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Fish passage and stream habitat restoration in Terra Nova National Park highway culverts


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ABSTRACT

Restoration action was taken on three culverts situated on small high gradient streams in Terra Nova National Park with the objectives of reestablishing natural fish movements and naturalizing stream habitat. Old corrugated pipe culverts, which had excessive water velocities and were "perched" at the outflow, were replaced with oversized pipe culverts set at-grade, modified with concrete scour baffles and bedded with large substrate. Due to the naturally high gradients of the streams, two of the three restored culverts were installed at gradients higher than recommended in the literature. Restoration action was evaluated by comparing environmental conditions (water velocity, water depth), fish density, and invertebrate diversity within restored and unrestored culverts and in adjacent natural reaches. Upstream migrants and fish activity within culverts were also examined in restored and unrestored systems. The restored culverts appeared to benefit upstream migration of salmonids as successful passage occurred in all restored culverts, of which two were previously impassable. Hydraulic conditions within the restored culverts had similarities to the natural reaches over the discharges examined. Water velocities and depths in restored culverts were comparable to that measured in natural reaches and were consistent with the swim speeds capabilities of the salmonids that inhabit these streams. Fish activity in restored culverts was greater than unrestored culverts though densities were lower than that found in the natural reaches. Further, size distribution of fish in restored culverts more closely represented natural reaches than unrestored culverts. In contrast, very few fish were observed in non-restored culverts even though fish passage by larger individuals was observed. Finally, the taxonomic diversity of stream invertebrates was similar to adjacent reaches in restored brooks but was lower in unrestored culverts. This study suggests that less expensive pipe culverts, modified with baffles, have some utility in restoring fish passage and habitat, particularly in small high gradient streams where restoration options are limited.

INTRODUCTION

Poorly installed culverts are a widespread problem (Langill and Zamora 2002), for both anadromous and nonanadromous fish populations that exhibit seasonal movements within a watershed (Baker and Votapka 1990). Culverts negatively impact fish movements because they often create difficult or impossible drops for fish to bypass at the culvert outflow. Culverts also channel water flow, creating excessive water velocities and poor quality habitat. An outflow drop or ‘perching’ can be caused by improper culvert installation or by heightened velocities associated with channeling. Channeling flow is desirable to engineers as water is moved efficiently through a watercourse. Unfortunately, an associated negative feature is that the accelerated water flow increases erosion at the outflow. When high velocity water leaves the culvert and hits natural substrates, the downstream substrate erodes and a drop is created. The increased water velocities within culverts can also bar upstream movements of fish. Even relatively low gradients (>0.5%) create velocities that can obstruct fish passage (Fisheries and Oceans Canada 2003). Compounding this problem is the relatively smooth metal surface of conventional pipe culverts, which eliminates current irregularities (micro-eddies) that fish utilize in natural streambeds (e.g. Barbin and Krueger 1994). Standard culverts are also unlikely to provide other habitat features important to fish (e.g. refuge and benthic prey). In Terra Nova National Park (TNNP), the Trans-Canada Highway (TCH) severs most watersheds. Little research has been conducted to evaluate the impact the (TCH) has had on aquatic ecosystems even though there is great potential to alter fish (Dryden and Stein 1975; Katapodis et al. 1978) and invertebrate (Nedeau et al. 2000) communities, impact genetic flow between populations, reduce production, and alter fish behaviour (Dryden and Stein 1975). During an assessment of salmonid fish production in TNNP streams, Thompson (1981a) reported an absence of salmon above the TCH culvert in Terra Nova Brook; despite an abundance of the species below the culvert. He speculated that the culvert obstructed fish passage and caused the disparity. Though bridges span all higher order brooks in the park, all low order streams are routed through potentially problematic pipe culverts.

RATIONALE FOR RESTORATION

The *Canada National Parks Act* states that the maintenance or restoration of ecological integrity shall be the first priority when considering the management of parks. Currently, over 200 km^2 of watershed lie upstream of the TCH and are influenced by the 84 culverts located on the highway. Of these 84 culverts, at least 37 occur on fish bearing streams. In many areas, access to upstream spawning grounds has been severed, gene flow (Baker and Votapka 1990) has been eliminated, and/or seasonal movements to critical habitats (e.g. Robertson 2004) have been restricted. It is also quite likely that fish production of some species has been reduced (Thompson 1981a). In the event of a local extinction caused by poor environmental conditions, natural recolonization of these areas may no longer occur. Clearly, past construction practices are having a significant impact on TNNP's aquatic wildlife and it is important to find environmentally responsible solutions to mitigate the effects of the highway.

DESIGN CRITERIA

TNNP's goal is to restore fish passage where it naturally occurred prior to the construction of the highway and to attempt to recover habitats within the culverts themselves. Although the Department of Fisheries and Oceans (2003) has outlined specific recommendations (specifying minimum water depths inside the culvert as well as water velocity and culvert gradient limits) to ensure fish passage through culverts, Parks Canada's relevant legislation/policy provides slightly different direction. Parks Canada views historically isolated habitats as intrinsically valuable in that they contribute to the biological diversity of the landscape. As a result, TNNP will not attempt to enhance fish passage (e.g. with the use of fishways) but will restore or "naturalize" existing stream crossings. In specific cases this may result in stream crossings that are not in accordance with the recommendations set by DFO, and these culverts may continue to partially or completely bar fish passage. However, this is not inconsistent with Parks Canada direction and is compatible with DFO's mandate in that fish passage will most likely be improved and will not be further degraded.

Unfortunately, there is little specific knowledge of the topography of the land in the vicinity of the TCH prior to its construction. In absence of this information, streams will be restored to the gradient of the land adjacent to the highway. It is fully recognized that returning a culvert to the slope of the adjacent land is not sufficient. In their natural condition streams are rarely channeled. Natural streams meander, have adjacent vegetation, and contain irregularities in the stream bottom that affect water flow. This variety in bottom type and water velocity provides essential microhabitats that fish and other aquatic life use to move, feed, and seek refuge. As a result it is also important to maintain a natural stream bottom. Bridges are preferable to culverts in that they allow streams to maintain their natural course and bank side vegetation (National Marine Fisheries Service 2000). Unfortunately these structures are often cost prohibitive and would be difficult to implement in all the small brooks within TNNP. The most desirable alternative is the bottomless arch (National Marine Fisheries Service 2000). While these designs may interfere with bank-side vegetation, they still allow for a natural streambed. They are slightly more expensive than a pipe culvert but are limited by the geo-technical requirements of the design. These culverts are prone to collapse if erosion of underlying sediments occurs and therefore can only be installed in areas with solid substrates. Similar to the arch culvert is the embedded pipe culvert. These culverts are installed below grade and partially backfilled with substrate, which allows the stream to flow through a naturalized channel. These culvert installations, however, require low gradients so that substrates are not flushed out at high flow. Another option is a modified pipe culvert. These designs incorporate a series of baffles (weirs) that maintain water depth and reduce current velocities. From a biological perspective this design may not be as attractive as the others but it is appealing in that it can be installed in a wider range of locations, and is relatively inexpensive. To further enhance the baffled culvert design, rocks can be placed within these structures to improve the quality of habitat within the culvert and to create flow characteristics similar to that in a natural streambed.

PRELIMINARY WORK / PRIORITIZATON

With the initiation of the TCH improvements, funds became available to restore fish passage in some priority brooks flowing past the highway. Prioritization was based on previous recommendations from Parks reports (e.g. Thompson 1981a), the presence of fish, the occurrence of natural obstructions and the size of the watershed. Electro-fishing was conducted in all watercourses crossing the TCH except those that were obviously storm drainage culverts (Appendix A). It is important to note that this brief survey was capable of decisively demonstrating the presence of fish but it could not conclusively prove that fish were absent. Nonetheless, it served as a valuable tool as many brooks thought not to bear fish did contain them. Subsequent to the electro-fishing surveys, all identified fish bearing brooks in the proposed construction zones were surveyed for other natural obstructions to fish passage.

Three culverts were selected for restoration within the highway repair zone; Arnold's Pond Brook, Square Pond Brook, and Terra Nova Brook (Figure 1; Appendix B). A fourth, Charlottetown Brook, was examined in its unrestored condition. All four systems are utilized for recreational fishing and Terra Nova and Arnold's Pond have potential to sustain anadromous populations above these barriers. Arnold's Pond is a relatively small (4 ha), shallow (mean depth = 2.1 m) pond frequented by recreational fishermen (Thompson 1981b). Brook trout are the only fish species found in the lacustrine area of the watershed (Cote et al. in press). Arnold's Pond Brook is a first order stream that runs 1 km from the pond to its outflow at Southwest Arm. Along the way it passes below the Trans-Canada Highway (approximately 0.2 km from the ocean) and a secondary access road at Southwest Arm Day Use area (0.1 km above the estuary). The Arnold's Pond Brook culvert at the Trans-Canada Highway is thought to be a complete barrier to fish passage as there is a significant drop (0.67 m) at the outflow and no pool enabling fish to jump. Furthermore, fish passage was likely inhibited within the culvert because of high water velocities and shallow depths. Atlantic salmon and eels are found downstream of this barrier but have not been located above. The stacked double culvert at the Southwest Arm Day Use Area has a less significant drop and a more suitable jumping pool at the outflow. Nonetheless it is likely a partial barrier to fish passage as water velocities within the culvert may be beyond the swimming capacities of some fish.

The culvert on the Square Pond system lies between Square Pond and the marine environment. Square Pond, which is bisected by the park boundary, is also a popular recreational fishing area where brook trout and American eels are the only species present (Kerekes 1968). The culvert at the Trans-Canada is situated approximately 0.9 km from both the pond outlet and the ocean and is also considered impassable - though trout occur in the stream above and below the culvert. The water in this first order stream, flows over a significant drop at the culvert outflow (0.94 m) and splashes onto coarse rock before it continues downstream. With exception of a short section just below the culvert, the section between the Trans-Canada and the marine environment is characterized by relatively high topographic relief and may form at least a partial natural barrier for anadromous Atlantic salmon and brook trout - species known to occur near the estuary (Cote unpubl. data).

Terra Nova Brook (Appendix B), a second order tributary of the Big Brook watershed, has only a small headwater pond (Charlie Chaulk's Pond) and is predominantly a lotic system. Thompson (1981a) highlighted this brook as the primary trout production area of the watershed. He also stated that the culvert at the Trans-Canada was a complete barrier to fish passage (salmon were not found upstream of the culvert) despite a lower outflow drop (0.32 m) relative to the previous culverts and the occurrence of a pool suitable for jumping. Three kilometres of brook lie above the Trans-Canada and there is approximately 2.4 km between the culvert and the confluence with Big Brook. Big Brook, the park's most popular fishing location (Thompson 1981b), flows 1.6 km from the confluence into Newman Sound. Diadromous populations of brook trout, Atlantic salmon and American eel occur in this system.

Charlottetown Brook (Appendix B) runs 2.5 km from its headwaters to the marine environment in Clode Sound. Along the way, the brook passes though two culverts; at the TCH and in the community of Charlottetown. Below the community of Charlottetown, the brook flows over a waterfall that is considered a complete obstruction to anadromous salmonids. Six ponds occur in the headwaters and are popular locations for angling. Brook trout and American eel are the only fish species that occur above the waterfall.

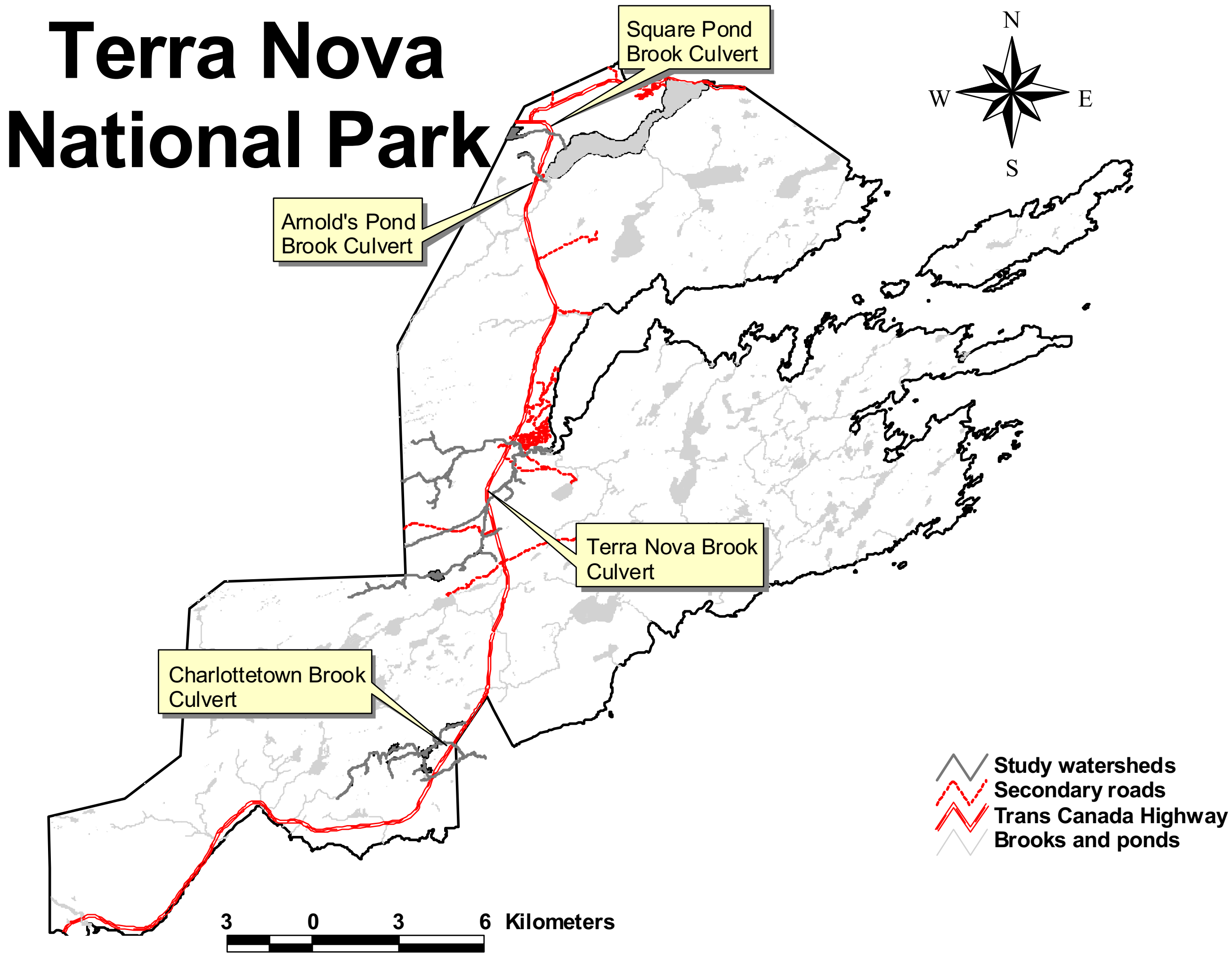

Figure 1: The distribution of study culverts along the Trans-Canada Highway, TNNP.

MONITORING RESTORATION SUCCESS

Monitoring is a key component of any restoration initiative as it assesses the success of previous activities and provides direction for future management action. Monitoring programs provide valuable information for future restoration plans inside and outside the Park; particularly in cases where culvert installations deviate from DFO's recommendations. For road culvert restoration, Dryden and Stein (1975) maintain that baffle configuration cannot be considered successful until fish passage under field conditions is determined. This study uses a variety of complimentary approaches to directly assess the impact of culvert restoration efforts.

METHODS

ENVIRONMENTAL CONDITIONS

The effectiveness of culvert restoration was evaluated, in part, by comparing environmental conditions within restored and unrestored culverts to that of the adjacent natural stream bed during mid-low water conditions. Cross sectional stream profiles, substrate composition and water velocity data were collected within the culverts (inlet, mid-culvert, and outlet) and in riffle sections of the adjacent streambed. Cross sectional profiles were done at 10 cm intervals across the wetted width of the channel. Substrate was classified as: bedrock; boulder: > 30 cm; cobble: 5 – 29.9 cm; gravel: 0.5 cm – 4.9 cm; sand : 0.1 cm - 0.4 cm; and silt: < 0.1cm. Water velocities were taken with a digital flowmeter (Geopack Mjp-Basic) in the thalweg of all sites. Habitat specific water velocities were compared to projected burst, and sustained swimming speeds described by Peake et al. (1997) for Newfoundland Atlantic salmon parr and brook trout.

FISH DENSITY AND BIOMASS

Fish density and biomass were assessed within restored and unrestored culverts and in the natural reaches upstream and downstream of the culvert. Total counts were used to quantify densities within culverts while Delury estimates (Anderson and Neumann 1996) were used to quantify fish density in adjacent natural areas. Fish abundance in natural reaches was determined in 50 m sections. Each site was isolated using barrier nets at the upper and lower ends to prevent fish from entering or escaping during sampling. Sweeps were made downstream with a Smith-Root Type VIII electrofisher until depletions exceeded 50% of the previous run for three consecutive passes. A regression line, obtained from a catch per run – cumulative catch plot, was used to forecast the abscissa for the population estimate of the section fished. Sampled fish were placed in recovery tanks between sweeps, measured (for fork length and weight) and marked. Fish were given capture-location specific marks on the pelvic fin (left fin for fish caught below the culvert and right fin for those caught above) to allow for identification in future mark-recapture efforts. All fish were released at the site of capture.

Stream surface area was calculated by multiplying the average wetted width (measured every 5 m along the sample reach) by the section length. Fish densities within culverts were calculated over the entire length and therefore sampled sections deviated from 50 m. Comparisons of density and biomass were examined with a one-sample t-test and, with one exception (the Terra Nova Brook culvert in its restored condition), were restricted to data collected in July of 2002 to eliminate the effects of seasonal variation.

Site locations

Site selection of natural reaches was restricted to areas adjacent to the culvert primarily for the benefit of the mark-recapture component of this study. Pools directly adjacent to culverts were not included in any of the sample reaches. In some brooks, the safety hazard of operating electrofishing equipment in dense riparian vegetation limited site selection to a few areas.

Terra Nova Brook

Surveys were conducted in Terra Nova Brook on July 10, 2002. A second survey of the culvert was conducted on September 24, 2002 after restoration efforts were completed (Sep 18, 2002). Water velocities and wetted width were similar for both periods (Appendix D). Three adjacent downstream sections were surveyed starting approximately 25 m below the culvert outlet. Three adjacent upstream sections were also surveyed, with the first section starting directly above the culvert inlet. In total there were 150 m of brook surveyed on each side of the culvert. These natural sections were characterized by average bankfull widths of 4.7 m and gradients were 2.7% (Appendix D) and mean monthly discharges over the study period were estimated to range from 0.2 – 0.5 m^3/s (Appendix E). The culvert sample area was 60 m in length.

Arnold's Pond Brook

Arnold's Pond Brook was sampled in July and October, 2002. Due to dense canopy cover, only one 50 m section was surveyed on each side of the culvert. The downstream section started approximately 30 m below the culvert while the upstream section started just above the inlet pool. The culvert section was 40.5 m in length. Natural reaches near the TCH culvert were characterized by bankfull widths of 3.2 m, gradients of 5.6% and an estimated mean monthly discharge of 0.1 - 0.3 m^3/s during the period of study.

Square Pond Brook

Low water levels, stream morphology and dense canopy prevented any upstream sampling at this site, therefore, only one 50 m section was surveyed downstream. It was situated 25 m down from the culvert outlet. The 40 m culvert section was surveyed in July and October in its restored state. Bankfull widths of natural reaches of Square Pond Brook at the TCH were 2.8 m and gradients were 6.9%. Estimated mean monthly discharge ranged from 0.1 to 0.3 m^3/s for the study period

Charlottetown Brook

Three adjacent downstream sections were surveyed starting approximately 10 m below the culvert outlet. There were also three adjacent upstream sections surveyed, with the first section starting directly above culvert inlet. In total, 300 m of brook were surveyed. The culvert section was 31.5 m in length. Sampling was conducted on July and October. The estimated mean monthly stream discharge during the study period was estimated to from 0.2 to 0.5 m^3/s, while bankfull widths were 5.8 m. Natural reach gradients were 3.7% on average.

MARK - RECAPTURE

Voluntary movements of fish through the culverts were monitored with a mark-recapture approach. During fish density measurements (downstream and within the culverts) all fish were marked according to their capture location. Subsequent upstream surveys on Jul 4, 10, and 11; Oct 31; Nov 1 and 7 (2002) and Sep 2, Oct. 31, and Nov 1 (2003) were conducted to determine if any fish had moved upstream.

VIDEO MONITORING

Fish activity and migration was monitored at restored (n = 4) and unrestored culverts (n = 2) through video monitoring. At each site video cameras (Sea-View 150) were installed at the upstream and downstream entrances to the culverts. The cameras were positioned vertically (Figure 2) to provide an overhead view of water passing through the culvert. To increase visibility of fish, 3M reflective material was affixed to the culvert bottom (Figure 3). Each camera was hard-wired to a time lapse VCR unit (Sanyo SRT – 612 DC) that recorded the video footage generated by the camera. Sample periods were limited by the recording time on a VHS cassette (18-24 h). Footage was acquired for day, twilight and night periods – with twilight and night footage acquired with white infrared lighting. Video footage was reviewed and the numbers and direction of fish passing below the cameras were tabulated. Fish length was estimated from the videotapes using gradations marked on the 3M reflective surfaces. In those culverts where fish entered solely for the purpose of migration, comparisons of fish numbers between cameras enabled the calculation of the number of successful passage events versus the number of failed attempts. However, in many cases, fish were found to spend considerable time within culverts and it was not possible to discriminate individuals and therefore the successful passages and failed attempts. Thus in such samples, discrete sightings of individuals were tabulated and used as a measure of activity within culverts. Sampling dates for culverts are shown in Table 1.

Table 1: Video monitoring periods for Terra Nova National Park culverts, 2002.

Culvert	Dates sampled	Restoration status
Arnold's Pond Brook (TCH)	May 23, 24, 27, 28, June 4, 7, 12, 18, 25, 28, Jul 4	restored
Arnold's Pond Brook (Southwest Arm)	July 23, 25, Aug 16	unrestored
Terra Nova Brook (Trans-Canada Highway)	May 16, 17, 21, 22, June 6, 11, 17, 20, 24	unrestored
Terra Nova Brook (Terra Nova Road)	July 17, 22, 24, 27, Aug 1, 8, 20	unrestored
Square Pond Brook	May 29, 30, June 5, 19, 26	restored
Charlottetown Brook	July 31, Aug 7, 9, 13	unrestored

Figure 2: Before (left) and after (right) the restoration of fish passage in the Arnold's Pond Brook culvert located at the TCH (Station 39-224). A video camera set-up is shown at the culvert's outflow (right) monitoring the success of the restoration activities.

Figure 3: Silhouette of a fish against reflective material observed with a monitoring camera.

FORCED SWIMS

It was uncertain that fish would be motivated to move up culverts that had previously been barriers to upstream movements for over 40 years. Therefore manipulations were undertaken to evaluate the ability of fish to return to upstream habitats after displacement and / or their ability to utilize the culverts as habitat. Culverts were barred with barrier nets and electrofished with a Smith-Root Type VIII electrofisher. All fish were identified, measured (length, weight), marked (caudal fin clip) and placed downstream to augment the mark/recapture component. Subsequently, a sample of 10 fish (72 – 170 mm) were collected upstream of the culvert, measured (length and weight) and marked on the right pelvic fin. In one case (Terra Nova Brook-TCH) 2 fish escaped from the recovery cage and as a result the trial was done with 8 individuals. Where possible, brook trout were selected for testing since their swimming capacity is less than those of juvenile salmon (Peake et al. 1997), however in cases where they were unavailable in suitable numbers, juvenile salmon were utilized. All fish were given a minimum of 30 minutes of post-capture recovery time before being placed directly above the barred outflow of the culvert. Fish that could not maintain station within the culvert and were flushed against the barrier net were removed, given 5 minutes of rest and re-released into the culvert. After three unsuccessful attempts, a fish was considered incapable of moving upstream and removed from the experiment. Those able to maintain station in the current were left for a period of 24 h after which time the culvert was resampled with an electrofisher. Operators moved upstream so that any fear reactions elicited by the study team would tend to move fish upstream (if capable). Fish were recaptured, re-measured and the distance upstream from the release point was noted.

INVERTEBRATE COMMUNITY

Invertebrate communities were sampled in two brooks with restored culverts (Square Pond and Arnold's Pond) and two brooks with unrestored culverts (Charlottetown and Terra Nova Brook – prior to restoration). Three samples were taken from random locations within culverts and an additional 3 were taken in the adjacent streambed. Substrate was collected from a 50 cm x 50 cm grid at each location and scrubbed to dislodge the invertebrates. Disturbed fauna were captured immediately downstream in a 400 μm mesh net and fixed in a 10% formalin solution and later stored in 70 % ethanol. All invertebrates were separated, identified to family (Merritt and Cummins 1996) with a dissecting microscope and enumerated. Invertebrate taxonomic diversity was compared with a t-test (Systat v. 10. 0) between sites within a brook and among brooks.

RESULTS

ENVIRONMENTAL CONDITIONS

Water Velocity

Water velocities within restored culverts were similar to those found within the natural reaches of the adjacent brooks except for the short distances where the flow poured over the scour baffles (Figure 4). In contrast, the relatively low gradient Terra Nova Brook culvert at the TCH, prior to restoration (1.4%; Appendix C), showed greatly elevated water velocity when compared to natural areas of the brook. Culvert velocities in the unrestored Charlottetown Brook did not appear to differ greatly from that of its natural reaches but the gradient of this culvert was relatively low (1%). Comparisons of culvert velocities to sustained and burst swimming speeds of trout and salmon (Peake et al. 1997) indicate that restored culverts appear to provide conditions suitable for fish passage for individuals larger than 12.5 cm. Within the Terra Nova Brook culvert, in its unrestored state, water velocities were only suitable for trout >24 cm.

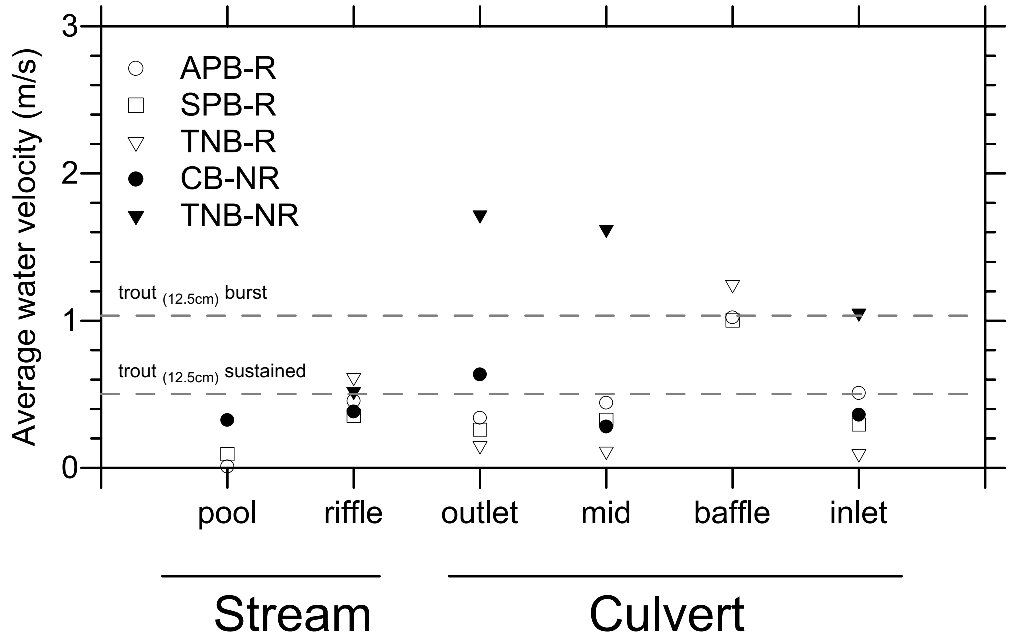

Figure 4: Average water velocities during the study period of restored (open symbols) and unrestored (solid symbols) culverts and the adjacent natural reaches in Terra Nova National Park, 2002. Burst and sustained swimming speeds of a 12.5 cm brook trout (Peake et al. 1997) are represented by dashed lines APB-R: Arnold's Pond Brook – restored condition; SPB-R: Square Pond Brook – restored condition; TNB-R: Terra Nova Brook – restored condition; CB-NR: Charlottetown Brook - unrestored condition; TNB-NR: Terra Nova Brook – prior to restoration.

Water Depth

Minimum depths (in the middle of flow) within the restored and unrestored culverts exceeded 5 cm over the study period, except at Charlottetown Brook where the outlet had 2 cm depth at low flow. During low flows in Square Pond Brook, the pools created by the scour baffles did not extend the entire distance to the upstream baffle. As a result, in these areas flow depth was similar to that found in its unrestored condition. In contrast, the depths of the natural riffles downstream and upstream of the culvert sites were greater than 10 cm depth except in Arnold's Pond and Square Pond brooks, which were 2.5 cm deep at low flow. The linear distance of these low depth zones in natural reaches was 10 to 20 cm, whereas in the unrestored culverts, the shallow depths could extend tens of meters.

Stream profiles

Qualitative analysis of the stream profiles showed that, during periods of low discharge, the natural reaches of the brooks had low velocity zones on either side of the thalweg with sufficient water depth. In contrast, the unrestored culverts had high velocity zones that extended for many meters, with no low velocity zones for fish to navigate. The cobble and baffles in restored culverts formed pools and riffles that mimicked the natural brook. Water flow on either side of the thalweg was slow and sometimes reversed upstream. The cobble also provided low velocity shelter for fish.

Substrates differed between natural reaches, restored culverts and unrestored culverts. Natural reaches were characterized by cobbles with a mixture of fine sediments. In restored culverts, little fine sediment was present at the time of study and in unrestored culverts sediments were absent.

FISH BIOMASS

The dominant species present in the study brooks were Atlantic salmon *Salmo salar* and brook trout *Salvelinus fontinalis.* Also present at one site were a few American eels *Anguilla rostrata*. There were no sticklebacks or anadromous brook trout captured at the time of sampling; however, during fish removal for culvert restoration on Terra Nova

Brook, one sea trout was captured downstream. The absence of anadromous trout is most likely due to sampling dates not coinciding with run timing.

Fish density was lower (44 – 73%) in reaches upstream of the Trans-Canada than that found downstream in all three brooks where upstream and downstream sites were sampled. The disparity was most notable for Atlantic salmon, which were at densities of 5-10% of that found downstream. Brook trout density was more similar (62 - 127% of downstream), though upstream densities only exceeded the downstream densities in one brook (Terra Nova). Total fish biomass in natural reaches was greatest in Arnold's Pond Brook followed by Square Pond, Charlottetown, and Terra Nova brooks (Table 2). Brook trout and salmon juveniles in Terra Nova Brook were present at a ratio of 1:2 downstream, 6:1 upstream and 1:1 combined (Table 2). American eels were captured downstream but in very low numbers. Brook trout in Arnolds Pond Brook, relative to juvenile salmon, were present at a ratio of 3:1 downstream and 26:1 upstream. The Square Pond Brook fish community consisted only of brook trout, as was the case for Charlottetown Brook.

Fish density and biomass was significantly greater in the natural reaches of Terra Nova Brook (density $_{TN}$: $t_{d.f. = 5} = 4.51$, $p = 0.006$; biomass $_{TN}$: $t_{d.f. = 5} = 4.53$, $p = 0.006$) and Charlottetown Brook (density $_{CB}$: $t_{d.f. = 5} = 8.51$; $p < 0.001$; biomass $_{CB}$: $t_{d.f. = 5} = 4.67$; $p = 0.005$) compared to levels found within unrestored culverts, where no fish were captured (Table 2; Figure 5). Subsequent to the restoration of the Terra Nova Brook culvert, fish biomass increased to a level that did not differ significantly ($t_{d.f. = 5} = 0.45$; $p = 0.67$) from that found in natural reaches while fish density improved though it was still significantly lower than in adjacent reaches ($t =_{d.f. = 5} 2.84$; $p = 0.036$). In both Arnold's Pond Brook and Square Pond Brook, the salmonid biomass in the restored culverts was lower than in natural reaches (Arnold's: 33%; Square Pond: 36%) but there were insufficient samples to allow for statistical testing. Lengths of fish in restored culverts were of a similar range within the restored Terra Nova Brook culvert to that of the natural reaches. In Arnold's Pond, the tail ends of the distribution (30-70 mm and 130-160 mm) were absent while in Square Pond the 30-60 mm size-classes were absent (Figure 6).

Table 2: Density, biomass and condition factor of fish within Terra Nova National Park brooks for June and July 2002.

Brook	Location	Brook trout density (fish/m^2 ± SE)	Atlantic salmon density (fish/m^2 ± SE)	Total fish density (fish/m^2 ± SE)	Brook trout biomass (g/m^2 ± SE)	Atlantic salmon biomass (g/m^2 ± SE)	Total fish biomass (g/m^2 ± SE)	Fulton's condition factor ± SE (brook trout)	Fulton's condition factor ± SE (Atlantic salmon)
Terra Nova	Upstream	0.13 ± 0.01	0.02 ± 0.01	0.15 ± 0.02	1.65 ± 0.34	0.41 ± 0.14	2.06 ± 0.45	1.19 ± 0.09	1.18 ± 0.09
	Downstream	0.10 ± 0.02	0.20 ± 0.08	0.30 ± 0.08	1.16 ± 0.33	2.11 ± 0.79	3.26 ± 1.08	1.13 ± 0.04	1.09 ± 0.03
	$\bar{x}$ (Upstr. & Downstr.)	0.12 ± 0.01	0.11 ± 0.05	0.23 ± 0.05	1.40 ± 0.24	1.26 ± 0.52	2.66 ± 0.59	1.14 ± 0.04	1.14 ± 0.05
	Culvert (unrestored)	0	0	0	0	0	0	NA	NA
	Culvert (restored)	0.42	0.42	0.84	1.73	0.66	2.39	1.06	1.19
Arnold's Pond	Upstream	0.43	0.01	0.44	4.38	0.07	4.45	1.09	1.34
	Downstream	0.69	0.31	1.00	9.40	1.49	10.89	1.13	1.44
	$\bar{x}$ (Upstr. & Downstr.)	0.56	0.16	0.72	6.89	0.78	7.67	1.11	1.39
	Culvert	0.16	0.02	0.18	2.04	0.49	2.53	1.07	1.29
Square Pond	Upstream	NA	NA	NA	NA	NA	NA	NA	NA
	Downstream	0.54	0	0.54	6.24	0	6.24	1.09	NA
	$\bar{x}$ (Upstr. & Downstr.)	NA	NA	NA	NA	NA	NA	NA	NA
	Culvert	0.18	0	0.18	2.22	0	2.22	1.17	NA
Charlottetown	Upstream	0.22 ± 0.02	0	0.22 ± 0.02	2.51 ± 0.37	0	2.51 ± 0.37	1.09 ± 0.02	NA
	Downstream	0.30 ± 0.05	0	0.30 ± 0.05	4.33 ± 1.31	0	4.33 ± 1.31	1.07 ± 0.01	NA
	$\bar{x}$ (Upstr. & Downstr.)	0.26 ± 0.03	0	0.26 ± 0.03	3.42 ± 0.73	0	3.142 ± 0.73	1.08 ±	NA
	Culvert	0	0	0	0	0	0	NA	NA

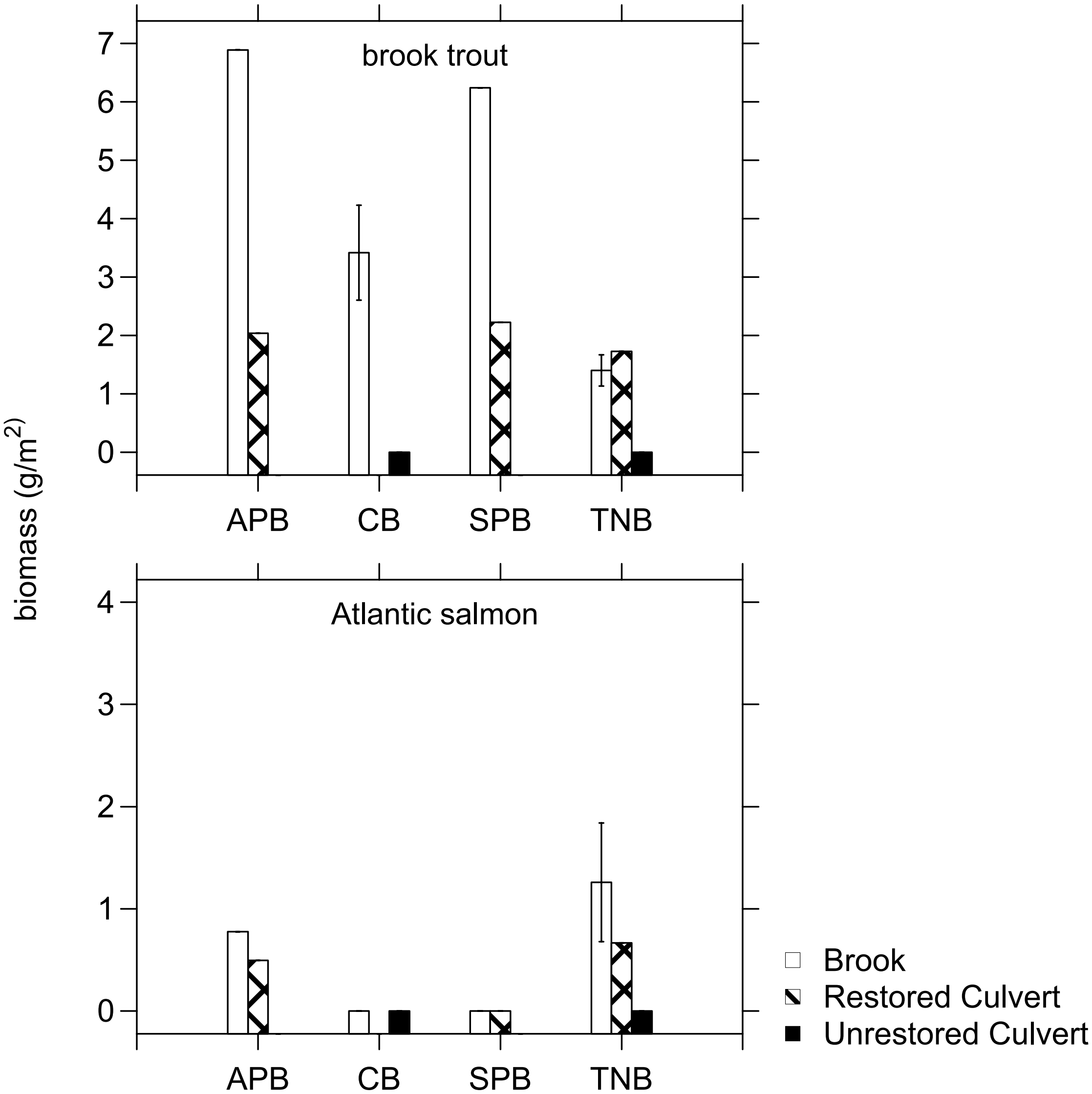

Figure 5: Salmonid biomass in natural stream reaches and in restored and unrestored culverts on the Trans-Canada Highway, Terra Nova National Park, 2002. APB: Arnold's Pond Brook (after restoration); CB: Charlottetown Brook (unrestored); SPB: Square Pond Brook (after restoration); TNB: Terra Nova Brook (before and after restoration). Errors bars represent the SE.

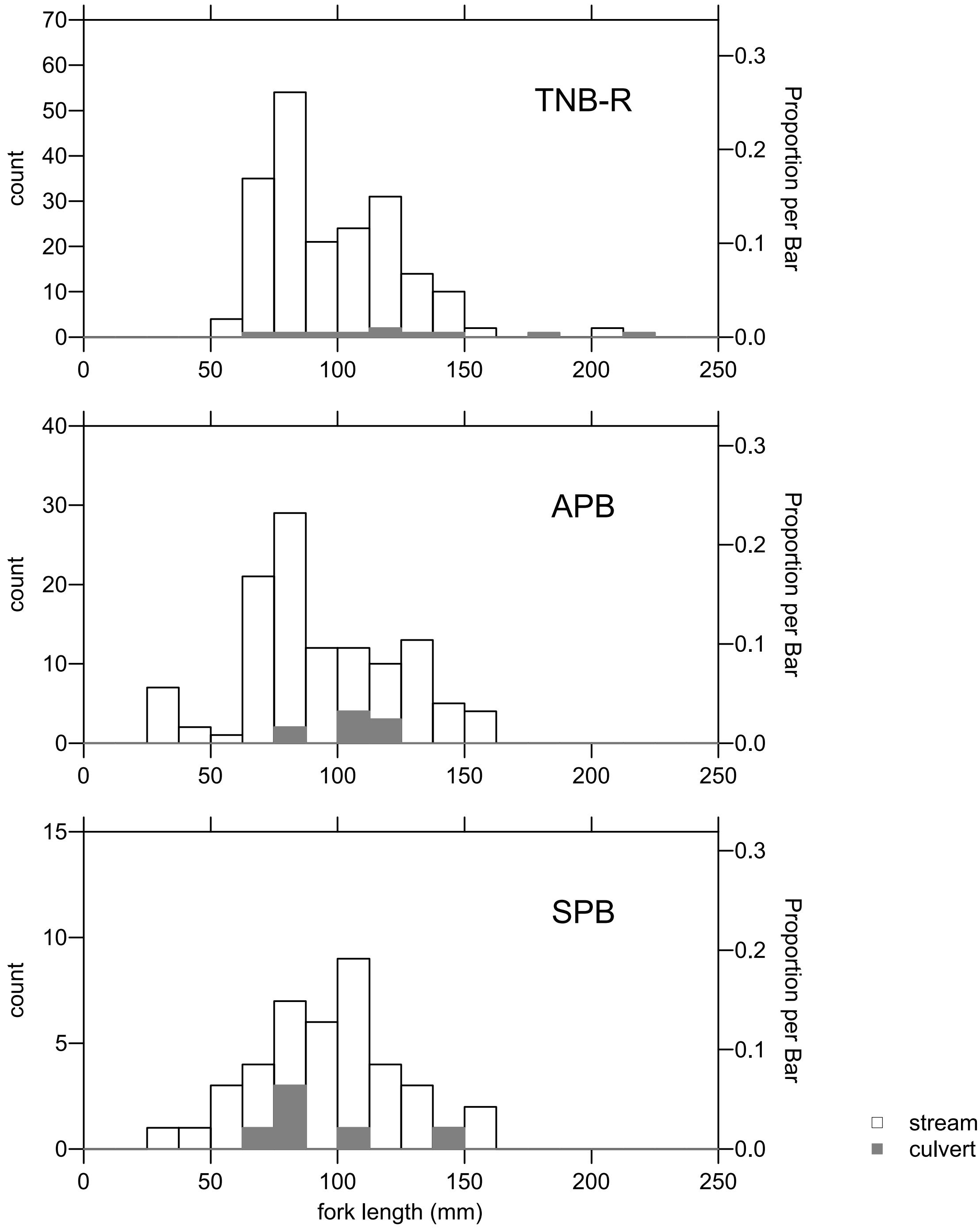

Figure 6: Length distribution of salmonids captured by electrofishing within restored culverts and in natural reaches. TNB-R: Terra Nova Brook after restoration; APB: Arnold's Pond Brook; SPB: Square Pond Brook.

SALMONID RECAPTURES

In total 553 (n_{2002} = 283; n_{2003} = 270) fish were marked and released downstream of the culverts (Table 3). In each of the culverts studied, some fish successfully passed to upstream areas (Table 4). In 2002, 5 fish were recaptured upstream of the restored Arnold's Pond Brook culvert. Electrofishing in Square Pond Brook was not possible due to dense overhanging foliage and low water conditions. However, fall surveys were unsuccessful in locating marked fish upstream or at the marking site downstream of the culvert. In Terra Nova Brook, one individual was found upstream prior to restoration efforts. In 2003, all 3 restored brooks had brook trout successfully navigate the restored culverts and Terra Nova Brook had a successful salmon parr migrant. Sizes of fish migrating through the culverts ranged from 72 to 129 mm; the smallest occurring in Arnold's Pond Brook and the largest occurring in the unrestored Terra Nova Brook culvert (Table 4).

Table 3: Fish marked and released downstream of culverts identified for restoration. Note: Marking of fish in Terra Nova, 2002 was conducted prior to restoration.

	2002		2003		Total		
	brook trout	Atlantic salmon parr	brook trout	Atlantic salmon parr	brook trout	Atlantic salmon parr	trout + parr
Terra Nova	51	82	105	31	156	113	269
Arnold's Pond	75	24	89	4	164	28	192
Square Pond	51	0	41	0	92	0	92
Total	**177**	**106**	**235**	**35**	**412**	**141**	**553**

Table 4: Recaptured fish successfully migrating upstream through culverts on the Trans-Canada Highway.

Brook	Year	Species	Recaptures upstream (% of marked fish)	Forklengths (mm)
Arnold's Pond	2002	brook trout	5 (6.7)	72, 76, 79, 101, 113
	2003	brook trout	1 (1.1)	75
Terra Nova (not restored)	2002	brook trout	1 (1.9)	129
Terra Nova (restored)	2003	brook trout	5 (5.6)	74, 94, 98, 108, 165
		Atlantic salmon parr	1 (3.2)	110
Square Pond	2002	brook trout	0 (0)	-
	2003	brook trout	1 (2.4)	119

VIDEO MONITORING

The Terra Nova Brook culvert, prior to restoration, was the only culvert in which migrating fish showed directed movements upstream. On 21 June, 5 fish successfully moved up through the culvert. The smallest was in the 12.5 – 17.5 cm size class, 3 were of the 17.5 – 22.5 cm class and 1 was of the 22.5 - 27.5 cm size class. Migrants maintained relatively constant ground swimming velocities under upstream and downstream cameras even though water velocities differed substantially (Figure 7). Swimming speeds of these individuals (1.8 – 1.9 m/s) exceeded those predicted by models of prolonged and burst swim speed (Peake et al. 1997).

Activity in restored culverts was much greater than in unrestored culverts (Figure 8). Even in unrestored culverts (e.g. Charlottetown Brook) with low gradients, observations of fish were few. The inlet of Terra Nova Brook (TCH) was the exception as it had higher activity than the inlet in Square Pond Brook. Diel patterns in activity were variable as Terra Nova Brook and Arnold's Pond Brook had diurnal activity rates more than double the nocturnal activity. In Square Pond Brook, nocturnal activity was slightly greater than the daytime. The size distribution of fish in restored culverts, based on camera observations, included smaller size classes and were more representative of the adjacent stream than in the one unrestored culvert with fish observations (Terra Nova

Brook) (Figure 9). The size range of active individuals in Terra Nova Brook ranged from 12.6 to > 27.5 cm while in the restored culverts the largest fish were in the 17.5 – 22.5 cm size-class and length modes were in the 7.5 – 12.4 cm class for Square Pond Brook and 12.5 - 17.4 cm class for Arnold's Pond Brook. Fish smaller than 12.6 cm were not observed in Terra Nova Brook culvert despite being common in the natural stream reaches.

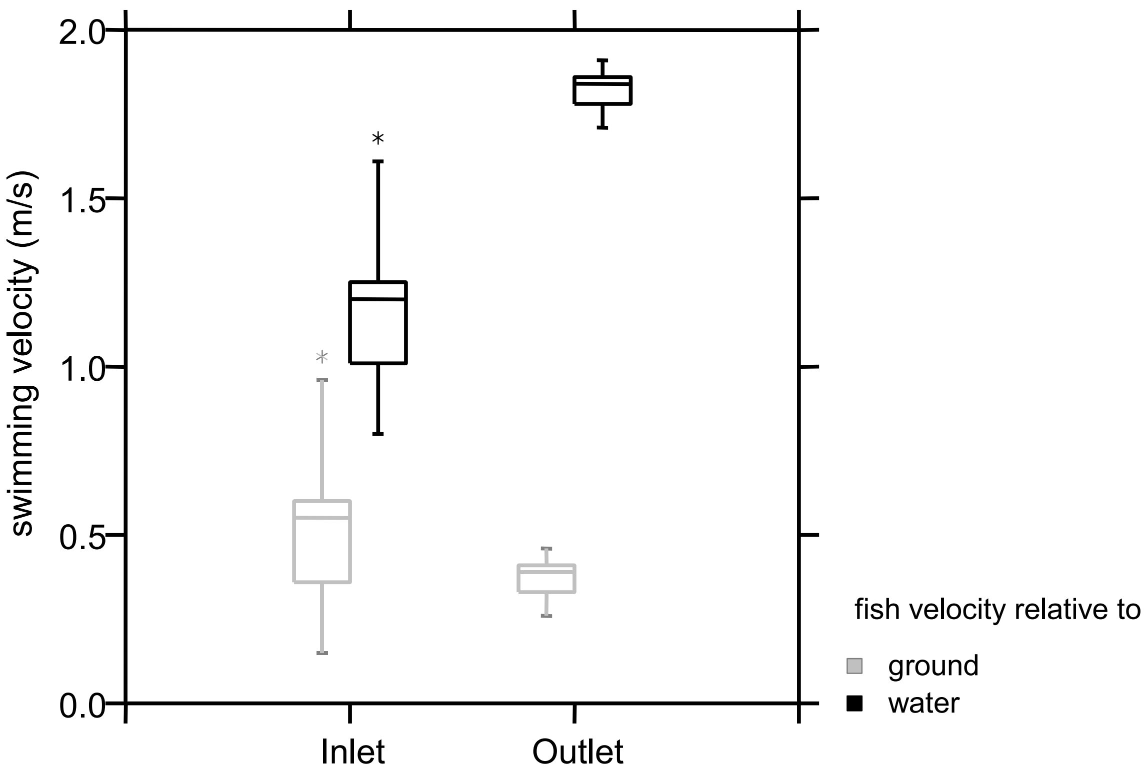

Figure 7: Swimming velocity of salmonids observed swimming upstream through the unrestored Terra Nova Brook culvert on 21 June 2002. Boxes represent mid-quartile range, mid lines represent median swimming velocity and asterisks represent outside values (>1.5 interquartile ranges from the median).

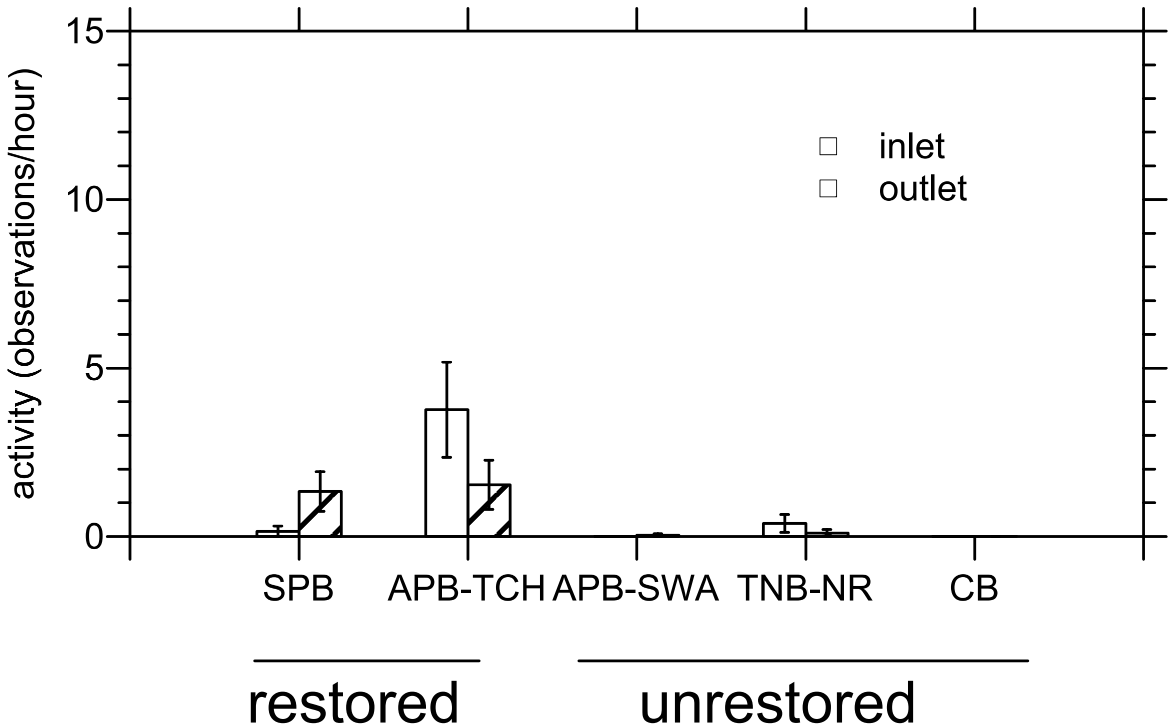

Figure 8: Activity of salmonids within restored and unrestored culverts in Terra Nova National Park, 2002. SPB: Square Pond Brook; APB-TCH: Arnold's Pond Brook at the TCH; APB-SWA: Arnold's Pond Brook at Southwest Arm Day Use Area; TNB-NR: Terra Nova Brook in its unrestored condition; and CB: Charlottetown Brook. Error bars represent SE.

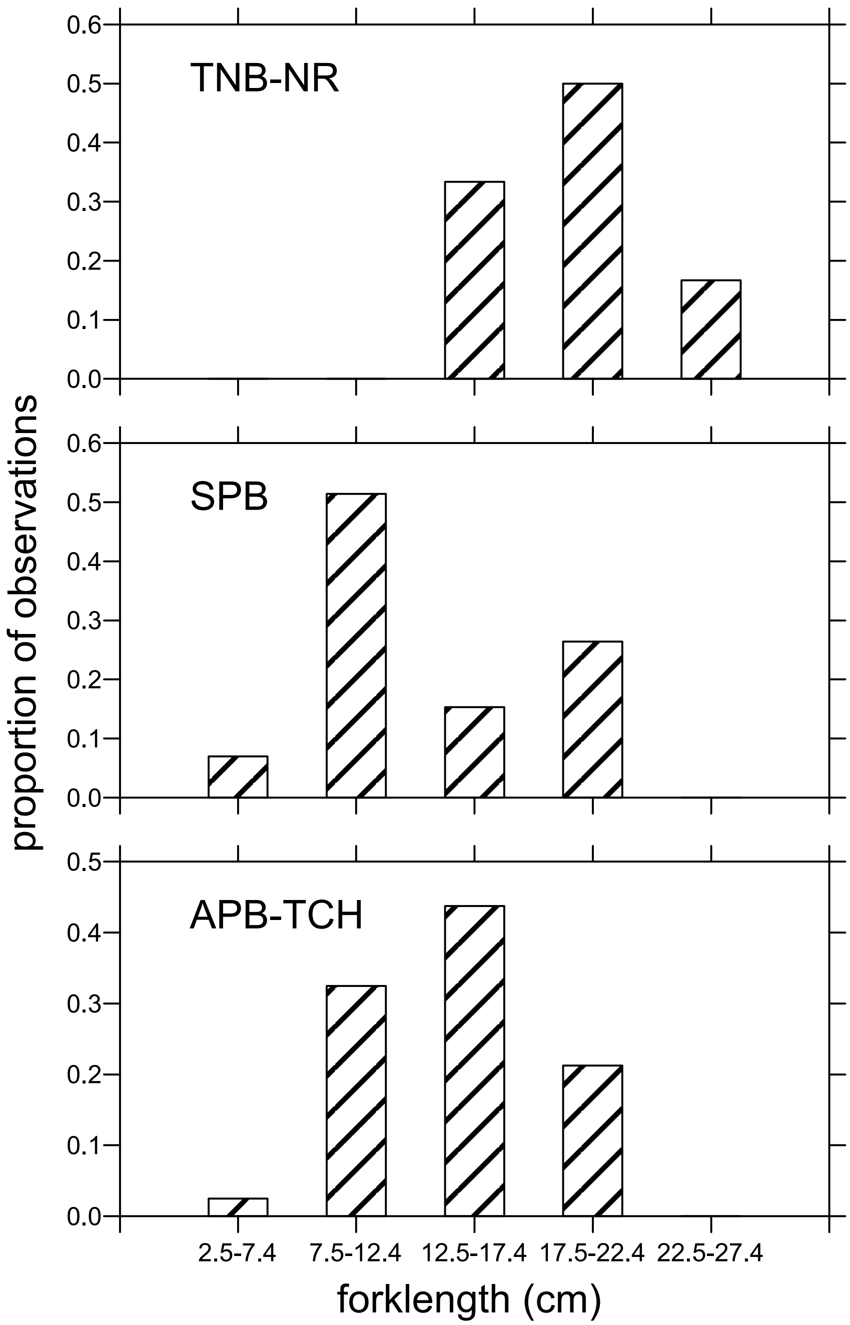

Figure 9: Size distribution of fish observed during video monitoring of culverts in Terra Nova National Park, 2002. APB-TCH: Arnold's Pond Brook at the Trans-Canada (restored); SPB: Square Pond Brook at the Trans-Canada (restored); TNB-NR: Terra Nova Brook at the Trans-Canada (prior to restoration).

FORCED SWIMS

All sample fish were able to withstand the current when placed in the culvert, with the exception of the Terra Nova Brook culvert at the TCH. At Terra Nova Brook all fish were flushed back into the barrier net on the first and second release; however on the third release one fish (Table 5) remained in the culvert towards the interface of the culvert and the water. No forward progress of this individual was observed. In the remaining unrestored culverts (Terra Nova Brook at Terra Nova Road and Charlottetown Brook), fish were able to withstand the water velocity and all moved upstream through the culvert. Water velocity in the Terra Nova Road and Charlottetown culvert was 0.69 m/s and 0.44 m/s respectively; considerably lower than that found in the Trans-Canada highway culvert on Terra Nova Brook (1.35 m/s).

Fish in the restored Arnold's Pond and Square Pond culverts hid in the substrate upon release. Electrofishing 24 h later revealed, that in Arnold's Pond Brook (0.13 m/s), one fish (76 mm) was found in the upstream pool and 4 had moved up 35 - 85% of the culvert length. The remaining three fish were not recaptured and were likely concealed within the substrate. In Square Pond Brook (0.18 m/s) no fish were found upstream of the culvert but three had migrated up 10 to 25% of the culvert length. The remaining fish were relocated above the lowest baffle and were holding station in the current.

In 2003, a second trial was conducted in the restored culverts. In Arnold's Pond, seven of ten fish were recaptured and were found upstream 5-83% of the distance of the culvert while in Square Pond only three of ten fish were recaptured. These fish had moved 5-68% of the distance in the culvert. In the restored Terra Nova Brook culvert no fish were recaptured but relatively deep water and coarse substrate made recapture more difficult.

Table 5: Upstream dispersal of fish placed in the lower end of road culverts. NR – fish not recaptured within the culvert; * weights unavailable.

Brook	Date	Water velocity (m/s)	Culvert length (m)	Species	Length (mm)	Weight (g)	Upstream displacement at recapture (m)
Square Pond (restored)	July 4, 2002	0.179	40	Brook trout	85	6	8 – 10
					85	6	10 – 12
					87	6	0 – 2
					93	7	2 – 4
					102	11	0 – 2
					104	11	0 – 2
					106	12	2 – 4
					117	17	0 – 2
					122	17	0 – 2
					128	22	0 – 2
Arnold's Pond (restored)	July 5, 2002	0.129	40.5	Brook trout	72	*	16 – 18
					76	*	32 – 34
					76	*	40+
					77	*	14 – 16
					88	*	NR
					88	*	NR
					95	*	NR
					96	*	30 – 32
Terra Nova (TCH) (unrestored **)	July 2, 2002	1.35	60.7	Brook trout	90	8	Failed
					113	12	Failed
					128	20	Failed
					129	21	Failed
					137	29	Failed
					148	37	Failed
					150	35	Failed
				Juvenile Salmon	134	27	Failed
Charlottetown (unrestored)	July 4, 2002	0.439	31.5	Brook trout	83	*	31.5+
					83	*	31.5+
					88	*	31.5+
					91	*	31.5+
					91	*	31.5+
					93	*	31.5+
					95	*	31.5+
					98	*	31.5+
					109	*	31.5+
					122	*	31.5+
Terra Nova Brook (Terra Nova Road) (unrestored)	July 3, 2002	0.689	20	Brook trout	170	41	20+
				Juvenile Salmon	84	6	20+
					110	18	20+
					111	16	20+
					112	15	20+
					115	19	20+
					123	22	20+
					124	22	20+
					129	25	20+
					130	24	20+
Terra Nova Brook (TCH) (restored)	July 8, 2003	0.22	62	Juvenile salmon	112	16.6	NR
					130	24.4	NR
					113	15.1	NR
					117	18.2	NR
					114	16.8	NR
				Brook	110	16.3	NR
					96	9.0	NR

				trout	114	14.8	NR
					98	10.2	NR
					83	6.5	NR
Square Pond Brook (restored)	July 8, 2003	0.13	38	Brook trout	165	51.8	NR
					145	36.1	2-4
					119	16.8	26-28
					132	19.1	4-6
					117	16.1	NR
					108	13.6	NR
					101	10.2	NR
					108	11.2	NR
					113	14.5	NR
					102	10.2	NR
Arnold's Pond (restored)	July 8, 2003	0.52	40	Salmon juvenile	105	15.1	23-25
				Brook trout	180	33.3	NR
					101	10.2	2-5
					135	25.7	NR
					86	8.7	2-5
					101	12.5	2-5
					102	11.3	NR
					111	14.4	12-14
					95	8.9	27-29
					94	7.8	33-36

INVERTEBRATE COMMUNITY

Taxonomic diversity of stream invertebrates in restored culverts was similar to that found in the natural stream reaches (Figure 10; Square Pond Brook: $t_{d.f.=4} = 0.32$, $p = 0.77$; Arnold's Pond Brook: $t_{d.f.=4} = 0.71$; p 0.52). In unrestored culverts, family diversity was approximately half found in natural riffles though it was only statistically significant in Terra Nova Brook (Terra Nova Brook: $t_{d.f.=4} = 2.5$, $p= 0.013$; Charlottetown Brook: $t_{d.f.=4} = 4.2$, $p = 0.082$). Due to small sample sizes, statistical power was quite low. Unrestored culverts were dominated by dipterans (e.g. Simulids) whereas natural reaches and restored culverts had relatively high numbers of Trichoptera, Plecoptera, Ephemeroptera and chironomids.

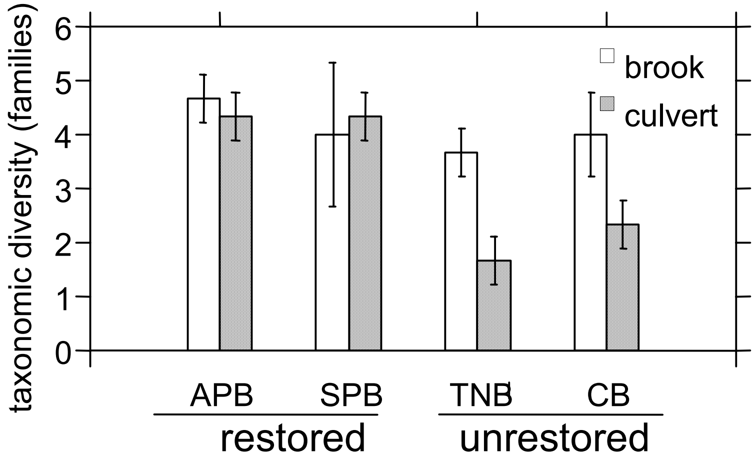

Figure 10: Taxonomic diversity of stream invertebrates within restored and unrestored culverts and natural reaches of brooks. APB: Arnold's Pond Brook; SPB: Square Pond Brook; TNB: Terra Nova Brook; CB: Charlottetown Brook. Error bars represent SE.

DISCUSSION

Recommendations for culverts installations limit their use to gradients of 5% or less when baffles are used (Katapodis et al. 1978; U.S. National Marine Service 2000; Fisheries and Oceans Canada 2003). In small, high gradient streams, such as those found in Terra Nova National Park, these recommendations cannot be achieved without creating a substantial outflow drop. This study suggests that less expensive pipe culverts, modified with baffles, have some utility in restoring fish passage and habitat.

Highway culverts in Terra Nova National Park have had negative impacts on fish migration and possibly production. For the brooks examined, fish biomass and density was lower in upstream reaches than downstream reaches, particularly for anadromous Atlantic salmon. These findings suggest reduced production and support those of Thompson (1981a) who indicated an absence of salmon above the TCH culvert in Terra Nova Brook. Obstructions are likely to negatively impact production as fish are unable to move about a system to meet changing ontogenetic habitat needs (Dryden and Stein 1975; Baker and Votapka 1990). In Newfoundland, nonanadromous and anadromous salmonids move from fluvial to lacustrine habitats as juveniles (Hutchings 1985; Robertson 2003) and adults (Hutchings 1985). Lacustrine habitats are known to promote growth (Hutchings 1985), whereas fluvial habitats support the young-of-the-year age classes. Seasonally, movements between lacustrine and fluvial habitats may be beneficial as thermal regimes differ, as does the availability of suitable cover during low water periods. For adults, access to spawning grounds often requires upstream movements to headwater areas.

The restored culverts employed in this study appeared to benefit upstream migration of salmonids as upstream movements occurred in all restored culverts, of which two were previously impassable. As expected (based on Engel 1974), migration success in restored culverts appeared to be negatively correlated with slope. Though sample sizes of recaptures were small, the most recaptures were taken in Terra Nova Brook (gradient = 2.7%), followed by Arnold’s Pond (gradient = 7.1%) and Square Pond Brook (gradient = 8.9%). Gradients such as that found in Square Pond Brook and Arnold’s Pond Brook exceed that recommended for closed bottom culverts in Virginia (3%; Fitch 1995) and British Columbia (6%; B.C. Ministry of Forests 2002) rivers. Bryant (1981), however, reported successful fish passage of small (<120 mm) Dolly Varden char, coho salmon, and cutthroat trout at low discharge on an artificial baffled culvert with a gradient of 10%. Other baffle designs (e.g. spoiler and offset baffles) were not able to pass target species because spawning migrations coincided with high discharges – conditions in which baffles are less effective (Katapodis et al. 1978). At very low flows, the high gradient of Square Pond Brook resulted in inadequate water depths for short distances immediately downstream of the scour baffles. Scour baffles in this culvert were not of sufficient height to impound enough water to create a pool that extended to the baffle immediately upstream. These conditions may have contributed to the low rates of upstream migration observed in that culvert. The addition of coarse substrates to restored culverts may also have improved fish passage, as has been documented for American eel elvers (Barbin and Krueger 1994). Unfortunately, the effects of substrate cannot be discriminated from the effects of the scour baffles in this study.

Hydraulic conditions within the restored culverts had similarities to the natural reaches over the discharges examined. Water velocities in restored culverts were comparable to that measured in natural reaches and were consistent with swim speeds typically occupied by Atlantic salmon parr (0.33-0.36 m/s; Heggenes et al. 1999). In the natural reaches, high velocity riffles only extended for 10 to 20 cm - similar to that found in the vicinity of the scour baffles in the restored culverts. Conversely, in unrestored culverts, water velocity greatly exceeded that found in natural reaches and extended for the entire length of the culvert. Since burst-swimming speeds of brook trout can be 2-3 times greater than sustained swimming speeds (Peake et al. 1997), the short zones of high velocity in restored culverts were passable by fish. Extended zones of high velocity, such as found in the unrestored culverts, require prolonged swimming and can act as barriers. Only in cases where gradients were quite low (e.g. Charlottetown Brook), was water velocity similar to that found in natural reaches. Katapodis et al. (1978) documented flow characteristics of standard pipe culverts with those modified with spoiler and offset baffles. Standard pipe culverts exhibited laminar flow with high velocities occurring through a large area in the center of the channel and a small boundary layer of lower velocity water at the water's interface with the culvert. Profiles of baffled culverts showed a greater prevalence of low flow zones in the cross sectional profile. Although somewhat different in design, the scour baffles employed in this study had qualitatively similar features. High velocity was restricted to a relatively small area in the middle of the channel and only in the vicinity of the baffles. Further disruption of flow was caused by the coarse substrate. At elevated discharges however, site inspections revealed water flow well above the baffles and substrate and high flows occurred across the entire water surface. Though temporary, such high flows can be a barrier and alter fish behaviour (e.g. delayed access to spawning grounds; Dryden and Jessop 1974). Depths within restored culverts were considerably deeper than in the unrestored condition though still below recommended (20 cm) in Square Pond and Arnold's Pond brooks. However, this appeared to be typical of natural reaches in these small first order brooks.

Comparisons of culvert velocities to burst and sustained swimming speeds from Peake et al. (1997) indicate that brook trout >10 cm should be able to sustain swimming in the restored culverts whereas fish smaller than 12.5 cm may have difficulties surmounting flows found at the baffles. For Atlantic salmon parr, all individuals (5.5 - 14.7 cm) should be capable of holding position in culverts but all may have difficulty surmounting water velocities typically found at the baffles. In Terra Nova Brook, in its unrestored state, trout smaller than 24 cm were likely obstructed, as were salmon parr. Interestingly, of the three fish detected to migrate up the unrestored culvert (maximum sizes were 17.5, 22.5, and 27.5 cm), two were smaller than 24 cm and the other, which was larger than 24 cm, was swimming at velocities higher than would be predicted given the predictions of Peake et al. (1997). Heggenes et al. (1999) report that snout velocities of Atlantic salmon are considerably lower than the associated surface velocities of that habitat. Since water velocities were measured at the surface in this study, they may not have been representative of those the fish were experiencing if utilizing the boundary layer. An alternative explanation is that motivational differences between fish in natural environments and in experimental conditions differ.

Clear differences were observed in restored and non-restored culverts in terms of fish activity. Small fish were able to withstand the current within restored culverts and were observed to inhabit these areas. In contrast, very few fish were observed in non-restored culverts even though fish passage was possible for larger individuals. In Charlottetown, water flow was comparable to that in the streambed and in restored culverts but still no fish were found within the culvert suggesting a habitat suitability issue – perhaps a lack of instream cover or insufficient depth. Densities of fish within culverts, obtained through electrofishing, validated these findings. Fish biomass in restored culverts ranged from 33 to 90% of the adjacent stream whereas in unrestored culverts (Terra Nova Brook and Charlottetown Brook) no fish were obtained through electrofishing.

Size distribution of fish observed or sampled within the restored culverts appeared more representative of what was available in other reaches of the stream, than those sampled within unrestored culverts. In Terra Nova Brook prior to restoration, use by salmonids appeared to be restricted to fish greater than 12.5 cm; likely a result of the relatively high water velocities measured. Nonetheless, during electrofishing surveys, the smallest size-classes seemed under represented (30-70 mm) in two of the three restored culverts and the largest were absent from Arnold's Pond Brook. However, because these size-classes are relatively rare in natural reaches, these findings may be an artifact of the small sample of fish captured in the culverts. This hypothesis is supported by the fact that video observations of fish in Arnold's and Square Pond Brook indicate a size distribution that includes those size classes (< 7.5 cm and > 12.5 cm) not detected during electrofishing.

The density of aquatic invertebrates differed little between natural reaches and restored and unrestored culverts. Improper highway culvert installation has been reported to have negative impacts on benthos due to scouring and increased levels of silt and/or chemical toxicants from roads (Dryden and Stein 1975). Taxonomic diversity, however, was similar in restored culverts and natural reaches – likely owing to the improved diversity of habitat types. Whether the more naturalized invertebrate communities improve conditions for fish is uncertain particularly since fish observed under cameras were driftfeeding. Nonetheless, such results are another indication that positive improvements have been achieved.

All of the monitoring in this study was conducted in summer and fall during low to mid-level water flows. These periods are known to be important to Atlantic salmon and anadromous and non-anadromous trout spawning migrations (Scott and Crossman 1990). Late fall and winter movements have also been highlighted as a period of movement and behaviour shift for juvenile Newfoundland salmonids (Robertson 2004). These periods coincide with higher discharges and therefore the restoration efforts implemented in this study may not be effective in such conditions. Though it was not the intent to allow fish passage during all flow conditions (if not the natural condition) it is likely that restored culverts are less effective at high flows. In restored culverts, no flood plains exist to dissipate floodwaters as found in natural areas. Also, the addition of substrate to reduce flow velocity becomes less effective as water depths increase. In fact, there is an exponential decrease in the impact that the coarse substrates has on flow as discharge increases (Hicks and Mason 1991). As less water comes in contact with the rough bottom, the culvert water flow begins to resemble an unrestored smooth-bottomed culvert. Discharge estimates for the study brooks, based on a nearby river in Terra Nova National Park, (Appendix E), indicate March and April may result in the poorest conditions for upstream fish passage. To assess the performance during high water flows will require other techniques as video monitoring is ineffective in turbulent water and electrofishing would be unsafe at high flows. Other technologies like PIT tags have promise but instilling motivation in fish to swim up culverts is a challenge to be addressed.

Each of the techniques used in this initiative had limitations. Video monitoring was ineffective to determine successful passage rates in restored culverts primarily because individuals did not pass through the culvert in a deliberate fashion and often stayed within the culvert for extended periods of time. Furthermore, in the relatively deep, coloured waters of Terra Nova Brook (post restoration) it was difficult to distinguish passing fish. The approach was satisfactory for monitoring fish passage only in unrestored culverts but was useful for monitoring use by fish. Mark-recapture techniques provided definitive information on voluntary passage success but sample sizes of recaptured fish upstream were small – perhaps because the study period did not encompass any migrations. The fish passage manipulations also demonstrated that fish were able to move up through culverts and/or occupy culvert habitats for sustained periods of time. However, successful upstream passage was likely underestimated as many individuals were not recaptured and the remaining fish were not monitored continually. Finally, fish density was likely underestimated in restored culverts during electrofishing. Recapture of fish within culverts was difficult due to low light levels and the tendency of shocked fish to go into the interstitial spaces of the coarse substrates. Despite these limitations, these components each contribute insight to the effectiveness of this restoration approach.

A primary concern with baffled culverts is the potential for debris build up (Fitch 1995; Baker and Votapka 1990; National Marine Fisheries Service 2000). After approximately 2 years, we are able to report on preliminary maintenance requirements. Congestion within the culverts from debris has not been an issue, though sedimentation is beginning to occur within the scour baffles. Given the original goal of having a naturalized channel, this is viewed as a positive development. Sediments are filling interstitial spaces and resulting in a greater resemblance to natural areas. In Arnold's Pond Brook, however, flash floods scoured coarse substrate from the top half of the culvert to the bottom half and the adjacent downstream pool. Potential mitigation solutions for this problem are to use larger boulders to disrupt flow or increase the height of scour baffles. Increased scour baffle height may also mitigate the shallow water depths observed on Square Pond Brook at low flows. Such modifications, however, cannot be done without consideration of the impacts to the hydraulic capacity of the culvert.

This study documents a restoration approach that has enhanced highway culverts for fish passage and habitat quality at low flows despite being installed at gradients greater than recommended. As a result, these economical designs may have utility for use in small high gradient streams.

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APPENDIX A

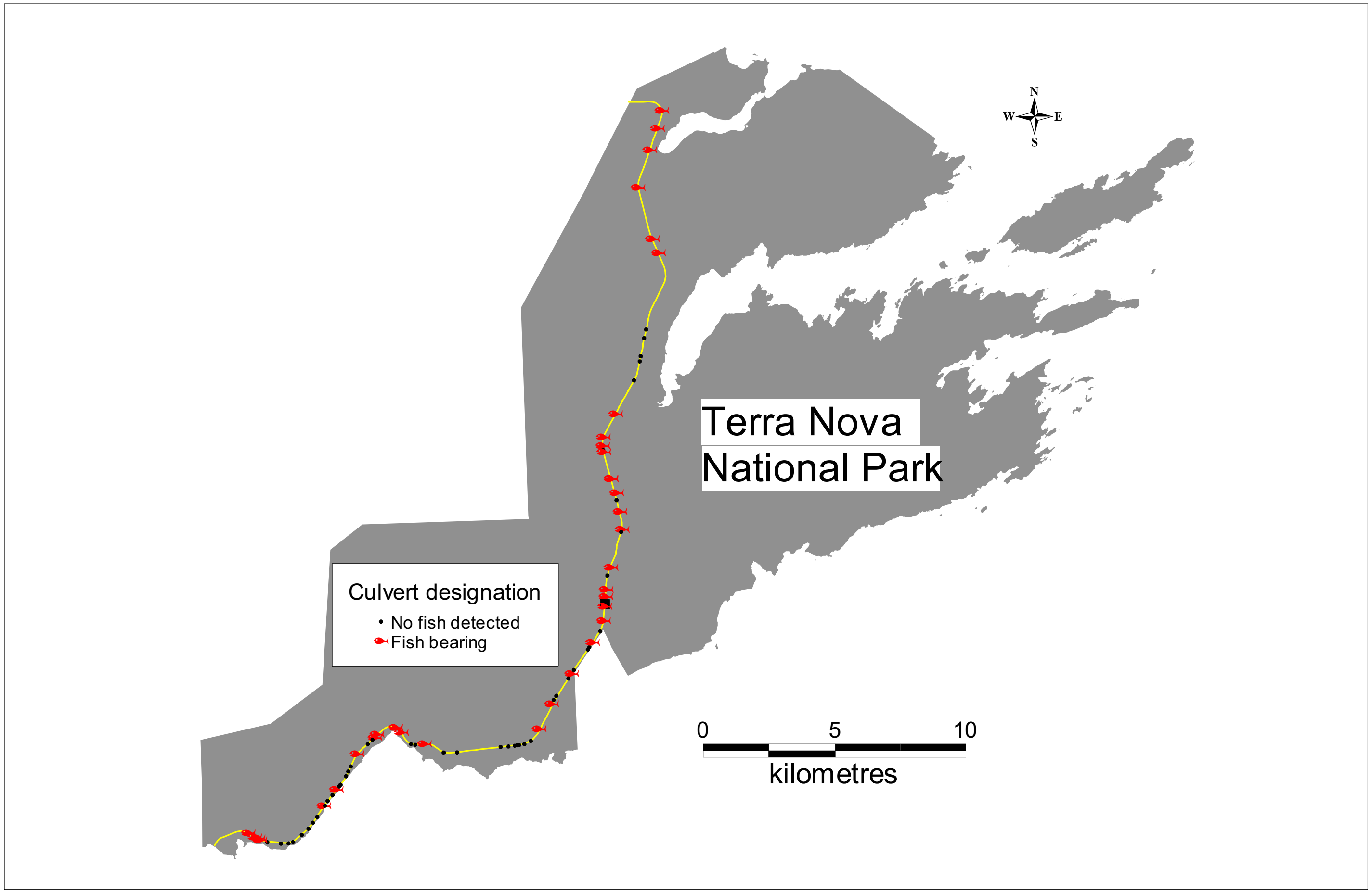


Figure A1: The distribution of culverts (fish and non-fish bearing) on the Trans-Canada Highway, TNNP.

Table A1: Fish bearing status of brooks in Terra Nova National Park. Station number indicates distance on road from southern park boundary. NS: not sampled.

Station No.	Survey Date	Species
01-570	05/07/01	Trout
01-855	05/07/01	Trout
01-999	05/07/01	Trout
02-089	05/08/01	Trout, Stickleback
02-396.5	05/10/01	None
02-892.6	05/10/01	NS
03-197.4	05/10/01	NS
03-399.3	05/10/01	NS
03-791.6	05/16/01	Trout
04-151.9	05/16/01	NS
04-426.4	05/16/01	NS
04-695.4	05/16/01	NS
05-087.3	05/10/01	Trout
05-233.8	05/16/01	NS
05-420.4	05/16/01	NS
05-715.1	05/16/01	NS
05-933.4	05/10/01	Trout
06-146.1	05/16/01	NS
06-222.9	05/16/01	NS
06-613.3	05/16/01	NS
06-815.4	05/16/01	NS
07-022.4	05/16/01	NS
07-266.3	05/14/01	Trout, Salmon
07-509.7	05/14/01	Trout
08-106.7	05/16/01	NS
08-348.6	05/16/01	NS
08-465.3	05/16/01	Trout
08-596.1	05/16/01	Trout
09-429.3	05/16/01	Trout
09-701	05/16/01	Trout
10-292.4	05/16/01	NS
10-469.7	05/22/01	NS
10-806.8	05/16/01	Trout
11-637.3	05/22/01	NS
12-144	05/07/01	NS
13-820	05/07/01	NS
14-110.4	05/22/01	None
14-352.4	05/22/01	NS
14-443.2	05/22/01	NS
14-525.7	05/22/01	NS

Station No.	Survey Date	Species
14-726.6	05/22/01	NS
15-003.8	05/22/01	
15-527.7	05/07/01	Trout
16-604	05/07/01	Trout
16-793.2	05/07/01	NS
16-975	05/07/01	NS
17-781.2	05/22/01	NS
17-998.9	05/08/01	Trout
18-127.9	05/08/01	NS
19-119	05/22/01	No fish
19-215.7	05/14/01	NS
19-421.1	05/14/01	Trout
19-931	05/22/01	NS
20-334.8	05/14/01	Trout
20-909.2	05/14/01	Trout
20-990.3	05/22/01	NS
21-022.4	05/22/01	No fish
21-264.8	05/22/01	Trout
21-516.6	05/22/01	Salmon
22-099.5	05/22/01	NS
22-403.1	05/22/01	Trout
23-845.8	05/22/01	No fish
23-918.6	05/14/01	Trout
24-616.7	05/22/01	Trout
25-093.3	05/22/01	NS
25-388	05/22/01	Trout
25-905	05/22/01	Trout
25-937.5	05/14/01	Trout
26-937.5	05/22/01	Trout, Salmon
27-060	05/22/01	NS
27-205.1	05/22/01	Trout
27-542.3	05/25/01	Trout, Stickleback
28-546.7	05/22/01	Trout
30-022.3	05/22/01	No fish
30-774.2	05/22/01	NS
30-973.2	05/22/01	NS
31-688.2	05/07/01	No fish
31-688.2a	05/07/01	No fish
31-980.2	05/08/01	No fish
35-112	05/10/01	Trout
35-682	05/10/01	Stickleback
37-700	05/07/01	Trout
39-224	05/07/01	Trout
40-063	05/08/01	Trout
40-798	05/07/01	Trout

APPENDIX B: Study site locations.

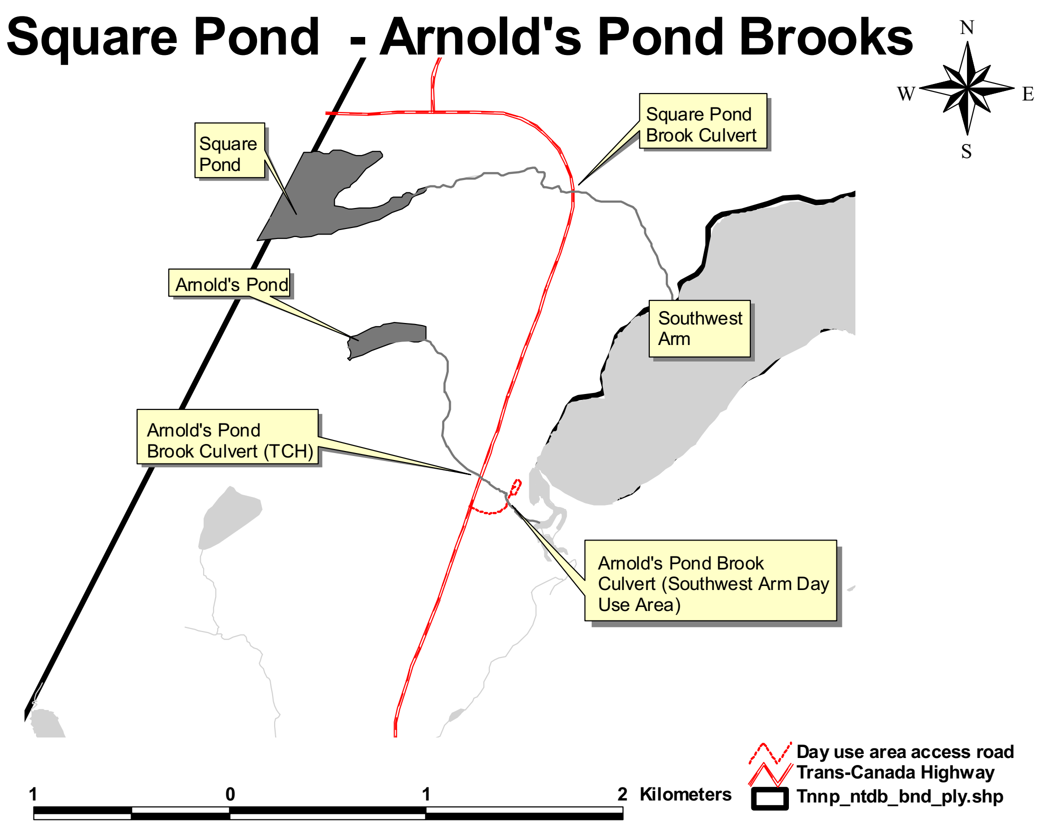


Figure B1: Study locations in the Square Pond and Arnold's Pond watersheds.

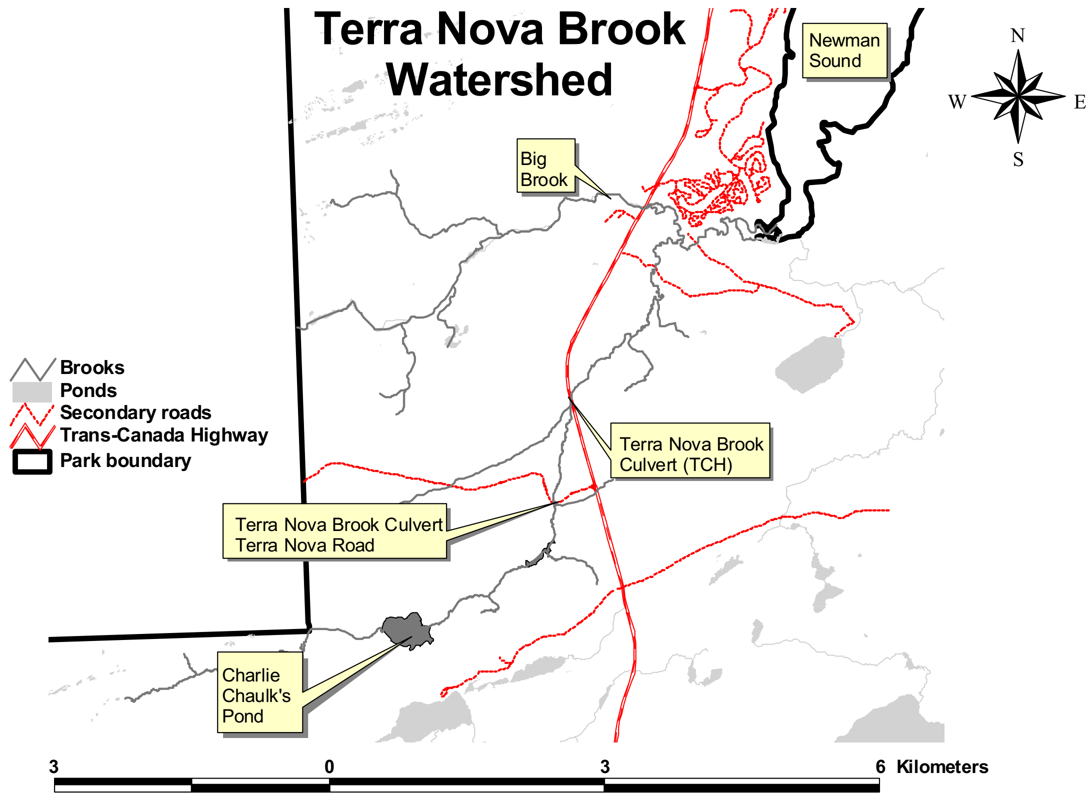


Figure B2: Study locations in the Terra Nova Watershed.

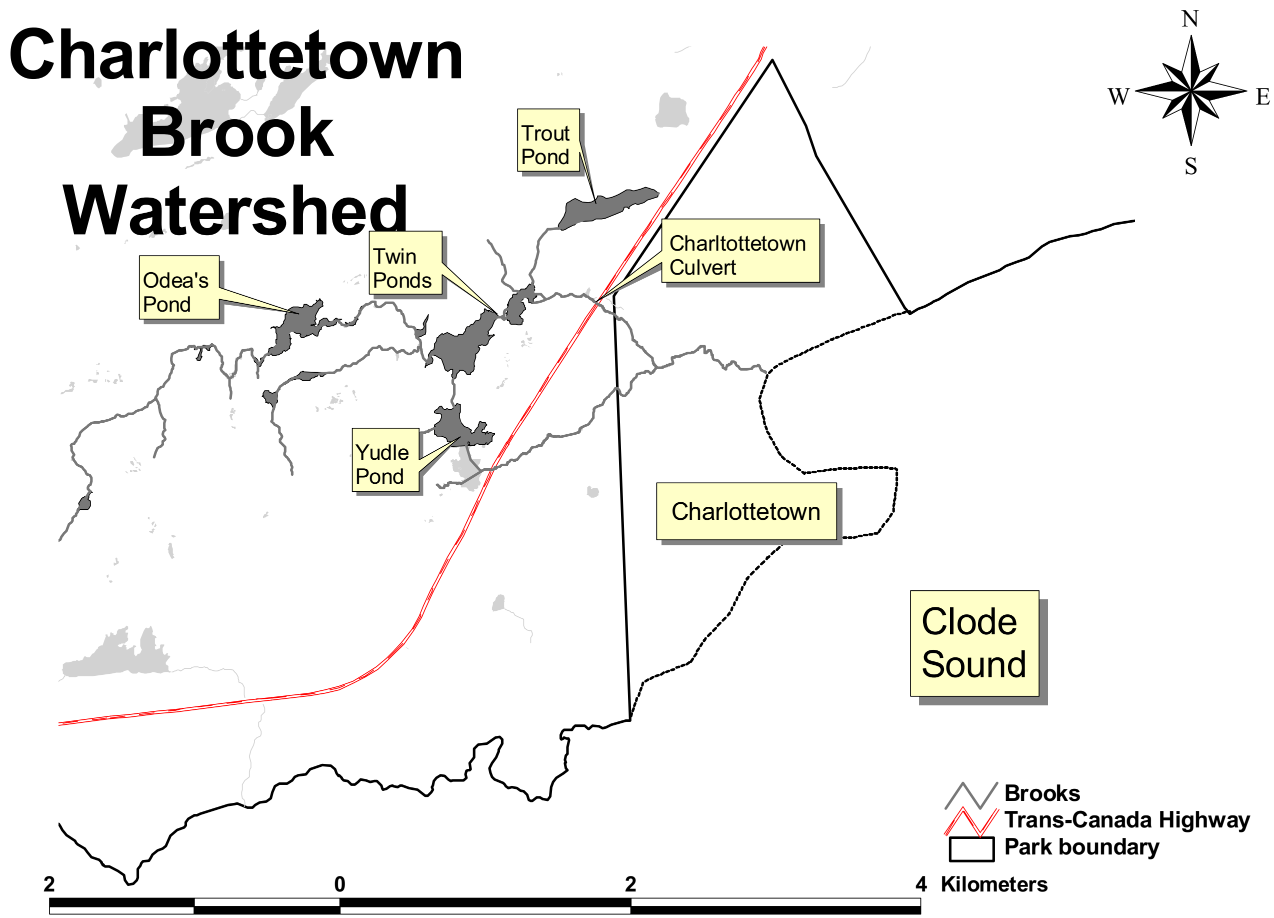


Figure B3: The study location in the Charlottetown watershed.

APPENDIX C

Characteristics of the three restored and two unrestored culverts examined in Terra Nova National Park.

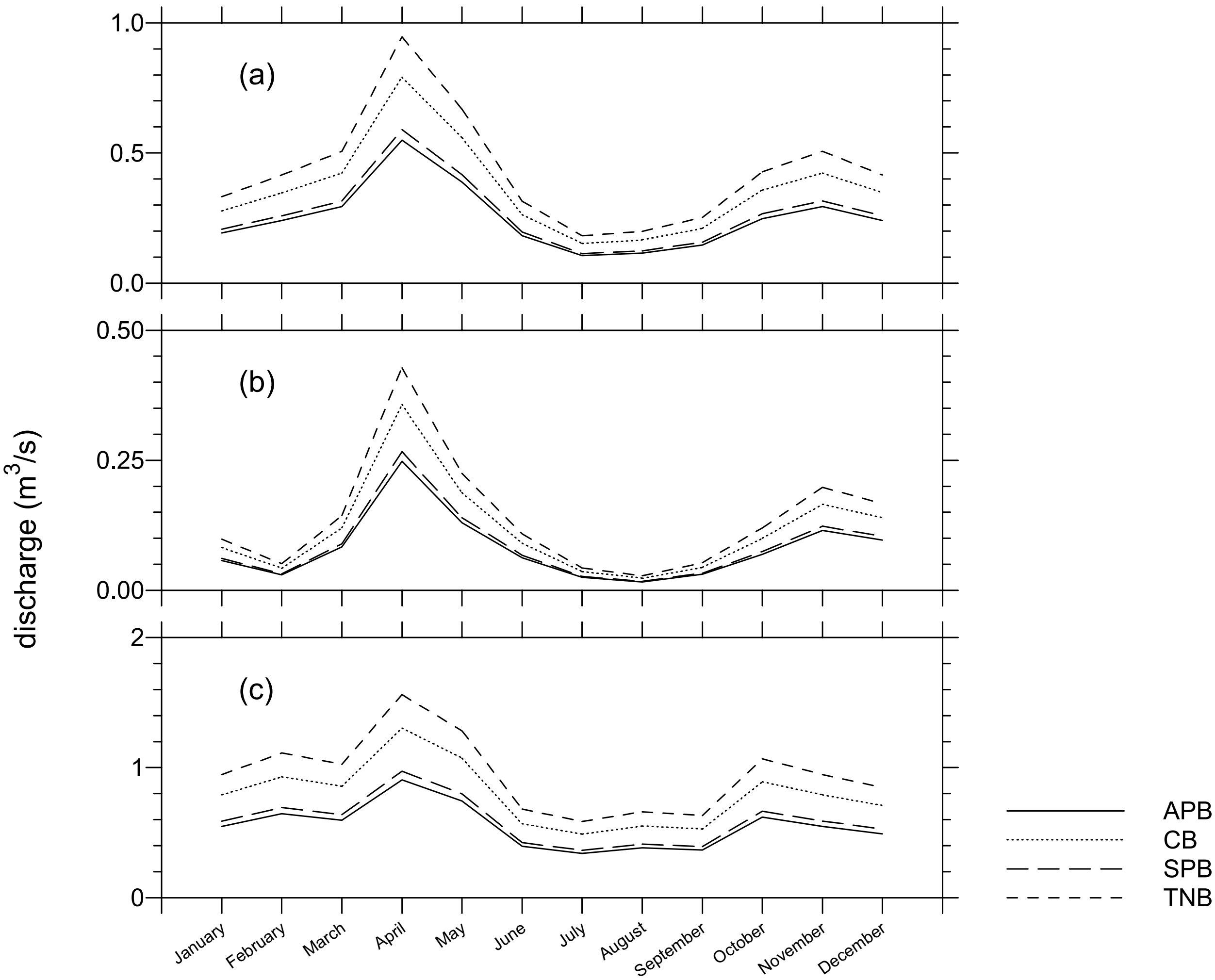
	Pre-restoration			Post restoration		
	Length (m)	Slope (%)	Outlet drop (m)	Length (m)	Slope (%)	Outlet drop (m)
Charlottetown	30.8	1.0	0	-	-	-
Arnold's Pond	40	5.2	0.67	40	7.1	0
Square Pond	38	5.8	0.94	38	8.9	0
Terra Nova - TCH	61.5	1.4	0.32	62	2.7	0
Terra Nova – Terra Nova Road	17.2	1.9	0	-	-	-

APPENDIX D

Stream characteristics of study brooks upstream (U) and downstream (D) of study culverts and for both combined (U+D).

Brook	Location	Stream Order	Average Section Gradient (%)	Average Canopy Coverage (%)	Average Substrate Length (cm)	Average Wetted Width (m)	Average Bankfull Width (m)	Thalweg Velocity (m/s)	Average Depth (cm)
Arnold's	U	1	5.6	80	11.9 Range: 7 - 18.5	1.43 Range: 0.91 - 2.13	3.20 Range: 1.95 - 3.9	0.18	11.2
	D		5.3	50	11.1 Range: 2.5 - 25	1.39 Range: 0.75 - 2.45	3.10 Range: 1.9 - 5.7		13
	U+D		5.5	65	11.5 Range: 2.5 - 25	1.71 Range: 0.75 - 2.45	3.18 Range: 1.95 - 5.7		12.1
Square Pond	D	1	6.9	75	13.7 Range: 3 - 44	1.42 Range: 0.63 - 3.05	2.79 Range: 1.55 - 4.85	0.17	10
Terra Nova	U	2	2.7	60	13.3 Range: 8 - 27	2.89 Range: 1.46 - 4.78	4.52 Range: 3.4 - 6.8	1.50	14.6
	D		2.3	67	13.9 Range: 4 - 22	3.77 Range: 1.98 - 5.43	4.95 Range: 3.28 - 6.9	1.70	20.9
	U+D		2.5	63	13.6 Range: 4 - 27	3.33 Range: 1.46 - 5.43	4.73 Range: 3.28 - 6.9	1.60	17.8
Charlottetown	U	2	3.5	10	19.5 Range: 6 - 44	2.07 Range: 0.46 - 5.6	5.96 Range: 3.65 - 8.7	2.18	16.4
	D		3.6	17	15.7 Range: 6 - 37	1.83 Range: 0.38 - 5.28	5.72 Range: 4.4 - 8.6	1.78	17.9
	U+D		3.5	13	17.7 Range: 6 - 44	1.95 Range: 0.38 - 5.6	5.84 Range: 3.65 - 8.7	1.98	17.2

APPENDIX E



Seasonal (a): mean; b) minimum; c) maximum) discharge of study brooks estimated from discharge at the Southwest Brook monitoring station, Terra Nova National Park and adjusted for watershed area. APB: Arnold's Pond Brook; CB: Charltottetown Brook; SPB: Square Pond Brook; TNB: Terra Nova Brook. Discharge (Q) estimated from: $Q_{\text{Brook x}} = Q_{\text{Southwest Brook}} [(\text{Watershed area}_{\text{Brook x}}) / (\text{Watershed area}_{\text{Southwest Brook}})]^{0.8}$.