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# Manipulations of feed ration and rearing density: effects on river migration performance of Atlantic salmon smolt

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Examensarbete i biologi, 30 hp, A2E

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## Manipulering av fodernivå och fisktäthet vid odling av laxsmolt: effekt på vandringsbeteende och överlevnad efter utsättning i älven

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Keywords: Atlantic salmon, smolt, feed restriction, rearing density, migration, mortality, migration speed

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## Abstract

The out-migration of Atlantic salmon smolts was studied at the lower part of the Umeå River (River Umeälven) from the Norrfors dam towards the sea (Bothnian Bay) in northern Sweden. Two-year old hatchery-reared Atlantic salmon (n=250) were tagged with acoustic transmitters and released downstream of the Norrfors dam and monitored while migrating downstream. The aim of this study was to determine the effects of feed restriction and rearing density on the migratory behaviour of Atlantic salmon smolts in the lower part of the flow-controlled river Umeälven in northern Sweden.

Twenty acoustic receivers were deployed along the river section to cover all possible migration routes. Hatchery-reared Atlantic salmon smolts from five treatment groups were tagged using acoustic transmitters and released in late May 2012. A majority of the smolts migrated to the sea within a week after release. The smolts showed different migration speeds at different parts of the river. However, the average migration speed was similar for all treatment groups except for the strongest feed restricted treatment group that was significantly slower. The total mortality was higher in the old river channel downstream the dam to the Confluence area. No effects of any treatments could be detected on either migration speed or mortality.


## Introduction

Atlantic salmon (*Salmo salar*) populations are known for their ability to migrate through rivers and oceans. They are mostly anadromous which means that they migrate to sea for feeding purposes and return to freshwater for spawning (Jonsson *et al*. 2011). Before the young fish start migrating towards the sea, they undergo a smolting process which make them physiologically and morfologically prepared to adapt to different environmental conditions (Thorpe *et al.* 1998). They migrate as smolts downstream, actively or with the water current (passive displacement), to the estuaries and later as post-smolts into the open ocean (Thorpe *et al.* 1998, Jonsson *et al.* 2011). The time of migration is generally in spring or early summer. The timing and success of this movement from freshwater to marine environment is proposed to be important for survival of smolts and their following return as adult fish (Hansen *et al.* 1989, McCormick *et al.* 1998).

Atlantic salmon populations have been in decline worldwide and also in Sweden (Parrish *et al.* 1998, McKinnell *et al.* 1999, Lans *et al.* 2011). There are several human activities such as constructing of hydropower dams, overfishing, pollution, water regulation, climate change, etc., that have negatively affected the populations and led to this decline (Parrish *et al.* 1998, Serrano *et al.* 2009). To restore and enhance decreasing salmon populations, a large number of stocking programs and artificial reproduction to produce hatchery fish are in place (Økland *et al.* 2011). However, the efficiency of hatchery programs has been in debate and the main question has always been whether hatchery-reared fish can ecologically compensate the decline of wild populations (Ryman *et al.* 1987, Thorpe 1998). Efforts are being implemented to design effective rearing programs to produce hatchery fish that their physiological and behavioral characteristics are more similar to wild fish (Zydlewski *et al.* 2003).

There are several studies that have looked into either effects of feed regimes (Lans *et al.* 2011, Vainikka *et al.* 2012) or effects of rearing density (Soderberg *et al.* 1987, Brockmark *et al.* 2007, Jonsson *et al.* 2010) on migration behavior of different fish species. To my knowledge, no studies have examined the effect of both these factors simultaneously on fish migration. Previous studies have revealed that hatchery-reared fish have difficulties adapting to wild conditions; resulting in reduced growth, lower reproductive success, and lower survival in comparison to wild populations (Ellis *et al.* 2005, Araki *et al.* 2007). These deficiencies are largely a consequence of environmental effects and genetics caused by rearing conditions (Price 1999). Rearing conditions such as amount of feed availability, rearing density, temperature, and day length may negatively affect the smolting process, and physiological condition of the fish. These effects can persist even after they have been released into the wild (McCormick *et al.* 2003, Saloniemi *et al.* 2004).

Earlier studies have shown that feed availability and density, influence growth rate and behaviour in hatchery-reared salmonids (Holm *et al.* 1990, Serrano *et al.* 2009). The interaction between feed availability and density may lead to aggressive behavior or growth depression and may have a later influence on migratory behavior and mortality rate of hatchery-reared fish (Holm *et al.* 1990). Furthermore, faster smolt migration shortens the time they are exposed to predators in the riverine migration and they will reach the comparatively higher productive coastal areas earlier (Raymond 1979).

The main objective of this study was to observe the effects of rearing density and feed restriction on the in-river migration performance of two-year old hatchery-reared Atlantic salmon smolts. I used fish from an ongoing project where fish experienced different densities and different feed restrictions in the hatchery (Persson and Alanärä, unpublished).

I used ultrasonic telemetry to monitor downstream migration of smolts through the lower part of the River Umeälven. To evaluate downstream migration patterns and mortality rates, I used the recorded acoustic transmitter data from the tagged fish, stored in submerged acoustic receivers along the migratory route. Data on number of fish detected and date and time of the detections were compiled and analyzed and the migratory performance and mortality rate among different treatment groups were compared. I predicted that fish reared under more natural condition (i.e., at lower density or lower food availability) would have lower mortality rate and a higher swimming speed in the river than fish reared in standard hatchery condition. I also predicted that reared fish with strongest reduced feed ration (SRFR) that were closest in size to wild fish would have a better survival in natural condition and also a better migration speed in comparison to all other treatment groups.

## Materials and methods

### *Study area*

The River Umeälven in northern Sweden enters the Bothnian Bay at N63°45´, E20°20´ ca. 450 km from its origin. The annual mean flow is about 430 $m^3/s$. The River Umeälven is regulated by several hydroelectric power plants and the last dam - the Norrfors dam- is located ca. 32 km from the coast. The Atlantic salmon population in the River Umeälven was destroyed by the dam construction in the early 1950's (Rivinoja *et al.* 2001). A hatchery below the dam therefore produces fish to compensate for losses of wild populations and ca. 80,000 salmon smolts are released every year downstream the Norrfors dam (Vattenfall AB).

The study area comprised approximately 29 km of the remaining river, from the Norrfors dam to the Bothnia bay (Figure 1). The study area was divided into nine parts. The first section (Approximately 8 km) between release site and the power-station outlet (250 m long and 40 m deep) at the Confluence area is called the old river channel. This section acts as a bypass channel at the time of migration as water is released from the dam from 20$^{th}$ of May to 1$^{st}$ of October each year (most of the water from the dam diverts to Stornorrfors power-station and the water goes back into the River Umeälven at the Confluence area after a 4 km underground discharge tunnel) (Rivinoja et al. 2001). The old river channel has four rapids; at Laxhoppet, upper and lower Kungsmofallen and Baggböle. From the Confluence area to Gimonäs (considered as the second section of the river), the water is fast flowing and without any rapids or falls. The last section of the river including four parts from Gimonäs to the estuary at Holmsund, have relatively slow flowing water (Figure 1).

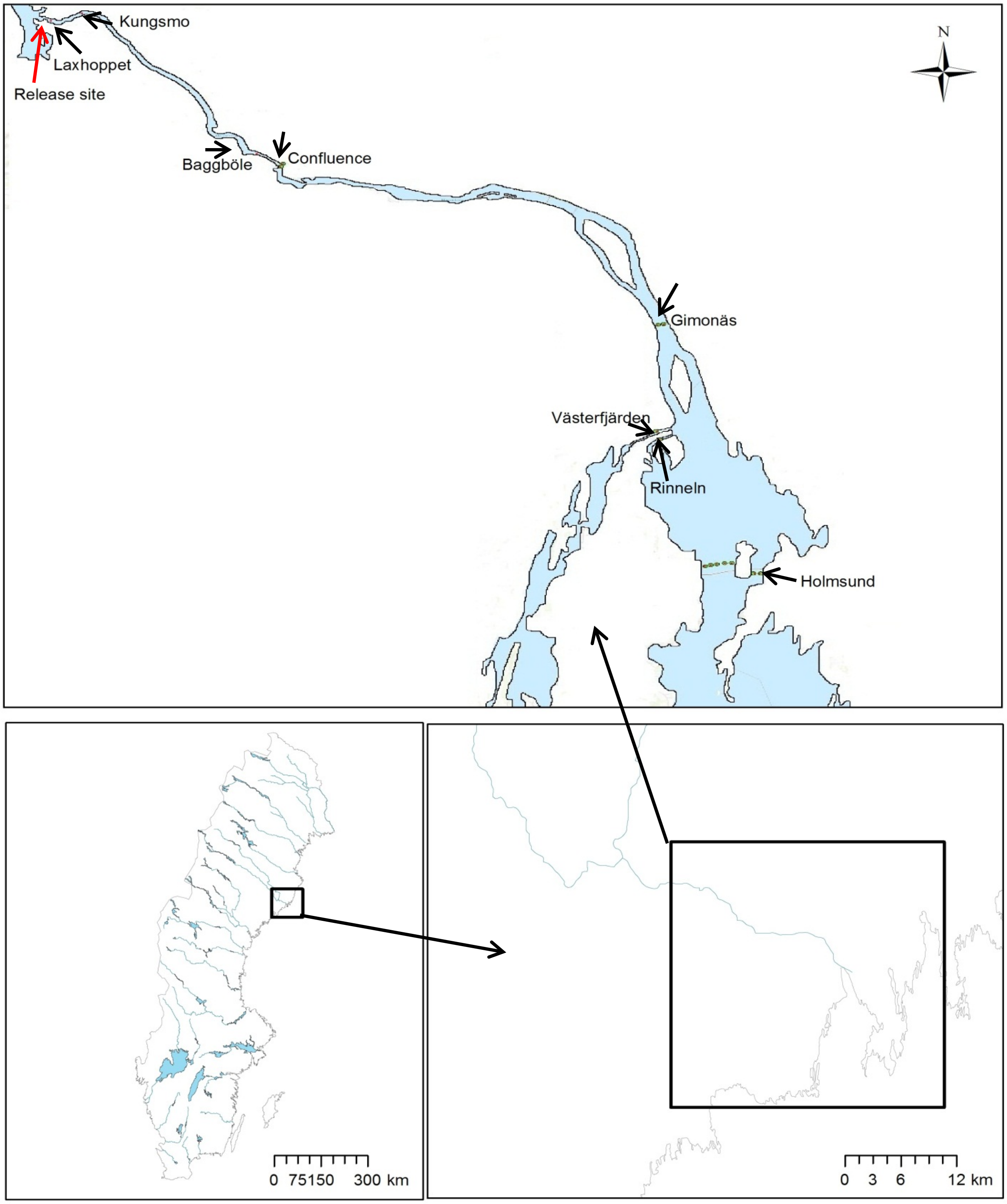


**Figure 1.** Location of the river Umeälven in northern Sweden. The large square on the right, shows the study area. On the top, red arrow shows the Release site and the stations and receiver positions (black arrows) are shown.

## Fish

Fish experienced different feed ration and density treatments in the hatchery (Table 1). High densities represent standard hatchery densities.

**Table 1.** Rearing density and feed ration applied to different treatment groups in the hatchery during the rearing period.

| Treatment's Abbreviation | Treatment | Feed ration | Number of fish in each tank | Density |
|---|---|---|---|---|
| **SRFR** | Strongest Reduced Feed Ration | 0,73% per day | 80 | 80 fish/ $m^2$ |
| **LRHD** | Low Ration + High Density | 1,46% per day | 7500 | 80 fish/ $m^2$ |
| **LRLD** | Low Ration + Low Density | 1,46% per day | 2500 | 27 fish/ $m^2$ |
| **HRHD** | High Ration + High Density | 2,88% per day | 7500 | 80 fish/ $m^2$ |
| **HRLD** | High Ration + Low Density | 2,88% per day | 2500 | 27 fish/ $m^2$ |

## Water flow and temperature

The smolts were released on 25th of May. During the tracking period in 2012 (from 25th of May to 20th of June), the mean flow rate per day in the old river bed was between 10 m³/s up to 523 m³/s when water was spilled over the dam (Figure 2) with the minimum water discharge per hour of ca. 9.5 m³/s and maximum water discharge of ca. 1036 m³/s (data from Norrfors Hatchery Station). There was a sharp increase in the flow rate on two occasions between the 29th of May to the 31st of May and the 6th of June to the 12th of June, from ca. 10 m³/s to 580 m³/s and 9.5 m³/s to 1036 m³/s respectively. Moreover, water temperature during the monitoring period increased from 9.5 °C at the beginning to 12.5 °C in the end of the study period (Figure 2). The temperature decreased to 8.6 °C, from 28th of May to 4th of June and increased again to the end of the monitoring period (Figure 2).

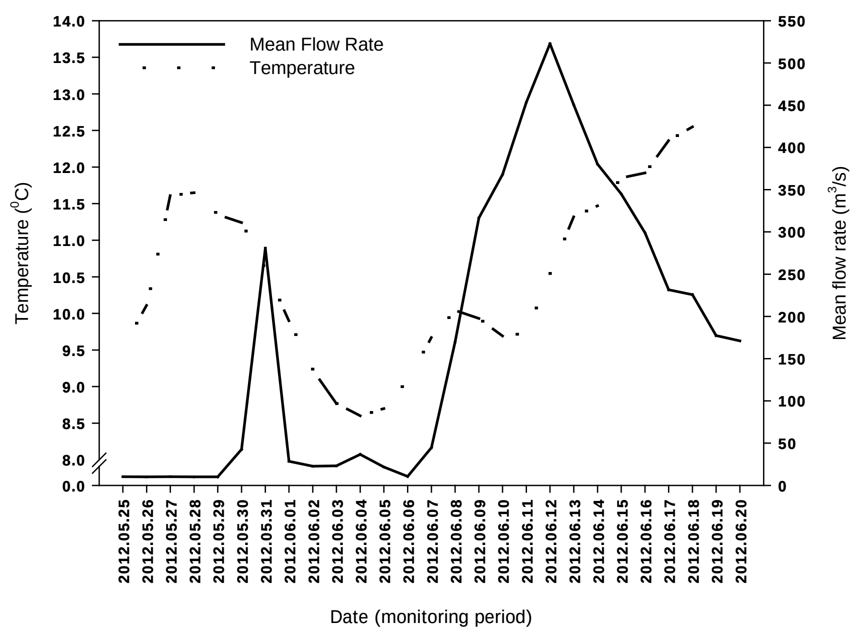

**Figure 2.** Flow rate (Solid line) and temperature (Broken line) in the River Umeälven during the monitoring period between May 25th and June 20th.

## Tagging and telemetry tracking of smolts

The study was carried out in May-June 2012. A total number of 250 hatchery-reared Atlantic salmon smolts from five different treatment groups were tagged (implanted) with coded acoustic transmitters (Thelma Biotel, 7.3 x 18 mm, mass in air 1.9 g) (Figure 3).

**Figure 3.** Placement of surgically implanted acoustic transmitters (left). Applying two sutures for closing each incision (right), (May 2012).

During tagging, fish were anaesthetized with MS222 and placed ventral side up in a wetted absorbent towel in a U-Form shape in a tub to experience less stress during surgery. The transmitter was sanitized in 95% ethanol and implanted in the body cavity. The incision was closed with two sutures (Figure 3). The handling time was between 2-3 minutes for each individual. After handling, the tagged fish were kept into a water tank to recover. Fish remained in the hatchery, for around 20 days before release into the river. During this period, all fish were observed to be in good condition. Only two smolts died during the recovery period (both from the same treatment group) and their transmitters were re-implanted in two other smolts. All tagged hatchery fish were released with non-tagged hatchery-reared smolts at 09:00 pm on the 25th of May

In order to avoid adverse effects on swimming performance and migration behaviour Lacroix *et al.* (2004) recommended a transmitter length of 16% or less of fish length and a transmitter weight under 8% of fish weight for juvenile Atlantic salmon. This study meets these criteria since the tags were less than 11.8 % of fish length and less than 6.7 % of fish weight.
Prior to tagging the Fork Length (FL) and Weight (W) of smolts were measured to the nearest (mm) and (g). Furthermore, the smolt status was evaluated according to these criteria: 0. parr marks clearly visible, no silvering, 1. parr marks visible, some silvering, 2. parr marks slightly visible, silvered and some fin darkening, 3. no parr marks, silvery and with dark fin margins (see results in Table 2).

**Table 2.** Mean (± SD) weight and fork length of Atlantic salmon smolts from five treatment groups in the hatchery. The evaluated smolt status scores before release have shown as percentage in each treatment groups.

| | | | Smolt Status Score | | |
|---|---|---|---|---|---|
| **Treatment** | **Weight (g) ± SD** | **Fork Length (mm) ± SD** | **1** | **2** | **3** |
| **SRFR** | 34.5 ± 3.71 | 152.32 ± 4.83 | 8 % | 44 % | 48 % |
| **HRHD** | 116.76 ± 25.11 | 217.76 ± 13.79 | 0 % | 10 % | 90 % |
| **HRLD** | 117.75 ± 35.11 | 215.68 ± 21.84 | 0 % | 4 % | 96 % |
| **LRHD** | 67.18 ± 21.22 | 183.42 ± 17.98 | 0 % | 38 % | 62 % |
| **LRLD** | 55.63 ± 12.21 | 173.38 ± 12.69 | 0 % | 60 % | 40 % |

The condition of the fins (dorsal fin, pectoral fins, and caudal fin) of each individual smolt were examined and scored visually on the basis of following criteria: 1.fins are in a good condition without damage, 2.fins are a little damaged (less than 50 percent), 3.fins are severely damaged (more than 50 percent).

Considering all treatment groups, the pectoral fins, and dorsal fin were little damaged, (score two). The proportion of fish with severe damage on pectoral fins and dorsal fin (score three) was low. The only exception was SRFR group with larger proportion of fish with damaged dorsal fin (score three). The condition of caudal fin was better and most fish had no damage (score one) and no fish with severely damaged caudal fin (score three) was seen (Table 3). All the smolt status and fin condition scores were made by the same person to avoid bias.

**Table 3.** Fish fins condition for all tagged-smolts before release. Numbers (in percent) show fish with different fin damage score for each treatment and each type of fin.

| | | Fin Condition Score | | |
|---|---|---|---|---|
| **Fin Type** | **Treatment** | **1** | **2** | **3** |
| **Dorsal Fin** | SRFR | 34 % | 30 % | 36 % |
| | HRHD | 40 % | 58 % | 2 % |
| | HRLD | 40 % | 58 % | 2 % |
| | LRHD | 16 % | 72 % | 12 % |
| | LRLD | 20 % | 80 % | 0 % |
| **Pectoral Fin** | SRFR | 20 % | 78 % | 2 % |
| | HRHD | 6 % | 90 % | 4 % |
| | HRLD | 40 % | 58 % | 2 % |
| | LRHD | 22 % | 76 % | 2 % |
| | LRLD | 14 % | 86 % | 0 % |
| **Caudal Fin** | SRFR | 68 % | 32 % | 0 % |
| | HRHD | 66 % | 34 % | 0 % |
| | HRLD | 56 % | 44 % | 0 % |
| | LRHD | 88 % | 12 % | 0 % |
| | LRLD | 74 % | 26 % | 0 % |

The release site was downstream the Norrfors dam in an area close to Laxhoppet. To monitor the downstream migration patterns of the tagged hatchery smolts, acoustic receivers (VEMCO, VR2, and VR2-W) were submerged in the water with the help of ropes, weights (in both sides of the rope) and a buoy (in the middle). This structure was used for parts of the river that were at least 2-3 m deep. The position, the number of the receivers, and percentage of detection are described in table 4 and from now on the position of the receivers will be referred to as stations (other five receivers deployed between Gimonäs and Holmsund are not listed. I used them to observe other possible migration routes and no data were recorded in two receivers placed in Sandskar). The number of receivers in each station was relevant to river width to be sure that the receivers detected all passing fish.

**Table 4.** Number of receivers submerged in the water in different parts of the river, referred as stations and detectability of receivers in each station.

| Stations | No. of Receivers | Percentage of Detection | Receiver's Functionality |
|---|---|---|---|
| **Laxhoppet** | 1 | 50.4 % | All receivers stored data |
| **Kungsmo** | 2 | 68.8 % | All receivers stored data |
| **Baggböle** | 1 | 52 % | All receivers stored data |
| **Confluence** | 2 | 33.2 % | All receivers stored data |
| **Gimonäs** | 2 | 48.8 % | All receivers stored data |
| **Holmsund** | 7 | 80.8 % | All receivers stored data |

It should be noted that between Gimonäs and Holmsund, five receivers were deployed in Västerfjärden (1), Rinneln (1), Sandskar (2) and Hedmansgrundet (1) to observe which route fish preferred for their migration towards the sea. Receivers recorded ID number, date and time from the transmitters when fish passed the receivers' detection range (ca. 100-150 meters). To put the receivers in their right place a GPS device was used.

Migration speed and mortality rate of fish from each treatment were calculated for each part of the river (between stations), and for the whole study area.

## Data analysis

The time fish spent before they started to migrate was calculated between release site and first receiver at Laxhoppet. The time was calculated as the time interval between the time of release and the last time the individual was detected in Laxhoppet. This was done since fish may stay for a while to adapt to the natural environment and therefore swimming speed is not a good indicator of migration performance at this part of the river. Net ground speed was calculated as the migration time (day) between two adjacent receiver stations divided by the distance (km) between the stations. The time here, was calculated as the time interval between the last time the individual was detected at one station and the first time that the individual was detected at the adjacent downstream station. Comparisons were made only among fish that were detected at both adjacent receiver stations. The number of fish registered at both adjacent receiver stations were 79 (Laxhoppet-Kungsmo), 89 (Kungsmo-Baggböle), 59 (Baggböle-Confluence), 52

(Confluence-Gimonäs), and 120 (Gimonäs-Holmsund). The average migration speed from release site to Holmsund, calculated as migration time (day) between the time of release and the first time fish registered at Holmsund divided by the distance (km) between the release site and Holmsund.

Analysis of data was performed with the statistical package JMP for windows v.9.0.3. For comparisons of different treatment groups at each station, the one-way ANOVA test was used and in case of any significant difference, a post-hoc Tukey-HSD test was applied to determine which groups that differed from the others.

## Results

Out of 250 tagged-smolts, 126 smolts were registered at the first receiver at Laxhoppet, i.e., the release site area. Eight fish were never registered at any of the receivers. Combining the information from all receiver stations (Figure 1), indicated that 242 smolts initiated downstream movement from the release site area, which shows 3.2 % of smolts were lost during the start of the migration. Of the 242 smolts that initiated downstream movement, 202 fish were registered at the final station in Holmsund, giving an overall loss of 18.8%. Two smolts, were registered at Holmsund but were never registered at any of receivers on their way before that. One smolt, migrated downstream in approximately six hours and registered at Holmsund, but the fish registered again in Kungsmo six days later. One possible reason could be that a trout migrating upstream ate the fish and brought it back to Kungsmo.

### *Migration time and swimming speed*

After the release, fish spent on average nine hours at the release site area before they started their downward migration. Sixteen fish spent more than one day at the release site area, whereas 64 fish stayed less than one hour before they left Laxhoppet. There was no significant differences in the initiation of migration between treatment groups (p=0.11, oneway ANOVA, DF=4).

The whole study area was about 29 km from the Release site to Holmsund and the average migration speed (Net Ground Speed; km day $^{-1}$) was 5.28 km day $^{-1}$ (133 ± 2.26 hours), with an individual variation of 0.18 km day $^{-1}$ to 139.2 km day $^{-1}$. Average migration speed of SRFR treatment group was significantly lower than all other treatment groups (Table 5).

On average, the migration speed from Laxhoppet to Kungsmo was 4.2 km day $^{-1}$ (28 ± 3.36 hours). The migration speed was close to being significant between different treatments at this part. A post hoc Tukey-HSD test revealed that fish with SRFR treatment was different from HRHD treatment (Table 5). Fish spent on average 7.8 hours in Kungsmo before they left the station. The average migration speed from Kungsmo to Baggböle was 7.3 km day $^{-1}$ (76 ± 4.08 hours) and there was no significant difference in migration speed, among treatments in this part of the river (Table 5). All registered fish in Baggböle, spent on average 0.22 hours before they left the station. The average migration speed from Baggböle to the Confluence area was 64.5 km day $^{-1}$ (9 ± 3.44 hours) and migration speed did not differ among treatments at this part (Table 5). Here, fish spent on average 10.5 hours before they left the confluence area. From the Confluence to Gimonäs, the migration speed was on average 89.3 km day $^{-1}$ (3 ± 0.29 hours) and no significant difference for migration speed was found among treatments for this part of the river (Table 5). Fish spent on average 0.03 hours before they left Gimonäs. The average migration speed from Gimonäs to river mouth at Holmsund was 52.4 km day $^{-1}$ (9 ± 2.08 hours), with no significant differences among treatment groups (Table 5).

### *Smolt status*

There was no significant effect of smolt status on average migration speed (p=0.207, oneway ANOVA, DF=2) (Figure 4-a), nor any interaction between smolt status and body size (weight) on average migration speed (p=0.414, oneway ANOVA, DF=2). The external smolt status, i.e. degree of parr marks and silvery coloration, differed between treatment groups. In general, there was a significant positive linear relationship between body weight and proportion of fish having external smolt status score of three (linear regression: $r^2$=0.896, p= 0.0147), with a higher proportion for larger individuals (Figure 4b).

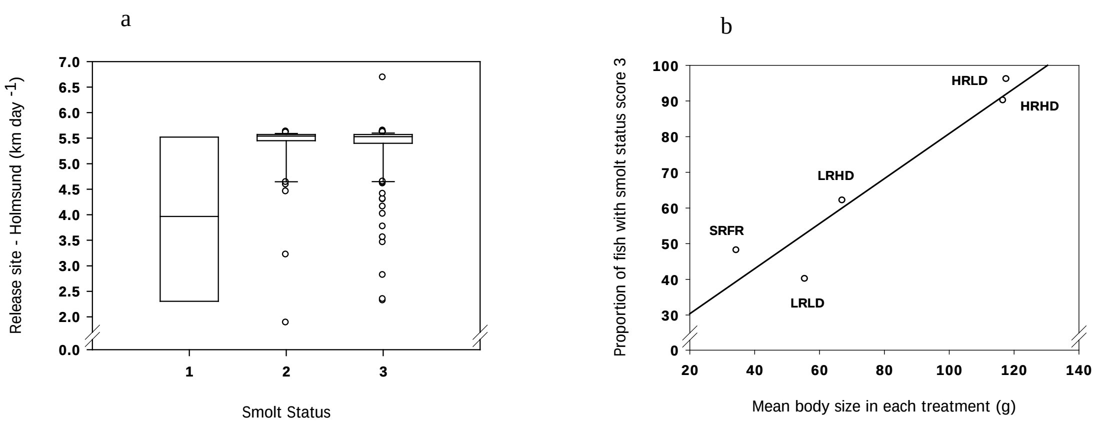


**Figure 4.** Average migration speed (km day $^{-1}$) in relation to smolt status (Left-a) and the relation between mean body size (g) in each treatment group and the proportion of fish with smolt status score 3 (Right-b).

**Table 5.** Migration speed expressed as Mean Net Ground Speed (km day $^{-1}$) ± SE of hatchery-reared Atlantic salmon smolts for five treatment groups.

| | | Treatment groups | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Stations** | **Distance (km)** | **HRHD** | **HRLD** | **LRHD** | **LRLD** | **SRFR** | **F. Value** | **P. Value** |
| **Laxhoppet-Kungsmo** | 0.88 | 2.20 $^{B}$ ± 1.13 | 4.61 $^{A,B}$ ± 1.16 | 3.48 $^{A,B}$ ± 1.65 | 3.31 $^{A,B}$ ± 1.50 | 7.41 $^{A}$ ± 1.30 | 2.449 | 0.053 |
| **Kungsmo-Baggböle** | 6.15 | 6.60 ± 3.09 | 6.39 ± 3.37 | 6.06 ± 4.13 | 10.14 ± 3.99 | 8.41 ± 4.13 | 0.197 | 0.939 |
| **Baggböle-Confluence** | 1.16 | 54.46 ± 10.47 | 67.49 ± 10.86 | 76.05 ± 14.81 | 73.005 ± 10.86 | 57.45 ± 11.31 | 0.650 | 0.628 |
| **Confluence-Gimonäs** | 12.2 | 81.26 ± 5.69 | 93.25 ± 5.09 | 83.03 ± 8.05 | 93.32 ± 5.09 | 93.37 ± 9.86 | 0.997 | 0.418 |
| **Gimonäs-Holmsund** | 8.27 | 50.53 ± 4.32 | 59.26 ± 3.92 | 49.18 ± 4.15 | 53.12 ± 3.92 | 46.95 ± 5.18 | 1.245 | 0.295 |
| **Release Site-Holmsund** | 28.8 | 5.372 $^{A}$ ± 0.098 | 5.398 $^{A}$ ± 0.1007 | 5.370 $^{A}$ ± 0.103 | 5.411 $^{A}$ ± 0.103 | 4.903 $^{B}$ ± 0.101 | 4.550 | 0.0015* |

Speeds (± SE) are given for five migration distances and for the whole study area between Release site and Holmsund. For statistical analysis, Oneway Anova test was used. In case of significant differences marked with(*), a post hoc Tukey HSD test was used and levels which are not connected with the same letter are significantly different.

### *Body size*

The size of the smolts (weight) varied considerably among individuals within treatment groups (Table 2). Smolts in HRHD and HRLD treatments weighed between 48.8 g to 191.6 g and fish in LRHD and LRLD treatments ranged from 34.6 g to 128.5 g. Smolts in SRFR treatment had a weight ranging between 28.8 g to 45 g. To evaluate the effect of body size on average migration speed, I divided all fish into different size classes (see Figure 5 for weight classes and number of fish in each class). The smolt size had a very small effect on average migration speed. Most fish, independent of size, migrated with approximately the same speed. The only size class that differed was the smallest fish (<40g) that migrated significantly slower than all other size classes (p=0.0008, oneway ANOVA, DF=5) (Figure 5).

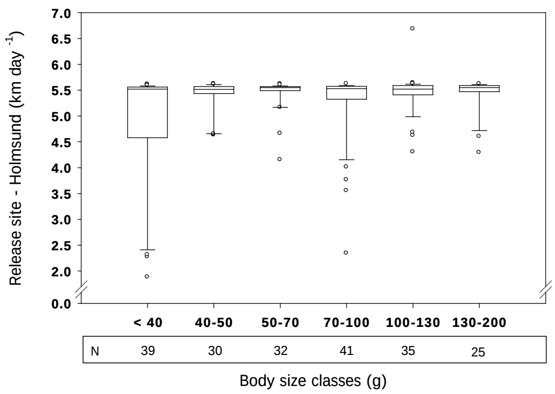


**Figure 5.** Atlantic salmon smolts registered in Holmsund station divided into six size classes (weight (g)) and the average migration speed (km day $^{-1}$) for each size class.

### *Fin condition*

The condition of the different fins did not affect the average migration speed of the smolts. Particularly, there was no effect of dorsal fin condition on average migration speed (p=0.066, oneway ANOVA, DF=2). The condition of pectoral fins and caudal fin was good with no significant differences between treatment groups. In addition, the condition of those fins had no significant effect on average migration speed (oneway ANOVA; Pectoral fins: p=0.437, DF=2, Caudal fin: p=0.368, DF=1).

Since fish in SRFR treatment group had higher proportion of severely damaged dorsal fin (Table 3), the proportion of fish in each treatment group with dorsal fin score three, mean body size (weight) of each treatment group, and interaction between these two, were compared to average migration speed. There was no effect of dorsal fin condition score three (p=0.683, oneway ANOVA, DF=1), nor any interaction between dorsal fin condition score three and mean body size, on average migration speed (p=0.107, oneway ANOVA, DF=1).

### *Smolt mortality*

Out of the 250 tagged-smolts that were released downstream the Norrfors dam, eight (3.2 %) smolts were never registered at any of the stations, and half of them were from treatment group SRFR. Overall, 47 (18.8 %) smolts, including the fish that were not registered at any of the stations, were lost along the route and presumed as dead. Total loss for each treatment group in the whole study area was 20% (SRFR), 14% (HRHD), 16% (HRLD), 22% (LRHD), and 22% (LRLD).

Only one smolt migrated by Västerfjärden and was not detected in Holmsund, but was considered as survived for mortality analysis (Figure 6). The mortality was highest in the old river channel, with the mortality rate of 16.4 %. Once they reached the confluence area, the total mortality decreased and was 2.4 % during the migration to Holmsund. The highest mortality was found in the river part between Kungsmo rapid and Baggböle rapid in all treatment groups except the group with the smallest body size (SRFR) (Figure 6). The SRFR treatment had the highest mortality within the release site area and between the confluence area and Gimonäs (Figure 6).

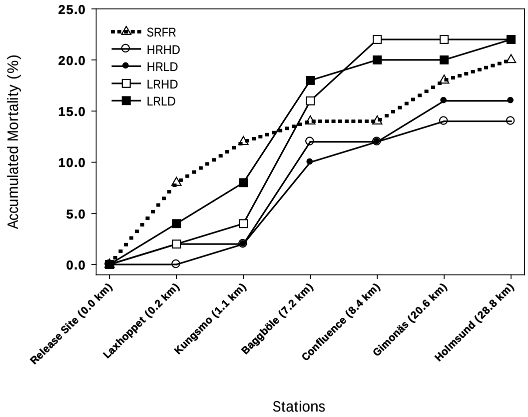


**Figure 6.** Accumulated mortality (%) of tagged-smolts in each treatment group at each station from Release site to Holmsund. Numbers given in parenthesis are approximate distances and calculated as the distance between each station to release site.

## Discussion

Earlier studies have shown that hatchery-reared smolts initiate their movement downstream soon after release if they are stocked in an appropriate period when wild smolt start migrating (Moore *et al.* 1998, Hansen *et al.* 2006, Kennedy *et al.* 2008). In the present study, a large proportion of smolts initiated their movement shortly after release indicating that fish were physiologically prepared and the environmental triggers; such as water temperature, water discharge and photoperiod were suitable for stimulating smolts to migrate downstream (Jonsson *et al.* 1985, Jonsson 1991).

Smolts showed different swimming speeds at different parts of the river. The speed was slower at the beginning of the journey and fish showed faster migration when they reached Baggböle rapid. Before they reach Baggböle a sharp increase in water flow occurred in the river due to high water discharge from the dam upstream, which might have helped them to migrate faster. This was also indicated by the large proportion of smolts that were registered at Holmsund, within one day, after they were registered at Baggböle. The relation between water flow and downstream migration of smolts has been demonstrated in previous studies e.g. (Hesthagen *et al.* 1986, Jonsson 1991). Moore *et al.* (1998) discussed that augmentation in river flow may be an important factor resulting in rapid downward movement of smolts. It is obvious that fish swim much faster at high water flow than low water flow (McCormick *et al.* 1998, Aarestrup *et al.* 2002). Moreover, it is known that smolts swim actively (Hansen *et al.* 1985) or with the help of water current (passive displacement) (Bourgeois *et al.* 1988). Furthermore, Thorstad *et al.* (2012) described that net ground speed of downward movement is a combination of each smolts' own movement and water velocity. I could not find any significant difference in swimming speed among treatment groups at different parts of the river or the different size of fish so I would clearly see the downstream migration among the tagged fish as passive displacement.

Food availability has been shown to influence the decision to migrate (Olsson *et al.* 2006). It has been also demonstrated that low feed ration resulted in faster outmigration for smolts (Tipping *et al.* 1996, Lans *et al.* 2011). Moreover, larger fish that have relatively higher fat levels (relative estimation by condition factor), presumably are less motivated to migrate and this may affect migration speed (Thorstad *et al.* 2012). This, to a large extent can be correct because fish with higher fat content can survive for a longer period and they may have less motivation to migrate (Byström *et al.* 2006, Vainikka *et al.* 2012). I hypothesized that SRFR fish would have a better migration speed than any other groups. I expected that strongly reduced feed ration would motivate smolts to migrate and swim faster to food-rich coastal areas. In contrast to my expectations, the SRFR treatment group was found to be significantly slower than the other treatment groups. The slower average migration speed of SRFR fish might have been the result of having smaller body size than all other treatment groups. Smolt size has been proposed to affect migratory behavior (Beckman *et al.* 1998). Bohlin *et al.* (1993) found that larger smolts swim faster than smaller fish in wild population of sea trout. Likewise, it has been found that in hatchery-reared Atlantic salmon, larger smolt migrated earlier than small fish (Hansen *et al.* 1985). This is somewhat consistent with my results showing that SRFR fish having smaller body size were slower than larger fish.

Silvering is known as the most denoting characters associated with smolting and it has been suggested that physiological smolt development is correlated with propensity to migrate downstream (Muir *et al.* 1994, Stefansson *et al.* 2003, Ellis *et al.* 2005). Furthermore, Brockmark *et al.* (2007) demonstrated that fish at reduced densities had a more silvery coloration than fish reared at high densities. The morphological data showed that fish reared at high feed ration were at a better smoltification stage than fish reared at low feed ration. Hence, smoltification was affected more by feed restriction than rearing density in this study. However, in contrast to their study, the experimental design in this case, cannot separate effects of feed restriction from density-dependent effects. Vainikka *et al.* (2012) suggested that feed restriction during the smolting period might have impeded the smoltification process in salmon. The morphological data indicated that smaller fish with lower feed availability were less visually smolted. This is especially true for SRFR treatment group that had a low proportion of fish with smolt status score three. This shows that this group might have been at less advanced state of smoltification and therefore had lower tendency to migrate in comparison to all other groups (Beckman *et al.* 1998). However, the result showed no effect of smolt status on average migration speed.

The present study found no effect of feed availability or density on pectoral and caudal fin condition between treatment groups. However, the dorsal fin was found to be more eroded in feed restricted treatment groups, particularly in SRFR group. It has been demonstrated in some studies that higher rearing density may lead to aggressive behavior in hatchery reared fish (Fenderson *et al.* 1971, Ellis *et al.* 2005) and result in increasing fin damage (Ellis *et al.* 2005, Brockmark *et al.* 2007, Person-Le Ruyet *et al.* 2008). Feed shortage may also lead to competition and aggressive behavior (Nicieza *et al.* 1997, Dunbrack *et al.* 2005) and feed restriction has been shown to have negative effects on fin damage (Vainikka *et al.* 2012). It has been found that aggression is the main cause of fin damage and especially when it comes to the dorsal fin in salmonids (MacLean *et al.* 2000, Latremouille 2003). Smolts with more damaged fin may have a lower swimming ability (Maheshkumar 1985) and may be more susceptible to predation (Soderberg *et al.* 1987). Pectoral fins and caudal fin are less likely to be attacked in aggressive encounters in comparison to dorsal fin and this is consistent with the result in the present study (Latremouille 2003). In another study done by Moutou *et al.* (1998) it has been shown that reduced feed ration sustained more fin damage and in particular on the dorsal fin. Moreover, Gregory *et al.* (1998) showed that reduced feed level led to fin damage, which resulted in impaired swimming ability of fish. A high proportion of fish with dorsal fin condition score three in SRFR treatment was presumably a result of extremely reduced feed availability and high rearing density. However, in this study no effect of fin damage on average migration speed could be detected.

The loss of smolts might not be only because of mortality, but rearing conditions and smolt quality might affect smolts willingness to migrate (Økland *et al.* 2011). However, in this study, the smolts seemed to be motivated to migrate downstream. In this study, loss of fish in the migratory route presumed as mortality and the total mortality of smolts was low and almost evenly distributed in all treatment groups. Two mortality patterns were seen: first, most smolts died during three to four days after release in the old river channel. Noticeably, it seemed like they had difficulties passing through this part especially between Kungsmo and Baggböle and the mortality pattern was the same for all treatment groups except SRFR treatment. A probable explanation for mortality of smolts at this part is that they might have difficulties to adapt to the new environmental condition after release, especially when it comes to encountering predators. Environmental shift has been shown to affect mortality rate due to predation (Byström *et al.* 2003). Fish spent more time at old river channel, increasing the time of exposure to predators that probably made them susceptible to predation (Serrano *et al.* 2009). A different pattern was observed from the confluence area to Holmsund in which fish had lower mortality in all treatment groups in comparison to the old river channel. When fish reached this part, they had much higher migration speed, which might have helped them to survive better. Moreover, it could be related to an increase in flow rate that caused higher river turbidity, which perhaps made them less visible to predators.

In summary, the mortality pattern and migration speed were similar for all treatment groups but SRFR treatment. The manipulation of density and feed regimes in hatchery might have affected both physiological and morphological status of fish. However, the status of the fish did not influence migration speed or mortality in this study.

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