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FISH TELEMETRY

Mid-winter activity and movement of Atlantic salmon parr during ice formation events in a Norwegian regulated river

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Abstract A telemetry study in a Norwegian regulated river was conducted through a 12-day period in mid-winter 2003. The objective was to study activity (defined as number of movement per hour) and movement (defined as distance moved per hour) during different ice formation events. Twenty-four Atlantic salmon (*Salmo salar* L.) parr were radio tagged and continuously monitored by both manually tracking ($N = 24$) and by fixed recording stations ($N = 15$). Detailed data on climate, flow and ice formation and its spatial distribution were collected and used in the analyses. Fish activity was not found to be affected by their size (L_F). There was a significant difference in activity between diel periods with highest activity during dusk (5–6 p.m.). Between high and low flow (mean ± SD, 21.1 $m^3 s^{-1}$ ± 1.7 SD and 11.1 $m^3 s^{-1}$ ± 1.7 SD, respectively) no significant difference in activity was found. During the experiment extensive anchor ice growth occurred mainly in the riffle part with thickness up to 50 cm. Juveniles tend to avoid riffle section during anchor ice formation and exploited ice covered areas, indicating critical and preferable habitats respectively. Further, a significant difference in movement was found between five selected ice events with highest mean movement during an anchor ice event and lowest mean movement during an ice break up with no anchor ice formation. No significant difference in activity or movement between parr exposed to frazil ice and parr not exposed were found.

Keywords Winter habitat · Atlantic salmon parr · *Salmo salar* L · Radio telemetry · River ice · Frazil ice

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Developments in Fish Telemetry

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Introduction

In sub-arctic latitudes different forms of ice are important when considering winter conditions for fish in lotic environments. Physical habitat conditions depend on several variables, and the most important are related to stream flow variables, substrate, cover and temperature (Heggenes et al., 1993; Cunjak, 1996b; Alfredsen, 1997; Tesaker, 1998; Alfredsen & Tesaker, 2002). Formation and presence of ice will influence most of these variables, and are therefore of great importance in an assessment of available winter habitat.

In the past decade winter habitat of stream fish has gained increased interest. Research implies that winter survival is a primary factor affecting fish population dynamics in cold region rivers (Power et al., 1993; Cunjak et al., 1998; Bradford & Higgins, 2001; Annear et al., 2002). As the water temperature drops below 8–10°C juvenile Atlantic salmon change from day activity to predominantly nocturnal behaviour (Fraser et al., 1993; Heggenes et al., 1993; Gries et al., 1997; Cunjak et al., 1998; Hiscock et al., 2002b). During daytime they spend most of the time sheltering within the substrate and emerging at night to feed. This behaviour has been stated as being an adaptation to avoid day active endothermic predators (Fraser et al., 1993), but has been later associated also with reduced energy expenditure (Fraser & Metcalfe, 1997). In a recent experiment conducted in a regulated by pass section by Scruton et al. (2005) fish were found to move significant less during winter than summer time. As noted by several authors (Cunjak & Power, 1986; Cunjak, 1988; Cunjak et al., 1998; Bremset, 1999; Hiscock et al., 2002b; Vehanen & Huusko, 2002) juveniles are often found in the deeper parts of the river during the cold season. In such areas hydraulic shelter is pronounced and the risk of predation is decreased. In a recent field study by Roussel et al. (2004) results implied that fish inhabiting pool during freeze up had higher emigration rates than fish in the riffle. This may indicate that the fish were exposed to some physical changes in pools that caused them to abandon the habitat. In the same study juveniles were also found beneath 10 cm anchor ice in the riffle section, suggesting suitable habitats. In another study by Heggenes et al. (1993), a hypothesis was suggested that fish moved from riffles in order to avoid anchor ice while conversely Whalen et al. (1999) observed fish to stay within riffles during an anchor ice event. Tack (1938) reported trout (*Salmo trutta*) being suffocated by frazil and Brown et al. (1994) made observations of trout shifting habitat from frazil exposed areas into habitats were they could avoid frazil and anchor ice (ice covered areas).

While several studies have been conducted on winter behaviour of juvenile salmonids very little research has focused on the interaction between the physical environment and fish behaviour (Roussel et al., 2004). This is particularly true in regulated rivers, which are often characterized by an unstable winter ice regime due to power demand. Hydropower production, particularly high-head systems with deep reservoir intakes and river releases, alters the discharge regime by releasing warm water into the river causing fluctuations of the flow. The ice regime is characterized by repeated ice break ups and increased ice production. In this paper, data obtained from a fish telemetry study conducted mid-winter 2003 in a Norwegian regulated river are analyzed and presented. The main objective of this study has been to investigate how physical events, especially different forms of ice, affect the fish behaviour. The hypothesis was that fish increased their activity during night, were more active in riffles than in pools, and that riffles were considered less suitable during anchor ice formation.

Materials and methods

The experiment was carried out in Orkla River (63°17′ N, 9°50′ E, Fig. 1). The Orkla River has a catchment's area of about 3,053 km^2 with an annual average runoff of 70 $m^3 s^{-1}$. It was first regulated in 1981, and today, five large hydro power plants operate in the river system. The lower 80 km of the river system is ascendable for anadromous salmonids with annual recreational catches reaching more than 30 tonnes in recent years.

The study site was located in middle portion of the river system approximately 10 km downstream of nearest hydropower discharge. The site was 300 m long and ranged from 30 m to 60 m in wetted width. The habitat is predominantly run, pool and riffle with cobbles covering the bed and

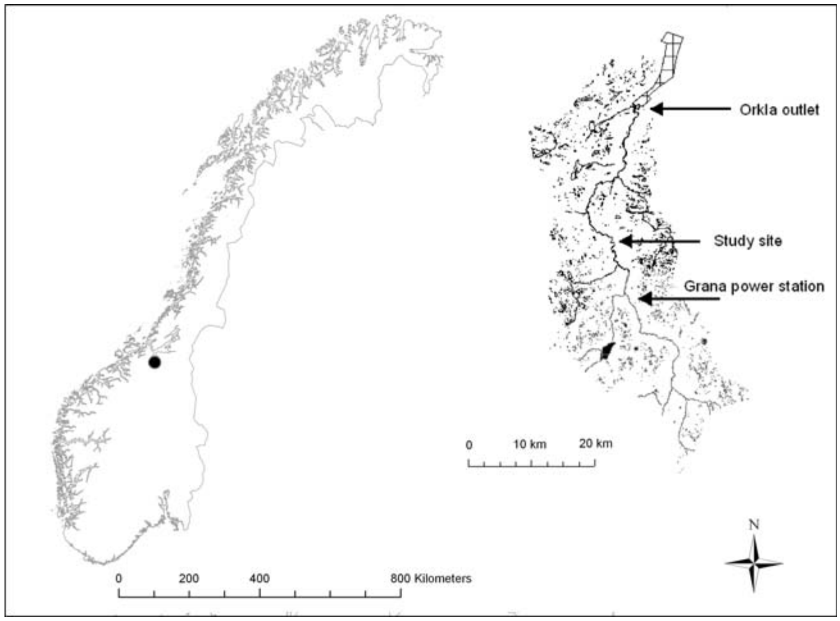

Fig. 1 Location of the study site (•), the Grana power station and the outlet. Note the short (10 km) distance between the power station and the study site. Warm production water keeps the study site free of surface ice during winter and increases the dynamic ice formation

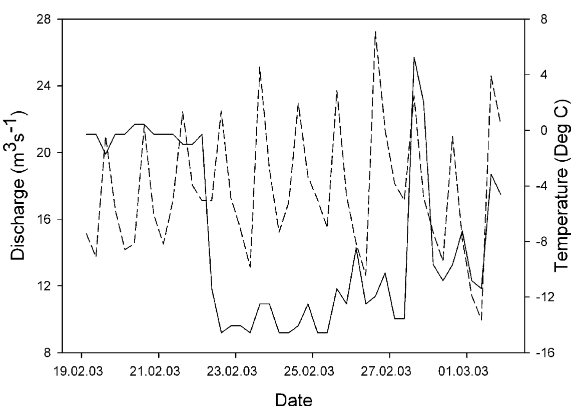

Fig. 2 Discharge (line) and temperature (dotted line) conditions during the experiment

boulders located along the margins. Minimum flow is 4 and 20 $m^3 s^{-1}$ in winter and summer, respectively. Water discharge (Fig. 2) was stable high (mean ± SD, 21.1 $m^3 s^{-1}$ ± 1.7 SD) during the first three days of the experiment, then decreased to low flow condition (11.1 $m^3 s^{-1}$ ± 1.7 SD) reducing the wetted area by 30%. The discharge level was then maintained low throughout the entire period except one day when water was released to prevent ice build up (February 28th). Maximum depth was 2 m (0.51 m ± 0.39 SD) on low flow and 2.4 m (0.75 ± 0.53 SD) on high flow. Water temperature ranged from –0.12 to 0.60°C (0.17°C ± 0.87 SD) while air temperature ranged from 2.2°C to –13.6°C (–5.3 ± 3.6 SD). Along the margins surface ice covered 27% of total wetted area. Frazil ice production and anchor ice growth (Tsang, 1982; Matousek, 1984; Prowse, 1993) had a diurnal cycle; growth during nighttime and cessation at daytime. Anchor ice formed every night in which four events had extensive ice formation (Table 1) mainly in the riffle section with thickness up to 50 cm. During the night of March 1st the air temperature dropped to –13.6°C and caused extensive growth of anchor ice, which established within the entire open area. During the night of February 22nd an artificial ice break up occurred due to a decrease in water discharge from 22 $m^3 s^{-1}$ to 11 $m^3 s^{-1}$. Here, no anchor ice formation was observed.

Radio telemetry was used to investigate the activity and movement of Atlantic salmon (*Salmo salar* L.) parr during a 12-day period mid-winter (February 19th to March 2nd). A total of 24 juveniles (mean ± SD fork length, L_F, 13.6 cm ± 0.69 SD and mass, 21.5 ± 5.0 SD) were caught using a 24 V backpack electro fisher (Smith Root Model 12). Radio transmitters (Model Lotek MBFT 7M; 7.3 × 18 m, 1.4 g in air, and 9M; 8.2 × 19 mm, 1.8 g in air, Lotec Wireless,

Table 1 Physical conditions of four selected events with significant production of frazil and anchor ice formation (event I–IV) and one event (V) with no anchor ice during the study period

Physical condition	Ice event	Ice event I Night 23rd	Ice event II Night 24th	Ice event III Night 28th	Ice event IV Night 1st[t]	Ice event V Night 22nd
Flow level		Low	Low	Low	Low	High $\rightarrow$ low
Anchor ice distrib.		Riffle	Riffle	Riffle	All open area	No anchor ice
Wetted area total: 20,048 m^2 (100%)			Surface ice area: 5,388 m^2 (27%)		Anchor ice area: 2,666 m^2 (13%)	

Wetted area is calculated on discharge 22 $m^3 s^{-1}$ and ice distribution on night 22nd to give an understanding of the physical conditions

6.7 ± 0.1% of fish body mass) were surgically implanted using similar procedure as Adams et al. (1998) and Moore et al. (1990). Fish were anesthetized by immersion in an aqueous solution of 2-phenoxy-ethanol EEC No 204 589-7 (0.5 ml per l water) and placed dorsal side down on a foam pad. Fork length (mm) and weight (0.1 g) were determined. The transmitter was inserted through a 10 mm long incision posterior to the pelvic fin. The transmitter antenna was treaded through the body wall by means of a needle (Jelco; 18 G, 38 mm) 5 mm posterior and dorsal to the incision. The incision was closed with two sutures of 4–0 Ethicon braided silk. The surgery took no longer than 4 min, and during this time, tepid water was poured over the fish's gills to prevent freezing. After surgery, tagged fish were held in a bucket for some minutes to recover before they were brought to a cage in the river. The fish were kept for 24 h before releasing them into their respective habitats.

Fish location was recorded every 6th hours (03:00, 09:00, 15:00, 21:00) using a handheld H-antenna. Position was determined by using a total station (Leica TC 307). Movement was calculated as distance moved per hour, defined as standardized movement (SM). Frequency of movement was determined by three fixed recording stations (Lotek, SRX 400) located on the river banks. Interval logging was set to every 8 min and data was downloaded every morning between 09:00 and 10:00. Data was collected from a total of 15 juveniles. Movement was determined through fluctuations in signal strength, ranging from 0 dB to 236 dB. Calibration determined that a signal change of 30 represented a movement of approximately 1 m. As field conditions (substrate, ice) influence the signal strength, the distance of fish movement was not quantified by the fixed telemetry stations. Alternatively, the approach described by David & Closs (2001) was used. Standardized activity (SA) was defined as number of movements per hour based on the time the fish was recorded at the actual station. Movement between sunrise and sunset (i.e., daylight hours) were considered daytime movement and sunset to sunrise was considered nighttime movement. Dawn and dusk was considered separately and defined as one hour between 07:00 and 08:00 and 17:00 and 18:00, respectively (The Norwegian Meteorological Institute, pers. comm.).

Detailed data on meteorological and hydrological conditions were collected during the study period. A climate station (Campbell Scientific) was located on the study site recording air temperature, radiation, humidity and wind direction. Six thermographs (Vemco model Minilog TR) were placed upstream, middle and downstream the riffle section recording water temperatures in the surface and on the bottom. In addition three Lakeland thermistors chains were placed out on same locations giving a transverse temperature profile in each of the different habitats. Discharge was monitored at the Syrstad gauging station located approximately 1 km upstream. Data on substrate and bathymetry were collected using a total station (Leica TC 307). Distribution of surface and anchor ice was mapped three times during the study period using the total station. Otherwise, visual observations were conducted every 6th hours related to 20 transects evenly spaced every 15 m along the river reach.

Statistical analysis was conducted using Minitab v. 14.1 and SPSS v. 13.0 for Windows.

Assumptions of normality and homogeneity of variance were tested and, when these conditions were violated, non parametric tests were used. Results were considered significant at the $P = 0.05$ α level. A sub period (25th February to 1st of March) with general low flow was chosen as basis for analysis of SA while four events with extensive frazil ice production and one event with ice break up were selected for analysis of SM (Table 1).

Results

Small scale movements versus diel and flow activity and response to ice

The relationship between fish length (L_F) and diel activity was not found to be significant ($r = -0.055$, $P = 0.81$) and therefore was not considered in the further analyses. A significant difference between the four diel periods was found ($S = 13.3$, $P = 0.004$) with the highest mean SA at dusk (Fig. 3). No significant difference between day and night SA ($U = 56$, $P = 0.84$) was apparent, nor between dusk and dawn ($U = 7$, $P = 1.0$). The mean SA during low and high discharge was 0.02 ± 0.004 and 0.03 ± 0.008, respectively. The fish showed no significant difference in SA between the two discharges ($U = 36$, $P = 0.10$). During periods with change in discharge no movements were observed in the monitored fishes.

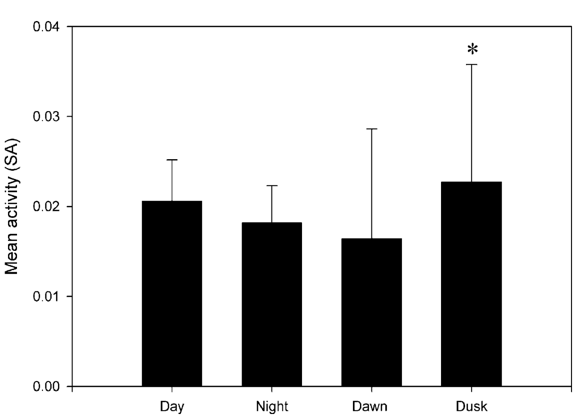

Fig. 3 Movements per hour (mean + S.E.) of diel activity of radio tagged Atlantic salmon parr

During the selected sub period (25th of February to 1st of March) twelve fish located on the antennas were consistently using surface ice covered areas while three stayed in open areas exposed to anchor ice formation. Only two fish changed position between the two areas. There were no significant difference in SA between the fish using surface ice and the fish in riffle areas ($F_{1,13}$, $P = 0.43$). Further, there was no difference in SA between fish inhabiting ice covered areas and fish in open areas in general ($U = 18.5$, $P = 0.16$).

Large scale movements versus frazil, anchor ice and ice break up

Standardized movement among the five selected ice events was significantly different ($S = 19.2$, $P = 0.001$) with highest standard movement during ice event II with anchor ice formation (4.72 ± 1.1 m/h) and lowest during event V with no anchor ice formation (0.96 ± 0.42 m/h) (Fig. 4). Of the four events with frazil ice production event IV had the lowest SM (1.34 ± 1.1 m/h). Outliers and extreme values were found in all events except event IV. Highest extreme number ($N_{\mathrm{Extreme}} = 4$) was found during event I and III. Event V was significant different from event II and III ($W = 204$, $P = 0.002$ and $W = 194$, $P = 0.001$, respectively). Flow level was stable low on event I–IV, but high on event V (Table 1). Anchor ice formed mainly in the riffle

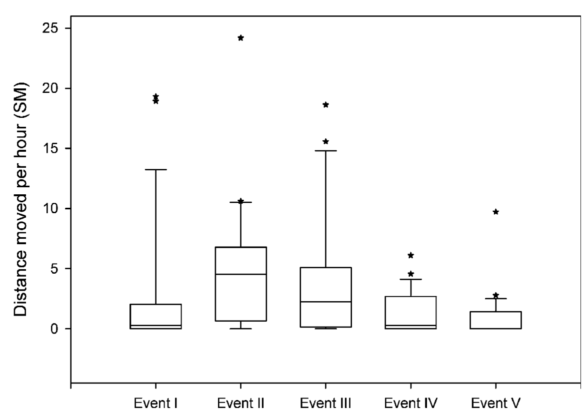

Fig. 4 Comparison of distance moved per hour of Atlantic salmon parr during four events with frazil ice production (event I–IV) and one event with ice break up (event V). *Potential outliers and extreme values

part in all events, except event IV when extensive ice formation occurred in all open areas. During event I and III none fish were observed to exploit anchor ice exposed areas (riffles). On event II four fish were located in an anchor ice exposed area before the ice formed, but during the night three fish emigrated out of the exposed area.

Only during two events (III and IV) with frazil ice production eight fish were located in open areas and exposed to drifting frazil. There was no significant difference in SM between fish exposed and fish not exposed to frazil ice ($U = 178.5$, $P = 0.19$). Further, parr ($n = 5$) inhibiting a deep pool downstream the study area were located below an established hanging dam during event IV. No significant difference in SM ($U = 18$, $P = 0.09$) was found between fish below the hanging dam and fish using ice covered areas, nor between fish below the hanging dam and fish exposed to frazil ice ($U = 6$, $P = 0.41$) located upstream in the river reach.

Discussion

Previous comparable studies, using telemetry, have been constrained by the number of fish that can be concurrently studied; for example Hiscock et al. (2002a, b) studied twelve juveniles while Robertson et al. (2004) studied eleven. Additionally, previous studies have used different approaches for analyzing observed fish behaviour including home range calculations, observed distance moved and number of movements per hour. Comparisons with previously reported studies are therefore difficult. In this study a total of 24 Atlantic salmon parr were monitored during a 12-day period mid-winter with highly variable environmental conditions using a telemetry technique as described by Hiscock et al. (2002a). The results, based on activity and movement detections, did not reveal any clear pattern in behaviour of Atlantic salmon parr despite the variable conditions. In contrast to many other studies this study indicated that juvenile activity was significantly not affected by their size, probably due to the narrow range in fish size distribution (L_F, 13.6 cm ± 0.7 SD). Heggenes et al. (2004), for example, found a positive relationship between fish size and size of home range while Hiscock et al. (2002b) found a significant decrease in activity with increasing fork length.

The hypothesis of nocturnal activity has been demonstrated in previous studies (Cunjak, 1988; Whalen & Parrish, 1999; Bremset, 2000; Hiscock et al., 2002b). In the study by Robertson et al. (2004) they found no differences in activity mid-winter among diel periods while Scruton et al. (2005) found less diel movement during winter than summer. In present study, our findings showed no significant difference in activity between day and night or dusk and dawn. There was however, a significant increase during dusk in activity pattern. Additional, the fish had contributory activity during the day, which may be attributed to the variable physical conditions we found in the regulated study river. During daytime fluctuating flow and cessation of anchor ice were observed and such conditions greatly alter the physical habitat and may force the juveniles to seek other locations.

In regulated rivers flow are frequently changed due to changes in power production. During the experiment the fish did not show a significant increase in SM between high and low flow. In the studies by Robertson et al. (2004) and Berland et al. (2004) similar results were obtained. These findings correspond well with our results although latter study was conducted during summer conditions. During event V (night 22nd, Table 1) a decrease in the discharge by 44% within 4 h triggered a break up of the border ice causing a small ice run. In some regulated rivers this is a normal operational strategy in order to prevent ice coverage from forming during low discharge and thereby avoiding larger and potentially damaging ice break ups when discharge for power production is again increased. During this event parr showed significant less movement compared to events with frazil ice production. These results may indicate that juveniles were not affected by this small ice release, most likely because of the impact of the ice release was not large enough to influence the fish in their holding positions. This does not imply that the same would be the case with a large scale ice break up. Another explanation may be that fish were positioned within coarse substrate, thereby protecting them from moving surface ice. Substrate provides important cover against predators together with hydraulic shelter and may decrease the activity and movement of juveniles (Alfredsen et al., 2004).

In winter time when the water temperature is low rapid decrease in flow at night time has been shown to cause an increase risk of pool trapped stranding, but decreased risk of beached type stranding of juveniles (Bradford et al., 1995; Bradford, 1997; Berland et al., 2004) suggesting habitats along the river margins and in shallow areas may be critical. Saltveit et al. (2001) found decreased risk of stranding during daytime at low temperatures. In the present study a rapid decrease occurred during night 22nd. Here, a group (n = 3) of juveniles was trapped in a small pool close to the river bank indicating critical habitats during flow fluctuations. Several existing winter studies, including this one, demonstrated that the habitats along the river margins are important refuges for fish during winter due to available ice cover and suitable velocity conditions. However, during fluctuating flow conditions these areas are most exposed to stranding. These findings underline the importance of a controlled discharge strategy in regulated rivers, especially during winter time.

Studies on juvenile Atlantic salmon inhibiting ice covered areas are very few, especially in natural environments. However, Whalen et al. (1999) indicated that fish avoided open areas in mid-winter. Alfredsen et al. (2004) found a positive correlation between fish located in open water and movement suggesting that fish in open water are more susceptible to move. In laboratory experiments by Finstad et al. (2004) ice cover was shown to be a positive factor in relation to energy storage in three juvenile Atlantic salmon stocks. These findings may indicate that ice covered areas during winter time are preferred by juvenile salmon owing benefits associated with energy expenditure and sheltering. During the selected sub period (25th of February to 1st of March) parr tend to use the ice covered areas (pools and runs) and avoided open riffles where anchor ice formed. The available habitat in riffle areas was highly variable between day and night because of formation of anchor ice. A test on activity between juveniles in ice covered areas and juveniles in areas exposed to anchor ice revealed no significant difference, which is somewhat not surprisingly due to the dynamic ice conditions in the riffles. In the study by Roussel et al. (2004) they observed fish dwelling beneath the anchor ice and concluded anchor ice to be a suitable habitat due to hydraulic shelter and protection from super cooled water. In the study by Cunjak & Power (1986) velocity and substrate were found to be the most important selection criteria in winter. Whalen et al. (1999) showed a similar use of anchor ice covered areas, while most other studies (Brown & MacKay, 1995; Caissie and Cunjak, 1997; Jakober et al., 1998) indicate that areas exposed to anchor ice are less suitable for fish. In this study anchor ice was observed to accumulate between the boulders thereby blocking the available substrate shelter. Test on movement between anchor ice formation events and events with no anchor ice formation showed that fish made significant more movements during ice formation. Further, during ice event I and III none individuals were found in ice exposed areas. On ice event II three of four fish emigrated from the riffle to the ice covered area in the pool. Based on our observations preferable habitats may be defined as surface ice covered and not anchor ice exposed areas (riffles).

Only a few studies have observed response of juvenile salmonids to frazil ice events. Tack (1938) observed trout (*Salmo trutta*) mortality due to tiny ice particles in the water column and Whalen et al. (1999) made only few observations of juvenile Atlantic salmon on nights with heavily frazil ice production. In the study by Roussel et al. (2004) 40% of the Atlantic salmon parr disappeared indicating long-distance-movements during the freezing period. Other radio-tracking studies (Brown & Mackay, 1995; Jakober et al., 1998; Annear et al., 2002) have related occurrence of frazil ice with more frequent winter movements of distances longer than 1 km. The data from Orkla River does not concur with these observations. Parr exposed to frazil ice showed no significant difference in movement pattern versus juveniles that were not exposed and none of the observed individuals made long emigrations. In our study less than eight fish were found in frazil exposed areas during two of the five selected ice events. Considering that very few individuals were found in these areas our results may still indicate that fish avoid areas exposed to heavy frazil transport.

Despite the general belief that winter time is critical for survival of stream fishes, the number of studies is limited compared to other seasons (Cunjak, 1996a; Roussel et al., 2004). One obvious reason for this is the difficult working environment and the methodological difficulties encountered during the winter. Bradford & Higgins (2001) showed in their study that behaviour of juvenile salmonids during winter is complex. Results from this study support that notion. More research on winter behaviour, especially in rivers with variable environmental conditions, is required in order to discover more of the factors controlling behaviour and survival of juvenile Atlantic salmon during winter time.

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