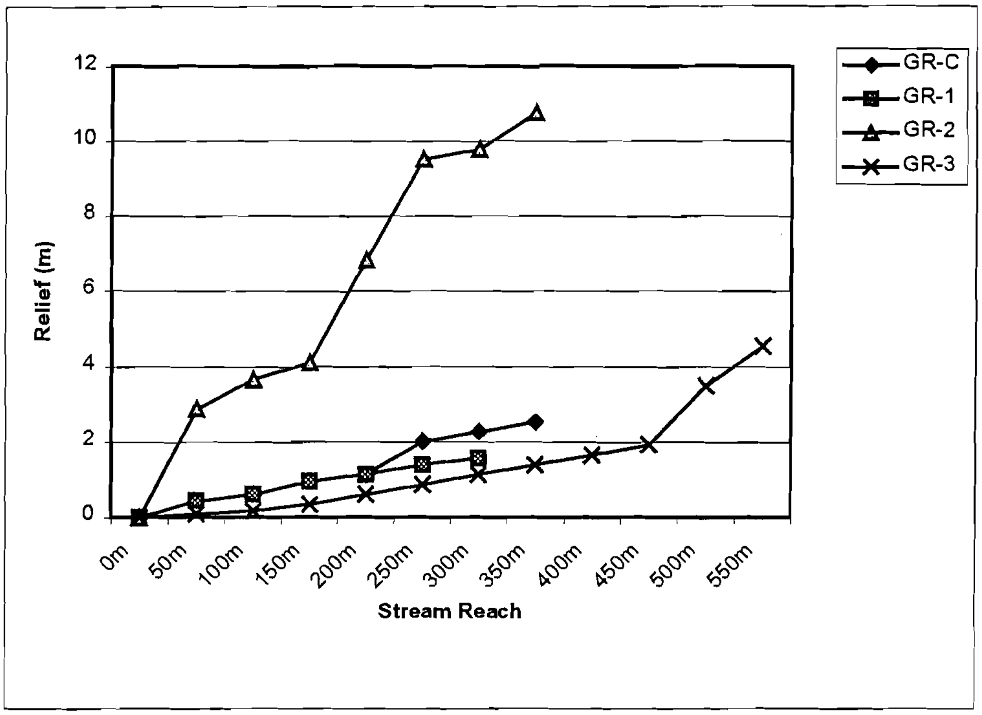


Figure 5. Total stream gradients (taken every 50m) for each of the sampled stream sections in the Gander River watershed.

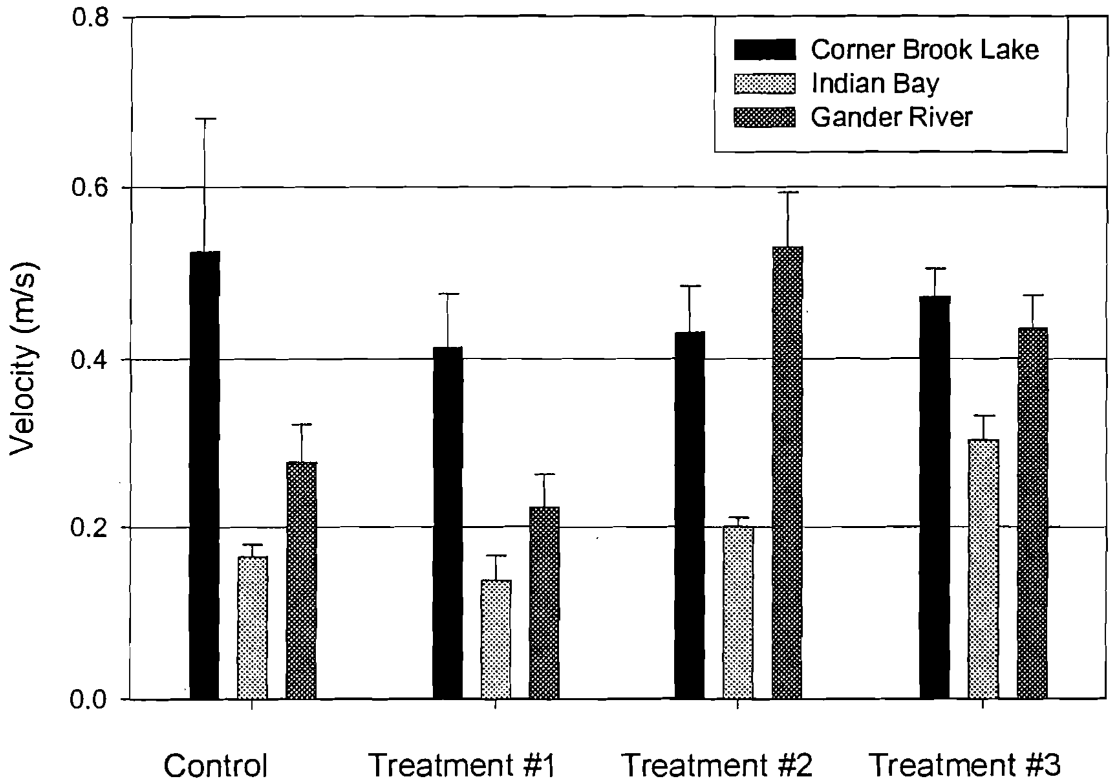


Figure 6. Average stream surface velocity (m/s + S.E.) for each of the sampled stream reaches.

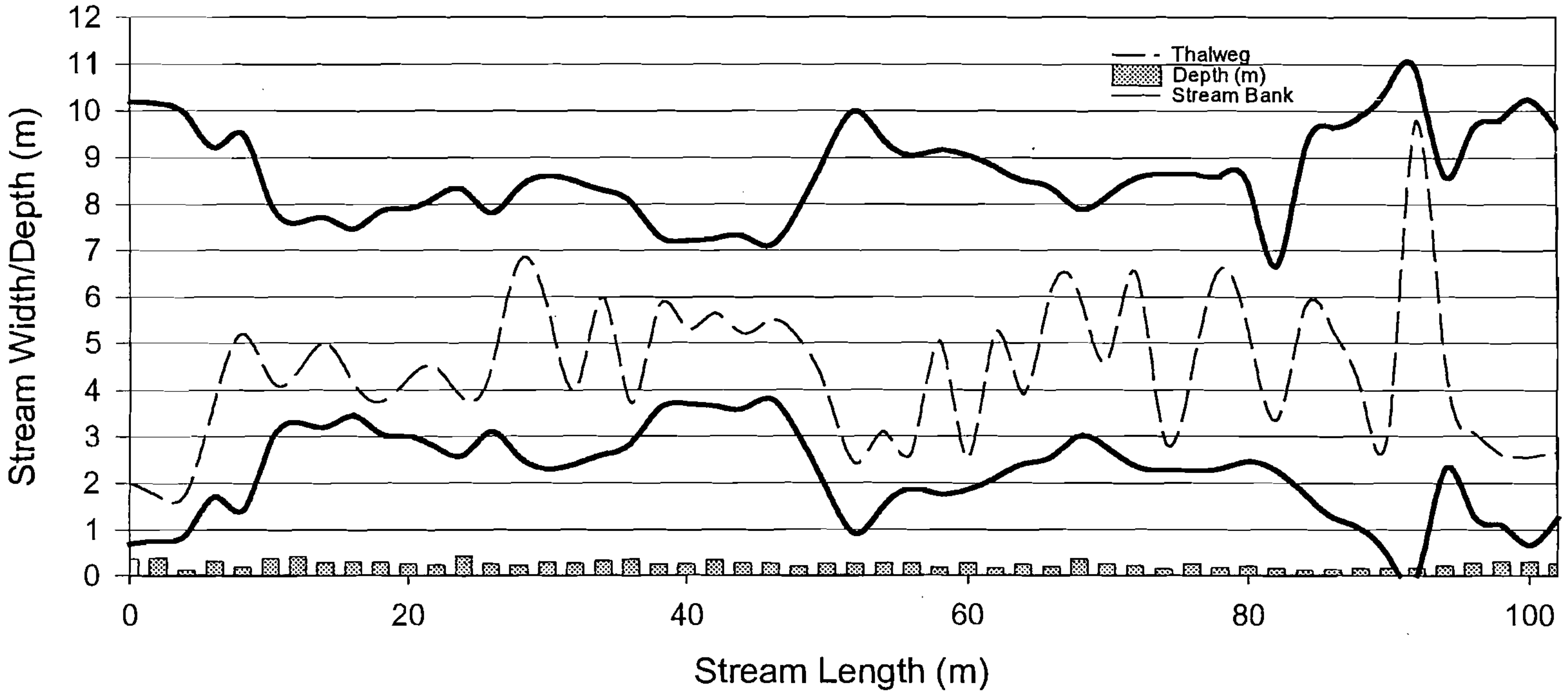


Figure 7. Thalweg profile for CB-C (entire stream reach electrofished).

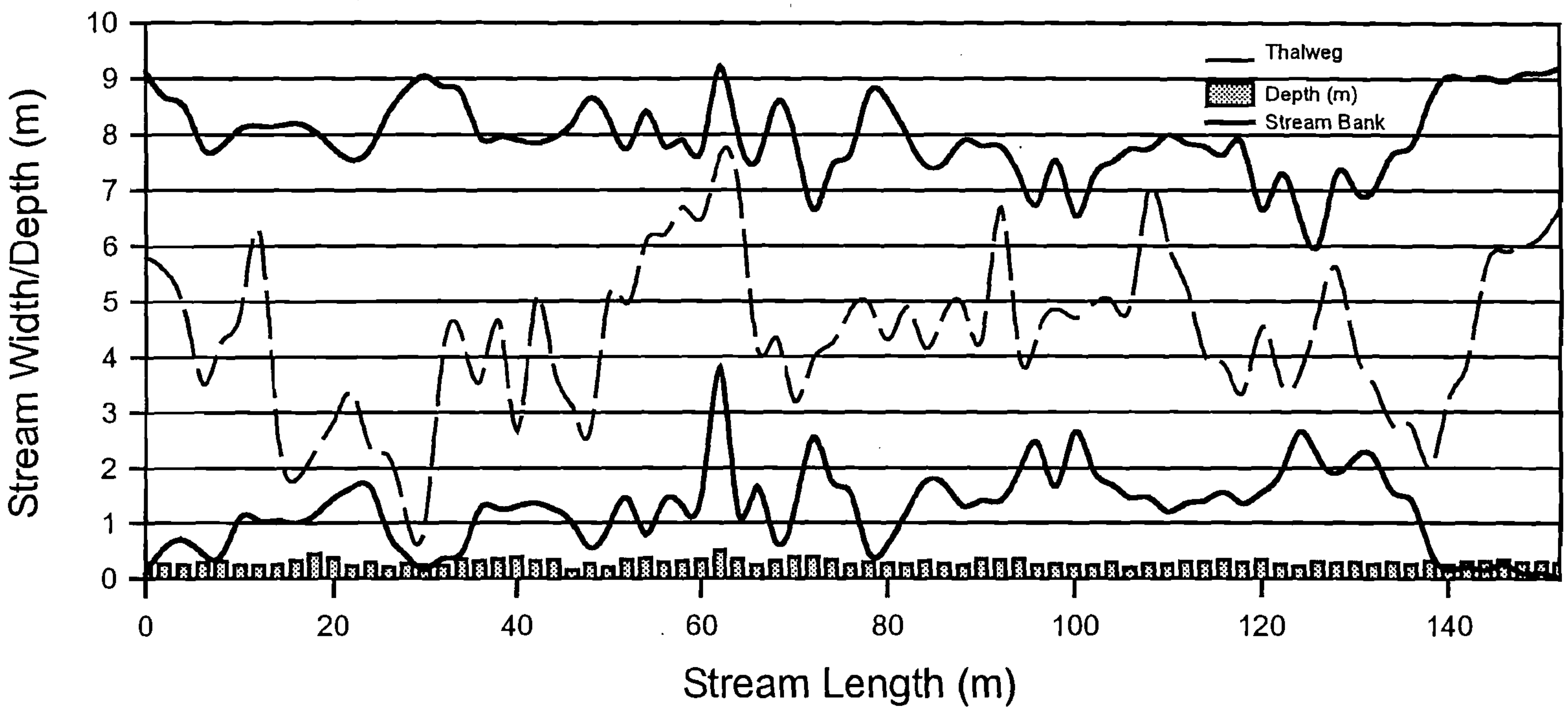


Figure 8. Thalweg profile for CB-1 (entire stream reach electrofished).

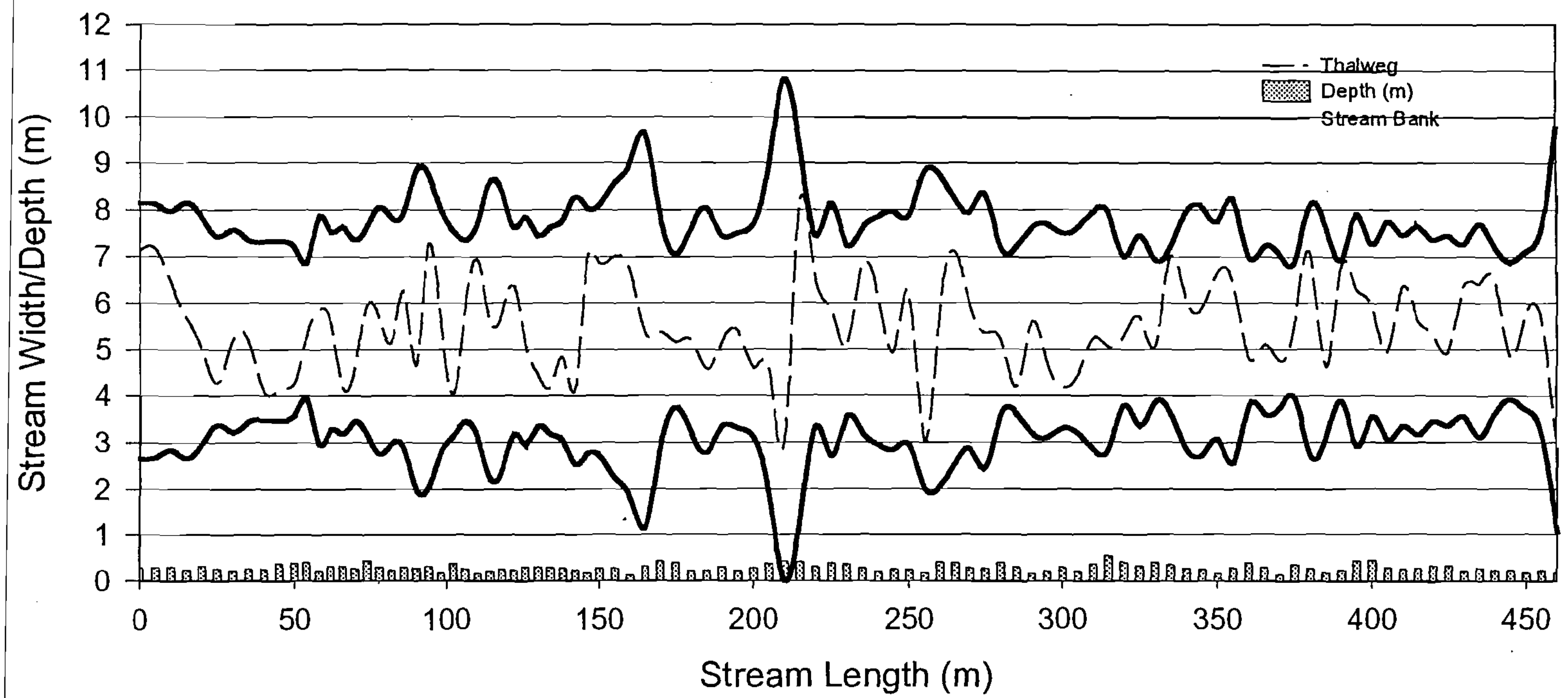


Figure 9. Thalweg profile for CB-2 (electrofished from 50–150 m).

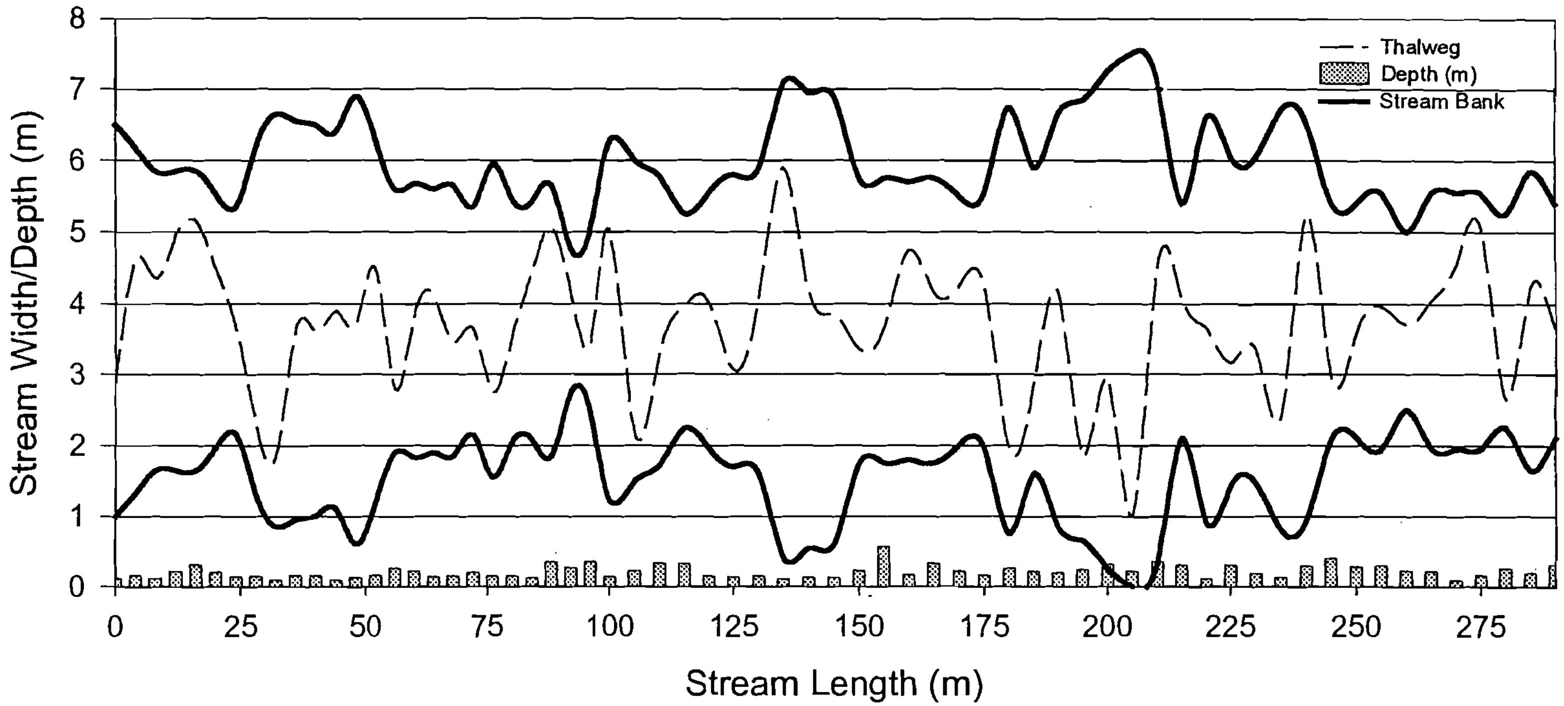


Figure 10. Thalweg profile for CB-3 (electrofished from 0–100 m).

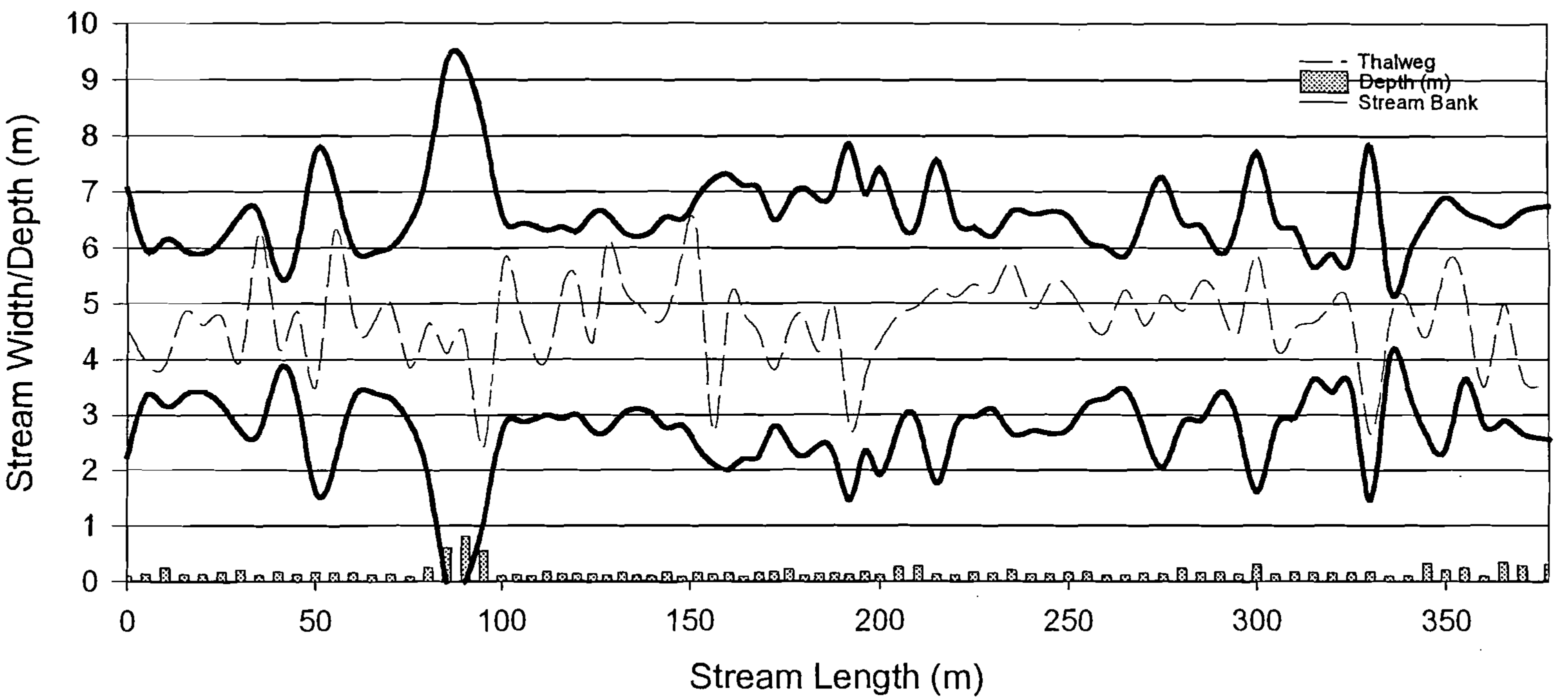


Figure 11. Thalweg profile for IB-C (electrofished 100–200 m).

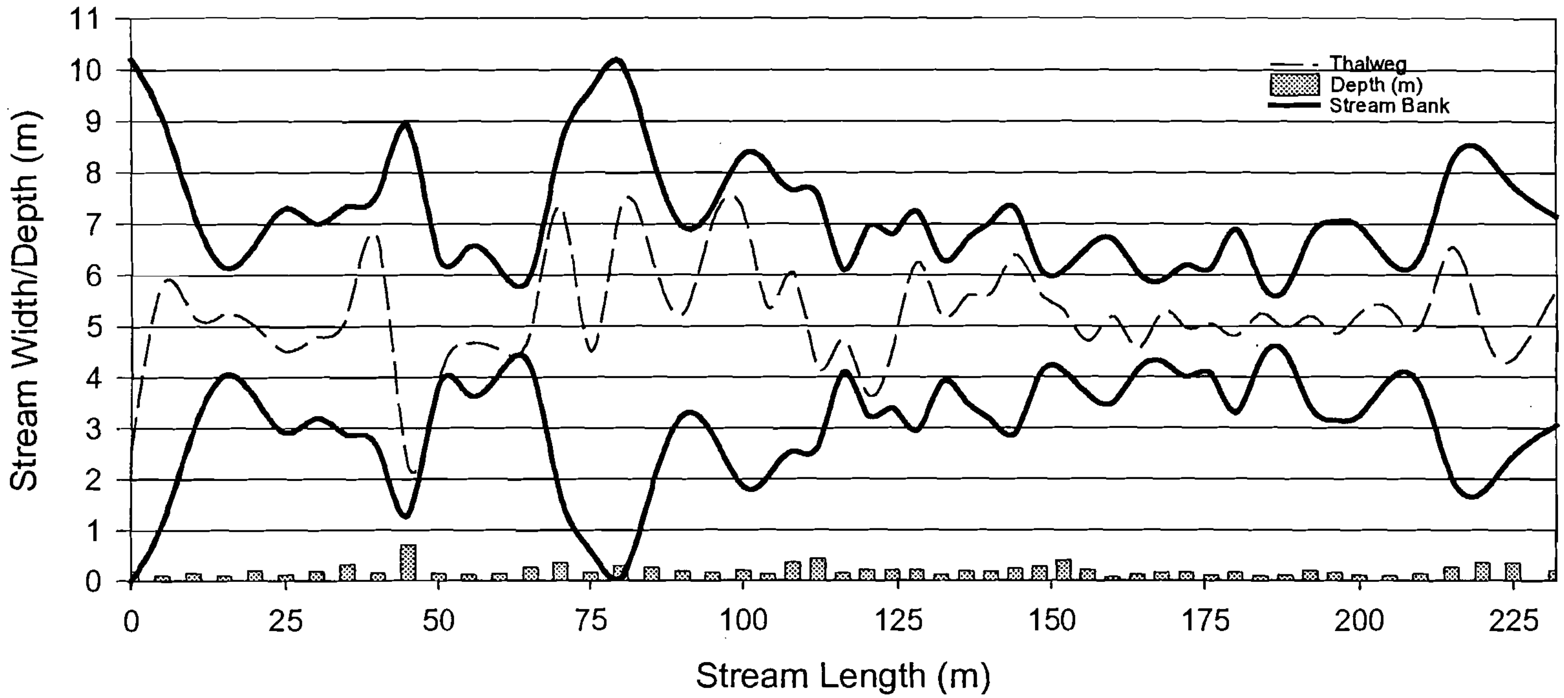


Figure 12. Thalweg profile for IB-1 (electrofished 100–200 m).

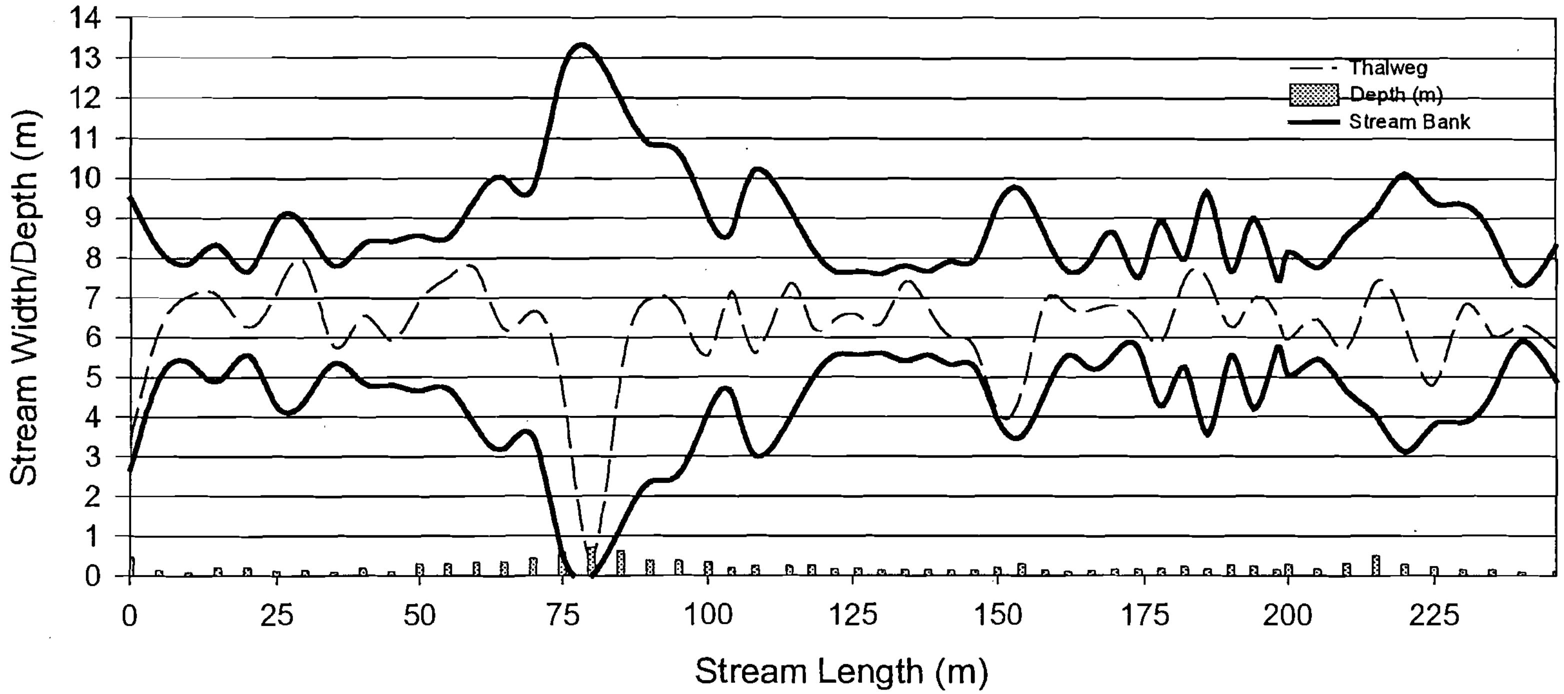


Figure 13. Thalweg profile for IB-2 (electrofished 100–200 m).

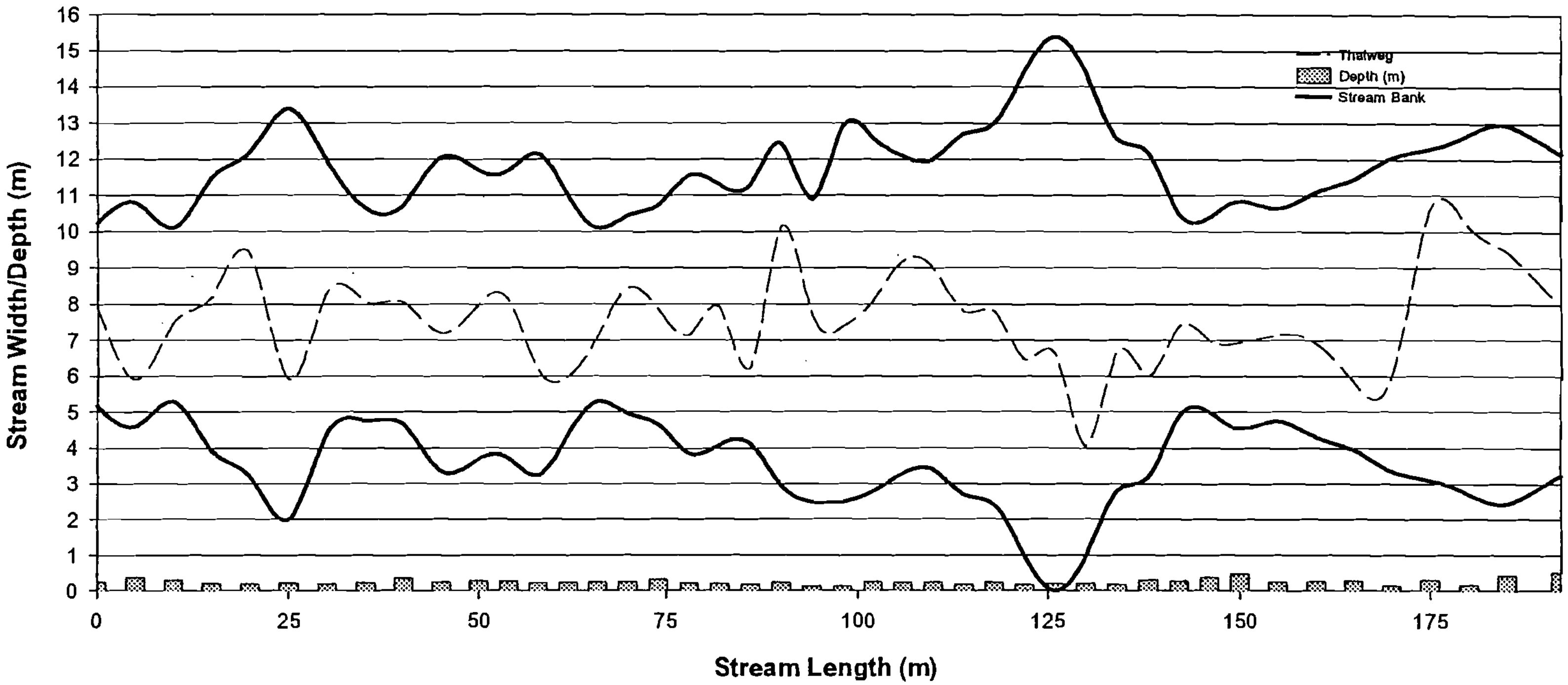


Figure 14. Thalweg profile for IB-3 (electrofished 50–150 m).

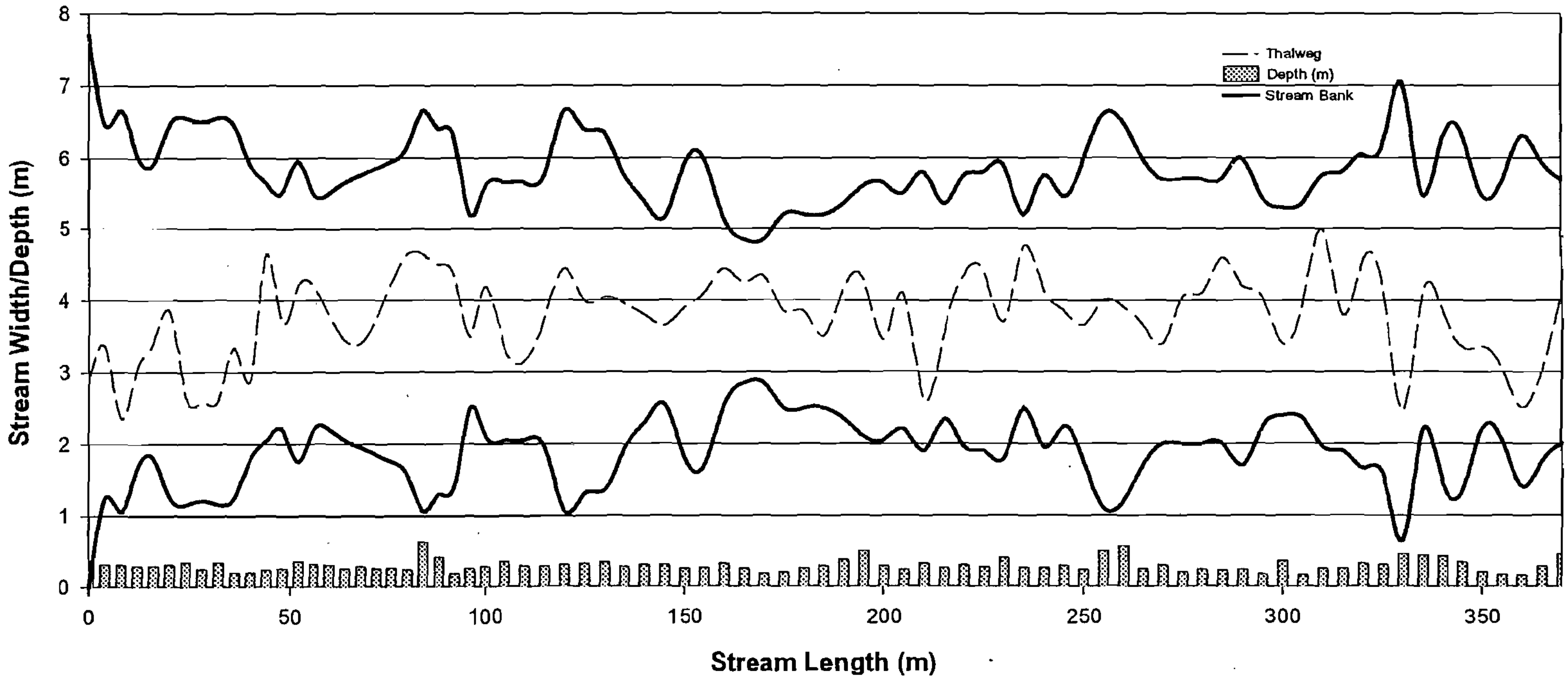


Figure 15. Thalweg profile for GR-C (electrofished 0–100 m).

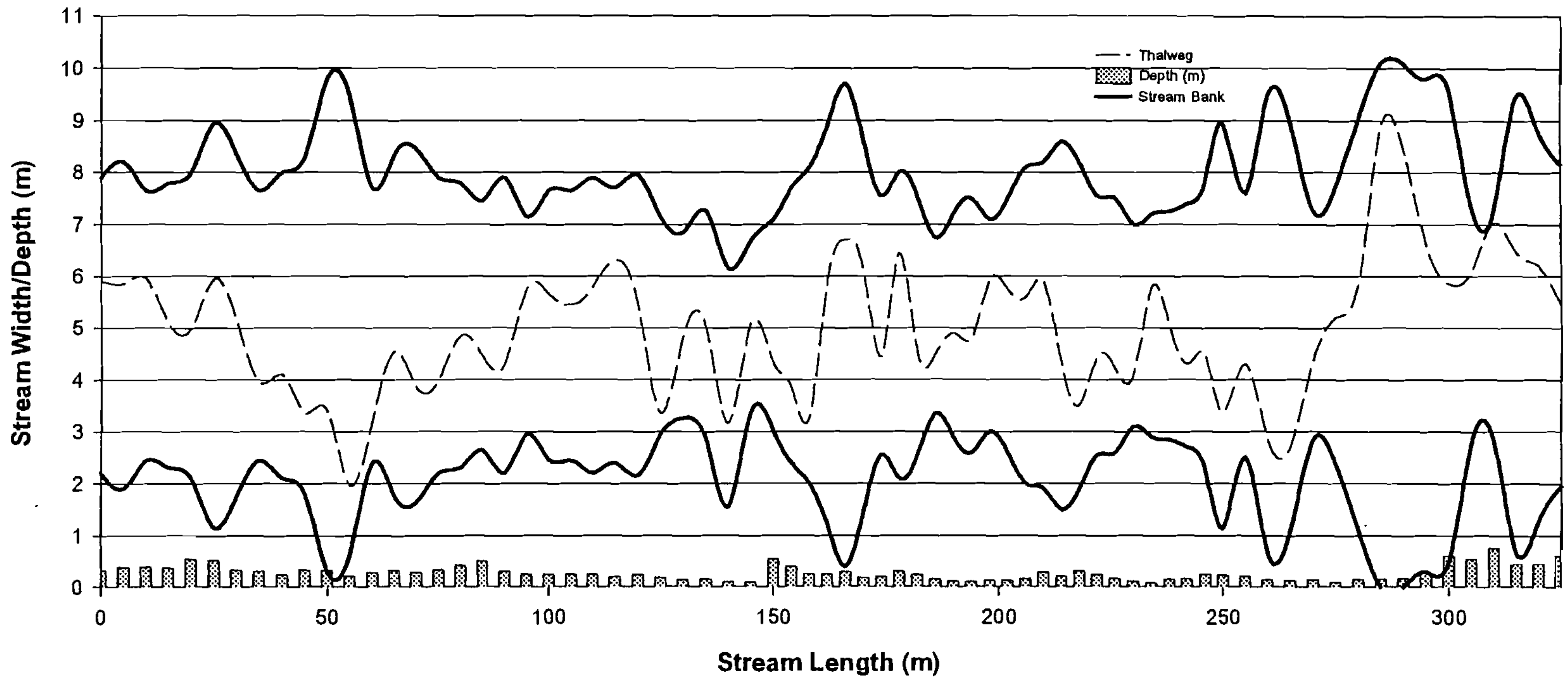


Figure 16. Thalweg profile for GR-1 (electrofished 150–250 m).

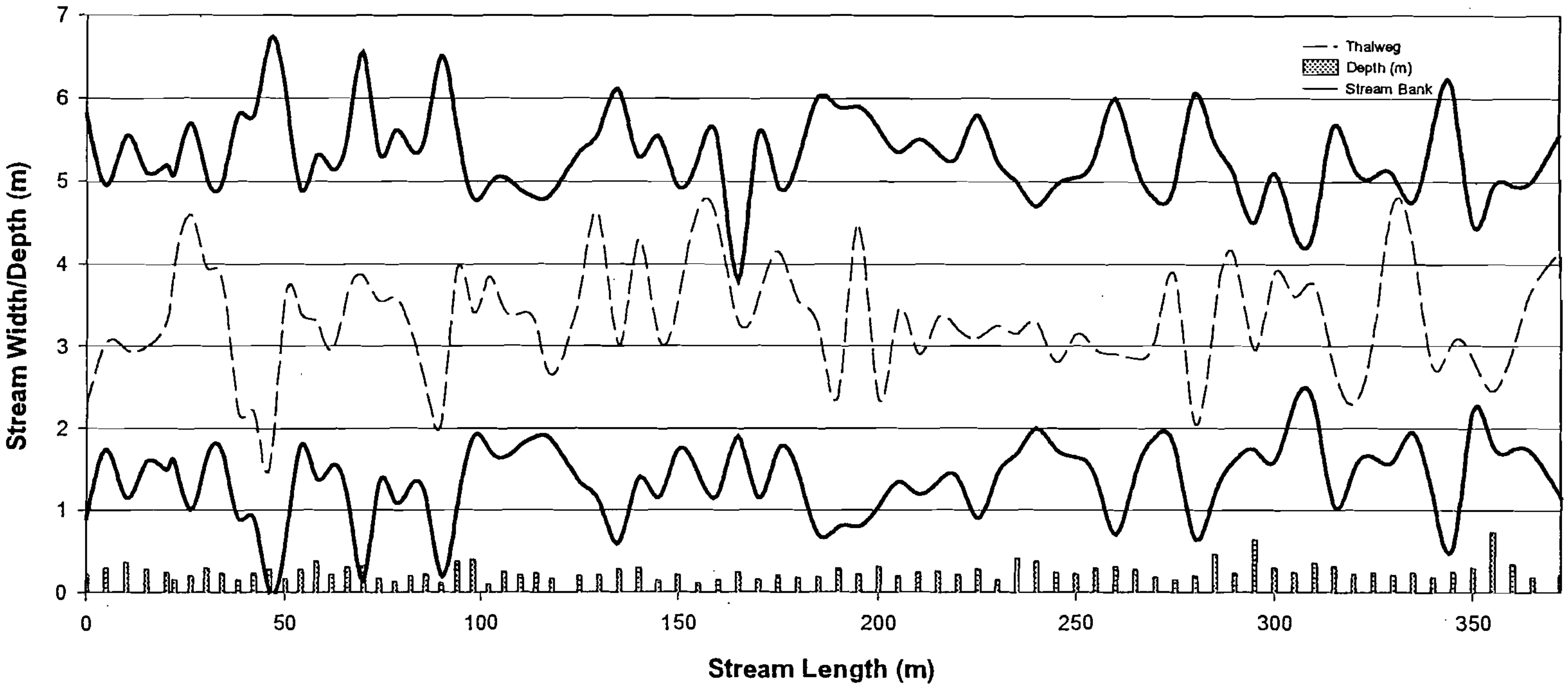


Figure 17. Thalweg profile for GR-2 (electrofished 20–120 m)

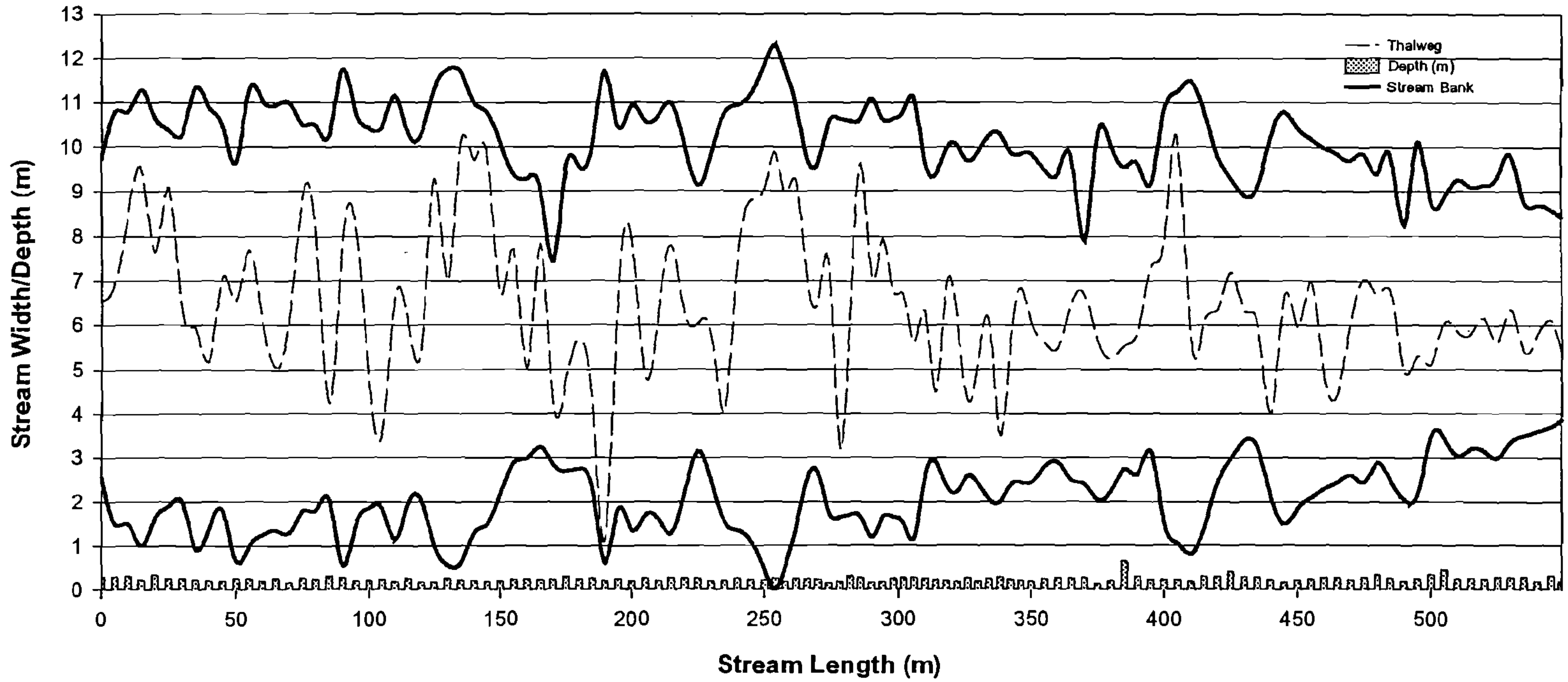


Figure 18. Thalweg profile for GR-3 (electrofished 250–350 m).

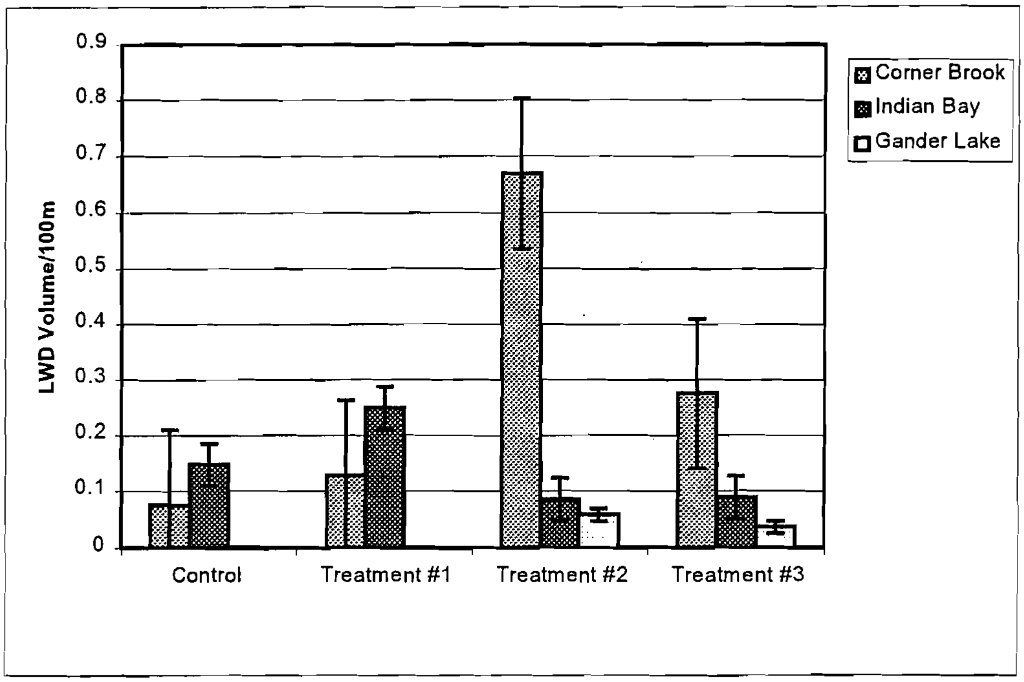


Figure 19. The volume ($m^3 \pm$ S.E.) of LWD/100m for each of the sampled stream reaches.

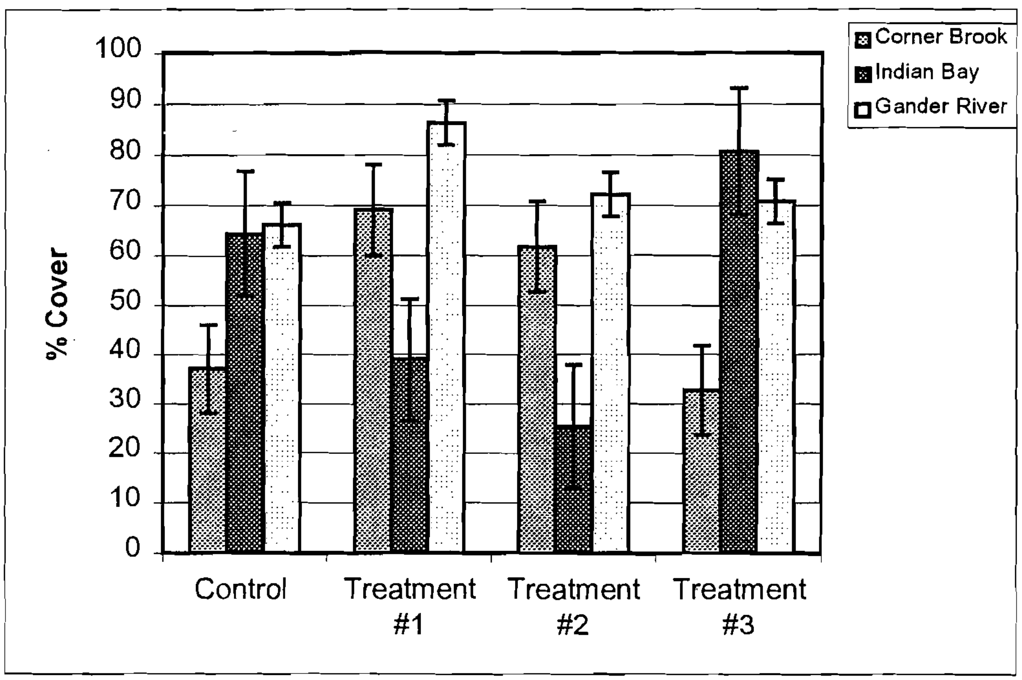


Figure 20. The average cover (% ± S. E.) within sampled riparian buffers adjacent to the study stream reaches.

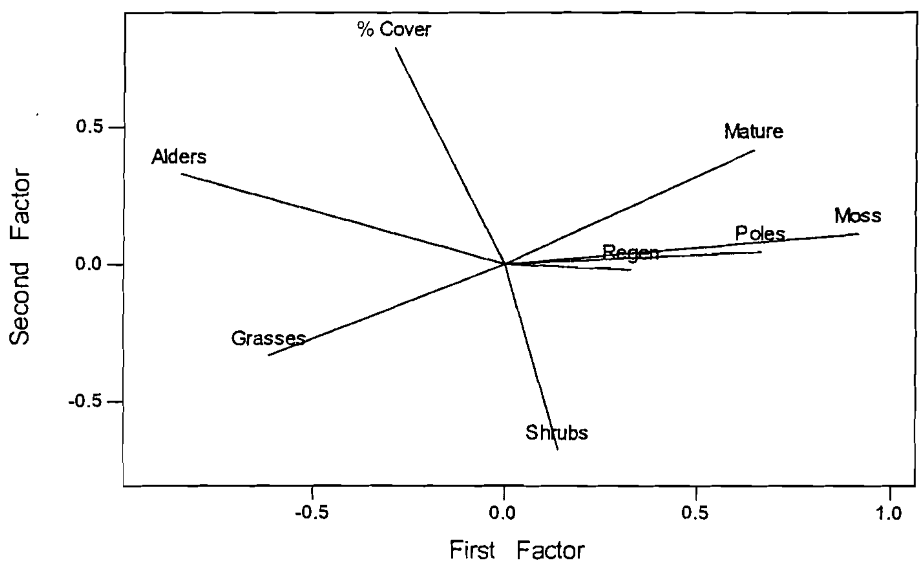


Figure 21. Factor analysis of all the parameters measured and recorded for the riparian buffers from the 12 study reaches.

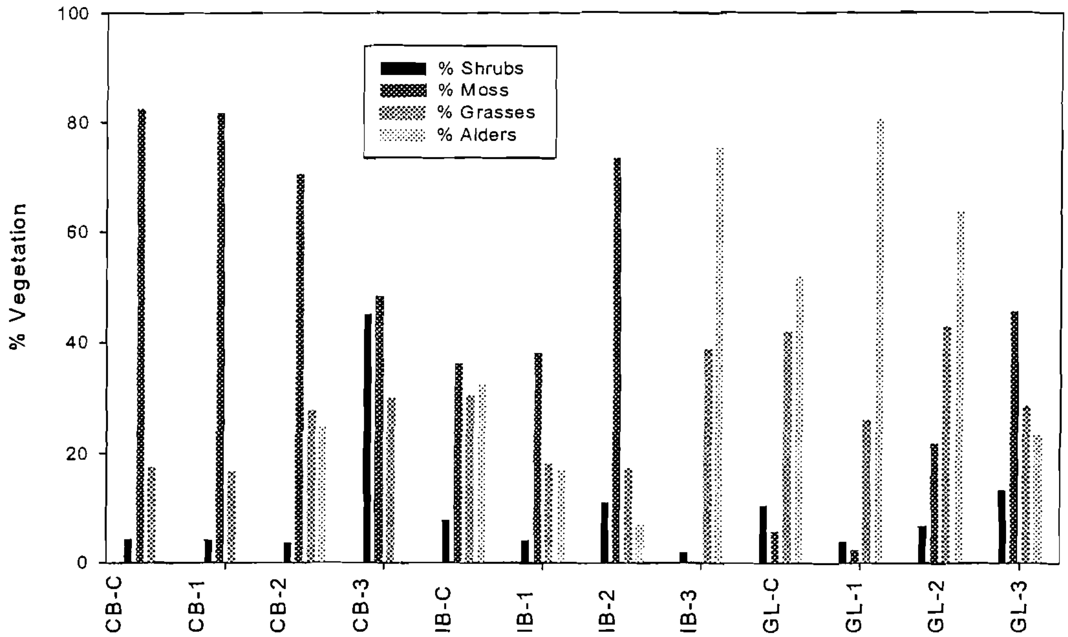


Figure 22. Percent vegetation (+ S.E.) within sampled riparian buffer adjacent to the 12 reaches.

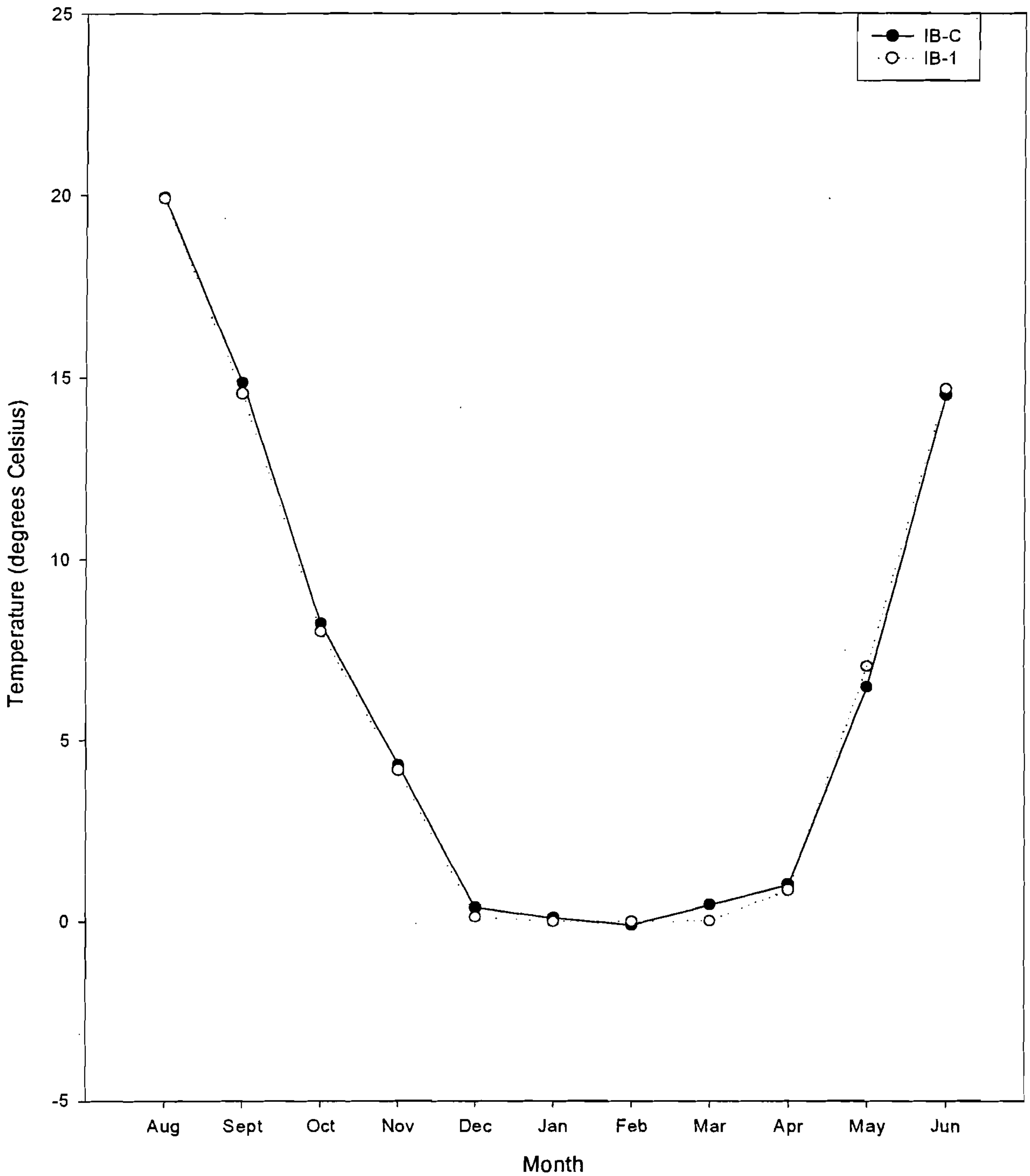


Figure 23. Average monthly stream temperatures (°C) for the control (IB-C) and treatment # 1 (IB-1) stream reaches in the Indian Bay watershed.

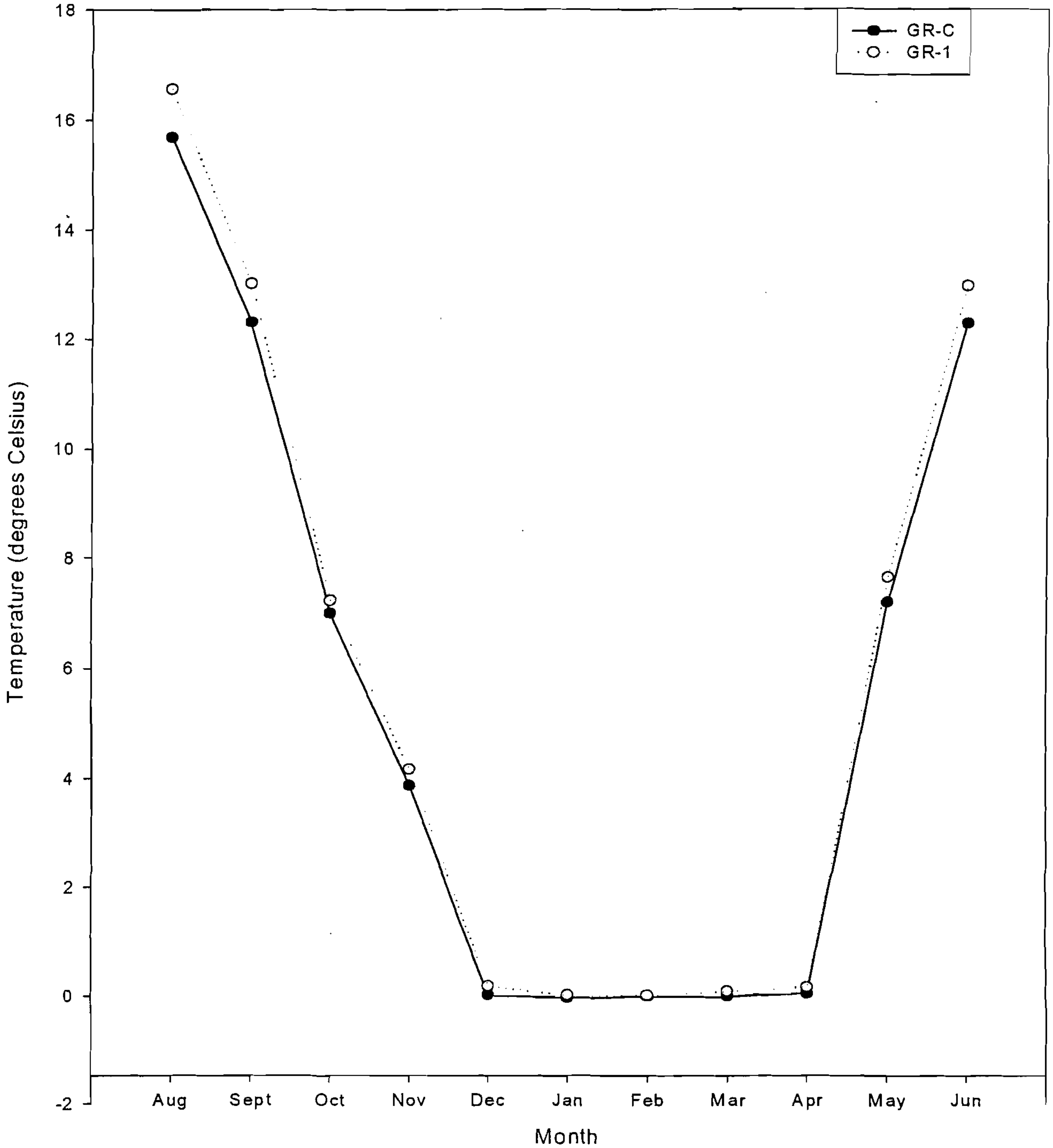


Figure 24. Average monthly stream temperatures (°C) for the control (GR-C) and treatment # 1 (GR-1) stream reaches in the Gander River watershed.

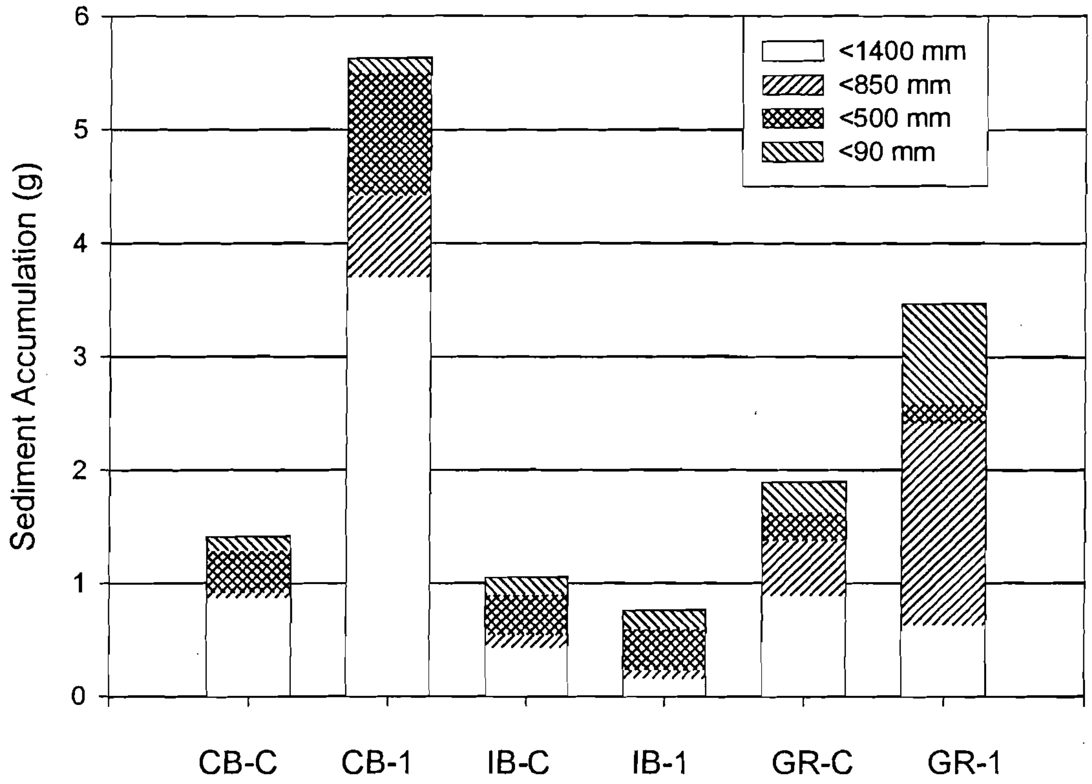


Figure 25. Fine particulate accumulation per sediment trap within each of the four sieve sizes for the three sampled watersheds.

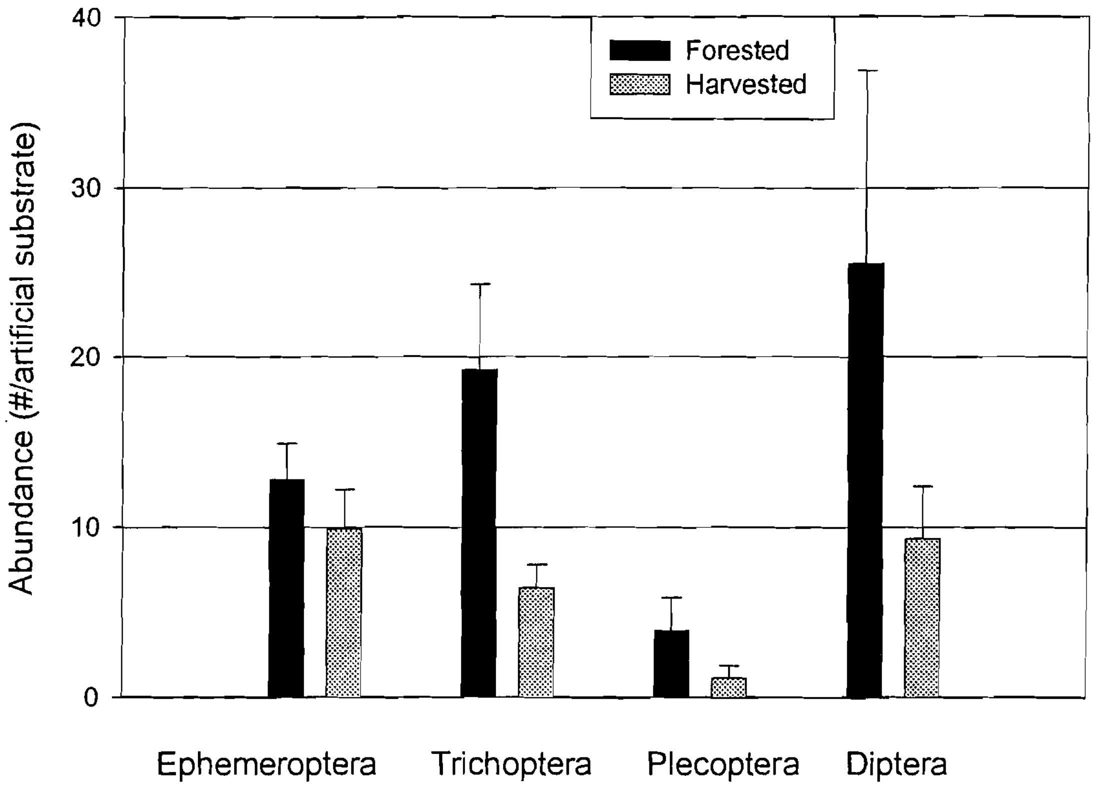


Figure 26. Abundances of major macroinvertebrate taxa within forested (control) and harvested (treatment) study streams.

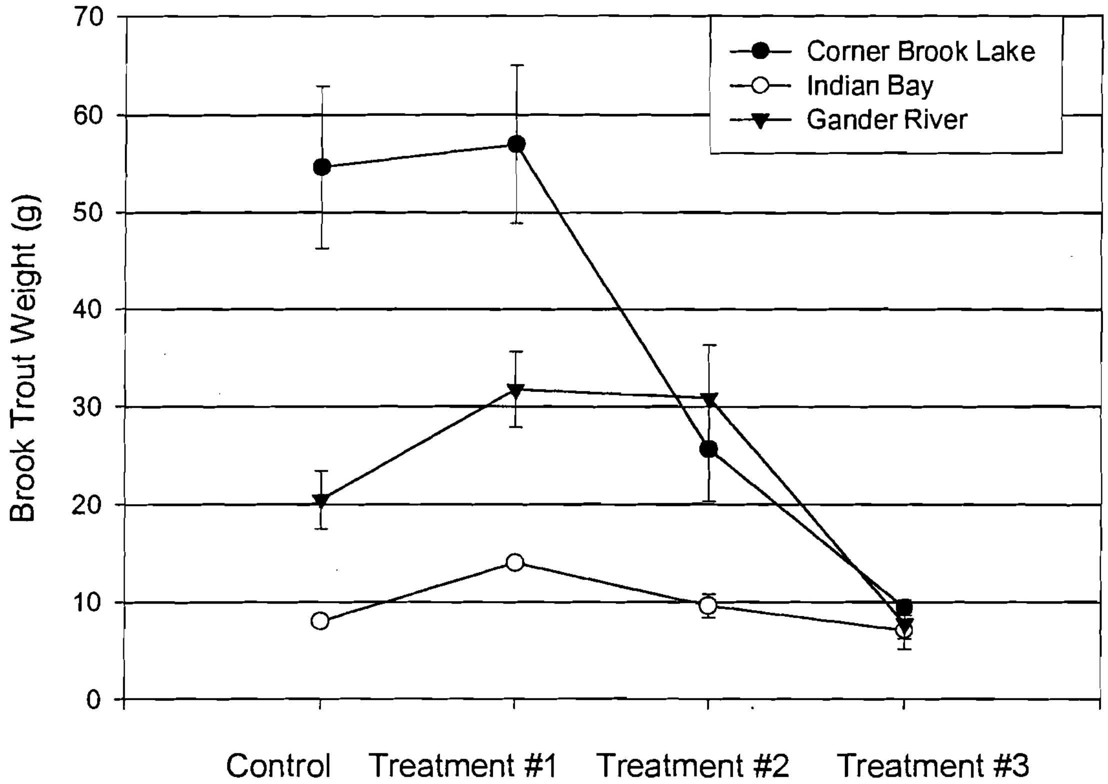


Figure 27. The average brook trout weight (g ± S.E.) sampled from each of the 12 sampled reaches within each of the three watersheds.

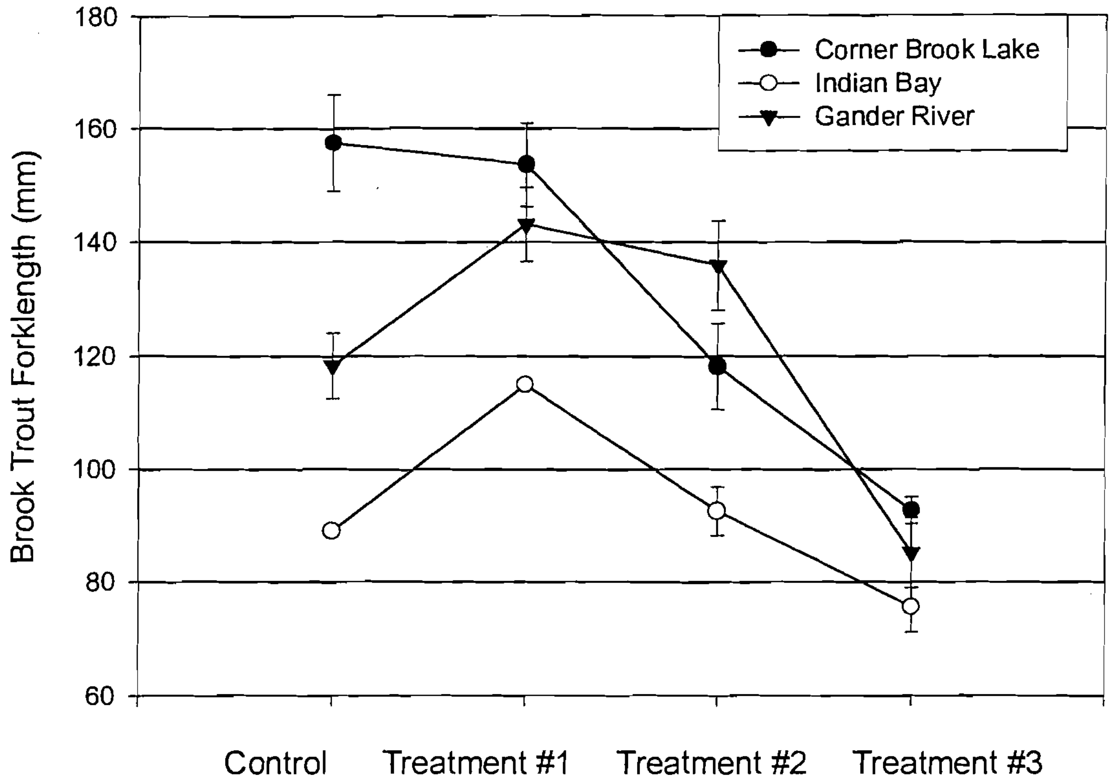


Figure 28. The average brook trout length (mm ± S.E.) sampled from each of the 12 sampled stream reaches within each of the three watersheds.

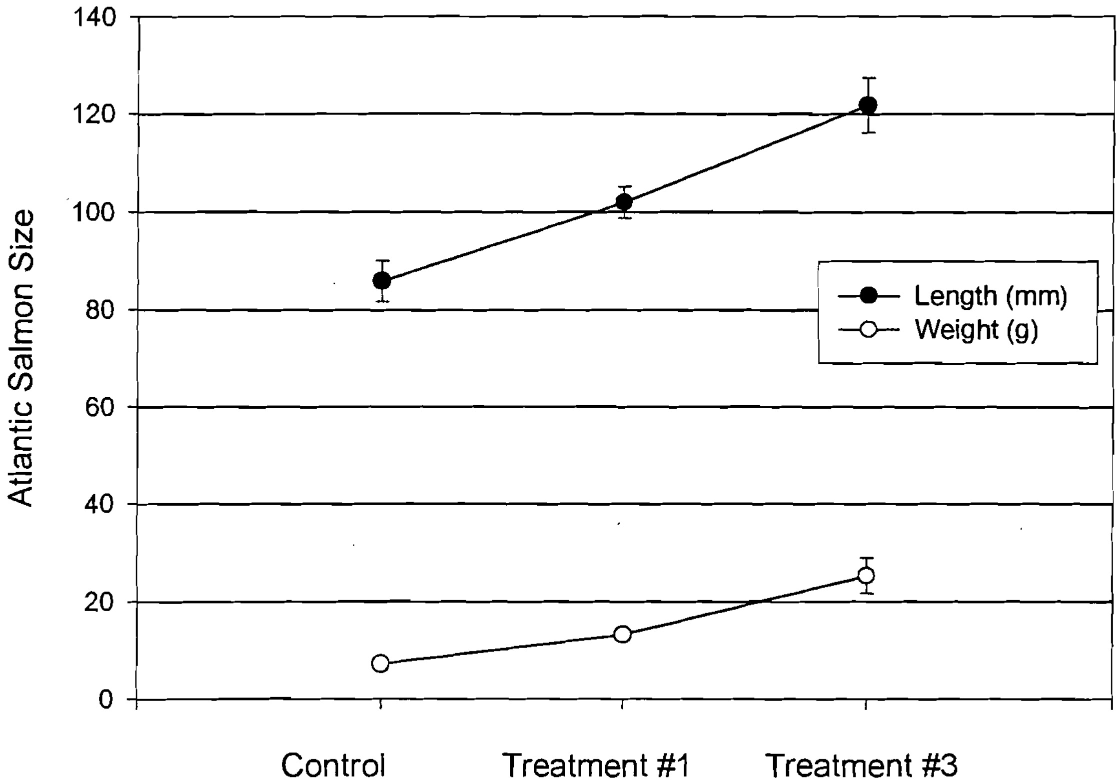


Figure 29. The length (mm ± S.E.) and weight (g ± S.E.) of Atlantic salmon sampled within the Indian Bay watershed.

APPENDIX A

GENERIC STREAM SURVEY FORM

STREAM SURVEY FORM

1. LOCATIONAL/GENERAL INFORMATION

Stream Name ______________________ River code ____________________

Tributary of ______________________ Map Reference ________________

Tributary No. ______________________ Section Number ________________

Stream Order ______________________ Date(y/m/d) ___________________

Field Crew ____

Coordinates (lower) ____________________ (upper) ____________________

Weather ______________________Time of Day ___________________

Description ____

____

____

Comments: ____

____

____

2. SECTION CHARACTERISTICS (GENERAL)

Section Length (m) ___________________ Water Level (l/m/h) ______________

Water Temp. °C _________ Air Temp. °C _______ Water Samples (y/n) ___________

Photos (y/n) __________ Roll # ____________ Exposures __________

Width (m) Start _______ Middle ________ End ________ Mean _____________

Surface Velocity ($m.s.^{-1}$) 1_________ 2_________ 3_________ Mean __________

3. CROSS SECTIONS (to be taken at Start, Middle and End)

Detailed Transects (y/n) ____________________ (use separate sheet)

(i) **Start** (bottom) Check is same as end of last section ________________

Location (m from start of section) ____

Channel Width (m) ____________________ Wetted Width (m)________________

Depth (cm) ¼ _____________ ½ _____________ ¾ __________ Mean ______

Bank Height (m) (Left) _______________ (Right) ______________

Ice Scour Height (m) (Left) _______________ (Right) ______________

(ii) **Middle**

Location (m from start of section) ____

Channel Width (m) ____________________ Wetted Width (m)________________

Depth (cm) ¼ _____________ ½ _____________ ¾ __________ Mean ______

Bank Height (m) (Left) _______________ (Right) ______________

Ice Scour Height (m) (Left) _______________ (Right) ______________

(iii) **End**

Location (m from start of section) ____

Channel Width (m) ____________________ Wetted Width (m)________________

Depth (cm) ¼ _____________ ½ _____________ ¾ __________ Mean ______

Bank Height (m) (Left) _______________ (Right) ______________

Ice Scour Height (m) (Left) _______________ (Right) ______________

4. HABITAT CHARACTERISTICS (GENERAL)

% Pool ______________________ % Riffle ______________________

% Run ______________________ % Steady ______________________

% Flat ______________________ % Rapids ______________________

% Other (falls, cascades, pond) ____________________

5. POOL CHARACATERISTICS

No. of pools ____________________ Pool/riffle ratio ________________

Pool #	Length (m)	Width (m)	Depth (cm)
1.	________	________	________
2.	________	________	________
3.	________	________	________
4.	________	________	________
5.	________	________	________
6.	________	________	________
7.	________	________	________
8.	________	________	________
9.	________	________	________
10.	________	________	________

Comments: ____

____

____

____

____

____

6. SUBSTRATE

	% of Section		% of Section
Bedrock	_______	Lg. Boulders (>1 m dia)	_______
Sm. Boulders (25 cm-1m)	_______	Rubble (14-25 cm)	_______
Cobble (6-13 cm)	_______	Pebble (3-5 cm)	_______
Gravel (20 mm-3 cm)	_______	Sand (0.06-20 mm)	_______
Mud, Clay (0.004-0.05 mm)	_______		

Degree siltation (described) ____

____

____

____

____

____

7. COVER

	% of Section	
Overhanging (riparian)	(y/n) _______	% of Section _______
Instream (large substrate, logs debris, etc.	(y/n) _______	% of Section _______
Instream (vegetation)	(y/n) _______	% of Section _______
Canopy cover	(y/n) _______	% of Section _______

8. RIPARIAN HABITAT

Vegation:	Hardwood	(y/n) _______	% of Section _______
	Softwood	(y/n) _______	% of Section _______
	Alders, etc.	(y/n) _______	% of Section _______
	Shrubs	(y/n) _______	% of Section _______
	Grasses	(y/n) _______	% of Section _______
	Bog	(y/n) _______	% of Section _______

Stream bank:

Eroding Banks (y/n) ________________ % of Section ______________

Bank Stability (good/fair/poor) ____

Undercut Banks (y/n) _______________ Left Hand Bank (%) ________

Right Hand Bank (%) ________

9. OBSTRUCTIONS

Obstructions (y/n) __________________ Type/Number ______________

Vertical Height (m) _________________ Slope (°) ___________________

Width (m) ________________________ Length (m) ________________

Photo (y/n) ______________ Roll # ____________ Exposures __________

Comments: ____

____

____

____

____

____

____

(include sketch is possible, next page, with dimensions)

10. IMPROVEMENT OPPORTUNITIES

Comments: ____

____

____

____

____

____

____

11. SCHEMATIC SKETCH or DRAWING (include location of cross-sections, pools, undercut and eroding banks, obstructions, (in detail, separate drawing), springs, tributaries, and other points of interest and major landmarks, i.e. instream debris, siltation, culverts, sewer outfalls, etc.).

APPENDIX B

GENERIC THALWEG PROFILE FORM

Thalweg Profile

Date **River:** **Tributary:** **Section:**

Distance (m)	Depth (m)	Location in Stream	Habitat Type

APPENDIX C

GENERIC LARGE WOODY DEBRIS (LWD) FORM

LOD Information (detailed) Date ________ River ________ Tributary ______ Section _______ Page ___

LOD	Stream	LOC Length (m)		Diameter (cm)			Height above			Orientation	Comments
#	Width (m)	Subm.	Total	Top	Middle	Base	water (cm)			Degrees	(Species, Bark, Pool type, Branches, Twigs, etc.)

APPENDIX D

GENERIC BUFFER ZONE COMPOSITION FORM

Buffer Zone Measurements

Date: River: Tributary:

Stream Section	Buffer Boundary Type	Buffer Width (m)	Buffer Slope (°)	Buffer Cover (%)	Buffer Blowdown (%)	Buffer Species Composition