Characterization of the large woody debris in Catamaran Brook, New Brunswick, 1990 to 1997

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ABSTRACT

Clément, M., P. Hardie, D. Caissie, and R.A. Cunjak. 2008. Characterization of the large woody debris in Catamaran Brook, New Brunswick, 1990 to 1997. Can. Tech. Rep. Fish. Aquat. Sci. 2794: vii + 43p.

The abundance, size, species, orientation, habitat association and movement of large woody debris (LWD) were evaluated in five reaches of Catamaran Brook, a third order tributary of the Miramichi River, New Brunswick. This characterisation of LWD was part of a long-term forestry impact study on lotic habitats and fish communities. This study provides baseline data to assess potential changes in the quantity and dimension of LWD. The survey was conducted annually for 8 years (1990 to 1997) and covered approximately 2.5 km or 13% of the length of Catamaran Brook. Coniferous species contributed to 40% of the identified LWD. The overall abundance of LWD decreased downstream from the upper reaches through the Middle reach and the Gorge reach but increased again in the Lower reach. The highest mean volume of LWD pieces was observed in the Middle reach. The variability in the abundance and size of the pieces of LWD seemed to be influenced by a combination of factors (e.g., stream discharge, stream gradient and characteristics of adjacent and upstream riparian forest) in Catamaran Brook. Most of the marked LWD items (> 80%) were observed in subsequent years within 90 m of the marking location in the upper reaches. In the downstream reaches (Middle, Gorge and Lower reaches), between 50% to 59% of the LWD items were observed near their marking location (≤ 90m) whereas up to 46% of the marked items were not relocated in subsequent years in these reaches. This high proportion of missed items suggests a downstream movement of LWD items. The lack of association between the occurrence of LWD and the pool habitat type in our study further indicates the need for a better understanding of the functional role of LWD in streams, particularly with the increase in popularity of placing LWD in streams during habitat restoration or enhancement projects in order to create pool habitat.

RÉSUMÉ

Clément, M., P. Hardie, D. Caissie, and R.A. Cunjak. 2008. Characterization of the large woody debris in Catamaran Brook, New Brunswick, 1990 to 1997. Can. Tech. Rep. Fish. Aquat. Sci. 2794: vii + 43p.

L'abondance, la taille, l'espèce, l'orientation, l'association avec l'habitat et le mouvement des débris ligneux grossiers (DLG) ont été évalués dans cinq tronçons du ruisseau Catamaran, un affluent de troisième ordre de la rivière Miramichi, Nouveau-Brusnwick. Cette caractérisation des DLG a été effectuée au cours d'un projet à long terme visant à étudier les impacts des activités forestières sur l'habitat et faune lotiques. Cette étude fournie des données de base permettant de déterminer d'éventuels changements de la quantité et dimension des DLG. Le recensement a été effectué annuellement sur une période de 8 années (1990 - 1997) et s'est étendu sur approximativement 2.5 km ou 13% du cours d'eau du ruisseau Catamaran. Les conifères ont contribuées à 40% des DLG. En général, l'abondance des DLG a diminué à partir du tronçon Upper, Middle et Gorge mais a augmentée dans le tronçon Lower. Le volume moyen maximal a été observé dans le tronçon Middle. La variabilité de l'abondance et de la dimension des DLG semble être influencée par une combinaison de facteurs (par exemple, le débit du ruisseau, la pente du cours d'eau et les caractéristiques de la forêt adjacente ou localisée en amont du cours d'eau) dans le ruisseau Catamaran. La plupart des morceaux de DLG marqués (> 80%) ont été retrouvées à moins de 90 m de leur lieu de marquage dans les tronçons Upper. Dans les tronçons situées en aval (Middle, Gorge et Lower), entre 50% et 59% des morceaux de DLG ont été retrouvés à proximité de leur lieu de marquage (≤ 90m) mais jusqu'à 46% des morceaux marqués n'ont pas été relocalisées dans ces tronçons durant les années subséquentes. Cette proportion élevée de morceaux non observés suggère un mouvement aval des DLG. Le manque d'association entre la présence des DLG et les fosses indique la nécessité de mieux connaitre le rôle fonctionnel des DLG dans les cours d'eau, particulièrement suite à l'augmentation de la popularité d'utiliser des DLG afin de créer des fosses lors des travaux de restauration ou d'amélioration de l'habitat.

INTRODUCTION

Large woody debris (LWD) plays an important role in modifying stream channel morphology by creating pools, waterfalls, gravel bars and affecting the transport and deposition of sediments. LWD also influences the retention of organic matter in streams and provides habitats for aquatic biota (see Bisson et al. 1987 and Naiman et al. 1992 for a review). Historically, the removal of LWD from streams and rivers was frequently practiced to facilitate navigation, transport of harvested logs or to improve access to headwater spawning habitats by anadromous fish species. LWD entering streams during timber harvesting activities was previously considered to be detrimental to fish populations and was often purposely removed (Bisson et al. 1987). The importance of LWD to stream ecology is now well recognized and artificially increasing the amount of LWD in streams is a habitat restoration and/or enhancement technique frequently used in riverine fisheries management (White 1996).

The influence of LWD on fish populations has been identified in several studies. For example, Rosenfeld et al. (2000) concluded that reducing the amount of LWD entering streams by harvesting riparian forests could significantly degrade cutthroat trout (*Oncorhynchus clarki*) habitat in British Columbia streams. Fausch and Northcote (1992) observed lower pool frequency, standing crop and weight of coho salmon (*Oncorhynchus kisutch*) and cutthroat trout in sections of streams where LWD was removed compared to undisturbed sections. Dolloff (1986) selectively removed small (< 6 cm in diameter) and larger but unstable pieces of woody debris in study reaches established in two small tributaries (< 2 m wide) in Southeast Alaska. Despite the selective removal of woody debris, Dolloff (1986) observed a decline in the abundance of coho salmon and Dolly Varden (*Salvelinus malma*) compared to undisturbed study reaches. However, negative relationships between LWD and brook trout densities were found in small headwater streams in Newfoundland, Canada (Clarke et al. 1997, 1998). Furthermore, Warren and Kraft (2003) observed varying response of brook trout (*Salvelinus fontinalis*) to woody debris removal in high-gradient streams in the Adirondack Mountains (New York) and concluded that the importance of LWD may diminish in section of streams with abundant boulder and high habitat complexity. Placing LWD in streams to improve fish habitat has also shown varying results in modifying fish abundance and growth depending on species, age or life stages, and seasons (Riley and Fausch 1995, Roni and Quinn 2001).

In this study, we quantified the characteristics of the LWD in five reaches of Catamaran Brook from 1990 to 1997. Catamaran Brook is a third-order tributary of the Miramichi River, New Brunswick. This project is part of a long-term forestry impact study on lotic habitats and fish communities (Cunjak et al. 1990, 1993) Timber harvesting of different intensities has occurred in the Catamaran Brook drainage basin since the late 1700s. During this period, old growth white pine (*Pinus strobus*) was selectively harvested throughout the Miramichi Basin for the British Navy (Cunjak et al. 1990). The riparian forests may have also been altered by the Great Miramichi Fire of 1825. Selective harvesting of saw logs from the Catamaran Basin occurred in the 1920's and 1930's. Aerial photographs from 1944 indicated that extensive harvesting activities occurred in the riparian forest, particularly in the Lower reach of Catamaran Brook. The remains of 3 splash dams can still be found in the Gorge and Lower reaches of Catamaran Brook used to hold back flood waters and to subsequently carry out harvested logs downstream at sawmills located at the mouth of the brook. It is believed that the last logs were driven on Catamaran Brook in the early 1950s (Cunjak et al. 1990).

Periods of clear-cut and selective harvesting occurred between 1960 to 1985. During this time period, clear cutting was conducted on 15% of the Catamaran Brook basin and selective harvesting was practiced on 23% of the drainage area (St-Hilaire et al. 1996). In the fall of 1996, timber clear-cut harvesting activities were resumed within 4 harvest blocks adjacent to Catamaran Brook and represented 5% of the drainage basin (Jolicoeur et al. 2007). The forest in the Catamaran Brook basin is now characterized by second-growth vegetation. In 1991, an estimated 56% of the forest was mature. Overall, the forest in the Catamaran Brook basin was estimated to comprise 32% pulp species (predominantly spruce *(Picea* spp.) and balsam fir (*Abies balsamea*)) and 28% hardwood. The other 40% of the forest comprised eastern white cedar (*Thuja occidentalis*), eastern hemlock (*Tsuga Canadensis*) and alder (*Alnus* spp., St-Hilaire et al. 1996). The riparian vegetation is characterized as predominantly coniferous species in the upstream reaches with increasing occurrence of mixed-wood species (coniferous and deciduous) in the Lower reach (Cunjak et al. 1990).

The general objective of the present study was to determine the LWD characteristics in Catamaran Brook during an 8 year time period (1990 - 1997). Specifically, the abundance, size, species, orientation and movement of LWD items and their association with fish habitat were quantified in 5 different reaches. Information pertaining to the role of LWD in relation to aquatic habitat and fish communities in eastern boreal forest regions is scarce. This study provides baseline data to assess future changes in characteristics and function of LWD in Catamaran Brook and allows comparison with other studies.

MATERIALS AND METHODS

Five reaches in Catamaran Brook were surveyed to quantify LWD (≥ 10 cm in diameter and ≥ 2 m in length; Bilby and Ward 1989) during summer low flow conditions from 1990 to 1997 (Fig. 1). The upper reaches are located in the headwaters of Catamaran Brook (Upper East-West (UEW) and the Catamaran Lake outflow tributary (UOUT); Fig. 1). These upper reaches are characterized by mean bankfull channel widths < 6 m (Table 1). The mean bankfull width increases downstream to 12 m in the Middle reach, 16 m in the Gorge reach and 18 m in the Lower reach (Fig. 1; Table 1). Mean water depth varied between 0.20

m (Gorge) to 0.41 m (Lower) and the mean stream gradient varied from 0.51% (Lower) to 2.82% (UOUT; Table 1). Although the mean stream gradients were similar between the Middle and Gorge reaches (Table 1), the Gorge reach is characterized by both low and high gradient sections of stream (Cunjak et al. 1993). The streambed of the Gorge reach is predominately composed of bedrock while a gravel/cobble substrate characterizes the other reaches. The estimated mean annual stream discharge increases from 0.20 m^3/s in UOUT to 1.23 m^3/s in the Lower reach (Table 1). Habitat surveys conducted along the entire length of Catamaran Brook in 1991, 1993, 1995 and 1997 (R. Cunjak, unpublished data) indicated that riffles and runs are the most abundant habitat types in all reaches except in UEW where flat and run habitat types predominate (Fig. 2). Pools represent < 10% of all habitat types in Catamaran Brook.

During the fall of 1996, timber harvesting occurred in cut blocks adjacent to UOUT and the Gorge reaches (Fig. 1). UEW was located upstream of all harvesting while the Middle and Lower reaches were located downstream of the forestry activities (Fig. 1). Timber harvesting also occurred in the headwater of Tributary 1 but LWD was not quantified in this tributary. A forested riparian zone of 30 m was prescribed along the tributaries, where applicable, and 60 m along the main stem of Catamaran Brook.

LWD surveys were conducted in August or September in all years except in 1993 and 1995, where the surveys were conducted at the end of July - early August and late May - June, respectively (Table 2). The reach lengths surveyed in 1990-91 showed some variations compared to subsequent years. However, the reach lengths remained more consistent from 1992 to 1997. Overall, the mean length of the surveyed reaches ranged from 68 m in UEW and 1365 m in the Lower reach (Table 2). The LWD surveys were conducted in sections representing 6% to 46% of the total reach where the habitat surveys were conducted (Fig. 2, Table 2). Each reach was divided into 30 m units and all pieces of LWD located within the bankfull channel (Gordon et al. 2004) per 30 m unit were recorded. When a LWD item was encountered, the location, total length, length located within the wetted width of the channel or the length above the wetted width, the diameter of the large end, mid-point (during 1990 to 1993 only) and small end (during 1994 to 1997 only) of the log were recorded (Table 3). Length measurements were obtained with a cloth 30 m measuring tape and diameters were measured with a calliper. The species, orientation (angle of the LWD item in relation to the bank), the habitat type (flat, pool, riffle, run, back water) associated with the item, and the stream bankfull width were also recorded (Table 3).

Tagging of LWD items with colour and number coded cattle ear tags was initiated in 1992 to quantify LWD movement or retention (Table 3). In subsequent years, the location of the marked items was recorded and additional unmarked items were tagged. Each year, between 75 and 138 additional pieces of LWD were tagged, for a total of 633 items tagged between 1992 and 1997 (Table 4). The exact location of the 30 m survey units within a reach varied between years. This was due to the uncertainty related to the method used to measure the length of the units (cloth tape measurements) or the loss of stakes marking the starting point of each reach. The variation in the location of the boundaries of a 30 m unit and loss of bench marks made calculations difficult at that spatial resolution. Therefore, to reduce this uncertainty, 3 consecutive units were combined and LWD movement was analyzed over a stream length of 90 m.

The volume of each piece of LWD was calculated using Huber's formula (equation 1) when the diameter at the mid-point of the log was measured (1990 - 1993). Huber's formula assumes that the average sectional area is located at the mid-point of a log (Avery 1967).

$$V = B_{1/2}(L) \qquad (1)$$

where:

V = Volume of the log (m^3)
$B_{1/2}$ = Area at log midpoint (m^2)
L = Log length (m)

Smalian's formula was used to calculate the volume of the LWD when the diameter of the large and small end of the logs were measured (1994 – 1997; Avery 1967):

$$V = \left(\frac{B+b}{2}\right) L \qquad (2)$$

Where:

V = Volume of the log (m^3)
B = Area at large end of log (m^2)
b = Area at large small end of log (m^2)
L = Log length (m)

The inaccessibility of several pieces of LWD, particularly when aggregated in log jams, prevented the measurement of the dimensions of some of the LWD items. The volume of 18% of the enumerated pieces of LWD was not calculated, and this percentage varied between reaches (i.e. 0.8% in the UEW to 22.4% in the Lower reach). Therefore, the amount of LWD is only presented in terms of the total number of pieces of LWD per 100 m stream length rather than a total volume of LWD per 100 m stream length.

To relate LWD movement with stream discharge, the maximum daily discharge which occurred between 2 consecutive surveys was obtained from the Catamaran Brook hydrometric station operated by Environment Canada (station 01BP002, latitude: 46° 51' 27" N and Longitude 66° 11' 18" W). Flood occurrence intervals for these periods of maximum daily discharge during the study period were calculated using a 3-parameter lognormal distribution (Kite 2004).

RESULTS

A total of 3577 pieces of LWD were enumerated during the 8 years of the study. The species of almost half (45.1%) of the pieces of LWD (all reaches combined) were not identified because of bark loss or difficulty in observing aggregated items (Table 5). Nonetheless, coniferous species contributed 39.5% of the identified LWD while 15.4% of the items were deciduous species (Table 5). Balsam fir was the most frequently identified coniferous species (14.7%) while the most frequently identified deciduous species were sugar and red maple (*Acer* spp., 6.1%, Table 5). The percentage of coniferous species varied from 33.9% in the Lower reach to 51.0% in the UOUT reach while deciduous species varied between 0.8% in the UEW reach to 19.1% in the Lower reach (Table 5).

In average, the upper reaches (UEW and UOUT) contained the highest amount of LWD items (mean = 25 and 28 pieces per 100 m stream length, respectively, Fig. 3a). Compared to these upper (smaller width) reaches, the mean number of pieces of LWD per 100 m stream length decreased by 50% in the Middle and the Gorge reaches (Fig. 3a, ANOVA and Sheffé test, $P < 0.05$). The mean amount of LWD in the Lower reach was lower than the upper reaches, but not statistically different (mean = 20 pieces / 100 m stream length; Sheffé test, $P = 0.47$; Fig. 3a).

Although the upper reaches contained the highest abundance of LWD per 100 m stream length, the lowest mean volume of the LWD items was recorded at these locations (ANOVA and Sheffé test < 0.001, Fig. 3a and 3b, Table 6). In contrast, the Middle reach contained the lowest mean number of pieces of LWD per 100 m stream length but the most voluminous items (0.4 m^3 ± 0.05 (SE)). However, the mean volume of the LWD items was not statistically different from the volumes measured in the Gorge and Lower reaches (Sheffé test P > 0.05, Figs. 3 b). A single large white pine (volume = 16.3 m^3) in the Middle reach was recorded each year and accounted for 70% of the original mean volume of LWD items. This large pine was excluded from the data summary. The mean length per LWD item varied from 6.7 m (UEW reach) to 8.0 m (Gorge reach, Fig. 3b). The longest items were observed in the Gorge reach but were only statistically different from the lengths measured in the UEW and Middle reaches (ANOVA and Sheffé test P < 0.05).

The number of pieces of LWD per 100 m stream length was not statistically different between years (ANOVA, P = 0.63; Fig. 4a, Table 6). Only one year post-harvesting (1997) is available and no detectable effects of timber harvesting on the amount of LWD was observed in reaches adjacent to the cut blocks in 1997 (UOUT and Gorge reaches; Table 6). However, a 20% decrease in the mean number of pieces of LWD per 100 m stream length was observed in 1991 compared to 1990 (Fig. 4a). A 50% increase of the mean volume and 27% increase of the mean length of the LWD items (all sites combined) were also observed in 1991 (ANOVA and Sheffé test P < 0.01, Fig. 4b). These variations were principally observed in the Middle reach, where the abundance of LWD decreased by 75% (Table 6), the mean volume of LWD items tripled (Tables 7) and a 2 fold increase of the mean length of LWD items was observed (Table 8).

The number of pieces of LWD per 100 m stream length in the Gorge reach, located downstream of the Middle reach, also doubled in 1991 compared to 1990 (Table 6) but the mean volume remained constant (Tables 7). In the Lower reach, the abundance of LWD decreased (Table 6) and the mean volume doubled (Table 8). An increase in mean length of the LWD items was observed in all sites in 1991 (Table 8). More than 70% of the total length of the pieces of LWD was found in or above the wetted width of the channel in all reaches (Table 8). The volume and length of the LWD items were not related to the mean bankfull channel width in Catamaran Brook ($R^2 < 0.02$; Fig. 5). Statistical analyses were performed using all data; however, for clarity Fig. 5 shows mean volume and mean length of LWD only.

After 1991, the mean of pieces of LWD per 100 m stream length showed a tendency for increasing through time, but the mean volume and length of the LWD items remained constant (ANOVA $P > 0.10$, Fig. 4). The 1991 survey was conducted following the highest maximum daily discharge (13.0 m^3/s) recorded by Environment Canada during the study period (Fig. 6). This event was calculated as having a recurrence interval of 1 in 50 years. The second highest maximum daily discharge (8.8 m^3/s) occurred between the 1993 and 1994 surveys and this event corresponded to approximately a 1 in 5 year event. No variation in the mean number of pieces of LWD per 100 m stream length, mean volume and mean length of the LWD items was observed during the 1994's survey (Fig. 3a and 3b). A 20% decline in the number of pieces of LWD per 100 m stream length and a 29% increase in the mean volume of the LWD items was observed in the Middle reach in 1994, but mean length of the LWD items remained similar to 1993 (Tables 6, 7 and 8). Nonetheless, these variations are within the range observed in other years and reaches (Tables 6, 7 and 8).

Most (41.1%, all reaches combined) of the pieces of LWD were oriented in a downstream direction (angle ≤ 45°, Table 9). However, the proportion of LWD oriented perpendicular to the channel (46° < angle ≥ 135°) was higher in the upper reaches (UEW and UOUT) compared to the downstream reaches (Table 9). Half of the pieces of LWD (all reaches combined) were observed in a run habitat type while only 8.2% of the items were associated with pools (Fig. 7). Those proportions coincided with the habitat availability recorded in Catamaran Brook where run and pool habitat types represented the highest (41.5%, all reaches combined) and lowest (7.5%, all reaches combined) of the habitat types in Catamaran Brook, respectively (Fig. 2).

The retention of LWD was high in the upper reaches, with more than 80% of the marked items being located at the marking location or moved ≤ 90 m in subsequent years (Table 10). The proportion of the items which remained at the tagging location or moved ≤ 90 m decreased to 49% - 59% in the downstream reaches (Table 10). No movement > 91 m was observed in the upper reaches while some (2% - 4%) LWD moved between 91 m and 360 m in the Middle reach, Gorge reach and Lower reach. Movement > 361 m was observed only in the Lower reach (Table 10). However, 34% - 46% of the tagged items were not able to be relocated in the Middle, Gorge and Lower reaches compared to < 10% in the upper reaches (Table 10). These lost items may have been carried downstream of the survey reaches, the tags were not visible (lost or hidden), missed by the surveyors (8% of the marked items were not observed during a specific survey but were located in subsequent years at the same location), or did not meet the LWD criteria. Indeed, 2% of the marked LWD items were excluded from the sample because the item broke into shorter pieces and no longer met the criteria of a LWD (≥ 10 cm in diameter and ≥ 2 m in length, Table 10). Four percent of the tagged items were located at the fish counting fence installed at the mouth of Catamaran Brook (Table 10).

DISCUSSION

The mean number of pieces of LWD per 100 m stream length in the upper reaches (UEW and UOUT) and the Lower reach were higher than the Middle and Gorge reaches. The variation in the abundance of the LWD in the five reaches of Catamaran Brook could be attributed to differences in the transport capability due to differences in water flow, channel gradients and channel widths. Although the channel gradient in the upper reaches was high (UEW = 1.8% and UOUT = 2.8%), the stream discharge is presumably not sufficient to move most pieces of LWD and the narrower channel width possibly contributed to the retention of smaller pieces of LWD. The transport of LWD items could increase with higher stream discharge in the Middle and Gorge reaches. Although stream discharge was highest in the Lower reach, the low gradient within this reach may have resulted in deposition of LWD.

In Catamaran Brook, variations in the mean volume of LWD between reaches seem to reflect the retention or displacement of the small pieces of LWD. For example, the upper reaches contained the highest abundance of LWD but the less voluminous items. The lower stream discharge and narrow channel width in the upper reaches could retain smaller pieces of LWD compared to the downstream reaches. The availability of voluminous LWD could have also affected the variations in the mean volume among reaches. Rot et al. (2000) related the size of the LWD to the age and successional stage of the riparian forest in the western Cascade Mountains (Washington State). Prior to 1996, timber harvesting of different intensities and time periods occurred in the riparian forests of Catamaran Brook. The difference in the mean volume of the pieces of LWD observed in the reaches of Catamaran Brook may in part reflect past harvesting activities and the successional stage of the riparian forest, with lower availability and recruitment of large trees. Although not quantified in this study, the riparian forest in the Lower reach is characterized by a mixture of coniferous and deciduous while the proportion of coniferous increases in the upstream reaches (Cunjak et al. 1990). This difference in the riparian forest composition may be reflected in the lower percentage of coniferous species among the pieces of LWD we observed in the Lower reach.

The decrease in abundance of LWD and increased mean volume observed in 1991 coincides with the occurrence of the highest maximum daily discharge (1 in 50 year flood) during the 8 year survey period. Although not statistically significant, the decrease in the abundance of LWD following this hydrologic event may have been the result of increased transport of LWD out of the study reaches. The increased mean volume of the pieces of LWD in 1991 appears to be related to the transport of the smaller pieces of LWD downstream of the study reaches, particularly in the Middle and Lower reaches. The abundance of LWD increased in the Gorge reach but the mean volume of the pieces of LWD remained similar between 1990 and 1991. The overall channel gradients of the Middle and Gorge reaches are similar, but the Gorge reach is characterized by a low gradient section followed by a steep increase in the slope. This could explain the increase in the abundance of the pieces of LWD observed in the Gorge reach in 1991 with LWD that was flushed from upstream lodging in the low gradient section of the Gorge Reach. However, the monitoring of movement of the pieces of LWD did not commence until 1992 and it is not possible to determine if the LWD that was flushed from the Middle reach moved into the Gorge reach.

The second highest flow event (1 in 5 year event) which occurred during the period of this study caused minimal changes in the abundance or characteristics (dimensions) of the LWD. It is possible that the critical threshold to induce significant movement of the pieces of LWD in Catamaran Brook may require higher return floods greater than 1 in 5 year floods. However, further investigation and a longer-time series of LWD would have been required to determine the critical threshold which induces large-scale movement of LWD in Catamaran Brook.

The study of LWD movement initiated in 1992 further supports the apparent high retention of LWD items in the upper reaches compared with the downstream reaches. Indeed, more than 80% of tagged items in the upper reaches were located in subsequent years at < 90 m from their tagging location. The majority of the marked items were located in these upper reaches, with less than 10% of the items not found in subsequent surveys. Fewer LWD (50% - 59%) were found ≤ 90 m from their tagging location in the Middle, Gorge and Lower reaches and 33% - 46% of the marked items were not recovered in these reaches. Although the tags could have been lost, hidden (accumulation of debris on top of the tag, roll over of the pieces of LWD, or items present but not located by the surveyors), the high proportion of pieces of LWD not found in these reaches could have been the result of downstream movement. Therefore, the movement of LWD may have been underestimated in this study. Most of the LWD moving > 90 m was observed in the Lower reach (12%). The length of this reach was at least 3 times the length of the other study reaches. The small amount of LWD moving > 90 m and relocated in the Middle and Gorge reaches (< 6%) could have been the result of the smaller surveyed stream length (≤ 441 m) and the shorter distance required for the transport of marked items out of the study reaches. Five percent of the tagged items in the Lower reach were seen leaving the system at the counting fence at the mouth of the brook. These items presumably would have left the system without the presence of the counting fence.

Variations in the abundance and size of LWD have often been related to stream width. Bilby and Ward (1989) surveyed 22 streams (second to fifth order streams) in western Washington State and found a negative relationship between the abundance of LWD and stream width and a positive relationship between the size of the pieces of LWD and stream width. They attributed the decrease in the abundance and increase in the size of LWD to the increase in stream discharge and the associated increase in the capacity of the water flow in larger streams to transport the LWD, i.e., higher transport energy. Therefore, only the larger, more stable pieces of LWD remain in the larger streams while the smaller pieces of LWD are carried downstream. The relationship between the abundance of LWD and stream width was also observed in streams draining old-growth, clear-cut and second growth forests in southwestern Washington (Bilby and Ward 1991). However, no relationship between the size of the pieces of LWD and stream width was observed in clear-cut and second-growth forests in Bilby and Ward’s (1991) study. Ralph et al. (1994) did not observe a significant relationship between the abundance of LWD and stream width in drainage basins subjected to different intensities of timber harvesting (un-harvested, moderately harvested and intensively harvested) in western Washington State. Similarly, Clarke et al. (1997, 1998) found no relationship between the abundance or size of LWD and stream width and attributed the lack of a relationship to the small range of stream widths and small sample size. The lack of a significant relationship between the abundance and size of LWD and stream width in our study can be attributed to the comparison of different study reaches within a single stream, variation in the stream gradient between these reaches and small sample size.

Clarke et al. (1997, 1998) observed a decrease in the abundance of LWD one year following timber harvesting (without riparian buffer zone) in a small stream in Newfoundland and attributed the decrease in abundance of LWD to a reduction in LWD inputs from the harvested riparian forest to the stream or flushing of LWD after a rainstorm event. Flebbe and Dolloff (1995) reported higher abundance and larger pieces of LWD in streams draining old-growth forest compared to a second-growth forest in North Carolina. Ralph et al. (1994) observed no effects of timber harvesting on the abundance of LWD but the size of LWD was reduced in harvested sites. Bilby and Ward (1991) concluded that timber harvesting reduces the abundance and size of LWD in streams larger than 10 m in width but suggested that the reduction in the size of LWD may have been the result of the manual removal of LWD from the stream during the harvesting operations. Timber harvesting occurred in the UOUT and Gorge reaches of Catamaran Brook during the fall of 1996 but no effect on the abundance or volume of LWD was detected in 1997. The presence of the riparian buffer zones may have reduced the effects of harvesting on LWD in Catamaran Brook, at least during the first year following harvesting. A study of windthrow in the Gorge reach riparian zone conducted in 1997 found an 18% increase in the blowdown of trees in the 60m buffer compared to an un-harvested control site (Lloyd 1999). This finding suggests that although the retention of a forested buffer along streams may mitigate large-scale, short-term changes in the quantity and quality of LWD, an increase in recruitment of LWD to the stream could be anticipated from stream-side leave-strips susceptible to windthrow.

Several studies have documented an association between LWD and pool habitat type (Bisson et al. 1987, Bilby and Ward 1989, Abbe and Montgomery 1996, Rosenfeld et al. 2000, Rot et al. 2000, Collins et al. 2002) but the influence of LWD in the process of pool formation is reduced in larger rivers (Andrus et al. 1988, Evans et al. 1993). In contrast, the LWD items in our study were most frequently observed in the run habitat type and LWD does not appear to play a significant role in the pool formation process in Catamaran Brook, especially over the time period of the study. Berg et al. (1998) also found that LWD played a limited role in pool formation in six streams of Central Sierra Nevada, California. Pieces of LWD situated perpendicular to the stream channel appear to be the primary factor influencing pool formation in small streams (Bilby and Ward 1989, Richmond and Fausch 1995, Hauer et al. 1999). The downstream orientation of most of the pieces of LWD in Catamaran Brook may explain the reduced role of LWD in pool formation. The effects of past transportation of harvested logs in watercourses remain in several streams (see Bisson et al. 1987). Possibly, Catamaran Brook may also have not yet recovered from the clearance of LWD and habitat destruction caused by past harvesting activities and the driving of logs in the brook.

The potential relationships between LWD characteristics and the Atlantic salmon population of Catamaran Brook were not analyzed in the present study because spawning and recruitment in the upstream reaches of Catamaran Brook are largely controlled by the presence or absence of beaver dams (Cunjak and Therrien 1998). Although several studies have shown the importance of LWD in providing habitat for native fish populations (Dolloff 1986, Fausch and Northcote 1992, Rosenfeld et al. 2000), the relationship between LWD and fish densities has not been observed in small boreal forest streams (Clarke et al. 1997, 1998). Placing LWD in streams is a frequently used technique in the attempted restoration or enhancement of fish habitat. However, the effectiveness of these manipulations remains unclear (Reeves et al. 1991). Furthermore, LWD may have negative effects on bank stability by redirecting water flow (Naiman et al. 1992) or positively affect a fish species to the detriment of other species. For example, Roni and Quinn (2001) compared stream reaches which were subjected to LWD placement with reaches which were not manipulated in 30 streams in western Oregon and Washington States. These authors suggested that the observed increase of pool area and decrease of riffle area in the treatment reaches was beneficial to juvenile coho salmon but not to juvenile steelhead trout which occupy riffle habitat during the summer. Our data suggests that LWD in Catamaran Brook currently plays a limited role in the pool formation process. The historical anthropogenic alterations of the landscape and evidences of past LWD disturbances in streams should be taken into consideration to reach a better understanding of the functional role of LWD in eastern boreal forest streams and elsewhere. A sound comprehension of the importance of LWD in the processes of lotic aquatic habitat formation is essential, particularly with the increasing practice of placing LWD in streams as a habitat restoration and enhancement technique.

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The LWD survey at Catamaran Brook was realized with the contribution of many people, often under less than ideal conditions. We have received field assistance from interns hired through the Career Edge and Science and Technology Interns programs. In addition, we have received assistance from students of the New Brunswick Community College Environmental Technology Program (Bathurst and Miramichi, N.B.) and the Holland College (Summerside, P.E.I.) within the Renewable Resource Management Program. Many other people have contributed time and energy to the collection of this information and we extend a sincere thank you. We also acknowledge the significant contribution of the New Brunswick Environmental Trust Fund and the Miramichi Salmon Association which contributed to the long-term success of the Catamaran Brook Habitat Research Project.

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Table 1: Mean (range) bankfull channel width, water depth, stream gradient and stream discharge in the reaches where the large woody debris surveys were conducted in Catamaran Brook, 1990 - 1997.

Reach	Bankfull width (m)	Water depth (m)[1]	Channel gradient (%)[1]	Annual discharge (m^3/s)[1]
UEW	5.9 (3.6 - 11.0)	0.27 (0.25 - 0.29)	1.80 (1.19 - 2.41)	0.23
UOUT	4.6 (3.0 - 8.2)	0.25 (0.24 - 0.25)	2.82 (2.67 - 2.97)	0.20
MIDDLE	12.3 (5.4 - 20.6)	0.28 (0.18 - 0.37)	0.96 (0.20 - 2.24)	0.69
GORGE	15.9 (7.0 - 29.4)	0.20 (0.16 - 0.32)	1.00 (0.10 - 2.95)	0.89
LOWER	17.9 (6.0 - 39.0)	0.41 (0.25 - 0.63)	0.51 (0.00 - 2.37)	1.23

[1] Data obtained from Cunjak *et al.* (1993)

Table 2: Dates and reach length surveyed for pieces of large woody debris in Catamaran Brook, 1990 - 1997.

Year	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	
Survey date	28-Aug - 04-Sept	24-Aug - 05-Sept	05-Aug - 19-Aug	31-Jul - 04-Aug	01-Aug - 16 Aug	30-May - 28-June	13-Aug - 23-Sept	14-Aug - 20-Aug	
Reach	**Reach length (m)**								**Mean (SE)**
UEW	120	60	60	60	60	60	60	60	68 (7.5)
UOUT	120	180	210	210	240	240	210	210	203 (13.6)
Middle	360	360	390	390	390	390	390	420	386 (6.8)
Gorge	450	470	420	420	450	420	450	450	441 (6.6)
Lower	1020	1170	1440	1380	1440	1530	1440	1500	1365 (62.6)

Table 3: Parameters measured during the large woody debris surveys conducted in Catamaran Brook, 1990 - 1997.

Year	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
Location	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
Total length	x	x	x	x	x	x	x	x
Length in or above the wetted width	x	x	x	x	x	x	x	x
Large end diameter	x	x	x	x	x	x	x	x
Mid-point diameter	x	x	x	x	na	na	na	na
Small end diameter	na	na	na	na	x	x	x	x
Species	x	x	x	x	x	x	x	x
Orientation	x	x	x	x	x	x	x	x
Habitat type	x	x	x	x	x	x	x	x
Bankfull width (m)	x	x	x	x	x	x	x	x
Movement	na	na	x	x	x	x	x	x

Table 4: Number of pieces of large woody debris tagged in Catamaran Brook, 1990 - 1997.

Reach	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**Total**
UEW	0	0	8	5	0	3	6	1	23
UOUT	0	0	17	13	9	16	12	7	74
Middle	0	0	14	12	7	8	10	17	68
Gorge	0	0	11	20	16	1	11	14	73
Lower	0	0	25	70	76	48	99	77	395

Table 5: Tree species, expressed in percentage of the number of large woody debris observed or identified during the surveys (all years combined) in Catamaran Brook, 1990 - 1997.

	Species (percent)													
		Coniferous							Deciduous					
Reach	U	F	S	C	H	P	UC	all spp	M	B	AP	A	UD	all spp
UEW	51.9	18.0	11.3	11.3	0.0	0.0	6.8	47.4	0.0	0.0	0.8	0.0	0.0	0.8
UOUT	30.5	22.4	13.0	8.8	0.0	0.0	6.8	51.0	7.9	0.0	1.3	0.0	9.2	18.5
MIDDLE	47.3	19.8	6.8	7.1	1.8	3.0	5.6	44.1	5.0	1.2	0.9	0.0	1.5	8.6
GORGE	46.4	26.1	7.8	13.2	0.0	0.7	2.8	50.6	0.7	2.1	0.0	0.0	0.2	3.1
LOWER	47.0	10.0	7.0	3.2	1.6	0.9	11.2	33.9	7.3	3.6	2.8	0.4	5.6	19.1
All reaches	45.1	14.7	8.0	5.8	1.1	0.9	9.0	39.5	6.1	2.6	2.0	0.3	4.4	15.4

Legend

AP = Trembling aspen and balsam poplar (*Populus* spp.)
A = White and black ash (*Fraxinus* spp.)
B = White and yellow birch (*Betula* spp.)
C = Eastern white cedar (*Thuja occidentalis*)
F = Balsam fir (*Abies balsamea*)
H = Eastern hemlock (*Tsuga canadensis*)
M = Sugar and red maple (*Acer* spp.)
P = White pine (*Pinus strobus*)
S = White, red and black spruce (*Picea* spp.)
U = Unknown (coniferous and deciduous combined)
UC = Unidentified coniferous spp.
UD = Unidentified deciduous spp.

Table 6: Number of pieces of large woody debris per 100 m stream length observed in Catamaran Brook, 1990 - 1997.

Reach	1990	1991	1992	1993	1994	1995	1996	1997
UEW	23.3	15.0	20.0	23.3	23.3	26.7	33.3	33.3
UOUT	22.5	28.9	26.2	27.1	26.7	25.0	35.2	31.4
MIDDLE	22.8	5.8	6.9	10.8	8.7	11.5	9.2	12.1
GORGE	6.2	11.9	13.1	12.9	12.0	11.9	13.6	14.9
LOWER	17.7	11.9	14.1	17.8	21.5	21.6	29.8	25.9

Table 7: Mean volume of the large woody debris items observed in Catamaran Brook, 1990 - 1997. Number in brackets indicates the standard error of the mean.

Reach	1990	1991	1992	1993	1994	1995	1996	1997
UEW	0.19 (0.04)	0.12 (0.02)	0.16 (0.03)	0.14 (0.03)	0.17 (0.04)	0.14 (0.03)	0.14 (0.02)	0.14 (0.02)
UOUT	0.16 (0.02)	0.20 (0.03)	0.16 (0.02)	0.17 (0.02)	0.16 (0.02)	0.16 (0.02)	0.15 (0.02)	0.15 (0.02)
MIDDLE	0.19 (0.03)	0.63 (0.18)	0.50 (0.21)	0.38 (0.11)	0.49 (0.19)	0.46 (0.16)	0.52 (0.20)	0.34 (0.07)
GORGE	0.24 (0.03)	0.27 (0.03)	0.27 (0.04)	0.28 (0.04)	0.30 (0.04)	0.32 (0.04)	0.28 (0.03)	0.27 (0.02)
LOWER	0.26 (0.03)	0.42 (0.05)	0.33 (0.04)	0.35 (0.04)	0.34 (0.04)	0.30 (0.03)	0.32 (0.03)	0.33 (0.02)

Table 8: Mean length of large woody debris items and mean percentage of the total length in or above the wetted width of the channel observed in Catamaran Brook, 1990 - 1997. Number in brackets indicates the standard error of the mean.

Reach	1990	1991	1992	1993	1994	1995	1996	1997	Percent of length in or above the wetted width
UEW	6.62 (0.63)	8.03 (0.87)	7.45 (0.88)	6.69 (0.88)	6.67 (0.89)	6.26 (0.93)	6.40 (0.81)	6.37 (0.75)	85.6 (2.0)
UOUT	7.42 (0.77)	8.37 (0.65)	7.75 (0.62)	8.34 (0.74)	7.45 (0.57)	6.84 (0.56)	6.54 (0.48)	6.60 (0.51)	74.3 (1.4)
MIDDLE	4.36 (0.41)	9.56 (1.40)	8.39 (1.14)	7.74 (0.92)	7.29 (0.92)	7.09 (0.84)	8.07 (1.09)	7.45 (0.74)	84.9 (1.6)
GORGE	7.31 (0.90)	8.61 (0.59)	8.14 (0.60)	8.00 (0.63)	7.86 (0.56)	7.96 (0.57)	7.72 (0.54)	7.77 (0.50)	79.9 (1.5)
LOWER	7.36 (0.29)	8.23 (0.34)	7.60 (0.28)	7.89 (0.27)	6.97 (0.23)	7.25 (0.26)	6.88 (0.21)	7.15 (0.21)	88.5 (0.6)

Table 9: Orientation of the pieces of large woody debris (all years combined) observed in Catamaran Brook, 1990 - 1997. 0° = downstream, 180° = upstream, NR = not recorded.

Reach	Angle (degree) 0-45 (%)	46-90 (%)	91-135 (%)	136-180 (%)	NR (%)
UEW	30.1	37.6	25.6	6.0	0.8
UOUT	34.3	34.7	16.9	9.5	4.6
MIDDLE	47.0	19.2	5.3	8.0	20.4
GORGE	52.0	13.9	2.6	4.0	27.5
LOWER	40.2	14.7	8.0	10.5	26.6
All reaches	41.1	18.4	8.9	9.2	22.4

Table 10: Movement of the pieces of large woody debris, expressed as percentage of the items marked and retrieved in Catamaran Brook, 1992 - 1997. NF = Not found, NC = Not meeting LWD criteria, F = LWD found at the counting fence.

	Distance (m)							
Reach	0 - 90	91-180	181-270	271-360	> 361	NF	NC	F
UEW	86.4	0.0	0.0	0.0	0.0	9.1	4.5	0.0
UOUT	80.6	0.0	0.0	0.0	0.0	9.0	10.4	0.0
MIDDLE	52.5	1.7	0.0	0.0	0.0	45.8	0.0	0.0
GORGE	58.8	0.0	2.0	3.9	0.0	33.3	2.0	0.0
LOWER	49.4	3.1	1.5	0.9	6.2	34.0	0.3	4.6
All reaches	56.2	2.1	1.1	1.0	3.8	31.0	1.9	2.9

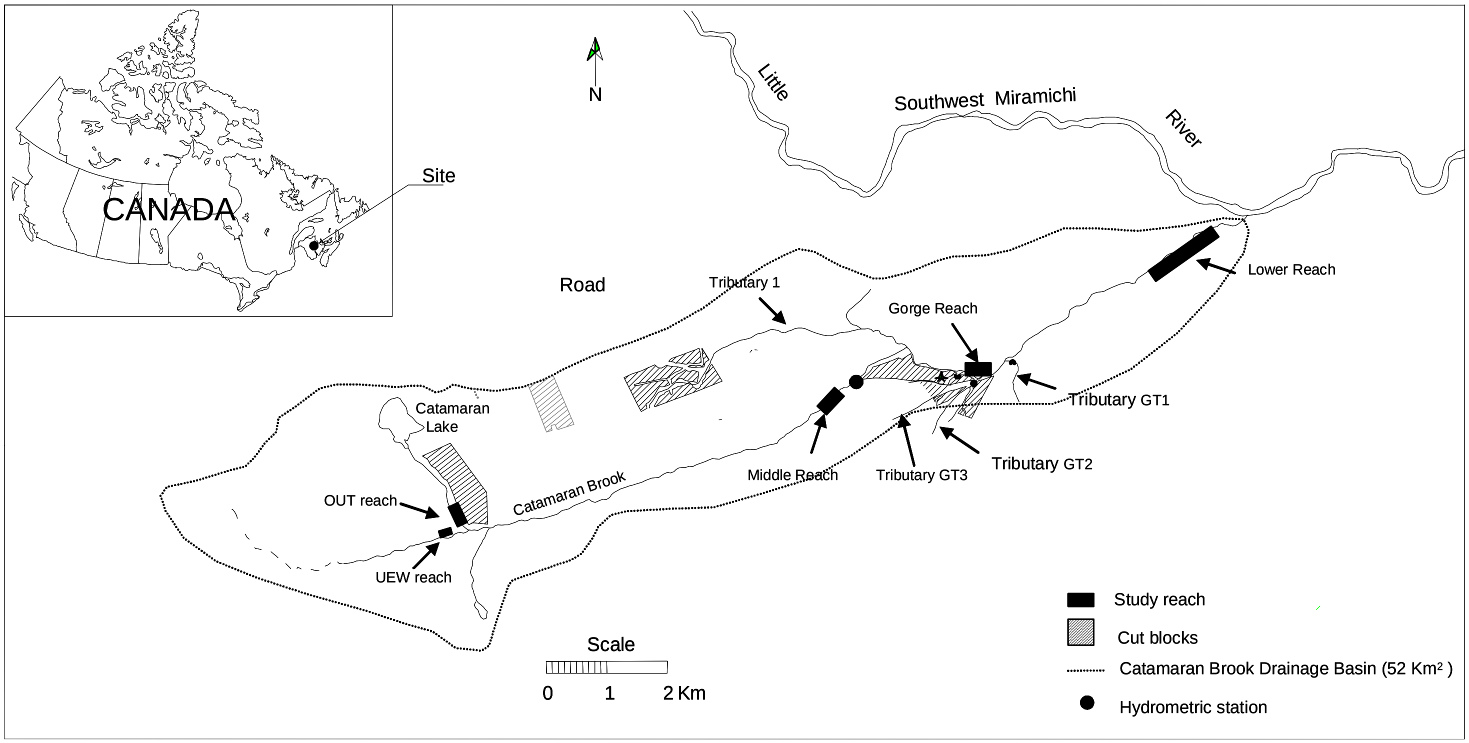

Figure 1: Study reaches where the large woody debris surveys were conducted (1990 -1997) and timber harvest blocks in Catamaran Brook.

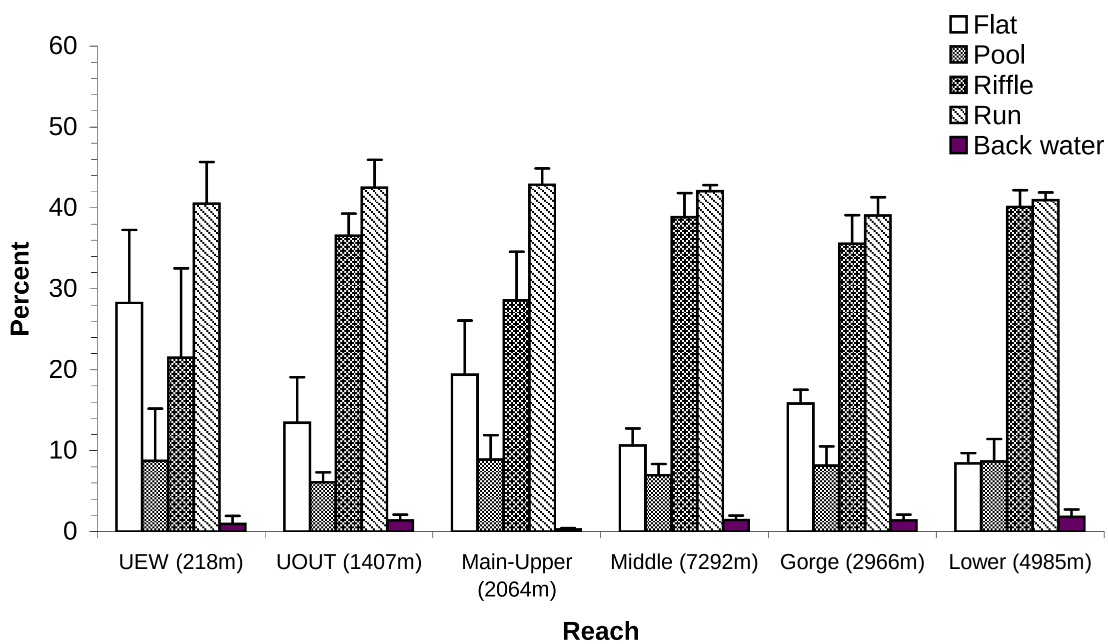

Figure 2: Mean percent of habitat types observed in the entire length of Catamaran Brook in 1991, 1993, 1995 and 1997. Main-Upper refers to the stream reach of the main channel located downstream of the confluence of UEW and OUT. Number in brackets indicates the mean stream length of each reach. Vertical bars denote the standard error of the mean. Unpublished data, R.A. Cunjak.

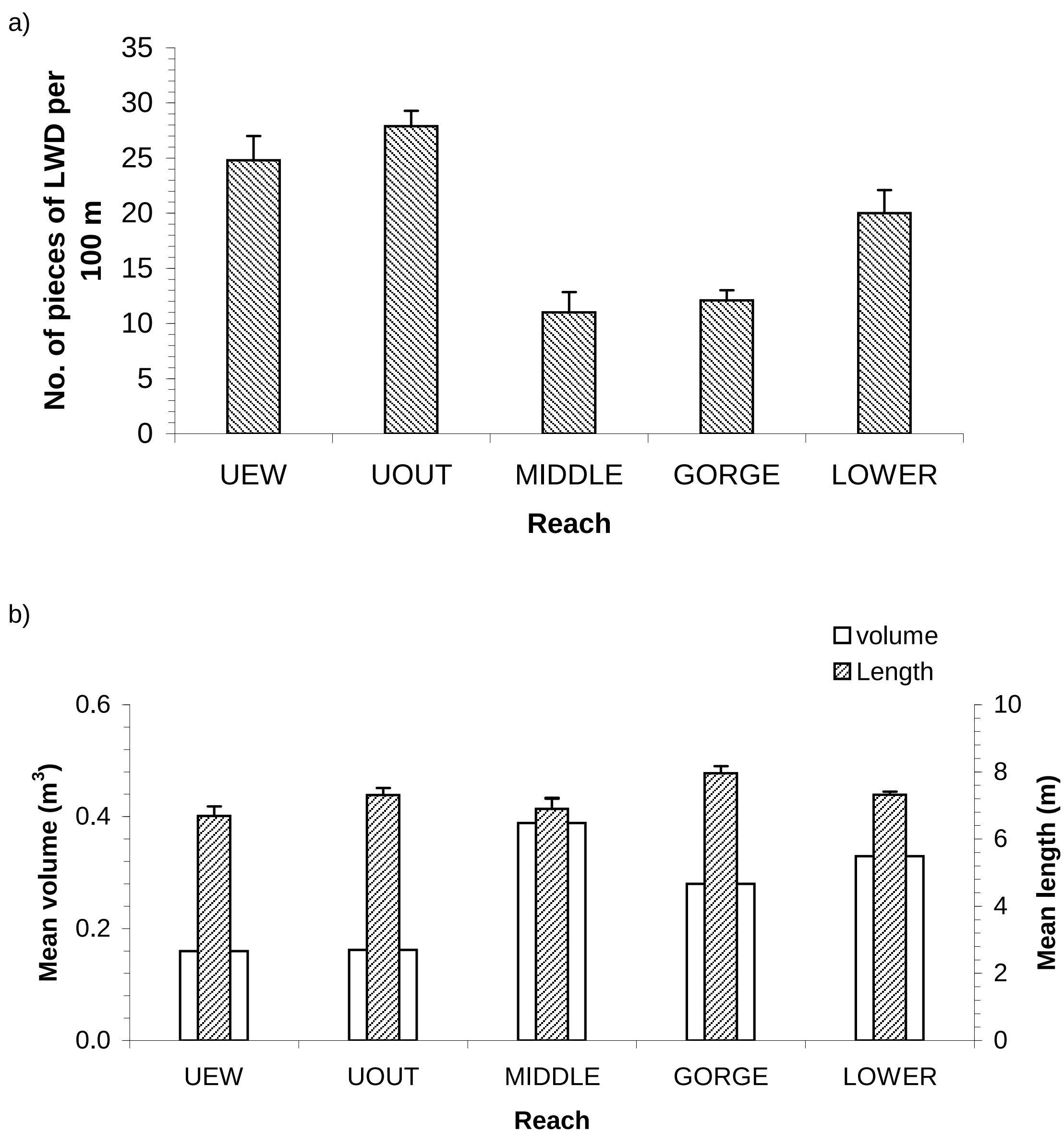

Figure 3: Mean (all years combined) number of pieces of large woody debris per 100 m stream length (a) and mean volume and total length of the large woody debris (b) observed in Catamaran Brook, 1990 - 1997. Vertical bars denote the standard error of the mean.

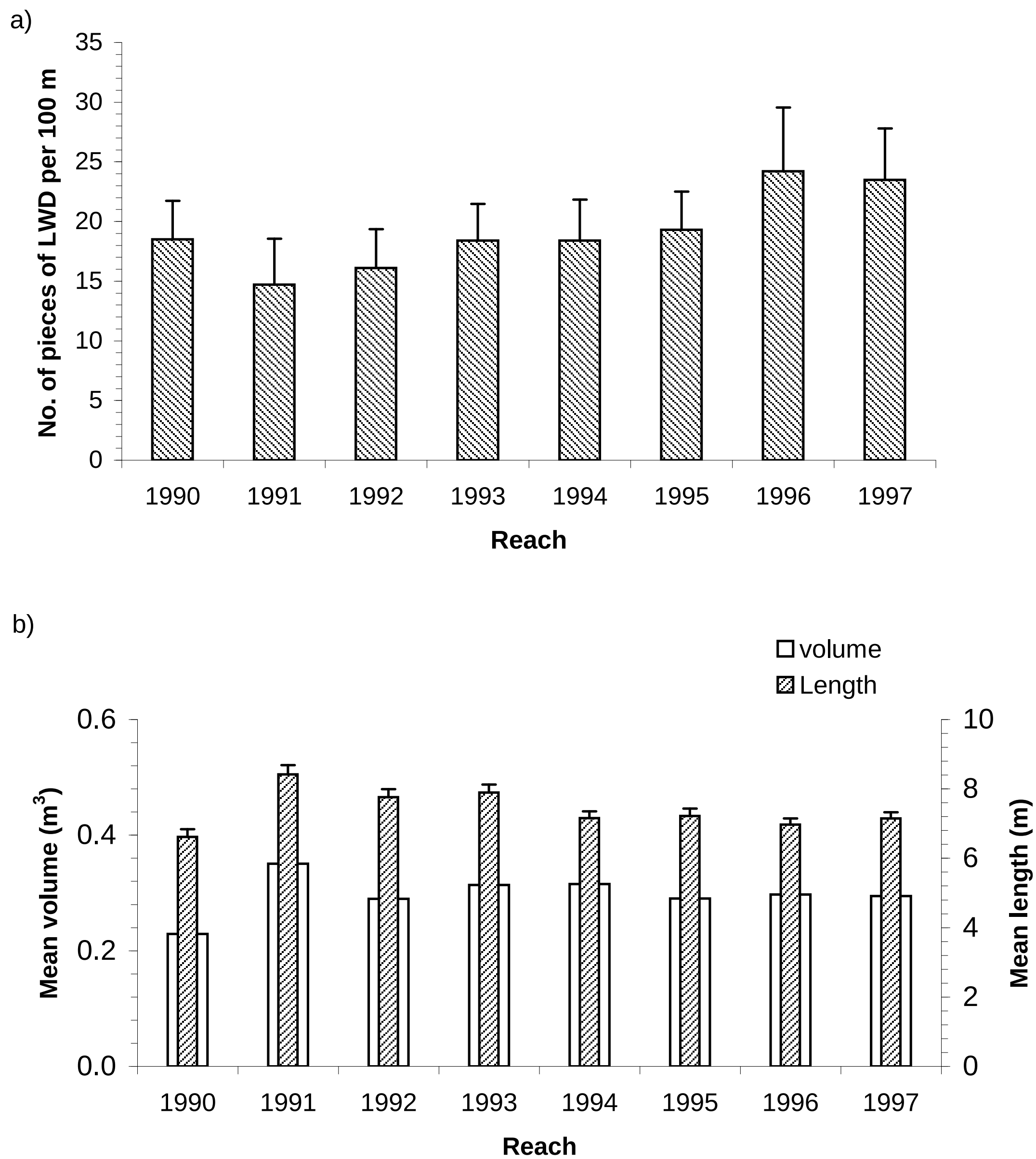

Figure 4: Mean (all reaches combined) number of pieces of large woody debris per 100 m stream length (a), mean volume and total length of large woody debris (b) observed in Catamaran Brook, 1990 - 1997. Vertical bars denote the standard error of the mean.

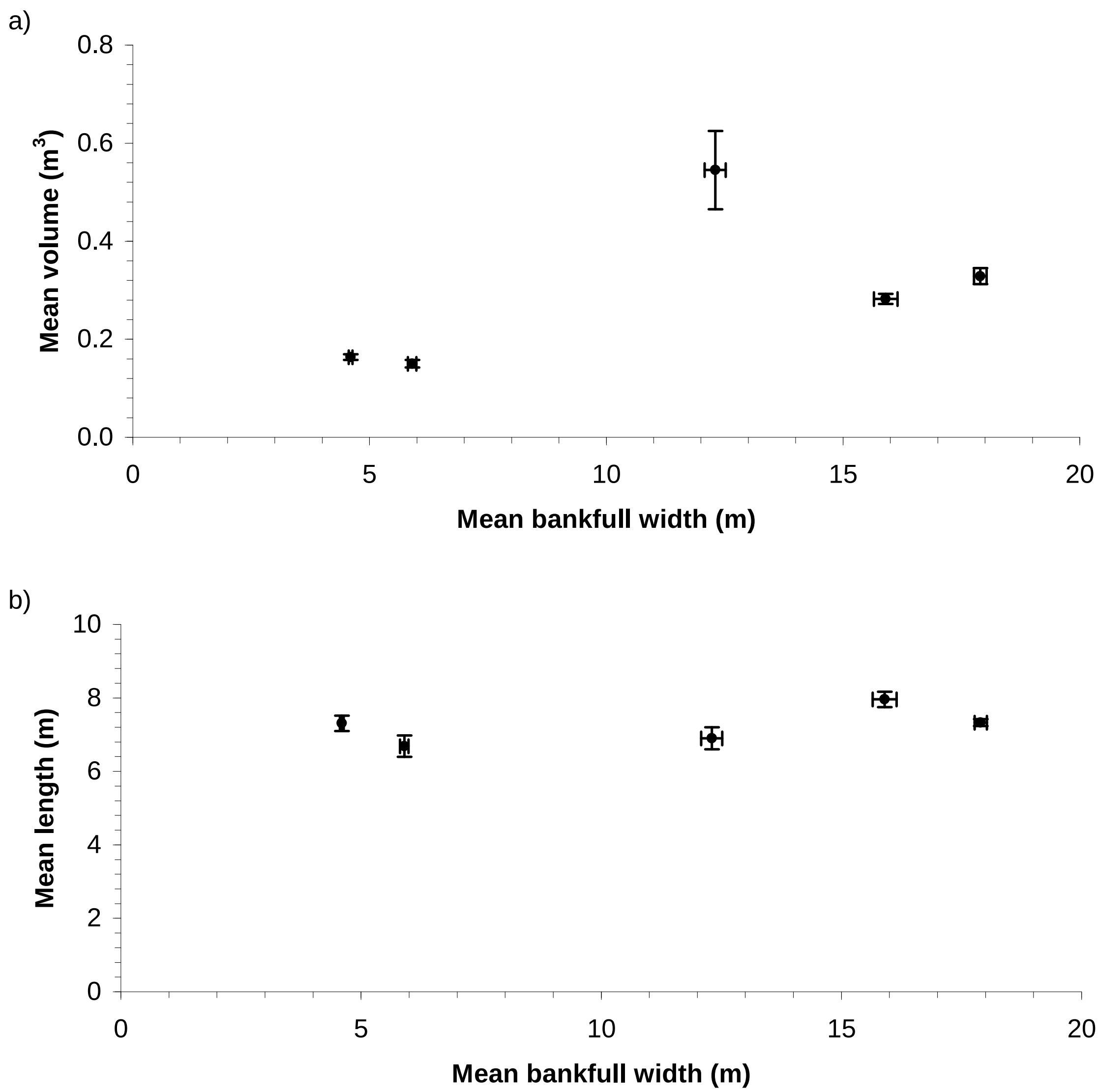

Figure 5: Mean (all years combined) volume (a), and total length (b) of the pieces of LWD in relation to the mean bankfull width measured in the 5 reaches surveyed in Catamaran Brook, 1990 to 1997. Vertical bars denote the standard error of the mean.

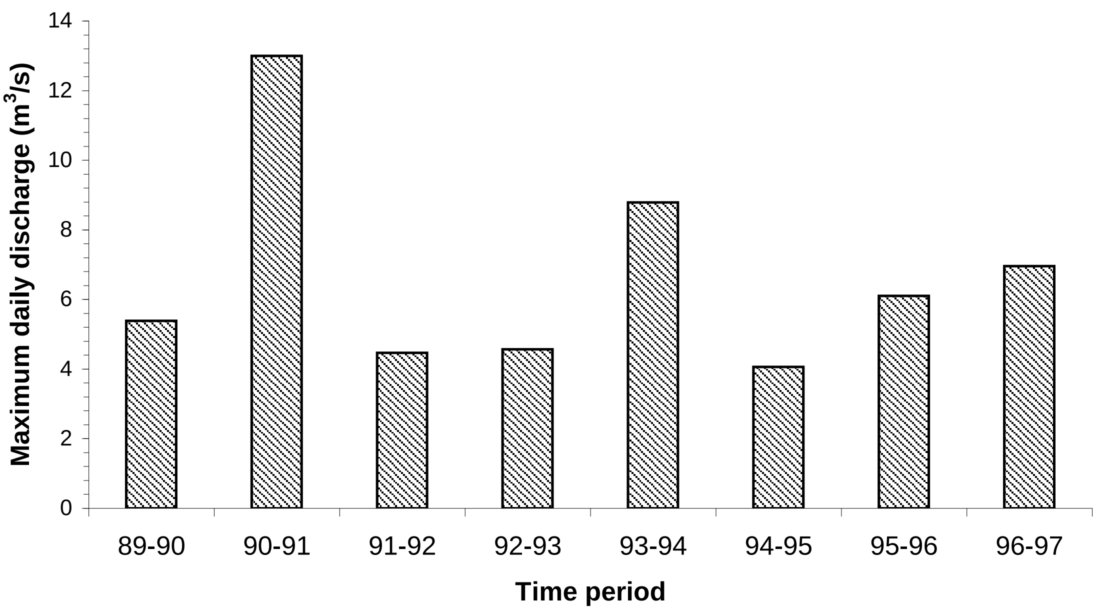

Figure 6: Maximum daily discharge recorded between large woody debris surveys in Catamaran Brook, 1990 - 1997. Discharge data were obtained from the hydrologic station operated by Environment Canada in Catamaran Brook (station 01BP002, Latitude: 46° 51' 27" N and Longitude 66° 11' 18" W).

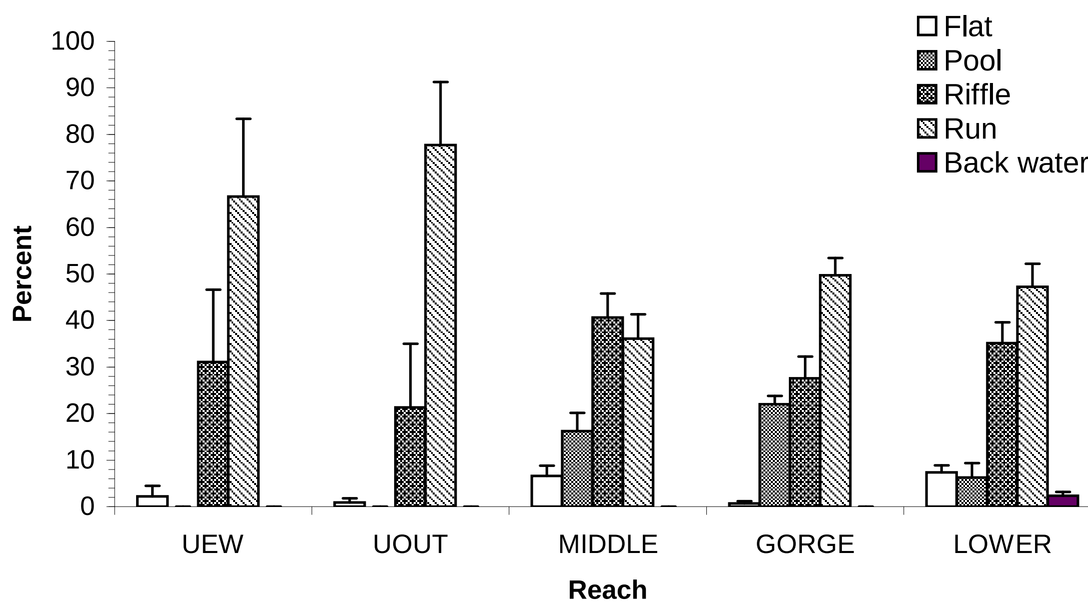

Figure 7: Mean percent of the pieces of large woody debris (all years combined) observed in different habitat types in Catamaran Brook, 1990 - 1997. Vertical bars denote the standard error of the mean.