# Downstream migration and survival of Atlantic salmon (Salmo salar L.) kelts and fallbacks when passing a hydropower plant

*Nedströms vandring och överlevnad för retirerande lax (Salmo salar L.) och lax-kelt vid passage förbi ett vattenkraftverk*

Frans Byström

Master’s thesis • 30 credits
Swedish University of Agricultural Sciences, SLU
Department of Wildlife, Fish, and Environmental Studies
Forest Science programme
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# Abstract

Repeat spawners of Atlantic salmon may be of great importance for population stability, the return spawners can significantly contribute to recruitment of juveniles. To have a significant proportion of repeat spawners in the population, it is necessary that salmons can successfully migrate back to the sea after spawning upriver. Studying fish behaviour and movement connected to hydropower plants is important in order to improve fish passage solutions and aid future management. In this study, we use acoustic telemetry to look at migration and survival of kelts and fallbacks at the power station Stornorrfors in river Umeälven, Northern Sweden.

36 out of the 56 spawners tagged at the fish ladder in Stornorrfors initiated downstream migration during the time of the study. 25 out of the 36 salmons immediately cancelled their migration and fell back downstream after tagging, while the remaining 11 first spawned upriver and returned downstream as kelts. All fish that migrate downstream passed through the turbines at Stornorrfors, no individual was found to use the alternative passage route via the fish ladder. 23 (64%) individuals had their last registration at the powerhouse intake and no further registrations downstream. Out of the remaining 13 (36%) that passed through the turbines, an additional 6 (17%) was lost before reaching the last downstream receiver at the river mouth. In the end, only 7 (19%) individuals that initiated downstream migration managed to get to the coast. With this low survival rate, it is apparent that management actions to improve the situation for downstream migrating kelts in the River Umeälven are necessary. However, we could not identify a key area where such measures should be implemented, further studies should have a more heterogeneous sample including more large sized individuals and higher resolution telemetry.

*Keywords:* Migration, kelt, iteroparous, anthropogenic obstacle, survival, turbine passage

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# 1. Introduction

The Atlantic salmon (Salmo salar L.) is widely distributed across the northern hemisphere (Klemetsen *et al.*, 2003). The salmon together with other anadromous species are top predators in the Baltic Sea. Apart from their important role in the ecosystem, they also hold economic importance for both recreational and commercial fisheries (ICES 2018). The Baltic salmon became red-listed in 2013 due to declining population size, likely because of over-harvesting and migration barriers in rivers (HELCOM 2013).

The reproductive success of Atlantic salmon depends on the successful migration to its freshwater habitat. Anthropogenic obstacles such as dams and hydroelectric power plants, disrupts the upstream passage of mature individuals to the spawning areas (Rivinoja *et al.*, 2009). The Atlantic salmon is iteroparous, meaning that it may spawn repeatedly (Klemetsen *et al.*, 2003). An adult salmon must therefore overcome the present obstacles during both upstream and downstream migration. In iteroparous populations, this adaption might be fundamentally important for population stability (Carscadden & Leggett, 1975). The survival and successful downstream migrating of salmons is fundamental for the occurrence of repeat spawners, which may play an important role in stock-recruitment of Atlantic salmon (Halttunen, 2011). Especially as the post-smolt mortality is very high in the Baltic Sea, with return rates of just a few percent for first time spawners (Friedland *et al.*, 2016).

Post-spawning survival can be high in anadromous Atlantic salmon and vary between zero to more than 80% (Nyqvist *et al.*, 2015). In a free-flowing river, it was estimated that 20% of the population consisted of repeat spawners with high survival, that grew large in size and contributed to 27% of eggs in the river, indicating that return spawners might be an important buffer during years of poor recruitment (Halttunen, 2011). Much like the upstream migration of spawners, downstream migration of kelts have also been shown to suffer by dams and power stations. These obstacles leads to increased mortality both by directly causing physical harm to the fish and indirect as individuals use up more energy as result of the delay when bypassing (Nyqvist *et al.*, 2017; Wertheimer & Evans, 2005; Scruton *et al.*, 2002).

since 2014, with an increasing numbers of fish that have been observed dead or dying before spawning (Asker, 2019). This weakened state of the salmons might explain why there was such a high number of fallbacks right after tagging. Increasing the success of these fallbacks to reach the sea, might give them a higher chance to recover, and giving them the possibility to migrate upstream again during a subsequent year.

## 1.1. Aims of the study

The aim of this study is to use acoustic telemetry (a fish tracking method) to answer questions about the movement, behaviour and survival of Atlantic salmon kelts and fallbacks when passing the Stornorrfors power station and dam during downstream migration. Specifically, we will investigate:

i. How many individuals migrate downstream as kelts and as fallbacks?
ii. Do salmons make use of the fish ladder and old-river bed or move through the turbine tunnel?
iii. When migrating to the intake of the power plant, which path do they take?
iv. How many of the fish descending toward the intake also pass through the turbines?
v. What is the mortality rate of fish passing through the turbine?

# 2. Method

## 2.1. Study area

The main water flow in Umeälven (*figure 1*) is diverted through the turbine intake leading to four Francis turbines. The power plant is obliged to spill at least 21 $m^3/s$ through the 8 km old riverbed during the migration season (May 20th to September 30th). About 12 km upstream Stornorrfors, Umeälven is joined by its largest tributary, the river Vindelälven. Both rivers originate from the mountain areas close to the Norwegian border. Acoustic receivers were placed around the power station, upstream in both Vindelälven and Umeälven and downstream the dam, all the way toward the coast (*figure 1*). In some areas multiple receivers were placed to cover the full width of the river and to achieve better resolution when studying movement. Specific coordinates and deployment schedule can be found in appendix 1.

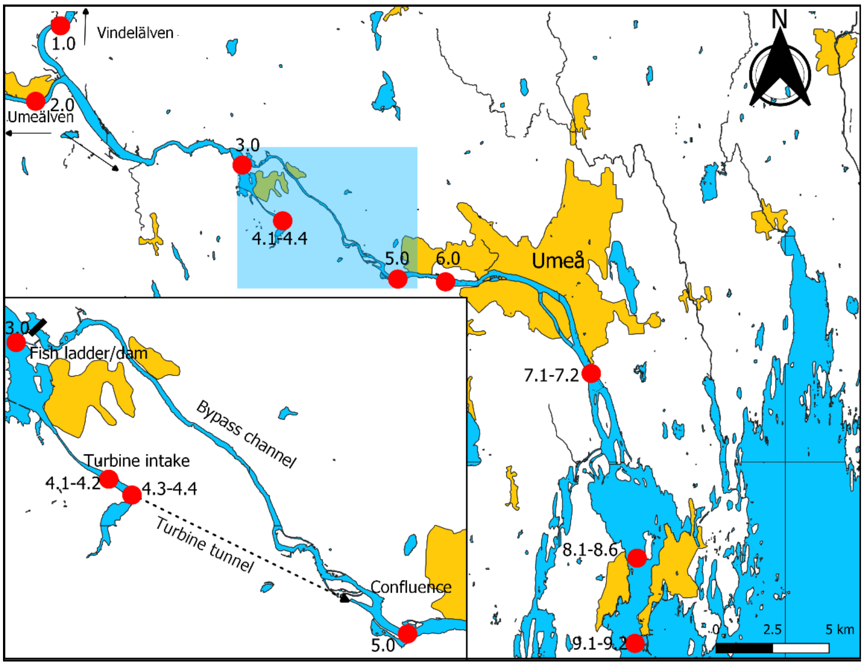

*Figure 1. Umeälven study area, red dots represent approximate locations of receivers, for names of locations, see table 1.*

*Table 1. Names and receiver number for locations where receivers have been deployed.*

| Receiver nr | Location |
|---|---|
| 1.0 | “Upstream Vindelälven” |
| 2.0 | “Upstream Umeälven” |
| 3.0 | “Fish ladder” |
| 4.1–4.4 | “Turbine intake” |
| 5.0 | “Below confluence” |
| 6.0 | “Upstream Umeå” |
| 7.1–7.2 | “Gimonäs” |
| 8.1–8.6 | “Obbolabridge” |
| 9.1–9.2 | “Coast” |

### 2.1.1. Tracking movement

Improvements in technology have made telemetry for aquatic animals more efficient and less invasive (Hussey *et al.*, 2015). Acoustic telemetry is used in this study as it has become a common method for studying fish behaviour, survival and migration (Patterson & Pillans, 2019; Núñez-Rodríguez *et al.*, 2018; Cooke *et al.*, 2008). Acoustic receivers are deployed in fixed-locations along the river (*figure 2.*) (e.g., Sackett et al., 2007). Once a fish tagged with an acoustic transmitter is close enough to a hydrophone, its unique transmitter ID and time for registration is recorded. If the fish resides close to the receiver, multiple registrations will be recorded. The data is later downloaded from the receivers, providing info about which individual that was present at a certain location at a certain time. Having such data allows for tracking movement between different parts of the river, how long time it takes to move between locations and how much time is spent in certain areas.

For this study 19 VEMCO, VR2W (180 kHz) receivers were deployed from the tributary Vindelälven down to the cost (*table 1*) between May 10th and June 18th. Receivers where retrieved between October 1st and October 29th (appendix 1). Receivers at the turbine intake and the fish ladder show which path the salmon are taking when migrating down, multiple receivers at the turbine intake will also provide more details on migration paths when approaching the power station, while a reciver below the confluence area pick up successful passes.

56 Atlantic salmons were captured by manual netting in the top pool of the fish ladder (49 wild and 7 hatchery-reared, 1 female and 55 males), during 20/08 to 11/09 2019. The salmons were anaesthetized and VEMCO V9 transmitters (*table 2*) were surgically (*n=52*) or gastrically (*n=4*) implanted. The gastric implantation was due to staff experienced in surgical implantations was not present at the time

of tagging. With a weight of 3.7 grams and the smallest tagged salmon weighing 1100 grams, the transmitters never exceeded the general recommendation of 2% of the fish body mass (Jepsen, 2004). Externally attached transmitters can cause damage to a growing fish and gastric insertions might impair feeding, while surgically tagged fish have been shown to survive with the implanted transmitter for years (Jepsen *et al.*, 2002). The majority of the individuals was also PIT-tagged (*n=44*) which can be registered at antennas in the fish ladder. The majority of the fish were weighted (*n=44*) with mean weight (±1SD) of 1.85 ± 0.5 kg (range = 1.1–2.8 kg), all was measured with mean length (±1SD) of 61 ± 6 cm (range = 52–94 cm). DNA samples were collected from 52 individuals to confirm which river system they originate from.

*Table 2. Description of the transmitter type used in the study.*

| Transmitter | Frequency (kHz) | Diam. (mm) | Length (mm) | Mass in air (g) | Mass in water (g) |
|---|---|---|---|---|---|
| V9 | 180 | 9 | 25 | 3.7 | 2.1 |

All fish are released just downstream of the opening to the fish ladder (63°52'41.0"N 20°0'48.3"E). To reach the confluence area, they must either pass through the fish ladder or the turbines. The focus of the study will be on all the individuals that at some point visited the turbine intake or goes through the fish ladder.

## 2.2. Data analysis

Extraction of data from the receivers was done using the software VUE from Vemco. Data analysis and statistics were carried out with the statistical software R with package Glatos (Holbrook *et al.*, 2018) and Microsoft Excel for Windows (Excel, 2016).

### 2.2.1. Determination of migration route and fate

All unique individuals that had their last registration at the turbine intake or at the receiver below the confluence had migrated downstream from the point of release. Atlantic salmons that were detected at the fish ladder and had the next detection event below the confluence area was considered to have used the old riverbed. Fish that were detected at the turbine intake and then below the confluence are considered to have passed through the turbines, while the fate of fish that had their last recorded detection at the intake were considered unknown.

### 2.2.2. Migration path to the intake

Which path that salmons took were decided for 24 individuals. The movement of all tagged individuals could not be recorded as receivers 4.1, 4.2, and 4.4 was not deployed at the beginning of the study (*figure 2*). Whether salmons moved on the northern or southern side of the island were investigated using the four receivers upstream the power station. Both island receivers have a detection radius of +100m so when overlapping recordings occur on both receivers, the individual was considered to still reside upstream of the island. As the island provide signal shadowing, several consecutive recordings on only one of the two upper receivers, followed by registrations on either receiver 4.3 or 4.4 counted as a migration event pass the island. The analysis was done by visually interpreting spatiotemporal plots of the registrations, using the Glatos package in R (see example in appendix 2). The turbine flow was being measured at the time that a fish was first registered in the area. Binominal logistic regression analysis was performed to see if different water flows would influence which migration route the salmons took, using turbine flow as the explanatory variable and which side of the island a salmon migrated as the response variable.

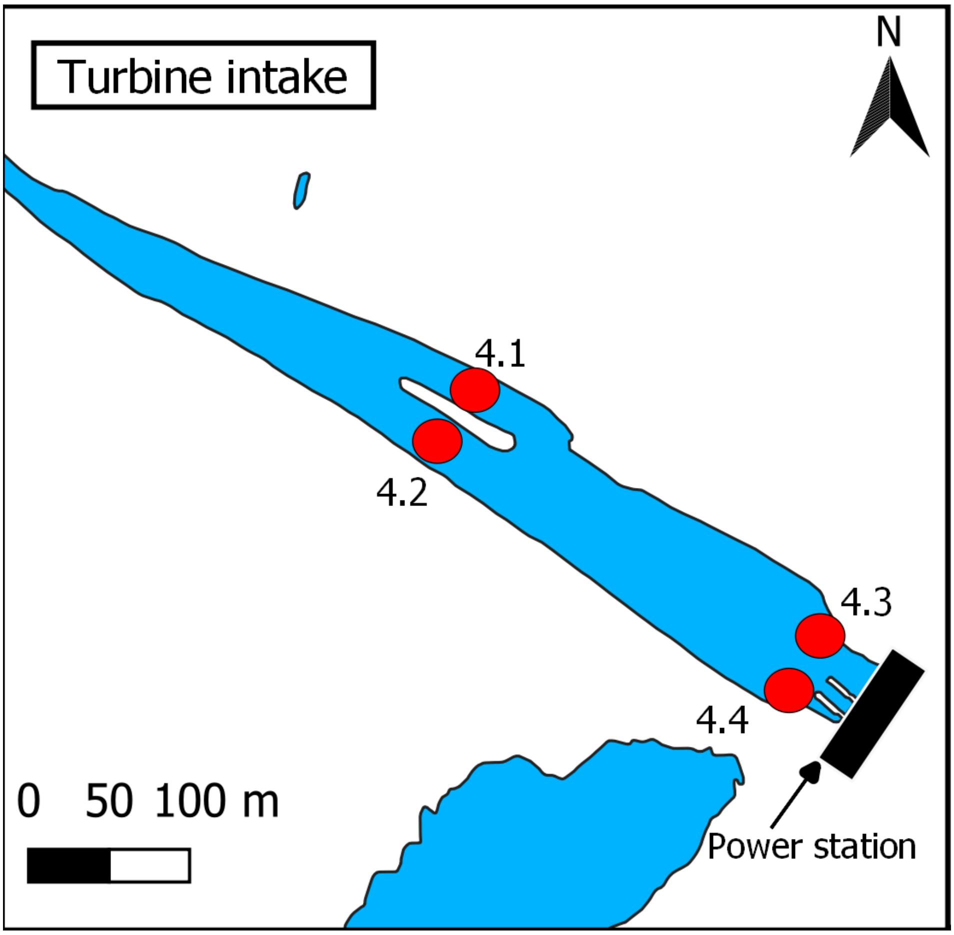

*Figure 2. Two upper receivers covering the norther and southern side of the island, and two lower receivers at each side are represented as red dots*

### 2.2.3. Behavior after reaching the turbine intake

By looking at the time difference between the first and the last detection at the turbine intake of an individual, the time that a fish is delayed at the turbines could be calculated. After reaching the turbine intake three different fates was found, a salmon would either migrate upstream, successfully pass through the turbines and be recorded downstream or were lost at the intake. The group of fish that had their last detection at the turbine intake was analysed further to provide answers on their fate. The group of fish that was lost at the powerhouse were compared to those who successfully passed through the turbines. Cox regression and Kaplan Meier Estimator, a time-to-event survival analysis, was used to compare and visualise the delay at the turbine intake. The regression is a proportional hazards model which returns an expected rate for the passage event to have happened at a given time, the model can then be compared between different groups (Nyqvist *et al.*, 2017; Castro-Santos & Perry, 2012). The length was compared with a Welch Two Sample t-test assuming unequal variances as groups were of different sizes. Another binominal logistic regression analysis was performed to predict fate after the last detection at the turbine intake, using the water flow at the time of the last detection at the turbine intake as explanatory variable and whether an individual was detected again further downstream or were lost at the powerhouse as response variable. Which could provide insight if different water flows through the turbines effect the rate of successful passages through the turbines.

### 2.2.4. Atlantic salmons passing through the turbines

To investigate if the individuals that passed through the turbines were still alive or a dead body flowing with the current, a few criteria for signs of life with varying strength were defined (*table 3*). Moving against the current is something only a living fish is able to achieve, displaying such movement is definite proof that a fish is alive. Fish that accelerate in areas where the current is otherwise slowing down is considered as something a dead individual should not be capable of. A salmon reaching the estuary below the "Obbolabridge" (20 km below the outflow of the powerhouse) before the receivers were retrieved would also be considered as possibly alive, while individuals whose final recording is at an "in-river" location when receiver were retrieved were likely dead.

*Table 3. Definitions of different signs of life with varying strength.*

| Definition | Sign of life |
|---|---|
| If moving upstream between two receivers after passage through turbines | Definite |
| Acceleration in speed between two river stretches, where the river itself move slower | Strong |
| Final recorded location before retrieval of receivers is at location "Obbolabron" | Weak |

To measure acceleration, the river below the confluence was split into three stretches based on four different receiver locations (*table 4*). Distance was measured for each stretch, the time it took to swim between two receivers was based on the last detection on the upper receiver and the first detection on the next receiver downstream. Swimming speed on a river stretch was calculated in body lengths per second (BL/s) by dividing the speed (m/s) with the body length (m) (*Equation 1*).

*Table 4. River stretches, the used receiver locations and distance between locations*

| Stretch | Locations | Distance (m) |
|---|---|---|
| 1 | "Below confluence" - "Upstream Umeå" | 2230.00 |
| 2 | "Upstream Umeå" - "Gimonäs" | 8990.00 |
| 3 | "Gimonäs" - "Obbolabridge" | 8610.00 |

*Equation 1*

$$BL/s = \left(\frac{Distance\ [m]}{Time\ [s]}\right)/BL[m]$$

# 3. Results

## 3.1. Migration

After tagging, 23% (*n*=13) individuals moved upstream the Vindeln river and stayed in potential spawning areas throughout the study. 13% (*n*=7) first visited the turbine intake after tagging to later move upriver where they remained until the end of the study. 20% (*n*=11) were assumed to have spawned in the river Vindeln or Umeälven to later migrate downstream towards the sea. The last 44% (*n*=25) were fallbacks which cancelled their migration immediately after tagging and tried to move downstream.

Out of the original 56 tagged salmons, 36% (*n*=20) had their final detection in connection with spawning or overwintering sites upriver, so their downstream migration behaviour could not be observed as they had not yet initiated downstream migration. 64% (*n*=36) of the tagged individuals tried to pass the power plant (*table 5*). No salmon was registered in the fish ladder, and all fish that migrated downstream were registered at the turbine intake before being lost or observed further down the river.

*Table 5. Summary of different fates for the 36 fish that migrated downstream.*

| Fate | No of fish | Percentage |
|---|---|---|
| Lost at turbine | 23 | 64 |
| Registered in confluence | 13 | 36 |
| Registered at the Obbolabridge | 7 | 19 |

When approaching the turbine intake, 50% of the salmon passed the island on each side with, 12 individuals following either the northern or southern side of the island (*table 6*).

*Table 6. Observed island passages and the turbine flow that occurred when passage was initiated.*

| **Island passage** | | **Turbine flow** (m³/s) | |
|---|---|---|---|
| | *N* | Mean | SD |
| North | 12 | 315.4 | 27.6 |
| South | 12 | 306.5 | 24.4 |
| **Total** | 24 | 311.2 | 18.1 |

The turbine flow was not a reliable predictor of which side of the island the fish migrated. No significance was found for the binominal logistic regression model ($p = 0.803$), which only made 52% correct predictions (*table 7*). Only three of the individuals that was observed to pass on the southern side was also predicted to do so. Nine of the individuals observed to pass on the northern side was predicted to do so by the regression model. In total only 12 passages out of the 23 observations were predicted correctly.

*Table 7. The observed sides where fish passed the island, and the sides predicted for passage by the regression model.*

| | **Predicted side** | | |
|---|---|---|---|
| **Observed side** | South | North | % correct |
| South | 3 | 8 | 27.27 |
| North | 3 | 9 | 75.00 |
| **Overall % correct** | | | 52.17 |

## 3.2. The turbine intake

Out of the thirty-six fish that ended up at the turbine intake, 13 passed through the turbine and 23 was lost as their last detection were at the turbine intake. Mean length was (±1SD) 59.8 ± 2.74 cm (range = 55–63 cm) for fish that passed through the turbines and (±1SD) 62.4 ± 8.35 cm (range = 52–94 cm) for individuals that were lost (difference not statistically significant; Welch t-test, $p = 0.178$).

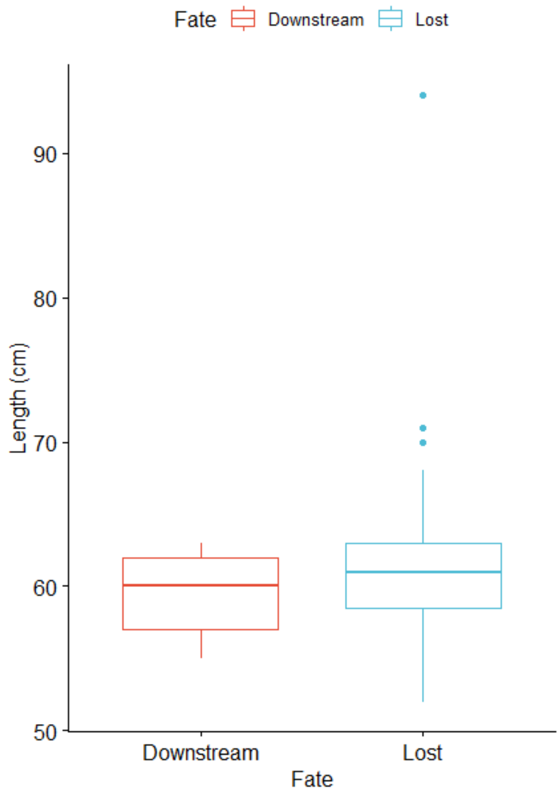

*Figure 3. Boxplot over median length, lower and upper quartiles for individuals that had their last registration at the powerhouse (blue) or was registered downstream of the powerhouse (red.*

The median delay for fish that was lost at the turbines were 21h (range = 0.2-315.1h) compared to 37.5h (range = 0.4-202.8h) for individuals that passed through the tunnel (*figure 4*). Results from the Cox regression analysis showed no significant difference (Hazard ratio: 1.463, 95% Cl for HR; 0.7311-2.927, log-rank test; p = 0.3)

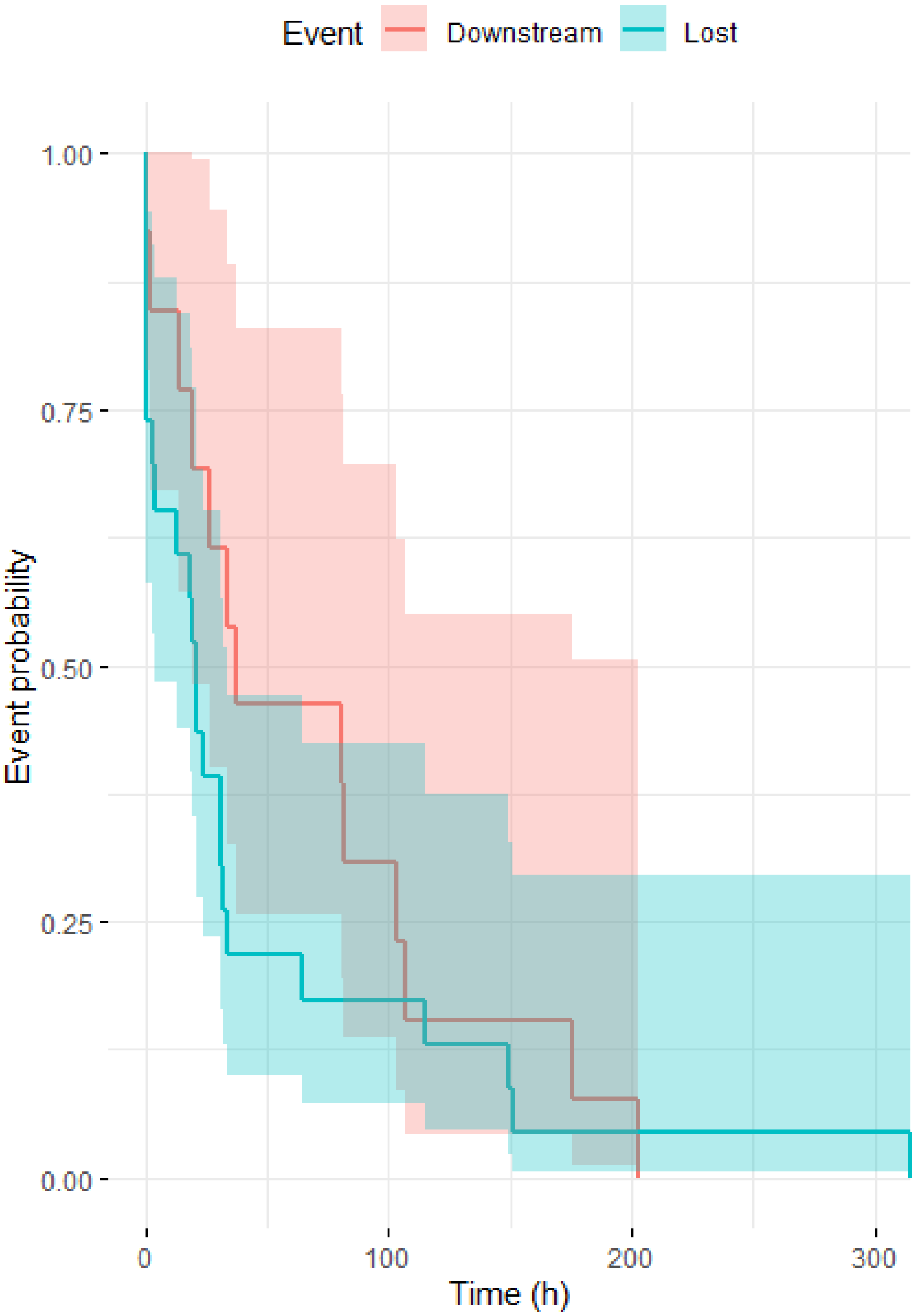

*Figure 4. Kaplan-Meier estimator curve, showing the probability with 95% confident intervals that an individual is still at the intake depending on time spent at the intake (hours).*

The binomial regression model with the turbine flow as a predictor for fate (*figure 5*) was not significant between individuals that were lost or registered further downstream (p = 0.086). The model predicted correctly in 62.86% of the outcomes (*table 9*). 20 of the individuals that was observed to be lost at turbines was also predicted to be lost. Only two of the individuals that successfully passed was also predicted to do so. In total, 22 out of the 35 observations were predicted correctly by the binominal regression model.

*Table 8. Observed fates at the turbines and fates predicted fates by the regression model*

| | **Predicted Fate** | | |
|---|---|---|---|
| **Observed fate** | Lost | Downstream | % correct |
| Lost | 20 | 2 | 70.97 |
| Downstream | 11 | 2 | 30.77 |
| **Overall % correctness** | | | 62.86 |

Visually some relationship appears to exist between fate and turbine flow, with indications that higher flows lead to more individuals making it through the turbine tunnel (*figure 5*). Higher total water flow usually means that more turbines are being used, and the mean flow through each turbine is lower (*table 9*).

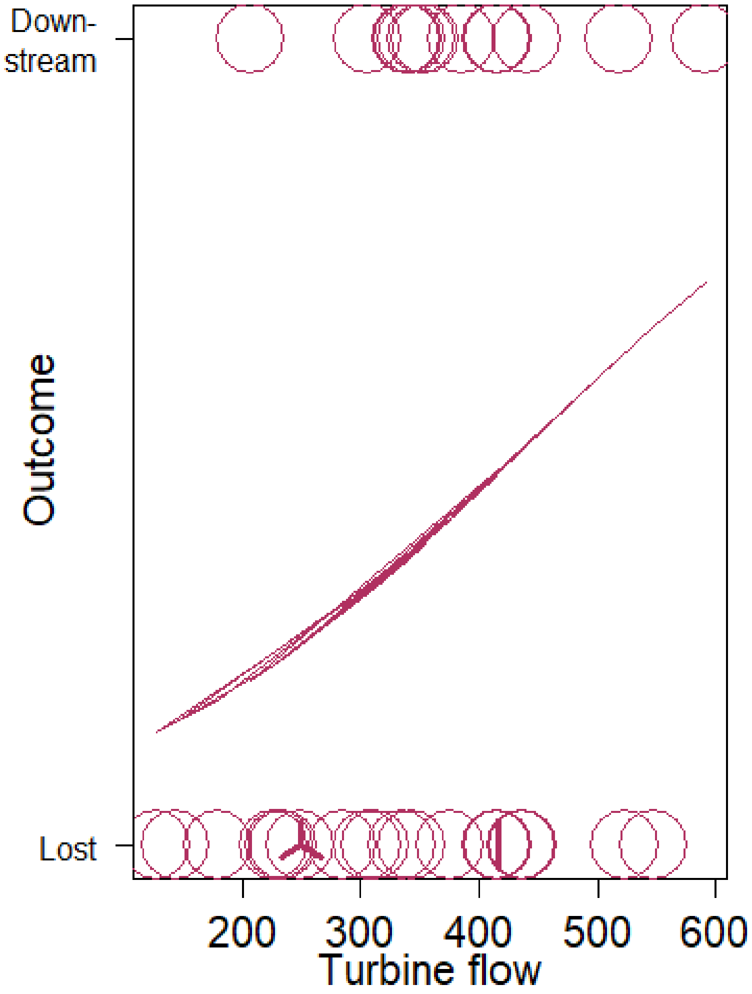

*Figure 5. Sunflower plot over different observed outcomes as a function of turbine flow (m ³/s) at the time of the last registration at the turbine intake. One single observation at a specific flow is represented by a circle. When several observations occur at the same flow, it is symbolized as a sunflower where each petal equals one observation.*

*Table 9. Mean water flow (and range) through one turbine as different numbers of turbines are running at the power station.*

| **Active turbines** | 1 | 2 | 3 |
|---|---|---|---|
| **Mean flow per turbine** (m$^3$/s) | 183 (127-234) | 175 (39-250) | 169 (20-204) |

.

## 3.3. Post-turbine survival

Thirteen salmons were detected in the confluence area. 46% (n=6) had their last registrations at locations upstream the “Obbolabridge”, one was only registered at the confluence, two was last registered at the location “Upstream Umeå” and three at “Gimonäs”. September 13th was the last date any of these individuals were registered (in river receivers were retrieved between October 1st and 2nd). As such, the fish had not been registered for at least 18 days by the time that the receivers were retrieved and were considered as likely dead.

54% (n=7) showed signs of life with varying degree of confidence. Three were considered as definitely alive after observed upstream movements. two individuals accelerates in areas where the river is slowing down and all seven made it to the receivers at the “Obbolabridge” (*figure 6*).

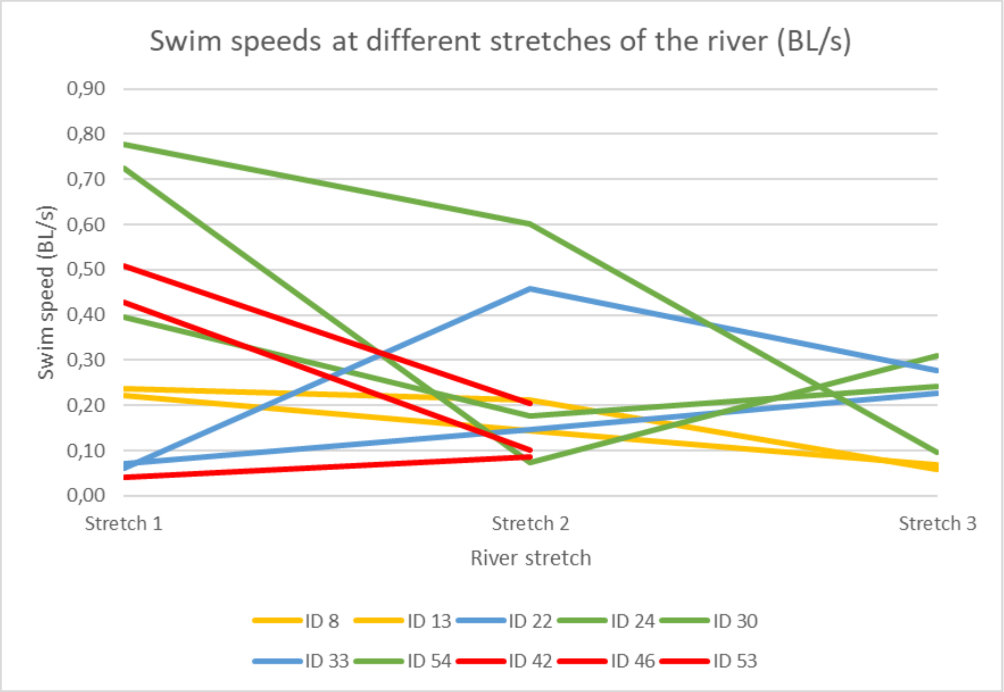

*Figure 6. Individuals 24, 30 and 54 (green) were observed swimming upstream. ID 22 and 33 (blue) accelerates in areas where the river slows down. ID 8 and 33 (yellow) made it to the "Obbolabridge". ID 42, 46 and 53 (red) are lost at the location “Gimonäs”.*

# 4. Discussion

## 4.1. Fate

The overall success of downstream migrating salmons was weak in this study with only 19% (n=7) out of the thirty-six downstream migrating kelts and fallbacks making it pass Stornorrfors and out to the coast (*table 5*). 64% of the losses can be traced to the turbine intake, 20 km from the coast. In contrast, for River Alta which is unregulated along the downstream migration path it was shown that 95% of acoustically tagged Atlantic salmon kelts survived the final 11-21 km river stretch when migrating to the sea (Halttunen *et al.*, 2009). What actually happens with the fish that are lost at the turbines is unknown. Some might have died before arriving at the intake, and previously fish have been found dead at the thrash rack (Östergren & Rivinoja, 2008). If the majority of the lost individuals were already dead at the intake, we would have expected a longer delay at the intake compared to successful migrants. The results show no significant difference in time spent at the turbines, there was also no difference in fish lengths between the two groups. This indicates that the fish that was lost were in similar condition and behaved as the ones that was registered downstream. Meaning that they also tried to migrate downstream but are lost along the way, likely somewhere inside the powerhouse.

There are indications that salmons manage to better pass Stornorrfors during increased flow (e.g. *figure 5*). The binominal regression model for this was not significant, but still with a low p-value. When water flow increases through the power station, they tend to send water through more of the turbines and the mean water flow per turbine decreases, and on occasions really low flows can be found (*table 9*). Lower water velocity would mean that the fish is subjected to less pressure when passing through.

## 4.2. Migration route

There was no specific pattern found for which route the kelts and fallbacks took when migrating down towards the turbines, with 50% (*n*=12) of the individuals moving on either side of the island. Some difficulty in deciding exact movement of individuals could be due to short distances between receivers, resulting in most salmons were being registered by two or more receivers simultaneously. Some error might occur when visually determining which side a fish have passed on, this error can be assumed to be the same for both sides, ending with the same result. For better details on movement, high resolution receivers and transmitters should be used in future studies (for example; VEMCO HR2, High Residence Receiver).

For efficient measures to improve the situation for salmons, it would be important to know where they are moving. This study fails to identify a small spatial area that the majority of fish pass through. This study lacks large-sized females among the tagged fish, any future studies should try to include this group. They are the most valuable individuals for reproduction as egg size and numbers tend to increase with body mass (Klemetsen *et al.*, 2003). When deciding on measures one should not stare blindly on the numbers of fish, but also look at the individual level and consider attributes like sex and size.

The binominal regression model failed to predict which side the fish decide to move on, depending on different water flows. The water flow used in this study is based on the time of the first registration on either of the two upper receivers at the turbine intake. At times there was some delay between the first registration and the event where a fish passed the island. This means that the used water flow in the model might not be the occurring water flow when the individual passes the island.

## 4.3. Turbine survival

Of the thirteen individuals registered downstream Stornorrfors, 53% (n=7) were found to be possibly alive after passing through the turbines, this was based on the fish making it to the receivers at “Obbolabridge” as previous acoustic telemetry studies have assumed fish to be alive after passing the last receiver close to the river mouth (Hubley *et al.*, 2008). This assumption is not without its issues and might overestimate the survival. There is a possibility that dead-drifting individuals get transported via the flow. To strengthen the argument that they were alive, other factors was also taken into account. Swim speed alone was considered, but as the results can show by the fish that is definitely alive (green) in figure 6, they are the ones swimming the fastest but also the slowest on stretch 2. Instead, acceleration was used, as increasing in speed on a stretch where the water moves slower would not be expected of a dead individual. Even if seven individuals are considered possibly alive, there is only definite proof for the three that were observed swimming upstream.

## 4.4. Tagging and sample quality

Noteworthy is that 25 out of the 56 tagged salmons immediately aborted their upstream migration after tagging. The tagged fish was in varying condition, with few having minor superficial injuries. Previous studies show that migrating up to the fish ladder is a difficult journey with many individuals aborting migration before even reaching the ladder (Leonardsson *et al.*, 2013; Rivinoja *et al.*, 2009). Since 2014, the river Vindel salmon have shown signs of being sick, with increasing number of observations of dead or dying fish pre-spawning (Asker, 2019). The weakened state of the salmon may explain why so many tagged fish went downstream directly after tagging.

The sampled individuals are a homogenous group, consisting of primarily 50-70 cm long, wild, one sea winter, male salmons. This does not cover all variations generally found within the salmon population. Assumptions about other parts of the population should be drawn with care. The problems connected to passage over Stornorrfors will probably be similar over the population, but specific movement, behaviour and mortality rates might vary.

## 4.5. Survival

The results of this study show that 64% of the migrating salmons was lost at the turbines in Stornorrfors, this is similar to the 69% loss of brown trout, and 52% loss previously found for salmon (Lundqvist *et al.*, 2015; Östergren & Rivinoja, 2008). Direct passage survival in the same studies was estimated to 31% for brown trout and 28-64% for salmon, both of which are higher than the 19% found in this study. The higher estimate of 64% survival rate by Lundqvist *et al*,. 2015, assumes that fish that are lost have been able to make it undetected to the coast. In this thesis, it would be very unlikely that an individual would be able to pass all four downstream receiver locations without being detected. The survival rates in the previous studies (28% and 31%) are based on registrations at in-river locations ("Gimonäs" in Lundqvist *et al*,. 2015 and "Below confluence" in Östergren & Rivinoja, 2008). If the same definitions would have been used here, the survival would have been similar (28% and 33%). Using such assumptions could result in an overestimation of the survival, as the results of this study show that losses can occur even downstream "Gimonäs". A model assessing blade strike mortality in Francis turbines expected ca 40% mortality (Ferguson *et al.*, 2008), the observed mortality has been higher. The model only including direct mortality from blade strikes could explain this. Other factors might also influence mortality, like fish behavior, altitude and pressure differences during passage.

Like previous studies, no fish were registered in the fish ladder. The inefficiency of the ladder and guidance structure cannot be based on all 36 salmons in this paper. Since 25 salmons immediately canceled their migration after tagging, they never passed the guidance structure and fish ladder.

## 4.6. Conclusions

This thesis investigates the behavior and survival of Atlantic salmon kelts and fallbacks when migrating downstream pass the hydropower plant Stornorrfors in the river Umeälven. The aim was to improve knowledge about the occurring situation for salmons in the river and identifying migration routes which can be important for future management measures to improve the rate of successful migration.

It is clear that the mortality of salmons in the final 20 km of the river Umeälven is much higher than what would be expected in a natural system. High mortalities are caused by passage through the power station, and actions need to be taken which provides a possibility for kelts and fallbacks to move downstream without going through the turbines. In the short term, measures based on trapping and moving fish in the narrow parts of the turbine intake channel could improve survival. For such actions to become successful and cost-efficient, future studies are needed where movement can be tracked in finer detail than presented in this thesis. Such a study should also include more fish in larger size classes, as they are more valuable for the population stability. Even a rather inefficient method could be a large improvement from the low 19% survival rate presented here. In the long term, improvements should focus on the guidance system and attraction of the fish ladder, which in its present state is inefficient for improving kelt migration pass Stornorrfors.

# References

Asker, N. (2019). *SYNTESRAPPORT Östersjölaxens Hälsa*. Göteborg: Göteborgs Universitet.

Carscadden, J.E. & Leggett, W.C. (1975). Life history variations in populations of American shad, Alosa sapidissima (Wilson), spawning in tributaries of the St John River, New Brunswick. *Journal of Fish Biology,* 7(5), pp. 595-609.

Castro-Santos, T. & Perry, R.W. (2012). Time-to-event analysis as a framework for quantifying fish passage performance. In, pp. 427-452.

Cooke, S.J., Hinch, S.G., Farrell, A.P., Patterson, D.A., Miller-Saunders, K., Welch, D.W., Donaldson, M.R., Hanson, K.C., Crossin, G.T., Mathes, M.T., Lotto, A.G., Hruska, K.A., Olsson, I.C., Wagner, G.N., Thomson, R., Hourston, R., English, K.K., Larsson, S., Shrimpton, J.M. & Van Der Kraak, G. (2008). Developing a Mechanistic Understanding of Fish Migrations by Linking Telemetry with Physiology, Behavior, Genomics and Experimental Biology: An Interdisciplinary Case Study on Adult Fraser River Sockeye Salmon, 33(7), pp. 321-339.

Excel (2016). [Computer Program].

Ferguson, J., Ploskey, G., Leonardsson, K., Zabel, R. & Lundqvist, H. (2008). Combining turbine blade-strike and life cycle models to assess mitigation strategies for fish passing dams. *Canadian Journal of Fisheries and Aquatic Sciences,* 65, pp. 1568-1585.

Friedland, K.D., Dannewitz, J., Romakkaniemi, A., Palm, S., Pulkkinen, H., Pakarinen, T. & Oeberst, R. (2016). Post-smolt survival of Baltic salmon in context to changing environmental conditions and predators. *ICES Journal of Marine Science,* 74(5), pp. 1344-1355.

Halttunen, E. (2011). Staying alive : the survival and importance of Atlantic salmon post-spawners.

Halttunen, E., Rikardsen, A.H., Davidsen, J.G., Thorstad, E.B. & Dempson, J.B. (2009). Survival, Migration Speed and Swimming Depth of Atlantic Salmon Kelts During Sea Entry and Fjord Migration. In: Nielsen, J.L., Arrizabalaga, H., Fragoso, N., Hobday, A., Lutcavage, M. & Sibert, J. (eds) *Tagging and Tracking of Marine Animals with Electronic Devices*. Dordrecht: Springer Netherlands, pp. 35-49. Available from: https://doi.org/10.1007/978-1-4020-9640-2_3.

Holbrook, C., Hayden, T. & Binder, T. (2018). *Glatos: A package for the Great Lakes Acoustic Telemetry Observation*. [Computer Program].

Hubley, P.B., Amiro, P.G., Gibson, A.J.F., Lacroix, G.L. & Redden, A.M. (2008). Survival and behaviour of migrating Atlantic salmon (Salmo salar L.) kelts in river, estuarine, and coastal habitat. *ICES Journal of Marine Science,* 65(9), pp. 1626-1634.

Hussey, N.E., Kessel, S.T., Aarestrup, K., Cooke, S.J., Cowley, P.D., Fisk, A.T., Harcourt, R.G., Holland, K.N., Iverson, S.J., Kocik, J.F., Mills Flemming, J.E. & Whoriskey, F.G. (2015). Aquatic animal telemetry: A panoramic window into the underwater world. *Science,* 348(6240), pp. 1255642-1255642.

Jepsen, N. (2004). A brief discussion of the 2% tag/bodymass rule. *Aquatic telemetry: advances and applications*.

Jepsen, N., Koed, A., Thorstad, E.B. & Baras, E. (2002). Surgical implantation of telemetry transmitters in fish: how much have we learned? *Hydrobiologia,* 483(1-3), pp. 239-248.

Klemetsen, A., Amundsen, P.-A., Dempson, J.B., Jonsson, B., Jonsson, N., O'Connell, M.F. & Mortensen, E. (2003). 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), pp. 1-59.

Leonardsson, K., Karlsson, R., Nilsson, J. & Lundqvist, H. (2013). *Uppströmsvandring i den restaurerade gamla älvfåran samt funktionskontroll av ny fisktrappa i Norrfors (Umeälven) under laxens vandringssäsong 2012-2013*. (Rapport (Sveriges lantbruksuniversitet, Institutionen för vilt, fisk och miljö) ; 2013:7. Umeå: Institutionen för vilt, fisk och miljö, Sveriges lantbruksuniversitet.

Lundqvist, H., Leonardsson, K., Lindberg, D.-E., Westbergh, S., Forssén, Å. & Hellström, G. (2014). Laxens nedströmsvandring mot fiskavledare till Stornorrfors fisktrappa i Umeälvens nedre del. Umeå: Sveriges lantbruksuniversitet. Institutionen för vilt, fisk och miljö.

Lundqvist, H., Leonardsson, K., Williams, J., Östergren, J., Hellström, G. & Forssén, Å. (2015). Problematiken kring flergångslekare av lax, öring och steelhead i vildlaxförande stora flödesreglerade vattendrag. Umeå: Rapport / Sveriges lantbruksuniversitet, Institutionen för vilt, fisk och miljö (12093069).

Lundqvist, H., Rivinoja, P., Leonardsson, K. & McKinnell, S. (2008). Upstream passage problems for wild Atlantic salmon (Salmo salar L.) in a regulated river and its effect on the population. *Hydrobiologia,* 602(1), pp. 111-127.

Núñez-Rodríguez, J., Vela Díaz, A., Bazan-Albitez, R., Rebaza Alfaro, C., Koua, D., Núñez, L., Testi, B., Renno, J.-F., Duponchelle, F. & Pella, H. (2018). Use of an acoustic telemetry array for fine scale fish behaviour assessment of captive Paiche, Arapaima gigas, breeders. *Aquaculture Research,* 49(6), pp. 2296-2304.

Nyqvist, D., Bergman, E., Calles, O. & Greenberg, L. (2017). Intake Approach and Dam Passage by Downstream-migrating Atlantic Salmon Kelts*,* 33(5), pp. 697-706.

Nyqvist, D., Calles, O., Bergman, E., Hagelin, A. & Greenberg, L. (2015). Post-Spawning Survival and Downstream Passage of Landlocked Atlantic Salmon (Salmo salar) in a Regulated River: Is There Potential for Repeat Spawning? *River Research and Applications,* 32.

Patterson, T.A. & Pillans, R.D. (2019). Designing acoustic arrays for estimation of mortality rates in riverine and estuarine systems. *Canadian Journal of Fisheries and Aquatic Sciences,* 76(9), pp. 1471-1479.

Rivinoja, P., Lindberg, D., Leonarddson, K., Wiklund, B.-S., Hockersmith, E., Rambo, S., Axel, G. & Lundqhist, H. (2009). *Upstream passage of wild Atlantic salmon and seatrout in the regulated part of River Umeälven (Sweden)*.

Rivinoja, P., McKinnell, S. & Lundqvist, H. (2001). Hindrances to upstream migration of atlantic salmon (Salmo Salar) in A Northern Swedish River caused by a hydroelectric power-station. *Regulated Rivers Research & Management,* 17, pp. 101-115.

Scruton, D.A., McKinley, R.S., Kouwen, N., Eddy, W. & Booth, R.K. (2002). Use of telemetry and hydraulic modeling to evaluate and improve fish guidance efficiency at a louver and bypass system for downstream-migrating Atlantic salmon (Salmo salar) smolts and kelts. In: Thorstad, E.B., Fleming, I.A. & Næsje, T.F. (eds) *Aquatic Telemetry: Proceedings of the Fourth Conference on Fish Telemetry in Europe*. Dordrecht: Springer Netherlands, pp. 83-94. Available from: https://doi.org/10.1007/978-94-017-0771-8_10.

Wertheimer, R.H. & Evans, A.F. (2005). Downstream Passage of Steelhead Kelts through Hydroelectric Dams on the Lower Snake and Columbia Rivers. *Transactions of the American Fisheries Society,* 134(4), pp. 853-865.

Östergren, J. & Rivinoja, P. (2008). Overwintering and downstream migration of sea trout (Salmo trutta L.) kelts under regulated flows-Northern Sweden. *River Research and Applications,* 24, pp. 551-563.

# Appendix 1

*Table over receivers, their location, coordinates and deployment schedule*

| Receiver no | Location | coordinates | Deployed | Retrieved |
|---|---|---|---|---|
| 1.0 | Upstream Vindelälven | N63° 56.333' E19° 51.278' | 2019-07-18 | 2019-10-17 |
| 2.0 | Upstream Umeälven | N63° 54.612' E19° 49.297' | 2019-07-17 | 2019-10-17 |
| 3.0 | Fish ladder | N63° 52.753' E20° 00.786' | 2019-05-27 | 2019-10-28 |
| 4.1 | Turbine intake (north of island) | N63° 51.419' E20° 02.464' | 2019-08-29 | 2019-10-29 |
| 4.2 | Turbine intake (south of island) | N63° 51.372' E20° 02.346' | 2019-08-29 | 2019-10-29 |
| 4.3 | Turbine intake (north) | N63° 51.241' E20° 02.959' | 2019-05-27 | 2019-10-29 |
| 4.4 | Turbine intake (south) | N63° 51.182' E20° 02.898' | 2019-08-29 | 2019-10-29 |
| 5.0 | Bellow confluence | N63° 49.707' E20° 08.424' | 2019-05-14 | 2019-10-02 |
| 6.0 | Upstream Umeå | N63° 49.625' E20° 11.031' | 2019-05-14 | 2019-10-16 |
| 7.1 | Gimonäs (west) | N63° 47.177' E20° 18.508' | 2019-05-14 | 2019-10-02 |
| 7.2 | Gimonäs (east) | N63° 47.172' E20° 18.403' | 2019-05-14 | 2019-10-02 |
| 8.1 | Obbolabridge | N63° 42.772' E20° 20.484' | 2019-05-13 | 2019-10-01 |
| 8.2 | Obbolabridge | N63° 42.768' E20° 20.314' | 2019-05-13 | 2019-10-01 |
| 8.3 | Obbolabridge | N63° 42.752' E20° 20.216' | 2019-05-13 | 2019-10-01 |
| 8.4 | Obbolabridge | N63° 42.725' E20° 19.851' | 2019-05-13 | 2019-10-01 |
| 8.5 | Obbolabridge | N63° 42.721' E20° 20.018' | 2019-05-13 | 2019-10-01 |
| 8.6 | Obbolabridge (Side channel) | N63° 42.459' E20° 20.766' | 2019-05-13 | 2019-10-01 |
| 9.1 | Coast | N63° 40.515' E20° 19.799' | 2019-05-10 | 2019-10-01 |
| 9.2 | Coast | N63° 40.549' E20° 19.597' | 2019-05-10 | 2019-10-01 |

# Appendix 2

*Example of visually determining which side of the island a fish passed, in a plot created in R with the package Glatos. Red dots represent registrations at a receiver*

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