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Low detection rate in visual observations of stream salmonids in winter

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ABSTRACT

Visual methods in detecting juvenile Atlantic salmon (*Salmo salar* L.) in winter were assessed, both in a natural subarctic river in northernmost Finland (70°N) and in an experimental flume, both under ice and in open water. Video surveillance was used under different conditions, and at one field site, data from video cameras and snorkeling were compared with subsequent electrofishing at the same site. In addition, the activity and visibility of juvenile salmon in cold water was studied under controlled experimental conditions using video, PIT tags and a known number of fish present in a laboratory flume. We documented a poor underwater detection rate for juvenile Atlantic salmon by visual observations in wintertime, both in day and night, and both with and without ice cover. Comparison of successively conducted field experiments at the same site resulted in two salmon parr observations by snorkeling, one by video and 63 individuals by electrofishing. In the laboratory experiment the maximum proportion of fish observed was 33 and 50% of those present in the flume by using video-surveillance and PIT tracking, respectively. Both methods indicated that salmon parr were significantly more visible during the darkness compared to the illuminated hours. These results pose critical questions to the traditional visual observation methods used in winter studies on stream salmonids.

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Salmo salar; salmon parr; habitat; winter; behavior; methodology

Introduction

Ability to detect and locate individuals is the crucial requirement for studying habitat use and behavior of stream-dwelling fish. Methods for conducting such studies vary from observing visually from stream bank or underwater to electrofishing and locating electronically tagged fish (see Ellis et al. 2013 and references therein). Comparative studies have revealed varying strengths and weaknesses across these methods, depending on study locations and their environmental conditions (Cunjak et al. 1988; Hegggenes et al. 1990; Peterson et al. 2005; Ellis et al. 2013).

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Although winter has been considered the understudied season in running waters (cf. Heggenes et al. 2018), interest in winter as a critical period for fluvial salmonid fish in sub-arctic and boreal fresh waters has increased markedly over the last couple of decades (see Huusko et al. 2007; Heggenes et al. 2018 for reviews), and several studies have since focused on diel activity, habitat use, survival, growth, feeding, and energetics of fish during winter (Cunjak and Power 1987; Fraser et al. 1993; Heggenes et al. 1993; Metcalfe et al. 1998). Although a number of such studies have been conducted in experimental environments (Parrish et al. 2004; Linnansaari et al. 2008; Watz et al. 2015, 2016), field studies on activity and habitat use of fish have largely been dependent on visual observations, which are especially challenging to acquire in running waters during winter with low temperatures, short day length and possible ice cover. Recently, electronic tagging techniques have enabled remote field detection of radio- (Robertson et al. 2003) or PIT-tagged fish (Roussel et al. 2004; Linnansaari and Cunjak 2010) in studies on habitat use under northern winter conditions, but information can be obtained from tagged fish only, which may limit the number of observations. In addition, video surveillance has been used in winter both in the wild (Davis et al. 2017), and in near-natural canals and experimental flumes (Vehanen et al. 2000). In addition, fish have also been located and sampled by electrofishing in winter (Mäki-Petäys et al. 2004).

The question remains, how to visually observe juvenile salmonid fishes in low temperatures and what degree of accuracy is possible? Typically, winter time studies based on direct visual field observations in the field have been conducted by snorkeling (Heggenes et al. 1993), but this method is limited to periods without ice cover, or—at most—some snorkeling observations have been done at stream margins under border ice (Whalen et al. 1999; Ellis et al. 2013). Indeed, a large proportion of research on so called “winter” conditions in running waters has been carried out in small streams, temperatures well above freezing point, and without the presence of ice (Huusko et al. 2007).

It has been widely reported that the general activity of stream salmonids decreases with decreasing water temperature towards winter, they become nocturnal, seek for shelter, and may prefer different habitat compared to the warmer season (see reviews by Gibson 1993; Huusko et al. 2007; Heggenes et al. 2018). Therefore, one would argue that observing fish and their behavior visually is more challenging during winter than in summer, and that ice cover poses a particular difficulty for such studies. Consequently, making inferences on fish abundance and behavioral patterns, and comparing such features between seasons, may face substantial methodological obstacles.

Here we assessed the capacity of various methods in detecting juvenile Atlantic salmon (*Salmo salar*) in winter, both in the wild in a subarctic river (Studies I–III), and in an experimental setting (Study IV). For comparison, we analyzed video data between seasons in the field, but also compared different field methods in winter. In addition, we studied the activity and visibility of juvenile salmon in cold water under controlled experimental conditions with a known number of fish present in a laboratory flume.

Material and methods

Four different studies for detecting juvenile Atlantic salmon were conducted: (1) long-term point-checking video filming comparing juvenile salmon abundance between winter and summer, (2) “snap shot” video filming under ice across a number of observation points in various habitats providing data on possible spatial variation, (3) comparison between three field methods (successive snorkel counts, video, electrofishing) in winter

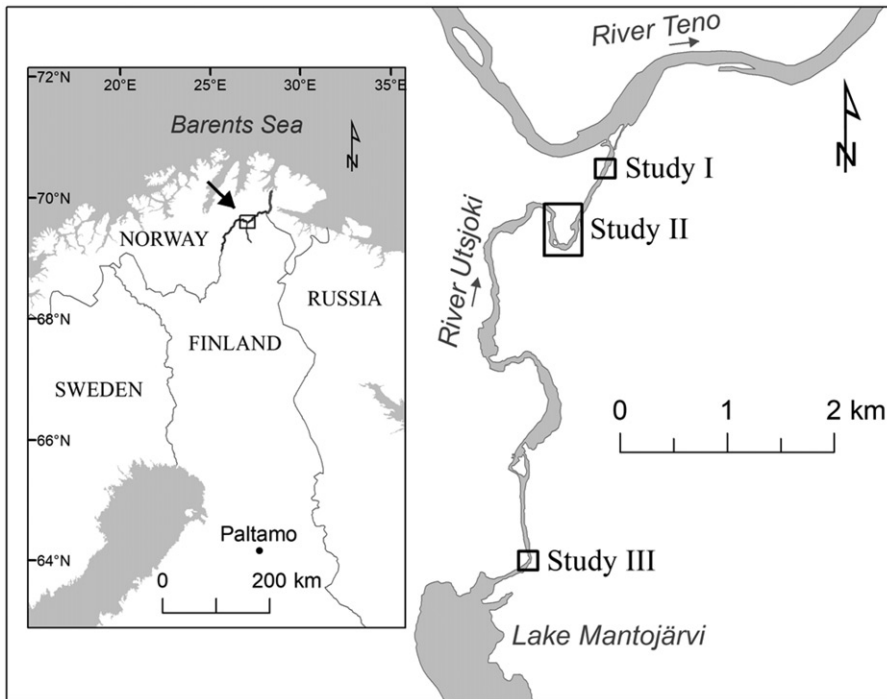


Figure 1. Map showing the locations of the field sites (Studies I–III) at the River Utsjoki, and the experimental facility in Paltamo, northern Finland (Study IV).

with no presence of ice, and (4) a laboratory experiment in a cold-water flume using a known number of fish monitored by video surveillance and PIT tags.

The field studies (I–III) were carried out in the River Utsjoki, tributary to the large subarctic River Teno, in northernmost Finland (70°N, 27°E; Figure 1). The study sites were in the lowermost part of the river, where water temperature remains constantly below 1 °C between late October and mid-May and reaches a maximum of 13–18 °C in late July–early August. Ice covers the river typically for more than six months from November until mid-May (see Mäki-Petäys et al. 2004; Orell et al. 2007 for detailed description of the study area). The laboratory study (IV) was conducted at the Kainuu Fisheries Research Station of the Natural Resources Institute Finland in Paltamo (64° N, 27°E; Figure 1; e.g. Mäki-Petäys et al. 2000; www.kfrs.fi).

Study I

Three underwater video cameras (Lamberg Bio Marin; 3.5 mm wide-angle lens, a 0.5 inch Charge Coupled Device (CCD) image sensor) were placed into the lowermost part of the River Utsjoki, in close proximity to a bridge (see Orell et al. 2007; Figure 1), under the ice. The cameras were installed on the river bottom on a lead mounting and positioned c. 20 cm above the substratum. The site at the video cameras was a flowing flat section of the river with flow velocities between 26 and 67 cm s⁻¹ (mean 48 cm s⁻¹) and water depths between 29 and 68 cm (mean 52 cm). Both ice and snow thicknesses were c. 50 cm during the camera installation in winter. The cameras covered an area of c. 1.9 m², which was measured both in winter and summer. Artificial infra-red light (wave length 730 nm) illumination was used in winter throughout the 24-h filming periods (see below). Video

material was later analyzed with Panasonic video recorders (AG-TL 700 and AG-7355; Panasonic, Kadoma, Japan) and black and white monitors (JVC TM-A140PN; JVC, East Kilbride, Scotland, UK, and Panasonic WV-CM 140) by experienced research personnel.

Two 24-hour filming sessions were conducted in February (11–12; 25–26 Feb) and three in July (2–3, 16–17, 30–31 July) 2003. The video data from February were analyzed entirely, whereas subsamples of first 2 minutes of every hour were analyzed from the July material. This was done because of the vast difference in numbers of fish observations between months. The final figures are the results of standardization of the raw recordings according to the minutes per hour analyzed, and the number of filming sessions per month. Since the actual number of individual fish in the video data cannot be confirmed (same individual could have been filmed multiple times), we refer to parr observations rather than true number of parr observed in Studies I–III.

Study II

Eighteen holes were drilled in the 25–55 cm thick ice of the River Utsjoki in 24–25 February 2005, and video camera with artificial infra-red light (both similar to the Study I above, camera positioned c. 20 cm above the river bed like in the Study I) was deployed with aid of a 3.5-m aluminum rod. The 18 holes covered six different areas spanning over the lowermost kilometer of the river, including three shallow flowing sections (flow velocity 20 cm above the bottom 20 and 40 cm s^{-1} , water depth under ice 70–100 cm), and three deeper pool-type sections (flow velocity 2–30 cm s^{-1} , depth 160–260 cm) with three holes drilled at each section. Thickness of snow on the ice varied between 5 and 20 cm. All holes were filmed once in the mid-day—early afternoon (noon–3 p.m.) and in the night (10 p.m.–2 a.m.). Short, 2-minute periods were filmed in four directions: one straight downstream, one upstream and two sideways, in a 90° angle to the up- and downstream directions. In addition to the 2-minute periods, four longer filming sessions (3–4 hours, two sessions in day, two at night) were used in one deep and two shallow sections.

Study III

Three different methods (snorkeling, video, electrofishing) were compared at an ice-free rapid area in the River Utsjoki, 4 km upstream the confluence of rivers Utsjoki and the Teno (location described by Mäki-Petäys et al. 2004) in 26–27 April 2005. Electrofishing was used for validating the two visual methods in this ice-free area where such comparison was possible in wintertime. Because of the large Lake Mantojärvi directly upstream of this site (Figure 1), some small areas in the upper part of the rapid section, including our study site, are typically ice-free over the entire winter. This site was approximately the same as described by Mäki-Petäys et al. (2004) with a mean depth of c. 30 cm, and water velocity c. 30 cm s^{-1} . The snorkeled, larger area included additional slightly deeper areas (50–70 cm) compared to the smaller area that was video-filmed and electrofished.

First, a c. 400 m² area was carefully snorkeled in mid-day, and all observations of salmon parr were recorded. Then, a subset of this area (c. 100 m²) was video-filmed by wading the area in a zig-zag fashion processing sideways and upstream with c. one meter intervals. At each point, the video camera (same camera, similarly attached to an aluminum rod as in Exp II) was placed close to the bottom and pointed upstream for 2 minutes before moving slowly to the next spot sideways or upstream. The video-filming was carried out both during day (noon time) and night (at midnight, using artificial illumination, see Study I). Thirdly, the same 100 m² area was electrofished once with similar zig-zag

fashion, using the method described by Niemelä et al. 1999, but in day-time only. Salmon parr were aged from scale samples using a microfiche reader with a magnification of $\times 30$, following the standard procedures and international guidelines (ICES 2011).

Study IV

The experiment was conducted in an indoor flow-through flume with a 6-m long and 0.4 m wide experimental arena (total area 2.4 m²), located at the experimental research facility of the Natural Resources Institute Finland in Paltamo (Figure 1). The channel had a slope of 0%, and it was closed by wire-mesh panels (mesh size 6 mm) from both ends. Channel bed consisted of a layer of coarse gravel/pebble (40–70 mm in diameter), with 30 stones (10–15 cm in diameter, density 12 stones m⁻²) placed evenly along the channel in groups of 3–4 stones. Water (1.4 °C) was drained into the channel from the nearby lake. Ambient temperature in the experiment room was 9 °C. Water depth and water column velocity (at 0.6* depth) were recorded at two points in six cross-sectional transects placed 0.8 m apart, yielding mean water depth of 19.6 cm (SD 2.2 cm, $N=12$) and mean water column velocity of 17.7 cm s⁻¹ (SD 5.6 cm s⁻¹, $N=12$). Water discharge in the channel was 141 s⁻¹.

At the start of the experiment, on 22 February 2012, six young-of-year Atlantic salmon, originated from captive reared broodstock of the River Oulujoki (Finland) strain (Erkinaro et al. 2011), were randomly selected from the hatchery rearing tank. During the rearing period, the daily photoperiod following local diurnal rhythm was provided by artificial lights. The salmon parr were tagged with individually coded passive integrated transponder (PIT) tags (tag model HDX Oregon RFID, tag size 12 mm \times 2.15 mm, weight 0.1 g) under anesthesia with clove oil in standard laboratory conditions. Fish were measured for their total length and mass (83.0 \pm 3.9 mm (average ± 1 SD, $N=6$), and 5.3 \pm 0.8 g). Thereafter fish were introduced into the channel, resulting in a density of 2.5 fish m⁻², which is in the upper range of Atlantic salmon fry densities in northern Finnish rivers (Niemelä et al. 1999). Salmon were allowed to habituate to stream conditions for 4 days before starting the monitoring (at midnight on 27 February). During the monitoring period of next 5 days, artificial light was provided on a 16:8 dark-light (D:L) photoperiod. Daylight conditions (room light 90 lux) were maintained at 0800–1600 hours, darkness (< 1 lux) at 1600–0800 hours. Fish were not fed during the study period.

Salmon behavior, either being visible (hovering on channel bed substrate or swimming) or not (sheltering/hidden in the crevices among the substrate) were monitored by six black-and white submersible video cameras (Sony CCD, provided by CCTV Systems Inc., TX). Cameras were fixed at regular intervals on the channel bed so that 80% of the experimental arena was covered by their field of vision. Cameras were operated through NUUO Surveillance Systems (NUUO Inc, Taipei, Taiwan) including a digital video recorder and viewer software. In the night, infrared lights were used to ensure the sufficient conditions for recording. Video recording was continuous during the experiment but for analyzing the monitoring of salmon behavior, the first 1-minute period per hour was used by surveying simultaneously all camera views, and the number of different fish individuals observed was counted. Thus, the procedure yielded 24 such periods per day during which the experimental arena was searched for the visible fish.

In addition, salmon movements in the channel were monitored by PIT tracking. The PIT-tag detection system consisted of four stationary, swim-through gate antennas (Texas Instruments Radio Frequency Identification Series 2000 system; e.g. Linnansaari and Cunjak 2010). The antennas were placed in the channel, 1.2 m apart at regular intervals,

each covering the whole cross-sectional water column of the channel. By each of the antennas, a 20-cm wide zone of fine gravel (diameter <0.8 cm) was placed into the channel bed to create potentially unfavorable habitat conditions for fish, in order to avoid their long term stay in the antenna detection range. Antennas were connected through tuning modules (RI-ACC-008B) to readers (consisting of modules RI-RFM-008B and RI-CTL-MB2A), each of the antennas having an own reader. The antennas were tuned to resonance so that detection signal from a tag was received anywhere within the swim-through field. A laptop computer was used for data storage (tag-id, antenna number, date and time). The number of different fish individuals detected per an hour was counted.

Results

Study I

In February, a mean of seven (range 3–14) Atlantic salmon parr were observed (standardized observations, see Methods) over a 24-h period in each of the three video cameras. In contrast, the mean number of parr observations was 1620 per 24 h per camera (range 700–2380 observations, extrapolated from the subsamples) in July.

Study II

The “snapshot” video shooting under the ice in February yielded two observations of Atlantic salmon parr in the flowing sections, and one parr in the pool sections during the day. No fish were detected at night. Similarly, no fish were detected in the longer filming sessions (3–4 h, both day and night).

Study III

Snorkeling over the 400 m² ice-free area in April resulted in observations of two Atlantic salmon parr. One parr was detected by video filming in a smaller (100 m²) subarea. Single-pass electrofishing in the same 100 m² area resulted in a catch of 63 salmon parr (age-2: $n = 22$; age-3: $n = 39$; age-4: $n = 2$).

Study IV

Irrespective of the method used, the number of fish detected at each of the monitoring periods was low (Figure 2). The maximum number of fish observed was two (2 out of 6, 33%) for video-surveillance and three (50%) for PIT tracking, but 53% and 51% of the observation periods yielded no fish detection in video surveillance and PIT tracking, respectively. Both the video-surveillance and the PIT tracking indicated that salmon parr were visible over the channel bed or moved in the water column of the flume significantly more during the darkness compared to the illuminated hours (Figure 2; difference between D:L for video $t_{df118} = -2.151$, $p = 0.034$; for PIT $t_{df118} = -3.751$, $p < 0.001$).

Discussion

This study revealed a low underwater detection rate for juvenile Atlantic salmon by visual observations in wintertime, both in day and night, employing multiple methods (short and long term video observations, snorkeling), and both with and without ice cover.

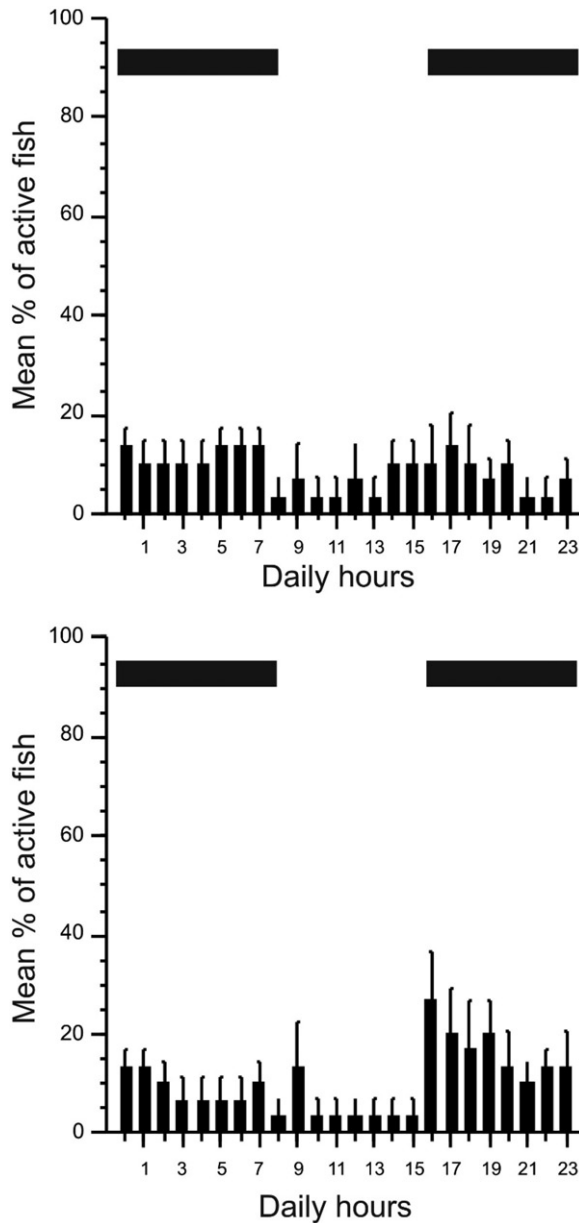


Figure 2. Diurnal activity rhythm of salmon parr in the experimental channel (Study IV) over a 5-day period. Above: mean percent (+1SE) of fish visible at each of the daily hours observed by video-surveillance; below: mean percent (+1SE) of fish tracked at each of the daily hours by a PIT-antenna array. Black thick lines indicate periods of darkness.

Subsequent electrofishing in the Study III yielding an abundant catch of fish present in the area revealed the low performance of visual observations. In addition, our laboratory study with known number of fish in a PIT-tag-controlled experimental flume resulted in the same pattern and confirmed the results of the visual methods from the field studies and the video recordings at the experimental arena. Moreover, the suitability of habitats for juvenile salmon in studies I–III is confirmed by other studies: sampling sites in that

area are included in a long term electrofishing programme and show high summertime juvenile salmon densities between 110 and 200 ind. per 100m² (Niemelä et al. 1999; unpublished data; see also Mäki-Petäys et al. 2004 for winter data in another time).

Although several central studies on salmonid behavior in winter are based on snorkeling observations (e.g. Cunjak 1988; Heggenes et al. 1993; Fraser et al. 1993; Contor and Griffith 1995; Whalen et al. 1999; Bremset 2000), the studies have not included validation of the observational method by other methods or known numbers of fish. Recently, Davis et al. (2017) introduced advanced action camera deployment for studying fish in an ice-covered stream. They stated that the technique was 'effective in observing fish behavior, communities and habitat preference' but did not provide data or evaluation of the method. The apparently poor visibility of fish in winter and low detection rate in visual observations documented in this study suggests problematic methodological issues in studies on wintertime habitat use and behavior in stream-dwelling salmonids. In addition to the fact that only a fraction of the present individuals can be visually detected, an important question is what are the few individuals that are visible and active in winter, are they random individuals of the local population, or are they special in their habitat use, behavior, diel rhythm or social status?

Individual differences in behavior and performance have been detected in various taxa, including fish, and such traits are often linked to fitness factors like growth (Steingrímsson and Grant 2003), immune function (Kortet et al. 2010), and resting metabolic rate which is directly linked to behavioral output (e.g. aggressiveness) and productivity (e.g. somatic growth) of an individual (see Biro and Stamps 2010 for a review). Roy et al. (2013) have demonstrated marked individual differences in activity patterns (nocturnal, diurnal, cathemeral, crepuscular) of juvenile Atlantic salmon, and also showed that individuals change their behavior adopting different activity patterns in different times and under varying environmental conditions. Thus, there is state- and context-dependent individual variation in behaviors, habitat use and related performance (Metcalfé et al. 1998; Alvarez and Nicieza 2005). In winter, the main behavioral strategy in salmonids is risk-reducing sheltering and nocturnalism, and the basic survival strategy is minimizing the usage of energy storage (e.g. Huusko et al. 2007; Heggenes et al. 2018). Both strategies favor an inactive and less energetically costly lifestyle, typically in form of keeping out of sight among stream bed structures. Further, under stressful winter conditions low resting metabolic rates may be advantageous through providing higher resistance to starvation. However, resting metabolic rates show considerable variation within populations and individuals (Lahti et al. 2002; Alvarez and Nicieza 2005; Finstad et al. 2007). Interestingly, in ice-free, complex semi-natural stream-environments during winter, young Atlantic salmon individuals with a lower resting metabolic rate used more cover, whereas individuals with a higher resting metabolic rate were more risk-prone, using more areas outside cover for successful feeding to compensate higher energy loss (Finstad et al. 2007). High metabolic rate individuals are typically also of high status and/or highly aggressive (Metcalfé et al. 1995; Watz et al. 2015).

With respect to surface ice conditions, Watz et al. (2015) reported that brown trout (*Salmo trutta*) parr left their holding positions on the experimental flume bottom and actively swam in the water column to a greater extent than under ice-free conditions, still the fish with high resting metabolic rate were more active than the fish with low rate. However, the experimental arenas used by Watz et al. (2015) were structurally simple (one shelter element covering 2.3% of the gravel (<3 cm in diameter) bed), and thus the fish behavior remained unresolved under conditions of complex bed structure and surface ice cover. Nevertheless, in another experiment by Watz et al. (2016),

similar observations with trout leaving their shelter were documented in experiments carried out in natural streams with a simulated, artificial ice cover. To this end, our experiments in the natural channel of the River Utsjoki suggested that majority of Atlantic salmon parr were invisible under such conditions with natural stream bed structure and natural ice cover.

The diurnal activity pattern observed in the experimental flume indicated a similar tendency with several earlier studies: juvenile salmonids in cold water show higher nocturnal activity than during the day (e.g. Fraser et al. 1993; Heggenes et al. 1993; Huusko et al. 2007). Contor and Griffith (1995) reported that emergence of juvenile rainbow trout (*Oncorhynchus mykiss*) from concealment to visible, active exposure to the water column started immediately after sunset, and within an hour the number of emerged fish stabilized. Similarly, at dawn, concealing into the stream bed takes place fast: Riehle and Griffith (1993) found high density of visible trout 30 min before sunrise, but all trout were concealed 10 min prior to sunrise. The abrupt increase in activity once the illumination was switched off in the afternoon detected by the PIT-tag data compared to the more smooth change in the video observations (Figure 1) was surprising. Likely explanations include the different data sampling in the two methods in that the first minute per hour was used for the video data in contrast to a full hour of PIT observations that may have overemphasized the activity change in the PIT data. An abrupt change in illumination and the concurrent activity increase in fish have probably been more visible in the 1-hour PIT data compared to the short, one-minute video clip at the beginning of that hour. On the other hand, there have been relatively many visible fish during the early morning hours in the video material, but apparently they have moved less actively between the PIT antennas (Figure 1). Hence, one should practice caution in comparing activity information collected by these two methods, especially when different time periods are sampled by each of the methods.

Despite certain limitations in our data, e.g. that the comparison of visual observations and subsequent electrofishing did not include spatially repeated measurements (Study III), the results are very clear with few visual observations in field studies and dramatic differences in abundance indices between methods. Both experimental and field observations presented in this investigation suggest that visual observations in winter are not well indicative of the actual abundance of juvenile salmonid fish in the area. These results pose critical questions on the quality of traditional visual observation methods used in winter especially in natural habitats with complex river bed structure.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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Eero Niemelä completed his PhD thesis at the University of Oulu and has worked at the River Teno Research Station of the Natural Resources Institute Finland (Luke).

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