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Monitoring of salmon spawning run in the River Tornionjoki

A Finnish-Swedish collaborative research report

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CONTENTS

Abstract

Atlantic salmon spawning run into the River Tornionjoki/Torneälven was monitored by Dual-frequency Identification Sonar (DIDSON) in 2010 and 2011. Two DIDSON units were deployed through the migration season at Kattilakoski about 100 km upstream from the sea. The plan was to enumerate all upstream migrants that passed the site by monitoring the whole river transect.

At the Kattilakoski site monitoring supposedly covered the period from the end of May until the late August. Acoustic data were collected for 98% and 84% of the available sample time on the Swedish and the Finnish shore, respectively. The near-bottom area at the 15-20 meters wide deepest mid-cannel was in constant shadow with those two sounders but was temporary covered with the third DIDSON unit. The results of the double counted data set proved that three counters were able to see almost the same number of fish but there were differences in the length measurements of fish.

Counts at Kattilakoski were expanded across the unsampled periods, and according to the results of third DIDSON it was concluded that no salmon passed the monitoring site through the mid-channel shadow area. Records and catch samples from angling, and fish ladder data from the nearby River Kalixälven were used to infer the species composition and the separation between grilse (1SW) and multi-sea-winter (MSW) salmon in the counts. It was concluded that length measurements from the DIDSON data underestimated the true length of the observed fish. After 5 cm correction of length measurements and species identification it was concluded that 17 221 salmon and 643 fish of other species (mainly sea trout) passed the site. Salmon counts were further divided between grilse (1182 ind.) and MSW salmon (16 039 ind.). The median date of salmon migration (grilse and MSW salmon combined) was on 1st July. The preliminary calculations taking into account salmon that ascended the river but did not pass the Kattilakoski site (either being caught or spawned below the site) indicated that totally about xx 000 – xx 000 salmon ascended the river in 2010.

1. Introduction

In salmon research and management, collecting accurate information on the number of salmon spawners entering and the subsequent number of smolts leaving reproduction area has been among the top priorities. This data is specifically called stock-recruit (S/R) data and it is the starting point of a modern fisheries management (Hilborn and Walters 2003). ICES (e.g., 2008, 2009) has repeatedly suggested establishment of so-called salmon index rivers in the Baltic Sea, in which S/R data would be collected. The IBSFC Salmon Action Plan (SAP) nominated several salmon rivers around the Baltic Sea as index rivers, and the River Tornionjoki/Torneälven was one of them. Also the recently revised EU Data Collection Regulation (DCR, Council Regulation 199/2008 and the following Commission Decision 2008/949/EC) calls for collection of S/R data from the Baltic salmon index rivers.

Annual monitoring of number of smolts started in the Tornionjoki/Torneälven in the 1990s. However, monitoring of number of spawners has not been successfully established in the river in spite of some attempts (e.g., Anon. 1999, Romakkaniemi et al. 2000). In the 2000s, Sweden and Finland have been negotiating about fisheries management in the Tornionjoki/Torneälven and its estuary area as a part of the revision of the border river agreement. Within the negotiation process the need for monitoring annual salmon spawning runs into the river was again recognized and underpinned. In addition to counting of migrating spawners, also monitoring of the timing of the spawning run was regarded as an important objective.

The Finnish Ministry of Agriculture and Forestry allocated 300,000 € in 2009 for the investments necessary to establish the monitoring system in the river. The monitoring activities were also included in the Finnish national plan of DCR program. Moreover, the Swedish Board of Fisheries (SBF) funded a project with 20,000 € in 2009 in order to support the monitoring program. Furthermore, Swedish researchers applied for and received 25,000 € for 2009-10 from Gränsälvskommissionen, which is organizing much of the cooperation between Finland and Sweden concerning the river. The actual task to establish a monitoring was shouldered by the Finnish Game and Fisheries Research Institute (FGFRI), with some assistance from the Swedish Board of Fisheries.

Recent technological development has facilitated collection of S/R data even in circumstances where more traditional methods like capturing and counting fish are impossible. Dual-frequency Identification Sonar (DIDSON) has been available on the market for some years and it has proven to be a suitable equipment to observe and count migrating fish (Holmes et al. 2005, Cronkite et al. 2006). DIDSON uses sound to produce video images of underwater areas (Sound Metrics Corporation 2010). FGFRI rented one DIDSON unit in the summer 2007 for a trial run in the River Simojoki. Due to the promising results FGFRI purchased one DIDSON in 2008 and started to monitor Simojoki salmon runs by this technique. Three more DIDSON units were purchased in the early 2009 using the above mentioned investment fund and this equipment have been used to start to monitoring the salmon run into the Tornionjoki/Torneälven (Lilja et al. 2010).

For convenience, from now on the River Tornionjoki/Torneälven is written using only its Finnish name.

2. DIDSON site in Kattilakoski

In 2008, sites suitable for DIDSON monitoring were sought on the lower part (0 – 100 km from sea) of the river. At first, potential river sections were chosen from a map and on-site inspections were done at several places, basically all narrow passages were examined. Three sites were chosen for field testing and these tests were carried out during the summer 2008 at both high and low water levels. The suitability of potential sites for DIDSON sounders was estimated using the criteria given by Enzenhofer and Cronkite (2000). The best potential area was found in Kattilakoski, where the DIDSON monitoring project was started in 2009 (Lilja et al. 2010). Kattilakoski is situated about 100 km from the river mouth (Fig. 1) and the DIDSON site is in the upper part of Kattilakoski rapids (Fig. 2).

At the Kattilakoski site, the river width fluctuates between 150 – 175 m. The maximum depth on the DIDSON site is 4 – 5 m depending on the water level (Fig. 2). Two sets of DIDSON systems were used, one for each river bank, and the third DIDSON unit was temporary used The west bank of the river belongs to Sweden and the DIDSON sonar was located beside a restaurant building, which was also used for housing the top-site equipment of the system (computer, power supplies, etc). On the east bank (Finnish shore), a steel field box was used for housing the top-site equipment. On both sides, the mains electric current was used to charge batteries, whisch were used to power up the systems. However, back-up devices were also used to prevent systems from voltage peaks and to ensure data collection during short blackouts.

Figure 1. A map of River Tornionjoki (Torneälven) and DIDSON site on Kattilakoski. The green colour illustrates the distribution of Atlantic salmon in the river system. The stippled line shows the border between Finland and Sweden.

Figure 2. An aerial view from Kattilakoski DIDSON site and contour lines (25 cm intervals) illustrates the bottom shape at the counting area. Long and bold contour lines represent shorelines, when the water level was low. MML/VIR/ILMA/021/09. Copying without permission prohibited.

3. Data collection procedures and data processing

3.1. Didson setup

Two sets of DIDSON systems were used, one for each river shore. Steel stands were used to deploy the sounders offshore and in the river, just downstream from sounders, short fish deflection weirs were installed to prevent fish from swimming at too close range from DIDSON sounders (Fig. 3). At the beginning of the season, the sounder stands were placed on each bank in a position close to shore but they were moved further out as the water level dropped. Throughout the season, changing water levels resulted in frequent relocation of sounder stands. Horizontal and vertical aiming of each sounder was remotely controlled by a dual-axis electronic pan and tilt system. In an ideal situation, the upper part of the sonar beam edges followed the water surface and the bottom was reached for whole field of view (window length). DIDSON sounders were placed to maximize the counting range of the main migration route and to occasionally cover the entire cross section of the river between the Finnish and the Swedish bank.

Figure 3. A steel stand for DIDSON and a fish deflection weir in Kattilakoski, Finnish shore.

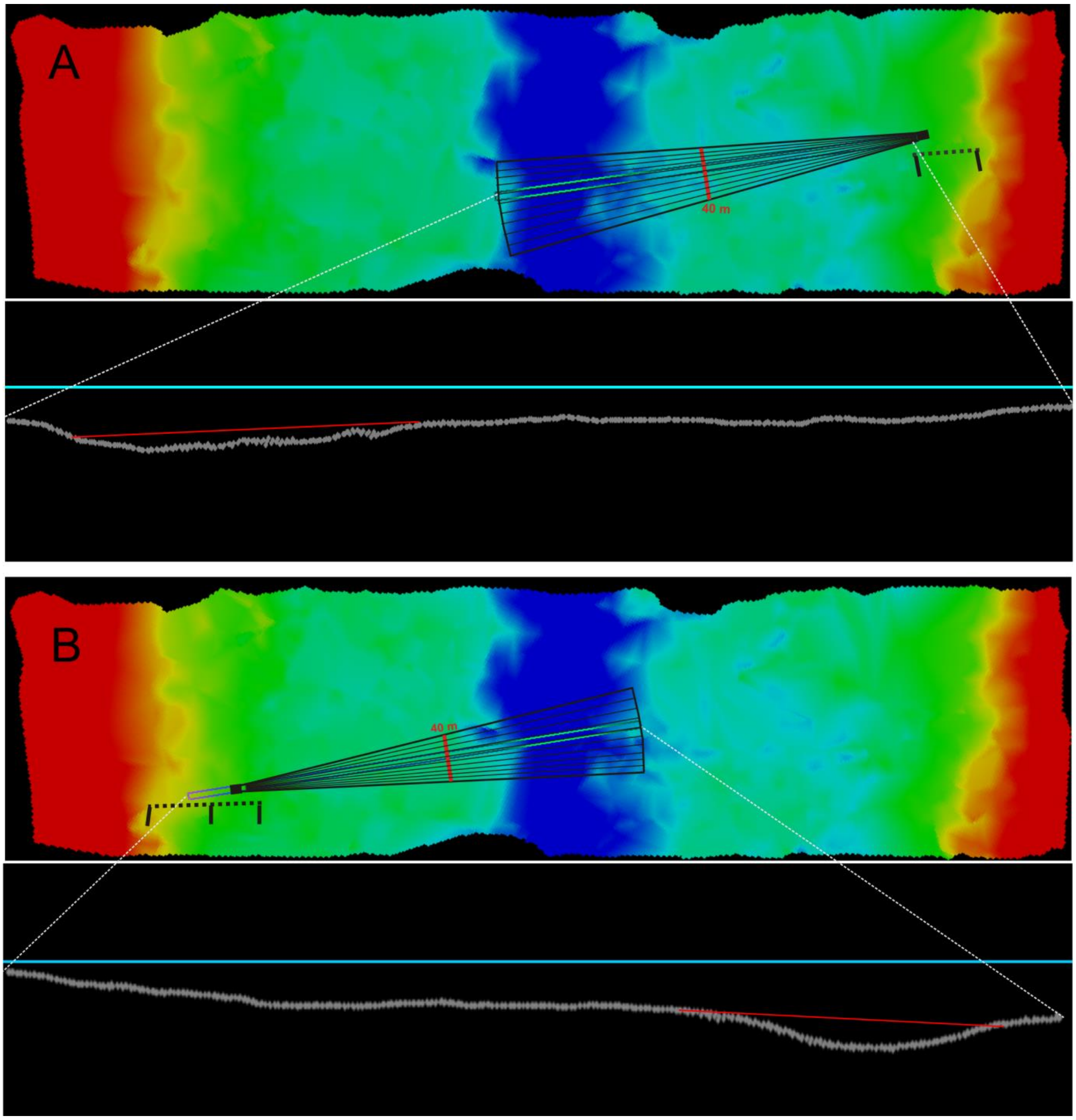

Figure 4. Bottom maps and river banks (red area) of Kattilakoski site. DIDSON sounders next to Finnish (A) and Swedish (B) shore with echo beams. The red lines across the echo beams indicate the 40-meter distance from the transducers, which was the shorter window length often used in the data collection (see chapter 3.4). Cross-sectional views of the covered area (below contour maps). The area between red lines and the bottom lines (grey) represents the uncovered area, where DIDSON beams were not able to reach the bottom.

A 15-20 meter wide mid-channel area at Kattilakoski could not be fully covered by two permanently used DIDSON units, as the near-bottom area was in constant shadow (Fig. 4). During the monitoring of 2009, it was assumed that no salmon passed the monitoring site through this shadow area. This assumption was tested by third DIDSON unit, which was temporary installed on the anchored boat (three point anchoring), about 45 m distance from the DIDSON of Swedish shore (Fig. 5). The place for the third DIDSON was sought from Swedish site of the river because the current was slower and the bottom was better for anchoring than in Finnish site. All equipment including data collection computer and gasoline generator were pleased on the boat. It was plan to collect data with a large scale of water level in order to get good conception of fish migration through the deep mid-channel area.

Figure 5. The third DIDSON unit was installed on the anchored boat (three point anchoring) about 45 m distance from the DIDSON of Swedish shore.

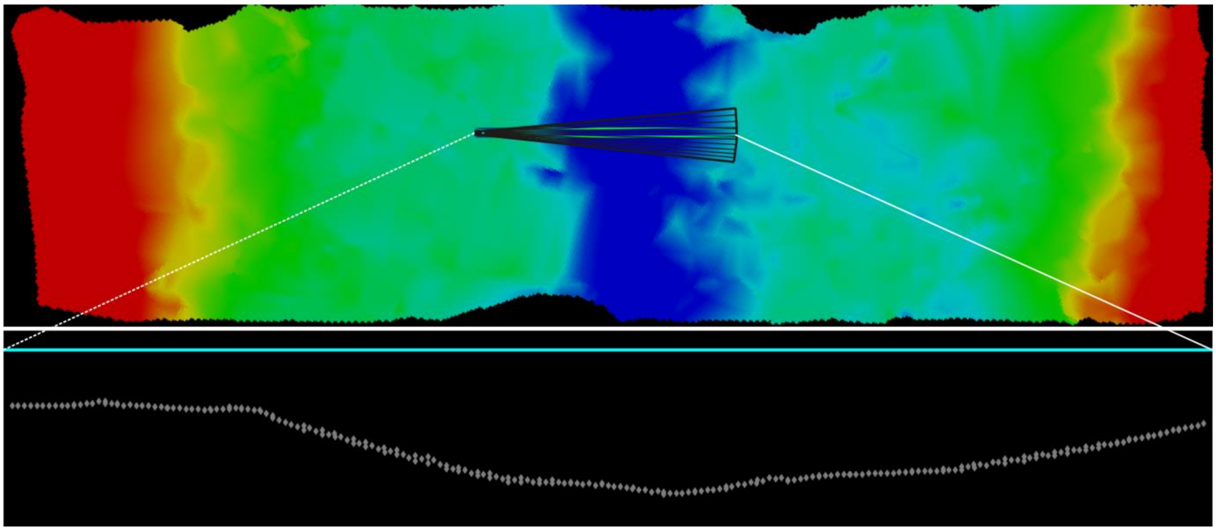

Figure 6. Acoustic beams of the third DIDSON covered the deep mid-channel of the river.

3.2. Data collection

Acoustic data were collected from the 24th May until late August in 2010 (Table 1 & 2). Thus, the total available sample time was 99 days (2362 hours). Data collection was first started on the Swedish side and two days later on the Finnish side. At the beginning of the season, a 40 m window length was used on both shores because all fish seemed to travel upstream near shores due to high flow of the river. However, the data collection with 80 m window length was used in the beginning and occasionally also later, but most of the time the 40 m window length was used in order to get high quality images of fish in the main migration range.

Short interruptions on data collection were caused by the relocations and maintains of DIDSON units during the season. In addition, owing to charging problems with batteries, there were few interruptions on data collection during nights. Data collection was stopped on Finnish site two weeks earlier than on Swedish site.

Table 1. Data collection and sampling design on the Finnish shore in 2010. A period when data is not available is highlighted in gray, short interruptions on data collection were not marked. (WL = used window length).

Start		Stop			
Date	Time	Date	Time	Duration (h)	Sample time (min/h) / WL (m)
26.5.2010	15:00	31.5.2010	22:00	125	60 min / 40 m
31.5.2010	22:00	1.6.2010	10:00	12	No data
1.6.2010	10:00	5.6.2010	9:00	95	60 min / 40 m
5.6.2010	9:00	7.6.2010	12:00	51	No data
7.6.2010	12:00	11.6.2010	4:00	88	60 min / 40 m
11.6.2010	4:00	11.6.2010	15:00	11	No data
11.6.2010	15:00	13.6.2010	12:00	45	60 min / 40 m
13.6.2010	12:00	18.6.2010	3:00	112	50 min / 40 m & 10 min / 80 m
18.6.2010	3:00	18.6.2010	11:00	8	No data
18.6.2010	11:00	24.6.2010	3:00	136	50 min / 40 m & 10 min / 80 m
24.6.2010	3:00	24.6.2010	9:00	6	No data
24.6.2010	9:00	27.6.2010	2:00	65	60 min / 40 m
27.6.2010	2:00	27.6.2010	15:00	13	No data
27.6.2010	15:00	1.7.2010	6:00	87	50 min / 40 m & 10 min / 80 m
1.7.2010	6:00	1.7.2010	15:00	9	No data
1.7.2010	15:00	22.7.2010	10:00	499	50 min / 40 m & 10 min / 80 m
22.7.2010	10:00	23.7.2010	10:00	24	No data
23.7.2010	10:00	27.7.2010	12:00	98	60 min / 40 m
27.7.2010	12:00	28.7.2010	9:00	21	No data
28.7.2010	9:00	31.7.2010	17:00	80	60 min / 40 m
31.7.2010	17:00	2.8.2010	10:00	41	No data
2.8.2010	10:00	14.8.2010	7:00	285	60 min / 40 m
14.8.2010	7:00	15.8.2010	18:00	35	No data
15.8.2010	18:00	20.8.2010	9:00	112	60 min / 40 m
20.8.2010	9:00	30.8.2010	9:00	240	No data

Table 2. Data collection and sampling design on the Swedish shore in 2010. A period when data is not available is highlighted in gray, short interruptions on data collection were not marked. (WL = used window length).

Start		Stop			
Date	Time	Date	Time	Duration (h)	Sample time (min/h) / WL (m)
24.5.10	16:00	28.5.10	21:00	101	60 min / 40 m
28.5.10	21:00	29.5.10	15:00	18	No data
29.5.10	15:00	30.5.10	4:00	13	60 min / 40 m
30.5.10	4:00	30.5.10	21:00	17	No data
30.5.10	21:00	7.6.10	13:00	184	60 min / 40 m
7.6.10	13:00	13.6.10	13:00	144	50 min / 40 m & 10 min / 80 m
13.6.10	13:00	18.6.10	2:00	109	40 min / 40 m & 20 min / 80 m
18.6.10	2:00	18.6.10	11:00	9	No data
18.6.10	11:00	23.6.10	10:00	119	40 min / 40 m & 20 min / 80 m
23.6.10	10:00	24.6.10	1:00	16	50 min / 40 m & 10 min / 80 m
24.6.10	1:00	24.6.10	10:00	9	No data
24.6.10	10:00	26.6.10	22:00	60	50 min / 40 m & 10 min / 80 m
26.6.10	22:00	27.6.10	12:00	14	No data
27.6.10	12:00	30.6.10	15:00	75	50 min / 40 m & 10 min / 80 m
30.6.10	15:00	22.7.10	11:00	524	40 min / 40 m & 20 min / 80 m
22.7.10	11:00	23.7.10	11:00	24	No data
23.7.10	11:00	27.7.10	12:00	97	50 min / 40 m & 10 min / 80 m
27.7.10	12:00	28.7.10	9:00	21	No data
28.7.10	9:00	30.8.10	9:00	793	50 min / 40 m & 10 min / 80 m

Table 3. Data collection and sampling design on the Finnish shore in 2011. A period when data is not available is highlighted in gray, short interruptions on data collection were not marked. (WL = used window length).

Start		Stop			
Date	Time	Date	Time	Duration (h)	Sample time (min/h) / WL (m)
18.5.2011	17:00	11.6.2011	19:00	578	60 min / 40 m
11.6.2011	19:00	12.6.2011	11:00	16	No data
12.6.2011	11:00	20.6.2011	11:00	192	60 min / 40 m
20.6.2011	11:00	25.6.2011	12:00	121	50 min / 40 m & 10 min / 80 m
25.6.2011	12:00	27.6.2011	19:00	55	No data
27.6.2011	19:00	30.6.2011	9:00	62	60 min / 40 m
30.6.2011	9:00	14.7.2011	4:00	331	50 min / 40 m & 10 min / 80 m
14.7.2011	4:00	15.7.2011	13:00	33	No data
15.7.2011	13:00	17.7.2011	20:00	55	50 min / 40 m & 10 min / 80 m
17.7.2011	20:00	18.7.2011	12:00	16	No data
18.7.2011	12:00	22.7.2011	4:00	88	50 min / 40 m & 10 min / 80 m
22.7.2011	4:00	22.7.2011	9:00	5	No data
22.7.2011	9:00	25.8.2011	5:00	812	50 min / 40 m & 10 min / 80 m
25.8.2011	5:00	25.8.2011	10:00	5	No data
25.8.2011	10:00	30.8.2011	11:00	121	50 min / 40 m & 10 min / 80 m

Table 4. Data collection and sampling design on the Swedish shore in 2011. A period when data is not available is highlighted in gray, short interruptions on data collection were not marked. (WL = used window length).

Start		Stop			
Date	Time	Date	Time	Duration (h)	Sample time (min/h) / WL (m)
19.5.11	13:00	27.5.11	19:00	198	60 min / 40 m
27.5.11	19:00	28.5.11	16:00	21	No data
28.5.11	16:00	6.6.11	10:00	210	60 min / 40 m
6.6.11	10:00	11.6.11	19:00	129	50 min / 40 m & 10 min / 80 m
11.6.11	19:00	12.6.11	12:00	17	No data
12.6.11	12:00	26.6.11	0:00	324	50 min / 40 m & 10 min / 80 m
26.6.11	0:00	28.6.11	10:00	58	No data
28.6.11	10:00	30.6.11	11:00	49	60 min / 40 m
30.6.11	11:00	17.7.11	12:00	409	40 min / 40 m & 20 min / 80 m
17.7.11	12:00	28.8.11	2:00	998	50 min / 40 m & 10 min / 80 m
28.6.11	2:00	30.8.11	11:00	57	No data

3.3. Data post-processing

The DIDSON sounders were programmed to create new files (time and date stamped) beginning at the top of the hour. All data were recorded and post-processing of fish counts was made using Version 5.25 of the DIDSON operating system software (Sound Metrics Corporation 2010). DIDSON data was saved to external hard drives, creating two identical copies that were adequate for archiving and storage purposes.

The display images used for upstream and downstream counts were processed with two corrections. First, the transmission loss of sound was used to increase the detectability of fish over the range. This correction equalizes the intensity of the images of the long-range and short-range fish. Without transmission loss correction, fish at short-ranges from the transducer appear much brighter than fish at longer ranges. The application of transmission loss to the data files initially decreases the perceived brightness of the images but this can be adjusted by the observer using the intensity control slide bar in the playback software. Second, the background subtraction was used to remove the static portion of the acoustic image, showing only moving objects such as fish. This feature of DIDSON software really increased the detectability of fish. The following procedure was used to compile fish count and length measurements from DIDSON files:

- Files were played back with the transmission loss and the background subtraction. The play back frame rate depended on the original data collection frame rate but was usually 10 times faster than the original frame rate.
- Once a fish was detected the file was paused (freeze-frame) and a box was drawn around the image to allow magnification of the image.
- Frames which contained the fish image were stepped through one at a time until the clearest image was attained.
- The Mark Fish option was enabled to provide a cursor with which the fish length could be measured, its range marked and then entered to a fish count file.
- Play back was continued and the next fish was sought.

Once the DIDSON-files were analyzed, two data sets were constructed; 1) all measured fish were collected into the same file (RAW-fish file), and 2) daily passages for fish larger than 67.5 cm as well as fish in length class 45 – 67.5 cm were summed up. The species identification in the DIDSON data can mainly be based on two factors: the time of fish detection and the estimation of size of fish. By this information we filter out other species and conclude that the remaining fish are salmon.

Providing timely and accurate spawning run estimates to fishery managers was an overall objective of this project. Therefore, one of the goals throughout the season was to provide daily in-season counts and estimates of the total spawning run. Data screening and fish measuring were labour intensive due to huge amounts of data.

3.4. Length distributions

The length distribution of upstream migrants at Kattilakoski in 2010 fits again poorly with the length distribution of caught salmon (chapters 4.2. & 5.1.1.), although the available information indicates that the large majority of the detected fish were salmon. A closer examination of the length distribution indicates that the length measurements of the detected fish are probably underestimates of the true lengths. In the length histograms of DIDSON data there is the deepest and the most persisting hollow in the length category 60 (57.5 - 62.5) cm, while in the length histograms of catch data the only hollow is in the category 65 (62.5 - 67.5) cm. This coincides with the threshold length (67.5 cm) between grilse and multi-sea-winter salmon. Moreover, during the periods when either there were presumably only sea trout and multi-sea-winter salmon present (early and mid-June) or when the grilse run was peaking (mid-July), DIDSON data indicate about 5 cm shorter dominant length for sea trout and grilse than what is the dominant length in the catch data. At the largest size categories in the DIDSON data (MSW salmon) the dominant length varies a lot by period and by distance from the transducer, which makes comparison of these subsets of DIDSON and catch data difficult.

Based on the information above it seems likely that in the lower end of the range of measured lengths the true lengths of the detected fish were about 5 cm longer than the measured lengths. There is a strong possibility that similar error occurs also at the largest length categories. In the agreed protocol of length measurements, weak echo signals were excluded from the tail end of the fish images because these pixels resemble the abundant background noise in the data. As an afterthought, this practice may have lead to exclusion of the tail from the measurement. Consequently, we increased 5 cm to all the measured lengths and used this revised data as the basis of all calculations of salmon abundance.

The length distribution of sea trout greatly overlaps with salmon (mainly grilse). However, sea trout migrate upstream before July, i.e. before grilse migration starts at Kattilakoski. In addition, there were high proportion of large sea trout (<72.5 cm) in the river catch data before the middle of June. Consequently, we assume that all fish smaller than 72.5 cm detected before 16th June are sea trout and being smaller size than the minimum size of MSW salmon (<67.5 cm) before 5th July are non-salmon, presumably sea trout.

3.5. Expanding counts across unsampled periods and cross-sectional area

In 2010, acoustic data were collected for 86 % and 95 % of the available sample time on the Finnish and the Swedish shore, respectively. However, there was only 18 hours (<1%) of the available sample time that data have not been collected at all (see Tables 1 & 2). In addition, data from the deep mid-channel were also collected by the third DIDSON unit. The total operation time of the third unit was 167 hours. During that period only one salmon size fish was measured to swim upstream. Consequently, we assumed that insignificant number of salmon passed upstream through the deep mid-channel during 2010. However, we need to continue that experiment also during the next year in order to get data from longer period and also with low water level.

In 2011, (see Tables 3 & 4).

Daily passages for each shore were counted by summing the 24 hourly counts starting from midnight. There were two strategies for expanding counts across the unsampled time periods. First, when the sounder on one shore was not operating, a count was calculated by use of a conversion factor based on the observations on the opposite shore. This conversion factor was calculated from the data sets when sounders on both shores were operated simultaneously. Second, when one or more hours were missing from both sides during a day, the missing counts for a given hour were averaged from previous and next day counts made during the same hour.

By using a 40 m window length, approximately 47 - 67% of the river width was covered by DIDSON beams. However, soundings were occasionally extended to the 80 m range using a 20-min or 10 min sample periods per hour. During that time, the area coverage of both DIDSON sounders was about 100% of the river width, excluding a mid-channel shadow area below the DIDSON beams (see Fig. 4). Expanding counts across unsampled areas at the range 40 – 80 m were calculated by raising the number of detected fish during the short sampling periods in relation to the proportion of the unsampled time.

3.6. Comparison between counters

Comparing DIDSON counts between observers is necessary for estimating observer error and is maintained as part of the standard approach to quality control (precision). In all 32 and 29 hours (files) were counted by three and two counters in 2010 data from Swedish and Finnish site, respectively. Selected data set from the Swedish site was picked up using a random sampling design (Table 5), as well as from Finnish site (Table 6). Both Finnish and Swedish observers counted the data set and the fish numbers were compared as well as the length measurements of fish. In all 180 measured fish were selected for a comparison between three counters from data of Swedish site and 75 fish for a comparison between two counters from data of Finnish site, respectively. All those fish could be identified from the counters data according to the time and range stamp of the measured fish.

Table 5. Triple counted data set in 2010 that consisted of 32 file from the DIDSON of Swedish site.

Hour/Date	4-Jun	11-Jun	16-Jun	26-Jun	28-Jun	4-Jul	6-Jul	11-Jul	13-Jul	3-Aug	4-Aug	8-Aug	9-Aug
0									■				
1				■		■							
2								■					
3													
4							■					■	
5						■							
6		■											
7				■				■					
8					■						■		
9													
10	■												
11							■						
12	■				■						■		
13						■			■			■	
14													
15		■	■										
16										■			
17													■
18				■									
19		■	■										
20	■								■				
21		■								■			
22													
23			■										

Table 6. Double counted data set in 2010 that consisted of 29 file from the DIDSON of Finnish site.

Hour/Date	4-Jun	11-Jun	16-Jun	26-Jun	28-Jun	4-Jul	6-Jul	11-Jul	13-Jul	3-Aug	8-Aug	9-Aug
0									■			
1				■		■						
2								■				
3		■										
4							■					
5						■						
6												
7				■				■				
8					■							
9												
10							■					
11												
12	■				■							
13						■			■		■	
14												
15			■									
16		■								■		
17												■
18				■								
19		■	■									
20	■								■		■	
21		■								■		
22												
23			■									

Table 7. Double counted data set in 2011 that consisted of 54 file from the DIDSON of Swedish site.

Hour/Date	1-Jun	8-Jun	15-Jun	22-Jun	29-Jun	6-Jul	13-Jul	20-Jul	27-Jul
0									
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
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15									
16									
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18									
19									
20									
21									
22									
23									

We assessed the precision of the DIDSON counts and length measurements among counters using the method of an average percent error (*APE*) as was done by Holmes et al. (2006) and is commonly used to assess the precision of the fish ageing process.

$$APE = \frac{1}{N}\sum_{j=1}^{N}\left[\frac{1}{R}\sum_{i=1}^{R}\frac{|X_{ij}-\bar{X}_j|}{\bar{X}_j}\right] \times 100 \quad (1)$$

where X_{ij} is number of fish or fish length that was measured by counter i for file or fish j, respectively, $\bar{X}_j$ is mean of counts or lengths in event j, R is number of counters, and N is number of one hour files or measured fish.

4. Results and discussion

4.1. Escapement estimate and daily counts

After the correction of length measurements and the separation of salmon from other species, the resulting expanded estimates of upstream migration through the Kattilakoski site was 17 221 salmon and 643 fish of other species (mainly sea trout). Salmon counts can be further divided between grilse (1182 ind.) and MSW salmon (16 039 ind.). Figure 7 shows the daily estimates of these fish categories.

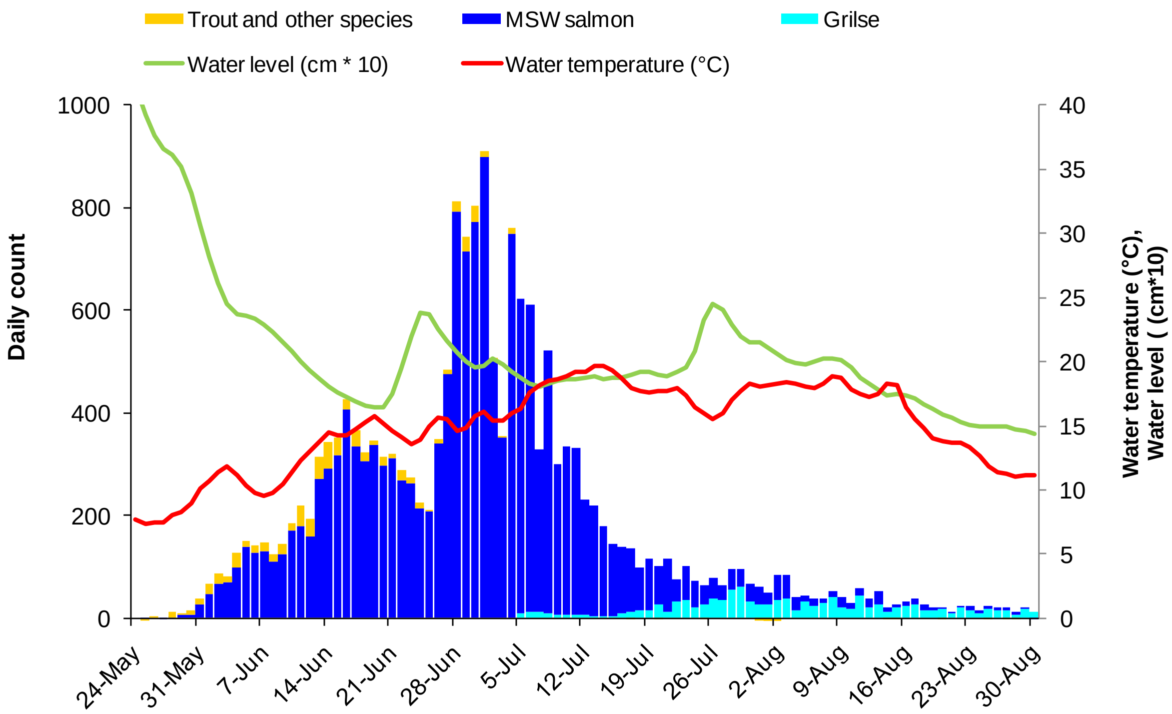

Figure 7. Corrected daily estimates of net-upstream fish in Kattilakoski counting site in 2010. Measured fish length was increased by 5 cm and the threshold length between grilse/trout and MSW salmon is 67.5 cm. Fish shorter than 67.5 cm are regarded as grilse if they migrated after 5th July, but if they migrated before July they are regarded as trout and other species than salmon.

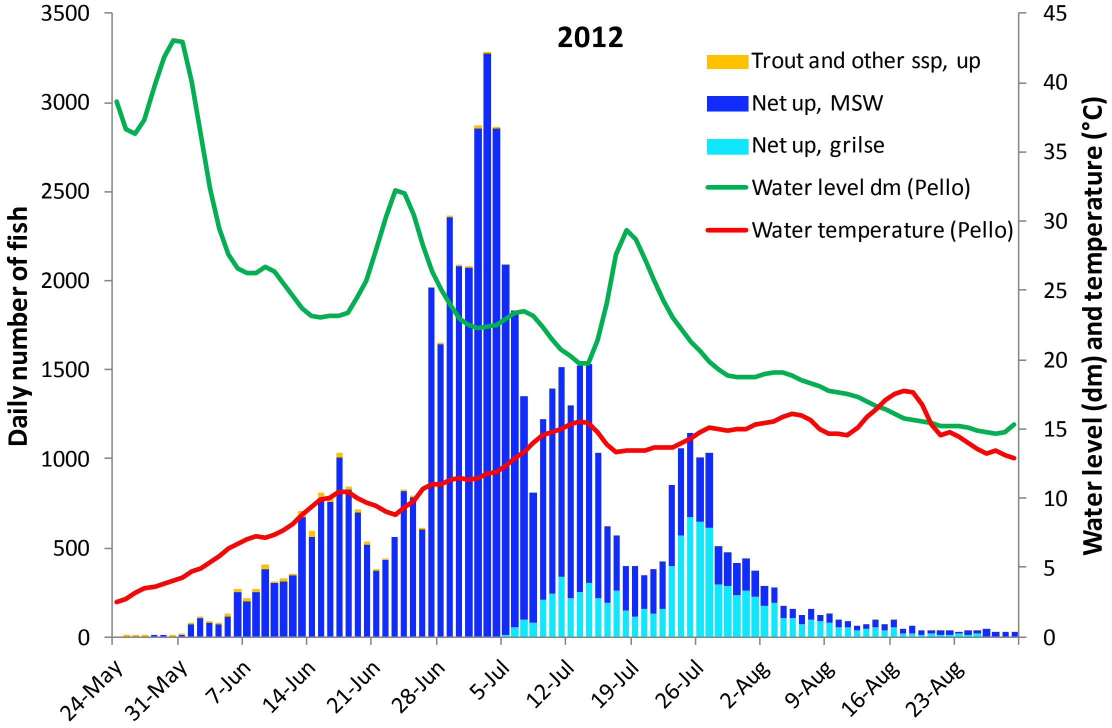

Figure 8.

Figure x displays the daily and cumulative salmon (grilse and MSW) counts for the river in 2010. The upstream migration of salmon began around May 27 and the number of migrants dropped down on the end July, and continued at low level until end of the monitoring period. The daily escapement plot displays multi-modal run timing with a maximum daily net upstream escapement estimate of 899 fish on 1st July, 2010 (Fig. 8). The halfway point in the 2010 salmon run, when 50% of the total estimate had passed the Kattilakoski site, was also detected on 1st July.

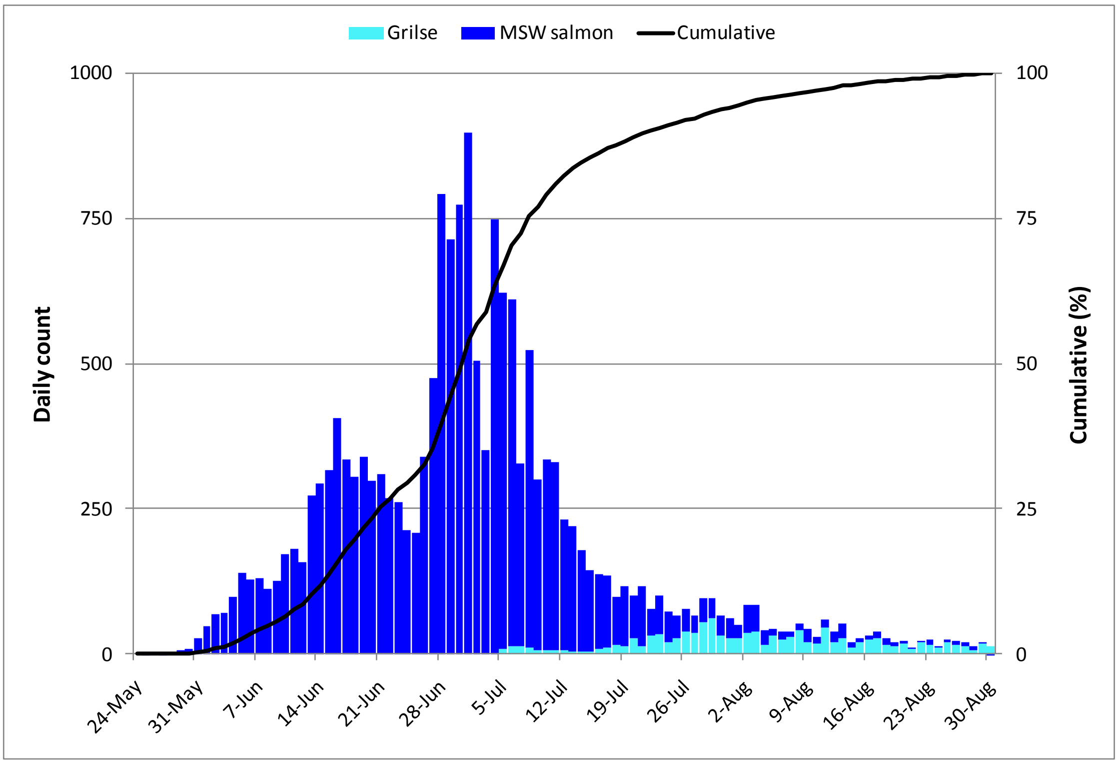

Figure 9. Corrected daily estimates of net-upstream salmon passage in Kattilakoski counting site and the cumulative curve of the spawning run.

The upstream migration of the smaller fish (e.g. trout) started also on the last week of May (Fig. 9). With regard to the other species, their occurrence partly overlaps in length distribution with salmon (mainly grilse), but their overall occurrence in the DIDSON data is probably small. Moreover, these species are likely to occur in the data mainly in late spring - early summer, when their annual migration activity is at the highest level (aggregation of spring-spawning species, change from overwintering to summer feeding habitat). Thus, exclusion of grilse-sized fish from salmon counts from before 5th July (as described chapter 3.3.) is likely to filter out most of the other species as well.

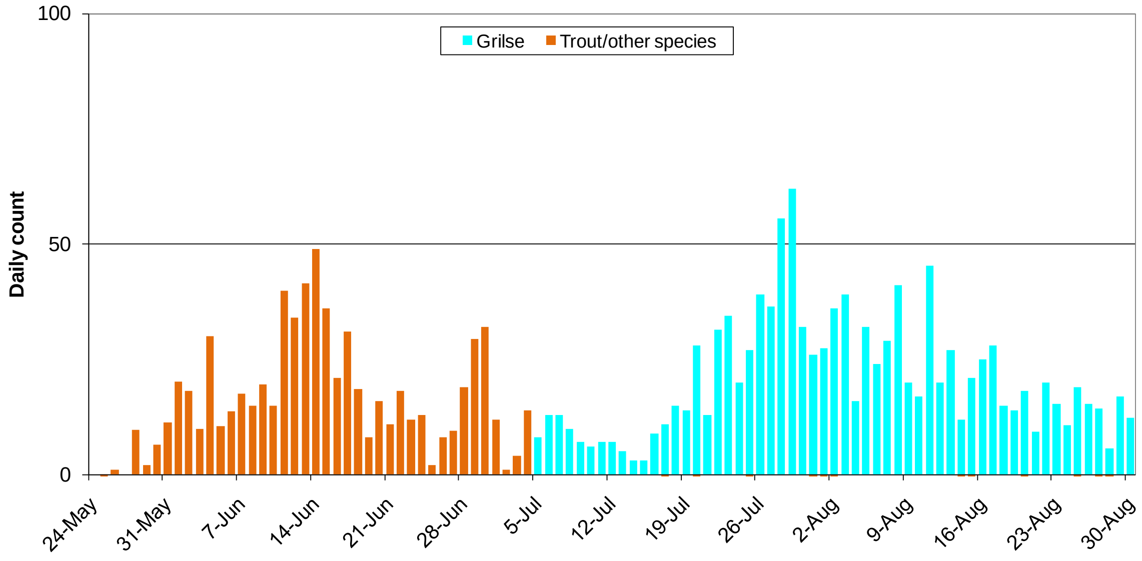

Figure 10. Daily numbers of trout/other species and grilse that passed the Kattilakiski site in 2010.

The potential error sources that were investigated included: 1) uneven capture probabilities inherent in the fish wheel data, 2) fish migrating outside the coverage of the sonar beam, 3) reduced fish detection within the sonar beam, 4) observer counting errors, 5) the sampling design, and 6) truncation of the field season (Maxwell).

DIDSON imaging sonar systems are widely used to enumerate migrating adult salmon populations in Canada and the United States of America. Most projects use manual counting techniques with trained observers counting each fish image in a file or a timed subset of a file. Manual counting has proved accurate and precise but tedious and time consuming for data processing personnel in the field, especially when the numbers of migrating fish are extremely large. We derived an alternate method of determining the numbers of fish in a DIDSON file that uses fish speed, mean range of migration and time in the acoustic beam to derive estimates of salmon flux (fish/second) and therefore the total number of salmon in the data file. We found this alternate method produced results not significantly different from the manual counts produced by experienced observers. The method can be faster to perform than manual counting, especially for files with large numbers of migrating fish. The entire collected file can be used to make the estimate, as temporal sub-setting to reduce effort is not required. Streamlining of the existing software could be done to further speed up the analysis process. Manual counting of some data files is needed to act as a check on the accuracy and precision of the Snapshot method (Cronkite).

Fixed hydroacoustic techniques are often the only way to obtain inseason escapement estimates for migratory fish stocks in rivers that are too wide for weir structures and too occluded for visual observations.

Our DIDSON sampling has also shown that steelhead behavior in the stream is fairly complex. Issues with fish behavior (i.e., milling) made image analysis difficult, especially later in the spawning season as small numbers of spawners were still heading upstream and large numbers of kelts were traveling downstream (Simojoki).

4.2. Length distributions

There was no clear difference between length distributions in data recorded from the Finnish and Swedish shore (Fig. 10). From the length distribution, of the registered salmon in the both shores, grilse and MSW shows a breaking point around 65 cm

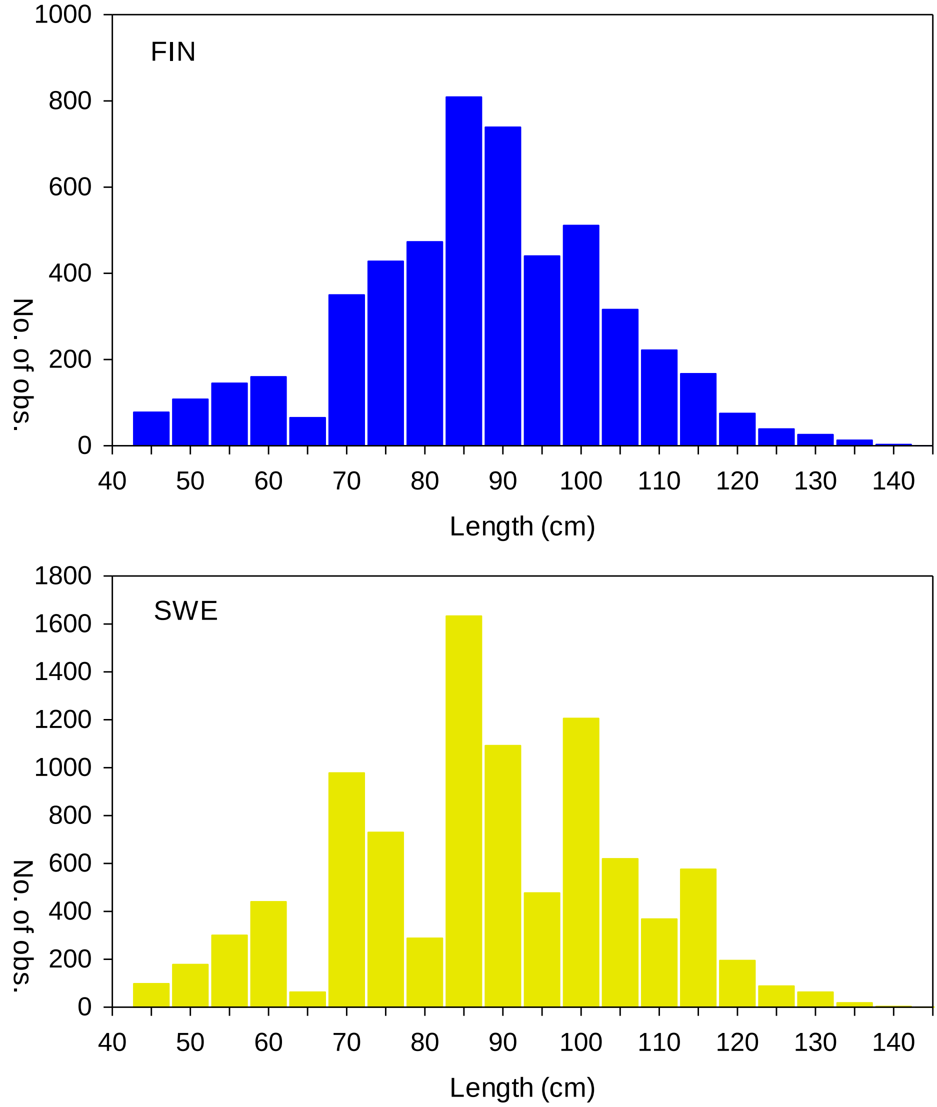

Figure 11.Length distributions of upstream moved fish (length ≥ 42.5 cm) in Finnish (FIN) and Swedish (SWE) shore.

According to Burwen et al (2007), DIDSON measurements of fish size showed good association with a true fish length both in treated and free-swimming fish, however, these measurements were done at a short distance with a standard-DIDSON, which utilizes 96 independent sound beams. They pointed also out that there was a slight positive bias (DIDSON measurements were larger than true fish length) for fish less than 68 cm and a slight negative bias for fish greater than 68 cm, measured with 133 free-swimming fish. Our measurements in Kattilakoski have been done by LR-DIDSON sounders with 48 beams and using relative long distances. Therefore, the image resolution was not as good as in the case of Burwen at al. (2007) even if we have used the High Resolution Large Lenses, which doubles the horizontal resolution of DIDSON. However, there were clear differences between our DIDSON length distribution and the length distribution of caught salmon. According to experience from the monitoring of 2009 (Lilja et al. 2010), we tried put more attention to the length measurements, however, we still lightly underestimated the length of fish.

4.3. Migration time

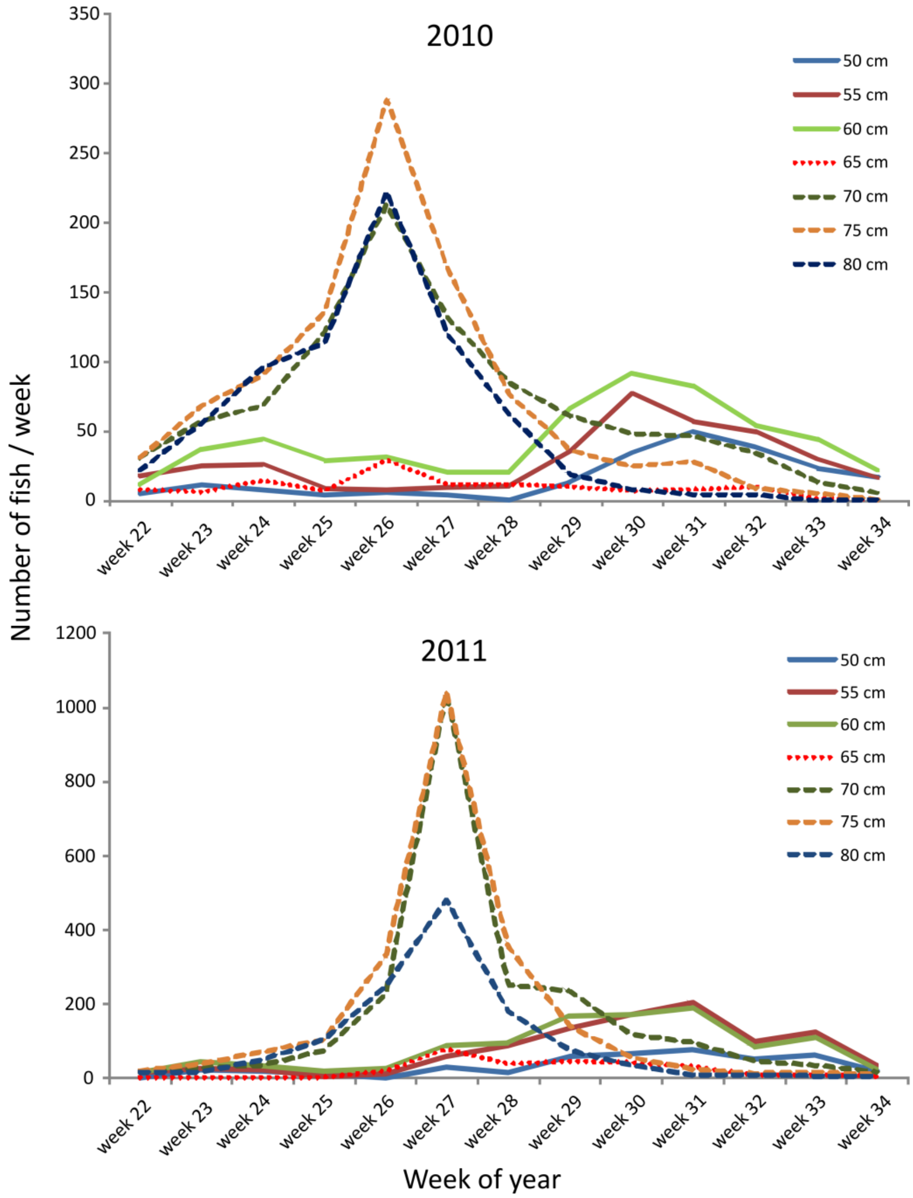

Figure 12. Weekly number of different size of upstream migrants that passed the Kattilakoski site in 2010 - 2012.

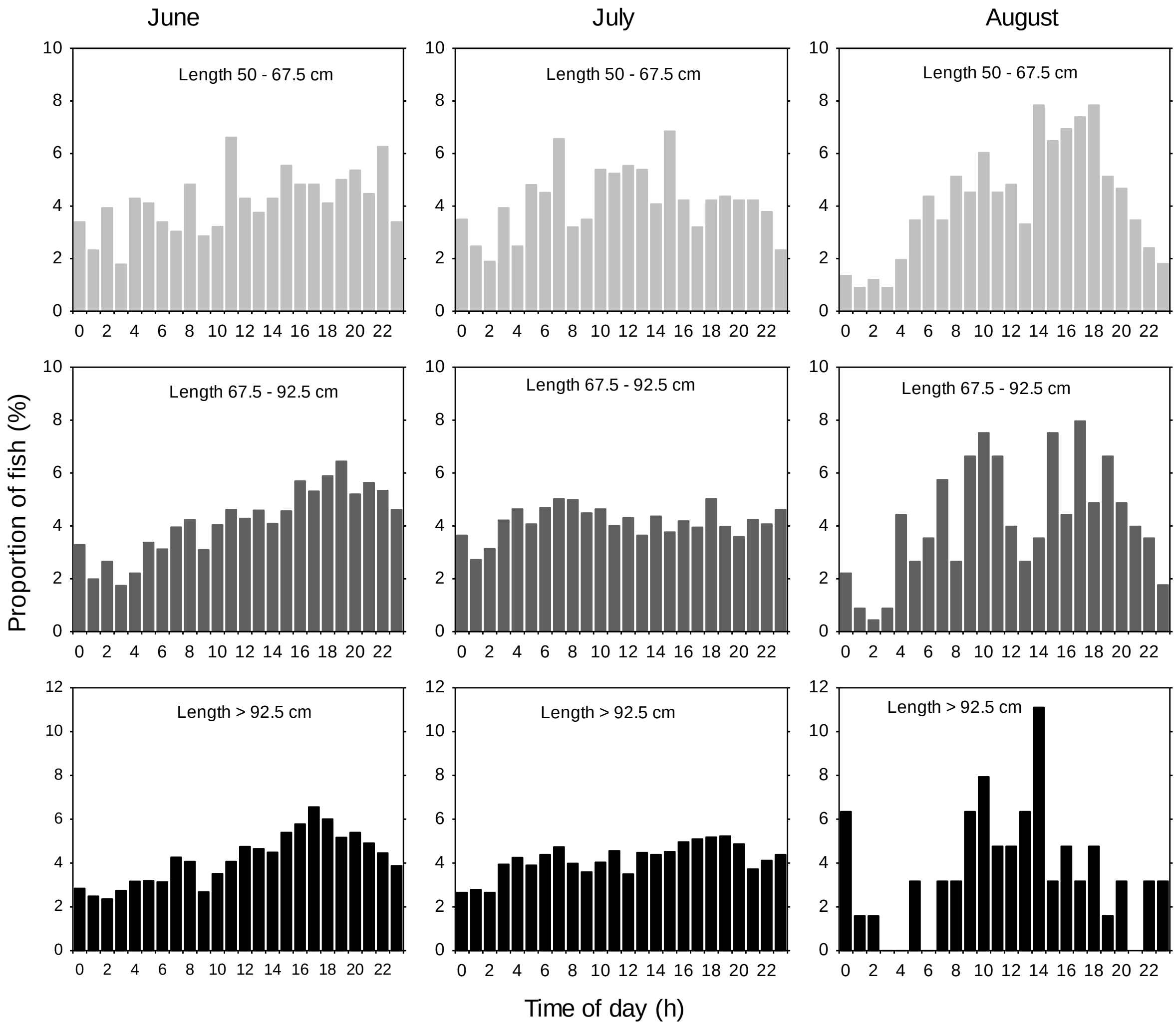

Figure 13.Diurnal distribution of upstream migrating grilse (50 - 67.5 cm), 2 SW salmon (67.5 - 92.5 cm), and 3 SW + older salmon (>92.5 cm) in June, July, and August 2010.

4.4. Spatial distribution of observations across river

Major part of salmon (64 %) was measured with the DIDSON on Swedish shore, where 36 % was observed to migrate upstream via Finnish half of the river. On the Finnish side of the river, the upstream migrations of small salmon (50 – 67.5 cm) were shore-oriented (Fig. 13). Most of detected fish passed the DIDSON less than 20 m distance. Some larger fish were also detected at longer distance. The horizontal distribution of measured fish with the different size-classes of fish shows that the proportion of smaller fish was bigger at a short distance from shore than further afield.

On the Swedish side of the river, most fish were observed to swim upstream at a distance around 20 m (Fig. 13). There were also some minor peaks at a distance of about 14 m, 45 m, and especially for large salmon at 43 m. The water velocity on the Swedish side of the river was not as fast and strong as on the opposite side so the fish were able to spread more widely when travelling upstream.

Shore-oriented migratory behaviour is typically observed for sockeye salmon migrating through high velocity environments (Holmes at al. 2006, Enzenhofer et al. 1998). Holmes et al. (2006) hypothesised that DIDSON counts with a short window length would be accurate at sites in which high water velocities resulted in shore-oriented migratory behaviour in salmon. However, water velocity in the River Tornionjoki fluctuated during the migration season of salmon so the suitable migration routes may be occasionally found on farther ahead from the sounder. Thus, the soundings in Kattilakoski were occasionally reached as far as 80 m from both shores.

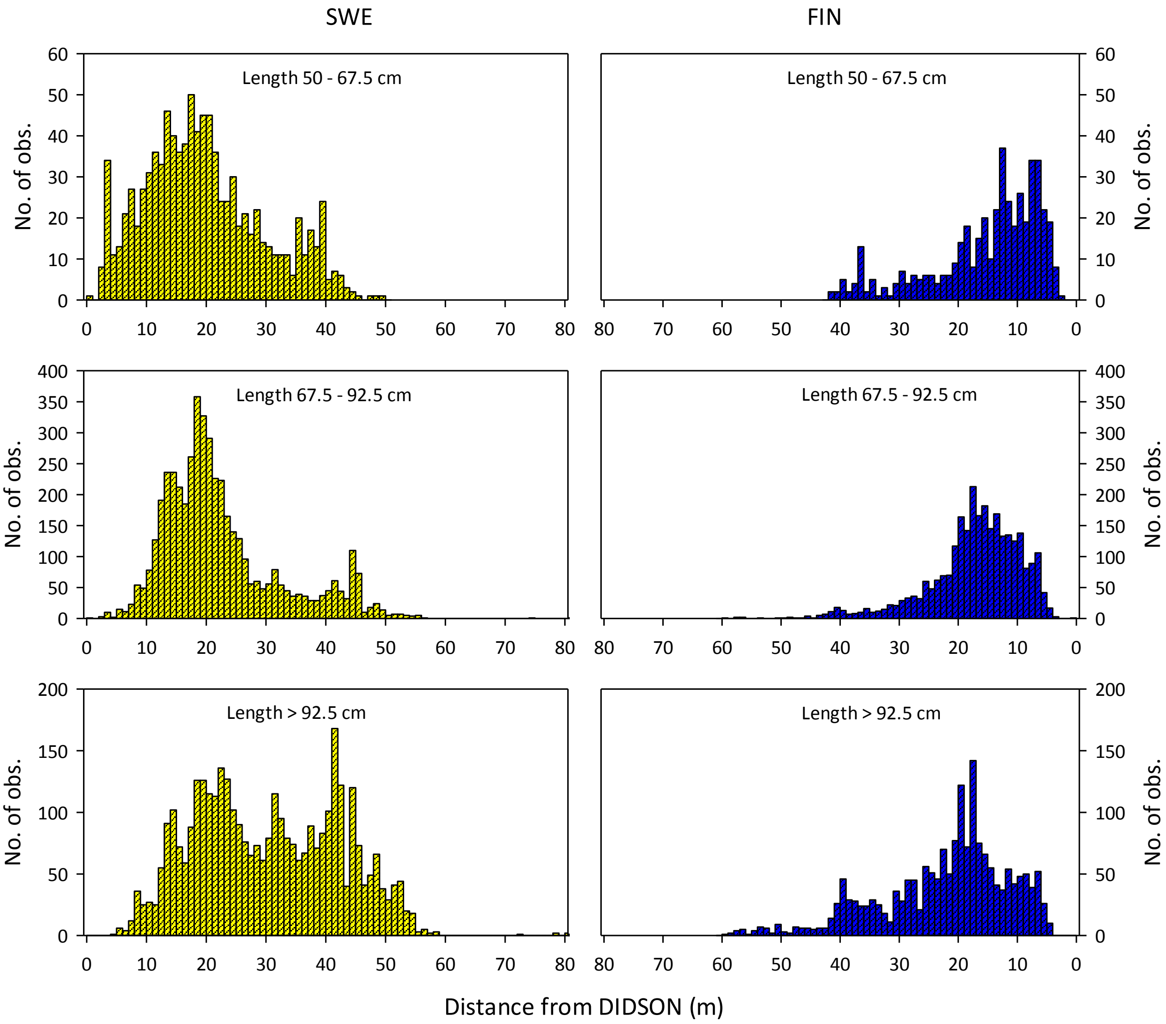

Figure 14.Spatial (horizontal distance from DIDSON) distribution of observed upstream moving fish on the Swedish (SWE) and the Finnish (FIN) sides of the river with three different size-classes. Note that in all histograms the numbers of observations could be biased after 42 m owing to sampling design.

4.5. Comparison between counters

4.5.1. Number of migrants

The results of the triple counted data set from 2010 are presented in Figure 14. The first counter got the total number of 241 fish where the second and third counter got 234 and 238 fish, respectively. These results proved that all counters were able to see almost the same number of fish. Owing to low numbers of migrants, the average percent error (*APE*) was relative high 5.7 % and 6.6 % for three and two counters data, respectively.

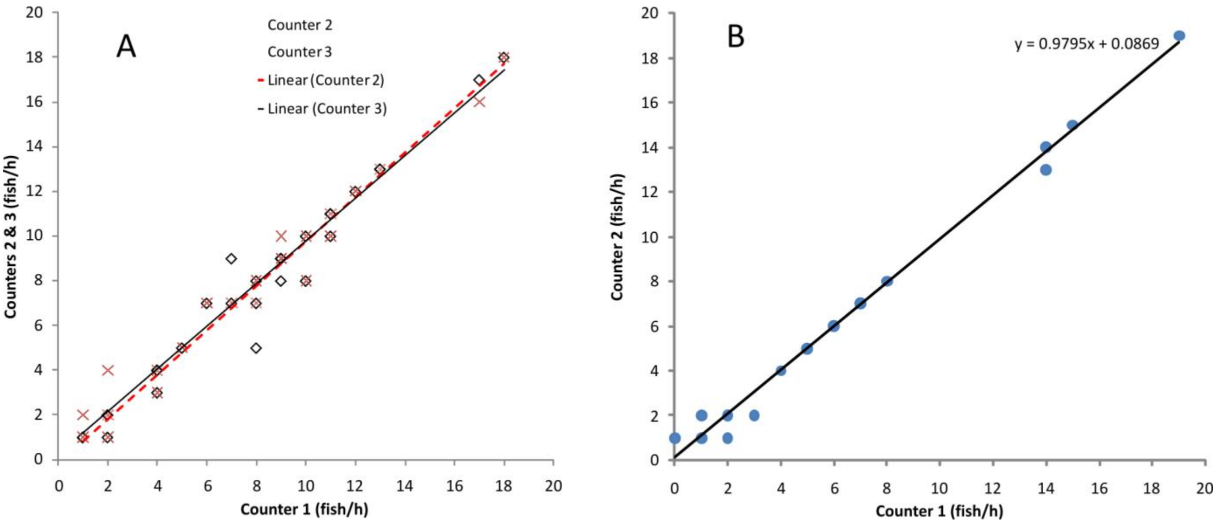

Figure 15. Relationships between

In 2011,

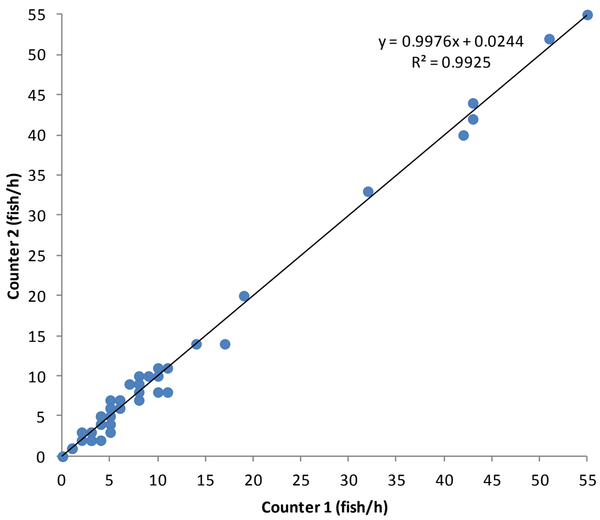

Figure 16. Linear regression between

4.5.2. Length measurements

There were clear differences in the length measurements between counters. The average percent error (*APE*) was 7.4 % and 7.7 % for three and two counters data, respectively. Figure 15 shows the length measurements between counters. The main reason for the large variation in the length measurement was addressed to be a frame (image) selection during the measurement procedure. It was noticed that with the same frame number, almost same fish length was measured by all counters.

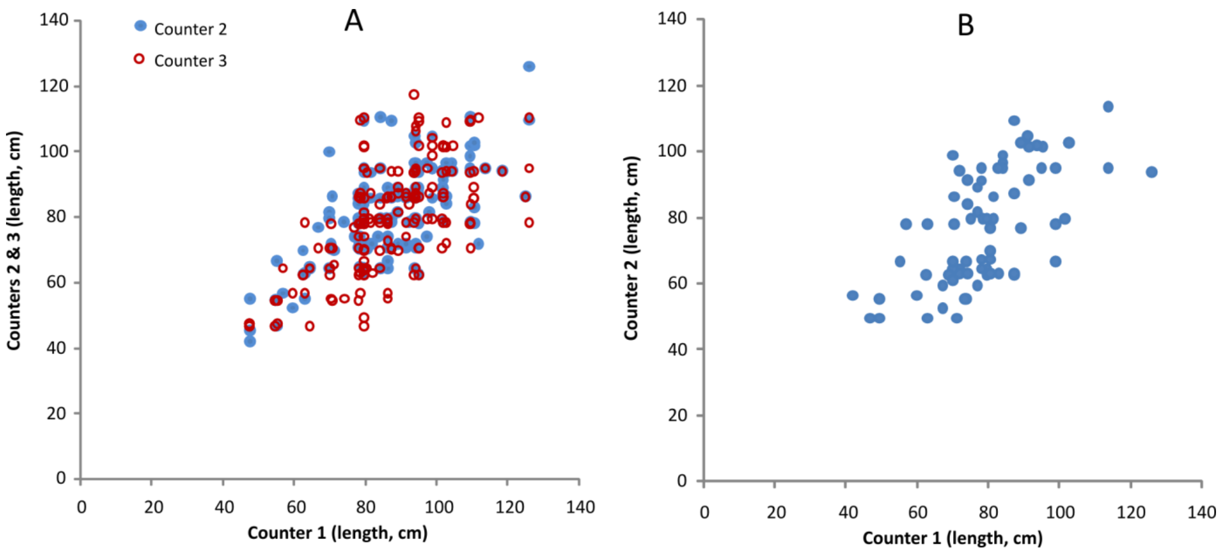

Figure 17.

5. Auxiliary information supporting the monitoring

5.1. Information from Tornionjoki

The size distribution of salmon catch in 2010 is presented in figure 16. The. From the length distribution, of the registered salmon in the catch statistic, grilse and MSW shows a breaking point around 65 cm. However, the catch data of 2010 contains 23 grilses, which have very low frequency of occurance. The size distribution of the caught sea trout is also unimodal and a majority of fish was 70 cm long (Fig. 17).

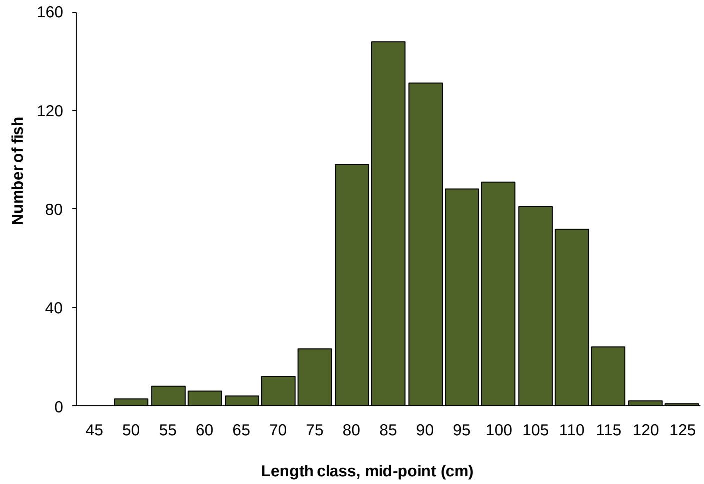

Figure 18.Size distribution (rounded to nearest 5 cm) of caught salmon in 2010 based on anglers' voluntary catch statistics collected along the border river (N= 792).

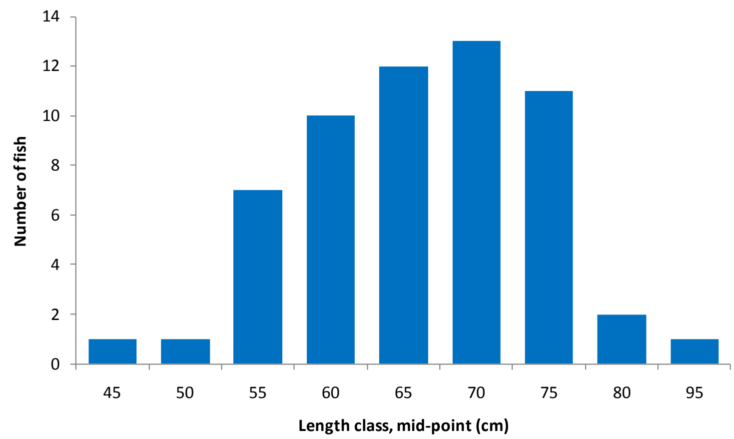

Figure 19.Size distribution (rounded to nearest 5 cm) of caught sea trout in 2010 based on anglers' voluntary catch statistics collected along the border river (N= 58).

5.2. Information from other rivers

In the fish ladder in Jockfall, Kalixälven was totally six species (salmon, trout, whitefish, grayling, bream, and ide) registered in 2007 – 2010 (Table 5). On average, salmon accounted for 96% and trout accounted for 2% of the total fish passage.

Table 8. Number of fish registered in the fish ladder in Kalixälven (Jockfall) 2007-2009.

Year	Salmon	Trout	Bream	Grayling	Ide	Whitefish
2007	6 499	139	57	21	33	22
2008	6 845	121	12	13	12	2
2009	6 173	128	133	4	51	16
2010	3 192	173	40	9	22	0

Yearly the electronic counter is installed in the fish ladder when the high water level decrease to lower level so installation of the equipment is possible. In 2010 the first and last salmon (MSW) passed 6-June and 30- Sept. respectively. The fish ladder is open the whole year but counting occurs earliest from the end of May to beginning of October due to water level and ice conditions. Numbers of not counting salmon in May are probably insignificant. Trout ascend the river earlier than salmon and there might be some unregistered trout passing in the end of May. When counting is ended in the end of September – beginning of October the spawning period, both for salmon and trout, has probably finished. The halfway point in the 2010 run, when 50 % of the total amount had passed occurred on 30th July compared to Kattilakoski, when 50 % passed on 1st July. Until the middle of July only 10 grilse had passed. Higher occurrences of grilse begin in the beginning of August (Figs 18 and 19).

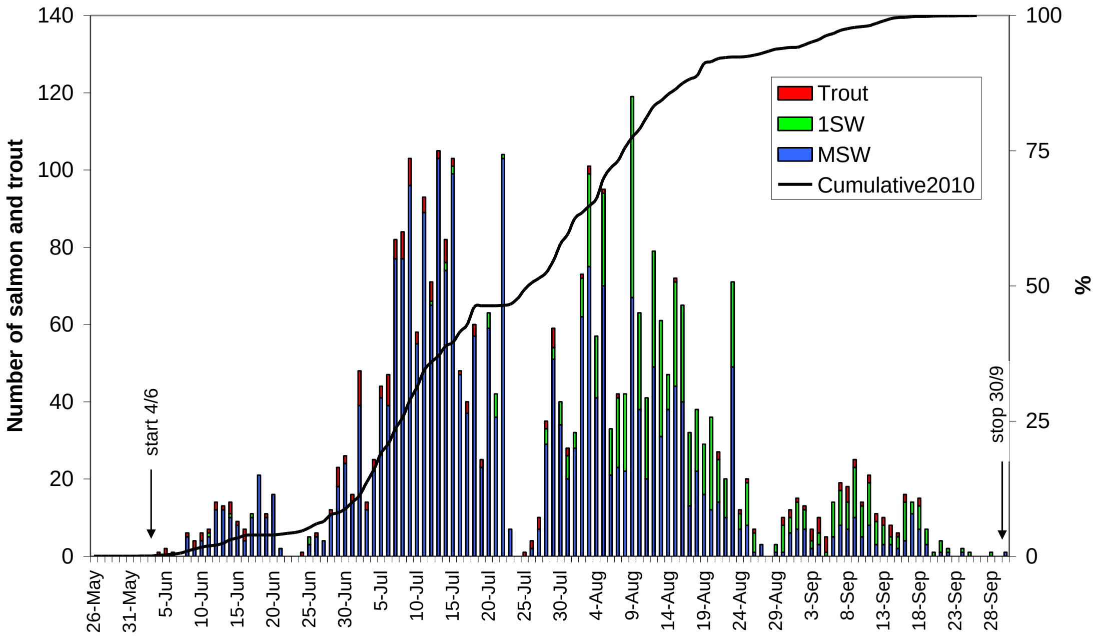

Figure 20. Number of salmon and trout 2010 registered in the fish ladder in Kalixälven (Jockfall) and its cumulative distribution for salmon. Salmon are divided into size categories of 1SW and MSW salmon. Start and stop indicate the operation time for the fish counter.

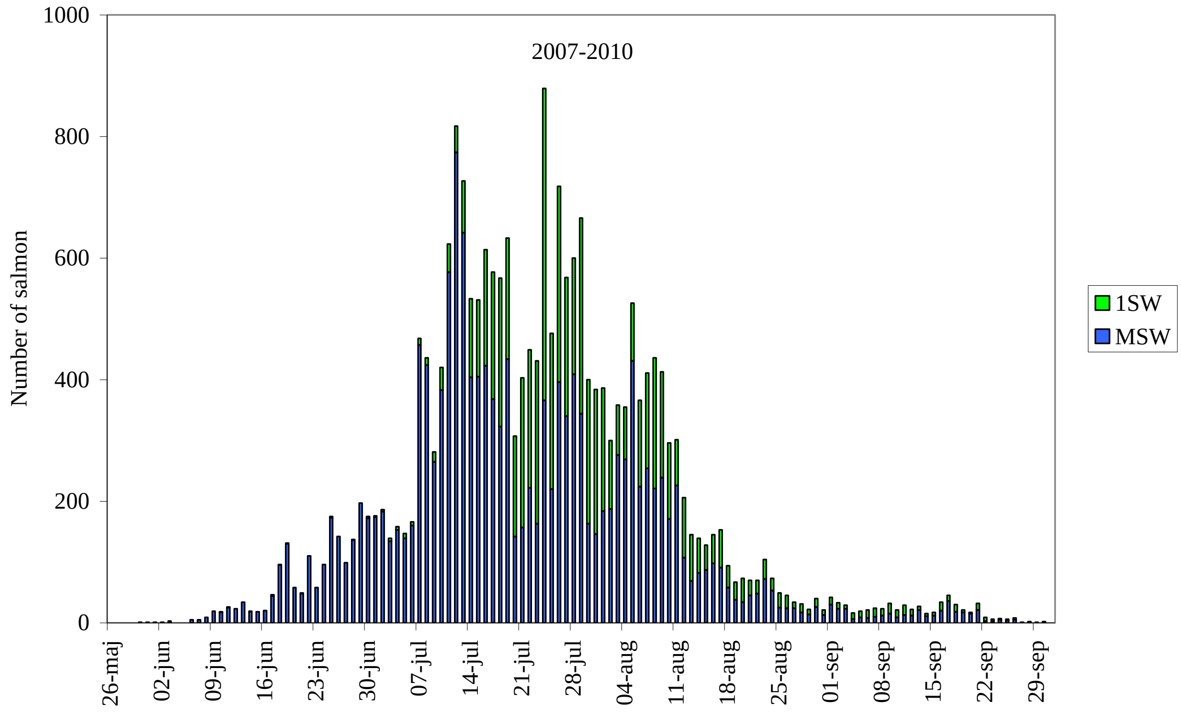

Figure 21. Daily summarized number of salmon for 2007-2010 registered in the fish ladder in Kalixälven (Jockfall). Salmon are divided into size categories of 1SW and MSW salmon.

From the length distribution, of the registered salmon in the fish ladder, grilse and MSW shows a breaking point around 65 cm (Fig. 20).

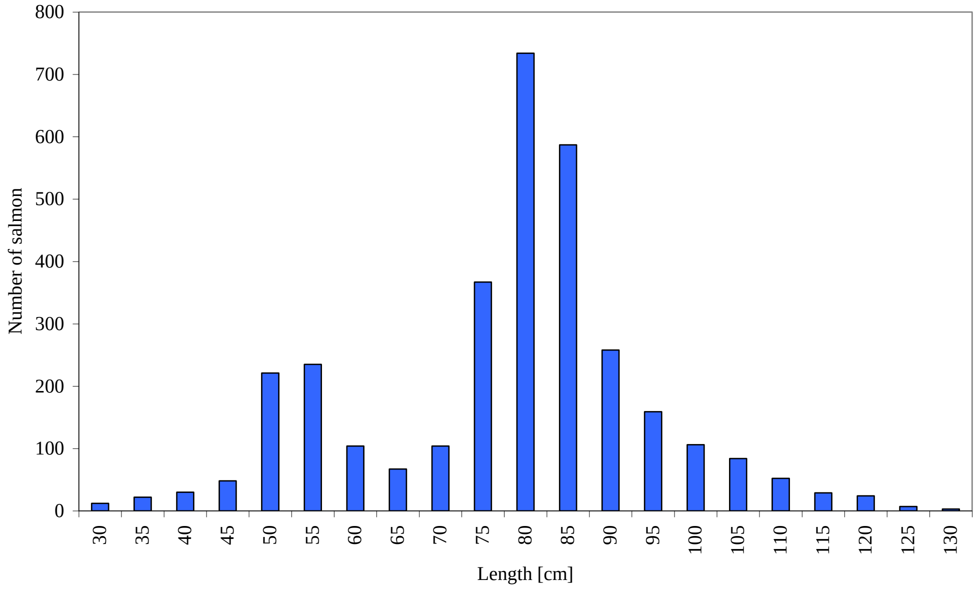

Figure 22.The length distribution in 5 cm classes of salmon in the fish ladder in Kalixälven (Jockfall) 2010.

Most of the upstream migration of salmon in Kalixälven was registered in the fish ladder during the daytime, 85 % of the registration occurred between 08:00 and 20:00 (Fig. 21). During nigh time between 23 and 05 only 5 % of the total migration occurred. The pattern of the daily distribution is the same in other Swedish rivers where salmon is registered in fish ladders i.e. Piteälven, Åbyälven, and Byskeälven.

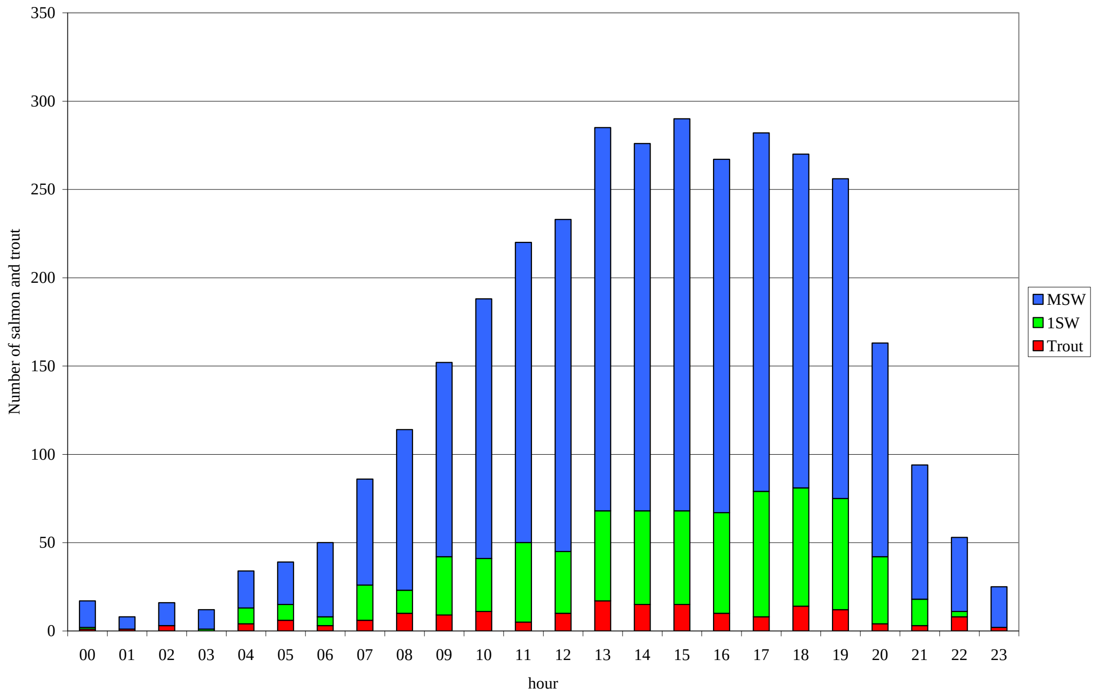

Figure 23. Distribution of salmon (1 SW and MSW) and trout during 24-hour period in the fish ladder in Kalixälven (Jockfall) 2010.

The number of trout passing the fish ladder during 1980 – 2010 has varied the four latest years between 121 and 173, mean 140. In the 2010 run, 50% of the total run had passed in the middle of July. No clear pattern occurs concerning size and time for upstream migration (Fig. 22). Of other species registered in the fish ladder bream and ide dominate and the proportion was 1% and 0.5 % respectively. The largest bream was 60 cm (two ind.).

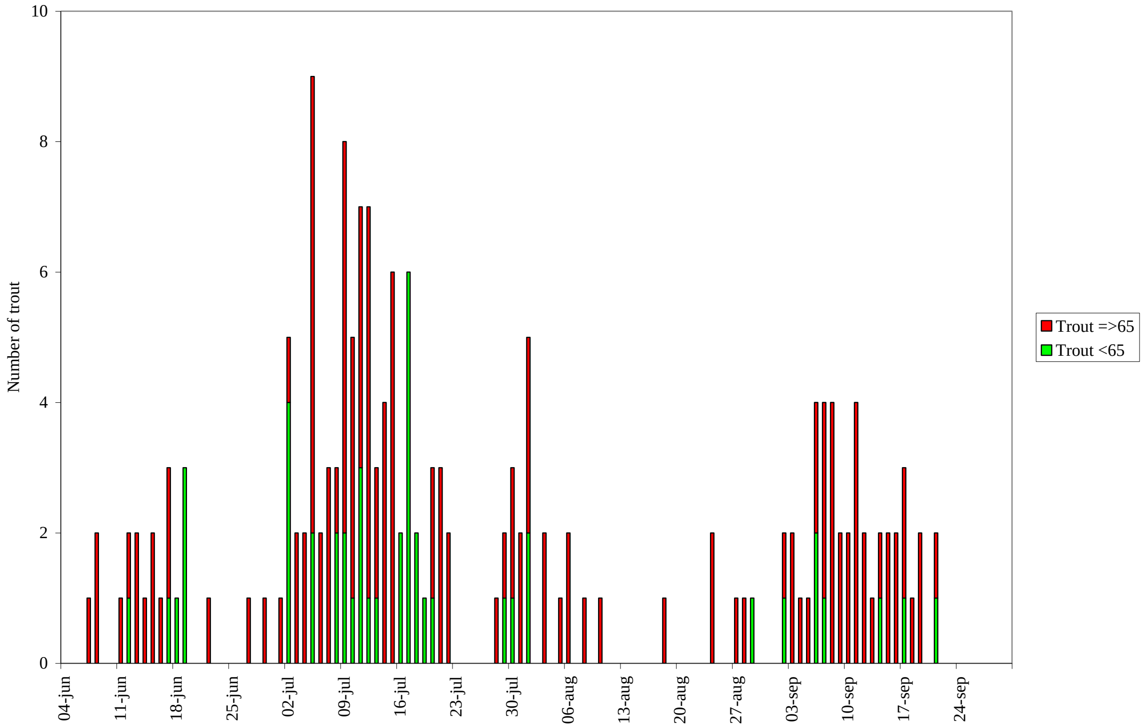

Figure 24. Number of trout, divided into two groups (<65 cm and =>65 cm), 2010 registered in the fish ladder in Kalixälven (Jockfall).

6. Inferring total salmon run into the river

Chapter 4.1. provides an estimate of the number of salmon that migrated upstream through Kattilakoski counting site. In order to get an estimate of the total number of total salmon escapement into the River Tornionjoki, it must add to this the number salmon that:

a) were caught by river fishing below Kattilakoski (chapter x.x); and
b) stayed and spawned below the counting site Kattilakoski (chapter x.x).

Adding salmon which entered the river but did not pass the Kattilakoski site

a) The estimate of salmon catch below Kattilakoki in 2010 is xx salmon. Of these fish some would presumably have stayed and spawned below Kattilakoski and some would have passed Kattilakoski and spawned further upstream. Assuming that the river fishing below Kattilakoski was catching salmon similarly regardless of their ultimate destination in the river, x-x% of the downstream catch was salmon that would have stayed below Kattilakoski.

b) 2-6% of salmon juvenile production may originate from below Kattilakoski. Assuming that same amount of offspring per spawner is produced both below and above Kattilakoski, 2-6% of the Tornionjoki salmon spawners may spawn below Kattilakoski (see Lilja et al. 2010).

Resulting total number of salmon entering Tornionjoki in 2010

Based on all the simplifying assumptions made here and last year report (Lilja et al. 2010), one can calculate a range estimate of the total number of salmon which ascended Tornionjoki:

Run size assuming 2% of abundance below Kattilakoski = 1/0.98*(x + 0.98*858) = x

Run size assuming 6% of abundance below Kattilakoski = 1/0.94*(x + 0.94*858) = x

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