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A Decade of Salmonid Habitat Improvement and Restoration in Newfoundland, Canada: What Have We Learned?

by

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Abstract

There has been a large interest in the economic potential of the recreational salmonid fisheries in Newfoundland, Canada over the past 10 years. In light of this interest, there have been a number of government sponsored, public delivered, habitat improvement and restoration programmes undertaken in the Province. Programmes have included a 5-year (1988 to 1992) Newfoundland Inshore Fisheries Development Agreement (NIFDA), Small Stream Component which included 62 projects and expenditures of $1.0 million. This was followed by a second 5-year program, a Cooperation Agreement for Salmonid Enhancement and Conservation (CASEC), Habitat Improvement and Restoration Component, conducted from 1992 through 1997, involving 80 projects and $2.0 million. A number of other programs 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 have supported regional habitat restoration initiatives. Funding from these programmes has, in many instances, 'levered' considerable financial and human resources from other sources.

An important component of these programmes has included scientific evaluation of key projects to provide information on the effectiveness of techniques and approaches undertaken. This paper provides an overview of the various components of regional habitat improvement and restoration programmes highlighting representative initiatives that have undergone scientific evaluation. Projects are presented as case studies in relation to programme components including: (i) habitat inventory, (ii) planning and

delivery, (iii) projects restoring habitat degraded from historic forest harvesting practices, (iv) projects where migration barriers were removed to open new habitat, and (v) projects improving habitat through the use of instream structures. Results from experimental research to address transferability of techniques for application to regional biophysiography and fish fauna are also reviewed. A major project involving construction of artificial fluvial habitat as compensation for habitat destroyed by highway construction is also discussed. Case studies are selected to demonstrate the scope of projects undertaken and to identify successes and failures of the various initiatives.

Introduction

Habitat restoration and improvement is an essential component of any initiative directed at developing a sustainable basis for fishery resources as habitat forms the basis of all natural fish production systems. Freshwater fishery resources in Newfoundland are suffering from continual habitat degradation from anthropogenic sources (e.g. acidic deposition, global warming) and as a result of development pressures (e.g. forest harvesting, urbanization, mining, hydroelectric development, road construction, etc.). These influences 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 focused attention on maintaining and restoring salmonid habitat.

As a result of increased emphasis on fish habitat, a number of major habitat improvement and restoration programmes have been undertaken in Newfoundland and Labrador in the ensuing 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 first comprehensive programme announced to support publically delivered habitat improvement and restoration projects was the Newfoundland Inshore Fisheries Development Agreement (NIFDA), Small Stream Component which sponsored 62 projects and included expenditures of $1.0 million from 1988 to 1992. The main emphasis of NIFDA was on providing support funding (less than $25 K) for small projects involving (i) habitat restoration, (ii) salmonid enhancement, and (iii) public information and awareness. The overall goal of this programme was to increase stocks of Atlantic salmon (*Salmo salar*), brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*) and arctic charr (*Salvelinus alpinus*).

A second large programme was initiated in 1992 in response to major declines in commercial Atlantic salmon catches in Newfoundland waters during the mid to late 1980's. These reductions, coupled with pressure from recreational and environmental groups, prompted the closure of commercial salmon fishery in the waters of insular Newfoundland in 1991. The Government of Canada and the Province of Newfoundland responded by implementing a 5-year, 21 million dollar Cooperation Agreement for Salmonid Enhancement and Conservation (CASEC). The main objective of this agreement was to maximize sustainable economic benefits from the recreational fishery by improving and maintaining salmonid stocks. There were five sub-programs within CASEC including: (i) stock assessment, (ii) salmonid enhancement, (iii) cooperative enforcement, (iv) planning and industry development and (v) habitat restoration and improvement. The Habitat Restoration and Improvement Program of CASEC has had total funding of $2.0M and has supported 80 projects. The main objective of the program was to increase the size of salmon and trout stocks by restoring and developing the habitats that support salmonid fishes.

Early in these programmes it was agreed that there was a need to scientifically evaluate a proportion of these projects. Assessment and evaluation was required to transfer technology developed elsewhere for use with endemic species and local biophysical conditions, support development of region specific techniques and applications, verify the success and cost effectiveness of these initiatives, and provide the scientific basis for project planning to ensure a net gain in the productive capacity of habitats. Projects evaluated were selected from various programme components including: (i) habitat inventory, (ii) planning and delivery of regional programmes, (iii) projects that restored habitat degraded by historic forest harvesting practices, (iv) projects where migration barriers and/or major obstructions were removed to open new habitat, and (v) projects in small stream urban and rural locales that improved habitat through the use of instream structures.

Experimental research has also been conducted to compliment evaluation studies. Under controlled conditions, research studies have been undertaken to test the transferability of techniques developed in other jurisdictions for use with endemic species (primarily Atlantic salmon and brook trout) and regional biophysical conditions. This research and the results of evaluation studies have assisted in the development of region-specific criteria to guide publically sponsored habitat initiatives. Stream improvement techniques have long been used in habitat compensation projects where habitats that have been degraded or destroyed from human development. Habitat compensation projects are therefore an important component of regional habitat restoration programmes and are included in this review.

This paper reviews the major components of habitat improvement and restoration programmes conducted over the last decade in Newfoundland and Labrador with an emphasis on representative studies that have undergone evaluation (Fig. 1). These studies are discussed in the context of objectives met, habitat alteration and 'gains', and response of salmonids to the habitat manipulations.

Regional Habitat Improvement/Restoration Programme Components

Habitat Inventory

Comprehensive inventory data is integral to all aspects of a regional habitat improvement/restoration program allowing for assessment of fish production potential of watersheds, spawning escapement requirements, sensitive habitat areas for protection, identification of habitat improvement/enhancement opportunities, and to provide the basis for tracking change in habitat quantity and quality. Existing habitat inventory data needed to be updated, geo-referenced, amended to include standing waters, and refined to reflect sensitivities and parameters that are reflective of productive capacity (potential) of all habitats. This inventory was to provide the necessary infrastructure for cataloguing and priorization of habitat restoration and development opportunities.

DFO undertook extensive helicopter-based river surveys in the 1960's and 1970's to locate major obstructions to anadromous populations and to estimate accessible and inaccessible fluvial spawning and rearing habitat in these systems (Porter et al. 1974; Anderson 1985). This information formed the basis of a GIS-based computerized habitat inventory and has been supplemented by additional information collected by groups undertaking enhancement, assessment, and habitat projects. Digital topographic data was organized to create watershed specific basemaps and available information was georeferenced and added as layers (streams as vectors, lakes as polygons) or points associated with attribute tables. This inventory is maintained in the InFocus/Quickmap database/GIS system supported by digitizing capability of AutoCad. To date, a total of 280 river systems have been added to the inventory, essentially compiling all available information for systems on the island of Newfoundland. Current efforts are directed at completing a similar inventory for rivers in Labrador.

Another project conducted under the inventory component of the regional programme involved the development of standardized approach and protocol for habitat surveys of small streams. Many project sponsors have proposed detailed stream surveys as the initial step in a river or watershed based habitat restoration project. A manual was subsequently produced (Scruton et al. 1992) detailing a systematic approach for surveying small streams for use by groups with limited biological experience and training. The manual describes planning requirements, survey methods and materials, requirements for data compilation and reporting, and provided standardized forms for data collections with detailed instructions. This approach has since been employed on approximately 30 habitat, enhancement and assessment projects. A DOS and Windows database program (River Habitat Database System, RHDS) was subsequently developed to assist project sponsors in organization, computerization, interpretation and reporting of stream survey data.

Case Study: Status of Fish Habitat on Bay St. George Salmon Rivers

The GIS-based habitat inventory database has been utilized in an assessment of major declines in anadromous Atlantic salmon stocks since the early 1970's on 15 rivers in Bay St. George, western Newfoundland. Available habitat inventory data was compiled, updated and coupled with a similar georeferenced database on forest harvesting to determine the effects, if any, of long standing forest management practices in these watersheds. This comprehensive inventory data was used to evaluate habitat changes over time and to relate this to the spatial extent of harvesting and construction of resource roads in the watersheds, from 1940 to present (Anderson et al. 1996). Data on available hydrologic, water quality, and stock status were reviewed in relation to the forest harvesting history. Despite the long standing and extensive harvesting (e.g. 38 % of Highland's River watershed) on these rivers, no clear trends were apparent to explain a habitat basis for the extensive stock declines on these rivers (Scruton and Anderson 1995).

Planning and Delivery

Effective planning, coordination, and delivery of habitat improvement initiatives undertaken by third party sponsors was an important component of major regional habitat restoration programmes conducted under NIFDA (1988 to 1992) and then CASEC (1992-1997). Activities included consultation and provision of advice to sponsors, identification and priorization of habitat improvement opportunities, assistance in seeking funding for projects, training, on-site support during project implementation (delivery), review of proposals and project reports, monitoring and auditing of project achievements. These activities were essential to ensure coordinated and well developed projects to achieve maximum benefits for the available financial resources.

Case Study: Workshops, Manuals, and Training Videos

A major workshop was held in 1990 during the NIFDA program to increase public awareness as to the types of initiatives that could be conducted, highlight successful projects conducted under NIFDA, and to attempt to scope out emerging priorities under an ongoing regional effort. The workshop included invited participation from other parts of North America to demonstrate projects from regions where there have been long standing histories of major habitat improvement/restoration activities (e.g. the American Mid-west). Under the CASEC program, annual training workshops have been held to provide direct 'hands-on' training for projects sponsors that received financial support for the coming year. These workshops have emphasized themes common to types of projects being undertaken and have encouraged sponsors to present and discuss their experiences on projects undertaken.

In the initial stage of the 5-year NIFDA program, it was readily apparent that many potential project sponsors were unfamiliar with the concept of habitat restoration and improvement and the strategies and techniques available for such initiatives. A 'Technical Manual for Small Stream Improvement and Enhancement in Newfoundland and Labrador' (Buchanan et al. 1989) was subsequently produced to provide guidance to public groups wishing to undertake projects. The manual included an overview of options available for use in small stream improvement, provided advice on project planning, summarized the life history and habitat requirements of salmonid species in Newfoundland, discussed habitat based limiting factors, detailed how physical structure affects stream geomorphology, provided a detailed set of specifications for implementation of various habitat improvement techniques, and highlighted the need for monitoring and maintenance.

A series of professional quality training videos have also been produced to provide additional support for public groups undertaking projects. To date, seven videos have been produced and have varied from detailing a 'how-to' approach for a specific improvement technique or structure to more general videos describing a variety of approaches to achieve a particular objective (e.g. obstruction removal).

Habitat Restoration - Opportunities Related to Historical Forest Harvesting

In assessing regional opportunities for small and large scale habitat restoration projects, it was immediately apparent that poor historical forestry practices offered a diverse array of potential projects of varying scope and wide geographical distribution. Extensive areas of habitat have been destroyed from unregulated forest harvesting activities providing many opportunities for increasing habitat available for sustainable fish production. Consequently, a specific program element was developed in relation to restoration of small to medium sized streams and lakes destroyed/degraded due to historical forestry activities. Projects have included removal of inoperative dams acting as partial or complete obstructions and focus points for poaching activities, clearing of other obstructions and blockages, stream improvement in channelized reaches, re-watering of diverted stream reaches, removal and scouring of accumulated debris in lakes and streams related to historical waterborne transportation of wood, cleanup of field camps and concentrations of logging debris, and remedial work in areas affected by hydrological changes and loss of riparian habitats. Projects of this type had potential for significant gain in habitat.

Case Study 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, to facilitate water borne transport of logs to a pulp and paper mill (Fig. 2). To expedite transportation of harvested pulpwood within the Pamehac Brook watershed, the headwaters of the system was 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. 1996). 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 (Fig. 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 (Fig. 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. (Fig. 3). Detailed stream habitat surveys were completed in 1990, prior to restoration, and again in 1992 and 1996, after restoration. 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).

Population estimates indicated that salmonid densities in the first year (1991) after restoration were not significantly ($P<0.05$) different from pre-restoration levels, and in fact biomass levels were lower. Both densities and biomass increased substantially in the second year after restoration (1992) with most of the increase attributable to greater densities of salmon fry and brook trout (> 0+ in age). Trout fry densities for the entire watershed were similar before and after restoration, however numbers increased 3-fold in the stations below the diversion after restoration. Surveys indicated an increase in 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). The '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 survey and fish population data allowed estimation of the 'habitat gain' and the increase in productive capacity associated with this project. Pre-restoration fish biomass and available habitat suggested a production potential for the fluvial habitat in the watershed (for 1990) of 18.01 kg excluding standing waters and steadies. The average fish biomass in 1992, 2 years after project restoration, and available habitat indicated a potential production of 51.46 kg. The restoration project has therefor resulted in a habitat gain of some 449.3 units (62 % increase) and an increase in potential production of some 33.45 kg (185 % increase). A similar assessment will be completed based on data collected in 1996.

Case Study 2: Joe Farrell's Brook, Salmon River Habitat Restoration Project

A long-term evaluation of a major habitat rehabilitation project on Joe Farrell's Brook, a second order tributary of the Salmon River (Main Brook, Newfoundland), is currently ongoing (van Zyll de Jong 1995). This 4-year scientific evaluation has assessed fish-habitat response to the introduction of several types of instream structures intended to restore habitat affected by historical forest harvesting activities (1946 until 1971). Clear cut harvesting and pulp transportation have resulted in channelization and alteration of stream hydrology which has reduced the amount and diversity of fluvial habitat. The main objectives of this project were to: (i) evaluate the long term effectiveness and stability of rehabilitation procedures on both physical habitat and juvenile fish populations and (ii) act as a regional model to provide information on effective approaches to stream rehabilitation.

Three types of stream rehabilitation treatments were applied to Joe Farrell's Brook: (i) boulder clusters, (ii) V-dam structures and (iii) half-log covers (Fig. 4). Biological and physical habitat variables were sampled at eleven stations on Joe Farrell's Brook which included treatment sites (n=5), sub-basin control sites (n=1), and sites downstream of treatment locations (n=5). Stations were surveyed annually prior to installation of structures (1993) and each subsequent post-treatment year (1994 to 1996). Physical attributes measured at transects established at each site included stream gradient, width, depth, bottom substrate, water velocity, and cover. Quantitative estimates of fish population (abundance 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 (Figs. 5, 6). Mean densities were statistically compared with Duncan's Multiple Range Test (significance at $P< 0.05$).

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 and greater variability in depth (i.e. increased diversity). V-dams increased the percentage of pool as well as increasing shallow riparian areas. Half-log covers increased the percentage of instream cover.

Sites with boulder cluster additions demonstrated significant ($P < 0.05$) increases in densities of age 0+ and 1+ juvenile Atlantic salmon and in 0+ brook trout in both post-treatment years (1994, 1995) as compared to pre-treatment. Older age classes of both species demonstrated no significant change. At the V-dam sites, salmon fry (0+) density increased significantly in the second post-treatment year (1995) as compared to pre-rehabilitation and the first post-treatment year while 1+ salmon density was significantly higher for both post-treatment years. There was no significant change in density of any age class of brook trout at the V-dam sites. Salmon fry density also increased significantly in the post-treatment years an the half-log cover site while older salmon (1+ and greater) and all ages of brook trout showed no significant trend. The combined effect of all rehabilitation efforts on Joe Farrell's Brook were examined in relation to control sites. Salmon of age 0+ , 1+ , and 3+ demonstrated increased densities in the post-treatment years in response to habitat restoration while all trout age classes and age 2+ salmon did not change at treatment sites in comparison to control stations.

The study results suggest that boulder cluster additions were successful in creating diverse microhabitat conditions and habitat complexity with a significant response in 0+ and 1+ juvenile Atlantic salmon. While a positive response of older salmon parr was expected, the increase in 0+ 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. 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 0+ (second year after restoration) salmon. Additionally, the half-log structure was intended to benefit juvenile brook trout however trout densities declined after treatment while salmon fry responded positively. Site specific conditions associated with treatments were considered important in these results. Results suggest 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 age classes. Secondary benefits of rehabilitation methods may be as beneficial as the primary objectives.

Stream Obstruction Removal

In Newfoundland, there are many rivers which contain anadromous populations of Atlantic salmon, brook trout, brown trout, and arctic charr with populations limited by available habitat as a result of partial or complete obstructions limiting upstream migration. A program component was developed to address the removal of barriers on small coastal watersheds using low technology remedial methods and, where suitable, use of small portable fishways. These activities were considered to have the potential to cost effectively open up additional habitat to increase production potential for sea-run fish. Techniques considered for application to these types of projects included blasting of falls and creations of steps and pools, improvement of plunge pool conditions below barriers, debris removal, and the possible use of small portable fish ladders intended for seasonal use only.

Case Study: Dead Wolf Brook

Dead Wolf Brook, a tributary of the Southwest Gander River, was completely obstructed to upstream migration by anadromous salmon by a series of four falls at the mouth which prevented access to upstream fluvial habitat (Fig. 7). A remedial project was undertaken in 1994 to blast a series of pools and chutes in and around the upper three falls. In 1995, a series of three pools and connecting channels were blasted around the lower falls. A concrete wall and spillway was also installed to maintain depth in the lower pool. Additional remedial activity was conducted on the upper three falls, to increase the depth in one of the plunge pools. Construction crews observed successful fish passage after completion of remedial activities in 1995.

Evaluation of the success of this initiative will be conducted in August 1996 using state-of-the-art coded tag radio telemetry coupled to digital antennae switching. Coded radio transmitters will be implanted (surgical or reproductive 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 a three month 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.

Urban and Small Stream Habitat Improvement

A program element was developed specifically for restoration of fish habitat in rivers flowing through urban areas in Newfoundland. A variety of historical, and in some instances ongoing, degradation has occurred in urban environments including channelization, diversion, alterations to natural drainage patterns, poor culvert installation, problems related to chemical contamination (e.g. spills and routine discharges), sedimentation, removal of riparian vegetation, etc. providing many opportunities for projects and a number have been undertaken. Realization of these opportunities can occasionally be constrained by concerns related to flooding, access, and potential damage to private and public property. Further, strategies and techniques needed to consider unique applications related to the altered hydrograph of urban rivers (excessive peaks and low flows) and physical constraints imposed by property boundaries (i.e. often re-introduction of natural sinuosity cannot be achieved).

A variety of small stream improvement projects have also been undertaken in rural areas using regionally applicable techniques including bank stabilization, provision of instream and streambank cover, pool creation and scouring, increased habitat diversity (boulder additions), increased stream sinuosity (current deflectors), and others. As most improvement techniques considered for use in Newfoundland have been developed elsewhere it was deemed important to evaluate selected projects to (i) confirm transferability of techniques, (ii) determine optimum conditions for project implementation, (iii) provide regional examples for other project sponsors, and (iv) generally to improve awareness of the value of habitat. Generally, projects have been implemented on streams where there has been some form of habitat degradation or where local knowledge has identified habitat limitations in natural streams (e.g. spawning habitat, see case study to follow).

Case Study: Northeast 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 is currently 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 in the late 1960's which bisected the river, 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 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 (Fig. 8). 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 same sites will be resurveyed in subsequent years (after gravel addition). 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 a (i) repetition of the electrofishing survey annually, (ii) annual redd counts 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 29-67% at the other five sites. Results from post-project sampling in 1996 are not yet available. In November 1995, 7 redds were observed in the newly added gravel confirming the newly placed gravel was selected for and used by spawning salmon. Emergence was missed in the spring of 1996 but both these techniques will be repeated in subsequent years. A major area for concern in a project of this nature is the long term stability of gravel placed in the river. A visual assessment in the summer of 1996 suggested the majority of the gravel (> 90%) has remained were it was placed however, the spring runoff in 1996 was abnormally low. These visual assessments will also be repeated in association with other project components.

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

Assessment and Evaluation

Assessment and evaluation in support of habitat improvement and restoration was considered a vital programme element to ascertain if project objectives were being met and that a gain in productive capacity of habitat was being achieved. This feedback was important for technology transfer and for evaluation of region-specific implementation of these techniques. The aim of the assessment and evaluation programme component was to provide a scientific basis for future planning and implementation of projects with due consideration for endemic species associations, biophysical conditions, and with respect to regionally applicable constraints and levels of third party expertise. Scientific evaluations of selected key projects were conducted in an attempt to assess the full scope of various types of projects undertaken. These evaluations were in some instances conducted by the project sponsors, with advice and experimental design provided by government scientists, were completed as cooperative ventures with government researchers, or in some instances were completed by students as part of post-graduate (M.Sc.) research. This component has also included investigations in a controlled (experimental) setting to evaluate the preference of juvenile salmonids for habitat attributes created by stream habitat improvement structures (to follow). The results of selected evaluation studies have been discussed in the case studies representative of each of the programme components.

Experimental Research

An experimental research program was also developed to compliment the scientific evaluation of selected improvement and restoration initiatives. The main focus of this research agenda was, under rigorous controlled conditions, to address the transferability of techniques developed in other jurisdictions for use with endemic species (primarily Atlantic salmon and brook trout) in Newfoundland and under regional biophysical conditions. 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 publically 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.

Case Study: Noel Paul Brook Experimental Channel

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 centre 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 (Fig. 9). 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, and were subsequently removed from each treatment by electrofishing. All streamside vegetation was removed so not to introduce bias as this was a variable to be included in future study.

Results indicated that there was no difference in preference between 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 allopatry or sympatry. 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 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 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. Results from these studies will help provide design and implementation criteria for future projects.

Habitat Compensation

Habitat compensation is the concept of replacing habitat that is to be lost or destroyed as a result of some development. DFO's Policy for the Management of Fish Habitat states that developments can proceed if habitat conservation ('no-net-loss') can be achieved and often habitat compensation is the only option available. Habitat compensation can involve the replacement of damaged or destroyed habitat with newly created artificial habitat or, alternatively, improvement of the productive capacity of other natural habitats. Frequently habitat compensation involves the same concepts and approaches as restoration and improvement and similar techniques are employed and hence are included in this paper. Habitat loss associated with highway construction adjacent to the Seal Cove River was a major regional compensation initiative involving construction of artificial fluvial habitat. The project has undergone detailed scientific evaluation (Scruton 1994a; Scruton 1996) and will be discussed as a case study.

Case Study: Seal Cove River Habitat Compensation Project

In 1987, the provincial transportation agency in Newfoundland requested approval from DFO for destruction of 162 m of Seal Cove River to accommodate twinning of the Trans Canada Highway (Fig. 10). They were required to compensate for this loss through construction of a replacement section of stream. This project was the first in the region involving habitat construction and was viewed as a regional model from which resource agencies could learn when considering future developments. Consequently a major research study was undertaken to evaluate the success of the initiative including: (i) design and implementation considerations of habitat construction, (ii) comparison of key habitat attributes between the destroyed stream reach and the artificial replacement section, and (iii) utilization of the replacement habitat by resident fish.

Conceptual plans for habitat replacement were developed in consideration of the habitat features in the section to be destroyed and the entire stream reach (predominance of shallow riffles). A decision was taken to design the compensatory habitat to benefit adult salmonids, primarily brook trout, and included provision of a number of holding pools with bank cover features to improve overwintering and low summer flow habitats. Additional features included: (i) increased stream length as provided by meander, (ii) removal of vegetation from the excavated stream channel only, (iii) addition of substrate material in proportions similar to the destroyed habitat, (iv) planting of streamside vegetation for rapid stabilization of riparian areas, and (v) precise positioning of stream features in consideration of site specific geomorphology. Construction was completed in 1989 and additional activities were conducted in 1990 to remedy problems associated with infilling of pools with finer substrates eroded from the compensatory stream.

Detailed habitat surveys, including detailed rod and level assessment of stream topography, was completed for the 162 m stream reach to be destroyed in 1987. Similar surveys were completed in 1991 and 1993 on the compensatory stream reach to evaluate pre- and post-project differences and stability of the constructed artificial habitat. Fish populations were sampled once annually from 1988 to 1993. In the two years prior to construction, five quantitative electrofishing stations were surveyed: two in the habitat reach to be destroyed and three upstream as controls. After construction, from 1991 to 1993, electrofishing was conducted on nine stations in the compensatory reach (for detailed assessment of relative productivity of holding pools and riffle sections), the three upstream control sites, plus an additional two downstream stations to assess any problems related to erosion. Fish population estimates (density and biomass) were made at each station for all salmonids and separately for each species and age class.

The study results indicated an increase in total stream area of 125 m^2 (+23%) largely related to the increased thalweig length (+20%) as a result of the designed sinuosity. The habitat design also increased the amount and proportion of pool habitat including: pool area (+134%), pool volume (+281%); pool: riffle ratio (+223%), and pool depth (+29%) (Table 3). Fish biomass, after an initial decline in the first year after construction (1991), increased to the highest level during the study of 93.5 g per 100 m^2 in 1993, a 2.1 fold increase over the mean pre-construction biomass. A decrease in densities was also apparent primarily reflecting a shift in species/age composition from Atlantic salmon fry (0+) to larger, older brook trout confirming the desired response to the designed habitat features (Table 4). An assessment of the habitat gain associated with this project, considering biomass as an indicator of habitat productive capacity and the increase in habitat quantity, indicated there was a 2.58 fold increase in productive capacity over the stream habitat lost through the construction of artificial fluvial habitat. In the context of DFO's Policy for the Management of Fish Habitat, a 'net gain' had been achieved.

Artificial undercut bank ('lunker') structures were incorporated into two of four large pools constructed in the compensatory habitat reach to evaluate the usefulness of this technique for habitat projects in Newfoundland (Scruton 1994b). Two (2) 'lunker' units (5 m length per pool) were installed on the outside bend of two of the large pools. A comparison of salmonid use of the compensatory pools, with and without artificial undercut bank habitat (Table 4) indicated numbers (density) and biomass of brook trout were greater in pools with lunkers than without in all three years of study. Conversely, the density of young-of-the-year of both species were greatest in pools without the structures. From 1991 through 1993, total salmonid biomass increased from 64.8 $g \cdot unit^{-1}$ to 369.6 $g \cdot unit^{-1}$ (5.8 fold increase) in the 'lunker' pools as compared to 73.3 to 112.5 $g \cdot unit^{-1}$ (1.5 fold increase) in the other pools. Results indicated that the use of undercut bank structures improved the pool habitat quality for larger, older brook trout.

Discussion

It is important to include both physical and biological considerations when designing and undertaking habitat improvement and restoration projects. Biological considerations can include: target species and age/size, understanding of 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 compensation 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.

A true measure of the performance of habitat rehabilitation structures can be related to the ability to demonstrate improvement in habitat quality which can then be linked to observed changes in fish populations. Many evaluations of stream restoration projects have focussed on fish populations and angling data as a measure of success while a lesser number have related these responses to physical changes in habitat (e.g. Hunt 1988). In Newfoundland, several of the major projects have attempted to relate fish population response to changes in physical habitat and/or a general gain in habitat quantity.

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 wether 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).

Successful stream habitat rehabilitation must create hydraulic conditions that consider fluvial processes, stream geometry, site specific hydraulics and biological processes (Newbury and Gaboury 1993). Habitat modifications need to be fine tuned to local hydrological and geomorphological conditions in consideration of limiting habitat variables and life histories of resident fish species (Beak Consultants 1993). Successful artificial modifications are those that minimally affect the natural stream channel morphology (Frissell and Nawa 1992) and failure of many instream structures has most often been attributed to the failure to consider hydraulic principles (Hunt 1988). Often stream habitats most in need of rehabilitation (e.g. channelized reaches) are least amenable to structural modification with stream enhancement technology (Frissell and Nawa 1992). Some researchers have found stream gradient to be most important in long term stability of instream structures with higher 'failure rates' associated with higher gradients (Hamilton 1989). 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. In Newfoundland, hydraulic factors have been considered in several of the technically complex projects (e.g. Seal Cove River compensation) and are considered important design criteria in projects involving creation of spawning habitats (e.g. N.E. Placentia River spawning gravel additions). However, in a majority of small projects undertaken by non-technical personnel, it is likely stream hydraulics have been given limited consideration.

In Newfoundland, and other northern locales, critical periods for resident salmonids in small streams are the low flow period 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). Additionally, habitat improvement methods that can increase summer growth and condition may improve overwintering success. 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.

Conclusions

In general, fish populations have responded positively to habitat features provided in major watershed level restoration projects (e.g. Pamehac Brook), stream compensation initiatives (e.g. Seal Cove River), and projects related to addition of instream structures (e.g. Joe Farrell's Brook). In several of the projects, species and age class specific responses due to the specific features and structures have also been observed (e.g. large trout response to artificial undercut bank in the Seal Cove River). In other instances, a more general increase in salmonid populations has been apparent and response of certain components of the fish community have been unexpected (e.g. response of salmon fry and 1+ parr to addition of structures on Joe Farrell's Brook).

Results have provided evidence as to a variety of habitat improvement techniques and approaches that can be considered for application to other projects in Newfoundland where conditions, species composition, and project budgets permit. Some approaches (e.g. blasting of falls for obstruction removal) are labour intensive, costly, and require considerable expertise for proper implementation and should be cautiously considered for broader application. Habitat improvement and restoration programmes over the last decade have increased public awareness of the importance of fish habitat and a number of projects have contributed to a gain in habitat.

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

	1990 (Pre-Restoration)			1992 (After Restoration)	% Change
	Above Diversion	Below Diversion	Total Watershed		
Total Stream Length (km)	1.99	4.52	6.51	7.30	+ 12 %
Total Habitat Area (100 m^2 units)	175	547	723	1172.3	+ 62 %
Mean Wetted Width (m)	8.9	9.8	9.5	13.7	+ 44 %
Mean Depth (cm)	29.1	15.4	18.7	26.0	+ 39 %
Habitat Area by Type (units, %)					
Riffle	118.1 (67.5	519.2 (94.9	637.3 (88.2	942.0	+ 48 %
Pool	0 (0 %)	2.2 (0.4 %)	2.2 (0.3 %)	2.3	+ 4 %
Steady	29.2 (16.7 %)	6.0 (1.1 %)	35.2 (4.9 %)	87.6	+ 148 %
Run	14.9 (8.5 %)	0 (0 %)	14.9 (2.1 %)	29.9	+ 100 %
Rapids/Other	6.1 (3.5 %)	19.7 (3.6 %)	25.8 (3.6 %)	110.5	+ 289 %
Substrate Composition (%)					
Large Boulder	9.7	2.1	3.9	6.6	+ 69 %
Small Boulder	13.1	15.6	15.0	24.1	+ 60 %
Rubble	37.2	42.9	41.5	26.9	- 54 %
Cobble	21.7	27.8	26.3	21.1	- 24 %
Gravel	18.3	8.6	10.9	2.1	- 419 %
Bedrock	-	3.0	2.3	8.0	+ 247 %

Table 2. Changes in habitat parameters 1993-1995 in control and treatment sites for Joe Farrell's Brook.

Site	Year	Surface Area (m^2)	Velocity (m/s)	Stream Width (m)	Max Depth (cm)	Mean Depth (cm)	Bottom Substrate (%)*									Surface Character (%)		
							1	2	3	4	5	6	7	8	9	Pool	Riffle	Glide
Boulder Site 1	1993	464	0.46	11.6	45	20	0	11.1	21	37.6	21.1	5.2	2	1	1	10	85	5
	1994	496	0.34	12.4	37	16.1	0	9.3	15	22.3	23.7	22	7.7	0	0	17	83	0
	1995	444	0.35	11.1	27	14.1	0	0	10	51.7	23.3	11.7	3.3	0	0	20	80	0
Downstream Site 1	1993	324	0.42	8.1	72	29.7	0	11.1	21	37.6	21.1	5.2	2	1	1	25	60	15
	1994	316	0.35	7.9	65	25.2	0	10.2	15.5	18.7	22.3	21.5	6	0	5.8	25	70	5
	1995	284	0.43	7.1	50	9.8	0	0	26.7	56.7	13.3	3.3	0	0	0	25	70	5
Boulder Site 2	1993	360	0.37	9	49	25.7	0	1	2.3	8.5	18.9	45.9	22.6	0.7	0	15	80	5
	1994	384	0.35	9.6	37	18.4	0	11.3	16.8	18.5	32.2	16.3	4.4	0.5	0	25	70	5
	1995	392	0.39	9.8	26	10.1	0	0	6.7	13.3	6.7	40	23.3	10	0	27	73	0
Downstream Site 2	1993	404	0.38	10.1	54	23.4	0	11.4	18.3	28.6	25.9	11.2	4	0.5	0	0	100	0
	1994	396	0.38	9.9	38	16.5	0	6.8	8.7	19.3	35.7	18.8	9	1.7	0	0	100	0
	1995	352	0.41	8.8	35	10.2	0	26.7	16.7	33.3	13.3	10	0	0	0	0	100	0
V-Dam Site 1	1993	384	0.36	9.6	62	26.9	0	18.7	25.1	21.8	22.8	9.6	1.7	0.3	0	23	77	0
	1994	392	0.18	9.8	64	22.3	1.7	7.8	17.7	48.3	18.8	4.8	0.8	0	0	46	54	0
	1995	364	0.34	9.1	46	13	0	33.3	23.3	36.7	6.7	0	0	0	0	50	50	0
Boulder Site 3	1993	348	0.28	8.7	56	24.9	0	18.7	23.4	26.2	20	8.9	2	0.9	0	18	76	4
	1994	312	0.22	7.8	48	20.6	0	8.6	19.2	43.7	21.8	5.3	1	0	0.3	18	76	4
	1995	300	0.32	7.5	47	11.9	0	23.3	33.3	30	13.3	0	0	0	0	10	76	4
V-Dam Site 2	1993	388	0.31	9.4	61	31.2	0	11.3	21	20.7	29.7	9	5.7	2.7	0	30	70	0
	1994	376	0.04	9.7	77	29.4	0	7.2	15.2	32.2	29.3	11.8	4	0.3	0	60	40	0
	1995	348	0.14	8.7	54	9.3	0	6.7	23.3	36.7	30	3.3	0	0	0	60	40	0
Downstream Site 4	1993	320	0.42	8	54	23	0	9.5	21.7	22.8	30.4	13	2.6	0	0	15	85	0
	1994	352	0.21	8.8	47	16.9	0	6.2	13.8	43.8	23.5	10.7	2	0	0	15	85	0
	1995	348	0.25	8.7	41	18.4	0	6.7	16.7	16.7	46.7	13.3	0	0	0	15	60	5
Half Log Site 1	1993	349	0.22	8.9	68	29.9	0	0.8	5.2	8.3	46.3	21.9	14	3.5	0	5	20	75
	1994	348	0.05	8.7	44	19.5	0.8	9.2	12.6	20.3	21.9	18.2	10.4	6.2	0.3	10	20	65
	1995	352	0.19	8.8	34	15.4	0	0	23.3	16.7	6.7	10	13.3	30	0	15	25	60
Downstream Site 5	1993	332	0.18	8.3	59	35.3	0	5.8	7.8	11.7	32.3	16.3	10	16	0	15	85	0
	1994	328	0..07	8.2	53	20.9	0	9.2	16.3	30.7	16.5	7	2.8	17.5	0	15	85	0
	1995	372	0.23	9.3	34	15.1	0	0	6.7	28.3	20	23.3	18.3	3.3	0	15	65	0
Sub Basin Control	1993	488	0.23	12.2	46	24.4	2	11	13.5	13.2	27	16.7	8.3	8.3	0	10	50	40
	1994	484	0.08	12.1	42	23.8	0	11.7	19.7	26.5	27.5	12	2.7	0	0	10	50	40
	1995	500	0.31	12.5	41	18.4	0	0	23.3	6.7	23.3	43.3	3.3	0	0	10	50	40

*Key: 1 - Large Boulder, 2 - Small Boulder, 3 - Rubble, 4 - Cobble, 5 - Pebble, 6 - Gravel, 7 - Sand, 8 - Silt, 9 - Bedrock

Table 3. Comparison of habitat attributes between the stream reach destroyed by highway construction (1988) and the compensatory habitat (1991 and 1993) in the Seal Cove Brook, Newfoundland.

	1988	1991		1993	
Habitat Attribute	**Original (Lost) Habitat**	**Compensatory Habitat**	**% Change ***	**Compensatory Habitat**	**% Change ****
Total Length (m)	162	194.6	+ 20%	195.2	+ 1%
Mean Width (m)	3.42	3.49	+ 2%	3.51	+ 1%
Total Area (units)	5.54	6.79	+ 23%	6.85	+ 1%
Total Pool Area (units)	0.73	1.71	+ 134%	1.69	-1%
Total Riffle Area (units)	4.81	5.08	+ 6%	5.16	+ 2%
Total Pool Volume (m^3)	17.16	48.22	+ 281%	57.63	+ 20%
Pool Proportion (%)	13	24	+ 85%	25	+ 4%
Riffle Proportion (%)	87	76	-13%	75	-4%
Pool:Riffle Ratio	1:7.6	1:3.2	+ 209%	1:3.0	+ 4%
Gradient ($m \cdot km^{-1}$)	27.8	23.6	-15%	23.5	-
Mean Depth (cm)	13.6	17.6	+ 29%	20.8	+ 15%
Mean Pool Depth (cm)	23.5	28.2	+ 20%	34.1	+ 17%
Mean Riffle Depth (cm)	11	8.6	-8%	8.8	+ 2%
Mean Bank Slope ($m \cdot m^{-1}$)	0.66	1.77	+ 295%	1.75	-1%
Total Undercut Bank (m)	0	9.75	+ 100%	9.55	-2%

* Percent change between the original (lost) habitat (October 1987) and the compensatory habitat (June 1991)

** Percent change in compensatory habitat features between years (June 1991 to July 1993)

1 unit = $100\ m^2$

Table 4. Summary of mean fish population estimates (numbers, N, and biomass, Biom) for stations studied in the destroyed/compensatory and control reaches over the pre-construction (1988, 1989), construction/remedial (1989, 1990), and post-construction (1991-1993) period. Estimates were derived for all salmonids and separately for Atlantic salmon YOY (AS 0+), salmon 1+ and greater (AS >1+), brook trout YOY (BT 0+), and trout 1+ and greater (BT >1+).

Original (Lost) Stations

Compensatory Stations

	1988		1989		1990	1991		1992		1993	
	N	Bio	N	Bio		N	Bio	N	Bio	N	Bio
AS 0+	42.0	6.9	37.1	4.7		18.7	0.9	26.9	5.3	15.4	2.6
AS > 0	1.7	2.5	1.1	2.7		3.0	5.0	2.6	3.4	3.3	3.4
BT 0+	16.5	3.8	16.5	2.3		31.6	2.4	27.2	12.3	9.6	6.6
BT > 0	24.7	46.0	13.8	22.1		16.3	43.4	24.3	60.2	23.8	80.7
Total	84.7	59.2	68.4	29.8		69.7	52.1	81.7	81.4	52.1	93.5

Control Stations

	1988		1989		1990		1991		1992		1993	
	N	Bio	N	Bio	N	Bio	N	Bio	N	Bio	N	Bio
AS 0+	9.1	2.2	1.3	0.3	30.9	4.8	8.2	0.7	2.7	0.8	2.1	0.6
AS > 0	0.7	1.0	0.9	1.3	2.4	2.9	3.8	4.9	2.1	4.5	1.1	2.0
BT 0+	5.8	1.8	2.5	0.4	8.0	1.5	2.7	0.4	9.3	3.0	4.6	1.7
BT > 0	12.1	20.5	10.5	24.9	11.6	24.2	12.0	22.9	16.3	33.7	19.6	39.8
Total	27.6	25.4	15.3	26.9	53.2	33.6	27.0	28.9	30.4	41.9	27.4	43.8

Table 5. A comparison of fish density (Dens) and biomass (Biom) per habitat unit between pools with and without lunker structures in the Seal Cove River compensatory habitat.

	1991				1992				1993			
	Lunker Pools		Non-Lunker Pools		Lunker Pools		Non-Lunker Pools		Lunker Pools		Non-Lunker Pools	
	Dens	Biom	Dens	Biom	Dens	Biom	Dens	Biom	Dens	Biom	Dens	Biom
Trout 0+	2.8	0	28.5	1.9	5.8	23.1	28.6	4.3	5.8	34.8	14.1	3.0
Trout > 0+	20.2	64.8	17.9	54.7	31.9	113.7	28.9	76.7	58.0	331.9	34.2	102.5
Salmon 0+	0	0	13.1	0	0.9	0.1	19.1	5.2	0	0	23.9	4.0
Salmon > 0+	0	0	7.0	15.4	1.2	3.5	0	0	2.8	8.8	3.0	4.0
Total Salmonid	23.0	64.8	66.5	73.3	39.8	140.4	77.4	86.2	66.7	369.6	75.2	112.5

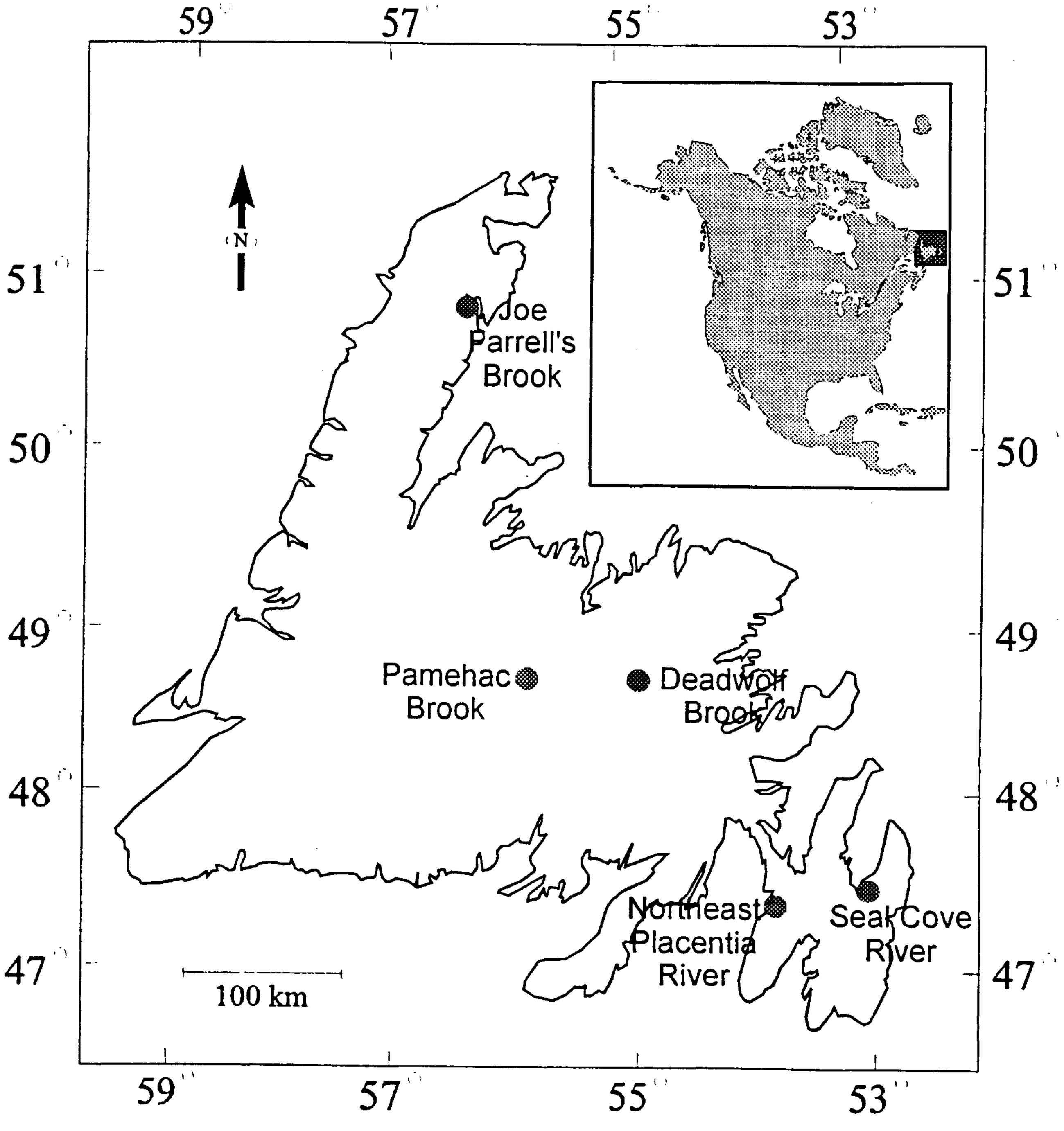

Figure 1. Habitat improvement and restoration case studies in Newfoundland as discussed in this paper.

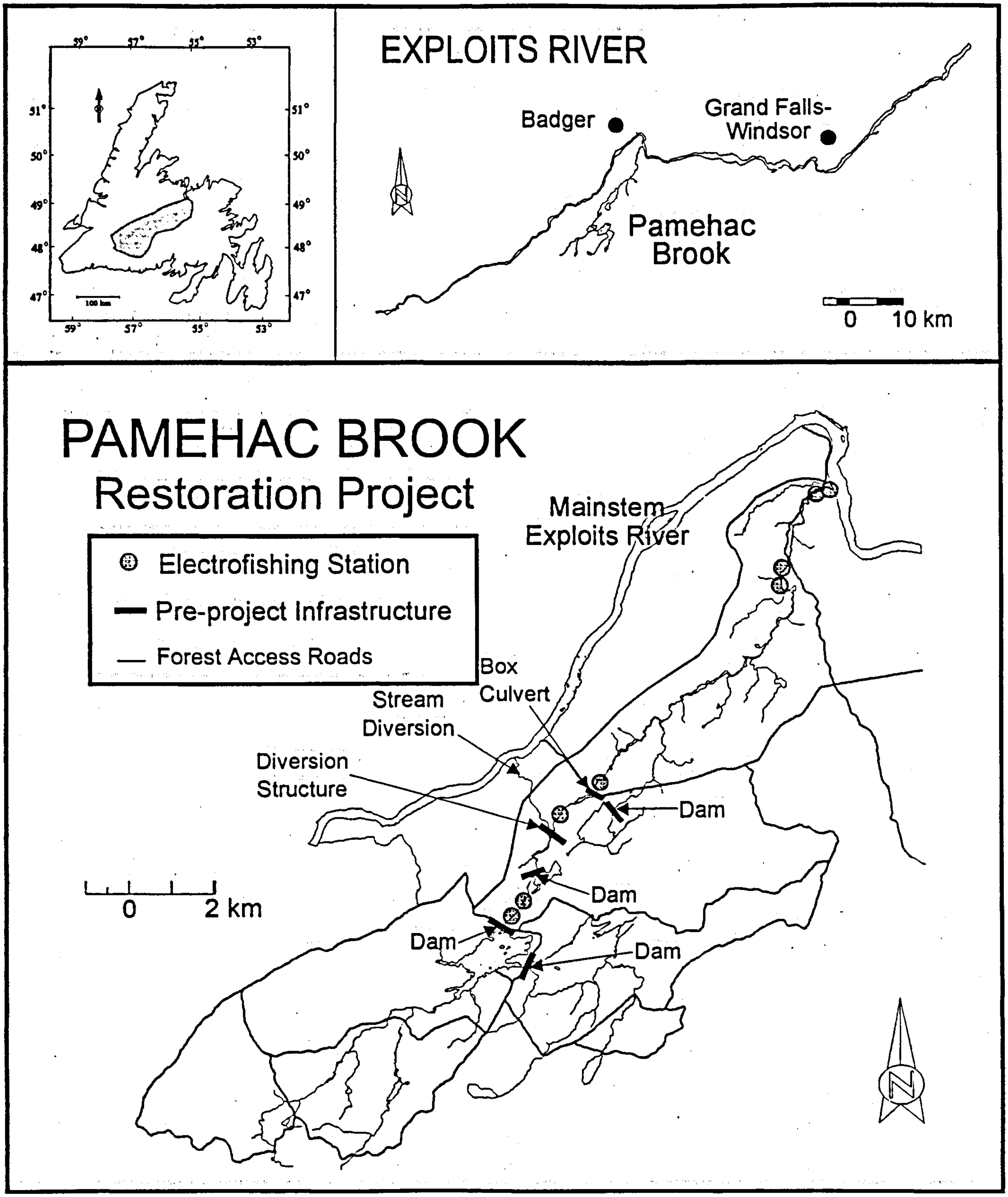

Figure 2. Pamehac Brook, Exploits River, including sites of remedial activities and electrofishing stations.

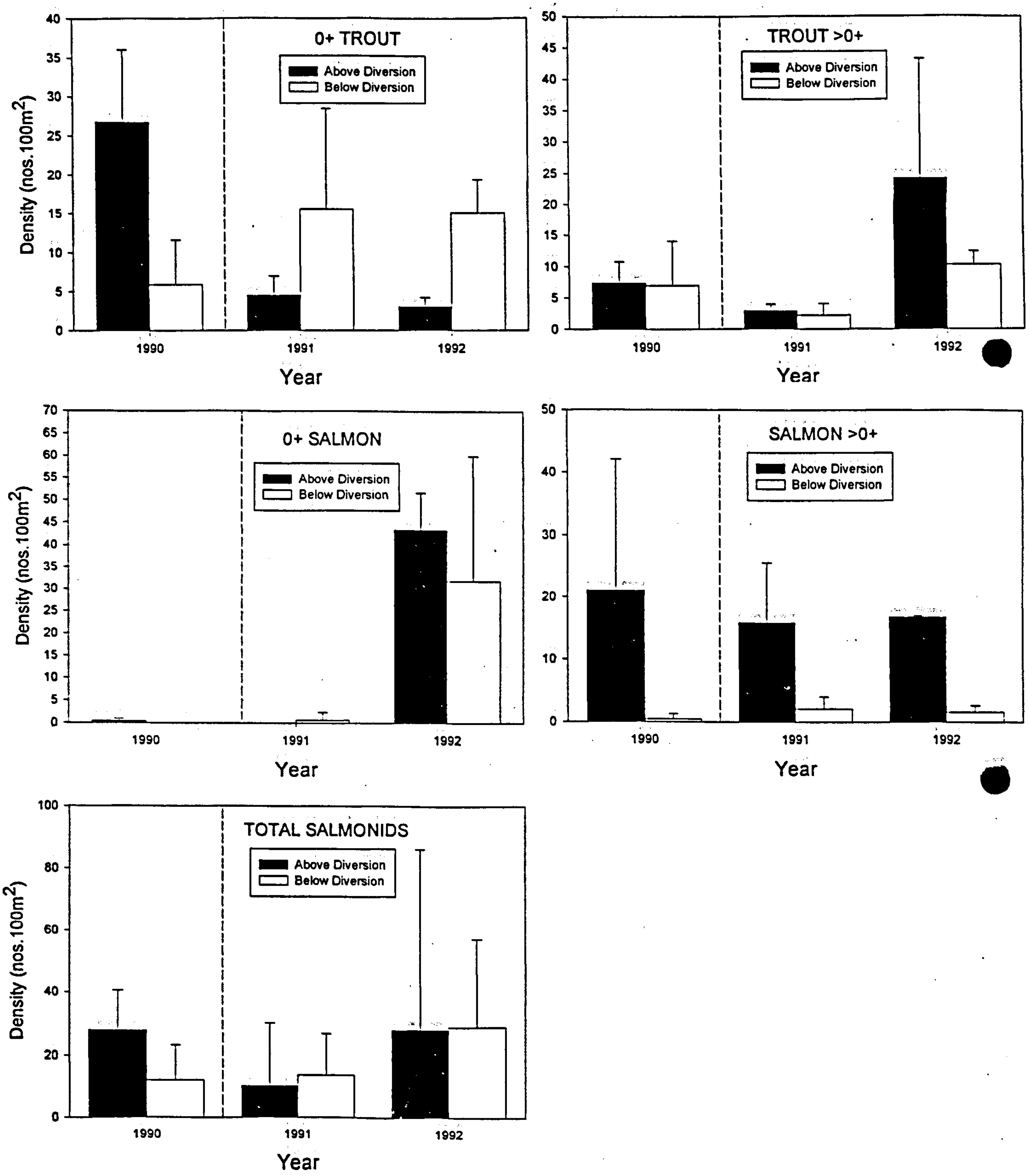

Figure 3. Salmonid population density before and after restoration of Pamehac Brook.

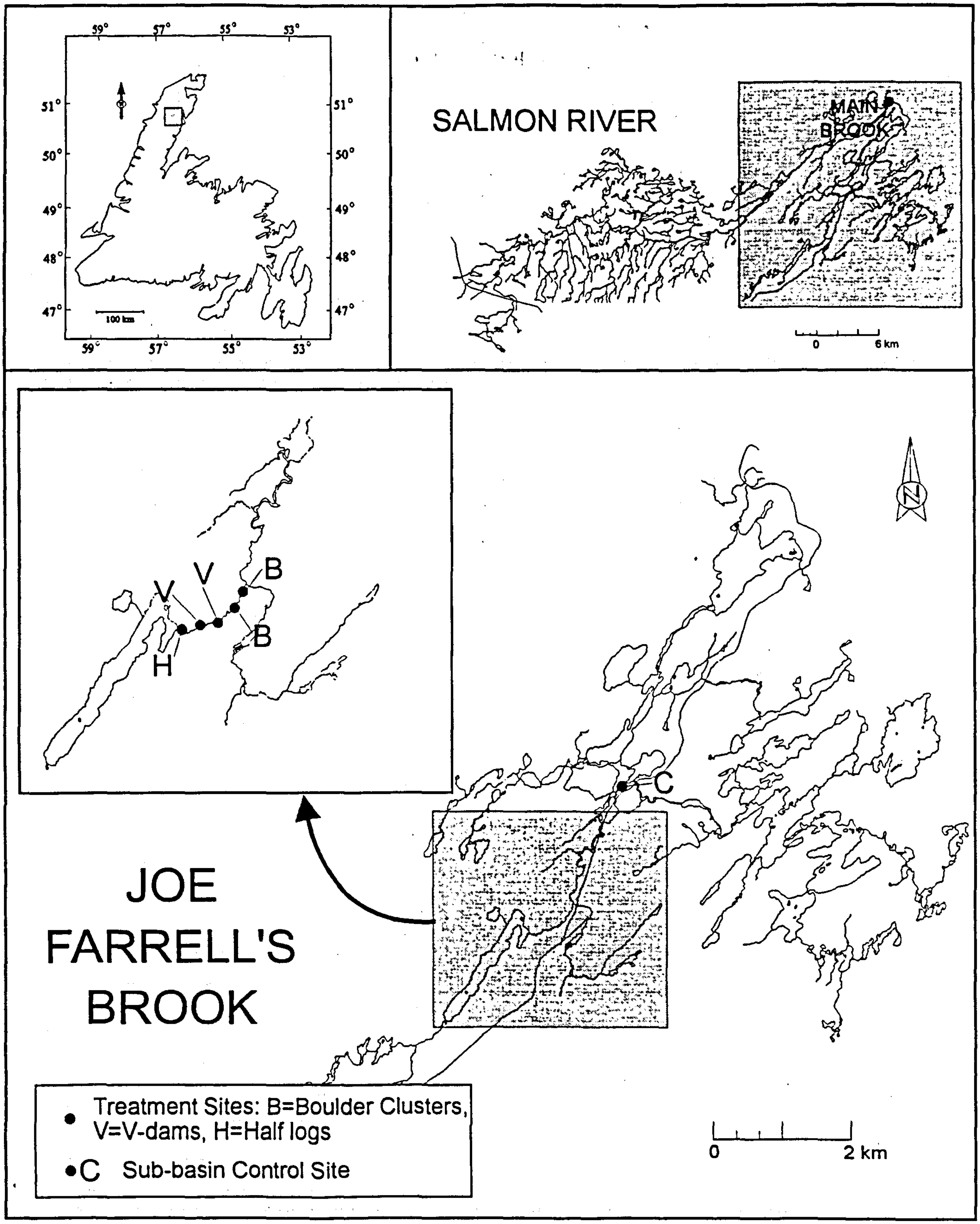

Figure 4. Joe Farrell's Brook, Salmon River, including habitat restoration sites.

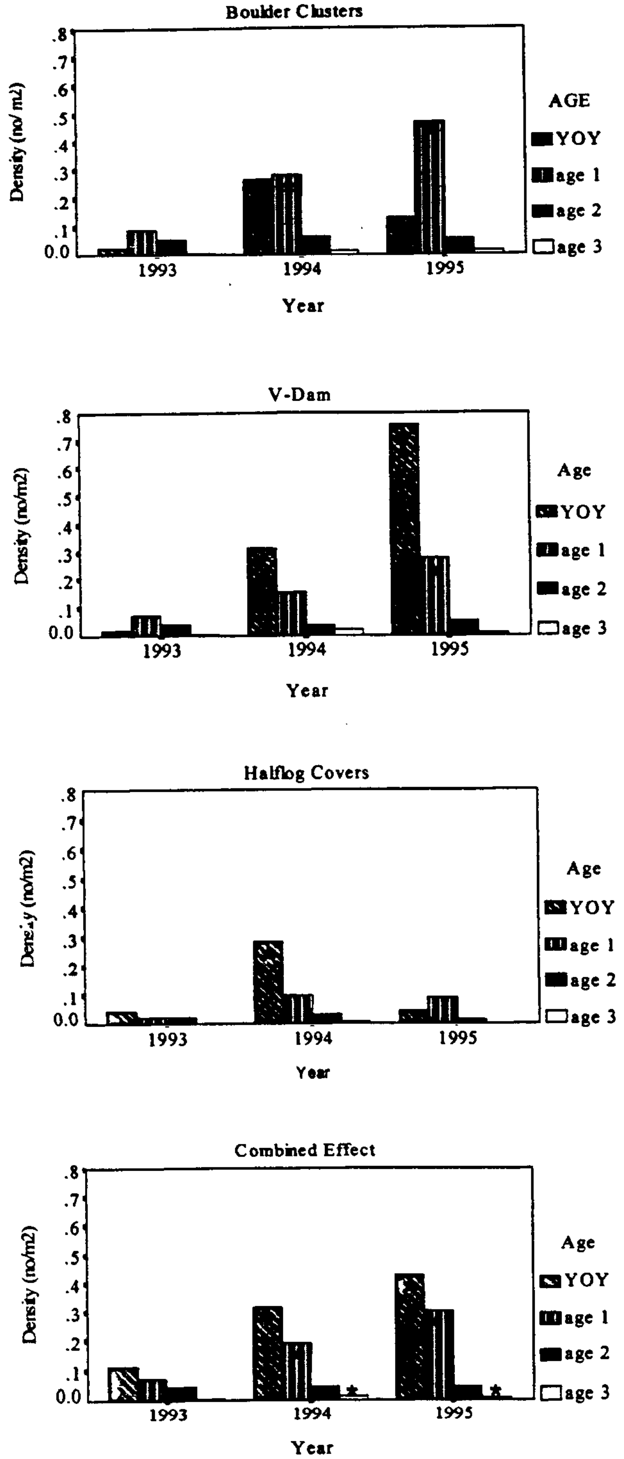

Figure 5. Mean density at age composition for juvenile Atlantic salmon, 1993 to 1995, for individual treatments and combined effect in Joe Farrell's Brook. Significant (P<0.05) changes in density are denoted by an asterisk (*).

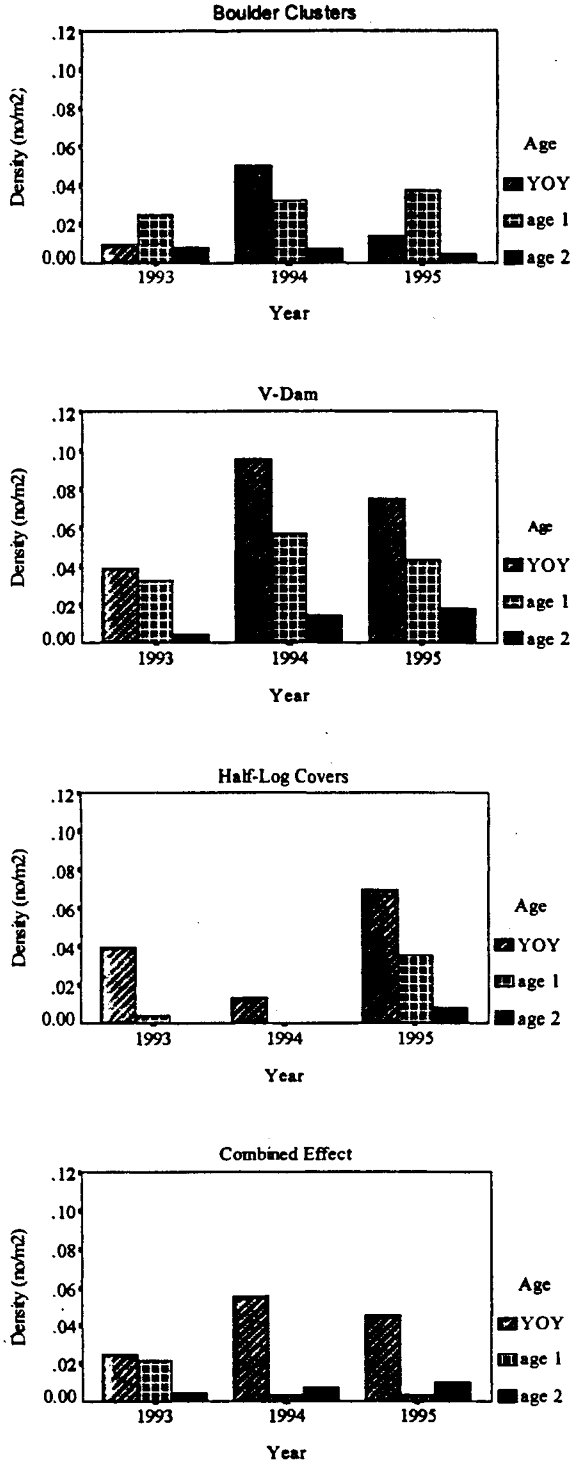

Figure 6. Mean density at age composition for juvenile brook trout, 1993 to 1995, for individual treatments and combined effect in Joe Farrell's Brook. Significant ($P < 0.05$) changes in density are denoted by an asterisk (*).

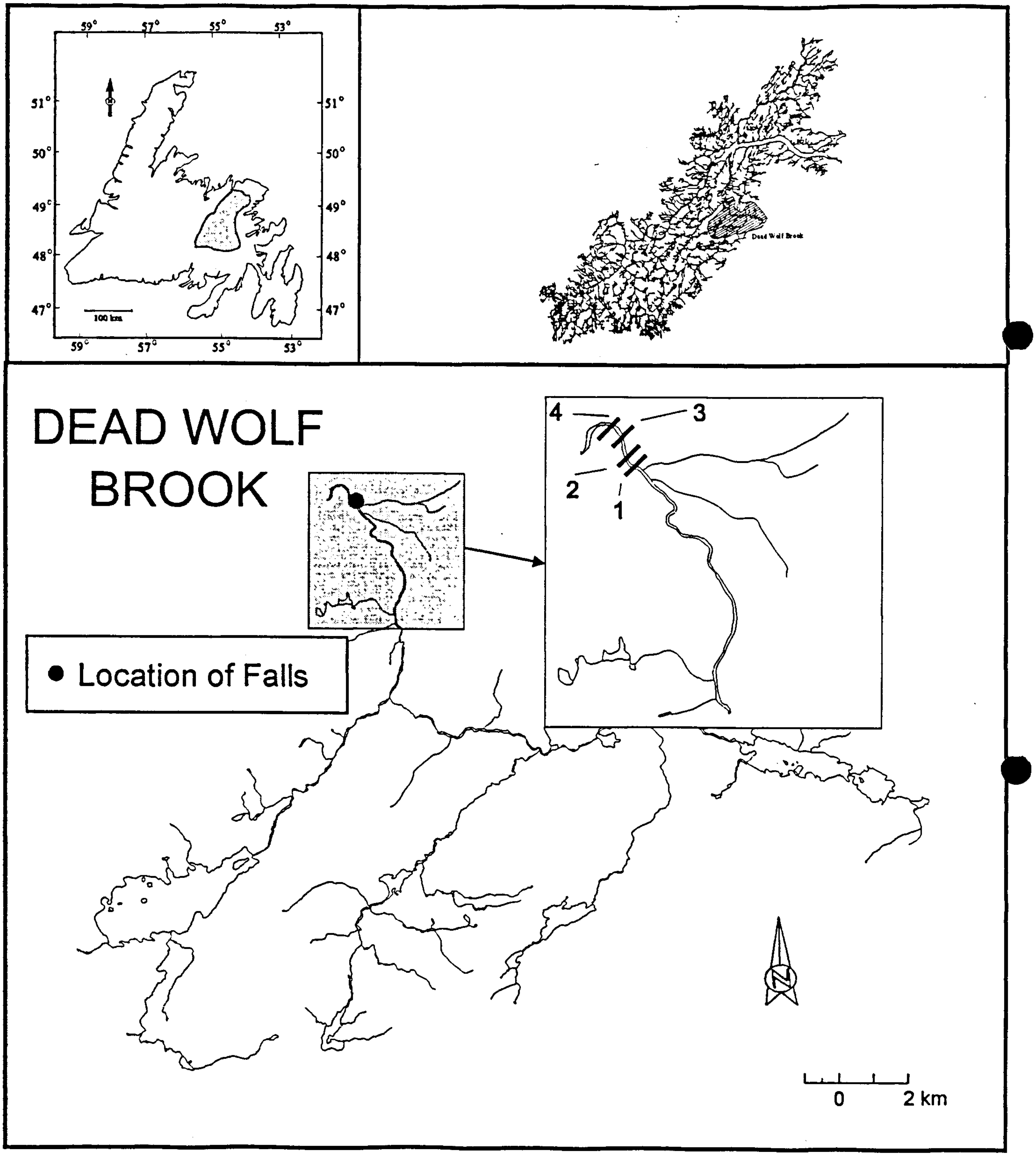

Figure 7. Dead Wolf Brook, Southwest Gander River, including location of falls where remedial activities were conducted.

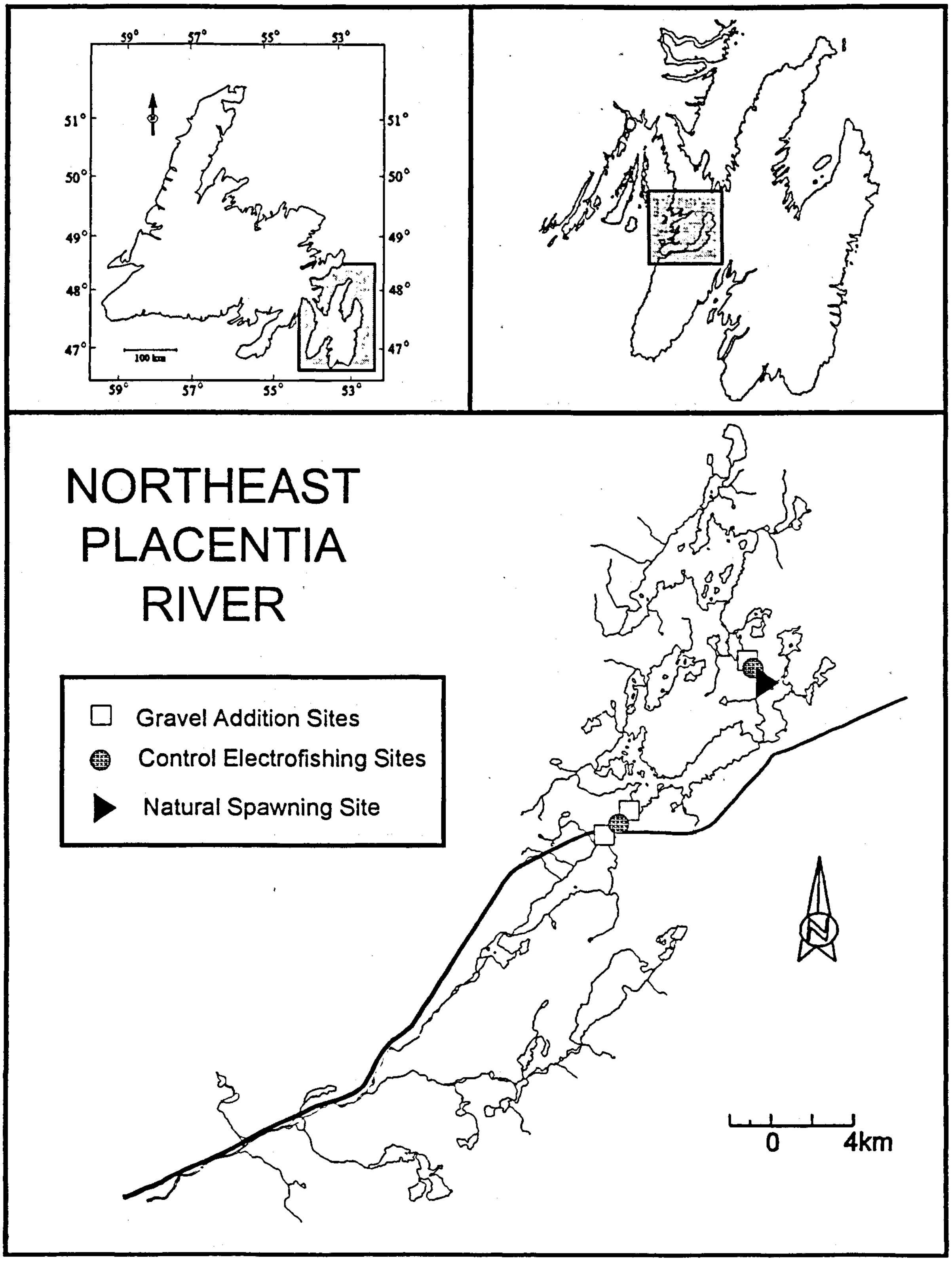

Figure 8. Northeast Placentia River including the location of additions of spawning gravels.

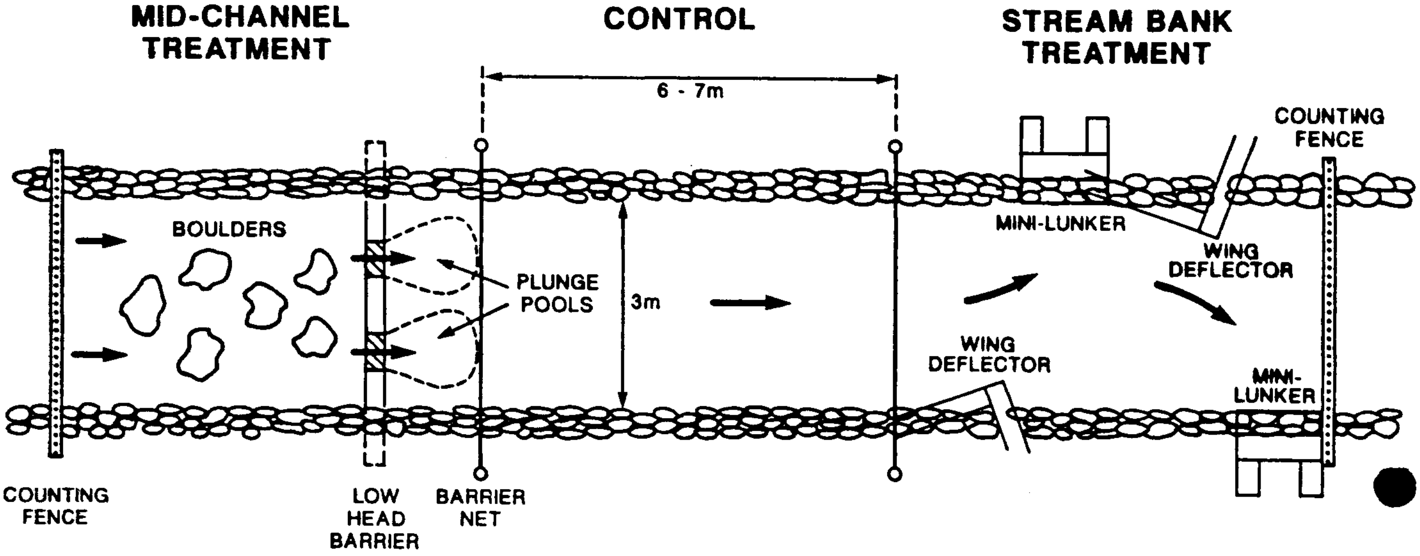

Figure 9. Schematic of habitat improvement 'treatments' used in research at an experimental channel at Noel Paul Brook, Exploits River.

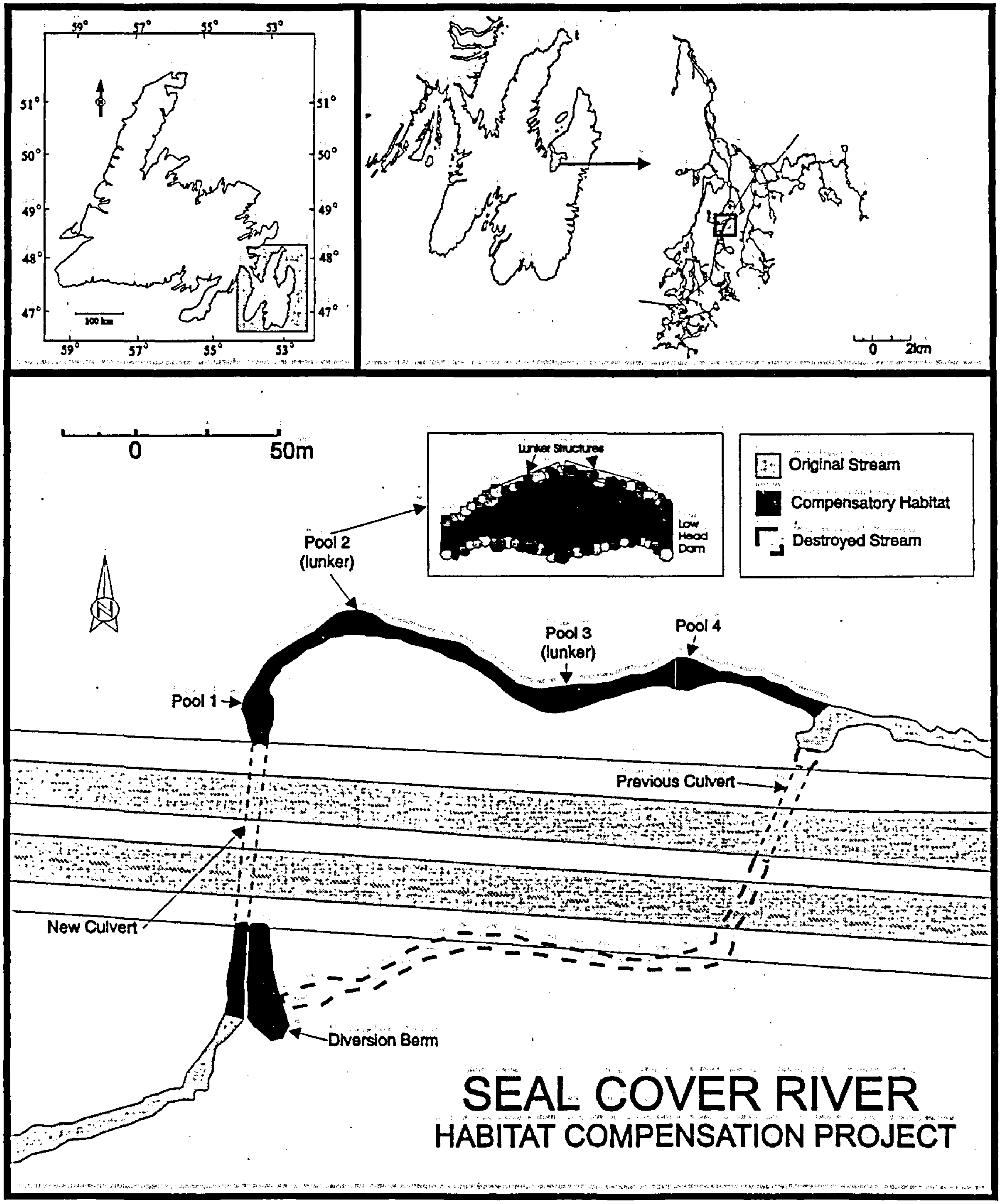

Figure 10. Seal Cove River showing river alignment before and after highway construction.