Sveriges lantbruksuniversitet
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Examensarbete i ämnet biologi

Department of Wildlife, Fish, and Environmental studies
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Abstract

Atlantic salmon (*Salmo salar*) depends on two major migrations to fulfil their life cycle, from their birth place in rivers to sea, and back upstream the river again to spawn. Salmon stocks have been heavily reduced during the last century due to human activities such as hydropower and timber floating. Construction of fish ladders and restoration of rivers are recent management actions taken aiming at improving the remaining salmon stocks. Salmon are monitored during their migrations to get information on the stock status. This study focused on how environmental factors correlated with adult salmon upstream spawning migration data from two rivers in northern Sweden, Västerbotten County, Umeälven and Byskeälven. Salmon data from both rivers were obtained from fish counters placed in fish ladders. The fish ladder in river Umeälven was equipped with two VAKI fish counters, and salmon data from 2010-2013 was used. Salmon data from 2009-2013 from river Byskeälven were used, the fish ladder was equipped with a PORO fish counter 2009-2012, and a VAKI fish counter 2013. There were three questions that led the study; (I) which environmental variables can explain the daily variations in salmon upstream migration? (II) Are there any major differences between the factors influencing salmon spawning migration in an exploited river compared to an unexploited river? (III) Can an environmental factor be of greater or less importance for salmon upstream migration during the first and the last half of the season? Stepwise linear regressions were used to create models to find how the environmental factors correlated with salmon upstream migration. Both rivers had a seasonal migration pattern with most of the salmon migrating early in the season. Water flow had most influence on the salmon upstream migration in the studied rivers. There was a difference in which environmental factors had most influence on salmon migration between the first and second 50 % of migrating salmon in river Byskeälven. Adjusted Julian day number explained most of the migration in the best model for the migration first half of the season. Water temperature, water flow, and adjusted Julian day number explained the migration in the second half of the season.

Key Words: Environmental factors, VAKI, fish ladder, water flow, water temperature, seasonal migration pattern

Background

Atlantic salmon (*Salmo salar*) is depending on two migrations, from and to fresh water, to fulfil their life cycle, as juveniles to migrate to sea and as adult returning to their birth site to spawn (Klemetsen *et al.*, 2003, Jonsson *et al.*, 1991). Migrations have been hindered in many rivers by hydropower dams and timber floating, resulting in the decline or even elimination of salmon stocks (ICES, 2014, Klemetsen *et al.*, 2003, Thorstad *et al.*, 2003b, Rivinoja *et al.*, 2001, Karlsson and Karlstrom, 1994). Fish ladders have been built to give the salmon a chance to pass the dams and access their spawning grounds and the fish ladders are equipped with fish counters and cameras. Many Atlantic salmon stocks in these rivers are being monitored and counted as they return from the sea to their home waters to spawn (Gowans *et al.*, 1999). This gives a good base of information to compare migrating salmon within and between years and to monitor salmon stock development. Despite intense monitoring, little is known about how and which environmental factors affect Salmon within stream migration. There are few studies present on this subject that investigate how more than one factor correlate to other environmental factors (Thorstad *et al.*, 2003a). The most common approach to what is affecting the salmon upstream migration is to look at the river flow and water temperature. Studies on the importance of water flow for salmon upstream migration have shown varying results that differ between rivers and studies (Mitchell and Cunjak, 2007). Dahl *et al.* (2004) found a significant positive correlation between salmon upstream migration and water temperature in the rivers but no significant correlations between water flow and salmon upstream migration. Thorstad *et al.* (2005) and Mitchell and Cunjak (2007) found that water flow was a significant factor for salmon upstream migration in small rivers but not in large rivers. The importance of water flow on salmon upstream migration are related to the specific river's properties of waterfalls and streams, river passages can become impossible for salmon to pass at certain water flows (Thorstad *et al.*, 2008). The water temperature has a significant effect on the capacity the water to hold oxygen. The oxygen holding capacity decrease with increasing temperature, and will therefore affect the salmon's upstream migration success (Thorstad *et al.*, 2008). The upper and lower water temperature limits for salmon upstream migration is related to the structural properties of the river and how much effort is needed to migrate to the spawning site (Thorstad *et al.*, 2008). Even if many agree that some factors are more important than other, the focus on flow and water temperature may have caused a blindness for the other factors of importance (Thorstad *et al.*, 2008).

The aims with this study were to investigate: (I) which environmental variables can explain the daily variations in salmon upstream migration? (II) Are there any major differences between the factors influencing salmon spawning migration in an exploited river compared to an unexploited river? (III) Can an environmental factor be of greater or less importance for salmon upstream migration during the first and the last half of the season?

The environmental variables included in the analyses were; water flow, water temperature, precipitation, direct irradiation and atmospheric pressure.

Material and methods

Study area

The study focuses on the salmon migration in two different rivers in northern Sweden, Västerbotten County, Umeälven and Byskeälven (Figure 1).

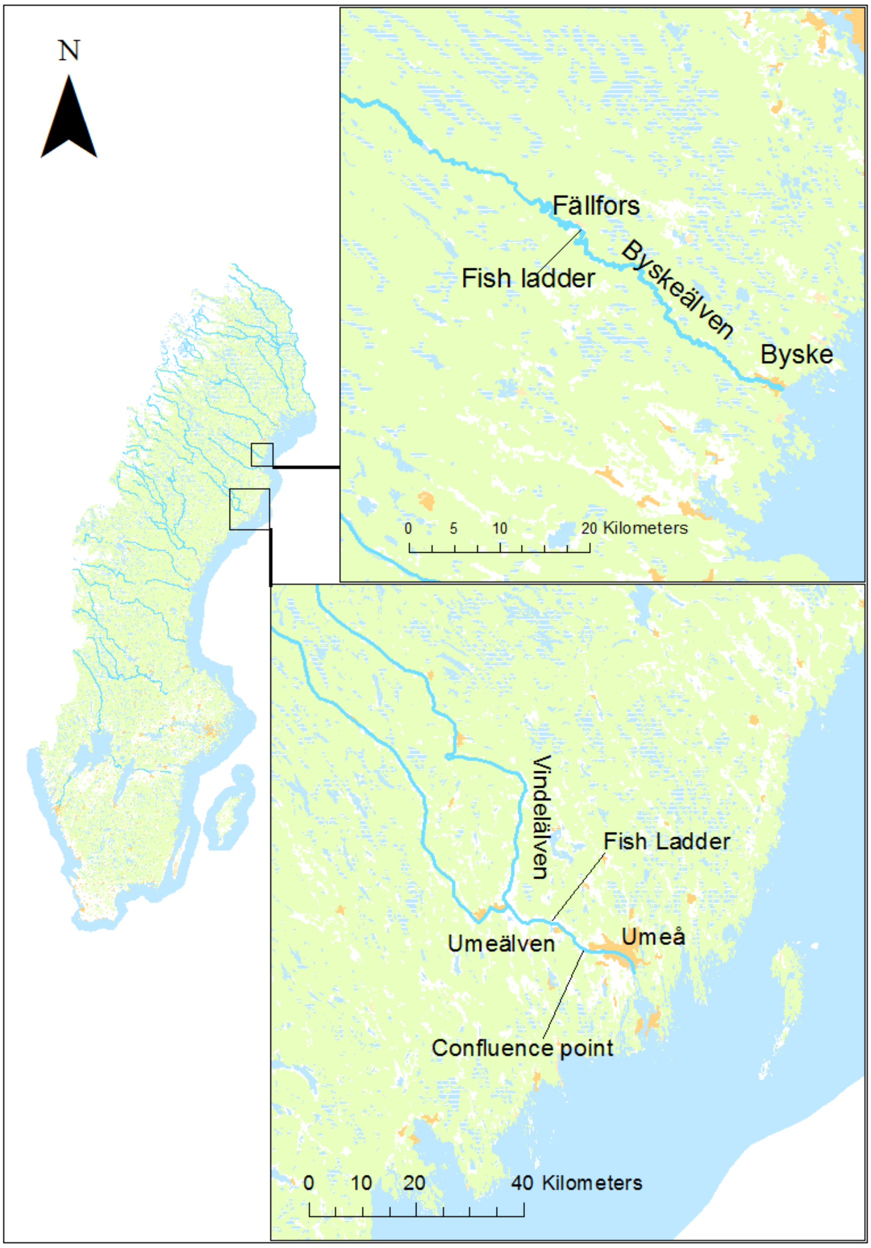

Figure 1: Study area, Byskeälven at the top with its fish ladder in Fällfors c. 40 km from the coast. The fish ladder in Byskeälven is situated by a waterfall but there are no artificial migration hinder in the streambed. Umeälven below, with the fish ladder c. 30 km from the coast .The fish ladder is constructed to help fish get past the hydro-power dam in Norrfors. The stretch between the confluence point, which is where the turbine water outlet is and the river Umeälven returns to full size, and the fish ladder is the original streambed in the river Umeälven. © Lantmäteriet, i2014/764

River Umeälven

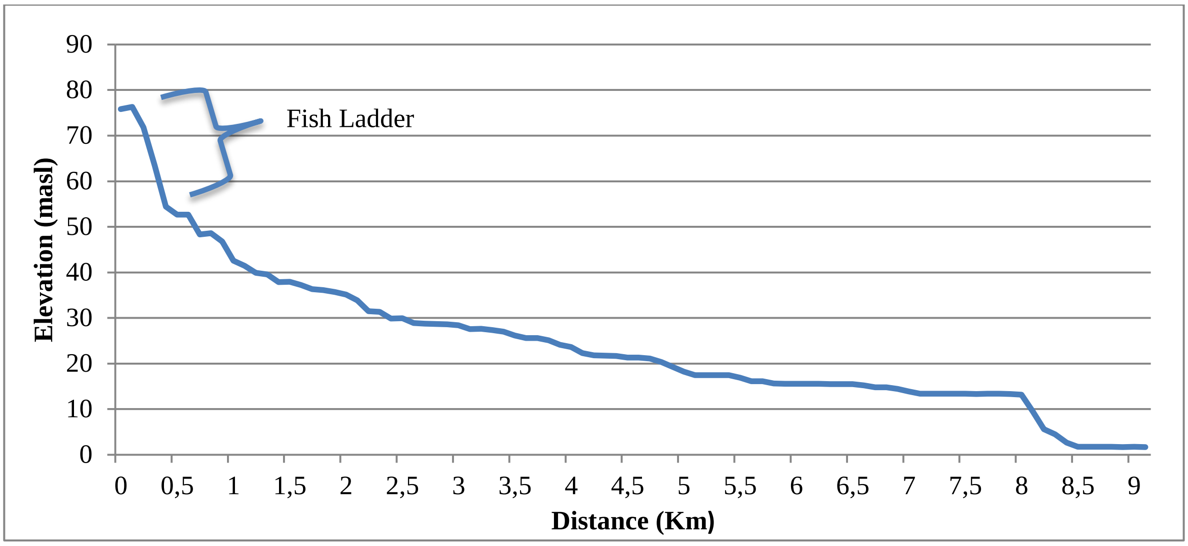

Figure 2: Elevation (meters above sea level) profile for the original streambed of river Umeälven from above the fish ladder to the confluence point, which is where the turbine water channel meets the original streambed. The fish ladder is marked in the figure; the elevation is 53 meters at the bottom and 75 meters at the top.

Umeälven is heavily exploited with 19 hydro electrical power plants along its 450 km way from the mountains close to the Norwegian border down to Umeå. The most downstream power plant is Stornorrfors, Sweden's biggest hydro electrical power plant, with a maximum turbine capacity of 1000 m^3s^{-1}. This is situated downstream from the confluence point with Vindelälven, which originates from the same area as Umeälven in a parallel watershed. Vindelälven is free from hydro electrical power plants and artificial dams. Vindelälven is the goal for all of the wild salmon that enters Umeälven from sea but to reach the spawning areas they have to pass the dam at Stornorrfors. In 2010 a new fish way was constructed in Norrfors (63°52'43.7"N 20°1'2.4"E, WGS84). It consists of 77 steps and is 283 meters long to climb up the height difference of 22 meters (Vattenfall, 2014a). There are two VAKI fish counters with IR-cameras that register the passing fish and also record a ten second video clip to enable determination of species, sex and to see if it is a hatchery reared or wild Salmon. At the same time Vattenfall built a mini hydro electrical power plant besides the fish way so extra water could run through its turbines and generate electricity and to give enough flow to the original streambed to attract the salmon (Figure 3). The original streambed is 8 km long before the confluence point with the turbine outlet. This stretch has a controlled water flow. Legislation requires minimum spills to the bypass of 10 m^3s^{-1} from 20 May to 15 June, 20-50 $m^3s^{-1}$from 15 June to 31 August, and 10-15 m^3s^{-1} in September (Lundqvist *et al.*, 2008). 0.3 m^3s^{-1} is released into the bypass from 1 October to 20 May (Vattenfall, 2014b). The fish ladder flow is maintained at c. 1.1 m^3s^{-1}, with additional 20-22 m^3s^{-1} attraction flow from the mini power plant at the entrance of the fish ladder. Leonardsson *et al.* (2013) did a telemetry study on salmon upstream migration in river Umeälven and found that the median time for their tagged salmon to migrate from the confluence point to the top of the fish ladder (figure 1) was 25.1 days. They also found that salmon migrated throughout the day.

After testing artificial freshets to motivate the salmon to choose the bypass channel instead of the turbine outlet, with successful results, c. 20 – 30 m^3s^{-1} has been used as a continuous flow regime of a few days up to a week alternated by a few days with 50 m^3s^{-1}. The extra water added to create the freshets comes via the spillways (figure 3) by opening the dam, c. 27 m^3s^{-1} comes from the spillways and c. 20 m^3s^{-1} from the ladder entrance (figure 3). Water flow exceeding 1000 m^3s^{-1} is spilled from the spillway dam to the original stream bed. The highest registered spill flow was 2022 m^3s^{-1} in 1995.

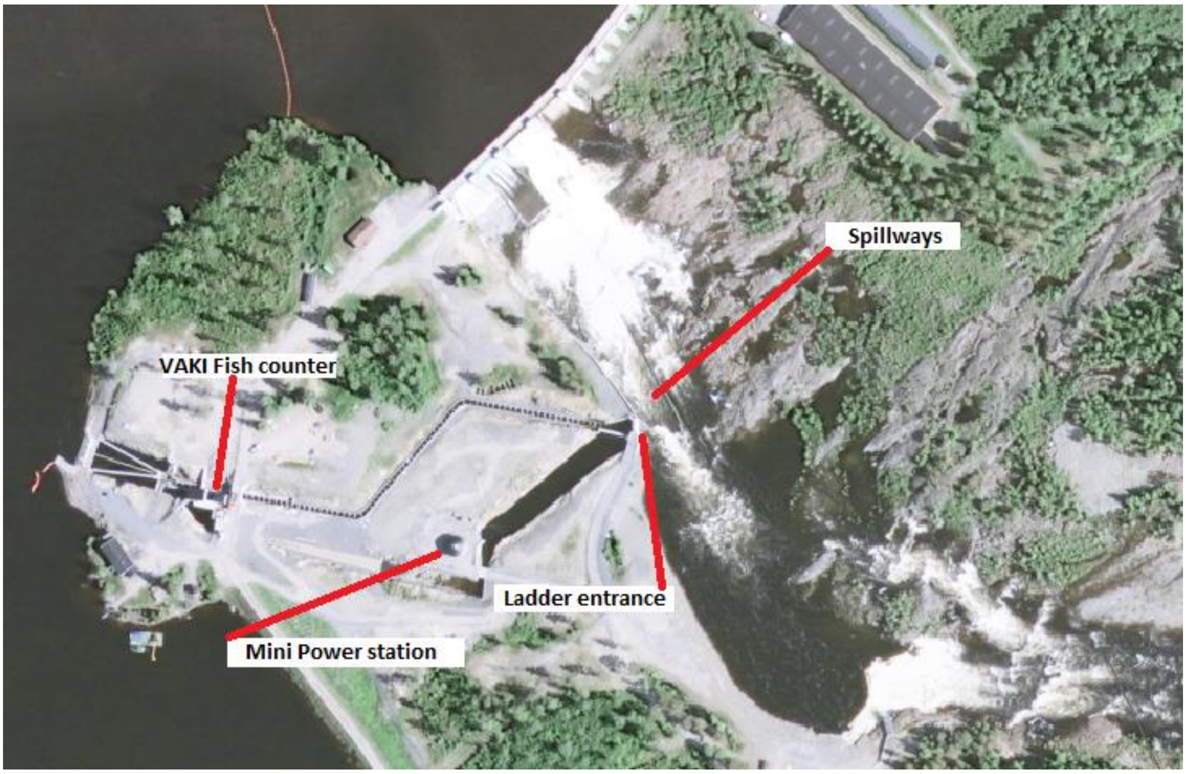

Figure 3: Norrfors fish ladder in river Umeälven. The fish ladder has a flow of c. 1.1 m^3s^{-1} and extra water runs through the mini power station to attract salmon in to the ladder. The mini power station has a maximum capacity of 23 m^3s^{-1}. Spillways are used for artificial freshets to make the salmon choose the original stream bed instead of the turbine outlet on their migration route upstream, and in case of floods with too much flow for the Stornorrfors power station (1000 m^3s^{-1}). © Lantmäteriet, i2014/764.

River Byskeälven

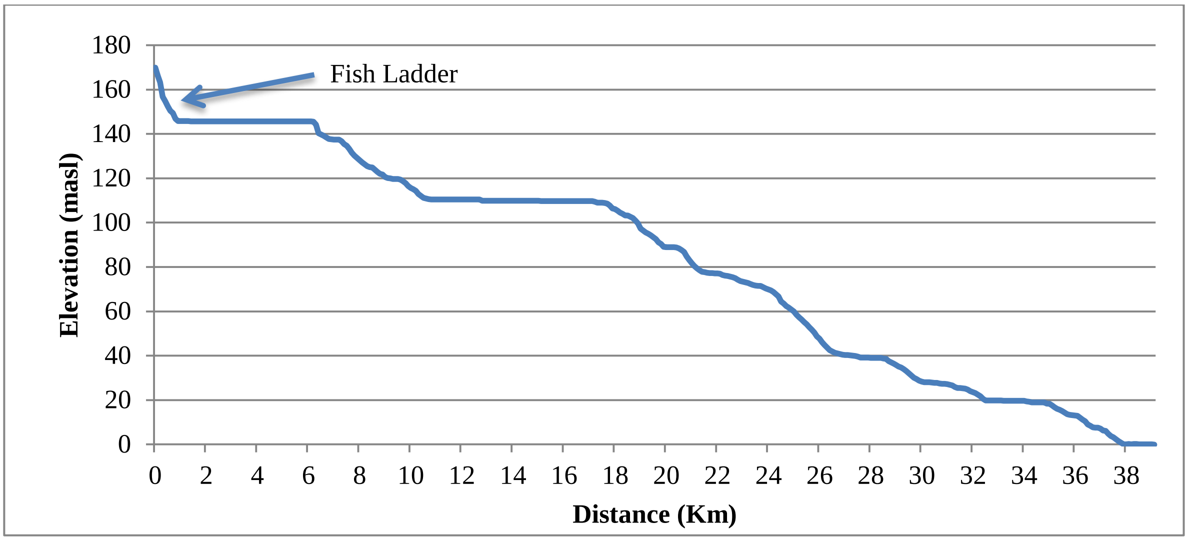

Figure 4: Elevation profile for river Byskeälven from Fällfors, where the fish ladder is situated at the elevation of c. 160 meters, to the outlet in the Bothnian Bay.

Byskeälven is with its 215 km Sweden's second longest forest river, with natural flow regimes. Byskeälven has two fish ladders, situated 38 km from the coast in Fällfors (65°7'28.7"N 20°47'30.9"E, WGS84) (Figure 1) at the elevation of c. 160 meters (Figure 4). The old fish ladder (Figure 5) is the ladder used by the salmon, while a negligible amount of fish uses the new ladder (Figure 5). The new fish ladder was equipped with a VAKI fish counter without video recording during the period from which the analysed data originates. The small amount of fish that used the new fish ladder was added to the old ladder data. The old fish ladder was equipped with a PORO fish counter with video recording during 2009 to 2012 and was replaced 2013 by a VAKI fish counter with video recording that registers every passing fish. Salmon has difficulties using the old fish ladder at water flows higher than 80 m^3s^{-1} and lower than 15 m^3s^{-1} (Söderlund, 2015). Fish can also pass in the rapid without using the fish ladder (Figure 5). There are no data available on how many fish pass via the rapid but it is a negligible amount according to people working with salmon in Byskeälven. Mean flow during the study period was 42 m^3s^{-1}. Maximum flow was 359 m^3s^{-1} and a minimum flow was 6 m^3s^{-1}.

Figure 5: The two fish ladders at Fällfors in river Byskeälven 38 kilometres from the coast. The old fish ladder (on the left in the figure) is the fish ladder that salmon uses for upstream migration and also where the VAKI fish counter is situated. The new fish ladder (to the right in the figure) is rarely used by salmon. Fish can also pass this section without usage of the fish ladders. © Lantmäteriet, i2014/764.

Data

For Umeälven I used VAKI data from the new fish way, 2010-2013. For Byskeälven I used PORO data from 2009-2012 and VAKI data from 2013.

Salmon upstream migration count data, water temperature and water flow data for Umeälven was obtained from Vattenfall Vattenkraft AB. Precipitation, atmospheric pressure and water flow data for the rivers Vindelälven and Byskeälven. Vindelälven flow data was used to calculate the proportion of the total flow in the fish ladder at Norrfors that originated from Vindelälven. Air temperature data from the Byske river region was collected from the Swedish Metrological and Hydrological Institute (SMHI, 2014). Direct irradiation was collected from the Swedish Radiation Safety Authority (STRÅNG, 2014). Water temperatures for Byskeälven were only available for 2013. The water temperatures for the years 2009 - 2012 were therefore reconstructed by using a regression of water and air temperature data from 2013. Precipitation data was not available for the area around the fish ladder so precipitation data for Byskeälven was obtained from four surrounding areas (Fagerheden, Jörn, Kursmark, and Piteå) from which daily means were calculated.

All the data was managed to represent daily means.

Two different salmon data setups were used in the study. In one dataset normalised salmon moving averages (NSMA) were calculated as nine days moving averages of the proportions of salmon that passed the counter per day. Five percent was removed from the beginning and the end of each year’s time series respectively. It is a typical seasonal pattern with few individuals in the beginning and in the end of the migration period and these few individuals are not likely to indicate poor migration conditions, which they would if included in the analyses. These few individuals were rather the first and the last ones to migrate. The NSMA was compared to different environmental factors in scatterplots in Excel (Microsoft, 2010) to get a visual analysis on which factors may have an important role in salmon’s upstream migration.

The second setup was called proportional data, where two, three and five days proportional salmon count data was calculated by dividing the current day’s counts by the sum of count from the following two, three and five days respectively. An example of the proportional data is shown in figure 6. The proportional data was calculated to simulate the relative proportion of the salmon migrating and to tackle the problem of not knowing how many salmon there were present downstream the fish counter that could have reacted to changes in environmental factors.

Multiple variations of day’s Lag where added as independent variables to the analyses to be able to detect responses to environmental changes in the past (Figure 6) and for salmon that were stationed downstream from the counting point. A maximum of six days lag was used and that determined the stretch of the river that was relevant in the study. This stretch contained a number of structural hinders for the salmon to pass, the fish ladder was one of them but I could not grade the difficulty for salmon to pass each of them.

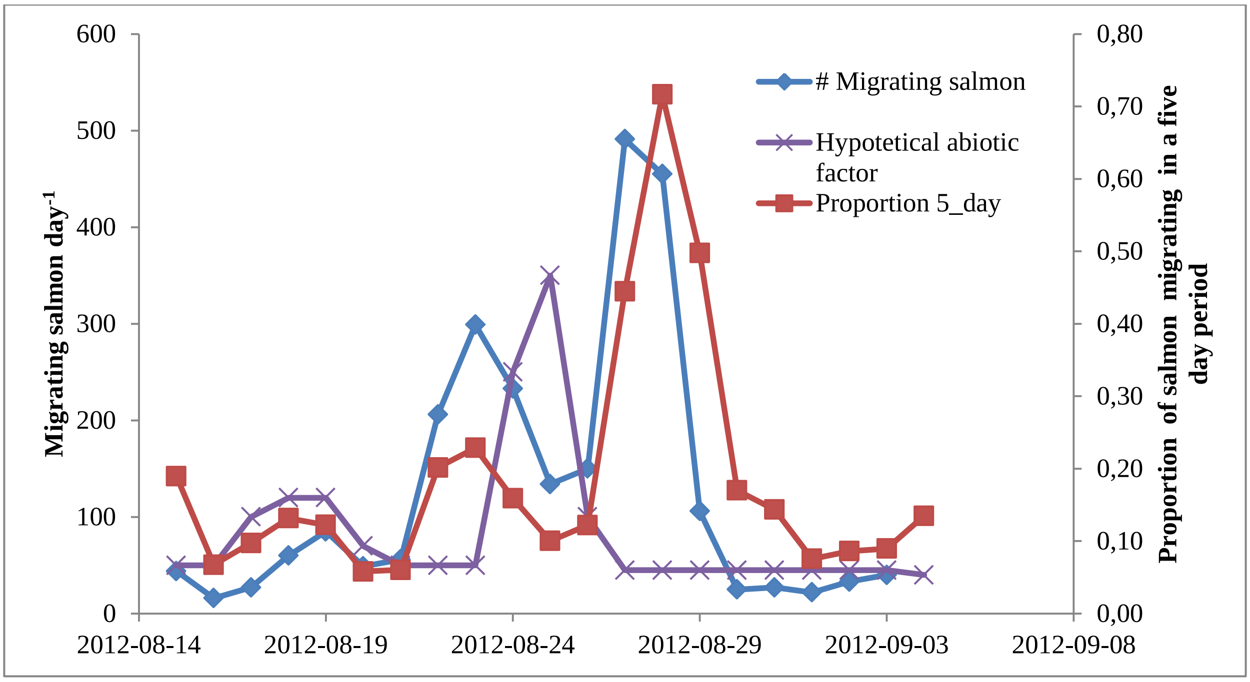

Figure 6: A visualization of how lagged environmental data can explain daily variations in salmon migration, purple line compared to blue and red line. Red line show the function of the proportional data, where the value of a point on the red line is the value of a point on the blue line the same day, divided by the sum of that day and the following four days of salmon counts.

Adjusted Julian day number squared was added to eliminate the seasonal variation in migration and to enable detection of salmon response to changes in environmental factors. The Julian day number was adjusted to have its zero value at the median date, when 50 % of the salmon had passed the fish counter. River Byskeälven had the adjusted Julian day number zero value at July the 4th and river Umeälven had its adjusted Julian day number zero value at August the 4th.

Migrating seasons for river Byskeälven was divided in a first and second half. The cut was made where 50 % of the season's total migrants had passed the fish ladder. This data setup was performed on the NSMA data. River Byskeälven was chosen for this analysis because it is unexploited by hydropower dams, with a natural flow regime, and the natural seasonal variations intact.

Statistical analyses

Scatterplot's with regression and Lowess smoother lines (Minitab, 2013) were used to see how well each variable could explain the upstream migration and the Lowess smoother was used to see trends. Matrix plots of scatterplots with regression were made to see how the environmental factors related to each other. A critical value table for Pearson's Correlation Coefficient was used to find the critical R-Sq values for significance. Scatterplot's with regression was also used to determine how many days of lag that would be used for each variable. The days of lag with best R-Sq for each variable was analysed in a stepwise linear regression with alpha to enter 0.15 and alpha to remove 0.15. The stepwise linear regression was used to get the best collaborated R-Sq and hence the best model to explain the salmon spawning migration in the relevant stretches of the studied rivers.

R-Sq was used to interpret most of the results in this study, R-Sq describes how much of the Y-axis value (salmon migration) can be explained by the X-axis (environmental factors). Negative and positive correlation was used to see in which direction changes in the environmental factors affected salmon migration.

Boxplots were used to visualize the distribution of migrating salmon in the three artificial flows (10, 23, and 50 m^3s^{-1}) in the original streambed of river Umeälven. Median value and interquartile range (IQ-range) was used to compare the flows. IQ-range is the difference between the upper and lower quartiles and shows the distribution of the middle 50 % of the data.

Results

Salmon migration in both river Byskeälven and river Umeälven had a seasonal migration pattern where many of the seasons total migrants passed the fish counters early in the season (Figure 7, 8). The seasonal migration pattern was stronger in river Byskeälven.

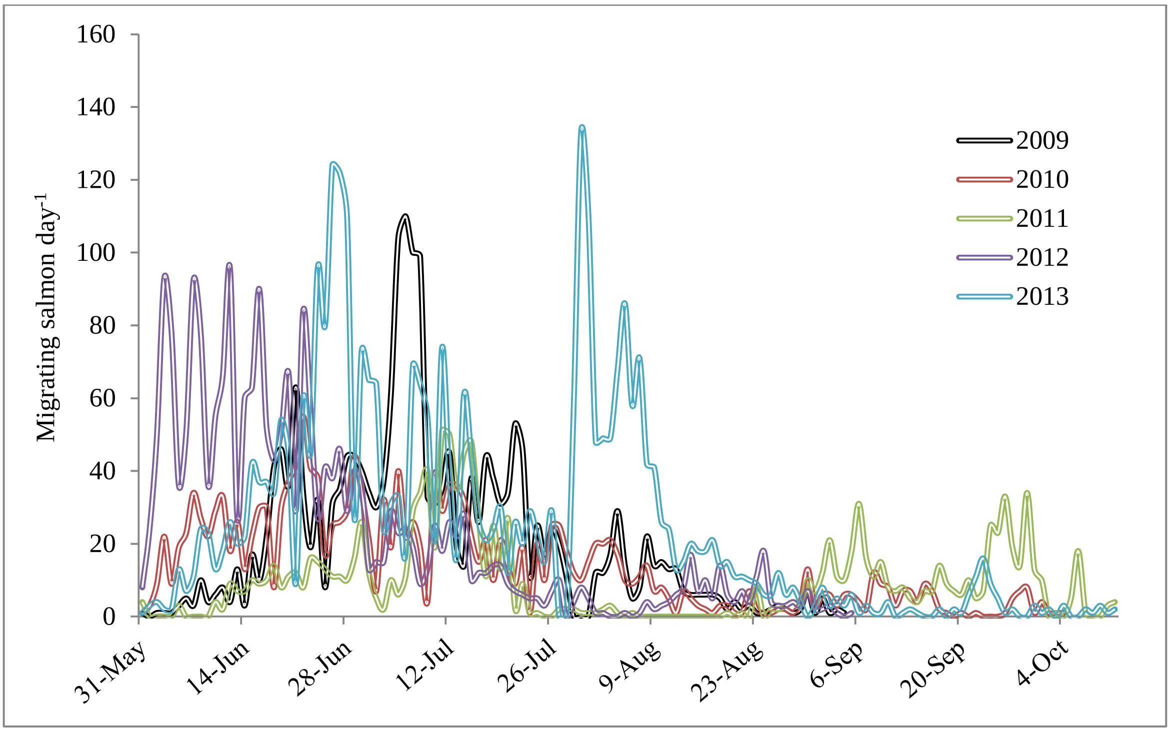

Figure 7: Salmon upstream migration 2009 - 2013 in river Byskeälven.

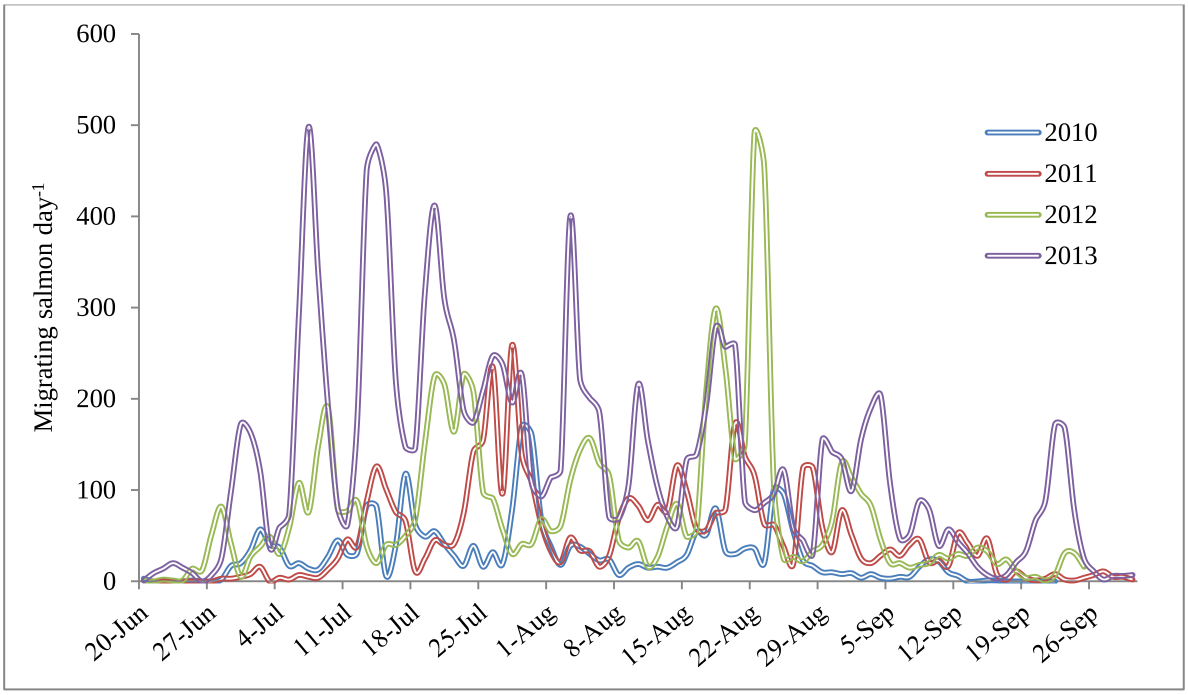

Figure 8: Salmon upstream migration 2010 - 2013 in river Umeälven

Salmon upstream migrations in the original streambed of Umeälven had a strong correlation with the artificial freshets of 50 $m^3 s^{-1}$ (Figure 9). The salmon was more attracted to the spillways from the dam (Figure 3) during the artificial freshets. There is no water in the spillways when the artificial freshet ends, and then more salmon entered the fish ladder.

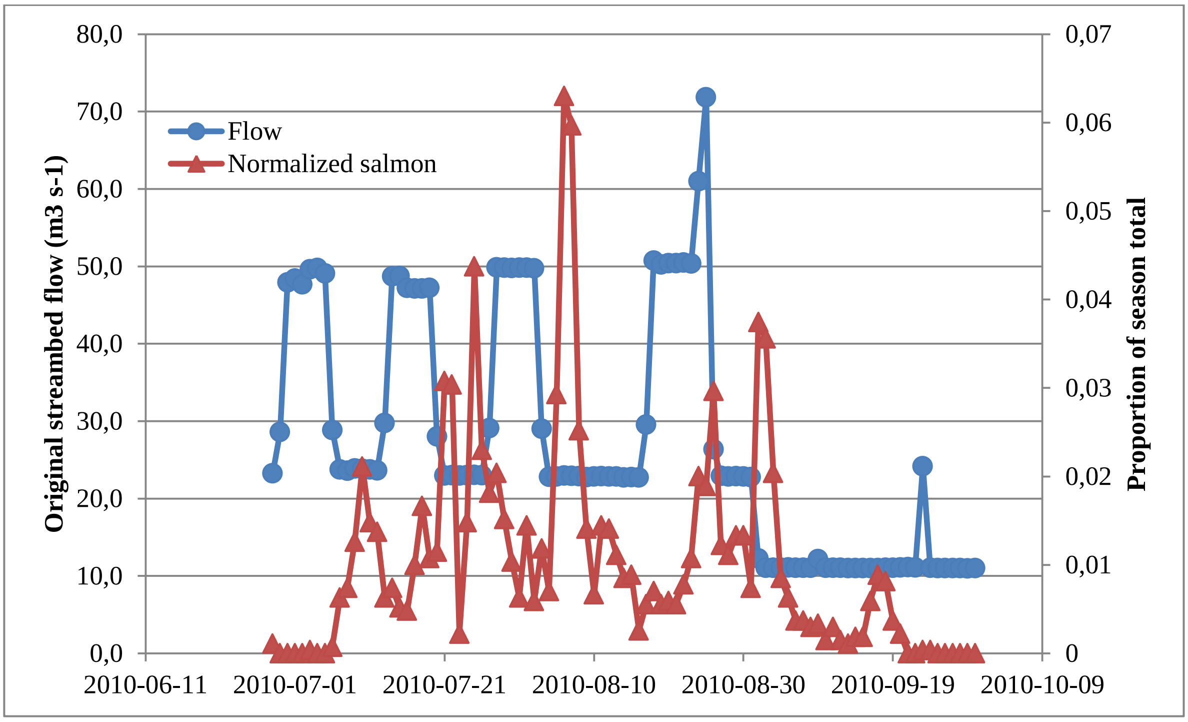

Figure 9: Salmon upstream migration compared to the flow with the artificial freshets in the original streambed of Umeälven. Flow line represents the flow in the original stream bed of river Umeälven, with the peaks being the artificial freshets. Normalized salmon is the salmon data with normalization to the season's total amount of counted salmon in river Umeälven. Salmon migration for all years had the same pattern related to the changes in water flow in river Umeälven.

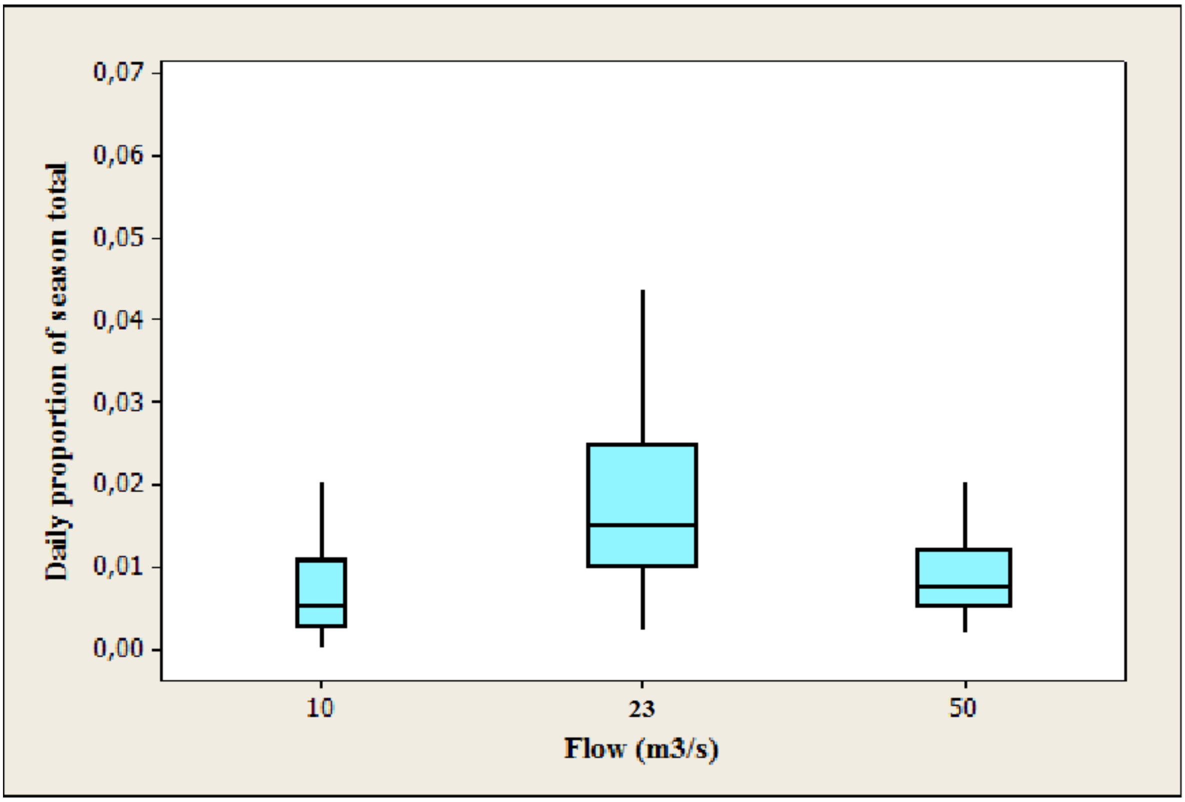

Figure 10: Proportion of migrating salmon per day for, all years, in the three flows in the original streambed of river Umeälven. Box widths represent the sample size.

Most salmon in umeälven passed the fish counter when the flow was 23 and 50 m^3 s^{-1} and 23 m^3 s^{-1} was the flow with highest median proportion (0.015) of salmon migrating per day. This flow also had the highest sample size (134) hence, this was the most common flow in the data but also highest IQRange (0.015) (Figure 10), which means that it had the highest variation within data. The longer upper whisker indicates that all three flows have a slight positive skewness, the right tail of the distribution is longer than the left tail. Salmon was more attracted to the spillways, than the ladder entrance (Figure 3) when the flow was 50 m^3s^{-1}. Salmon chose the fish ladder when the flow was lowered to 25 m^3s^{-1} and the dam was closed and no water run in the spillways.

Scatterplot with regression of normalized seasonal migration counts

Figure 11 and table 1 show the relationship between Salmon upstream migration (NSMA), adjusted Julian day number squared and the environmental factors; flow spill (the flow in the original streambed of river Umeälven), proportion water from river Vindelälven (how much of the total water that originates from the river Vindelälven), precipitation, direct irradiation, water temperature and atmospheric pressure. Adjusted Julian day number had a negative correlation with NSMA (R-Sq = 22.3 %) which means that most of the salmon migrated around the median date and fewer salmon migrated towards the beginning and the end of the season. The flow in the original streambed of river Umeälven was controlled at three main flow levels (10, 23 and 50 $m^3 s^{-1}$), which can be seen in figure 9 and 10, where 23 $m^3 s^{-1}$ and 50 $m^3 s^{-1}$ was the most common flow in the data. The correlation between NSMA and water flow spill was positive (R-Sq = 10.3 %), indicating that fewer salmon migrated in the beginning and the end of the season when the flow was 10 $m^3 s^{-1}$. Salmon migration had low correlation with the proportion of water from river Vindelälven (R-Sq = 0.4 % negative), precipitation (R-Sq = 3.2 % positive) and direct irradiation (R-Sq = 0.8 % negative). Water temperature and salmon migration had a positive correlation (R-Sq =3.2 %), meaning that more salmon migrated at higher temperatures. Atmospheric pressure had a positive correlation (R-Sq = 2.1 %) with salmon upstream migration. Water temperature vs spill flow had a positive correlation (R-Sq = 32 %), and spill flow vs precipitation had negative correlation (R-Sq = 2.3 %). These factors have lost their natural correlation since the spill flow is controlled. Water temperature vs direct irradiation had positive correlation (R-Sq = 7.9 %), increasing direct irradiation increased water temperature. Precipitation vs atmospheric pressure had negative correlation (R-Sq = 1.6 %), higher atmospheric pressure gave less precipitation. Direct irradiation vs atmospheric pressure had positive correlation (R-Sq = 9.6 %), direct irradiation increased with increasing atmospheric pressure. Significance are shown in table 1

Table 1: Correlation between salmon upstream migration and environmental factors, and correlation between environmental factors in river Umeälven. Critical R-Sq for significance was 1.9% (df = 256).

Y-axis	X-axis	R-Sq	Correlation
NSMA	Adjusted Julian day number squared	**22.3%**	Negative
NSMA	Water flow	**10.3%**	Positive
NSMA	Proportion of water from river Vindelälven	0.4%	Negative
NSMA	Precipitation	**3.2%**	Positive
NSMA	Direct irradiation	0.8%	Negative
NSMA	Water temperature	**3.2%**	Positive
NSMA	Atmospheric pressure	**2.1%**	Positive
Water temperature	Water flow	**32.0%**	Positive
Water flow	Precipitation	**2.3%**	Negative
Water temperature	Direct irradiation	**7.9%**	Positive
Precipitation	Atmospheric pressure	1.6%	Negative
Direct irradiation	Atmospheric pressure	**9.6%**	Positive

River Umeälven

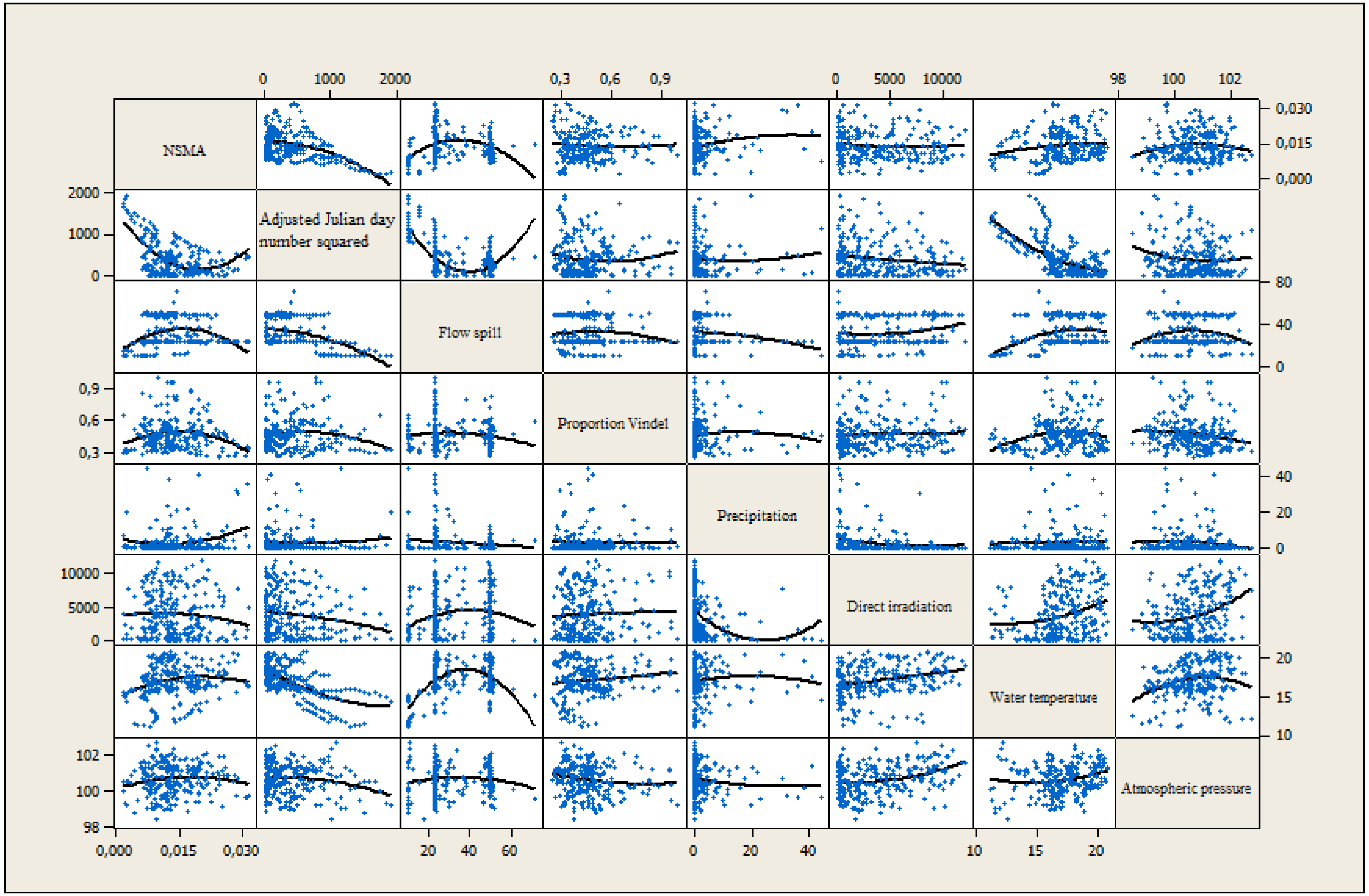

Figure 11: Matrix scatterplot with squared regression lines for river Umeälven with the salmon migration data as normalized salmon moving average (NSMA), adjusted Julian day number squared and the environmental factors; original streambed water flow, water temperature, precipitation, direct irradiation, and atmospheric pressure.

River Byskeälven

Figure 12 and table 2 show the relationship between Salmon upstream migration (NSMA), adjusted Julian day number squared and the environmental factors; water flow, precipitation, direct irradiation, water temperature, and atmospheric pressure. Julian day number squared had a negative correlation with NSMA (R-Sq = 46.5 %) which means that there was a seasonal migration pattern where most of the salmon migrated around the median date. NSMA had a positive correlation with water flow (R-Sq = 13.3 %). Migrating salmon had a weak negative correlation with precipitation (R-Sq = 0.8 %), meaning that more precipitation would result in less salmon migrating upstream. Migrating salmon had a weak positive correlation with direct irradiation (R-Sq = 1.8 %), higher direct irradiation would result in more salmon migrating upstream. Salmon migration had a positive correlation with water temperature (R-Sq = 7.5 %), more salmon migrated upstream at higher water temperature. Salmon migration had a weak positive correlation with atmospheric pressure (R-Sq = 0.7 %), predicting more migrating salmon for higher atmospheric pressure. Water temperature vs water flow had a negative correlation (R-Sq = 8.7 %), increasing flow gave lower water temperature. Water temperature vs direct irradiation had a positive correlation (R-Sq = 5.7 %), increased direct irradiation gave increased water temperature. Precipitation vs atmospheric pressure had a negative correlation (R-Sq = 17.4 %), increased atmospheric pressure gave decreased amounts of precipitation. Direct irradiation vs atmospheric pressure had a positive correlation (R-Sq = 25.7 %), higher atmospheric pressure gave increased direct irradiation. Precipitation vs flow had a weak positive correlation (R-Sq = 1.0 %), more precipitation gave increased flow. Significance are shown in table 2.

Table 2: Correlation between salmon upstream migration and environmental factors, and correlation between environmental factors in river Byskeälven. Critical R-Sq for significance was 0.96% (df = 398).

Y-axis	**X-axis**	**R-Sq**	**Correlation**
NSMA	Adjusted Julian day number squared	**46.5%**	Negative
NSMA	Water flow	**13.3%**	Positive
NSMA	Precipitation	0.8%	Negative
NSMA	Direct irradiation	**1.8%**	Positive
NSMA	Water temperature	**7.5%**	Positive
NSMA	Atmospheric pressure	0.7%	Positive
Water temperature	Water Flow	**8.7%**	Negative
Water Flow	Precipitation	**1.0%**	Positive
Water temperature	Direct irradiation	**5.7%**	Positive
Precipitation	Atmospheric pressure	**17.4%**	Negative
Direct irradiation	Atmospheric pressure	**25.7%**	Positive

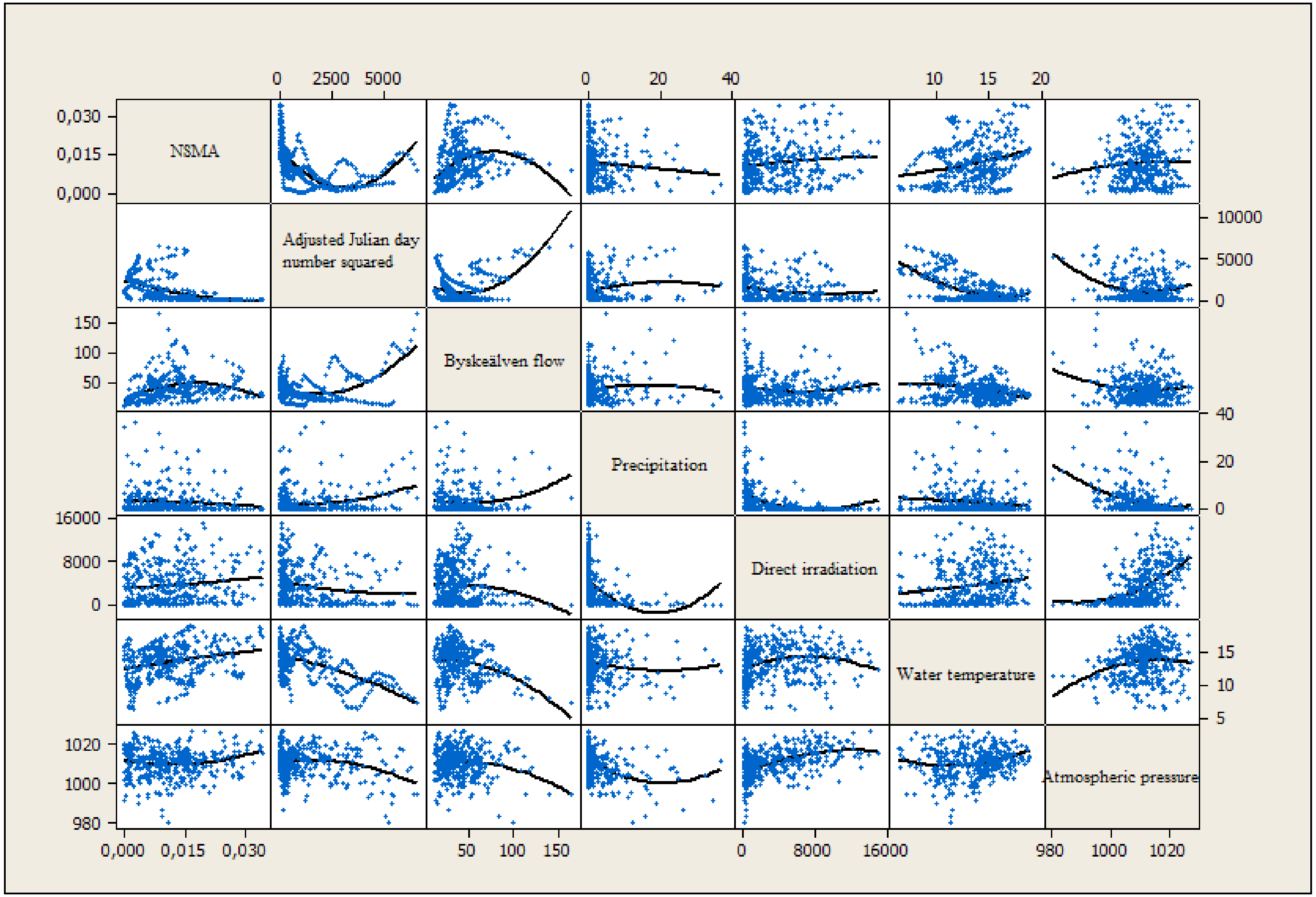

Figure 12 Matrix scatterplot with squared regression lines for river Byskeälven with the salmon migration data as normalized salmon moving average (NSMA), adjusted Julian day number squared and the environmental factors; water flow, water temperature, precipitation, direct irradiation, and atmospheric pressure.

Stepwise linear regression

NSMA data setup for river Umeälven

Stepwise linear regression for salmon migration in river Umeälven with NSMA as response and the six environmental factors, including adjusted Julian day number, as predictors gave a model with four predictors and R-Sq (adj) of 32.5 % (Table 3). Predictors included in the model are described in stepwise order, beginning with first step of the model with accumulated R-Sq (adj) in parenthesis. The predictors where; adjusted Julian day number squared; negative correlation (18.9 %), water flow spill with six days lag; positive correlation (29.08 %), Precipitation with one day lag; positive correlation (32.2 %), and Proportion Vindel with four days lag; negative correlation (32.5 %). The two last steps (precipitation and proportion Vindel) contributed little to the explanation.

Table 3: The best stepwise linear regression model for NSMA for river Umeälven with various days of lag on the seven best predictors from the single response regression analyses, R¯Sq (adj) = 32.5 %. Predictors included in the analysis where; adjusted Julian day number squared, water flow with six days lag, proportion of water from river Vindelälven with four days lag, precipitation with one day lag, direct irradiation with six days lag, atmospheric pressure with four days lag, and water temperature with six days lag.

Response is NSMA on 7 predictors, with N = 258				
Step	1	2	3	4
Constant	$1.6E^{-02}$	$1.1E^{-02}$	$1.0E^{-02}$	$6.6E^{-02}$
Adjusted Julian day number squared	$-1.0E^{-05}$	$-1.0E^{-05}$	$-1.0E^{-05}$	$-1.0E^{-05}$
T-Value	$-7.8E^{+00}$	$-7.3E^{+00}$	$-7.1E^{+00}$	$-7.2E^{+00}$
P-Value	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
Water flow		$1.6E^{-04}$	$1.6E^{-04}$	$1.6E^{-04}$
T-Value		$6.2E^{+00}$	$6.4E^{+00}$	$6.3E^{+00}$
P-Value		$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
Precipitation			$1.9E^{-04}$	$1.8E^{-04}$
T-Value			$3.6E^{+00}$	$3.5E^{+00}$
P-Value			$0.0E^{+00}$	$0.0E^{+00}$
Atmospheric pressure				$-5.6E^{-04}$
T-Value				$-1.5E^{+00}$
P-Value				$1.5E^{-01}$
R-Sq	19.2	29.6	33.0	33.5
R-Sq(adj)	18.9	29.1	32.2	32.5
Mallows Cp	50.3	12.9	2.3	2.2

NSMA data setup for river Byskeälven

Stepwise linear regression for river Byskeälven with NSMA as response and the six environmental factors, including adjusted Julian day number, as predictors gave a model with four predictors and R-Sq (adj) of 44.7 % (Table 4). Predictors included in the model are described in stepwise order, beginning with first step of the model with accumulated R-Sq (adj) in parenthesis. The predictors where; adjusted Julian day number squared; negative correlation (22.0 %), water flow with six days lag; positive correlation (43.4 %), direct irradiation with four days lag; positive correlation (44.2 %) and water temperature with no lag, positive correlation (44.7 %) (Table 4). The two last steps (direct irradiation and water temperature) contributed little to the explanation.

Table 4: The best stepwise linear regression model for NSMA for river Byskeälven with various days of lag on the six best predictors from the single response regression analyses. R-Sq (adj) = 44.7 %. The six predictors included in the analysis where; adjusted Julian day number squared, water flow with six days lag, precipitation with two days lag, direct irradiation with four days lag, water temperature with zero days lag, and atmospheric pressure with two days lag.

Response is NSMA on 6 predictors, with N = 400				
Step	1	2	3	4
Constant	$1.4E^{-02}$	$7.1E^{-03}$	$6.2E^{-03}$	$2.0E^{-03}$
Adjusted Julian day number squared	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
T-Value	$-1.1E^{+01}$	$-1.4E^{+01}$	$-1.3E^{+01}$	$-1.1E^{+01}$
P-Value	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
Water flow		$1.8E^{-04}$	$1.8E^{-04}$	$1.9E^{-04}$
T-Value		$1.2E^{+01}$	$1.2E^{+01}$	$1.3E^{+01}$
P-Value		$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
Direct irradiation			$0.0E^{+00}$	$0.0E^{+00}$
T-Value			$2.6E^{+00}$	$2.3E^{+00}$
P-Value			$1.1E^{-02}$	$2.4E^{-02}$
Water temperature				$2.9E^{-04}$
T-Value				$2.1E^{+00}$
P-Value				$3.5E^{-02}$
R-Sq	22.2	43.7	44.6	45.2
R-Sq(adj)	22.0	43.4	44.2	44.7
Mallows Cp	163.4	11.1	6.5	4.0

Proportional data setup for river Umeälven

The proportional data gave low explanation for the salmon spawning migration. The best model was the one with five days proportional data with R-Sq (adj) = 24.5 % (Table 5). Predictors included in the model are described in stepwise order, beginning with first step of the model with accumulated R-Sq (adj) in parenthesis. The predictors where; water flow with four days lag; positive correlation (20.0 %), precipitation with two days lag; negative correlation (23.2 %), and atmospheric pressure with one day lag; negative correlation (24.5 %). The two last steps (precipitation and atmospheric pressure contributed little to the model.

Table 5: The best stepwise linear regression model for the proportional salmon data for river Umeälven, R-Sq (adj) = 24.5 %. The six predictors included in the analysis where; water flow, proportion Vindel, precipitation, direct irradiation, water temperature, and atmospheric pressure.

Response is Proportion 5_day on 6 predictors, with N = 258			
Step	1	2	3
Constant	$3.4E^{-01}$	$3.3E^{-01}$	$-1.4E^{+00}$
Water flow	$-3.8E^{-03}$	$3.8E^{-03}$	$-3.8E^{-03}$
T-Value	$-8.05E^{+00}$	$-8.2E^{+00}$	$-8.2E^{+00}$
P-Value	$0.00E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
Precipitation		$3.6E^{-03}$	$3.8E^{-03}$
T-Value		$3.4E^{+00}$	$3.6E^{+00}$
P-Value		$1.0E^{-03}$	$0.0E^{+00}$
Atmospheric pressure			$1.8E^{-02}$
T-Value			$2.4E^{+00}$
P-Value			$1.9E^{-02}$
R-Sq	20.3	23.8	25.4
R-Sq(adj)	20.0	23.2	24.5
Mallows Cp	16.6	6.7	3.2

Proportional data setup for river Byskeälven

The best model for the proportional salmon data for river Byskeälven was the one with five days proportional data. It gave low explanation to the salmon migration with R-Sq (adj) = 3.0 %. Predictors included in the model are described in stepwise order, beginning with first step of the model with accumulated R-Sq (adj) in parenthesis. The predictors where; water temperature with four days lag; positive correlation (1.6 %), and water flow with four days lag; positive correlation (3.0 %).

Table 6: The best stepwise linear regression model for the proportional salmon data for river Byskeälven, R-Sq (adj) = 3.0 %. The five predictors included in the analysis where; water flow, precipitation, direct irradiation, water temperature, and atmospheric pressure.

Response is Proportion 5_days on 5 predictors, with N = 400		
Step	1	2
Constant	$1.2E^{-01}$	$7.1E^{-02}$
Water temperature	$6.5E^{-03}$	$7.8E^{-03}$
T-Value	$2.7E^{+00}$	$3.2E^{+00}$
P-Value	$7.0E^{-03}$	$1.0E^{-03}$
water flow		$8.2E^{-04}$
T-Value		$2.6E^{+00}$
P-Value		$9.0E^{-03}$
R-Sq	1.8	3.5
R-Sq(adj)	1.6	3.0
Mallows Cp	9.6	4.6

Stepwise linear regressions on first and second half of the season in river Byskeälven

The best model from stepwise regression for the first half of the spawning migration season gave a model with four predictors, R-Sq (adj) = 39.6 % (Table 7). The predictors where, in stepwise order with accumulated R-Sq (adj) in parenthesis; adjusted Julian day number squared; negative correlation (34.2 %), precipitation; negative correlation (37.8 %), direct irradiation; positive correlation (38.7 %), and water flow; positive correlation (39.6 %). The three last steps (precipitation, direct irradiation, and water flow) contributed little to the explanation.

Table 7: The best stepwise linear regression model for the first half of the season in river Byskeälven, R-Sq (adj) = 39.6 %. The five predictors in the analysis where; adjusted Julian day number squared, precipitation with three days lag, water flow with three days lag, direct irradiation with three days lag, and water temperature with three days lag.

Response is NSMA on 5 predictors, with N = 123				
Step	1	2	3	4
Constant	$2.2E^{-02}$	$2.3E^{-02}$	$2.1E^{-02}$	$1.9E^{-02}$
Adjusted Julian day number squared	$-3.0E^{-05}$	$-3.0E^{-05}$	$-3.0E^{-05}$	$-3.0E^{-05}$
T-Value	$-8.0E^{+00}$	$-8.3E^{+00}$	$-8.5E^{+00}$	$-8.6E^{+00}$
P-Value	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
Precipitation		$-3.0E^{-04}$	$-2.2E^{-04}$	$-1.9E^{-04}$
T-Value		$-2.8E^{+00}$	$-1.9E^{+00}$	$-1.6E^{+00}$
P-Value		$6.0E^{-03}$	$6.2E^{-02}$	$1.2E^{-01}$
Direct irradiation			$0.0E^{+00}$	$0.0E^{+00}$
T-Value			$1.7E^{+00}$	$1.9E^{+00}$
P-Value			$9.9E^{-02}$	$6.7E^{-02}$
Water flow				$5.0E^{-05}$
T-Value				$1.6E^{+00}$
P-Value				$9.8E^{-02}$
R-Sq	34.7	38.8	40.2	41.6
R-Sq(adj)	34.2	37.8	38.7	39.6
Mallows Cp	11.8	5.7	4.9	4.2

The best model from stepwise regression for the second half of the season gave a model with four steps, R-Sq (adj) = 34.3 % (Table 8). The predictors where, in stepwise order with accumulated R-Sq (adj) in parenthesis; water temperature; positive correlation (10.1 %), water flow; positive correlation (23.5 %), and adjusted Julian day number squared with positive correlation (34.3 %).

Table 8: The best stepwise linear regression model for the second half of the season in river Byskeälven, R-Sq (adj) = 34.3 %. The five predictors included in the analysis where; adjusted Julian day number squared, precipitation with three days lag, water flow with three days lag, direct irradiation with three days lag, and water temperature with three days lag.

Response is NSMA on 5 predictors, with N = 277			
Step	1	2	3
Constant	-2.4E^{-03}	-8.4E^{-03}	2.1E^{-03}
Water temperature	7.7E^{-04}	9.0E^{-04}	2.2E^{-04}
T-Value	5.7E^{+00}	7.1E^{+00}	1.5E^{+00}
P-Value	0.0E^{+00}	0.0E^{+00}	1.5E^{-01}
Water flow		1.2E^{-04}	1.6E^{-04}
T-Value		7.0E^{+00}	9.7E^{+00}
P-Value		0.0E^{+00}	0.0E^{+00}
Adjusted Julian day number squared			0.0E^{+00}
T-Value			-6.8E^{+00}
P-Value			0.0E^{+00}
R-Sq	10.4	24.1	35.0
R-Sq(adj)	10.1	23.5	34.3
Mallows Cp	101.6	46.6	3.0

Discussion

Salmon migration in both rivers was explained by similar environmental factors. All stepwise linear regression models, except models for the second half of migration seasons in river Byskeälven, were mostly explained by adjusted Julian day number and water flow. Adjusted Julian day number had a significant negative correlation, and water flow had a significant positive correlation with salmon upstream migration. Orell *et al*. (2007) found similar migration patterns, where salmon migrated in the earlier parts of the season. Thorstad *et al.* (2005) and Mitchell and Cunjak (2007) found that water flow was a significant factor for salmon upstream migration in small rivers but not in large rivers. River Umeälven is a large river but with the water flows in the original streambed, where the focus of this study on river Umeälven has been, it is considered a small river. Dahl *et al*. (2004) did not find any significant correlation between salmon upstream migration and water flow but they did find a significant correlation between water temperature and salmon upstream migration. Water temperature had a significant correlation with salmon upstream migration in the second half of the migrating season in river Byskeälven (Table 8).

Water flow was the most influential environmental factor for salmon upstream migration in some of the models (Table 3, 5, 8). Jensen *et al.* (1986) did a study similar to what I have done where they searched for correlations between salmon upstream migration and environmental factors in river Vefsna, Norway. Their salmon data was collected by a fish counter in a fish ladder. They used salmon migration data where the water temperature was above 8 ºC and water flow was between 80 and 300 m^3s^{-1}. They found that only two factors significantly affected salmon upstream migration; increase in water flow and increase in water temperature. However increase in water temperature and water flow can occur at both low and high flows and temperatures. Such specific changes in environmental factors were not analysed in this study. Taylor *et al.* (2010) did a study where they investigated the correlation between precipitation and salmons ability to reach spawning grounds further upstream in a third order stream in northern Nova Scotia, Canada. They found that there was a correlation between rainfall and hence water flow, where increased water flow enabled salmon to reach further up the stream. Although precipitation could only affect salmon upstream migration to a certain extent, where more precipitation at a certain limit didn’t resulted in more spawning reeds. The correlation between precipitation and water flow was weak (R-Sq =2.3 %) and negative for river Umeälven (Table 1). That result suggests that water flow would decrease with increasing precipitation; it can be explained by the fact that the natural correlation between precipitation and water flow has been eliminated since the flow is regulated. Precipitation did however have a weak positive effect on the salmon spawning migration in river Umeälven (Table 1), suggesting that precipitation might influence salmon spawning migration in other than flow related ways. This might be related to increasing water turbidity after a rainfall or to the salmon’s olfactory navigation system; by increasing the “home water” scent in the water.

The environmental factors seemed to be of less importance during the first half of the season. Table 7 show the best model from stepwise linear regression for the first half of the season in river Byskeälven. The model had four steps with adjusted Julian day number first, contributing with 34.2 % to the accumulated R-Sq, and water flow as fourth step, only providing c. 1 % to the accumulated R-Sq in the model. Table 8 show the best model for the second half of the season. The model had three steps with water temperature as first predictor, water flow as second and adjusted Julian day number as third, each contributing c. 10 % to the accumulated R-Sq. Based on these results (Table 8) it seems that the salmons requirement for the most important environmental factors (water flow and water temperature) are not so specific in the first half of the season. However water flow needs to be within the range where all difficult parts of the river can be passed. Water flow, in term of low water level, is rarely a problem in the first half of the season due to spring floods. The best model for the second half of the season was completely different to the first half (Table 7, 8) with water temperature and water flow as the first two steps in the model, indicating that water temperature and water flow are of more importance for salmon migration the second half of the season. Gowans *et al.* (1999) did a telemetry study on salmon in the river Tay system in Scotland where they found water temperature to have direct correlation with salmon entering the fish ladder at the study site. Salmon would not enter the fish ladder at temperatures below 9 ºC, but with a positive correlation between salmon rate of ascent in the fish ladder and higher water temperatures. Water temperature is biologically important for salmon since they are ectothermic and their body temperature is changing with water temperature. Important physiological processes needed for the salmon to manage upstream migration through difficult parts of the river cannot keep up when water temperature is too low. Too high water temperatures also result in reduced upstream migration ability for salmons due to reduced capacity of the water to hold oxygen. There is no exact answer to the question what the critical water temperature for salmon migration is. Holbrook *et al.* (2009) noticed fall backs in salmon upstream migration when the water temperature exceeded 22 °C. (Jonsson and Jonsson (2009)) wrote in a review that the upper lethal water temperatures for Atlantic salmon range from 22 – 33 °C.

Differences in salmon migration between the studied rivers

One of the objectives of the study were to compare if there were any difference in the influence of environmental factors on salmon upstream migration between a river with hydropower regulation and one with a natural flow regime. Salmon migration in both rivers had similar seasonal migration patterns and water flow as the most important environmental factors. Many of the stepwise linear regression models for both rivers included other environmental factors than adjusted Julian day number squared and water flow but there was only one model (Table 8) where those other factors gave more than a marginal contribution to the accumulated explanation of the models.

The results from the stepwise regression analyses with proportional data gave low explanation rates for both rivers. The model with five days proportional salmon data had highest R-Sq of all stepwise regressions on proportional data for both rivers. The best model for salmon migration in river Byskeälven could explain 3.0 % of the migration (Table 6), while the same model for salmon migration in river Umeälven could explain 24.5 % of the migration (Table 5). The slightly higher explanation rate for river Umeälven indicate that salmon in river Umeälven tend to accumulate close to the fish ladder entry, and can thereby, to some extent, be targeted with this analysis method. This theory is supported by the salmon behaviour related to the artificial freshets (Figure 9). Whereas it seems like salmon in river Byskeälven tend to migrate pass the fish ladder area at a steadier phase.

Data uncertainties

The best stepwise linear regression models in this study could explain c. 30 % of the salmon upstream migration for river Umeälven (Table 3), and c. 40 % (Table 4) for river Byskeälven. That is far from satisfying explanation rates, which would be of at least 60-70 %. There were some data uncertainties that could have had some impact on the explanation rates. Precipitation data was not available for the area around the fish ladder so precipitation data for Byskeälven is actually a mean of three surrounding areas. This may be a reason why precipitation only could explain 1 % (Table 2) of the water flow. But it is difficult to estimate how precipitation would affect the water flow since there is a varying time lag between precipitation and flow that depend on air temperature and the degree of saturation in the ground. The purpose of including precipitation data in the study was to address increasing turbidity of the water with the theory that a heavy local rainfall would create a turbidity effect. The way the precipitation data was obtained could have had an impact on the results. Precipitation intensity would be a better parameter to assess the turbidity of the water. But this data has just recently (2014) begun to be collected by SMHI, even with their data I think it would be better to collect the environmental factor data that are of interest at the counting sites. However the best would be to measure the turbidity of the water directly. Water temperature for Byskeälven was only available for 2013 so the water temperature for the other years was created by a regression from water and air temperature of 2013 to get estimates of the water temperatures for the years 2009 – 2012. This could have been a source of error when searching for a correlation between salmon upstream migration and water temperature.

Adjusted Julian day number, water flow, and water temperature were the factors that had highest explanation rates for salmon upstream migration for both rivers in the study. A possibility find the relevance of the other factors could be to normalise these factors to favourable conditions. That would require large sets of data, where water flow and water temperature within certain favourable limits would create a subset of data. These factors would then be excluded from the analyses to detect the importance of the other environmental factors. One has to consider if that would be worth the effort. Many of the environmental factors relate to each other. Precipitation affects turbidity, water flow, and water temperature to some extent. Direct irradiation has an influence on water temperature; high direct irradiation also means many hours of sun, which affect light conditions in the water, and little or no precipitation. Atmospheric pressure has correlations with cloud coverage, precipitation, direct irradiation and hence water temperature.

Method uncertainties

Water flow data in my study was analysed with linear regression, it could probably have given higher explanation rates if it had been analysed with squared regression. A linear regression gave a positive correlation between salmon upstream migration and water flow in the river Umeälven (Tabe 1). This result contradicts the result from figure 9, which show how the flow is controlled at three main levels (10, 23 and 50 m^3s^{-1}) and that most salmon migrated through the fish ladder at 23 m^3s^{-1}, some at 50 m^3s^{-1}, and very few at 10 m^3s^{-1}. A squared regression would probably be better to target the peak at 23 m^3s^{-1}.

Most of the salmon migrate upstream in the first half of the season. This creates a problem of finding correlations between environmental factors that change over the season, since there are fewer fishes left to respond to the environmental factors later in the season (Leonardsson *et al.*, 2013). Another problem when conducting a study like this, is the fact that the number of fish that are present downstream of the counting site prior to passage is unknown. If 30 fishes are registered in the fish counter one day and 300 fishes another day there is a tenfold increase in absolute numbers but it is unknown how that amount of fish relates to the total amount of fish available that had the option to react to the stimuli. This makes it difficult to evaluate the results on how big impact environmental factors have on salmon upstream migration. Environmental conditions may have been optimal but there were simply no fish present close enough to the fish counter at that time to be registered or the other way around, many fish may have had favourable conditions when entering the river from sea, so what seems to be an reaction to present conditions may not be what it looks like (Davidsen *et al.*, 2013). The proportional data configuration was calculated in an effort to simulate this unknown number of salmon but they gave little result. Logistic regression would have been a better method for the proportion data where salmon data range from zero to one, but it was not done due to limitations in output from the statistical software Minitab available for students at Swedish University of Agricultural Sciences (SLU). Could have been done in R but there was not sufficient time to learn.

Lag data were used to investigate how many days lag had the peak R-Sq for all the environmental factors. Up to six days lag was used and for some factors, water flow in particular, the R-Sq was the highest on the six days of lag and with a trend of increasing R-Sq for each day so for those particular factors it would be an idea to continue with more lag days until the peak is achieved. The size of the lag on water flow would probably be greater at higher water flows, since it takes longer time for the salmon to swim against a higher flow. An important thing to have in mind when working with the lags is the need for the lags to be explained by biological factors. For example, if R-Sq for migrating salmon's response to water flow is 60 days in the beginning of the season when they probably weren't present in the river at all, then one has to realize that the lag is not realistic. Another problem is that usage of many days' lag would also mean that a longer stretch of the river is being targeted, and this can increase the uncertainties in the study. Instead of working with many days lag, it would be probably be preferable to study smaller sections of the river independently. It would be good to map the migration route and identify migration hinders for the salmon to make it easier to estimate how many days lag that is biologically realistic in analysis. Telemetry studies would be a good method to find which passages are of difficulties for the salmon and at what water flows and water temperatures structural hinders become a migration problem.

The relevant stretch of the rivers in my study contained a number of structural hinders and the fish ladder was one of them. The salmon could be more sensitive in that kind of artificially created environment and react to very specific changes and these conditions may differ from the natural river and may be specific for each site (Thorstad *et al.*, 2008, Banks, 1969). But since the structural hinders, both natural and artificially created, could not be graded it was assumed that the relevant stretch could be analysed as one unit.

The use of predictors with different days lag in the same stepwise regression may be questioned. It was assumed that various days lags on the environmental factors could be used as response, without compromising the results of the stepwise regressions. The uncertainty originates from the fact that the position and abundance of salmon downstream the counting point is unknown. It is difficult to know which methods are most reliable. Telemetry studies would give better information on the location of individual salmon each day.

Conclusion

Many of the environmental factors analysed in the study had low degree of explanation for salmon upstream migration in rivers Umeälven and Byskeälven. This result could be explained by uncertainties in the data, and especially so in the migration response. Adjusted Julian day number, water flow were the factors that had highest explanation rates for salmon upstream migration for both rivers in the study. The only models were water temperature could explain more than a marginal part of the salmon migration was in the model for the second half of the migration season in river Byskeälven and for the proportional data model for river Umeälven. More reliable results could be achieved if the data collection would be study specific and designed for these kinds of studies to get more precise data than the data in this study. Based on the results from this study water flow, water temperature, and the turbidity of the water would be of most interest for future studies. Turbidity should be measured directly instead of trying to assess it from precipitation data as in this study. The studied river should be mapped and structural migration problems in the studied river should be identified so that the biological relevance of data lag can be secured. Telemetry studies are probably a necessary method to identify migration problems and stimuli for individual salmon.

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