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Linda Vikström

Examensarbete i ämnet biologi
Department of Wildlife, Fish, and Environmental studies
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Linda Vikström

Supervisor: Hans Lundqvist, Dept. of Wildlife, Fish, and Environmental Studies

Assistant supervisor: Kjell Leonardsson, Dept. of Wildlife, Fish, and Environmental Studies

Examiner: Anders Alanärä, Dept. of Wildlife, Fish, and Environmental Studies

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Abstract

Hydropower poses a major threat to both upstream and downstream migrating Atlantic salmon *(Salmo salar L.)*. To ensure a relatively safe route for migrating fish, fish ways and different guidance structures are constructed to help fish to bypass the turbine intakes to power stations. The success of these constructions varies and is generally dependent on the local river conditions.

In 2010, a fish guiding structure was installed in Sikfors power station, River Piteälven, to improve the downstream migration for smolts of Atlantic salmon. In the year of installation, a study aimed to evaluate the success of the guidance structure failed due to technical problems. The aim of this thesis was to evaluate the fish guidance structures ability in helping downstream seaward migrating salmon smolts in Piteälven with a safe passage through the power station and the dams. During the period May 25th to June 15th, a total of 117 hatchery reared smolt were marked with radio-tags and then released 2. 6 km upstream the hydropower station. Tagged and released smolts had an average length of c. 201 mm. To understand the effect of the guidance structure before and after installation, the obtained data was analyzed together with data from previous studies conducted in Sikfors (Lundstrom *et al.*, 2015, Rivinoja, 2005a).

74 smolts (85 %) made the passage through the spill gates while 13 smolt (15 %) passed through the two Kaplan turbines. The survival was higher for fish passing through the spill gate (c. 80 %) compared to fish passing through the turbines (c. 69 %). Flow greater than 100 m^3/s resulted in a higher mortality rate for passing smolt and thus the flow regime seemed to be an important abiotic factor to consider when discussing safe fish passages and guidance structures. Of the original tag group with 117 individuals, 37 completed the downstream seaward migration. These data give in short a relatively good picture on smolt passage effects that can affect the whole life-cycle. The result on survival was significantly better for downstream migrants when the guidance structure was installed compared to a system without this structure. With the guidance structure in place a majority of the released smolts was directed into the spillway instead of having to pass through the turbines on their seaward migration.

Sammanfattning

Vattenkraft utgör ett stort hot mot både uppströms och nedströmsvandrande Atlantlax *(Salmo salar L.)*. För att förse migrerande arter med en säkrare vandringsväg kan olika konstruktioner bidra med en ökad säkerhet vid passage, både upp- och nedströms, genom kraftverksområden. Oftast varierar funktionen hos dessa konstruktioner beroende på ett flertal lokala förhållanden som strömningar, flöden etc.

Under 2010 installerades en fiskavledare i Sikfors kraftstation, (Piteälven) för att förbättra nedströmsvandringen för lax- och öringungar. Under året när fiskavledaren installerades genomfördes en studie med syfte att utvärdera dess framgång. På grund av tekniska problem som ledde till att ledarmen inte flöt kunde ingen tillförlitlig studie genomföras för att utreda funktionen. Syftet med detta arbete är att utvärdera effektiviteten hos fiskavledaren när det kommer till att kunna förse laxsmolten i Piteälven med en säker väg på deras nedströmsvandring ut mot havet. Under perioden mellan 25 maj till den 15 juni, har totalt 117 individer av odlad smolt märkts med radiosändare och släppts 2. 6 km uppströms vattenkraftverket Sikfors. Medellängden för smolten var ca 201 mm. Den märkta fisken har sedan följts på sin väg nedströms mot kraftverket där ledarmen monterats uppströms dammen. För att utvärdera fiskavledarens effektivitet jämfördes erhållet data med resultat från tidigare studier (Lundstrom *et al.*, 2015, Rivinoja, 2005a).

74 smolt (85 %) passerade via spillet medan 13 smolt (15 %) istället gick genom de två kaplan turbinerna. Överlevnaden var högre för passage genom spill med ca 80 % jämfört med en turbinpassage på ca 69 %. Flöden större än 100 m^3/s resulterade i en högre dödlighet för passerande smolt. Flödesregimen bedöms som en viktig variabel att ta hänsyn till i samband med fiskavledande strukturer. Av den ursprungliga gruppen på 117 individer lyckades 37 genomföra en lyckad migration ut till havet. Detta pekar på den betydelse vattenkraften kan ha på laxens livscykel. Det är viktigt att överlevnaden maximeras för den naturligt producerade avkomman i dessa unika bestånd. Fiskavledaren hade en positiv effekt på laxungarnas överlevnad då de i större utsträckning passerade kraftverksbyggnaden via ytvattenspillet över dammen och inte via turbinerna.

Introduction

The environmental impact of hydropower in flow regulated rivers generally cause loss of connectivity for many fish species and destruction of river habitats for spawning and growth of juveniles. The anadromous Atlantic salmon *(Salmo salar* L.*)* is dependent on a variety of habitats in order to complete their life cycle and is thus a species heavily affected by hydropower. As a migratory fish with seasonal movements between spawning areas in rivers and their growth areas in the sea it is of great importance for the future survival of the population to protect these river habitats (Jonsson and Jonsson, 2009, McCormick *et al.*, 1998). During the last decade, a lot of efforts have been made on improving fish passage for both upstream and downstream migrating fish (Calles *et al.*, 2013b). Hydropower developments have generally a negative impact on salmonids populations since turbine mortalities on passing smolt can be relatively high (Thorstad *et al.*, 2012).

One way to increase the survival of migrating fish is by implementing more fish friendly passage routes. These fish-ways are either structures or hydraulic systems that strive to reduce the negative impact on the passing fish movements and their biological requirements (Odeh, 2000). One example of such a structure is a fish guiding device which can provide downstream migrating smolts and other fish with a safe downstream passage, working as an "artificial" shoreline guiding them through the spill gates instead of passing through the turbines. Spill gates, also called SFO (surface flow outlet), is a passage which is water-efficient and help fish and water to pass over the dam without having to go through the turbines (Johnson and Dauble, 2006). These SFO´s can be more or less successful as a safe migration route for the smolts even if the overflow spillways still can provide some mortality among smolts (Calles *et al.*, 2013a). Worldwide, a lot of work is done on evaluating different fish ways and passage routes for fish to lower their mortalities when passing (Williams *et al.*, 2012).

The migratory stage for smolts is one most critical stage in the salmon life cycle (Jonsson and Jonsson, 2011), since they are transformed physiologically at the same time as they are changing their river habitat and face a variety of new dangers (Thorstad *et al.*, 2012). Passing through a hydropower complex is not an easy route and can be responsible for both direct and indirect mortality. The direct mortality is caused by mechanical damage and pressure during passage while the indirect mortality is mortality after they have passed as a result of stress, injuries or predation (Coutant and Whitney, 2000). The damage caused by the turbines is generally higher for small hydro power plants due to the smaller size together with higher rotation of the turbines (Larinier, 2008). Depending on what kind of turbine that is installed, the survival of passing fish can differ. Bigger size Kaplan turbines with a slower rotation of the turbine blades are known to provide with a safer passage than other turbine types (Näslund *et al.*, 2013). Still, passage through the turbines often result in the highest mortality rates and therefore active measurements are taken in order to direct the smoltsowards a safer passage through the spill gates (Calles *et al.*, 2013a).

It's difficult to prove the effect of predation on smolts under natural conditions but it is assumed to be the main natural cause of death during the migration stage (Karppinen *et al.*, 2014, Thorstad *et al.*, 2012). Hydropower structures can lead to an aggregation of predators and increase the risk of mortality during the smolt migration (Koed *et al.*, 2002, Jepsen *et al.*, 2000).

Smolts migrating downstream usually follow the main flow with the highest water velocities (Rivinoja *et al.,* 2004) and are surface oriented (Rivinoja, 2005b). In increased flows, smolts often show a behavior to orient themselves towards the flow instead of drifting freely *(Arenas et al.,* 2015). Previous studies have pointed out the importance of considering the flow regime in connection to application of fish ways during downstream migration of fish (Calles, 2005, Williams *et al.,* 2012). By usage of the water turbulence and increasing velocity in close connection to the dam the success of passing on the seaward migration could be increased (Coutant, 2001).

In 2010 a guidance structure was placed upstream the Sikfors power station in Piteälven with the aim to guide the migrating smolts towards an overflow spill gate instead of having smolts to swim through the turbine intake and turbines. Previous studies done in Sikfors before and after the installation of the guidance structure showed in 2003 that 36 out of 40 smolts (salmon and trout) made the passage through the power station via the turbines (Rivinoja *et al.*, 2005). This states the problematics regarding fish passage through the power station and also point towards the need for the guidance structure. During the same year as installation, a telemetry study on smolt was carried out but due to technical problems regarding the structure (2/3 of the lower section was under water before the study begun), no efficient data could be obtained in order to make the analysis. In 2015, LTU (Luleå Techniqual University) used a two-frame Particle Tracking Velocimetry algorithm to derive the velocity field of the water and this was then compared to CFD simulations in order to find out if passively moving particles could be guided by the structure. The results showed that the majority of the particles released were successfully directed towards the spill gates instead of the turbines and thus concluding that if the smolt passively follows the flow of the water they are assumed to be directed towards the spill gates (Lundstrom *et al.,* 2015).

The aim of this thesis was to evaluate the fish guidance structures potential to direct tagged smolts towards the spill gates in order to provide them with a safer passage through the power station on their downstream migration. Three main questions were established:

1) How effective is the guidance structure in Piteälven in directing the smolts towards the spill gates instead of the turbines?

2) Does the spill gates provide the smolt with a safe way through the power station in Sikfors?

3) How many individuals manage to succeed in their downstream migration out to the sea?

Materials and method

Area of study

Piteälven (River Piteälven) located in the northern part of Sweden is one of four Swedish national Rivers, stretching its way from the Norwegian border and northeast to the Bothnian Bay at 65°14´N, 21°31´E (Figure 1). The River, which is c. 450 km in length, has been small scale regulated since the beginning of the 1900s. Sikfors is the only power station in the river and is located c. 40 km from the sea. My main study area stretches from c. 2. 6 km upstream the power station and down to the sea. Piteälven has important reproduction areas for salmon and seatrout (Calles *et al.*, 2013b, Östergren, 2006), and like the other three Swedish national rivers (the Torneälven, Kalixälven and Vindelälven), it is protected from further hydropower developments by the Swedish environmental law (Renofalt *et al.*, 2010).

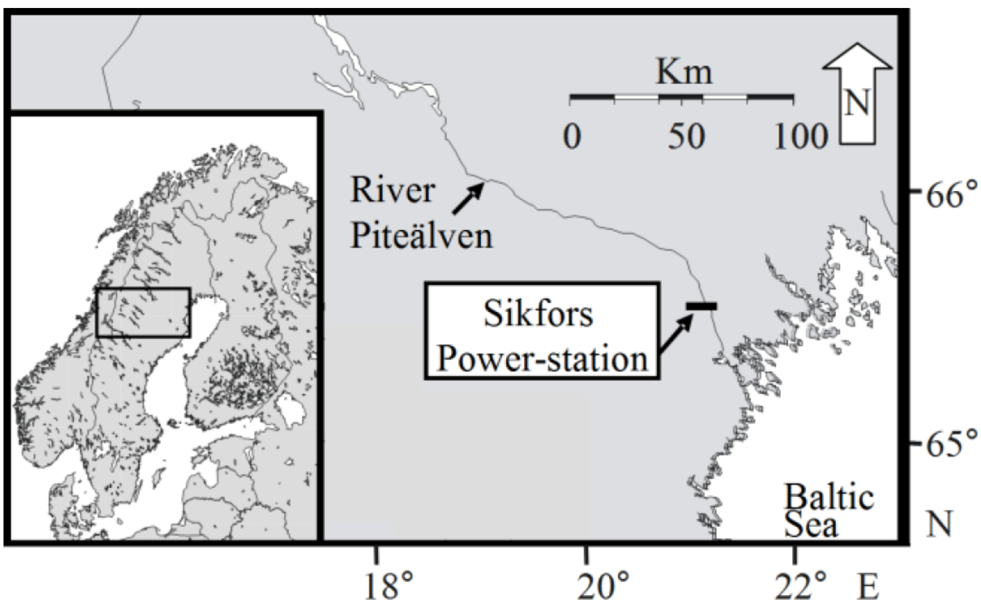

Figure 1. Map showing the location of Piteälven in northern Sweden together with Sikfors hydro-power plant within the river.

Atlantic salmon smolt in Piteälven

Piteälven is home to a wide range of fish species, including the Atlantic salmon. After spending 1-4 years in the sea, they reach sexual maturity and return to freshwater in order to spawn (Jonsson and Jonsson, 2011). The natural population of Atlantic salmon in Piteälven initiates their downstream migration during spring. In 2015, a total of 2919 salmon passed the fish ladder in Sikfors, Piteälven (SwedishLapland, 2015).

Sikfors power station

The power station is located at the lower part of the river which probably hinder the salmon and seatrout to easily migrate between their feeding and spawning grounds (Calles *et al.,* 2013a). In 1992, a fish ladder was installed making it possible for upstream migrants of salmon and seatrouts to pass the power station. The ladder is located next to the spill gates (Figure 2). Sikfors power station consists of two Kaplan turbines (3.95 m in diameter and a speed of 167 rpm) that have a total capacity of 260 m^3/s producing a maximum of c. 25 MW each. The water from the turbines follows an underground tunnel that empties 0. 6 km downstream the power station. The dam also consists of three spill gates, two of them spill water at the bottom and one spill gate (named B) is surface oriented. One purpose of Spill gate B is to provide the smolt with a safe passage over the power station during the main time of migration. The vertical drop for the water passing the power station is approximately 19, 5 m.

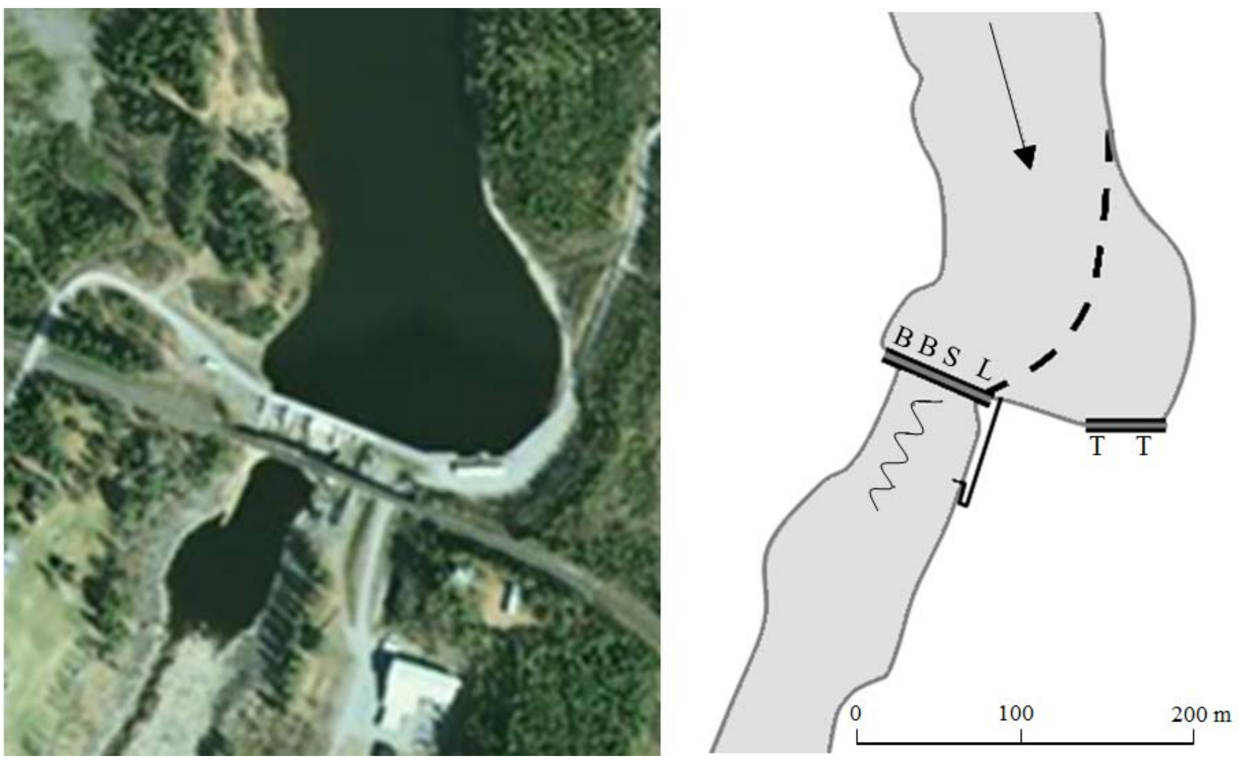

Figure 2. An up close picture of the power station with the different openings marked (B=bottom spill, S=surface spill and L=fish ladder and T=turbine intake), the dashed line shows the placement of the guidance structure and the arrow shows the direction of the river flow.

To make the passage through the station safer for fish passing downstream, a guidance structure was installed in mid May 2010. The structure consist of 26 floating booms, each boom have a steel structure covered by impregnated wooden planks with widths of c. 5 m and depths of c. 2 m stretching approximately 130 m across the River (Figure 4). The wall is attached with the help of a wire, keeping it floating 2 m deep from the opposite side of the river upstream and connects to the power stations spill gates. During the downstream migration of smolt they tend to be surface oriented (Rivinoja, 2005b). Most important is therefore that the guidance structure covers the surface area in order to successfully direct the downstream migrating smolt.

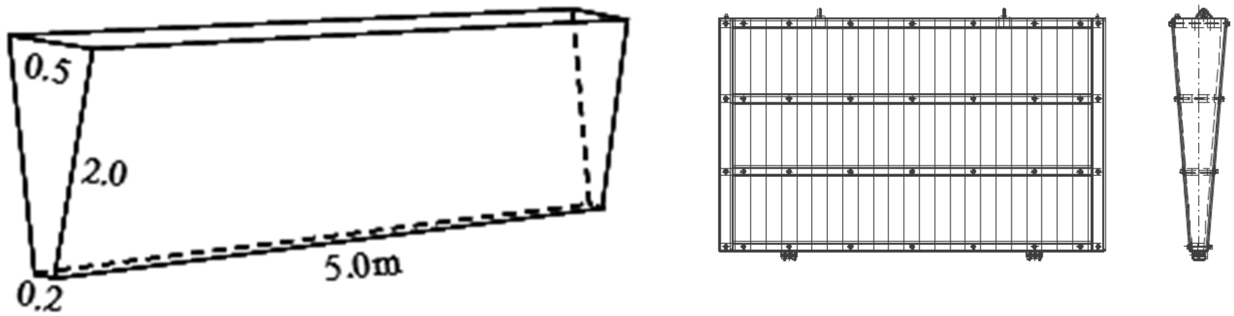

Figure 3. A model of the guidance structure.

The purpose of the wall is to guide the migrating smolts toward the spill gate B instead of having them to pass the turbine intakes and the turbines. The position of the structure is angled in a way that makes it possible to use the flow of the River in order to redirect the fish towards the spill gates.

Figure 4. Picture showing the guidance structure that stretches from the north shoreline to the mid-section of the dam, thus guiding fish away from the power station (Photo: Linda Vikström).

Water flow and temperature

Water temperature and flow have the biggest impact on the smolt migratory activity (Jonsson and Jonsson, 2011). During the period of study, 25th of May till the 15th of July, the flow in Piteälven ranged between c. 600 m^3/s in the beginning of June to c. 290 m^3/s at the end of June (data from Skellefteå Kraft AB)(Figure 5). In the beginning of June the flow passing spill gate B dropped from c. 43 m^3/s to c. 28 m^3/s. This was due to adjustments made for the additional release where different flows were tested in connection to passage through the power station. In May, the flow thru Spill gate C had an average of c. 114 m^3/s and spill gate D had an average of c. 85 m^3/s compared to June when gate C had an average of c. 70 m^3/s and gate D c. 147 m^3/s. The amount of water released thru the spill gates depends on the spring flood and is controlled by Skellefteå Kraft AB.

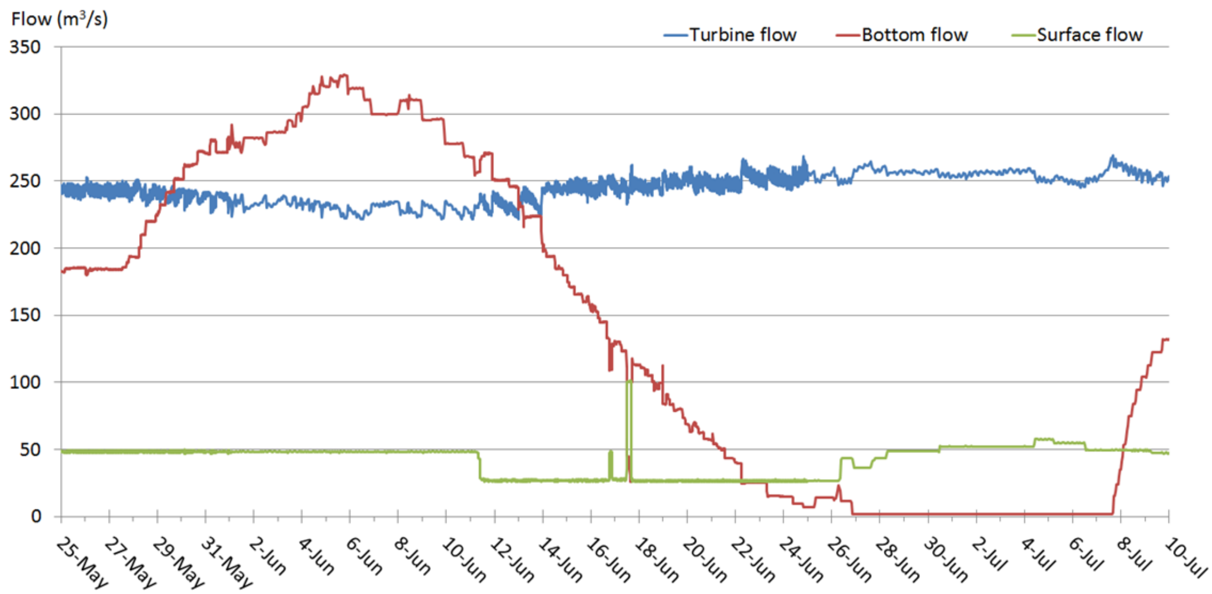

Figure 5. Graph displays the total flow (m^3/s), thru the different passage options (turbines, bottom spill gates and the surface spill gates) in the power station in Sikfors, Piteälven during the period of study.

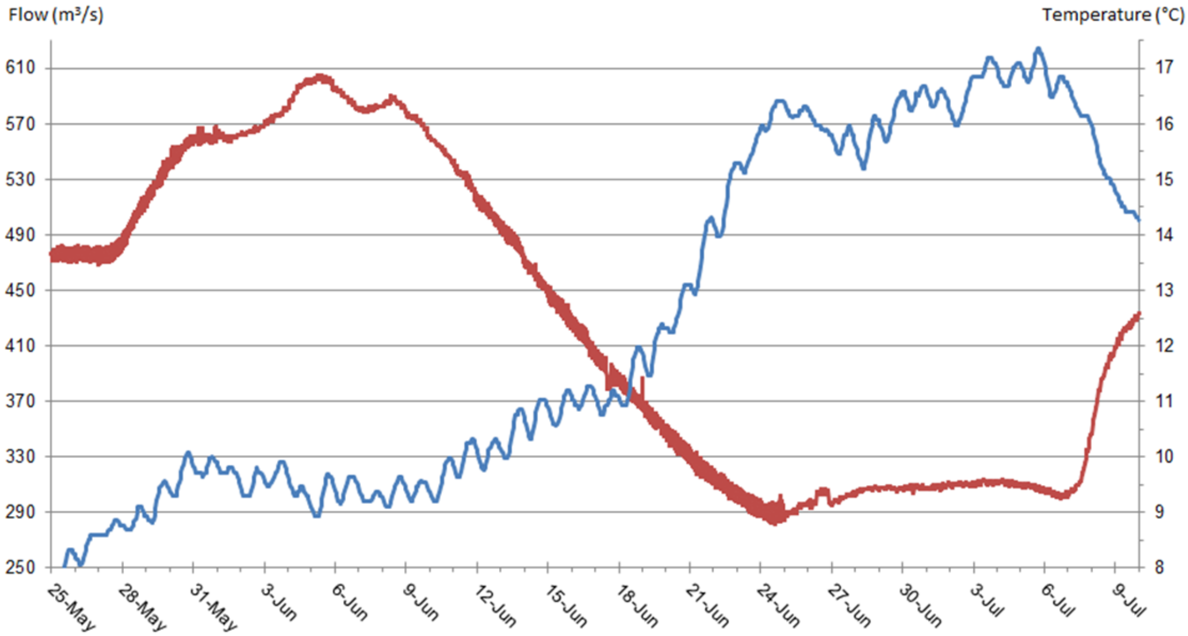

Figure 6. Graph displays the total flow in m^3/s (red line) and temperature in °C (blue line) during the period of study in Sikfors, Piteälven.

The peaks in flow are coinciding with the spring snow melting up in the mountains and occur at the same time as the smolt start their migration downstream (Calles et al., 2013b). The water temperature during the study varied from 7. 9 °C in May and increased to 16. 2 °C at the end of the study (Figure 6).

During high water flows, spill water from the gateways hit the entrance area of the downstream located fish ladder with high speed and power(Figure 7).

Figure 7. Picture showing the area below spill gate B were the water released from the spill gates hit the opening of the fish ladder (Photo: Linda Vikström).

Smolt Radio-Tagging and release

Before the study took place, a permit of planting 500 individuals of hatchery reared salmon smolt was approved by the county board in Norrbotten. In addition an ethical permit for the marking of fish was approved. When dealing with living organisms such as fish, there are many things that have to be considered. Jepsen *et al.* (2014) pointed out the importance to gently handle, tag and transport fish so they are not wounded during the process. The personnel working on the project were well experienced and had all been educated in the marking procedure.

A total of 117 Atlantic salmon smolts were surgically radio tagged during six occasions in 2015. We used 2-year old hatchery smolts from the Luleälven. The individuals chosen had a desired length and were in good condition. The tagged smolts were then released in Grenforsen (2, 6 km upstream the dam) during the time of the year when the wild salmon smolt generally migrate downstream which cover the period from the end of May until the end of June (Rivinoja, 2005b, Rivinoja *et al.*, 2005). 3 out of the 120 marked individuals were released in the salmon ladder as a test. In addition, a group of 58 individuals (29 living and 29 dead) were used to estimate the migration route for living versus dead individuals during different flow regimes when passing either the turbines or the spill gates. The dead fish was dropped in connection to the spill gate B or the turbine intake and then the movement was traced and recorded with the help of both stationary and manually receivers.

The transmitters used were of the model ATS-1525 (Figure 8) with an individual weight of 0.7 g and a lifetime of c. 2-3 weeks (Appendix 2). Each transmitter was transmitting on 151 MHz and therefore 78 of them overlapped and had to be separated from each other by c. 10 kHz. The recommendation for transmitters inserted into Atlantic salmon smolt (weight of 35-45 g) is 8 % of their own body weight (Lacroix *et al.*, 2004). The radio tagged smolt marked during the study had a length between 167 - 257 mm (average size 201 mm and median 202 mm). The length of the smolts did not vary considerably within the test groups nor between the two periods of releases (Table 1). During a survey in Sikfors 2004, 55 individuals of salmon smolt was used in order to calculate a length-weight correlation (Unpublished). According to this, smoltsizes comparable with our mean value represent a weight range between 70 - 80 g and are therefore within the recommendation of usage when it comes to transmitters of 0.7 g.

Figure 8. One of the ATS-1525 transmitters.

Table 1. The average length and the standard deviation for smolt used during the original and the additional release with dead and alive individuals.

Place and status	Period	Number (N)	Average length	± SD (mm)
Grenforsen 1	26-28 May	60 (58+2)*	197,8	12,3
Grenforsen 2	13-15 June	60 (59+1)*	204,5	14,6
Spill gate B 25 m3/s - Alive	16 June	7	199,6	13,0
Spill gate B 25 m3/s - Dead	16 June	7	207,6	6,1
Spill gate B 50 m3/s - Alive	16 June	8	204,5	12,7
Spill gate B 50 m3/s - Dead	16 June	8	200,8	19,9
Spill gate B 100 m3/s - Alive	17 June	7	227,1	13,0
Spill gate B 100 m3/s - Dead	17 June	7	208,1	29,3
Turbine - Alive	17 June	7	213,3	22,3
Turbine - Dead	17 June	7	226,0	19,4

The fish was held in two separate net constructions connected to the fish ladder with fresh water flowing through on a daily basis. Before inserting the tags, the fish were caught with a hoop-net and then put in a separate container with anesthesia solution (MS 222). MS 222 have been shown not to affect the swimming performance for hatchery reared salmon smolt (Peake *et al.*, 1997). After being anaesthetized, the transmitter was surgically implanted into the fish as described by Okland *et al.* (2004) and (Stich *et al.*, 2014). A small cut of roughly 10 mm was made in the belly of the fish together with a whole 2-4 cm from the incision, making it possible to stick the antenna out. The placement of the transmitter inside of the smolt can be seen in Figure 9. The whole handling procedure was c. 1-2 minutes per individual and the cut was closed using one suture (Figure 10). They were then put in a container with fresh water from the fish ladder in order for the fish to recover. Marking of fish was done the night before release so the health of the fish could be examined 24 hours after marking. No individual died during the marking procedure or during the time of recovery.

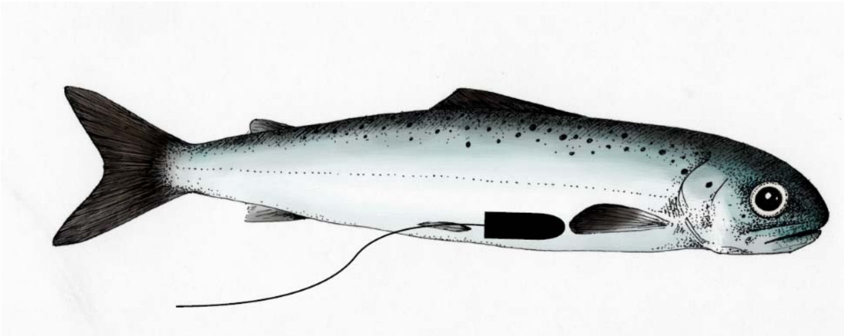

Figure 9. Picture showing the placement of the transmitter surgically implanted into the smolt (Illustration: Johanna Hägglund).

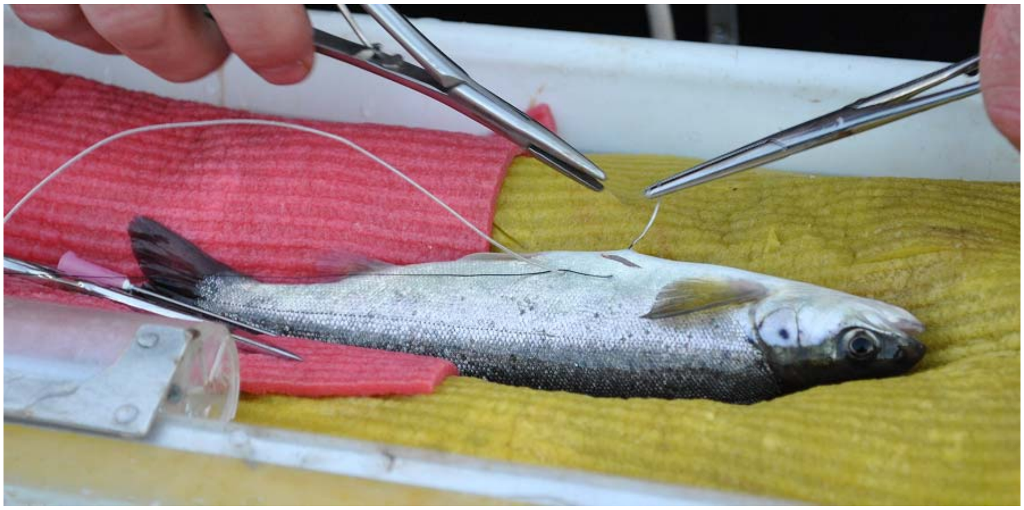

Figure 10. Picture showing the surgically incision done in order to place the transmitter into the sedated smolt (Photo: Linda Vikström).

Three releases were carried out between the 26th of May to the 15th of June and 20 marked individuals were released each time together with 50-100 untagged “follow fish”. The location of the release site was a slower flowing part of the river located c. 2. 6 km upstream the power station. The releases were performed during late evenings, around 20:00-22:00 pm.

An additional release with marked individuals was carried out with a test group (n=58) in order to evaluate the movement of dead and alive individuals together with flow regime impact on survival (Table 1). They were released in pairs with one dead individual together with one alive, either in the turbine intake or just above the spill gates. This was done during three different flow values (25 m^3/s, 50 m^3/s and 100 m^3/s) in order to test the impact of flow regime on the survival. The route that dead individuals traveled downstream (0-2100 m) was then compared with the route of alive individuals.

Telemetry tracking

A range test was carried out before the release of tagged fish and the receivers was configured before installed with a scan time of 2 seconds and the gain set to 80-85 in order to get a higher chance of receiving the signal from the passing transmitters. This was done for all receivers except LL1 were the gain was set to 95 in order to be able to scan a larger area. The receivers were controlled and emptied every day to allow a longer scanning time and thus be able to capture more frequencies.

To track the smolt movements, a total of nine loggers were used, five in close connection to the power station and the additional four in different strategically located places downstream. The models used were four LOTEK SRX_800 loggers and three ATS 2100 loggers. These loggers were connected to Yagi antennas (both 9 and 4 elements). The telemetry logger LL1 was placed close to the riverbank downstream the guidance structure and upstream the power station (c. -550 m), LL2 was placed by the Spill gate B (c. -200 m), LL3 close to the turbine intake (c. -10 m), LL4 close to the Spill outlet (c. 200 m), LL5 close to the turbine outlet (c. 750 m), LA6 next to the Camping site of Sikfors (called “Bastun”) (c. 1000m), LA7 at Stenvall (c. 2100 m), LA8 at Tora Ceder (c. 8300 m), LA9 in close connection to the sea (called “E4”) (c. 30000 m), (Table 2 and Figure 11-13). In addition to the stationary receivers, a mobile receiver of the model ATS was used together with a handheld Televilt RX-8910 to get more exact positions for some of the individuals.

Table 2. The information for the nine automatic telemetry loggers that were used during the survey in Sikfors 2015. Coordinate system used: SWEREF99 ™.

Name	Area	Placement (m)	Coordinates (X, Y)	Logger	Antenna
LL1	Guidance structure	-550	7282374, 786742	SRX_800	9
LL2	Spill gate B	-200	7282218, 786651	SRX_800	4
LL3	Turbine intake	- 10	7282190, 786746	SRX_800	4
LL4	Spill outlet	200	7282159, 786642	SRX_800	4
LL5	Turbine outlet	750	7281470, 786582	SRX_800	4
LA6	Bastun	1000	7281304, 786369	ATS_4500	9
LA7	Stenvall	2100	7280956, 785532	ATS_4500	4
LA8	Tora	8300	7275694, 787449	ATS_4500	9
LA9	E4	30000	7258632, 798415	ATS_4500	9

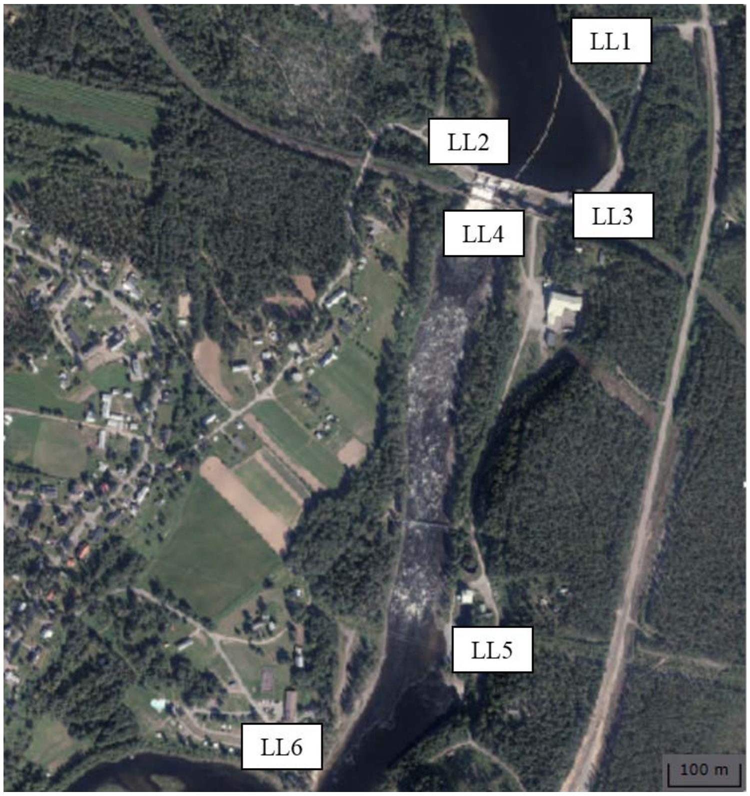

Figure 11. The placement of logger LL1-LL5 which were in close connection to the power station in Sikfors. © Lantmäteriet, i2014/764

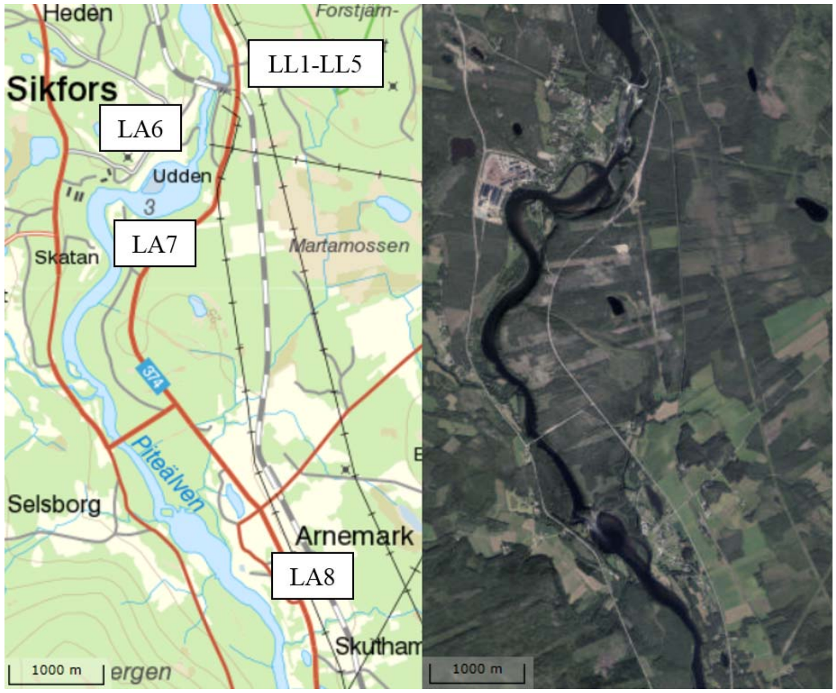

Figure 12. The placement of logger LL1-LL5 and LA6-LA8, used during the smolt radio-tagging study in Sikfors. © Lantmäteriet, i2014/764

Figure 13. The placement of logger LA9, the last logger positioned close to the sea. © Lantmäteriet, i2014/764

Data processing and analysis

The data from stationary and manual receivers (giving the smolt position and time) together with the obtained total flow (m^3/s) through the different passages in the power station (logged each 15 minutes) was processed and joined using Excel (2013). A list with criteria for evaluating signals was developed based upon guidelines from previous studies together with knowledge from experienced personal (Appendix 1). Environmental disturbances so called “Noise” was classified as signals with exceptional high or low values of BPM (bits per minute) and signal strength, this together with unknown frequencies study were excluded from the analysis. The migration success of the marked smolt was evaluated by looking at the received signals in each logger. The results of the additional release (release of the 58 individuals) was studied and used in order to detect the movement of dead individuals and this was then compared with the individuals of the original release.

Data from the survey conducted by LTU in 2015 (Lundstrom *et al.,* 2015) together with the survey in 2003 (Rivinoja, 2005a) were compared with the contained data and a chi-square test was performed using Minitab (Minitab 17). To test if the length had an influence on the behavior and survival of smolt, a binary logistic regression analysis was performed using Minitab, with survival and passageway set as response variables.

Results

87 out of 117 (74, 4%) made their way to the power station with various migration speed between individuals. A faster migration was seen during the second release when the temperature had increased from c. 7, 9 °C to c. 9 °C. Of the individuals that reached the power station, 74 in total (85 %) passed thru the Spill gate and the remaining 13 (15 %) passed thru the turbine intake (Table 3). A total of 117 Atlantic smolt were released at the release area in Grenforsen 2, 6 km upstream the power station. The tagged smolts released above showed differences in behavior when 20 individuals remained above the dam throughout the study and never initiated their downstream migration. By using manually receivers, some of these fish could be found positioned in a slow flowing area not far from the place of release. The fate of additional 10 individuals stayed unknown throughout the whole study period.

The smolt survival for Spill gate passage was c. 80 % compared to smolts passing through the turbine intake that had a survival of c. 69 % (Table 3). There were no significant effect on survival depending on passage route through the Spill gate or the turbine intake (p=0,363, Binary logistic regression, df=84).

Table 3. The migration success for the smolt releases upstream the power station in Sikfors.

Way	Spill gate B	Turbine	Remain	Unknown	Sum
Alive	59 (79, 7%)	9 (69, 2%)			
Dead	14 (18, 9%)	4 (30, 8%)			
Unknown	1 (1, 4%)				
Number	74	13	20	10	117

The data for the migration success (Table 3) was tested together with the survey conducted during 2003 (no guidance structure) when 36 out of 40 smolts (both salmon and trout) went by the turbines. The results from the chi-square test showed a significant difference in efficiency of the guidance structure between our results when it was present compared to 2003 when it was absent (Pearson Chi-Square = 97,332; DF = 1; P-Value = 0,000 Likelihood Ratio Chi-Square = 109,598; DF = 1; P-Value = 0,000). The data (Table 3) was also tested together with data from LTU´s modelling of passively moving particles in 2015 when the structure was present. The results from the second chi-square test showed no significance (Pearson Chi-Square = 0,833; DF = 1; P-Value = 0,362 Likelihood Ratio Chi-Square = 0,837; DF = 1; P-Value = 0,360).

The binary logistic regression analysis on the effect of smolt length on fate and/or way showed that smolt length had no effect (p=0, 53, df=84) on their way downstream, either by the turbine passage or the spill passage and also no effect on the fate after passing (p=0, 102, df=84). One individual that was registered as passing the spill gate had insufficient data regarding survival after passing and was therefore excluded from further analysis. A total of 18 deaths were registered when passing the power station with 9 deaths at both periods of releases (May and June). In May we observed five smolt mortalities for fish passing the spill gate while four smolts died when passing the turbines compared to the June release when nine individuals died after spill gate passage. In June, the total spill gates flow was 207 m^3/s (27 m^3/s overflow spill at gate B) and 244 m^3/s through the turbines resulting in a total flow of c. 452 m^3/s. In May, the total flow thru the spill gates was 243 m^3/s (48 m^3/s spill gate B) and 243 m^3/s passing through the turbines, the total flow was c. 487 m^3/s.

The results from the additional release showed both a direct and indirect mortality for smolt passing the power station in Sikfors (Table 4). Smolt that died in connection to passage (direct mortality) were undetected at the tunnel outlet for more than one hour. If suffered indirect mortality, they showed an abnormal long migration time or stayed stationary in the calmer water area in Arnemark, ca 6 km downstream the power station. Looking at the difference in flow regime during the additional release, the highest survival of passing smolts seemed to occur when the flow was less than < 100 m3/s.

Table 4. The mortality for smolt passing thru different passage routes during different flows in Sikfors, Piteälven.

Way	Number	Direct mortality	Indirect mortality	Total mortality
Spillgate B (25 m3/s)	7	2 (29%)	1 (14%)	3 (43%)
Spillgate B (50 m3/s)	8	2 (25%)	1 (13%)	3 (38%)
Spillgate B (100 m3/s)	7	5 (63%)	1 (14%)	6 (86%)
Turbine	7	3 (43%)	1 (14%)	4 (43%)
Ladder	3	1 (33%)		1 (33%)
Total	32	13 (41%)	4 (13%)	17 (53%)

Of the 117 tagged smolt originally released at Grenforsen, 68 individuals survived the passage through the power station. Of these 68 smolt, 37 (54, 4%) successfully completed the migration out to the sea.

Discussion

My study showed a significant effect of the guidance structure installed in Sikfors on helping the smolts to find the spill-gate opening and thus further strengthen the results from the LTU study in 2015 (Lundstrom *et al.,* 2015). It is a clear improvement compared to the results from 2003 when the structure was absent and the majority of smolt instead passed through the turbines (Rivinoja, 2005a). The guidance structure in Sikfors is similar to the guidance structure currently installed in Norrfors, Umeälven. Lundqvist *et al.* (2014) concluded that the efficiency of the guidance structure in Norrfors has varied between 0 and 100% during the season but that the total efficiency is c. 4-5 %. The efficiency of the guidance structure at 85 % installed in Sikfors could thus be considered to be more functional than the same type of structure installed in Umeälven. Calles *et al.* (2013a) pointed out that the structure in Norrfors power station only cover a part of the broad intake compared to the device installed in Sikfors which cover almost the whole area of the intake. Norrfors is a large scale hydropower station with c. four times higher flow than the flow in Piteälven. A combination of these two factors could explain the higher success in the guidance structure in Piteälven. Lundstrom *et al.* (2015) stressed that the guidance efficiency for smolts in Sikfors could be improved even further by prolonging the structure at the northern shoreline in order to stop individuals from entering the turbine intake area.

As mentioned earlier, turbine passage often results in higher mortality rates for smolts while spill gates are considered to provide them with a safer route. This was rather obvious in our study when we observed a higher survival for fish entering the spill gate passage with c. 80 % compared to passage through the turbines that had a survival of c. 69 %. By successfully direct smolts towards a safer way through the spill gates, the survival can be increased. The turbine induced mortality in Sikfors is relatively high compared to other areas (17 %) and could be explained by the long underground tunnel that empties out 0, 6 km downstream (Rivinoja *et al.,* 2005). The results of this study revealed an even higher turbine induced smolt mortality of 31 %. In a previous study carried out in Sikfors a size-dependent relationship of losses at passage was seen (Rivinoja *et al.,* 2005). No size-dependent mortality by passage could be proven during this study which could be explained by the small sample of 13 individuals that passed by the turbines, and their small variation in size, making it impossible to show if size of fish had an effect on their rate of survival after passing the turbines. Other factors such as behavior of fish just before entering should be taken into account and can play a big role in the mortality rate caused by the turbines (Vowles *et al.,* 2014, Coutant and Whitney, 2000).

The mortality at spill gate passage was surprisingly high with 20 %. Larinier (2008) discussed the need for fish to travel safely over the spill gates with a deep landing pool on the downstream side of the power station together with no over-aggressive baffles. In Sikfors, the water from the spill gates hit the opening of the ladder with high speed and power when higher flows are released (se also Figure 7). Another reason for higher mortalities for fish passing over the spill gate in high-flow water is that the water may be supersaturated with air that can cause stress and indirect mortalities (Schilt, 2007). One hypothesis is that the situation in Sikfors is not meeting the requirements of a safe passage over the spill gates which could explain the high mortality for spill gate passage. There is a need for future analyzing the situation below the spillway in order to lower the mortalities for fish passing in this area.

One difficulty was to determine which of the three spill gates that smolts used when passing the dam. One assumption is that weak signals is recorded when they pass through the bottom spill. Calles *et al.* (2013a) stated that the surface orientated spill gates are considered to be more effective due to the fact that smolt usually displays a surface oriented behavior and that they are more likely to avoid bottom spill because of high acceleration and water velocities. The conclusion is hence that the majority of the passing smolt in this study has used the surface oriented spill gate during their exit through the power station. This theory was supported when using manually receivers on the approaching smolt during one of the conducted releases. This is something to be considered in further research and more effort should therefore be on determine the exact way of passage in order to make accurate assumptions and direct management efforts.

The additional release with dead and alive individuals in connection to the passage over the spill gate showed that flows >100 m3/s resulted in a higher mortality rate. The sample sizes of the additional release of fish is too small to make any scientific conclusion. The importance of flow regimes on the survival of smolt in connection to fish ways has been previously been stressed and should therefore be given more attention in future management and research (Williams *et al.,* 2012, Stich *et al.,* 2015a, Enders, 2009). Fjeldstad *et al.* (2012) showed that an increase in total discharge decreased the bypass migration while increased flow directly into the bypass increased the bypass migration. This states the importance of considering not only the fishway itself but also the seasonal flow regime in the bypass (Calles, 2005). The flow released through the power station usually follows the snow melt which is coinciding with the temperature rise in the river. The migration of salmon smolts risk to be affected by flow manipulations, therefore temporal patterns of both temperature and flow are important variables to consider while managing flow-controlled rivers (Sykes *et al.,* 2009). To control the flow regime during the period of the smolt migration could be problematic for Skellefteå Kraft AB when the river mainly comes from the snow melt in the mountain region.

The majority, 87 out of 117 (74 %) smolts managed to arrive to the power station while 30 individuals (26 %) failed in their migration out to the sea. One explanation for the 10 undetected individuals could be due to technical problems such as low battery of the transmitter or antenna dysfunctions. When it comes to the effects of handling and surgically implanting the transmitter, it may have contributed to the failed migration for some of the individuals. The smolts were carefully examined 24 h after they were marked, and thus the direct effect could be evaluated. A clear trend was seen with a faster migration during the second release when the temperature had increased from c. 7, 9 °C to c. 9 °C. Zydlewski *et al.* (2005) showed that the downstream movement of Atlantic salmon smolt can be affected by different temperature regimes. Predation pressure on smolts is shown to increase when their migration is delayed (Karppinen *et al.,* 2014, Stich *et al.,* 2015a). The calm area above the power station is a known habitat for Pike (*Esox lucius*) and one assumptions is hence that the failed migration for some of the smolts could be the result of predation. If the effects of predation is not considered it can lead to misinterpretation of data and thus misleading estimates on the smolt survival (Gibson *et al.,* 2015). Thorstad *et al.* (2012) pointed out the need to evaluate the differences of hatchery-reared and wild salmon in order to gain a higher understanding on how they risk of being affected in different ways. The wild salmon smolt are presumably more adapted to the natural environment and therefore more likely to succeed in their migration. Further management of salmon should therefore consider the possibility of including both wild and reared smolt in this type of studies in order to gain more knowledge about their differences and also to get more reliable results.

A problem connected with using ATS-systems is the great amounts of noise being recorded and thus the data requires an evaluation in order to sort out the valuable signals. The area around Sikfors has a relatively low amount of radio interference but the last logger placed next to the sea showed some amount of noise, mostly due to the close placement to the bridge where heavy traffic pass daily. It's important to be aware of the effect the surrounding environment may have on the loggers so that reliable data can be extracted. Areas with heavy traffic should therefore as far as possible be avoided as locations for loggers. The data from this logger were carefully examined and the individuals that had registrations were assumed to have made a successful migration out to the sea. These results may provide a full scale picture of the problem regarding the Atlantic salmon smolt run in Piteälven. Stich *et al.* (2015b) evaluated the effect of hydropower on the speed of smolt migrating downstream, showing a high increase in speed after dam removal and thus making the way out to the sea considerably safer for smolt. With 37 out of 68 individuals that made a safe passage through the station, the survival of the individuals that completed the migration was 54, 4 %. This can give a picture of the problems a fish can face when passing a hydropower complex and help in understanding the full-scale effect on migrating populations.

The results of this thesis state the importance of fish guiding structures when it comes to the migration success for salmon smolt and also the need for these to be functional in order to reduce passage losses in connection to hydro power. Even though measurements have been taken to implement safer ways, they still need proper evaluation and continuous improvements in order to stay functional. The efficiency of the guidance structure in Sikfors could be improved further by prolonging the side on the northern shoreline as previous studies has stated. Also, this thesis stresses the importance of considering the possible impact of flow regime. During the additional release the highest survival of passing smolt seems to occur when the flow were less than < 100 m3/s. Different variables like flow regime in connection to fish ways, have to be reviewed further in order to determine the combined effects of factors cooperating in the influence on the survival. The ability to provide smolt with a safe passage thru power stations includes conditions both before and after passage. Therefore the situation in connection to the area downstream the spill gate should be further evaluated in order to analyze why smolts die in relatively high number after passage. If continued research is done in the areas pointed out above, the Atlantic salmon in the northern part of Sweden may have a brighter future to come.

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Appendix 1

Criteria used during data evaluation and the motive behind them:

- If an individual had no registration in connection to the power station but further downstream, the individual were then assumed to have made the passage through the spill gates.

The individual may have succeeded the passing but somehow the loggers in connection to the power station did not record the signal. This could happen if the fish passed together with more individuals in high speed and thus the logger did not have enough time to record one or more of the individuals. There is also a possibility that the signal got lost in high flows or deeper water areas. Previous studies in Sikfors have concluded that when smolt make a fast passage while showing a normal migration behavior and with just a few registrations upstream, they usually take the route through the spill gates. For individuals that instead pass the turbines, they often show a so called "milling behavior" were they hesitate to dive into the turbine intake and instead circle around the opening for an amount of time, making the passing slower in contrast to passage through the spill gates. All of the individuals that were recorded downstream not long after passage were therefore assumed to have made the passage through the spill gates.

- Signals that display an "unnatural behavior" are excluded from the analysis.

Signals that show an unnatural migration pattern can't be trusted as being accurate signals and should therefore be excluded from the analysis. To know what to classify as accurate signals and natural migration behavior, range tests were carried out before the releases, giving a picture of the movement of fish passing the power station and also what signal strength that could be expected.

- The data was filtered by BPM (bits per minute), with a normal registration of around 40-50.

Previous studies with similar techniques have used the criteria of (>90) as signal strength. For areas with more disturbances, the BPM may be a more accurate value to consider due to the fact that more signals recorded give a higher chance of being a trustful registration. In this study we choose to use BPM ranging between 40-50 based upon previous studies and knowledge. Signals that showed a much higher BPM than this were excluded from the analysis.

- The last and most accurate recorded signal is the one used to estimate passage route.

If the second last signal is more accurate than the last recorded signal then the second signal is used. This is due to the fact that there can be a back loop signal from the antenna that records a misleading signal after passage.

- If a fish had successfully passed the logger LA8, they were assumed to have made a safe journey through the power station.

Based upon the releases with dead and alive individuals, a clear trend was seen for dead smolt in contrast to living. The distance between the power station and the logger LA8 is approximately 8300 m which is a long way to travel just by floating. Even if the current downstream in some areas can reach high velocities, it is still not enough to transport a dead smolt this distance during the period of study.

- For individuals that had either an abnormal long migration time or stayed stationary in the calmer water area in Arnemark, ca 6 km downstream the power station were ascribed as (victim of direct or indirect mortality) dead from passing or victim of predation.

Individuals that showed this behavior don’t match the normal migration behavior of Atlantic salmon. Based on previous studies done in Piteälven using manually receivers to track individuals in order to determine their fate, this kind of behavior have often been seen with smolt being victim of predation.

- Direct mortality by passing was noted when an individual remained undetected at the tunnel outlet for more than one hour and indirect mortality was noted when smolt stayed stationary for several days.

This criteria is based upon a previous study in Sikfors, Piteälven (Rivinoja *et al.,* 2005).

- Individuals that have no registration at the last logger are assumed alive if they were not located by manually receivers.

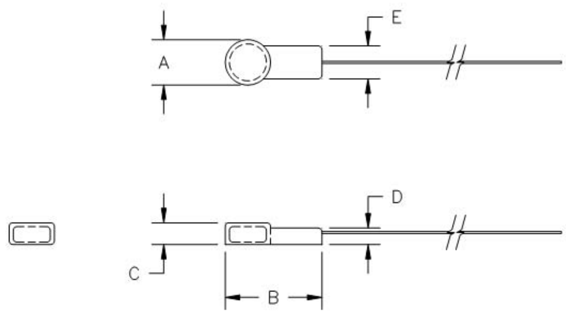
A manually receiver was used downstream to track missing individuals and to see if anyone was left behind.

Appendix 2

ATS
ADVANCED TELEMETRY SYSTEMS

FISH BODY IMPLANT

Series F1505



Technical Specifications

Transmitter type:	Crystal controlled 2-stage
Calibration tolerance:	± 2.5kHz
Frequency stability:	± 2.5kHz, -20°C to 40°C
Pulse rate and width:	Typical on time 15ms, off time 1.5-4.0sec (controlled by astable circuit)
Pulse rate variation:	5%/volt, ± 20% for temperatures -20°C to +40°C
Battery:	Silver Oxide
Activation:	By removing magnet
Encapsulation:	Electrical resin, water-proof, specific gravity: 1.12

MODEL	BATTERY	BATTERY CAPACITY (days)				DIMENSIONS (mm)					WEIGHT (grams)	PRICE GROUP
	1.5V	15 ppm	24 ppm	30 ppm	40 ppm	A	B	C	D	E		
A2412	410	22	15	12	9	5	12	1.5	2.5	4	0.20	F
A2414	337	45	30	24	18	5	12	3	2.5	4	0.30	C
F1515	337	45	30	24	18	5	13	3	4	5	0.50	A
F1525	317	68	45	36	28	6	14	3	4	5	0.65	A
F1535	319	90	60	48	37	6	14	4	4	5	0.75	A
F1545	377	135	89	72	55	7	15	4	4	5	0.90	A
F1555	392	216	143	116	88	8	16	5	4	5	1.20	A

Above models available only in 48.00-50.66MHz, 144.06-151.98MHz, and 164.00-167.99MHz ranges.

Warranty life is 50% of battery capacity.

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1/6/09

SENASTE UTGIVNA NUMMER

2015:15 The effect of migratory fish on freshwater ecosystem nutrient dynamics
Författare: Magnus Enbom

2015:16 Restoration of natural disturbances: impact on distribution and performance of dominant ants (*Formica spp.*) by fire and gap dynamics
Författare: Rebecca Larsson

2015:17 Life History Trade-offs in Anadromous Burbot Lota Lota (*Linnaeus 1758*) from Rickleån and Sävarån, Northern Sweden
Författare: Mikael Sandberg

2015:18 Laxens uppströmsvandring i den restaurerade och flödesreglerande Umeälvens nedre del
Författare: Joakim Johansson

2016:1 Moose (*Alces alces*) browsing patterns in recently planted clear-cut areas in relation to predation risk of the gray wolf (*Canis lupus*) in Sweden
Författare: Suzanne van Beeck Calkoen

2016:2 Ecological requirements of the three-toed woodpecker (*Picoides tridactylus L.)* in boreal forests of northern Sweden
Författare: Michelle Balasso

2016:3 Species Composition and Age Ratio of Rock Ptarmigan (*Lagopus muta*) and Willow Grouse (*Lagopus lagopus*) Shot or Snared in The County of Västerbotten: Possible Implementations For Grouse Winter Management
Författare: Alisa Brandt

2016:4 Prevalence of Puumala virus (PUUV) in bank voles (*Myodes glareolus*) after a major boreal forest fire
Författare: Seyed Alireza Nematollahi Mahani

2016:5 Dispersal of young-of-the-year brown trout (*Salmo trutta* L.) from spawning beds - Effects of parental contribution, body length and habitat
Författare: Susanna Andersson

2016:6 Intra and interhabitat migration in junvenile brown trout and Atlantic salmon in restored tributaries of the Vindelriver
Författare: Matti Erikoinen

2016:7 Skogsarbete i björnområde – en pilotstudie om arbetsmiljöfrågor
Författare: Moa Walldén

2016:8 Älgavskjutning och slaktviktsutveckling Malingsbo-Klotenområdet
Författare: Sofie Kruse

2016:9 Immediate effects on the beetle community after intensive fertilization in young Norway spruce *(Picea abies)* stands
Författare: Martin Johansson