Norges miljø- og
biovitenskapelige
universitet

Master's Thesis 2018 60 ECTS
Faculty of Environmental Sciences and Natural Resource Management
Jonathan Edward Colman

Responses in Fish and Macroinvertebrates to Channelization and Restoration in two Arctic Rivers.

Andreas Lium
M-BIOL, Master of Science in Biology
Faculty of Environmental Sciences and Natural Resource Management

Acknowledgements

This paper is a part of my two-year master's programme in biology, and completes my master's degree. It is written at the Faculty of Environmental Science and Natural Resource Management (MINA), Norwegian University of Life Sciences (NMBU).

My main supervisor; Associate Professor at MINA, Jonathan Edward Colman, most definitely deserves the first and biggest thank you, for making this paper possible. From the inspiration and insight into the field of restoration ecology initially provided through the course «Restoration Ecology» (ECOL350), to helping out with all the practicalities associated with my fieldwork, and invaluable guidance throughout my writing period. I would also like to thank Knut Ivar Aune Hoseth, Anders Bjordal and Tommy Johan Granheim at The Norwegian Water Resource and Energy Directorate *(NVE)* in Narvik, for providing me with a car, electrofishing equipment and the funding and background data necessary for this project. Geir A. P. Dahl-Hansen from Akvaplan NIVA in Tromsø drove two and a half hours each way to assist me on a long day of electrofishing – an invaluable learning experience. Kurt-Jan Kvernmo working for the Salangen municipal government provided me with housing during both of my field trips, and valuable information regarding Kvernmoelva and its history. Finally, I have to thank my pregnant girlfriend for being patient and supportive during my field trips and the demanding last couple months of writing.

All photographs are taken by the author unless otherwise stated.

Norwegian University of Life Sciences

Ås, May 2018

Andreas Lium

Abstract

The two rivers Salangselva and Kvernmoelva in Troms county, were both channelized and erosion secured during the 1980s. This stimulated agricultural activity in adjacent properties in the following years. In parallel, a decline in fish stocks, number and diversity of birds, and the total area with important floodplain forest habitat, were observed in and around the channelized and erosion secured stretch of Salangselva in the Bones area. Restoration measures aiming to mitigate these adverse effects were implemented at Bones during the years 2005-2008, while ecological monitoring ceased in 2009. This is the first study in eight years, investigating juvenile brown trout *(Salmo trutta)* density and benthic macroinvertebrate diversity in the Bones area of the river Salangselva. No previous surveys have been conducted in Kvernmoelva, following the channelization. To replicate previously used methodology at Bones as closely as possible, electrofishing and kick-sampling were the means of sampling resident juvenile brown trout and benthic macroinvertebrates respectively – in both rivers. Registration of environmental variables were conducted at all sampling stations for use in statistical analysis.

The aims of this study were to evaluate the restoration measures' effect on juvenile brown trout density and benthic macroinvertebrate diversity in the Bones area, and assess whether or not the restoration project is a success. In Kvernmoelva, the effects of channelization were investigated through the analysis of juvenile brown trout density and benthic macroinvertebrate diversity. The effect of registered environmental variables in Kvernmoelva were investigated through statistical analysis.

The restoration measures at Bones have not been functioning according to the objectives, thus the goals of the restoration project have not yet been met. There are plans to do corrective maintenance and improvements in the years following 2017. A high rate of sedimentation in the primary meander Storøra and the tributary Budalsfaret needs to be adressed. Accumulation of sand, gravel and cobble were also found to be problematic around inlets and outlets. Densities of juvenile brown trout at Bones remain largely unchanged in 2017 compared to 2003-2009. With

benthic macroinvertebrates as bio-indicators, no improvement of ecological condition in the reopened – and previously sampled tributary Budalsfaret was found. Densities of juvenile brown trout, and the diversity of benthic macroinvertebrates were too low to conduct a meaningful analysis of the effect of environmental variables in the area. To my knowledge, 2017 is the first year where environmental variables have been registered at the sampling stations in the Bones area.

In Kvernmoelva, there was a clear trend that 1+ and >1+ brown trout age classes preferred the naturally meandering stretch of the river over the channelized stretch, while the density of 0+ brown trout were higher in the shallower and faster flowing channelized stretch. Statistical analysis indicate that depth is the single most important variable explaining the difference in distribution of 0+ and older juvenile brown trout in Kvernmoelva. This supports the importance of physical heterogeneity in the form of pool-riffle sequences in juvenile brown trout habitat. No significant difference in benthic macroinvertebrate diversity was found between the two stretches of Kvernmoelva in this study.

The study area at Bones is highly exposed to spring floods from the two primary tributaries Budalselva and Stordalselva, as well as from several smaller tributaries. The sediment load in the area requires a certain minimum flow to avoid silt settling in the reopened meanders and tributary Budalsfaret. A detailed monitoring program needs to be implemented to evaluate the recovery processes according to specific objectives and realistic goals.

Sammendrag

De to elvene Salangselva og Kvernmoelva i Troms, ble begge kanalisert og erosjonssikret på 80-tallet. Dette slo positivt ut for jorbruksaktiviteten på tilstøtende eiendommer i årene som fulgte. Parallelt ble det observert en negativ utvikling i fiskebestand, fugleliv og arealer med rik flommarksskog i og ved Salangselva ved Bones. Et omfattende restaureringsprosjekt med målsetting om å motvirke disse negative effektene ble gjennomført ved Bones i årene 2005-2008, men all økologisk overvåking opphørte i 2009. Dette er det første studiet på åtte år som undersøker tetthet av juvenil brunørret *(Salmo trutta)* og diversitet av bentiske makroinvertebrater i dette området. I Kvernmoelva er ingen lignende studier gjennomført etter kanaliseringen på 80-tallet. El-fiske og sparkeprøver (*«kick-sampling»*) var metodene som ble brukt for innsamling av data, for å kopiere tidligere brukt metodikk ved Bones.

Restaureringstiltakene har ikke fungert som planlagt, og det foreligger en plan for vedlikehold og utbedring av de fysiske tiltakene i årene som kommer. Problematikken med høy sedimentasjonsrate i sideelven Budalsfaret og meanderen Storøra må tas tak i. Akkumulering av sand, grus og noe større stein viste seg også å være problematisk ved flere inntak fra hovedkanalen. Tetthet av juvenil brunørret ved Bones er nærmest uforandret i 2017, sammenliknet med perioden 2003-2009. Med bentiske makroinvertebrater som bio-indikator, ble ingen forbedring i økologisk status påvist i Budalsfaret. Tettheten av juvenil brunørret, og diversiteten av bentiske makroinvertebrater var for lav til å gjennomføre en grundig analyse av effekten av miljøvariabler i området. Såvidt meg bekjent, er 2017 det første året hvor miljøvariabler er registrert i forbindelse med stasjonene samplet i Bones-området.

I Kvernmoelva var det en tydelig trend at årsklassene 1+ og >1+ av brunørret foretrakk naturlige meandere fremfor den kanaliserte delen av elva. Årsklassen 0+ derimot, viste høyest tetthet i den kanaliserte delen. Noe som indikerer viktigheten av fysisk heterogenitet i form av pool-riffle sekvenser i habitatet til juvenil brunørret. Ingen signifikante forskjeller i diversitet av bentiske makroinvertebrater ble påvist mellom de to strekningene av Kvernmoelva.

Studieområdet ved Bones i Salangselva er svært utsatt for vårflom både fra Budalselva, Stordalselva, og flere mindre sideelver. Sedimentlasten i området krever en viss minimumsvannføring og erosjonssikring for å unngå sedimentering av silt i åpnede meandere og i sideelven Budalsfaret. En detaljert plan for overvåking må implementeres, for å evaluere restaureringsprosessen i henhold til spesifikke målsettinger og realistiske økologiske mål.

Table of Contents

1 Introduction

It is well documented that our ecosystems are experiencing increasing pressures due to human population growth and subsequent fragmentation and loss of habitat (Feld et al. 2011; Preston 1996; Slingenberg et al. 2009). Lotic ecosystems provide us with a host of attractive services, and have thus caused humans to settle in their vicinity for thousands of years (Adeloye 2003; Rundle & Malmquist 2002). As a result of this, lotic ecosystems are among the ecosystems under pressure being worst off globally (Rundle & Malmquist 2002). Resulting from the increasing awareness regarding the health of our water bodies, the EU Water Framework Directive (WFD), which Norway was obliged to implement through the EEA agreement (NVE 2016), was implemented into Norwegian law through «*Vannforskriften*» (2006), six years after the directive came into force. The WFD encompasses all bodies of water; coastal waters, transitional waters, lotic ecosystems, lentic ecosystems and groundwater, and its aim is to achieve a minimum of «good ecological status» in all bodies of water with a final deadline set in the year 2027 (European Commission 2016).

In Norway, modifications of rivers such as channelization and the construction of dams are common. The first for purposes such as facilitating the transport of timber and to mitigate erosion problems and damage caused by floods in urban and agricultural areas. The latter for hydroelectrical purposes. To channelize a river is defined as «*the alteration of a natural stream by excavation, realignment, lining or other means to accelerate the flow of water*» (Landy 1979). Channelization of rivers to accelerate the flow of water is a proven measure to protect agricultural areas from flooding and erosion (Shankman & Samson 1991). However, channelization can have adverse effects on the ecosystem in and around the river in question (Brooker 1985; Johansson 2013).

The number of restoration projects in Norway has been increasing rapidly since 1990 (Hagen & Skrindo 2010). Ecological restoration is defined as «*the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed*», by The Society of Ecological Restoration (SER 2004). The goal of river restoration is to bring an ecosystem back to its historic trajectory, which is not necessarily back to its origin, due to the ever changing nature of ecosystems (SER 2004). Being a comparatively young science, restoration ecology lacks data on long-term effects of restoration projects (Palmer et al. 2005; Nilsson et al. 2016; Haase et al. 2013). Hence, it is important to keep monitoring an ecosystem for several years after the implementation of restoration measures to add data to the existing knowledge base (Nilsson et al. 2016). For river restoration, there are still no standardized approaches to evaluate the degree of success (Jähnig 2011). In the evaluation of whether or not a restoration project has been successful, one should ask if the objectives were met and the goals attained. Answers to these questions can only be valid if goals and objectives were stated before the restoration work began (SER 2004).

In this thesis, I take a closer look at two channelized rivers in Troms County, Northern Norway (Figure 1). The river Salangselva is a well known, unregulated fishery with more than four tonnes of anadromous fish caught by recreational fishermen in 2017 (SSB 2018). My study area is located in Bones, approximately 45 kilometers from the sea, and 25 kilometers upstream from the main anadromous stretch. In the Bones area, brown trout (*Salmo trutta*) and arctic char (*Salvelinus alpinus*) are the species of fish to be found. At Bones, the largest flood protection project in Northern Norway was conducted during the mid 1980's, with extensive channelization and modification of the river and tributaries. Agricultural land adjacent to this typical spring flood river experienced less erosion and damage due to flooding following the successful flood protection project. However, fish stocks declined, erosion and sedimentation caused problems in unprotected sidelets and former river meanders, and important biotopes for birds and floodplain forests were negatively affected (Hoseth, K. A. 2017, The Norwegian Water Resources and Energy Directorate (NVE), pers. commun.). To mitigate the negative effects of the flood protection project, NVE in cooperation with Norwegian Institute for Nature Research (NINA) and Akvaplan NIVA implemented restoration measures during the period 2005-2008. Monitoring of fish populations and macroinvertibrate diversity ceased in 2009.

The other river being studied, the river Kvernmoelva, is a smaller river system that shares some characteristics with Salangselva. It is located approximately 20 kilometers from Bones, and is a typical spring flood river with a majority of its catchment at high elevation. Brown trout is the only species of fish present above the hydroelectric dam. The river was channelized in the late 1980's. What makes Kvernmoelva interesting is the sharp transition from the channelized stretch through an agricultural area to a naturally meandering stretch of river that runs through a rich floodplain forest. No restoration work has been done in Kvernmoelva.

I aimed to test and compare a number of aspects for each river separately and in comparison. With regard to Salangselva, I replicated the sampling and observations done in the years 2003-2009, eight years later, to assess the long-term effects of the restoration project by comparing my findings to the existing sampling data from 2003-2009. The analysis of fish population and benthic macroinvertebrate diversity, in addition to the inspection of the structural changes that occurred during the restoration project, will provide valuable insight into long-term effects of restoration measures used for this type of river in the subarctic Troms County. Kvernmoelva, with its very distinct transition from a homogenous channel to a naturally meandering stretch of river through a rich floodplain forest provides the opportunity to compare data from the two stretches. Data on juvenile fish numbers as well as macroinvertebrate diversity for both the aforementioned stretches of Kvernmoelva provide insight into long-term effects of channelization in a stretch of river in a relatively small lotic ecosystem in the subarctic Troms County.

Similar sampling of benthic macroinvertebrates and juvenile fish was conducted in both rivers. The methodology was chosen based on previous work done in Salangselva, for comparative purposes. The river Bognelv in western Finnmark County approximately 210 kilometers northeast of Salangselva, has also been extensively studied since 2010 (Schedel 2010; Sødal 2014, Nordhov & Paulsen 2016), using the same bio-indicators as in my study of Salangselva and Kvernmoelva. The high sensitivity of different taxa and species of benthic macroinvertebrates to disturbances in their environment makes them very useful in assessing the ecological condition of surface waters (WFD 2000/60/EC 2000; Fierro et al. 2017).

The aims of my study were to [1] evaluate the cumulative effects of restoration measures implemented in the Bones area of Salangselva on juvenile fish density and length, and benthic macroinvertebrate diversity, eight years after monitoring ceased. Analysing data from Kvernmoelva, I will [2] compare juvenile fish density and length, and benthic macroinvertebrate diversity from a channelized stretch of the river with the corresponding data from a naturally meandering stretch of the river, to assess the effects of channelization. Furthermore, I [3] evaluated the different environmental variables that affect benthic macroinvertebrate diversity and juvenile brown trout density, to indicate challenges with - and potential returns from further restoration work in Salangselva in the Bones area. Finally, I [4] evaluated the recovery processes in Salangselva, and whether they are reflecting the goals and desired outcome of restoration measures implemented in the period 2005-2008.

2 Materials and Methods

2.1 Study area

The river Salangselva is located south in Troms County, and enters the fjord Sagfjorden in Sjøvegan (UTM 33, 7642017 N, 615154 E), Salangen municipality (Figure 1).

NVE (2018) provides the following factual information about the river. Salangselva has a catchment size in Norway of 539 km², with a small part of its catchment located in Sweden. The catchment is characterized by being mostly alpine, with calcareous bedrock (NGU 2018) and a rich flora. The river takes the name Salangselva at the confluence of the river Stordalselva and the river Budalselva at Bones. Salangselva is protected from future hydropower development since 1973 through «*Verneplan for Vassdrag I*», and has the watercourse number 191.Z.

The Bones study area in upper Salangsdalen valley (Figure 2) is located in a flat valley bottom, approximately 215 meters above sea level with surrounding steep hillsides and peaks reaching heights of 1000-1450 m. a. s. l. Local farmers report sudden and violent flash floods in the tributaries during spring, occasionally mobilizing and transporting sand, gravel, cobble and even boulders into their fields. The channelized main river is a typical spring flood river, and has a loose rocky substrate, consisting of mostly gravel and cobble. Unfortunately, there is no monitoring of discharge or turbidity in the Bones area, but the typical spring flood followed by several smaller peaks in discharge is clearly visible in monitoring data from Øvrevatnet close to where Salangselva enters the sea (Appendix A).

The river Kvernmoelva is located south in Troms County (Figure 1), and enters the fjord Gratangsbotn in Gratangen municipality (UTM 33, 7619928 N, 608893 E). The river has a catchment characterized by calcareous bedrock (NGU 2018), and being mostly alpine and above the treeline. The river is formed by the confluence of the river Skoltelva and the river Kvernmoelva near the Kvernmo settlement, where it flows north-northwest through the study area in a flat agricultural area (Figure 3). The river takes several different names on its way to the sea, but I chose to stick to the name Kvernmoelva for practical purposes and to avoid any confusion in this thesis. Kvernmoelva is located in the watercourse area 190, and its catchment measuring 23.21 km² has the designated identifier 190.3AZ (NVE 2018). Kvernmoelva is regulated by a hydroelectric dam located 800 meters downstream from the study area, and is a typical spring flood river. The river connects to the lake Bjørnarvatnet above the dam, and just downstream from the study area.

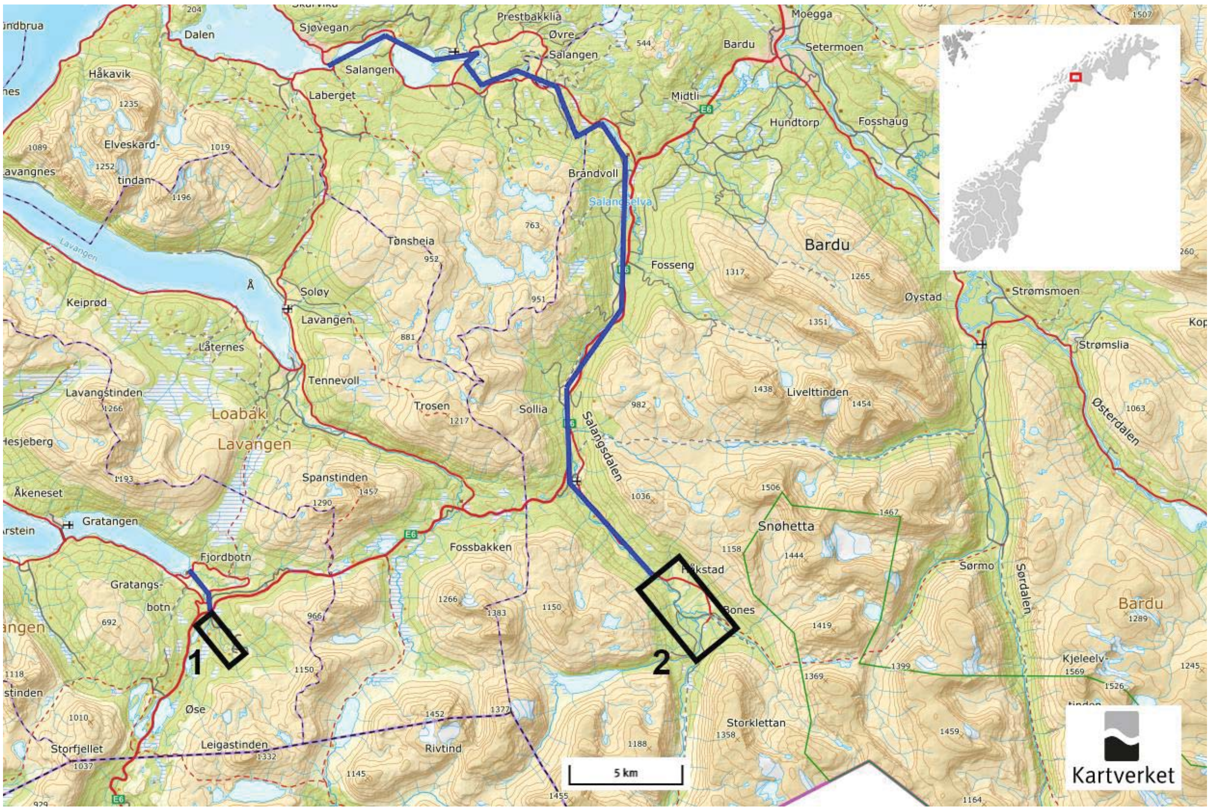


Figure 1. Map with black squares showing the location of study area 1 (Kvernmoelva) and 2 (Salangselva) in Northern Norway (www.norgeskart.no).

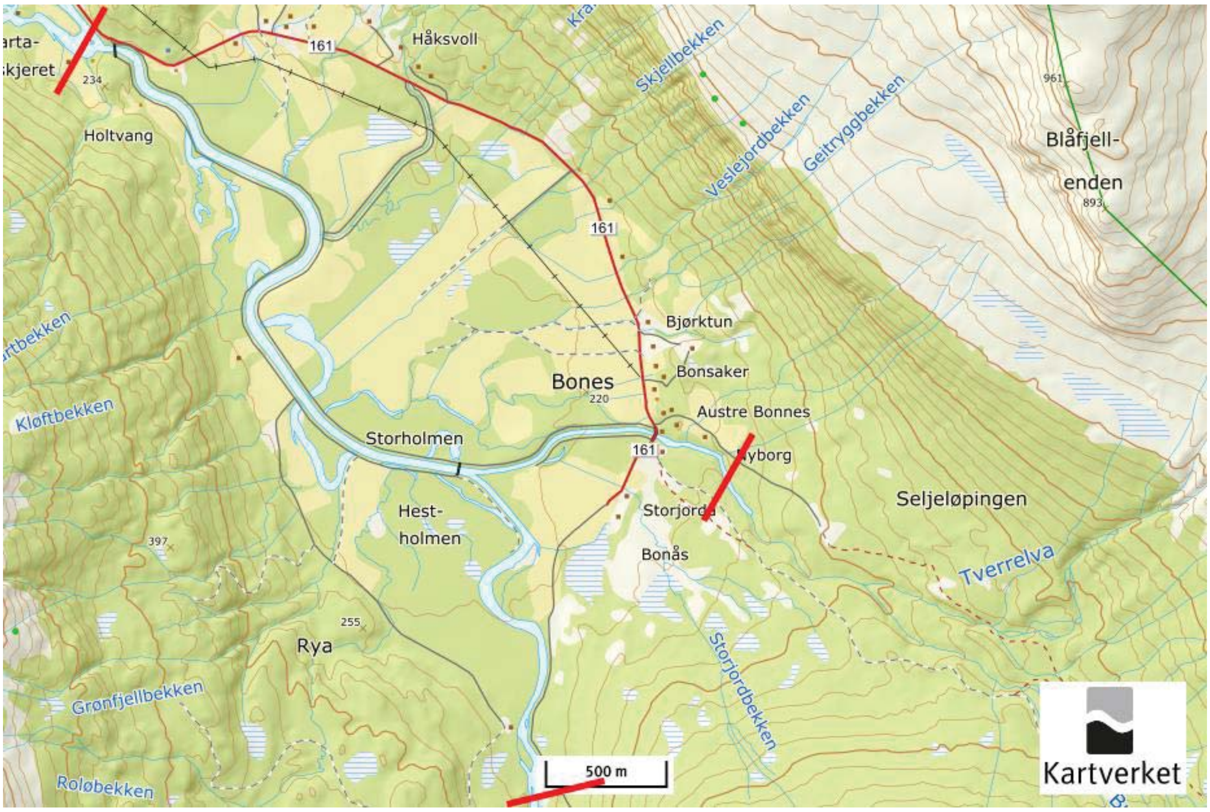


Figure 2. The study area at Bones, Salangselva, with red lines marking downstream and upstream boundaries (www.norgeskart.no).

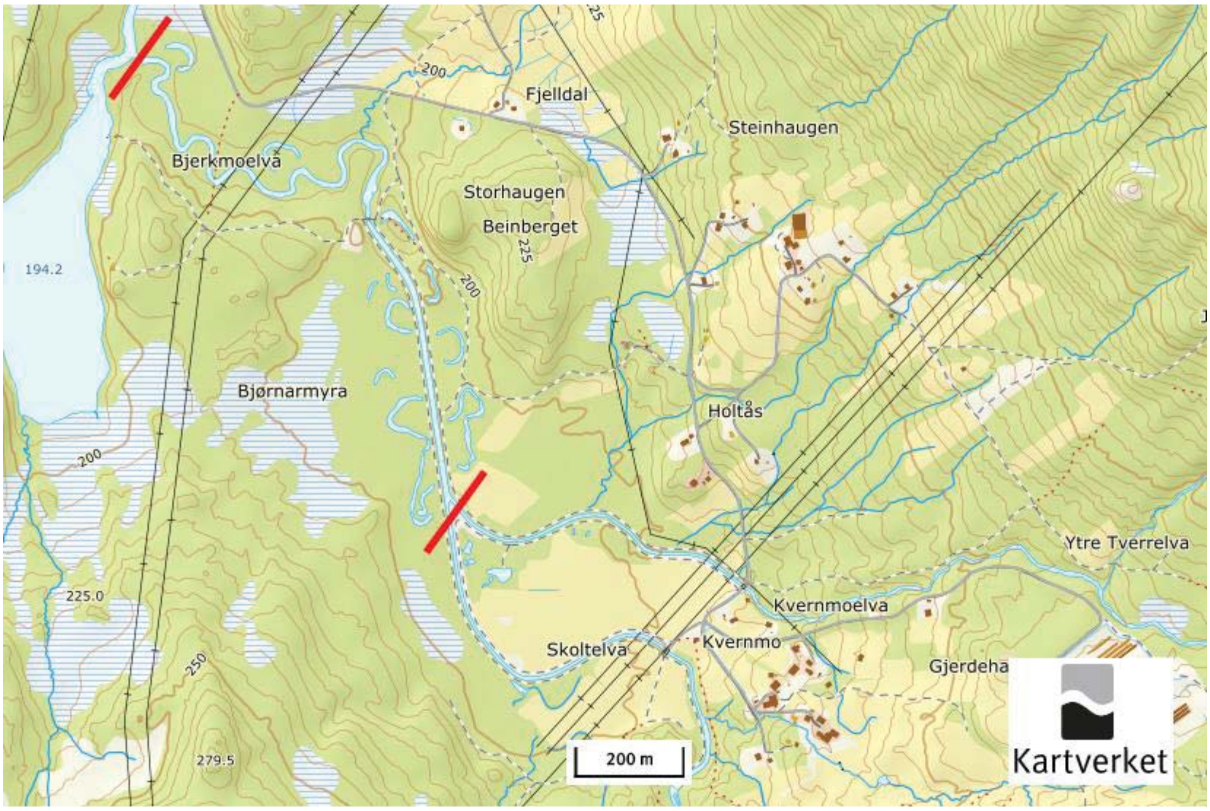


Figure 3. The study area at Kvernmo, Kvernmoelva (www.norgeskart.no).

2.2 History of anthropogenic modifications

Prior to Salangselva being heavily flood protected in the mid 1980’s, the Bones area had typical floodplain forest, where the river and its side channels made its way through the valley in wide meanders as a dynamic and natural river system (Figure 4). The flood protection project led to several of the meanders being partly or completely closed off in the process of channelizing the main river (Figure 5). Channelization reduced the problems associated with flooding in the area, and stimulated farming in adjacent fields in the following years (Rikardsen et al. 2004). At the same time, the area suffered a loss of important habitat for birds and floodplain forest. Fish stocks in the area were drastically reduced, and sedimentation in stagnant – or almost stagnant former meanders led to further deterioration of this important habitat for fish and benthic macroinvertebrates (Hoseth 2017).

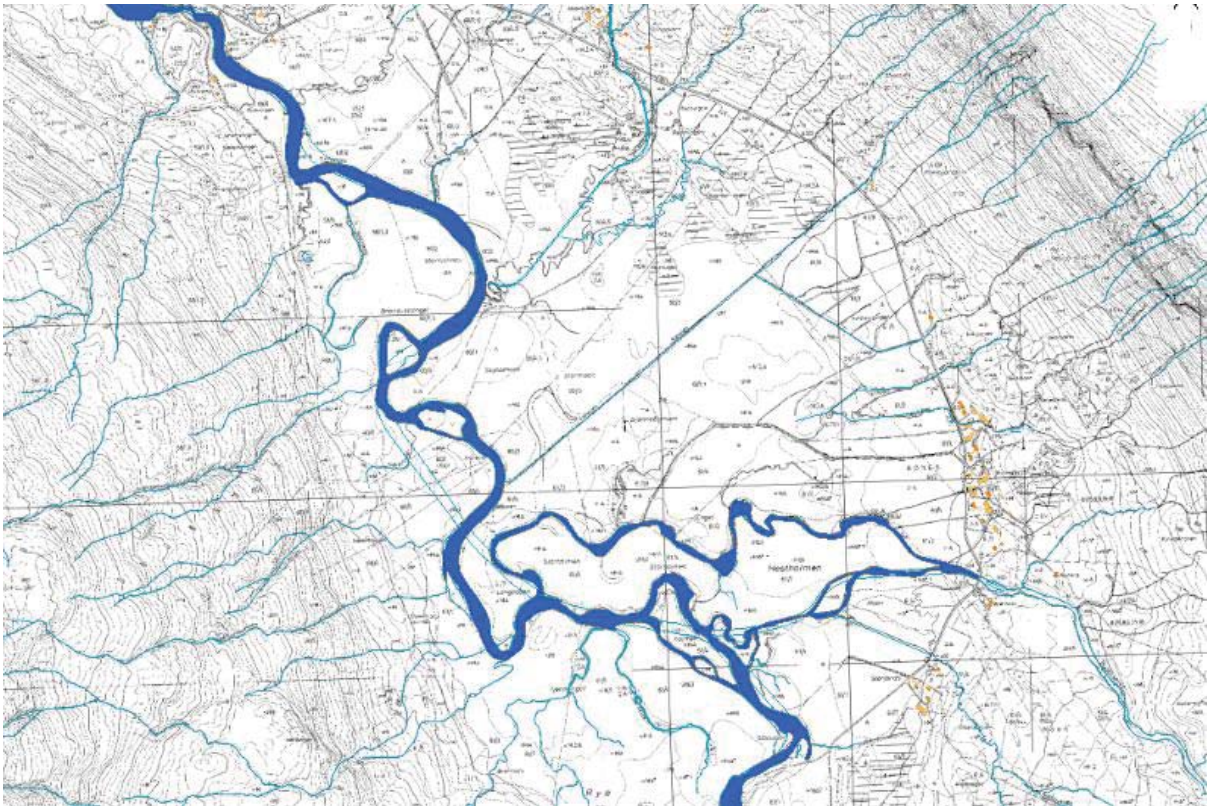


Figure 4. Salangselva through the Bones area, prior to the flood protection project. A dynamic river system with wide meanders, and rich floodplain forest (Hoseth 2017).

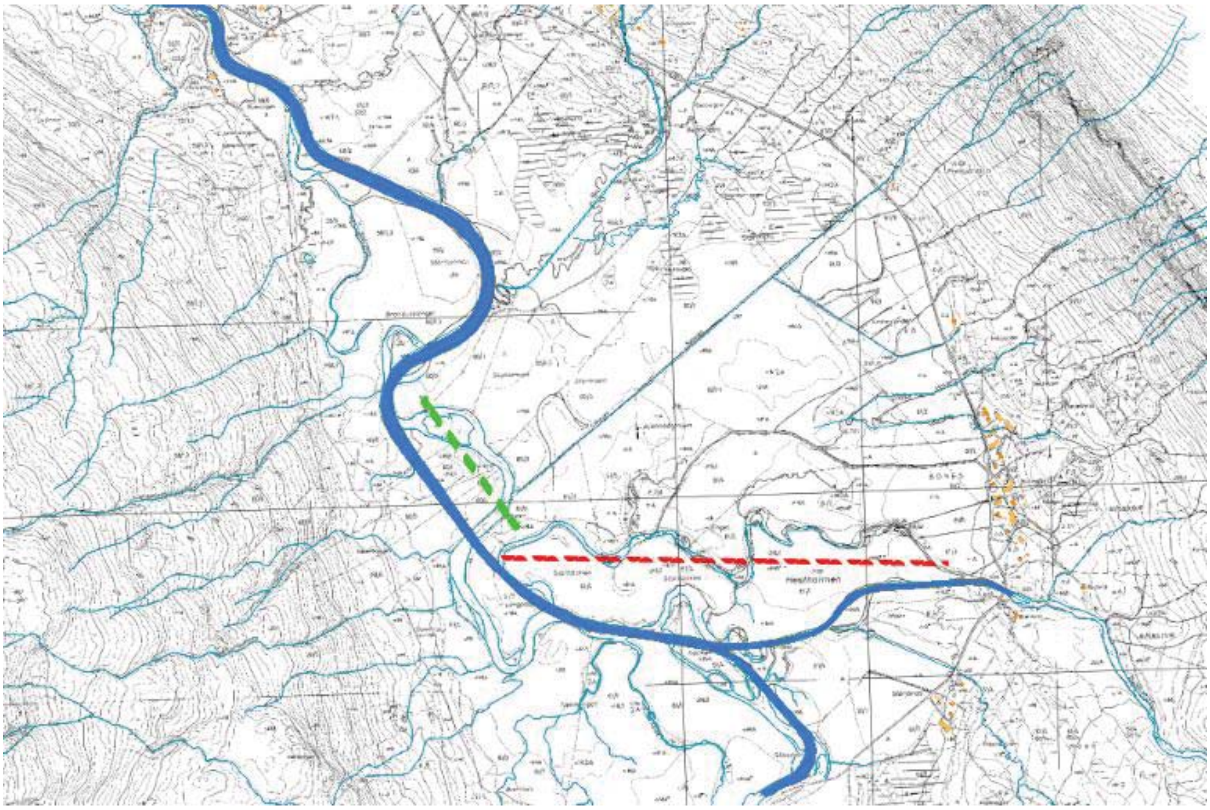


Figure 5. Salangselva through the Bones area, after the flood protection project. Extensive channelization accelerated the flow of water through the valley (Hoseth 2017). The red dotted line marks the tributary Budalsfaret, and the green dotted line marks the primary meander Storøra.

Kvernmoelva was modified in much the same way as Salangselva, also in the 1980’s. A section of the river was channelized, closing off several meanders completely (Figure 7). To my knowledge, no previous studies on the effects of channelization on fish and/or benthic macroinvertebrates has been done in this river. No restoration measures are planned or implemented.

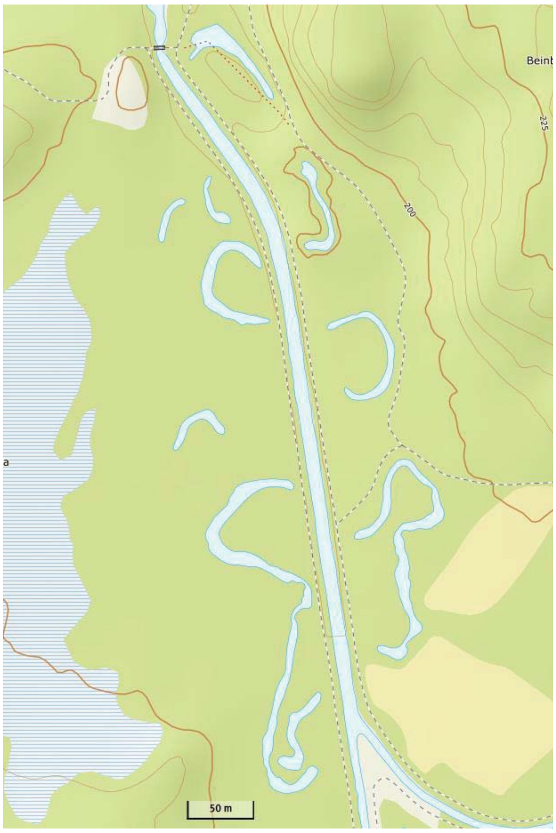


Figure 7. The channelized section of Kvernmoelva, in the southern part of the study area. Former meanders clearly visible as oxbow lakes on either side of the channel. (www.norgeskart.no).

During the years 2005-2008, extensive restoration measures were implemented at Bones with a budget of 2.2 million NOK, funded by NVE. The main objectives of the restoration project were to remove some of the flood protection structures along the river banks, reconnect former meanders to the main river, reduce sedimentation in slow flowing meanders, reopen the primary tributary Budalsfaret and to add groups of boulders in the main river channel to increase structural heterogeneity. See Appendix B for more detailed information on the restoration measures implemented. The goals of the restoration project were to increase the flow of water through primary meanders and Budalsfaret, to better mobilize fine particles and avoid the high rate of sedimentation. The increased flow of water should improve habitat quality for benthic macroinvertebrates, fish, birds and floodplain forest. At the same time, the flood protection of adjacent fields should be maintained (Hoseth 2017). In addition, the removal of former flood protection structures in areas a safe distance from fields is supposed to further improve natural processes necessary to maintain a rich floodplain forest in the river valley.

2.3 Study species

Brown trout

Brown trout and arctic char are the dominant species of fish in the Bones area, and the species of fish that were sampled in previous studies. Locals have been practicing stocking of thousands of nonnative arctic char in the area for years, making interpretation of arctic char counts difficult (Strann et al. 2010). Since the construction of fish ladders further downstream, the migration of anadromous fish such as salmon (*Salmo salar*), sea trout and arctic char is possible all the way to Bones, but observations and catches of any of these three species are extremely rare in the study area. In the river Kvernmoelva brown trout was the only species of fish observed during the study, and the only species of fish present according to locals.

Salmonids are sensitive species, and thus relevant as indicator species when assessing ecological status and water quality (Bergan et al. 2011). In both rivers, the resident salmonid brown trout were the only species of fish observed during the study period (Figure 8). Brown trout spawn during the autumn in well oxygenated flowing water, and spawning occurs on a substrate composed of various sizes of gravel (Louhi et al. 2008). Deposition of fine sediment in the streambed has been found to negatively affect brown trout egg survival by creating anoxic conditions (Massa et al. 2000). Furthermore, scouring and winter disturbances such as ice formation and breakup are associated with an increased mortality rate for fish eggs (Gauthey et al. 2015; Weber et al. 2013). However, the ecological role of winter disturbances remains somewhat unclear due to a lack of relevant studies (Weber et al. 2013).

Figure 8. A brown trout parr from Salangselva, northern part of the study area.

Type of habitat is important for brown trout growth and reproduction. Mainly due to intraspesific competition, the distribution of brown trout in different habitats in a river is size structured (Heggenes et al. 1999). Small trout parr (<70mm) prefer shallow and fairly swift moving water (10-50cm s^{-1}) with coarse substrate such as gravel and boulders, while bigger brown trout prefer deeper and slower moving water further from the river bank (Heggenes et al. 1999; Bremset & Berg 1999). Juvenile brown trout are territorial, and as a consequence, food availability and structural heterogeneity affects their population density (Heggenes et al. 1999; Jonsson & Jonsson 2011).

Macroinvertebrates

Benthic macroinvertebrates are the primary food source for resident brown trout in both study areas. They represent an incredibly species rich group of organisms, with differing tolerances regarding variables such as acidity, eutrofication and pollution. In addition, they have short life-cycles and are less mobile than fish (Veileder 2:2013, Klassifisering av miljøtilstand i vann). Short life-cycles make macroinvertebrates quick responders to changes in their environment (BIOKLASS 2006). During the aquatic stages of their life-cycle they have limited mobility, making them easy to sample. Thus, they are a valuable tool for assessing ecological status in a lotic ecosystem (Fierro et al. 2017).

Previous studies in Salangselva calculated an average score per taxon *(*ASPT) index for each sampling station based on the observed benthic macroinvertebrate diversity (Strann et al. 2010). The ASPT-index is a measure of benthic macroinvertebrates' tolerance to organic compounds and nutrients. The calculation is based on categories of indicator taxa assigned a tolerance score from 1-10, where 1 represents the highest tolerance to organic compounds and nutrients (Veileder 2:2013, Klassifisering av miljøtilstand i vann) (Figure 9). Calculating precise estimates of benthic macroinvertebrate density per area is extremely work intensive in the field and lacks standardized scientific methodology (BIOKLASS 2006). Thus, density observations are not used in any calculations in this thesis.

Index value	Ecological condition
< 4,4	Very poor
5,2 - 4,4	Poor
6,0 - 5,2	Moderate
6,8 – 6.0	Good
> 6,8	Very good
6,9	Unaffected

Figure 9. Categories of ecological condition of benthic fauna, from «Very poor» to «Unaffected», and its corresponding ASPT-values (Strann et al. 2010).

2.4 Data collection

For comparative purposes the sampling methods were chosen based on previous studies done in the Bones area (Strann et al. 2010). When reports from studies at Bones lacked detail on methodology, I cross-referenced with studies from Bognelv (Schedel 2010; Sødal 2014; Nordhov & Paulsen 2016), or conferred with my main supervisor J. E. Colman. G. Dahl-Hansen at Akvaplan-NIVA in Tromsø supervised the electrofishing in Salangselva. Sampling methods used in Salangselva and Kvernmoelva are identical. Fieldwork, including all of the data collection for both rivers, was conducted during two periods in 2017; 25 – 31 July and 25 August – 5 September. Due to late snowmelt and spring flood, most of the sampling was done in period two, for both practical and safety reasons. Previous sampling of macroinvertebrates at Bones were done 20 May 2009, at three stations in Budalsfaret and one station in Budalselva. Previous electrofishing in the main river channel and in Budalsfaret took place in the years 2003 – 2009, and 2007 – 2009 respectively, mostly during June - September (Strann et al. 2010).

Macroinvertebrates

Macroinvertebrates were sampled at 16 stations in Kvernmoelva and 10 stations in the Bones area – including the three stations sampled previously in Budalsfaret in 2009 by Strann et al (2010). Specimens from the orders *Ephemeroptera*, *Plecoptera* and *Trichoptera* (EPT) were classified to family or species, while specimens from other orders relevant to calculating the ASPT-index were classified as necessary.

The ASPT-index has previously been used in describing ecological condition in the Bones area of Salangselva (Strann et al. 2010). The ASPT-value is used for the calculation of normalized EQR-values (nEQR), used for comparison between different quality elements measured in a body of water (Veileder 2:2013, Klassifisering av miljøtilstand i vann).

Benthic macroinvertebrates were sampled using the «kick-sampling method», where a net measuring 30x30 cm with a mesh size of 450 µm was placed firmly on the river bottom. Upstream from the net, rigorous kicking of the river bottom was performed for 20 seconds. For each station, a total of nine spots were kick-sampled for 20 seconds, giving a total of three minutes of kick-sampling at each station (Figure 10). The sampled macroinvertebrates were kept in ethanol 96% until classification. See Appendix C1 for coordinates and maps describing all benthic macroinvertebrate sampling stations in both rivers.

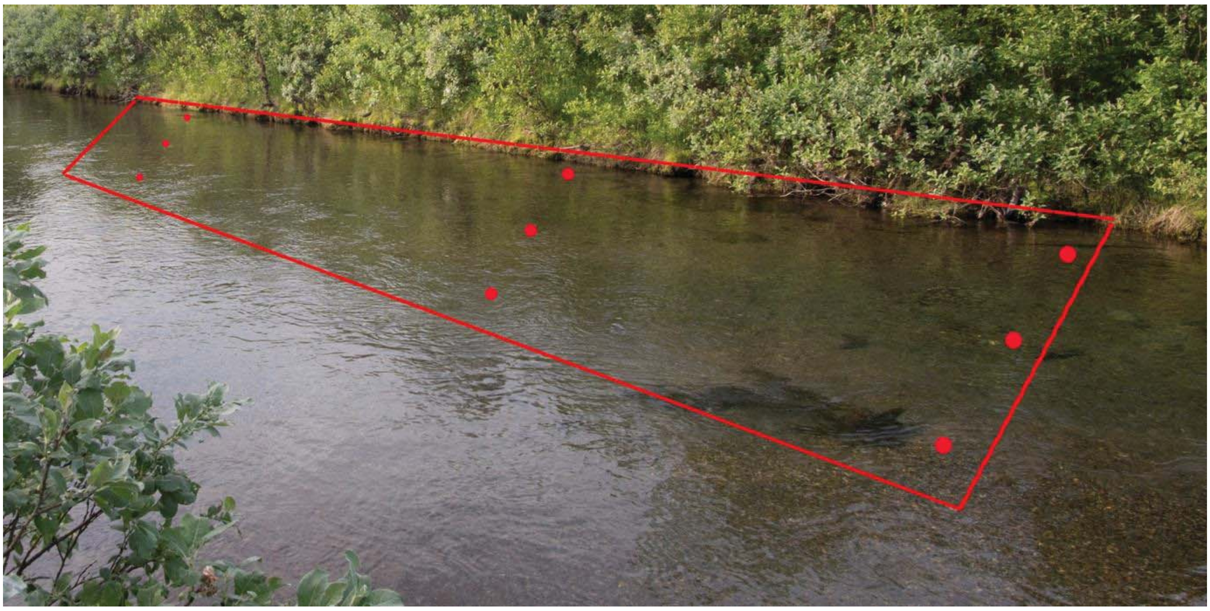


Figure 10. Photograph from Kvernmoelva, with drawing of the general layout used when kick-sampling a station. 20 seconds of kicking were done at each of the nine spots marked by red dots. Each station approximately 15m long.

Electrofishing

The method used for immobilizing and capturing juvenile brown trout was electrofishing. When electrofishing, I was always accompanied, for safety reasons. The generator used was a Terik Technologies FA-4, 175-1400V. Most of the stations electrofished in both rivers had suitable conditions during sampling, with good visibility and a moderate current velocity (Forseth & Forsgren 2008).

In the Bones area of Salangselva, the main river channel was electrofished along the bank (Figure 11). The Storøra meander and Budalsfaret tributary were easier to electrofish more thoroughly because of the shallower water. In addition to the aforementioned replication of previous studies done in the area, I also electrofished one station in the tributary Budalselva, two stations in the tributary Stordalselva, as well as one station further downstream at the northern boundary of the study area. Due to the low densities of fish to be found, only one pass of electrofishing was conducted at all stations, assuming 50% of fish present at the station being caught and registered (Strann et al. 2010). Catches were stored in a bucket until the electrofishing of one station was completed, and then measured to the nearest millimetre before being released.

Figure 11. Photograph of electrofishing in the main river channel in Salangselva, Bones. Photo: Geir Dahl-Hansen 2017.

In Kvernmoelva, a total of ten stations were electrofished; five in the channelized stretch and five in the naturally meandering stretch of the study area. For the five stations in the naturally meandering stretch of the river, I employed removal techniques in order to estimate juvenile brown trout population size, due to high densities of fish (Zippin 1958). Three passes were conducted at each of the five stations, with a minimum of 20 minutes separating each pass. Three assumptions needs to be fulfilled to achieve satisfactory precision of the estimate using this method; [1] the population is closed, [2] all individuals have equal catchability, and [3] equal catchability during each pass (Seber 1973). In real life applications, this method tends to be biased resulting in an underestimation of population size due to violations of one or more of the aforementioned assumptions (Forseth & Forsgren 2008). The method used for estimating population size where I used the three-pass removal technique was the model from Bohlin et al. (1989). For the five stations in the channelized stretch of the river, I assumed that 50% of the fish present at the station were caught and registered during one pass of electrofishing. See Appendix C2 for coordinates and maps describing all electrofishing stations in both rivers.

When determining age groups (0+, 1+, >1+) of brown trout by analysing their length distribution in Salangselva, it was necessary to confer with previous results from Bognelv (Sødal 2014; Nordhov & Paulsen 2016) in addition to my own results. This was due to the low number of fish caught and measured in Salangselva in 2017, and that length distribution histograms were used as the means for determining age groups.

In addition to electrofishing, visual observations of older and larger fish was possible in Kvernmoelva during both periods of fieldwork (Figure 12). This was done wearing polarized sunglasses on sunny days, and conducted in the entire study area.

Figure 12. Photograph of a brown trout (approx. 45cm) observed actively surface feeding on adult mayflies in the Baetidae family, Kvernmoelva.

Environmental variables

Environmental variables were logged at all sampling stations. The methodology used was the same as Sødal (2014), see Appendix D for more in-depth information. Canopy cover of the riverbank and river, as well as vegetation cover on the riverbank were assigned a category based on observed percentage. Water velocity was determined by visual assessment, and assigned a category from one to four. Substrate composition was also determined through visual assessment, and assigned a category based on approximate average grain size. Further; depth, algae cover, moss cover, number of pools and large woody debris (LWD), width of the river channel and percentage of width covered with water were registered. Regarding Salangselva, Strann et al. (2010) discuss the variables substrate composition, and temperature as an indirect measure of streamflow through Budalsfaret and Storøra. Temperature was not logged during the study period in 2017.

2.5 Statistical analysis

For processing data, organizing datasets and creating tables Microsoft Excel (Microsoft Office Professional Plus 2010) was used. Most of the statistical analysis was done in R version 3.5.0 (R Development Core Team 2018). Figures were created in both software packages. In general, p-values were considered significant if $\alpha \leq 0.05$. Due to limited amounts of data being available from previous surveys, visualization of data in plots and charts was deemed more reasonable in certain instances, rather than statistical analysis of complex relationships with low sample sizes.

Environmental variables

Not all of the registered environmental variables were used in the statistical analysis. Vegetation cover of the river bank in Kvernmoelva was close to 100% at all stations, thus the variable was omitted in statistical analysis. Other registered variables omitted from analysis are algae and moss cover of the bottom (close to zero at all stations), river width (less than 10% variation), and pools (close to zero registered). The selection of environmental variables to use for analysis were based on previous work done in Bognelv by Sødal (2014), where the variables describing depth, substrate and current velocity were important in predicting juvenile brown trout density. I also included LWD (large woody debris) and canopy cover of the bank and river. The variables concerning canopy cover of the river bank and the river were merged into one, with the mean percentage of the measured category for the two variables used in statistical analysis. For the variables substrate and surface water velocity, the median of the measured category was used and LWD at each station were counted. Details on environmental variables and categories are given in Appendix D.

Effects of environmental variables on juvenile brown trout density and benthic macroinvertebrate diversity were investigated through model selection with AICc-criteria on fitted multiple linear models (Burnham & Anderson 1998), only considering additive effects between predictor variables due to the limitations of small datasets.

Juvenile brown trout age groups and densities

Juvenile brown trout age groups were determined based on length distribution histograms for each of the two rivers separately. Due to low numbers of registered juvenile brown trout in the Salangselva study area, it was necessary to confer with the results of previous age group determination done in Bognelv in Northern Norway (Sødal 2014; Nordhov & Paulsen 2016). Density estimates are given per 100 m², and with the exception of five sampling stations in Kvernmoelva, one-pass electrofishing assuming 50% catch was conducted. In the naturally meandering stretch of Kvernmoelva, a commonly used three-pass removal technique was employed, with subsequent density estimation as per Bohlin et al. (1989). A one-way Welch anova (not assuming equal variances) was used to test for statistical significance in the occurrence (channelized or natural stretch) of each age group of juvenile brown trout in Kvernmoelva.

Macroinvertebrates

nEQR-values, benthic macroinvertebrate community composition and EPT-diversity for all sampling stations were charted to assess ecological condition and look for trends in the data. Linear models with single environmental variables as predictors explaining nEQR for the 16 stations in Kvernmoelva were examined to look for significant interactions between environmental variables and ecological status.

3 Results

3.1 Brown trout length distribution and age groups

Juvenile brown trout age groups (0+, 1+ and >1+) were defined from the length intervals (Table 1) and distribution (Figure 13) of sampled fish from both rivers separately.

Table 1. Length interval of brown trout age groups in 2017, measured in millimetres.

	Age groups		
Brown trout	**0+**	**1+**	**>1+**
Kvernmoelva	20-56mm	57-100mm	>100mm
Salangselva	<57mm	57-90mm	>90mm

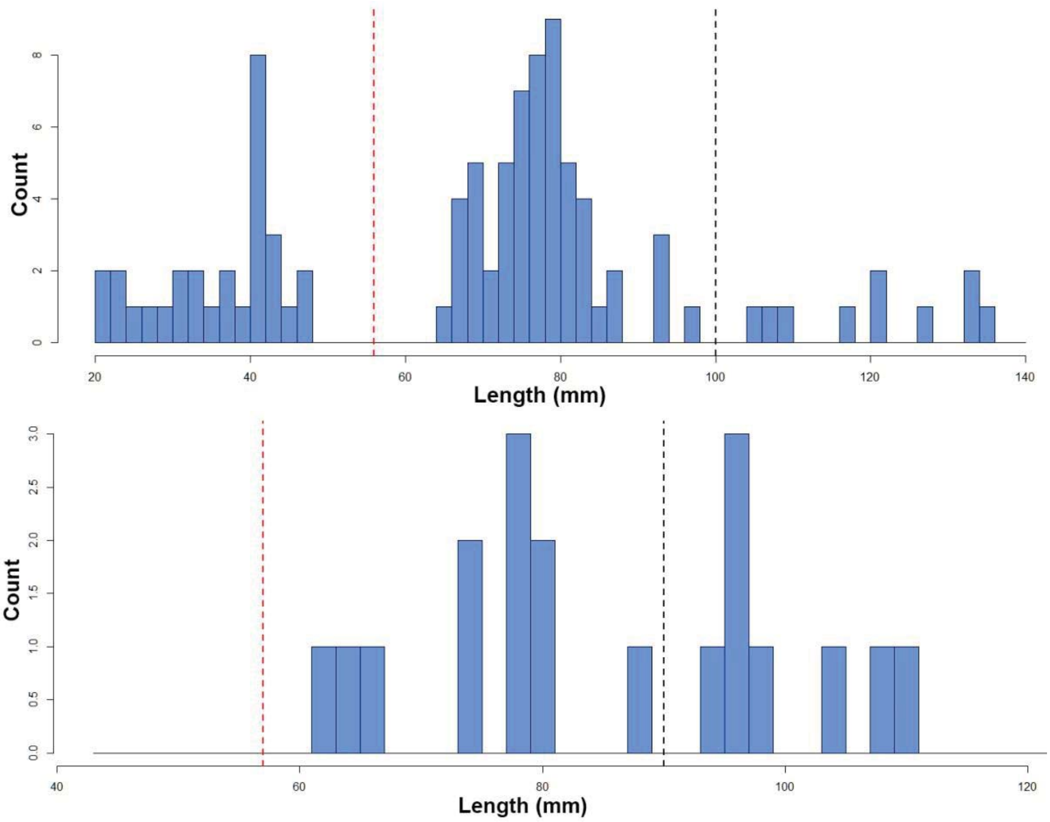


Figure 13. The length distribution of sampled brown trout in Kvernmoelva (top) and Salangselva (bottom). The 0+ age group is to the left of the red dotted line, the 1+ age group is between the red and black dotted line, and the >1+ age group is to the right of the black dotted line.

3.2 Brown trout density estimates

With the exception of the year 2003, densities (per 100 m²) from all electrofishing conducted in the period 2003-2017 for the main river channel and the tributary Budalsfaret in the Bones area were consistently low (Table 2 and 3, and Figure 14).

Table 2. Electrofishing in the main river channel in Salangselva. Data from 2017 added to the table from Strann et al. (2010). Density given per 100 m², and 50% of the fish present is assumed to have been caught and registered (one pass). Only habitat close to the bank was sampled, in all years.

Year	Date	Area (m²)	trout 0+	trout 1+	trout >1+	trout, total	trout, density
2003	08-Oct	600	52	18	3	73	24,3
2004	08-Aug	800		4	1	5	1,3
2004	23-Sep	800		2		2	0,5
2005	31-May	500		1	1	2	0,8
2005	30-Jun	1400		10		10	1,4
2005	08-Aug	1000		1	4	5	1,0
2006	05-Jun	1100	7		1	8	1,5
2006	14-Aug	1100	3	2	1	6	1,1
2007	09-Aug	1100	4	7	4	15	2,7
2007	30-Sep	600	3	6	1	10	3,3
2008	30-Jun	800	9	4	1	14	3,5
2008	01-Aug	800		4	2	6	1,5
2009	09-Jun	800	13	5		18	4,5
2009	01-Aug	800	9	1		10	2,5
2009	01-Sep	800	2	3	1	6	1,5
2017	04-Sep	345		4	1	5	2,9

Table 3. Electrofishing in Budalsfaret. Data from 2017 added to the table from Strann et al. (2010). Density given per 100 m², and 50% of the fish present is assumed to have been caught and registered (one pass). The upper 250 m of Budalsfaret were electrofished all years. In 2007, the slow flowing lower parts were also electrofished. In 2017, the connection between Budalsfaret and Storøra were electrofished.

Year	Date	Area (m²)					
			trout 0+	trout 1+	trout >1+	trout, total	trout, density
2007	30-Sep	600				0	0
2008	30-Jun	500		1	2	3	1,2
2008	01-Aug	500		1	4	5	2
2009	10-Jun	500		1	1	2	0,8
2009	01-Aug	500		3		3	1,2
2009	01-Sep	500		2		2	0,8
2017	04-Sep	540		1	4*	5	1,9

*= Two captured in the lower part of Budalsfaret connecting to Storøra

During this study, electrofishing was conducted in some areas not previously electrofished (Table 4). Due to low flow and several years with a high rate of sedimentation, the entire primary meander Storøra was possible to electrofish with ease during the second period of fieldwork. Note that not a single fish was caught or seen in the entire meander. Station 10 (Martafossen) just downstream from the channelized Bones area had coarser bottom substrate (approx. 60-300mm).

Table 4. Other locations electrofished in Salangselva and its tributaries in 2017. Location and station number given in the left column. Density given per 100 m², and 50% of the fish present is assumed to have been caught and registered (one pass).

Location	Date	Area (m²)					
			trout 0+	trout 1+	trout >1+	trout, total	trout, density
Storøra, 1	04-Sep	2000*				0	0
Budalselva, 7	05-Sep	60			1	1	3,3
Stordalselva, 8	06-Sep	200		1	1	2	2
Stordalselva, 9	07-Sep	75				0	0
Martafossen, 10	08-Sep	100		5	1	6	12

*= Low flow, low percentage suitable bottom substrate for fish, and good visibility.

In kvernmoelva five stations were electrofished in each of the two stretches of the river (Table 5).

Table 5. Electrofishing in the channelized stretch (top) and the naturally meandering stretch (bottom) of Kvernmoelva, and estimated densities. Density given per 100 m².

Station	Date	Area (m²)	trout 0+	trout 1+	trout >1+	trout, total	trout, density
1	05-Sep	110	4	1	1	6	10,9
2	06-Sep	202,5	5	3		8	7,9
3	07-Sep	100	6	2		8	16
4	08-Sep	95	4	5		9	18,9
5	09-Sep	142,5	2	2	2	6	8,4

Station	Date	Area (m²)	trout 0+	trout 1+	trout >1+	trout, total	population estimated (ŷ)	trout, density
6	05-Sep	150	6	11	1	18	24,86	16,6
7	06-Sep	75		13	2	15	17,58	23,44
8	07-Sep	40	2	6		8	8,71	21,78
9	08-Sep	105		5	3	8	9,61	9,15
10	09-Sep	60		9	1	10	13,28	22,13

Restoration measures were implemented at Bones in the period 2005-2008, with relatively small effects on fish densities since then (Table 2 and 3, and Figure 14). Regarding Budalsfaret (Figure 15), the density is still very low. Considering the low sample size and that two of the >1+ brown trout from 2017 were caught in an area not electrofished the previous years, the plot shows no significant trend.

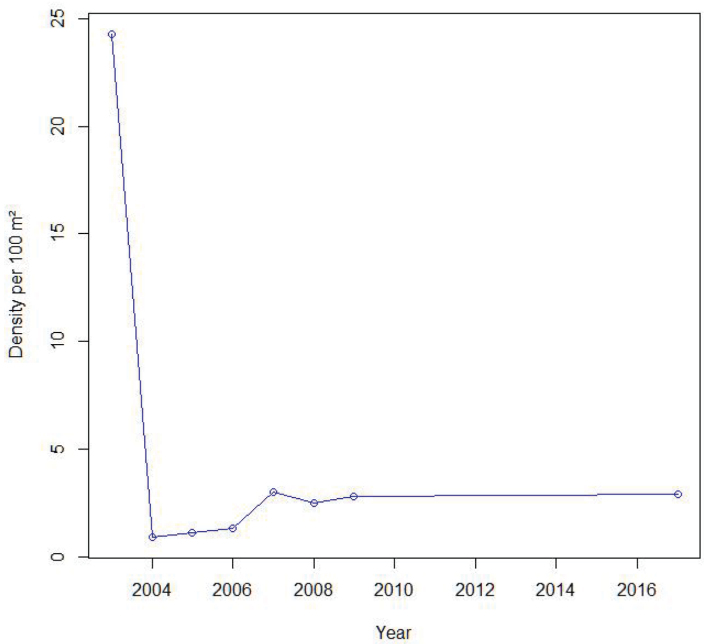


Figure 14. The density development of juvenile brown trout (0+, 1+ and >1+) in the main river channel at Bones, from 2003 to 2017. SD = 7,9 (SD = 0.93 when the year 2003 is removed from the calculation).

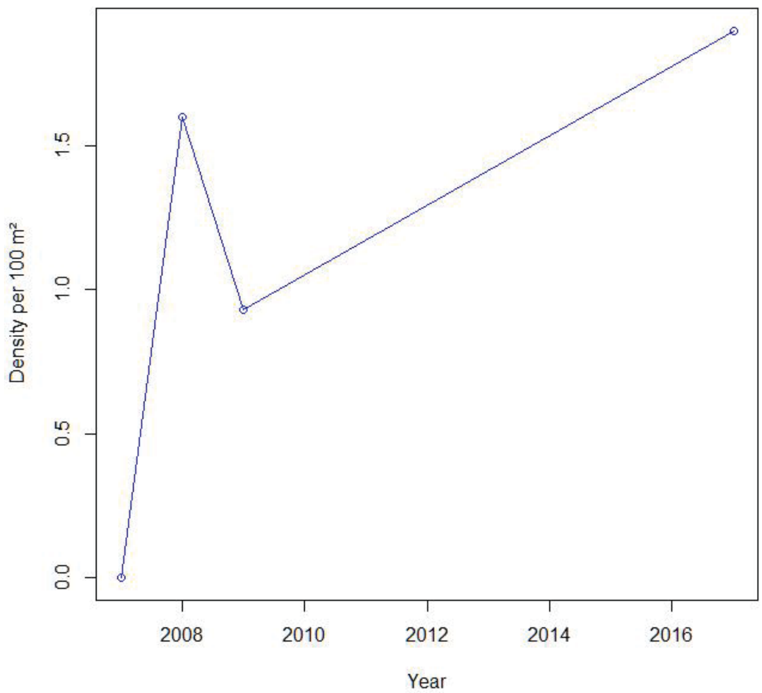


Figure 15. The density development of juvenile brown trout (0+, 1+ and >1+) in Budalsfaret, from 2007 to 2017. SD = 0.84.

3.3 Variations in brown trout density in Kvernmoelva

For Kvernmoelva, I compared the densities from stations in the channelized stretch with the densities from the naturally meandering stretch of the river, and added trendlines in the plot below (Figure 16) to visualize the difference between the two.

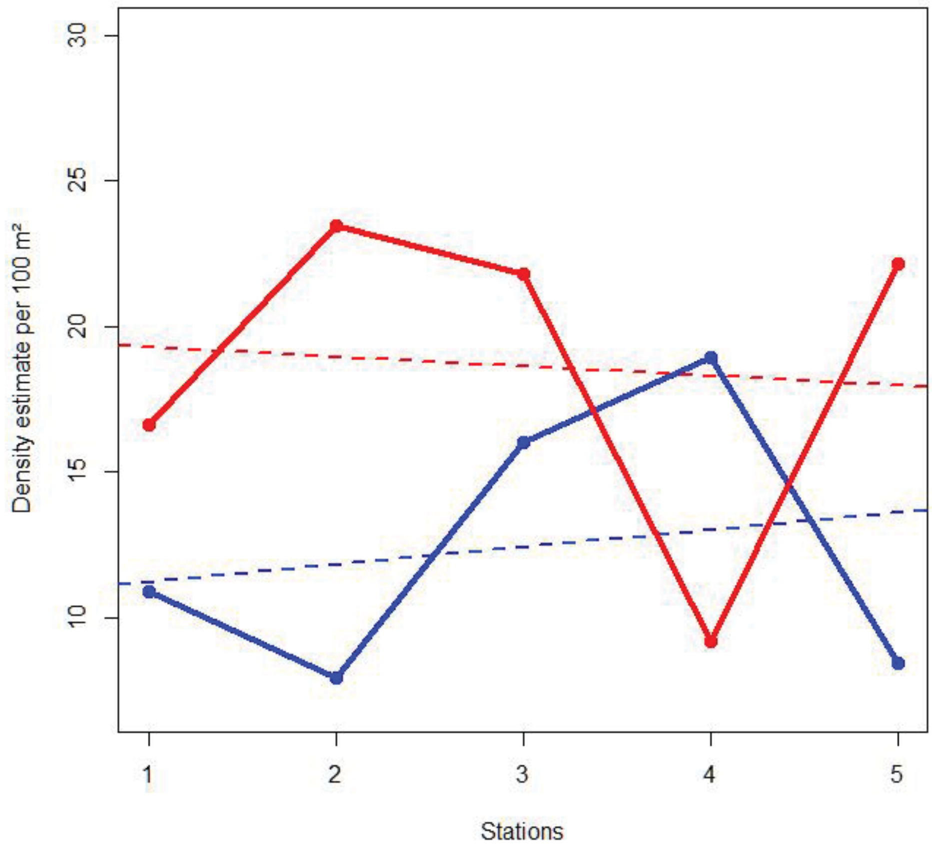


Figure 16. Estimated densities of juvenile brown trout in the channelized stretch (blue line) and the naturally meandering stretch (red line) of Kvernmoelva. Corresponding dotted trendlines added to visualize the difference between the two. The x-axis numbers represent the five stations in each stretch. The mean estimated density is 12.4 for the channelized stretch, and 18.6 for the naturally meandering stretch.

A one-way Welch (not assuming equal variances) analysis of variance was performed for each of the three age groups to check for statistical significance in the difference between the channelized and the naturally meandering stretch of Kvernmoelva (Table 6). A low sample size of >1+ brown trout contributes to the higher p-value.

Table 6. The one-way Welch ANOVA, investigating variation between the two stretches in Kvernmoelva for the three age groups. F greater than one, indicates that there is a difference. The p-value shows the significance level.

Age group	F	num df	denom df	p-value
0+	3.7556	1	6.343	0.09812
1+	14.237	1	5.576	0.0106
>1+	2.381	1	7.571	0.1635

Looking at the box plots below to visualize the differences discovered in Table 6, the differences in occurrence of juvenile brown trout from a given age group in each stretch of the river can be clearly seen (Figure 17).

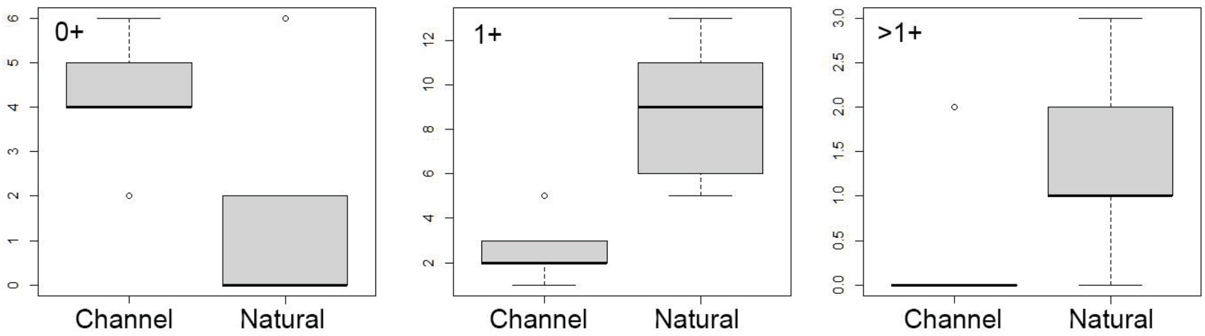


Figure 17. Difference in occurrence of juvenile brown trout between two stretches in Kvernmoelva, for each age group (0+, 1+ and >1+).

3.4 Brown trout density as a function of environmental variables

Environmental variables were not measured in the years before 2017. Thus, the model selection is based on data from 2017 only. Due to low numbers of >1+ brown trout at all sampling stations, model selection with AICc criteria was first conducted for the age classes 0+ and 1+ (Table 7), and then for the total juvenile brown trout estimated densities. AICc is recommended when dealing with many parameters (K) and small sample sizes (n), when n/K<40 (Burnham & Anderson 1998). Only the electrofishing conducted in Kvernmoelva yielded enough data to run a meaningful model selection procedure. With ten stations sampled, I only considered additive interactions between variables to avoid overfitting the models. The response variable used in the model selection is the estimated density of 0+ and 1+ brown trout per 100 m² for each station.

Table 7. The most supported models explaining the density of the brown trout age classes 0+ and 1+ respectively.

Age class 0+

No	Predictor variables	AICc	ΔAICc	AICcWt
1	Depth	58.8	0	0.9119
2	Depth + Velocity	63.5	4.7	0.0862
3	Vegetation + Depth + Velocity	71.2	12.4	0.0019
4	Vegetation + Depth + Velocity + LWD	86.2	27.3	<0.001

Age class 1+

No	Predictor variables	AICc	ΔAICc	AICcWt
1	Substrate + Depth + LWD	77.2	0	0.9956
2	Substrate + Depth + Velocity + LWD	88.1	10.8	0.0044

The coefficients for the two most supported models reveal a significant negative effect of depth on 0+ density, and a significant positive effect of depth on 1+ density (Table 8).

Table 8. The coefficients for the most supported model explaining the density of brown trout age classes 0+ and 1+ respectively.

Age class 0+

Coefficients	Estimate	Std. error	SD	t value	Pr(>|t|)
Depth	-0.1334	0.0507	19.8746	-2.629	0.0302*

Age class 1+

Coefficients	Estimate	Std. error	SD	t value	Pr(>|t|)
Substrate	-0.0555	0.0321	73.0393	-1.728	0.1348
Depth	0.7323	0.1970	19.8746	3.718	0.0099**
LWD	-10.0730	3.9773	0.7678	-2.533	0.0445*

** = Significance level <0.01

* = Significance level <0.05

Plots of estimated brown trout density explained by single predictor variables for the 0+ and 1+ brown trout age classes in the entire Kvernmoelva study area reveal opposite trends for 0+ and 1+ (Figure 18). The corresponding coefficients are summarized in Table 9, where the most interesting and only significant relationship is density ~ Depth for both age classes.

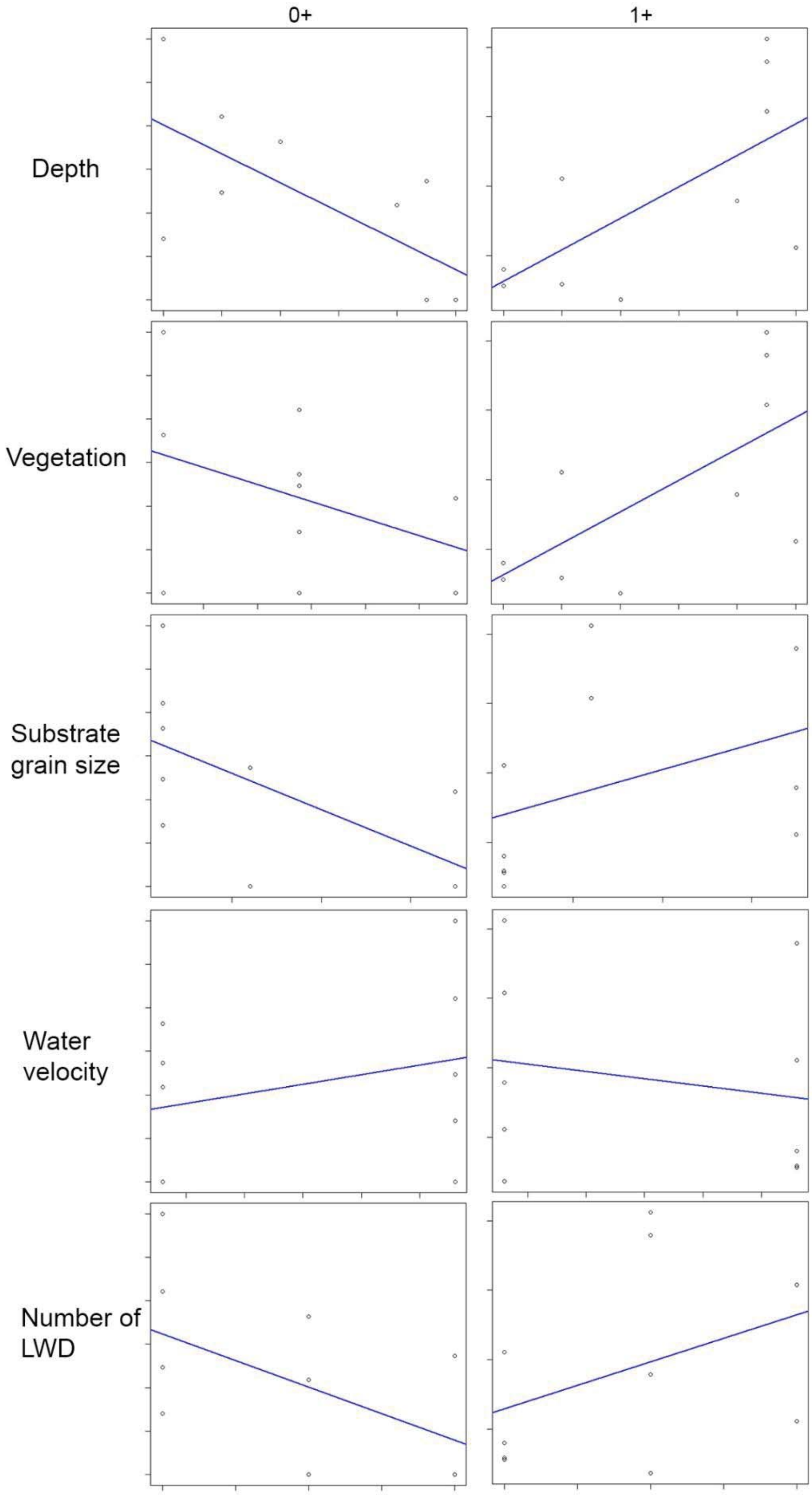


Figure 18. Associations between estimated densities of brown trout (y-axis) in Kvernmoelva, and the different environmental variables (from top to bottom); depth, vegetation, substrate grain size, water velocity and number of large woody debris. Upward sloping trend-line represent a positive relationship, and vice versa.

Table 9. Coefficients of density ~ single environmental variable predictors for age class 0+ and age class 1+ respectively, in Kvernmoelva.

Age class 0+, density ~ single predictors				
	Estimate	Std. error	t value	Pr(>|t|)
Depth	-0.1334	0.0507	-2.6290	0.0302*
Vegetation	-0.0785	0.0654	-1.2000	0.2644
Substrate	-0.0333	0.0147	-2.2630	0.0535
Velocity	0.0887	0.1027	0.8640	0.4130
LWD	-2.4410	1.5710	-1.5530	0.1589
Age class 1+, density ~ single predictors				
	Estimate	Std. error	t value	Pr(>|t|)
Depth	0.2273	0.0905	2.5120	0.0362*
Vegetation	0.1105	0.1179	0.9370	0.3760
Substrate	0.0365	0.0303	1.2030	0.2635
Velocity	-0.1045	0.1839	-0.5680	0.5855
LWD	3.3860	2.8950	1.1700	0.2760

*= Significance level <0.05

Model selection on the effects of environmental variables on estimated densities of juvenile brown trout from all age classes (0+, 1+, and >1+) in the entire Kvernmoelva study area revealed that the predictor depth was included in the four most supported models (Table 10).

Table 10. The most supported models explaining juvenile brown trout density in the entire Kvernmoelva study area.

Juvenile brown trout (0+, 1+ and >1+)

No	Predictor variables	AICc	ΔAICc	AICcWt
1	Depth	70.8	0	0.8891
2	Depth + LWD	75	4.2	0.1073
3	Substrate + Depth + LWD	81.8	11.1	0.0035
4	Vegetation + Substrate + Depth + LWD	96.1	25.3	<0.001

The most supported model includes only depth as the predictor, with p=0.17 (Table 11). Due to the differing densities of 0+ and 1+ age classes in the two stretches of river, the results from this analysis was not significant.

Table 11. Coefficients of the most supported model explaining juvenile brown trout density in the entire Kvernmoelva study area.

Juvenile brown trout (0+, 1+ and >1+)					
Coefficients	**Estimate**	**Std. error**	**SD**	**t value**	**Pr(>|t|)**
Depth	0.14	0.0923	19.8746	1.518	0.1680

3.5 Macroinvertebrates

ASPT index in Kvernmoelva

For the sampled benthic macroinvertebrates in Kvernmoelva, average score per taxon (ASPT) was calculated for each station, for each of the two stretches of the river, and for the entire study area. The table below lists both ASPT- and nEQR-values for the Kvernmoelva study area (Table 12).

Table 12. Calculated ASPT- and nEQR-values for Kvernmoelva. For «Section» and «Total», the mean is calculated from associated sampling stations.

Station	ASPT	nEQR
1	5.75	0.54
2	4.86	0.31
3	5.57	0.49
4	5.13	0.38
5	5.67	0.52
6	5.57	0.49
7	5.89	0.57
8	5.89	0.57
9	5.57	0.49
10	6.00	0.60
11	5.75	0.54
12	6.10	0.63
13	6.00	0.60
14	5.14	0.39
15	5.80	0.55
16	5.75	0.54
Section		
Channel	5.54	0.48
Natural	5.76	0.54
Total		
	5.65	0.51

Charting the nEQR-values with the background showing the boundaries between different categories of ecological condition, only a few stations were categorized as being in good ecological condition (Figure 19).

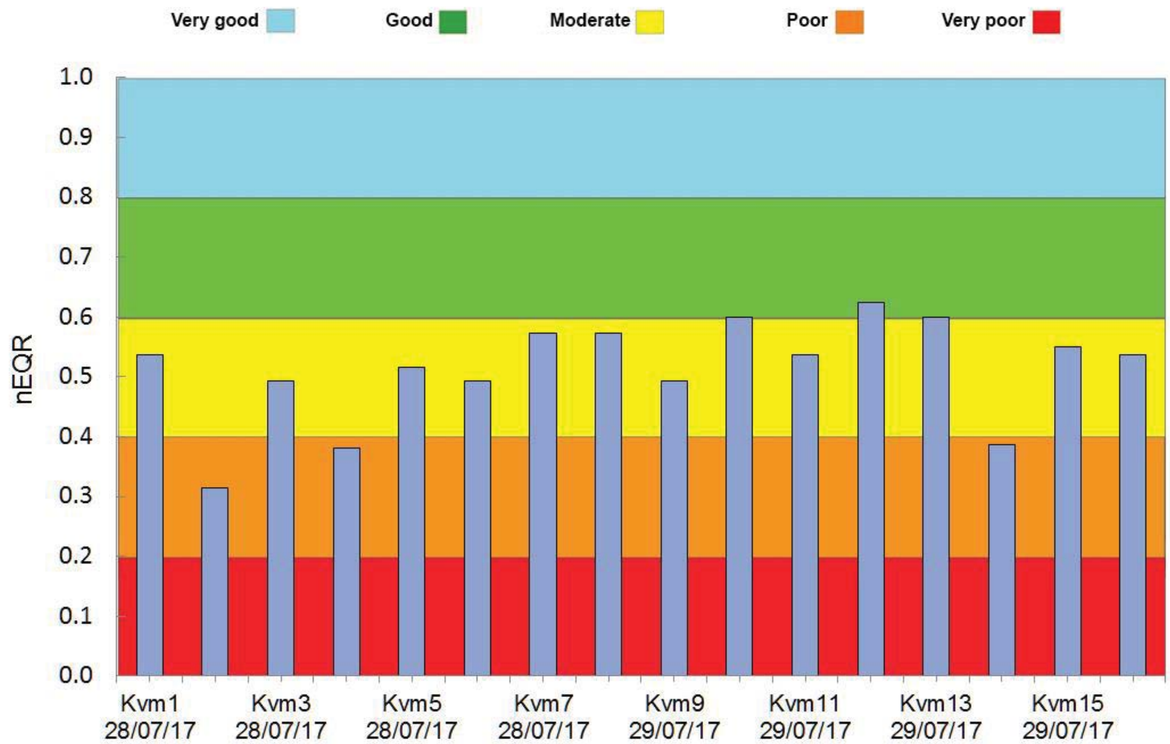


Figure 19. Normalized EQR-scores for the different sampling stations in Kvernmoelva, with color coded ecological condition categories.

Effects of environmental variables on nEQR in Kvernmoelva

In Table 12, there is a slight difference in calculated nEQR means for the two sections of Kvernmoelva. However, from the coefficients of the linear models predicting nEQR from single environmental variables in the entire Kvernmoelva study area, no significant associations with environmental variables were found (Table 13).

Table 13. Interactions between predictors and nEQR in Kvernmoelva.

nEQR as a function of environmental variables				
Coefficients	**Estimate**	**Std. error**	**t value**	**Pr(>|t|)**
Vegetation	0.0006	0.0017	0.3410	0.7403
Substrate	0.0010	0.0006	1.7030	0.1190
Depth	-0.0024	0.0014	-1.6740	0.1252
Velocity	-0.0045	0.0026	-1.7700	0.1072
LWD	0.0394	0.0325	1.2130	0.2531

Exploring this further by looking at benthic macroinvertebrate community composition at each station, did not reveal any interesting differences between station 1-8 (channel) and station 9-16 (natural) (Figure 20).

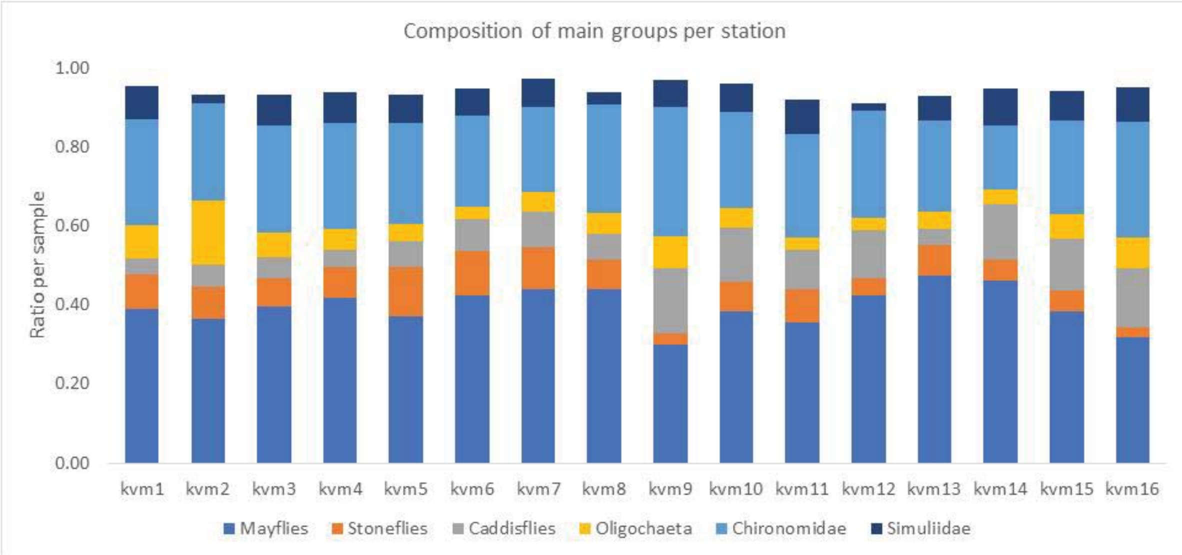


Figure 20. The composition of main groups of benthic macroinvertebrates for each station in Kvernmoelva. Kvm1-kvm8 is in the channelized stretch, and kvm9-kvm16 is in the naturally meandering stretch of the river.

ASPT index in Salangselva

For the stations where benthic macroinvertebrates were sampled in Salangselva, ASPT was calculated for each station, for Budalsfaret and the main channel, and for the river system as a whole. The table below lists both ASPT- and nEQR-values for the Salangselva study area (Table 14).

Table 14. Calculated ASPT- and nEQR-values for Salangselva. For «Section» and «Total», the mean was calculated from associated sampling stations. Station 1 was located in the primary meander Storøra, stations 2-4 were previously sampled stations in Budalsdaret (Strann et al. 2010), and stations 5-11 were located in the main river channel.

Station	ASPT	nEQR
1	6.13	0.63
2	5.75	0.54
3	4.86	0.31
4	5.14	0.39
5	4.83	0.31
6	4.83	0.31
7	5.14	0.39
8	4.83	0.31
9	4.50	0.23
10	5.14	0.39
11	4.83	0.31
Section		
Budalsfaret	5.25	0.41
Main channel	4.87	0.32
Total		
	5.09	0.37

Previous sampling of benthic macroinvertebrates in the Bones area was limited to three stations in Budalsfaret and one station in the Budalselva tributary, sampled only in 2009. In this study, stations 2-4 corresponds to the three stations in Budalsfaret, while stations 5-11 in the main channel were sampled instead of Budalselva. A comparison of the results from 2009 and 2017 is shown below (Table 15).

Table 15. Comparison of calculated ASPT-values for the years 2009 and 2017 in the Bones area of Salangselva. Colors represent the different categories of ecological condition; green: «Good», yellow: «Moderate», orange: «Poor» and red: «Very poor».

Station	2009	2017
Budalsfaret 1	4.0	5.8
Budalsfaret 2	6.1	4.9
Budalsfaret 3	6.7	5.1
Budalselva	6.1	
Main channel		4.9
Budalsfaret mean	5.6	5.25

Taking a closer look at the composition of main groups of benthic macroinvertebrates in the Bones area stations sampled in 2017 (Figure 21), we see a higher ratio of Oligochaetes in stations where the sediment load is high. Station 1 was in the Storøra meander, while stations 2-4 corresponds to «Budalsfaret 1», «Budalsfaret 2» and «Budalsfaret 3» in Table 15 above. An overview of the EPT-diversity found in Salangselva is presented in Appendix E.

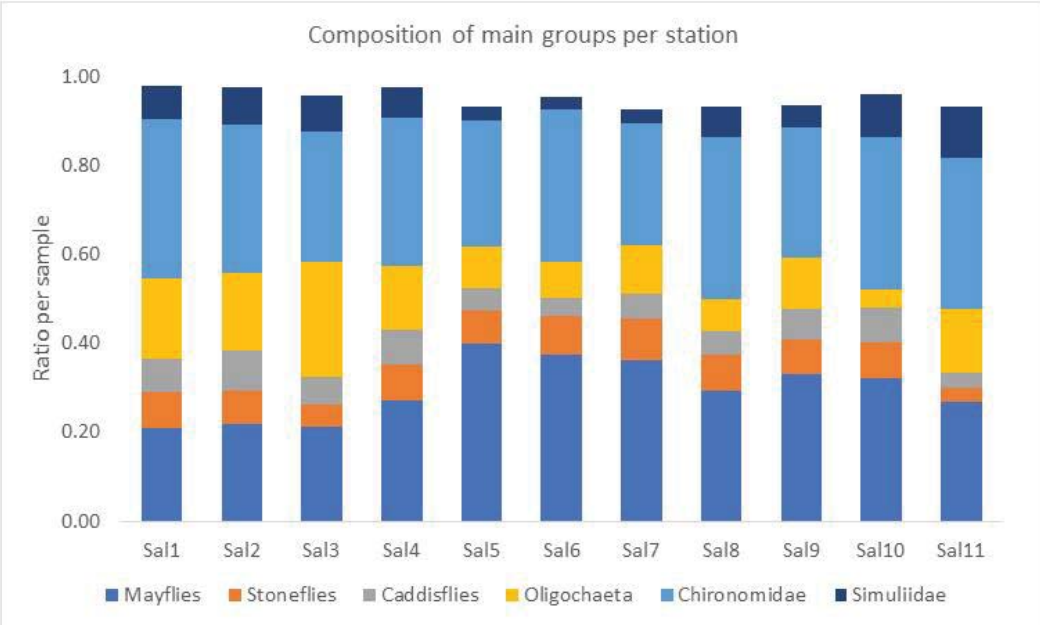


Figure 21. The composition of main groups of benthic macroinvertebrates in the Bones area, 2017.

3.6 Visual observations

Restoration measures at Bones

Due to a high sediment load and low flow, fine sediment settled on the stream bottom in Budalsfaret (Figure 22; Figure 23).

Figure 22. Bottom substrate at station 3 («Budalsfaret 2»). Photograph from 2007: Geir Dahl-Hansen.

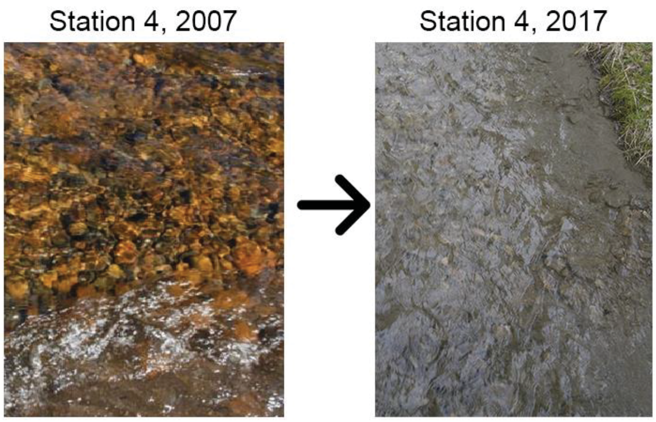


Figure 23. Bottom substrate at station 4 («Budalsfaret 3»). Photograph from 2007: Geir Dahl-Hansen.

Accumulation of sand, gravel and cobble is problematic when intakes are constructed at a 90 degree angle to the main channel. Turbulence leads to accumulation of sand and gravel, and effectively blocks the flow of water (Figure 24; Figure 25).

Figure 24. The intake at Gåsodden, where the intake is constructed at a 90 degree angle to the main channel. Location indicated with a «G», on the map of the Salangselva study area in Appendix C2.

Figure 25. The reopened tributary at Gåsodden, where the intake causes accumulation of sand, gravel and cobble.

The Storøra meander with its high sediment load (Hoseth 2017) also struggles with accumulation of sand at its outlet, primarily due to low flow (Figure 26).

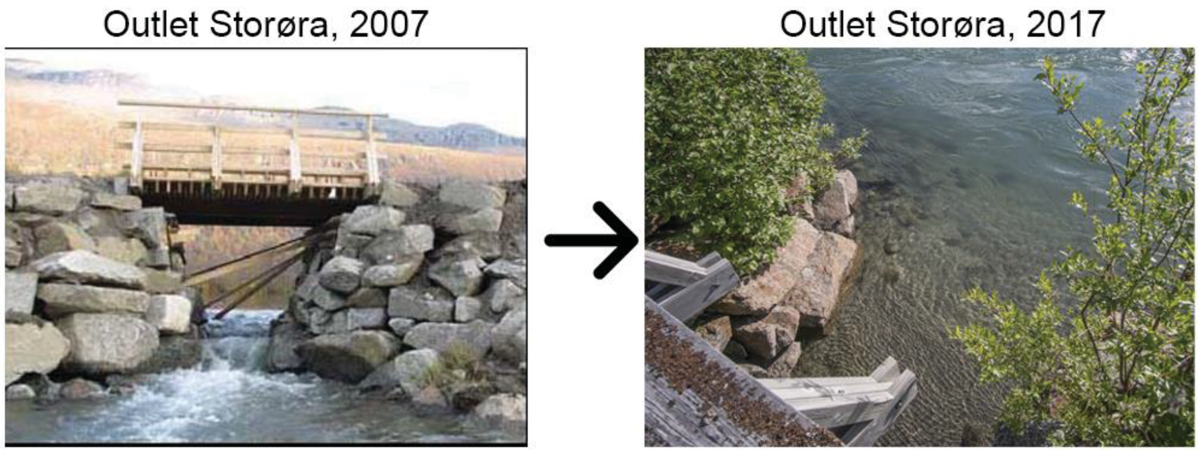


Figure 26. The outlet of Storøra, where sand accumulates due to low flow through the meander and into the main channel. Photograph from 2007: Geir Dahl-Hansen.

Erosion protection structures were removed along the bank at the junction between Budalselva and Stordalselva in order to reduce stream velocity and support natural river processes (Hoseth, K. A. 2017) (Figure 27).

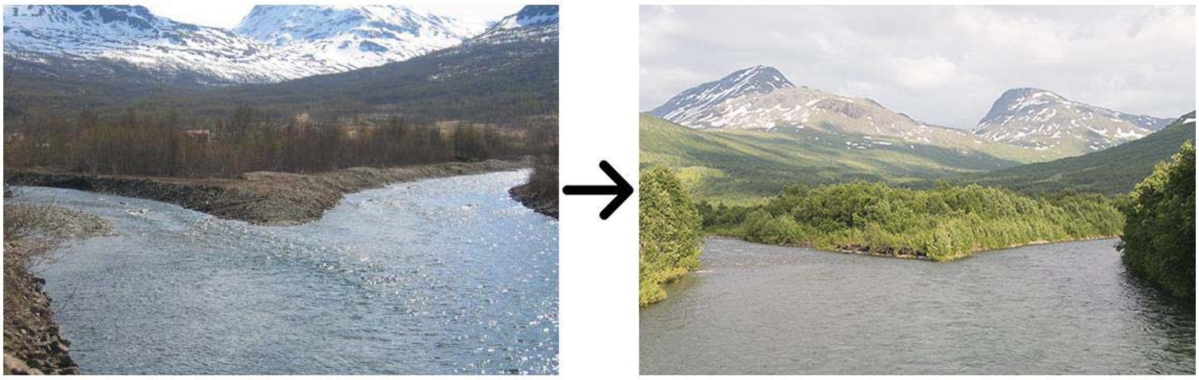


Figure 27. From 2007 (left) (Hoseth, K. A. 2017) just after the removal of erosion protection structures along the bank, and 2017 (right) where vegetation has recolonized – effectively reducing erosion naturally.

Kvernmoelva

During the first period of fieldwork, water levels were fairly high in Kvernmoelva due to the late snowmelt in Troms in 2017. A total of seven ~2lbs brown trout were observed, and only two of them in the channelized stretch of the river (Figure 28). These two brown trout were seen actively feeding (Figure 12) on small mayflies (Baetidae) in the lowermost parts of the channel. When spooked, they both fled downstream to the nearest deep refuge at the beginning of the naturally meandering part of the river. During the second period of fieldwork, water levels were lower. Only two ~2lbs brown trout were observed in the Kvernmoelva study area (Figure 28), both in the naturally meandering stretch of the river.

Figure 28. Observations of ~2lbs brown trout during the first (red dots) and second (bright green dots) period of fieldwork. Bjørnarvatnet to the left (www.norgeskart.no).

4 Discussion

Channelization is known to degrade fluvial ecosystems and adjacent floodplain forest habitat (Brooker 1985; Duvel et al. 1976; Oswalt & King 2005). The increase in water velocity associated with channelization results in stronger erosive forces in the channel. The bottom substrate becomes more unstable and sterile (Kristiansen 2011). It is not only the increased erosive force that cause a more sterile substrate in a channel. The shearing forces of ice during extreme ice breakout events can also be problematic in homogenous channels where dynamic ice breakup tend to occur in the entire channel at the same time, especially within the arctic region where winters are harsh (Weber et al. 2013). However, more research is needed on extreme winter events and its ecological significance.

In the Bones area of Salangselva, restoration measures were implemented during the years 2005-2008. The goal was to increase suitable habitat for benthic invertebrates, fish, birds and floodplain forest. During this study, it became clear that the objectives were not yet met. NVE is aware of this, and have planned corrective maintenance and improvements in the following years. Local landowners are generally positive to the restoration project, and like the idea of being able to practise recreational fishing in the area. However, the landowners interviewed during this study did not paint a picture of the Bones area as ever having been a fantastic fishery, and they wanted to keep flood protection as is. In sum, the restoration project at Bones is a challenging one.

In the following, I will discuss my main findings in relation to the aims of the study.

Cumulative effects of restoration measures implemented in Salangselva.

The first aim of my study was to evaluate the cumulative effects of restoration measures implemented in the Bones area of Salangselva on juvenile brown trout density and length, and benthic macroinvertebrate diversity eight years after ecological monitoring ceased.

No significant change in juvenile brown trout density was observed in either Budalsfaret or the main river channel, compared to sampling data from the years 2007-2009 and 2004-2009, respectively. However, there was a slight but insignificant increase in juvenile brown trout density in the main river channel for the years 2007-2017 compared to the years 2004-2006, possibly indicating that some of the habitat restored in 2005-2008 have been used as spawning grounds and/or nursery habitat. Brown trout populations are also known to fluctuate naturally (Bergan et al. 2011; Daufresne & Renault 2006). Density estimates for the main river channel and the Budalsfaret tributary were low, at 2.9 / 100m² and 1.9 / 100m² respectively, in 2017. During the years 2004-2008, 32-200 fish / year were caught in the lowermost slow flowing pool in the Storøra meander (Strann et al. 2010). Some of these were stocked arctic char. During this study, no fish were caught during electrofishing or observed during visual inspection in Storøra. Low flow and several years with a high rate of sedimentation in the meander were probably to blame. Erosion in a surface drainage channel flowing directly through an agricultural area delivers several thousand cubic metres of silt directly into the Storøra meander (Hoseth 2017).

Interestingly, not a single 0+ brown trout was caught during electrofishing in the Bones study area in the years 2008 and 2017. This could be explained by random chance when the total density of juvenile brown trout is low, a theory supported by the findings of 1+ brown trout in the same area in 2009. Other explanations could be that extreme events such as drought and/or ice in the reopened Budalsfaret tributary and Storøra meander are fatal to 0+ brown trout, or force them to disperse into the main river channel where they are more exposed with less places to hide from spring floods, predators such as mink, birds and larger fish, and a possibly fatal ice breakout.

No improvement of ecological condition in Budalsfaret was found when comparing calculated ASPT-values from 2009 with the ASPT-values from the same sampling stations in 2017. Analysing benthic macroinvertebrate diversity from sampling done in 2017, ecological condition was found to have deteriorated. In the report by Strann et al. (2010), sampling station 1 in Budalselva was characterized by having a fine bottom substrate and low diversity of indicator taxa resulting in the ecological condition «Very poor». Observational data from this study documented with photographs reveals a change in the bottom substrate for the other two sampling stations in Budalsfaret. Silt had covered most of the substrate visible on photographs from 2007. Sedimentation of fine particles degrades interstitial space habitat important to benthic macroinvertebrates (Gayraud & Philippe 2003; Harrison et al. 2007), and may cause anoxic conditions in the bottom substrate (Massa et al. 2000). This would explain the negative trend in ecological condition in Budalsfaret. No previous sampling of benthic macroinvertebrates has been conducted in the main river channel.

The restoration measures implemented in the Bones area have increased usable habitat and habitat heterogeneity for juvenile brown trout and benthic macroinvertebrates, particularly through the reopening of the tributary Budalsfaret and the restoration of the Storøra meander. In addition; a new culvert construction (Appendix B) increased the flow of water in a small sidelet at Gåsodden, a second meander was restored, and flood protecting structures have been removed in certain areas. Groups of stone have been placed in the main river channel to improve physical heterogeneity and reduce water velocity. However, there are problems that need to be adressed before the aforementioned restoration measures can reach optimal function and the objectives of the restoration project can be met.

The effects on juvenile brown trout density and benthic macroinvertebrate diversity of adding boulder groups in a channel, are subject to debate. Palmer et al. (2010) conducted an extensive review of habitat and benthic macroinvertebrate data from 78 independent restoration projects from all over the world, examining benthic macroinvertebrate diversity in relation to increased habitat heterogeneity in channelized rivers. Only two of the 78 restoration projects showed a significant increase in macroinvertebrate diversity. This finding is also supported by Lepori et al. (2005) and Pretty et al. (2003) that indicate that increasing physical habitat heterogeneity did not increase fish or invertebrate diversity in a number of restored European rivers. Palmer et al. (2010) suggests that increasing physical heterogeneity in a channelized stretch of a river should not be the driving force when planning a restoration approach for most rivers. In Salangselva, the addition of stone groups in the main river channel could perhaps act as barriers mitigating the ecological impact of extreme ice breakout events.

Juvenile brown trout density and length, and benthic macroinvertebrate diversity in two stretches of Kvernmoelva.

The second aim of this study was to compare juvenile brown trout density and length, and benthic macroinvertebrate diversity from a channelized stretch of Kvernmoelva with the corresponding data from a naturally meandering stretch of the river to assess the effects of channelization.

The distribution of age groups of juvenile brown trout differed between the channelized stretch and the naturally meandering stretch of Kvernmoelva. 0+ mean density was higher in the channelized stretch, while density of 1+ and >1+ were higher in the naturally meandering stretch. Mean density combined for all age groups was higher in the naturally meandering stretch (18.6 per 100 m^2), than in the channelized stretch (12.4 per 100 m^2).

The variable depth was the only significant environmental variable explaining the occurrence of both age classes 0+ ($p=0.03$) and 1+ ($p=0.01$) in this study. The positive coefficient estimate for the variable depth in the most supported model explaining 1+ occurrence indicate a preference for deeper areas, and the negative coefficient estimate for the variable depth in the most supported model explaining 0+ occurrence indicates a preference for shallower areas. This is consistent with findings from Heggenes et al. (1999) and Bremset & Berg (1999). Heggenes et al. (1999) also states that the size-structured habitat use among juvenile brown trout appear to be a result of intraspecific competition, and that small trout parr (<7cm) are abundant in shallow swift water with cobble substrate, while larger trout show increasingly strong preferences for deeper water such as pools.

Larger fish (~2lbs) were observed in the naturally meandering part of Kvernmoelva (Figure 29). Seven during the first period of fieldwork (25-31 Jul.), and only two during the last period of fieldwork (25 Aug. – 5 Sept.). Only two of the larger trout were observed in the channelized stretch of Kvernmoelva. Their location in the lowermost part of the channel at the time of observation can possibly be explained by the high concentration of food during a hatch of the mayfly A.*Inopinatus*. Both fled downstream when spooked, to the nearest deep refuge in the naturally meandering part of the river. From my visual observations and previous knowledge on brown trout behaviour, I suggest that larger brown trout from Bjørnarvatnet migrate in and out of the river Kvernmoelva, using it as feeding grounds during early summer and spawning grounds in the autumn.

Figure 29. Larger brown trout (~2lbs) observed in the naturally meandering stretch of Kvernmoelva.

Most juvenile brown trout caught and registered in the Kvernmoelva study area were associated with hiding places under or between cobble and boulders. The registered bottom substrate at each station was the dominating grain size, thus the low power of the variable substrate in the statistical analysis might be misleading. Scattered cobble and boulders were more numerous in the naturally meandering part of the river than in the channel (Figure 30). In addition, fine-scale variation of the variables LWD and water velocity might have been lost during the registration of means within each station. Observations indicate that there were indeed more coarse organic material, boulders, and variations in water velocity both horizontally and vertically in the naturally meandering stretch of the river compared to the channelized stretch of the river – as would be expected.

Figure 30. Scattered boulders clearly visible in a pool in the naturally meandering stretch of Kvernmoelva (left) where sand is the dominating bottom substrate grain size, and homogenous gravel bottom substrate in the channelized stretch of Kvernmoelva (right).

For benthic macroinvertebrate diversity and community composition, no significant differences between the two stretches and no significant interactions with environmental variables were found. However, when charting community composition of the main benthic macroinvertebrate taxa based on taxa ratio per sampling station, it seems that Trichopterans are more dominating in the naturally meandering stretch of the river. Due to the higher microhabitat diversity and more coarse organic material present, it was to be expected to find more benthic macroinvertebrates from the functional feeding group shredders, such as Limnephilids, in the natural stretch.

Communities of Ephemeroptera, Plecoptera and Trichoptera (mayflies, stoneflies and caddisflies, EPT) are widely used and analysed in evaluation of water quality in rivers. Species from these taxa tend to have low tolerances for the presence of pollutants in their environment, and thus, they are very useful bio-indicators (Hamid & Rawi 2017). An overview of the EPT-diversity found in Kvernmoelva is presented in Appendix E. EPT-diversity did not differ significantly between the two stretches, but with a slightly more positive result in the naturally meandering stretch of the river compared to the channel. Due to differences in physical characteristics of the two stretches, one should expect to see more variation in community composition between station 1-8 and 9-16 if there was a significant effect of registered environmental variables on nEQR in the study area.

A higher microhabitat diversity was found to be positive in an evaluation of 19 restoration projects throughout Europe by Verdonschot et al. (2015). The low statistical power in the analysis of benthic macroinvertebrate data in Kvernmoelva might suggest that variables other than those related to channelization evaluated in this thesis are limiting macroinvertebrate diversity in the Kvernmoelva study area. Well defined reference conditions for this river type in this part of Norway would have provided useful insight.

The differences in juvenile brown trout densities in Kvernmoelva, and the different age class habitat preferences indicate an importance of physical heterogeneity in juvenile brown trout habitat. In particular, natural pool-riffle sequences are found to be beneficial (Heggenes et al. 1993; Bremset & Berg 1997). Structures such as boulders can also mitigate the pressure from intraspecific competition among salmonids, due to limiting the line of sight and increasing physical microhabitat in a stream (Maki-Petäys et al. 1997; Jonsson & Jonsson 2011). A lack of physical heterogeneity and variation in water velocity and depth is associated with channelization and widely recognized as having detrimental effects on river fauna (Brooker 1985; Duvel Jr. et al. 1976; Kristiansen 2011).

Environmental variables affecting juvenile brown trout density and benthic macroinvertebrate diversity in the Bones area.

The third aim of this study was to evaluate the different environmental variables that affect benthic macroinvertebrate diversity and juvenile brown trout density in the Bones area, to indicate challenges with – and potential returns from further restoration work in the area.

Juvenile brown trout densities were too low per sampling station to conduct a meaningful model selection procedure, with an average estimated density of juvenile brown trout per 100 m² of; 2.9, 1.9, 0, 3.3 and 1, for the areas «main river channel», «Budalsfaret», «Storøra», «Budalselva» and «Stordalselva» respectively (excluding one station downstream of the channelized stretch of the main river). However, all of the juvenile brown trout caught and registered were associated with boulders providing hiding places. The bottom substrate dominating grain size were mostly gravel in the entire study area, thus the registered environmental variable «substrate» did not reflect the presence of scattered boulders or boulders lining the bank as erosion protection. Gravel as the dominating bottom substrate might limit the juvenile brown trout density, and the lack of hiding places could expose fish to predation from birds and mink.

Benthic macroinvertebrate diversity, community composition and EPT-diversity showed very little variation among stations in the study area. The sedimentation of silt in Budalsfaret may explain the slightly higher ratio of Oligochaetes found here, compared to the community composition in the main river channel. Although present, very low numbers of high ranking indicator taxa were found in the entire study area.

Regarding Budalsfaret and the Storøra meander, the high rate of silt sedimentation and periodically low flow conditions appear to be detrimental to these areas as both juvenile brown trout and benthic macroinvertebrate habitat. The bottom substrate in the tributaries Budalselva and Stordalselva appeared unstable and sterile, much like the substrate in the main river channel. Due to local farmers worrying about a destructive spring flood in 2017, much of the intake of water from Budalselva into the Budalsfaret tributary were blocked by a truckload of boulders (Granheim, T. J. 2017, The Norwegian Water Resources and Energy Directorate (NVE), pers. commun.), from June through the entire study period (Figure 31). This might have caused juvenile brown trout to disperse away from the Budalsfaret tributary and the Storøra meander due to low flow, prior to sampling being conducted.

Figure 31. Boulders blocking the intake to Budalsfaret, due to fear of a destructive flood.

In sum, the conditions and thus results were less than ideal for later analysis of the effects of registered environmental variables on juvenile brown trout density and benthic macroinvertebrate diversity through model selection methods. However, there are some obvious limiting factors regarding juvenile brown trout density and macroinvertebrate diversity in the Storøra meander and the tributary Budalsfaret. A certain minimum flow needs to be ensured through the reconstruction of intakes, as this will reduce sedimentation of fine particles (Allan & Castillo 2009) and increase usable habitat for both juvenile brown trout and benthic macroinvertebrates during periods of drought. During the study period, the Storøra meander with its near blocked outlet functioned much like a dam, trapping sediments and effectively starving the main channel from nutrition carried by fine particles at the same time (Kondolf et al. 2014). In addition, the erosion in the artificial channel delivering silt to the Storøra meander needs to be addressed to avoid the need for regular sediment removal (Granheim, T. J. 2017, The Norwegian Water Resources and Energy Directorate (NVE), pers. commun.).

Some of the restoration measures in the Bones area were damaged during a big flood in 2012 (Hoseth 2016). At the time of writing, there are well documented issues negatively affecting juvenile brown trout density and benthic macroinvertebrate diversity in the area, and NVE have plans to do corrective maintenance and improvements to restoration measures previously implemented in order to meet the original objectives (Hoseth 2016).

It is important to have concrete and realistic goals for any restoration process, and use reference conditions as guidance when determining appropriate ecological goals and expectations (SER 2004). In combination with documentation of ecological conditions prior to anthropogenic impact, one can estimate the potential in restoring a lotic ecosystem.

Evaluation of the recovery processes in Salangselva, in light of the stated goals and desired outcome of the restoration project.

The fourth and final primary aim of this study was to evaluate the recovery processes in Salangselva, using juvenile brown trout and benthic macroinvertebrates as bio-indicators. I also evaluated whether the recovery processes are reflecting the goals and desired outcome of restoration measures implemented in the years 2005-2008.

Reviews on the outcome of river restoration projects show mixed results, and as already mentioned Palmer et al. (2010) show that only two of 78 evaluated studies found a statistically significant increase in biodiversity after increasing structural heterogeneity in a stretch of river. Palmer & Bernhardt (2011) states that river restoration through river engineering, neglecting the importance of catchment processes, is like working «at the wrong end of the pipe», and suggests that the approach to river restoration should focus more on the retention of nutrients, contaminants and storm waters in the catchment. Haase et al. (2013) further supports this by suggesting that stressors other than hydromorphological degradation still affects the biota in restored stretches of rivers, after showing that only one of 24 river restoration projects in Germany resulted in the restored section achieving «good ecological status» as defined in Annex V of the Water Framework Directive (WFD 2000/60/EC 2000).

In this study, eight years after ecological monitoring ceased in the Bones area, no significant improvement of juvenile brown trout density or benthic macroinvertebrate diversity was found, as previously discussed. Thus, the recovery processes do not reflect the goals and desired outcome of the restoration project – yet. The plan ahead is for NVE to make use of experiences acquired during the past eight years, and do corrective maintenance and improvements in the years following 2017. The following improvements and adjustments are listed in «*Tiltaksplan, Salangsdalselva ved Håkstad – Bones, vedlikehold*» (Hoseth 2016).

The artificial channel draining an adjacent agricultural area will be erosion secured further to reduce sedimentation load entering the Storøra meander. Sand and cobble blocking inlets and outlets from tributaries and meanders will be removed. The inlet from Budalselva to Budalsfaret still cause flooding of agricultural land during spring flood conditions, a problem further amplified by trees growing in the Budalsfaret river channel. To mitigate this issue, trees in Budalsfaret will be removed, and the inlet needs to be adjusted. As a suggestion, the inlet could be constructed narrower and taller/deeper to ensure a more stable discharge in Budalsfaret year round. The culvert intake at Gåsodden does not work (Figure 24 and Figure 25), and the plan is to move it further upstream. I would suggest constructing the intake at an acute angle to the current rather than the previously used 90 degree angle. This could reduce the problem of turbulence leading to accumulation of sand, gravel and cobble blocking the intake, but flood risk needs to be taken into account. In sum, these improvements will further increase the usable habitat for juvenile brown trout and benthic macroinvertebrates, while possibly also increase the quality of the usable habitat in the Storøra meander and Budalsfaret.

Potential sources of error

An obvious problem with the registration of environmental variables in this study is the lack of fine-scale evaluation of the habitat at each station. Due to the variables being means of several different points within each station, detailed and important information on microhabitat is lost. The kick-sampling method did not function optimally in areas with low water velocity, and might lead to an underestimation of benthic macroinvertebrates present. This is especially relevant for the naturally meandering stretch of Kvernmoelva. Small sample sizes due to limited data available from previous years and limited work capacity for one person during fieldwork in 2017 contributes to low statistical power. Hence, it is difficult to distinguish effects occurring by random chance from ecologically significant effects. A higher number of observations typically result in a higher statistical power (Whitlock & Schluter 2009).

In Kvernmoelva, two different methods of density estimation were used for the two different stretches of the river due to differences in juvenile brown trout density. This is obviously a potential source of error, and the three-pass removal technique employed in the naturally meandering stretch of the river are known to give uncertain estimates if densities are relatively low and the catch probability is low (Forseth & Forsgren 2008).

Finally, the truckload of boulders dumped in June, partly blocking the flow of water into the tributary Budalsfaret in the Bones study area might have caused juvenile brown trout to migrate away from Budalsfaret and the Storøra meander prior to sampling in 2017. Benthic macroinvertebrates are less mobile, thus I assume the low flow to have had less of an impact on the macroinvertebrate sampling than on the electrofishing.

5 Conclusions

Following my first aim, no significant increase in juvenile brown trout density was found in this study. However, a slight but insignificant increase in juvenile brown trout density in the main river channel in the years immediately following the restoration project could perhaps indicate that some of the habitat restored in 2005-2008 have been used as spawning grounds and/or nursery habitat. No improvement of ecological condition in Budalsfaret with benthic macroinvertebrates used as bio-indicator was found when comparing calculated ASPT-values from 2009 with the ASPT-values from the same sampling stations in 2017. Calculated nEQR-scores from sampling done in 2017 showed that ecological condition were poor or very poor in the entire Bones study area. EPT-diversity was still low.

For my second aim, 0+ brown trout preferred the shallow channel, while 1+ brown trout preferred the more heterogenous and deeper naturally meandering stretch of the river. Depth was the only predictor variable significant in explaining the occurrence of both 0+ and 1+ brown trout. No significant differences in benthic macroinvertebrate diversity was found between the two stretches, however a slightly higher ratio of shredders (Trichopterans) and a slightly higher total density of macroinvertebrates were noted in the naturally meandering stretch of the river.

For the third aim, densities of juvenile brown trout were too low to conduct a meaningful model selection procedure. However, all juvenile brown trout caught and registered were associated with boulders lining the bank providing hiding places, indicating that the dominating gravel substrate and lack of hiding places is limiting juvenile brown trout diversity and exposing fish to predation from birds and mink. Sterile bottom substrate in the main channel and sedimentation of silt in Budalsfaret and Storøra appear to be the main variables limiting the benthic macroinvertebrate density and diversity in the area.

The final fourth aim of my study supported no significant improvement of juvenile brown trout density or benthic macroinvertebrate diversity. Thus, the recovery processes does not reflect the goals and desired outcome of the restoration project. NVE plans to address this in the years to come.

The restoration project at Bones is a challenging one, and an important learning process regarding restoration work within the arctic region. Regular future monitoring and evaluation is important in order to add new information to the existing knowledge base (Nilsson et al. 2016). Well documented ecological effects of a restoration project of this magnitude will be of great value to future projects. Verdonschot et al. (2013) states that restoration ecology is a site, time and organism group-specific activity, and that it therefore is difficult to generalise.

References

Adeloye, A. J. (2003). Fresh Surface Water, Vol. III. *Encyclopedia of Life Support Systems (EOLSS)*. Paris: Eolss Publishers. pp. 117-138.

Allan, J. D. & Castillo, M. M. (2009). *Stream Ecology: Structure and Function of Running Waters*. 2nd ed. Netherlands: Springer, p. 44.

Bergan, M. A., Nøst, T. H. & Berger, H. M. (2011). Laksefisk som indikator på økologisk tilstand og miljøkvalitet i lavereliggende småelver og bekker: Forslag til metodikk iht. vanndirektivet, 2011:6224. Trondheim: Norwegian Institute for Water Research. 55 pp.

BIOKLASS (2006). Klassifisering av økologisk status i norske vannforekomster – elver. Forslag til bunndyrindeks for definisjon av Vanndirektivets fem nivåer for økologisk status. NINA report 113, 22 pp.

Bohlin, T., Heggberget, T. G., Rasmussen, G. H. & Saltveit, S. J. (1989). Electrofishing – Theory and Practice with Special Emphasis on Salmonids. *Hydrobiologia*, 173(1), pp. 9-43.

Bremset, G. & Berg, O. K. (1999). Three-dimensional microhabitat use by young pooldwelling Atlantic salmon and brown trout. *Animal Behaviour*, 58 (5), pp. 1047-1059.

Bremset, G. & Berg, O. K. (1997). Density, size-at-age, and distribution of young Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) in deep river pools. *Canadian Journal of Fisheries and Aquatic Sciences,* 54(12), pp. 2827-2836.

Brooker, M. P. (1985). The Ecological Effects of Channelization. *The Geographical Journal*, 151(1), pp. 63-69

Burnham, K. P. & Anderson, D. R. (1998). Model selection and multimodel inference : a practical information-theoretic approach. New York: Springer. pp. 323-333.

Daufresne, M. & Renault, O. (2006). Population Fluctuations, Regulation and Limitation in Stream-living Brown Trout. *Oikos*, 113(3), pp. 459-468.

Direktoratsgruppa for gjennomføring av vanndirektivet 2009. Veileder 01:2009. Klassifisering av miljøtilstand i vann. Økologisk og kjemisk klassifiseringssystem for kystvann, grunnvann, innsjøer og elver. ISSN: 1891-4586.

Direktoratsgruppa for gjennomføring av vanndirektivet 2013. Veileder 02:2013. Klassifisering av miljøtilstand i vann. Økologisk og kjemisk klassifiseringssystem for kystvann, grunnvann, innsjøer og elver. 230 pp.

Duvel Jr., W. A., Volkmar, R. D., Specht, W. L. & Johnson, F. W. (1976). Environmental Impact of Stream Channelization. *Journal of the American Water Resources Association*, 12(4), pp. 799-812.

ec.europa.eu. (2016). WFD: Timetable for implementation. European Commision's official website. [Online] Available at: http://ec.europa.eu/environment/water/water-framework/info/timetable_en.htm [Accessed 24 Apr. 2018].

Feld, C. K., Birk, S., Bradley, D. C., Hering, D., Kail, J., Marzin, A., Melcher, A., Nemitz, D.,Pedersen, M. L. & Pletterbauer, F. (2011). From natural to degraded rivers and back again: A test of restoration ecology theory and practice. *Advances in Ecological Research*, Vol. 44. pp. 119-209.

Fierro, P., Valdovinos, C., Vargas-Chacoff, L., Bertrán, C., & Arismendi, I. (2017). Macroinvertebrates and Fishes as Bioindicators of Stream Water Pollution. In: H. Tutu, 1st ed., IntechOpen. [Online] Available at: https://www.intechopen.com/books/water-quality/macroinvertebrates-and-fishes-as-bioindicators-of-stream-water-pollution [Accessed 24 Apr. 2018]

Forseth, T. & Forsgren, E. (Eds.) 2008. El-fiskemetodikk – Gamle problemer og nye utfordringer. - NINA Rapport 488. 74 pp.

Gauthey, Z., Lang, M., Elosegi, A., Tentelier, C., Rives, J. & Labonne, J. (2015). Brown trout spawning habitat selection and its effect on egg survival. *Ecology of Freshwater Fish*, 26(1), pp. 133-140.

Gayraud, S. & Philippe, M. (2003), Influence of Bed-Sediment Features on the Interstitial Habitat Available for Macroinvertebrates in 15 French Streams. *International Review of Hydrobiology*, 88(1), pp. 77-93.

geo.ngu.no, (2018). *Berggrunn - Nasjonal Berggrunnsdatabase.* [Online] Available at: http://geo.ngu.no/kart/berggrunn/ [Accessed 25 Apr. 2018]

Haase, P., Hering, D., Jähnig, S. D., Lorenz, A. W., & Sundermann, A. (2013). The impact of hydromorphological restoration on river ecological status: a comparison of fish, benthic invertebrates, and macrophytes. *Hydrobiologia*, 704(1), pp. 475-488.

Hagen, D. & Skrindo, A. B. (Eds.). (2010). Restoration of nature in Norway – a glimpse into the tematic field, professional institutions and ongoing activity. NINA Temahefte 42. 109 pp.

Hamid, S. A. & Rawi, C. S. M. (2017). Application of Aquatic Insects (Ephemeroptera, Plecoptera And Trichoptera) In Water Quality Assessment of Malaysian Headwater. *Tropical Life Sciences Research,* 28(2), pp. 143-162.

Harrison, E. T., Norris, R. H. & Wilkinson, S. N. (2007). The impact of fine sediment accumulation on benthic macroinvertebrates: implications for river management. *Proceedings of the 5th Australian Stream Management Conference.*

Heggenes, J., Baglinière, J. L. & Cunjak, R. A. (1999). Spatial niche variability for young Atlantic salmon (*Salmo salar*) and brown trout (*S. trutta*) in heterogenous streams. *Ecology of Freshwater Fish*, 8(1), pp. 1-21.

Heggenes, J., Krog, O. M. W., Lindås, O. R., Dokk, J. G. & Bremnes, T. (1993). Homeostatic behavioural responses in a changing environment: brown trout (*salmo trutta*) become nocturnal during winter. *Journal of Animal Ecology*, 62, pp. 295-308.

Hoseth, K. A. (2016). Tiltaksplan, Salangsdalselva ved Håkstad – Bones, vedlikehold. *NVE Region Nord*. 27 pp.

Hoseth, K. A. (2017). Restoration of the Salangselva River, Bones. 46 pp.

Jähnig, S. C., Lorenz, A. W., Hering, D., Antons, C., Sundermann, A., Jedicke, E. & Haase, P. (2011). River restoration success: a question of perception. *Ecological Applications*, 21(6), pp. 2007-2015.

Johansson, U. (2013). *Stream channelization effects on fish abundance and species composition.* Master thesis. Linköpings Universitet, Department of Physics, Chemistry and Biology. 22 pp.

Jonsson, B. & Jonsson, N. (2011). *Ecology of Atlantic salmon and brown trout. Habitat as a template for life histories*. The Netherlands: Springer. 708 pp.

Kondolf, G. M., Gao, Y., Annandale, G. W., Morris, G. L., Jiang, E., Zhang, J., Cao, Y., Carling, P., Fu, K., Guo, Q., Hotchkiss, R., Peteuil, C., Sumi, T., Wang, H-W., Wang, Z., Wei, Z., Wu, B., Wu, C. and Yang, C. T. (2014). Sustainable sediment management in reservoirs and regulated rivers: Experiences from five continents. *Earth's Future,* 2(5), pp. 256-280.

Kristiansen, G. (2011). Miljøtiltak i vassdrag med erfaringer fra Nord-Norge. *Vann*, 46 (2), pp. 192-201.

Landy, M. (1979*). Environmental Impact Statement Glossary: A Reference Source for EIS Writers*, *Reviewers, and Citizens*. New York, London: IFI/Plenum.

Louhi, P., Mäki-Petäys, A. & Erkinaro, J. (2008). Spawning habitat of Atlantic Salmon and brown trout: General criteria and intragravel factors. *River Research and Applications*, 24(3), pp. 330 - 339.

Maki-Petäys, A., Muotka, T., Huusko, A., Tikkanen, P. & Kreivi, P. (1997). Seasonal change in habitat use and preference by juvenile brown trout, *Salmo trutta*, in a northern boreal river. *Canadian Journal of Fisheries and Aquatic Sciences,* 54(3), pp. 520-530.

Massa, F., Baglinière, J-L., Prunet, P. & Grimaldi, C. (2000). Egg-to-fry survival of brown trout (Salmo trutta) and chemical environment in the redd. *Cybium: international journal on ichtyology*, 24, pp. 129-140.

Nilsson, C., Aradottir, A. L., Hagen, D., Halldórsson, G., Høegh, K., Mitchell, R. J., Raulund-Rasmussen, K., Svavarsdóttir, K., Tolvanen, A., & Wilson S. D. (2016). Evaluating the process of ecological restoration. *Ecology and Society,* 21(1), p. 41.

Nordhov, P-F. R. & Paulsen, S. M. (2016). *River Restoration in Bognelv, Northern Norway – Salmonid and Macroinvertebrate Responses to Restoration Measures.*Norwegian University of Life Sciences, Department of Ecology and Natural Resource Management.

nve.no, (2016). Vanndirektivet/Vannforskriften. [Online] Available at: https://www.nve.no/vann-vassdrag-og-miljo/vanndirektivet-vannforskriften/ [Accessed 24 Apr. 2018].

nve.no, (2018). 191/4 Salangselva. [Online] Available at: https://www.nve.no/vann-vassdrag-og-miljo/verneplan-for-vassdrag/troms/191-4-salangselva/ [Accessed 25 Apr. 2018]

nve.no, (2018). NVE Nedbørfelt (REGINE). [Online] Available at: https://gis3.nve.no/link/?link=nedborfelt [Accessed 27 Apr. 2018]

Oswalt, S. N. & King, S. L. (2005). Channelization and Floodplain Forests: Impacts of accelerated sedimentation and valley plug formation on floodplain forests of the Middle Fork Forked Deer River, Tennessee, USA. *Forest Ecology and Management*, 215(1-3), pp. 69-83.

Palmer, M. A., Bernhardt, E. S., Allan, J. D., Lake, P. S., Alexander, G., Brooks, S., Carr, J., Clayton, S., Dahm, C. N., Follstad Shah, J., Galat, D. L., Loss, S. G., Goodwin, P., Hart, D. D., Hassett, B., Jenkinson, R., Kondolf, G. M., Lave, R., Meyer, J. L., O'Donnell, T. K., Pagano, L. & Sudduth, E. (2005). Standard for ecologically successful river restoration. Journal of Applied Ecology, 42(2), pp. 208-217.

Palmer, M. A., Menninger, H. L. & Bernhardt, E. L. (2010). River restoration, habitat heterogeneity and biodiversity: a failure of theory or practice? *Freshwater Biology,* 55(1), pp. 205-222.

Preston, S. H. (1996). The effect of population growth on environmental quality. *Population Research and Policy Review*, 15(2), pp. 95-108.

Rikardsen, A., Strann, K. B. & Dahl-Hansen, G. (2004). Foreløpig framdriftsrapport for 2004: Økologiske konsekvenser av restaurering av elveforbygninger og avsnørte meandre. Tromsø: NINA, Akvaplan-NIVA, NVE. 11 pp.

Rundle, S. & Malmquist, B. (2002). Threats to the Running Water Ecosystems of the World. *Environmental Conservation*, 29(2), pp. 134-153.

Schedel, J. B. (2010). *River Restoration and Habitat Improvements in the Sub-arctic River Bognelva: Effects on Anadromous Fish.* Master thesis. Norwegian University of Life Sciences, Department of Nature Conservation.

Seber, G. A. F. (1973). *The Estimation of Animal Abundance and Related Parameters.* London: Charles Griffin. 506 pp.

SER. (2004). The SER International Primer on Ecological Restoration, version 2. *Society for Ecological Restoration International Science & Policy Working Group*.

Shankman, D., Samson, S. (1991). Channelization effects on Obion River flooding, Western Tennessee. *Journal of the American Water Resources Association*, 27(2), pp. 247-254.

Slingenberg, A., Braat, L., Windt, H., Rademaekers, K., Eichler, L. & Turner, K. (2009). *Study on understanding the causes of biodiversity loss and the policy assessment framework*. European Commission – Directorate-General for Environment, Report.

Sødal, K. M. (2014). *Salmonid and Macroinvertebrate Responses to River Restoration Measures in the Channelized River Bognelv, Northern Norway.* Master thesis. Norwegian University of Life Sciences, Department of Ecology and Natural Resource Management.

ssb.no. (2018). Statistics Norway's official website. [Online] Available at: https://www.ssb.no/statbank/table/08991/tableViewLayout1/?rxid=91effa90-03ca-41e9-b06e-6df82d6efa78 [Accessed 24 Apr. 2018]

Strann, K.-B., Rikardsen, A., Bjerke, J.W. & Dahl-Hansen, G. (2010). Økologiske konsekvenser av restaurering av elveforbygninger og avsnørte meandre ved Bones, Salangselva. Sluttrapport 2003-2009. NINA Report 575. 40 pp.

Valiente, A. G., Juanes, F., Nuñes, P. & Garcia-Vazques, E. (2010). Brown trout (Salmo trutta) invasiveness: plasticity in life-history is more important than genetic variability. *Biological Invasions*, 12(3), pp. 451-462.

Vannforskriften. (2006). *Forskrift om rammer for vannforvaltningen*.

Verdonschot, P. F. M., Spears, B. M., Feld, C. K., Brucet, S., Keizer-Vlek, H., Borja, A., Elliott, M., Kernan, M. & Johnson, R. K. (2013). A comparative review of recovery processes in rivers, lakes, estuarine and coastal waters. *Hydrobiologia*, 704(1), pp. 453-474.

Verdonschot, R. C. M., Kail, J., Mckie, B. G. & Verdonschot, P. F. M. (2015). The role of benthic microhabitats in determining the effects of hydromorphological river restoration on macroinvertebrates. *Hydrobiologia,* 769(1), pp. 55-66.

Weber, C., Nilsson, C., Lind, L., Alfredsen, K. T. & Polvi, L. E. (2013). Winter Disturbances and Riverine Fish in Temperate and Cold Regions. *BioScience*, 63(3), pp. 199-210.

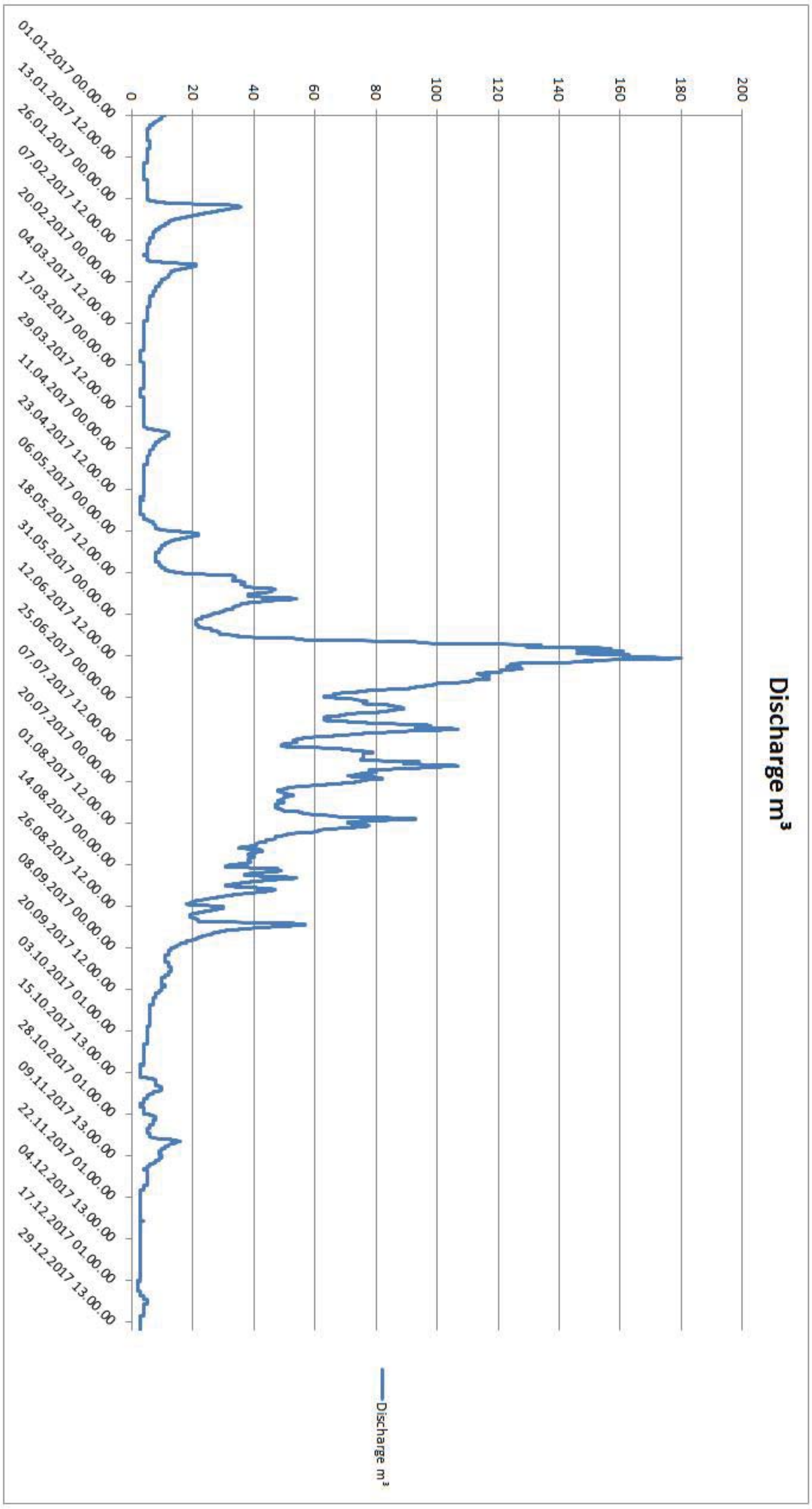
WFD 2000/60/EC. (2000). *Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy.*

Whitlock, M. C. & Schluter, D. (2009). *The Analysis of Biological Data*. Colorado: Roberts and Company Publishers. p. 138.

Zippin, C. (1958). The removal method of population estimation. *The Journal of Wildlife Management*, 22 (1), pp. 82-90.

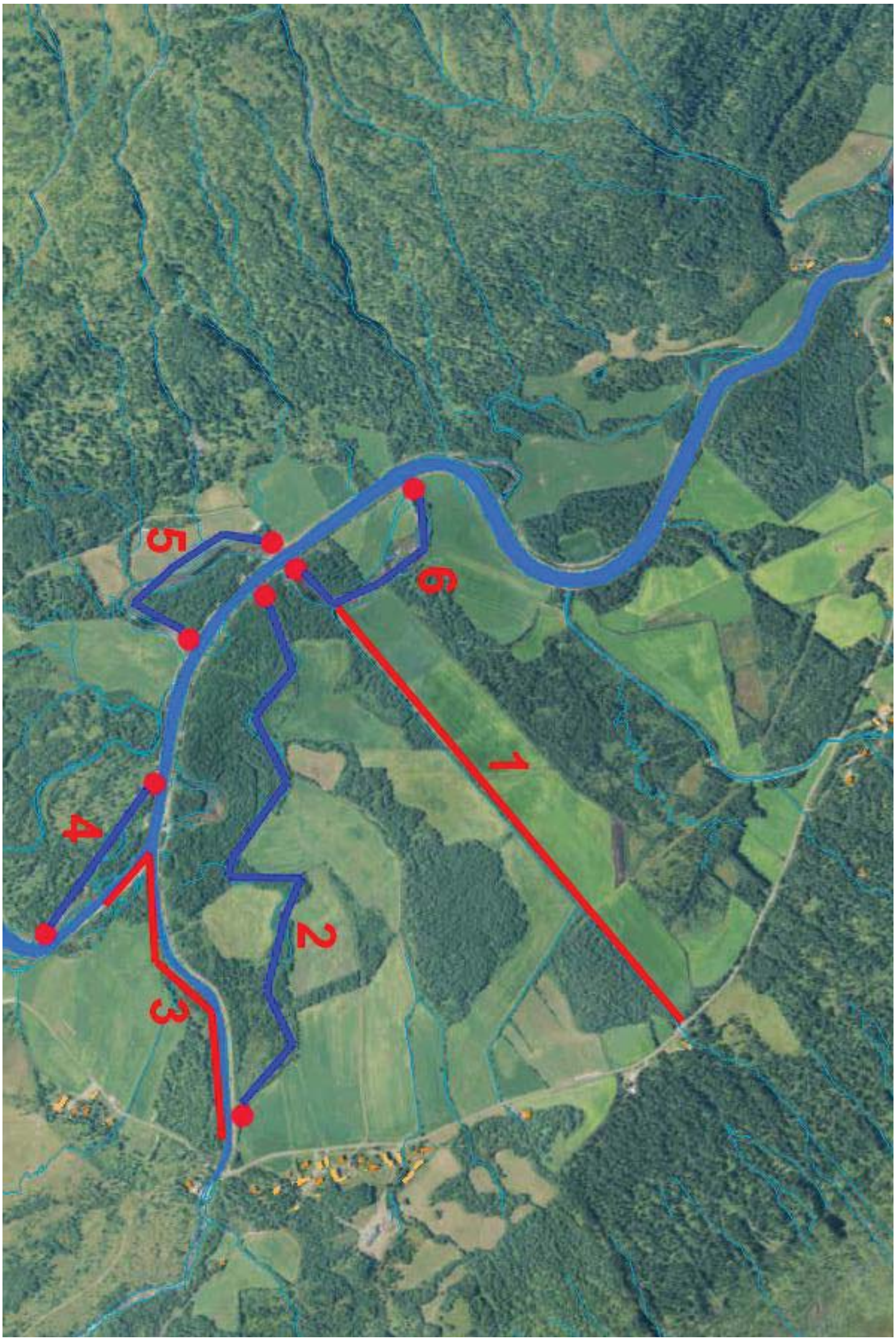
Appendices

Appendix A. Discharge at Øvrevatnet monitoring station 2017.

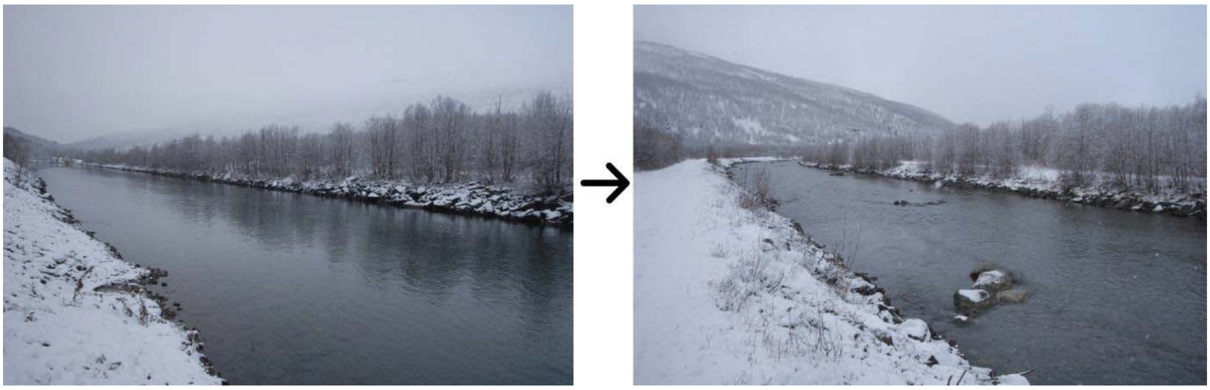


Appendix B. Primary restoration measures implemented in Salangselva 2005-2008.

The following information and figures are found in the presentation «Restoration of the Salangselva River, Bones» by Knut Aune Hoseth, NVE (2017). Explanatory drawing on the figure done by the author.



What	Why
1, Erosion control measures, canal through agricultural area.	To prevent the high rate of sedimentation seen in the Storøra meander. Improves habitat for fish, benthic macroinvertebrates and birds in the meander.
2, Reopening/modification of Budalsfaret.	Increase the flow of water to improve potential fish spawning and nursery habitat, reduce the rate of sedimentation, increase benthic macroinvertebrate diversity and density and contribute to recreating and maintaining a rich floodplain forest – especially on the river island.
3, Removal of erosion control structures.	Occasional floods helps recreate and maintain a rich floodplain forest; important habitat for birds and macroinvertebrates. Flooding of the forest also adds organic debris to the river, an important food source for benthic macroinvertebrates.
4, Reopening/modification of tributary from Gåsodden.	Increase the flow of water to help recreate and maintain a rich floodplain forest. Increase habitat for benthic macroinvertebrates and juvenile fish.
5, Reopening/modification of Langodden meander.	Increase the flow of water to help recreate and maintain a rich floodplain forest. Provide habitat for waterfowl and fish.
6, Reopening/modification of Storøra meander.	Increase the flow of water to help recreate and maintain a rich floodplain forest. Provide habitat for waterfowl and fish.



Channelized main river channel at Bones, before and after the addition of stone groups (Hoseth 2017).

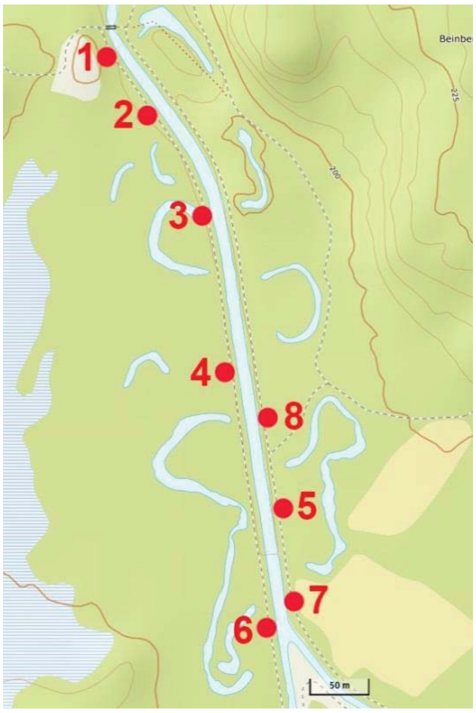
Stone groups in the main river channel at Bones, seen from above (www.norgeskart.no).

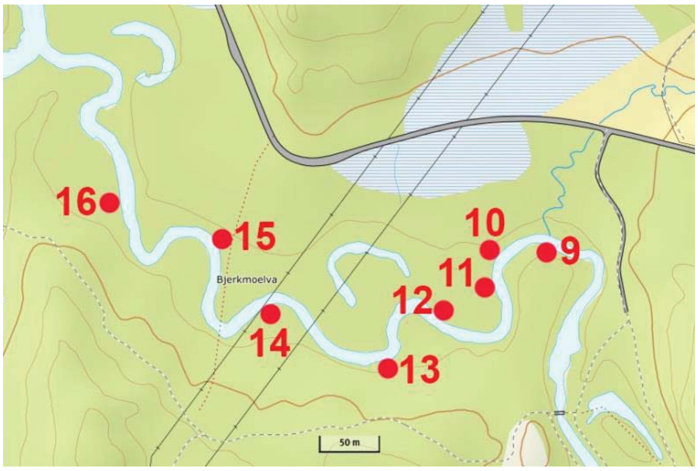
Culvert constructions at Bones; old (left) and new (right). New culvert construction facilitating the movement of organisms between the main river channel and its tributary (Hoseth 2017).

Appendix C1. Locations and maps of macroinvertebrate sampling stations in Kvernmoelva and Salangselva.

Location and maps (www.norgeskart.no) of benthic macroinvertebrate sampling stations in Kvernmoelva. Coordinates registered at upstream edge of each sampling station. Stations 1-8 are in the channelized section, and stations 9-16 are in the naturally meandering section of the river.

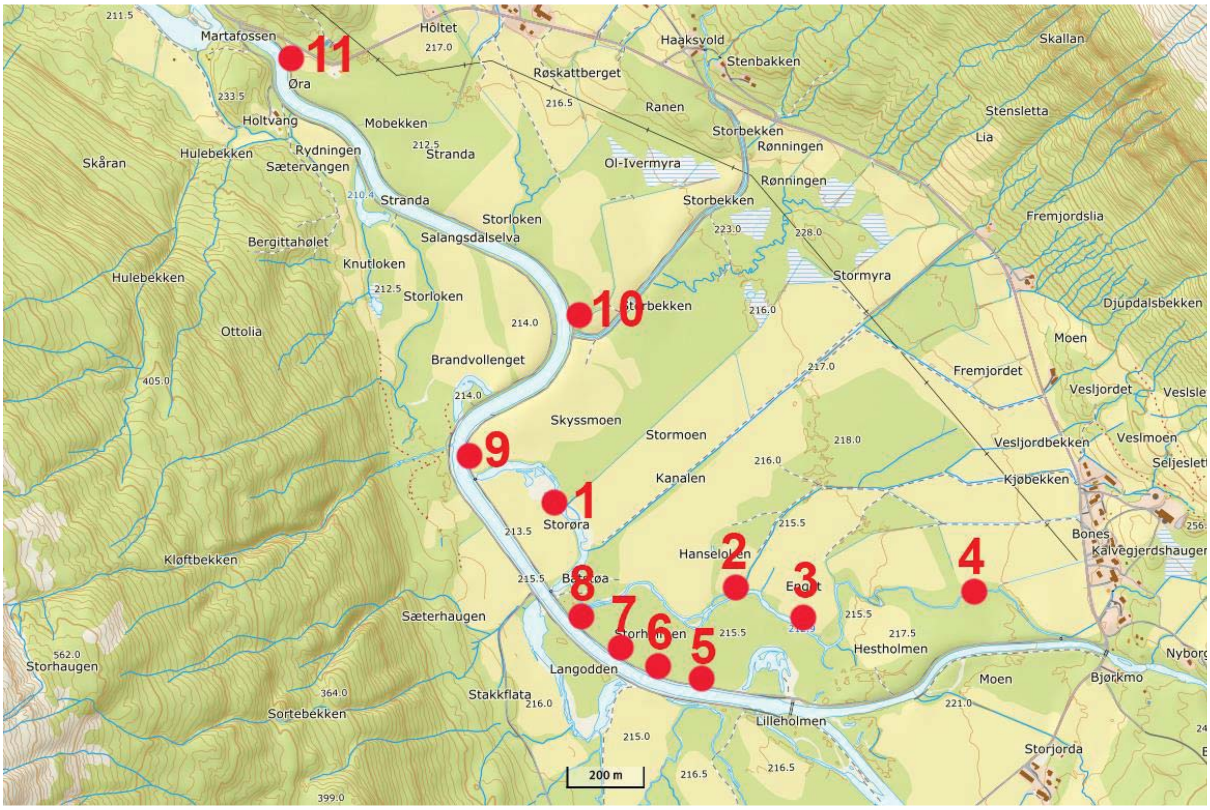
Station	UTM-zone	N-coordinate	E-coordinate
1	33	7617225	610186
2	33	7617187	610214
3	33	7617110	610257
4	33	7616973	610284
5	33	7616856	610317
6	33	7616760	610314
7	33	7616766	610336
8	33	7616934	610307
9	33	7617383	610189
10	33	7617394	610143
11	33	7617373	610128
12	33	7617332	610082
13	33	7617294	610039
14	33	7617339	609945
15	33	7617384	609903
16	33	7617418	609820





Location and maps (www.norgeskart.no) of benthic macroinvertebrate sampling stations in Salangselva. Coordinates registered at upstream edge of each sampling station.

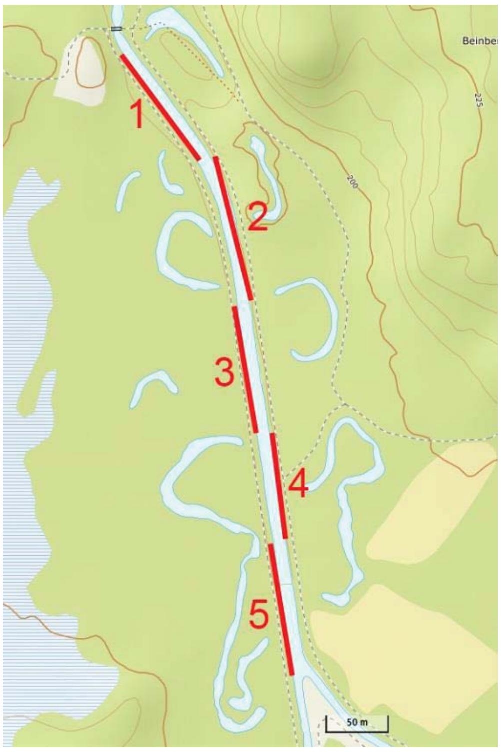
Station	UTM-zone	N-coordinate	E-coordinate
1	34	7617481	386705
2	34	7617234	387120
3	34	7617155	387261
4	34	7617179	387694
5	34	7617011	387011
6	34	7617036	386922
7	34	7617067	386851
8	34	7617197	386705
9	34	7617612	386471
10	34	7617966	386751
11	34	7618737	386099

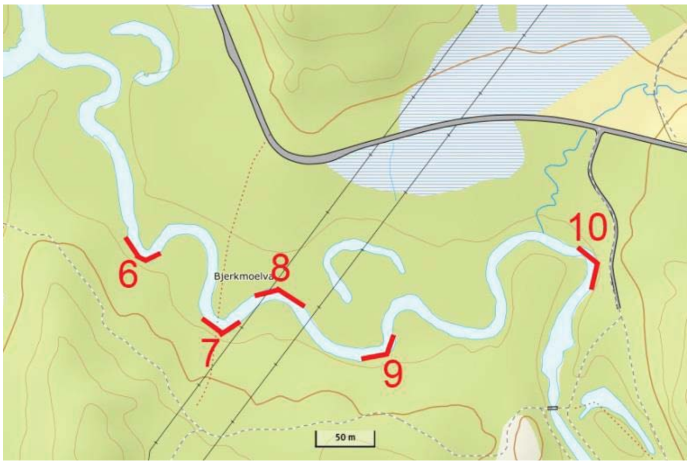


Appendix C2. Locations and maps of electrofishing stations in Kvernmoelva and Salangselva.

Location and maps (www.norgeskart.no) of electrofishing stations in **Kvernmoelva**. Coordinates registered at upstream edge of each station. 1-5 are in the channelized section, and 6-10 are in the naturally meandering section of the river.

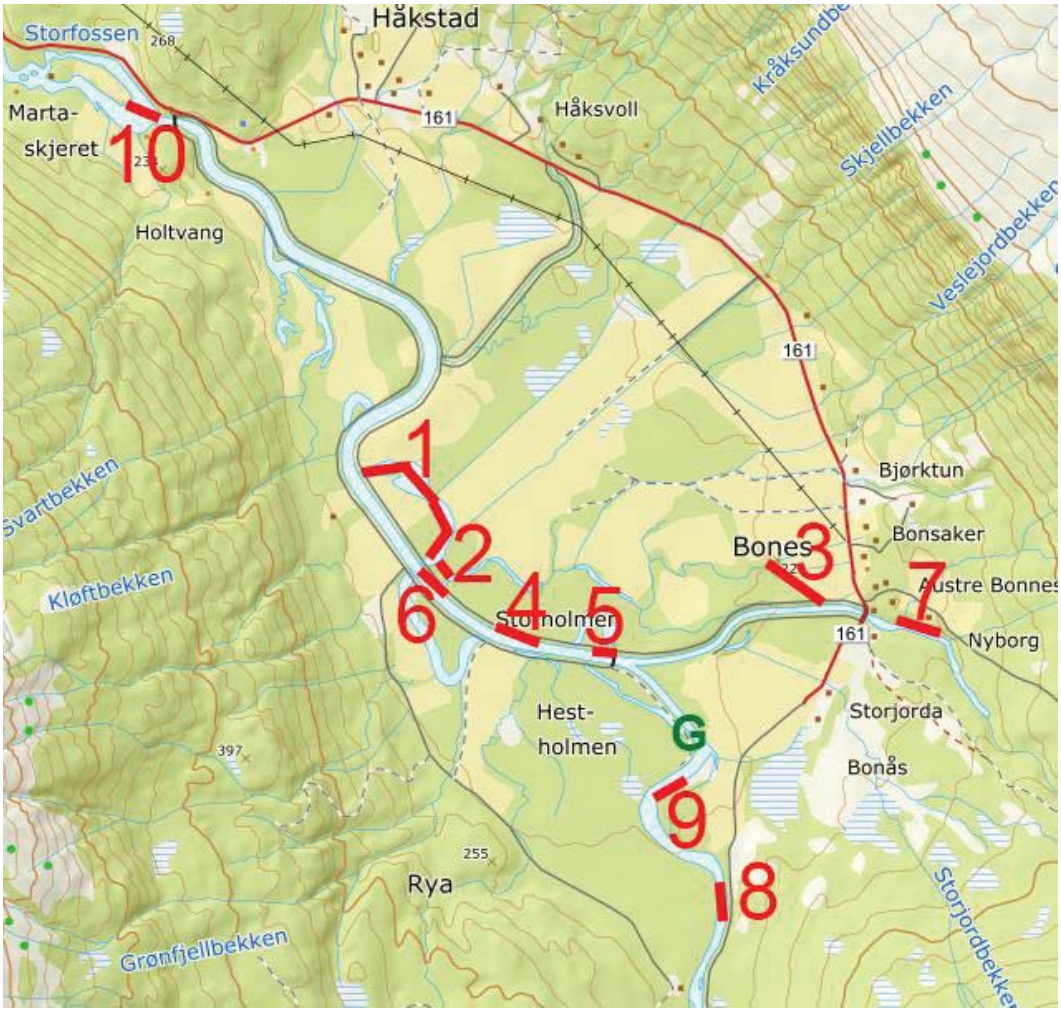
Station	UTM-zone	N-coordinate	E-coordinate
1	33	7617155	610238
2	33	7617044	610288
3	33	7616940	610283
4	33	7616850	610315
5	33	7616744	610319
6	33	7617380	609855
7	33	7617323	609920
8	33	7617342	609970
9	33	7617312	610051
10	33	7617362	610217





Location and maps (www.norgeskart.no) of electrofishing stations in **Salangselva**. Coordinates registered at upstream edge of each station. «G» indicates the location of Gåsodden, referenced in the text.

Stations	UTM-zone	N-coordinate	E-coordinate
1	34	7617310	386663
2	34	7617274	386706
3	34	7617043	387929
4	34	7617007	387002
5	34	7616948	387227
6	34	7617251	386664
7	34	7616957	388147
8	34	7616086	387492
9	34	7616516	387377
10	34	7618792	385960



Appendix D. Environmental variables and methodology.

Environmental variables were assessed every 5 meters within a station, with a minimum of three data points for each station. The values were averaged and logged.

Canopy cover of the riverbank
Measured as percentage branch cover of the riverbank, determined visually. Riverbank defined as approx. 0-1m from the river channel. Category 1: 0%, category 2: 1-25%, category 3: 26-50%, category 4: 51-75%, category 5: 76-90%, category 6: >90%.

Canopy cover of the river (0-2m from the bank)
Measured as percentage branch cover, of the first two meters of river measured from the bank. Determined visually, and categories identical to the variable «Canopy cover of the riverbank».

Riverbank vegetation cover
Measured as percentage vegetation cover of one meter riverbank. Determined visually, and categories identical to the variable «Canopy cover of the riverbank».

Water velocity
Determined visually, and assigned one of the following categories: 1: still, 2: slow, 3: moderate, and 4: fast. Categories represent the following surface velocities 1: 0cm s^{-1} , 2: 1-25 cm s^{-1} , 3: 26-50cm s^{-1}, 4: >50 cm s^{-1}

Substrate composition
Determined visually, and assigned a category based on the dominating grain size. Category 1: 0-2mm, category 2: 2-20mm, category 3: 20-100mm, category 4: 100-250mm, category 5: >250mm.

Depth
Measured at one and two meters from the bank. For stations where the stream was narrower than two meters, I measured at one meter from the bank and in the middle.

Algae cover
Percentage cover of the bottom assessed visually, and assigned a category. Category 1: 0%, category 2: 1-33%, category 3: 34-66%, category 4: >66%.

Moss cover
Percentage cover of the bottom assessed visually, and assigned a category. Category 1: 0%, category 2: 1-33%, category 3: 34-66%, category 4: >66%.

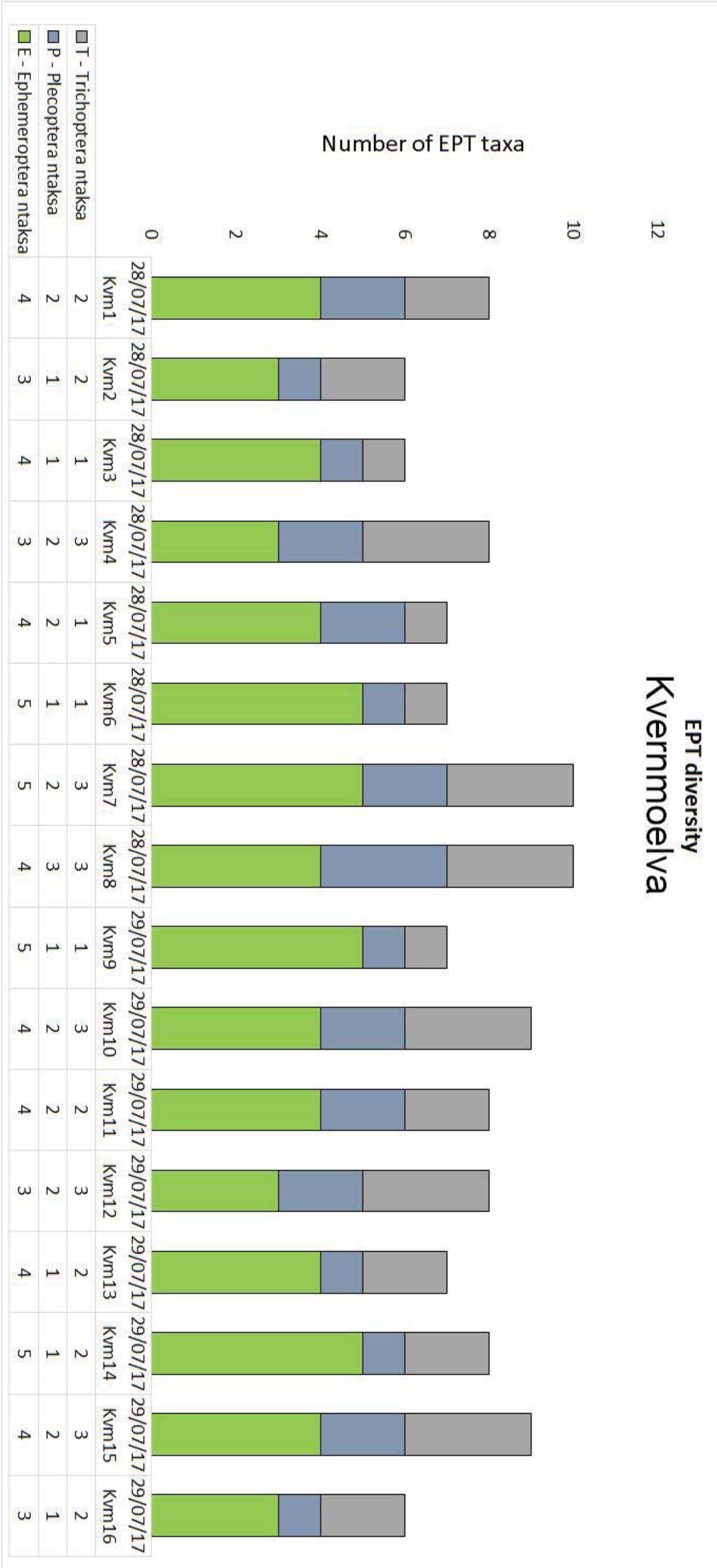
Number of pools
A pool was defined as an area of still water. The number of pools were counted in the entire station. Category 1: 0 pools, category 2: 1-2 pools, category 3: 3-4 pools, category 4: 5-6 pools, category 5: 7-8 pools, category 6: >8 pools.

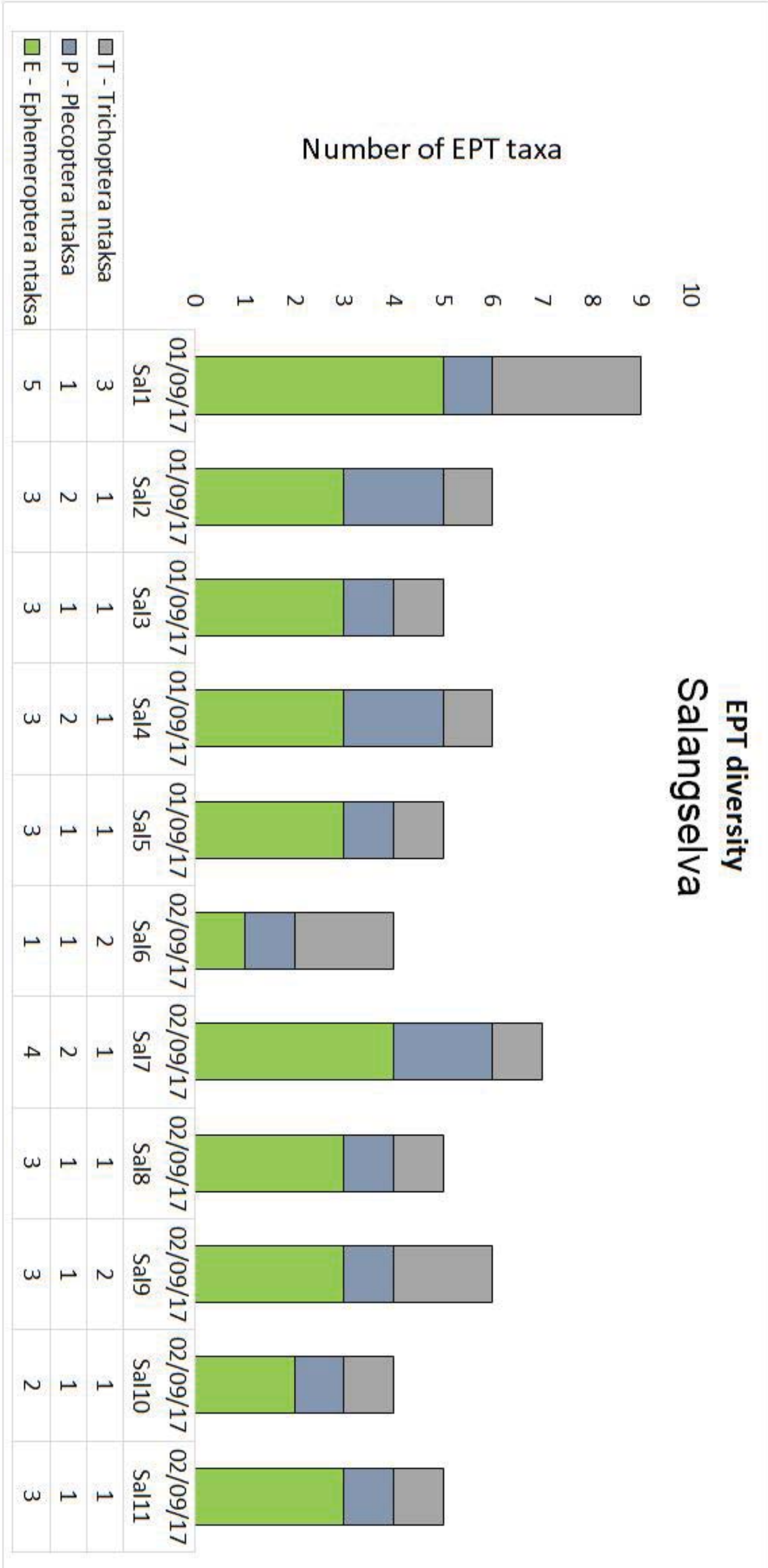
Large woody debris (LWD)
LWD was defined as being > 0.1 x 1m in size. When smaller woody debris had accumulated, it was also classified as LWD. LWD were counted for the entire station.

Width of river channel
Based on GPS-location, the width of the river was measured in meters in the field using the mobile application «Norgeskart».

Width of river channel covered by water
Determined in the field, by visual assessment. Measured in meters.

Appendix E. Macroinvertebrates, EPT diversity.




EPT diversity
Salangselva
Number of EPT taxa
0
1
2
3
4
5
6
7
8
9
10
01/09/17 Sal1
01/09/17 Sal2
01/09/17 Sal3
01/09/17 Sal4
01/09/17 Sal5
02/09/17 Sal6
02/09/17 Sal7
02/09/17 Sal8
02/09/17 Sal9
02/09/17 Sal10
02/09/17 Sal11
T - Trichoptera ntaksa 3 1 1 1 1 2 1 1 2 1 1
P - Plecoptera ntaksa 1 2 1 2 1 1 2 1 1 1 1
E - Ephemeroptera ntaksa 5 3 3 3 3 1 4 3 3 2 3

Norges miljø- og biovitenskapelige universitet
Noregs miljø- og biovitskapelege universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway