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Low survival of hatchery-released Atlantic salmon smolts during initial river and fjord migration

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Even though release strategies have been improved, recapture rates of hatchery-reared Atlantic salmon as adults have been low in the River Eira, Norway. To evaluate whether loss of fish occurs in the river immediately after release, in the early marine phase in the fjord, or during the subsequent feeding migration at sea, 20 smolts were equipped with acoustic transmitters. The survival and movement pattern of the smolts were monitored along the 9-km-long river and during the first 37 km of the fjord migration. Only 25% of the smolts survived from release in the upper part of the river and until passing the fjord site 37 km from the river mouth. The within-river loss (15%, 3 of 20 smolts) was smaller than the marine mortality (71%, 12 of 17 smolts). The marine mortality was largest in the inner part of the fjord, with 41% mortality during the first 3.6 km, 40% mortality during the next 6.0 km, and only 17% mortality during the last 27.5 km (i.e., 11.4%, 6.7% and 0.6% mortality per km, respectively). The data suggested that at least 9 of the 12 smolts lost in the fjord were eaten by predatory fish (i.e. 45% of the fish released in the river were lost to fish predators). Hence, our results indicate that a considerable proportion of hatchery-reared smolts released in rivers might be lost due to predation before they actually leave the fjords.

Introduction

Atlantic salmon populations have declined dramatically during the last century (Parrish *et al.* 1998, WWF 2001). The release of artificially produced Atlantic salmon from hatcheries is a common management practice over large parts of the distribution area to enhance and conserve wild populations, for example to compensate for destroyed spawning areas or to re-establish lost populations (Finstad and Jonsson 2001, Einum and Fleming 2001). Similar to many other salmon rivers, hatchery-reared smolts are released in the River Eira in western Norway to compensate for reduced fish production due to hydropower regulation (Jensen *et al.* 2009). Recovery rates as adults have been low (Jensen *et al.* 2009), even though release strategies have been improved, by for instance acclimating smolts in a net-pen at the release location for 48 hours before release to reduce transport related stress and mortality (Finstad *et al.* 2003). It is not

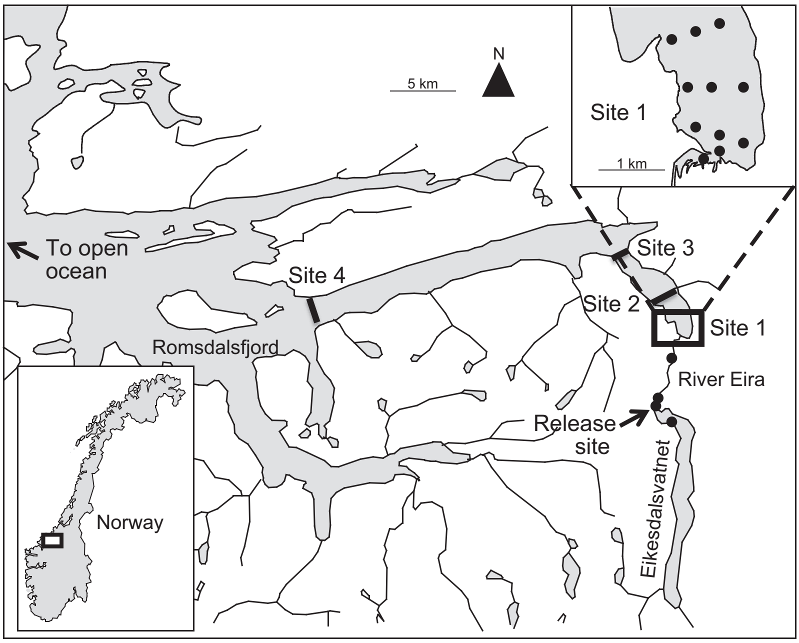

Fig. 1. Map of the study area showing the smolt release site and the receiver sites. In Eikesdalsvatnet, River Eira and at Site 1 in the fjord, individual receivers are indicated by ●. At Sites 2–4 in the fjord, several receivers were placed in a line across the fjord.

known whether the loss of fish occurs in the river or fjord immediately after release or during the subsequent feeding migration at sea. To evaluate the survival and movement patterns of hatchery-reared Atlantic salmon smolts during the outward migration from release in the River Eira, we tagged hatchery-reared smolts with acoustic transmitters and monitored their movements from the release site 9 km upriver and during the first 37 km of the fjord phase.

Material and methods

The study was carried out in the River Eira and Romsdalsfjord system in western Norway (62°40´N, 8°10´E, Fig. 1). The 9-km-long River Eira originates in Eikesdalsvatnet and has a mean annual water discharge of 17 $m^3 s^{-1}$. Annually, 14 000–30 000 wild smolts left the river during 2001–2008 (Jensen *et al*. 2009). In addition, 50 000 hatchery-reared Atlantic salmon smolts, which are first-generation offspring of the River Eira stock, are annually released from the Statkraft Energy AS hatchery in Eresfjord.

A 24-h seawater challenge test (Blackburn and Clarke 1987) performed on Atlantic salmon smolts in the hatchery on 11 May 2009 revealed mean plasma sodium levels of 187 ± 24 mM, and resulted in no mortality, indicating that most of the smolts were ready to enter sea water (Sigholt and Finstad 1990). Plasma sodium levels of 170 mM and below are regarded as a good smolt status (Clarke and Blackburn 1977, Blackburn and Clarke 1987, Sigholt and Finstad 1990), and values for 4 of 10 analysed smolts were within this limit. The wild smolt run in the River Eira occurs usually during May, most years with a median migration date between 11 and 17 May (Jensen *et al*. 2009).

Twenty hatchery-reared smolts (mean body mass = 208 g, range = 103–370 g, mean total length = 280 mm, range = 222–330 mm, age 2+) were tagged with individually coded acoustic transmitters (VEMCO Ltd., Canada, model V9P-1L-69KHz-S256, 9 × 39 mm, weight in air/water of 5.2/2.7 g) 7 days prior to release, following methods described in Finstad *et al*. (2005). The transmitters were equipped with a depth sensor, measuring water depths down to 50 m (continuing to indicate water depth 50 at greater depths). The smolts were transported by car in a tank with oxygenated water (4.5 km by road) to the acclimation net-pen at the release location 9 km upriver on 12 May 2009, for a 48-hour acclimation period together with approximately 6000

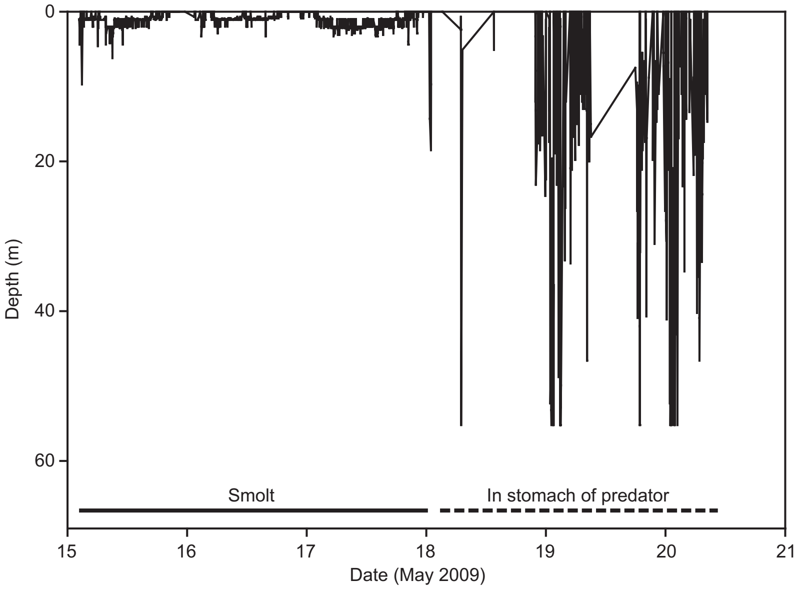

Fig. 2. Depth recordings of a representative smolt believed to have been eaten by a marine predator after leaving the river and entering the fjord on 15 May 2009. The record documents a sudden change in swimming depth of the smolt after its presumed death by predation on 18 May. The post-18 May depth profile is atypical of a smolt but characteristic of a fish predator (cod or saithe), and indicates that the transmitter is within the stomach of the predator.

untagged smolts. The pen was opened on 14 May 2009 at 22:00. When the pen was checked 12 hours later, all smolts had left. The water temperature in the river on the release date was 6.0 °C, and the daily average for the following two weeks was 6.5 °C. The water discharge on the release date was 20 $m^3 s^{-1}$, and the daily average for the following two weeks was 26 $m^3 s^{-1}$.

The fish were recorded by 32 receivers (VEMCO VR2) deployed in the river, Eikesdalsvatnet, and at four sites in the fjord system (Fig. 1). Signals from the transmitters were recorded automatically when a fish was within the detection range of a receiver. The transmitter identification code, detection date, time and depth were recorded. At site 1, a grid of 11 receivers was placed in the inner part of the fjord close to the river mouth. The distance from the river mouth to the outermost receiver of the grid was 2.2 km. At site 2, 3.6 km from the river mouth, 4 receivers were distributed evenly in a line across the fjord. At site 3, 9.6 km from the river mouth, 5 receivers were distributed evenly in a line across the fjord. The fjord is 1.5 km wide at both site 2 and site 3. At site 4, 37.1 km from the river mouth, 8 receivers were distributed evenly across the fjord, where the fjord is 2.6 km wide. The receiver range was typically 200–450 m for transmitters at 0.5–3.0 m depth, but varied with factors such as wave action, salinity and depth, and the range could be reduced during bad conditions. Overlapping detection ranges during good conditions ensured that post-smolts were not likely to pass any arrays without being recorded. This was confirmed by the finding that all fish detected at a site had been recorded when passing all previous sites. Sea depths at receiver sites were 26 to 288 m, and receivers were attached at 3–5 m depth. Data was downloaded on 15 July 2009.

As salmon post-smolts normally show a clear and rapid directional movement from the river outlets and out of the fjords (Finstad *et al*. 2005), fish were characterized as dead when they disappeared between two receiver sites, or the transmitter remained stationary at a receiver site without any horizontal or vertical movements for the remaining study period. Depth recordings were also used to distinguish between live and preyed upon post-smolts (E. B. Thorstad unpubl. data). Post-smolts typically swim close to the surface. Abrupt changes from an assumed normal depth use pattern for a smolt, with subsequent utilisation of much greater depths, were interpreted as predation (Fig. 2). In a previous study in the same fjord system, mean swimming depths of post-smolts were 0.4–1.1 m, whereas Atlantic cod *Gadus morhua* and saithe *Pollachius virens*, the main fish predators in the fjord (Jepsen *et al*. 2006), were recorded down to a maximum of 43–103 m (E. B. Thorstad unpubl. data).

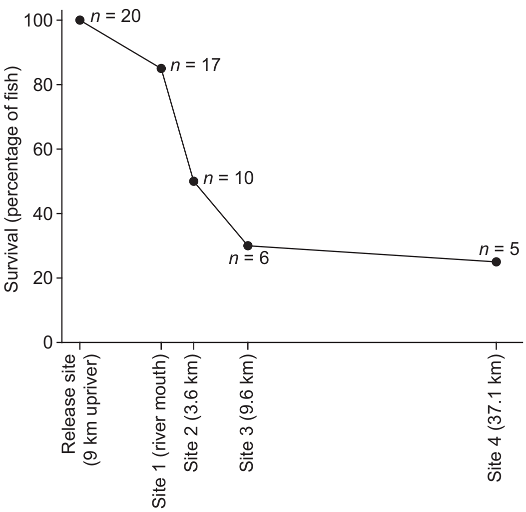

Fig. 3. Proportion of acoustically tagged smolts released 9 km upriver (n = 20) that were recorded alive at the different receiver sites in the fjord (sites 1–4). Number (n) of tagged smolts recorded alive at each site is also given in the figure.

Results

There was a high total mortality during the initial seaward migration, as only 25% (5 of 20) of the released smolts were recorded at the outermost fjord site 37 km from the river mouth (site 4, Figs. 1 and 3). The within-river loss (15%, 3 of the 20 smolts released in the river) was smaller than the loss in the fjord (71%, 12 of the 17 smolts entering the fjord).

In the river, two smolts disappeared in the middle part of the river, between the receivers positioned 1.5 and 8.5 km from the river mouth. In addition, one smolt disappeared in the lower part of the river, after being recorded by the receiver 1.5 km from the river mouth. All smolts entering the fjord followed a one-way route downriver, except one smolt first moving upstream to Eikesdalsvatnet, before subsequently moving downstream and entering the fjord.

When looking at the mortality in the different parts of the fjord system, the marine mortality was largest in the innermost part close to the river mouth, with 41% mortality (7 of 17 smolts) during the first 3.6 km, 40% mortality (4 of 10 smolts) during the next 6.0 km, and only 17% mortality (1 of 6) during the last 27.5 km (i.e., 11.4%, 6.7% and 0.6% mortality per km, respectively, Fig. 3). Based on variation in recorded swim depth, at least 9 of the 12 smolts lost in the fjord were eaten by fish predators (e.g. Atlantic cod or saithe). This means that at least 45% of all the smolts released in the river and 53% of the smolts that reached the river mouth (n = 17) were lost to marine fish predators. Body length or mass did not differ between smolts still alive 37 km from the river mouth (n = 5) and those lost at an earlier stage (n = 15) (Mann-Whitney U-test: df = 19, length: $U = 26.5$, $p = 0.34$, mass: $U = 0.33$, $p = 0.74$).

The median period from the time that the net-pen was opened until the first recording of a fish in the river mouth (Site 1) was 24.1 hours (range = 2.5–1092.4, n = 17) (site 1). The time from release until first recording in the river mouth did not depend on body length or mass (linear regression: df = 16, length: $r^2 = 0.03$, $p = 0.55$, mass: $r^2 = 0.02$, $p = 0.63$). The median periods from the first recording in the fjord to sites 3 and 4 were 7.0 hours (range = 3.7–21.1, n = 6) and 10.6 hours (range = 9.4–15.7, n = 5), respectively. The time from first recording in the river mouth until first recording 9.6 km from the river mouth did not depend on body length or mass (linear regressions: df = 5, length: $r^2 = 0.04$, $p = 0.70$, mass: $r^2 = 0.22$, $p = 0.35$). However, it should be noted that the sample size for this analysis was small. An analysis for fish recorded 37.1 km from the river mouth was not performed due to the small sample size. The migration speeds correspond to a median migration rate of 0.36 bl s^{-1} (range = 0.01–3.39) in the river, 1.51 bl s^{-1} (range = 0.42–2.43) during the first 9.6 km of the marine migration and 3.35 bl s^{-1} (range = 2.05–4.26) during the first 37.1 km of the marine migration.

Discussion

Our study indicates a large loss of hatchery-reared smolts during the first few days after release. Some loss occurred in the river (15% loss of the fish released in fresh water), but the largest mortality occurred after the smolts entered the marine environment (71% mortality of the fish exiting fresh water). Previous studies have pointed to an even larger loss of hatchery-reared smolts in the river than found in the present study (E. B. Thorstad unpubl. data). It has been speculated that the within-river loss might not only be due to mortality, but that rearing conditions in the hatchery and smolt quality might affect an individual's urge to migrate, resulting in some hatchery-reared smolts remaining in fresh water (E. B. Thorstad unpubl. data). However, the smolts in the present study seemed to be motivated to migrate to the sea. Three of the smolts were not detected beyond the river. They may have suffered predation by birds, American mink *Neovison vison* or otter *Lutra lutra*, mortality by other reasons, failed to migrate to sea due to low seawater tolerance (as indicated by high plasma sodium levels in some smolts in the hatchery), or undergone a transmitter failure. The latter possibility is judged unlikely. The mortality factors in the river and fjord, physiological smolt status and the motivation to migrate, might also vary over time and among years (McCormick *et al*. 1998).

Predation was judged to be the main cause of post-smolt mortality in the fjord. At least 75% of the post-smolts lost in the fjord had a vertical movement pattern indicating that they had been eaten by fish predators like Atlantic salmon or saithe. The fate of the remaining lost post-smolts is not known, but they might have been consumed as well, by fish predators or marine mammals out of receiver range, or by sea gulls *Larus* spp., which could have brought them out of water and hence out of receiver range. The mortality was largest close to the river mouth and decreased as post-smolts proceeded outwards the fjord, which is consistent with a previous study showing high predation pressure by Atlantic cod and saithe in this river mouth (Jepsen *et al*. 2006). The first part of the marine migration may also be a stage of elevated mortality not only for hatchery-reared smolts, but also for wild smolts (e.g. Kocik *et al*. 2009). In the estuaries of the Norwegian Rivers Orkla and Surna, cod was estimated to consume 20% and 25%, respectively, of all wild and hatchery-reared smolts (Hvidsten and Møkkelgjerd 1987, Hvidsten and Lund 1988). In contrast, Davidsen *et al*. (2009) tagged wild smolts in the Norwegian River Alta, and followed their migration in the river and during the first 17 km of the fjord migration using similar methods to our study. Survival rates in the fjord were higher than in the present study, and ranged from 97.0%–99.5% per km.

While it cannot be ruled out that tagging in some way affected smolt behaviour and survival, large negative effects from the small transmitters used were not expected (Jepsen *et al*. 2002). If tagging effects significantly influenced swimming performance and survival, it should have resulted in a high and rapid loss of fish in the river. This was not the case as the bulk of the mortality we documented occurred after the smolts had left the river. The fish were also given one week to recover from the tagging procedure before release. Furthermore, earlier studies have shown that similar transmitters did not significantly affect viability and swimming performance of hatchery-reared salmon smolts (Peake *et al*. 1997, Jepsen *et al*. 2002). Moore *et al*. (2000) recommended that transmitters for Atlantic salmon post-smolts should be less than 5% of the fish body mass to minimise effects on behaviour and survival. In the present study, this ratio (average = 1.4%, range = 0.7%–2.6%) was well below this recommendation. The high swimming speeds in our study, similar to smolt swimming speeds recorded by Hyvärinen *et al*. (2006), also confirmed that the fish had recovered well from the tagging. However, the risk of predation may still potentially be increased by tagging, and the mortality rates recorded in this study may be regarded as maximum mortality rates.

It has been shown that hatchery-reared Atlantic salmon have a lower overall survival than wild smolts at sea, both in the Atlantic Ocean and the Baltic Sea (Jonsson *et al*. 1991, Kallio-Nyberg *et al*. 2004). Thus, the large loss of hatchery-reared fish already during the first few days after release highlights the importance of producing a more "natural" smolt to improve the success of hatchery-releases. It should be possible to produce hatchery-reared smolts with a size, fat content and physiological smolt status more similar to wild smolts. However, the fact that the main loss was due to predation in the marine environment also points to other issues when using hatchery-reared fish to enhance wild populations. In general, as compared with wild fish, hatchery fish demonstrate poor anti-predator behavior perhaps due to the lack of exposure to predators under hatchery conditions and relaxed selection on antipredator traits in hatchery populations (Einum and Fleming 2001). Thus, predator conditioning in hatcheries could improve survival of hatchery origin smolts (Vilhunen 2006). Strategies for improving the natural salmon production in rivers, such as habitat adjustments and removal of migration barriers, could also be considered as an alternative to releasing hatchery-reared fish.

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