

EVALUATION OF ATLANTIC SALMON PARR RESPONSES TO HABITAT IMPROVEMENT STRUCTURES IN AN EXPERIMENTAL CHANNEL IN NEWFOUNDLAND, CANADA

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ABSTRACT

Distributional patterns and microhabitat selection of Atlantic salmon (*Salmo salar*) parr were investigated in relation to habitat improvement structures in a controlled flow experiment channel at Noel Paul's Brook, Newfoundland. The channel consisted of six replicates, each containing three randomly arranged treatments. Each replicate included a control treatment with no habitat modification, a mid-channel treatment with a boulder cluster and low-head barrier dam, and a stream bank treatment with undercut banks and wing deflectors. The influence of size class, density, discharge and diurnal/nocturnal differences on microhabitat selection were evaluated. Results showed that the mid-channel treatment did not serve its purpose at lower discharges ($0.032\text{--}0.063\text{ m}^3\text{ s}^{-1}$), and as a result was not the treatment of choice. However, as the discharge increased ($0.13\text{ m}^3\text{ s}^{-1}$), more salmon took up residence in this treatment. In all experiments, greater depths were selected in the stream bank treatment, and salmon parr in the mid-channel treatment consistently selected positions closer to cover. Larger parr preferred greater depths and were found closer to the improvement structures. Benthic and drifting food availability were also estimated, and results showed that 'funneling effects' of the drift were created near the structures. This study indicates that these structures have the potential to create favourable feeding sites, and provide the necessary physical characteristics required by salmon parr. © 1998 John Wiley & Sons, Ltd.

KEY WORDS: habitat improvement; *Salmo salar*; Newfoundland; microhabitat; distribution; food availability

INTRODUCTION

Habitat improvement structures are devices used to repair or improve damaged fish habitat and, in some instances, to increase the productive capacity of natural habitats. Many rivers in Newfoundland have been affected by human activities. As a consequence, problems, such as channelization, unstable stream banks, heavily silted gravels and areas completely lacking in instream and overhanging cover arise. It is important to restore such degraded habitats using the best available techniques to maintain and increase fish productivity. Stream restoration techniques, including pool creation, placement of instream and overhanging cover, bank stabilization and revegetation, must be assessed and the problems associated with degraded habitats must be documented to justify the costs involved.

Fish habitat improvement has been common practice in North America for decades but has not been widely used or tested under Newfoundland and Labrador conditions (Bourgeois *et al.*, 1993). Stream restoration should create desirable microhabitat conditions and many techniques have been used with varying degrees of success (Saunders and Smith, 1962; Hunt, 1976; House and Boehne, 1985, 1986; Knudsen and Dille, 1987; Moore and Gregory, 1988; Näslund, 1989; Armantrout, 1991; Binns, 1994; House, 1996). However, the question arises as to whether habitat improvement techniques used elsewhere in North America, and developed primarily for trout species, are applicable to local conditions and species, in particular Atlantic salmon. It is important to know which techniques are appropriate and whether they can be improved for use in Newfoundland waters.

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This study involved the investigation of both macrohabitat use and selection for microhabitat features, created by mid-channel and stream bank improvement structures, by Atlantic salmon (*Salmo salar*) parr. The objectives were, first, to determine the applicability of habitat improvement techniques to local conditions and species by evaluating habitat preferences in a broad distributional context under varying discharges and densities; secondly, to evaluate microhabitat conditions selected by salmon parr; and thirdly, to determine the influence of size class and diurnal/nocturnal differences on microhabitat selection and choice of position in relation to the improvement structures. Habitat selection and distribution of fish are not only dependent on the physical environment, but are also related to a number of limiting factors including food availability (Chapman, 1966). Therefore, the fourth objective of this study was to test the hypothesis that these structures were causing a 'funnelling effect' of the drift in the channel. Although the study focused on the commonest species, Atlantic salmon, a few brook trout (*Salvelinus fontinalis*) were also observed in the channel. However, they were excluded from the study as there were too few observations.

STUDY SITE

The Exploits River is the longest river and the largest drainage basin on the island of Newfoundland. The river is 267 km long and drains an area of 11272 km². An abandoned spawning channel at an incubation facility at Noel Paul's Brook, a large tributary of the middle Exploits, was modified in 1990 (Bourgeois *et al.*, 1993). The channel was brought to uniform gradient (0.41% slope) with an average width of 3 m (2.0–3.4 m) and gravel substrate (2.4–7.5 cm). The banks of the channel were stabilized with large rip-rap (boulders 15.0–60.0 cm diameter). The channel was then divided into six replicates of approximately 20 m × 3 m. Each replicate consisted of a control, mid-channel and stream bank treatment (Figure 1).

The control received no further modification and consisted exclusively of rip-rap along the banks and gravel substrate. The mid-channel treatment contained a low-head barrier dam and a boulder cluster of five large boulders (30.0–60.0 cm diameter). The stream bank treatment contained two artificial undercut banks (mini-lunkers) and two wing deflectors. The channel was further modified, in 1994, to include overhanging cover in the first three stream bank treatments. Three blinds, constructed of a basic wooden frame covered with camouflage netting, were placed on the stream bank, one at each treatment. Treatments were separated by wooden frames into which screens (0.5 cm mesh) could be inserted. This

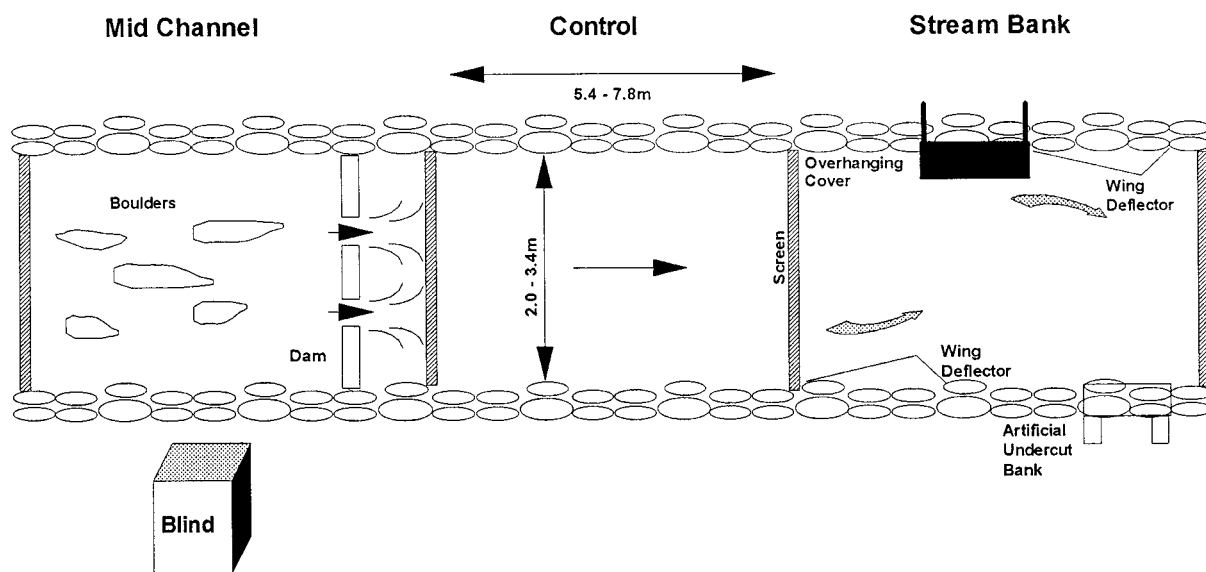


Figure 1. Schematic representation of one replicate showing the control, mid-channel and stream bank treatments

allowed the treatments to be either open or partitioned from each other. At medium discharge, the average depths for the control, mid-channel and stream bank treatments were 19.92, 23.55 and 23.58 cm, respectively. Average water column velocities were 0.157, 0.164 and 0.174 m s⁻¹ for the control, mid-channel and stream bank treatments, respectively.

A 50 m branch of Noel Paul's Brook, behind an island approximately 500 m below the dam, was selected as a reference. The average depth and water column velocity were 18.59 cm and 0.125 m s⁻¹, respectively.

MATERIALS AND METHODS

Distribution and microhabitat

Three experiments were performed in 1995. The first experiment involved the natural density of fish in the channel (68 fish/100 m²). No fish were introduced or removed from the channel. Fish took up residence voluntarily, and there were no restrictions to the movement of fish in, out or within the channel (i.e. no screens were placed). In the second experiment, the channel was stocked with fish to represent a 1.5 times increase in the natural density (99 fish/100 m²), and the uppermost and lowermost screens were kept in place to restrict fish movement to the experimental channel. The fish were allowed at least 3 days to distribute themselves within the channel before any observations were made. These two experiments were performed from 22 June to 25 July and consisted of five day and five night observations. The water temperature during these experiments ranged from 12.9 to 23.5°C and the channel was maintained at a low to medium discharge.

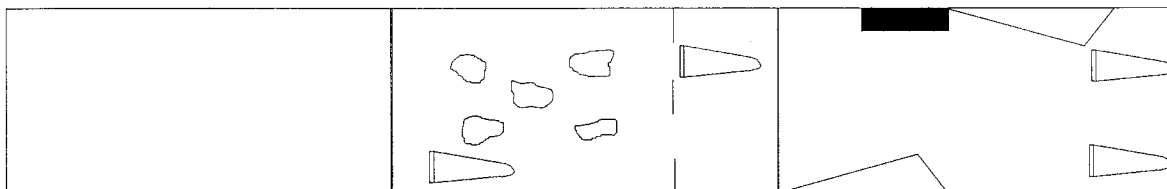
The channel was stocked at the natural fish density in the third experiment, and the fish were exposed to three different discharges: low (0.032 m³ s⁻¹), medium (0.063 m³ s⁻¹) and high (0.13 m³ s⁻¹). The discharge was controlled by an intake valve which was manually opened to increase the flow. This experiment consisted of five night observations at each of the flows and took place from 24 August to 4 October. The water temperature range during this experiment was 4.0–18.5°C. Day observations were not possible owing to the fish becoming more nocturnal as temperatures decreased.

Day observations, in the channel, consisted of two 30 min observations at each blind between 09:00 and 15:00 h. Polarized sunglasses were used to minimize glare from the water surface and to increase visibility. During observations the holding position, species, length (cm) and focal depth (height off substrate in cm) of each fish were noted and the positions were then marked. Markers consisted of button tags attached to 7/16 in. nuts. Features measured at each holding position included depth (cm), bottom velocity (m s⁻¹ at 1.5 cm above substrate), nose velocity (m s⁻¹), water column velocity (m s⁻¹ at 0.6 depth), substrate diameter (cm), distance from nearest structure (cm), distance from cover (cm) and distance from nearest fish (cm). Velocity was measured with an American Sigma velocity meter. Cover was defined as any object beneath which fish could be hidden from view, such as the rip-rap along the banks, a boulder, a wing deflector or an undercut bank. Structure was defined as any of the structures in the mid-channel or stream bank treatments, including a boulder from a boulder cluster, a low-head barrier dam, a wing deflector or an undercut bank.

The distribution and number of fish in the experimental channel and reference site were determined by night counting. Night counts were performed 2 h after sunset at approximately midnight. Counts began at the downstream end and consisted of two people walking slowly up either side of the channel or the reference. Light was provided by a Coleman Powerhouse lantern 290A700C which was swept slowly over the water surface. Fish were counted and divided into three size classes: FL ≤ 5 cm, 5 < FL ≤ 10 cm, and FL > 10 cm (where FL = fork length). These size classes conform roughly to age 0+, 1+ and 2+ parr, respectively. Double counting was avoided by nudging counted fish downstream. Holding positions of fish in those treatments with blinds were marked (as above) and the features were measured the following day.

At the completion of each experiment screens were placed during the night to isolate each treatment, and fish were removed the next day by electro-fishing. Three passes were made in each treatment using a

A)



B)

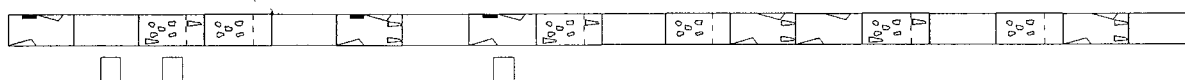


Figure 2. Schematic diagram showing the position of drift nets in (A) the mid-channel and stream bank treatments and (B) in the entire channel

Smith Root VIII A, 12 volt DC unit. Each fish was identified, measured to the nearest mm and weighed to the nearest 0.1 g using an Acculab model 5001 electronic digital balance. Scale samples were collected from fish measuring 5 cm or more. The following night, a count was conducted to determine the number of fish left after electro-fishing.

Normality and homogeneity-of-variance were tested by examining the residuals graphically. Using the night-counting data a two-way ANOVA was performed, with treatment and replicate as the main effects, to determine whether fish preferred one treatment over another, and to test for an interaction between the numbers of fish per treatment and replicate. If there was no interaction between treatment and replicate and a significant difference was found between the treatments, then pair-wise comparisons were performed using Tukey–Kramer analysis (Sokal and Rohlf, 1981). Using a randomized-block design, a two-way ANOVA was performed using treatment and time (day and night) as the main effects to test whether the microhabitat data varied between treatment and time. Again, pair-wise comparisons were performed if significant differences were found. All statistical analyses were conducted with SYSTAT 5.0 and significance was determined at $p \leq 0.05$.

Habitat availability was measured in the three treatments by recording depth, bottom velocity, water column velocity and substrate diameter along equally spaced transects. Habitat availability and use were derived from frequency analysis (Bovee, 1986). Habitat preference was computed as the ratio between the observed relative frequencies from the habitat use and availability histograms at each interval. The resulting ratio was then normalized and a curve fitted to the mid-point at each interval.

Food availability

Drifting invertebrates were sampled on 29 July, 15 August and 15 September 1995 with 200 μ m mesh nets having a mouth of 30 cm \times 22 cm. The nets were attached to metal rods which were permanently placed in each treatment. A pair of drift nets was placed in each replicate, in the mid-channel and stream bank treatments, alternately (Figure 2). One net was placed near a structure, either at the tip of a wing deflector or at the opening notch of a low-head barrier dam, while the other was placed in an open area away from any structure. Invertebrate sampling was conducted during the day between 13:00 and 18:00 h for 2, 4 and 5 h in July, August and September, respectively. At the mouth of each net, water velocity and water depth (± 0.5 cm) were measured, and discharge was calculated by multiplying the water depth by the width of the net and the water velocity. This was then used to calculate drift density (number of drifting invertebrates/100 m³ water filtered) (Allan and Russek, 1985).

Benthic invertebrates were collected on 16 August 1995 using a Surber sampler with a quadrat measuring 30 cm \times 30 cm (0.09 m²) and a net with a mesh size of 0.2 mm. Three randomly picked replicates of each treatment (control, mid-channel and stream bank) were selected and three samples were collected from each, making a total of 27. Surber samples were randomly obtained from each treatment. The larger rocks were cleaned and removed and the remaining substrate was vigorously moved from side to side within the quadrat.

Benthic and drift invertebrates were collected in the reference site along six transects on 9 and 13 September, respectively. Drift nets were also placed for 5 h to obtain data comparable to the September drift sampling in the channel. All invertebrates were preserved in 70% alcohol. The total counts of invertebrates per sample were used for analyses.

All statistical analyses were conducted with SYSTAT 5.0 and significance was determined at $p \leq 0.05$. The residuals were examined graphically to test for normality and homogeneity-of-variance. Data that did not meet these assumptions were transformed. Paired t -tests were performed to compare drift densities and abundances in the channel and reference site. Independent t -tests were used to compare the channel and reference site food availability. A two-way ANOVA was performed using treatment and replicate as the main effects to compare the distribution of benthic invertebrates in the channel.

RESULTS

Distributional patterns

At natural densities, the number of fish counted in the channel and the reference site were 50.44 ± 7.77 and 10.68 ± 1.13 fish/100 m², respectively (average \pm S.D.). There was a significant difference in the number of fish per treatment (as estimated by night counting) in the channel ($p = 0.021$). The number of fish differed significantly between the mid-channel and the stream bank treatments. On average (\pm S.D.), 10.57 ± 2.94 , 8.53 ± 4.45 and 11.06 ± 3.38 fish were counted in the control, mid-channel and stream bank treatments, respectively (Figure 3).

On average, the number of fish counted in each treatment at 1.5 times the natural density were 8.90 ± 3.61 , 9.50 ± 5.15 and 8.73 ± 4.94 in the control, mid-channel and stream bank treatments, respectively (Figure 3). The results showed that there were no significant differences between the treatments ($p = 0.780$).

At natural densities and varying discharge the number of fish counted varied from one replicate to the next (replicate \times treatment interaction $p < 0.001$), and therefore there was no overall treatment effect.

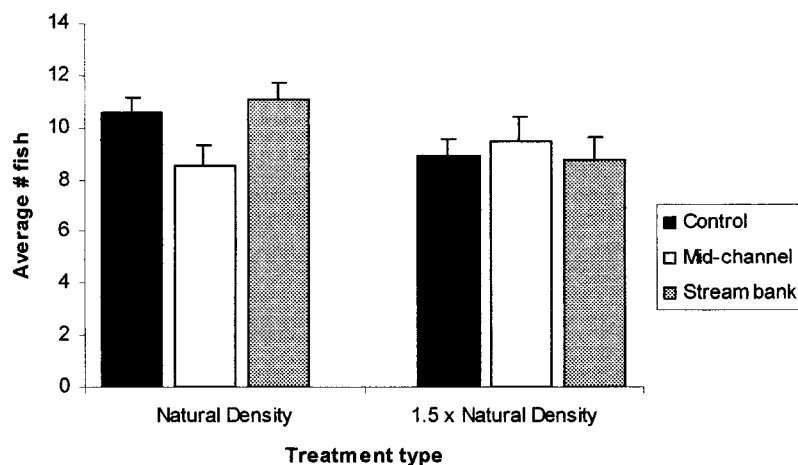


Figure 3. Average number of fish (\pm S.E.) in the control, mid-channel and stream bank treatments at natural (Exp1) and $1.5 \times$ natural density (Exp 2)

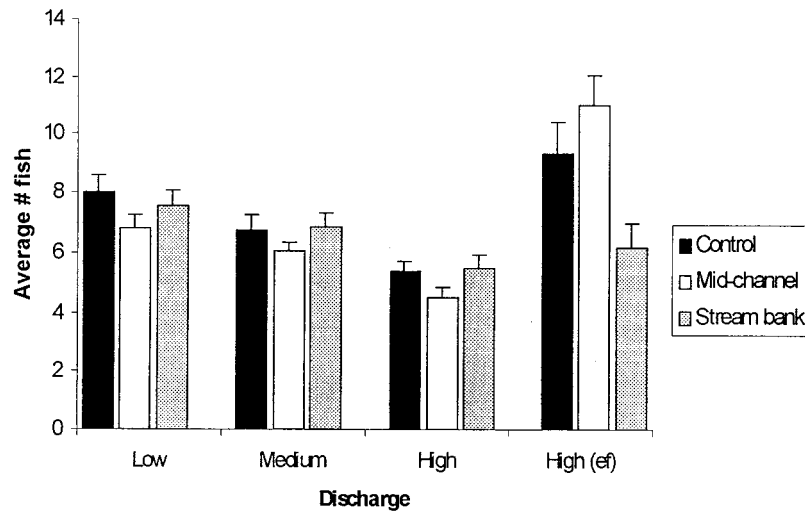


Figure 4. Average number of fish (\pm S.E.) counted in the control, mid-channel and stream bank treatments at low ($0.032 \text{ m}^3 \text{ s}^{-1}$), medium ($0.063 \text{ m}^3 \text{ s}^{-1}$) and high ($0.13 \text{ m}^3 \text{ s}^{-1}$) discharge. Electro-fishing data (ef) are also shown for high discharge

However, there was a significant discharge effect ($p < 0.001$). The average number of fish counted decreased as the discharge increased: 7.46 ± 2.87 , 6.53 ± 2.49 and 5.16 ± 2.14 for low, medium and high discharge, respectively. Using electro-fishing data at high discharge, a significant difference was found between the treatments ($p = 0.021$). On average the number of fish counted were 9.33 ± 2.66 , 11.00 ± 2.61 and 6.17 ± 1.94 in the control, mid-channel and stream bank treatments, respectively (Figure 4).

Microhabitat use

For microhabitat variables of salmon parr, at natural density, the results showed that there were differences between treatments in the selection of depth ($p < 0.001$) and distance to the nearest cover ($p = 0.002$). Greater depths were selected in the stream bank treatment ($21.43 \pm 2.83 \text{ cm}$) and the parr, in the mid-channel treatment, consistently selected positions closer to cover ($33.22 \pm 19.19 \text{ cm}$) than in the other treatments (Figure 5). There was also a diel difference in the selection of substrate size ($p < 0.001$). During the day, parr selected larger substrates ($9.22 \pm 5.77 \text{ cm}$) than at night ($5.77 \pm 4.33 \text{ cm}$) (Figure 6).

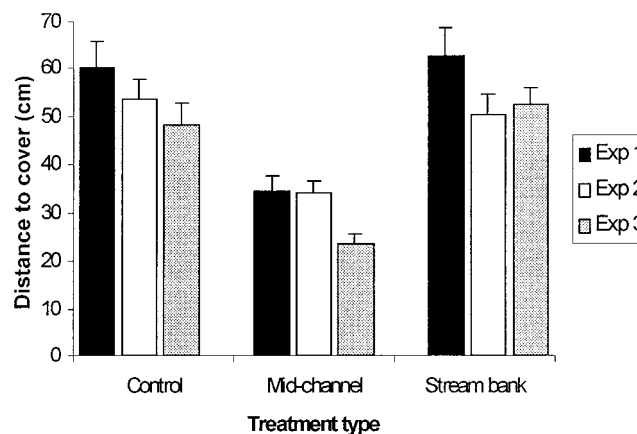


Figure 5. The average distance to the nearest cover (\pm S.E.) selected by Atlantic salmon (*Salmo salar*) parr in the control, mid-channel and stream bank treatments at natural (Exp 1), $1.5 \times$ natural (Exp 2) densities and at natural densities with variable discharge (Exp 3)

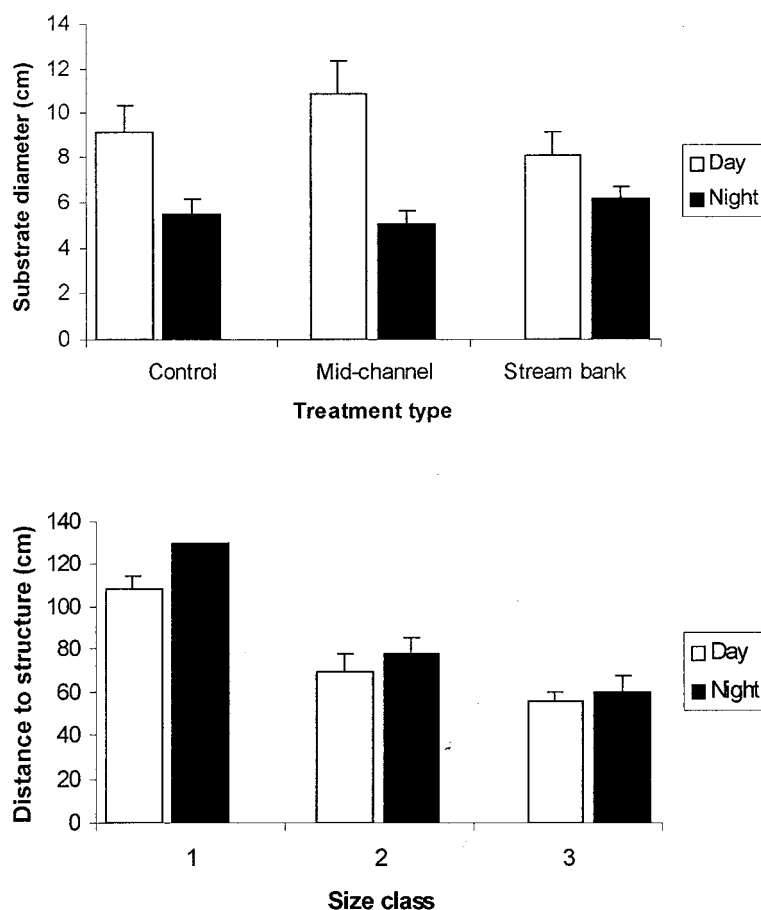


Figure 6. Day and night differences in the selection of substrate diameter and distance to nearest structure (average \pm S.E.) by three size classes of Atlantic salmon (*Salmo salar*) parr (FL ≤ 5 , $5 < \text{FL} \leq 10$ and FL > 10 cm 1–3, respectively) in the control, mid-channel and stream bank treatments

The influence of parr size on microhabitat selection was determined using size class and time as the main effects. The results showed that there were differences between the three size classes in the selection of depth ($p = 0.045$ size class \times time), water column velocity ($p = 0.011$ size class \times time), distance to the nearest cover ($p = 0.003$ size class \times time) and distance to the nearest structure ($p < 0.001$). The larger salmon parr (FL > 10 cm) preferred greater depths during the day (20.47 ± 3.02 cm) and were found closer to the improvement structures (61.33 ± 34.88 cm). The young-of-year selected greater depths at night (23.5 ± 2.78 cm) and were found at greater distances from the structures (109.64 ± 24.59 cm). The larger salmon parr selected higher water column velocities during the day ($0.118 \pm 0.053 \text{ m s}^{-1}$), and the young-of-year selected greater velocities at night ($0.125 \pm 0.035 \text{ m s}^{-1}$).

When the total density of fish was increased, there were significant differences between treatments in the selection of bottom velocity ($p = 0.046$), nose velocity ($p = 0.028$) and distance to the nearest cover ($p = 0.001$) (Figure 5). As in the natural density experiment, positions were selected closer to cover (34.23 ± 20.14 cm) in the mid-channel treatment. Higher bottom and nose velocities were selected in the control treatment, 0.082 ± 0.046 and $0.091 \pm 0.047 \text{ m s}^{-1}$, respectively.

In the discharge experiment there was a significant difference between the treatments and flows in the selection of depth ($p = 0.001$), substrate size ($p = 0.014$), distance to the nearest cover ($p < 0.001$) (Figure 5) and distance to the nearest fish ($p = 0.046$). Again, greater depths were selected in the stream bank

treatment (25.11 ± 3.41 cm) and as the flow increased so did the depth selection. Among the treatments the largest substrates and positions closest to cover were selected in the mid-channel treatment at all flows. As the flows increased, the distances to the nearest fish also increased.

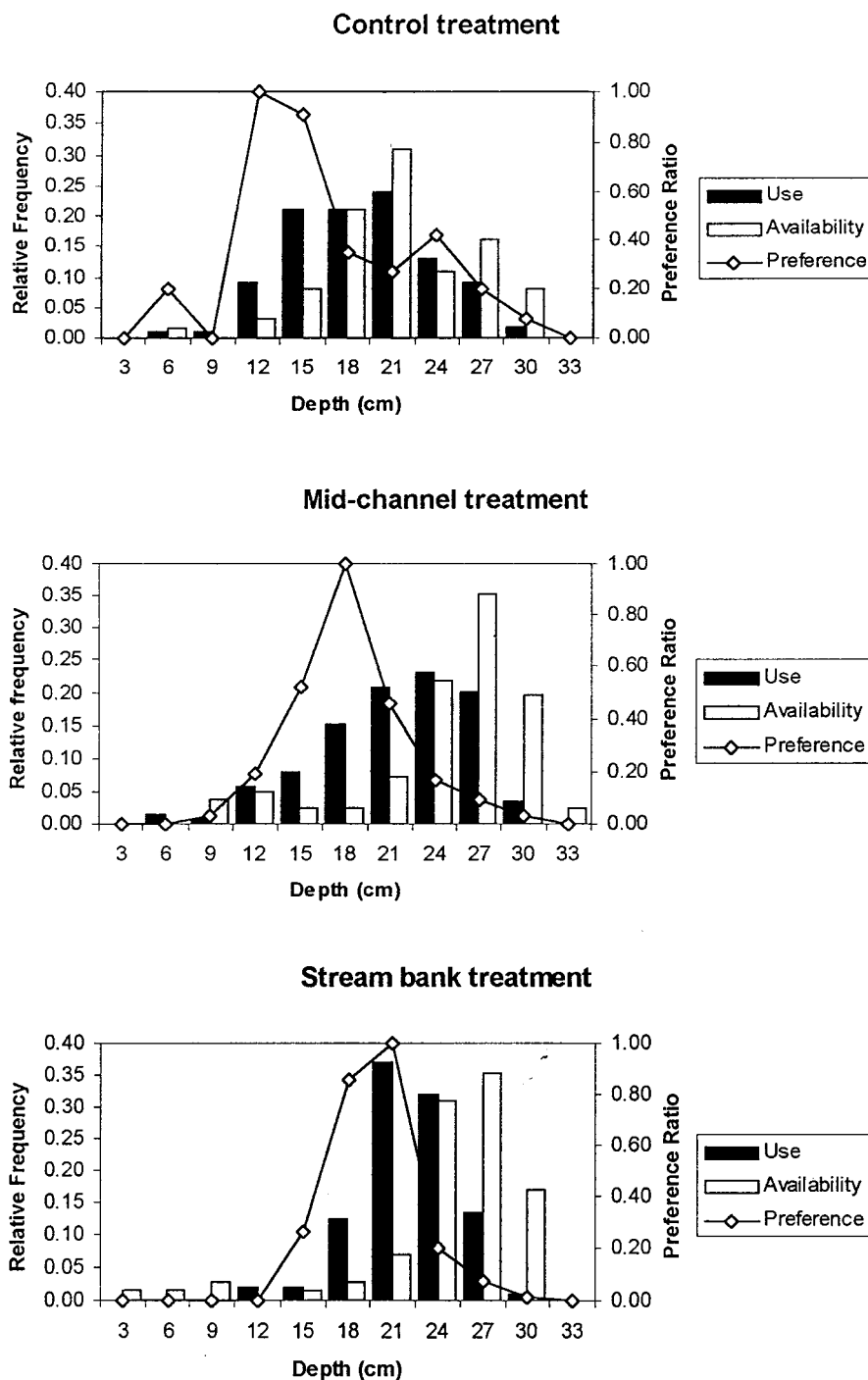


Figure 7. Habitat availability, use and preference of depth (cm) for all size classes in the control ($n = 110$), mid-channel ($n = 137$) and stream bank treatments ($n = 103$) for Exp 1 and Exp 2 combined

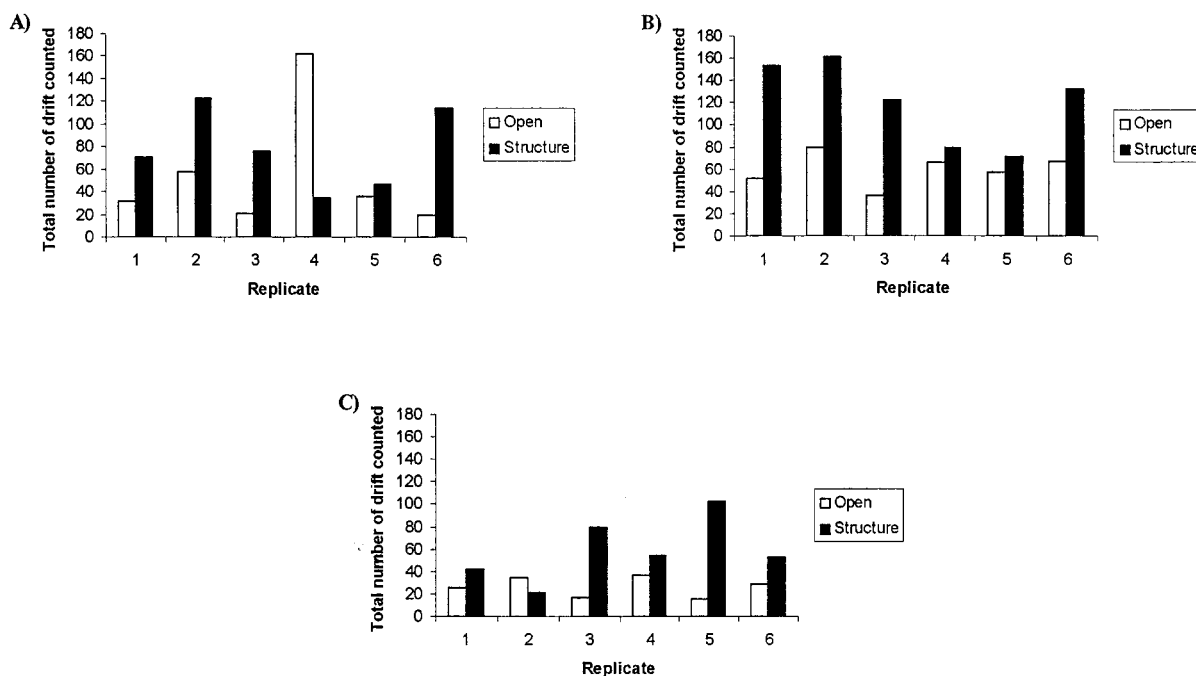


Figure 8. Drift abundances of invertebrates in the mid-channel and stream bank treatments near the structures and in open areas in the experimental channel over a 2, 4 and 5 h period on (A) 29 July, (B) 15 August and (C) 15 September 1995, respectively

Habitat use and availability

Compared with the available habitat in the control treatment, salmon parr preferred areas with shallow depths (10–15 cm) (Figure 7), low bottom velocities ($0.03\text{--}0.05\text{ m s}^{-1}$) and high water column velocities ($0.14\text{--}0.16\text{ m s}^{-1}$). In the mid-channel treatment, parr preferred depths of 15–18 cm (Figure 7), bottom velocities of $0.05\text{--}0.15\text{ m s}^{-1}$, and slow water column velocities ($0\text{--}0.05\text{ m s}^{-1}$). Salmon parr preferred deeper areas (15–21 cm) (Figure 7), low bottom velocities ($0.03\text{--}0.06\text{ m s}^{-1}$) and high water column velocities ($0.09\text{--}0.16\text{ m s}^{-1}$) in the stream bank treatment.

Invertebrate drift

Drift densities varied considerably throughout the channel on 29 July 1995. Densities ranged from 26.18 to 1515.15 invertebrates/100 m^3 filtered water in the open areas and 30.53 to 181.37 invertebrates/100 m^3 filtered water at the structures. On 15 August, drifting densities in the open areas ranged from 33.52 to 173.13 invertebrates/100 m^3 filtered water, and at the structures from 18.38 to 207.67 invertebrates/100 m^3 filtered water. In the last experiment, 15 September, the densities decreased, with ranges from 15.13 to 66.14 and 6.89 to 68.92 invertebrates/100 m^3 filtered water in the open areas and at structures, respectively.

No significant difference was found between drift densities in the open and structured areas ($p = 0.268$) on 29 July. The average drift density (\pm S.D.) was 407.95 ± 562.50 and 90.72 ± 70.45 in the open and structured areas, respectively. There was no significant difference found between drift densities on 15 August ($p = 0.690$) with the open areas having an average of 98.26 ± 54.71 , and the structured areas with 94.03 ± 65.60 invertebrates per 100 m^3 water filtered. On 15 September, the average drift density in the open areas was 32.71 ± 18.64 and in the structured areas was 24.43 ± 22.67 . There was no significant difference ($p = 0.219$). When all the drift densities were pooled, no significant difference was found between the open and structured areas ($p = 0.110$).

Drift abundances (actual counts of invertebrates per sample) in the open areas were consistently lower than in the structured areas (Figure 8). No significant difference was found between the open and

structured areas ($p = 0.284$) on 29 July. The average number of invertebrates (\pm S.D.) was 54.50 ± 54.35 and 77.50 ± 34.91 in the open and structured areas, respectively. However, a significant difference was found on 15 August ($p = 0.011$) with the open areas having an average of 59.50 ± 14.79 , and the structured areas with 120.50 ± 37.19 invertebrates per sample. On 15 September, the average number of invertebrates found in the open areas was 26.17 ± 8.42 and in the structured areas was 58.83 ± 28.88 (Figure 8). There was a significant difference at 0.1 α -level ($p = 0.084$). When all the data were pooled a significant difference was found between the open and structured areas ($p = 0.003$) which averaged 46.72 ± 34.38 and 85.61 ± 41.43 , respectively. A weak, but positive, correlation was found between drift abundance and water velocity with a Pearson correlation coefficient of $r = 0.273$.

Benthic invertebrates

There were no significant differences found in the densities of benthic invertebrates in each replicate ($p = 0.480$) or treatment ($p = 0.866$). The average numbers of benthic invertebrates per m^2 in the control, mid-channel and stream bank treatments were 204.94 ± 142.41 , 177.78 ± 82.77 and 203.70 ± 150.62 , respectively.

Drift and benthic invertebrates in the reference site

The drift in the channel was compared to the drift in the reference site and a significant difference was found ($p = 0.012$). The channel had an average drifting density of 28.57 ± 20.26 (numbers per 100 m^3 water filtered), while the reference site had an average of 79.70 ± 77.42 drifting invertebrates per 100 m^3 water filtered. There was no significant difference ($p = 0.240$) in the benthic invertebrate densities in the channel and in the reference site. Benthic densities ($\#/\text{m}^2$) were 195.47 ± 124.46 in the channel and 149.99 ± 91.57 in the reference site.

DISCUSSION

Physical characteristics

The improvement structures used in this study were chosen to create habitat features suitable for the indigenous species of Newfoundland (Buchanan *et al.*, 1989). Atlantic salmon parr have been studied for many years and their habitat requirements are relatively well known (Keenleyside, 1962; Gibson and Power, 1975; Symons and Heland, 1978; Rimmer *et al.*, 1984; DeGraaf and Bain, 1986). In general, parr tend to occupy riffle areas in the centre of streams with a gravel or cobble substrate. However, habitat preference varies depending on the age and size of the fish. The principle variables influencing habitat use are believed to be nose velocity in the summer (DeGraaf and Bain, 1986; Morantz *et al.*, 1987) and substrate size and water depth in autumn (Rimmer *et al.*, 1984). The habitat improvement structures were evaluated to determine whether they created suitable microhabitat features.

The mid-channel treatment consisted of a low-head barrier dam and a boulder cluster. Low-head barrier dams are used to create pools with turbulent surface water that serve as cover for larger salmonids and increase oxygen content in the water. Boulders are simple, inexpensive and natural looking. The placement of boulders instream can increase availability and diversity of habitat, provide protective cover for juveniles and increase the amount of substrate for settlement of benthic invertebrates. Results demonstrated that the mid-channel treatment did not serve its purpose at lower discharges, and as a result was not the treatment of choice. However, as the discharge increased, more salmon took up residence in this treatment. The mid-channel treatment was also preferred by Atlantic salmon parr in an initial study (Bourgeois *et al.*, 1993). At increased flows, the large boulders and plunge pools created by the low-head barrier dams, provided a greater diversity in habitat with respect to velocity and cover. The increased surface water turbulence provided more cover and distinct holding areas, with a higher degree of visual isolation than the other treatments. Fish were found further from each other in the mid-channel treatment

at higher discharges, because there was more available cover and shelter owing to the increased surface water turbulence.

The stream bank treatment contained undercut banks and wing deflectors. In theory, this treatment was more suited to juvenile brook trout, which tend to occupy stream margins with riparian, overhanging and instream cover (Gibson and Power, 1975). Mini-lunkers are used to create artificial undercut banks to increase cover for juvenile and adult salmonids in prime feeding and holding areas. Wing deflectors are intended to increase the quality of salmonid habitat by accelerating channelized streams to their natural meander pattern by improving the sinuosity, increasing the velocity and inducing scouring of deep channels. In this experiment, however, the structures did not create these features to the extent intended. Some scouring occurred but to a minimal extent. This was most likely a result of the fact that the channel was not subjected to the natural variation in discharge that would have resulted in greater diversity (Bourgeois *et al.*, 1993). Even though the stream bank treatment was the treatment of choice at low to medium discharge, the distinction between the treatments was minimal. The low-head barrier dams in the mid-channel treatments were not effective in creating cover via plunge pools. Therefore, cover was provided by the boulders and rip-rap along the channel banks. However, at low flow, the undercut banks and wing deflectors in the stream bank treatments provided cover and protection as well as the rip-rap along the banks, and salmon parr found more cover and protection there. At increased discharge, fish tended to aggregate in the low flow areas behind the wing deflectors. Since there were few other areas providing shelter from high flows this treatment was avoided at high flows.

In all three experiments, salmon parr were found closer to cover in the mid-channel treatment and selected greater depths in the stream bank treatments. The positions selected within the mid-channel treatment were always near cover owing to the placement of the boulders in the centre of the treatment. Greater depths were preferred in the stream bank treatment because increased velocities at wing deflectors caused some scouring, and many salmon parr selected positions at the tips of the deflectors.

At natural densities, salmon parr preferred larger substrates during the day than at night. Substrate as cover is an important variable for juvenile salmonids (Gibson, 1978; Rimmer *et al.*, 1984; Heggenes, 1988). The larger the substrate, the more cover is available in the interstitial spaces. During the day, juvenile salmonids are at risk from visual predators, such as piscivorous birds, and therefore need the protection and cover provided by the larger substrates. However, at night substrate size becomes less important as the risk from visual predators decreases. Heggenes (1988) found similar results with brown trout (*Salmo trutta*). Larger substrates can also provide shelter from high water velocities (Gibson, 1978). This was evident when larger substrates were selected in the mid-channel treatment at high discharge. The low temperatures seen during this experiment also caused the salmon to undergo a summer–autumn transition in microhabitat selection. When temperatures fall below 10°C juvenile salmon tend to hide in crevices under stones and they become more nocturnal (Gibson, 1978; Rimmer *et al.*, 1983, 1984; Heggenes and Saltveit, 1990; Fraser *et al.*, 1995). Not only were the salmon parr sheltering from the increased velocities, but they also began taking refuge in the substrate when the temperature dropped below 10°C.

The three size classes selected different depths, with the larger parr selecting deeper areas. Although the values differ, owing to the nature of the channel, these results are consistent with earlier works where habitat suitability curves were developed for juvenile Atlantic salmon (Morantz *et al.*, 1987; Scruton and Gibson, 1993). The larger parr also chose positions closer to improvement structures and these could be used as cover. These stations enabled the fish to take advantage of varying velocities and depths near to the structures. Mikheev *et al.* (1994) found that larger juvenile Atlantic salmon remained in shelter for longer periods of time to avoid risky situations. Grant and Noakes (1987) suggested that larger juvenile brook trout were more conspicuous and vulnerable and so showed a greater wariness towards predators. These opinions are consistent with our observations, the larger parr in the channel selected positions close to the structures.

Higher bottom and nose velocities were selected in the control treatment in the second experiment with increased densities. Higher velocities were more prevalent in this treatment as there were no structures present to provide diversity of velocities. Salmon parr were displaced into all treatments, and so less

preferred positions were selected in the control treatment owing to increased competition for the best positions. During this experiment, the numbers of fish counted in each treatment did not represent 1.5 times increase in density. Three possible explanations for this include: first, because of increased numbers, the dominant fish took up residence quickly while the subordinates were forced into hiding to avoid the intense competition; secondly, the fish were displaced into less preferred treatments where they were more conspicuous to predators; and thirdly, although the uppermost and lowermost screens were in place, some fish might have escaped the channel.

As seen in this experiment, discharge is an important factor in the performance of habitat improvement structures. Sufficient flows are required to produce the desired effects, such as the scouring at wing deflectors and the creation of plunge pools and surface water turbulence by the low-head barrier dams. Habitat improvement techniques are not always successful and can cause harm if not properly planned and implemented (Frissell and Nawa, 1992). Therefore, both biological and physical parameters need to be taken into consideration when planning a stream improvement project.

Food availability

Salmon parr are opportunistic feeders and feed mainly on drifting prey captured from defended territories (Kalleberg, 1958; Keenleyside and Yamamoto, 1962; Wankowski, 1981; Stradmeyer and Thorpe, 1987). Therefore, they will most likely feed on the most abundant available prey (Elliott, 1970b, 1973; Jenkins, 1971; Allan, 1981). Salmon parr were observed holding positions near the habitat improvement structures in the mid-channel and stream bank treatments. Increased velocities were found at or near these improvement structures and the drift abundance was significantly higher near the structures compared with the open areas. Since there is a positive correlation between water velocity and drift abundance (Chapman and Bjornn, 1969; Elliott, 1970a; Everest and Chapman, 1972; Wankowski and Thorpe, 1979; Fausch, 1984; Allan and Feifarek, 1989; Poff and Ward, 1991) salmon will choose positions near fast flowing water. In doing so, more drift is available to them per unit time.

The growth of stream salmonids is related to net energy gain, which is obtained when the energy input, from drifting invertebrates, exceeds the energy costs of maintaining position (Fausch, 1984). So, optimal stream positions would be those that maximize the rate of net energy gain. Stradmeyer and Thorpe (1987) investigated the feeding behaviour of wild Atlantic salmon parr in the River Tilt, Scotland, and found that two-thirds of the drifting prey were captured by an indirect movement of the fish. They suggested that more energy would be required when using a direct method of feeding (rapid burst swimming). Fish in the open areas of the channel would most likely have to use direct feeding more often than those near structures. Drifting invertebrates would be transported towards fish near the structures, and so there would be less energy expenditure when capturing prey.

As stated earlier, the larger parr were found closer to the improvement structures. Dominant fish tend to obtain the best feeding areas, which provide maximum net energy gain, and are therefore likely to grow faster (Jenkins 1969; Fausch, 1984; Metcalfe, 1986). Fausch (1984) calculated the specific growth rates of three species of juvenile salmonids, coho salmon (*Oncorhynchus kisutch*), brook trout and brown trout, and found that individual fish that held optimal stream positions showed the highest specific growth rate. Metcalfe (1986) investigated the interactions between dominance status, feeding rate and growth in rainbow trout (*Salmo gairdneri*) and also found that dominant fish obtained a greater rate of food intake for a given energy expenditure. Bachman (1984) found that brown trout held positions in foraging sites requiring minimal energy expenditure, this was evident from the tail-beat frequencies when the fish were waiting in the site. Since a greater abundance of drift was found near the structures, these were considered the best feeding areas and so the larger parr were found closer to the structures. The smaller, and thus subordinate, fish were forced into poor feeding stations that had either areas of slow current (less food availability) or fast current with little shelter. This would force the fish to maintain position by rapid swimming, and so increase the energetic cost (Metcalfe, 1986).

The results showed that there were no differences between the drift densities (as opposed to the drift abundance) in the open and structured areas. There were also no differences between the benthic

invertebrate densities throughout the channel. This result was partly a consequence of the large variances associated with the estimates of mean densities, and suggests that there are no predictably favoured places where prey densities are high in the channel. However, this conclusion is misleading when the distribution of currents transporting drift past the feeding stations of fish are considered. Drift numbers in the channel were significantly less than those in the reference site, perhaps because the water source to the channel was the head pond feeding the former hatchery. Yet, when the channel was open to colonization, natural densities of parr were higher in the channel than the reference site.

Two explanations seem possible. The fish recognize in some way and respond to the more stable flow regime of the channel. Alternatively, the improvement structures in the channel provided several advantages for the fish. Increased velocities were created around the structures, which provided greater abundances of drifting invertebrates per unit time. Salmonids are visual predators and therefore feed during the day, which puts them at risk from other visual predators such as piscivorous birds. Hence, the structures provided cover, shelter and protection from these visual predators. The structures produced a 'funnelling effect' of the drift and therefore the salmon expended less energy when capturing food. Our observations showed that the larger, more dominant parr chose positions that provided cover and protection, and maximized their food intake, while at the same time minimized their energy expenditure.

CONCLUSIONS

Our study showed that salmon parr used the habitat improvement structures. The mid-channel treatment was successful in providing cover and low velocity microhabitats at higher discharge. The wing deflectors and undercut banks provided cover in the stream bank treatment, but to a less extent at higher flows than the mid-channel treatment. A diversity of depths were created by the structures, and as a result different size classes were able to select a variety of positions. However, for the structures to function optimally, sufficient discharge is required to produce the microhabitat features intended. Minimal differences were observed between all treatments at the lower discharges. When subjected to the natural variations in discharge of Newfoundland waters, the improvement structures would create a greater diversity of habitat, such as deeper plunge pools and more cover, although this occurred only to a limited extent under the controlled conditions in the experimental channel.

The improvement structures in the channel created microhabitat variables that were suitable for Atlantic salmon parr and, presumably, brook trout. At natural densities, the channel supported greater numbers of fish than the reference site, even though the reference site had more drifting invertebrates. The structures provided excellent feeding areas by creating 'funnelling effects' of the drift, while at the same time they provided cover and protection from predators. This study indicates that these structures not only provide the necessary physical characteristics required by salmon parr, but also create favourable feeding sites. It is therefore recommended that, with adequate planning, these structures be used in Newfoundland to improve degraded habitats to increase salmonid production.

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