Monitoring of the 2009 salmon spawning run in River Tornionjoki/Torneälven using Dual-frequency IDentification SONar (DIDSON)

A Finnish-Swedish collaborative research report

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ABSTRACT

Atlantic salmon spawning run into the River Tornionjoki/Torneälven was monitored by Dual-frequency Identification Sonar (DIDSON) in 2009. In the beginning of the spawning run, one DIDSON unit was deployed at the river mouth (Tornio site), and two DIDSON units were deployed about 100 km upstream from the sea (Kattilakoski site). The plan was to collect run timing index data from the Tornio site by monitoring only a part of the river transect, and to enumerate all upstream migrants at the Kattilakoski site by monitoring the whole river transect.

Monitoring at the Tornio site was started in late May and but it was interrupted after one month, when the unit was moved to the Kattilakoski site due to a system breakdown at that site. The results from the Torno site from the early part of spawning migration indicate that the site selection was not successful, as a too small fraction of the total upstream passage was detected in order to provide a reliable run timing index.

At the Kattilakoski site monitoring supposedly covered the whole migration period, i.e. from the end of May until the late August. Acoustic data were collected for 78% and 65% of the available sample time on the Swedish and the Finnish shore, respectively. The near-bottom area at the 15-20 meter wide deepest mid-cannel was in constant shadow. In spite of the monitoring problems due to the mid-channel shadow area and the equipment breakdowns due to voltage peaks during thunderstorms, the Kattilakoski site was found to be fairly suitable for permanent monitoring of the salmon spawning run.

Counts at Kattilakoski were expanded across the unsampled periods, but it was assumed 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 a preliminary correction of length measurements and species identification it was concluded that 31 780 salmon and 2130 fish of other species (mainly sea trout) passed the site. Salmon counts were further divided between grilse (5420 ind.) and MSW salmon (26 360 ind.). The median date of salmon migration (grilse and MSW salmon combined) was on 1 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 33 000 – 35 000 salmon ascended the river in 2009.

Future monitoring with auxiliary investigations may bring new information based on which the 2009 data have to be reassessed. The auxiliary investigations should include estimation of precision (detection rate may vary between persons post-processing the data) of counts, improving and verification of length measurements, data collection from the mid-channel shadow area, and special studies to quantify the amount of salmon that do not pass the counting site. A more permanent mounting system of the DIDSON units and fish deflection weirs could be planned and built up. Electronic equipment must also be better protected against breakdowns due to thunderstorms. Finally, obtaining direct information concerning the timing and dynamics of river entry of fish would require more test runs with one or several DIDSON units at various sites near the river mouth (Tornio).

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. 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 operated in the Tornionjoki/Torneälven over the summer 2009.

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

2. *Study sites*

2.1. Selection of sites

The success of DIDSON in counting upstream migrating salmons depends primarily on two basic prerequisites;

1) deployment of the system on a site that enables recording of representative and high-quality images.
2) accurate and precise measurement of fish during the data post-processing.

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 river bottom was quite uniform without large rocks or boulders that may obstruct the beams of DIDSON. As Kattilakoski is situated about 100 km from the river mouth, direct information concerning the river entry of fish can not be collected at that site. Such information was instead registered by one DIDSON unit placed near the river mouth, on the town of Tornio. Consequently, the migration of Atlantic salmon into the Tornionjoki was monitored by DIDSON sonars at two sites in 2009. First, on the site in the town of Tornio (later called the "Tornio site") that was located about 5 km upstream from the river mouth, and second, on the site in the upper part of Kattilakoski rapids (later called "Kattilakoski site") that was located about 100 km upstream from the river mouth (Fig. 1).

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

2.2. Tornio site

The aim of the Tornio site was to collect an index data for the river entry of salmon and compare that information to data from the Kattilakoski site. At the Tornio site the river is approximately 280 m wide with a maximum depth of 8-10 m. The DIDSON sonar was deployed just downstream from a stone construction on the east shore of the river (Fig. 2). The sonar beams were aimed at the middle river just upstream from the east pillar of the bridge. A guiding net of 10 m was used to prevent to fish swim too close to the sonar. Hence, the soundings covered about one third of the river width.

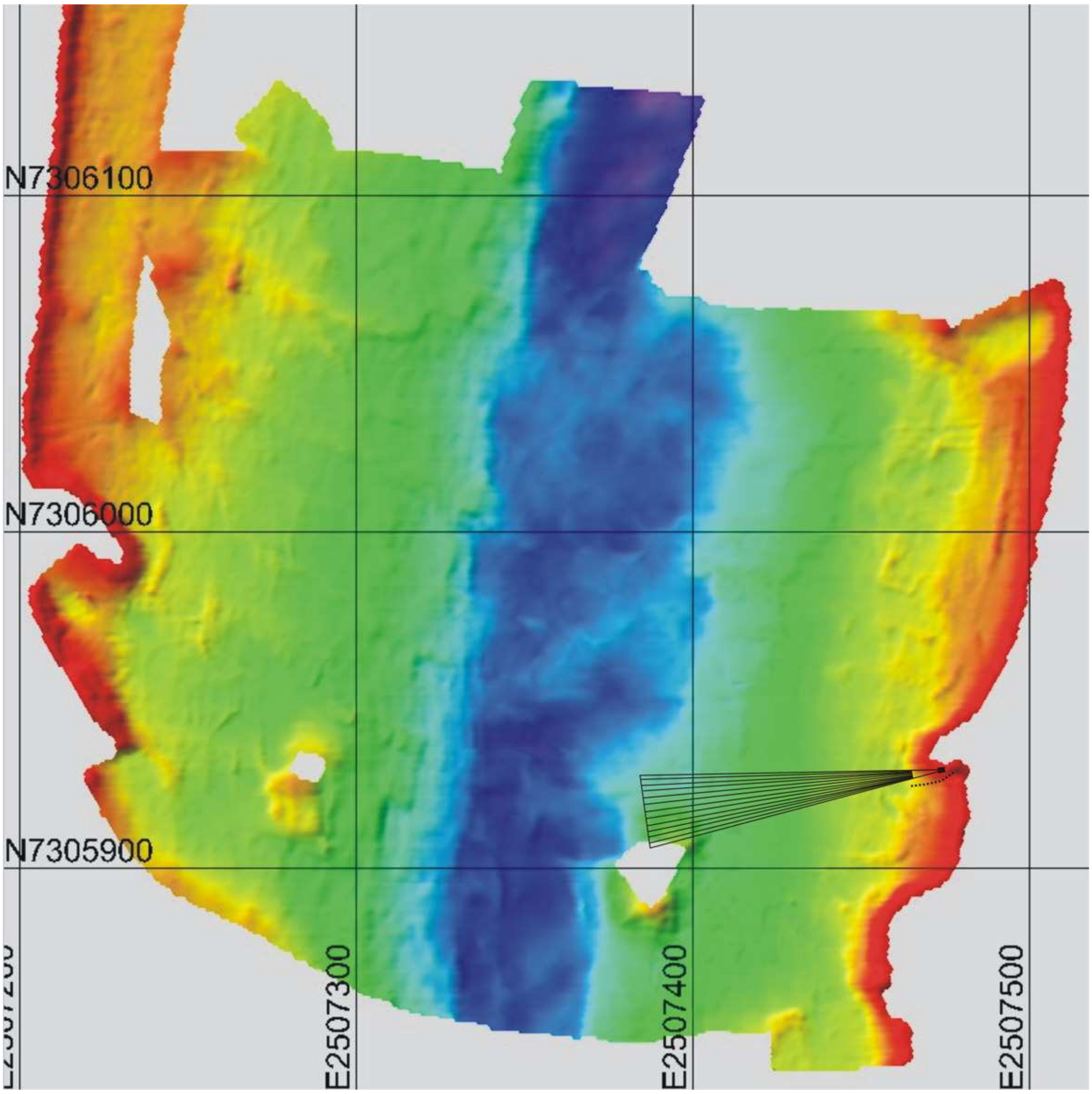

Figure 2. A bottom map of the Tornio site. The DIDSON sounder on the east shore and the beam coverage. Blue colour describes the deepest and red the shallowest area of the river. Finnish national coordinates with 100 × 100 m grid lines.

2.3. Kattilakoski site

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. 3). Two sets of DIDSON systems were used, one for each river bank. The west bank of the river belongs to Sweden and the DIDSON sonar was located beside a restaurant building (Fig. 4), which was also used for housing the top-site equipment of the system (computer, power supplies, etc). On the east bank (Finnish shore), a field cabin was used for housing the top-site equipment. On both sides, the mains electric current was used to power up the systems. However, back-up devices were used to prevent systems from voltage peaks and to ensure data collection during short blackouts. In the river, just down stream from sounders, short fish deflection weirs were installed to prevent fish from swimming at too close range from DIDSON sounders.

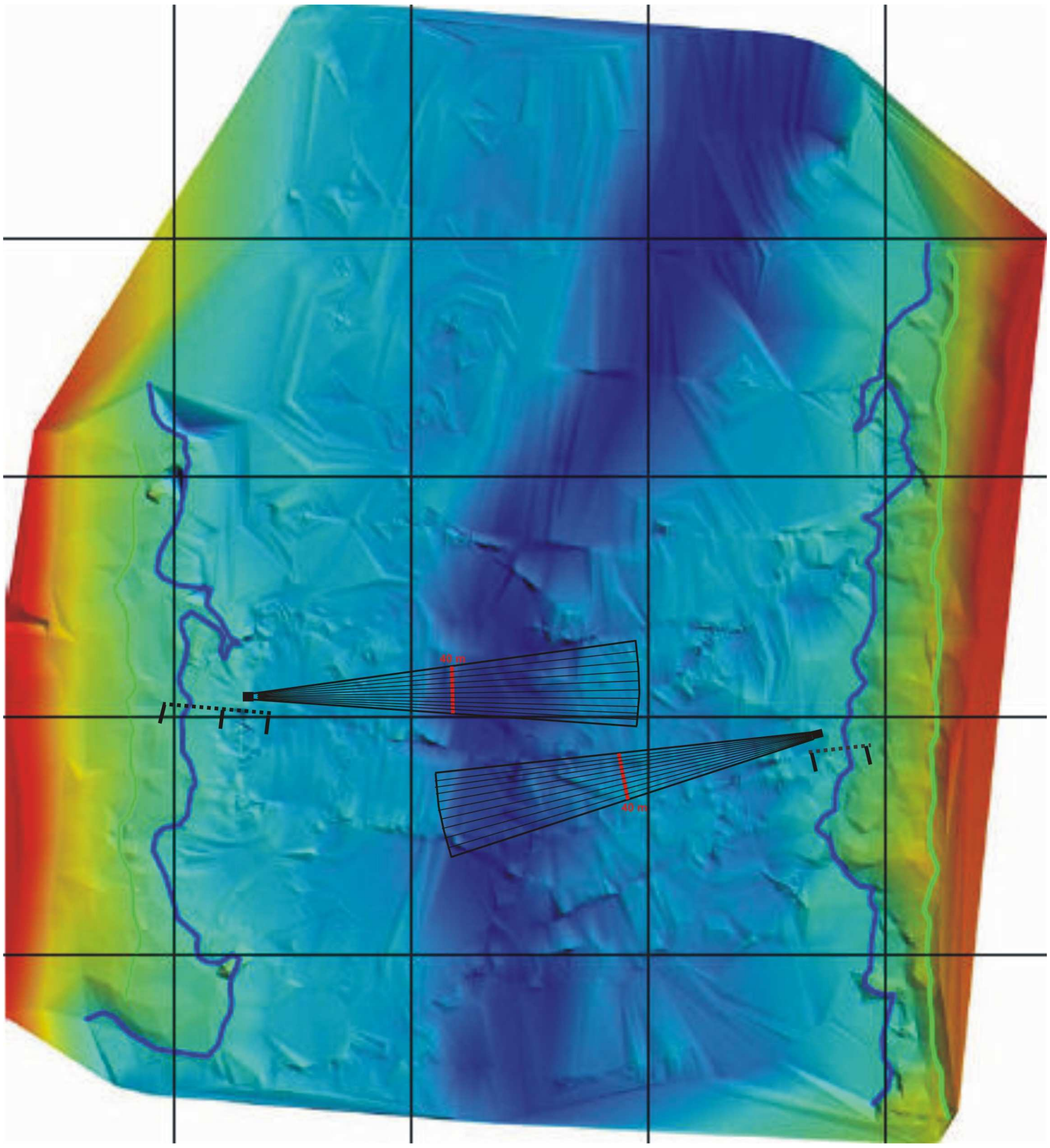

Figure 3. A bottom map and river banks of Kattilakoski site with 50 × 50 m grid lines. DIDSON sounders next to both shores and the covered areas. The darker the blue colour the deeper the river channel is. Green areas are below water at floods, but land at low-water periods. Red areas describe the river banks. The situation on Aug-24 2009 is shown, when the water level was the lowest recorded, hence the distance between the sounders was the shortest (120 m; blue lines are shorelines). 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 3.3).

Figure 4. A DIDSON sonar next to the Swedish shore. The restaurant building was used for housing the top-site equipment of the sounder.

3. Data collection procedures and data processing

3.1. DIDSON sounders

Long range (LR) DIDSON acoustic imaging systems were used at both counting sites in the river. As well as a standard version, the long range DIDSON is capable of utilizing two different frequencies (modes) for data collection. When operated at high frequency mode (HF = 1200 kHz), the maximum window length setting permitted is 20 m, although the start length can be set at up to 13 m which provides viewing out to a maximum of 33 m. If this distance is inadequate, switching to low frequency mode (LF = 700 kHz) will be necessary. When operated at LF, the window length setting can be increased to 40 or 80 m. The River Tornionjoki is too wide to allow that the HF mode is used, so the sounders were set to use the LF mode. In this mode DIDSON utilizes 48 sound beams focused through movable lens systems. The sounders were also equipped with High Resolution Lens Sets which produce a nominal field of view 14° horizontally and 8° vertically, 14° horizontally and 14° vertically, in Kattilakoski and Tornio, respectively. In order to build up a frame (image), each beam was divided in 512 segments (sample) in longitudinal direction, and the image is constructed by echo-intensity values in the matrix of 48 by 512 (Fig. 5).

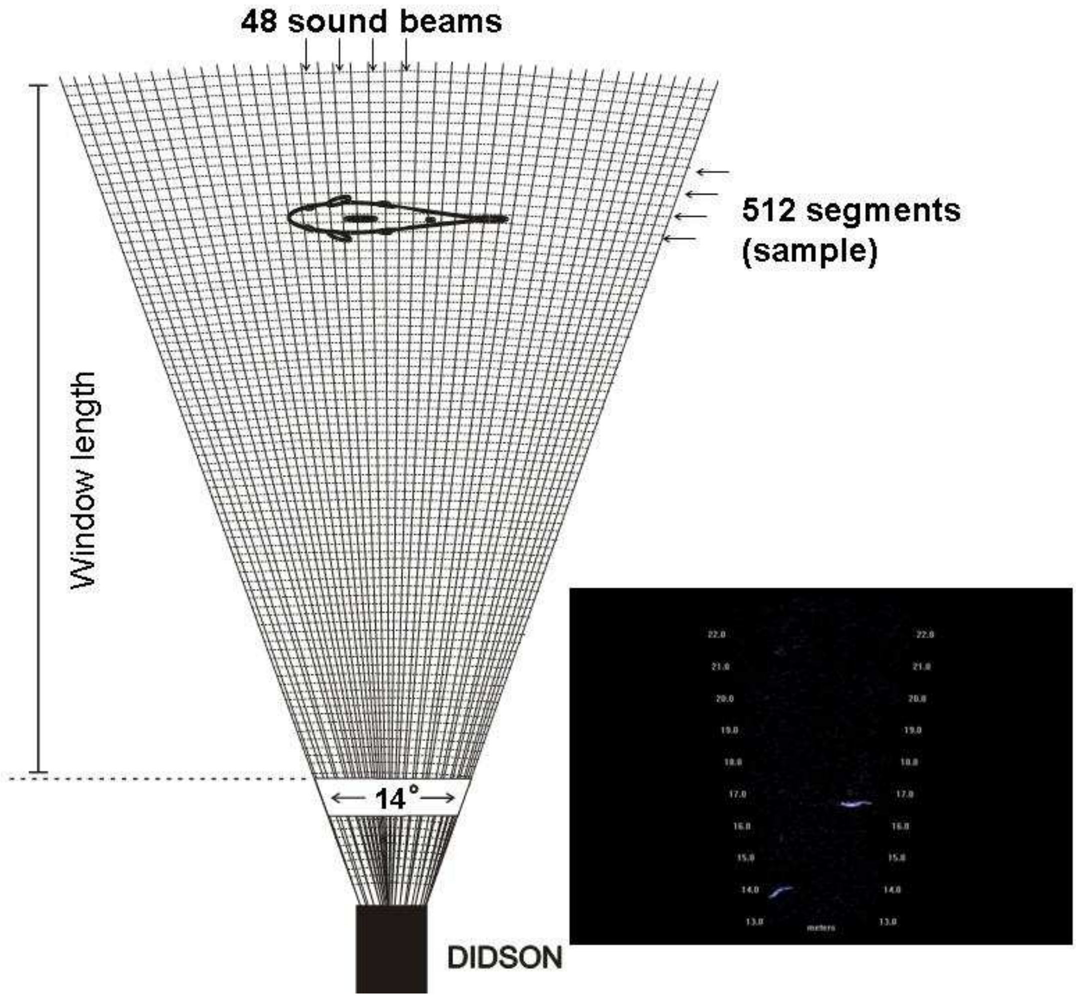

Figure 5. A schematic picture (from above) of a DIDSON frame (image) and a snapshot of the DIDSON screen where two salmon were swimming from right to left.

3.2. Data collection on Tornio site

Data collection was started on May 21, and it continued without interruption until June 23, when the sonar system was moved to the Kattilakoski site due to a system breakdown at that site. Thus, the survey period consisted of acoustic data during 33.2 days (796 hours). A steel stand was used to deploy the sounder offshore and a dual-axis electronic pan and tilt system was used to aim sound beams horizontally and vertically. The DIDSON was set to use the window length of 80 m, starting at 8 m, for data collection. By using the 80 m window length, the maximum frame rate was 2 frames/sec. Sliding bars on the stand enabled to drop and raise the sounder following by fluctuating water level.

3.3. Data collection on Kattilakoski site

Two sets of DIDSON systems were used, one for each river shore. Steel stands were used to deploy the sounders offshore (Fig. 6). 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 6. A steel stand for DIDSON and a fish deflection weir in Kattilakoski, Finnish shore.

Acoustic data were collected from the end of May until late August (Table 1 & 2). Thus, the total available sample time was 96 days (2300 hours). Data collection was first started on the Finnish side and a few days later on the Swedish 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. 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.

The main reason for interruptions of data collection was thunderstorms with lightning. A voltage peak somehow got in to the units and failed them. The electrical storm activities in the area did not affect the topside power supply at all so the voltage peaks were maybe induced into the cables or directly from water surrounding the sonar. Short interruptions on data collection were also caused by the relocations of DIDSON units during the season.

Table 1. Data collection and sampling design from the Finnish shore. A period when data is not available is highlighted in gray. (WL = used window length).

Date	Duration (h)	FIN
19.5., 17:15 – 20.5., 16:25	24	60 min; WL = 40 m
20.5., 16:25 – 21.5., 18:45	43	No data
21.5., 18:45 – 23.5., 12:10	25	60 min; WL = 40 m
23.5., 12:10 – 29.5., 13:00	144	No data
29.5., 13:00 – 3.6., 13:30	121	50 min; WL = 40 m & 10 min; WL = 80 m
3.6., 13:30 – 8.6., 16:30	122	No data
8.6., 16:30 – 11.6., 13:00	69	60 min; WL = 40 m
11.6., 13:00 – 17.6., 16:00	147	60 min; WL = 80 m
17.6., 16:00 – 18.6., 13:10	22	60 min; WL = 40 m
18.6., 13:10 – 23.6., 21:15	127	No data
23.6., 21:15 – 26.6., 17:00	68	60 min; WL = 40 m
26.6., 17:00 – 2.7., 09:10	137	40 min; WL = 40 m & 20 min; WL = 80 m
2.7., 09:10 – 9.7., 10:00	168	No data
9.7., 10:00 – 10.7., 12:00	26	40 min; WL = 40 m & 20 min; WL = 80 m
10.7., 20:00 – 9.8., 18:20	719	60 min; WL = 40 m
9.8., 18:20 – 19.8., 13:00	234	No data
19.8., 13:00 – 24.8., 10:15	119	60 min; WL = 40 m

Table 2. Data collection and sampling design from the Swedish shore. A period when data is not available is highlighted in gray. (WL = used window length).

Date	Duration (h)	Sample rate (min/h)
22.5., 10:00 – 29.5., 12:00	164	60 min; WL = 40 m
29.5., 12:00 – 3.6., 14:00	123	No data
3.6., 15:00 – 11.6., 10:30	188	50 min; WL = 40 m & 10 min; WL = 80 m
11.6., 11:00 – 17.6., 10:55	144	60 min; WL = 80 m
17.6., 11:00 –18.6., 13:10	27	40 min; WL = 40 m & 20 min; WL = 80 m
18.6., 13:10 – 22.6., 14:00	96	No data
22.6., 14:00 – 23. 6., 16:00	26	40 min; WL = 40 m & 20 min; WL = 80 m
23.6., 16:00 – 2.7., 11:00	211	No data
2.7., 11:00 – 9.7., 09:10	167	40 min; WL = 40 m & 20 min; WL = 80 m
9.7., 09:10 – 10.7., 19:00	33	No data
10.7., 19:00 – 6.8., 11:35	641	40 min; WL = 40 m & 20 min; WL = 80 m
6.8., 12:10 – 19.8., 13:00	312	60 min; WL = 40 m
19.8., 13:00 – 24.8., 10:15	119	No data

3.4. 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 5.21 of the DIDSON operating system software (Sound Metrics Corporation 2009). 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 equalises 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 60 cm as well as fish in length class 45 – 60 cm were summed up.

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.

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 54 hours (files) were counted by two observers in 2009. Selected data set from the Swedish shore was picked up using a systematic sampling design (Table 3). Every fourth hour of day was double counted once a week. Both Finnish and Swedish observers counted the data set and the fish numbers were compared. Because there were some differences between used computers time zones, the DIDSON software stamped output files differently. Therefore, we compared only the total numbers of observed fish (salmon size > 60 cm).

Table 3. Double counted data set that consisted of 54 files.

Place	Week	Date	Analysed files
Kattilakoski-SWE	23	4-Jun	every fourth h, 00-01, 04-05, 08-09, 12-13, 16-17, 20-21
Kattilakoski-SWE	24	10-Jun	every fourth h, 00-01, 04-05, 08-09, 12-13, 16-17, 20-21
Kattilakoski-SWE	25	15-Jun	every fourth h, 00-01, 04-05, 08-09, 12-13, 16-17, 20-21
Kattilakoski-SWE	26	23-Jun	every fourth h, 00-01, 04-05, 08-09, 12-13, 16-17, 20-21
Kattilakoski-SWE	27	3-Jul	every fourth h, 00-01, 04-05, 08-09, 12-13, 16-17, 20-21
Kattilakoski-SWE	28	12-Jul	every fourth h, 00-01, 04-05, 08-09, 12-13, 16-17, 20-21
Kattilakoski-SWE	29	18-Jul	every fourth h, 00-01, 04-05, 08-09, 12-13, 16-17, 20-21
Kattilakoski-SWE	30	24-Jul	every fourth h, 00-01, 04-05, 08-09, 12-13, 16-17, 20-21
Kattilakoski-SWE	31	1-Aug	every fourth h, 00-01, 04-05, 08-09, 12-13, 16-17, 20-21

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

In 2009, acoustic data were collected for 78% and 65% of the available sample time on the Swedish and the Finnish shore, respectively. However, there was only 7% of the available sample time that data have not been collected at all (see Tables 1 & 2). 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 sample period 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. 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.

4. *Auxiliary information supporting the monitoring*

4.1. Information from Tornionjoki

4.1.1. Size distributions of salmon and other species in the angling catch in 2009

The size distribution of salmon catch in 2009 is bimodal, with the modal length categories of 57.5-62.4 cm and 82.5-87.4 cm (Fig. 7). The lower and the upper modal categories correspond with the modal size of grilse (1SW) and 2SW salmon, respectively (Fig. 8). The size distribution of the caught sea trout is also bimodal and a majority of fish were 55-70 cm long (Fig. 9).

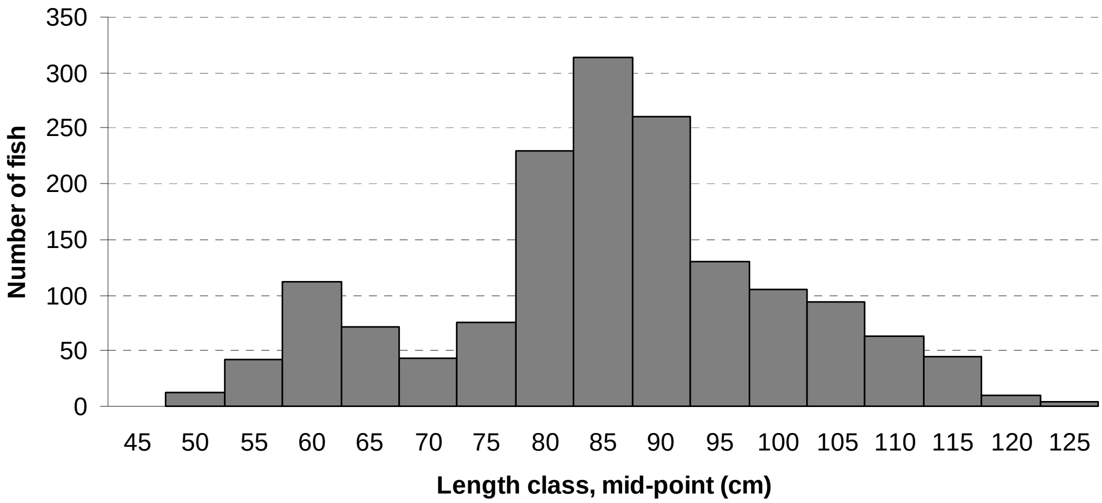

Figure 7. Size distribution (rounded to nearest 5 cm) of caught salmon in 2009 based on anglers' voluntary catch statistics collected along the border river (N= 1611).

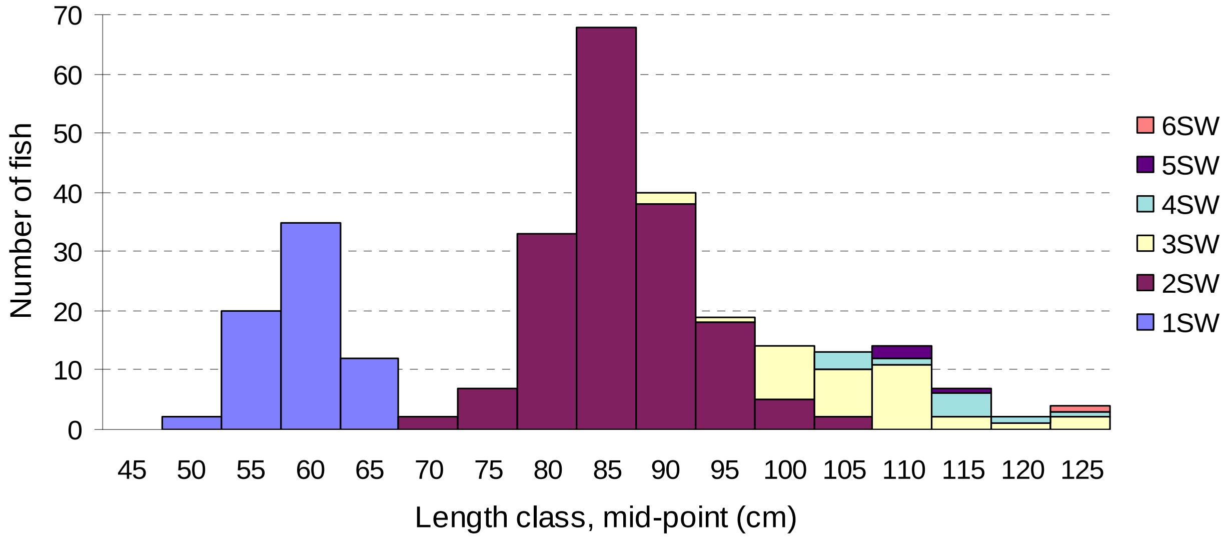

Figure 8. Size distribution (rounded to nearest 5 cm) of caught salmon by sea-age in 2009 based on aged catch samples collected along the border river (N= 292).

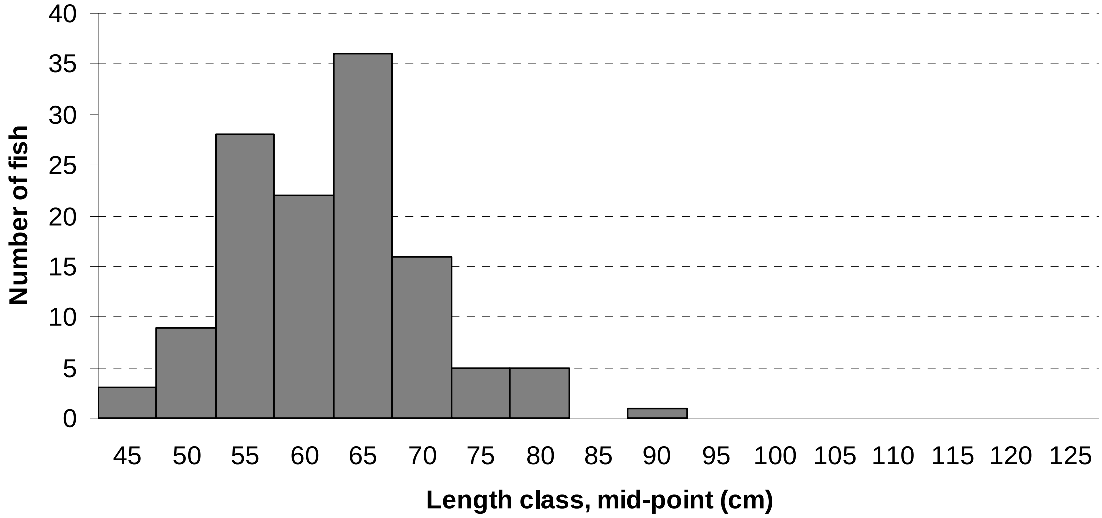

Figure 9. Size distribution (rounded to nearest 5 cm) of caught trout in 2009 based on anglers' voluntary catch statistics collected along the border river (N= 125).

4.1.2. Seasonal differences in size and species composition of catch

Anglers' voluntary catch statistics contain much data (N=646) from Pello district, 0-65 km upstream from Kattilakoski. Figure 10 shows the timing of salmon and trout catches over the fishing season 2009, in which salmon are divided into two size categories: 1SW (grilse) and MSW sized salmon. Trout occurred abundantly in catches from late May to mid-June. Grilse started to appear in early July. There were two observations of grilse sized salmon before July, but these fish were close to the upper limit of the grilse size category, i.e. they may have been very small MSW salmon. Moreover, there is a chance for an inexperienced fisherman to misidentify the species between trout and salmon.

In the much smaller data of the anglers' voluntary catch statistics below Kattilakoski (N=92), all trout were caught 17 May - 11 June and the first grilse sized salmon was caught 27 June.

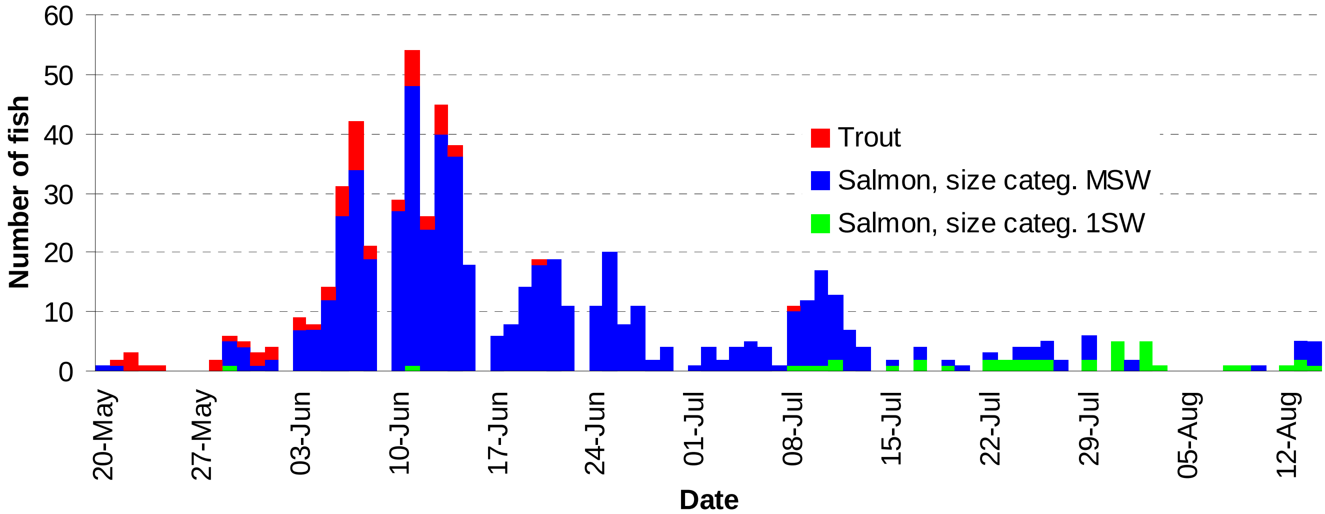

Figure 10. Number of caught trout and salmon over the summer 2009 in the Pello district, 0-65 km upstream from Kattilakoski. Salmon are divided into size categories of 1SW and MSW salmon, based on the aged catch samples (see Fig. 8).

4.1.3. Proportions of salmon and other species within the monitored fish size categories

Approximations of proportional abundances of salmon spawners vs. sea trout spawners passing Kattilakoski can be obtained from two existing data sets: catch statistics and monitoring of smolt runs.

In 2005-2009, salmon accounted for on average 80% of the total catch of salmon and trout in the whole river system (Table 4). Some immature trout seem to visit the lowermost part of the river system (below Kattilakoski). Therefore, catch statistics from above Kattilakoski are likely to give a more trustworthy idea about the proportion of trout vs. salmon passing upstream Kattilakoski. Here, salmon accounted for on average 94% of the catch (Table 5).

Among smolts in the smolt trap from 2005-2009, salmon accounted for on average 98.8% and trout 1.2% (Table 6). Smolt trapping likely misses the earliest part of the annual trout migration. Therefore, the above percentages are probably underestimates of the true abundance of trout in the smolt run. Salmon and trout smolts may have very different survival rates back to river. Due to the above facts, one must be extra cautious when inferring proportions of salmon and trout in the spawning runs based on smolt run data.

Table 4. Estimated total number of caught salmon and sea trout in the Tornionjoki river fishery, years 2005-2008.

Year	Number of salmon	Number of trout	Sum of trout and salmon	Proportion of salmon, %
2005	4745	1148	5893	81%
2006	2033	1248	3281	62%
2007	3982	1030	5012	79%
2008	11 536	950	12 486	92%
2009	5770	1069	6839	84%
Average	4 133	1089	5256	80%

Table 5. Number of salmon and trout registered on the anglers' voluntary catch statistics in the Tornionjoki above Kattilakoski, years 2007-2009.

Year	Number of salmon	Number of trout	Sum of trout and salmon	Proportion of salmon, %
2007	1111	124	1231	90%
2008	2280	63	2343	97%
2009	1533	112	1645	93%
Average	1641	100	1741	94%

Table 6. Number of caught salmon and trout smolts in the Tornionjoki smolt trap, years 2005-2009.

Year	Number of salmon	Number of trout	Sum of trout and salmon	Proportion of salmon, %
2005	24 929	421	25 350	98%
2006	41 047	743	41 790	98%
2007	50 647	206	50 853	100%
2008	70 058	859	70 917	99%
2009	35 370	514	35 884	99%
Average	44 410	549	44 959	99%

There is no data available on occurrence of other species among size category of salmon in the Kattilakoski. Kattilakoski-Juoksenki(Juoksengi) area represents the uppermost range of the distribution of migratory whitefish in the river (Petersson 1975, Toivonen 1962). According to the local people, whitefish migrate above Kattilakoski only in years with exceptional circumstances. Grayling and ide are typical species in the area and the largest of them may reach the size of grilse, similar to migratory whitefish. Further, pike and burbot are also common species and they may even reach the size of MSW salmon. The crucial question when assessing the occurrence of non-salmon species in the DIDSON data is, how much these species pass the exact counting site. Apart from grayling and ide, the above mentioned species typically inhabit slow flowing river sections, whilst the counting site represents a fast flowing edge of a strong rapid.

4.1.4. Proportion of salmon ascending Tornionjoki but not passing Kattilakoski

Salmon ascending the river from the sea may not pass the Kattilakoski counting site for two reasons:

(1) Salmon is caught by the river fisheries before they reach Kattilakoski, or
(2) The spawning site of salmon is located on the lowermost river stretch, i.e. below Kattilakoski

The influence of the first point can be assessed from catch statistics, and the influence of the second point may be approximated from the spatial distribution of salmon reproduction in the rivers system.

The Finnish catch statistics allow division of catches below/above Kattilakoski, while the Swedish catches can not be divided similarly. If one assumes similar proportions of salmon catches above/below Kattilakoski for the Swedish catch as for the Finnish, it would mean that in the recent years 475-1659 salmon have been caught below Kattilakoski (Table 7). The results of 2009 catch inquires indicate that in total 858 salmon were caught below Kattilakoski.

Table 7. Estimated catch of salmon downstream from Kattilakoski, years 2005-2008.

Year	Number of salmon caught by Finns below Kattilakoski	Total number of caught salmon by Finns	Proportion of catch below Kattilakoski, %	Estimated annual number of caught salmon below Kattilakoski
2005	1104	3190	35%	1642
2006	396	1470	27%	547
2007	316	2651	12%	475
2008	1260	8762	14%	1659
2009	695	4675	15%	858
Average	754	4150	18%	1036

The inventory of salmon parr rearing habitats (Romakkaniemi, unpublished, Karlström, unpublished) indicate that there is 363-515 hectars of parr rearing habitat downstream Kattilakoski (lower part of Kattilakoski rapid included). The lower bound of the range indicate the amount of riffles and rapids traditionally regarded as parr habitat, while the upper bound also includes the swiftly flowing ‘pools’ possibly suitable for salmon parr. Similarly, the total salmon parr rearing area in the Tornionjoki river system is traditionally estimated to approx. 5000 hectars. More recent studies suggest that the area may be up to 2000-3000 hectars larger due to observations that parr may also utilise swiftly flowing ‘pools’ (Karlström, unpublished, Linnansaari 2003).

Consequently, salmon parr rearing habitat downstream Kattilakoski accounts for 5-10% of the parr rearing habitat in the whole river system. In 2005-2009, salmon parr densities below Kattilakoski have been 61% (range 32-82%) of the average densities in the whole river system. If one assumes that parr densities on the electrofishing sites directly indicate relative differences in smolt-production-per-unit-area between river stretches, approximately 2-6% of Tornionjoki salmon smolts currently originate from below Kattilakoski. Whether this further directly corresponds to the proportion of salmon spawning below Kattilakoski depends on several assumptions. Due to e.g., faster growth and thus younger smolting age on the lowermost reach, the proportion of spawners may be somewhat higher than that indicated by the above calculations.

4.2. Information from other rivers

The waterfall (Jockfall) in river Kalixälven is situated about 110 km from the river mouth, the same distance as Kattilakoski. The waterfall is 9 meter high and it is a partial obstacle for salmon and trout migration. A fishladder was built in 1980 to enable passage of salmon and trout into the upper river sections. The number of fish passages has been controlled in the fishladder since 1980, first manually and from 1998 by an electronic infrared fish counter. The counter registers time for fish passage, fish size, up or down movement, creates a silhouette of the fish and also registers water temperature. In 2007 an underwater camera was installed to enable registration of species. Fish from all species passing upstream can be distinguished by the video recordings due to the high transparency of the water and the high quality video pictures. Totally six species (salmon, trout, whitefish, grayling, bream, and ide) where registered in 2007 – 2009 (Table 8). On average, salmon accounted for 96% and trout accounted for 2% of the total fish passages.

Table 8. Number of fish registered in the fishladder 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

Yearly the electronic counter is installed in the fishladder when the high water level decreases to a level that allows installation of the equipment. In 2009 the first and last MSW salmon passed 30 May and 30 Sept. respectively. The fishladder is open the whole year but counting occurs earliest from the end of May to the beginning of October due to the high water level and ice conditions. The number of not counted salmon in May is 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 migration period, both for salmon and trout, has probably finished The halfway point in the 2009 run, when 50% of the total estimate had passed occurred on July 16 compared to Kattilakoski where 50% passed on June 27. Until the end of June only two grilse had passed. Higher occurrence of grilse begins in the middle of July (Fig. 11 & Fig. 12). The upstream migration in the fishladder is affected by fluctuations in water discharge. Especially when the water level increases quickly the migration in the fishladder decreases, however a slowly decreased water discharge does not affect the migration intensity. One example of the effect of an increased water discharge occurred between 15 June and 20 June in 2009 when the migration almost stopped (Fig. 11). The decreased migration between 5 - 15 July depended on installation work in the fishladder with a partial (3 h.) closure of the fishladder.

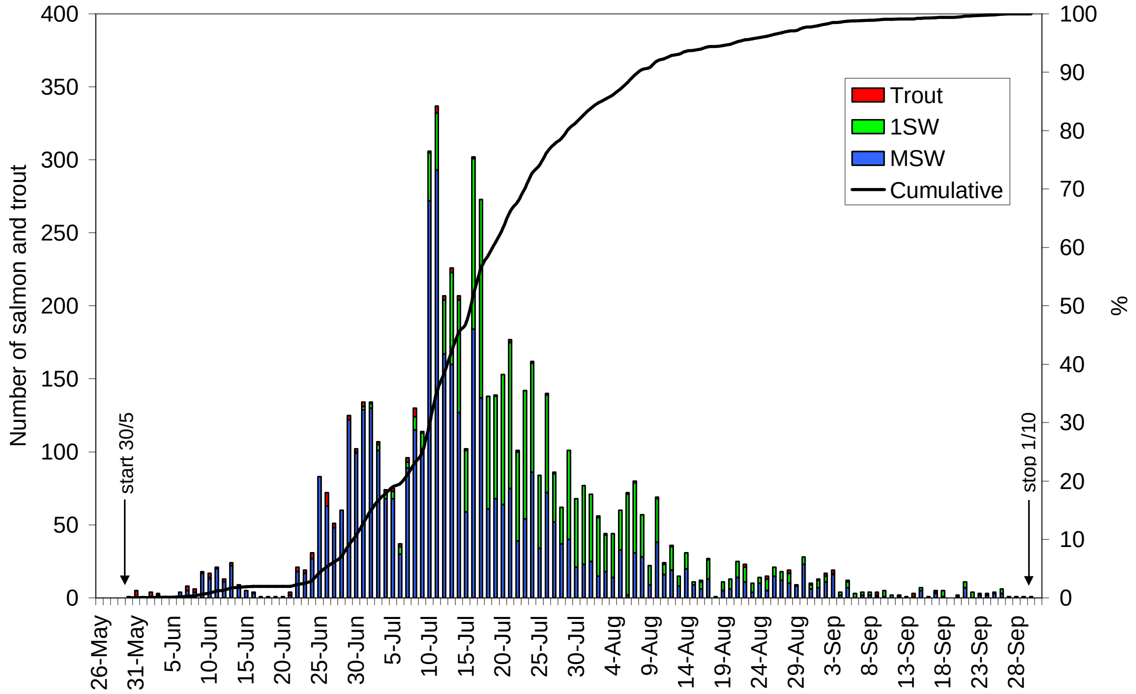

Figure 11. Number of salmon and trout 2009 registered in the fishladder in Kalixälven (Jockfall) and its cumulative distribution for salmon. Salmon are divided into size categories of 1SW and MSW salmon, based on the aged catch samples (see Fig. 8). Start and stop indicate the operation time for the fish counter.

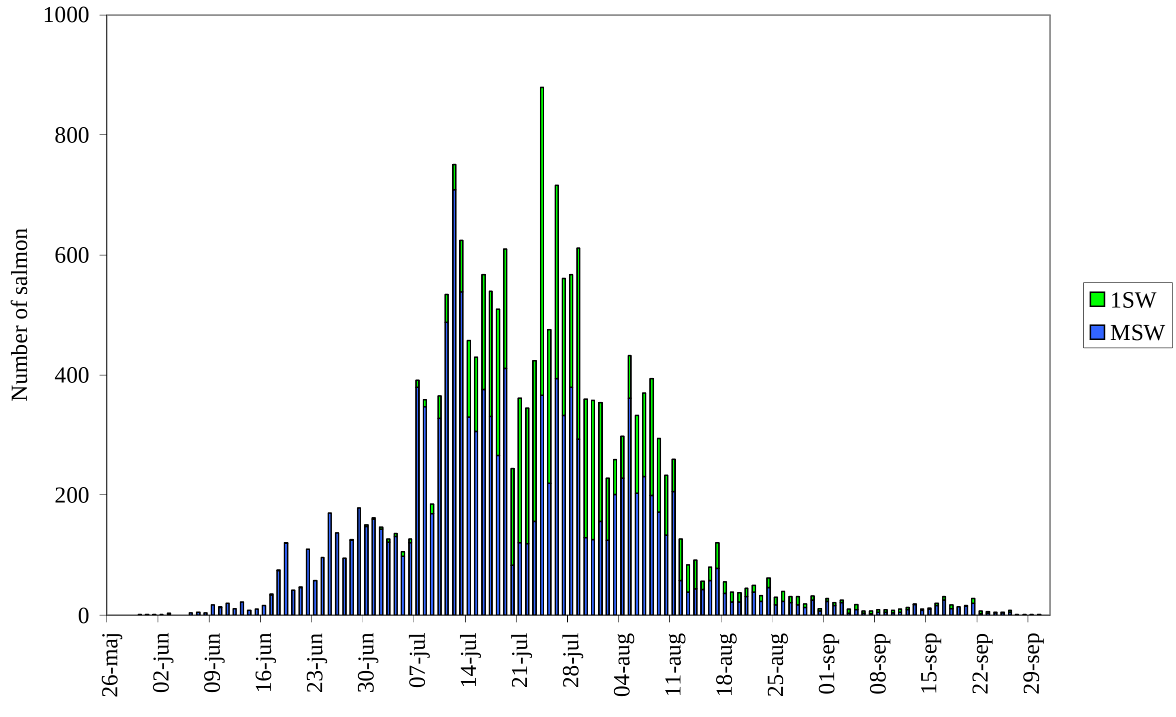

Figure 12. Daily summarised number of salmon for 2007-2009 registered in the fishladder in Kalixälven (Jockfall). Salmon are divided into size categories of 1SW and MSW salmon, based on the aged catch samples (see Table 8).

Judged by the length distribution of the registered salmon in the fishladder, there is a dividing line between grilse and MSW at approximately 65 cm (Fig. 13).

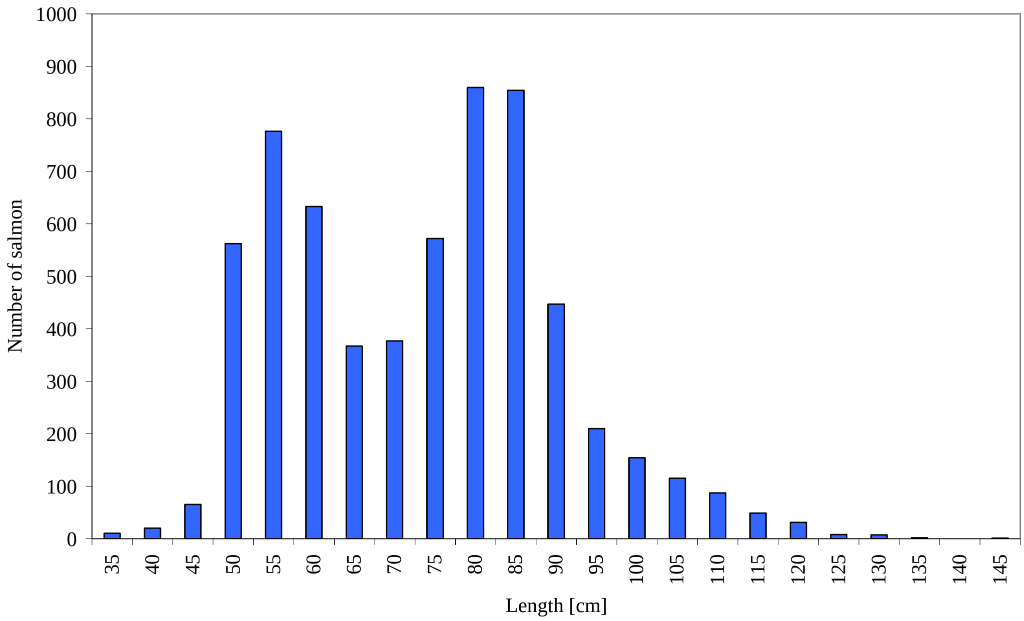

Figure 13. The length distribution in 5 cm classes of salmon in the fishladder in Kalixälven (Jockfall) 2009.

Most of the upstream migration of salmon in Kalixälven was registered in the fishladder during the daytime, 53% of the registration occurred between 09 and 15 (Fig. 14). During the night between 23 and 04 only 6% of the total migration occurred. The pattern of the daily distribution is the same in other Swedish rivers where salmon is registered in fishladders i.e. Piteälven, Åbyälven and Byskeälven.

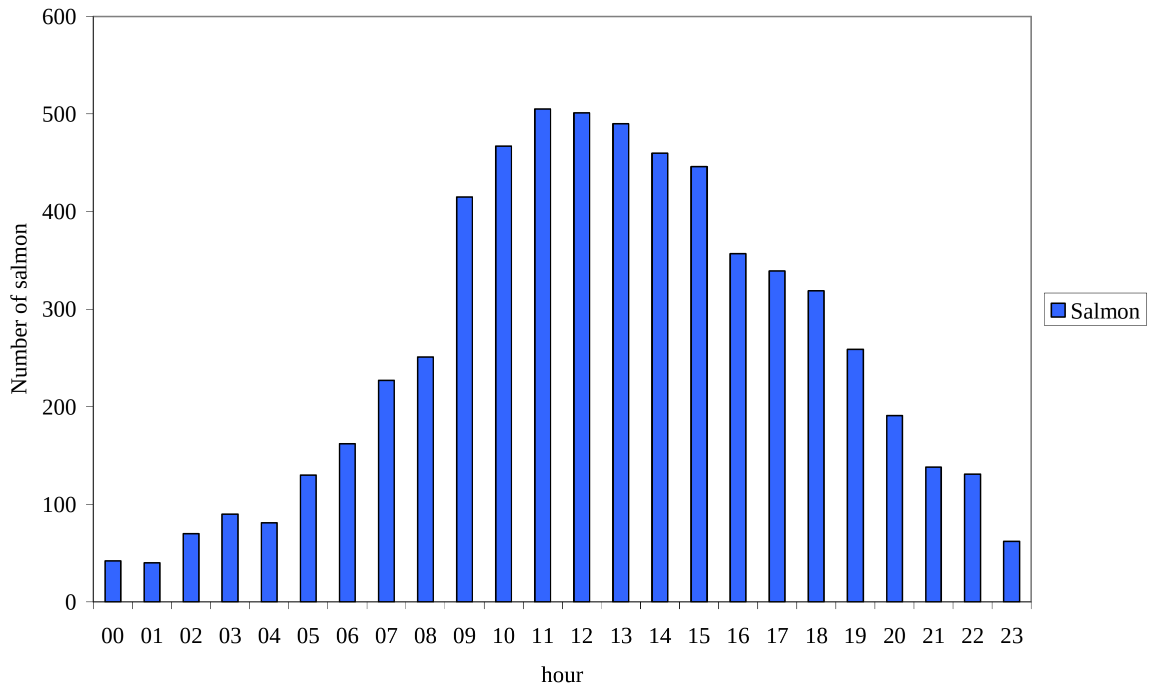

Figure 14. Distribution of salmon passages (grilse and MSW) during a 24-hour period in the fishladder in Kalixälven (Jockfall) 2009.

The mean number of trout passing the fishladder during 1980 – 2009 has been 57 and it has varied between 3 and 139. In the 2009 run, 70% of the total run had passed in the middle of July. No clear pattern occurs concerning size and time for upstream migration (Fig. 15).

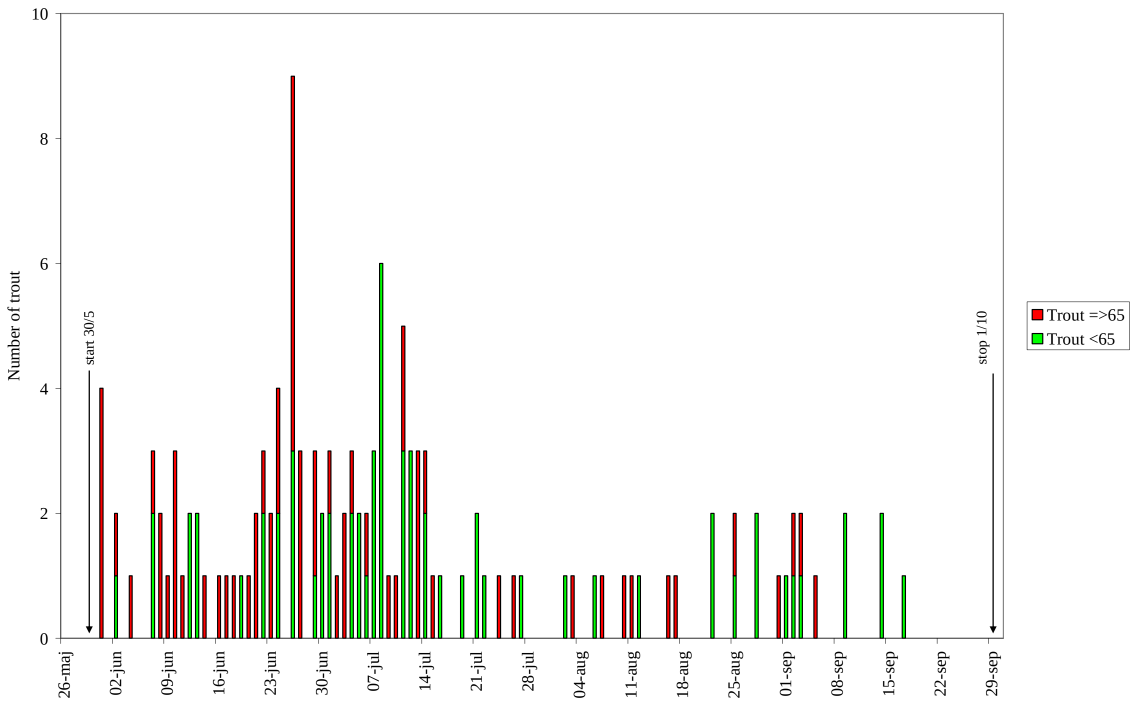

Figure 15. Number of trout, divided into two groups (<65 cm and =>65 cm), 2009 registered in the fishladder in Kalixälven (Jockfall). Start and stop indicate the operation time for the fish counter.

The length distribution shows that half of the trout passing the fishladder was larger than 65 cm (Fig. 16). The 65 cm size limit is only used for comparison with salmon.

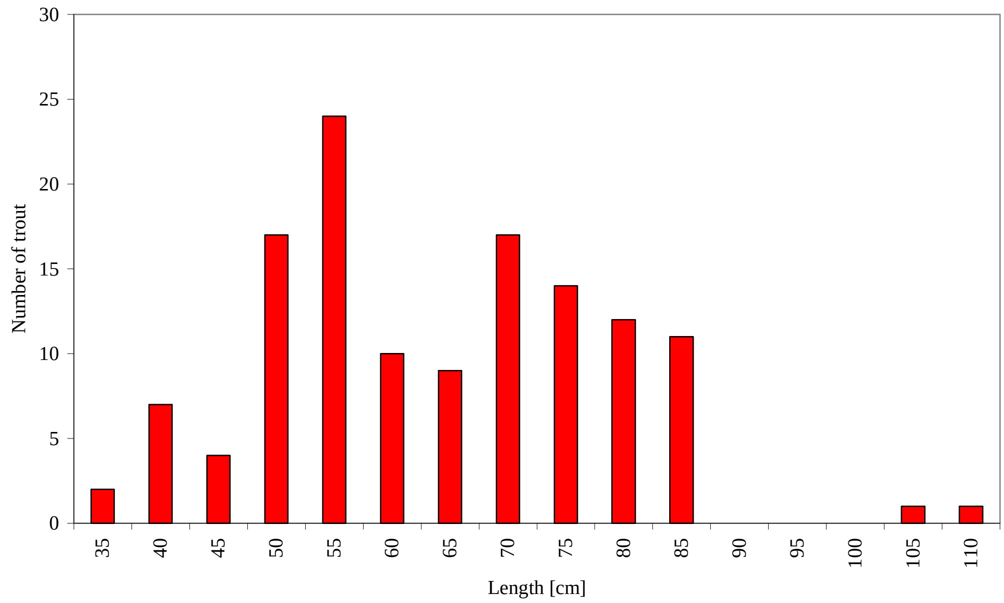

Figure 16. The length distribution of trout in 5 cm classes in the fishladder in Kalixälven (Jockfall) 2009.

The distribution of trout during 24-hour follows the pattern of salmon. Most of the trout was registered during daytime and very few registered during night time (Fig. 17).

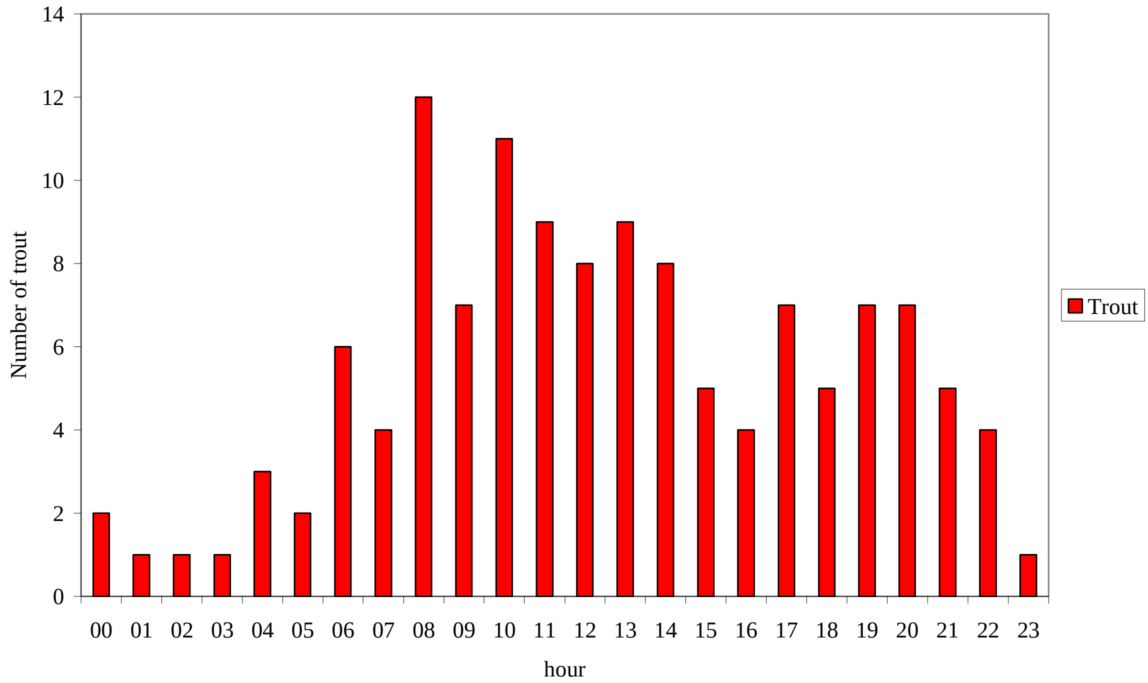

Figure 17. Distribution of trout during 24-hour period in the fishladder in Kalixälven (Jockfall) 2009.

Of other species registered in the fishladder bream and ide dominate and the proportion was 2% and 1% respectively. Only one bream was larger than 65 cm and eight was in the interval of 60-64 cm.

Table 9. Size distribution (5 cm) of other species registered in the fishladder in Kalixälven (Jockfall) 2009.

Length [cm]	Bream	Ide	Whitefish	Grayling
25-29	2	5	4	1
30-34	1	8	5	2
35-39	28	8	6	1
40-44	25	17		
45-49	25	15	1	
50-54	23			
55-59	22			
60-64	8			
65-69	1			

The migrations pattern of bream and ide was almost the same and they were registered in the fishladder from middle of June to middle of August. Most of the withefish passed from the end of August to end of September but the two highest number per day occurred 10 and 14 June (Fig. 18).

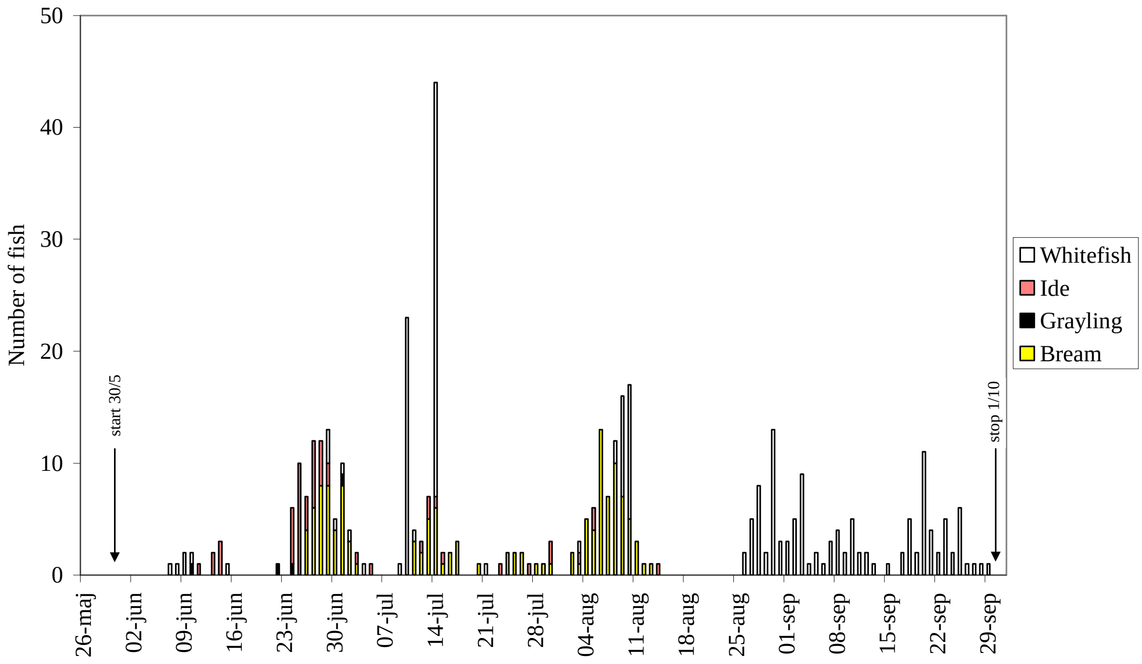

Figure 18. Number of fish belonging to other species registered in the fishladder in Kalixälven (Jockfall) 2009.

5. Results and discussion

5.1. Tornio site

In all 1315 fish (> 60 cm) were measured to move upstream at the Tornio site during the survey period. The daily numbers of migrants fluctuated between 20 – 60 fish/day (Fig. 19). There was no clear peak in the migration pattern during this one month period. Based on the small number of detected fish it is obvious that a large majority of passing fish were not detected at the site, even if the soundings were covered about 1/3 of the river width. Consequently, the most of fish had to migrate on the middle of the channel or on the opposite bank of the river.

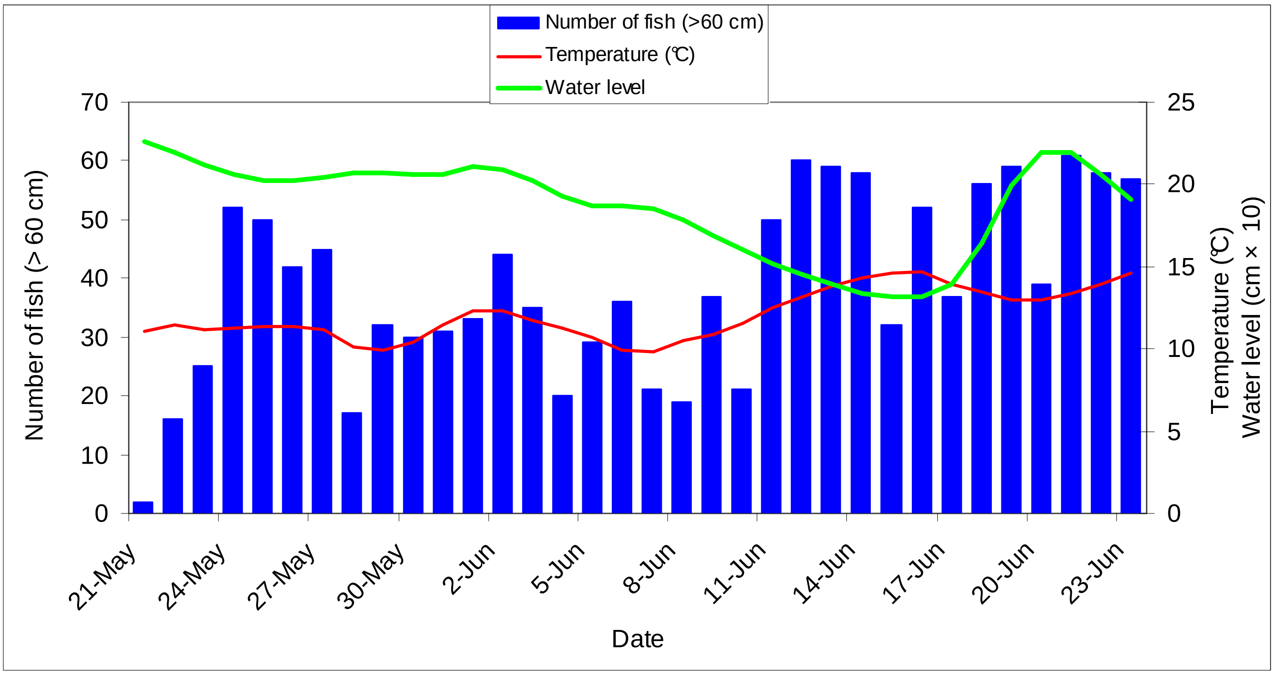

Figure 19. Daily numbers of fish (>60 cm) passed the Tornio site, daily mean temperature and water level measured about 3 km upstream from DIDSON site.

The length distribution of the measured upstream moving fish shows that the most of the fish were in the length class of 65 cm (62.5 – 67.5 cm) (Fig. 20). Other peaks of the length distribution were in the length classes of 80 cm, 95 cm, and 110 cm. All those peaks could be also found in the length distributions of Kattilakoski data.

The distance of fish from the DIDSON transducer varied from 10 – 88 m and showed a relative strong bimodal distribution with peaks at 37 m and 65 m (Fig. 21). The east pillar of the bridge was situated 81 – 83 m from the DIDSON and a small proportion of fish could be detected to swim upstream out of the pillar.

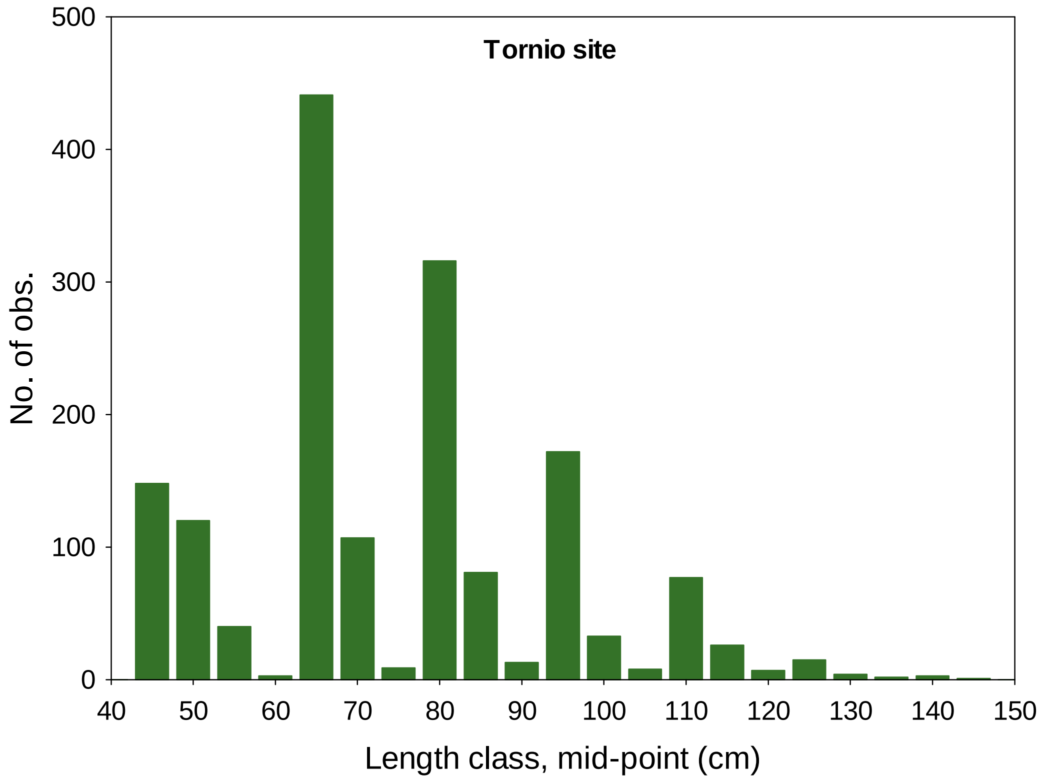

Figure 20. The length distribution of all measured upstream fish in the Tornio site.

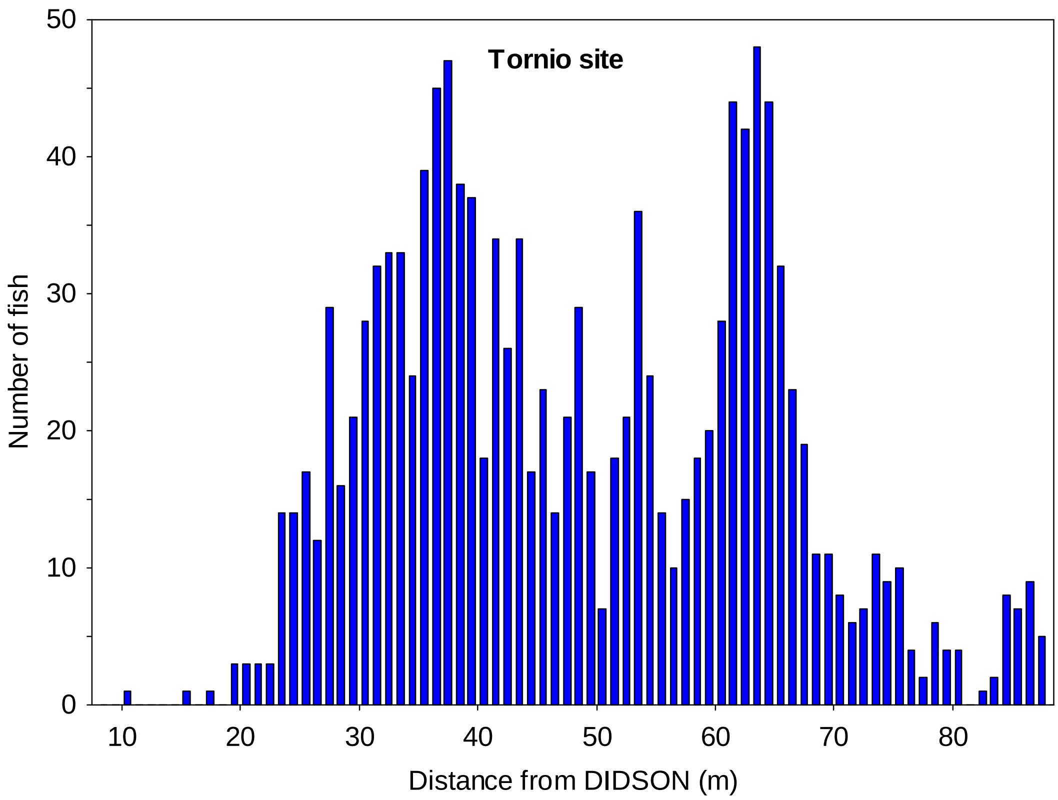

Figure 21. Spatial (horizontal distance from DIDSON) distribution of upstream moving fish (> 60 cm) on Tornio site.

5.2. Kattilakoski site

5.2.1. Daily counts

The expanded 2009 fish escapement estimate through the Kattilakoski site was 26 700 upstream fish that were larger than 60 cm and 5740 upstream fish with a size of 45 – 60 cm. Thus, the total escapement estimate through that site was 32 440 upstream migrants in 2009. Figure 22 displays the daily and cumulative counts (fish > 60 cm) for the river in 2009. The 2009 upstream migration began around May 27 and finished on the end July. The daily escapement plot displays multi-modal run timing with a maximum daily net upstream escapement estimate of 1130 fish on July 5, 2009 (Fig. 22). The halfway point in the 2009 run, when 50% of the total estimate had passed the Kattilakoski site, occurred on June 27.

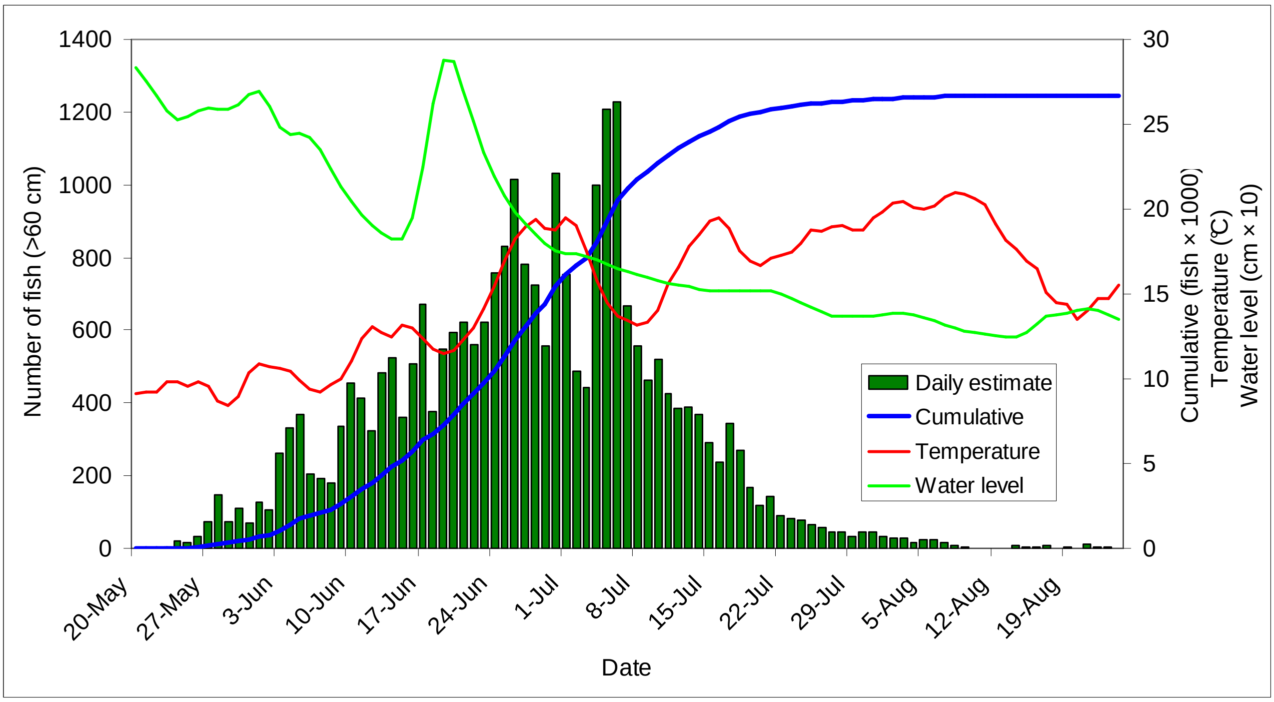

Figure 22. Daily numbers of fish (>60 cm) passed the Kattilakoski site and its cumulative proportion. The water temperature and water level at Pello (about 40 km upstream of Kattilakoski).

The upstream migration of the smaller fish (45-60 cm) started also on the last week of May (Fig. 23). There were in particular two periods when the smaller fish passed the Kattilakoski sampling site. First, the week in mid-June, when about 850 fish passed the site. Second, the whole July was an active migration period. During August, only a few fish of any size category were observed to move upstream through the Kattilakoski.

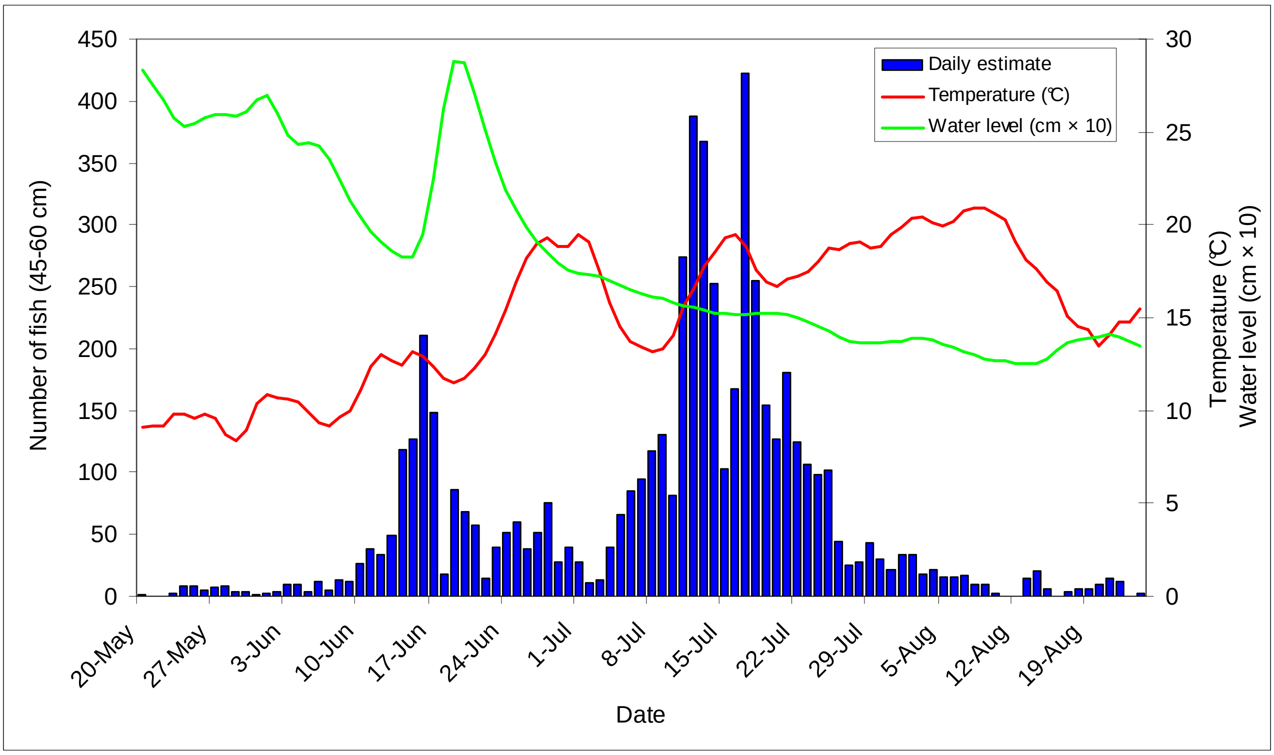

Figure 23. Daily numbers of smaller fish (45 - 60 cm) passing the Kattilakoski site, the water temperature and water level at Pello (about 40 km upstream of Kattilakoski).

5.2.2. Length distributions

The length distribution of all measured upstream moving fish shows that about 4500 fish were included in the length class of 65 cm (62.5 – 67.5 cm) (Fig. 24). There was no difference between length distributions in data recorded from the Finnish and Swedish shore (Fig. 25). The length distribution of measured fish with different distance from sounders shows that the proportion of smaller fish was bigger at a short distance from shore than further afield (Fig. 26).

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. Consequently, we will need to put more effort to confirm and adjust our DIDSON length measurement in following years.

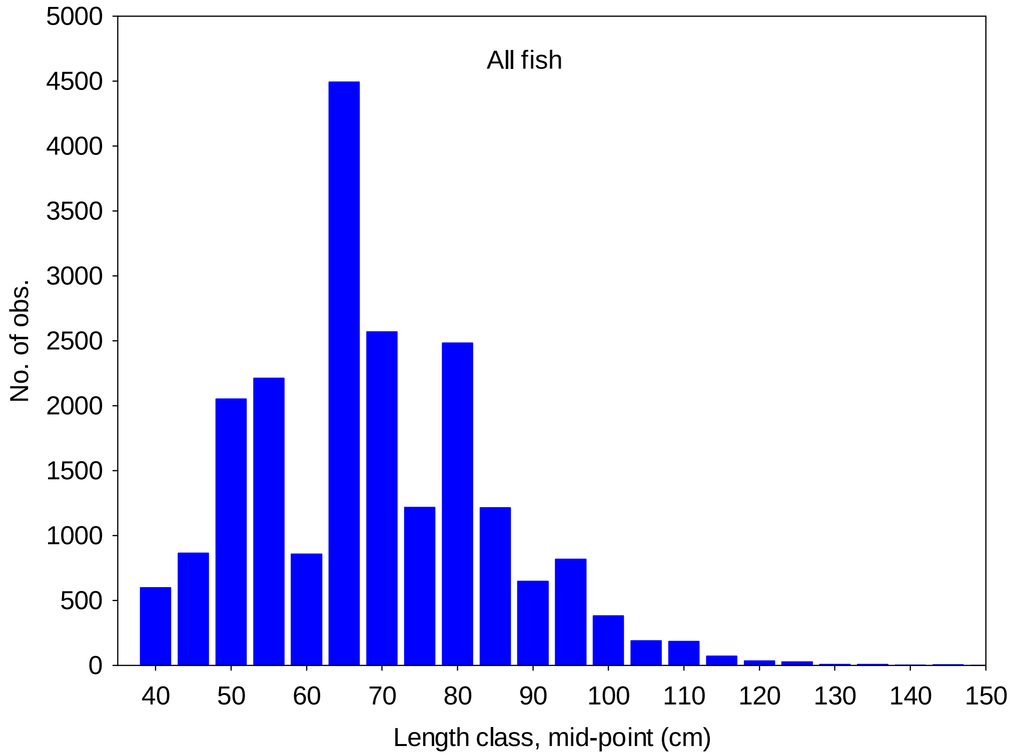

Figure 24. The length distribution of all measured upstream fish in the Kattilakoski site.

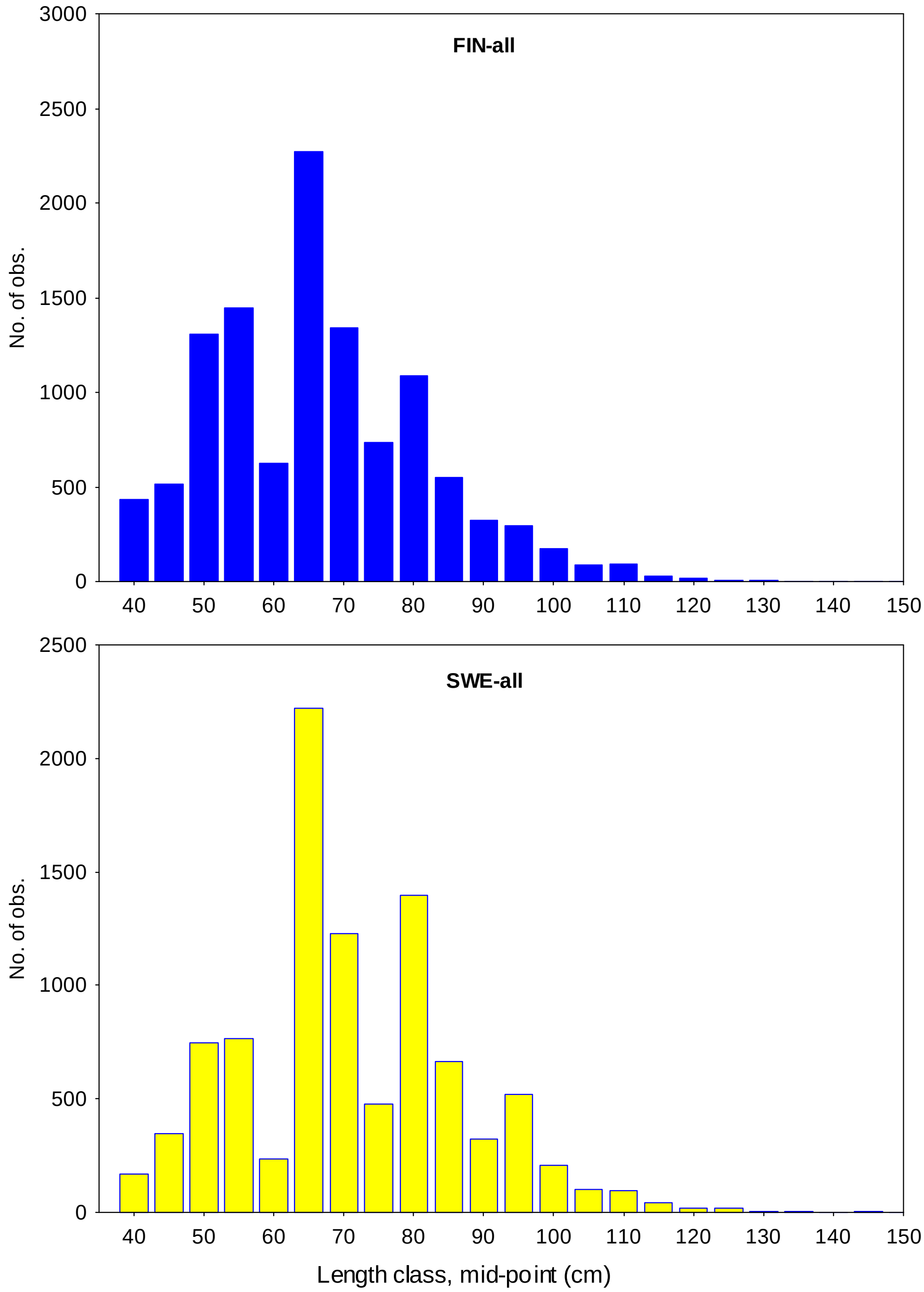

Figure 25. Length distributions of all measured fish in Finnish (FIN-all) and Swedish (SWE-all) shore.

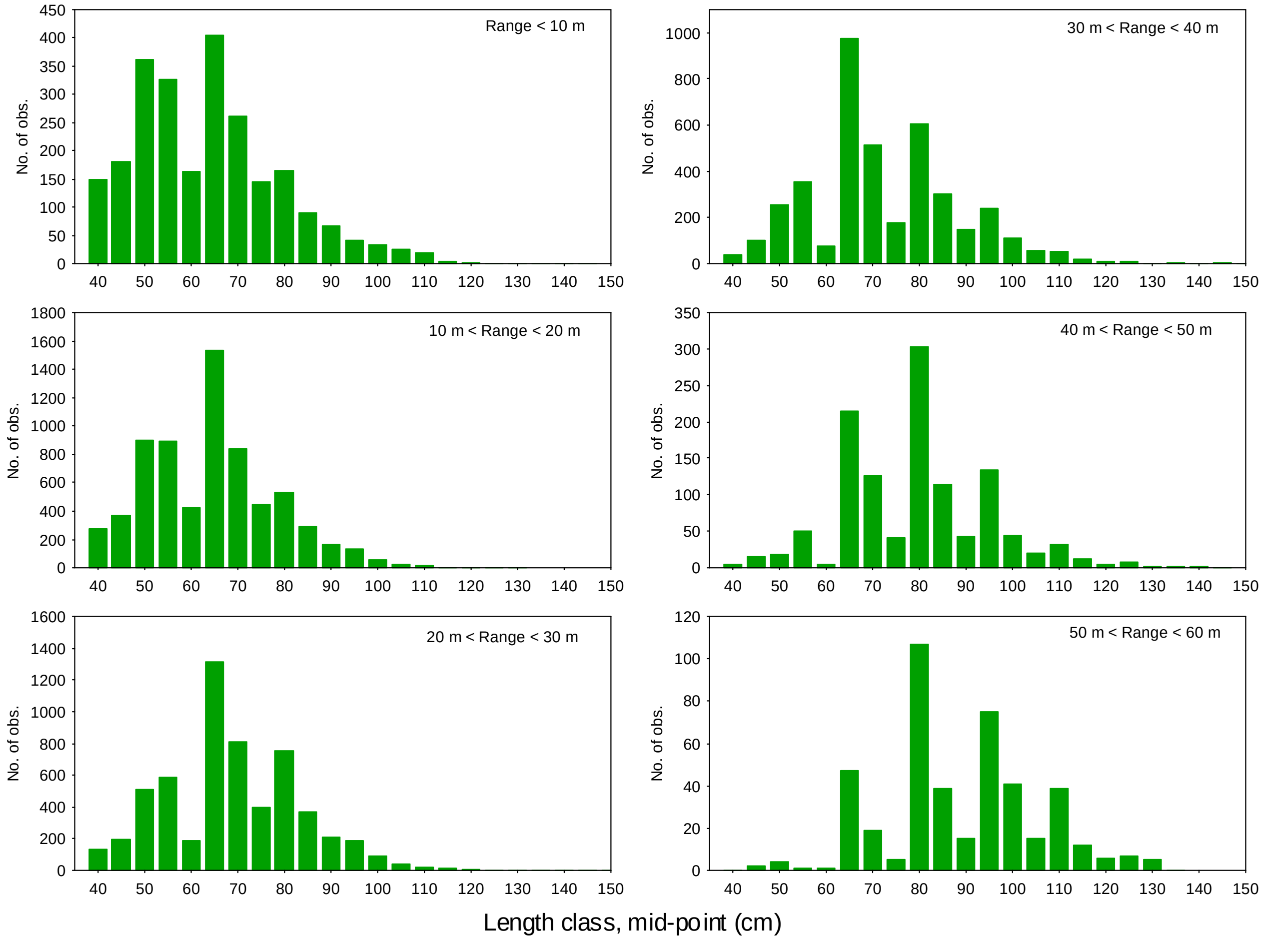

Figure 26. Length distributions of measured fish at six distances from the sounder.

5.2.3. Spatial distribution of observations across river

On the Finnish side of the river, upstream fish were shore-oriented (Fig. 27 & Fig. 28). 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.

On the Swedish side of the river, most fish were observed to swim upstream at a distance between 10 – 40 m (Fig. 27 & Fig. 29). There were some minor peaks at a distance of about 20 m, 30 m, and 40 m. The water velocity on the Swedish side of the river was not as fast as on the opposite side so the fish were able to spread more when travelling upstream.

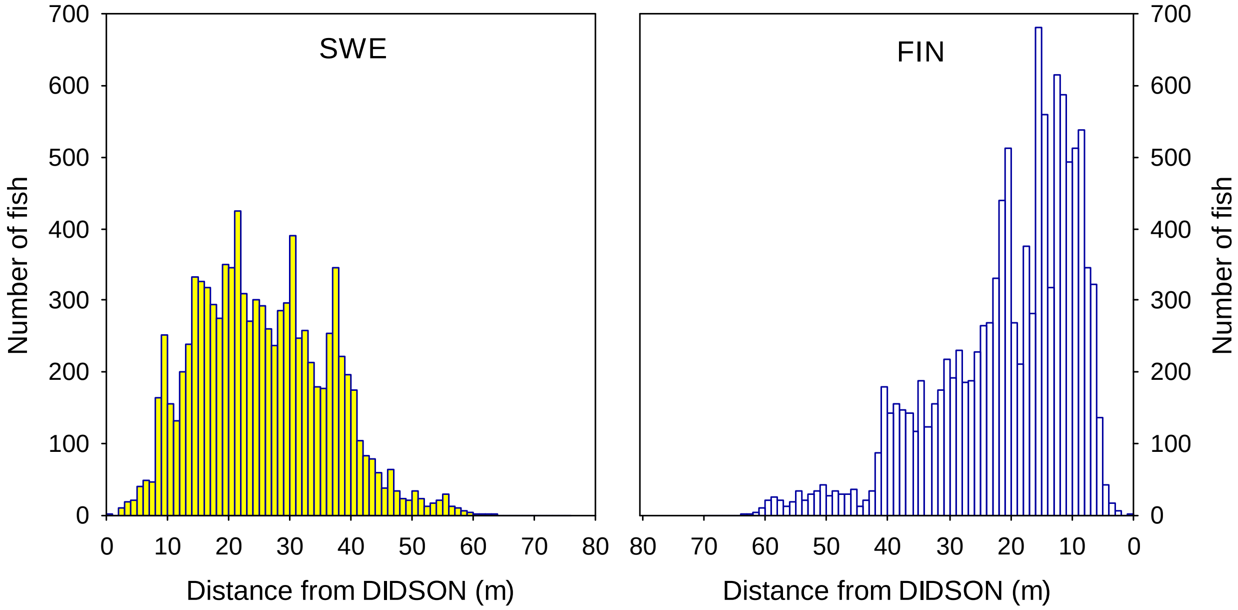

Figure 27. Spatial (horizontal distance from DIDSON) distribution of all observed upstream moving fish on the Swedish (SWE) and the Finnish (FIN) sides of the river. Note that in both histograms the numbers of observations are biased after 42 m owing to sampling design.

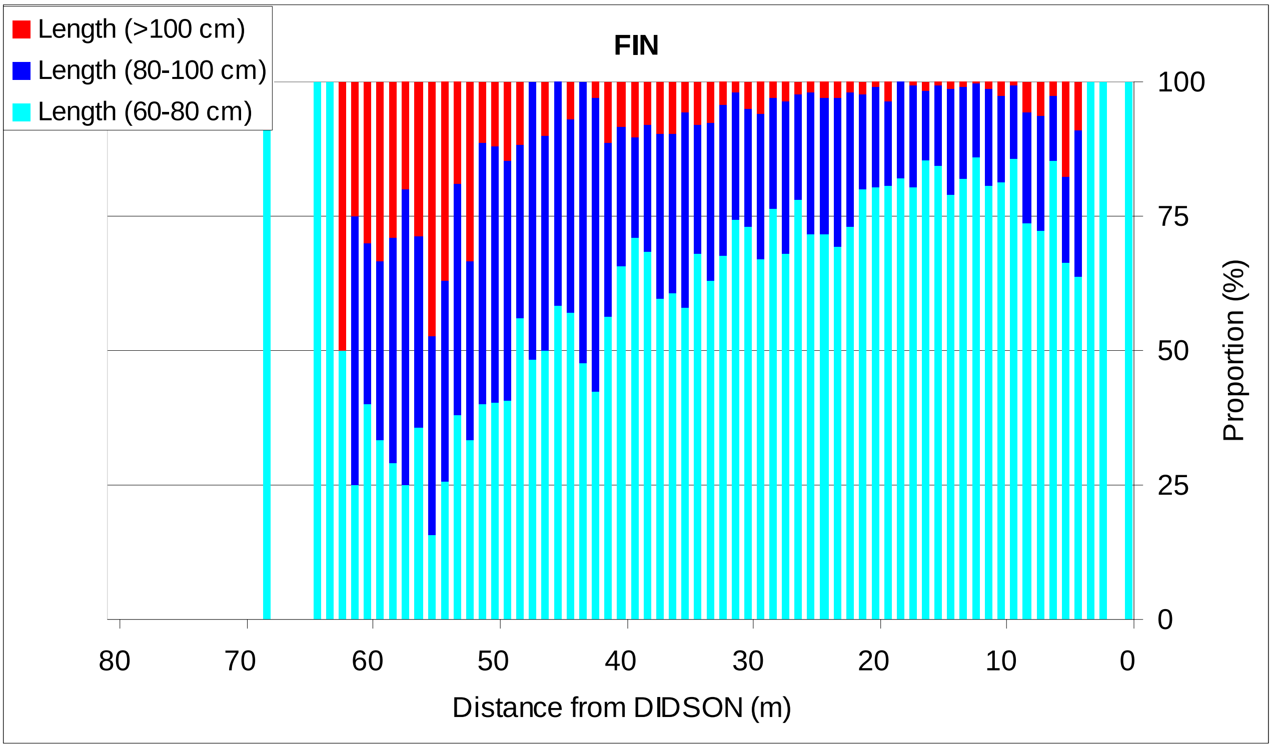

Figure 28. Spatial (horizontal distance from DIDSON) proportion of fish (length > 60 cm) on the Finnish side of the river split in three size group. Note that DIDSON is situated on right.

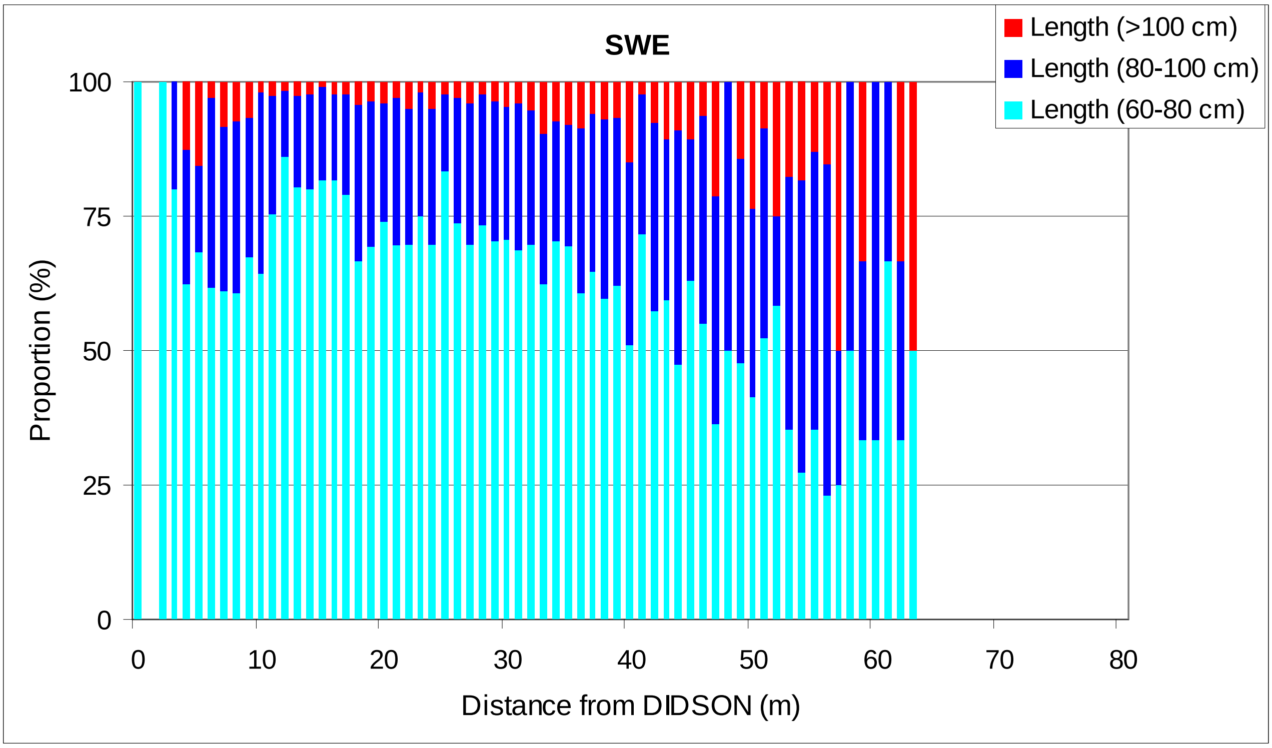

Figure 29. Spatial (horizontal distance from DIDSON) proportion of fish (length > 60 cm) on Swedish shore split in three size group.

5.2.4. Double counted DIDSON files

The results of the double counted data set are presented in Table 10. The Swedish counter got the total number of 453 salmon-size fish where the Finnish counter got 451 fish. These results proved that the both counters were able to see almost the same number of fish but there were some differences in the daily and hourly counts. As mentioned in chapter 3.4, the analyzed data set was same but depending on the time or the time-zone settings of the post-processing computer the time stamp in the output file differed between the two counters. We tried to correct the problem by moving the “unexpected” fish to the next hour that was included in the data set. Even though the total number of counted fish is in good agreement, there is a considerable disagreement in some days and the reasons for the deviations need to be further checked.

Table 10. Data sets that were counted by both a Swedish (SWE) and a Finnish (FIN) observer.

SWE

Hour / Date	4-Jun	10-Jun	15-Jun	23-Jun	3-Jul	12-Jul	18-Jul	24-Jul	1-Aug	Total
0	1	8	14	4	23	10	10		1	71
4	6	8	9	10	8	1	8	4	1	55
8	15	10	23	15	8	5	16		4	96
12	5	5	9	6	6	30	9	7		77
16	6	8	16		1	8	28			67
20	9	15	14		14	24	8		3	87
Total	41	46	85	35	60	78	79	12	8	**453**

FIN

Hour / Date	4-Jun	10-Jun	15-Jun	23-Jun	3-Jul	12-Jul	18-Jul	24-Jul	1-Aug	Total
0	1	8	13	3	22	11	11		1	70
4	5	8	9	10	11	2	6	4	2	57
8	15	6	21	17	9	6	17		4	95
12	4	5	9	6	7	44	10	9		94
16	7	9	7		2	13	13	6	1	58
20	8	13	6		12	27	9		2	77
Total	40	49	65	36	63	103	66	19	10	**451**

5.3. Inferring total salmon run into the river from the monitoring results

Chapter 5.2.1 provides an estimate of the number of fish that migrated upstream through Kattilakoski counting site. In order to get an estimate of the total number of salmon passing the site, the counts must be corrected for:

a) the likely errors in length measurements, which in turn will affect the total number of fish that are inferred to be potential salmon (chapters 4.1.1 and 5.2.1); and
b) the estimated occurrence of other species than salmon in the counts (chapters 4.1.2 and 4.2)

Once there is an estimate about the number of salmon that passed Kattilakoski, one must add to this the number salmon that:

c) were caught by river fishing below Kattilakoski (chapter 4.1.4); and
d) stayed and spawned below the counting site Kattilakoski (chapter 4.1.4),

in order to get an estimate of the total salmon escapement into the River Tornionjoki.

a) Correction of length measurements

The length distribution of upstream migrants at Kattilakoski fits poorly with the length distribution of caught salmon (chapters 4.1.1 and 5.2.2), 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 70 (67.5-72.5) cm. This coincides with the threshold length 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 a 5-10 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 5-10 cm (10-20%) longer than the measured lengths. Whether similar error occurs also at the largest length categories is unclear. 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. The caudal fin of salmon and trout makes up about 10-11% of the total fish length.

Consequently, we increased 11% to all the measured lengths and used this revised data as the basis of further calculations of salmon abundance (Fig. 30). It is however important to note that the basis of this correction must be further investigated and verified in the future data collection.

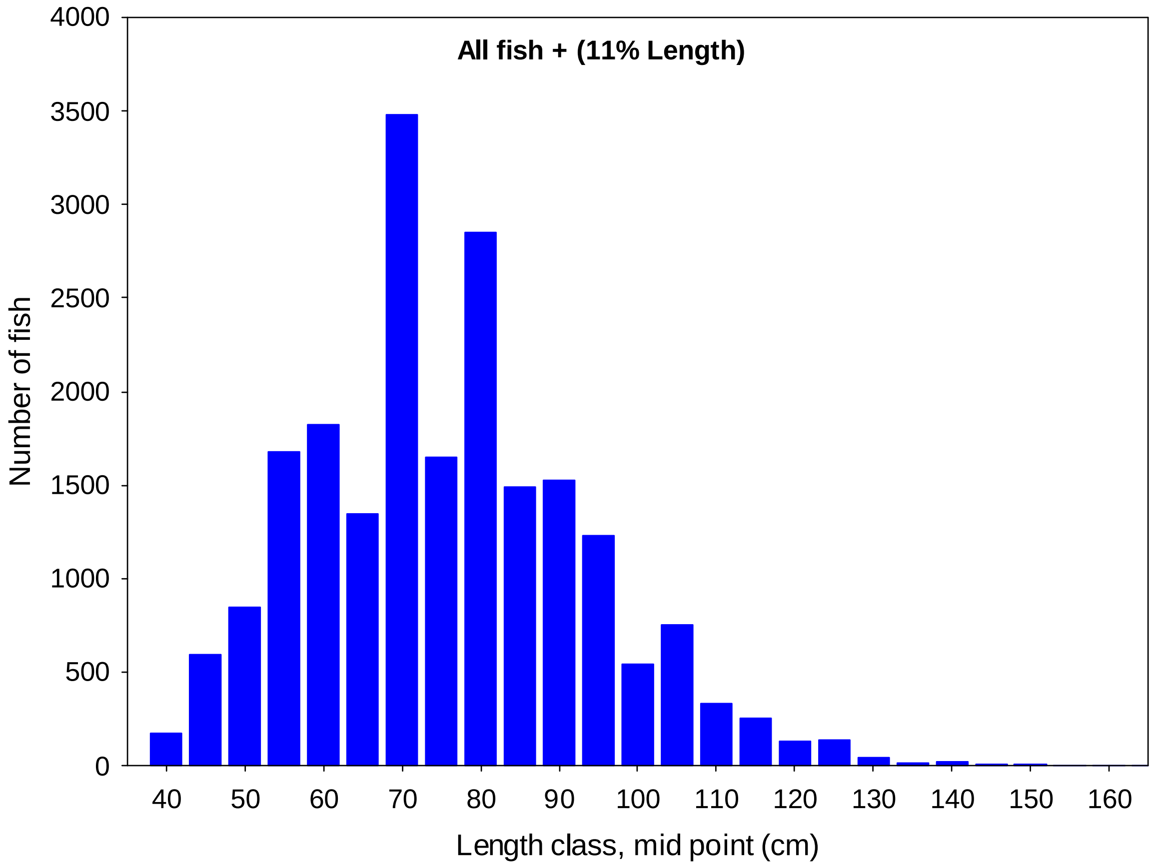

Figure 30. The length distribution of all measured upstream moving fish in the Kattilakoski site corrected with 11% gain in individual lengths.

b): Correction for estimated occurrence of other species

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 these information we filter out other species and conclude that the remaining fish are salmon.

The length distribution of sea trout greatly overlaps with salmon (mainly grilse; chapter 4.1.1). However, sea trout migrate upstream before July, i.e. before grilse migration starts at Kattilakoski (chapter 4.1.2). Consequently, we assume that all fish detected before July and being smaller size than the minimum size of MSW salmon (<67.5 cm) are non-salmon, presumably sea trout.

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 (chapters 4.1.3 and 4.2). 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 July (as described above) is likely to filter out most of the other species as well.

Resulting counts of salmon and other species in Kattilakoski

After the preliminary correction of length measurements (a) and the separation of salmon from other species (b), the resulting estimates of upstream migration through the Kattilakoski is 31 780 salmon and 2130 fish of other species (mainly sea trout). Salmon counts can be further divided between grilse (5420 ind.) and MSW salmon (26 360 ind.). Figure 31 shows the daily estimates of these fish categories. The median date of salmon migration (grilse and MSW salmon combined) was the 1 July.

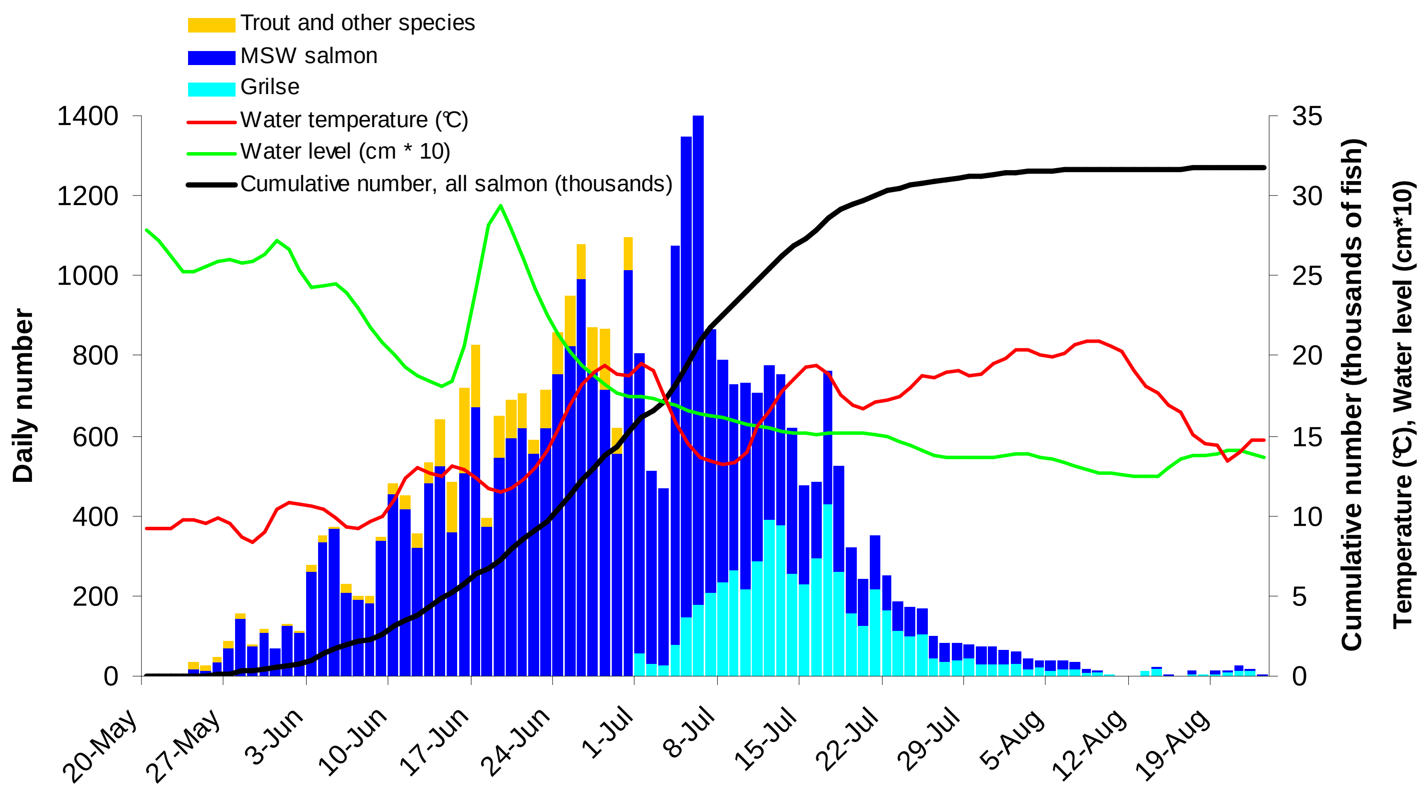

Figure 31. Corrected daily estimates of net-upstream fish in Kattilakoski counting site. Measured fish length was increased by 11% and the threshold length between grilse/trout and MSW salmon is 67.5 cm. Fish shorter than 67.5 cm are regarded as grilse if they migrated after June, but if they migrated before July they are regarded as other species than salmon.

c) and d) Adding salmon which entered the river but did not pass the Kattilakoski site

2-6% of salmon juvenile production may originate from below Kattilakoski (chapter 4.1.4). 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.

The estimate of salmon catch below Kattilakoki in 2009 is 858 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, 2-6% of the downstream catch was salmon that would have stayed below Kattilakoski.

Resulting total number of salmon entering Tornionjoki in 2009

Based on all the simplifying assumptions made here and in chapter 4.1.4, 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*(31 780 + 0.98*858) = 33 290

Run size assuming 6% of abundance below Kattilakoski = 1/0.94*(31 780 + 0.94*858) = 34 670

It is important to note that a 15-20 meter wide mid-channel area at Kattilakoski could not be fully covered by DIDSON monitoring, as the near-bottom area was in constant shadow (chapter 6.2). In the above calculations it is assumed that no salmon passed the monitoring site through this shadow area. If this assumption does not hold, then the estimates should be raised. However, the shadow area makes up only about one tenth of the river width and salmon were observed to be shore-oriented (within the range of detection), which both point to the conclusion that only a minor proportion of the total salmon run was missed due to the shadow area. Future investigations may provide information about the mid-channel migration of salmon at the site.

6. Problems with data collection

6.1. Tornio

With the current technique it is too difficult and costly to try to cover the whole river transect at Tornio by the DIDSON monitoring. Therefore, the monitoring at Tornio must so far be based on the idea of detecting only a sample of upmigrating salmon and use that as an index of the timing of migration into the river.

Clearly, one of the main challenges in this procedure is how to detect a representative sample of salmon. Salmon may swim in different parts of the river transect at different flow and water temperature (even turbidity) conditions. Also, salmon of different size may utilise different parts of the river transect, as indicated by the results from Kattilakoski.

The problem of how to identify salmon and separate them from other upmigrating species is much bigger at Tornio than at Kattilakoski: large spring-spawning species like pikes may enter the river from the sea and spawn there, sea trout may dwell close to the estuary area and enter/leave the river infrequently, and migratory whitefish start to enter the river around the same season with grilse and their size distributions partly overlap.

The small amount of salmon sized fish detected at Tornio in June 2009 indicates that the chosen monitoring site is probably not suitable for the index monitoring. The part of the river transect that was covered by the DIDSON seems to be off the main migration paths of salmon and the monitoring results may therefore be especially vulnerable to e.g. changes in the river conditions. The length distribution of the detected fish indicates that length measurements are imprecise, which makes species identification difficult.

6.2. Kattilakoski

As mentioned earlier, thunderstorms were the main reason for interruptions of data collection at Kattilakoski. The entire field season, incoming power lines were protected by UPS-devices on both shores, however, that did not protect the underwater devices. We consulted with people in Sound Metrics Corp. (manufacture) but they did not have any direct in-season application suitable for solving that problem. Consequently, after the field season 2009, all DIDSON units were sent back to the manufacturer, where an internal surge protection was installed.

There were also some problems with drifting debris that stuck to the surface of DIDSON lenses. That did not interrupt the data collection but it decreased the image quality and the measurement accuracy of fish. The worst situation occurred in the middle of June, when the downpour mixed the pollen of the pine into the water. The drifting pollen covered the lenses of DIDSON and blocked the emission of sound beams (Fig. 32). The decreased image quality was noticed on the next day and all lenses were cleaned immediately.

Figure 32. A clean (left) and pollen covered lens (right).

Each DIDSON sonar assessment projects should likely have to perform a beam-mapping protocol with fish sized targets or establish by some other means that all fish above a certain size within the field of view are being detected and can be followed as individual fish through the horizontal array of beams. We were able to determine the maximum distance of detection without any acoustically shadowed areas within the field of view. DIDSON beams were not able to reach the bottom at the deepest part in the middle of the river (dark blue area in Fig. 3). This area was about 15 – 20 m wide and it extends similar both upstream and downstream from the exact sounding site.

Throughout the season fluctuating water levels resulted in frequent relocation of sounders and stands. On the upper part of Kattilakoski, mounting of the system at high water levels was a dangerous task due to the high water velocity and slippery rocky bottom. Therefore, only slight movements could be done and they had to be repeated several times per month. Adjusting the system according to changes in water level is also a data quality issue because the sound beams have to be re-aimed after relocation and some changes in detection probability could occur. Interference between DIDSON units facing each other has to also be taken into consideration when re-aiming both systems. This does not block out fish echoes but may confuse counters and make not see all fish. Moreover, automatic counting software had serious problems when two systems were cross-talking.

7. Problems with data processing

The DIDSON software has several tools to assist the user in measuring and recording the lengths of selected fish. However, the user selected pixels that define head and tail of the fish are the most critical areas of the measurement procedure. According to Cronkite et al. (2006), the bias in the length measurements made with DIDSON system may be due to three factors:

1. Uncertainty in what we are actually measuring with DIDSON – fork length, total length, or something else.
2. Acoustic beam spreading with range, including the fact that a beam sample cannot be partially occupied by a target.
3. Decreased image resolution with increased range, which limits measurement resolution.

Consequently, the empirical length measurements with salmon-sized target should be carried out on-site in future, which would increase the confidence in the DIDSON length measurements of the salmon population.

Species identification with the DIDSON system is based on the figure identification of fish from a dorsal aspect. Therefore, this feature is very limited and only length measurements were used to distinguish small-sized species from others. However, by using the maximum resolution of DIDSON (very short window length), more detailed information could be seen and some species would be distinguished, but with the long window length different fish species with the same size can not be distinguished from each other.

8. Costs and benefits

Use of DIDSON system for counting upstream migrating salmons in the River Tornionjoki did have a high initial capital cost associated with the purchase of DIDSON systems and required equipments such as computers, motorboat, stands for sounders, and fish deflection weirs. Excluding the capital costs of the DIDSON systems itself, the operational costs of project were similar to project where personnel were required to work during the day. In general, the day-to-day operation of a DIDSON fish counting project could be handled by 2 to 3 trained personnel for most tasks, especially data processing and analysis. However, extra personals would be needed for a short period during the set-up of the sounders and weirs. Moreover, due to the expensive and valuable equipment, an electronic onsite security system was required.

An important benefit of using the DIDSON system to count upstream migrating salmon is that daily estimates of upstream migration can be provided, usually the following day. This timeliness in the delivery of data allows the examination of migration patterns from the beginning to the end of the migration, hourly and diurnal variation in passage rates, and cumulative escapement to a river system. Timely data on cumulative escapement may be useful to fisheries managers to fine-tune adjustments to in-season fisheries to achieve specific escapement goals. A preliminary escapement estimate is therefore available as soon as the migration period ends. The data also allows the accurate plotting of the daily run timing curves in-season. Moreover, the fixed-location, side-looking sonar techniques are often the only way to obtain in-season count estimates for migrating fish stocks in rivers, which are too wide for weir structures and too occluded for visual observations. The DIDSON sounder is also easy to aim and easy to operate, compare e.g. split-beam sounder, resulting in minimal operational errors, and subsequently a higher level of accuracy in the count results of system.

9. Future development of monitoring

On following years, the field crew will conduct random daily double counts (two observers count the same file) e.g. 1 or 2 times daily on both Swedish and Finnish shore DIDSON units each for a total of 2 - 4 double counts/day. Thus, we will assess the precision of the DIDSON counts 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. Further, if data of any hour or day will be missed, the variance estimator will be derived and the confidence intervals of upstream migrants will be calculated by adding the variance components of different sources (Eggers et al. 1995, Lilja et al. 2008).

Considerable time would be saved if the automatic counting software will function exactly and provide accurate counts of upstream moving fish. Until that time, each fish will need to be manually measured to ensure data integrity.

Length measurement from fish images needs to be improved and verified. This work includes, among other things, comparison of different length measurement practices, empirical tests of length measurements with artificial or real fish targets of known size, and continued comparisons of the length measurements with the length frequencies observed in the catch.

The mid-channel shadow area at Kattilakoski must become covered by, e.g. periodic monitoring. The first step is to check if salmon is using this area at all for upstream migration. If there are indications that salmon do occur in this part of the river transect, then either a continuous or periodic monitoring must be organized, allowing assessment of total numbers of salmon swimming in the area. A third DIDSON unit need to be used and special mounting technique must be developed in order to be able to cover the mid-channel section in various flow conditions.

DIDSON equipment must get better protected against breakdowns due to thunderstorms. Already next summer a wireless technique will be tested as a connection between the computer and the rest of the equipment. Moreover, batteries will be used as power supply for the underwater parts of the equipment. This setup does not need long cables (which may easily create electric fields with voltage differences) and no voltage peak can reach the underwater parts of equipment through mains current or computer cable.

Provided that good sectors can be identified along which the DIDSON beams can always be successfully aimed across the river, more permanent mounting systems for the transducers and the fish deflection weirs could be planned and built up. This would make monitoring easier, safer, labour-saving and more reliable in a long run.

In order to obtain an estimate of total salmon run into the Tornionjoki, the number of salmon that will not pass the Kattilakoski site (spawning below the site, salmon catch below the site) must always be assessed. The assessment procedure that is presented in this report (chapter 5.3) could be improved. For instance, the current Swedish catch statistics do not allow separate catch estimate for the fishing below Kattilakoski. A special study using radio telemetry to track tagged salmon would give information on in-river behaviour and distribution of salmon spawners.

Finally, obtaining direct information concerning the timing and dynamics of river entry of fish would require more test runs with a DIDSON unit at various sites near the river mouth (Tornio area). Even several DIDSON units may be required to verify means for obtaining representative run timing information. A large-scale telemetric study with a close tracking of migration routes of tagged salmon near the river mouth would possibly reveal suitable monitoring sites of the river entry.

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