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Assessment of Water Temperatures and Substrate Composition in Relation to Atlantic Salmon (Salmo salar)Production in the River Kvina, Norway

Spatiotemporal Environmental Variation in a Highly Regulated River

Kamilla Skaalsveen

PREFACE

This master thesis was written for the Department of Ecology and Natural Resource Management at the Norwegian University of Life Sciences. The study was carried out in collaboration with Bioforsk Soil and Environmet and symbolizes the completion of my five year degree. The direct and indirect effects of hydropower regulations in the river Kvina have been the subject of a number of assessments, with the goal of increasing the knowledge base surrounding the issue of restoring the Atlantic salmon (*Salmo salar*) population to its historical state. I hope this thesis will provide a positive contribution towards achieving this goal.

Planning and developing the issue that this thesis explores, carrying out the field work during the summer of 2013, processing data and evaluating results has been an immensely educational process. I have learned more about one of my main fields of interest, which I recognize as a highly current and important topic on both a national and international scale.

I would like to take this opportunity to thank the Sira-Kvina Hydropower Company for the economic support provided which helped cover my expenses, such as field equipment and transport. I would also like to thank my three outstanding supervisors; Thrond Oddvar Haugen (NMBU), Lars Jokob Gjemlestad (Bioforsk) and Ståle Haaland (Bioforsk). Without their abilities, experience, great ideas and helpful guidance, the final result would not have been possible. Lars Jakob in particular has contributed greatly with his comprehensive knowledge of the river, local information and assistance with field work which I could not have done without.

For assisting me with great parts of my field work, I would like to thank Hamish Richard Beaven, who additionally contributed with proof reading. I would also like to thank my fellow students and good friends at Ås for brightening up every day of my University life.

Ås, May 2014

Kamilla Skaalsveen

CONTENTS

ABSTRACT

Kvina is a heavily modified river that has faced many alterations of great magnitude caused by anthropogenic activity. Parts of the Kvina watercourse have been transferred to the Sira watercourse, contributing to the reduction in discharge from approximately 63 m³/sec to 19 m³/sec. In addition, upstream of the salmon bearing stretch the river water is stored in a reservoir, allowing the power company Sira-Kvina to regulate the river discharge through the year.

In the early 1990s the original Atlantic salmon (*Salmo salar*) population became extinct as a result of acidification. After initiating liming of the river the salmon repopulated the river once again. Input of sand from the Knaben molybdenum mines has also contributed to degradation of the river. The reduced discharge has caused a great quantity of fines to accumulate on the riverbed, reducing the amount of shelter and functional spawning gravel in the river.

Numerous assessments and management measures have been carried out as a means to restore the salmon population to the historical level of around 36,000 smolts, which is approximately 20,000 more than today numbers. This study was carried out in order to map some of the spatial and temporal environmental variation in Kvina throughout the summer. An assessment was carried out to investigate the functionality of the spawning areas, in terms of substrate composition and quality. Water temperature was measured in different sections of the river stretch through the summer in order to identify which weather conditions and velocities are challenge the salmon's probability of survival.

The 2013 summer was very warm, leading to periods in July of water temperatures disadvantageous to salmon, especially during low discharge. The spatial differences became far more pronounced during July than in June or August, with large variability even within delimited parts of the river. The temperature fluctuations between day and night were in some places very large, especially in shallow areas and pools. During the warmest periods these fluctuations were of around 10-15 °C at some locations, with the highest temperature registered being 32.6 °C while the lowest was 12.1 ° C. Sections of the river of greater depth or velocity did not become as warm, potentially functioning as refuges during the warmest periods, highlighting the importance of habitat variation. There seemed to be an increasing temperature trend from north to south, which may have been a contributing factor to the observed decreased length of 0+ down the river stretch.

The substrate samples were evident of large influence of fine material in the spawning gravel, potentially reducing the oxygen supply to the eggs and promoting a selection for small eggs. There were large variations in substrate quality within each of the three stations assessed, but still a general declining trend in the downstream direction.

In this study the potential impacts of high summer temperatures and low discharge have been recognized as an important bottleneck, even though the minimum summer discharge of 3.7 m³/sec is higher than the minimum winter discharge of 1.3 m³/sec. By increasing the minimum discharge to 5-6 m³/sec in both summer and winter by installing a water bank for example, the highest peaks in temperature during the summer would most likely be reduced. In addition it may, to some extent, prevent fines from clogging and degrading habitats.

Maintenance and improvement of habitat for young salmon is also essential in order to maximize smolt production.

1. INTRODUCTION

The habitat required by young Atlantic salmon (*Salmo salar*, “salmon” hereafter), is to a certain extent changing throughout its lifetime. Individuals are generally distributed throughout the river in relation to their size, available shelter and the hydro-physical conditions present (Heggenes et al., 1996). Changes in river depth and stream velocity are by many considered the main factors controlling this pattern (Heggenes and Dokk, 2001, Heggenes et al., 1996). Salmon are often found to be more abundant in the faster flowing parts of the river than in the slower parts (Heggenes and Dokk, 2001, Heggenes et al., 1996).Water temperature and river substrate are also important factors affecting the abundance and distribution of salmonids. As seasonal changes in temperature occur, so do fish metabolism rates. Temperatures that are too high, often associated with the high-summer season, are shown to have negative effects on salmon survival and growth (Sternecker et al., 2013).

Adequate substrate quality is an important requirement for both spawning habitat (Lapointe et al., 2004) and the habitat for young salmon (Heggenes and Dokk, 2001). Redds are preferably established at the upstream limit of riffles in stretches of the river with moderate to high flow of around 20-80 cm/s and substrate dominated by coarse gravel within the size interval 32-62 mm (Barlaup et al., 2008). The female individuals excavate a depression in the river substrate by flipping their caudal peduncle and fin to remove fine materials and create space for the eggs (Sternecker et al., 2013). After being fertilized by one or more males the eggs are buried at a substrate depth of 15-35 cm substrate depth (Barlaup et al., 2008). A continuous interstitial flow-through is of great importance for oxygen supply and largely dependent on the composition and distribution of gravel grain sizes (Greig et al., 2007). If a spawning site has a large content of fines (0.5-2 mm), the inter-coarser materials cavities are likely to fill up resulting in decreased water flow, and thus potentially leading to anoxic conditions lethal to the salmon eggs (St-Hilaire et al., 2005, Greig et al., 2007). During the winter the characteristics of the river intragravel flow determine the survival-to-emergence rate to a large extent, as the overlying gravel protects the eggs from predators (Dumas and Marty, 2006).

Following hatching, the alevins begin their journey up through the gravel of the river bed. These individuals still have not resorbed their yolk sacs, supplying them with nutrients (Dumas and Marty, 2006). The “swim-up” is the alevin’s first real exposure to predators as they swim to the river-bed surface to engulf air-bubbles to fill their swim bladder. At this stage they are facing the so called critical phase, which is a highly density-dependent process causing high mortality as a result of natural selection (Teichert et al., 2011). The young salmon are very territorial and the higher the density, the greater the competition. Larger individuals often have an advantage when it comes to defending their territories and therefore have a higher chance of survival (Einum et al., 2011). Studies show that there is a high correlation between egg size and the size of the offspring (Cote et al., 2012). This means that the production of larger eggs is likely to be an advantage. On the other hand, the larger egg volume requires a higher oxygen uptake to develop. This means that in many cases oxygen might be a limiting factor, and in order to produce large individuals the substrate and water quality conditions must be favourable (Dumas and Marty, 2006, Sternecker et al., 2013).

The lack of areas suitable for inhabitance, and overcrowding of these leads to more aggressive behavior amongst the fry as their ability to disperse is quite limited. The costs associated with emigration are often higher than the benefits, both in terms of predation risk and territorial behavior by other individuals (Einum et al., 2011, Kvingedal and Einum, 2011). Fish growth and maturity are also density dependent (Teichert et al., 2011, Einum et al., 2011), and both the development of gonads and smoltification age may be affected by the distribution and number of redds (Einum et al., 2011). Essential for successful salmon production is the connectivity between areas where redds are located and areas with the right stream velocity, water depth and shelter for the growth of young salmon. The distances must be short enough for the fry to travel, as they seldom disperse further than 100 meters within their first two years (as 0+ and 1+) (Foldvik et al., 2012). Older salmon are more mobile and are better able to migrate to better habitats with higher water levels and lower density of other individuals, often with energetic benefit as the result (Einum et al., 2011)

The river Kvina has experienced significant variation in the salmon population during the last decades due to anthropogenic activity (Sternecker et al., 2013, Langedal, 1997, Ugedal et al., 2004). The watercourse is located in the Vest-Agder County in the south of Norway and was well known for its large salmon population during the last century (Ugedal et al., 2004). Salmon production in Kvina decreased significantly as a result of channel morphology changes, mostly caused by mining activity, regulation for hydropower purposes (Langedal, 1997) and acidification (Ugedal et al., 2004, Sivertsen, 1989). According to (Bremset et al., 2008) the historical production of smolts in the Kvina was approximately 36,000 individuals, 20,000 more than today's production of approximately 16,000 smolts.

Mining activity at the Knaben Molybdenum Mines started in 1885, followed by a remarkable decrease in catch numbers after 1887. Mining was terminated in 1973 (Cote et al., 2012) after several years of adding tailings to Kvina, which was originally exposed to few natural sediment sources (Langedal, 1997). When the river was first regulated in 1963 (Larsen et al., 2005), decreased stream flow resulted in accumulation of fine materials and an elevation of the river floodplains (Langedal, 1997). The low gradient reaches were particularly exposed, and shields and course substrate important to the salmon have in many places been covered by tailings (Langedal, 1997). This has had a negative impact on areas suitable for spawning and the hatching success, as well as the habitat for young salmon (Ugedal et al., 2004, Gjemlestad, 2008). The Trælandsfoss power station is located in the upper section of the salmon-bearing stretch, 1.5 km downstream of the migration barrier - Rafossen. A challenge associated with the location of this power station is the loss of smolts, caused by the hydropower turbines (Bremset et al., 2008).

In addition to the artificial alterations applied to the river, Kvina has suffered from heavy acidification due to acidic rain and the poor buffering capacity of the catchment soil, as have many other water bodies in southern Norway (Kennedy and Strange, 1986, Sivertsen, 1989). Salmonids are known to be sensitive to these conditions (Nilsen et al., 2013), which is largely why the original salmon population in the river became extinct. There is evidence to suggest that no fry were present in Kvina (Sivertsen, 1989) before it was first limed in 1994 (Ugedal et al., 2004). The application of lime significantly improved water quality and salmon were able to recolonize. Acidic rain is somewhat of a diminished issue at present (Haaland et al., 2010) and its impact on the habitat of salmon has decreased drastically (Ugedal et al., 2004).

The river has been assessed and monitored for a number of years and measures have been taken in order to increase the production of salmon fry and smolts (Forseth et al., 2012, Bremset et al., 2008, Larsen et al., 2005, Ugedal et al., 2004, Gjemlestad and Haaland, 2013). In recent years, measures have been initiated to improve juvenile salmon habitats close to the city center and in the lower parts of the river. It is therefore important to take into account the demand for functional spawning habitats in the vicinity (Forseth et al., 2012, Gjemlestad and Haaland, 2013). This is partly why spawning gravel quality has been assessed in this study.

Some areas of the river with greater water depth were identified as suitable spawning areas, but unfortunately the river bed is largely dominated by tailings (Langedal, 1997). In order to maintain a minimum water table, weirs were built after the river was regulated. A great proportion of the sediments transported by the river are caught by these installations as the regulated water flow is unable to wash the deposited sandbars away (Langedal, 1997). The average river flow was historically around 63 m^3/sec, but has since been reduced to approximately 19 m^3/sec (Bremset et al., 2008).

In addition to the inability to keep sediments from accumulating, the reduced water flow may create a bottleneck in the salmon population (Heggenes et al., 1996). Low water levels during summer and winter are often problematic in terms of drought and bottom freezing (Larsen et al., 2005). In the summer, there have been several events recorded of water temperatures, velocities and river depths unfavorable to salmon (Bremset et al., 2008), however this has not been extensively documented. Therefore, more comprehensive documentation of the summer temperatures was attempted as a part of this assessment.

Through this study, I map some of the spatial and temporal variation of Kvina environmental conditions. Central is the functionality of the spawning areas, in terms of substrate composition and quality. Different variables such as water temperature were measured throughout the summer in order to identify which weather conditions and velocities challenge the salmon's survival probability.

In this thesis, I will attempt to elucidate the following research questions:

1) Which conditions lead to water temperatures that are unfavorably high for salmon juveniles?

2) How important is spatial heterogeneity in water depth and flow for physical and chemical variables and how is this affecting the habitat quality to salmon?

3) How suitable is the substrate at three different spawning sites for rearing of eggs and larvae?

4) How can spawning areas and nursery habitats be improved in the future?

2. MATERIALS AND METHODS

2.1. Study area

Kvina is situated in Vest-Agder County in south-western Norway (**Figure 1**). The Kvinesdal municipality reaches from the Fedafjorden in two parallel valleys; Vesterdalen and Austerdalen, draining the rivers Kvina and Litlåna, respectively. The landscape changes from plains in the southwest to mountain areas, between Kvinesdal and Sirdalen, further north in the municipality. The watercourse is heavily affected by regulations for hydropower purposes, and a mere 340 km² runoff of the total 1150 km² catchment is unregulated (Hindar, 1992). The rest of the catchment area has since 1963 fed the Sira watercourse where the Tonstad power plant is located, after regulations governed by the power company Sira-Kvina (Larsen et al., 2005). Originally the average flow of the river was 63 m³/sec, while the current average flow is about 19 m³/sec. The hydropower plant is required to provide a minimum flow of 1.3 m³/sec from the 1st of October to the 1st of May, while the requirement for the rest of the year is 3.7 m³/sec (Bremset et al., 2008).

Recently, Kvina has been suffering from heavy acidification, and has been limed since 1994 resulting in getting sensitive salmonids back to the river (Larsen et al., 2005). The river is also inhabited by brown trout (*Salmo trutta*) that experienced a decreased density after the return of salmon (Ugedal et al., 2004), European eel (*Anguilla anguilla*), European flounder (*Platichthys flesus*), three-spined stickleback (*Gasterosteus aculeatus*), and nine-spine stickleback (*Pungitius pungitius*) (Larsen et al., 2005).

The river substrate has experienced great changes after the mining started at the Knaben Molybdenum Mines in 1885. Tons of tailings have been transported by the river and a great part has deposited in weirs and low-gradient reaches, causing trouble for spawning salmon, eggs and young individuals in terms of habitat availability (Bremset et al., 2008).

The salmon-bearing stretch in Kvina is approximately 13 km, up to Rafossen. The Trælandfoss hydropower station is located within this stretch. It was constructed in 1909 to utilize the Rafosshølen water fall. The tributary Litlåna has a 2 km stretch that is utilized by salmon, which discharge is not affected by regulations. Hence, the total salmon-bearing stretch is approximately 15 km all together.

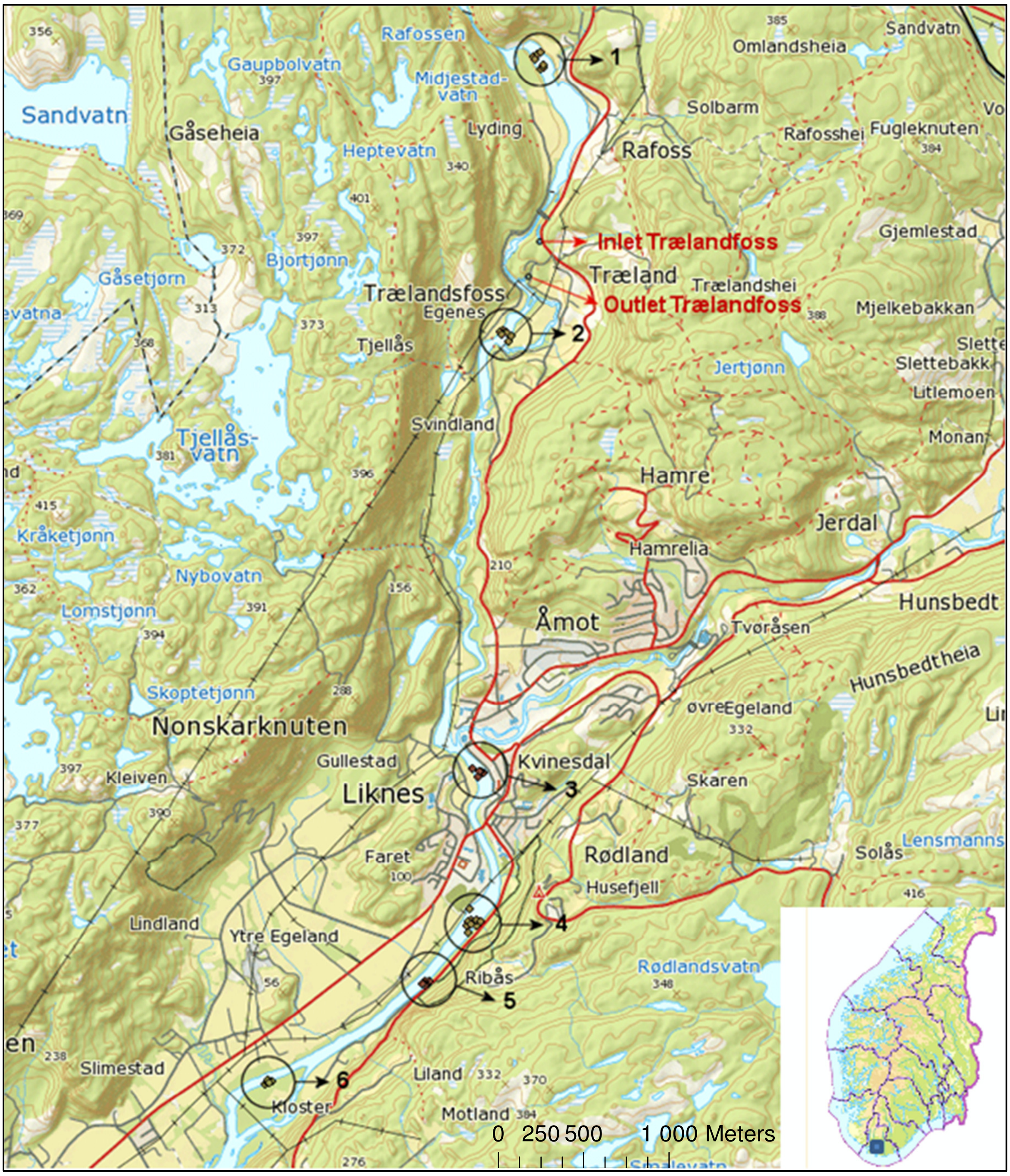


Figure 1. The salmon bearing stretch of Kvina that was assessed in the survey, from Rafossen (north) to Kloster (south). The six numbered red circles constitute the sampling stations: Rafossen (1), downstream Trælandfoss (2), Kvinesdal center (3), downstream the weir in Kvinesdal (4), Fidjan (5) and Kloster (6) (norgeskart.no).

2.2. Study species

The Atlantic salmon, with its prevalence mainly in the northern parts of the Atlantic Ocean (Maccrimmon and Gots, 1979), is an anadromous salmonid, i.e., it spawns and spends its juvenile period in running freshwater. Between the age of two and five years (normally with a length of 12-18 cm) the fry undergo large physiological, morphological and behavioral changes—a process called smoltification. The time of the occurrence of this phenomena preparing the salmon to migrate to the sea as smolt, is largely dependent on the local river conditions, with photoperiod and temperature being the main factors. Normally the actual emigration is lasting for about a month, taking place during the spring or the beginning of the summer (Jonsson and Ruudhansen, 1985). Unlike the trout that stay in fjords and coastal areas during their sea phase, the salmon swims out in the open ocean towards the North-Atlantic Sea (Rosseland, 1971). After one to up to four years of gaining weight in the ocean, it returns as a mature individual to spawn in its native river. The upwards migration is in Norway normally taking place from May to August, differing between rivers (Mills, 1989).

Salmon eggs are quite large, typically about 5.0-6.6 mm (Aulstad and Gjedrem, 1973), and this rather high investment into individual offspring quality is secured by providing shelter in terms of burying the eggs into non-randomly selected river-bed gravel. Almost immediately after spawning occurs in late autumn the eggs start developing. The eggs are normally hatched during the spring or early summer after 6 to 12 weeks, largely dependent on temperature. The river morphology, hydrology and chemistry are crucial factors for the salmon to attain high hatching success of the eggs (Barlaup et al., 2008, Payne and Lapointe, 1997, Levasseur et al., 2006, Dumas and Darolles, 1999, Greig et al., 2007).

2.3. Sampling stations

The field work took place at six different locations distributed in the river stretch from Rafossen (north) to Kloster (south). Station 1 (**Figure 2-Figure 4**) was the northernmost of the stations, situated just downstream the migration barrier at Rafossen. The river substrate was dominated by boulders in the northern parts and cobble in the southern parts of the area, with high shelter availability (Gjemlestad, 2008). A larger coherent spawning site along with some patches of spawning gravel behind boulders and in the main stream, was located at the station. About half of the appropriate gravel was found in shallow areas with the risk of freezing in the winter or getting drained or very warm during low flow periods in the summer (Forseth et al., 2012, Gjemlestad, 2008). Eight temperature loggers named K01, K02, K03, K04, K19, K21, K22 and K23 were installed in this river segment at varying depths.

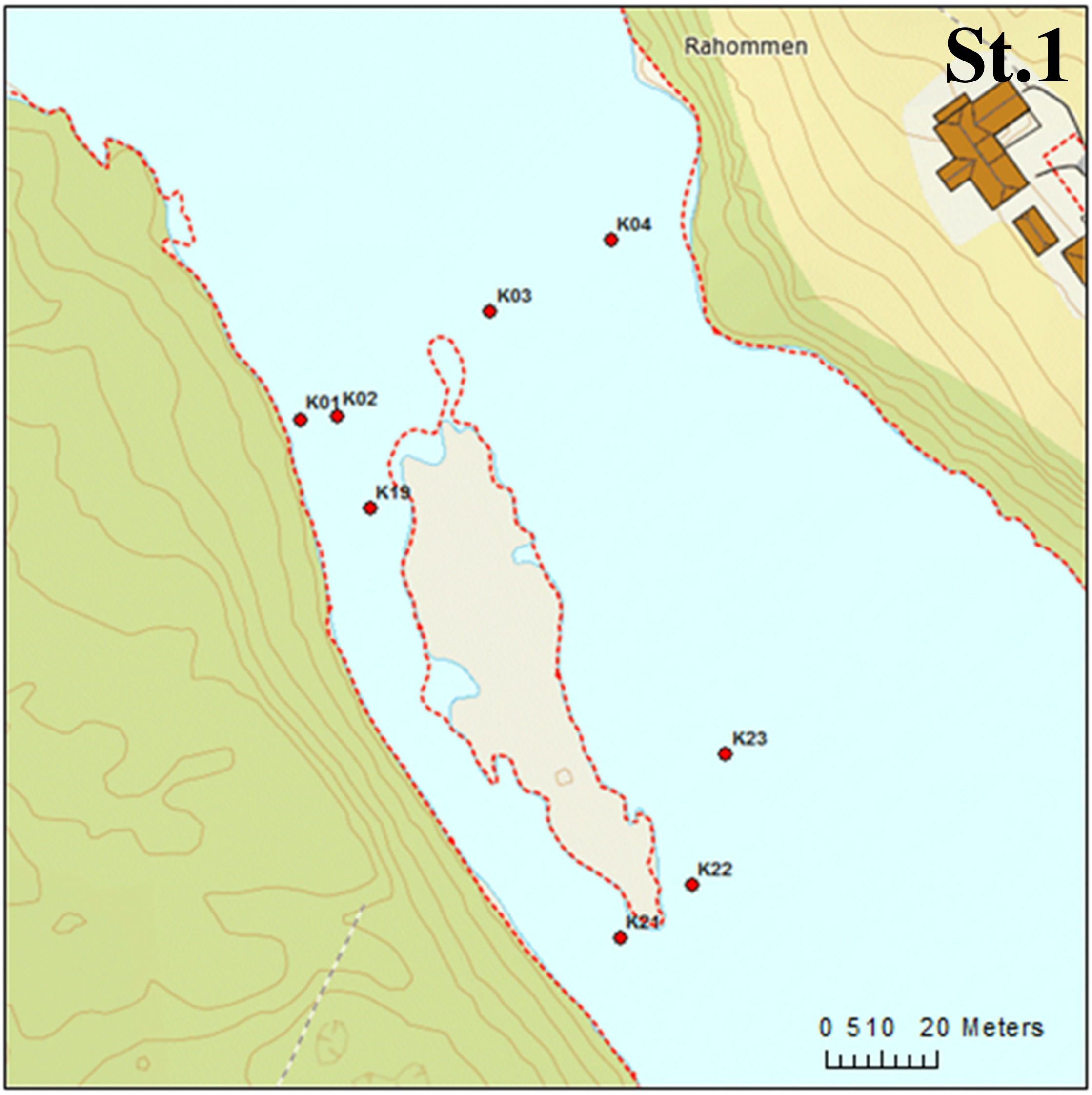


Figure 2. Station 1 consisting of eight temperature loggers (K01, K02, K03, K04, K19, K21, K22 and K23) situated downstream Rafossen (north-west) (norgeskart.no).

Figure 3. Aerial photography of station 1 (Norgeibilder.no).

Figure 4. Station 1 (west bank - downstream direction).

Station 2 (**Figure 5**-**Figure 7**) was located just downstream the outlet of the Trælansfoss power plant. The area had high shelter availability with substrate dominated by cobble (Gjemlestad, 2008). A rather large spawning location was situated in the southeastern part of the station as well as occasional patches of spawning gravel. Some of these sites are located in shallow parts of the river stretch, which might freeze in the winter or get drained or very warm during low flow periods (Forseth et al., 2012, Gjemlestad, 2008). Six temperature loggers were distributed in this area named K05, K06, K07, K08, K24, K25, K26 and K28.

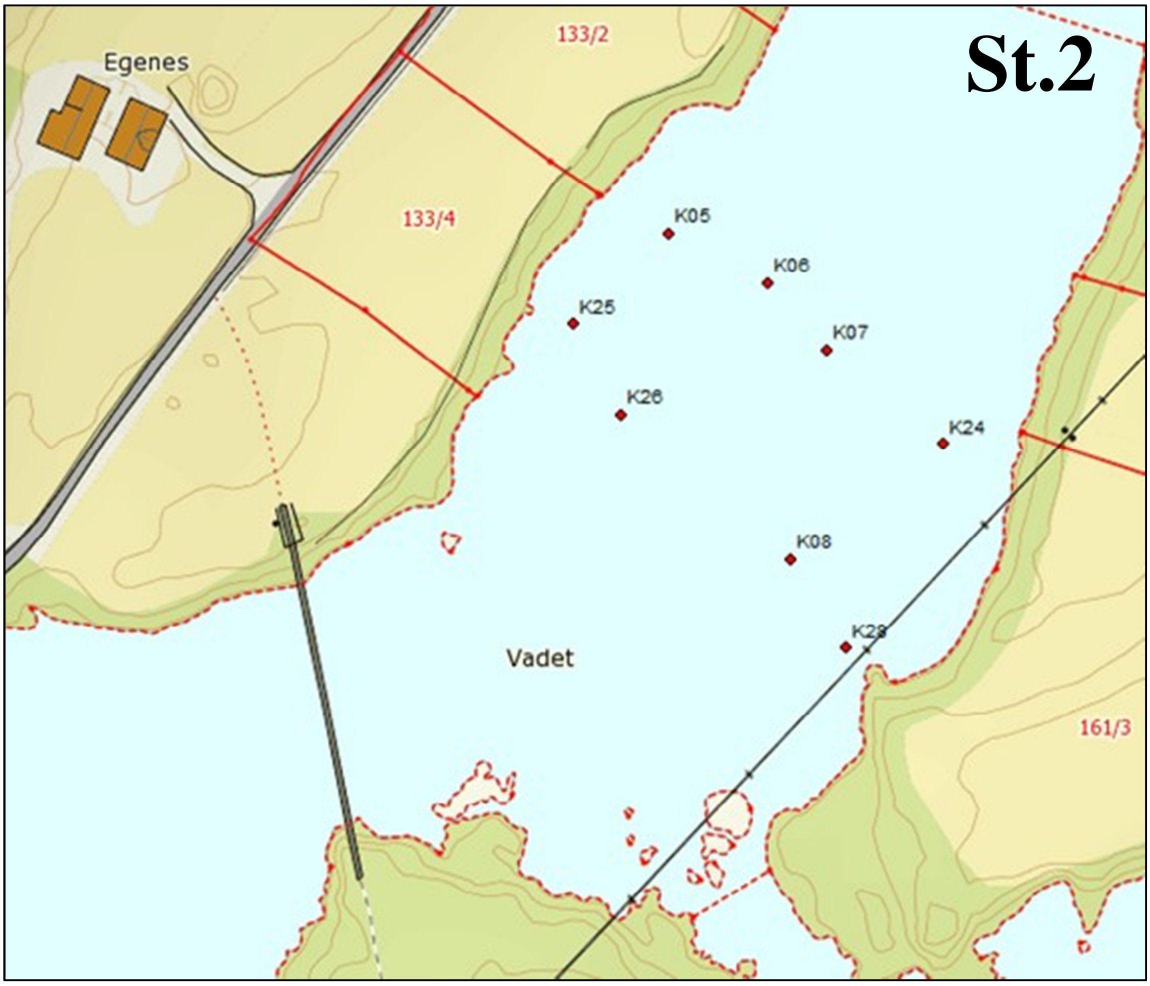


Figure 5. Station 2 downstream Trælandfoss consisting of the eight temperature loggers K05, K06, K07, K08*, K24, K25, K26 and K28 (*position might be inaccurate due to uncertain coordinates) (norgeskart.no).

Figure 6. Aerial photography of station 2 (Norgeibilder.no).

Figure 7. Station 2 (west bank - upstream direction).

Station 3 (**Figure 8-Figure 10**) was located at a river stretch that was running through the Kvinesdal city center (Liknes), as a part of the basin upstream the large weir at Station 4. Habitat improving measures have been carried out in this area in order to provide more shelter to juvenile salmon. The basin area as a whole was dominated by sand, but the parts assessed that was classified as a spawning site was dominated by cobble accompanied by an area of coarse pebble and some boulders (Gjemlestad, 2008, Forseth et al., 2012). Five substrate samples were conducted at this station named SS1, SS2, SS3, SS4 and SS5.

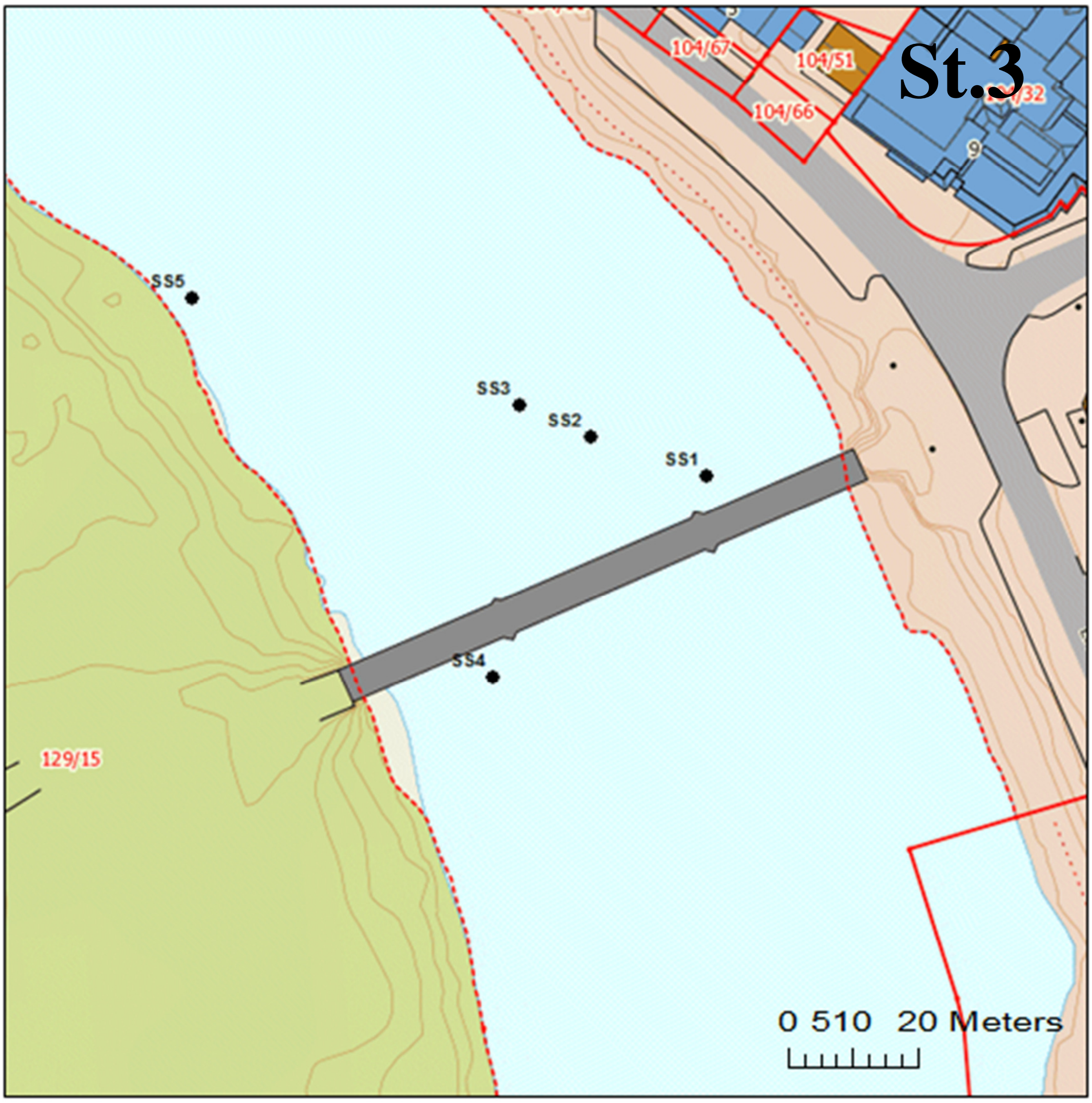


Figure 8. Station 3 where the five substrate samples SS1, SS2, SS3, SS4 and SS5 were collected. The river stretch is located in the middle of the Kvinesdal city centre at a spawning area. The substrate was sampled from former redds (norgeskart.no).

Figure 9. Aerial photography of station 3 (Norgeibilder.no).

Figure 10. Station 3 (east bank - upstream direction).

Station 4 (**Figure 11**-**Figure 13**) was situated close to the Kvinesdal sports field, downstream the weir between Fidjan and Liknes city center. As habitat measures, large amounts of cobbles and boulders are distributed in order to make more shelter and alter the flow pattern in the river stretch (**Feil! Fant ikke referansekilden.**). Two parallel channels and several deeper pools were constructed for better water flow downstream the weir. The weir itself was modified to increase the area of juvenile habitat and facilitate easier migration for adult individuals. This is an important nursery habitat for young salmon migrating from smaller spawning habitats both within the station area and probably also from reds at Station 5. Most of the spawning gravel at Station 4 was located in very shallow parts of the river stretch, likely to freeze or getting drained during low flow periods (Forseth et al., 2012, Gjemlestad, 2008, Larsen et al., 2005), as well as getting hot in the summer. The loggers K09, K10, K11, K12, K13, K15, K16, K17 and K18 were placed in addition to a grid consisting of 64 manually measured points.

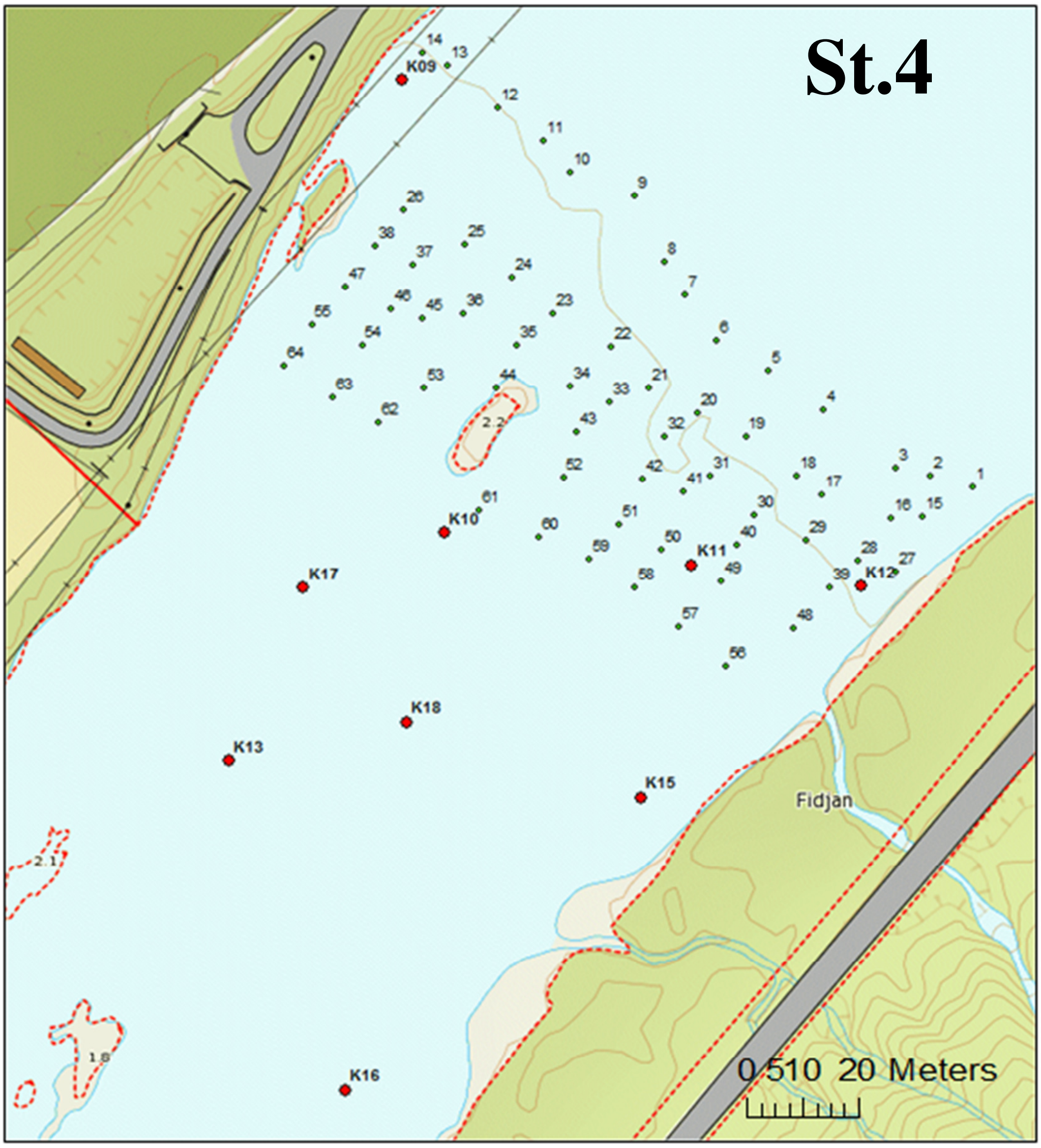


Figure 11. Station 4 downstream the weir in Kvinesdal consisting of nine temperature loggers (K09, K10, K11, K12, K13, K15, K16, K17 and K18) and six manually measurements transects. The Transects all together consisted of 64 measuring points conducted by a multivariable sensor (norgeskart.no).

Figure 12. Aerial photography of station 4 (Norgeibilder.no). The picture was taken prior to the management measures.

Figure 13. Station 4 (southeast bank - downstream direction).

Station 5 (**Figure 14-Figure 15**) was located near Fidjan along the southeastern river bank, which is the part of the river stretch that is used for spawning. This area is dominated by spawning gravel and cobble, but with a stripe of sand along the northwestern river bank that is normally avoided by salmon (Gjemlestad, 2008, Forseth et al., 2012). The spawning site is situated at a shallow part of the river in risk of drainage and freezing during low flow periods (Larsen et al., 2005). Shelter was almost absent (Gjemlestad, 2008), which is why salmon fry from this area are dependent on upwards migration to the coarse substrate that was placed between station 4 and 5 in 2013. Measures have been carried out to create greater connectivity between the two stations. The three loggers K14, K20 and K27 were situated at this station, in addition to the locations of five substrate samples; F1, F2, F3, F4 and F5.

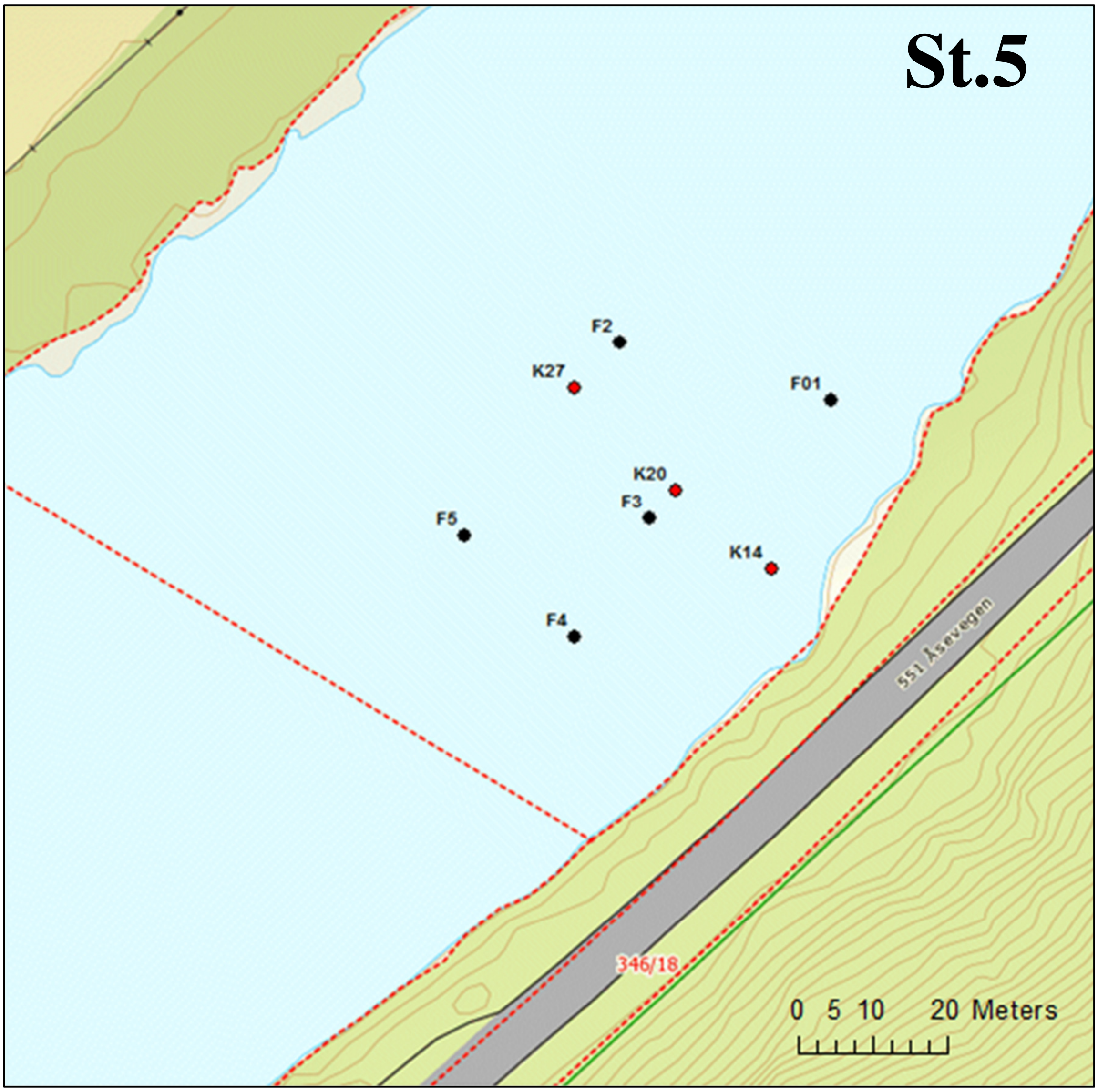


Figure 14. Station 5 at a spawning location in Fidjan. The five substrate samles (F01, F02, F03, F04 and F05) were conducted from former redds. The three loggers K14, K20 and K27 were also situated in this area (norgeskart.no).

Figure 15. Aerial photography of station 5 (Norgeibilder.no).

The southernmost area assessed was Station 6 (**Figure 16**-**Figure 18**). The station was placed on the northwestern side of the Kloster Island, dividing Kvina River in two. The substrate was largely dominated by gravel, but with some deposited sand in the inner curve. Both upstream and downstream this area larger stretches with substrate dominated by sand was found (Gjemlestad, 2008). Large parts of the station is used for spawning (Forseth et al., 2012, Larsen et al., 2005), but there was not much shelter in the area (Gjemlestad, 2008) until habitat measures were carried out in 2013. Five substrate samples were collected named KS1, KS2, KS3, KS4 and KS5.

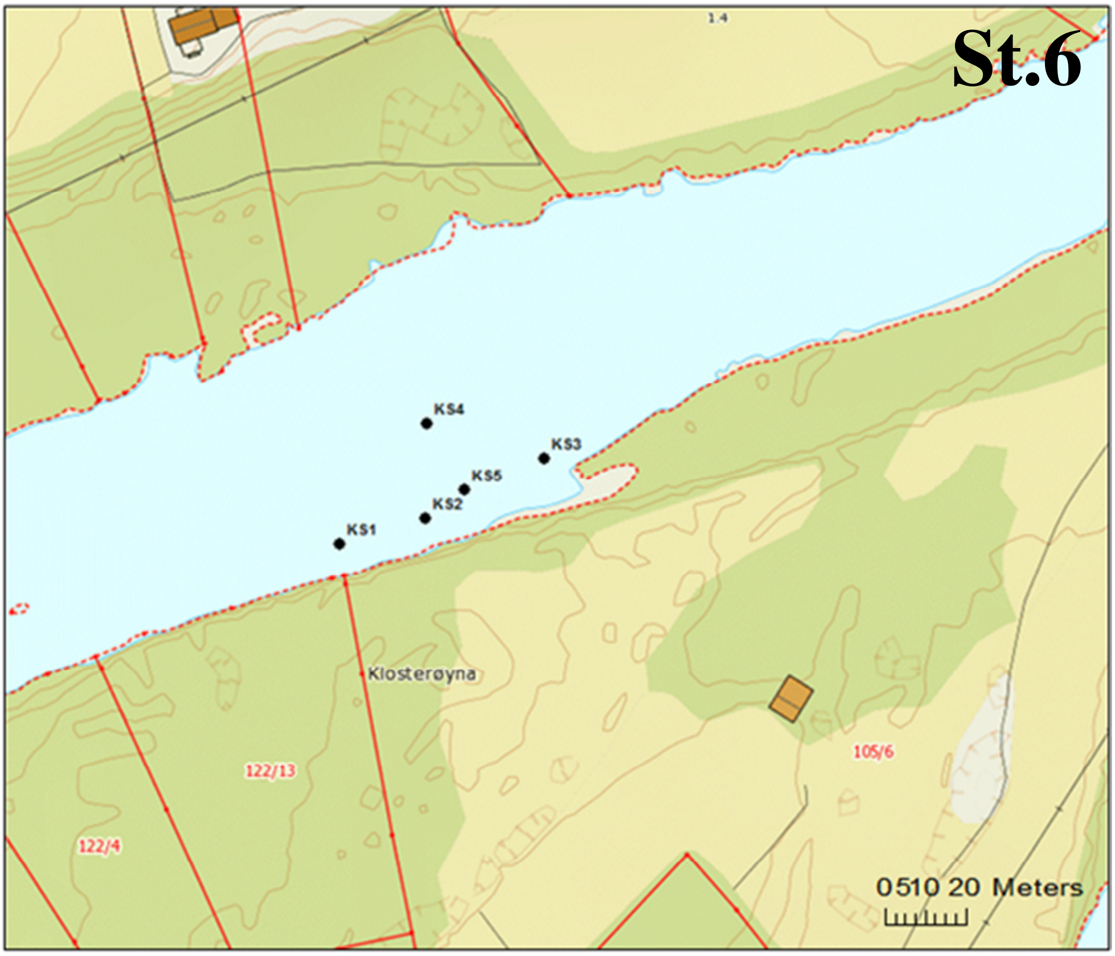


Figure 16. Substrate samples KS1*, KS2, KS3, KS4 and KS5 situated at Kloster at the north western side of the Kloster island (*position might be inaccurate due to uncertain coordinates) (norgeskart.no).

Figure 17. Aerial photography of station 6 (Norgeibilder.no).

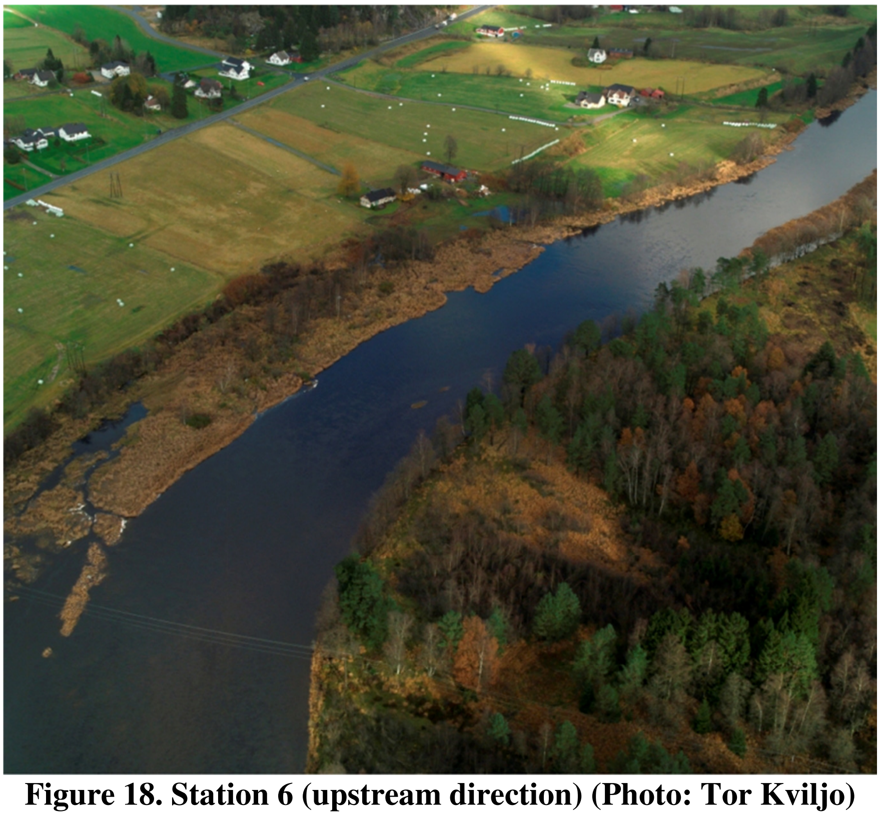


Figure 18. Station 6 (upstream direction) (Photo: Tor Kviljo)

2.4. Data collection

The data was collected during summer of 2013 using three methods: logging of water temperature and light, manually measured transects of different variables and river substrate samples. All sample- and measuring point coordinates were registered in a GPS (GARMIN GPSmap® 62s).

2.4.1. Loggers

Time series of temperature and light data were sampled by HOBO® loggers (**Figure 19**) (http://www.onsetcomp.com\products\data-loggers\ua-002-64), programmed to log every ten minutes. These small devices were attached to 0.5-0.7 m reinforcement bars (12 mm) that were pounded into the river bed. The loggers were all installed in the downstream direction of the bars and a few centimeters above the substrate, in order to allow some movement without hitting the ground. Altogether 28 loggers were distributed in four different parts of the river; Stations 1, 2, 4 and 5. The battery life time was 100 days, so there was no need for changing these during the logging period. The accuracy of the temperature data logged by the HOBOs were ± 0.47°C at 25°C.

Figure 19. HOBO® logger for measuring temperature and light time series in Kvina (Station 1, 2, 4 and 5).

The first 13 loggers (number 1-13) were installed at 12th of June, and the rest (number 14-28) 10-11 July. Three of the original 13 loggers (14, 20 and 27) were then moved to Station 5 in order to achieve a more desirable distribution of loggers in the river. The loggers were retrieved on 1st of September and the data downloaded by using a USB reader and HOBO® data processing software.

Figure 20. Installing a reinforcement rod to which a HOBO® logger is attached at station 1.

2.4.2. Air-to-water drivers data

In order to fit models to be used for predicting water temperatures air-temperature data and river discharge data was obtained from other external sources. Data on air temperatures (TAM) were retrieved from a meteorological station at Lista fyr (station number 42160, eklima.no), as well as with discharge data registered by Sira-Kvina at Stegemoen.

2.4.3. Grids

Grids of temperature, water level, pH, oxygen content and conductivity were measured manually by a SEBA MPS-K16/Qualilog-16 multivariable sensor (www.seba-hydrometrie.com) (**Figure 21**). The temperature sensor had an accuracy of ± 0.1°C, and the pH meter of ± 0.1 pH units. The optical oxygen sensor had an accuracy of ± 0.02 mg/l for concentrations <2mg/l and ± 1% when >2 mg/l. For the conductivity the same number is ± 0.1mS/cm for measuring values <20mS/m.

Figure 21. SEBA multivariable sensor for manual measurements of river transects.

The first measurements were carried out at 26.07.2013, while the second took place at 25.08.2013. Both were performed at the same 64 spots in station 4 (according to the GPS waypoints) with approximately ten meters between each point, as well as between all of the six different transects. The distances were some places differing due to an islet located at the northwestern side of the river, as well as areas with too little water for the sensor to measure. Along with the distribution of large boulders and the river width, this also reduced the number of points per transect with 14 points (Transect 1) at the most and eight at the lowest (Transect 5).

During the measurements the values of the different variables were shown on a screen on the logger. This data was written down in a form made from waterproof paper and later entered into an excel file.

2.4.4. Substrate samples

Altogether 16 substrate samples were gathered from stations 3, 4, 5 and 6, which all correspond to assigned salmon spawning sites. Former reds were detected by oblong elevations of the river bed and reduced abundance of algae and other organic material on the gravel compared to neighboring areas. All samples were conducted from potential spawning gravel/habitats, but not all were evident of being former redds. Samples were taken from locations of different distribution in the river segment, both in the middle parts of the river segment and closer to the banks.

A 25x25 cm metal-framed net (250 µm mesh) extended by squares of plywood was held just downstream the sampling spots to prevent finer substrate to escape. The substrate was collected by a shovel between the two plywood walls and to a depth of 20 cm in the river substrate. Finer material, gravel and stones were either shoveled directly into a bucket or caught by the net (which was emptied in the bucket as well). Each sample comprised two buckets of ten liters of substrate. The sampling was conducted at days of low flow in order to make them as accurate as possible. The distribution of different fractions on the substrate surface was described and photographed before conducting each sample.

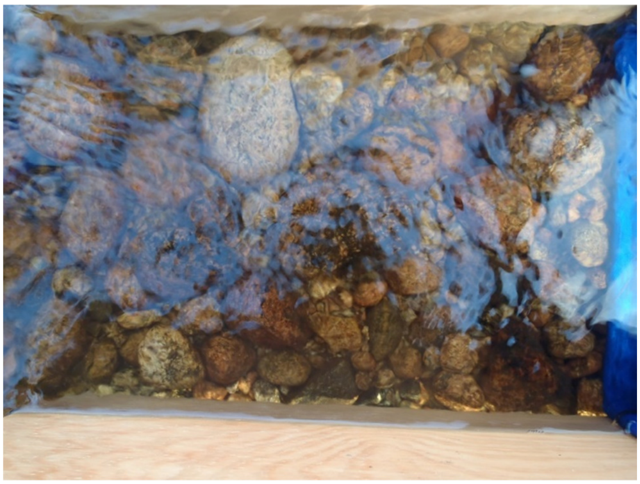


Figure 22. River substrate surrounded by two plywood walls (top and bottom) and a metal-framed net that prevented fines from escaping (to the right). Samples were conducted within this area to a depth of 20 cm.

All gravel samples were dried in a heating cabinet at >80°C until they were totally dry and sorted using sieves with mesh sizes 0.125, 0.25, 0.5, 1, 2, 4, 8, 16, 32, 64, 100, 128 and 256 mm, based on the Wentworth scale. The textural composition was plotted in a distribution curve for each sample as the accumulating weight, in order to calculate the spawning gravel potential. The Fredle index (F_i) as described by Lotspeich and Everest (1981), was the method used for further calculations. The index is expressed by the geometric mean particle size (D_g) divided by the sorting coefficient (S_o).

$$\mathbf{F_i = \frac{D_g}{S_o}}, \textbf{(Equation 1)}$$

The geometric mean is calculated by the midpoint diameter of a given sieve (d) to a power equal to the decimal fraction of the weight (w). All of the values representing each fraction of a sample are then multiplied to find the D_g.

$$\mathbf{D_g = [d_1^{w_1} \times d_2^{w_2} \ldots\ldots \times d_n^{w_n}]}, \textbf{(Equation 2)}$$

The standard deviation of the geometric mean was found by the following equation (**Equation 3**), where A_i represents the weight proportion of the different substrate fractions, while μg is the average weight of the actual fraction and n the number of fractions.

$$\sigma_g = \exp\left(\sqrt{\frac{\sum_{i=1}^{n}(\ln \frac{A_i}{\mu_g})^2}{n}}\right), \textbf{(Equation 3)}$$

The sorting coefficient (S_o) is a product of the square root of the quotient of the 75th percentile (d_{75}) divided by the 25th percentile (d_{25}) of the sample.

$$\mathbf{S_o = \sqrt{\frac{d_{75}}{d_{25}}}}\text{, (Equation 4)}$$

Since the larger fractions of a sample can make a significant change in the calculated percentages it is useful to find the percentage of fines (Pfines) of each sample. Fines are defined by the proportion of sand and fine sand, consisting of respectively the fractions 0.5-2 mm and > 0.5 mm. The gravel fraction is defined by the size interval 4-32 mm and fine gravel by 2-4 mm.

$$\mathbf{Pfines = \frac{sand+finesand}{gravel+finegravel+sand+finesand} \text{ x } 100}\text{, (Equation 5)}$$

2.4.5. Survival models

In order to find the relation between the substrate composition (Fredle index and Pfines) and survival, three different models were applied. The first approach was developed by Tappel and Bjornn (1983) to calculate the survival of Chinook salmon (*Oncorhynchus tshawytscha*) eggs. The Atlantic salmon and Chinook salmon both have large individuals of comparable size, which should make the model valid for the data of this assessment.

$$\mathbf{\%survival_{Tappel} = 93.4 - 0.171\, P_{9.5}P_{0.85} + 3.87\, P_{0.85}}\text{, (Equation 6)}$$

The percent survival ($\%survival_{Tappel}$) is calculated by incorporating the percent volume of sediments < 9.5 mm ($P_{9.5}$) and the percent volume of sediments < 0.85 mm ($P_{0.85}$) into the equation.

The second survival model by Lapointe et al. (2004) was developed to calculate the survival to emergence of Atlantic salmon fry.

$$\mathbf{\%survival_{Lapointe} = 83 - 29(SI) - 6(SI \text{ x } \%Silt)}\text{, (Equation 7)}$$

The percent survival ($\%survival_{Lapointe}$) was found by using the percentage of silt (%Silt) defined by fractions < 0.063, and the Sand index (SI) developed by Peterson et al. (1981).

$$\mathbf{SI = \frac{S_c}{16} + \frac{S_f}{8}}\text{, (Equation 8)}$$

S_c is the percentage of the sample consisting of coarse sand (0.5-2 mm) while S_f is the percentage of fine to medium sand (0.06-0.5 mm).

Levasseur et al. (2006) made a threshold model to calculate the relation between the percentage of silt and very fine sand (%SVFS) and the percent of hatching of Atlantic salmon embryos. They defined silt and very fine sand as fractions <1.125 mm

$$\%\mathbf{survival}_{\mathbf{Levasseur}} = \mathbf{36.09} + \mathbf{54.49}/\left\{\mathbf{1} + \mathbf{exp}\left[\frac{\%\boldsymbol{SVFS}-\mathbf{0.17728}}{\mathbf{0.0037}}\right]\right\}, \textbf{(Equation 9)}$$

2.4.6. Salmon individual length data

The salmon individual length data was originally conducted by electrofishing as a part of an annually monitoring program of limed watercourses under the auspices of the Norwegian Environment Agency. The data from 2012 was available in the 2013 report (Miljødirektoratet, 2013), while results from the former years were provided by Svein Jakob Saltveit at the University of Oslo, who was responsible for these field surveys during that time period. The electrofishing data from 2013 was sent by NINA (Norwegian Institute for Nature Research) that is now responsible for the collection of these.

For this study the results from 2007-2010, as well as from 2012 and 2013 were applied in order to compare fish length from different parts of the river stretch and see if there were any relations to the findings in this study. The electrofishing stations relevant for this study was Station 3-10 (**Appendix 2**). Fishing station 3 and 4 were located in the same area as Station 1, fishing station 5 close to Station 2, fishing station 6 and 7 upstream Station 3, fishing station 8 in the same area as Station 3, fishing station 9 in the same area as Station 5 and fishing station 10 close to Station 6. The salmon length was divided into groups of 0+ and >0+ and an average of the stations was calculated for each year.

2.5. Statistics

In order to estimate percentiles for the gravel-size distribution a three-parameter Weibull function was fitted the cumulated weight fraction data as function of gravel size:

$$\mathbf{Pr}(\boldsymbol{x}) = \mathbf{a}^{e^{-e^{(\mathbf{b}\,\mathbf{log}(\boldsymbol{x})-\mathbf{log}(\mathbf{c}))}}}, \textbf{(Equation 10)}$$

, where Pr(x) is the probability for a given grain size x and a, b and c are parameters under estimation. The function was fitted using the drm package in R (R Development Core Team, 2012). Parameters were estimated using the log-likelihood method.

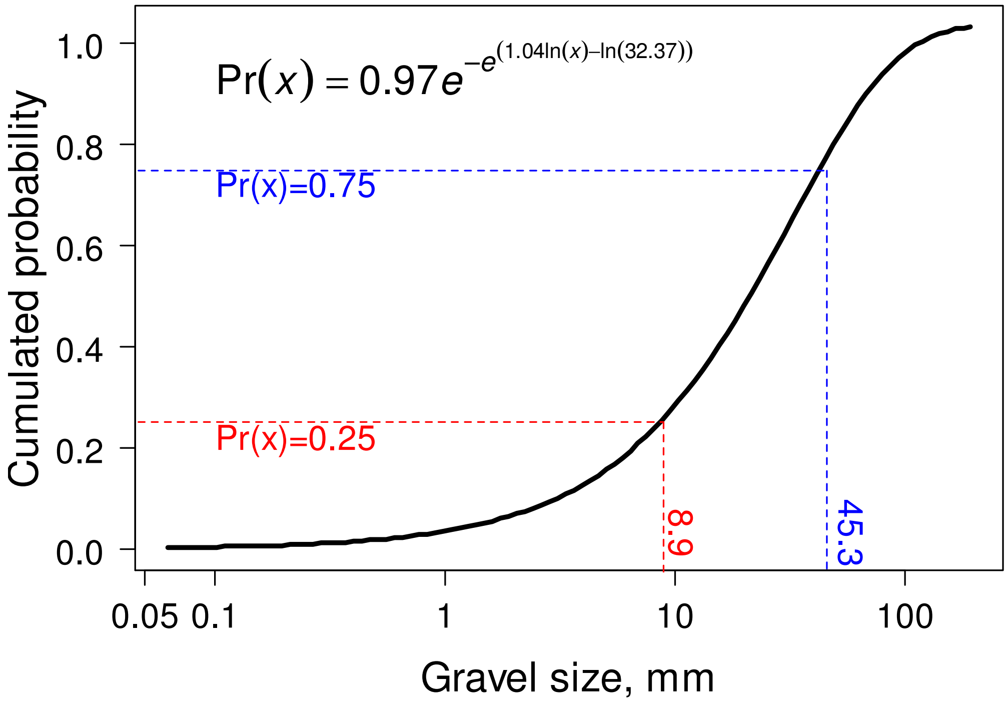


Figure 23. Example of a cumulated probability curve of gravel size distribution expressed by the three parameter Weibull function. The 25 percentile (red dotted line) and the 75 percentile (blue dotted line) provide the values necessary to calculate the sorting coefficient (So).

The quantiles for the gravel composition distributions (d75 and d25) were estimated by solving equation 10 for Pr(x)=0.75 and Pr(x)=0.25, respectively. This was done using the dose.p procedure available in the MASS package.

The air-to water model was fitted as a linear mixed effects model (LME, (Pinheiro and Bates, 2000) using the R package nlme (linear and nonlinear mixed effects models). As fixed effects different moving average levels for air temperature and discharge were used along with a categorical variable related to river depth and water velocity (relatively deep areas (D), pools (P), shallow areas (S) and shallow areas of high velocity (V)). Different alternative autocorrelation structures along with various candidate fixed effect model combinations were fitted and station used as random effect. Model selection was performed using Akaike's Information Criterion (AIC, (Akaike, 1974) following procedures described in Zuur et al. (2009).

3. RESULTS

3.1. Within river temperature variation

The water-temperature loggers (**Figure 24**) revealed generally high water temperatures in Kvina during the summer of 2013. Even though there are some spatial disparities in temperatures both within and between the different stations, they all had a similar pattern through the summer. The coefficient of variation (CV) was not differing much between the four stations during the summer. Still, all the stations were facing greater variability in relation to the mean in July than in June and August, which were reasonably similar and dominated by nine and ten percent variation in temperature at all the stations.

The lowest temperature measured at Station 1 was common for K01, K02, K03 and K04 of 12.2 °C; the same minimum temperature as at Station 2. The highest temperature registered at Station 1 of 26.6 °C at K21 was the second lowest, while the mean temperature of 18.1 °C was the lowest of all the stations. The mean coefficient of variation in July was eleven percent, as the different loggers were ranging between seven and 12 percent. At this station the mean variation was higher in June than August, with respectively ten and nine percent.

The minimum temperature at Station 2 was common for K07 and K08 and station 2 of 12.2 °C. The maximum temperature registered at the station was found at K05 of 25.4 °C, which is lower than at the three other stations. The mean temperature of 18.2 °C, on the other hand was higher than at the former station and lower than the two following ones. Station 2 was the one having the least prominent fluctuations during the low flow period, followed by Station 1. The temperature variation was of nine percent at all the loggers in June, while the ranging from eight to 13 percent with a mean of eleven percent in July. During the August period all loggers apart from K26 of nine percent, had ten percent variation in relation to the mean temperature.

Station 4 had the highest maximum water temperature of all the stations, registered at K17 of 32.6 °C. The lowest temperature of 12.1 °C was also registered at this station at logger K12. The second highest mean temperature was found in this area of 18.3 °C. The greatest variation in July temperatures was found at this station, with 13 percent as the mean. K17 had the largest coefficient of variation with 15 percent, followed by 14 percent at K13. At K15 and K18 the lowest temperature variability of the month was discovered of eight percent. June had the lowest mean of nine percent, while the mean of August had ten percent variation in relation to the mean temperature.

Station 5 had the most pronounced fluctuations during the warmest period, followed by Station 4. The lowest temperature measured at the station was 14.2 °C at K27, which is the highest minimum of the four stations, while the highest was measured at K14 of 31.7 °C. The mean temperature of 18.9 °C was the highest of all the stations. The greatest coefficient of variation of all the stations was found at K14 in July of 17 percent, while the mean of all three loggers was of 12 percent (ten percent at K20 and eight percent at K27). None of the loggers at Station 5 were installed in the river during June, so no data was registered from this period.

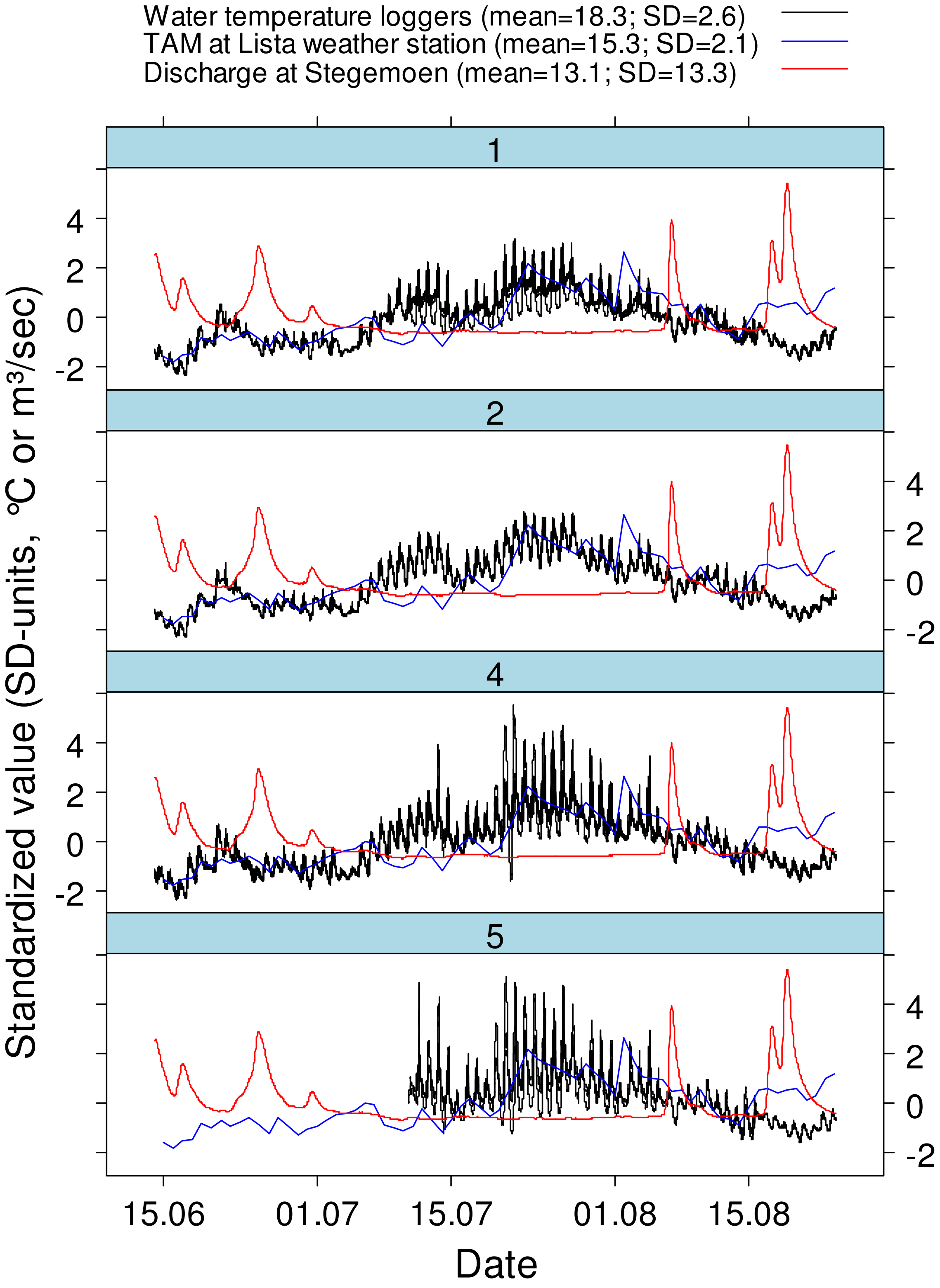


Figure 24. Time series illustrating temperature fluctuations registered by HOBO® loggers, air temperatures from Lista and water discharge from Stegemoen. The four plots represent Station 1, 2, 4 and 5 where the 28 loggers were distributed from the 12th of June (Station 1, 2 and 4), the 10th of July or the 11th of July (Station 5) to the 1th of September. All values have been standardized to global mean = 0 and global standard deviation =1. Standardization parameters are provided in figure legend.

In August, the mean variability of the area was of ten percent, ranging between nine percent at K20 and K27, and eleven percent at K14.

Kvina experienced some flow peaks in the beginning and the end of the period measured, with the largest discharge of 85.3 m³/sec in the very end of August. The discharge was at its lowest from the beginning of July to the beginning of August. During this time period precipitation was as good as absent leading to a minimum discharge of 3.9 m³/sec. At the same time the median air temperature rose to a maximum of 20.9 °C. The largest fluctuations in day and night temperatures were registered during this low flow period, as the water got heated up by sun radiation during daytime. Once the sun set, the water cooled down quickly. By elevated discharge the heat response of the river was less pronounced with respect to fluctuations. The mean discharge for the whole period was 13.1 m³/sec, while the mean air temperature was 15.3 °C.

There was not a very high degree of dispersion in temperature data between the stations in either June, July or August (**Figure 25**). The median temperature was higher in August than in June, and at its highest in July. In June the 75th percentile was a little higher at Station 1 than Station 2 and 4. In July Station 4 and 5 are distinguishing from the other two by having a larger number of outlier values. The very high *n* of the dataset is allowing the outliers to be rather numerous, probably representing the highest mid-day temperatures at the most sun exposed loggers. The 25th and 75th percentile at Station 4 had a little wider range than the other three loggers, while the 75th percentile was highest at Station 5.

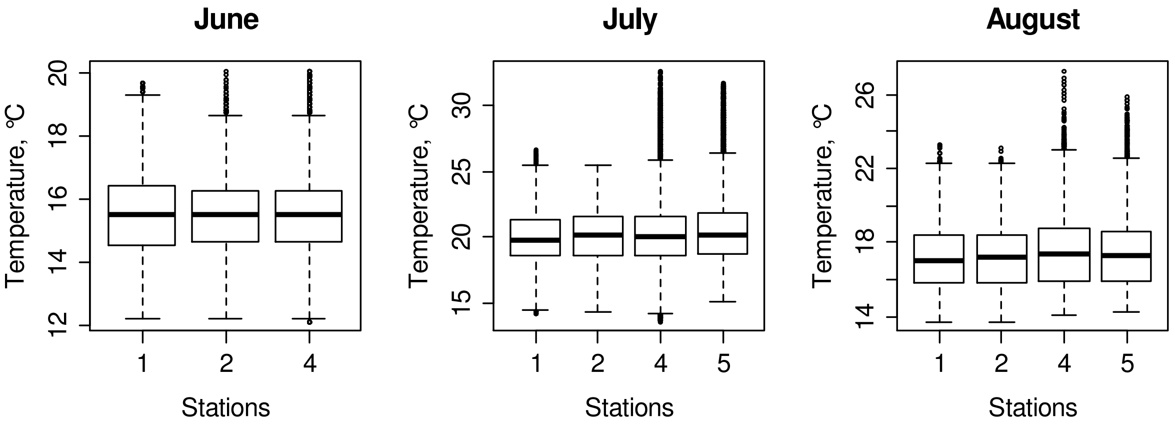


Figure 25. The median temperatures during June, July and August at Station 1, 2, 4 and 5 (there were no loggers located at Station 5 during June).

In August the 25th percentiles ranged over a much smaller amount of values than the 75th percentiles. Also here the outliners were in high numbers, but not to the same extent as in July.

The loggers were then distinguished into four habitat types regardless of to which station they belonged to (**Figure 26**). These were; relatively deep areas (D), pools (P), shallow areas (S) and shallow areas of high velocity (V).

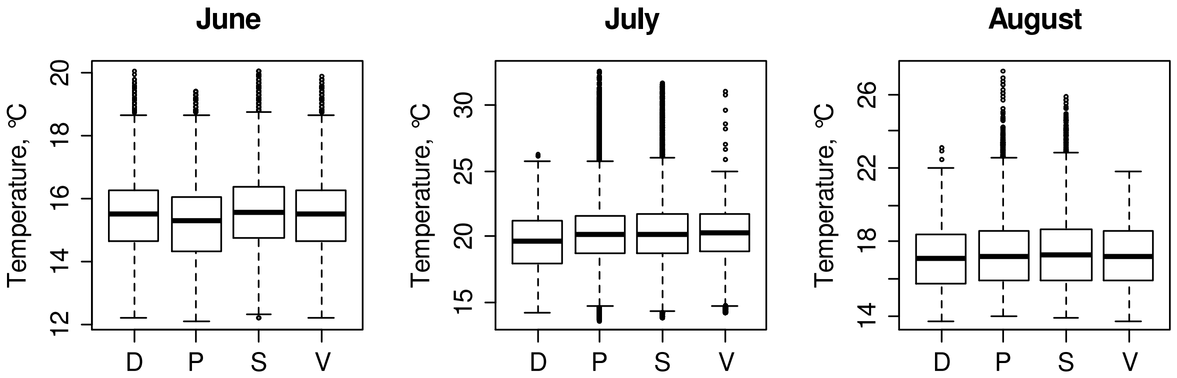


Figure 26. The median temperatures of the four habitat types; relatively deep areas (D), pools (P), shallow areas (S) and shallow areas of high velocity (V) during June, July and August.

In June pools differed a little from the other habitat types by having a lower median temperature than the other three. In July, on the other hand, deep areas had the lowest median, while the high velocity areas had the lowest 75th percentile and smallest distribution range of values. Pools had the highest single measurement and a great amount of outliers of high temperatures, as well as for values below the 25th percentile. This was also the case for the shallow areas that had the highest 75th percentiles of the four habitat types. In August pools and shallow areas still had the highest amount of high temperature values, while the high velocity ones had the lowest 75th percentile.

3.1.1. Air-to-water model

The most supported LME air-to-water model for the whole period differed by 1.9 AIC units to the second-most supported model (**Appendix 3**) and explained 78% of the variation in water temperatures. This model estimated water temperature to have a delayed response to air temperature and water discharge, but the lag differed between the two predictor variables. Air temperature moving-averaged to two days and discharge moving-averaged to four days had a significant interaction effect on water temperature ($p<0.0001$) in Kvina (**Table 1**). The most supported model contained an interaction effect between habitat type and month, but this effect was not significant ($p=0.44$, **Table 1**). When exploring the interaction coefficients involved in this effect the "pool" habitat type in July effect was estimated to be 0.54 °C (±0.34) higher than the default "deep" habitat (**Table 1**). In

Figure 27, predicted water temperatures for different combinations of discharge and air temperature for given station types are presented. According to the model the response in water temperatures due to increased river discharge was generally negative, and an elevation in discharge of one m^3/sec was on average responsible for decreasing the water temperatures by 0.33°C. However this negative effect decreased by a factor of 0.014 for every one increase in TAM*discharge.

The between-station random-effect variation in water temperatures (sd=0.066) was estimated to be far smaller than the between-loggers within-station variation (sd=0.170) (**Table 1**).

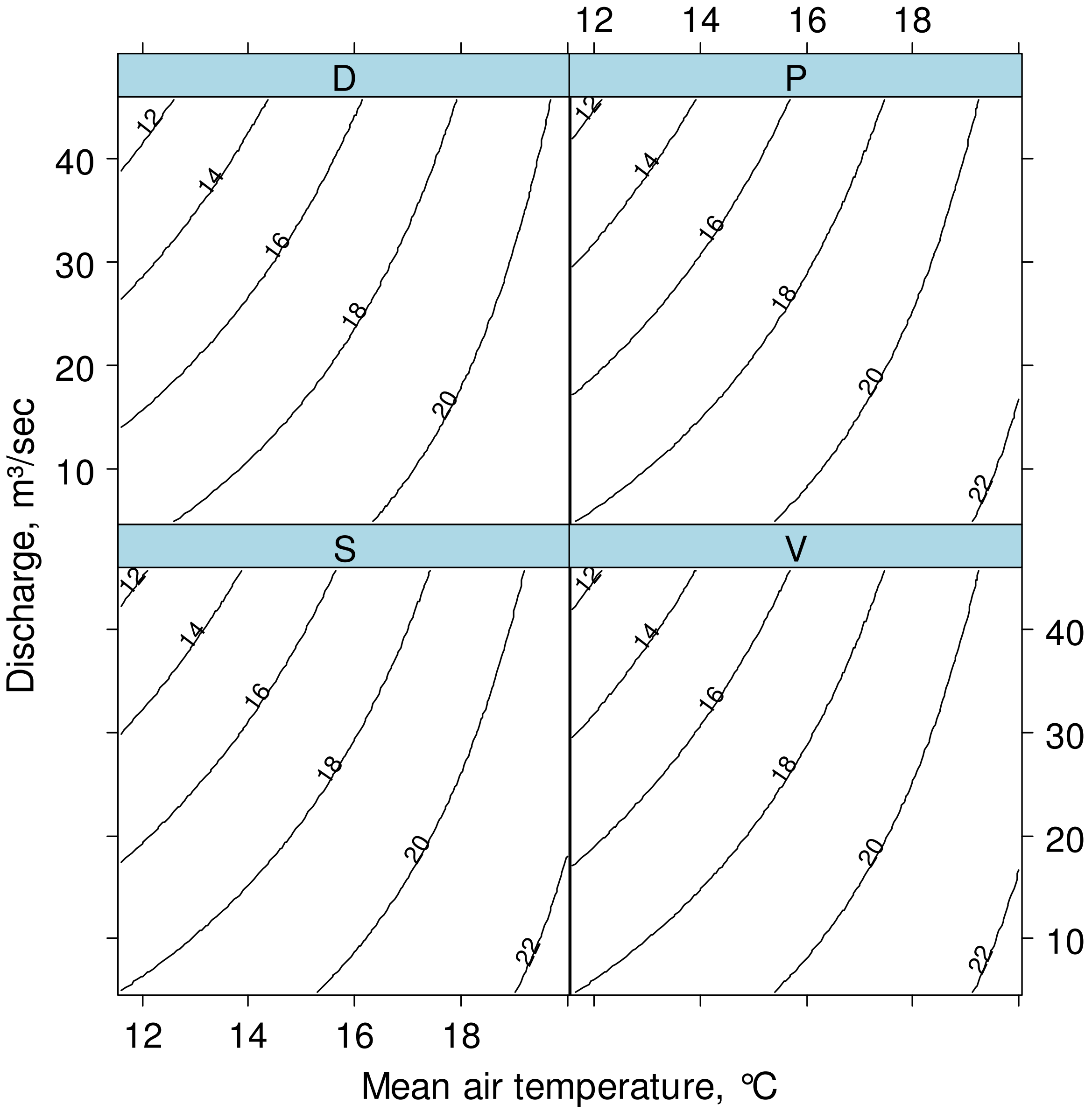


Figure 27. Predicted river temperature (°C) illustrated by the contours, modelled as a function of the river discharge (m³/sec) four days in advance and the air temperature (°C) two days in advance. Habitat types: deeper areas (D), pools (P), shallow areas (S) and shallow areas of high velocity (V)

Table 1. Air-to-water temperature model parameters for the most supported LME model for the whole period and for July (the lower part of the table). TAM = mean daily air temperature, DIS = discharge, maX = moving average over X days, phiX = autocorrelation with X days ago; Logger|Station corresponds to loggers nested under Station. The R2 of the model was 0.78.

Fixed					Autocorrelation		Random	
Term	Estimate	SE	t-value	p-value	Term	Est	Term	Est
Intercept[TypeD]	12.352	0.482	25.628	<0.0001	phi1*	0	Station	0.066
TAM(ma2)	0.466	0.024	19.296	<0.0001	phi2*	0	Logger|Station	0.170
DIS(ma4)	-0.328	0.043	-7.591	<0.0001				
Type[P]	-0.031	0.332	-0.094	0.926				
Type[S]	0.265	0.207	1.282	0.214				
Type[V]	0.262	0.256	1.025	0.317				
Month[Jul]	0.476	0.191	2.498	0.013				
Month[Aug]	-1.214	0.203	-5.980	<0.0001				
TAM(ma2)*DIS(ma4)	0.014	0.003	5.346	<0.0001				
Type[P]*Month[Jul]	0.537	0.335	1.602	0.109				
Type[S]*Month[Jul]	0.296	0.211	1.405	0.160				
Type[V]*Month[Jul]	0.242	0.261	0.925	0.355				
Type[P]*Month[Aug]	0.262	0.342	0.766	0.444				
Type[S]*Month[Aug]	0.029	0.220	0.132	0.895				
Type[V]*Month[Aug]	-0.068	0.271	-0.253	0.801				

*The most supported model hold no autocorrelation structure

3.2. Small-scale spatial variation

Results from the grid measurements show different values and patterns in July compared to August. The water discharge was higher during the latter registration with 5.66 m³/sec compared to the July discharge of 4.97 m³/sec, which along with the change in air temperatures might be explanatory variables for the differences seen. The lowest water level measured in July was of 0.06 meters. Areas of lower depth occurred, but these were impossible to measure with the logging sensor and therefore not taken into account. The highest water level measured in July was registered close to the Northwestern part of the weir of 0.93 meters. In August, the lowest water level was of 0.1 meters, while the highest registered was of 0.99 meters. The slightly elevation in water depth was contributing to wetting some of the areas that were dry in July.

There was an evident threshold between the frequencies of the manually measured variables from July and August (**Figure 28**). The former seemed to be spread out over a wider range of values than the latter, with a generally higher variation within the grid. The temperatures from the last measurement were mainly varying within the interval 15-16 °C, while the first registration had a more spread out temperature distribution. Still the interval 22-23 °C clearly appeared most frequently.

The temporal differences were less pronounced for the pH, which on the July registration showed a relatively broad distribution compared to the one in August. The former had two frequency peaks of respectively 6.4 and 6.6. In August the main emphasis was concentrated around pH 6.

Even though the most frequent water depth in July of < 0.05 m was lower than the one in August of approximately 0.2 m, they had a quite similar distribution pattern in the histogram **Figure 28**). The main emphasis is shifted to the left on both graphs with decreasing frequency at greater depths. Still the river segment was generally deeper in August as a result of the higher discharge of the river.

The frequency of dissolved oxygen was distributed over a wider range of percentages at the first assessment than the second, with a quite even amount of measurements between 110 and 120 percent. In August the values were more concentrated within the interval 110 to 115 percent.

The conductivity was of great similarity at the July and August registration with the highest frequencies between 1.5 and 2.0 mS/m. The greatest heterogeneity was discovered during the former measurements with elements of higher values.

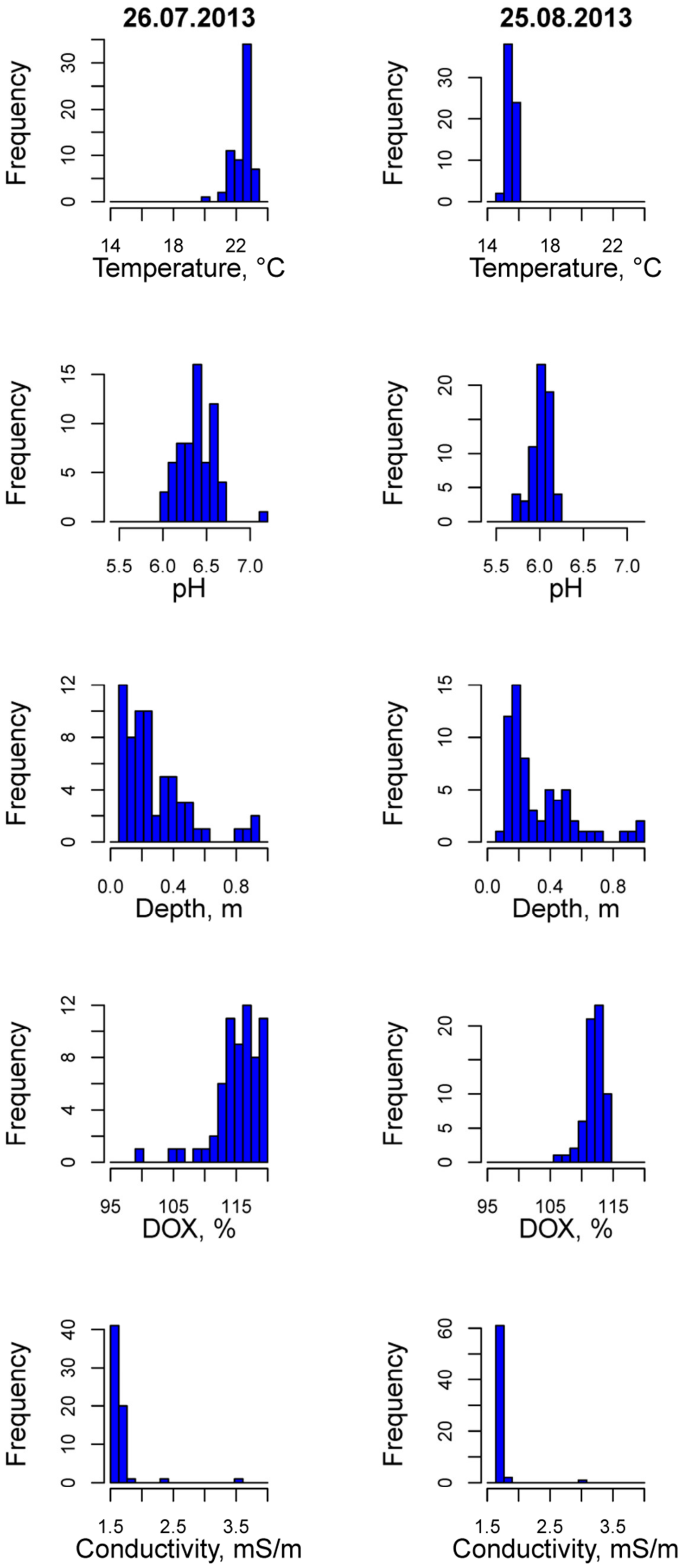
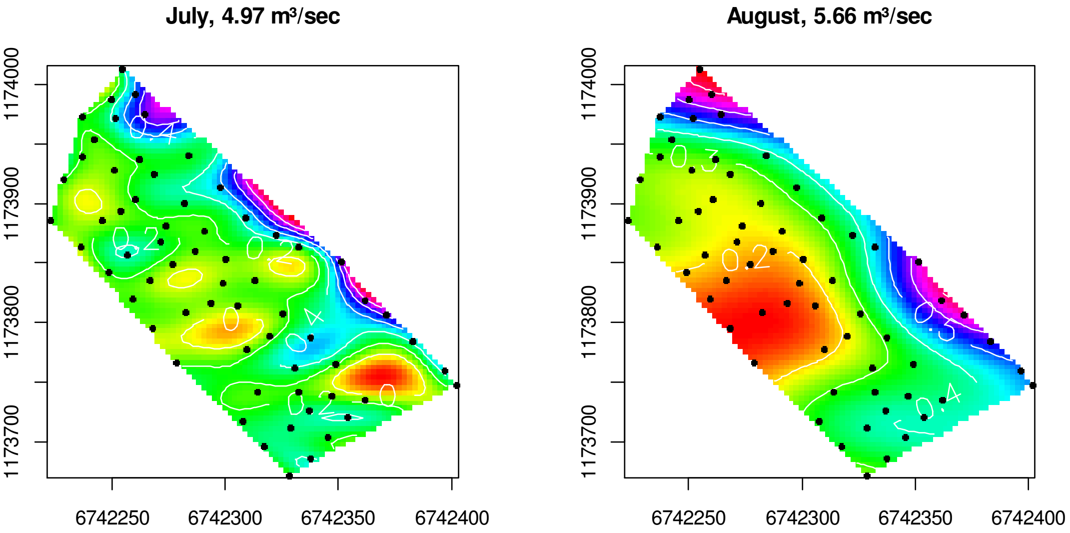


Figure 28. Grid data frequencies of temperatures (°C), depth (m), pH, dissolved oxygen (%) and conductivity (mS/m) illustrated by histograms. The data is from respectively 25.08.13 and 26.07.13.

The water level was low during both July and August (**Figure 29**), but was at its lowest during the former sampling period. The depth was varying largely within the river segment, with a shallow and partly drained area in the middle and two deeper parallel flow paths on each side. The greatest depths were found along the weir, where the water poured down into deeper pools. The mean water level rose by 0.05 meters from July to August, from 0.28 to 0.33 meters.



July, 4.97 m³/sec

August, 5.66 m³/sec

Figure 29. Spatial kriging plots expressing the variety in depth (m) of the grid data measured manually in July and August, with coordinates on the axis. The black dots are representing the GPS-positions of the 64 points monitored.

The temperatures within the river segment (Figure 30) did to a greater extent vary in the longitudinal direction during the July assessment than August, with the lowest temperatures along the weir of 20.0 °C (north east). The temperatures increased rapidly towards the shallow area in the southwestern part, were the highest temperature of 23.1 °C were registered. Along the eastern river bank generally lower temperatures were detected, with a rather homogenous area of around 22.5 °C at the northern part followed by more heterogeneous conditions towards the southernmost corner. This may be explained by a small tributary stream running from a nearby hill slope into the river. The August registration had a more clearly across river pattern with remarkably lower temperatures than the first assessment. Still some variance from this pattern is evident along the southeastern river bank. The temperature gradient of the river segment went from low to higher values in a downstream direction, from15.0 °C along the weir to 15.8 °C at the warmest. The tributary stream was in terms of temperature less pronounced in August, probably due to the elevated discharge.

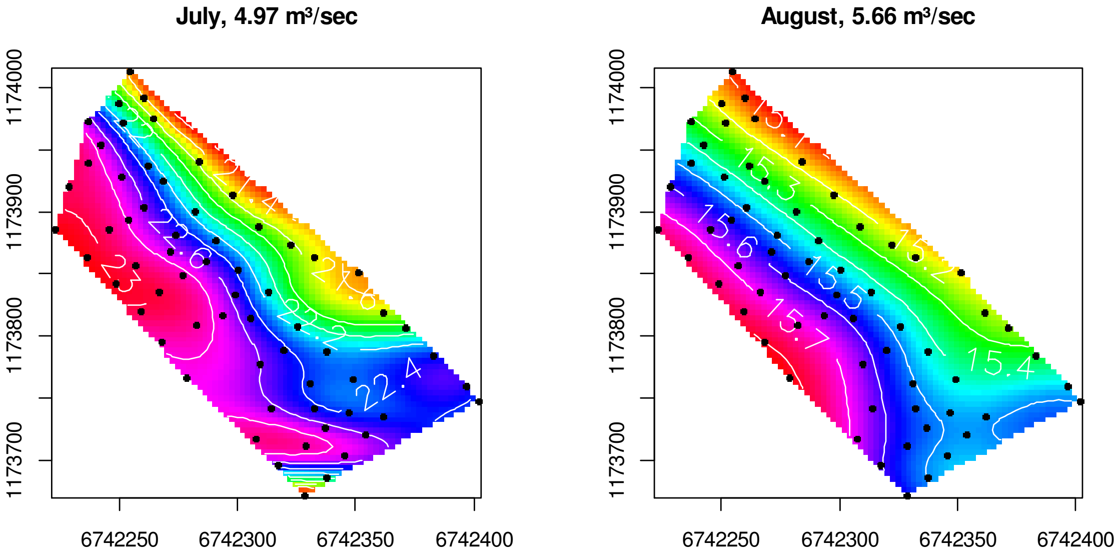


Figure 30. Spatial kriging plots expressing the variety in temperature (°C) of the grid data measured manually in July and August, with coordinates on both axis. The black dots are representing the GPS-positions of the 64 points monitored.

The variations in pH (Figure 31) were to some extent equivalent to the ones of the temperature, with the highest July values at the shallow mid-section area close to the islet of around pH 6.5.

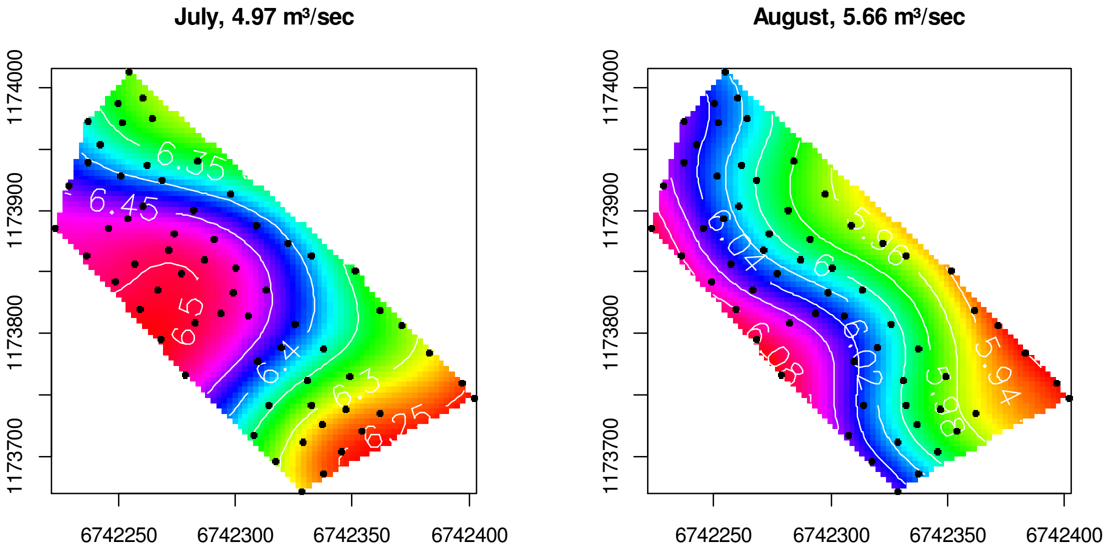
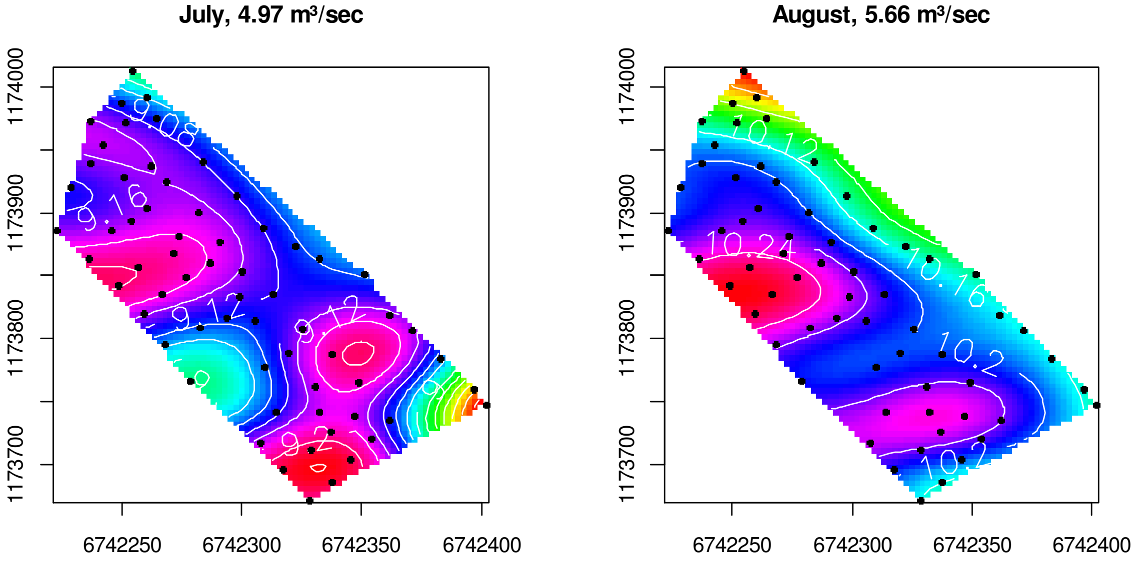


Figure 31. Spatial kriging plots expressing the variety in pH of the grid data measured manually in July and August, with coordinates on the axis. The black dots are representing the GPS-positions of the 64 points monitored.

From the northwestern to the Southeastern river bank the pH was changing from having an across river to a longitudinal pattern. The lowest registered pH of around 6.25 was measured along the southeastern river bank. Less spatial variation of pH was discovered during the August assessment. The values were increasing in the downstream direction, ranging from around 5.92 near the weir to 6.08 furthest downstream in an across river pattern. Still the pH was generally a little lower at the Southeastern side of the river than the equivalent in Northwest.

The oxygen concentration was increasing from July to August (Figure 32). The former observations did not show any clear patterns, but patches of higher oxygen concentration to the maximum of 9.45 mg/l. The lowest oxygen concentration of 8.23 mg/l was registered in the northern corner of the grid.


July, 4.97 m³/sec

August, 5.66 m³/sec

Figure 32. Spatial kriging plots expressing the variety in the concentration of oxygen (mg/l) of the grid data measured manually in July and August, with coordinates on the axis. The black dots are representing the GPS-positions of the 64 points monitored.

During the August assessment the oxygen distribution was more homogeneous. Lower concentrations were found along the weir, while two larger patches of higher oxygen concentrations were registered further downstream. Generally the oxygen concentration in the river section was high, with a top peak of 10.40 mg/l. The lowest value registered in August was 9.80 mg/l.

The rate of dissolved oxygen was decreasing from the first to the second assessment (Figure 33). Despite the lower concentrations in August the majority of the values were still above 100 percent, which may be explained by a high primary production in the river. The July measurements of dissolved oxygen were ranging between 99.22 and 119.90 percent, with the highest values in patches similar to the ones of oxygen concentration (**Figure 32**). It is worth mentioning that the former value was the only one below 100 percent.

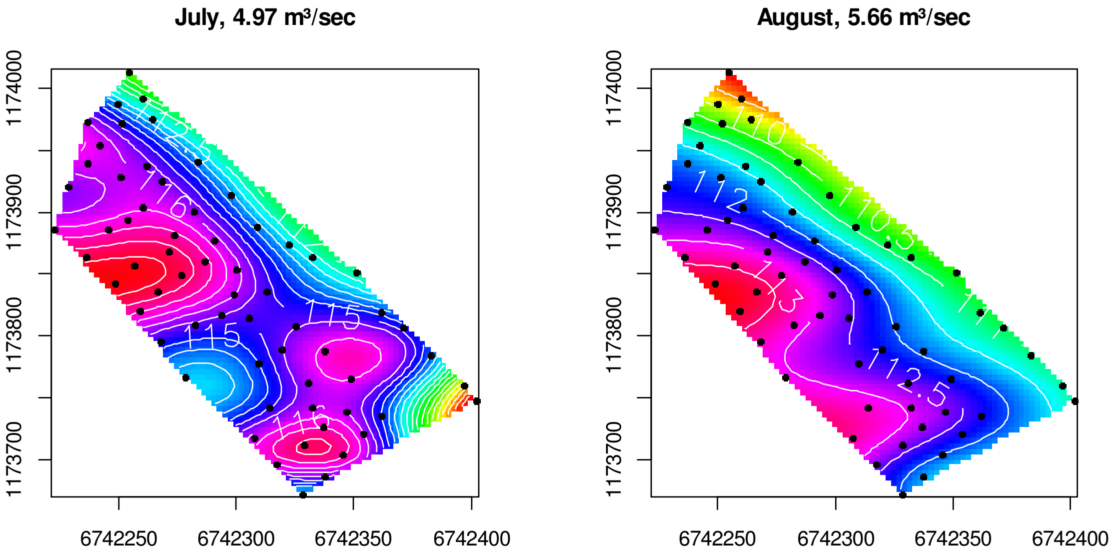


Figure 33. Spatial kriging plots expressing the variety in dissolved oxygen (%) in of the grid data measured manually in July and August, with coordinates on the axis. The black dots are representing the GPS-positions of the 64 points monitored.

In August the percentage increased in an across river pattern, but still with traces of the same patches of higher values as the oxygen concentration the same month. Along the weir the dissolved oxygen levels were at the lowest, increasing downstream from a minimum of.105.7 percent to a maximum of 114.5.

The conductivity (**Figure 34**) was not varying much either temporally or spatially, apart from at some points of altered values along the southeastern side of the river. In July the area was dominated by points of 1.7 and 1.6 mS/m, and only two points were differing with higher values of 2.4 and 3.6 mS/m, which explain the variation in the plot. The August assessment was dominated by conductivities of 1.7 mS/m at all points apart from three along the southeastern bank, whereas two points were of 1.8 mS/m and one of 3.0 mS/m.

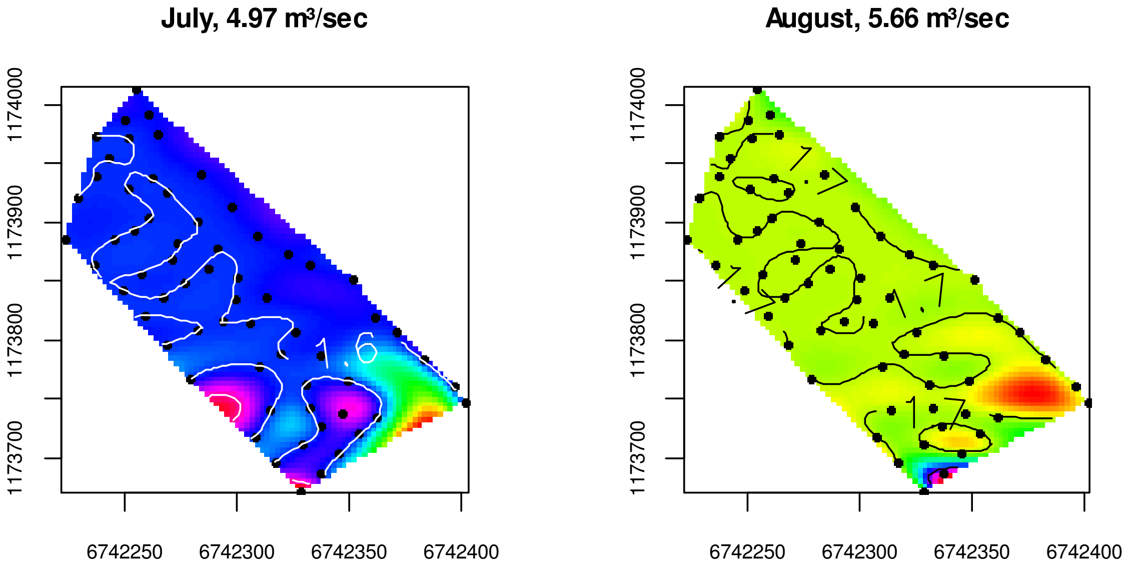


Figure 34. Spatial kriging plots expressing the variety in conductivity (mS/m) of the grid data measured manually in July and August, with coordinates on the axis. The black dots are representing the GPS-positions of the 64 points monitored.

3.3. Spawning gravel quality

There was great variation both within and between each of the three stations where substrate samples were collected, judging by the Fredle indices. Despite the variation within each of these river areas, Station 3 had a higher mean Fredle number than Station 5 and 6. The samples SS4 and SS5 excelled with respectively 22.05 and 12.97, indicating a very low degree of cavity clogged by fines. Both the samples had a high geometric mean (D_g) of 43.72 at SS4 and 30.22 at SS5, probably determining for the high Fredle numbers as a greater part of the samples were of course character. SS4 also had a low sorting coefficient (S_o) 1.98, relative to the other samples. The Weibull parameter c value and the accompanying standard deviation of 62.64 ± 6.53 were high relative to the other samples within the same station. The 25 and 75 percentiles also had relatively pronounced standard deviations of ± 2.04 and ± 10.12. The lowest Fredle number within Station 3 was found at SS2 with 6.36, probably due to the low geometric mean of 14.61.

At station 5 the Fredle indices varied within the range of 8.37 at sample F4 and 4.24 at F1. The former held the lowest sorting coefficient of 3.09, while the latter had a geometric mean of 13.89, which is the second lowest of all the samples. The second-highest geometric mean of 30.66 was also found in this area. The sorting coefficient was generally high at Station 5 compared to the two others, with 4.48 at F3 as a high point. The standard deviation of the Weibull parameter c and the 75 percentile was of very high character, especially at F3 and F5. For the former these were of respectively 103.42 ± 64.82 and 192.78 ± 130.81, while for the latter 167.04 ± 99.55 and 293.20 ± 186.73.

The lowest Fredle number of 4.22 and the lowest geometric mean of 12.54 were found at Station 6 representing sample KS2. The highest Fredle number in this area of 7.91 was found in sample KS1, which also had the station's highest geometric mean of 19.71. The standard deviation of KS4 was somewhat elevated compared to the other samples from Station 6, particularly pronounced at the Weibull parameter c and the 75 percentile, with respectively 34.34 ± 5.09 and 52.18 ± 9.02.

Even though the samples at Station 3 had generally higher Fredle numbers than the other two stations, the substrate surface (before collecting the samples) was at all samples apart from SS4 to a greater extent influenced by fines than at Station 5 and 6. The percentage of fines was still not any lower on average at these two stations, as the sandy material was distributed further down in the sample profile. SS4 and SS5 that both had high Fredle numbers compared to the rest of the samples had very low content of fines of respectively 1.67 and 4.71 percent (**Table 2**). The highest content of fines was found at F1 of 22.29 percent and KS2 of 20.78 percent, which is reflected by the low Fredle numbers of these samples. The percentage of fines was generally varying within each of the stations, but was on average lowest at Station 3.

Table 2. The three parameters of the Weibull function (a, b and c) and the associated standard deviation, the 25 percentile (D_{25}) and 75 percentile (D_{75}), geometric mean (D_g), sorting coefficient (S_o) and Fredle number (F_i) for all the gravel samples.

	Weibull parameters			Percentiles		Indices			
Sample	a	b	c	d_{25}	d_{75}	$D_g(mm)$	S_o	F_i	Pfines
SS01	0.86 ± 0.04	1.04 ± 0.02	32.28 ± 2.27	7.57 ± 0.5	47.21 ± 3.88	20.41	2.5	8.17	11.86
SS02	0.95 ± 0.03	1.01 ± 0.01	19.58 ± 0.73	5.24 ± 0.22	27.66 ± 1.22	14.61	2.3	6.36	12.47
SS03	0.95 ± 0.07	1.01 ± 0.02	24.07 ± 1.94	6.5 ± 0.58	33.92 ± 3.26	17.46	2.28	7.64	12.82
SS04	1.15 ± 0.11	1.06 ± 0.05	62.64 ± 6.53	21.18 ± 2.04	83.24 ± 10.12	43.72	1.98	22.05	1.67
SS05	0.93 ± 0.05	1.05 ± 0.03	46.42 ± 3.57	12.15 ± 0.78	65.97 ± 5.88	30.22	2.33	12.97	4.71
F01	0.66 ± 0.05	1.07 ± 0.05	28.12 ± 4.57	4.28 ± 0.54	46.06 ± 8.68	13.89	3.28	4.24	22.29
F02	0.61 ± 0.04	1.27 ± 0.14	94.92 ± 30.6	12.23 ± 2.66	162.42 ± 57.28	27.4	3.64	7.52	11.77
F03	0.52 ± 0.05	1.29 ± 0.24	103.42 ± 64.82	9.61 ± 4.25	192.78 ± 130.81	23.64	4.48	5.28	16.99
F04	0.7 ± 0.03	1.09 ± 0.05	52.58 ± 6.75	8.8 ± 0.71	83.99 ± 12.26	25.86	3.09	8.37	11.24
F05	0.58 ± 0.05	1.5 ± 0.32	167.04 ± 99.55	19.53 ± 8.74	293.2 ± 186.73	30.66	3.87	7.91	10.95
KS01	0.86 ± 0.04	1.02 ± 0.02	29.69 ± 1.72	6.99 ± 0.37	43.37 ± 2.96	19.71	2.49	7.91	11.15
KS02	0.72 ± 0.03	1.03 ± 0.02	21.36 ± 1.69	3.8 ± 0.28	33.58 ± 3.1	12.54	2.97	4.22	20.78
KS03	0.86 ± 0.05	1.03 ± 0.02	25.41 ± 1.99	6.01 ± 0.5	37.08 ± 3.4	16.44	2.48	6.62	14.45
KS04	0.78 ± 0.07	1.07 ± 0.05	34.34 ± 5.09	6.96 ± 0.88	52.18 ± 9.02	18.95	2.74	6.92	15.27
KS05	0.76 ± 0.04	1.04 ± 0.02	24.63 ± 2.04	4.81 ± 0.37	37.79 ± 3.66	14.5	2.8	5.17	17.21

3.3.1. Survival models

The three different survival models applied to the gravel data did all give different predictions in terms of survival in relation to the Fredle index (**Figure 35**). There are some quite pronounced gaps between each three of the models, whereas the %survival$_{\text{Tappel}}$ had the highest percentage of survival. For all the models the survival was gradually increasing with increasing Fredle numbers. Sample KS2 with the lowest Fredle number of 4.22 had an estimated survival of 58.53 percent. According to %survaval$_{\text{Lapointe}}$ this same sample only indicates 31.52 percent survival. The model %survival$_{\text{Levasseur}}$ had more similar predictions to %survaval$_{\text{Lapointe}}$ for the lowest Fredle numbers, starting with 36.09 percent survival. The similarity between these two models was though decreasing with higher Fredle numbers as the %survival$_{\text{Levasseur}}$ is a threshold model. The only one sample having a higher survival rate than 36.09 percent was SS4 with Fredle number 22.05 and an estimated survival of 90.58. The %survival$_{\text{Tappel}}$ model was not indicating any great changes in survival between sample SS4 and SS5 with the highest Fredle numbers of 12.97 and 22.05 and an estimated survival of respectively 89.46 and 93.83 percent. Similarly the model %survival$_{\text{Lapointe}}$ predicted 70.48 and 78.70 percent survival.

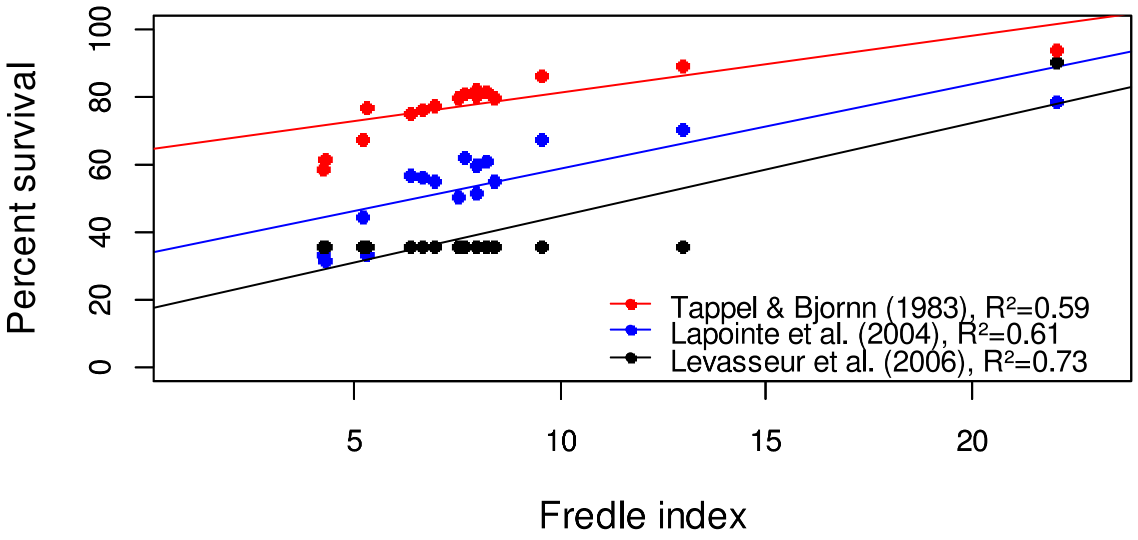


Figure 35. Relation between the Fredle index (F_i) and survival based on the three different approaches %survival$_{\text{Tappel}}$ (red points), %survaval$_{\text{Lapointe}}$ (blue points) and %survival$_{\text{Levasseur}}$ (black points).

It seems to be a declining trend in survival with higher percentage of fines (Pfines) (Figure 36) for all the three models. This content is varying largely between the different samples with a smallest percentage of 5.12 in sample SS4. The highest content, on the other hand was found in sample F3 of 28.41 percent. The slope of the trend line is steeper for the model by %survaval$_{\text{Lapointe}}$ than the other ones.

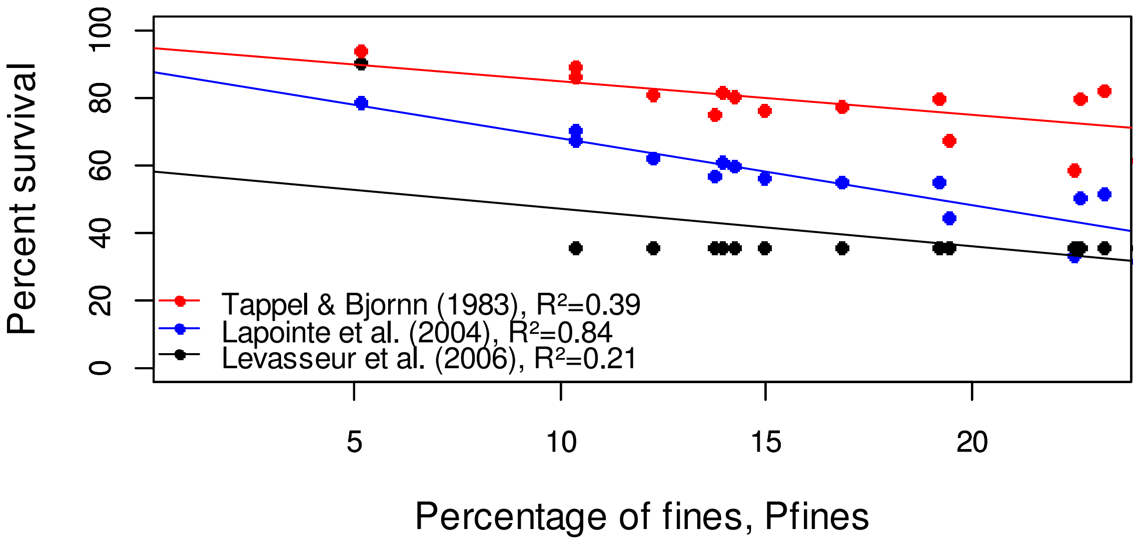


Figure 37. Relation between the percentage of fines < 2 mm (Pfines) and survival based on three different approaches %survival$_{\text{Tappel}}$ (red points), %survaval$_{\text{Lapointe}}$ (blue points) and %survival$_{\text{Levasseur}}$ (black points).

3.4. Salmon length data

The length data from 2007, 2008, 2009 and 2013 showed a significant decreasing trend in 0+ length in a north to south direction on the salmon bearing stretch (**Figure 38**). In 2007 (p_{trend} = 0.0116), the minimum average length was found at fishing station 8 of 51.30 mm, while the largest average was found at fishing station 3 of 69.00 mm. The station holding the smallest average length in 2008 (p_{trend} = 0.0313) was 10 of 52.86 mm, which was a higher minimum than the former year. The maximum average length in 2008 was registered at Station 3 of 66.34 mm. The length data from 2009 (p_{trend} = 0.016) showed generally lower numbers than the former two years and the smallest average length was found at fishing station 10 of 51.33 mm, while the largest average of 58.19 mm was registered at Station 6. In the 2013 data (p_{trend} = 0.0443), the smallest average length was found at fishing station 10 of 45.67 mm. The largest average length of 59.43 mm was from Station 3. In addition there has been a negative development in average 0+ length from 2007 to 2013.

For 2010 and 2012, no significant north-to-south trend was found. At the former there were no registration of 0+ length at Station 7 and 8 (**Figure 39**). The minimum length was found at Station 4 of 50.42 mm, while the maximum of 62.25 mm was found at Station 3. In 2012, the minimum average length of 47.4 mm was found at fishing station 10. The maximum average length of 59.43 mm was found at fishing station 4.

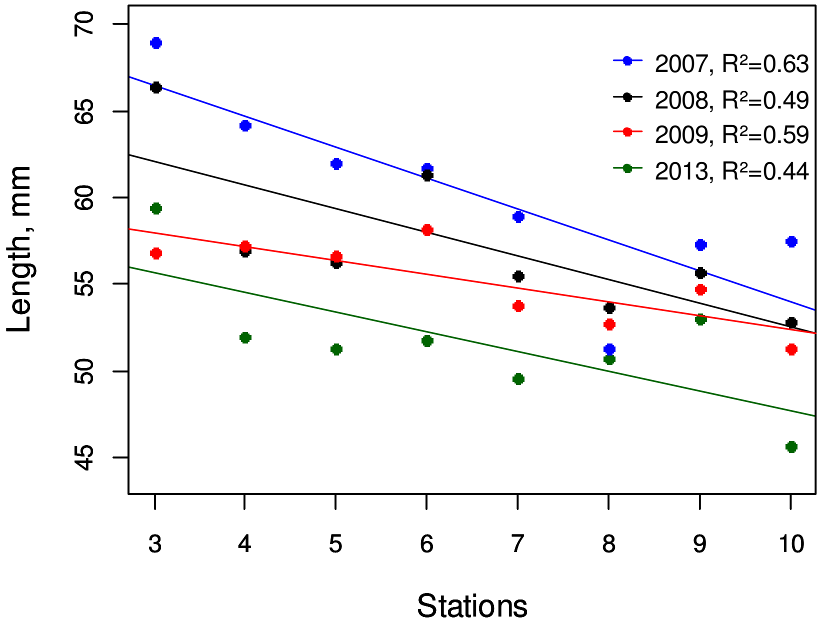


Figure 38. The salmon length data for 0+ from 2007-2009 and 2013 showing a significant decreasing trend in a north to south direction (data from the Norwegian Environment Agency).

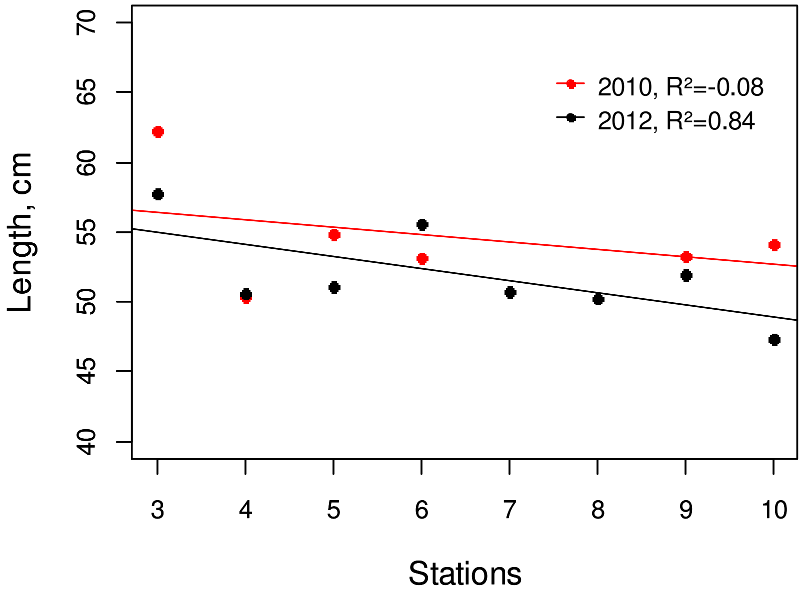


Figure 39. Salmon length data for 0+ from 2010 and 2012 showing no significant trends (data from the Norwegian Environment Agency).

Judging by the density data (**Table 3**) 2009 and 2010 had remarkably lower recruitment than the other four years, with the sum of 81 and 67 caught 0+ individuals, respectively. In 2012 the highest number of 492 individuals of 0+ was registered, accompanied by a short average length. The numbers from 2013, which are the most relevant for this study are evident of low

0+ growth compared to former years (despite 2012). The density of 329 individuals of 0+ was lower than the former year, but higher than both 2007, 2009 and 2010. Fishing station 4 (in the same area as this study's Station 1) and 5 (Station 2) had the highest recruitment of 0+ if seeing all years as one, while fishing station 3 (upper parts of Station 1) and 6 (upstream Station 3) had the lowest recruitment. In 2013 the lowest density of 0+ was found at fishing station 3 as well, and the highest density at fishing station 8 (at Station 3).

Table 3. Density data for 0+ and >0+ salmon in Kvina in 2007-2009, 2010, 2012 and 2013 (data from the Norwegian Environment Agency).

Stations							
0+	2007	2008	2009	2010	2012	2013	Sum
3	2	41	5	4	23	7	82
4	39	78	19	12	103	53	304
5	45	79	9	23	63	38	257
6	15	22	21	13	22	37	130
7	29	41	5	0	55	53	183
8	10	52	7	0	57	60	186
9	49	27	9	9	90	48	232
10	27	43	6	6	79	33	194
Sum	216	383	81	67	492	329	1568
>0+	2007	2008	2009	2010	2012	2013	Sum
3	3	8	7	8	5	9	40
4	4	6	7	9	0	6	32
5	25	13	16	20	17	27	118
6	18	10	18	14	5	22	87
7	5	7	8	0	5	7	32
8	1	0	2	5	0	1	9
9	1	2	6	2	5	6	22
10	1	0	0	1	3	0	5
Sum	58	46	64	59	40	78	345

For individuals >0+ there were no trend in terms of decreasing length in the downstream direction, but instead a clear pattern of where the largest individuals were found. Fishing station 3 had the highest average length of >0+ salmon both if seeing all years as one, and for 2013 of 111.78 mm on average. The density of >0+ at this station was of medium character of 9 caught individuals. At fishing station 4 and 5 the second and third largest individuals were found with an average of respectively 107.83 mm and 108.67 mm in 2013. The >0+ density at the former may also be characterized as medium of 6 caught individuals, while the latter had the highest density of all the stations of 27 individuals. The second highest density was found at fishing station 6, but here with smaller individuals of 100.86 mm on average in 2013. At fishing station 7-10 the individuals were either small or in very low numbers. At fishing station 7 (a little upstream Station 3) the average in 2013 was of 84.14 mm, while it at fishing station 9 (close to Station 5) was of 97.83.

4. DISCUSSION

4.1. Within river temperature variation

The temperature data from Station 1, 2, 4 and 5 is creating an overview of the temperature conditions in the southern parts of Kvina through the summer, and how these values differed between and within various sections of the river. This is, as far as we know, the first detailed temperature study that has been carried out in the river, providing valuable information about how this factor was potentially affecting the salmon through the 2013 summer. As the watercourse is regulated for hydropower and the discharge restricted to a minimum, the flow events experienced during this time period were most likely caused by precipitation events only. Due to the discharge data from Stegemoen the water level seemed to adjust back quickly, even after larger rainfall events. Periods of elevated discharge contributed to decreased water temperatures, as shown by the air-to-water model. This negative influence on temperatures was greater in July than in other months, suggesting that even small changes in discharge during low flow periods may have grat impact on water temperatures. Decreased discharge caused by the absence of precipitation combined with elevated air temperatures seemed to be largely responsible for the rapid water temperature increase experienced during July. The model is only taking the influence by discharge and air temperatures into account when predicting water temperature. Several factors may affect this value, however 78% of the variation in water temperature can be explained by these two variables. The delayed response is most likely increasing when approaching autumn as the water level becomes higher and the air temperatures lower. In the spring on the other hand, elevated air temperatures and sun radiation are likely to decrease the water temperature, as melting ice and snow contribute with cold melt water to the watercourse.

River water temperature was found to follow the air temperature closely, and to a greater extent at locations where the highest temperatures were registered. For instance, in ligated pools which occurred due to the decreasing discharge through the summer, water temperatures seemed to be influenced more by air temperatures and sun radiation (e.g. K17 with the highest maximum temperature) than in other places. This may explain some of the greater fluctuations between day and night temperatures of the river, detected by the temperature loggers. On the other hand deeper pools with continuous water flow held some of the lowest main temperatures, even in generally warm areas (e.g. K12 with the lowest minimum temperature). Water flow was also an important key factor at Station 2 where the least variation in temperature was found. This was the most homogenous of the areas assessed. Unlike some of the more heterogeneous stations such as Station 4 with large fluctuations and variation, the river water at Station 2 was running evenly throughout the entire river segment without large differences in velocity. Electrofishing data from the Norwegian Environment Agency show that this area had both good recruitment of 0+ and a high number of >0+ of large size. This may be due to high velocity water maintaining good habitats and spawning gravel, in combination with somewhat lower water temperatures. For all the stations, local variation in temperature was less pronounced during June and August than in July, probably due to higher river discharge and lower air temperatures.

Generally temperature seemed to increase in a downstream direction with the most elevated temperatures at Station 4 and 5, which were the most southern of the four stations containing temperature loggers. This may be one of the reasons why the electrofishing data shows a significant decreasing trend in salmon 0+ length (north-to-south) in four of the six last registrations. The largest individuals and highest numbers of >0+ were also found in the northern parts of the river. In the stretch from Station 3 to Station 6 the >0+ were either very short or few in numbers. However, as predicted by the LME model (Table 1), the largest variations in river temperature were often found within each station altered in accordance to discharge, air temperatures and the river morphology. The optimal temperatures for salmon growth are normally within the interval 16-20 °C (Jonsson et al., 2001), while temperatures of 22-30 °C are considered the upper critical zone (Elliott, 1994). The temperature development in Kvina throughout the summer is evident of both periods of optimal temperatures and periods of temperatures that, if prevailing over years to come, may indicate poor prognosis for the local salmon population. When exceeding the optimal temperature, salmon are at the risk of reduced growth as a result of unfavorably high metabolism (Kullgren et al., 2013), which is probably the case in Kvina during some of the warmest days in July. In this case, they will have to eat more in order to prevent negative growth, which may require a greater feeding territory. This can result in more agonistic behavior among size classes (Harwood et al., 2001). The average length of 0+ caught in Kvina has shown a decreasing trend during recent years, with the 2013 registration showing the lowest average length of individuals. Even though many factors are likely to influence these results, the short growth season caused by late spring and ice thaws, together with especially high temperatures during this summer were likely to be an important contributors as well.

Some of the mid-day temperatures registered in Kvina of > 30 °C during this period are not only in risk of causing negative growth due to high metabolic activity, but may also be lethal to salmon (Elliott, 1991). In these conditions thermal refuges are of essential character to young salmon. These refuges consist of locations were the river is influenced by factors such as a colder side stream for example of ground water (Dugdale et al., 2013). In Kvina the areas of higher velocity or of greater depth may function as refuges, judging by the colder temperatures observed in these parts of the river. For the fry to be able to utilize these areas they must be located in immediate vicinity to where they initially reside, since their ability to disperse is limited (Einum et al., 2011). This study shows that water temperature is largely influenced by factors such as air temperature, water depth, velocity and meteorological conditions, suggesting that the physical design of the river with habitat variation is of great importance to the local salmon population.

With respect to the remarkably high temperatures registered by some of the loggers, it is reasonable to consider that they may have been above the water surface when the discharge was at its lowest. These loggers were however controlled during this time period and confirmed to be submerged under water. It is still essential to keep in mind that the summer of 2013 was considerably warmer over a longer time period than an average year, with very little precipitation. This may have resulted in somewhat higher values than one would expect in an average year. In addition there were sections of the river stations where the water level was either too high (e.g. in the middle of the deepest flow paths of high velocity) or too low (some of the shallow middle sections of Station 4) to place loggers. It was attempted to distribute the loggers in a way that would cover the diversity within the river station, but due to the limited number of loggers it was impossible to register all of the variation. These factors may have led to somewhat biased temperatures results in different sections of the river.

4.2. Small-scale spatial variation

The grid data from Station 4 shows that pronounced spatial differences may occur within delimited parts of the river. During the warmest parts of the summer the river segment became more heterogeneous resulting in a mosaic of microhabitats of varying suitability to salmon. The coldest temperatures were measured just downstream the weir, probably due to the higher water level upstream. The temperature increasing gradually downstream, as depth decreased. During the low discharge periods, water was dammed in shallow pools by masses of sand nearby and downstream of the islet. This was probably an important contributor to some of the high temperatures registered, along with areas of low water depth.

None of the 64 points of measurement had pH values lower than the limits of what is considered acceptable to salmon during that time of the year (Sandøy and Langåker, 2001). Liming of the watercourse is largely responsible for these values, as the catchment has a low ANC (Acid Neutralizing Capacity) (Finstad et al., 2004, Ugedal et al., 2004). Despite the unnatural occurrence of calcium carbonate ($CaCO_3$) in the river there were still spatial and temporal differences even within this small area. The lowest pH values were registered in August, probably due to greater precipitation during that month. Runoff from the watershed contributes to the leaching of H^+, increasing acidity in the river. (Lydersen et al., 2004). The lowest measured pH value of 5.92 is on the borderline of what is generally considered adequate for salmon and some of its main pray (Nilsen et al., 2013). At night, the carbon dioxide (CO_2) level of the river water may increase due to the photorespiration of algae and form carbonic acid (H_2CO_3). The dissociation of carbonic acid forms e.g. H^+ contribute to altering pH values. During the day, carbon dioxide is largely utilized for photosynthetic purposes, elevating the pH of the river (Allan and Castillo, 2007). This may indicate a lower pH during nighttime than what was measured during the day, possibly lower than what is optimal for salmon. According to a study by Staurnes et al. (1995) a pH of around 6 or lower is likely to be harmful to smolt, even with low concentrations of aluminum (Al) in the river, over short periods of time. Smolts are though at the most sensitive stage of their life, more susceptible than other individuals.

The oxygen concentration also varied as well, holding reasonable high values. Even though the concentration was lower in July as an expected consequence of the elevated temperatures (Bahadori and Vuthaluru, 2010, Nakova et al., 2009), the rate of average dissolved oxygen was far beyond one hundred percent. As Kvina is rather wide with a large surface area of running water the oxygen is taken up easily by diffusion. Another contributing factor may be the occurrence of primary producers adding oxygen through photosynthesis throughout the day, leading to a higher concentration of oxygen in the water than in the surrounding air. In these cases the differences between day and night concentrations are normally rather high (Allan and Castillo, 2007). If the consumption rate of oxygen for decomposition of dead organic matter and photorespiration is high during the night, evident fluctuations in oxygen concentrations may occur. Low discharge improves the ability for algae to attach to the river substrate, and for macrophytes to root. High occurrence of plant and algae attachment to the substrate may also impair salmon habitat by decreasing the amount of available shelter or degrading the spawning gravel (Pulg et al., 2013).The only macrophytes registered were located at the shallow area along the northwest river bank.

As the grid data collection was conducted manually, measured one point at the time, the process was rather time consuming. A source of error may be changes in river conditions and temperatures over the time period in which measurements were collected, given that a river is a system that is changing continuously and often rapidly. The GPS positions were registered during the first measurement in July so that the August measurement could be carried out at the exact same locations. The accuracy of the GPS used was of centimeter accuracy, meaning that the points of measurement may have differed slightly between the two months.

4.3. Spawning gravel quality

Analysis of the substrate samples leaved little doubt that Kvina is influenced by the tailings from Knaben (Gjemlestad, 2008, Ugedal et al., 2004, Forseth et al., 2012, Bremset et al., 2008). The current situation in Kvina, with deposited fines, is most likely due to the combination of added sand and a decrease in discharge – causing reduced transport of fines it throughout the river (Langedal, 1997, Gjemlestad, 2008). Similar to the temperature time series the variations within stations were often as great as between stations. Results from the samples analyzed are therefore not necessarily representable for the whole area, but an indication of the general conditions. However, there seemed to be a decreasing trend of Fredle numbers in a downstream direction, suggesting that the amount of deposited fines were increasing while the quality of spawning habitats were decreasing in a southward direction. This in spite of the general presumption that the weirs catch a large amount of fines (Hamarsland et al., 2003). Large, occasional flood events, combined with large masses of sand in continuous movement downstream may explain this pattern. Additionally, the southern parts of the river have a higher natural occurrence of sand (as a result of being located below the marine limit) which may also contribute to an increased content of fines in these spawning areas. The distribution of sand in the samples collected at Station 3 differed somewhat from samples collected at Station 5 and 6. The top layer of the substrate at Station 3 was largely influenced by sand, even though samples taken at the other stations had a generally low content of fines. This sandy surface probably settled after the spawning took place, potentially having a negative impact on the ability of the fry to emigrate from the red. The clogged substrate surface may also have affected the suitability of the 1+ habitat, as well as the ability for oxygen rich water to penetrate the substrate.

The three survival models used to translate Fredle numbers into percent survival all indicated a positive relationship between high Fredle numbers and percentage survival. The $\%\text{survival}_{\text{Lapointe}}$ model seemed to be the most plausible of the three as the $\%\text{survival}_{\text{Tappel}}$ only calculated just calculating egg survival and $\%\text{survival}_{\text{Levasseur}}$ provided threshold values. The mortality is normally high from hatching to emergence (Dumas and Marty, 2006), explaining the relatively large divergence between the two former models. As shown by $\%\text{survival}_{\text{Lapointe}}$ the majority of the samples had an estimated survival of less than 65 percent. When comparing these numbers to the percentage of fines (Pfines). In each sample there is a relatively strong relationship between the amount of fines and survival. The distribution of survival when seen in relation to fines is more evenly spaced than in relation to the more clustered pattern with the Fredle numbers. This may imply that the percentage of fines provides a more accurate indication of survival for this poorly sorted substrate. The survival models used in this study were all made considering salmon populations in other rivers, and may not be directly transferable to the Kvina population. In addition the %$\text{survival}_{\text{Tappel}}$ approach was originally created for Chinook salmon (approximately the same size as the Atlantic salmon). The results in terms of percent survival will only function as an indication, and not as definitive values.

Accumulation of sand challenges the survival of salmon eggs as the fines clog cavities in the coarse substrate, causing decreased interstitial water flow (Langedal, 1997). This may hinder oxygen supply as well as transport of toxic metabolic waste in the red (Sternecker et al., 2013). Under such conditions fry may struggle to swim up from the gravel as the overlaying substrate is packed and impermeable (Sternecker and Geist, 2010). Even though the fines in Kvina are dominated by sand fractions and not silts, they are clearly decisive for the salmon survival. The amount of oxygen available to the eggs has a major impact on the selection of egg size, as they are dependent on oxygen diffusion through the egg surface. If the oxygen supply is low, the growth rate must also be low to ensure egg survival. In that case it would be a natural selection for small eggs, resulting in small individuals (Cote et al., 2012). Once the fry leave the gravel there is a shift in which factors determine success, as the competition for feeding territories and shelter is high (Teichert et al., 2011). Large, aggressive individuals are likely to conquer the best microhabitats by fighting off smaller individuals, and therefore have the highest chance of survival (Einum et al., 2011). In other words; there is a tradeoff between the density independent mortality in redds and the density-dependent mortality above the gravel.

The substrate preferences amongst young salmon are dynamic, both due to individual size and season of the year. This is illustrated by **Figure 40** that was originally made considering trout, but still applicable to salmon (normally with somewhat higher substrate fractions). During the summer, small salmon normally prefer pebble-cobble substrate, while the larger juveniles utilize somewhat coarser materials. In the autumn, most size classes select boulders and cobble, while finer substrate is often preferred through the winter (Heggenes and Dokk, 2001). Challenges may occur if the young salmon habitat is clogged by fines, as shelter in terms of cracks and cavities in the substrate is essential to avoid predators (Langedal, 1997, Teichert et al., 2010, Heggenes and Dokk, 2001, Heggenes et al., 1996). If a great part of the habitat is unavailable, competition for the remaining shelter will be high. Combined with the fact that habitat preference varies through the year, a smaller part of the river area will be suitable. Even though the substrate composition may decrease survival, the total amount of spawning areas is probably great enough to produce enough individuals to inhabit the juvenile salmon habitats. Higher densities in these areas potentially leading to stress and illness is an important bottleneck of the system and a good argument for the approach that was used in Kvina by rectifying habitats before improving spawning gravel (Forseth et al., 2012).

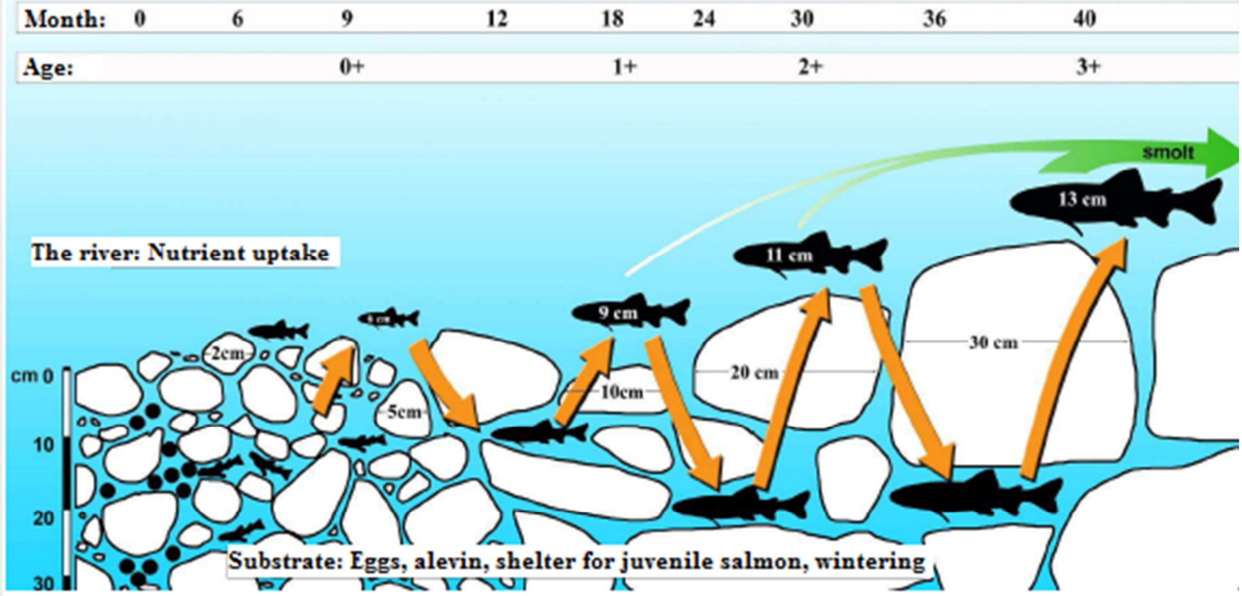


Figure 40. Illustration of the sea trout habitat from the egg phase to smoltifications. The same preferences are applicable to salmon, but with a little larger gravel fractions (modified version of illustration by Pulg et al. (2013)).

The samples were gathered from former and potential redds in the middle of the summer, so the redds had been empty for some time before samples were collected. When spawning, the female salmon removes as much fines as possible before the eggs are buried. Therefore it is reasonable to assume that some of the fines were added later, after the emergence. The gravel samples from this study are not necessarily representable for the entire area where they were collected. Pronounced differences in stream velocities in different sections of the stations assessed are likely to have great impact on substrate composition. In areas of higher velocity or depth fines may have been more likely to escape during the sampling process and therefore be underrepresented.

4.4. Management measures

A number of management measures have been carried out in order to increase the smolt production in Kvina. The demand for habitat restoration was early recognized as a necessity through studies of the production capacity of the salmon bearing stretch (Ugedal et al., 2004, Larsen et al., 2005, Gjemlestad, 2008). Coarse material has been distributed in the river to provide habitats for young salmon with shelter and connectivity to nearby spawning sites. An example is the measures that have been carried out downstream from the weir at Station 4. A great amount of blocks and boulders was distributed strategically in the river in order to create deeper flow paths and pools. The latter was intended to create habitats or refuge for larger individuals during low flow periods (Hamarsland et al., 2003). The advantage of these measures is of course the guarantee of continuous flow in parts of the river cross-section, but at the same time other parts of the area may be more or less drained. The accumulation of sand in some of the shallow areas is perhaps also a disadvantage along with the somewhat higher risk of young salmon becoming trapped or stranded in the middle section of the river. During the winter, spawning habitats located in these areas are likely to freeze, which may kill the salmon eggs.

Ugedal et al. (2004) claimed that biotope-improving measures would not be sufficient in order to restore the population to its former state, suggesting that an extension of the salmon bearing stretch by the use of a salmon ladder at Rafossen could be a possible solution. Bremset et al. (2008), on the other hand stressed the importance of the Trælandfoss power plant, being responsible for around 70 percent of the losses of smolt produced upstream of the hydropower turbines. Prior to enabling salmon migration beyond the barrier at Rafossen, Trælandsfoss must be rectified for this measure to be economically and ethical feasible (Gjemlestad and Forseth, 2009). An assessment was later performed by NIVA, due to a concession from 2009 imposed to Borregaard Trælandsfoss AS as a means to prevent salmon from migrating through the turbines (Kristensen et al., 2011).

Another factor identified in a number of reports as an important bottleneck in population growth from Kvina is the river discharge (Ugedal et al., 2004, Bremset et al., 2008, Gjemlestad, 2008). The pronounced responses seen in river Kvina was probably largely influenced by the river morphology. In such a wide river channel, the surface area to volume ratio is high, as the discharge decrease. These types of systems are sensitive to abiotic variables making them very susceptible to rapid changes. The water masses are normally heated rapidly in the spring and similarly cooled down quickly in the autumn (Saltveit, 2006, Caissie, 2006). The low minimum winter discharge of 1.3 m^3/sec is likely to be responsible for a big part of an estimated annual production loss of around 37 percent, due to freezing of the river (Bremset et al., 2008). In this current study the potential impacts of low summer discharge and temperatures in the river has been recognized as another important bottleneck, even though the minimum limit of 3.7 m^3/sec during the summer is higher than in the winter.

An increased minimum discharge of 5 m^3/sec or 6 m^3/sec during the summer and winter was suggested by Forseth et al. (2012) as part of a larger project developing environmental design in Kvina. The construction of a water bank that would allow more adaptive management inspired by the “Building block methodology” (Tharme and King, 1998) was suggested in that context, and later mentioned as a possible measure by Gjemlestad and Haaland (2013). In relation to the issues detected through this study, this would probably have bettered the situation remarkably, both in terms of preventing the highest temperature peaks and in keeping fines from settling to the same extent as they do today. Drainage in certain areas of the river during summer and freezing during the winter would probably also be reduced or eliminated entirely. A great part of the measures applied in Kvina (e.g. biotope improvement at Station 4) were developed considering the increased discharge that is planned, indicating that these would function even better with increased minimum discharge.

Despite the unfavorably high temperatures and negative influence by tailings the heavily modified river has what appears to be a reasonably strong population of salmon, accompanied by a smaller population of brown trout. Earlier assessments have initiated that the current population is not anywhere near being as large as it was historically, with an approximate smolt production of 16,000 individuals compared to the earlier 36,000 (Bremset et al., 2008). The conditions discovered through this survey may play an important role, together with the more direct effects of hydropower plants like mortality to smolts caused by turbines. On a positive note, the conditions in Kvina have gradually been well documented by a number of assessments and reports. This has provided a solid basis for further improvements through management measures.

5. CONCLUSION

Through this study the rapid changes in temperature throughout the summer and the sometimes large variations within delimited parts of the river have been documented. The high air temperatures during July in combination with low discharge led to extremely high water temperatures, especially in ligated pools and shallow parts of the river of low velocity where it could reach over 30 °C. A temperature gradient from north to south in the river was also discovered, probably contributing to the decreasing 0+ length in a downstream direction.

Variation in depth, velocity and river morphology is important in order to provide good living conditions for different cohorts of salmon, as preferences often change with individual size. Physical and chemical variables can vary largely within relatively small areas and throughout the day. Therefore, some areas may be less suitable to juvenile salmon due to lower pH, high temperatures and low oxygen concentration, among others. As a result, decreased proportions of the habitat will be available. The location of the most suitable conditions is likely to vary throughout the year, or even throughout the day, making the mosaic of microhabitats valuable.

The three spawning habitats assessed were found to be largely influenced by fines, but with different distribution within the samples. Station 3 had the lowest mean content of sand, but a greater dominance of fines on the substrate surface than the other two stations. Generally the percentage of sand seemed to increase from north to south, but most likely with a higher amount of naturally occurring fines in the lower parts of the river.

The best method of improving the quality of the spawning gravel and juvenile salmon habitat is probably to increase the minimum flow, as suggested. This will hopefully prevent the highest peaks in water temperatures during the warmest part of the summer and freezing and drainage during winter, as well as it may prohibit fines from clogging and degrading habitats to the same extent as today. Maintenance and improvement of habitat for young salmon, as well as good connectivity between redds and nursery habitats, is essential to provide high carrying capacity and an increased smolt production.

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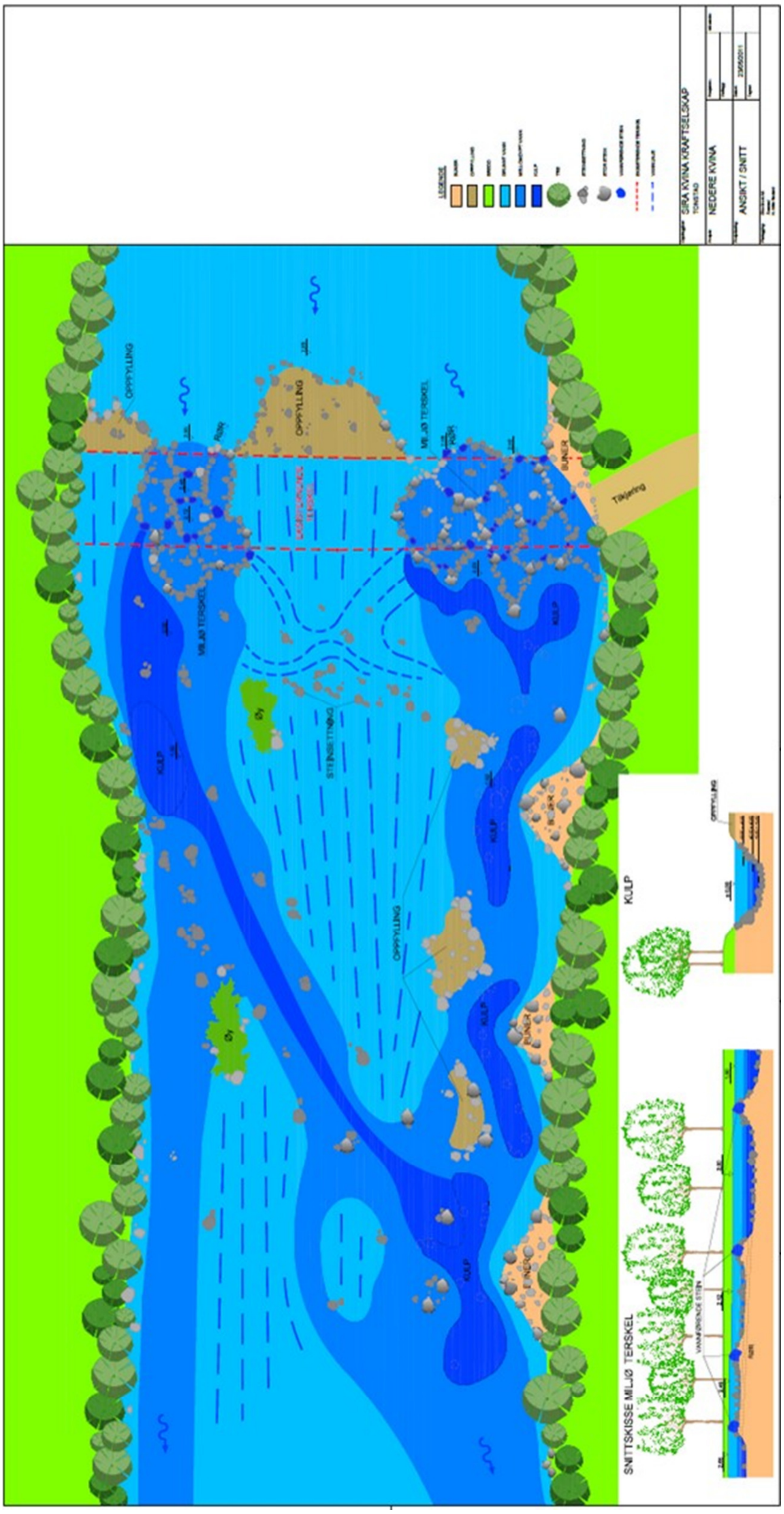
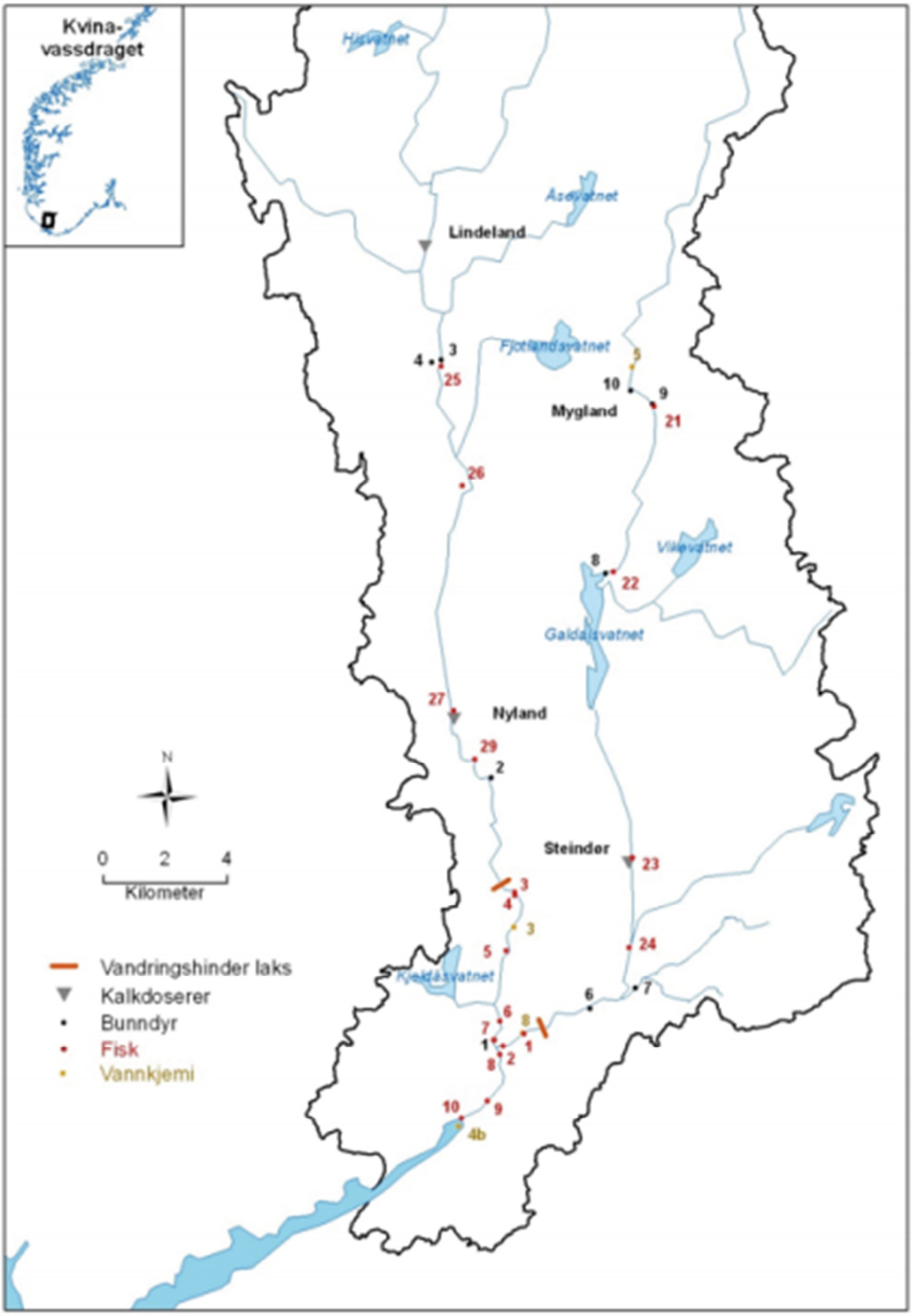
7. APPENDICES

Appendix 1. Management measures downstream the weir at Station 4 (Developed by Øko-Grønt AS for Sira-Kvina Hydropower Company).



Appendix 2. Map from the Norwegian Environment Agency including the electrofishing stations (red point 3-10 in the southern parts of the watercourse) (Miljødirektoratet, 2013).



Appendix 3. AIC model selection table for the mixed effects ARMA models fitted to predict daily mean water temperatures in Kvina. AR(x) the temporal autocorrelation level x. ma.2.TAM = moving average over two days for TAM; ma.4.D = moving average over four days for discharge; 1|month/Station/Logger = nested random effects structure.

Model structure	df	AIC	ΔAIC
ma.2.TAM*ma.4.D+Type*month; random=1|Station/Logger; AR(0))	18	4867.9	0
ma.2.TAM*ma.4.D+Type*month; random=1|Station/Logger; AR(1)	19	4869.8	1.9
ma.2.TAM*ma.4.D+Type*month; random=1|month/Station/Logger; AR(2)	21	4871	3.1
ma.2.TAM*ma.4.D+Type*month; random=1|Station/Logger; AR(2)	20	4871.7	3.8
ma.2.TAM*ma.4.D+Type*month; random=1|Station/Logger; AR(3)	21	4873.5	5.6
ma.2.TAM*ma.4.D+Type; random=1|month/Station/Logger; AR(2)	13	4879.4	11.5
ma.2.TAM*ma.4.D+Type; random=1|Station/Logger; AR(2)	12	5412.9	545
ma.2.TAM*ma.4.D; random=1|Station/Logger; AR(2)	9	5416.2	548.3
ma.2.TAM+ma.4.D; random=1|Station/Logger; AR(2)	8	5421	553.1
ma.2.TAM*ma.4.D*Type; random=1|Station/Logger; AR(2)	21	5428.6	560.7

Appendix 4 . The script used to analyze the substrate samples.

```
gravel.data<-read.csv("Substrate.cum.csv", sep=";")

str(gravel.data)


head(gravel.data)


library(mgcv)  #gam-verktøy

library(MASS)  #dose-verktøy

library(drc)   #dose-responseverktøy


gravel.size<-c(0.0625,0.1875,0.375,0.75,1.5,3,6,12,24,48,82,114,192) # creating vectors of the gravel data

gam.fit<-gam(logit.cum.fract~s(gravels.size,k=3),data=test.data.S01[1:11,])

plot(logit.cum.fract~gravels.size,test.data.S01)


#This is solved using the drc-package, adjusting for a number of dose-response relations and  extracts
percentiles


test<-drm(cum.fract~gravels.size, data=test.data.S01, fct=W2.3())

test2<-drm(cum.fract~gravels.size, data=test.data.S01, fct=W2.3(),type="binomial")


new.data=data.frame(gravels.size=gravel.size)


new.data$pred<-predict(test,new.data,se.fit=T)

new.data$pred<-predict(test2,new.data,se.fit=F)


plot(pred~gravels.size, data=new.data)


new.data=data.frame(gravels.size=0.85)

predict(test,new.data, se.fit=T)
```

```
as.numeric(summary(test)$coef[,1])


#making a plot or the M&M to show the principles of estimating of q25 og q75
require(graphics)
qq.25.75<-as.matrix(ED(test, c(25,75), display=F))
par(pty="m",cex=1)
plot(test, pch="",xlab=list("Gravel size, mm", cex=1.2), ylab=list("Cumulated probability", cex=1.2),lwd=3,
yaxt="n")
lines(c(0.01,qq.25.75[2,1]),c(0.75,0.75),lty=2, col="blue")
lines(c(qq.25.75[2,1],qq.25.75[2,1]),c(0.75,-0.05),lty=2, col="blue")
lines(c(0.01,qq.25.75[1,1]),c(0.25,0.25),lty=2, col="red")
lines(c(qq.25.75[1,1],qq.25.75[1,1]),c(0.25,-0.05),lty=2, col="red")
#axis(2,at=c(0,0.25,0.5,0.75,1),labels=c("0.0","0.25","0.5","0.75","1.0"))


text(qq.25.75[2,1]+6,0,paste(round(qq.25.75[2,1],1)),srt=270, col="blue", adj=0.8, pos=c(3,4))
text(0.1,0.72,"Pr(x)=0.75", col="blue", adj=0)
text(qq.25.75[1,1]+0.5,0,paste(round(qq.25.75[1,1],1)),srt=270, col="red", adj=0.8, pos=c(3,4))
text(0.1,0.22,"Pr(x)=0.25", col="red", adj=0)
text(0.1,0.95,labels=expression(Pr(italic(x)) == 0.97*italic(e)^{-italic(e)^{(1.04*ln(italic(x))-ln(32.37))}}),
adj=0,cex=1.2)


plot(test2, add=T, col="red")


sim1 <- rdrm(nosim=10, fct=W2.3(), mpar=coef(test), xerror=gravel.size, onlyY=F)
test.data.S01$gravels.size


plot(sim1$x,sim1$y)


ED(test, 25, ci = "delta")


qq.25.75<-as.matrix(ED(test, c(25,75), display=F))
as.numeric(ED(test, c(25,75))[[1,1]])
```

```
#estimation of the fredle index

dg.S01=gravel.data[1,15]  #21.44


So.S01=(qq.25.75[2,1]/qq.25.75[1,1])^0.5  #2.25107


fredle.S01=dg.S01/So.S01 #9.524358


#Making for-loop to estimate all of the Fredle indices


fredle.table<-data.frame(sample=gravel.data$sample,fredle=rep(1.0,16),qq25=rep(1.0,16),qq25.se=rep(1.0,16),qq75=rep(1.0,16),qq75.se=rep(1.0,16),


a=rep(1.0,16),a.se=rep(1.0,16),b=rep(1.0,16),b.se=rep(1.0,16),c=rep(1.0,16),c.se=rep(1.0,16),So=rep(1.0,16),surv.Lapointe=rep(1.0,16),surv.Levasseur=rep(1.0,16),surv.Tappel=rep(1.0,16),pfines=rep(1.0,16))


new.data.surv=data.frame(gravels.size=c(0.063,0.125,0.5,2,32))

new.data.surv2=data.frame(gravels.size=c(0.85,9.5))


for(i in 1:16)

{

  temp.data<-data.frame(gravel.size=gravel.size,cum.fract=as.numeric(gravel.data[i,2:14]))

  fit.temp<-drm(cum.fract~gravel.size, data=temp.data, fct=W2.3())

  qq.25.75<-as.matrix(ED(fit.temp, c(25,75), display=F))

  dg.temp=gravel.data[i,15]

  So.temp=(qq.25.75[2,1]/qq.25.75[1,1])^0.5

  fredle.table[i,2]=round(dg.temp/So.temp,2)

  fredle.table[i,3]=qq.25.75[1,1]

  fredle.table[i,4]=qq.25.75[1,2]

  fredle.table[i,5]=qq.25.75[2,1]

  fredle.table[i,6]=qq.25.75[2,2]

  fredle.table[i,7]=as.numeric(summary(fit.temp)$coef[1,1])  #extracting the coefficients
```

```
  fredle.table[i,8]=as.numeric(summary(fit.temp)$coef[1,2])

  fredle.table[i,9]=as.numeric(summary(fit.temp)$coef[2,1])

  fredle.table[i,10]=as.numeric(summary(fit.temp)$coef[2,2])

  fredle.table[i,11]=as.numeric(summary(fit.temp)$coef[3,1])

  fredle.table[i,12]=as.numeric(summary(fit.temp)$coef[3,2])

  fredle.table[i,13]=So.temp

  grav.pred<-predict(fit.temp,new.data.surv)*100

  grav.pred2<-predict(fit.temp,new.data.surv2)*100

  SI=((grav.pred[4]-grav.pred[3])/16)+((grav.pred[3]-grav.pred[1])/8)

  surv=83-29*SI-6*(SI*grav.pred[1])

  fredle.table[i,14]=surv

  surv2<-36.09+54.49/(1+exp((grav.pred[2]-0.17728)/0.0037))

  fredle.table[i,15]=surv2

  surv3<-94.7-0.1*grav.pred2[2]*grav.pred2[1]+grav.pred[2]^2

  fredle.table[i,16]=surv3

  pfines=(grav.pred[4]/grav.pred[5])*100

  fredle.table[i,17]=pfines

}

fredle.table$dg<-gravel.data[,15]

round(fredle.table[,2:13],2)


write.table(fredle.table, "fredle table.csv",dec=".")

write.csv(fredle.table,"fredle.table.csv")
```

Norwegian University
of Life Sciences

Postboks 5003
NO-1432 Ås, Norway
+47 67 23 00 00
www.nmbu.no