Universität für Bodenkultur Wien

University of Natural Resources and Life Sciences, Vienna

Department of Water, Atmosphere and Environment

Institute of Hydrobiology and Aquatic Ecosystem Management (IHG)

MASTER THESIS

In partial fulfillment of the requirements for

the degree of Master of Science

Within-river migration and time of sea entry for wild and hatchery Atlantic salmon smolts in the river Vosso

submitted by:

Hans Rund

Supervisor: Ao.Univ.Prof. Dipl.-Ing. Dr.nat.techn. Stefan Schmutz (BOKU)

Co-Supervisor: Dipl. Ing. Dr. Günther Unfer (BOKU)

Co-Supervisor: Dr. Bjørn Torgeir Barlaup (LFI)

Co-Supervisor: Dr. Knut Wiik Vollset (LFI)

Student number: 0940163

Date: 29.11.2017

Affirmation

I certify, that the Master Thesis was written by me, not using sources and tools other than quoted and without use of any other illegitimate support.

Furthermore, I confirm that I have not submitted this master thesis either nationally or internationally in any form.

Vienna 29.11.2017 Hans Rund Signature:

Acknowledgements

First, I would like to thank Dr. Bjørn Torgeir Barlaup for giving me the opportunity to do my master thesis at the Laboratory for freshwater Ecology and Inland fisheries (LFI) and his helpful support and input throughout the whole thesis writing process. Second, I would like to thank Dr. Knut Wiik Vollset, I am gratefully indebted to him for his very valuable comments on this thesis and his guidance during the writing process. Next, I want to thank Sebastian Stranzl M.Sc. for teaching me a lot about Passive Integrated Transponders (PIT) and for his helpful advices whenever I needed them. I am also grateful to Espen Olsen Espedal M.Sc. for his support during my stay at the LFI and for his unremitting help during field work. Furthermore I want to thank the entire LFI staff for the really good working atmosphere, all the support and for making this time unforgettable.

Next, I would like to thank my thesis advisors Prof. Stefan Schmutz and Dr. Günther Unfer from the department of Hydrobiology at the University of Natural Resources and Life Sciences, Vienna. I am grateful for Dr. Unfers valuable comments on the thesis and his helpful tips, especially during the final writing process.

I would also like to thank Tobias Frischmann B.Sc. for his valuable engagement and help on countless occasions in the laboratory and the field during my stay in Norway.

Finally, I want to express my very profound gratitude to my parents, my sister and my brother in law for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

Abstract

The aim of this study was to analyze differences in migration patterns of hatchery and wild Salmo salar smolts using passive integrated transponder (PIT) in a river with high discharge (mean discharge during study period was > 131 m^3/s). Wild fish were separated into two groups depending on their catch and release site. Wild native fish were caught, tagged and released on the same location, wild non-native fish on the other hand were caught, tagged and released on different locations. The study was conducted in western Norway in the Vosso River system between the 01.05.16 until 01.09.16. Overall 1201 hatchery, 509 wild native and 1283 wild non-native smolts were caught, tagged and released on different locations along the river stretch. The recapture of the fish was done with self-constructed PIT flatbed- and prototypes of floating PIT- antennas, as well as a smolts screw and a trap net. Hatchery fish showed the lowest recapture rates (4.8%) and their daytime migration as well as the number of days until detection showed clear differences to wild fish. Only 48% of the hatchery fish showed nocturnal migration behavior. In contrast 84.6% and 80.2% of wild native and non-native fish migrated at night, respectively. I conclude that the behavior and recapture rates of hatchery salmon smolts in the Vosso River deviates strongly from the behavior and the recapture rates of wild salmon. Furthermore fish from the upper parts of the river are delayed and show lower recaptures than fish from lower parts of the river. Furthermore I have demonstrated that the prototype floating PIT-antennas are suitable to register migrating salmon smolts, tagged with 23 mm PIT tags in large rivers with high discharge.

Table of Contents

1 Illustrations and tables

Figures

Pictures

Tables

Graphs

2 Introduction and thematic background

2.1 Major threats and impacts for Atlantic salmon

Wild Atlantic salmon (*Salmo salar L.*) is an iconic species and has a high economic, cultural and social value for Norway. However, in most Norwegian salmon rivers, wild salmon has suffered a slow and steady decline in abundance during the last few decades. Some stocks have reached historically low levels, some are designated as endangered and some have already gone extinct (Liu et al, 2011). Atlantic salmon is an anadromous species. This means that juvenile salmon hatch and spend their first years (normally 2-5 years) in freshwater. Afterwards they migrate to their marine feeding grounds where they mature. After 1-3 years at sea they return to their natal river to reproduce (Klemetsen et al. 2003). In addition to natural mortality factors, Atlantic salmon have to face negative human impacts on local, regional and global scales. In a study by Forseth et al. (2017) it was pointed out that threats like the parasite *G. salaris*, acidification, hydropower regulations and habitat destruction played a major role in the decline or loss of Atlantic salmon populations, but have low probability to cause future losses. Negative impact factors like occurrence of escaped farmed salmon, probably leading to genetic alteration and increased competition, and salmon lice (*Lepeophtheirus salmonis*) are recently considered as the major threats to the Norwegian salmon polulations. These threats are considered as non-stabilized and raise the concern that future increase in the number of declining populations may occur due to the aquaculture industry (Forseth et al. 2017).

2.2 Smolt migration and survival:

Migration is a distinct part of the lifecycle of anadromous fish like the Atlantic salmon. During spring and early summer, fish start to migrate from their freshwater habitats, downstream to their feeding areas at sea. Before their downstream migration begins, they have to undergo a transformation, preparing them for different environmental conditions in their marine habitats. The change of behavior (they quit their territoriality and begin schooling) (McCormick et al. 1998) and physiological features (body shape, skin, osmo-regulation and increased Na^+/K^+ ATPase in the gills) is known as smoltification. Individuals that have obtained these physiological features are called smolts which are ready to start migrating. Timing of smoltification and sea migration are environmentally controlled by specific geographical and hydrological characters (Heggberget et al. 1993). The initiation of the seaward migration is primarily influenced by the photoperiod and number of degree-days, annual variation of timing can be caused by water temperature and discharge fluctuations (Jonsson & Jonsson, 2011 ; Zydlewski et al. 2005). Hvidsten et al. (1998, 2009) pointed out, that smolts may use environmental triggers in the rivers, to time their downstream migration when ocean conditions are suitable. Smolts from different Norwegian rivers reach their marine habitats at different times in the season depending on the geographical latitude (Ugedal et al. 2014). Smolts from southern areas migrate earlier than smolts from northern areas. This is believed to be caused by the fact that the sea in northern areas reaches the preferred temperature of 8 °C later in the season (Hvidsten et al. 1998, Thorstad et al. 2012). Migration behavior does not only differ annually but also locally. Rivers in the same region can vary in migration timing caused by varying abiotic conditions. A study from Thorpe and Morgan (1978) indicated that seaward migration commonly occurs during the night, but can also occur throughout the day, especially later in the season. This nocturnal movement can be seen as an anti-predator behavior (Solomon 1982). According to Svendsen et al. (2007) smolts prefer to migrate near the surface in the middle of the river where the water is deep. They are active swimmers when they are searching for the best path inside the water column, but once they picked their position, they move along almost passively (Svendsen et al. 2007, Rivinoja et al. 2004). Several studies found varying migration speed patterns, most likely caused by different river morphology (Urke et al. 2013, Thorstad et al. 2011). Studies have shown that predation in the estuaries is a key factor for high mortality of smolts and post-smolts (Thorstad et al. 2011). Most common predators are piscivorous birds (Feltham 1995), seatrout in the freshwater - and cod in the estuary/marine areas (Vollset et al. 2016). Hvidsten et al. (1988) showed that there is no difference in the predation rate between wild and hatchery reared smolts, nevertheless the survival rate at sea seems to be higher in wild smolts compared to hatchery smolts (Jonsson et al. 2003). All these factors make the smolt stage a critical period in their lifecycle, resulting in partially high mortality rates (McCormick et al. 1998). Steady decline of salmon population in Norway have resulted in intensive stocking of hatchery reared smolts to overcome the negative environmental impacts which would otherwise result in lower fish production and yield (Saltveit 2006).

2.3 The Vosso project

Historically, the Vosso River inhabited one of the largest Atlantic salmon populations in the world and had a high local economic and cultural value. Due to environmental changes in the 1980`s, the stock collapsed. The factors for this drastic population decline were not understood in all aspects and led to a ban on salmon fishing from 1992 on. The number of remaining wild salmon dropped to a historical low. This led to increased hybridization with escaped farmed salmon, which are thought to have led to decreasing fitness and reproduction (Sægrov et al. 1997). To reestablish a healthy self-sustaining salmon population, a brood stock from the National Live Gene Bank for wild Atlantic salmon was established and a lot of effort has been put in deployment of roe, fry and smolts (Barlaup 2013). The Directorate for Nature Management founded the "Vosso project" in 2000, a cooperation between management, research, local forces and several industry partners including the power company BKK. A management plan with the aim to restore or at least improve the ecological status of the Vosso system has been established. Surveys on juveniles, smolts and returning salmon are carried out each year. It is important to identify the sources of high mortality within the watercourse and the productivity of different river sections to guarantee the successful continuation of the Vosso Project. To reestablish a healthy stock of Vosso salmon, a combined approach of stocking and reduction or elimination of possible threats within the watercourse has been applied. Cooperations between different research institutions have, at least partly, identified, implemented and evaluated, threats and solutions. Even though the salmon population has increased within the last decade, further research is needed to guarantee a recovery of the Vosso salmon stock. This study should fill knowledge gaps, especially concerning the mortality and migration of wild and hatchery smolts from the different river sections, and contribute to a better understanding of population dynamics.

2.4 Rationale and hypothesis

A study from Thorstad et al. (2012) showed that a major part of stocked fish gets lost immediately after release in the river, highlighting the needs for improving hatchery production and stocking management. This study aims to provide a deeper insight in migratory behavior, timing of sea entry and identifying sources of unnatural high mortality within the watercourse. To evaluate or improve already implemented restoration measures or for planning and applying of not yet existing restoration measures quantitative data are needed. The aim of this study was to find out how the timing of the smolt-run differs between hatchery and wild fish and between the different river sections of the Vosso River. The setup to analyze the migratory behavior consisted of a rotary screw trap, a trap net, three flatbed

PIT-antennas and four floating PIT-antennas which were located at the river outlet. The data, acquired by the PIT antennas and traps, were used to analyze the timing of the smolt-run, migratory behavior and detection rates. Following hypotheses were analyzed:

I. Fish with longer migration routes through the Vosso system show decreased detections.
II. Differences in the sea entry are related to migration distance and origin.
III. Migration timing differs between stocked hatchery smolts and wild smolts.
IV. Detection rates differ between stocked hatchery and wild smolts.
V. Migratory movement happens mainly during the dark hours of the day.
VI. Floating PIT-antennas are the most efficient way to recapture PIT tagged, near surface moving fish in big rivers.

To prove these hypotheses, several variables were analyzed. It was tested, if release location, origin of the fish, tagging date as well as length and weight distribution, influences the detection rate and the migration timing.

3 Material and Methods

3.1 Study site

The study was conducted in Hordaland at the River Vosso, located in a narrow fjord system northeast of Bergen (Appendix Figure 2). To reach the open sea, migrating fish have to swim about 110 km (Vollset et al. 2016). The catchment area of the whole system is 1497.3 km², and the fact that the river is about 81.4 km long, make the Vosso the second biggest waterbody in western Norway (Sægrov et al. 1997). The study area can be separated into different waterbodies: Strandaelva above Lake Vangsvatn, Lake Vangsvatn (8.6 km) below Vossevangen, the River Vosso (10 km) between Bulken and Evanger, Lake Evanger (8 km) below Evanger and the Bolstad River (2.5 km) located at Bolstadøyri which finally enters the Bolstadfjord (Figure 1). The surrounding areas of the rivers and lakes mainly consist of forests (31.6%) and mountains (54.3%). Mean annual discharge is about 85 m³/s and the mean annual precipitation is 1851 mm.

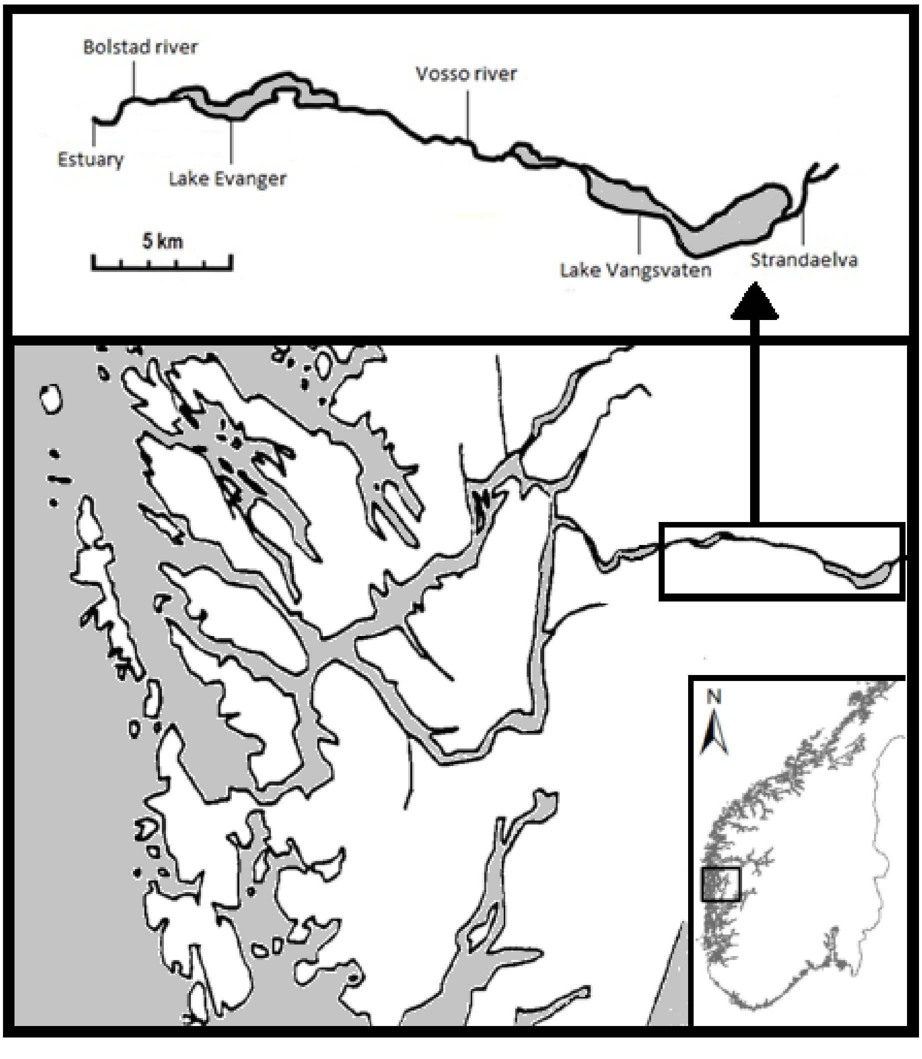


Figure 1 Study area and locations of the different waterbodies.

3.2 Experimental setup

3.2.1 PIT technology

Telemetry is an important tool to gather movement data. The most common electronic tags for fish telemetry are radio and acoustic transmitters, data storage tags, pop-up satellite archival tags and passive integrated transponder (PIT) tags. For this study PIT tags were used since they are cheap in comparison to the alternatives, they can be used in salt- and freshwater, last the whole lifetime of the tagged animal and they are best suited for small fish (Thorstad et al. 2013). PIT tags are small (the ones used for this survey were 23 mm long and had a diameter of 3.65 mm), inert and function without battery and they can last for the whole lifetime of the tagged animal (Bond et al. 2007). The tag consists of an integrated circuit chip, capacitor, and antenna coil contained in a glass cylinder and its operation requires an external energy source. An electromagnetic field generated by the PIT-antennas induces current in the antenna coil that energizes the integrated circuit, which allows the transmission of a signal to the reader. Tag detection differs with antenna geometry, alignment of the antenna, the cables which were used and the tag size (Roussel et al. 2000). This technology provides a variety of data, including exact time of detection, location of the fish when being detected and precise identification of each detected individual. PIT-technology is a commonly used tool for monitoring fish movement, but most PIT-systems are limited to small or heavily regulated rivers. Half Duplex Pit technology was used since it is easier to handle and allows more variety for antenna designs. No effective stationary antenna approach for big, fast flowing and turbulent rivers have been invented yet, especially if the goal is to detect and quantify near surface migrating fish. To overcome these limitations, prototypes of floating HDX (Half Duplex) PIT-antennas were created and successfully tested during this study. Additional information about antenna construction, advanteges and disadvanteges of different PIT systems (HDX, FDX) and antenna designs can be found in the appendix.

3.2.2 Study design

To analyze possible differences between release location, origin, tagging date, length and weight, a mark recapture approach was carried out. To recapture PIT tagged fish, a smolt screw, a trap net, three flatbed PIT antennas and four floating PIT antennas were used. Overall 2993 smolts were tagged for this survey, including 1201 hatchery, 1283 wild non-native and 509 wild native smolts. The lower number of wild native smolts is caused by the difficulty to catch smolts in the main channel, since the Vosso is a big natural river with limited accessibility. The wild salmon smolts were caught by electro fishing at different locations along the main river and the tributaries. The 23 mm PIT tags have been inserted in a small surgical incision between the pectoral and the lateral fin. Previous studies demonstrated good and fast healing of the incision (Zydlewski et al. 2001) and minimal tagging effects concerning their growth rate, survivability and migration behavior (Huusko et al. 2016). After tagging the smolts were released at different locations (Table 1).

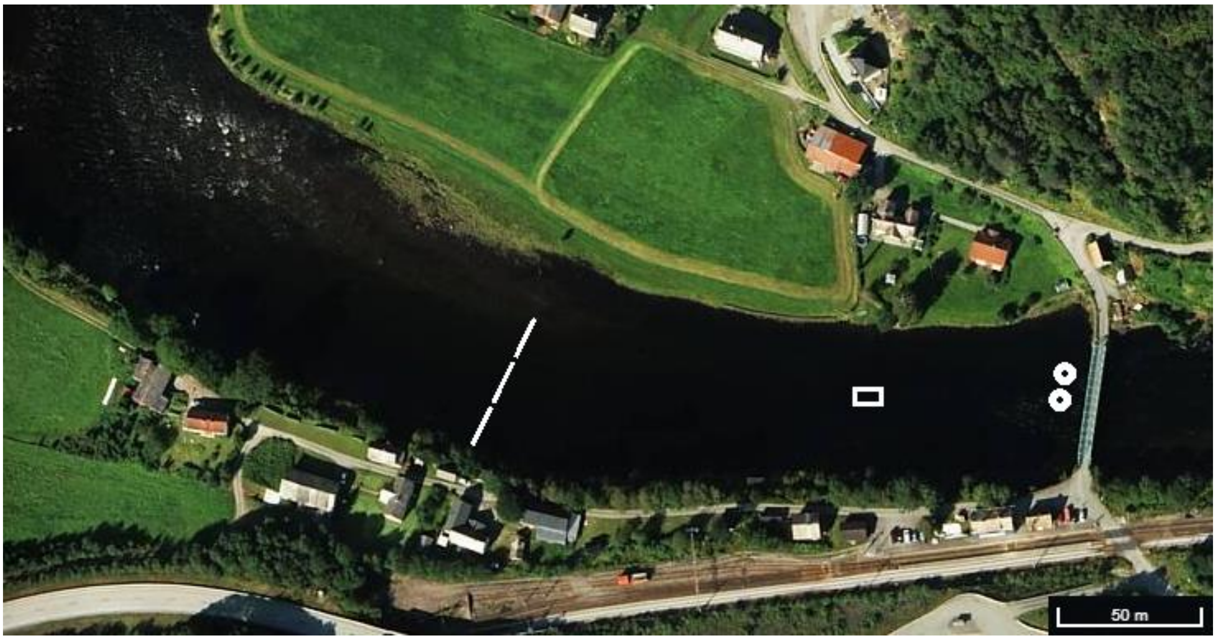
Table 1 List of all traps, PIT antennas and release locations, showing the number of released and recaptured fish. Smolts were separated into three groups: hatchery fish, wild native fish and wild non-native fish.

Release Site	Smolts released				Distance to the Estuary
	Hatchery	Wild Non-native	Wild native	Total	
Bolstad	601	40	650	1291	3 km
Vosso	600	260	632	1492	15.5 km
Strandaelva	-	209	1	210	30 km
Recapture location	**Smolts recaptured**				**Distance to the Estuary**
Bolstad floating (PIT)	30	39	96	185	500 m
Smoltscrew	-	3	8	11	425 m
Bolstad flatbed (PIT)	8	5	17	30	350 m
Trapnet	-	4	10	14	Located in the fjord

Depending on their release location, fish had to swim different distances to reach the sea and consequently had to swim through different types of waterbodies (rivers and lakes). The smolts had to pass two lakes, if they were released at Strandaelva, one lake if they were released in the Vosso and no lake if they have been released in the Bolstad River. Most recapture locations were located directly at the outlet of the Bolstad River, one of them (trapnet) was located inside the fjord. On the way to their marine habitats the smolts had to pass the recapture setup (Picture 1). These recaptures were used to analyze migration patterns and likelihood of being detected. To get a better understanding of how the origin of the fish influences their seasonal and daytime migration and their detection rates, fish have been distinguish into three groups:

- Group A: Wild native smolts. Fish were caught in the main river, tagged and released at their capture locations in the main river.
- Group B: Wild non-native smolts. Fish were caught in a tributary, tagged and moved to a release site in the main river.
- Group C: Hatchery smolts. Hatchery reared smolts, tagged at the hatchery and released at different locations in the main river.)

3.2.3 Recapture setup



Picture 1 PIT antennas and smolt screw setup in the Bolstad River. Each circle symbol represents two floating PIT antennas, the rectangle symbolizes the smolt screw. Each line represents a 15m flatbed PIT-antenna. (Source: https://kart.gulesider.no)

The recapture setup, located near the estuary region contained four floating antennas, tied to the bridge at Bolstad (Picture 2), a rotary screw trap and three flat-bed antennas. The floating antennas had a diameter of 1.15 m, three loops of 4 mm² copper cable were used and resulted in a reading range of 1.2 meters in depth. They covered only about 13% of the cross-section, but were placed in the main current to guarantee sufficient smolt detection, since they are mainly moving within the areas with the highest flow velocities.

Picture 2 Prototypes of floating PIT antennas, tied to the bridge at Bolstad. They were placed in the main current to increase detection probabilities.

Approximately 75 meters downstream the floating antennas a rotary screw trap was installed, this trap was emptied every day. The smolt screw was followed by three flat-bed antennas, which were located about 150 meters below the bridge at Bolstad and covered about 70% of the whole river cross-section. The swim over antennas (each of them 15 m x 0.5 m, Picture 3) where made out of 8 mm² copper cable in a single loop, resulting in a reading range of ~45 cm. All antennas where attached to synchronized HDX single antenna readers made by Oregon RFID. For the flat-bed antenna setup 3 Readers were synchronized and two synchronized readers were used for the floating antennas. The Half-Duplex PIT-system was used, because it is easier to handle (construction and implementation) and not as sensitive to noise and disturbances as the full duplex (FDX) systems. The trapnet was located in the Bolstadfjord with a distance of about 4.6 km to the river mouth.

Picture 3 Two out of three flatbed PIT antennas are displayed in this picture. They were placed in the Bolstad river and covered about 70% of the river cross-section.

3.2.4 Hatchery and broodstock

The origin of the hatchery smolts are eggs, produced at the national gene bank. The national gene bank main purpose is to conserve threatened salmon stocks and to maintain as much genetic variation as possible by use of modern genetic principles for breeding. The gene bank produce eggs that are delivered back to the respective salmon rivers for stocking and reintroduction or strengthening of indigenous salmon population. The production and stocking of cultivated smolts is a part of the Vosso project, financed mainly by the Norwegian Environment Agency, Bergenshalvøens Kommunale Kraftselskap (BKK) and Vossolauget (consortium of fish farmers). Hatchery smolts which were used in this study originated from a broodstock population sampled during the stock collapse period in 1991–1998, and kept in a living gene bank (Vollset et al. 2014). Over the years more wild salmon were supplied to the gene bank, increasing genetic diversity. After hatching the juveniles are kept in the Voss hatchery for a year before they are released as smolts (i.e. 1+ old smolts). During the last decades the Vosso broodstock consisted of several hundred wild salmon from Vosso and contributed over 8 million eggs to stocking programs.

3.2.5 Environmental data

The water discharge data for the whole study period were collected by a gauging station (number 62.5.0 run by the Norwegian Water Resource and Energy Directorate) located in the Vosso river system (coordinates: 60.62868 6.29254).

3.2.6 Electro fishing, measurements and tagging

Backpack electrofishing was used to catch wild smolts. Wild fish were caught in the main river (wild native smolts) and in the tributaries (wild non-native smolts). Length measurements were done with a yardstick, weight measurements with a scale. The measurements happened before the fish were tagged and released again. Wild fish were measured directly at the catch location, hatchery fish were measured in the hatchery. Only fish that showed the morphological features of pre-smolts were tagged and used for this study. After tagging, they were released at different locations. Depending on their origin and their release location, they were grouped into wild native and wild non-native fish.

3.2.7 Statistical analysis

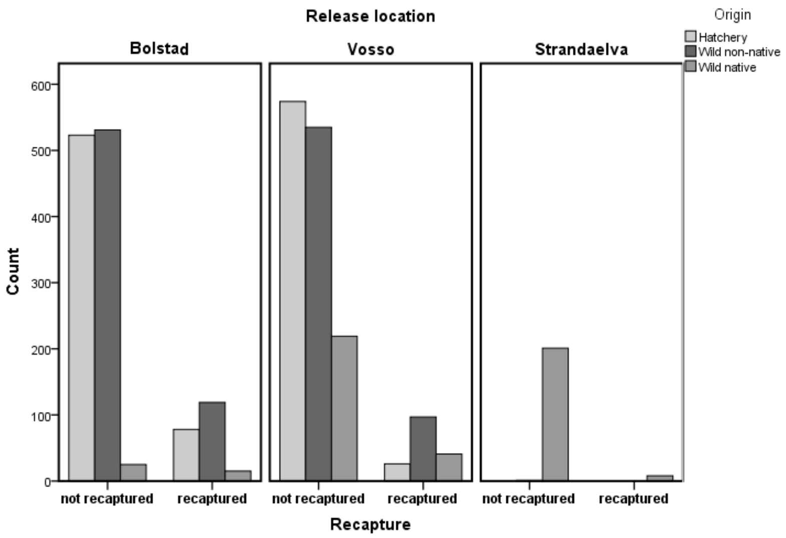
Statistical analysis was done with SPSS 21®. No normal distribution was found in the data, therefore non parametric test were used. To find differences between categorical and metric variables (length and weight), Kruskal-Wallis test were applied, if there were more than two groups. For groups of two, a Mann-Whitney-U test was used. To analyze the likelihood of a relation between 2 or more categorical variables, Pearson Chi² was used. Outliers in the box plots are represented by circles, the stars represent extreme outliers with a value higher or lower 3 times the height of the boxes.

4 Results

4.1 Detection rates

4.1.1 Detection rates and release locations

Overall 2993 PIT tagged smolts were released on three release locations along the Vosso River (Table 1). The releases from Bolstad contained 601 hatchery, 650 wild non-native and 40 native smolts. The biggest amount of fish was released in the Vosso, including 600 hatchery, 632 wild non-native and 260 native smolts. Only 1 wild non-native, 209 native and no hatchery fish were released at Strandaelva (Appendix Table 6).



Graph 1 Number of released and recaptured smolts, separated by origin and release location.

A Chi² test was used to analyze if there is a significant ($p > 0.05$) relation between detection rate and origin (hatchery, wild native, wild non-native), depending on the release location. The result indicates that there is a significant relation for Bolstad ($p<0.001$) and Vosso ($p<0.001$), wild fish were more likely to be detected. No no such relation was found for Strandaelva ($p=0.842$) since no hatchery fish were released at this location (Graph 1).

4.1.1.1 Bolstad releases

About 11.4% of all fish released in the Bolstad river stretch were recaptured at the trap setup in the river outlet. A Chi² test revealed a significant relation between origin and recapture rate ($p<0.001$). The group with the highest recapture percentage was the wild native group with 37.5% detections, followed by the non-native group with 13.4 % and the hatchery group with a recapture of 7.5% (Appendix Table 7).

4.1.1.2 Vosso releases

About 5.8 % of all fish released in the Vosso river stretch were recaptured at the trap setup in the river outlet. A Chi² test revealed a significant relation between origin and recapture rate ($p<0.001$). The group with the highest recapture percentage was the wild native group with 11.5% detections, followed by the non-native group with 7 % and the hatchery group with a recapture of 2.2 % (Appendix Table 8).

4.1.1.3 Strandaelva releases

About 2.9% of native fish released at the Strandaelva river stretch were detected at the river outlet (Appendix Table 9). No hatchery fish were released at this location.

4.1.2 Detection rate and origin of the fish

Chi² test was used to analyze if there is a significant ($p > 0.05$) probability that the origin (hatchery, wild native and wild non-native) of the fish, influences the detection rate. The result ($p<0.001$) indicates that there is a significant relation (Appendix Graph 16).

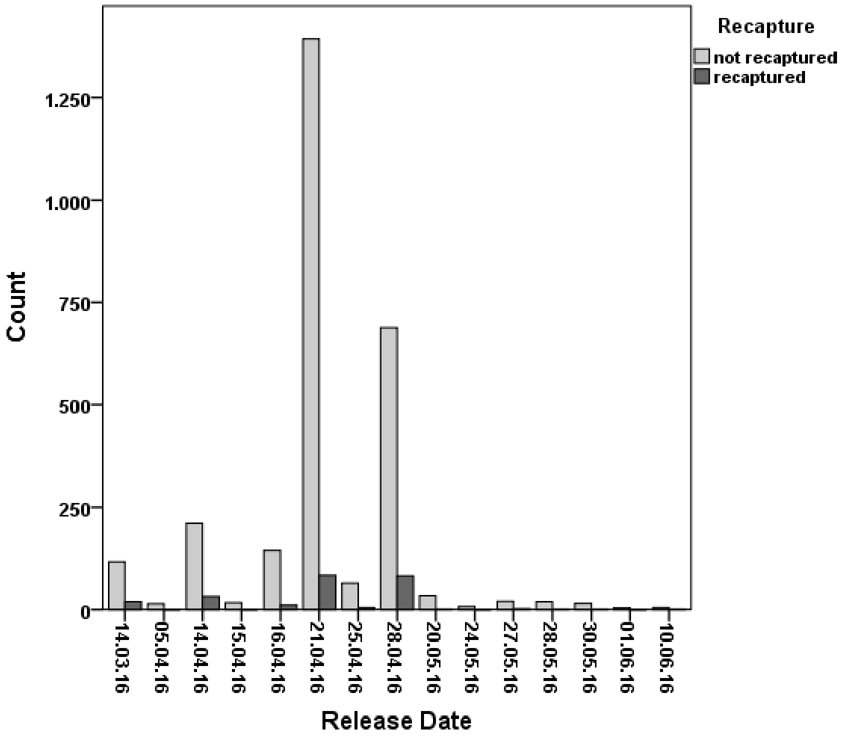
Table 2 Amount of recaptured and not recaptured smolts from all release locations, separated by their origin. The numbers in the parentheses show the percentage of recaptured fish for each group.

		Recapture		Total
		not recaptured	recaptured	
Origin	Hatchery	1143	58	1201 **(4.8%)**
	Wild non-native	1152	131	1283 **(10.2%)**
	Wild native	458	51	509 **(10%)**
Total		2753	240	2993

The group with the lowest detection rate was the hatchery fish group with 4.8%, followed by the wild native smolts with 10% and the non-native fish with a recapture rate of 10.2% (Table 2). When the fish released at Strandaelva were excluded, wild native fish had a recapture rate of 17.6%.

4.1.3 Detection rate and release date

A Chi² test was used to analyze if there is a significant ($p > 0.05$) probability that the factor release date, influences the detection rate (Graph 2). The result ($p<0.001$) indicates that there is a significant relation. Another Chi² test was used to analyze if there is a relation between release date and recapture rate. The results suggest a significant relation of these factors at the release locations in Bolstad ($p=0.004$) and Vosso ($p<0.001$) but not at release location Strandaelva ($p=0.335$) (Appendix Tables 10, 11, 12).



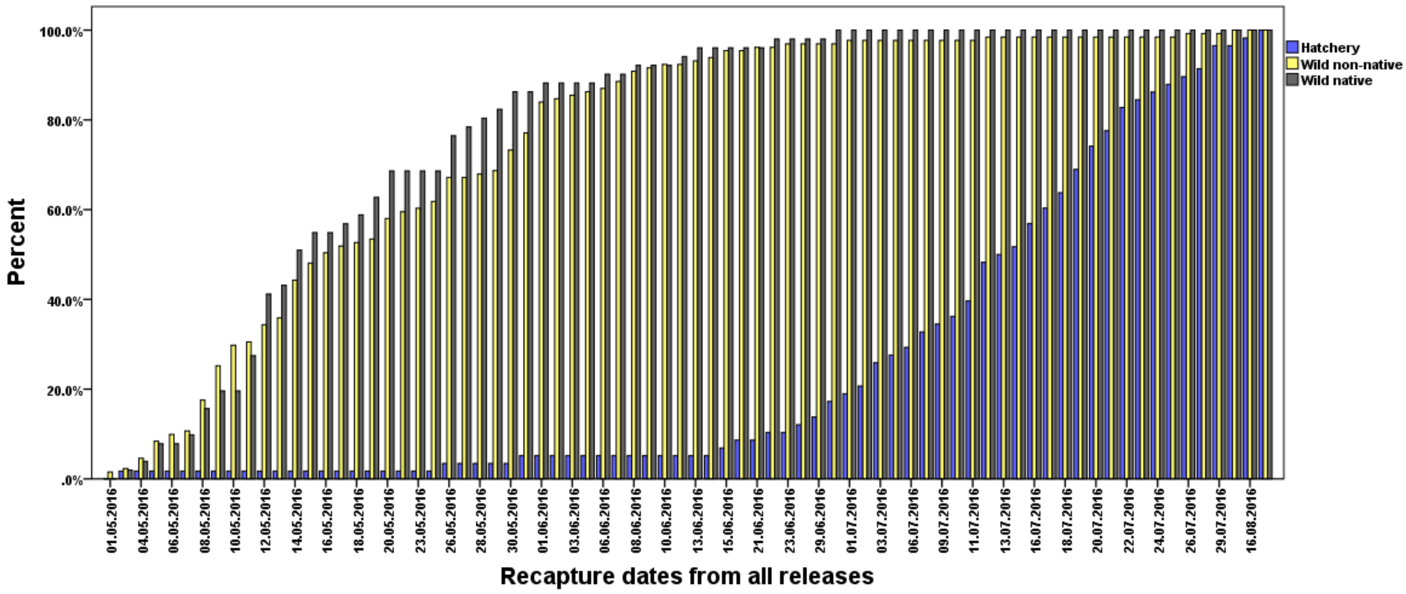
Graph 2 Count of recaptured and not recaptured fish from all release dates.

4.2 Detection time

4.2.1 Detection time and release locations

4.2.1.1 Seasonal detection

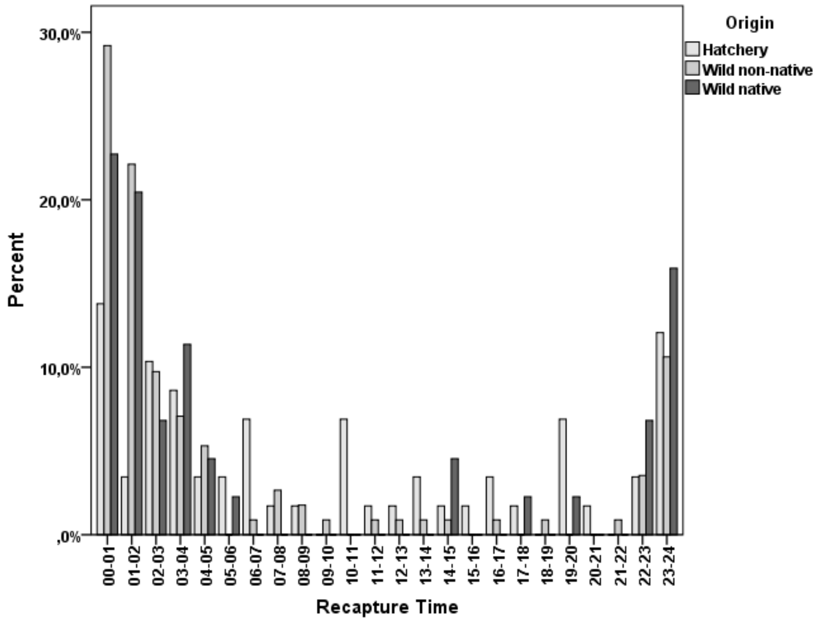
A Kruskal Wallis test showed a significant difference for date of recapture among the release locations ($p<0.001$), (Graph 3, Appendix Graph 14, 15). A Chi² test was used to see if the release location influences the date of first detection among all origin groups. The results suggest no relation of these factors for hatchery smolts ($p=0.514$), but indicate a significant linkage for wild native ($p=0.010$) and wild non-native ($p=0.008$) smolts. Wild fish (WN,WNN) released in the lower river sections were detected earlier in the season than wild fish released in the upper part of the river. Hatchery smolts show a clear delay in migration time throughout the season, no matter where they were released. Smolts from Strandaelva which had to swim the largest distance arrived at the river outlet before most of the hatchery smolts started migrating. (Appendix Graphs 14, 15)



Graph 3 Cumulative percentage of recaptured hatchery, wild native and wild non-native fish released at all release locations.

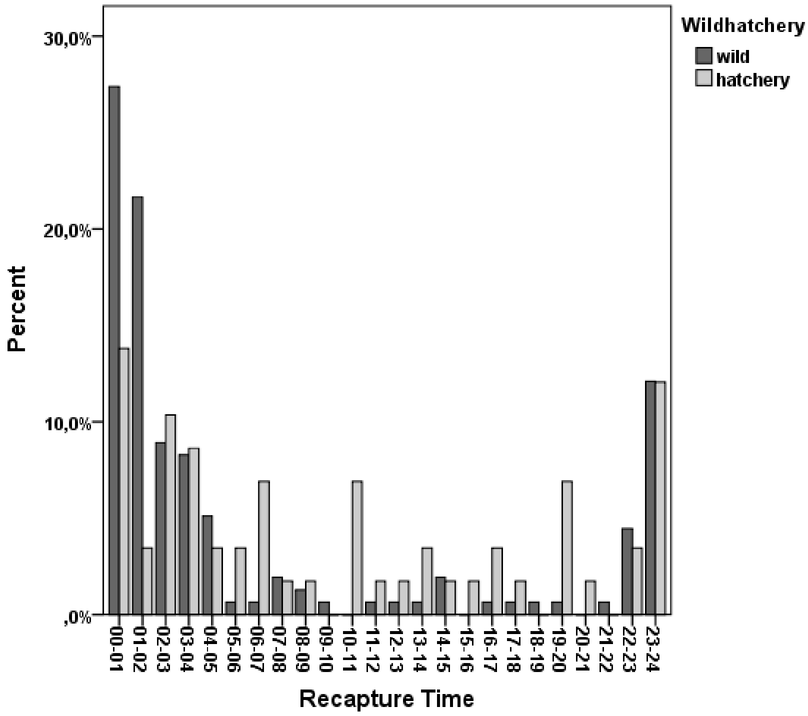
4.2.1.2 Daytime detection

For this analysis, only the fish recaptured with PIT-antennas were taken into consideration, since the exact time of recapture is not available for the smolt screw and the trapnet. The first recapture of each fish was used to analyze the movement pattern of 170 wild and 58 hatchery smolts concerning their daytime migration (Graph 4, Appendix Table 13).



Graph 4 Daytime recapture separated by origin of the fish. Only recaptures from PIT antennas were used.

The results of a Chi² test show a significant relation ($p=0.002$) between daytime movement and origin of the fish. To focus down on the differences between wild and hatchery fish, the wild non-native and the wild native fish were grouped in the following graph (Graph 5). Another Chi² showed an even stronger relation ($p<0.001$) between the grouped wild fish and the hatchery fish. Wild fish show a clear preference for nocturnal movement, whereas hatchery fish don`t show this behavior.



Graph 5 Daytime recapture of wild and hatchery fish. Wild native and wild non-native fish were grouped for this graph to highlight the differences.

4.2.2 Comparing daytime migration between flatbed and floating PIT antennas

4.2.2.1 Floating antennas

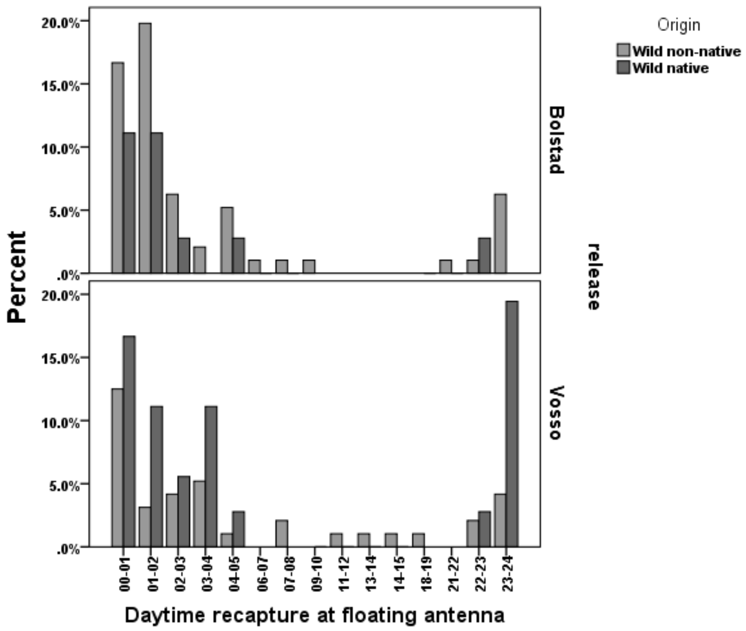
Throughout the whole season, 185 (50 hatchery, 96 wild non-native and 39 wild native) unique smolts from all release locations were recorded at the floating antennas at Bolstad (Table 14). Floating antennas were not working from the 21.05.16 until 24.05.16 due to destruction. To analyze if there is a significant relation between daytime migration of fish with different origin and recapture month, a Chi² test was used. The results show no such relation for hatchery fish ($p=0.079$), but it also showed a significant relation for native ($p=0.001$) and non-native (p<0.001) fish recaptured at the floating antennas. Early migrating smolts (May) show a clear tendency to migrate during the dark hours of the day. Graphs for August and September are not displayed here because the number of detected fish was too low (Appendix Graph 17). A Chi² test showed that recaptures from the floating antennas show no relation between recapture month and daytime migration in hatchery fish (p=0.079), but there is a significant relationship for wild native (p<0.001) and wild non-native fish (p<0.001).

4.2.2.2 Daytime recaptures at the floating antennas from Bolstad and Vosso releases

Table 3 Recaptured fish from Vosso and Bolstad, only data from floating antennas are used. The numbers in the parentheses show the percentage of nocturnal (between 11 PM and 4 AM) migrating smolts.

		Release location		Total
		Bolstad	Vosso	
Origin	Wild non-native	59 (**83.1%**)	37 (**75.7%**)	96 (**80.2%**)
	Wild native	11 (**81.8%**)	25 (**92%**)	36 (**88.9%**)
Total		70 (**82.6%**)	62 (**82.3%**)	132 (**82.6%**)

Only wild fish from release locations Bolstad and Vosso were used for this analysis. To analyze if there is a significant relation between daytime migration of the two groups of wild fish and different release locations, a Chi² test was used. The results for wild native (p=0.297) as well as for wild non-native (p=0.111) indicate no such significant relation (Graph 6, Table 3).



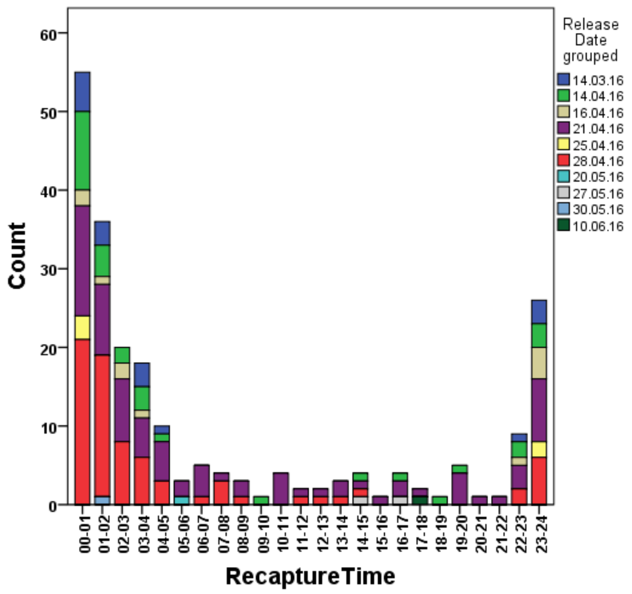
Graph 6 Daytime recapture of wild native and wild non-native fish, separated by their release location.

4.2.2.3 Flatbed antennas

To analyze if there is a significant relation between daytime migration of fish with different origin and recapture month, a Chi² test was used. The results show no such relation for hatchery fish ($p=0.313$), native ($p=0.405$) and non-native ($p=0.319$) fish recaptured at the flatbed antennas. Throughout the whole season, 30 (8 hatchery, 17 wild non-native and 5 wild native) unique smolts have been recorded at the Bolstad flatbed antennas. The graphs for August and September are not displayed due to the lack of detections (Appendix Graph 18). Chi² test showed that recaptures from the flatbed antennas show no relation between recapture month and daytime migration among hatchery fish ($p=0.313$), wild native ($p=0.421$) and wild non-native fish ($p=0.288$)

4.2.3 Time of detection and release date

To test the relation between date of first recapture and origin among all release locations another Chi² was used. Results showed a significant linkage for the release locations Bolstad ($p<0.001$) and Vosso ($p=0.003$). Strandaelva was excluded because the number of fish of different origin was too low.



Graph 7 Daytime recaptures from both PIT antennas grouped by release date.

A Chi² test was used to analyze if there is a significant ($p > 0.05$) probability that the factor release date, influences the daytime migration (Graph 7). The result ($p=0.180$) indicates that there is no such relation. A Kruskal Wallis test showed a significant difference ($p<0.001$) in recapture dates among all release dates (Graph 6).

4.3 Length and weight distribution

4.3.1 Release locations

A Kruskal Wallis test showed a significant difference between the release groups concerning length ($p<0.001$) and weight ($p<0.001$) distribution. Release locations in Vosso and Bolstad were compared, Strandaelva releases were excluded because only wild native smolts and one non-native smolt were released there. On both release locations, hatchery fish were the biggest and heaviest group, followed by wild non-native and wild native smolts (Appendix Graph 20).

Table 4 Mean length and weight for all origins depending on their release location.

	Release location					
	Bolstad			Vosso		
	Hatchery	Wild non-native	Wild native	Hatchery	Wild non-native	Wild native
Mean length	142 mm	131 mm	120 mm	139 mm	131 mm	126 mm
Mean weight	30 g	21 g	14 g	29 g	21 g	17 g

4.3.2 Recapture time

A Kruskal Wallis test showed significant differences between weight ($p=0.035$) of all fish and their nocturnal migration behavior, heavier fish tended to migrate during the day. No significant difference was found for the length ($p=0.054$) concerning the daytime migration. To analyze the differences between wild native and wild non-native a Mann Whitney U test was used. The distribution of length ($p=0.318$) and weight ($p=0.492$) in wild smolts is the same across all categories of recapture time.

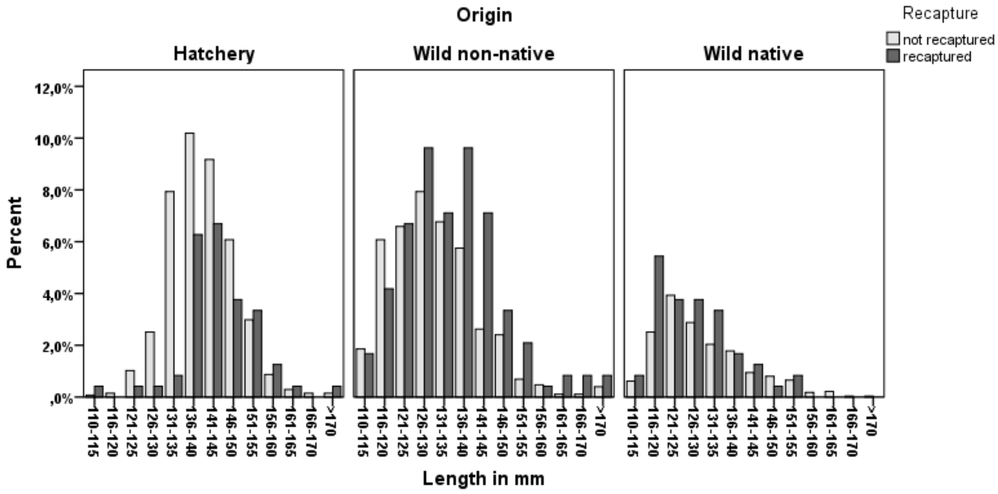
4.3.3 Recapture rates

4.3.3.1 Length

Mann Whitney U tests were used to analyze if the body length shows a significant (p >0.05) relation to the recapture rate, this was tested for all fish and release locations. No such relation was found for wild native fish (p=0.311) but it was found for hatchery fish (p=0.001) and wild non-native (p<0.001) fish (Graph 8). Recapture rates increased with the length of hatchery and wild non-native fish. (Appendix Table 17).

4.3.3.1.1 Comparing Bolstad and Vosso releases

Mann Whitney U tests were performed to see if the length influences the recapture probability. This was tested for all origins in Bolstad and Vosso. Hatchery fish released in Bolstad showed a significant difference in the length distribution (p=0.002) among recapture groups, the ones that got released in the Vosso showed no significant difference (p=0.835). Non-native smolts showed the opposite patterns, they show no significant differences when they were released in Bolstad (p=0.265), but a significant difference when they were released in the Vosso (p<0.001). Wild native smolts showed no significant differences between length and recapture when they got released in Bolstad (p=0.106) but they showed a difference when they were released in the Vosso (p=0.020).



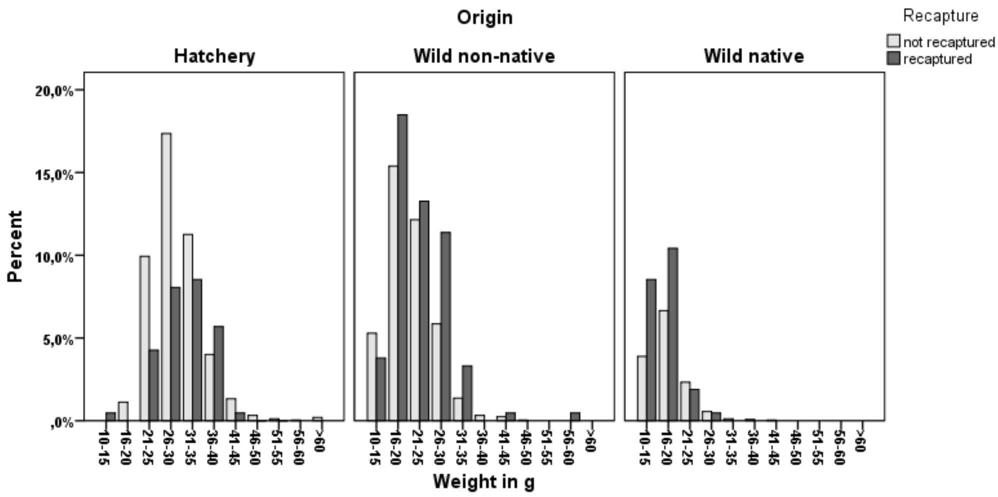
Graph 8 Percentage of recaptured and not recaptured fish for all length groups and origins.

4.3.3.2 Weight

Mann Whitney U tests were used to analyze if the body weight shows a significant ($p > 0.05$) relation to the recapture probability, this was tested for all fish from all release locations. A significant relationship for hatchery ($p=0.048$) and wild non-native ($p=0.009$) fish was found, no such relation was found for wild native fish ($p=0.101$) (Graph 9). Again the test was repeated with only 2 groups (hatchery and wild), the results indicate, that there is a significant relation for hatchery ($p=0.048$), but not for wild ($p=0.351$) fish (Appendix Table 18).

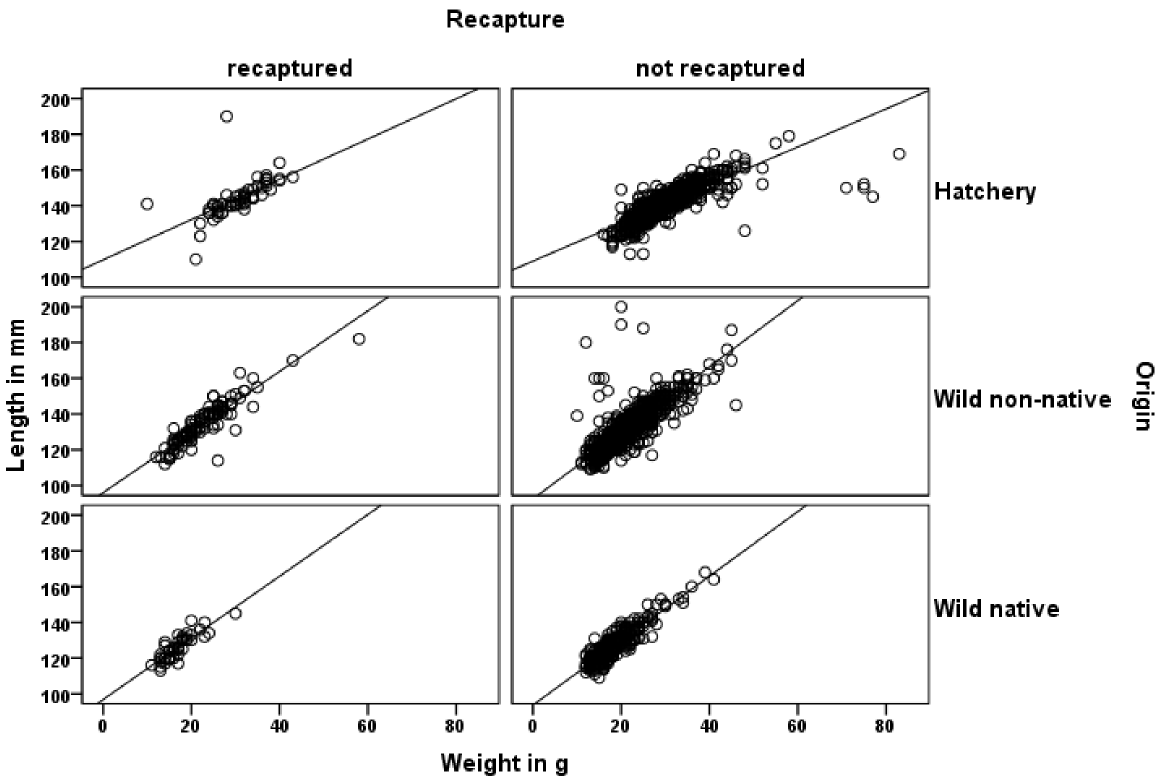
4.3.3.2.1 Comparing Bolstad and Vosso releases

Mann Whitney U tests were performed to see if the weight influences recapture probability, this was tested for all origins in Bolstad and Vosso. Hatchery fish released in Bolstad showed a significant difference in the weight distribution ($p=0.013$) among recapture groups, the ones that got released in the Vosso showed no significant difference ($p=0.160$). Non-native smolts showed no significant differences when they were released in Bolstad ($p=0.654$) but when they were released at Vosso ($p<0.001$). Wild native smolts showed no significant differences between weight and recapture no matter if they were released at Bolstad ($p=0.305$) or Vosso ($p=0.193$).



Graph 9 Percentage of recaptured and not recaptured fish for all weight groups and origins.

4.3.4 Origin of the fish



Graph 10 Length and weight distribution for recaptured and not recaptured fish from all origins.

A Kruskal Wallis test was applied for both, the length and the weight analyses. There is a significant difference concerning the length ($p<0.001$) and weight ($p<0.001$) between all groups of fish (Graph 10). A Mann-Whitney U test was performed to so see the differences between wild native and wild non-native fish. The result also indicate a significant difference for length ($p=0.003$) and weight ($p<0.001$). The scatter plots show that hatchery fish were bigger and heavier than the wild smolts.

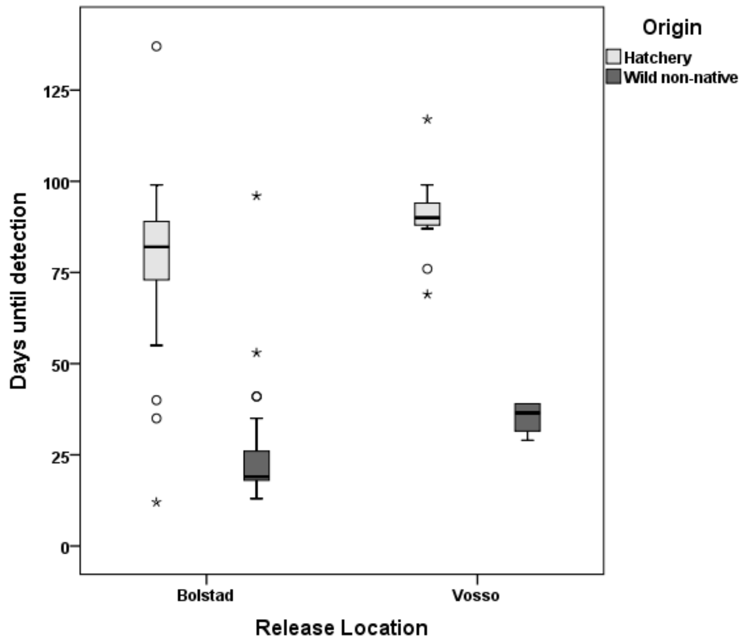
4.4 Days until detection

To get an idea, of how long it takes 2 groups of smolts (hatchery and wild non-native) from two release locations, to reach the recapture setup in the estuary region (Bolstad), the number of days until detection was analyzed. Unfortunately there was no release date where all 3 groups of fish were released at two locations. There is only one release date (21.4.16) where 2 groups of fish were released on two release locations (Bolstad and Vosso). From 1478 smolts released that day, only 84 (5.7%) got recaptured.

Table 5 Number of smolts released at the Vosso and Bolstad on the 21.04.16. The numbers in the parentheses show the number of recaptured smolts.

		Origin		Total
		Hatchery	Wild non-native	
Release Location	Bolstad	601 (**45**)	138 (**22**)	739 (**67**)
	Vosso	600 (**13**)	139 (**4**)	739 (**17**)
Total		1201 (**58**)	277 (**26**)	1478 (**84**)

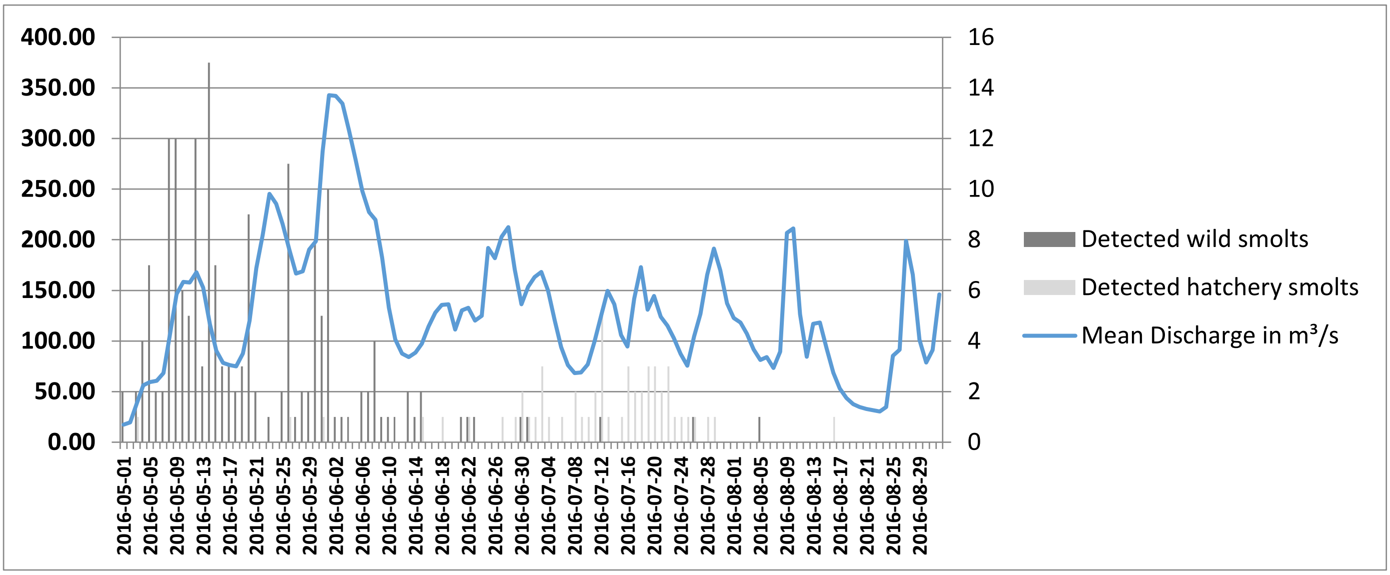
A Mann-Whitney-U test revealed a significant difference ($p<0.001$) between hatchery and wild non-native fish at both release locations concerning the days it took them to get detected.



Graph 11 On average, wild non-native fish needed only one third of the time hatchery fish needed to reach the estuary region. The pattern is the same for both release locations.

Hatchery fish released in Bolstad needed 79.1 days (n=45) on average to get detected while wild non-native fish needed only 26.8 days (n=22). It took the hatchery fish from the Vosso release-group 90.5 days (n=13) on average, the non-native fish only 35.3 days (n=4) to get detected (Graph 11). Mann-Whitney-U tests were used to analyze the possible differences in days until detection, comparing fish with the same origin (hatchery and wild non-native) but from different release locations (Bolstad and Vosso). A significant difference ($p=0.010$) was also found for hatchery, no such difference was found for non-native fish ($p=0.069$).

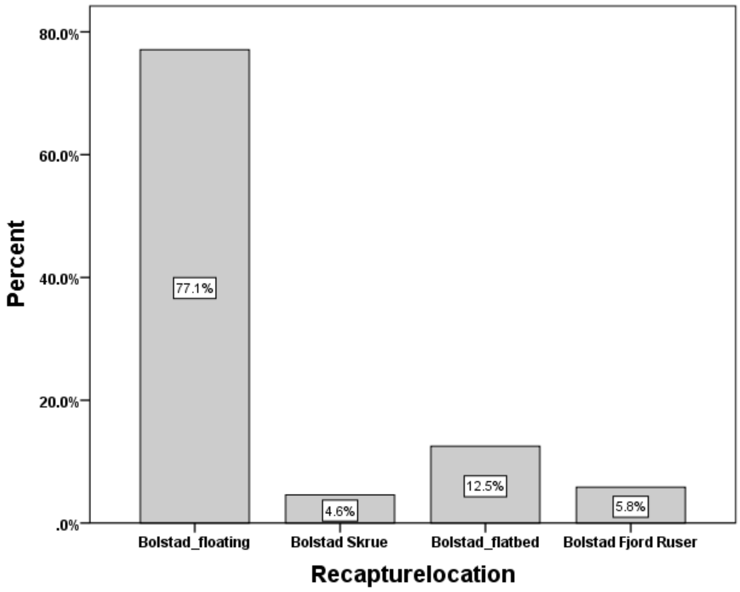
4.5 Discharge



Graph 12 The left y-axis shows the discharge in m³/s, the left y-axis shows the number of detected smolts. Hatchery fish migrated later than wild fish, but there was no significant difference between discharge on recapture day and origin of the detected fish.

A Chi² showed no significant relation ($p=0.386$) between discharge and number of detected fish (Graph 12). A Kruskal Wallis test showed no significant difference between discharge at recapture day and release date groups ($p=0.098$), recapture time ($p=0.587$), release locations ($p=0.108$), origin ($P=0.313$), grouped length ($p=0.949$) and grouped weight ($p=0.460$). But the test showed a significant difference between discharge at recapture day and the recapture locations ($p=0.009$).

4.6 Traps and PIT antennas comparison



Graph 13 Percentage of recaptured fish with all recapture devices.

Overall 77.1% of all fish detected, got detected by the floating antennas, followed by the flatbed antennas (12.5%) and the trapnets in the fjord (5.8%) the smolt screw (4.6%) showed the lowest amount of recaptures (Graph 13). No hatchery fish was detected in the trap nets in the Bolstad-fjord and in the smolt screw at Bolstad (Graph 34). A Chi² test was used to identify possible relations between recapture location and daytime recapture. No significant results were found for hatchery ($p=0.388$), native ($p=0.444$) and non-native ($p=0.456$) smolts. No relation between release location and recapture location was found in hatchery ($p=0.102$), wild native ($p=0.286$) and wild non-native ($p=0.136$) fish (Appendix Graph 16). A Kruskal Wallis test showed there is no significant difference in the distribution of length ($p=0.974$) and weight ($p=0.867$) among the recapture locations.

5 Discussion

Stocking of hatchery raised salmon smolts is a common strategy to reestablish endangered salmon populations in Norway. Despite a lot of effort is put into cultivation programs, there is only little knowledge about the performance of hatchery reared smolts in a natural river environment (Thorstad et al. 2012). The number of returning salmon as adults is reported to be very low, most likely due to high mortality. Especially factors of increased mortality in the riverine phase are not fully understood yet. It is necessary to identify all factors leading to decreased survival to improve stocking and therefore restoration strategies. The main hypothesis of this study was that, hatchery smolts differ from wild fish concerning their detection rates and migratory behavior (hypotheses can be found on page 10, each of them will be addressed in the following paragraphs).

In this study the detections of out migrating PIT-tagged smolts in the Vosso river system were counted, these counts were used as indicator for survival and time of sea entry. Fish were separated into three groups (hatchery, wild native and wild non-native) to find differences in the migration behavior of fish with different origin. They were released on three locations with different distance to the estuary region, depending on the release locations different types of water bodies (rivers and lakes) had to be passed. The recapture setup, containing self-constructed PIT-flatbed antennas, PIT-floating antennas and a smolt-screw were located in the estuary region of the river, a trapnet was located in the fjord. The location of the setup was chosen to guarantee the detection of out-migrating fish only. Significant behavioral differences between wild and hatchery fish were identified. Hatchery fish showed clear differences in their nocturnal migration behavior, delayed sea entry and lower detection rates in comparison to the wild native and wild non-native smolts.

5.1 Main findings

During the whole study period (May-September 2016) wild fish showed a clear preference for nocturnal movement, nearly 70.1% of all recaptured wild fish migrated during the night hours only. 77.2% of wild native smolts and 78.6% of the wild non-native smolts migrated during the night, while only 48.3% of the hatchery reared smolts migrated between 23 - 04 o`clock. The hypothesis, that migration happens mainly during the dark hours of the day, could only be verified for the two groups of wild fish, but not for hatchery smolts. This may indicate that hatchery fish are lacking their natural nocturnal migratory behavior. Earlier in the season wild fish were more likely migrate during the night. Osterdahl (1969) showed that fish tend to migrate during the day later in the season. The number of dark hours per day decreased throughout the season. This needs to be taken into consideration and may also explain lower recapture rates later in the season. According to Haraldstad et al. (2016) better visual conditions during the day may increase avoidance of recapture structures and result in lower recapture rates. Hatchery fish did not show the same movement patterns as the wild fish. They had <50% nocturnal migration throughout the whole study period. Based on a study with acoustic tagged smolts, Urke et al. (2013) pointed out, that the hatchery smolts released in Lærdalselva showed exclusively nocturnal movement, while wild smolts did not. The results from Urke et al. (2013) suggest that the nocturnal movement is an innate adaption even in hatchery fish. The results from the Vosso on the other hand draw a different picture. The recordings suggest that the wild smolts are better adapted to the nocturnal movement than the hatchery smolts. Even though the genetic of the Vosso salmon is used to produce smolts in the hatcheries, it seems like a major part of them lose their natural behavior to migrate mainly during night. Using genetic material of fish, native to the given watershed, is very important and increases stocking effectiveness. McGinnity et al. (2007) pointed out, that non-native hatchery or wild fish produce less well adapted offspring than native wild populations, leading to increased mortality among the stocked, non-native fish. A study from Swain et al. (1991) however, showed that the rearing environment has more influence on the development of certain morphological and behavioral characteristics than genetic differences between wild and hatchery fish. Domestication effects are a well-known problem. Fraser (2008) showed that fitness losses can occur within one or two generations of captive breeding. He also pointed out that, the longer the fish are kept in cultivation programs, the risk of degradations increases. Christie et al. (2016) showed that even a single generation of domestication can heritably alter the expression of genes. This means that even the offsprings of wild fish, which haven´t been kept in cultivation programs for long, can show degradations influencing the fitness and behavior (Fraser 2008). When all groups of fish were tested a significant relation between release date and recapture date was found, no such relation was found for the wild fish. This may indicate that the origin of the fish (hatchery, wild native and wild non-native) is the main factor influencing the daytime migration.

Even though wild and hatchery fish were released nearly at the same time, a bigger part of wild fish migrated earlier in the season than hatchery fish. The cumulative graph (Graph 3) shows, that about 80% of the wild fish have left the river until end of May, the hatchery fish took nearly 2 months longer to reach the same percentage. This supports the hypothesis that the migration timing differs between stocked and wild salmon smolts. Hatchery fish tended to migrate later in the season resulting in a delayed sea entry which may decrease survival rates at sea. Delayed smolts miss optimum ocean conditions if they arrive too late, with direct influence on survival and return rates as adults (Rikardsen et al. 2011). Karppinen et al. (2014) showed that especially hatchery smolts tend to have a delayed migration especially if they are released early in the season (end of April - early May). In the present study, the hatchery fish were released at the 21.04.16, this may explain, why it took them so long to reach the estuary region. There was no difference between wild native and wild non-native fish concerning their seasonal migration. Another interesting point is, that 100% of the recaptured fish (exclusively wild) released at Strandaelva (n=6) left the river before the hatchery fish, released at Vosso and Bolstad, even reached the 20% mark. The release location at Strandaelva, with a distance of over 30 km to the estuary, is the location which is the furthest away from the river outlet, the smolts even had to pass both the Lake Vangsvatn and Lake Evanger. This is surprising, since Hansen et al. (1984) showed that lakes delay the migration (lack of current and increased predation pressure) resulting in delayed sea arrival with direct negative influence on survival and return of adults. Even though they had to swim the longest distance and lost time in the lakes, they still entered the sea much earlier than the hatchery fish. All recaptured fish from Strandaelva were caught within 17 days after release, even though the distance between release location and location of detection is more than 30 km. Nevertheless the number of recaptured fish from Strandaelva is only 6 (2.9% of smolts released there), and only wild fish have been released there, but it still may show a trend to faster movement of wild fish or later initiation of migration in hatchery smolts. This result suggests that the hatchery reared smolts may need some time to adapt to the new environmental conditions before they start the downstream migration.

Wild native smolts showed a recapture rate of 10%, wild non-native smolts a rate of 10.2% and hatchery smolts 4.8%. The results indicate increased mortality among the hatchery fish and support the hypothesis that there is a difference between the detection rate of stocked and wild smolts. The recapture rate also differed between the release locations. The release location in Bolstad is about 3km away from the river outlet, the release location in Vosso is about 15km away and the one at Strandaelva is about 30km away from the estuary. The further the release location was located from the river outlet the lower the recapture rates were. The Bolstad releases (3km from the river mouth) showed a recapture rate of 7.5% for hatchery fish, 13.4% for wild non-native and 37.5% for wild native smolts. The Vosso releases (15km from the river mouth) had a lower recapture rate for all origin groups, only 2.2% of the hatchery, 7% of the wild non-native and 11.5% of wild native fish have been recaptured. The Strandaelva releases (30 km from the river mouth) showed a recapture rate of 2.9% for wild native fish, no hatchery fish and only 1 non-native wild fish have been released at this location. The floating antennas were not working between the 21.05.16 and the 24.05.16, so it is expected that less fish were detected. It is likely that especially fish from the Vosso release site are underrepresented since the incident happened during the smoltrun peak of this group. This may mean that the differences in recapture rates could be smaller between the Bolstad and Vosso release-site groups. Nevertheless, the results support the hypothesis that fish with longer migration routes through the Vosso show decreased detections. A study from McCormick et al. (2014) found the same patterns for detection and release location. He also stated that the detection rates may be related to survival, but factors like avoidance of traps have to be taken into consideration. This seems also plausible since the fish from Vosso had to pass one lake and the fish from Strandaelva had to pass two lakes. When migrating through lakes or reservoirs the movement is mainly passive, moving in the same direction and with the same speed as the surface water (Thorpe et al. 1981). The dependency on the current to move through the lake can cause a delay in migration time, which can result in increased mortality (Hansen et al. 1984). Bigger hatchery and wild non-native smolts seem to be more likely to be detected the bigger and heavier they were, those patterns were not found for wild native fish. McCormick et al. (2014) found the same length-recapture patterns for hatchery fish, bigger fish were more likely to be detected. The detection rate increases with increasing size of hatchery and non-native fish. It is interesting that wild non-native fish showed size and weight selectivity when they were released at Vosso, but not when they were released in Bolstad. This could indicate increased mortality among smaller fish when they get released at unfamiliar locations and in addition have to pass a lake. Since all hatchery fish have been released on the same date (21.04.16) it was not possible to analyze if the release date influences the recapture probability. The detection rate for native smolts was higher when they were released earlier in the season.

5.2 Additional findings:

The number of days from release until detection was analyzed for hatchery and wild non-native fish released at Bolstad and Vosso on the same day (Graph 11). Since there was no release date where all three groups of fish were released at two different sites, this analysis only compares wild non-native and hatchery fish released on the 21.04.16. Significant differences in the number of days until detection were found for hatchery fish, depending on where they were released, no such difference was found for the wild non-native fish. Since wild native and non-native fish show nearly no differences, it can be assumed that the wild native smolts would also take less time to get detected than the hatchery fish. The hypothesis was that the origin as well as the distance of the release location is related to the time of sea entry. The results on the other hand suggest that origin of the fish is the main factor causing the delay in sea entry and therefore increased mortality.Wild smolts, released at Bolstad and Vosso and recaptured at the floating antennas, showed no significant difference in the daytime migration. Even though, smolts released in Vosso had to swim ~12.5 km (5.5 km through the Vosso river and 7 km through the Evanger lake) more than the Bolstad fish until they reached the floating antennas. It seems like the Vosso smolts time their migration so they can pass the Bolstad river during night. During most days in May, wild fish released in Bolstad reached the antennas earlier than the fish released in Vosso. Some of the Bolstad fish were detected during daytime, nearly no Vosso fish was detected between 04 and 23 o`clock. This may mean that the Vosso fish pause their migration during the day and continue migrating during the dark, together with the Bolstad fish. As shown in many studies, smolts tend to migrate nocturnally. This is most likely an adaption to avoid predators like Seatrout (*Salmo trutta L.*), Atlantic salmon, Heron (*Ardea cinerea L.*), Otters (*Lutra lutra L.*) and predatory fish in the estuary regions (Roberts et al. 2009). Most of the hatchery fish tended to migrate during the day, which makes them more susceptible for visual predators. Therefore predation may explain the lower recapture rate of hatchery reared smolts.

The prototype floating antennas recaptured 77.1% of all fish detected, the flatbed antennas on the other hand only detected 12.5%. There is a significant difference between discharge and the probability of being detected at the floating or the flatbed antennas. The same test was repeated for all traps used (including smoltscrew and trapnet) and showed an even higher significant difference. The results show, that there are nearly no detections on the flatbed antennas above a discharge of 200m³/s, but there are still plenty of detections on the floating antennas even at discharge levels of 350m³/s. These results support the hypothesis, that floating PIT-antennas are the most efficient way to recapture near surface moving fish within big rivers. This indicates that high water levels and the natural behavior of the fish make the commonly used stationary PIT systems an inefficient tool to analyze the movement of smolts. Flat-bed antennas are a commonly used tool to monitor fish movement, even though they are not equally effective in monitoring different age classes of fish. Several studies (Armstrong et al. 1996, Zydlewski et al. 2001, Johnston et al. 2009) showed, that the detection range of this antenna type rarely exceed 45 cm. Flatbed and swim through antennas provide good detection efficiency if the channel is regulated, narrowed down or separated (e.g. fish ladders). When it comes to unregulated watercourses, the detection range may be enough to monitor movement of all fish in small shallow rivers, but it is insufficient for large unregulated rivers. Cooke et al. (2013) compared different electronic tags which are commonly used in freshwater research. The restriction of stationary and mobile PIT systems to shallow, small rivers has been highlighted. Spawners on the other hand, are migrating into the river and they tend to move close to the river bottom, therefore 45 cm may be adequate, even in big natural water bodies. But when it comes to monitor out-migrating smolts the flatbed approach seems inappropriate since smolts tend to migrate during high discharge events and close to the surface. Additionally, it cannot be ruled out that some detections on the flatbed antennas may be generated by dead fish drifting down the river. Choosing the wrong antenna system can bias the outcomes of different studies. If only flatbed antennas are used to quantify the survival or the population estimate of migrating smolts, the detection rate will be low, at least in large, deep rivers. The stationary floating antennas seem to be better applicable for this kind of studies and overcome the restrictions of the flatbed antennas.

5.3 Limitations and improvements to the study design

To have more possibilities to analyze the influence of the release dates, it would be better to release an adequate amount of fish from each group simultaneously on different locations. If this would be repeated several times in a given time span it could provide even better information on the movement speed and behavior differences of hatchery and wild fish. To get a valid result on the effect of release locations, all groups of fish need to be released on each release location. In this study, the releases from Strandaelva only contained wild native and non-native fish. This fact limited the possibility to compare all three release locations in all aspects. An improved study design as well as improved prototypes of floating PIT-antennas could provide a valuable tool to answer multiple questions concerning smolt migration. Within the right setup, these antennas could also be used for quantitative studies (e.g. population estimates). It would be interesting to see if the smolts which were caught, tagged and released in the tributaries show the same behavior as the smolts from the main river. In order to do that, fish would need to be released directly at the catch location.

5.4 Conclusion

Significant differences in the migratory behavior between hatchery and wild fish were found in the present study. Hatchery fish migrated later in the season, showed no preference for nocturnal movement and showed clear size selectivity (bigger fish were more likely to be detected) and had the lowest recapture rates. Wild native and non-native fish showed no differences in seasonal and daytime migration. Both groups migrated early in the season, preferred nocturnal migration and showed no differences in the recapture rates. The only significant difference between wild native and wild non-native fish was the size selectivity for non-native fish, from the Vosso release group. Wild non-native fish which had to pass a lake on their downstream migration were more likely to get detected in the estuary the heavier and bigger they were. Wild fish from the upper river sections seemed to interrupt their migration to synchronize the nocturnal migration with the fish from the lower river sections. They showed no difference in the daytime migration even though one group had to swim 12.5 km further to reach the recapture locations. In all groups, the recapture rate of smolts decreased with increasing distance of the release location to the river outlet. It seems like the origin of the fish and the release location were the main factors influencing the recapture probability. Even though, hatchery fish originate from a locally adapted broodstock, they show clear degradations concerning their behavior. Stocking may not be the ideal solution to restore Atlantic salmon populations since hatchery smolts are not well adapted to a natural riverine environment. It is important to identify the factors with direct negative influence and counteract them to maximize the survival of hatchery fish. In consideration with this study and further research better stocking strategies could be implemented.

6 Appendix

6.1 PIT technology

The ability of passive integrated transponder (PIT) tags to allow exact measurements of growth, survival and movement of individual fish, makes them a great tool for studying animal behavior and life history (Roussel et al. 2004). Because of these and other attributes, PIT tags have become a primary tool for monitoring juvenile salmonids, including migration timing and survival estimates (Skalski et al. 1998). Changing conditions like water discharge, conductivity and ambient radio frequency noise can influence the detection range and have to be taken into consideration (Zydlewski et al. 2006). The change of these parameters can also influence the fish behavior and alternate passage routes can prevent the fish from being detected (Connolly et al. 2008). Antenna systems are limited by factors affecting detection efficiency including tag size, power source, tag orientation, interferences caused by non-synchronized antennas (Zydlewski et al. 2006) and interference with the magnetic field caused by metal (Bond et al. 2007). There are different types of systems for monitoring fish with PIT tag technology, each system has its own advantages and disadvantages and should be selected appropriate to the *in situ* environmental conditions. For this study, a Half -Duplex System (HDX) has been used. These systems are more resistant than Full-Duplex systems (FDX), are easier to handle, have a better reading range, they are more flexible and allow more variety for antenna designs. The tags for the FDX systems are smaller than the ones used for HDX systems (23mm are the most commonly used tags for HDX systems) and need to be closer to the antenna to get detected. The biggest advantage of the FDX system is that it creates a continuous magnetic field and the tag can respond immediately (up to 30 times a second). The HDX system creates a pulsed magnetic field, they have a 50ms/20ms charge/listen cycle, enabling 14 reads per second (Source: Oregon RFID). There are mobile and stationary devices to detect fish within the watercourse, mobile detectors are limited to small wadeable rivers, stationary antennas can, depending on their design, be used in small to big scaled rivers. Since the survey was conducted in the Vosso, a big natural river, stationary antennas have been used. They are mainly used for investigations on habitat selection and movement behavior of tagged fish (Connolly et al. 2008), but the data can also be used for population estimates. In the present study the observation was done via self-constructed flat-bed (swim- over) and floating (swim-beneath) PIT antennas, a low cost but still very effective solution. Those antennas allow the monitoring of fish populations with no (or minimal) disruption to fish behavior (Zydlewski et al. 2006).

6.1.1 Different antenna types

6.1.1.1 Flatbed antennas

Flat-bed antennas are placed horizontally on the river bed, fish have to swim over it. This approach is suitable for broad river sections with relatively low water levels and fish have to swim close to the bottom substrate. It is very important to find the right spot to place them to guarantee maximal effectiveness. Their biggest advantage is, that they are very robust, unlikely to get destroyed and it is possible to cover big stream sections. Another important point is, that the antennas can be buried under the substrate or weighted down with big stones. As a result, they are stable and keep their geometry even during high flood events. In our case we added some weights (PVC pipes filled with concrete) to increase the stability of antenna geometry and to prevent the antenna from being washed away. This makes them highly resistant and they stay in place even during high discharge events. In this study we used 3 flatbed antennas, each with a length of 15 m and width of 0.5 m. Depending on the location, 3 respectively 2 synchronized antennas have been used in a combined approach at each study site. The biggest disadvantage is the reading range. All the flatbed antennas used in this study had a reading range of 40-45cm. Another problem is associated with fish "sitting" on or inside the antenna coil, this may prevent the detection of other fish passing the antenna. To circumvent this issue, the antenna should be placed so as to discourage fish from staying there e.g at a riffle section. This limits the possibility of utilization along the whole river, since the morphological conditions must be suitable.

6.1.1.2 Floating antennas

The tractor tube (diameter of 130 cm) provides excellent floating capacity, this ability to float gets enhanced by building foam. This antenna is designed to float on the surface of any given water body and detect PIT-tagged fish as they are moving beneath it. Each of the prototypes we built had the same circular geometry, the antennas consisted of 3 loops of 4mm² copper cable, had a diameter of 115 cm and resulted in a reading range of approximately 120 cm below the surface. This new approach allows to study the movement behavior or survival of salmon smolts, which are rarely detectable by flatbed antennas if the environmental conditions (e.g. water level too high) are not suitable. Smolts tend to migrate to the sea near the river surface, especially during high discharge events. This may also explain the low number of detections by the flatbed antennas, the detection range is just not efficient in big, deep rivers. The floating antennas overcome those limitations and make them an appropriate tool for monitoring near surface moving fish. The big disadvantage of the floating antenna prototypes we used was that they were very vulnerable to drift wood and got easily destroyed. During the investigation period 4 antennas have been destroyed and needed replacement. Since the antennas need to be held in place, there must be some natural structures on the shoreline (e.g. trees) or artificial structure (e.g. bridge) on which the antennas can be fixed, this leads to a limitation of possible implementations.

6.1.2 Future outlook

The data quality generated by the floating antennas was good in comparison to existing methods and it also turned out to be a cheap and effective solution. Within the next year, we hope to create custom made floating antenna, the floating device should be made of UV-resistant PVC or other material, which will make the floating antenna more tolerant against debris and prevent destruction especially during flood events. The antenna cable should be moulded into the plastic to maximize damage resistance and maintain antenna geometry which guarantees a constant detection range and it also makes it less vulnerable. To increase the reading range of the antenna, it is important to have a consistent wire spacing within the antenna. The drawback with the current design was that it was impossible to keep constant spacing between the antenna wires when we put them into the tube. However, tests with the newly constructed antennae showed that we can potentially increase the reading range (>120cm) if we provide proper wire spacing within a rigid molding. With further development and improving the overall function and robustness of the PIT-antenna, we could provide a valuable method that is able to meet the requirements often seen in the field with low maintenance needs.

6.2 Tables

Table 6 Release locations of different groups of origin.

		Origin			Total
		Hatchery	Wild non-native	Wild native	
release	Bolstad	601	650	40	1291
	Vosso	600	632	260	1492
	Strandaelva	0	1	209	210
Total		1311	1283	399	2993

Table 7 Detection of smolts at all traps and PIT antennas, released in the Bolstad river stretch. The number in the parentheses show the percentage of recaptured fish.

		Origin		
		Hatchery	Wild non-native	Wild native
Recapture location	Bolstad_floating	37	59	11
	Bolstad Fjord Ruser	0	9	0
	Bolstad_flatbed	8	14	3
	Bolstad Skrue	0	5	1
Total		45 **(7.5%)**	87 **(13.4%)**	15 **(37.5%)**

Table 8 Detection of smolts at all traps and PIT antennas, released in the Vosso river stretch. The number in the parentheses show the percentage of recaptured fish.

		Origin		
		Hatchery	Wild non-native	Wild native
Recapturelocation	Bolstad_floating	13	37	25
	Bolstad Fjord Ruser	0	1	3
	Bolstad_flatbed	0	3	1
	Bolstad Skrue	0	3	1
Total		13 **(2.2%)**	44 **(7%)**	30 **(11.5%)**

Table 9 Detection of smolts at all traps and PIT antennas, released in the Strandaelva river stretch. The numbers in the parentheses show the percentage of recaptured fish.

		Group
		Wild native
Recapturelocation	Bolstad_floating	3
	Bolstad Fjord Ruser	1
	Bolstad_flatbed	1
	Bolstad Skrue	1
Total		6 **(2.9%)**

Table 10 Amount and date of smolts released in the Bolstad river. The numbers in the parentheses show the percentage of recaptured fish.

Bolstad releases		Origin		
		Hatchery	Wild non-native	Wild native
Release Date	14.04.16	0	109 **(10.1%)**	40 **(37.5%)**
	21.04.16	601 **(7.5%)**	138 **(15.9%)**	0
	25.04.16	0	17 **(23.5%)**	0
	28.04.16	0	386 **(13%)**	0
Total		601 **(7.5%)**	650 **(13.4%)**	40 **(37.5%)**

Table 11 Amount and date of smolts released in the Vosso river. The numbers in the parentheses show the percentage of recaptured fish.

Vosso releases		Origin		
		Hatchery	Wild non-native	Wild native
Release Date	14.03.16	0	0	135 **(14.1%)**
	14.04.16	0	94 **(6.4%)**	0
	16.04.16	0	0	125 **(8.8%)**
	21.04.16	600 **(2.2%)**	139 **(2.9%)**	0
	25.04.16	0	14 **(7.1%)**	0
	28.04.16	0	385 **(8.6%)**	0
Total		600 **(2.2%)**	632 **(7%)**	260 **(11.5%)**

Table 12 Amount and date of smolts released in the Strandaelva river. The number in the parentheses show the percentage of recaptured fish.

Strandaelva releases		Origin	
		Wild non-native	Wild native
Release Date	05.04.16	1 **(0%)**	13 **(0%)**
	15.04.16	0	17 **(0%)**
	16.04.16	0	30 **(0%)**
	25.04.16	0	39 **(0%)**
	20.05.16	0	35 **(2.9%)**
	24.05.16	0	7 **(0%)**
	27.05.16	0	22 **(9.1%)**
	28.05.16	0	20 **(0%)**
	30.05.16	0	16 **(6.3%)**
	01.06.16	0	4 **(0%)**
	10.06.16	0	6 **(16.7%)**
Total		1 **(0%)**	209 **(2.9%)**

Table 13 Detection of PIT-tagged smolts throughout the season. Only detections from PIT-antennas have been taken into consideration, since the other traps do not provide exact time of detection.

		Origin			Total
		Hatchery	Wild non-native	Wild native	
Recapture_month	May	3	88	39	130
	June	7	21	5	33
	July	46	3	0	49
	August	1	1	0	2
	September	1	0	0	1
Total		58	113	44	215

Table 14 Number of fish detected at floating antennas per month. The numbers in the parentheses show the percentage of nocturnal movement within each group and month.

		Origin		
		Hatchery	Wild non-native	Wild native
Recapture_month	May	3 **(66%)**	78 **(85.9%)**	36 **(88.9%)**
	June	4 **(50%)**	17 **(58.8%)**	3 **(33.3%)**
	July	42 **(50%)**	0 .	0
	August	1 **(0%)**	1 **(0%)**	0
Total		50 **(48%)**	96 **(80.2%)**	39 **(84.6%)**

Table 15 Percentage of detected smolts at the flatbed antennas during the dark hours of the day (23 PM to 4 AM). The numbers in the parentheses show the percentage of nocturnal movement per month and group.

		Origin		
		Hatchery	Wild non-native	Wild native
Recapture_month	May	0	10 **(80%)**	3 **(33.3%)**
	June	3 **(66.6%)**	4 **(25%)**	2 **(0%)**
	July	4 **(25%)**	3 **(100%)**	0
	September	1 **(0%)**	0	0
Total		8 **(25%)**	17 **(70.6%)**	5 **(20%)**

Table 16 Number of recaptured smolts for all recapture locations, separated by their origin.

		Origin			Total
		Hatchery	Wild non-native	Wild native	
Recapturelocation	Bolstad_floating	50	96	39	185
	Bolstad Skrue	0	8	3	11
	Bolstad_flatbed	8	17	5	30
	Bolstad Fjord Ruser	0	10	4	14
Total		58	131	51	240

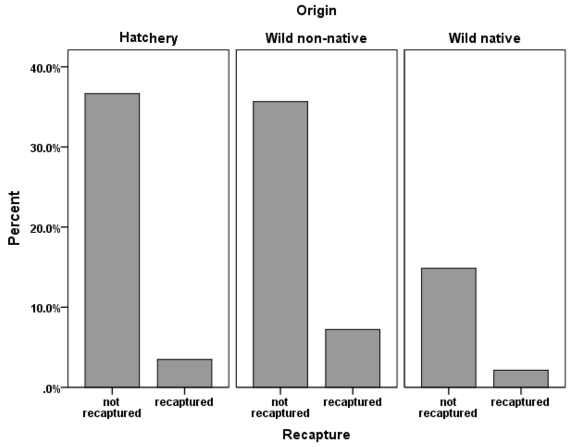
Table 17 Number of smolts for each length group, separated by their origin. The numbers in the parentheses show the percentage of recaptured fish for each group

		Origin						Total	
		Hatchery		Wild non-native		Wild native			
	110-115	3	**(33.3%)**	55	**(7.3%)**	19	**(10.5%)**	77	**(9.1%)**
	116-120	4	**(0%)**	177	**(5.6%)**	82	**(15.9%)**	263	**(8.7%)**
	121-125	29	**(3.4%)**	197	**(8.1%)**	117	**(7.7%)**	343	**(7.6%)**
	126-130	70	**(1.4%)**	241	**(9.5%)**	88	**(10.2%)**	399	**(8.2%)**
	131-135	220	**(0.9%)**	203	**(8.4%)**	64	**(12.5%)**	487	**(5.5%)**
	136-140	295	**(5.2%)**	181	**(12.7%)**	53	**(7.5%)**	529	**(7.9%)**
Length	141-145	268	**(5.9%)**	89	**(19.1%)**	29	**(10.3%)**	386	**(9.3%)**
	146-150	176	**(5.1%)**	74	**(10.8%)**	23	**(4.3%)**	273	**(6.6%)**
	151-155	90	**(8.9%)**	24	**(20.8%)**	20	**(10%)**	134	**(11.1%)**
	156-160	27	**(11.1%)**	14	**(7.1%)**	5	**(0%)**	46	**(8.7%)**
	161-165	9	**(11.1%)**	5	**(40%)**	6	**(0%)**	20	**(15%)**
	166-170	4	**(0%)**	5	**(40%)**	1	**(0%)**	10	**(20%)**
	>170	5	**(20%)**	13	**(15.4%)**	1	**(0%)**	19	**(15.8%)**
Total		1200	**(4.8%)**	1278	**(10.2%)**	508	**(10%)**	2986	**(8%)**

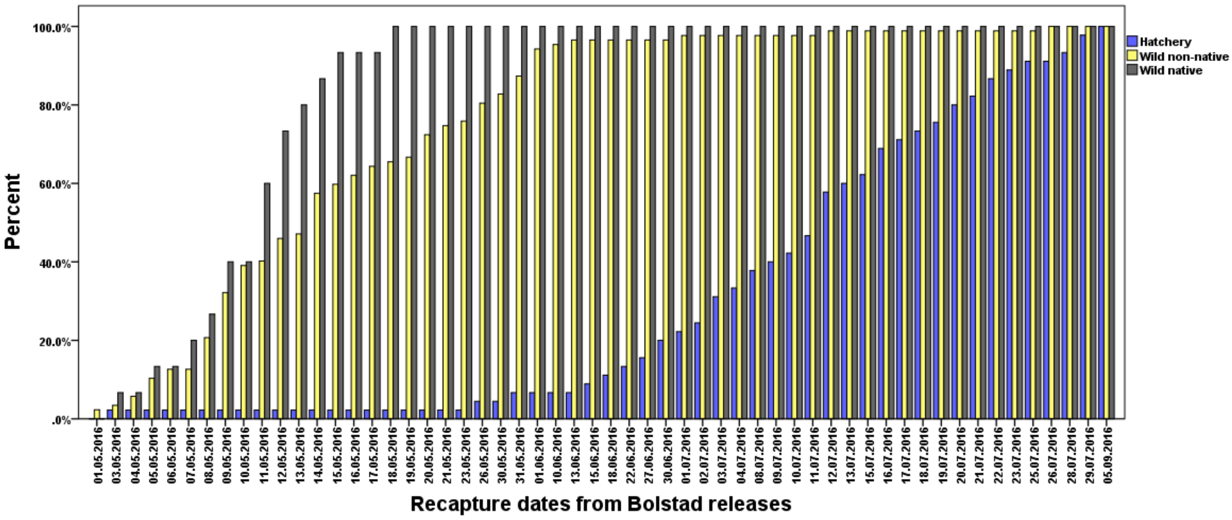
Table 18 Number of smolts for each weight group, separated by their origin. The numbers in the parentheses show the percentage of recaptured fish for each group.

		Origin					
		Hatchery		Wild non-native		Wild native	
	10-15	1	**(100%)**	140	**(5.7%)**	115	**(15.6%)**
	16-20	28	**(0%)**	423	**(9.2%)**	188	**(11.7%)**
	21-25	257	**(3.5%)**	331	**(8.4%)**	62	**(6.4%)**
	26-30	450	**(3.8%)**	170	**(14.1%)**	15	**(6.7%)**
	31-35	299	**(6%)**	41	**(17.1%)**	3	**(0%)**
Weight	36-40	112	**(10.7%)**	8	**(0%)**	2	**(0%)**
	41-45	34	**(2.9%)**	7	**(14.3%)**	1	**(0%)**
	46-50	8	**(0%)**	1	**(0%)**	0	
	51-55	3	**(0%)**	0		0	
	56-60	1	**(0%)**	1	**(100%)**	0	
	>60	5	**(0%)**	0		0	
Total		1198	**(4.8%)**	1122	**(9.6%)**	386	**(11.6%)**

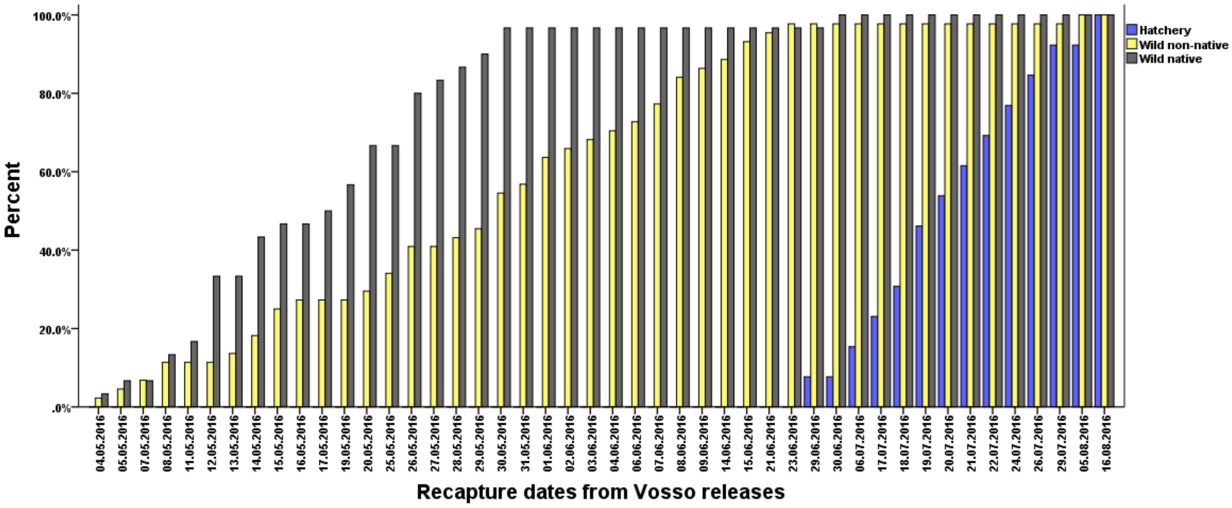
6.3 Graphs:



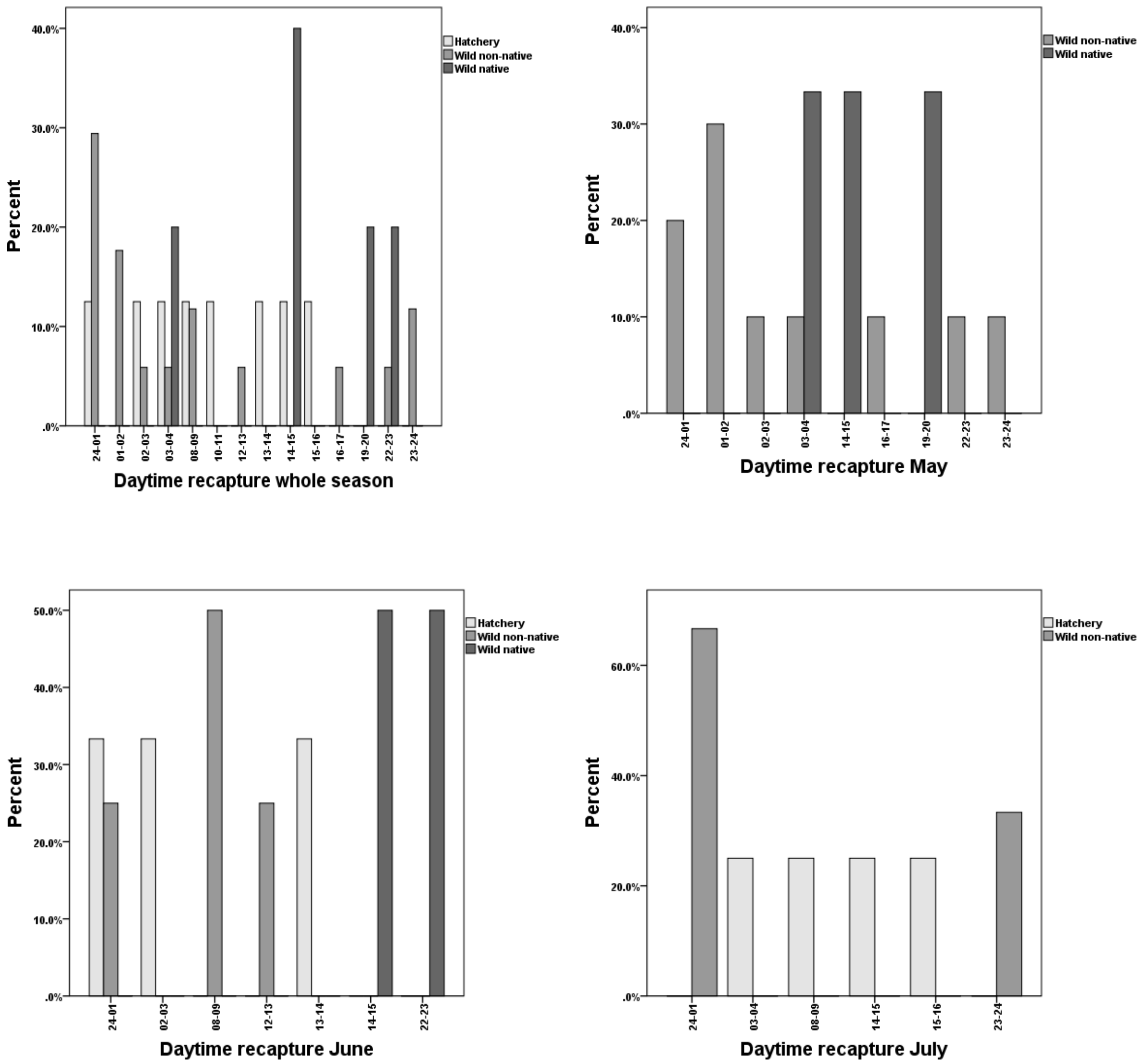
Graph 16 Recaptures of smolts from all traps and release locations depending on their origin.



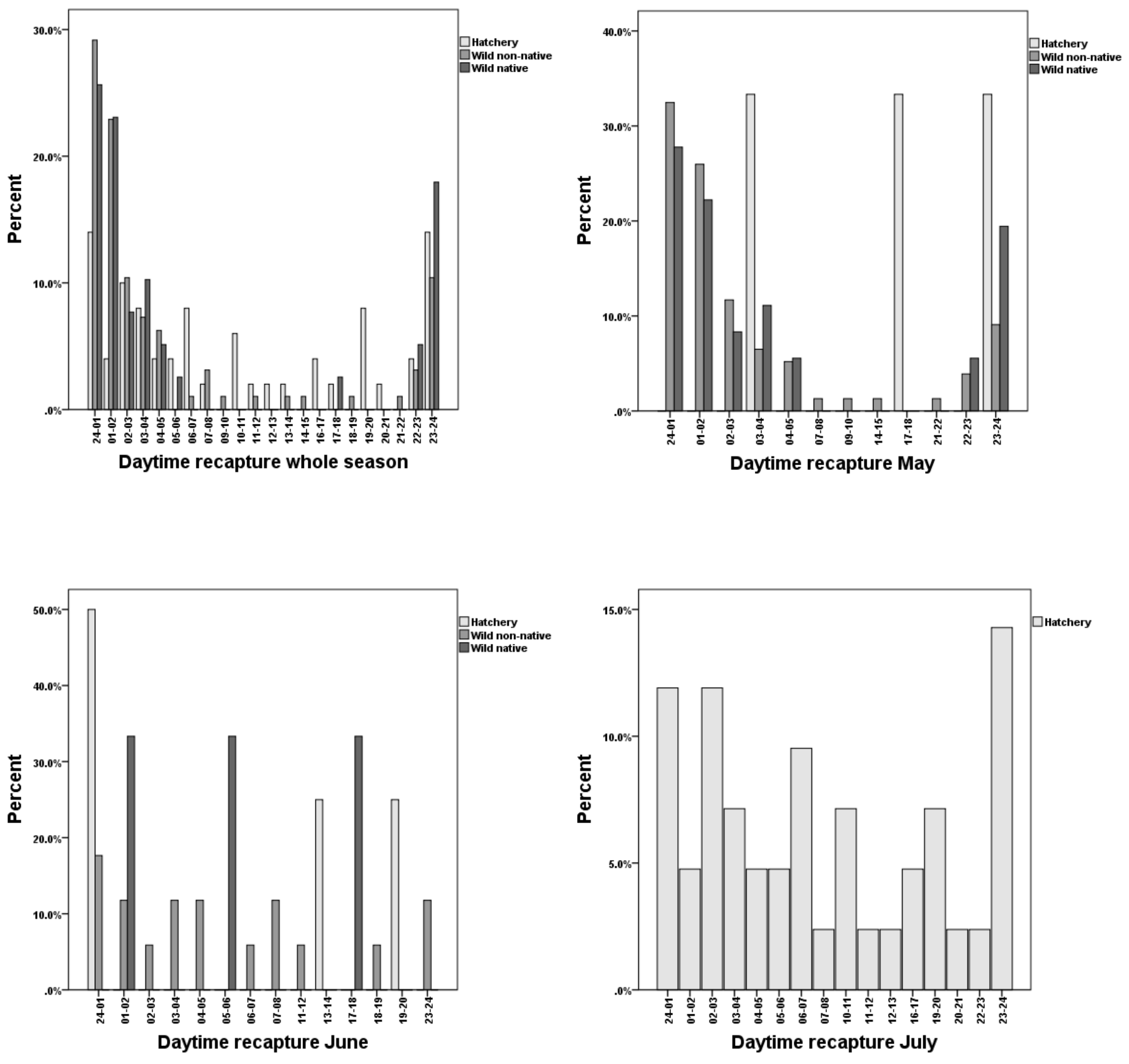
Graph 15 Shows the cumulative percent of recaptured wild and hatchery fish released at Bolstad. N=147



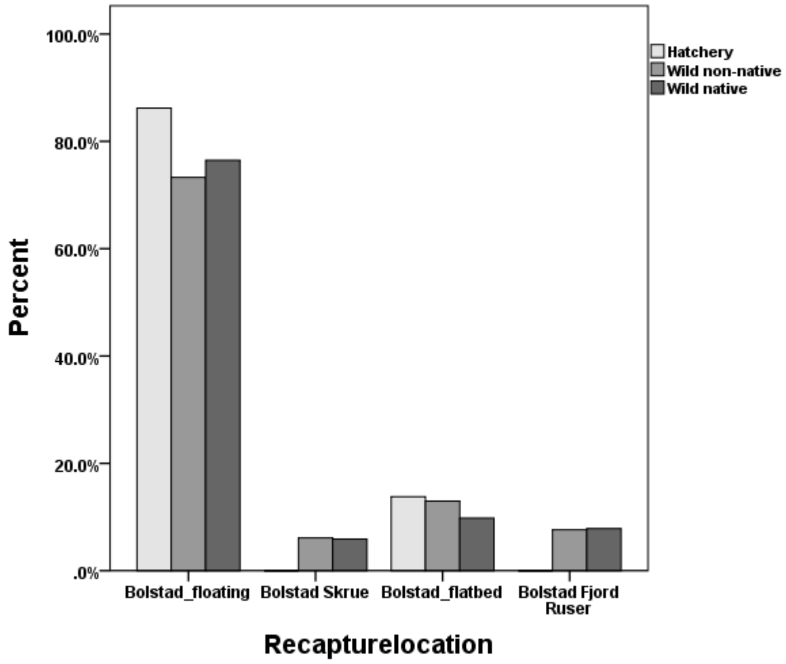
Graph 14 Cumulative percent of recaptured wild and hatchery fish released at Vosso. N=87



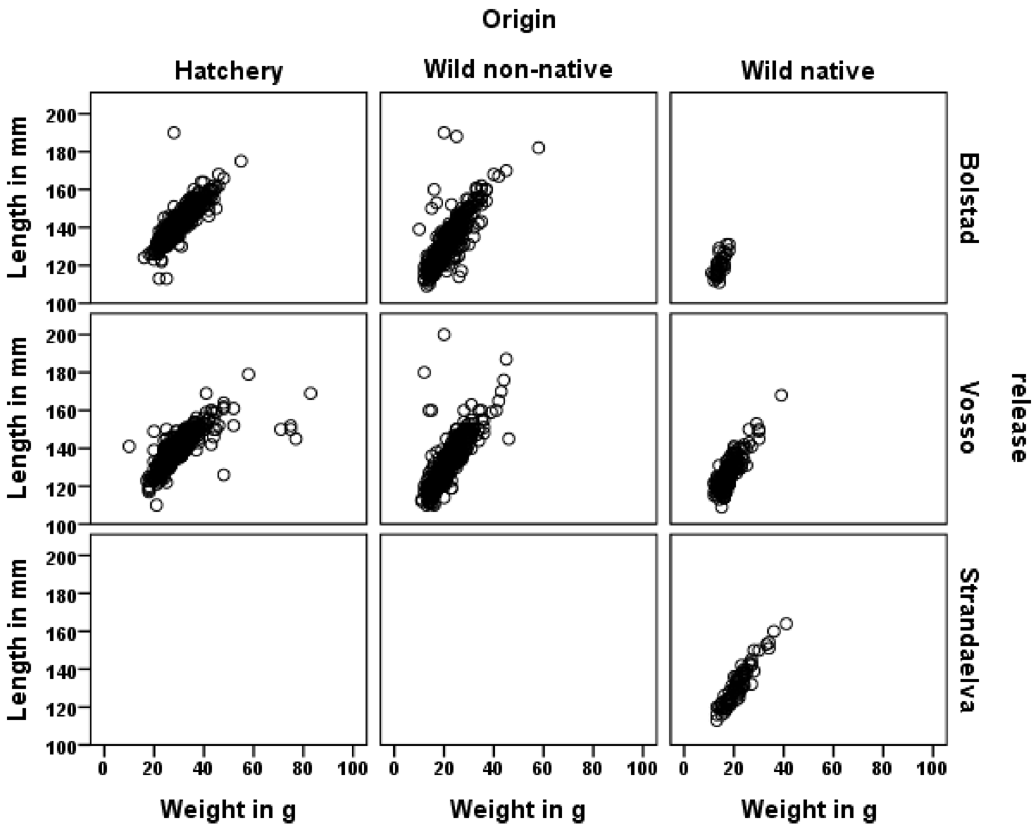
Graph 17 Daytime recaptures at the flatbed antennas for all months, Graphs for August and September are not shown due to lack of detections.



Graph 18 Daytime recaptures at the floating antennas for all months, Graphs for August and September are not shown due to lack of detections.



Graph 19 Percentage of recaptured fish, separated by their origin, for all recapture locations. N=240



Graph 20 Length and weight distribution for all origins and release locations.

7 Literature

Armstrong, J. D., Braithwaite, V. A., Rycroft, P. A flat-bed passive integrated transponder antenna array for monitoring behaviour of Atlantic salmon parr and other fish. J. Fish Biol. 48, 539–541. (1996)

Barlaup, B. T. (redaktør). Redningsaksjonen for Vossolaksen DN-utredning 1-2013

Bond, M. H., Hanson, C. V., Baertsch, R., Hayes, S. A., MacFarlane, R. B. A New Low-Cost Instream Antenna System for Tracking Passive Integrated Transponder (PIT)-Tagged Fish in Small Streams. Trans. Am. Fish. Soc. 136, 562–566. (2007)

Christie, M. R., Marine, M. L., Fox, S. E., French, R. A., Blouin, M. S. A single generation of domestication heritably alters the expression of hundreds of genes. Nature Communications, 7, 10676. (2016)

Connolly, P. J., Jezorek, I. G., Martens, K. D., Prentice, E. F. Measuring the Performance of Two Stationary Interrogation Systems for Detecting Downstream and Upstream Movement of PIT-Tagged Salmonids. North Am. J. Fish. Manag. 28, 402–417. (2008)

Cooke, S. J., Midwood, J. D., Thiem, J. D., Klimley, P., Lucas, M. C., Thorstad, E. B., Ebner, B. C. Tracking animals in freshwater with electronic tags: past, present and future. Animal Biotelemetry, 1(5). (2013)

Feltham, M. J. Consumption of Atlantic salmon smolts and parr city goosanders: Estimates from doubly-labeled water measurements of captive birds released on two Scottish rivers. Journal of Fish Biology 46: 273-281. (1995)

Forseth, T., Barlaup, B. T., Finstad, B., Fiske, P., Gjøsæter, H., Falkegård, M., Wennevik, V. The major threats to Atlantic salmon in Norway. ICES Journal of Marine Science. (2017)

Fraser, D. J. How well can captive breeding programs conserve biodiversity? A review of salmonids. Evolutionary Applications. (2008)

Hansen, L. P., Jonsson, B., Doving, K. B. Migration of wild and hatchery reared smolts of Atlantic salmon, Salmo salar L., through lakes. J. Fish Biol. 25, 617–623. (1984)

Haraldstad, T., Kroglund, F., Kristensen, T., Jonsson, B., Haugen, T. O. Diel migration pattern of Atlantic salmon (Salmo salar) and sea trout (Salmo trutta) smolts: an assessment of environmental cues. Ecology of Freshwater Fish, (June). (2016)

Heggberget, T. G., Johnsen, B. O., Hindar, K., Jonsson, B., Hansen, L. P., Hvidsten, N. A., Jensen, A. J. Interactions between wild and cultured Atlantic salmon: a review of the Norwegian experience. Fish. Res. 18, 123–146 (1993).

Huusko, R., Huusko, A., Mäki-Petäys, A., Orell, P., Erkinaro, J. Effects of tagging on migration behaviour, survival and growth of hatchery-reared Atlantic salmon smolts. Fish. Manag. Ecol. 1–9. (2016)

Hvidsten, N. A., Lund, R. A. Predation on hatchery-reared and wild smolts of Atlantic salmon, Salmo salar L., in the estuary of River Orkla, Norway. J. Fish Biol. 33, 121–126. (1988)

Hvidsten, N. A., Heggberget, T. G. & Jensen, A. J. Sea water temperature at Atlantic salmon smolt enterance. Nordic Journal of Freshwater Research 74, 79–86. (1998)

Hvidsten, N. A., Jensen, A. J., Rikardsen, A. H., Finstad, B., Aure, J., Stefansson, S., Fiske, P., Johnsen, B. O. Influence of sea temperature and initial marine feeding on survival of Atlantic salmon Salmo salar post-smolts from the Rivers Orkla and Hals, Norway. Journal of Fish Biology 74, 1532–1548. (2009).

Johnston, P., Bérubé, F., Bergeron, E. Development of a flatbed passive integrated transponder antenna grid for continuous monitoring of fishes in natural streams. 1651–166. (2009)

Jonsson, B., Jonsson, N. Ecology of Atlantic Salmon and Brown Trout: Habitat as a Template for Life Histories. Dordrecht: Springer Verlag. (2011)

Jonsson, N., Jonsson, B., Hansen, L. P. The marine survival and growth of wild and hatchery- reared Atlantic salmon. 900–911. (2003)

Karppinen, P., Jounela, P., Huusko, R., Erkinaro, J. Effects of release timing on migration behaviour and survival of hatchery-reared Atlantic salmon smolts in a regulated river. 438–452. (2014)

Klemetsen A., Amundsen P.A., Dempson J. B., Jonsson B., Jonsson N., O'Connell M. F., Mortensen E. Atlantic salmon Salmo salar L., brown trout Salmo trutta L. and Arctic charr Salvelinus alpinus (L.): a review of aspects of their life histories. Ecology of Freshwater Fish: 12: 1–59. (2003)

Liu, Y., Olaussen, O. J., Skonhoft, A. Wild and farmed salmon in Norway-A review. Mar. Policy 35, 413–418. (2011)

McCormick, S. D., Hansen, L. P., Quinn, T. P., Saunders, R. L. Movement , migration , and smolting of Atlantic salmon (Salmo salar). 55, 77–92. (1998)

Mccormick, S. D., Haro, A., Lerner, D. T., Dea, M. F. O. Migratory patterns of hatchery and stream-reared Atlantic salmon Salmo salar smolts in the Connecticut River , U . S . A . 1005–1022. (2014)

McGinnity, P., Eyto, E., Cross, T. F., Coughlan, J., Whelan, K., Ferguson, A. Population specific smolt development, migration and maturity schedules in Atlantic salmon in a natural river environment, In Aquaculture, Volume 273, Issues 2–3, 2007, Pages 257-268, ISSN 004

Osterdahl, L. The smolt run of a small Swedish river. In Salmon and trout in streams. Edited by T.G. Northcote. H.R. MacMillan lectures in fisheries, University of British Columbia, Vancouver, B.C. pp. 205–215. 1969

Rikardsen, A. H., Dempson, J. B. Dietary life-support: the marine feeding of Atlantic salmon. In Atlantic Salmon Ecology (Aas, Ø., Einum, S., Klemetsen, A. & Skurdal, J., eds), pp. 115–144. Oxford: Wiley-Blackwell. (2011)

Rivinoja, P., Östergren, J., Leonardsson, K., Lundqvist, H., Kiviloog, J., Bergdahl, L., Brydsten, L. Downstream migration of Salmo salar and S. trutta smolts in two regulated northern Swedish rivers. (2004)

Roberts, L. J., Taylor, J., Gough, P. J., Forman, D. W., de Leaniz, C. G. Night stocking facilitates nocturnal migration of hatchery-reared Atlantic salmon, Salmo salar, smolts. Fish. Manag. Ecol. 16, 10–13. (2009)

Roussel, J. M., Haro, A., Cunjak, R. A. Field test of a new method for tracking small fishes in shallow rivers using passive integrated transponder (PIT) technology. Can. J. Fish. Aquat. Sci. 57, 1326–1329. (2000)

Roussel, J. M., Cunjak, R. A., Newbury, R., Caissie, D., Haro, A. Movements and habitat use by PIT-tagged Atlantic salmon parr in early winter: the influence of anchor ice. Freshwater Biology 49:1026–1035. (2004)

Saltveit, S. The effects of stocking Atlantic salmon, Salmo salar, in a Norwegian regulated river. Fish. Manag. Ecol. 13, 197–205. (2006)

Sægrov, H., Hindar, K., Kålås, S., Lura, H. Escaped farmed Atlantic salmon replace the original salmon stock in the River Vosso, western Norway. ICES J. Mar. Sci. J. du Cons. 54, 1166–1172. (1997)

Skalski, J. R., Smith, S. G., Iwamoto, R. N., Williams, J. G., Hoffman, A. Use of passive integrated transponder tags to estimate survival of migrant juvenile salmonids in the Snake and Columbia rivers. Canadian Journal of Fisheries and Aquatic Sciences 55:1484–1493. (1998)

Solomon, D. J. Smolt migration in Atlantic salmon (Salmo salar) and sea trout (Salmo trutta). In Proceedings of the Salmon and Trout Migratory Behaviour Syposium. Edited by E.L. Brannon and E.O. Salo. University of Washington, Seattle, Wash. pp. 196–203. (1982)

Svendsen, J.C. , Eskesen, A.O. , Aarestrup, K. , Koed, A., Jordan, A.D. Evidence for non -random spatial positioning of migrating smolts (Salmonidae) in a small lowland stream. FreshwaterBiology 52, 1147 – 1158. (2007)

Swain, D. P, Riddell, B. E. & Murray, C. B. Morphological Differences between Hatchery and Wild Populations of Coho Salmon (Oncorhynchus kisutch): Environmental versus Genetic Origin. (1991)

Thorpe, J. E. and Morgan, R. I. G. Periodicity in Atlantic salmon Salmo salar L. smolt migration. Journal of Fish Biology, 12: 541–548. (1978)

Thorpe, J. E., Ross, L. G., Struthers, G. & Watts, W. Tracking Atlantic salmon smolts, Sulino salar L., through Loch Voil, Scotland. J. Fish Biol. 19, 519-537. (1981).

Thorstad, E. B., Uglem, I., Arechavala-Lopez, P., Økland, F., Finstad, B. Low survival of hatchery-released Atlantic salmon smolts during initial river and fjord migration. Boreal Environ. Res. 16, 115–120 (2011).

Thorstad, E. B., Whoriskey F., Uglem I., Moore A., Rikardsen A. H., Finstad B. A critical life stage of the Atlantic salmon Salmo salar: Behaviour and survival during the smolt and initial post-smolt migration. J. Fish Biol. 81, 500–542 (2012).

Thorstad, E. B., Rikardsen, A. H., Alp, A., Okland, F. The Use of Electronic Tags in Fish Research - An Overview of Fish Telemetry Methods. Turkish J. Fish. Aquat. Sci. 13, 881–896. (2013)

Ugedal O., Kroglund F., Barlaup B. T., Lamberg A. Smolt – en kunnskapsoppsummering . Rapport M-136. (2011)

Urke, H. A., Kristensen, T., Ulvund, J. B., Alfredsen, J. A. Riverine and fjord migration of wild and hatchery-reared Atlantic salmon smolts. Fish. Manag. Ecol. 20, 544–552. (2013)

Vollset K. W., Barlaup, B.T., Mahlum S., Skår B., Skoglund H., Norman E. S. Migration and predation of Atlantic salmon smolts from Vosso. Final report FHF project #900778. (2014)

Vollset, K., Mahlum, S., Davidsen, J., Skoglund, H., Barlaup, B. T. Interaction between migration behaviour and estuarine mortality in cultivated Atlantic salmon Salmo salar smolts. Journal of Fish Biology. 89. 1974-1990. (2016)

Zydlewski, G. B., Haro, A., Whalen, K. G., McCormick, S. D. Performance of stationary and portable passive transponder detection systems for monitoring of fish movements. J. Fish Biol. 58, 1471–1475 (2001).

Zydlewski, G. B., Haro, A., McCormick, S. D. Evidence for cumulative temperature as an initiating and terminating factor in downstream migratory behavior of Atlantic salmon (Salmo salar) smolts. Canadian Journal of Fisheries and Aquatic Sciences 62, 68–78. (2005)

Zydlewski, G. B., Dubreuil, T., Letcher, B., Casey, S., Zydlewski, J. Remote Monitoring of Fish in Small Streams, Fisheries, 31:10, 492-502. (2006)