The role of stream margins and pool habitats for Atlantic salmon parr in small streams during winter.

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Abstract

We examined the habitat use of 255 Atlantic salmon (*Salmo salar* L.) parr in pools and along the stream margins during winter in small streams in the northern temperate zone. The presented data is based on three separate PIT (Passive Integrated Technology) studies from research projects conducted in Norway and Canada during the winter periods of 2004/5 and 2005/6 with variable physical characteristics. Overall, a high variability in spatial distribution of parr was found, habitat use covering the whole wetted width throughout the winter. Only a very few parr inhabited pool habitats, both in ice free and ice covered periods. Our results indicate that stream margins and pool habitats may be of less importance as habitats than previously thought and that coarse substrate and low embeddedness are the key factors determining the habitat choice by salmon parr in small streams during winter. Thus, location of such habitats is of major importance when determining the spatial distribution of salmon parr during winter.

Introduction

In northern temperate regions winter is a substantial part of the year, normally lasting from four to eight months. In lotic environments different types of ice form and subsequently alter the physical conditions considerably (Prowse, 1994). In these environments stream fish have to adapt themselves to the changing environment (Chapman, 1966) by finding suitable habitats in order to minimize their energy expenditure and to survive through the cold season (see reviews by Cunjak, 1996; Huusko et al., in press). Habitat utilization of stream fishes has been extensively studied over the past three decades, in particular in relation to common habitat variables (depth, velocity and substrate). As most of these studies have focused on ice-free conditions on a micro-scale, an increased attention on in-stream habitats on a meso-scale during presence of ice is needed.

In-stream meso habitats (Borsányi, 2005) like pools and areas along the stream margins can be important for juvenile stream fish during winter (Cunjak, 1996). These habitats may provide cover against endothermic predators (e.g. mink, otter or birds), both in terms of water depth and overhanging cover (e.g. trees, undercut bank, boulders) and also provide shelter against high flow velocities. As poikilothermic animals, fish are less susceptible to move in low water temperatures, and thus finding suitable habitats during winter can be critical in order to survive (Huusko et al., in press). For example, Riehle and Griffith (1993) and Griffith and Smith (1993) found juvenile salmonids near banks during day. Heggenes et al. (1993) found juvenile brown trout seeking cover along stream margins at night due to anchor ice formation. Cunjak (1996) discussed the importance of habitat along stream edges under shelf ice cover for juvenile salmonids, and later, Simpkins and Hubert (2000) made observations of juvenile rainbow trout (*Oncorhynchus mykiss*) seeking cover in these areas. In a recent study by Mäki-Petäys et al. (2004) in a sub-arctic river, larger parr (11-17 cm) were found to be positioned closer to stream margins during winter in comparison to summer, although daily differences were not investigated. In contrast, Cunjak (1988) found juvenile Atlantic salmon closer to mid-stream than to stream margins during day hypothesizing the use of less embedded substrate (cover). However, in most winter studies the use of pools as winter refugee has been widely referred to (Cunjak et al., 1998; Huusko et al., in press). Pools provide cover in terms of water depth (Gibson and Power, 1975) against endothermic predators and shelter against energy demanding water velocities (Bremset, 1999), which together can be crucial for survival during the cold season (Cunjak, 1988).

In winter, formation of surface ice will most likely affect the use of in-stream habitats by juvenile stream fish. Ice cover significantly reduces the amount of light (Finstad et al., 2004 and Stickler et al., in prep.) penetrating into the water column (although dependent on thickness of ice and snow cover) and provide shelter against endothermic predators (e.g. Meyers et al., 1992). There is also some recent indication that surface ice may alter the level of daytime activity by salmon parr (Stickler et al. and Linnansaari et al., in prep.). Thus, differences in spatial distribution of juvenile stream fish can be expected between periods with and without surface ice. In the following, we focus on the effect of surface ice on the relative distribution of salmon parr to stream margins and on the use of pool habitats, both on a periodic scale (ice free, partly ice covered and total ice covered) and on a diurnal scale (day and night).

Methods

In this study Passive Integrated Technology (PIT) was implemented in order to gain information on the spatial distribution of Atlantic salmon parr during winter 2004/5 and 2005/6 (Table 1). A total of 255 juveniles (mean fork length ± SD; 11.9 cm ± 22.3, min, max fork length; 7.3 - 20.1 cm, mean fish mass ± SD; 17.7g ± 11.7, min, max fish mass; 5.1 - 77.5 g) was tagged and monitored following similar procedure as described by Roussel et al. (2000) and Linnansaari et al. (2006). In addition, fixed bed antennae in upstream and downstream end of study sites were established in South West River to gain control of in- and out moving individuals. Maximum reading distance of the mobile tracking device was 70 cm while the fixed antennae had a maximum reading distance of 25 cm. All tracking was conducted in upstream direction in order to decrease the disturbance of fish. The term "pool habitat" was defined according to Borsányi (2005).

Study sites and physical conditions

South West River

Southwest Brook is a small, natural river located in Terra Nova National Park (48˚ 36' 25'' N, 53˚ 58' 50'' W) on the north-east coast of Newfoundland, Canada. The river has a basin area of 36.7 km^2 with a mean winter discharge of 0.5 m^{3}s^{-1} (Nov-Mar). The selected study site was 300 m long with an average wetted width of 10.72 m, ranging from 6.5 to 22.5 m (mean winter flow) and average gradient of 1.3%. Within the study site two separated reaches (100 m apart) with different gradient (see below) were selected as study sites according to definition by Tesaker (1996). Section I (low gradient section; LGS) was 100 m long, 13.0 m in average wetted width and had a mean gradient of 0.3 % dominated by shallow (< 0.5 m) glide habitat. Section II (high gradient section (HGS) consisted of two sub reaches of 100 m long with an average wetted width of 9.9 m and an equal gradient of 1.8 % dominated by shallow riffles (< 0.4 m). Two pools were located within the study site; one in LGS (< 2 m deep) and one in HGS (< 1 m deep). Dominant substrate was medium sized boulders according to the Wentworth scale (Wentworth, 1922). No significant difference in substrate size between low and high gradient section was found. In both sections substrate had minimal compaction of fine sediments (low embeddedness) providing interstitial spaces. In addition to Atlantic salmon small populations of resident brown trout, *Salmo trutta* L. exists in the river.

Catamaran Brook

Catamaran Brook is a small, near pristine tributary to the Little Southwest Miramichi River situated in north-eastern New Brunswick and has a basin area of approx. 50 km^2. The study site was located in the Middle Reach (46° 51' 27" N ; 66° 11' 18" W) where the mean winter discharge is approx. 0.4 m^{3}s^{-1} (Nov -Mar). The selected study site was 125 m long, has an average wetted width of 7.2 m ranging from 4.3 to 17.4 m (during contrasting ice events) and a mean gradient of 0.6%. The uppermost 70 m is described by shallow (< 0.4 m) riffles and dynamic ice formations whereas the lowest 55 m is dominated by shallow (< 0.5 m) glides and has static ice build-up. The substrate is predominantly small to medium sized cobble (Wentworth, 1922) with low embeddedness.

Dalåa River

River Dalåa is a small, regulated river located 100 km east of Trondheim, Norway (63° 22' 1" N, 11° 49' 30" E) and has a basin area of about 100 km^2. Mean winter discharge is 0.5 m^{3}s^{-1} (Nov-Mar). The selected study site was 230 m long with an average wetted width of 14.1 m ranging from 9.7 to 23.4 m (mean winter flow). The study site included one shallow riffle (< 0.4 m) and two shallow (0.4m) glides in addition to a small pool (< 0.7m). Substrate composition varied from pebbles to large cobbles

(Wentworth, 1922). In addition to Atlantic salmon small populations of resident brown trout exists in the river.

Table 1: Physical conditions during winter 2004/5 (Dalåa River) and 2005/6 (South West River and Catamaran Brook) during the three studied periods (ice free, partly ice covered and ice covered). In each period, mean flow (m^3s^{-1}) and mean temperature (C^o) is given.

Winter period/Study site	Ice Free	Partly ice covered	Ice covered
South West River	Nov 27-Dec 3; April 24-27	Jan 20-26; Feb 10-16	March 16-21
Flow, mean	1.2	0.4	0.4
T_W, min, max	0.8, 5.5 (Dec); 3.4, 9.6 (Apr)	-0.03, 0.4	-0.07, 0.3
Catamaran Brook	Nov 8	Dec 8	Jan 10
Flow, mean	1.3	1.0	0.3
T_W, min, max	2.9, 3.5	0.0, 1.0	0.5, 0.5
Dalåa River	Nov 4; Apr 20	Dec 14	Nov 22; Feb 18
Flow, mean	0.4	1.0	0.4
T_W, min, max	1.1, 1.7 (Nov); 1.6, 2.0 (Apr)	0.0, 0.5	0.0, 0.0

Data analysis

Linear distance between the true position of each individual and nearest stream margin, hereafter assigned DS, was calculated in each river reach using ArcMap (ArcGIS, ESRI Inc.) with the *Spatial Analyst* extension. Then, DS of each individual was related to the wetted width on the specific location, hereafter assigned relative DS, RDS, in similar procedure as Mäki-Petäys et al. (2004). Thus, for near river bank positions RDS approaches 0 % whereas mid-river positions approach 50 %. The effect of surface ice on RDS was investigated using three ice periods; ice free, partly ice covered and fully ice covered (> 80%). The effect of diurnal pattern on RDS was analysed on the basis of two groups divided to night and day in accordance with light level. Groups between periods were assumed independent on the basis of reduced memory abilities in complex habitats (Laland et al., 2003) and the lack of evidence between spatial learning ability and ecological demand (Odling-Smee and Braithwaite, 2003, Bart Adriansson, Gøteborg University, personal communications). Statistical tests on temporal (ice periods; day/night) and spatial (static vs dynamic ice formation) scale were conducted using non-parametric tests (Mann-Whitney U-test, Kruskal Wallis test) due to non-normally distributed data. Ad-hoc tests for groups were conducted using Dunn's multiple comparisons of pairs for unequal sizes. Statistical analyses were performed using SPSS 14.0 for Windows (SPSS Inc. 2005). Assumptions of normality and homogeneity of variance were tested in each case using the Anderson test and Levene's test, respectively. Statistical analysis was considered significant at the $p = 0.05\alpha$ level.

Results

South West River

Mean (± SD) RDS during winter in South West River was 25.6 ± 13.8% ranging from 0.3% to 49.8%, i.e. covering the whole wetted width. The RDS differed significantly between ice periods (Kruskal Wallis test; $\chi^2 = 58.9$, $p < 0.01$) with the highest RDS during the ice-free period (mean ± SD; 24.4 ± 14.2). A significant difference in RDS between day and night was found (Mann Whitney U-test, $\chi^2 = 330505.5$, $p < 0.01$) with the highest RDS during the day (mean ± SD; 26.3 ± 13.7). RDS between ice free, partly ice covered and ice covered periods during the day differed significantly (Kruskal Wallis test; $\chi^2 = 17.6$, $p < 0.01$) with the highest RDS during ice-free period (mean ± SD; 28.1 ± 12.7). No difference in RDS was found during the night. Overall, only 0.3 % of the total recorded fish positions were located in pool habitats. During the ice-free periods, 4 % of the tagged individuals (n = 5) inhabited pools where all of these fish stayed both day and night. No fish were located in pools during the ice covered (partial or full ice) periods.

Catamaran Brook

Mean (± SD) RDS during winter in Catamaran Brook was 23.3 ± 12.8 ranging from 0.5 % to 49.6%, i.e. covering the whole wetted width. No significant difference in RDS between the three ice periods was found, but a significant difference in RDS between day and night was found (Mann Whitney U-test, $\chi^2 = 1616.5$, $p = 0.02$) with highest RDS during day (mean ± SD; 26.4 ± 16.1). No significant difference in RDS was found between the three studied ice periods, either day or night. Overall, 11 % of the total recorded positions were located in pool habitats. During ice-free period, 7 % of the tagged individuals (n = 2) inhabited pools and 10% (n = 3) during the partly ice covered and ice covered period.

Dalåa River

Mean (± SD) RDS during winter in Dalåa River was 23.1 ± 16.3 ranging from 1.4 % to 48.6 %, i.e. covering the whole wetted width. No significant difference in RDS was found between the ice periods or between day and night. Overall, only 5 % of total recorded positions were located in pool habitats. During the ice-free periods, 6 % of the tagged individuals (n = 2) inhabited pools while 3 % (n = 1) during ice covered periods. Individuals located in pools held the same meso habitat throughout the diel cycle.

Discussion and conclusion

In this study salmon parr generally showed highly variable spatial distribution throughout the winter, positioning themselves both in proximity to stream margins and to the middle of the stream. However, less than 20 % of the recorded positions were situated closer than 10 % of the wetted width. This is in contrast to other similar studies (Griffith and Smith, 1993; Heggenes et al., 1993; Mäki-Petäys et al., 2004; Riehle and Griffith, 1993) where stream margins have been proposed to be important habitats *per se* during winter. Despite the fact that the river margins didn't seem to be of crucial importance for salmon parr in general, it was observed that the fish were closer to mid-stream during day and moved towards the stream margins during night in two of the three investigated rivers (the South West River and Catamaran Brook). The result is in correspondence with earlier observations by Cunjak (1988) who explained this behaviour by the importance of access to daytime cover (coarse, unembedded substrate). Cunjak (1988) also hypothesized that parr were moving towards the stream margin at night, although this was not quantitatively measured. According to Heggenes et al. (1993), juvenile salmonid microhabitat selection is driven by two mechanisms during winter; 1) access to areas providing large substrate providing suitable size interstices for cover during the day and 2) the need to minimize the energy expenditure during the active phase at night (i.e. need to access low velocity areas). As the stream margins provide low flow velocities, it seems that the observed movement pattern in Catamaran Brook and South West River was indication of preference for the energy minimization. It was observed, however, that the movement towards stream margins is not a necessity even during the night as shown with the data from the Dalåa River. There, the parr were found to be positioned closer to mid-stream both during night and day, regardless of the present of surface ice, indicating high local fidelity throughout the diel cycle. In the Dalåa River coarse substrate was mostly found from the mid-stream and thus it appears that the coarse substrate was enough to create variety of suitable velocity zones for parr in this relatively low gradient stream.

Further, the presence of surface ice seemed to have only little effect on the distribution of parr. This was somewhat surprising as surface ice provides cover (Cunjak, 1996) and significantly reduces the amount of light penetrating into the water column (Finstad et al., 2004 and Stickler et al., in prep.). Some previous studies show that light conditions affect the activity of stream fishes and that fish prefer areas that provide shade (Gibson and Keenleyside, 1966; Reebs, 2002). Juvenile salmonids have also been shown to decrease their activity during day and increase at night (e.g. Cunjak, 1988; Scruton et al., 2005) as a trade-of between feeding and risk of predation (Metcalfe et al., 1999). In two recent studies (Stickler et al. and Linnansaari et al., in prep.) salmon parr were active not only at night, but there was also some indication of daytime activity in ice-covered areas. Thus it was hypothesized that the areas under ice would be preferable for salmon parr allowing more time being active due to the low light conditions and the available shelter. However, our results indicate that surface ice didn't provide such attraction and thus other variables should be considered more important affecting the fish's choice of habitat.

Finally, one of the corner stones of most winter studies on juvenile salmonids is the description of pools as important sheltering habitats due to cover and low energetic costs due to low flow velocities (review by Huusko et al., in press). Interestingly, pool habitats were found to have little or no attraction on the salmon parr in our study. In Catamaran, Dalåa River and South West River less than 10%, 6% and 4% of the total recorded positions were located in pools, respectively. Instead, parr exploited most of the remaining habitat (abundant with unembedded coarse substrates), covering a high diversity of various hydraulic features.

As noted already by Rimmer et al. (1984) substrate may be the most important habitat variable when the cold water temperatures are prevailing. In our study, coarse substrate with low embeddedness was present in all of the three investigated study sites. Such habitat provides interstitial spaces and hence valuable cover for juveniles. Based on the patterns in habitat choice observed in this study it appears that the unembedded substrate is one of the main factors affecting distribution of salmon parr during winter and it overrides the tendency of fish to move towards either stream margins or pools.

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