CGU HS Committee on River Ice Processes and the Environment
14th Workshop on the Hydraulics of Ice Covered Rivers
Quebec City, June 19 - 22, 2007

Habitat use of Atlantic salmon parr (*Salmo salar* L.) during winter

Eva C. Enders[1], Morten Stickler[2], Curtis J. Pennell[3], David Cote[4], Knut Alfredsen[2] and David A. Scruton[3]

[1] *NOAA - National Marine Fisheries Service, Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097, USA*
eva.enders@noaa.gov

[2] *Department of Hydraulic and Environmental Engineering, Norwegian University of Science and Technology, 7491 Trondheim, Norway*
morten.stickler@ntnu.no, knut.alfredsen@ntnu.no

[3] *Fisheries and Oceans Canada, Ecological Sciences Section, 80 East White Hills Road, P.O. Box 5667, St. John's, NL A1C 5X1, Canada*
pennellc@dfo-mpo.gc.ca, scrutond@dfo-mpo.gc.ca

[4] *Parks Canada, Terra Nova National Park of Canada, Glovertown, NL A0G 2L0, Canada*
david.cote@pc.gc.ca

Summer habitat use of Atlantic salmon parr (*Salmo salar* L.) has been extensively studied over the last two decades. However, few studies have been performed regarding habitat use during winter and under ice, although winter conditions have been suggested as a bottleneck for parr survival. To comprehend the effects of ice formation and physical variables on habitat use during winter, 145 parr were tagged using Passive Interactive Transponder (PIT) technology in a natural stream. Fish were tracked in a 450 m long river reach using both fixed gate antennae and manual tracking devices during late autumn, freeze-up, mid-winter and late winter. Fish positions were geo-referenced and corresponding physical habitat variables (water depth, mean flow velocity, and substrate) were measured on each fish position. The results indicate that (1) Atlantic salmon parr had a clear preference for habitat choosing boulder substrate with interstices representing refuge; and (2) winter habitat use differed significantly from summer habitat

preferences of Atlantic salmon parr from the literature. A better comprehension of the winter habitat use of parr may contribute to an improvement of habitat modeling and consequently in the conservation of Atlantic salmon.

1. Introduction

Fish selectively choose their nursery and spawning habitat on the basis of physical habitat variables (Armstrong et al., 2003). Several studies have demonstrated the importance of physical habitat variables such as water depth, mean flow velocity, substrate composition, and water temperature on the habitat use of riverine fish (DeGraaf and Bain, 1986; Morantz et al., 1987; Heggenes, 1990; Greenberg et al., 1996). Subsequently, habitat models have been developed to predict changes in abundance and distribution of fish populations within streams and rivers using these physical habitat variables (Bovee, 1982; Mäki-Petäys et al., 1999; Guay et al., 2000). However, studies on habitat choice of riverine fish are predominately performed under summer or autumn conditions (Scruton et al., 2003; Vehanen and Lahti, 2003; Berland et al., 2004). Only a few studies have been performed regarding habitat use during winter and under ice, although winter conditions have been suggested as a bottleneck for parr survival (Cunjak et al., 1998). Furthermore, anthropogenic and natural changes in physical habitat variables in streams and rivers such as changes from the existing climatic conditions are expected to have direct implications on fish populations (Stalnaker et al., 1996). Populations of cold water fish species in the northern hemisphere may be especially affected (Stenseth et al., 2002; Walther et al., 2002).

Atlantic salmon (*Salmo salar* L.) parr commonly spend between 2 to 5 years in streams and rivers before migrating to the North Atlantic (Mills, 1989). The species is distributed over a wide geographical region along the east and west coasts of the North Atlantic, occupying a wide range of freshwater habitats (MacCrimmon and Gots, 1979; Bardonnet and Baglinière, 2000). In the northern regions of the distribution, winter consists of a large part of the year, where water temperature decreases below the freezing point leading to ice formation. In these northern regions, streams and rivers are commonly covered by surface and in more turbulent reaches, anchor ice formation may occur. Only few studies were conducted during winter (Roussel et al., 2000; 2004), although the survival of Atlantic salmon parr in winter appears to be crucial.

To increase our understanding of the habitat use of Atlantic salmon parr during winter, we tagged individual fish with Passive Integrated Transponder (PIT) tags in autumn before ice formation and tracked them subsequently during late autumn, freeze-up, mid and late winter several times a day. At every fish position the three classic habitat variables, water depth, mean flow velocity, and substrate were measured. We wanted to test the hypothesis that parr choose coarser substrate associated with larger interstitial spaces during winter to seek shelter from ice formations. Consequently, habitat use would change throughout the winter and in comparison to summer habitat use. Availability of suitable overwintering habitat for parr would therefore play a central role in fish management in northern rivers and knowledge on the winter habitat use in streams and rivers are required.

The objectives of this study were to (1) analyze the habitat use of Atlantic salmon parr throughout the winter using PIT technology, and (2) compare the habitat use with summer habitat preferences of Atlantic salmon parr from the literature.

2. Materials and Methods

2.1 Study site

Habitat use of Atlantic salmon parr was studied in Southwest Brook in Terra Nova National Park, Newfoundland, Canada (Figure 1). The 450 m long study reach was located 4 km upstream from the river head (48°36' N; 53°58' W). At the study reach, Southwest Brook has an average width of 10 m. The substrate composition ranges from gravel to boulder. During the observation periods, water temperature ranged from -0.03 to 5.0°C and water discharge varied from 0.3 to 7.9 $m^3 \cdot s^{-1}$. Besides Atlantic salmon (*Salmo salar* L.), which was the dominant species, brook charr (*Salvelinus fontinalis* Mitchell) and American eel (*Anguilla rostrata* Lesueur) were also commonly observed in the river reach.

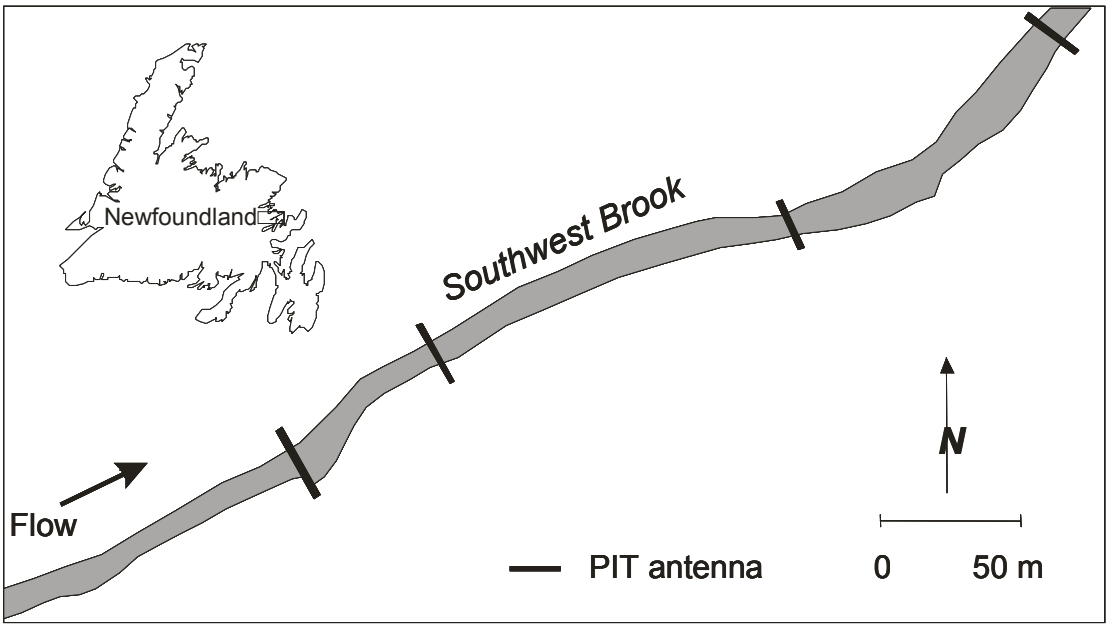

Figure 1. Map of the study reach and positions of PIT gate antennae in Southwest Brook, in insular Newfoundland, Canada.

2.2 Study species and tagging procedure

Atlantic salmon parr were electrofished (Smith-Root Inc.® backpack electrofisher, model 12-B) in November 2005. After capture, parr were individually anaesthetized (clove oil; 0.6 $mg \cdot l^{-1}$), weighed (wet body mass; g) and measured (fork length; cm). The 145 Atlantic salmon parr ranged in body mass from 11-93 g and in fork length from 10.2-20.9 cm. Captured fish were tagged with Passive Integrated Transponder (PIT) tags (model RI-TRP-WRHP; Texas Instruments Inc.; 23.1 mm in length and 3.9 mm in diameter, mass in air of 0.6 g). The PIT tags were surgically implanted. Fish were laid with their ventral side up on a wetted tissue soaked with anaesthetic. A midventral incision was made 5 mm anterior to the pelvic girdle, through which a PIT tag was inserted. The incision was closed with one suture (4-0 SoftSilk™). After surgery, fish were placed overnight in flow-through cages within the Southwest Brook to allow fish to recover before release.

2.3 Fish tracking and habitat characteristics

We used a portable PIT tag detector to track the fish. The radio frequency identification system (model Series 2000 RI-CTL-MB2A; Texas Instruments Inc.) was powered by a 12 V battery, which was carried in a backpack, connected to a loop antenna (60-cm diameter) mounted on a 3 m pole and a handheld computer using customized software. The detection range of the system varied between 30 and 60 cm depending on the orientation of the PIT tag to the antenna. While tracking, the operator waded in an upstream direction, sweeping the antenna from river bank to river bank. Additionally, four double gate loop antennae with PIT tag readers (model Series 2000; Texas Instruments Inc.) were installed for the duration of the study at the up- and downstream ends of the study reach and within the study area to monitor large movements and fish emigration (Figure 1).

In the first 48 h after surgery, fish were not tracked in order to exclude potential tagging and release effects. Fish were manually tracked during four surveys in autumn (November, 28 - December, 02, 2005), freeze-up (January, 22-26, 2006), mid winter (February, 13-17, 2006), and late winter (March 18-22, 2006). When a fish was found, the fish position was marked with a numbered fluorescent marker. Subsequently, the fish positions were geo-referenced using a total station (Sokkia Set 600) and microhabitat variables at the fish location were measured including mean water depth, mean velocity (at 0.6 of water depth; model 2000 portable flowmeter, Marsh-McBirney), substrate size and composition [gravel (0.004-3.2 cm), cobble (3.2-25 cm), boulder (> 25 cm) modified after Scruton et al., 1998].

2.4 Data analysis

Habitat use of Atlantic salmon parr was described using three abiotic habitat variables: water depth, mean flow velocity, and substrate. Data of the three habitat variables collected at the fish location were classified in categories and the percentage of utilization of each category was determined. For each of the three habitat variables, habitat use of Atlantic salmon parr was compared between the four surveys using the Friedman test. The obtained frequency distributions of habitat variables under winter conditions were further compared to frequency distributions of summer habitat use from the literature using Chi square tests (DeGraaf and Bain 1986). The significance level for all statistical tests was $p \leq 0.05$. All statistical analyses were performed using SPSS 11.0 for Windows (SPSS Inc.).

3. Results

3.1 Differences in habitat use between surveys

Of the 145 Atlantic salmon parr tagged, 130 parr were observed at least once during the first tracking survey in autumn. Subsequently, 91 parr were observed during freeze-up, 63 parr during mid winter, and 62 parr during late winter. However, only 48 parr were observed at least once during all tracking periods. Water depth used by parr, that were repeatedly observed during the entire study period, did not vary between tracking surveys (Friedman repeated measures analysis of variance on ranks; $\chi^2 = 5.04$, $p = 0.17$; Fig. 2a). Similarly, no significant differences in flow velocity was observed between the four survey periods ($\chi^2 = 1.08$, $p = 0.78$; Fig. 2b). In contrast, the substrate parr used varied significantly between the four survey periods ($\chi^2 = 17.96$, $p < 0.001$; Fig. 2c). In autumn, parr were predominately found in cobble/boulder habitat. In comparison to autumn, parr used at higher proportion boulder habitat during freeze-up, mid

winter, and late winter (Wilcoxon signed ranks tests, p always <0.05). No significant differences in substrate used were observed between freeze-up, late winter, and mid winter.

3.2 Comparison between summer and winter habitat use

Comparing summer habitat use of Atlantic salmon parr derived from DeGraaf and Bain (1986) with observed mid-winter habitat use, revealed no significant differences in water depth (Chi-square test; $\chi^2 = 5.1$, $p = 0.94$; Fig. 3a). However, mean flow velocity used by parr differed significantly between summer and winter ($\chi^2 = 56.9$, $p < 0.001$; Fig. 3b). In comparison to summer, parr used predominately slower flow velocity (0-40 $cm \cdot s^{-1}$) during winter. Significant differences were also observed in the use of substrate between summer and winter ($\chi^2 = 44.2$, $p < 0.001$; Fig. 3c). During summer parr used predominately cobble substrate whereas during winter a proportion of the parr (45%) were observed using boulder substrate.

4. Discussion

In the present study, no significant differences in water depth between the four survey periods were observed suggesting that water depth is not a limiting variable within the range of water depths available in the study reach. Furthermore, we did not observe any significant differences in mean flow velocity between the four survey periods. During summer, water velocity and especially "nose" or "focal point" velocity have been described as the principal and biologically most meaningful variable determining habitat use of Atlantic salmon parr (DeGraaf and Bain, 1986; Morantz et al., 1987). Unfortunately, focal point velocities are difficult to measure or estimate particularly during winter when fish display cryptic behavior by hiding in the interstitial spaces of the substrate in order to shelter from ice formation, from high flow velocities, and from homoeothermic predators. Furthermore, the PIT technology does not allow determining the exact position of the fish within the substrate; therefore we did not attempt measuring the focal point velocity. However, it may be hypothesized that parr used lower focal point velocity during winter when sheltering in the substrate in comparison to summer and autumn when they were observed above but in close contact to the substrate.

Our study revealed that Atlantic salmon parr in a small, steep river used coarser substrate during winter in comparison to autumn. Traditionally, Atlantic salmon rearing habitat has been typified as a riffle area with gravel or cobble substrate (Keenleyside, 1962; Symons and Heland, 1978). However, our study demonstrated that during winter a proportion of the parr use boulder substrate. Boulders are associated with larger interstitial spaces that provide shelter for parr from anchor ice, high flow velocities, and predators. Consequently, our study suggests that substrate may be the most important variable for winter habitat use.

Comparing summer habitat use of Atlantic salmon parr derived from DeGraaf and Bain (1986) with observed mid-winter habitat use, revealed no differences in water depth but significant differences in both mean flow velocity and substrate. Parr used predominately lower flow velocity and coarser substrate in winter. The study of DeGraaf and Bain (1986) conducted in Newfoundland was chosen for this comparison due to the proximity of the rivers studied with Southwest Brook.

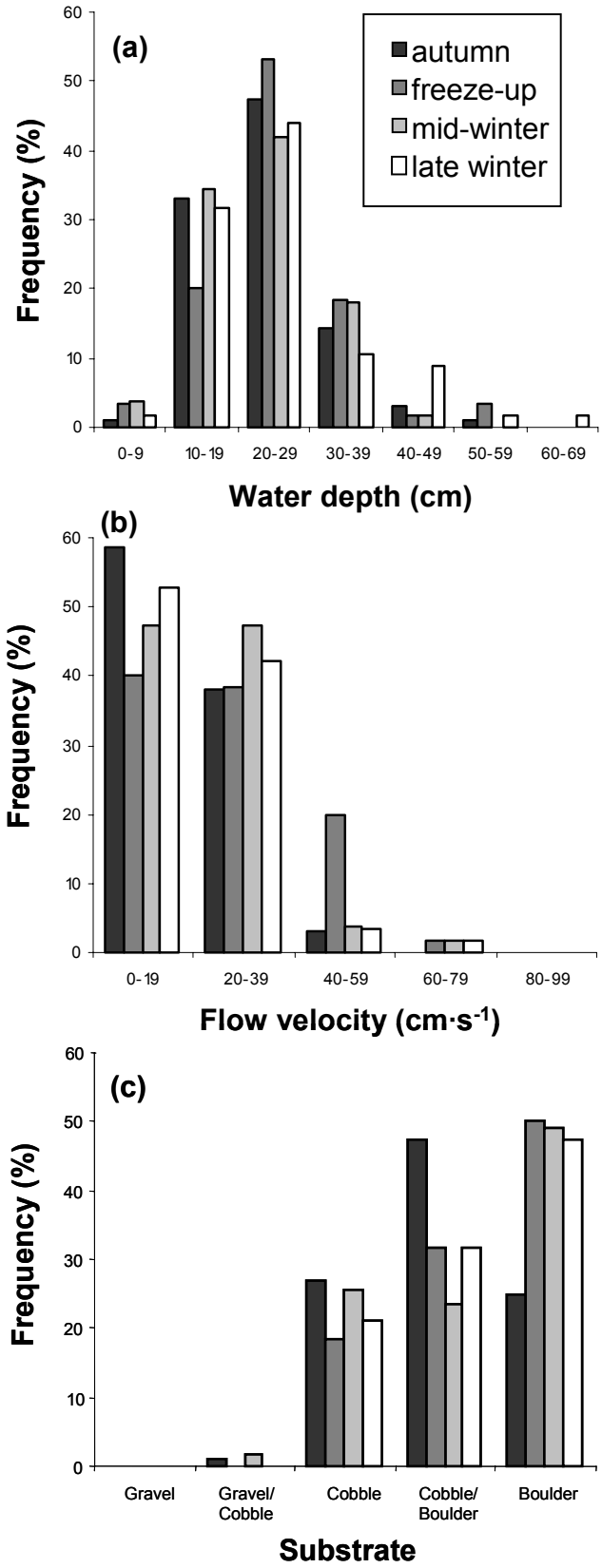

Figure 2. (a) Water depth, (b) mean flow velocity, and (c) substrate measured at Atlantic salmon parr positions during autumn, freeze-up, mid- and late winter.

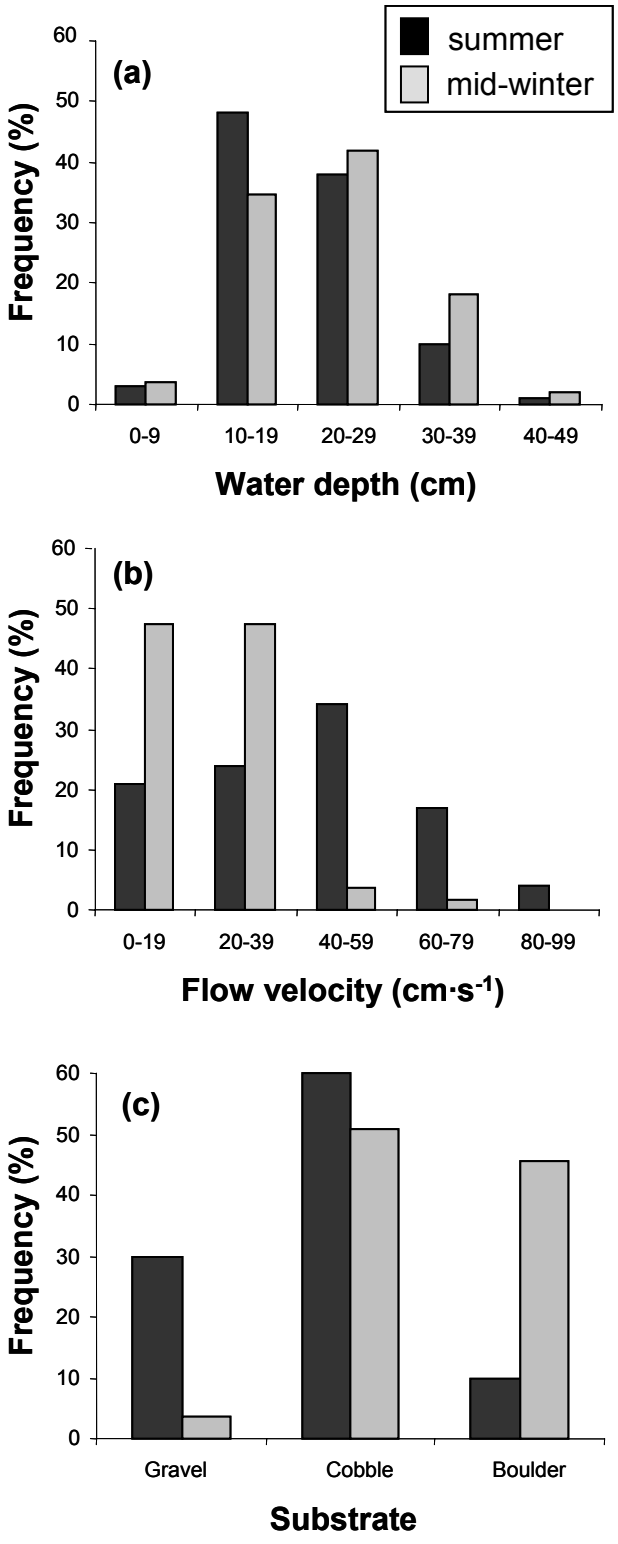

Figure 3. Comparison between summer habitat use of Atlantic salmon parr derived from DeGraaf and Bain (1986) with observed mid-winter habitat use for (a) water depth, (b) mean flow velocity, and (c) substrate.

.

During winter, parr mainly displayed shelter behaviour in habitats associated with boulders that provide interstitial space used by the fish for shelter. When sheltering, parr trade the cost of lost feeding opportunities against the benefits of predator avoidance (Orpwood et al., 2003). Appropriate shelter is of particular importance during winter because energy reserves may limit winter survival (Metcalfe and Thorpe, 1992; Bull et al., 1996; Cunjak, 1996; Finstad et al., 2004) and fish without adequate shelter spend more energy holding position. Shelter availability may therefore limit over-wintering density of Atlantic salmon populations, with those individuals failing to find suitable refuges likely to be removed from the population. Mortality may be caused by starvation and predation or by freezing due to stranding or to sub-zero temperature effects directly affecting the fish.

Changes in habitat use displayed by parr were associated with an increasingly stationary behaviour and mobility decreased on average 5.5-times during ice formations in winter in comparison to autumn (Enders et al., in press). In addition, it was observed that parr move closer to the shoreline during winter (Enders et al., in press). Seasonal differences in parr position in relation to shoreline have also been observed in larger rivers by (Mäki-Petäys et al., 2004), who showed that larger parr occupied territories farther from the shoreline in summer and moved closer to the shoreline during winter.

In conclusion, our observations showed that habitat use of Atlantic salmon parr varied between the tracking surveys regarding the substrate parr chose. In comparison to summer habitat use differences were observed in both mean flow velocity and substrate. We therefore suggest that for fishery and habitat management that winter habitat use of Atlantic salmon parr should be considered in fish habitat models.

5. Perspectives

As it is known that the fish become increasingly nocturnal when the water temperature decreases (Fraser and Metcalfe, 1997; Johnston et al., 2004), we will analyze habitat use changes on a daily cycle. We hypothesize that parr display daily pattern in habitat use. Furthermore, we will develop a habitat model for Atlantic salmon taking into account summer and winter habitat requirements.

Acknowledgments

We wish to thank Craig Kelly for the assistance in the field. This research was funded by Natural Resources Canada's (NRCan) Panel for Energy Research and Development (PERD) to DAS. The Norwegian University of Science and Technology (NTNU) and Fisheries & Oceans Canada provided travel grants to MS. ECE was supported by a Visiting Fellowship in Canadian Government Laboratories from the Natural Sciences and Engineering Research Council of Canada (NSERC).

References

Armstrong J.D., Kemp P.S., Kennedy G.J.A., Ladle M., Milner N.J., 2003. Habitat requirements of Atlantic salmon and brown trout in rivers and streams. Fisheries Research 62: 143-170.

Bardonnet A., Baglinière J.L., 2000. Freshwater habitat of Atlantic salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 57: 497-506.

Berland G., Nickelsen T., Heggenes J., Økland F., Thorstad E.B., Halleraker J., 2004. Movements of wild Atlantic salmon parr in relation to peaking flows below a hydropower station River Research and Applications 20: 957-966.

Bovee K.D., 1982. A guide to stream habitat analysis using the instream flow incremental methodology. U.S. Fish and Wildlife Service FWS/OBS 82/26.

Bull C.D., Metcalfe N.B., Mangel M., 1996. Seasonal matching of foraging to anticipated energy requirements in anorexic juvenile salmon. Proceedings of the Royal Society of London - Series B: Biological Sciences 263: 13-18.

Cunjak R.A., 1996. Winter habitat of selected stream fishes and potential impacts from land-use activity. Canadian Journal of Fisheries and Aquatic Sciences 53: 267-282.

Cunjak R.A., Prowse T.D., Parrish D.L., 1998. Atlantic salmon (*Salmo salar*) in winter: The season of parr 'discontent'? Canadian Journal of Fisheries and Aquatic Sciences 55: 161-180.

DeGraaf D.A., Bain L.H., 1986. Habitat use by and preferences of juvenile Atlantic salmon in two Newfoundland rivers. Transactions of the American Fisheries Society 115: 671-681.

Enders E.C., Stickler M., Pennell C.J., Cote D., Alfredsen K., Scruton D.A., in press. Seasonal variations in behavioural responses of Atlantic salmon parr in relation to water discharge and temperature during winter in a small, steep river. Hydrobiologia.

Finstad A.G., Forseth T., Næsje T.F., Ugedal O., 2004. The importance of ice cover for energy turnover in juvenile Atlantic salmon. Journal of Animal Ecology 73: 959-966.

Fraser N.H.C., Metcalfe N.B., 1997. The costs of becoming nocturnal - Feeding efficiency in relation to light intensity in juvenile Atlantic salmon. Functional Ecology 11: 385-391.

Greenberg L., Svendsen P., Harby A., 1996. Availability of microhabitats and their use by brown trout (*Salmo trutta*) and grayling (*Thymallus thymallus*) in the River Vojman, Sweden. Regulated Rivers: Research & Management 12: 287-303.

Guay J.C., Boisclair D., Rioux D., Leclerc M., Lapointe M., Legendre P., 2000. Development and validation of numerical habitat models for juveniles of Atlantic salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 57: 2065-2075.

Heggenes J., 1990. Habitat utilization and preferences in juvenile Atlantic salmon (*Salmo salar*) in streams. Regulated Rivers: Research & Management 5: 341-354.

Johnston P., Bergeron N.E., Dodson J.J., 2004. Diel activity patterns of juvenile Atlantic salmon in rivers with summer water temperature near the temperature dependent suppression of diurnal activity. Journal of Fish Biology 65: 1305-1318.

MacCrimmon H.R., Gots B.L., 1979. World distribution of Atlantic salmon (*Salmo salar*). Journal of the Fisheries Research Board Canada 36: 422-457.

Mäki-Petäys A., Erkinaro J., Niemela E., Huusko A., Muotka T., 2004. Spatial distribution of juvenile Atlantic salmon (*Salmo salar*) in a subarctic river: size-specific changes in a strongly seasonal environment. Canadian Journal of Fisheries and Aquatic Sciences 61: 2329-2338.

Mäki-Petäys A., Muotka T., Huusko A., 1999. Densities of juvenile brown trout (*Salmo trutta*) in two subarctic rivers: Assessing the predictive capability of habitat preference indices. Canadian Journal of Fisheries and Aquatic Sciences 55: 1420-1427.

Metcalfe N.B., Thorpe J.E., 1992. Anorexia and defended energy levels in over-wintering juvenile salmon. Journal of Animal Ecology 61: 175-181.

Mills D.D., 1989. Ecology and management of Atlantic salmon. London: Chapman & Hall.

Morantz D.L., Sweeney R.K., Shirvell C.S., Longard D.A., 1987. Selection of microhabitat in summer by juvenile Atlantic salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 44: 120-129.

Orpwood J.E., Griffiths S.W., Armstrong J.D., 2003. Effects of body size on sympatric shelter use in over-wintering juvenile salmonids. Journal of Fish Biology 63: 166-173.

Roussel J.M., Cunjak R.A., Newbury R., Caissie D., Haro A., 2004. Movements and habitat use by PIT-tagged Atlantic salmon parr in early winter: the influence of anchor ice. Freshwater Biology 49: 1026-1035.

Roussel J.M., Haro A., Cunjak R.A., 2000. Field test of a new method for tracking small fishes in shallow rivers using passive integrated transponder (PIT) technology. Canadian Journal of Fisheries and Aquatic Sciences 57: 1326-1329.

Scruton D.A., Ollerhead L.M.N., Clarke K.D., Pennell C., Alfredsen K., Harby A., Kelly D., 2003. The behavioural response of juvenile Atlantic salmon (*Salmo salar*) and brook trout (*Salvelinus fontinalis*) to experimental hydropeaking on a Newfoundland (Canada) River. River Research and Applications 19: 577-587.

Stalnaker C.B., Bovee K.D., Waddle T.J., 1996. Importance of the temporal aspects of habitat hydraulics to fish population studies. Regulated Rivers-Research & Management 12: 145-153.

Stenseth N.C., Mysterud A., Ottersen O., Hurrell J.W., Chan K.S., Lima M., 2002. Ecological effects of climate fluctuations. Science 297: 1292 - 1296.

Vehanen T., Lahti M., 2003. Movements and habitat use by pikeperch (*Stizostedion lucioperca* (L.)) in a hydropeaking reservoir. Ecology of Freshwater Fish 12: 203-215.

Walther G.R., Post E., Convey P., Menzel A., Parmesan C., Beebee T.J.C., Fromentin J.M., Hoegh-Guldberg O., Bairlein F., 2002. Ecological responses to recent climate changes. Nature 412: 389–395.