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Abstract

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Declining Atlantic salmon stocks, which forced the closure of the commercial salmon fishery on the island of Newfoundland in 1992, coupled with the increasing economic importance of the recreational salmonid fishery, has resulted in two major federal-provincial agreements over the past decade aimed at rebuilding the salmonid stocks of the Province. These agreements, the Newfoundland Inshore Fisheries Development Agreement (NIFDA) from 1988-1992, and the Cooperation Agreement for Salmonid Enhancement and Conservation (CASEC), from 1992 to 1997, included habitat improvement and restoration as a major strategy and supported a total of 142 projects at a total cost of $3.0 million . It was recognized that a proportion of these projects should undergo scientific evaluation to provide information on the effectiveness and transferability of techniques and to assist in developing region-specific criteria to guide publicly sponsored habitat initiatives. This report provides an overview of these evaluations, as selected case studies, including projects involving restoration of habitat degraded by historic forest harvesting (Joe Farrell's Brook and Pamehac Brook), removal of a natural migration barrier (Dead Wolf Brook), and the addition of spawning gravel to increase juvenile salmonid production (Northeast Placentia River). Results of a series of experiments in a controlled flow channel (Noel Paul's Brook) to investigate the effect of several habitat alterations on salmonid populations under Newfoundland conditions are discussed. Generally, the projects evaluated have been successful in increasing salmonid abundance and/or production. Results have highlighted the importance of hydrological and biological considerations to habitat improvement and restoration initiatives and recommendations are made for future projects.

Résumé

Scruton, D.A., K.D. Clarke, T.C. Anderson, A.S. Hoddinott, M.C. van Zyll de Jong and K.A. Houston. 1997. Evaluation of Habitat Improvement and Restoration Initiatives for Salmonids in Newfoundland, Canada. Can. Manuscr. Rep. Fish. Aquat. Sci. No. 2413: v + 35 p.

Le déclin des stocks de saumons de l'Atlantique, qui a provoqué en 1992 la fermeture de la pêche commerciale du saumon sur l'ile de Terre-Neuve, conjugué à l'importance économique de la pêche sportive des salmonidés, a suscité aux cours des dix dernières années la conclusion de deux ententes fédérales-provinciales majeures pour reconstituer les stocks de salmonidés de la province. L'Entente sur le développement de la pêche côtière à Terre-Neuve (1988-1992) et L'Entente de coopération sur la mise en valeur et la conservation des salmonidés (1992-1997), qui ont adopté l'amélioration et la remise en état d'habitats comme principale stratégie, ont donné lieu à 142 activités pour un coût total de 3,0 millions de dollars. Il était prévu qu'un certain nombre de ces activités feraient l'objet d'évaluations scientifiques, question de déterminer l'efficacité et la transférabilité des techniques utilisées, et de contribuer à la formulation de critères d'orientation régionaux pour toute activité environnementale financée par les fonds publics. Le présent rapport constitue un sommaire de ces évaluations, sous forme d'études de cas, notamment de remise en état d'habitats détériorés par de longues pratiques d'exploitation forestière (ruisseaux Joe Farrell et Pamehac), d'enlèvement de barrières naturelles à la migration (russeau Dead Wolf) et d'ajout de gravier de frai dans le but d'accroître la production de saumoneaux (rivière Northeast Placentia). Le résumé présente aussi les résultats d'une série d'expériences menées dans une frayère à débit réglé (russeau Noel Paul) pour étudier les effets de diverses modifications d'habitat sur les populations de salmonidés dans les conditions de Terre-Neuve. En général, les travaux évalués se sont soldés par un accroissement des populations ou de la production de salmonidés (ou des deux). Les résultats ont mis en relief l'importance des facteurs hydrologiques et biologiques dans les activités d'amélioration et de remise en état d'habitats. Des recommendations sont formulées pour les futures activités dans ce domaine.

1.0 Introduction

Ecological restoration is a process where an ecosystem is manipulated in order to return it to its original state after an external perturbation (Bradshaw 1996). Habitat improvement, on the other hand, generally refers to changes made in a natural ecosystem to improve the productive capacity of the entire ecosystem and thus benefit a target species and/or community. Both methods are widely used in aquatic ecosystem management, see papers in Kelso (1996) and references in Duff et al. (1995). These two approaches cover a wide range of ecosystem manipulations including fish population alterations (Winton and Hilborn 1994, O'Connell et al. 1983, Heggberget and Hesthagen 1981), chemical additions (Clarke et al. 1997, Lacroix 1996, Peterson et al. 1993) and physical habitat alterations (Geiling et al. 1996, van Zyll de Jong 1995, Elliot 1986) among others. This paper evaluates one of these ecosystem manipulation techniques, i.e. physical habitat alteration, as a method for restoration and improvement of Newfoundland freshwater systems.

The populations most often targeted in restoration and improvement projects in Newfoundland were those of anadromous and resident salmonids. The most abundant and widespread of these are the Atlantic salmon (*Salmo salar*) and the brook trout (*Salvelinus fontinalis*). These two species make up the basis of the recreational fishery in Newfoundland and until recently (1991) a viable commercial salmon fishery was conducted around the island. A general decline in stocks and the economic importance of both the recreational and commercial fisheries to the province has focussed attention on these species. It has been suggested that the decline of these stocks has been magnified by habitat destruction due to poor development practices. Thus, habitat restoration and improvement was considered an important component of stock rehabilitation for these species.

Most salmonid habitat related problems in Newfoundland are due to human development pressures which reduce or limit the ecosystem's productive capacity. The degradation caused by developments are then compounded by more widespread environmental problems such as acid rain and global warming. The developments that have caused the most concern are forest harvesting, urbanization, mining, hydroelectric development and road construction. These activities can affect distribution, survival, and production of fish and other aquatic organisms, disrupt community structure, and cause the loss and degradation of critical habitats. Considerable focus was placed on the importance of conserving and protecting fish habitat when, in 1986, the Department of Fisheries and Oceans (DFO) announced the Policy for the Management of Fish Habitat. The objective of this policy is to increase habitat supporting Canada's fisheries resources and habitat restoration was cited as one of the three main goals to achieve this objective.

A general decline in salmonid stocks in Newfoundland and Labrador, coupled with increasing demands on salmonid resources, has focussed attention on maintaining and restoring salmonid habitat. As a result of the increased emphasis on fish habitat, a number of major habitat improvement and restoration programmes have been undertaken in Newfoundland and Labrador in the past decade. Programmes have included two major 5-year federal-provincial agreements; the Newfoundland Inshore Fisheries Development Agreement (NIFDA), Small Stream Component (1988 to 1992) followed by the Cooperation Agreement for Salmonid Enhancement and

Conservation (CASEC), Habitat Improvement and Restoration Component (1992 to 1997). A number of other programmes have supported regional habitat restoration initiatives, including the Environmental Partner's Fund (EPF) of Environment Canada, Canada's Green Plan - Habitat Action Plan (HAP), Wildlife Habitat Canada, the Newfoundland Conservation Corps 'Green Teams', and others.

The federal provincial agreements (NIFDA and CASEC) have supported a total of 142 habitat improvement and restoration projects at a total cost of $3.0 million over the last decade. The majority of these projects have been small, non-technical projects delivered by local community and/or interest groups and they have generally utilized techniques that have been developed elsewhere in North America. The biophysiography and species composition of freshwater systems in Newfoundland differ from their mainland counterparts (Scott and Crossman 1973). Thus, the evaluation of a proportion of these projects was warranted to test their applicability for Newfoundland freshwater systems.

2.0 Case Studies

The following are case study summaries of selected habitat projects evaluated during NIFDA and CASEC. These projects were selected for evaluation because they were among the most technically complex projects conducted and were representative of specific approaches and/or techniques undertaken for restoration and improvement. Two major projects involved restoration of habitat degraded by historic forest harvesting practices (Joe Farrell's Brook and Pamehac Brook). One of these projects (Joe Farrell's Brook) made extensive use of instream structures while the other (Pamehac Brook) reopened a large section of stream which was de-watered to promote log driving activities. Two additional projects that were evaluated included the removal of a natural migration barrier to promote salmonid migration (Dead Wolf Brook) and the addition of spawning gravel to increase juvenile salmonid production (Northeast Placentia River). Finally, a series of experiments were conducted in a controlled flow channel at Noel Paul's Brook to experimentally investigate the effect of several habitat alterations on salmonid populations under Newfoundland conditions.

2.1: Pamehac Brook Restoration Project

In the early 1970's, control dams were constructed in the upper reaches of Pamehac Brook, a tributary of the Exploits River in central Newfoundland, Canada (Figure 1), to facilitate water borne transport of logs to a pulp and paper mill. To expedite transportation of harvested pulpwood within the Pamehac Brook watershed, the headwaters of the system were diverted into the main stem of the Exploits River. This resulted in the de-watering of 12 km of high quality brook trout and Atlantic salmon rearing and spawning habitat. Although the water borne transport of pulpwood ceased in the mid-1980's, the infrastructure (including storage dams and diversion channel) remained in place, resulting in fish migration problems and limited fish production potential. In the autumn of 1989, a project was conceived to address the manmade obstructions to fish migration and restore (re-water) the lower reaches of Pamehac Brook (Anderson et al. 1994, Scruton et al. 1997). This project was developed as a partnership arrangement between the Environmental Resources

Management Association (a local conservation group), Abitibi-Price Inc. (a pulp and paper company), the Environmental Partners Fund (of Environment Canada), and DFO.

The initial phase of the project entailed remedying the infrastructure related to historical log driving activities (Figure 2). A collapsed wooden box culvert on the mainstem of the river (about 11 km upstream from the mouth) and two control dams (at the outlets of Pamehac and Five Mile Lakes) were replaced with three new bridges to remove migration barriers and to accommodate the altered flow regimen after restoration. The existing diversion dyke across Pamehac Brook was then removed and natural flows were restored to the middle and lower portions of Pamehac Brook. The re-watered channel of Pamehac Brook was then surveyed for obstructions and a number of abandoned beaver dams, fallen trees and pulpwood were removed.

Project evaluation has consisted of (i) a quantitative assessment of juvenile fish populations before and after the project and (ii) comparison of available habitat before and after project implementation. Fish populations were sampled by quantitative electrofishing in 1990 (pre-project) and in 1991, 1992, and 1996 (post-project). A total of eight stations were electrofished in 1990, two above the diversion and six below the diversion (Figure 2). Maximum likelihood (ML) abundance estimates (numbers and biomass) were obtained for (i) all salmonids, (ii) separately for brook trout and Atlantic salmon and (iii) separately for each age class (Figure 3 and 4). Detailed stream habitat surveys were completed in 1990, prior to restoration, and again in 1992 and 1996, after restoration following methods outlined in Scruton et al. (1992). The surveys were conducted from the river mouth (confluence with the Exploits River) in 200 m long sections, or at other section lengths as determined by changes in habitat type. Data were entered into the River Habitat Database System (RHDS) and comparisons made between available habitat before restoration (both above and below the diversion) and after restoration (Table 1).

Habitat surveys conducted in 1990 and 1992 indicated an initial increase of 449.3 habitat units (1 unit=100 m^2), related primarily to re-watering of 0.79 km of river that had been completely de-watered and an increase in wetted width of fluvial habitat in lower reaches of Pamehac Brook (previously partially de-watered) (Table 1). The initial 'gain' in habitat included 304.7 units of riffle (48 % increase), 52.4 units of steady (148 % increase), 15.0 units of run (100 % increase), and 0.1 units of pool (4 % increase). Increases were also apparent in mean width (9.5 m to 13.7 m, 44 % change) and mean depth (18.7 cm to 26.0 cm, 39 % increase).

The data from the 1996 survey indicated a slight decrease in total habitat from 1992 but was still higher than that observed pre-restoration (1990) (Table 1). The decrease from 1996 to 1992 was mostly due to a reduction of wetted width (10.3 vs 13.7 cm). The more prominent habitat related change in 1996 however, was in the distribution of habitat types. There was a reduction in fast flowing habitats (rapids and riffle) and an increase in pools, steadies and runs (Table 1). This observation can be largely attributed to an increase of beaver activity in Pamehac Brook, with concurrent extensive construction of dams on the mainstem, since the 1992 survey. Beavers dams reduce stream velocity and creates slower deeper habitats, more suitable to the production of older/larger salmonids. These results are compatible to the trends observed in salmonid densities and biomass (see below).

There were no significant ($P<0.05$) changes in salmonid density (Figure 3) or biomass (Figure 4) in the first year after restoration (1991) as compared to pre-restoration levels (1990). In the second year after restoration (1992) significant increases in density were observed for 0+ salmon ($p = 0.002$) and older trout (>0+; $p = 0.012$) (Figure 3) but no significant changes in biomass were observed (Figure 4). These density increases translated into a significant increase ($p = 0.002$) in total salmonid density during 1992 as compared to pre-restoration (1990) levels. The large increase in 0+ salmon was the major proportion of this density increase and was attributable to fry stocking efforts conducted in 1992. These stocking practices confounded the restoration experiment and were subsequently discontinued to allow populations to reach a natural equilibrium.

Four years were allowed for the system to equilibrate after the stocking practices. A significant increase in density of older salmon (>0+; $p = 0.029$) was observed during the 1996 estimates (Figure 3). This was coupled with significant decreases in 0+ trout and salmon ($p = 0.001$ and 0.003, respectively) which translated into a significant decrease ($p = 0.001$) in total salmonid density in 1996 as compared to 1992 and 1990, pre-restoration (Figure 3). The more pronounced change however, was the significant increases in biomass of older (>0+) trout and salmon ($p = 0.014$ and 0.001, respectively) (Figure 4). These increases meant that total salmonid biomass was significantly greater ($p = 0.001$) in 1996 as compared to 1992 and pre-restoration levels (1990). These results suggest that the habitat developed through the re-watering of Pamehac Brook was most suitable for the rearing of larger, older salmonids.

The survey and fish population data allowed estimation of the 'habitat gain' and the increase in habitat 'productive capacity' associated with this project. Pre-restoration fish biomass and available habitat suggested a potential productive capacity for the fluvial habitat in the watershed (1990) of 18.01 kg excluding standing waters and steadies. The average fish biomass and available habitat in 1992, two years after restoration, indicated a potential productive capacity of 51.46 kg, a 2.9 fold increase. The estimate for potential productive capacity in 1996 was 263.94 kg, a 14.7 fold increase from pre-restoration levels. The restoration of Pamehac Brook has thus resulted in a habitat gain of 215 units (30 % increase) and an increase in potential productive capacity of 246 kg from 1990 to 1996.

2.2: Joe Farrell's Brook, Salmon River Habitat Restoration Project

A long-term evaluation of a major habitat restoration project on Joe Farrell's Brook, a second order tributary of the Salmon River (Main Brook, Newfoundland; Figure 1), is currently ongoing (van Zyll de Jong 1995). This multi-year scientific evaluation has assessed the response of salmonids and their habitat to the introduction of several types of instream structures. These structures were intended to restore habitat affected by historical forest harvesting activities (1946 until 1971). Clear cut harvesting and pulp wood transportation resulted in the channelization and alteration of stream hydrology in this area thus reducing the amount and diversity of fluvial habitat available for salmonid production. The main objectives of this project were to: (i) evaluate the long term effectiveness and stability of restoration procedures on both physical habitat and juvenile fish populations and (ii) provide a regional model for effective approaches to stream restoration.

Three types of stream restoration treatments were applied to Joe Farrell's Brook: (i) boulder clusters, (ii) V-dam structures and (iii) half-log covers (Figure 5) (van Zyll de Jong 1995). Biological and physical habitat variables were sampled at eleven stations which included treatment sites (n=5), sub-basin control sites (n=1), and sites downstream of treatment locations (n=5). Stations were surveyed prior to the installation of structures (1993) and in each subsequent post-treatment year (1994 to 1996). Physical attributes measured at each station included stream gradient (%), width (cm), depth (cm), bottom substrate (modified Wentworth scale; after Gibson 1993), water velocity ($m\ s^{-1}$), and cover (%). Quantitative estimates of fish density and biomass were obtained by electrofishing (Scruton and Gibson 1995). Raw density data were compared to look at absolute changes in different year classes of Atlantic salmon and brook trout between pre- and post-treatment years.

The sub-basin control site was necessary to provide an estimate of inter-annual variability of salmonid density within Joe Farrell's Brook. This is to assist in evaluating wether the initiatives resulted in increased production at the sites or whether fish have simply relocated to the rehabilitated reach with subsequent reductions at other locations. As well, anadromous salmonids (Atlantic salmon as in this project) experience natural population fluctuations related to escapement back to the rivers, sea survival of smolts, etc. that need to be controlled for assessment of restoration initiatives. The analysis, to follow, assesses the direction and magnitude of change observed in the sub-basin control as an indication of inter-annual changes which may have occurred in the study sections.

There were significant changes in several physical habitat variables measured (Table 2). The most significant change at the boulder sites was an increase diversity of substrate size with the different substrates becoming more evenly distributed. There was also a greater variability in depth (i.e. increased diversity) observed in the boulder cluster sites after additions (Table 2). V-dams increased the percentage of pool as well as increasing shallow riparian areas. Half-log covers increased the percentage of instream cover.

Juvenile salmon age class structure and densities were similar in boulder site one and its downstream counterpart before boulder additions in 1993 (Figure 6). These areas were mainly utilized by 1+ and 2+ Atlantic salmon with fewer YOY observed than in the sub-basin control (Figure 6). The densities of YOY and 1+ Atlantic salmon significantly increased ($P < 0.05$) in the addition and downstream sites in the first year after boulder additions (Figure 6). This trend was not observed in the sub-basin control. In the second year after the boulder additions, 1995, YOY densities were observed to decline in both the addition and its downstream site while 1+ Atlantic salmon remained at elevated levels. This is in comparison to a increase in YOY density in the sub-basin control during 1995. The density of 1+ salmon remained consent in the sub-basin control throughout the study.

The results observed in the second boulder addition site were similar to those of site one. Both YOY and 1+ Atlantic salmon densities increased significantly ($P < 0.05$) in the first year after additions (Figure 7). The 1+ salmon densities continued to increase in 1995 in both the addition and its downstream site (Figure 7). The YOY densities were also observed to increase in the boulder site in 1995, but were sightly lower in the downstream site. The YOY increase in 1995 is difficult to attribute to the boulder additions because a similar increase was also observed in the sub-basin control.

The boulder cluster addition sites appear to have enhanced microhabitat conditions and habitat complexity. This has resulted in significant density increases for 1+ Atlantic salmon with a possible initial benefit to YOY salmon. While a positive response of older salmon parr was expected, the increase in YOY and 1+ salmon was not and could be attributed to the stabilization of smaller substrate materials providing improved spawning conditions and overwintering sites for these smaller juveniles. The benefits of these boulder additions to juvenile Atlantic salmon will become clearer in subsequent years as the initially affected year class moves through the population. Results from the 1996 field season were collected but were not analyzed at the time of publication.

The populations in V-dam site 1 were similar to those of its downstream site and the sub-basin control before manipulation in 1993 (Figure 8). In 1994, the first year after construction, significant increases ($P < 0.05$) of YOY and 1+ Atlantic salmon densities were observed in both the V-dam and downstream sites as compared to the sub-basin control (Figure 8). These increases were of a higher magnitude in the downstream site as compared to the V-dam site. The second year after construction, 1995, saw a continued increase in YOY and 1+ salmon densities in the V-dam site (Figure 8). There was also a significant increase in the density of 2+ Atlantic salmon observed in this site during 1995. In the downstream site, the density of 1+ salmon increased in 1995 while the YOY density did not change significantly from that observed in 1994 (Figure 8). The sub-basin control had significant YOY density increases in 1995 which parallel the increase observed in the V-dam site. The increases observed in the V-dam site were however of a greater magnitude, 10-fold as compared to 4-fold. The same increases were not observed in the downstream site.

The second V-dam site did not affect any of the salmon year classes (Figure 9). There was a small, but significant increase in YOY and 1+ salmon density in the downstream site in 1994 (Figure 9). This trend was not continued through 1995 with the exception of YOY salmon which had increased densities in the river as a whole in 1995 as indicated by observations in the sub-basin control. The densities in the V-dam site actually declined in 1994 as compared to 1993 levels (Figure 9). The YOY densities were significantly higher in 1995 but these increases were mirrored in the sub-basin control and thus may not be a result of our manipulations.

The V-dams, a technique used to develop pool habitat in both a plunge pool and backwater area, created improved conditions in relation to the uniform, pre-treatment channelized reach. While this treatment was expected to primarily benefit trout, the most appreciable response was increased density of 1+ (both post-treatment years) and possibly 0+ (second year after restoration) salmon in site 1. There was no apparent response in juvenile salmonid populations at site 2.

Densities of YOY and 1+ Atlantic salmon increased significantly in both the half-log and downstream sites in 1994 (Figure 10). These increases did not persist at the half-log site but did continue in the downstream site in 1995 (Figure 10). Older fish, which this structure should benefit, were not observed to respond to the additional cover supplied by the half-log structure. The effect of these instream structures on brook trout populations was difficult to evaluate due to the low numbers encountered throughout the study. This problem was highlighted in the sub-basin control where only 4 brook trout were captured over the first three years of the study .

Several of the results observed, thus far, have been somewhat unexpected. Site specific conditions associated with treatments were considered important in these results. The low natural densities of brook trout and older salmon, which many of these structures were expected to benefit, suggests that there may be a time lag before the full extent of the effect of these structures on the juvenile salmonid populations of Joe Farrell's Brook can be understood. Results suggested that attention needs to be paid to construction and siting of rehabilitation techniques to provide microhabitat conditions preferred by target species and age/size classes. Rehabilitation techniques that provide diverse habitat conditions may benefit a number of species and/or age classes. Secondary benefits (non target size/age groups) of rehabilitation methods may have been as beneficial as the primary objectives.

2.3 Dead Wolf Brook Obstruction Removal Project

Dead Wolf Brook, a tributary of the Southwest Gander River (Figure 1), was completely obstructed to upstream migration by anadromous salmon by a series of four falls at the mouth of the river (Figure 11). A remedial project was initiated in 1994 which blasted a series of pools and chutes in and around the upper three falls. Follow up work in 1995 included blasting a series of three pools and connecting channels around the lower falls. A concrete wall and spillway were installed to maintain depth in the lower pool. Additional remedial activities were conducted in 1996 on the upper three falls, to increase the depth in one of the plunge pools and to remove any debris that may have inhibited migration. Construction crews observed successful fish passage after completion of the remedial activities in 1995 and fish were located below the falls in July 1996 but had either moved on or had returned downstream by August 1996.

Further evaluation to verify fish passage will be conducted in the summer of 1997 using state-of-the-art coded tag radio telemetry coupled to digital antennae switching. Coded radio transmitters will be implanted (surgical implant) in twelve adult Atlantic salmon in the large holding pool below Dead Wolf Falls. The receiver will be set up as a remote monitoring station (powered by solar panel) with continuous monitoring and data logging for three months covering the migration period until anadromous Atlantic salmon have spawned. Three separate underwater antennae will be established such that their reception zones are independent and discrete. One antennae will monitor the holding pool below the falls, another will be located in the middle of the set of falls, while the third will be established well above the falls in a location where there is no concern for fish falling back. This monitoring approach will be able to confirm successful fish passage over the falls and will also identify events where there have been unsuccessful attempts. These data, when coupled to extrapolated hydrological data for the site, may help establish hydrological conditions suited to passage and may identify further modifications that may need to be undertaken.

2.4: Northeast Placentia River Spawning Gravel Addition

In many rivers in Newfoundland, owing largely to regional geomorphology and stream gradient, spawning locations and suitable spawning substrates are considered potentially limiting to fish production. Several projects have proposed the addition of spawning gravels to address this limitation and this approach is considered cost effective and potentially highly beneficial. Projects conducted in the 1980's met with limited success owing to poor location of additions and failure to consider the hydrological power of candidate streams. A recent project on Northeast Placentia River has proposed a similar approach and was the subject of a detailed evaluation. Considerable effort has been expended to assist the project sponsor in sizing and utilizing suitable substrate material, in properly siting the gravel additions, introducing instream structures to promote stability, and in evaluating the success of the initiative.

A habitat survey was conducted on Northeast Placentia River during 1994 under the auspices of CASEC (Nicks 1994). This survey identified limited spawning habitat within the river system and all confirmed spawning activity was isolated to a 250 m area in the upper section of the river. The paucity of spawning habitat was not natural as historical redd surveys, conducted prior to road construction which bisected the river in the late 1960's, indicated several other spawning areas (Porter et al. 1974). It was speculated that highway construction had altered the river's hydrology leading to excessive erosion and loss of natural spawning substrates. It was determined that the preferred approach to increasing the productive capacity of this river was to provide alternate (additional) spawning areas for Atlantic salmon.

The habitat survey (Nicks 1994) identified possible locations for gravel addition and candidate sites were then surveyed for water depth and velocity to ensure they met criteria for preferred Atlantic salmon spawning habitat (e.g. Jones 1959, Pratt 1968, Beland et al. 1982). Subsequently, three sites met these criteria. Rounded beach gravel was then sifted, cleaned, and sorted to size and proportion specifications (Porter 1975, Peterson 1978) as substrate material for addition to these sites. Gravels were subsequently transported to the pre-selected sites and manually added to the stream in 1995 (Figure 12). Boulders and rock groins were added at two sites to stabilize gravel additions.

Size distributions of juvenile salmonids were determined by semi-quantitative electrofishing (Scruton and Gibson 1995) of various sections of the river prior to addition of spawning gravel. These sites were resurveyed in 1996 one year after gravel additions and will be monitored in subsequent years. A total of six electrofishing sites were established; three in the proximity of spawning gravel additions, two where historically no spawning had occurred and no additions were planned and one in a known natural spawning location. Each site (30 m in length) was fished completely (one sweep) with a backpack electrofisher keeping the fishing time consistent between stations. The success of the spawning gravel addition will be evaluated by (i) an annual electrofishing survey, (ii) redd counts to be conducted in November during the spawning period, and (iii) installation of emergence traps in the spring (May) where successful redds were observed in the previous fall.

The first phase of gravel additions was competed in the summer of 1995. The pre-project electrofishing survey revealed that 96% of the juvenile salmon found in the known spawning area were fry (young-of-the-year or 0+) as compared to 8-67% at the other five sites (Table 3). The number and proportion of fry increased in all stations during 1996 (Table 3). These increases were most pronounced in the gravel addition sites with the exception of site 5 which also was observed to have a large increase in fry (Table 3). This increase in one of the control sites may be due to migration from upstream or adjacent stations which were observed to have large increases in density in 1996 as compared to 1995. These trends will become clearer in subsequent years. More direct assessment of spawning success (using emergence traps) was attempted in the spring of 1996 however, owing to unusual incubation conditions emergence was missed. This technique will be repeated in subsequent years.

Seven redds were observed in the newly added gravel in November 1995 confirming the newly placed gravel was selected for and used by spawning salmon. These seven redds constituted 4% of the total redds counted during the survey. In November 1996 a total of 39 redds were observed in the new gravel for 23% of the total. The most successful addition site was located approximately 500 m above the main spawning area (station 6). This site had 4 redds in 1995 and 23 redds in 1996, it also had the highest success of gravel retention, >90% as compared to approximately 50% in the other sites. This difference in gravel retention was most likely due to a large meandering steady which reduces the hydrological power of the river at this location immediately above station 6. This observation highlights the need for an understanding of hydrological processes when developing this type of project.

While the evaluation of this project is ongoing, initial results have been very encouraging, so much so that a similar project and evaluation study has been initiated in partnership with Newfoundland and Labrador Hydro as part of a habitat compensation agreement. This type of small stream improvement technique is cost effective and has considerable potential to increase habitat productive capacity of a river altered through development.

2.5 Experimental Research: Noel Paul Brook Experimental Channel

An experimental research program was developed to compliment the scientific evaluation of selected improvement and restoration initiatives. The main focus of this research agenda was to address the transferability of techniques developed in other jurisdictions for use with endemic species (primarily Atlantic salmon and brook trout) in Newfoundland. Historically, habitat improvement initiatives in Newfoundland and Labrador have necessarily relied on design and implementation criteria developed in other regions (e.g. the American Mid-west and the Pacific Northwest) and for other species (primarily trout and Pacific salmonids). Owing to this limited regional experience, this research was undertaken to assist in developing region-specific criteria to guide publicly sponsored habitat initiatives. An understanding of habitat selection by juvenile salmonids in Newfoundland in association with various habitat improvement strategies and structures was considered a necessary component of a comprehensive regional habitat improvement/restoration strategy.

A research study was initiated in 1990 at the Noel Paul Brook incubation facility on the Exploits River, central Newfoundland (Bourgeois et al. 1993). An abandoned controlled flow spawning channel was modified to create physical habitat simulating a small stream. Habitat improvement structures were then introduced into this artificial stream according to an experimental design which was based on the known preferences of juvenile Atlantic salmon and brook trout; the dominant species in Newfoundland streams. The choice of structures for evaluation considered that young salmon tended to occupy faster flowing waters in the center of the stream in association with coarse substrates while trout tended to occupy the stream margins and pool habitats characterized by slower, deeper water, and riparian cover (Gibson 1993, Gibson et al. 1993). The experimental stream was divided into six replicates; each of which contained three randomly arranged habitat improvement 'treatments' including: i) control (no structures were added), (ii) a mid-channel treatment consisting of a low head barrier and associated plunge pool and five large boulders, and (iii) a stream bank treatment consisting of paired wing deflectors on opposite banks and artificial undercut structures embedded into each bank (Figure 13). In 1990 and then again in 1991, a total of nine 5-day experiments were conducted to examine preferences for selected habitat improvement structures (treatments) under conditions of different species composition (Atlantic salmon and brook trout) and density. In each experiment, fish were introduced into each replicate, allowed to volitionally distribute between treatments for 5 days, and were subsequently removed from each treatment by electrofishing. All stream side vegetation was removed to eliminate bias associated with riparian cover (this is a variable to be included in future study).

Results indicated that there was no difference in preference of trout and salmon for the two treatments tested. Both species preferred the mid-channel treatment over the bank treatment over the control whether in conditions of allopathy or sympathy. Increasing density displaced both species equally into the less preferred treatments. It was apparent under the experimental conditions that the habitat features associated with the stream bank treatment were not preferentially used by either species. Microhabitat conditions (depth, velocity and cover) on the stream margins created by addition of these structures may have been unsuitable or the removal of streambank vegetation may have reduced the quality of stream bank aquatic habitat.

A second series of experiments was conducted in the stream channel in 1994 and 1995 (Mitchell 1996, Mitchell et al. 1996). The focus of this research was to investigate the distributional patterns and microhabitat selection of juvenile Atlantic salmon in the experimental stream. Daytime bank observations and night counting were used to characterize selection for microhabitat attributes associated with the habitat improvement structures. The influence of fish size class, density, stream discharge, and diurnal/nocturnal differences were also evaluated.

Results suggested that under natural densities, young salmon preferred the stream bank treatment while at higher densities (1.5 X natural), fish were displaced into the less preferred treatments. In all experiments, greater depth was selected by fish in the stream bank treatment as compared to the mid-channel treatment. Habitat selection in the mid-channel treatment was primarily associated with cover attributes. Larger parr (age 1+ through 3+) preferred greater depths and were found in closer proximity to the treatment structures than were salmon fry (age 0+). At increasing discharge, fish selected higher bottom and focal water velocities. The primary diurnal/nocturnal difference in habitat selection was in relation to substrate with coarser substrates being selected during the day.

Observations from these experiments at Noel Paul Brook highlighted the importance of hydrologic conditions to the success of instream structures. The mid-channel treatment did not supply any benefit to salmonids under low velocity conditions but was the most preferred area when the velocity was increased. This suggests that these structures may not provide the needed cover and microhabitat areas required by salmonids during limiting low water periods such as those experienced in mid-summer and winter. These structures did however supply microhabitat refugia and cover, through turbulence, during increased velocity. This suggests that these structures would supply holding areas during high water events such as storms and spring runoff.

The stream bank treatment, specifically the wing deflectors, also did not produce the anticipated habitat features in these experiments. There was limited increased velocity and scouring around the wing deflector and instead of being selected for in high velocities, as hypothesized, this area was avoided due to the lack of protection from the current. This failure of the wing deflectors to provide the desired microhabitats was attributed to the lack of range in discharge owing to controlled flows that occurred in the experimental channel (Bourgeois et al. 1993, Mitchell 1996). The wing deflectors did however provide cover during low flow experiments (Mitchell 1996) and were preferred slightly by salmonids during these times. This observation indicates that although the wing deflectors did not work as hypothesized they supplied supplemental cover during low flow periods, that may have been as important to the salmonids as was their intended function.

Another observation of note during the 1994 and 1995 experiments (Mitchell 1996) was the role coarse substrate played as cover to the salmonids. It was noted earlier that salmonids preferred areas of coarser substrate during daytime observations as compared to night. This was attributed to use of substrate for the avoidance of visual predators. It was also noted that salmonids took refuge in the substrate during periods of high flow and when the temperature fell below 10 ^{0}C. These observations are important when considering structures that may alter the natural substrate composition in a stream and may provide a benefit under stressful conditions.

3.0 Conclusions

The habitat improvement and restoration projects that underwent scientific evaluation during NIFDA and CASEC were, for the most part, successful in increasing salmonid productive capacity. The most successful project was, not surprisingly, the initiative that addressed the most severe perturbation, that is the restoration of a dewatered reach of a natural stream bed (e.g. Pamehac

Brook). It was recognized at the outset of this project that there was considerable potential for increase in productive capacity associated with this undertaking and evaluation studies have confirmed this benefit. Other projects relied on smaller scale, site specific improvements, such as addition of instream structures, and these initiatives were also generally successful in the restoration and improvement of fish habitat. Benefits from these projects were however more subtle, biological response was more complicated, and there were some unexpected results (with respect to species and age/size class).

Several important physical and biological considerations were apparent throughout the course of the improvement and restoration projects which utilized instream modifications. These considerations, although not specific to Newfoundland, are important to the development of any future projects. The most prominent and possibly the most important physical considerations in habitat improvement and restoration is that of local hydrological and geomorphological conditions (Beak Consultants 1993). The failure of instream structures has most often been attributed to the failure to consider hydraulic principles and the need to consider long term stability under hydrological extremes (Hunt 1988). Often stream habitats most in need of rehabilitation (e.g. channelized reaches in urban watersheds) are least amenable to structural modification with stream enhancement technology (Frissell and Nawa 1992). Stream gradient may also be important in long term stability of instream structures with higher 'failure rates' associated with higher gradients and the concurrent high stream energies. As well, certain stream rehabilitation structures (e.g. log weirs and dams) have higher rates of failure than others (e.g. boulder additions) (Frissell and Nawa 1992). These experiences need to be considered when selecting appropriate techniques for use in certain circumstances.

Hydraulic factors have been considered in several of the technically complex projects in Newfoundland. However, the majority of projects under NIFDA and CASEC were undertaken by non-technical personnel and it is likely stream hydraulics were given limited consideration. Experiments conducted at Noel Paul Brook (Bourgeois et al. 1993, Mitchell 1996) have highlighted how hydraulic regimes can affect the functioning of instream structures and associated microhabitat conditions. For example, wing deflectors failed to provide the anticipated habitat characteristics during periods of high flow but did supply supplemental cover to fish during periods of low flow (Mitchell 1996). The mid-channel treatment did not supply any benefit to fish under low flow conditions but was the most preferred site during high flows. Both Bourgeois et al. (1993) and Mitchell (1996) cited the lack of natural hydrological variation in the controlled flow channel as a probable cause for these unexpected results. In some instances, streams selected for improvement structures may not be natural and channelization and/or control structures may often result in regulated or non-natural flows in the watershed. In these cases, detailed evaluation of candidate reaches would be warranted to determine if the altered hydrological regime is capable of achieving the desired results (e.g. pool scouring below a low head barrier). These results also suggest that although these structures did not always behave as anticipated they often supplied supplementary habitat features during limiting and stressful conditions (low and high flows). These results also highlight how microhabitat conditions, and associated benefits, can vary in relation to hydrology, seasonally, diurnally, and in relation to biological requirements (e.g. substrate sheltering for predator avoidance).

The other project that highlighted the importance of hydrologic considerations was the spawning gravel additions in Northeast Placentia River. One of the major limitations of this type of project is the potential loss of gravel from where it was placed during high water events. In the Northeast Placentia River, gravel loss was reduced by using natural hydrologic controls that exist in the river, specifically placing gravels below a large meander where stream energy is effectively dissipated. Instream structures (groins) were also used to prevent gravel erosion in the lower reaches but these were less successful than utilizing the natural river features. In addition to gravel retention, other hydrological conditions are necessary for successful reproduction including creating up welling (or down welling) conditions or ensuring substrates are cleansed of silt on a regular basis. These conditions are also related to proper siting. These considerations suggest that hydrologic surveys, and/or advice from a hydrologist would be important in projects that utilize spawning gravel additions.

Biological considerations are also important to the success of habitat restoration and improvement projects. These considerations include a knowledge of the target species, an understanding of the limiting habitat factors, microhabitat preferences of species in their natural habitats, intra- and inter-specific interactions, seasonal and life-stage specific habitat requirements, availability of food, and others. The design of habitat features in restoration and improvement projects must be based on the known habitat preferences of target species/age groups and methods that develop these features (Sedell and Beschta 1991). Biological considerations have been important in the planning and design of restoration, improvement, and compensation projects undertaken in Newfoundland and objectives specific to certain species and/or age groups have been set. Evaluation studies and experimental research have also been valuable in the provision of region-specific biological criteria for application to future projects.

Despite the consideration given to biological factors during the projects conducted in Newfoundland there were some unexpected results. These were most prominent in the Joe Farrell's Brook project. Several of the instream structures were intended to improve brook trout habitat however were unsuccessful in increasing brook trout density although they did create the desired habitat conditions. Juvenile Atlantic salmon (0+, 1+) however did respond positively to the addition of half-log and V-dams. It appears that the structures may not have provided adequate cover for brook trout (van Zyll de Jong 1995) and thus were not utilized by that species. Other microhabitat conditions either inherent to these sites or created by the structures may have made the sites more suitable to Atlantic salmon. Although the structures did not have the desired effect for the target species/age group in Joe Farrell's Brook they did supply benefits to co-habiting species. These benefits may have been just as important to the overall productive capacity of the river as the expected results would have been. These observations highlight the need for monitoring of large restoration and improvement projects to ensure the desired results are met and to expand our knowledge when they are not.

4.0 Recommendations

Restoration initiatives can provide benefits beyond target species/age classes, consequently evaluation of response to habitat manipulations need to consider the entire biological community (Everest et al. 1991). Many habitat projects, while well intentioned, lack the solid biological basis for planning and implementation and often few allowances are made to allow for biological evaluation (Hunt 1988). In some instances, it is difficult to ascertain wether the initiative has resulted in increased production at the site or reach or whether fish have simply relocated to the rehabilitated reach with subsequent reductions in populations at other locations. Other confounding factors can affect interpretation of evaluation studies. For example, anadromous salmonids experience natural population fluctuations unrelated to freshwater habitat conditions (e.g. sea survival rates of smolts) that can influence assessment of restoration initiatives. Consequently, there is a need for attention to experimental design when undertaking evaluation studies (Walters et al. 1989).

In Newfoundland, and other northern locales, critical periods for resident salmonids in small streams are the low flow periods in the warm part of the summer and overwintering periods. Consequently, strategies that provide habitat refugia during these limiting periods as well as during ecological extremes (e.g. droughts and floods) will be particularly beneficial (Thorpe 1994). Techniques intended to increase quantity (e.g. pool volume) and quality (e.g. substrate stability) of habitat during winter conditions may ultimately be more beneficial than those that provide microhabitat conditions during summer months (Power et al. 1993, Cunjak 1996). Additionally, habitat improvement methods that can increase summer growth and condition may improve overwintering success (i.e. survival). Unfortunately, most evaluation studies have been limited to assessments conducted during the summer period with interpretations of overwintering benefits limited to comparisons of inter-annual survival.

A major consideration in evaluation of habitat restoration projects is the time frame required for habitat features to stabilize and it may take additional time for fish populations to respond to these conditions (Reeves et al. 1991). Evaluation and monitoring of habitat projects must consider this temporal aspect and design assessments accordingly (Everest et al. 1991). Project sponsors must also plan for long term assessment and monitoring of projects and should develop contingencies for future modification and remedial work to maintain installations. Too often projects are undertaken with minimal short or long term follow-up as to effectiveness and/or structural stability. In Newfoundland, selected projects will be subject to long term monitoring and assessment, in part to address temporal aspects of biological response, but also to investigate stability of structures and rehabilitated habitats over a range of hydrological conditions.

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Table 1: A comparison of habitat quantities and attributes for Pamehac Brook as surveyed in 1990 (pre-restoration), 1992 and 1996 (after restorartion).

Measurement	1990 (Pre-Restoration)			After Restoration	
	Above Diversion	Below Diversion	Total	1992	1996
Total Stream Length (km)	1.99	4.52	6.51	7.90	9.00
Total Habitat Area (units)*	175	547	723	1172.3	938.3
Mean Wetted Width (m)	8.9	9.0	9.5	13.7	10.3
Mean Depth (cm)	29.1	15.4	18.7	26.0	27.4
Habitat Area by Type (Units)*					
Riffle	18.1	519.2	637.3	942.0	437.8
Pool	0.0	2.2	2.2	2.3	45.6
Steady	29.2	6.0	35.0	87.6	183.5
Run	14.9	0.0	14.9	29.9	183.3
Rapids/Other	6.1	19.7	25.8	110.5	88.0
Substrate Composition (%)					
Large Boulder	9.7	2.1	3.9	6.6	9.8
Small Boulder	13.1	15.6	15.0	24.1	21.4
Rubble	37.2	42.9	41.5	26.9	31.5
Cobble	21.7	27.8	26.3	21.1	10.4
Gravel	18.3	8.6	10.9	2.1	9.0
Bedrock	-	3.0	2.3	8.0	0.4
Mud/Organic	-	-	-	-	17.5

* 1 Unit = 100 m^2

Table 2: Changes in habitat parameters from 1993 (before additions) to 1996 (3 years after) in the study sites of Joe Farrell's Brook

Treatment	year	Surface Area (m2)	Velocity (m s-1)	Wetted Width (m)	Max Depth (cm)	Mean Depth (cm)	Substrate Category (%)*									Surface Character (%)		
							1	2	3	4	5	6	7	8	9	Pool	Riffle	Glide
Boulder (1)	1993	464	0.46	11.6	45	27	0	11.1	21	37.6	21.1	5.2	2	1	1	10	85	5
Boulder (1)	1996	468	0.44	11.7	53	14.3	0	24.5	14	29.5	16.5	1.5	1	8	5	20	80	0
Downstream	1993	324	0.42	8.1	72	34	0	11.1	21	37.6	21.1	5.2	2	1	1	25	60	15
Downstream	1996	308	0.37	7.7	29	8.9	0	15.5	24	38.5	19.5	2.5	0	0	0	25	70	5
Boulder (2)	1993	360	0.37	9	49	26	0	1	2.3	8.5	18.9	45.9	23	0.7	0	15	80	5
Boulder (2)	1996	379	0.44	9.5	30	10.8	0	9	12	36	26	10	1.5	5.5	0	27	73	0
Downstream	1993	404	0.38	10.1	54	22	0	11.4	18.3	28.6	25.9	11.2	4	0.5	0	0	100	0
Downstream	1996	384	0.37	9.6	31	11.5	0	22	13.5	37	21.5	6	0	0	0	0	100	0
V-Dam (1)	1993	384	0.36	9.6	62	22	0	18.7	25.1	21.8	22.8	9.6	1.7	0.3	0	23	77	0
V-Dam (1)	1996	380	0.33	9.5	48	18.6	3	18.5	24	32.5	13.5	3	1.5	4	0	50	50	0
Downstream	1993	348	0.28	8.7	56	23	0	18.7	23.4	26.2	20	8.9	2	0.9	0	18	76	4
Downstream	1996	320	0.35	8.0	55	18.2	0.5	21	31.5	40.5	6	0.5	0	0	0	10	76	4
V-Dam (2)	1993	388	0.31	9.4	61	28	0	11.3	21	20.7	29.7	9	5.7	2.7	0	30	70	0
V-Dam (2)	1996	371	0.26	9.3	51	16.6	0	7	12	24.5	36	10.5	5	5	0	60	40	0
Downstream	1993	320	0.42	8	54	24	0	9.5	21.7	22.8	30.4	13	2.6	0	0	15	85	0
Downstream	1996	340	0.17	8.5	63	26.5	3.5	13	10.5	35	27	10	1	0	0	15	60	5
Half log	1993	349	0.22	8.9	68	26	0	0.8	5.2	8.3	46.3	21.9	14	3.5	0	5	20	75
Half log	1996	352	0.23	8.8	40	21.9	1	7	9	28	14.5	11.5	11	18	0	15	25	60
Downstream	1993	332	0.18	8.3	59	27	0	5.8	7.8	11.7	32.3	16.3	10	16	0	15	85	0
Downstream	1996	344	0.21	8.6	46	21.5	0	13	8	10	26	23	19	1	0	15	65	0
Sub-basin Control	1993	488	0.23	12.2	46	27	2	11	13.5	13.2	27	16.7	8.3	8.3	0	10	50	40
Sub-basin Control	1996	491	0.27	12.3	44	20.7	2.5	23.5	18	20.5	17.5	14.5	2.5	0	0	10	50	40

* Key for the substrate categories 1 = Large Boulder, 2 = Small Boulder, 3 = Rubble, 4 = Cobble, 5 = Pebble, 6 = Gravel, 7 = Sand, 8 = Silt, 9 = Bedrock.

Table 3: Number of salmon fry (0+) and their percentage of the population (%) caught by semi-quantitative electrofishing in the Northeast Placentia River.

Year	Station 1 (Gravel Addition)	Station 2 (Control)	Station 3 (Gravel Addition)	Station 4 (Spawning)	Station 5 (Control)	Station 6 (Gravel Addition)
1995	8(40)	5(42)	5(8)	23(96)	2(29)	2(15)
1996	51(82)	7(50)	48(62)	70(93)	101(95)	118(89)

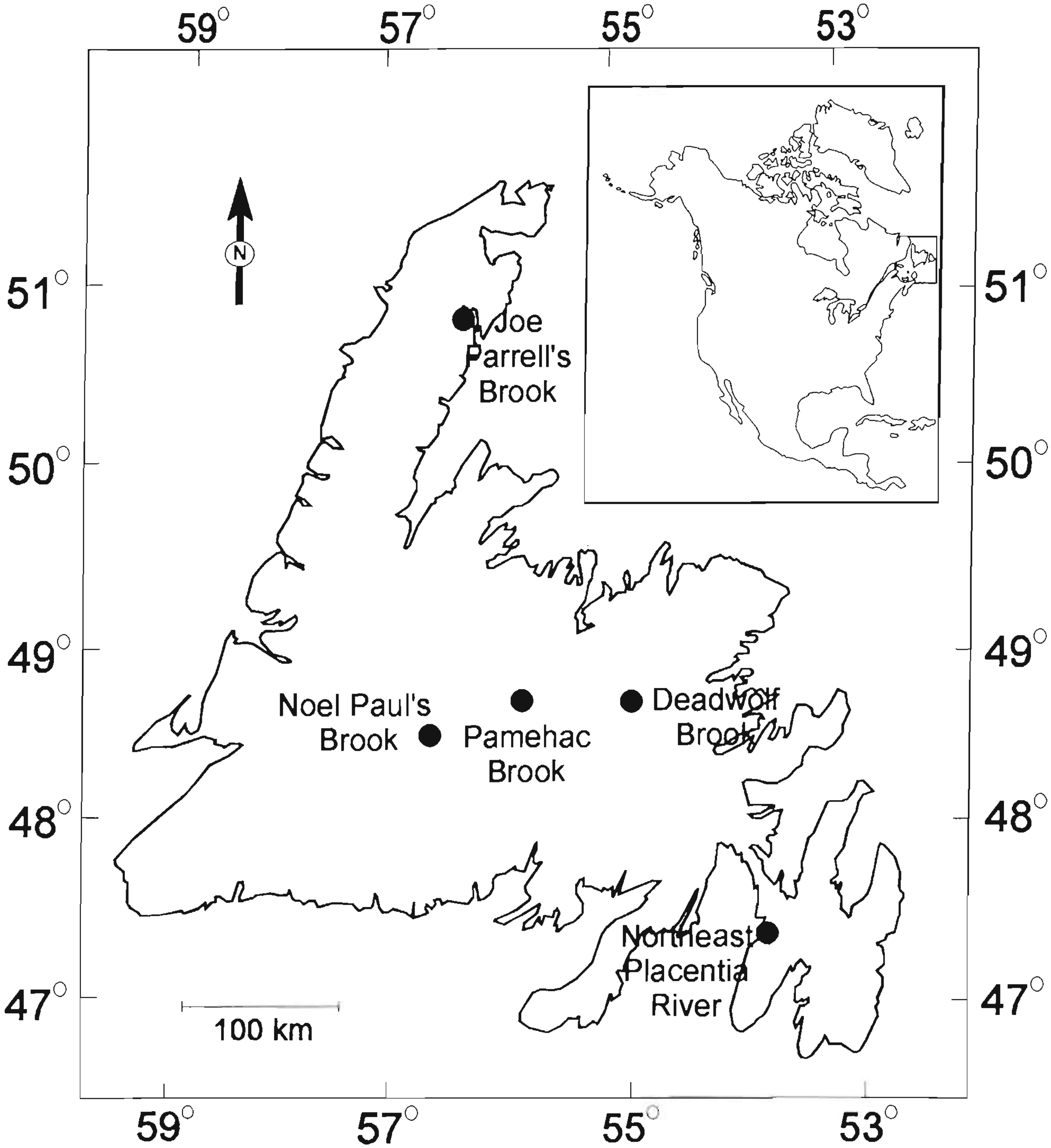

Figure 1: The island of Newfoundland with the location of habitat projects highlighted.

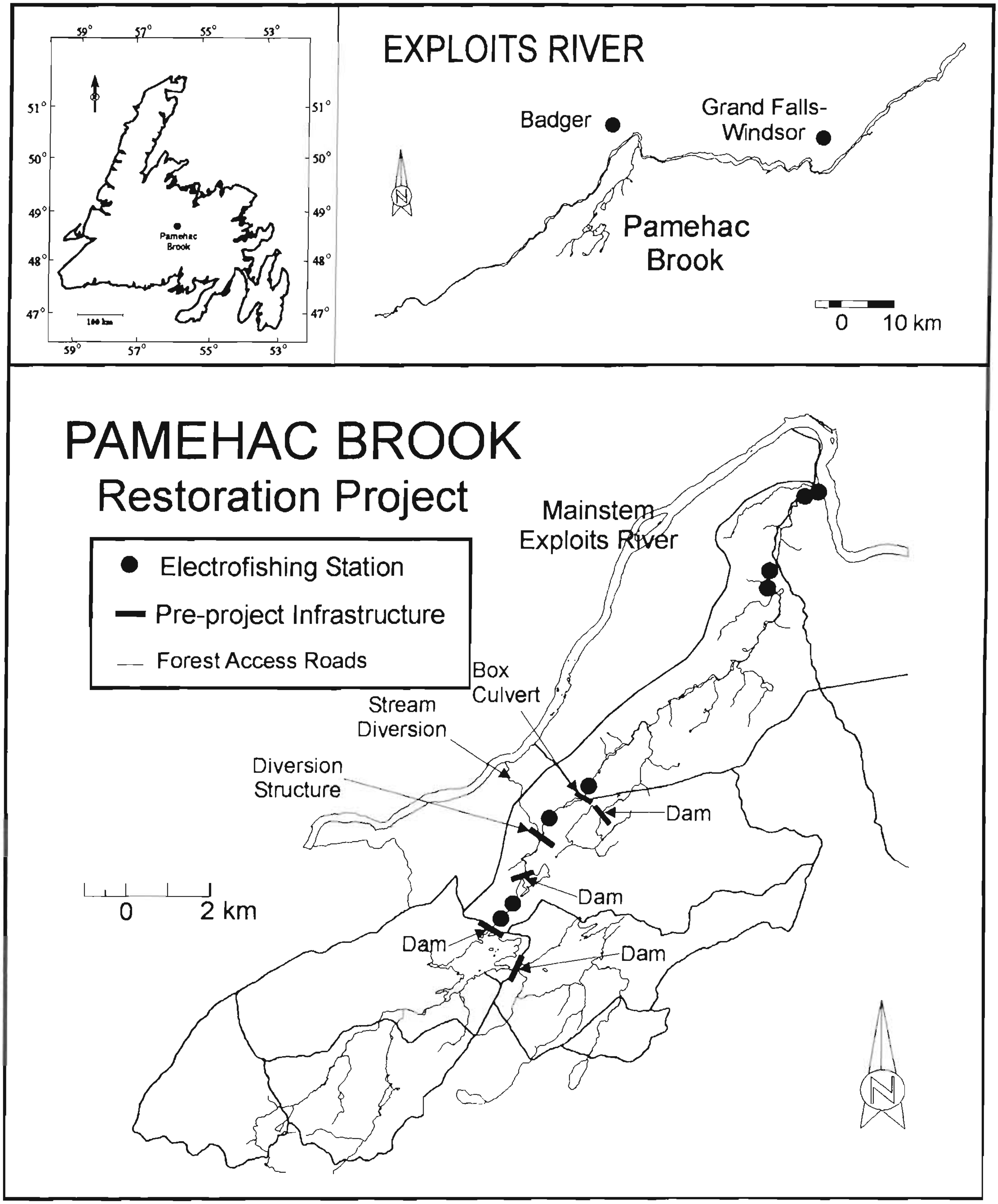

Figure 2: Pamehac Brook, Exploits River, with electrofishing sites and pre-project infrastructure.

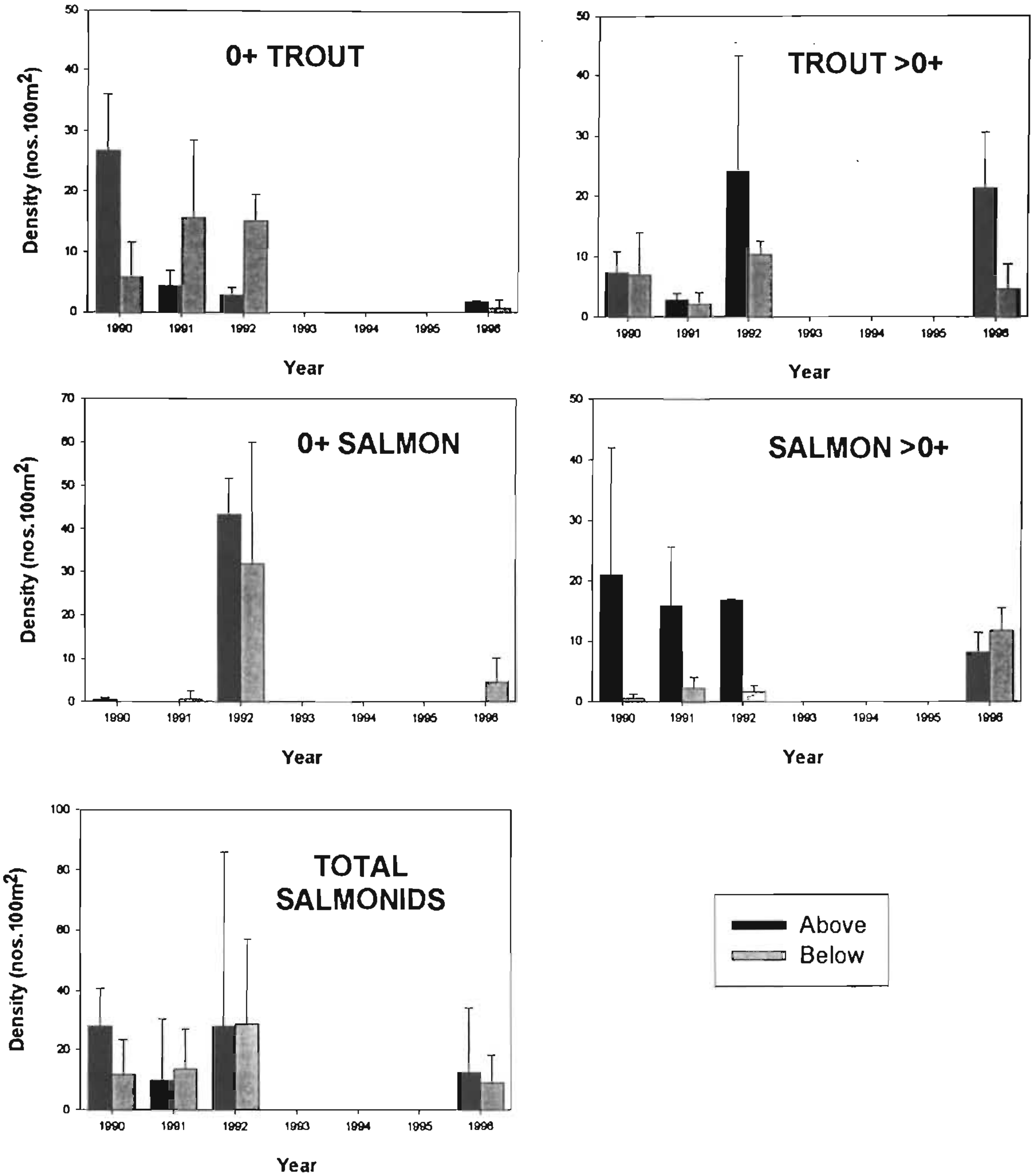

Figure 3: Salmonid densities before and after the restoration of Pamehac Brook.

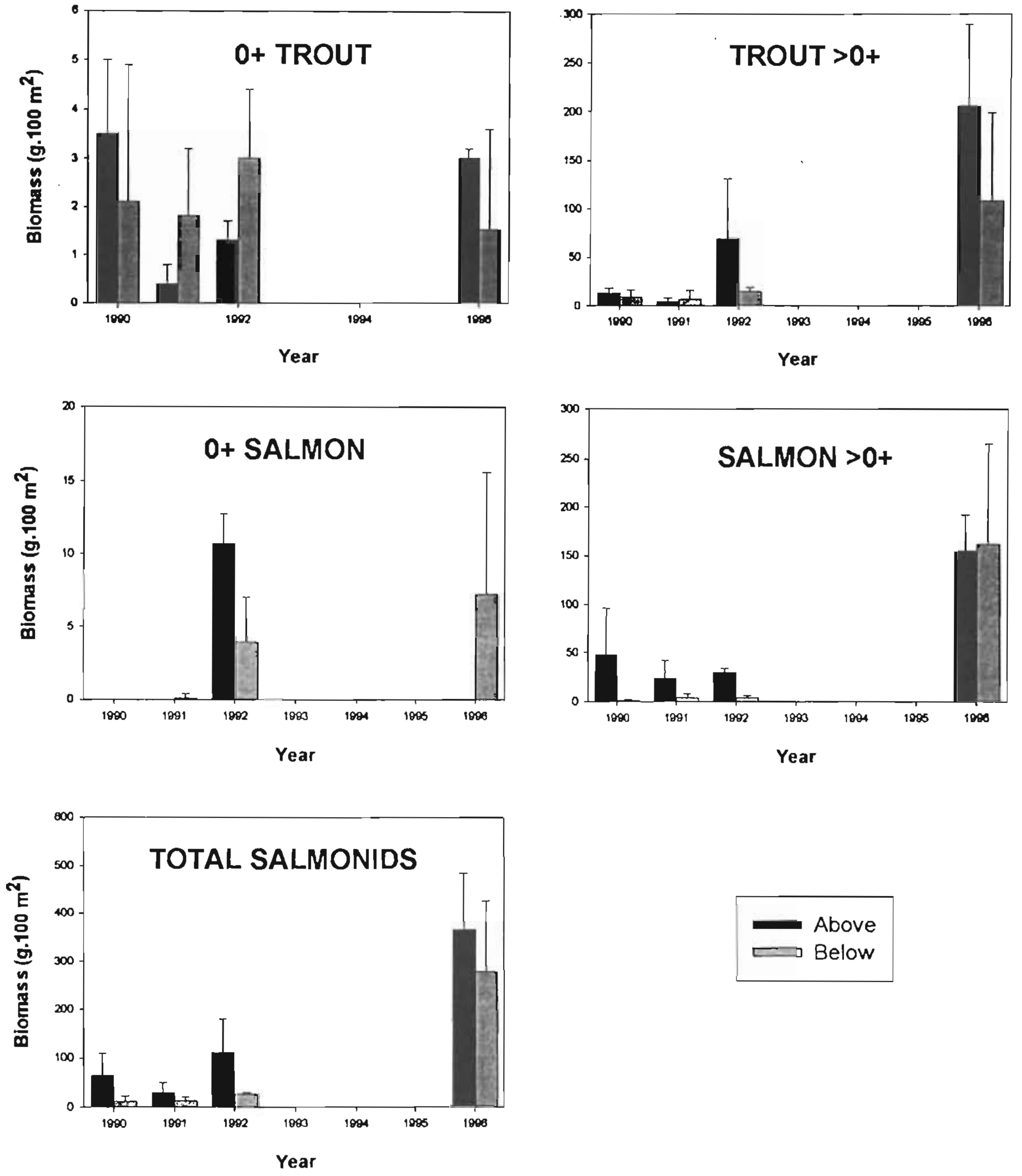

Figure 4: Salmonid biomass before and after the restoration of Pamehac Brook.

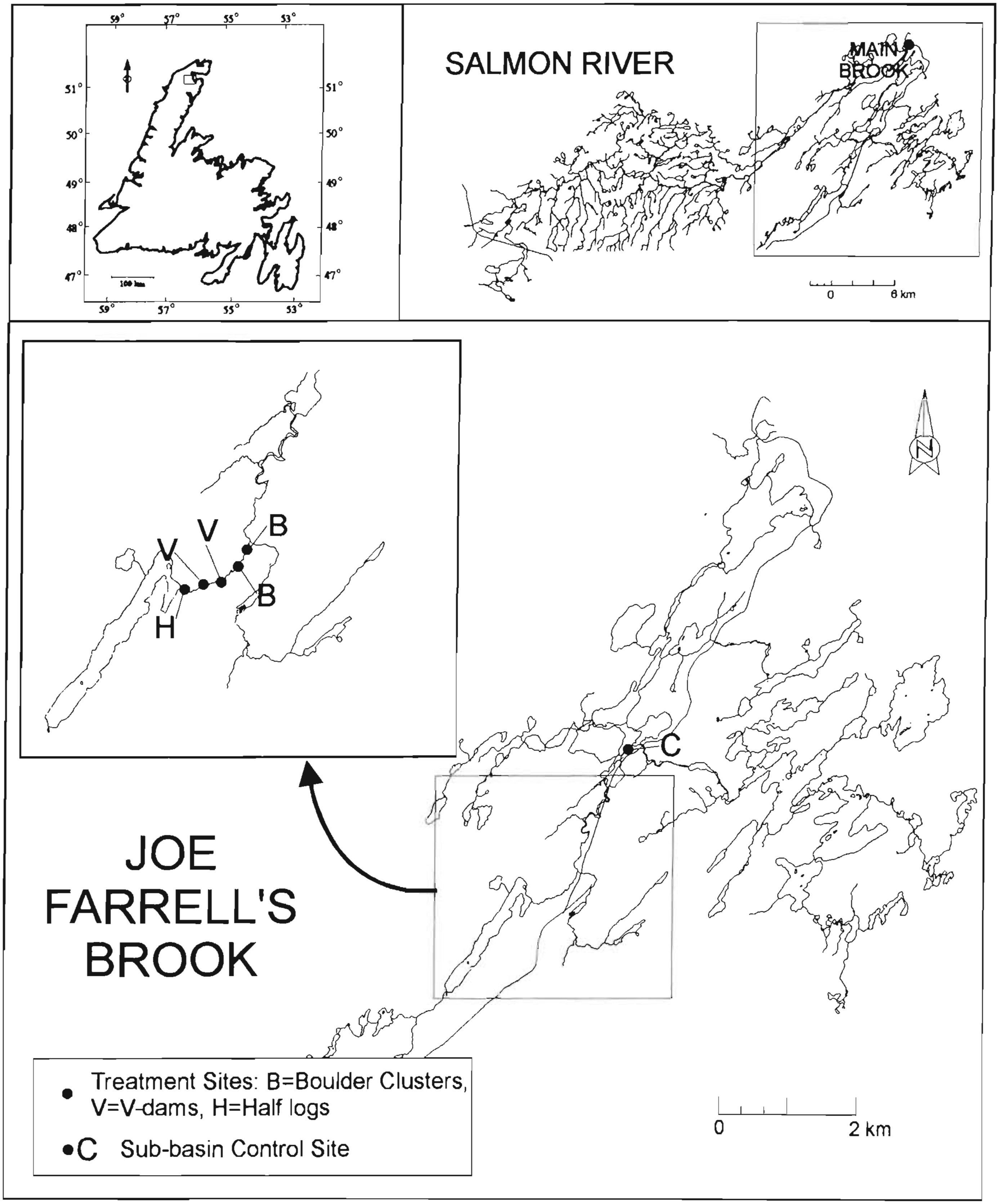

Figure 5: Joe Farrell's Brook, Salmon River, including habitat restoration sites.

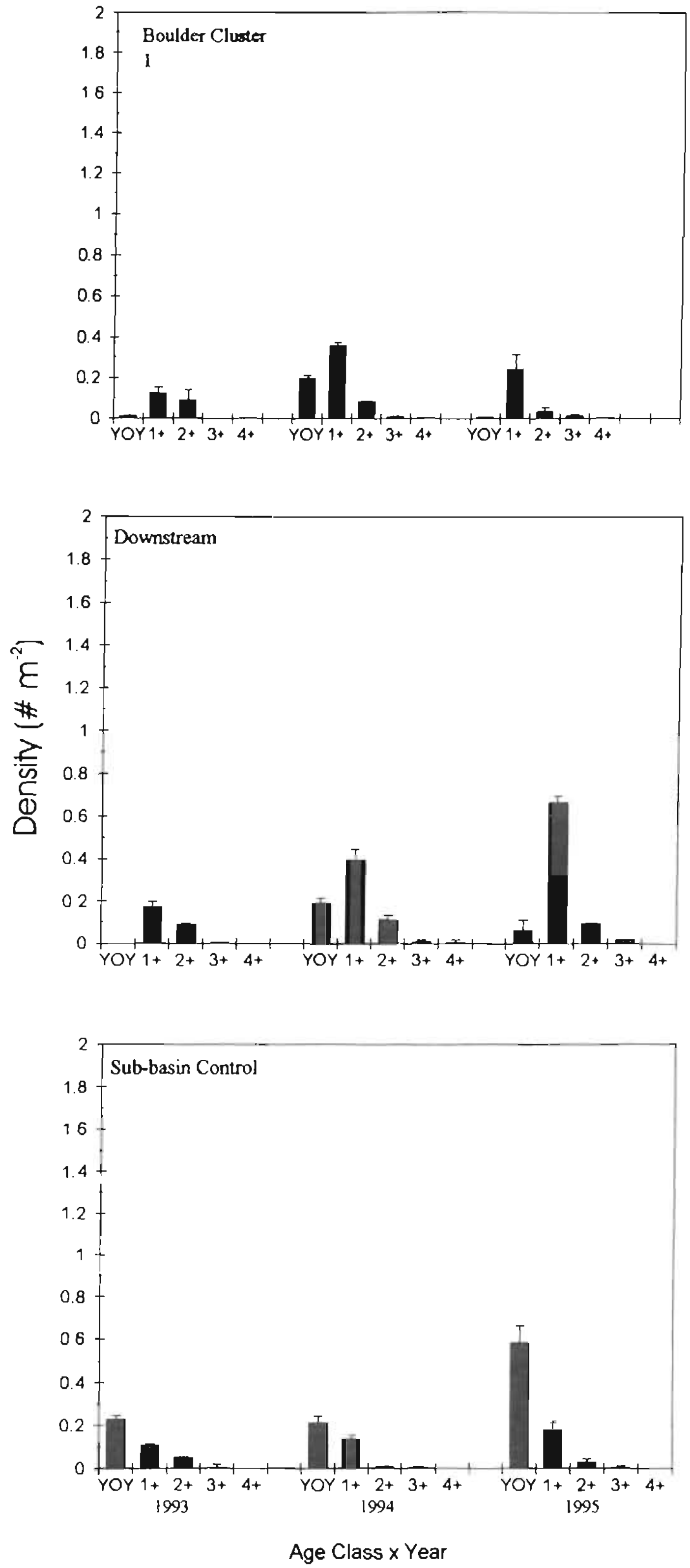

Figure 6: Year class densities of juvenile Atlantic salmon in Boulder site 1, its downstream site and the sub-basin control of Joe Farrell's Brook during the first three (1993-1995) years of the project.

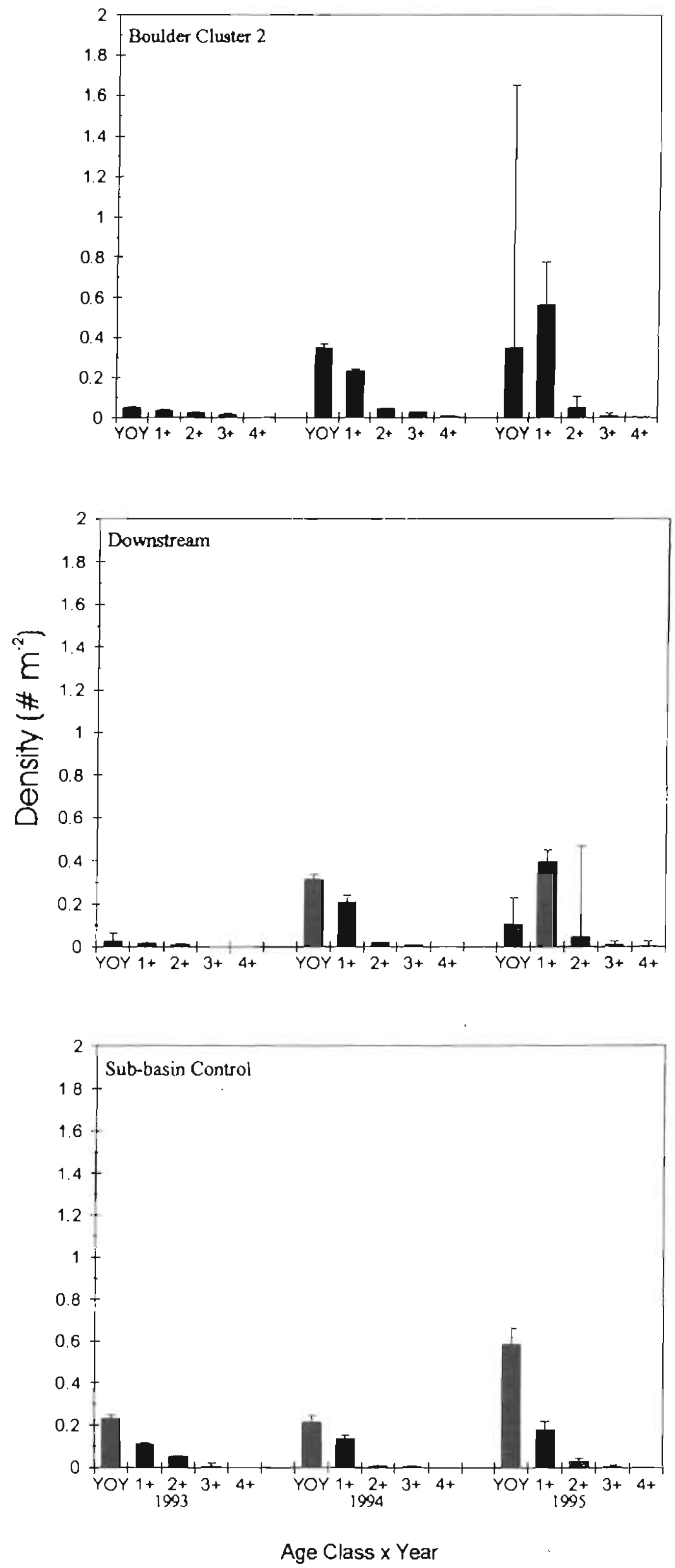

Figure 7: Year class densities of juvenile Atlantic salmon in Boulder site 2, its downstream site and the sub-basin control of Joe Farrell's Brook during the first three (1993-1995) years of the project.

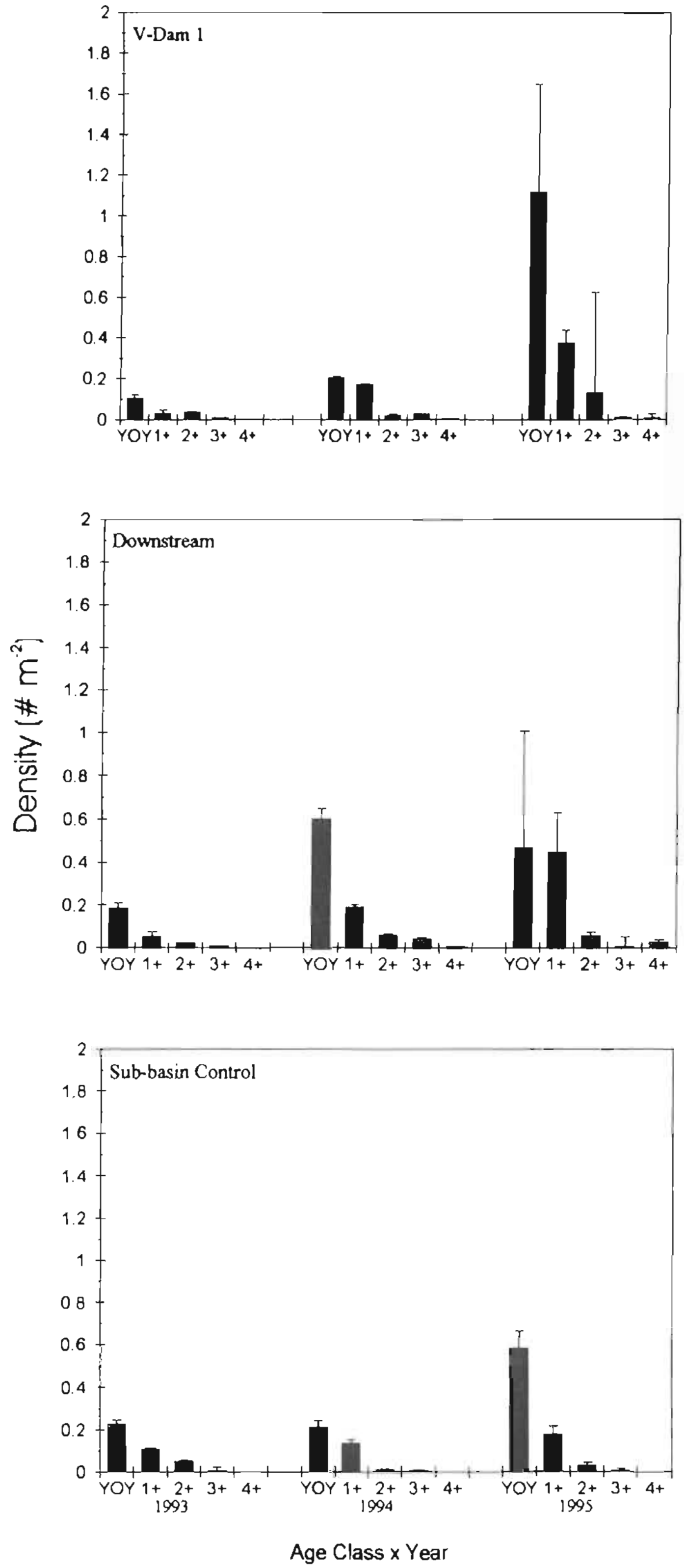

Figure 8: Year class densities of juvenile Atlantic salmon in V-dam site 1, its downstream site and the sub-basin control of Joe Farrell's Brook during the first three (1993-1995) years of the project.

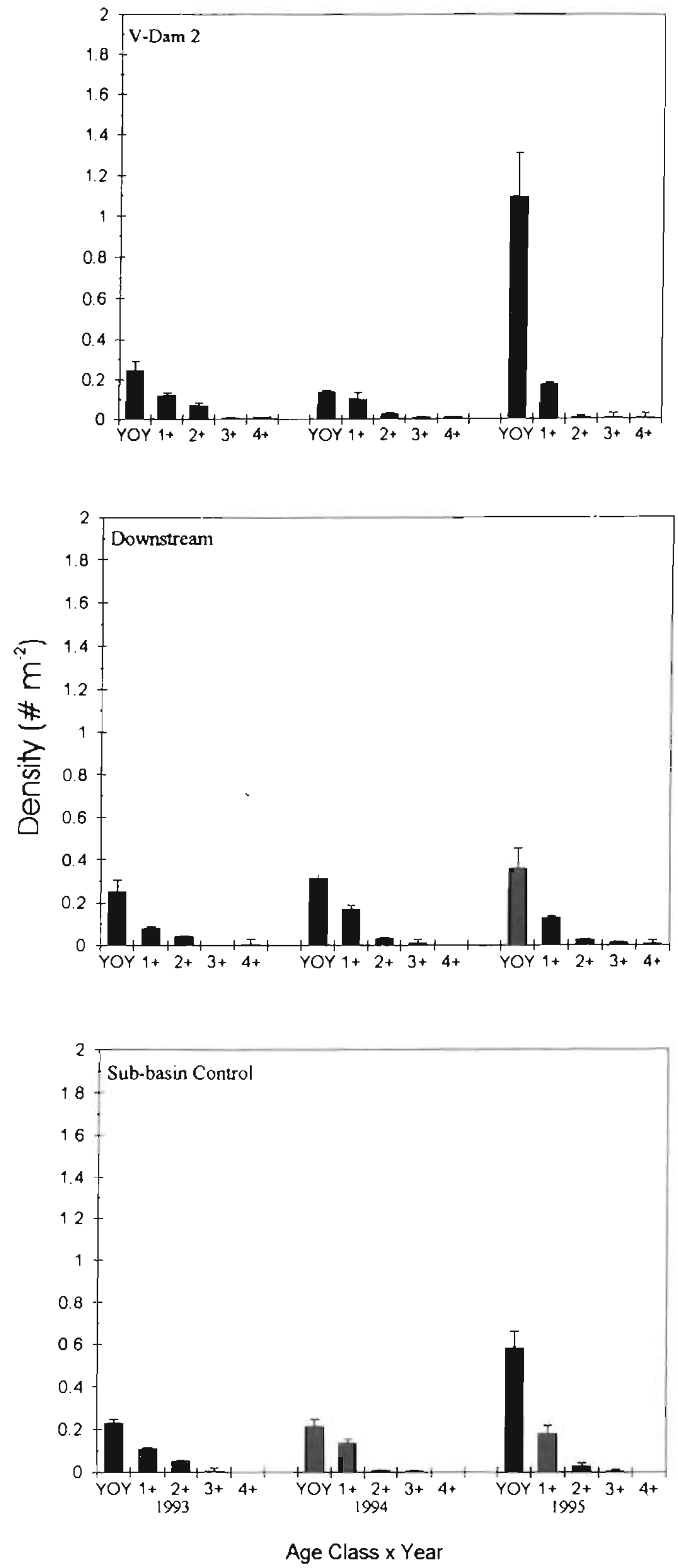

Figure 9: Year class densities of juvenile Atlantic salmon in V-dam site 2, its downstream site and the sub-basin control of Joe Farrell's Brook during the first three (1993-1995) years of the project.

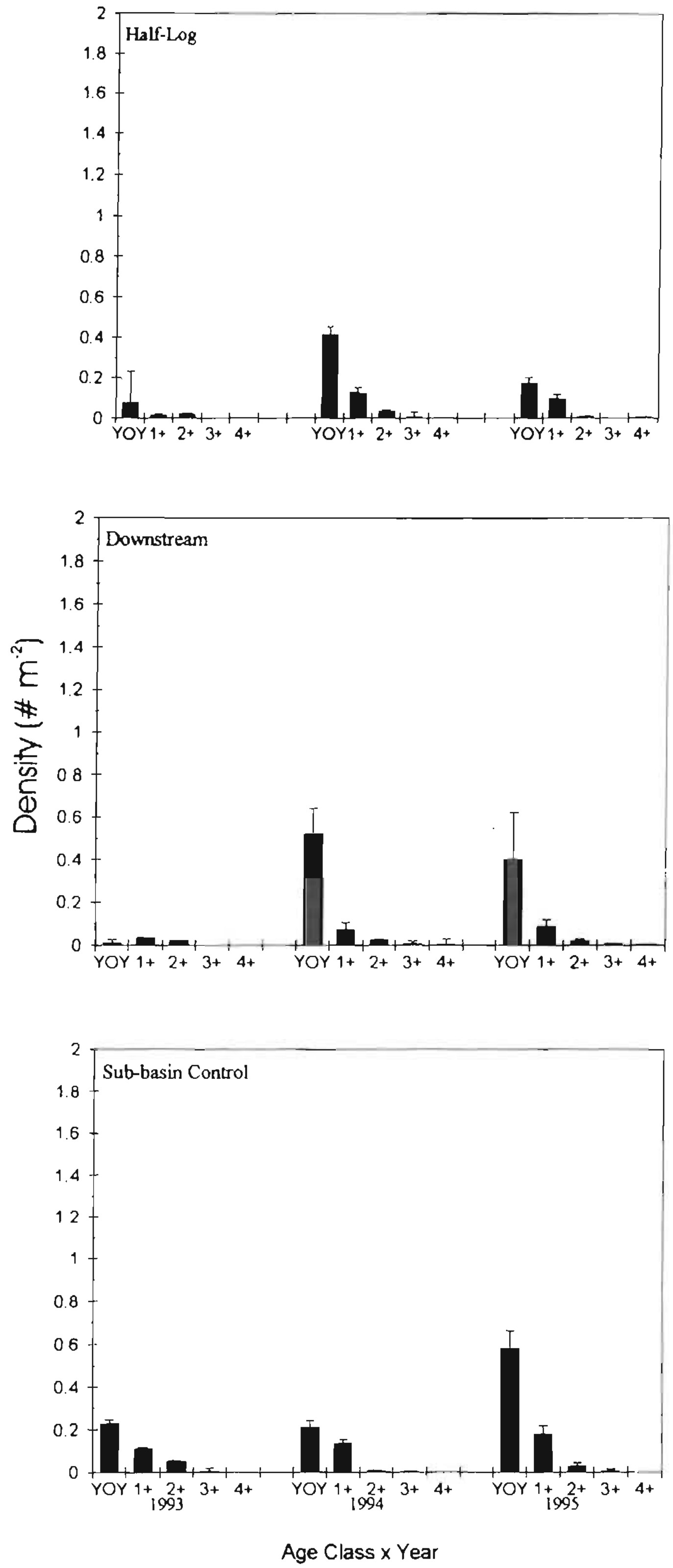

Figure 10: Year class densities of juvenile Atlantic salmon in half-log site, its downstream site and the sub-basin control of Joe Farrell's Brook during the first three (1993-1995) years of the project.

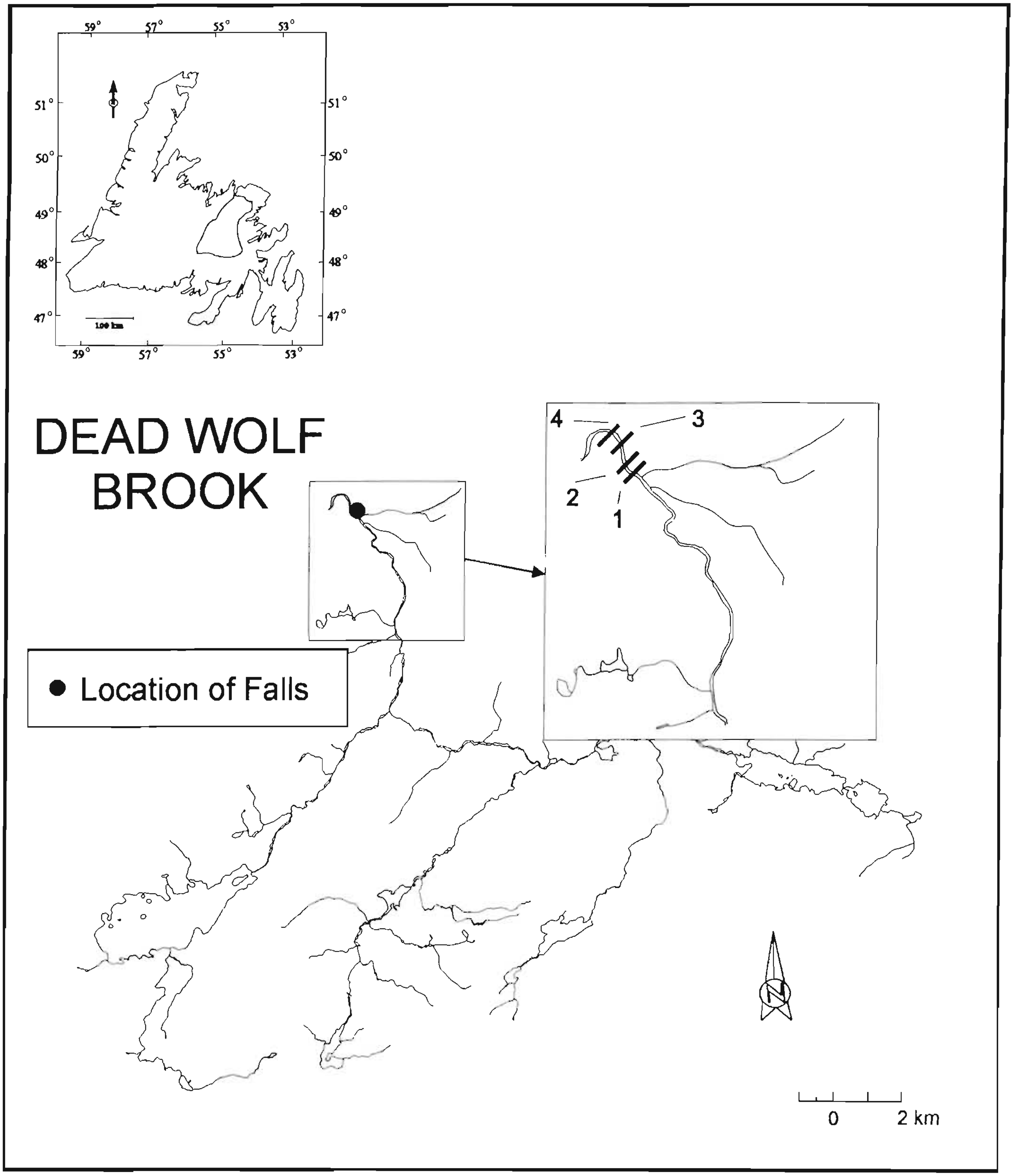

Figure 11: Dead Wolf Brook, including location of falls where remedial activities were conducted

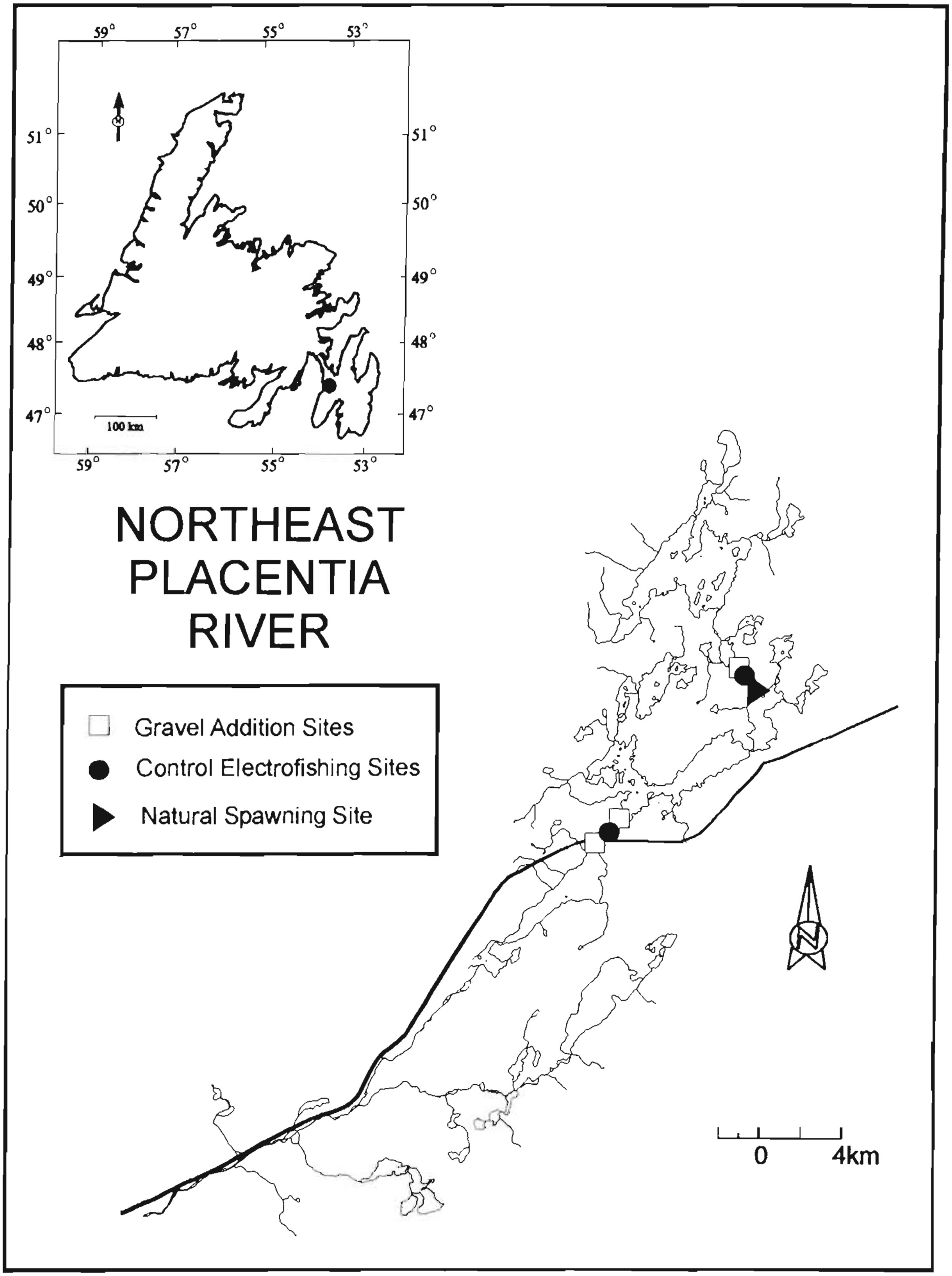

Figure 12: Northeast Placentia River including location of spawning gravel addition sites.

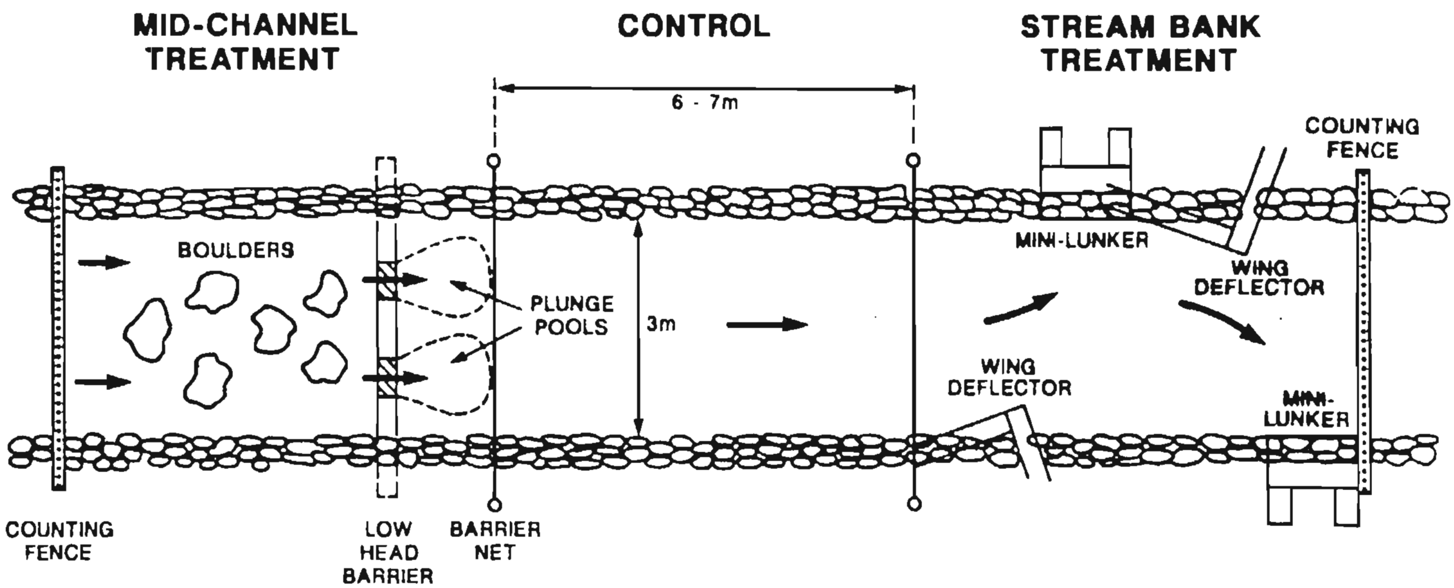

Figure 13: Schematic of habitat improvement "treatments" used in the experimental research conducted at Noel Paul Brook.