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River Restoration in Bognelv, Northern Norway

Salmonid and Macroinvertebrate Responses to Restoration Measures

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Preface

This thesis is written at Department of Ecology and Natural Resource Management (INA), Norwegian University of Life Sciences (NMBU) and constitutes the final part of our master degree in natural resource management.

First off all we want to thank you our supervisors, associate professor Jonathan Edward Colman and Thrond Oddvar Haugen at Department of Ecology and Natural Resource Management for valuable guidance and encouragement through field work, data analysis and the writing period. Writing and conducting this thesis would not be possible without you.
We want to thank Knut Aune Hoseth and Anders Bjordal at the local department of The Norwegian Water Resources and Energy Directorate (NVE) in northern Norway for giving us the opportunity to write our thesis about Bognelv, financing the project and supervising during the field work and writing process. We also want to thank Trond Bremnes and John E. Brittain at The Freshwater Ecology and Inland Fisheries Laboratory (LFI), University of Oslo for giving us an introduction to classification of macroinvertebrates and Anne Rønneberg for valuable help during the writing period.
In total, we spent three weeks with field work in Bognelv. We want to thank Ivar Mikalsen and Ole Magnus Rapp for their invaluable assistance during the field work and Langfjorden hunting and fishing association (LJFF) for background information.
Finally, we want to thank our families for support during the writing period and all our friends for making our studies in Ås so fantastic and enjoyable.

Photographs without crediting are taken by the authors.

Ås-NMBU, May 13th 2016

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Summary

This is the fourth study of the response of salmonids to river restoration in Bognelv in Finnmark County, Norway. Bognelv was channelized, erosion secured and flood protected during the late 1930s to early 1990s period, and as a consequence of this, salmonid densities declined dramatically. The first restoration measures were conducted in 2006, and the last restoration measure to date were conducted autumn 2014. Following previous surveys' sampling design, we sampled salmonid juveniles using electrofishing and benthic invertebrates were sampled by means of kick-sampling. Brown trout (*Salmo trutta*) responded quickly to restoration measures, already in 2008 with relatively much higher densities compared to before 2006, and continued to their highest overall mean production of juveniles in 2015. Atlantic salmon (*Salmo salar*) densities remained low through 2013, but then increased substantially in 2015, but not on the same level as brown trout. According to our data, Arctic charr (*Salvenius alpinus*) have barely responded to the restoration measures, being absent from all samples in 2013 and 2015, and was therefore excluded from our analyses. Macroinvertebrates were classified to the level of species for the first time in 2015 to better investigate their response to the restoration measures.

The most important environmental variables influencing density and length for Atlantic salmon and brown trout juveniles were; depth, duration of growth period, temperature during growth period, moss cover, 1+ density, gravel and distance from E6 (the estuary). An ordination analysis was carried out to reveal environmental and restoration effects on the macroinvertebrate community. The most important environmental variables that affected diversity of macroinvertebrates were; distance from E6 and water velocity. Macroinvertebrate diversity increased with increasing distance from E6 and increasing water velocity.

Type of restoration measure had different effects on brown trout and Atlantic salmon densities. Both species had highest 0+ densities in areas with weirs and riparian modifications, while brown trout and Atlantic salmon 0+ density was lower in side channels and tributaries than in unrestored stations. 0+ Atlantic salmon density increased with increasing time since restoration. 0+ brown trout length was greater in areas with weirs and riparian modifications, while length was lower in side channels and tributaries. 0+ brown trout length was greater in restored stations than in unrestored stations. 0 + brown trout length decreased with increasing time since first restoration measure (2006). 0+ Atlantic salmon length was greater in side channels and tributaries, while weirs and riparian modifications had little effect on their length. The highest diversity of macroinvertebrates was found in areas where riparian modifications and opening of side channels/tributaries was conducted. Areas with weirs had a similar effect as unrestored areas on diversity.

The restoration process appears to have started, with promising responses for brown trout production, but further monitoring and broader scaled sampling is needed to better test the effects of different restoration measures on all three salmonids and macroinvertebrates in Bognelv.

Sammendrag

Elverestaurering i Bognelv, Nord-Norge. Respons hos laksefisk og bunndyr på restaureringstiltak.

Dette er den fjerde M.Sc.-studien av anadrome laksefisks respons på restaureringstiltakene gjennomført i perioden 2006-2014 i elva Bognelv i Finnmark. Feltarbeidet ble gjennomført i juli og september 2015 der laksefiskyngel ble samlet inn ved elfiske og bunndyr ved sparkeprøver. Bognelv ble i årene mellom 1930-tallet og tidlig 1990-tallet kanalisert, flom- og erosjonssikret. Dette medførte at tettheten av fisk sank dramatisk. Etter restaureringen startet i 2006 har ørret *(Salmo trutta)* respondert raskt, med høyest gjennomsnittlig tetthet av ungfisk i 2015. Bestanden av laks *(Salmo salar)* hadde lav tetthet frem til og med 2013. I 2015 har tettheten økt betydelig, med høyest gjennomsnittlig tetthet siden restaureringsprosessen begynte. Dog har ikke tetthetsøkningen vært av samme omfang som for ørret. Røye *(Salvenius alpinus)* har tilsynelatende respondert dårlig på tiltakene og ble ikke fanget i verken 2013 eller 2015. Røye er derfor ikke inkludert i analysene i denne studien. Bunndyr ble for første gang artsbestemt i 2015 for å undersøke bunndyrs respons på restaureringstiltakene.

Dybde, lengde på vekstsesong, temperatur i vekstsesongen, dekningsgrad av mose, 1+ tetthet, substrat og avstand fra E6 (utosområdet) var de viktigste miljøvariablene til å påvirke tetthet og lengde hos ørret og laks. Artsdiversitet hos bunndyr ble i størst grad påvirket av miljøvariablene vannhastighet og avstand fra E6. Artsdiversiteten økte med økende avstand fra E6 og med økende vannhastighet. En ordinasjonsanalyse ble gjennomført for å undersøke påvirkningen av miljøvariabler og restaureringstiltak på bunndyrsamfunnet i elva.

Studien viser at ulike former for restaureringstiltak hadde ulike effekter på tettheten av laks og ørret. Tetthet av 0+ ørret var høyere i områder med terskler og kantvegetasjon og lavere i sideløp og mindre tilstøtende bekker. Tettheten av laks 0+ økte med tid siden restaurering. For 0+ ørret har lengden avtatt med tiden etter første restaurering (2006). Til tross for dette var lengden større i restaurerte stasjoner enn urestaurerte. Restaureringstiltak hadde svak effekt på lengde hos 0+ laks, mens lengden var størst i sidekanaler og bekker. Størst bunndyrdiversitet ble observert i områder med forbedret kantvegetasjon og åpning av sidekanaler og bekker. Bygging av terskler hadde omtrent samme effekt på diversitet hos bunndyr som områder der restaurering ikke var gjennomført.

Etter vår vurdering har restaureringsprosessen i Bognelv startet, med særlig lovende resultater for ørretproduksjonen. Det vil være viktig med videre studier i elven for å undersøke fisks og bunndyrs respons på restaureringstiltakene over tid.

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1. Introduction

In a world with dramatic human population growth and a constant need of more space, ecosystems as lotic systems are under increasing pressure (Lasne et al. 2007; Malmqvist & Rundle 2002). Human impact of ecosystems, habitats and species is a challenge in Norway, as well in the rest of the world, representing a major threat to biodiversity (Hagen & Skrindo 2010). Running-water ecosystems provide different ecosystem services, and human interventions in water bodies takes many different forms (MA 2005). In recent years, there has been a growing consensus about the importance of river restoration, coinciding with an increase in the number of restoration projects. The Society of Ecological Restoration (SER) defines ecological restoration as *"…the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed"* (SER 2004). The European Water Frame Directive (WFD) is a main driver for the increasing amount of restoration projects in Norway (Grabowski & Gurnell 2016; Haase et al. 2013). Norway has implemented the WFD into Norwegian law through "Vannforskriften (2006), and the WFD will have great importance in Norwegian water management in the years to come. The final objective in the WFD is that all water bodies achieve good ecological status by 2021 (Saltveit 2006; WFD 2000/60/EC 2000). Water management in Europe and Norway has been changed fundamentally after implementing the WFD, putting aquatic ecology and evidence-based knowledge at the base of management decisions (Hering et al. 2010). To get this knowledge, it is important to study environmental- and restoration related responses on aquatic species.

Despite increasingly more restoration projects, a lack of knowledge exits about the effects of restoration in terms of whether it truly achieves the goal of providing long term improvements to an ecosystem (Bernhardt et al. 2005; Feld et al. 2011; Grabowski & Gurnell 2016; Vehanen et al. 2010; Wohl et al. 2005). Results from former restoration projects in degraded river systems have not unambiguously demonstrated positive responses to restoration measures (Haase et al. 2013; Roni et al. 2006; Roni et al. 2008; Vehanen et al. 2010). Nevertheless, there are several restoration projects in degraded river systems resulting in positive impacts on the ecosystem in question (Friberg et al. 1994; Helfield et al. 2012; Hesthagen & Larsen 2003; Hvidsten & Johnsen 1992).

In this thesis, we focus on the ongoing restoration processes in the river Bognelv in northern Norway. Before the 1930s, Bognelv was a dynamic and meandering river, with clear flood peaks and known as a river with high densities of the salmonids, brown trout (*Salmo trutta*), Atlantic salmon (*Salmo salar*) and Arctic charr (*Salvelinus alpinus*) (Dønnum & Colman 2004; Hoseth & Josefsen 2005). Due to problems with erosion of agricultural land and flooding of the Bognelv valley, a 3.5 km section of the river was channelized and flood-secured in the period from early 1930s to early 1990s. The channelization solved the erosion problems, and to a large degree also reduced damaged during high water flow/floods. However, this also affected the fish populations negatively. Saltveit and Brabrand (1999) examined Bognelv in 1999, and described the densities of fish as "extremely low". To improve the conditions in Bognelv, the Norwegian Water Resources and Energy Directorate (NVE) made an environmental plan in 2005 with seven main measures that were conducted between 2006 to 2014 (Hoseth & Josefsen 2005; Sødal 2014).

As far as we know, our study design and time series are unique in Norway. There are many on-going or completed restoration projects in rivers in the US. Bernhardt et al. (2005) reported that as of July 2004, there were 37.099 registered restoration projects in the National River Restoration Science Synthesis (NRRSS) database. The number of restoration projects increased exponentially in the period 1995-2005, with the greatest number of projects in the Pacific Northwest, the Chesapeake Bay watershed and California. Palmer et al. (2010) conducted a literature search for restoration project publications from the 1975-2008 period. The search resulted in 113 articles with 78 articles presenting independent restoration projects after criteria set by the authors. Twenty of these projects were located in the Nordic countries, two in Denmark, four in Sweden and 14 in Finland. After searching for river restoration projects in Norway, we only found publications describing restoration in lotic systems that were developed for hydropower or cultivated by transplanting roe into the bottom substrate, and all studies were from the south-west coast of Norway. One publication, Hvidsten and Johnsen (1992), examined the river Søya after restoration measures were implemented to reverse channelization. This study was similar to ours and showed that coarser substrate and weirs had positive effects on juvenile brown trout densities. Searching the literature, several restoration projects in Finland and Sweden often focused on river systems channelized to facilitate timber floating (Hasselquist et al. 2015; Helfield et al. 2012; Korsu et al. 2010; Vehanen et al. 2010). None of the above studies had the extensive amount of restoration measures conducted in their systems, the time series of data that we have, or the number and type of species that we have.

Thus, we have the novel opportunity to see the effects of restoration measures in a long-term perspective and in a system with three sympatric salmonid species.

Different species can be used as bio indicators in freshwater systems. Fish and macroinvertebrates are recognized as good bio indicators of ecological conditions and extent of recovery in rivers (Chessman 1995; Harris et al. 1995; Lasne et al. 2007; Metcalfe 1989). McGeoch (1998) defines a bio indicator as a species or group that reflects the biotic or abiotic state of an environment, habitat or ecosystem. Our study is the fourth study examining the restoration process in Bognelv during the last decade using salmonids as the main bio indicator. We aimed to investigate the effect of the restoration measures by combining the collected data from Schedel (2010), Austvik (2012) and Sødal (2014) with our sampled data from 2015. The aim in all these studies was to examine whether the restoration measures conducted up to the date of the study had been successful, and all sampled the density of juvenile salmonids as a bio-indicator of restoration success. In 2013 and 2015, macroinvertebrates were also sampled to investigate additional trophic levels in the Bognelv ecosystem.

For comparative purposes with earlier studies, our study used the same methodology as earlier years with some improvements and adjustments. With similar methods, we could use former data, and put this into a new context with the data sampled in 2015. Because of the lack of knowledge about the effects of restoration, our main goal was to test the effect of the restoration measures conducted over the last decade in Bognelv. We combined and tested the different measures with sampled fish populations, macroinvertebrate community composition and a number of important environmental variables, such as temperature, depth, gravel size, riverside canopy cover, bottom substratum and more (Armstrong et al. 2003; Brown 2000; Faith & Norris 1989).

The aims of our study were similar to Schedel (2010), Austvik (2012) and Sødal (2014), with some adjustments. We aimed to:

1) Reveal why the restoration measures conducted in Bognelv over the last 10 years have increased the density of juvenile brown trout and not necessarily populations of Atlantic salmon or Arctic charr.

2) Investigate potential environmental variables (independent of restoration measures) that influence fish density, length and macroinvertebrate diversity.
3) Test restoration-measures-specific effects on juvenile salmonid species and the macroinvertebrate diversity.
4) Assess whether the ecological restoration processes of river Bognelv have begun, and what “works” and what “does not work”.

2. Materials and methods

The river Bognelv (Bávnnjajohka) is located in the western part of Finnmark county in Alta municipality, and flows down the valley Bognelvdalen (Figure 1 and 2), and has its outlet in the fjord Langfjorden (UTM 33 7784836 N, 777653 E).

The following information given for Bognelv is based on the background report by NVE (Hoseth and Josefsen (2005). Bognelv has watercourse number 211.8Z, and the river was conserved and protected from future hydropower development in 1980 (NOU 1976:15 1976; St. prp. nr 77 (1979-1980)). The catchment of the river is 88.5 km^2 and consists of natural- and cultural landscape with scattered settlements and agricultural areas. Major parts of the catchment are above the tree line, in the alpine zone with stable winters and snowfall. This part of the catchment belongs to the landscape region "Troms sub maritime birch-and pine forest region – Lyngen-Alta area". The catchment consists of about 20 lakes located between 500 and 700 meters above sea level. Some of the lakes are nutrient rich, because of the calcium rich bedrock, but most of the lakes are oligotrophic. None of the lakes are larger than 1 km^2, and several have populations of brown trout and Arctic charr. Approximately 6.5 km of the river is accessible to salmonids, of which 3.5 km is channelized. The areas along the riverside of Bognelv is classified as agricultural, nature, recreation and reindeer herding-areas (LNFR-area). NVE have calculated the 100 year flood to 58 m^3/s and the middle-flood to 27 m^3/s. The average streamflow in July is 7 m^3/s and 3 m^3/s in August, September and October.

Bognelv-valley is classified as "fjord villages in Finnmark" with a typical U shaped valley, with steep hillsides, flat bottom and marine soils. Birch *(Betula ssp.)* and Alder *(Alnus ssp.)* are dominating tree species in the bottom of the valley with perennial plants and scattered presence of herbs. The bedrock is described as calcareous, which increases the soil nutrition and productivity. Bognelvdalens valley bottom has rich deposits of marine sediments, and the marine limit is around 70 meters above sea level.

Despite the comprehensive channelization and erosion control processes in Bognelv, the river is not classified as SMVF (heavily modified water bodies) yet, but the local water authority concluded in 2012 that the river potentially can be classified as SMVF in the future (Altavassdraget Loppa og Stjernøya vannområdeutvalg 2012).

In 1999, The Freshwater Ecology & Inland Fisheries Laboratory at University of Oslo conducted a survey of fish densities in the part of river Bognelv were salmon is present (Hoseth & Josefsen 2005). This study was the first examination of Bognelv and concluded with low densities of brown trout, salmon and Arctic charr, especially juveniles. In 2004, Dønnum (2005) sampled the river with the same aim and concluded with similar results; extremely low densities of all three salmonid species.

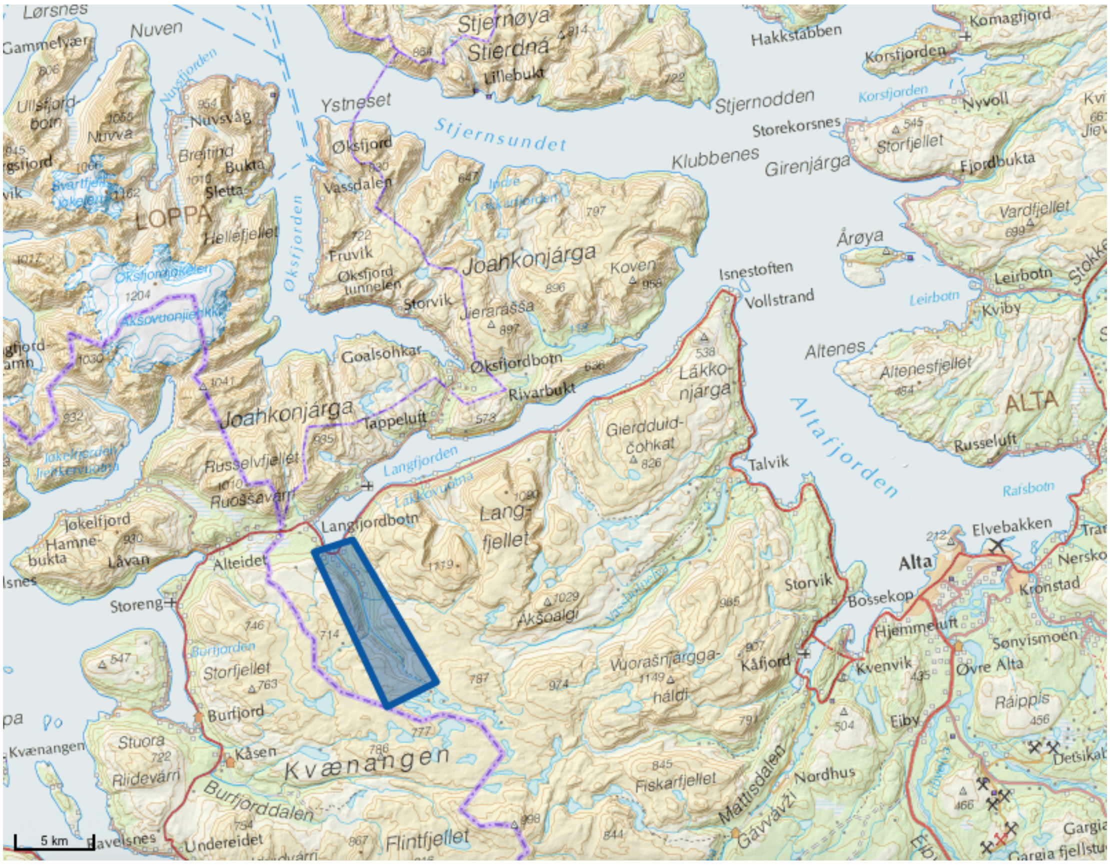

Figure 1. Map, demonstrating the western part of Finnmark and northern part of Troms, with the municipalities of Alta and Kvænangen. The blue square indicates the study area in Bognelvdalen. The map to the right shows the study area in a larger scale (Kartverket 2015).

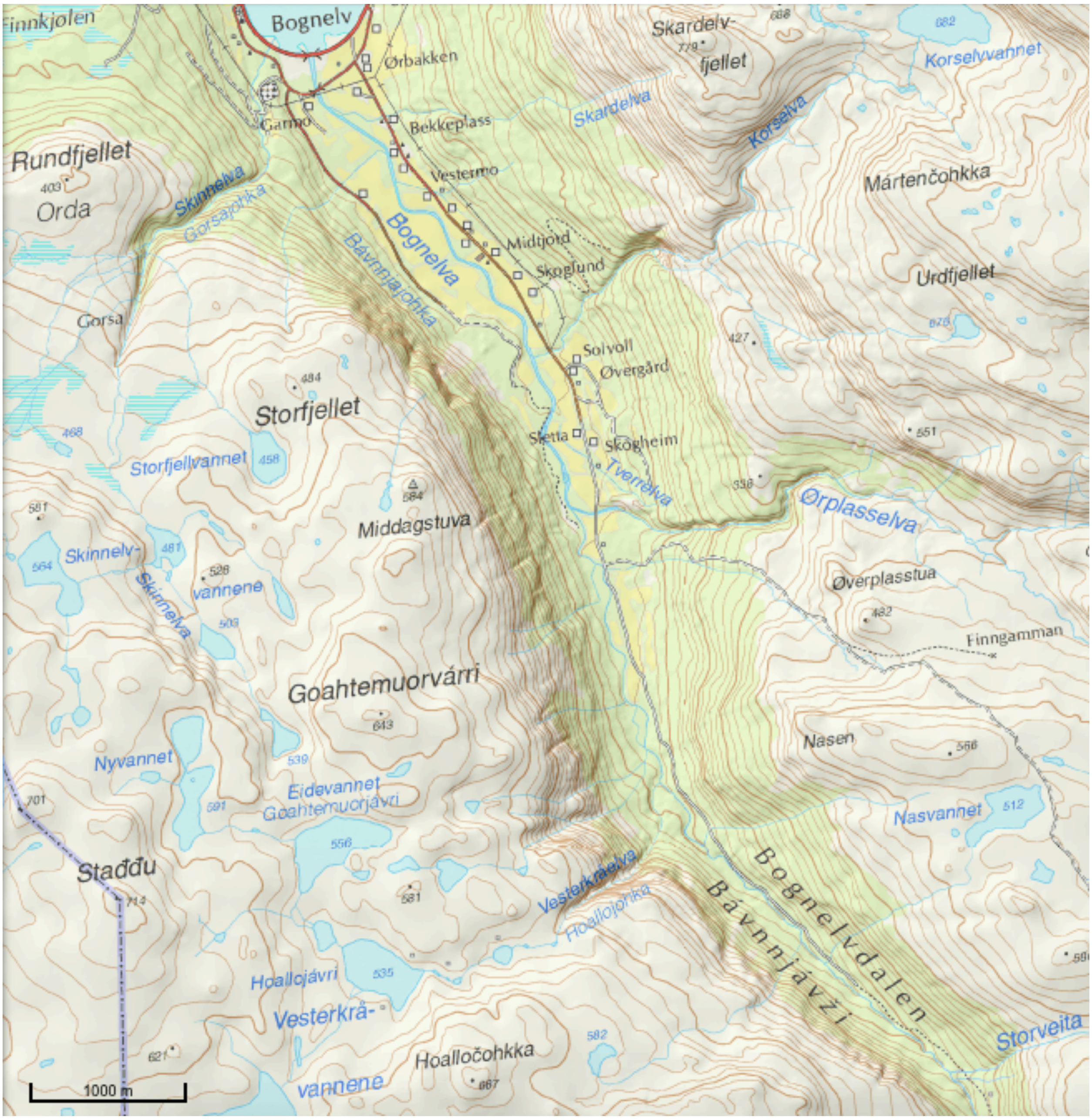

Figure 2. The study area in this study covers the entire Bognelv valley, but most focus was on the lower 3,5 section of the valley (Kartverket 2015).

In the period from late 1930s to the early 1990s, the river Bognelv was channelized, flood-protected and erosion-secured. A total of 3.5 km of the river was channelized, from the new E6 highway and up to where the river Ørplasselva drains into Bognelv (figure 2). The most recent restoration measures in Bognelv were conducted in autumn 2014. These actions included building a new island upstream “Oladammen”, re-opening of “Oladammen” and maintenance work on earlier conducted measures (Bjordal & Hoseth 2014).

For additional details, several reports have been published by NVE and others about the history of the river and upcoming or already conducted restoration measures (Bjordal & Hoseth 2006; Bjordal & Hoseth 2009; Bjordal & Hoseth 2012; Dønnum & Colman 2004; Dønnum 2005; Hoseth & Josefsen 2005; Hoseth & Josefsen 2007). Schedel (2010), Austvik (2012) and Sødal (2014) also featured these topics in their studies.

2.1 Data collection

Most of the methods used in this study were similar to those used in earlier studies of Bognelv (Schedel 2010; Austvik 2012; Sødal 2014) (Austvik 2012; Sødal 2014) (Austvik 2012; Sødal 2014) (Austvik 2012; Sødal 2014) (Austvik 2012; Sødal 2014) (Austvik 2012; Sødal 2014) (Austvik 2012; Sødal 2014) (Austvik 2012; Sødal 2014). Our study analyses new data sampled in 2015 together with data sampled in 2008, 2011 and 2013. Field work was undertaken in two rounds in 2015, from 5th July to 19th July and from 2th September to 9th September. Registration of environmental variables was done in July, and electrofishing and registration of macroinvertebrates was done in September. The registration of invertebrates and the electrofishing was undertaken at the same time period as earlier years. To test various restoration measures in Bognelv, we divided the river into 12 zones from the rivers outlet to about five kilometers upstream the outlet. Each zone had a number of stations that were 15 meters long and 2 meter wide. The stations were located along the riverside, side channels and tributaries. The study includes 56 stations in total; 50 stations were included from Sødal (2014) and 6 new stations were added in two new zones (11-12) in the upper undisturbed part of the river after inputs from our supervisors and NVE (Appendix X). Station 34 and 32 were excluded from our sampling because we forgot to electro fish these two stations during our fieldwork in 2015.

Macroinvertebrates

Macroinvertebrates were sampled along three transects within all stations. In Austvik (2012), the total number of invertebrate individuals were counted. Sødal (2014) classified in 2013 the macroinvertebrates to their taxonomic order. In 2015, we classified individuals to their species, or the lowest taxonomic level we could identify.

Both Austvik (2012) and Sødal (2014) sampled macroinvertebrates using a Surber-sampler after Surber (1937). We used the "kick-sampling method" as defined by Hynes (1961). The net consists of a quadratic frame with a 30 x 30 cm opening and a mesh size of 450 μm (Figure 3). The net was placed in the river, and an area of 0.09 m^2 were examined in 20 seconds by kicking the river bottom with the net placed downstream. Each station had three substations at 0, 7,5 and 15 meter, with three measuring points along a transect from riverside and out in the river. When kicking the river bottom, macroinvertebrates loosened and drifted with the current into the net. All of the collected material was put into plastic bags with ethanol 96%. The samples were transported to Ås and classified in the laboratory at Department of Ecology and Natural Resource Management, NMBU.


Figure 3. Photograph of the kick-sampler in action.

Electrofishing

Electrofishing was used to sample fish for estimating densities of juvenile fish. The electrofishing was done in the period from 03.09.2015 to 08.09.2015 with a GeOmega FA-4 generator produced by Terik Technology. The fishing was done with DC pulse, 35-70 Hz and 1400 V. Electrofishing is a common method for estimating densities of juvenile fish in rivers (Bohlin et al. 1989; Forseth & Forsgren 2009). According to Bohlin et al. (1989), two people conducted the electrofishing together. One person handled the anode, and both were catching fish with hoofs (small, rectangular nets on the end of a thin rod). The electrofishing was mainly conducted along the river sides, as in 2008 and 2011, and was done at all stations except for two as mentioned above. At stations with high to moderate fish densities, preferably three, but sometimes two passes were conducted. Two passes were conducted at stations with low catches in the second pass. This "three pass system" was used to be able to use the Zippin removal method for estimating fish densities (Bergan et al. 2011; Bohlin et al. 1989; Seber & Le Cren 1967; Zippin 1956; Zippin 1958). There was at least 30 minutes between each pass. Sampled fish from each pass were stored in dark grey 10 liter buckets on the river side until the fishing on each station was finished. Each removal was put in different buckets. After finishing the electrofishing, the fish from the different buckets were measured to the closest millimeter (total length) and classified to species (Figure 4).

Figure 4. Photograph of captured Atlantic salmon being measured.

Environmental variables

Environmental variables were measured at each station with the same methodology as Sødal (2014) and explained in more detailed in Appendix 4. Canopy cover of river and riverbank, as well as riverside vegetation were categorized into six categories at all stations. The categories were based on a percentage score. For substrate composition, the substrate was classified in five percentage grain-size groups. At each station, the river width and the percentage of water cover were estimated. In addition, depth at 1 and 2 meters, moss cover, algae cover, water velocity, the number of pools and the number of large woody debris (i.e., wood items with diameter > 10 cm and/or length >1 m) were registered. Distance from E6 is used as a measure for distance from estuary. Four temperature loggers (ibutton) were placed along the entire river section sampled to provide an average for the main river. These loggers were logging the temperature each hour from July to October.

We obtained metrological data from the climate database "eKlima" (Norwegian Metrological Institute 2016). Air temperature data was retrieved from the weather station at Alta airport (UTM33 818519 E, 7785240 N, number 93140). This station was used by Sødal (2014), and was the nearest station at a similar altitude as Bognelv reporting temperature. The weather station in Langfjordbotn, Sopnesbukt (UTM33 778300 E, 7788399 N, number 92910) was used to get snow depth and precipitation data. The snow-off period was defined as the period from the first day without snow cover until September 15. The snow-off period was defined as the growth season, and mean air temperature was calculated for this period. Growth season was set to end at the same date in both 2014 and 2015.

2.2 Study species

In Bognelv, there are three salmonid species; Atlantic salmon, brown trout and Arctic charr. Arctic charr was not found in 2013 or 2015, and therefore excluded on our thesis.

The habitat and hydromorphology of a river is important in determining the river's capacity of providing for various population densities of salmonids (Heggenes et al. 1999). While Atlantic salmon juveniles prefer more rapid water flow, juvenile brown trout are usually distributed along shallow riverbank areas with moderate to fast flowing water in larger streams (Jonsson & Jonsson 2011; Klemetsen et al. 2003). The size of brown trout often increases with increasing depth and distance from the riverbank (Bremset & Berg 1999). The availability of food is an important factor that directly affects density and survival of juvenile salmonids. Atlantic salmon and brown trout feed mainly on drifting invertebrates, and both also find food in the bottom substratum (Elliott 1994). Larvae of Trichoptera, Plecoptera, Chironomidae and Simulidae are important in the diet for both species (Jonsson & Gravem 1985; Jonsson & Jonsson 2011).

Benthic macroinvertebrates are important organisms in monitoring water quality, and an important nourishment for the salmonid species present in Bognelv. Macroinvertebrates connects with different trophic levels and their relatively short life history may allow them to quicly respond on restoration measures (Wallace & Webster 1996). Macroinvertebrates are less mobile than fish and relatively easy to sample and identify, and therefore widely used in European water quality monitoring programmes (Hering et al. 2006; Miljødirektoratet 2015). All the collected macroinvertebrates in the taxonomic orders mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddisflies (Trichoptera) were identified to species and are termed EPT-order. The EPT-species spend most of the time at egg- and nymph stadium in contact with water, and the species at nymph stadium has gills (Brittain 1982; Hynes 1976; Ross 1944; Ross 1967). In total, 284 EPT-species have been identified in Norway, of which 48 are in the order mayflies, 35 in the order stoneflies and 201 in the order caddisflies (Artsdatabanken n. d.-a; Artsdatabanken n. d.-b; Artsdatabanken n. d.-c). Macroinvertebrates from other orders were classified to the taxonomic level closest to species.

2.3 Statistical analysis

During the study of Bognelv (Schedel 2010, Austvik 2012 and Sødal 2014) there have been low catches of Atlantic salmon, and the relatively low number of observations of Atlantic salmon (n= 245) allowed for just limited statistical analyses on Atlantic salmon, due to the resulting low power. Brown trout have been sampled in 2008, 2011, 2013 and 2015 and will be used for statistical analysis (n=2751). Only four Arctic charr were sampled during the whole study period from 2008 to 2015, and therefore Arctic charr is excluded from statistical analysis.

Environmental data was prepared for statistical analysis; data from zone 1-9 was used, as data from zone 10 is only available from 2013 and zone 11-12 is only available from 2015. Environmental variables measured in 2008 were; substrate, current velocity, depth, riverbed profile, water temperature, overall vegetation cover and number of large woody debris. In 2011, 2013 and 2015, the same environmental variables were measured as described on page 10, large woody debris and number of pool are not included in the environmental data from 2011. Substrate categories for 2008 reached from 0 to 5. We altered substrate category 0 to category 1. Surrent velocity was in 2015 categorized in four different categories based on visual estimates; 1. still, 2. slow, 3. moderate, 4. fast, these categories were altered to continuous variables in cm s^{-1} based on measurements from Sødal's (2014) study of Bognelv by using a linear model. The formula used to produce continuous variables were;

$4.2745vel.cat^2 + 1.8216vel.cat – 4.9343$. The linear model had a adjusted R^2 -value of 0.998. Overall vegetation cover was not measured for 2011, 2013 and 2015 and is therefore based on a mean of canopy and edge vegetation for these three years. Macroinvertebrates were classified to taxonomic levels and the EPT orders were classified to species for the first time in 2015.

Microsoft Excel (Microsoft Office 2016) were used for data processing, while statistical analysis and figures are created in R version 3.2.2 (R Core Team 2015). There were some stations with zero catches of fish, data containing density was therefore ln(X+1) transformed to avoid ln(0).

We used Akaike's Information Criteria (AIC) (Akaike 1974) for model selection. AIC is a metric that estimate the balance between model precision and model bias by adding the model deviance (residuals) with the two times the number of parameters included in the model (i.e., AIC = deviance + 2np). Hence, by finding the candidate model with the lowest AIC value one get the model that most effectively predict the relationship between different explanatory variables and the respective response variables (i.e. fish density, fish length and benthic invertebrate diversity). We used ordinary linear models when fitting environmental and treatment effects on the mentioned response variables and candidate models with ΔAIC below 2 were taken into consideration when discussing results (Anderson & Burnham 2002). Parameter estimates and test statistics was retrieved from the summary for the most supported model and p-values were considered significant α=0.05.

Owing to more environmental variables being measured in 2011, 2013 and 2015 than in 2008, model selection was split into two different combination of years. Model selection for brown trout density was implemented on 0+ and 1+ age groups, model selection for length was only implemented on 0+ since we do not know the length for 1+ the previous season. Model selection for Atlantic salmon density and length was used with one combination of years; 2008, 2011 and 2015, since only four salmon was captured in 2013. Model selection for Atlantic salmon density and length was only implemented on 0+ age group. A histogram revealed the age distribution for brown trout (2015) and Atlantic salmon (2008, 2011 and 2015

To test if restoration measures had any effect on measured responses (density and length) after correcting for environmental variables, AIC-support was checked after adding Restoration measure as an effect to the most supported environment effect model. The most supported environment-effect model was first fitted alone, and then with time since restoration, time since last restoration measure, if the station was restored or not and type of restoration measure. Type of restoration measure was divided in four categories; 1. Weirs, i.e., building of weirs and buners in the river. 2. Side channel, i.e., reopening side channels and tributaries. 3. Riparian modifications, i.e., alterations of the riverside. 4. No measure. Type of restoration measure for each station was set to be the most dominant restoration measure, since in some stations different types restoration measures was conducted. Additive models are presented with parameter estimate tables, while more complex models are presented in contour plots and with parameter estimate tables in appendix.

In order to analyse effects from both restoration measures and environmental variables on the benthic invertebrate community we performed ordination analyses (e.g., (Jongman et al. 1995). The ordination analyses were undertaken using the vegan library in R (Oksanen et al. 2015). We started the ordination prosess by undertaking an unconstrained (i.e., no predictor structure) detrended correlation analysis (DCA) on the ln(x+1)-transformed taxon-specific abundance data. Based on the standard deviation value for the first axis of the fitted DCA, a decission was made whether to proceed using unimodal or linear ordination methods (Lepš & Šmilauer 2003). Base don this choice of ordination method, constrained candidate models were fitted (following the same routines as for the univariate models) and model selection was performed based on both AIC and and a combined forward and backward selection procedure implemented in the vegan library (ordistep).

3. Results

3.1 Brown trout and Atlantic salmon age groups

Brown trout age groups (0+, 1+ and >1+) were defined from length distribution of captured fish. The length of brown trout age groups for all years is shown in Table 1, while length distribution of age groups for all years is shown in Figure 5.

Table 1. Length interval of brown trout age groups in 2008, 2011, 2013 and 2015, measured in mm.

Brown trout	**Age groups**		
	0+	**1+**	**>1+**
2008	25-50	51-88	>89
2011	21-57	58-90	>91
2013	33-56	57-90	>91
2015	31-57	58-88	>89

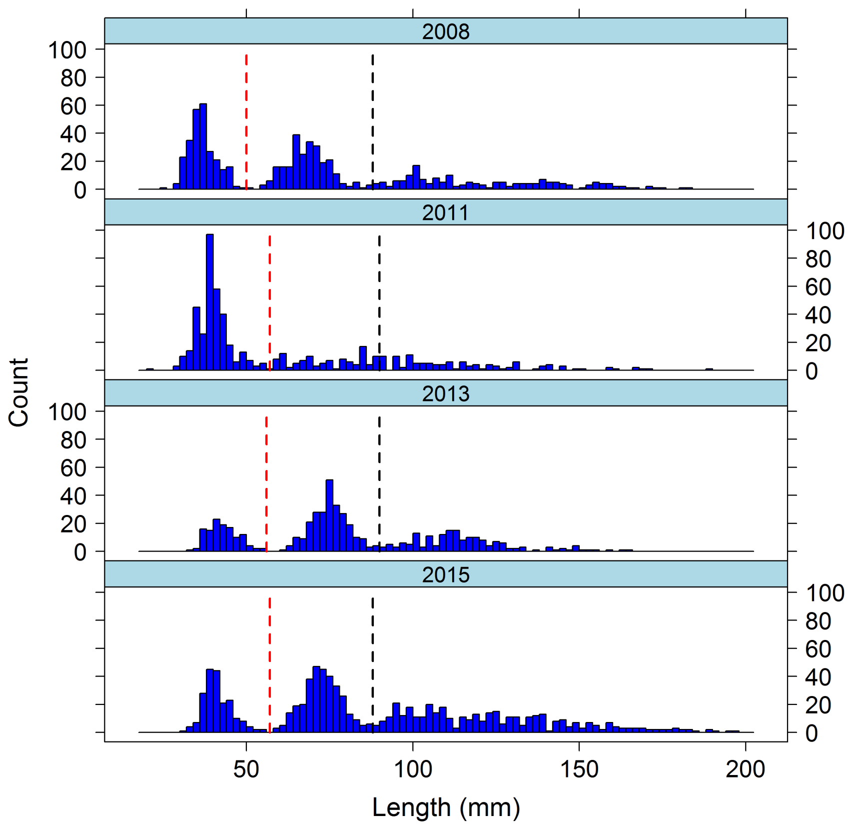

Figure 5. Histogram of the length distribution of age groups for brown trout sampled in 2008, 2011, 2013 and 2015. The 0+ age group is below the red dotted line, 1+ age group is between the red and black dotted line and the >1+ age group is above the black dotted line.

Atlantic salmon age groups (0+, 1+ and >1+) were defined from the length distribution of sampled fish. The length interval for Atlantic salmon age groups in 2008, 2011 and 2015 is shown in Table 2, while length distribution of age groups for the years 2008, 2011 and 2015 is shown in Figure 6.

Table 2. Length interval of Atlantic salmon age groups in 2015, measured in mm.

Atlantic salmon	Age groups		
	0+	**1+**	**>1+**
2008	33-52	53-75	>76
2011	31-52	53-107	>108
2015	33-48	49-90	>91

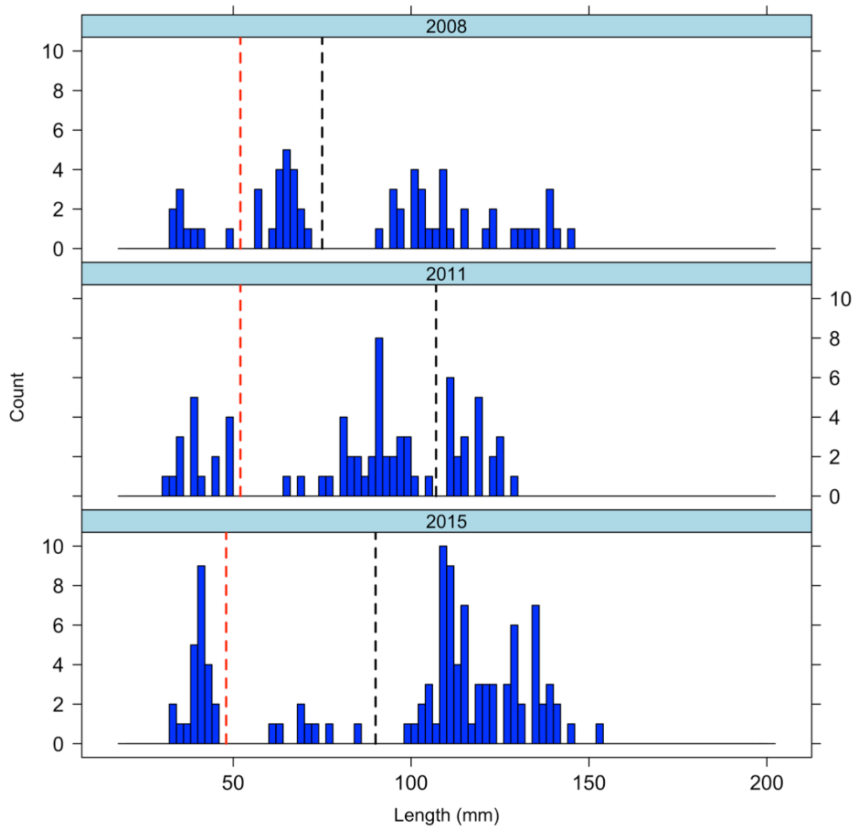

Figure 6. Histogram of the length distribution of age groups for Atlantic salmon sampled in 2008, 2011 and 2015. The O+ age group is below the red dotted line, 1+ age group is between the red and black dotted line and the >1+ age group is above the black dotted line.

3.2 Change in salmonid juvenile densities 1998 – 2015

Figure 7, 8 and 9 show the density distribution for the three salmonid species; Atlantic salmon, brown trout and Arctic charr in Bognelv between 1998 and 2015. 1998 and 2004 show the density distribution for the three salmonid species before restoration measures, and the density for all three species were extremely low. After the restoration process started in 2006, the density of brown trout increased substantially, albeit with some variability between the sampled years. The 0+ density for brown trout in 2013 is the lowest 0+ density since the restoration process started, with the highest density of 0+ in 2011. The 1+ brown trout density was highest in 2015 and lowest in 2011. The >1+ density of brown trout was lowest in 2011, but for the years 2008, 2013 and 2015 the >1+ density was approximately the same. The Atlantic salmon density increased after restoration but the density in general is low. The highest overall density of Atlantic salmon was found in 2015 and the lowest overall density was found in 2013 where only four Atlantic salmon was sampled. The highest >1+ and 0+ Atlantic salmon density and lowest 1+ density was found in 2015. Arctic charr was only found in 2008 and 2011 and the density is overall very low.

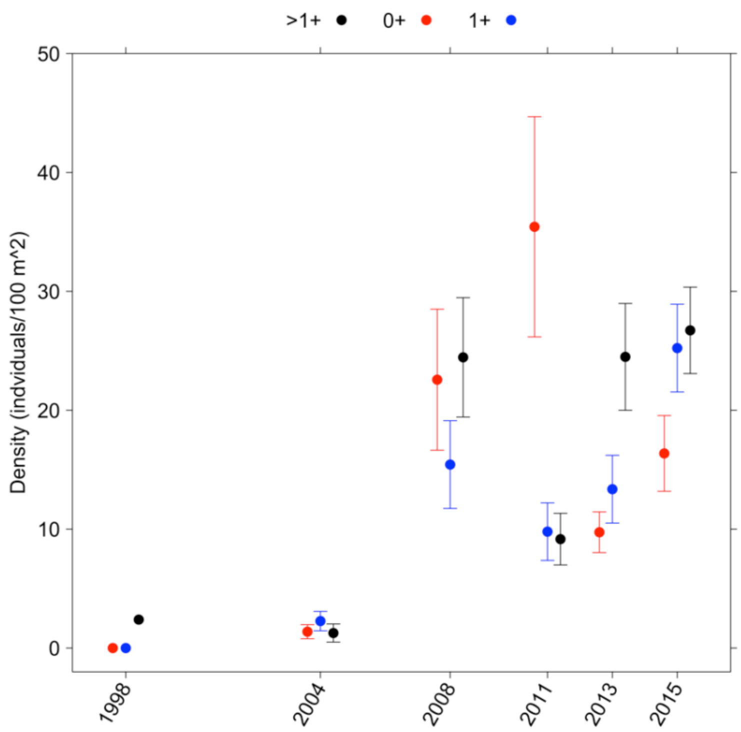

Figure 7. Change in brown trout density for 0+, 1+ and >1+ , in the period 1998 to 2015(± SE for the years 2004-2105). The restoration process started in 2006.

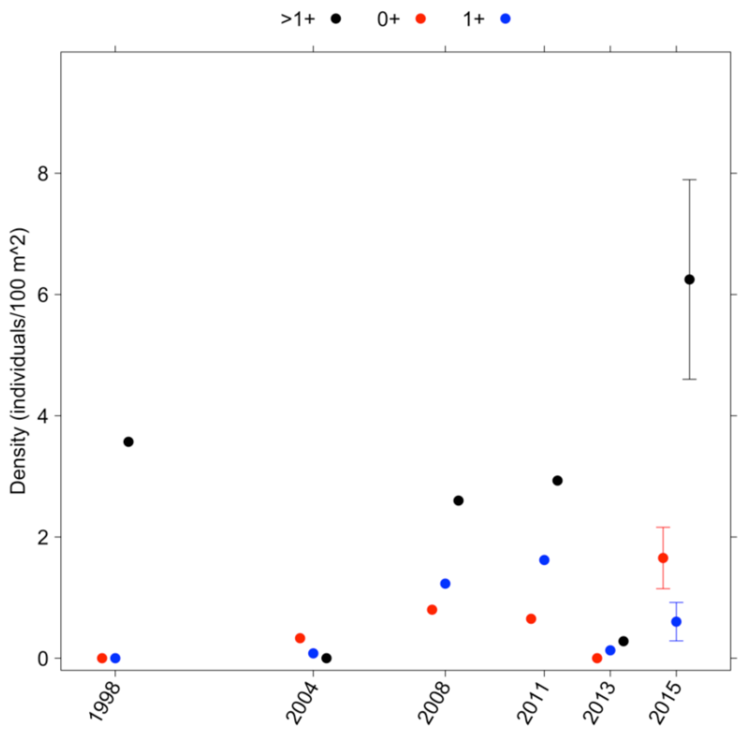

Figure 8. Change in Atlantic salmon density for 0+, 1+ and >1+ , in the period 1998 to 2015(± SE is only given for 2105). The restoration process started in 2006.

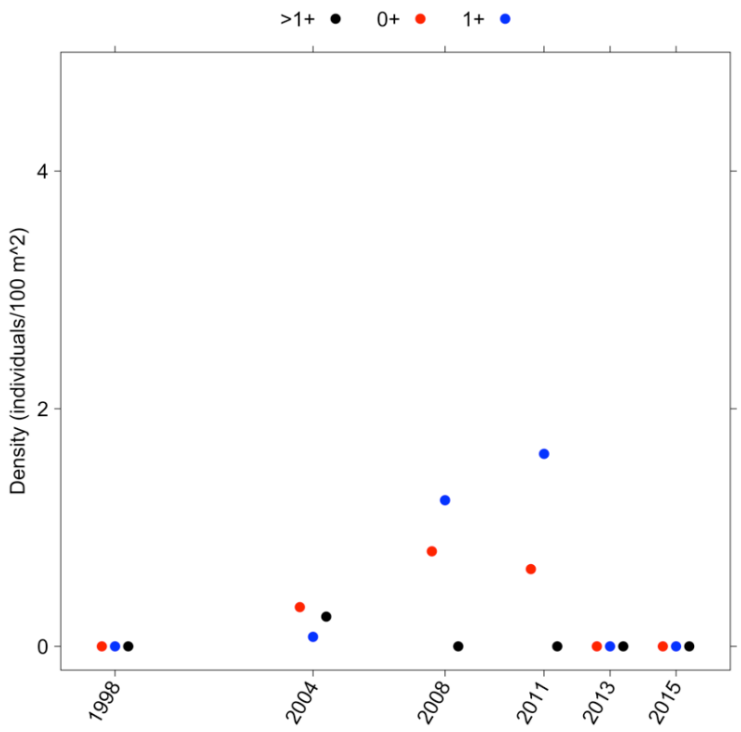

Figure 9. Change in Arctic charr density for 0+, 1+ and >1+, in the period 1998 to 2015. The restoration process started in 2006.

3.3 Spatio-temporal development of the salmonid juveniles production

The mean zone-wise brown trout juvenile density was 61.6±37.4 (inds/100 m^2, ±SD) in 2015. This is the by far highest juvenile brown trout density recorded since the monitoring was initiated in 2008. Same numbers were 34.0±36.4, 39.1±36.2 and 37.3±29.6 for 2008, 2011 and 2013, respectively. There is also an evident spatial pattern in the density development over time as zones between 4 and 10 have become increasingly more important production areas for brown trout during the 2008-2015 period– peaking in 2015 (Figure 11).

The mean zone-wise Atlantic salmon juvenile density is clearly lower than for brown trout juveniles, but a similar spatio-temporal development was found. In 2015, the mean total Atlantic salmon density was 8.1±9.4 inds/100 m^2. This is all-time high densities for the 2008-2015 period. Same numbers were 2.8±5.1 and 3.9±4.9 for 2008 and 2011, respectively. Just four Atlantic salmon individuals were captured in 2013. The same spatial pattern in the density development over time as observed in brown trout, was evident also for Atlantic salmon: zones between 4 and 10 have become increasingly more important production areas during the 2008-2015 period– peaking in 2015 (Figure 12).

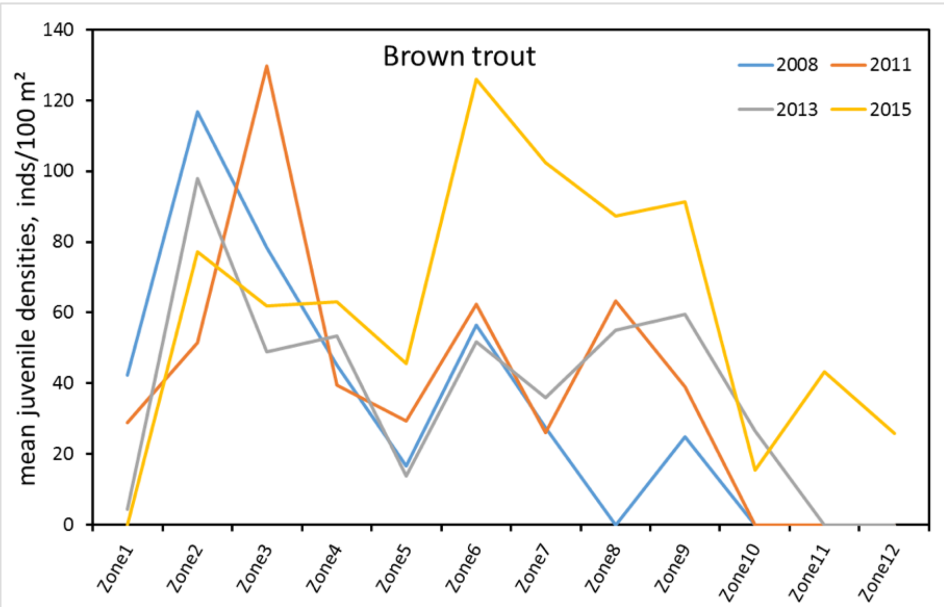

Figure 10A. Spatio-temporal juvenile density pattern in brown trout (A) and Atlantic salmon (Figure 10B) from Bognelv during 2008-2015 period. Densities represent mean total density per zone, i.e., total densities of 0+, 1+ and >1+.

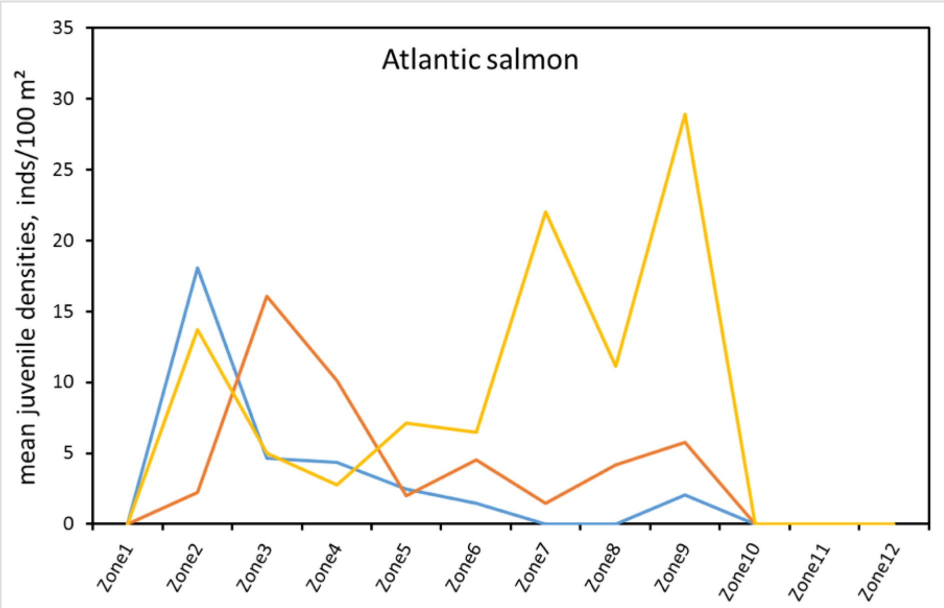

Figure 10B.

3.4 The distribution of brown trout density between zones

Variation in brown trout density among zones for age groups was tested with a one-way Welsh Anova test (Table 3). As seen in Figure 11, the test revealed significant variation in brown trout density among zones for the different age groups.

Table 3. One-way Welsh anova test revealing differences among zones for brown trout age groups. *** indicates a significant level <0.001.

Age group	F	df.Num	df.Den	p-value
0+	12.008	8.000	58.637	***
1+	5.334	8.000	60.324	***
>1+	5.9882	8.000	58.846	***

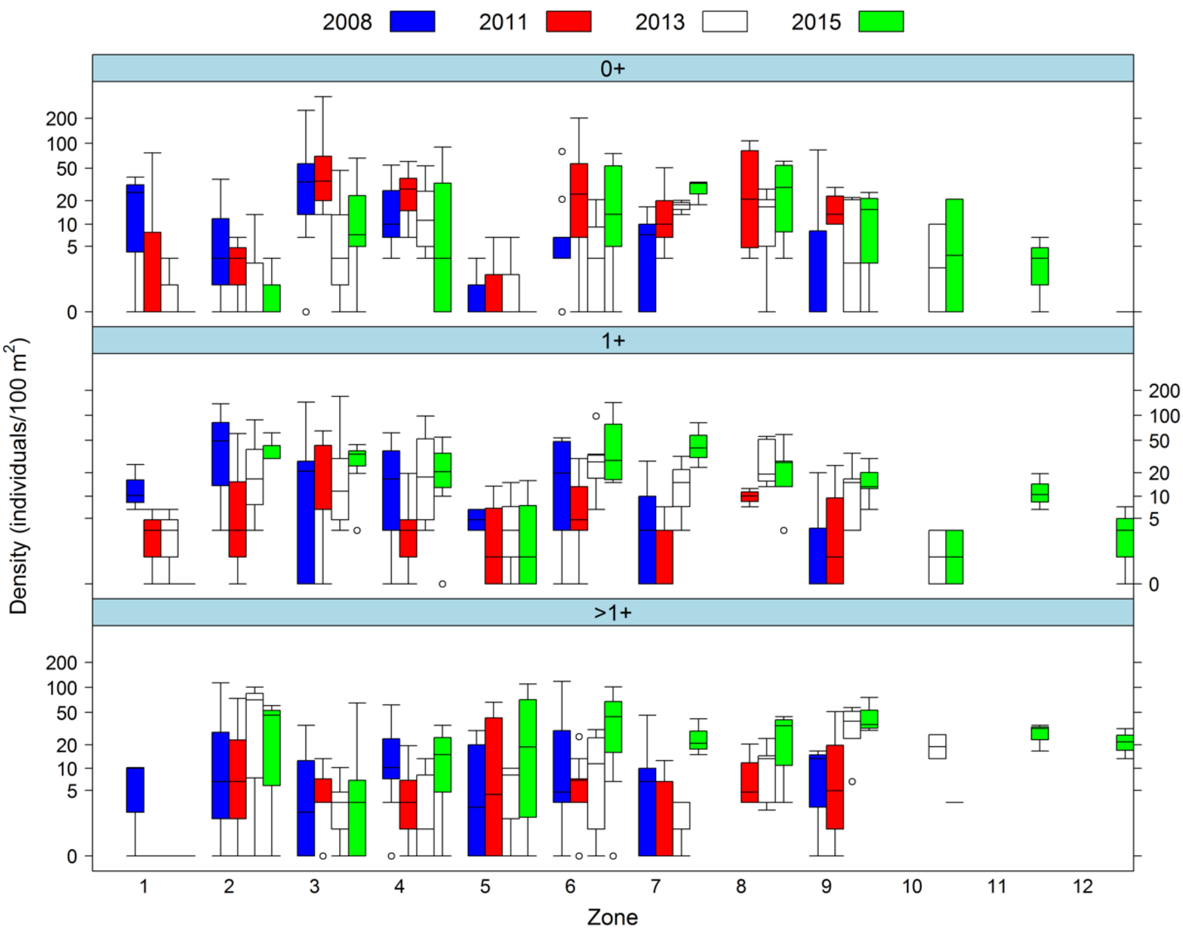

Figure 11. Box plot showing differences in density of brown trout age groups among zones. Zone 10 was added in 2013 and Zone 11 and 12 were added in 2015.

3.5 Effects of environmental variables on densities of juvenile brown trout and Atlantic salmon

0+ brown trout density - 2008 to 2015

There were two models predicting densities for 2008, 2011, 2013 and 2015 with an ΔAICc below 2 (Appendix 5, Table A1). The most supported model to describe 0+ density was; Depth average * Days * 1+ density * Mean temp. The backward-selected model version is presented in Appendix 5, Table A2 with a significant effect on 0+ density ($F_{9,173}$=8.938, p<0.05, R^2_{adj}=0.28). The 0+ density decreased with increasing depth, increased with increasing duration of growth period and increased with increasing mean temperature during the growth period (Figure 11, Appendix 5, Table A2). With a short growth period, high mean temperature during growth period and low 1+ densities, the 0+ density is high (Figure 11). During a medium – long growth period, the 0+ density is highest at low mean temperature during growth period and at high 1+ densities (Figure 12).

0+ brown trout density - 2011 to 2015

There were two models predicting 0+ densities for 2011, 2013 and 2015 with an ΔAICc below 2 (Appendix 5, Table A3). The most supported model to describe 0+ density was; Moss + Depth average + 1+ density. The model had a significant effect on 0+ density ($F_{3,131}$=12.6, p<0.05, R^2_{adj}=0.20). The 0+ density decreased with increasing cover of moss on the bottom substratum and with increasing depth (Table 4). The density of 0+ increased with increasing 1+ density (Table 4).

Table 4. Parameter estimates for the selected linear model (i.e., lowest AIC score in Appendix 5, Table A3) fitted to predict environmental variables effect on 0+ density, data from 2011, 2013 and 2015. The response variable and 1+ Density was ln-transformed. *** indicates a significance level of p<0.001.

Coefficients	Estimate	Std. Error	t-value	Pr(>|t|)
Intercept	2.830744	0.364873	7.758	***
Moss	-0.65065	0.166368	-3.911	***
Mean depth	-0.014869	0.006537	-2.275	0.024551
1+ density	0.36999	0.09261	3.995	***

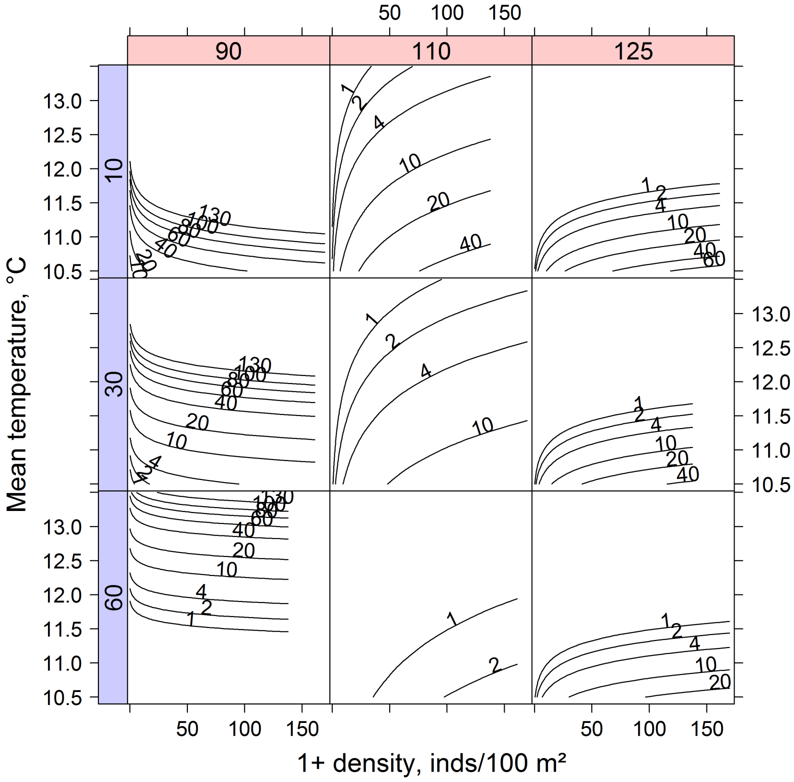

Figure 12. Prediction contour plot of the most supported 0+ density model for 2008, 2011, 2013 and 2015. Blue bars display mean depth (cm); red bars display duration of growth period (days).

0+ Atlantic salmon density

There were five models predicting 0+ density with ΔAICc below 2 (Appendix 5, Table A4). The most supported model to describe 0+ density became; Depth + Distance from E6. The model had a significant effect on 0+ density, but explained very little of the density variation ($F_{2,132}$=4.4.94, $p<0.05$, R^2_{adj}=0.05). 0+ density increased significantly with increasing distance from E6. Depth had no significant effect on 0+ density (Table 5).

Table 5. Parameter estimates for the selected linear model (i.e., lowest AIC score in Appendix 5, Table A4) fitted to predict environmental variables effect on 1+ density, data from 2008, 2011, 2013 and 2015. The response variable was ln-transformed. *** indicates a significance level of p<0.001.

Coefficients	Estimate	Std. Error	t-value	Pr(>|t|)
Intercept	3.98E-02	1.37E-01	0.29	0.77227
Depth	6.09E-04	3.06E-03	0.199	0.84247
Distance from E6	1.74E-04	5.83E-05	2.983	0.00339

1+ brown trout density – 2008 to 2015

There were two models predicting 1+ density for 2008, 2011, 2013 and 2015 withΔAICc below 2 (Appendix 5, Table A5). The most supported model to describe 0+ density was; Depth average * Velocity + Gravel. The model had a significant effect on 1+ density ($F_{4,180}$=9.416, p<0.05, R^2_{adj}=0.15). The 1+ density increased with increasing depth and gravel size, velocity had no significant effect on 1+ density, but in relation to depth the 1+ density was significant lower in areas with increasing depth and velocity (Figure 13, Appendix 5, Table A6).

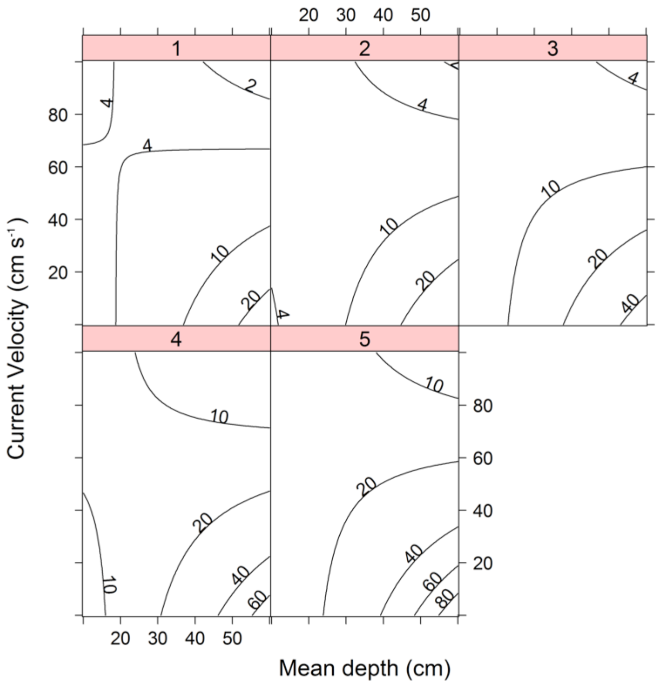

Figure 13. Predicted contour plot of the most supported 1+ density model in 2008, 2011, 2013 and 2015. Red bars display the different gravel categories; 1: 0-2 mm, 2: 2-20 mm, 3: 20-100 mm, 4: 100-250 mm, 5: >250 mm.

1+ brown trout density – 2011 to 2015

There were eight models predicting 1+ densities for 2011, 2013 and 2015 with ΔAICc below 2 (Appendix 5, Table A7). The most supported model to describe 1+ density was; Depth average + Algae. The model had a significant effect on 1+ density ($F_{2,134}$=11.39, p<0.05, R^2_{adj}=0.13). The 1+ density increased significantly with increasing depth, algae had no significant effect on 0+ density (Table 6).

Table 6. Parameter estimates for the selected linear model (i.e., lowest AIC score in Appendix 5, Table A7) fitted to predict environmental variables effect on 1+ density, data from 2011, 2013 and 2015. The response variable was ln-transformed. *** indicates a significance level of p<0.001.

Coefficients	Estimate	Std. Error	t-value	Pr(>|t|)
Intercept	1.910334	0.437778	4.364	***
Depth average	0.024031	0.005765	4.168	***
Algae	-0.115963	0.151721	-0.764	0.446

3.6 Effects from environmental variables on juvenile brown trout and Atlantic salmon length

0+ brown trout length – 2008 to 2015

There were two models predicting 0+ length for 2008, 2011, 2013 and 2015 with ΔAICc below 2 (Appendix 5, Table A8). The most supported model to describe 0+ length was; River section + Mean temp. + Days. The model had a significant effect on 0+ length ($F_{3,863}$=74.1, p<0.05, R^2_{adj}=0.20). The 0+ length was greater in the lower river section and smaller in the upper river section, 0+ length increased with increasing duration of growth period and increased with increasing mean temperature during growth period (Table 7).

Table 7. Parameter estimates for the selected linear model (i.e., lowest AIC score in Appendix 5, Table A8) fitted to predict environmental variables effects on 0+ length, data from 2008, 2011, 2013 and 2015. Default River section (intercept) is “Lower river section” and other levels effect have been estimated relative to this default level. *** indicates a significance level of p<0.001.

Coefficients	Estimate	Std. Error	t-value	Pr(>|t|)
Intercept	9.42035	2.19281	4.296	***
Upper river section	-1.94879	0.31789	-6.13	***
Mean temp.	1.37429	0.14983	9.172	***
Days	0.15382	0.01215	12.664	***

0+ brown trout length – 2011 to 2015

There were one model predicting 0+ length for 2008, 2011, 2013 and 2015, with ΔAICc below 2 (Appendix 5, Table A9). The most supported model to describe 0+ length was; Gravel * Zone * Mean temp. This model was dismissed since parameter estimates produced NAs for different zones, since in some zones there were only a few or no sampled fish for the different years. The next most supported model to explain length was; River section * Gravel

* 1+ Density * Mean temp, this model had ΔAIC over 2 (Appendix 5, Table A9). The backward-selected model version is presented in Appendix 5, Table A10. The model had a significant effect on 0+ length ($F_{14,591}$=7.543, $p<0.05$, R^2_{adj}=0.13). In the lower and upper river section, the relation between gravel size, mean temperature and 1+ density had different effects on 0+ length (Appendix 5, Table A10). Lower river section; 1. Areas with small gravel size (category 1 & 2) had the greatest 0+ length with high mean temperature during growth period and low 1+ densities (Figure 14). 2. Areas with medium gravel size (category 3) had greatest 0+ length at low mean temperature during growth period and high 1+ densities (Figure 14). 3. Areas with large gravel size (category 4 & 5) had greatest 0+ length with low mean temperature during growth period and high 1+ densities (Figure 14). Upper river section; 1. Areas with low (category 1& 2) and medium (category 3) gravel size had greatest 0+ length with high mean temperature during growth period and high 1+ densities (Figure 14). 2. Areas with large gravel size (category 4 & 5) had greatest 0+ length with low mean temperature during growth period and low 1+ densities (Figure 14).

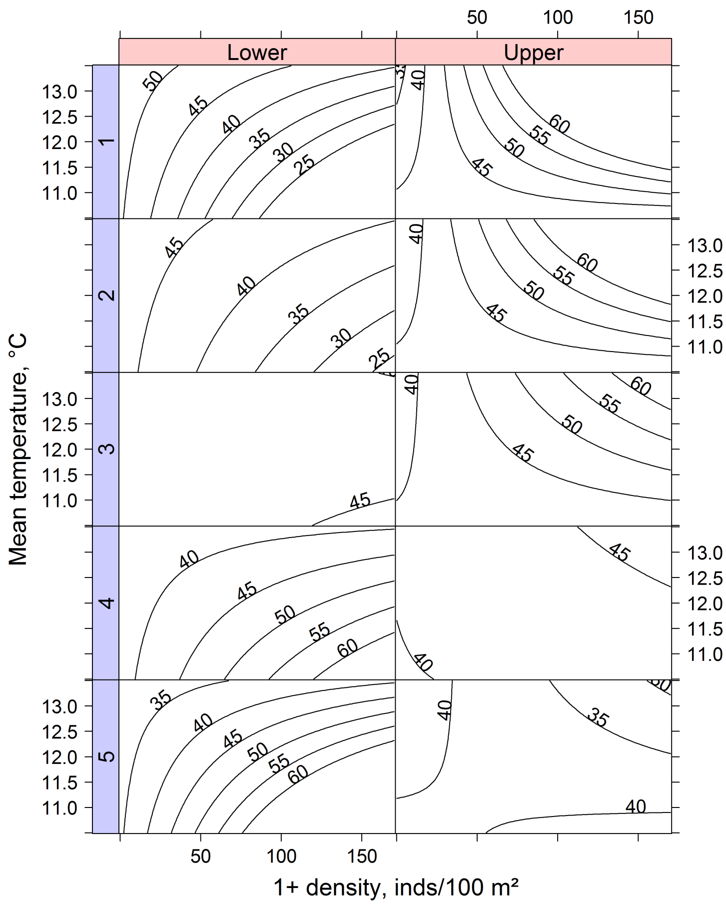

Figure 14. Predicted contour plot of the most supported 0+ length model in 2011, 2013 and 2015. Red bars display the different river sections. Blue bars display the different gravel categories; 1: 0-2 mm, 2: 2-20 mm, 3: 20-100 mm, 4: 100-250 mm, 5: >250 mm.

0+ Atlantic salmon length

There were four models predicting 0+ length with ΔAICc below 2 (Appendix 5, Table A11). The most supported model to explain 0+ length became; Distance from E6 * 1+ Density. The model had a significant effect on 0+ length ($F_{3,47}$=4.943, $p<0.05$, R^2_{adj}=0.19). 0+ length increased with increasing distance from E6 and 1+ density has a negative effect on length with increasing distance from E6 (Figure 15, Appendix 5, Table A12).

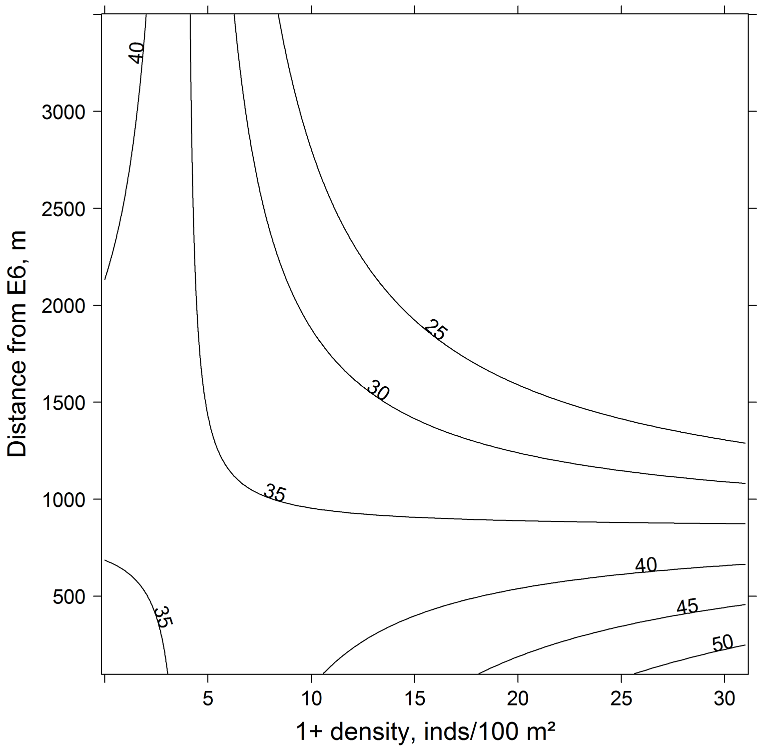

Figure 15. Prediction contour plot of the most supported 0+ length model for Atlantic salmon.

3.7 Restoration measures effect on brown trout and Atlantic salmon density

Restoration measures effect on brown trout 0+ and 1+ density

When testing without correcting for environmental variables in a linear model, there was no significant difference in 0+ density between restored and unrestored stations (p=0.14). There was no significant effect of time since restoration and time since last restoration measure on 0+ density (p=0.61 and p=0.09, respectively). However, there were a significant difference in effect on 0+ brown trout density between the different types of restoration measures ($F_{3,179}$=7.57, $p<0.05$). The highest 0+ brown trout densities were found in areas with weirs, the second-highest 0+ density was found in areas with riparian modifications and the lowest 0+ brown trout density was found in side channels. There was no significant difference in 1+ density between restored and unrestored stations, or between the different types of restoration measures ($p=0.37$, $p=0.63$). Nor was there a significant effect of time since restoration and time since last restoration on 1+ density ($p=0.09$ and $p=0.31$, respectively).

Restoration measures effect on 0+ Atlantic salmon density

When testing without correcting for environmental variables in a linear model, there was no significant difference in 0+ density between restored and unrestored stations ($F_{1,136}=2.23$, $p=0.14$) There was a significant effect of time since restoration on 0+ density ($F_{1,136}=4.33$, $p<0.05$), the 0+ density increased with increasing time since restoration. Time since last measure had a significant effect on 0+ density ($F_{1,136}=4.698$, $p<0.05$), 0+ density increased with increasing time since last measure. Type of restoration measure had a significant effect on 0+ density ($F_{1,134}=5.25$, $p<0.05$), the highest 0+ Atlantic salmon density was found in areas with weirs, the second highest density was found in areas with riparian modifications and the lowest 0+ density was found in side channels.

Restoration measures effects when added to the most supported environmental variable model for brown trout and Atlantic salmon density

0+ brown trout density – 2008 to 2015

0+ density for 2008, 2011, 2013 and 2015 was best explained if type of restoration measure was added to the most supported model presented in Appendix 5, Table A1. The model became; Depth average * Days * 1+ Density * Mean temp. + Type of measure. The backward-selected model version is presented in Appendix 5, Table A2, the model had a significant effect on 0+ density ($F_{12,170}=9.95$, $p<0.05$, $R^2_{adj}=0.37$). 0+ density was significantly higher in areas with weirs, second highest in areas with riparian modifications, while the lowest density of 0+ brown trout was found in side channels and tributaries (Appendix 6, Figure A1-A4, Table A13).

0+ brown trout density – 2011 to 2015

0+ density for 2011, 2013 and 2015 was best explained if type of restoration measure was added to the most supported model presented in Appendix 5, Table A3, there were no other models with ΔAICc below two. The model became; Moss + Depth + 1+ Density + Type of measure. The model had a significant effect on 0+ density ($F_{6,128}$=13.64, $p<0.05$, R^2_{adj}=0.36). The different types of restoration measures had different effects on 0+ density, 0+ density was significantly higher in areas with weirs, second highest 0+ density was found in areas with riparian modifications, while the significantly lowest density of 0+ brown trout was found in side channels and tributaries (Figure 16, Appendix 6, Table A14).

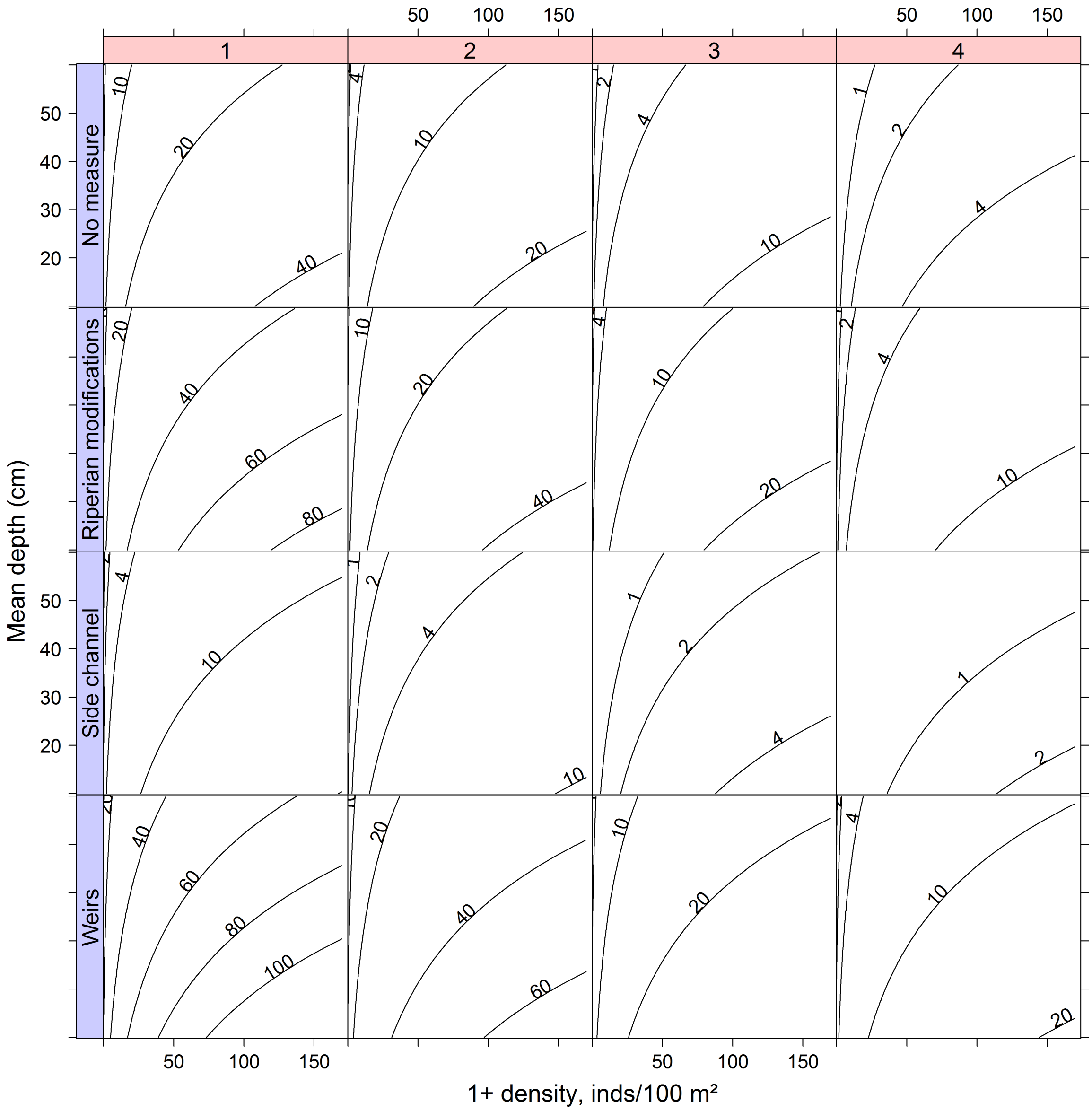

Figure 16. Prediction contour plot of the most supported 0+ density model in 2011, 2013 and 2015 with addition of type of restoration measure. Red bars display the different moss categories; 1: 0 %, 2: 1-33 %, 3: 34-66 %, 4: >66 %. Blue bars display the different type of restoration measures.

0+ Atlantic salmon density

0+ density was best explained if type of restoration measure was added to the most supported model presented in Appendix 5, Table A4, there were no other models with ΔAIC below two. The model became; Depth + Distance from E6 + Type of measure. The model had a significant effect on 0+ density ($F_{5,132}$=3.75, p<0.05, R^2_{adj}=0.09). The 0+ density was significantly higher where weirs were conducted, second highest in areas with riparian modifications and lowest in side channels and tributaries (Table 8).

Table 8. Parameter estimates for the selected linear model (i.e., lowest AIC score in Appendix 5, Table A4) fitted to predict effects of environmental variables and restoration effects on 0+ density, data from 2008, 2011 and 2015. Default Type of measure (intercept) is "No measure" and other levels effect have been estimated relative to this default level. The response variable was ln-transformed. *** indicates a significance level of p<0.001.

Coefficients	**Estimate**	**Std. Error**	**t-value**	**Pr(>|t|)**
Intercept	1.05E-01	1.38E-01	0.758	0.45
Depth	1.47E-04	3.01E-03	0.049	0.9611
Distance from E6	1.13E-04	6.60E-05	1.705	0.0905
Type of measure - Riparian modifications	1.95E-01	0.1767361	1.106	0.2708
Type of measure - Side channel	-1.45E-01	0.1544898	-0.939	0.3494
Type of measure - Weirs	6.24E-01	2.71E-01	2.302	0.0229

1+ brown trout density – 2008 to 2015

The 1+ density was best explained by the most supported model in Appendix 5, Table A5, without any restoration measures for the years 2008, 2011, 2013 and 2015.

1+ brown trout density – 2011 to 2015

The 1+ density was best explained by the most supported model in Appendix 5, Table A7, without any restoration measures for the years 2011, 2013 and 2015.

3.8 Restoration effects on brown trout and Atlantic salmon length

Restoration measures effect on 0+ brown trout length

When testing without correcting for environmental variables in a linear model, there was a significant difference in length between different types of measures ($F_{3,863}$=7.32, p<0.05). The significantly greatest 0+ brown trout length was found in areas with weirs, second greatest length was found in areas with riparian modifications and significantly lowest 0+ brown trout length was found side channels. There was no difference in 0+ length between restored and unrestored stations (p=0.46). Time since restoration and time since last measure had no effect 0+ length (p=0.56 and p=0.05, respectively).

Restoration measures effect on 0+ Atlantic salmon length

When testing without correcting for environmental variables in a linear model, there was no difference in 0+ length between restored and unrestored stations (p=0.12). Time since restoration and time since last measure had no effect on 0+ length (p=0.27 and p=0.36, respectively). Type of restoration measure had a significant effect on 0+ length ($F_{3,47}$=4.63, p<0.05). 0+ Atlantic salmon length was greater in side channels, while riparian modifications and weirs had little effect on 0+ Atlantic salmon length.

Restoration measures effects when added to the most supported environmental variable model for brown trout and Atlantic salmon length

0+ brown trout length – 2008 to 2015

0+ length for 2008, 2011, 2013 and 2015 was best explained if time since restoration was added to the most supported model presented in Appendix 5, Table A8. There were no other models with ΔAICc below two. The model became; River section + Mean temp + Days + Time since restoration. The model had a significant effect on 0+ length ($F_{4,862}$=58.53, p<0.05, R^2_{adj}=0.20). 0+ brown trout length decreased with increasing time since restoration (Table 9).

Table 9. Parameter estimates for the selected linear model (i.e., lowest AIC score in Appendix 5, Table A8) fitted to predict effects of environmental variables and restoration effects on 0+ length, data from 2008, 2011, 2013 and 2015. Default is Lower river section (intercept) and other levels effect have been estimated relative to this default level. The response variable was ln-transformed. *** indicates a significance level of p<0.001.

Coefficients	Estimate	Std. Error	t-value	Pr(>|t|)
Intercept	8.69367	2.19455	3.961	***
Upper river section	-1.38723	0.36459	-3.805	***
Mean temp	1.29202	0.15144	8.532	***
Days	0.17314	0.0136	12.73	***
Time since restoration	-0.24205	0.07815	-3.097	0.002016

0+ brown trout length – 2011 to 2015

0+ length for 2011, 2013 and 2015 was best explained with; if an area was restored or not, was added to the most supported model presented in Appendix 5, Table A9, there was one other model with ΔAICc below two. The model became; River section * Gravel * 1+ Density * Mean temp + Restored Yes/No. The backward-selected model version is presented in Appendix 6, Table A15. There was a significant difference in 0+ length between restored and unrestored station ($F_{15,590}$=7.37, p<0.05, R^2_{adj}=0.135), 0+ brown trout length increased in areas that were restored (Appendix 6, Figure A5-A6, Table A15).

0+ Atlantic salmon length

The 0+ length was best explained by the most supported model in Appendix 5, Table A11, without any restoration measures, there were one other model with ΔAIC below two which is the most supported model with the addition of type of restoration measure.

3.9 Macroinvertebrates

Diversity

Model selection of the macroinvertebrate diversity, measures as Shannon-Wiener index (SWI), favored a three-way interaction effect model between type of measure, distance to E6 and current velocity (Table 10). This model attained an AIC score at 6.3 units lower than the second-most supported model. After undertaking backward selection, the three-way interaction term and a two-way interaction term were removed resulting in the final model presented in Table 11. This model predicted SWI to generally increase with both distance to E6 and current velocity, but in somewhat different ways among type of measures. In general, SWI was highest in areas with riparian modifications and second highest in side channels. Areas with weirs had about similar SWIs as unrestored areas.

Table 10. AICc-based model selection statistics for candidate models fitted to predict Shannon-Wiener index based on macroinvertebrate data from Bognelv during September 2015. K = number of estimated parameters; MoldelLik= Model likelihood; AICcWt= the model AICc weight; LL=model log likelihood. All models were fitted using log-likelihood method. ToM=Type of Measure; DistE6=Distance from E6; CurrVel=Current Velocity

Model structure	K	AICc	ΔAICc	ModelLik	AICcWt	LL
ToM*DistE6*CurrVel	17	181.240	0.000	1.000	0.914	-71.495
ToM*DistE6	9	187.499	6.259	0.044	0.040	-84.157
DistE6*CurrVel	5	188.989	7.748	0.021	0.019	-89.302
ToM*DistE6*CurrVel*CanopyR	32	189.234	7.994	0.018	0.017	-54.431
ToM*DistE6*CurrVel*EdgeVeg	32	191.010	9.770	0.008	0.007	-55.319
ToM*CurrVel	9	192.801	11.561	0.003	0.003	-86.808
ToM*DistE6*CurrVel*Subst	32	202.198	20.958	0.000	0.000	-60.913
ToM	5	205.814	24.574	0.000	0.000	-97.715
ToM*MeanDepth	9	206.125	24.885	0.000	0.000	-93.470
ToM*AlgaeCat	9	209.940	28.700	0.000	0.000	-95.378

Table 11. Parameter estimates and corresponding test statistics for the selected linear model (i.e., lowest AIC score in Table 1) fitted to predict Shannon-Wiener index for benthic invertebrate data from Bognelv during August 2015. Default Type of Measure (intercept) is “No measure” and other level effects have been estimated relative to this default level. Model fit statistics: $F_{11,150}$=5.3; p-value: <0.0001; R^2_{adj}=0.27. ToM=Type of Measure; DistE6=Distance to E6; CurrVel=Current Velocity.

Parameter estimates				Effect test statistics				
Term	Category level	Estimate	SE	Effect	Df	SS	F	p
Intercept		0.16710	0.17570	ToM	3	1.335	2.807	0.0417
ToM	Riperian modification	0.97180	0.36880	DistE6	1	3.894	24.557	<0.0001
ToM	Side channel	0.46960	0.21420	CurrVel	1	1.246	7.858	0.0057
ToM	Weirs	0.16660	0.27330	ToM*DistE6	3	1.075	2.259	0.0839
DistE6		0.00009	0.00003	ToM*CurrVel	3	1.695	3.562	0.0158
CurrVel		0.00906	0.00318					
ToM*DistE6	Riperian modification	0.00003	0.00014					
ToM*DistE6	Side channel	-0.00016	0.00007					
ToM*DistE6	Weirs	0.00026	0.00010					
ToM*CurrVel	Riperian modification	-0.01293	0.00860					
ToM*CurrVel	Side channel	0.00175	0.00480					
ToM*CurrVel	Weirs	-0.01526	0.00576					

Ordination

An initial unconstrained detrended correlation analysis (DCA) yielded a first-axis axis length value of 3.7 (SD), indicating response assemblage chiefly to be linearly distributed. We therefore proceeded with redundancy analyses (PCA-based) when exploring environmental and treatment effects on the macroinvertebrate community. The model selection procedure (AICc and both-directional-selection) among candidate RDAs yielded a predictor structure with mean depth, current velocity, river zone and type of measure as predictors. A permutation test revealed that all included predictors had a significant effect on the invertebrate community structure (Table 12). From the biplot in Figure 17 one can read that weir measure stations are positively associated with chironomids and depth, whereas current velocity is positively associated with side channels and riparian modification and the mayflies *Baetis muticus* and the *Centroptilum luteum*. Not surprising, the Gammarids are positively associated with Zone 1 (Appendix 7, Figure A7).

Table 12. Partial R^2 and effect p-values for the selected RDA fitted to explain variation in the macroinvertebrate community composition in Bognelv during August 2015. The model explains 46% (R^2_{adj}) of the total benthic invertebrate community variation.

Effect	R^2	p-value
Mean depth	0.120	0.001
Current velocity	0.054	0.015
Zone	0.434	0.001
Type of Measure	0.134	0.001

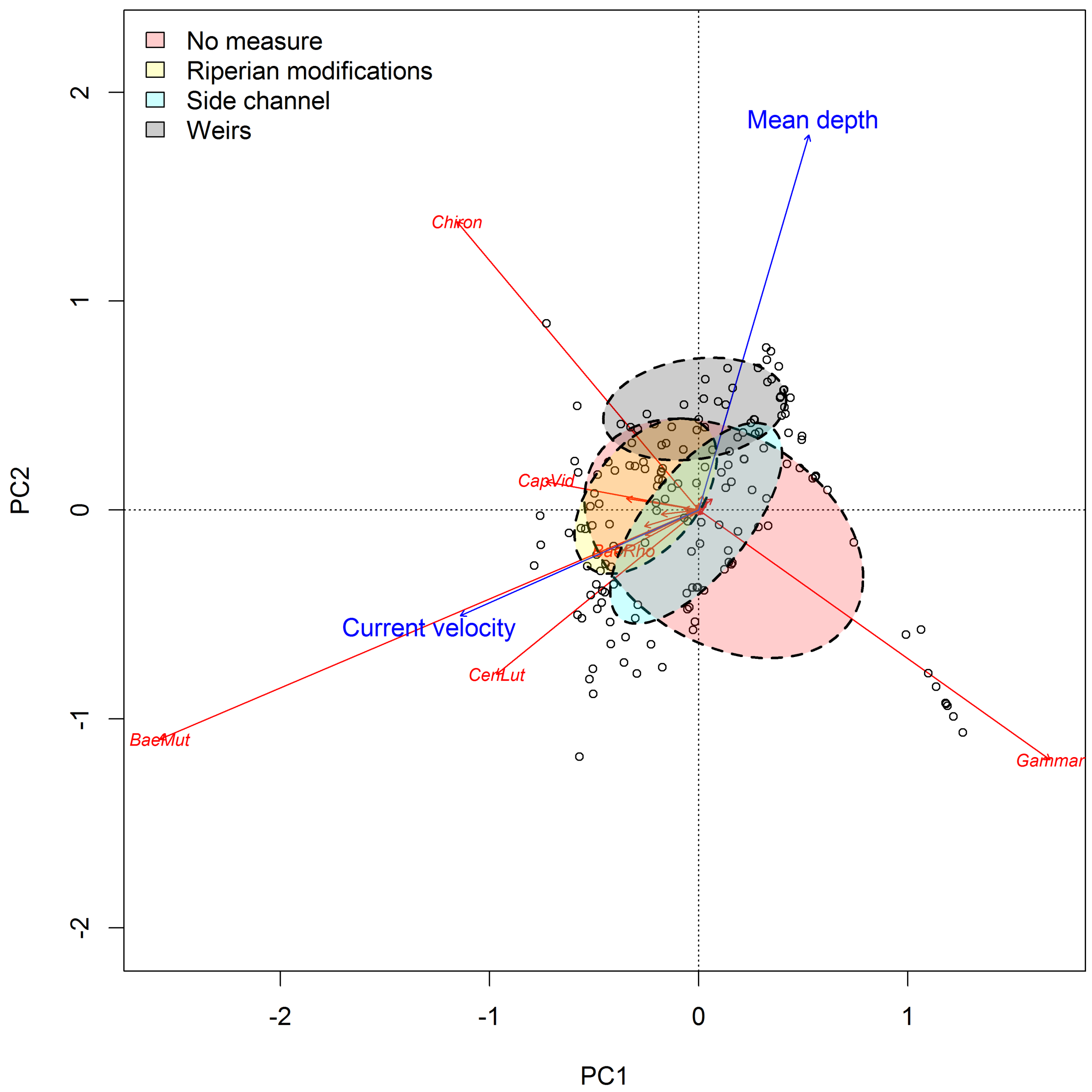

Figure 17. Biplot of the selected RDA (Table 12) where the five most influential species are shown as red vectors, continuous predictors as blue vectors and measure levels as 80% centroids. The zone-specific centroids are shown in Appendix 7, Figure A7.

4. Discussion

The trend in the years from 1998 to 2015 is an increase in density for all salmonids except Arctic charr. Brown trout responded quickly to the restoration measures with the highest overall mean production of juvenile brown trout in 2015. Atlantic salmon have also increased in density, but not as much as brown trout, with the highest overall mean production of juvenile Atlantic salmon in 2015. Arctic charr have been absent in electro-fishing sampling over the last two years, 2013 and 2015.

The most important environmental variables influencing juvenile Atlantic salmon and brown trout density and length were; Depth, duration of growth period, temperature during growth period, moss cover, 1+ density, gravel and distance from E6 (the estuary). Areas restored with weirs and riparian modifications had higher 0+ brown trout and Atlantic salmon densities, while the lowest densities were found in side channels and tributaries compared to density in unrestored areas. 0+ brown trout became smaller in length with increasing time since first restoration measure in 2006. 0+ brown trout was greater in length in areas with weirs and riparian modifications, while the length was smaller side channels and tributaries. 0+ brown trout was greater in length in restored areas than in unrestored stations. 0+ Atlantic salmon was greater in length in side channels and tributaries, while weirs and riparian modifications had little effect on length.

The mayflies *Baetis muticus* and *Centroptilum luteolum* were found in shallow habitats with higher water velocity. In habitats with increasing depth, slow floating water and restoration measures such as weirs, specimens from the family Chironomidae sp. were present. Gammaridea ssp. were found in shallow, brackish habitats with no restoration measures conducted and correlated positively with the most downstream zone 1.

To be able to assess effects of restoration measures a monitoring program is important to understand biological effects in a long-term perspective (Degerman 2008).

In the following, we will discuss our main findings in light of the addressed study aims.

Our first aim was to reveal why the restoration measures conducted in Bognelv over the last 10 years have increased the density of juvenile brown trout and not necessarily populations of Atlantic salmon or Arctic charr.

The restoration measures conducted in Bognelv have mainly being focused on re-opening side channels and tributaries, building of weirs and pools and increase the riparian vegetation (Sødal 2014). Our results show that both 0+ brown trout and 0+ Atlantic salmon tend to respond similarly towards the same restoration measures. As shown in Hesthagen and Larsen (2003), (Johnsen et al. 1999) and Weideborg et al. (n. d.), Atlantic salmon need more time to recover than brown trout. Johnsen et al. (1999) describes this phenomena as a result of low density of spawners. Hesthagen and Larsen (2003) presumes that at least 8-12 years are needed for more or less full recovery of Atlantic salmon after liming treatment. This assertion may be transferable to the situation in Bognelv. An explanation for the low catches of Atlantic salmon could be that the stations in earlier studies were located along river sides. Brown trout and Atlantic salmon differ in their habitat use, with the Atlantic salmon preferring more fast flowing water (Jonsson & Jonsson 2011). Sødal (2014) took this into account and located some of her stations mid river. Despite this, Sødal's salmon catches were extremely low. Other explanations for the low densities of Atlantic salmon could be the fact that Bognelv and its habitats have been degraded for decades and that the Atlantic salmon population need a longer period of time to recover. To be able to assess effects of restoration measures a monitoring program is important to understand biological effects in a long-term perspective (Degerman 2008).

Arctic charr have been absent during the two last surveys, and their densities were very low in 2004, 2008 and 2011 (Austvik 2012; Dønnum 2005; Schedel 2010; Sødal 2014). This may be due to the Arctic charr habitat requirements, as the Arctic charr are quite stationary and prefers cold water (Elliott & Elliott 2010; Klemetsen et al. 2003). One explanation for the low and absent catches of Arctic charr in all surveys, may be that our stations were placed in habitats not suitable for Arctic charr. Interestingly, fishermen catch Arctic charr in Bognelv every year (Lakseregisteret n. d.), and this fact substantiates our assertion that our stations are not placed in suitable habitat for Arctic charr. In an attempt to find Arctic charr elsewhere for comparative purposes, we sampled three sites in the neighboring river Alteidelva (Troms county). We found no charr in Alteidelva either. Another hypothesis in relation to the low numbers of Atlantic salmon, and especially Arctic charr, is that the river has been degraded too long to have indigenous stocks. On the other hand, we assume that there are indigenous stocks in Bognelv, and that the reason why we do not catch Arctic charr may be explained by the fact that our stations have been located at places not suitable for Arctic charr. The salmonids present in Bognelv today may also have come from other rivers nearby, but there are a few other rivers that drain into Langfjorden.

Despite documenting a general increase in brown trout density since the restoration process was initiated, we found large fluctuations in year-class strengths among surveys (Figure 7). In general Brown trout living in rivers are territorial, which means that space can be a factor regulating population density. Intercohort competition is believed to regulate survival of juvenile brown trout (Bohlin 1977). This kind of competition among year groups can be a factor in regulating the strength in different year-classes (Bohlin 1977; Hagstrøm 2012). Both Bohlin (1977) and Hagstrøm (2012) found evidence for intercohort competition among year classes of brown trout in their studies. They discovered a pattern, where high density of 0+ gives a low density in 1+, with succeeded with high density in 1+ and low density in 0+ age class the year after.

Juvenile Atlantic salmon often co-occur with brown trout and Arctic charr. With presence of Atlantic salmon and brown trout of similar size, brown trout tend to be more aggressive than Atlantic salmon. In interaction with Atlantic salmon, brown trout also tend to be more socially dominant to Atlantic salmon (Nislow et al. 2011). Atlantic salmon differ in habitat preferences compared to brown trout and Arctic charr. As Atlantic salmon often are associated with habitats with rapid flowing water, brown trout and Arctic charr prefer slower floating habitats (Nislow et al. 2011).

Our second aim was to investigate potential environmental variables (independent of restoration measures) that influence fish density, fish length and macroinvertebrate diversity

Environmental variables effect on brown trout and Atlantic salmon density

The most important environmental variables correlated with 0+ brown trout density were; depth, duration of growth season (days), mean temperature during growth season and moss cover. Depth is considered to be an important environmental variable for brown trout (Heggenes et al. 1999), and was found to be important in predicting 0+ brown trout density in our most supported models. Our models showed that 0+ brown trout density decreased with increasing depth, which is in accordance to literature on brown trout habitat requirements, where it has been shown that brown trout parr <7 cm prefer shallow areas of the stream, and as they grow they, will move into deeper habitat (Bohlin 1977; Kennedy & Strange 1982; Maki-Petäys et al. 1997). Temperature was an important environmental variable for 0+ density in our study. Mean temperature during growth season in this study were measurements of air temperature, and can be used as a substitute for water temperature, since water temperature follows air temperature closely in shallow rivers (Stefan & Preud'homme 1993). Temperature can affect the aggressiveness in brown trout (e.g. inter- and intraspecific competition) and therefor also regulate 0+ density in the river. Aggressiveness is reduced at lower temperatures (Fraser et al. 1993; Heggenes et al. 1993; Heggenes et al. 1999).

The study of 0+ brown trout density also revealed a difference in density in relation to duration of growth season (first snow off day – time of data sampling), a short growth season (90 days) had higher 0+ densites than in a longer growth season (125 days). 0+ density in relation to duration of growth season must be seen in relation to 0+ brown trout growth since the size of the 0+ brown trout can explain 0+ densities (e.g. competition, survival etc.). Lie & Sørensen (2013) hypothesize that high March and April temperature affect the alevin development negatively. And therefore influence first-year growth in brown trout in river Leira, based on the studies of Fleming & Gross (1990) and Jonsson & Jonsson (1999) where they found that larva size at hatching decreased with increasing incubation temperature. Lie & Sørensen (2013) further discussed that time for alevin emergence must be seen in relation to food availability, and that early spring (i.e. long growth season) could also mean an early hatching of macroinvertebrates while the alevins have not yet emerge from the gravel and that when the alevins finally emerge from the gravel they have missed the peak of drifting macroinvertebrates. While in a shorter growth season (i.e. late spring) the peak of drifting macroinvertebrates will occur during the same time as the alevins emerge from the gravel. This might be a reason for our findings of higher 0+ brown trout density in a short growth season and lower 0+ brown trout density in a long growth season. River Leira is located in southern Norway with a earlier spring than Northern Norway, where the winter season is usually at least on month longer i.e., peak of drifting macroinvertebrates occurs at least a month later than in southern Norway.

Moss cover was an important environmental variable in our most supported 0+ brown trout density model. Juvenile brown trout <7 cm frequently hide in river mosses when available (Heggenes 1988). Our study showed that moss cover had a negative effect on 0+ brown trout density, and this might be seen in relation to which type of moss community that is dominant in the river. Liver moss is a community that consist of species that form a dense mat on the bottom substratum, while the river moss community form long tufts (Heggenes & Saltveit 2002). Heggenes and Saltveit (2002) found that the river moss community increased the density of brown trout, while results for the liver moss community were inconclusive. The moss community that is dominant in Bognelv is liver moss (observations), and Heggenes and Saltveit (2002) stated that moss cover can both have a direct and indirect impact on the fish community, as they affect habitat and food availability. Furthermore, liver moss and river moss will have different effects on density due to their different growth forms i.e. different effects on the bottom structure. The liver moss creates a habitat of continuous carpet on the substrate, usually with sand underneath and it is known that brown trout in rivers do not prefer the finest substrates (Heggenes et al. 1999; Heggenes & Saltveit 2002).

The most important environmental variables on 0+ Atlantic salmon density was; depth and distance from estuary (Distance from E6). Depth had no statistically significant effect on 0+ Atlantic salmon in our most supported 0+ Atlantic salmon density model. But it seems reasonable to believe that depth is an important abiotic factor that will effect 0+ Atlantic salmon density, and that this effect might be biased in the statistical analysis based on the low catches of 0+ Atlantic salmon. Studies have shown that Atlantic salmon parr (<7 cm) are abundant in shallow areas of the river, but can also use a wide range of depths up to 100 cm (Baglinikre & Champigneulle 1982; DeGraaf & Bain 1986; Rimmer et al. 1984) (Heggenes et al. 1999). Distance from estuary (distance from E6) had a significant effect on 0+ Atlantic salmon density, and the 0+ density increased with increasing distance from the estuary. Some studies show that early-arriving Atlantic salmon migrate longer upstream to spawn and this may be an explanation for why the 0+ density is higher in the upper river sections than in the lower river section (Fleming 1996). 0+ Atlantic salmon usually do not migrate far from the red after the yolk-sac is consumed (Fleming 1996; Jonsson & Jonsson 2011) and this can also be an explanation as to higher 0+ density in the upper river section in relation to early-arriving Atlantic salmon. The total 0+ Atlantic salmon density was our sampled data, and this could be a result of the absence of stations located in habitats with lower water temperature and more rapid water flow (Elliott & Elliott 2010; Klemetsen et al. 2003).

The most important environmental variables correlated with 1+ brown trout density were; depth, gravel size and velocity. Depth was found to have an important effect on 1+ brown trout density in our most supported models, 1+ brown trout density increased with increasing depth. This is supported by Kennedy and Strange (1982), who found that 1+ brown trout were distributed in different depth-ranges and that there were higher 1+ brown trout density in mid-range depths. One of our most supported 1+ brown trout density models revealed a relationship between velocity and depth, where the highest 1+ densities was found in depths of 60 cm (mean) and in velocities below 20 cm s^{-1}. Brown trout parr are usually more abundant in less fast-flowing water and they rarely stay in areas where the water velocity exceeded 20 cm s^{-1} (Heggenes et al. 1999). Gravel had also an important effect on 1+ brown trout density in our most supported models as 1+ density increased with increasing gravel size. Brown trout prefer rivers with a stony bottom since this provide shelter, where they can hide from predators and high water velocities (Jonsson & Jonsson 2011). Juvenile brown trout >7 cm hide more between boulders than the smaller individuals, and an area with a structural complexity can increase population density since the presence of physical structures reduces territory size as they provide protection from aggressive competitors and predators (Bohlin 1977; Heggenes 1988; Jonsson & Jonsson 2011).

Environmental variables effect on 0+ brown trout and Atlantic salmon length

The most important environmental variables for 0+ brown trout length were; temperature during growth season, duration of growth season (days), 1+ density, river section and gravel. Temperature was included in both most supported models for 0+ brown trout length, and the length increased with increasing temperature. Fish are poikilotherms (ectotherms), meaning that the metabolic process and growth is influenced by temperature (Angilletta et al. 2002; Elliott 1976; Wootton 2012), and our results are therefore not unexpected. Growth influences important life-history stages such as survival rate, maturity age, age at smolting and the reproductive success of the fish (Jonsson & Jonsson 2011). A study of brown trout growth in twelve Norwegian rivers revealed higher growth rates in early summer than in late summer. This seasonal pattern was probably in relation to food availability. In northern Norway, the growth season is short and the emergence of macroinvertebrates is most concentrated in the first half of the summer (Huru 1986; Jensen 1990). Bærum et.al (2013) studied the interacting effects of temperature and density on resident brown trout growth performance in a small, cold forest stream in southern Norway. The study revealed that the general positive effect of temperature on growth minimised an negative effect of density on brown trout growth

(Bærum et al. 2013). They further argue that increased food availability with increasing temperature during summer growth season mitigate the negative density effect on growth (Bærum et al. 2013).

Duration of growth season was also an important environmental variable in our most supported 0+ brown trout length models, and the length of 0+ brown trout increased with increasing duration of growth season. This can be explained by the fact that increasing length of growth season has a positive effect on fish size, but length of growth season usually must be seen in relation to temperature during growth season due to temperature's effect on growth as discussed above (Brett 1979).

0+ brown trout length decreased with increasing gravel size but in relation to increasing 1+ brown trout the 0+ brown trout length increased in our most supported 0+ brown trout length models. The model revealed that the largest 0+ sizes in the lower river section was found in coarse gravel with high 1+ brown trout density, and that the largest 0+ sizes in finer substrates was found when 1+ brown trout density was low. In the upper river section, the largest 0+ sizes was found in finer substrates and when 1+ brown trout density was high. Jenkins et al. (1999) studied population density and individual growth for brown trout in streams and showed that individual growth decreased with increasing brown trout density. Finer substrates are often found in the shallower parts of Bognelv. As discussed above, juvenile brown trout <7 cm prefer shallower areas of the river. With the low 1+ brown trout density the 0+ brown trout length would not be regulated by 1+ brown trout density in finer substrates in Bognelv. Coarser gravel creates physical structures that act as shelter and reduces territory size, as they provide protection from aggressive competitors and predators. Thus, as supported in Jonsson and Jonsson (2011), high 1+ density will have little impact on 0+ brown trout length in relation to coarser gravel in Bognelv.

The most important environmental variables for 0+ Atlantic salmon length were; distance from estuary (distance from E6) and 1+ Atlantic salmon density. 0+ growth increased with increasing distance from E6 in our most supported 0+ Atlantic salmon length model. The length of 0+ Atlantic salmon increased with 0.003 mm for each meter from the estuary (distance from E6), meaning that 0+ Atlantic salmon living 3000 meter from the estuary had a 9 mm longer body length than 0+ Atlantic salmon living 100 meters from the estuary. Kristensen & Closs (2008) studied population dynamics of juvenile brown trout in a small

New Zealand river and revealed differences in length growth between the population living upstream and downstream in the river, with higher length growth in the population living downstream in the river. This is an opposite pattern to our findings in Bognelv. Our findings may be related to a combination of better growth conditions, less competition and food availability. 1+ Atlantic salmon density had a positive effect on 0+ Atlantic salmon growth in our most supported 0+ Atlantic salmon growth model. Imre et al. (2005, 2010) found a negative relationship between average body size of 0+ Atlantic salmon and population density of 0+ at the beginning and end of growth season and that density of 1+ Atlantic salmon counted for just a minor proportion of the variation in 0+ average body size. The findings in Imre et al. (2005, 2010) studies support our findings of 1+ Atlantic salmon density's positive effect on 0+ Atlantic length. The positive relationship between density of 1+ Atlantic salmon and 0+ Atlantic salmon length may also reflect that when conditions are generally good for 1+ Atlantic salmon, they are also god for 0+ Atlantic salmon. Since the juvenile densities for Atlantic salmon were generally low, the interaction effects are negligible.

Environmental variables effect on macroinvertebrate diversity

The most important environmental variables to describe macroinvertebrate diversity were; distance to estuary (E6) and velocity. In 2015 the diversity increased with increasing distance to estuary, the same phenomena were also found in Sødal (2014) study of Bognelv. This may be a function of the correlation between higher heterogeneity and higher diversity longer upstream river (Garcia et al. 2012). Macroinvertebrate diversity increased with increasing velocity.

An ordination analysis revealed a difference in preferred habitat for different species. *Baetis muticus* and *Centroptilum luteolum* preferred shallow areas with high current velocity. *Baetis rhodani* seems to be a habitat generalist, while *Capnia vidua* prefer somewhat deeper and slow-flowing areas of the river. Chironomidae ssp. was found in deeper water and with low current velocity. Plecoptera (Stoneflies) species are typically found in oxygen rich running waters, and the highest diversity of Plecoptera species are found in Finnmark county (Aagaard & Dolmen 1996).

Our third aim was to test restoration-measures-specific effects on juvenile salmonid species and the macroinvertebrate diversity.

Juvenile Atlantic salmon and brown trout response tor restoration measures

The results show differences in density and length in relation to type of restoration measure. Length and density of 0+ brown trout was greater in areas with weirs and riparian modifications, while the length and density decreased in side channels and tributaries compared to unrestored areas. 0+ Atlantic salmon density was higher in areas with weirs and riparian modifications, while their density was lower in side channels and tributaries compared to unrestored areas. Length of 0+ Atlantic salmon was greater in side channels, while riparian modifications and weirs had little effect on 0+ Atlantic salmon length. Studies have shown that brown trout parr <7 cm prefer shallow areas of the stream, and are usually more abundant in less fast-flowing water (Bohlin 1977; Heggenes et al. 1999; Kennedy & Strange 1982; Maki-Petäys et al. 1997). Atlantic salmon parr <7 cm are abundant in shallow areas of the river, but can also use a wide range of depths up to 100 cm and prefer fast-flowing habitats (Baglinikre & Champigneulle 1982; DeGraaf & Bain 1986; Heggenes et al. 1999; Rimmer et al. 1984). The weirs made in Bognelv provide such conditions, as they are built with rough stones, makes pools upstream and a more rapid water flow downstream (Figure 18). Also, building of weirs gives more water cover upstream, that in turn can be used as brown trout habitat. Riparian modifications may provide more cover (and food) in the river, and our results show that riparian modifications had a positive effect on 0+ Atlantic salmon density and 0+ brown trout density and length. Cover and food are obviously important for both Atlantic salmon and brown trout, and conducting riparian modifications may therefore have positive effect on 0+ brown trout density and length and 0+ Atlantic salmon density (Armstrong et al. 2003; Heggenes et al. 1999; Heggenes & Dokk 2001).

Our results show that 0+ brown trout length and density decreased in side channels compared to areas with no restoration measure. There are only a few side channels in Bognelv, and we do not believe side-channels have a strong effect on overall density and growth. Sødal (2014) mention that there have been problems with stable water flow in the side channels. Absence of water during winter, and low water-flow may be another explanation in why there are lower densities and smaller length in side channels and tributaries for 0+ brown trout. Furthermore, 0+ Atlantic salmon was greater in length in tributaries and side channels, while weirs and riparian modifications had little effect on 0+ Atlantic salmon length. The findings of larger 0+ size in tributaries and side channels was very surprising and not anticipated at all, since 0+ Atlantic salmon are not expected to be found in these slow-flowing of habitats. The results may be biased, by the fact that only the toughest and strongest (i.e., largest) individuals of 0+ Atlantic salmon can reside in these areas due to strong competition from brown trout (Nislow et al. 2011).

Weirs had little effect on 0+ Atlantic salmon length, but may influence length in older juvenile Atlantic salmon. As described above, the weirs conducted in Bognelv produce more rapid water flow and deeper areas, and this fits Atlantic salmon habitat preferences. The number of sampled 0+ Atlantic salmon is low, and may bias the result. 0+ Atlantic salmon densities have increased with increasing time since restoration, and this can be related to the highest overall mean density production of juvenile Atlantic salmon in 2015.

Our study showed that restoration measures conducted in Bognelv had no effect on 1+ brown trout density. This may be an indication that habitat preferred by 1+ brown trout are abundant in Bognelv, and that habitat is not a bottleneck for 1+ brown trout density.

Macroinvertebrate diversity response to restoration measures

Macroinvertebrates are an important nutrition source for salmonids (Stradmeyer & Thorpe 1987), and an ordination analysis was executed to examine macroinvertebrates response to restoration measures (Figure 17). Gammaridae ssp. density correlates with no measures, shallow water and high water velocity. Gammaridaes was identified to the family level only in our study, and it is therefore difficult to be specific in describing habitat preferences in detail. Hynes (1955) stated that several species in family Gammaridae ssp. live in brackish water. Gammaridae ssp. in Bognelv were concentrated to the lower part and the outlet of the river, which is close to Langfjorden. There are no restoration measures conducted in this section of the river.

Baetis muticus and Centroptilum luteolum was found in shallow places with high current velocity, with B. muticus preferring the highest water velocity. This is in acciordance with findings in Pardo and Armitage (1997) from the Mill Stream, England. Pardo and Armitage (1997) found that B. muticus preferred higher water velocity, while C. luteolum preferred somewhat lower current velocity. In the examination of Plitvice lake system, Croatia, Habdija et al. (2004) also found that B. muticus prefers high current velocity. Baetidae is important nourishment for brown trout and Atlantic salmon. Our results show that B. muticus tend to prefer restoration measures as riparian modifications, while C. luteolum tend to prefer opening of side channels (Figure 17). Nevertheless, both species have in common a lack of preference for habitats with weirs and increasing depth.

Baetis rhodani is plotted near to origo in the ordination analysis, and seems to be a habitat generalist, as the species tend to prefer restoration measures as side channels, riparian modifications and habitats without restoration measures. B. rhodani is important nourishment for brown trout (Bridcut 2000), and described as a species with flexible life cycle strategy, which enable it to select different water sheds (Bækken 1981). The flexibility in life cycle strategy supports our results in Bognelv.

Capnia vidua is another species who point out in the ordination analysis. C. vidua seems to prefer habitats with somewhat deeper and slower floating water. An investigation performed by Lillehammer (1985) showed that C. vidua have been sampled in running water in boreal and subalpine areas in Northern Norway and Sweden in Fennoscandia only.
An examination of Big Springs, Kansas, U.S. found that the highest macroinvertebrate diversity was in the pool habitat (Ferrington Jr et al. 1995).

Our results showed that the presence of Chironomidae ssp. correlated with deeper water, low water velocity and presence of weirs. We sampled a great amount of Chironomidaes, and this appear to be an important nutrition source. As shown in Figure 18, weirs make a rapid water flow down streams and more slow flowing water up streams. The weirs constructed in Bognelv seem to be suitable habitats for Chironomidae ssp. as they establish pool-like habitats with slow flowing water.

Figure 18. Picture showing weir and boulder structures in zone 7 in main river. The creek ravine of river Korselva can be seen in the background.

The most supported model to describe macroinvertebrate diversity, measured as Shannon-Wiener index (SWI), was type of measure, distance to E6 and current velocity. SWI was highest in areas with riparian modifications and second highest in side channels. Areas with weirs had about similar SWIs as unrestored areas. In earlier years, there were trends of increasing diversity with increasing distance from E6 (Sødal 2014). The same phenomena occurred with our collected macroinvertebrates. This may be a function of the correlation between higher heterogeneity and higher diversity (Garcia et al. 2012). Rempel et al. (1999) stated that highest macroinvertebrate density is to be found at stable river beds with low hydraulic stress. The side channels in Bognelv are often slow-floating and the riparian modifications may give more heterogeneity to the habitat (Figure 19). New side channels have not been restored since 2009 (Bjordal & Hoseth 2009). This seems to be enough time to establish stable river beds, and we hypothesize that the macroinvertebrate diversity may increase over the coming years. A study of rivers treated with rotenone in Norway showed that the macroinvertebrate community recovered rapidly (Johnsen et al. 1999). Areas with conducted riparian vegetation modifications may contain more organic matter. Brittain (1982) describes macroinvertebrates as mayflies as detritivore. Presence of riparian vegetation is likely an important source of nourishment (Bridcut 2000). As described above, different macroinvertebrates prefer different habitats. Variation in habitat may therefore be important to increase macroinvertebrate diversity, which in the next may be an important nutrition source.

Figure 19. A slow floating side channel with riparian vegetation, Bognelv, 2015.

As riparian modifications and opening of side channels and tributaries gave the highest macroinvertebrate diversities, these measures may produce areas with “food chamber” functions for down-stream salmonids.

Our fourth and final aim was to assess whether the ecological restoration processes of river Bognelv have begun, and what “works” and what “does not work”.

In river restoration projects, time-scale is important. Quick recovery of rivers can be achieved with small projects, but full recovery of rivers may take centuries (Davies-Colley et al. 2009; Pedroli et al. 2002). To further assess the success of the restoration measures, a monitoring program is important to get a full understanding of the biological effects in a long-term perspective (Degerman 2008).

As the first channelization measures were conducted in the 1930s, we have not been able to get catch statistics from the period before the degradation began. Comparing present salmonid population with the “pre-degradation population” would be valuable for assessing whether the restoration processes have started and how far from the original state the river is at present. Brown trout have dominated the sampling the last ten years, with low catches of Atlantic salmon and near absence of Arctic charr. As we do not have data from the period before channelization and flood secure measures, it is difficult to evaluate whether Bognelv actually maintained all three salmonids populations in high numbers or not. On the other hand, low catches of Atlantic salmon and Artic charr may indicate that Bognelv was primary a good brown trout river, with presence of Atlantic salmon and Artic charr. Yet reports of historic catches from before 1930s is of mostly Arctic charr (Ivar Mikalsen, pers. medd.). Notwithstanding this, it is only ten years since the first restoration measures were conducted and probably too early in the restoration process to conclude.

One explanation in why the density of Atlantic salmon is weaker than the brown trout density could be different recovery times for the species after restoration. Results from a study of the effect of liming in rivers in the Western and Southern Norway showed that Atlantic salmon was present one year after liming (Hesthagen & Larsen 2003). Furthermore, the study showed that the density increased significantly with the years after liming (Hesthagen & Larsen 2003). Our sampling from 2015 show an increase in the total density of Atlantic salmon, especially among the age groups >1+ and 0+. The total density in Atlantic salmon is “all time high” and may be a result of the fact that Atlantic salmon need more time to recover after restoration. The density of 0+ Atlantic salmon may support this theory, as the density of 0+ is the highest since the restoration process started.

There are also indicators from other river systems in Norway that brown trout are hardier and perhaps re-establish themselves in a river after extinction or near extinction sooner than Atlantic salmon. This is in accordance to Palm et al. (2007) study of River Kalix in Northern Sweden, where brown trout increased rapidly in density. It has been difficult to find references for this in terms of habitat destruction and restoration such as we have studied in Bognelv. However, many rivers with anadromous species on the south-west coast of Norway that were polluted by acid rain showed signs in the early 1990s of increasing brown trout numbers before Atlantic salmon, and with less effort in lime treatment (Weideborg et al. n. d.).

Since the first round of restoration measures in 2006, four more rounds of restoration measures have been conducted. For brown trout and Atlantic salmon, the densities have increased in density the last years. This may indicate that these species have responded positively to the restoration measures, and the restoration processes have started. For Arctic charr, the same cannot be said. On the other hand, Arctic charr were fished in 2015 by the locals, and the absence of Arctic charr in our data may be explained by biased sampling in that our stations have been located in habitats less suitable to Arctic charr.

The survey conducted in summer and autumn 2015 was the first to focus on macroinvertebrates in detail. In our opinion, it is too early to conclude whether the restoration processes have started among in the macro-invertebrate community and more investigations are needed. Furthermore, our results indicate that macroinvertebrates have responded well to the restoration measures. Riverside vegetation appears to have revegetated well so far and this will be a continuing process over the coming decades.

Looking at aerial fotos from early 1970s, Bognelv appears as a heavily channelized river with long stretches of flood protection- and erosion secure buildings. These structures are still present, and as far as we know, these sections will not be removed. However, some of these structures are broke down and some places, the meandering processes have been facilitated and this will change the river dynamics.

Potential sources of error

After finishing the field work, processing the data and writing this thesis, it is clear that there are some error sources in our study. During the electrofishing, sampling was primarily focused along the riverside and not in the middle of the river. As described above, brown trout and Atlantic salmon differ in habitat use, with brown trout preferring shallow, slow floating areas (Jonsson & Jonsson 2011). The fact that our sample sites was more concentrated along the riverside may have resulted in lower catches of Atlantic salmon, and thus biased estimated densities downwards. Two stations that were examined in earlier theses were forgotten, and this could have affected the total number of each species caught. Furthermore, these two stations were excluded from the statistical analysis. The total number of Atlantic salmon was low and Arctic charr were absent in our catch. This could be a result of the absence of stations located in habitats with lower water temperature and more rapid water flow (Elliott & Elliott 2010; Klemetsen et al. 2003).

All collected macroinvertebrates were classified to species, except specimens from some families. A source of error in this context may be incorrect classification of some specimens. We have not been able to find other studies of similar extent with similar environmental conditions in Scandinavia. This makes it difficult to compare our results with other reference studies. The environmental variables are on a quite rough scale, and have been the same in all the previous studies (Austvik 2012; Schedel 2010; Sødal 2014).

The fact that the environmental variables have been the same during the entire period makes it possible to compare registrations between years, but also inconsistent as different persons may classify the variables differently. The rough scale may also be too broad to capture real effects. Our reference zone is zone 1, in the lower part of the river. As discussed above, the location within the river constitutes different habitats. The reference zone is also located close to Langfjorden, and at high tide there are apparent influences of sea water. This affects e.g. the macroinvertebrate community, as Gammaridea ssp. prefers brackish water (Hynes 1955). We hypothesize that our reference zone to certain extent serves as a "transit-area" to salmonids that are migrating to the rest of Bognelv, and therefore not the most suitable reference.

Zippin's removal techniques was used to estimate densities for juvenile salmonids for all years, all stations were electro fished minimum two and maximum three pass for each station. Zippin's removal techniques depends on lower catches for each pass that was electro fished in a station. In some stations the catches were low in the first two passes but high in the last pass, which produced a problem for Zippin's removal techniques. In these stations, the total catch were divided by the estimated the overall catchability for a specie to produce population size. The total variation of the response variable are low in some statistical analysis due to low catches of fish e.g., 0+ Atlantic salmon density and therefore create bias in the results.

Suggestions for further measures and new surveys.

Several restoration measures have been conducted in Bognelv over the last decade. The river appears more nature-like today than just a decade ago. Our results show that pools positively affect both salmonids and macroinvertebrates. Building of more pools in the river may contribute to increasing the salmonid populations and diversify the water flow. Building of pools and deeper areas may increase the population of Atlantic salmon as 0+ Atlantic salmon prefers water deeper than 25 cm (Armstrong et al. 2003). Pools are also a key winter habitat for salmons (Muotka & Syrjänen 2007). Cover is important for both Atlantic salmon and brown trout (Armstrong et al. 2003; Heggenes et al. 1999; Heggenes & Dokk 2001). Both Austvik (2012) and Sødal (2014) suggested that planting of riparian vegetation could be beneficial for recovery of the system. We assume that planting of vegetation to increase canopy cover would be positive at places where measures are completed.

There are intensive fish farming in Northern Norway, and the industry produced 89 734 tonnes in 2013 in Finnmark only. The total growth in the production in the period 2007-2013 in Finnmark county alone was at almost 450%, and the total value creation along the coast of Northern Norway was in 2010 NOK 4,4 billions (Meld. St. 16 (2014-2015)). Presence of salmon lice *(Lepeophtheirus salmonis)* is related with presence of salmon farms. After current climate change models, temperature will increase in the future (Jonsson & Jonsson 2009). Increased temperatures may benefit life cycle of salmon lice and increase salmonid stress, with the result that salmonids disease resistance drops (Jonsson & Jonsson 2009; Marcogliese 2001). As far as we know, knowledge is lacking about the effects of salmon farms on wild populations of salmonids in the region. xA suggestion for a further survey may be to measure the effect of salmon farming by conducting a capture-re-capture investigation in Bognelv.

Our study is the first to classify macroinvertebrates to species in Bognelv. Macroinvertebrates are a good bio-indicators, and a further survey may focus more on the interaction amongst restoration success-macroinvertebrates-salmonids.

Salmonids make use of different habitats in rivers and has different juvenile-to-smolt survival (Klemetsen et al. 2003). An individual tagging study with PIT-tags would give the novel opportunity to discover movement of juvenile within the river and survival. In in addition, PIT-tags may be a valuable method to monitor long-term effects and life-time survival.

Arctic charr were absent in our catch. This could be a result of the absence of stations located in habitats with lower water temperature and more rapid water flow (Elliott & Elliott 2010; Klemetsen et al. 2003). We suggest that new stations should be located in tributaries in further surveys. As Degerman (2008) states in the Swedish river restoration guide, monitoring is important to reveal whether the restoration measures have had a positive effect or not. In this context, it would be important to monitor restoration effects in Bognelv in the future. It would also be valuable to start a survey in another river with the same conditions as a reference site for comparison.

5. Conclusions

Our first aim was to explore why the restoration measures conducted in Bognelv over the last 10 years have increased the density of juvenile brown trout and not necessarily populations of Atlantic salmon or Arctic charr. Adding our data to previous data, we found further evidence that brown trout have responded positively to the restoration measures, showing the highest over all mean production in 2015, while Atlantic salmon have not responded nearly as well. However, our data from 2015 indicate that Atlantic salmon have started to recover and may continue to increase in density over the coming years. Arctic charr were excluded from our analyses, as the species was absent in our catches. Yearly, there are reported angling catches of Arctic charr in Bognelv (Lakseregisteret n. d.). With this information, we assume that there are Arctic charr in Bognelv, and that a relocation of some stations will be valuable in future sampling.

The second aim of our study was to investigate potential environmental variables (independent of restoration measures) that influence fish density, length and macroinvertebrate community structure and diversity. Depth, duration of growth period, temperature during growth period, moss cover, 1+ density, gravel and distance from estuary (distance from E6) were the most important environmental variables influencing density and length of juvenile Atlantic salmon and brown trout in our study. Distance from estuary and water velocity were important environmental variables influencing macroinvertebrate diversity. The ordination analysis was able to connect macroinvertebrate species to preferred habitat and revealed differences in habitat preferences between different species of macroinvertebrates.

The third aim was to test restoration-measures-specific effects on juvenile salmonid species and the macroinvertebrate densities. Type of restoration measure had different effects on brown trout and Atlantic salmon densities. 0+ density for both species was higher in areas with weirs and riparian modifications, while 0+ density was lower for both species in side channels and tributaries than in unrestored stations. 0+ Atlantic salmon density increased with increasing time since restoration (2006). 0+ brown trout lengths were greater in areas with weirs and riparian modifications, while their length was smaller in side channels and tributaries. 0+ brown trout length was greater in restored stations than in unrestored stations, and this may indicate that brown trout population has started to stabilize and responded well to measures. 0+ brown trout have decreased in size in relation to increasing time since first restoration measure (2006), and this may be related to the increasing 0+ brown trout density. 0+ Atlantic salmon lengths was greater in side channels and tributaries, while weirs and riparian modifications had little effect on their length. 1+ densities of brown trout appeared to be unaffected by restoration measures conducted in Bognelv.

The highest diversity of macroinvertebrates was found in areas where riparian modifications and opening of side channels/tributaries was conducted. Areas with weirs had a similar effect as unrestored areas on diversity.

Our final aim was to assess whether the ecological restoration processes in Bognelv are in progress, and what "works" and what "does not work". Our results show that densities of both brown trout and Atlantic salmon in 2015 were at their highest level since the initiation of restoration measures. This indicates that the restoration processes in Bognelv have begun. The different restoration measures conducted over the last decade have had different effects on populations of juvenile brown trout and Atlantic salmon. Atlantic salmon density clearly increased over the last years, and will likely continue increasing in the coming years, as the species might need more time to recover. Brown trout have responded well to the restoration measures, with greater length in areas with weirs and riparian modifications. 0+ Atlantic salmon length increased in side channels and tributaries, while weirs and riparian modifications had little effect on 0+ Atlantic salmon length. As riparian modifications and opening of side channels and tributaries gave the highest macroinvertebrate diversities, these measures may produce areas with "food chamber" functions for down-stream salmonids.

The latest restoration measure was conducted in 2014. Due to delayed responses, as possibly is the case in Atlantic salmon, further monitoring and new surveys will be needed to be able to assess the restoration processes and ecological outcomes in Bognelv in the years to come.

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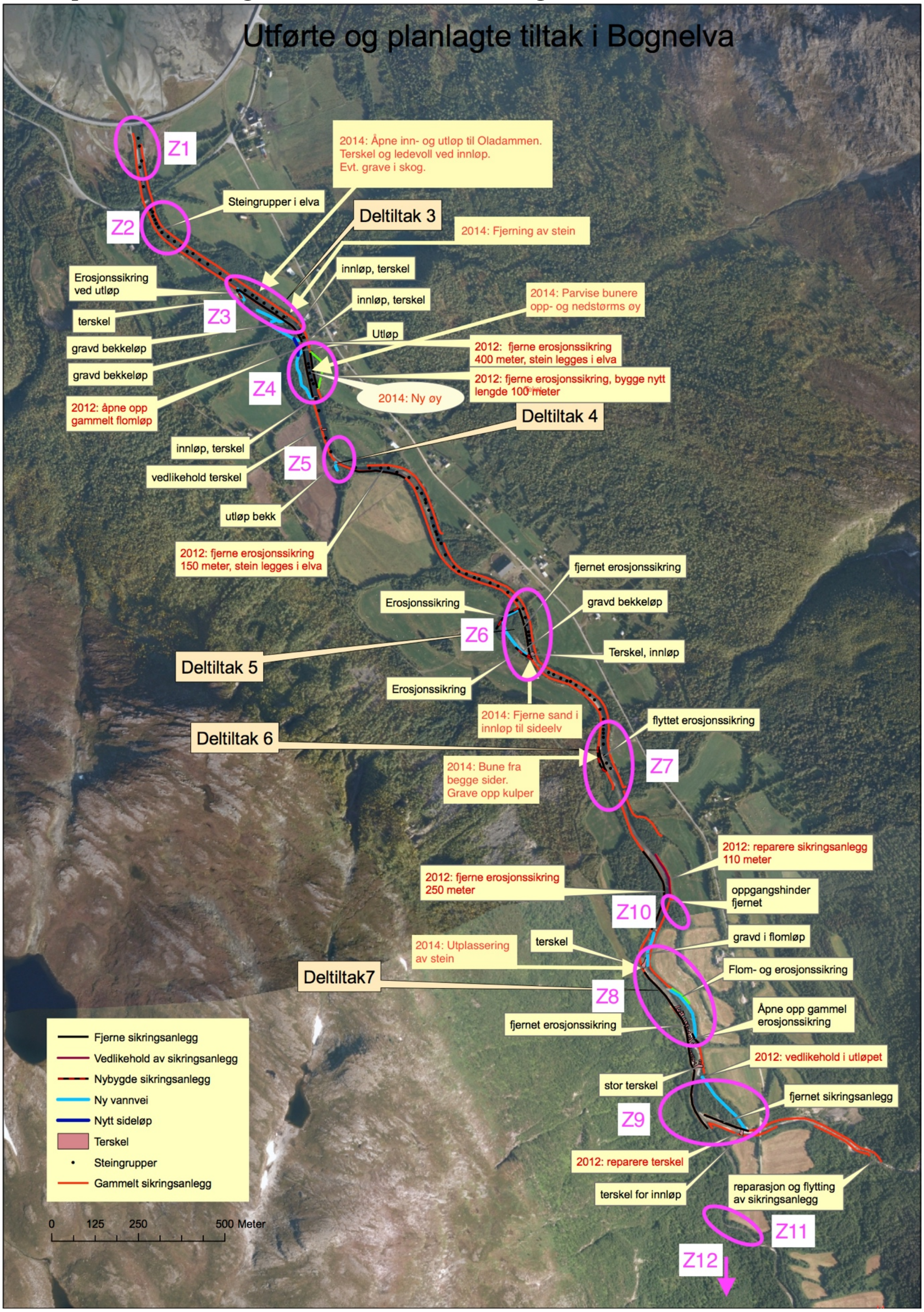
7. Appendices

Appendix 1.
Aerial photo illustrating conducted measures in Bognelv.



Appendix 2.

Short summary of all restoration measures conducted in Bognelv in the period 2006 to 2014.

Zone	**2006** Measure 3 and 5	**2007** Measure 4 and 6	**2009** Measure 7	**2012** Measure 3, 4 and 7	**2014** Mainly improvement and adjustment of earlier conducted measures.
1					
2					
3	- Opening of side channel, two inflows and one outflow. - Placement of rock clusters downstream the inflows to increase the water levels. - Placement of weir in outflow of side channel to increase the water level.	- Supplementary work to improve the water flow	- Reinforce and increase weirs by the inflows of the side channel.	- Removal of erosion control systems in the main river - Placement of rock clusters in the main river	- Re-opening of in- and outflow to Oladammen. - Establish weir by the inflow and rocket clusters to increase the water level. -Dig deeper inflow ditch to ensure constant water flow. -Placement of rocks in the river to vary the water flow.
4	- Opening of side channel. - Placement of rock clusters downstream the inflow to increase the water level. - Placement of weir in outflow of side channel to increase the water level.	- Supplementary work to improve the water flow	- Reinforce and increase weir by the inflow of the side channel.	- Removal of erosion control systems in the main river - Placement of rock clusters in the main river - New erosion control system to protect farmed area	-Removal of some rocks to increase water velocity in pool upstream Oladammen -Building of an island. -Bune up- and downstream new island.

5		- Opening of the tributary Mikkelveita - Two weirs were improved and repaired.			-Upstream zone 5, placement of rocks in the river to vary the water flow.
6	- Upgrade and removal of flood protection, and establishment of new flood protection. - Opening of side channel. - Placement of rock clusters downstream the inflow and by the outflows of side channel to increase the water levels.				-Removal of deposited sand from inlet to tributary.
7		- Relocation and improvement of flood protection - Split a big rock into several pieces.	- Relocation of flood protection systems.		-Removal of deposits to re-open pools. -Bune from both sides to concentrate water flow.
8			- Four new weirs were made. - Opening of an old river course. - Removal of erosion control systems. - New erosion control systems to protect farmed area.		-Placement of rocks in the river to better water flow into tributary.

9			- Maintenance of a weir. - Removal of erosion control systems. - Opening of the original river course for Ørplasselva. - Construction of a weir to get water into the original river course.	- Repairing of a weir in Ørplasselva - Removal of gravel	
10			- Removal of a migration barrier		
Rock clusters	- Zone 6. Rock clusters to increase diversity in water flow.	- Zone 1 – 7, from the new E6 up to Korselva. 2-3 rocks are added to each of the 78 originally single rocks, to create rock clusters. In addition 60 new rock clusters were made.	- Zone 8 and 9. Rock clusters to increase diversity in water flow.	- Zone 3 and 4. Placement of bigger rock clusters in the main river.	

Appendix 3.

Aerial photos of each zone, with stations marked with red line and number. Coordinates for each station is given in a separate table.

All aerial photos are taken in 2008 and downloaded from www.norgeskart.no

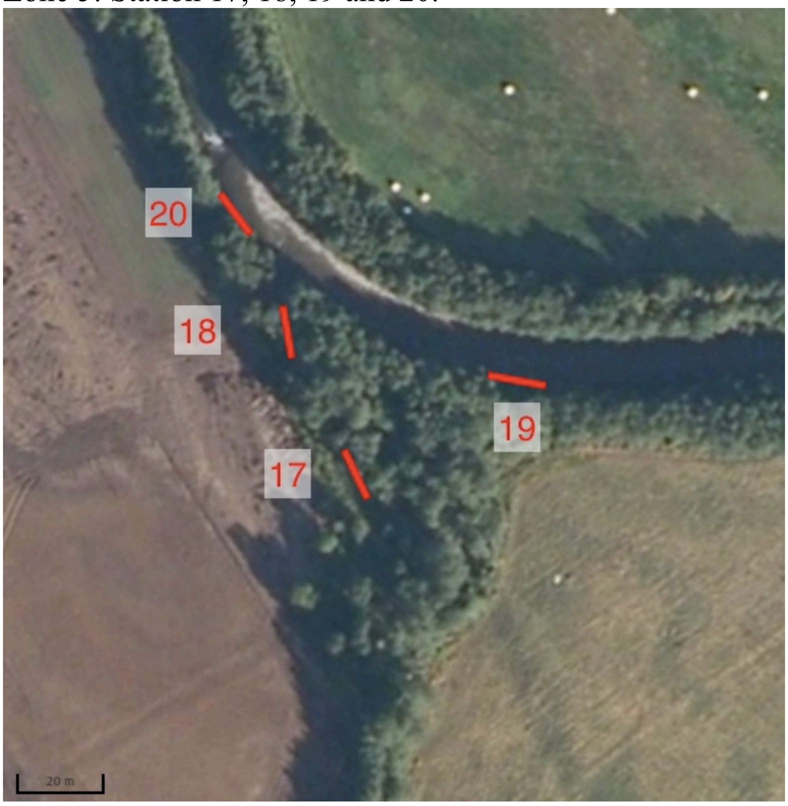
Zone 1: Station 50, 51 and 52. Zone 1 is reference zone.

Zone 2: Station 47, 48 and 49.

Zone 3: Station 34, 36, 40, 41, 42, 43, 44, and 45.

Zone 4: Station 21, 22, 24, 26, 28, 29, 30 and 32.

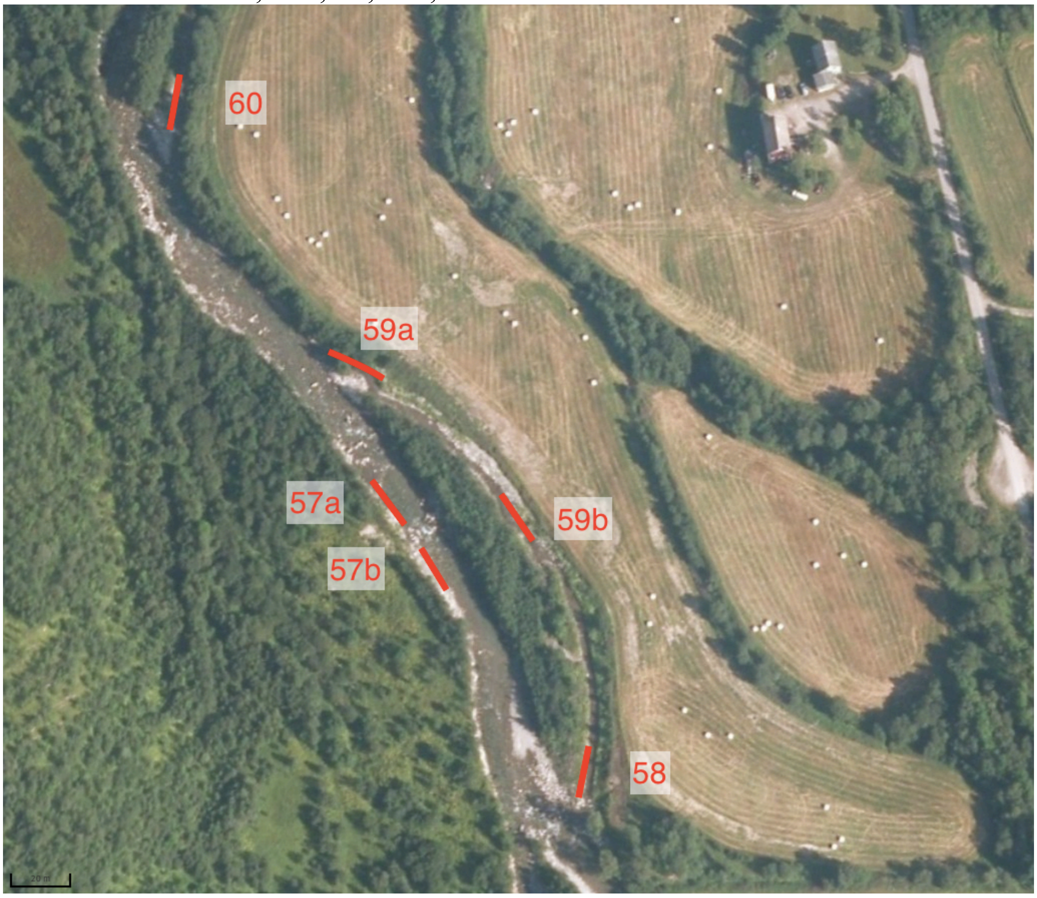
Zone 5: Station 17, 18, 19 and 20.



Zone 6: Station 6, 7, 8, 10, 12, 13, 15 and 16.

Zone 7: Station 1, 4 and 5.

Zone 8: Station 57a, 57b, 58, 59a, 59b and 60.



Zone 9: Station 54, 55, 56, 61 and 63.

Zone 10: Station 64 and 65.

Zone 11: Station 67, 68 and 69.

Zone 12: Station 71, 72 and 73.

Table showing station coordinates given in UTM.

Zone	Station	UTM Zone 33 E	UTM Zone 33 N
1	52	549426	7768892
1	51	549409	7768834
1	50	549430	7768769
2	49	549429	7768673
2	48	549443	7768632
2	47	549461	7768597
3	45	549710	7768396
3	44	549716	7768381
3	43	549778	7768339
3	42	549802	7768308
3	41	549677	7768402
3	40	549683	7768376
3	36	549702	7768340
3	34	549790	7768297
4	32	549834	7768238
4	30	549852	7768193
4	29	549843	7768153
4	28	549862	7768110
4	26	549818	7768207
4	24	549821	7768150
4	22	549829	7768108
4	21	549852	7768081
5	20	549882	7767924
5	19	549930	7767870
5	18	549896	7767880
5	17	549915	7767853
6	16	550364	7767456
6	15	550387	7767434
6	13	550409	7767379
6	12	550398	7767357
6	10	550376	7767415
6	8	550359	7767366
6	7	550381	7767314
6	6	550413	7767258
7	5	550592	7766988
7	4	550609	7766930
7	1	550604	7766896
8	60	550656	7766392
8	59	550710	7766278
8	59b	550754	7766230
8	58	550771	7766157
8	57	550708	7766243
8	57b	550721	7766221
9	63	550813	7765970
9	61	550776	7766026
9	56	550737	7765963

9	55	550841	7765871
9	54	550793	7765886
10	65	550764	7766463
10	64	550734	7766535
11	67	550801	7765627
11	68	550830	7765585
11	69	550880	7765544
12	71	551194	7764084
12	72	551212	7764063
12	73	551190	7764143

Appendix 4.

Data sampling.

The macroinvertebrates were sampled at 0, 7.5 and 15 meter at each station. The macroinvertebrates were sampled during September 2015.
Environmental data was measured at 0, 5, 10 and 15 meter cross-transects within each station. The cross-transects were 10 cm wide and two meters long. Habitat characteristics data were sampled in July 2015.

We used the same habitat categories as Austvik (2012) and Sødal (2014). We also used the same methodology as Sødal (2014).

Fish

At each station the number, length and species of fish were registered. The stations were 15 meters long, and two meters wide.

Invertebrates

Invertebrates were sampled using a kick-sampler. A kick-sampler is a dip-net with a quadratic metal frame with 30 x 30 cm opening and the net had mesh size of 450 μm.
The net was placed in the river, and an area of 0.09 m^2 were examined in 20 seconds by kicking the river bottom with the net placed downstream.
The macroinvertebrates caught in the net were conserved in plastic-bags with ethanol 96% and classified to species. We registered species from the families: Ceratopogonidae, Limonidae, Simulidae, Pediciidae, Chironomidae, Beatidae, Ephemerellidae, Heptageniidae, Siphlonuridae, Capnidae, Perlodidae, Taeniopterygideae, Nemouridae, Chloroperlidae, Perlidae, Rhyacophilidae, Glossosomatidae, Limnephilidae, Lepidostomatidae, Phryganeidae, Gammaridae.

Habitat measurements:

Cover of branches (canopy)

River: Percent cover of branches measured from the edge of the riverbank and 2 meters over the river (only wet areal).
Riverbank: Percent cover of branches over the riverbank.
Category 1: 0% cover, category 2: 1- 25% cover, category 3: 26- 50% cover, category 4: 51-75% cover, category 5: 76- 90% cover, category 6: ≥ 91% cover.

Riverside Vegetation

Percent cover of the riverbank
Category 1: 0% cover, category 2: 1- 25% cover, category 3: 26-50% cover, category 4: 51-75% cover, category 5: 76- 90% cover, category 6: ≥ 91% cover.

Substrate composition

The rocks in the riverbed were classified into five categories. The categories were given after the dominating substrate size.
Category 1: 0-2mm, category 2: 2-20 mm, category 3: 20- 100 mm, category 4: 100-250 mm, category 5: >250 mm.

Water velocity

Water velocity was obtained by visual assessment. The velocity was classified into four categories.
Category 1: still, category 2: slow, category 3: moderate, category 4: fast.

Depth
The depth was measured at 1 and 2 meters from the riverbank. In streams narrower than 2 meters, the depth was measured at 1 meter and in the middle.

Algae
Assessments of mean percentage cover of algae were obtained for each station.
Category 1: 0%, category 2: 1-33%, category 3: 34-66%, category 4: >66%.

Moss
Assessments of mean percentage cover of moss were obtained for each station.
Category 1: 0%, category 2: 1-33%, category 3: 34-66%, category 4: >66%.

Numbers of pools
The numbers of pools were based on large-scale characteristic of the station. A pool was registered if there were some areas with still water.
Category 1: 0 pools, category 2: 1-2 pools, category 3: 3-4 pools, category 4: 5-6 pools, category 5: 6-7 pools, category 6: ≥ 8 pools.

Large woody debris
Large woody debris (LWD) was classified as LWD if it had a diameter of 10 cm or wider, and the length was at least 1 meter. Large concentrations of small woody debris were also classified as LWD. Numbers of LWD items were counted per station.

Temperature
Water temperature was measured using four temperature loggers contained in the main river from July to October. The ambient temperature was logged every hour.

Air temperatures were retrieved from eklima provided by the Norwegian Meteorological Institutes weather station at Alta airport.

Snow cover/Growth season
The growth season was calculated as the period from the first day without snow cover until September 15.
Data were retrieved from eklima based on observations at Sopnesbukt, Langfjordbotten.

Additional
The width of the river and the area covered by water were measured for each station. The distance from the new E6 was measured from the lowest point at each station using a measurement tool in norgeskart.no

Appendix 5.

10 most supported AICc-based model selections statistics for candidate models and parameter estimates for the most supported AICc-based models with interaction.

Table A1. AICc-based model selections statistics for candidate model fitted to predict environmental variables effect on 0+ brown trout density based on data from 2008, 2011,2013 and 2015. K= number of estimated parameters; AICcWt= the model AICc weight; LL= model log-likelihood. All models were fitted using log-likelihood method.

No	Model structure	K	AICc	△AICc	AICcWt	Cum.Wt	LL
1	Mean depth * Days * 1+ density * Mean temp.	17	641.99	0	0.66	0.66	-302.14
2	Mean depth * Days * 1+ density	9	643.34	1.35	0.34	1	-312.15
3	Mean depth * 1+ density	5	657.03	15.05	0	1	-323.35
4	Mean depth * 1+ density + Mean temp.	6	657.56	15.57	0	1	-322.54
5	Mean depth * Distance from E6 * 1+ density	9	657.91	15.93	0	1	-319.44
6	Mean depth * Mean temp. + 1+ density	6	658.8	16.81	0	1	-323.16
7	Mean depth * Mean temp. * 1+ density	9	659.95	17.96	0	1	-320.45
8	Mean depth + Mean temp. * 1+ density	6	661.26	19.27	0	1	-324.39
9	Mean depth * Days	5	661.88	19.89	0	1	-325.77
10	Mean depth + Distance from E6 * 1+ density	6	662.87	20.88	0	1	-325.19

Table A2. Parameter estimates for the selected linear model (i.e., lowest AIC score in Appendix 5, Table A1) fitted to predict environmental variables effect on 0+ density, data from 2008, 2011, 2013 and 2015. The response variable and 1+ density was ln-transformed. *** indicates a significance level of $p<0.001$.

Coefficients	Estimate	Std. Error	t-value	Pr(>|t|)
Intercept	-1.34E+02	3.31E+01	-4.06	***
Mean depth	-0.40	1.16E-01	-3.435	***
Days	1.33	3.20E-01	4.147	***
1+ density	-0.51	6.34E-01	-0.806	0.421265
Mean temp.	1.36E+01	3.11E+00	4.367	***
Mean depth * Days	2.44E-03	5.90E-04	4.142	***
Mean depth * 1+ density	-3.29E-03	4.57E-03	-0.721	0.472171
Days * 1+ density	1.02E-02	6.55E-03	1.55	0.122857
Mean depth * Mean temp.	8.66E-03	6.15E-03	1.408	0.16088
Days * Mean temp.	-1.32E-01	3.01E-02	-4.386	***

Table A3. AICc-based model selections statistics for candidate model fitted to predict environmental variables effect on 0+ brown trout density based on data from 2011,2013 and 2015. K= number of estimated parameters; AICcWt= the model AICc weight; LL= model log-likelihood. All models were fitted using log-likelihood method.

No	Model structure	K	AICc	△AICc	AICcWt	Cum.Wt	LL
1	Moss + Mean depth + 1+ density	5	475.06	0	0.64	0.64	-232.3
2	Moss + Mean depth * 1+ density	6	476.62	1.57	0.29	0.93	-231.98
3	Moss * Mean depth * 1+ density	9	479.6	4.55	0.07	0.99	-230.08
4	Mean depth * Days * 1+ density	9	484.08	9.02	0.01	1	-232.32
5	Moss + Mean depth	4	488.42	13.36	0	1	-240.06
6	Moss * Mean depth	5	490.42	15.36	0	1	-239.98
7	Moss + Mean depth + Velocity	5	490.57	15.51	0	1	-240.05
8	Mean depth + 1+ density	4	491.87	16.81	0	1	-241.78
9	Year + Distance from E6 + Gravel	7	491.95	16.89	0	1	-238.54
10	Moss + Mean depth * Velocity	6	492.74	17.69	0	1	-240.04

Table A4. AICc-based model selections statistics for candidate model fitted to predict environmental variables effect on 0+ Atlantic salmon density based on data from 2008, 2011 and 2015. K= number of estimated parameters; AICcWt= the model AICc weight; LL= model log-likelihood. All models were fitted using log-likelihood method.

No	Model structure	K	AICc	△AICc	AICcWt	Cum.Wt	LL
1	Mean depth + Distance from E6	4	310.06	0	0.21	0.21	-150.88
2	Distance from E6 + Velocity	4	310.1	0.04	0.21	0.42	-150.9
3	Mean depth + Distance from E6 * 1+ density	6	310.85	0.79	0.14	0.56	-149.1
4	Mean depth * Gravel	5	311.77	1.72	0.09	0.65	-150.66
5	Distance from E6 * Velocity	5	311.87	1.81	0.09	0.73	-150.71
6	Mean depth * Distance from E6	5	312.12	2.06	0.08	0.81	-150.83
7	Mean depth + Distance from E6 * Velocity	6	313.96	3.9	0.03	0.91	-150.66
8	Mean depth * Days	5	314.34	4.29	0.02	0.94	-151.94
9	Mean depth * Distance from E6 * 1+ density	9	315.64	5.58	0.01	0.95	-148.12
10	Mean depth + Gravel	4	316.42	6.36	0.01	0.96	-154.06

Table A5. AICc-based model selections statistics for candidate model fitted to predict environmental variables effect on 1+ brown trout density based on data from 2008, 2011, 2013 and 2015. K= number of estimated parameters; AICcWt= the model AICc weight; LL= model log-likelihood. All models were fitted using log-likelihood method.

No	Model structure	K	AICc	△AICc	AICcWt	Cum.Wt	LL
1	Mean depth * Velocity + Gravel	6	623.99	0	0.45	0.45	-305.76
2	Year + Distance from E6 + Gravel	7	624.47	0.47	0.35	0.8	-304.92
3	Year + Distance from E6 * Gravel	8	626.53	2.53	0.13	0.92	-304.85
4	Mean depth * Velocity	5	628.96	4.97	0.04	0.96	-309.31
5	Mean depth * Year	9	629.51	5.51	0.03	0.99	-305.24
6	Mean depth	3	634.45	10.45	0	0.99	-314.16
7	Mean depth + Vegetation	4	635.71	11.72	0	0.99	-313.74
8	Mean depth + Distance from E6	4	635.84	11.85	0	0.99	-313.81
9	Year + Distance from E6	6	636.01	12.02	0	1	-311.77
10	Mean depth + Mean temp.	4	636.33	12.34	0	1	-314.05

Table A6. Parameter estimates for the selected linear model (i.e., lowest AIC score in Appendix 5, Table A4) fitted to predict environmental variables effect on 1+ density, data from 2008, 2011, 2013 and 2015. The response variable was ln-transformed. *** indicates a significance level of $p<0.001$.

Coefficients	Estimate	Std. Error	t-value	Pr(>|t|)
Intercept	0.490248	0.3789597	1.294	0.19744
Depth average	0.0435393	0.0094606	4.602	***
Velocity	0.0120492	0.0093081	1.294	0.19715
Gravel	0.3032166	0.1142044	2.655	0.00864
Depth average * Velocity	-0.0006488	0.0002286	-2.838	0.00506

Table A7. AICc-based model selections statistics for candidate model fitted to predict environmental variables effect on 1+ brown trout density based on data from 2011, 2013 and 2015. K= number of estimated parameters; AICcWt= the model AICc weight; LL= model log-likelihood. All models were fitted using log-likelihood method.

No	Model structure	K	AICc	△AICc	AICcWt	Cum.Wt	LL
1	Mean depth + Algae	4	454.4	0	0.16	0.16	-223.05
2	Year + Distance E6 + Gravel	6	454.63	0.22	0.14	0.31	-220.99
3	Moss + Mean depth * Velocity	6	454.83	0.43	0.13	0.44	-221.09
4	Mean depth * Year	7	454.88	0.47	0.13	0.56	-220.01
5	Year + Distance from E6 * Gravel	7	454.9	0.49	0.13	0.69	-220.02
6	Velocity * Mean depth + Gravel	6	455.11	0.7	0.11	0.8	-221.23
7	Moss * Mean depth	5	455.38	0.97	0.1	0.9	-222.46
8	Year + Distance from E6	5	456.19	1.79	0.07	0.97	-222.87
9	Mean depth + Distance from E6	4	460.33	5.93	0.01	0.98	-226.02
10	Mean depth + Canopy river	4	461.62	7.21	0	0.98	-226.66

Table A8. AICc-based model selections statistics for candidate model fitted to predict environmental variables effect on 0+ brown trout growth based on data from 2008, 2011, 2013 and 2015. K= number of estimated parameters; AICcWt= the model AICc weight; LL= model log-likelihood. All models were fitted using log-likelihood method.

No	Model structure	K	AICc	△AICc	AICcWt	Cum.Wt	LL
1	River section + Mean temp. + Days	5	5023.75	0	0.64	0.64	-2506.84
2	River section +Mean temp. * Days	6	5024.88	1.13	0.36	1	-2506.39
3	Days + Mean temp.	4	5058.69	34.93	0	1	-2525.32
4	Days * Mean temp.	5	5060.61	36.85	0	1	-2525.27
5	Gravel * Zone * Mean temp.	33	5073.5	49.75	0	1	-2502.41
6	River section * Gravel * 1+ density * Mean temp.	17	5099.22	75.47	0	1	-2532.25
7	Distance from E6 * Gravel *1+ density * Mean temp.	17	5114.32	90.56	0	1	-2539.8
8	Distance from E6 *Gravel * 1+ density *Mean temp.	17	5118.56	94.8	0	1	-2541.92
9	Gravel * Zone + Mean temp.	19	5124.35	100.6	0	1	-2542.73
10	Gravel *Mean temp	5	5134.95	111.2	0	1	-2562.44

Table A9. The ten most supported AICc-based model selection statistics for candidate model fitted to predict 0+ growth based on data from 2011, 2013 and 2015. K = number of estimated parameters; AICcWt = the model AICc weigth; LL = model log-likelihood. All models were fitted using log-likelihood method.

No	Model structure	K	AICc	△AICc	AICcWt	Cum.Wt	LL
1	Gravel * Zone * Mean temp.	28	3520.62	0	1	1	-1730.9
2	River section * Gravel * 1+ density * Mean temp.	17	3545.29	24.66	0	1	-1755.12
3	River section + Mean temp. * Days	5	3555.13	34.51	0	1	-1772.52
4	Distance from E6 * Gravel * 0+ Density * Mean temp.	17	3559.23	38.61	0	1	-1762.09
5	Gravel * Zone + Mean temp.	18	3560.6	39.98	0	1	-1761.72
6	Distance from E6 * Gravel * 0+ Density	9	3573.54	52.92	0	1	-1777.62
7	Distance from E6 * Gravel * 1+ density * Mean temp.	17	3574.61	53.98	0	1	-1769.78
8	Distance from E6 * Gravel * 0+ Density + Mean temp.	10	3575.06	54.43	0	1	-1777.34
9	River section	3	3578.65	58.02	0	1	-1786.3
10	Distance from E6 * Depth average	5	3580.05	59.42	0	1	-1784.97

Table A10. Parameter estimates for the selected linear model (i.e., second lowest AIC score in Table 10) fitted to predict environmental variables effects on 0+ growth, data from 2011, 2013 and 2015. Default River section (intercept) is "Lower river section" and other levels effect have been estimated relative to this default level. *** indicates a significance level of p<0.001.

Coefficients	Estimate	Std.Error	t-value	Pr(>|t|)
Intercept	44.16307	42.36528	1.042	0.297636
Upper river section	40.58246	39.57448	1.025	0.305561
Gravel	-0.52773	13.98415	-0.038	0.96991
1+ density	-1.69678	0.84382	-2.011	0.044796
Mean temp.	0.9989	3.48481	0.287	0.774486
Upper river section * Gravel	-11.17061	12.93476	-0.864	0.388152
Upper river section * 1+ density	-0.26023	0.21069	-1.235	0.217274
Gravel * 1+ density	0.61528	0.24725	2.488	0.013105
Upper river section * Mean temp.	-5.03862	3.25708	-1.547	0.122405
Gravel * Mean temp.	-0.33787	1.14782	-0.294	0.768589
1+ density * Mean temp.	0.11832	0.06745	1.754	0.079905
Upper river section * Gravel * 1+ density	-0.15245	0.04233	-3.601	***
Upper river section * Gravel * Mean temp.	1.39172	1.0603	1.313	0.189837
Upper river section * 1+ density * Mean temp.	0.06654	0.02093	3.18	0.001552
Gravel * 1+ density * Mean temp.	-0.04349	0.01947	-2.233	0.025905

Table A11. AICc-based model selections statistics for candidate model fitted to predict environmental variables effect on 0+ Atlantic salmon growth based on data from 2008, 2011 and 2015. K= number of estimated parameters; AICcWt= the model AICc weight; LL= model log-likelihood. All models were fitted using log-likelihood method.

No	Model structure	K	AICc	△AICc	AICcWt	Cum.Wt	LL
1	Distance from E6 * 1+ density	5	329.95	0	0.23	0.23	-159.31
2	Distance from E6 + 0+ Density	4	331.65	1.7	0.1	0.32	-161.39
3	Distance from E6 + Depth * 0+ Density	6	331.69	1.73	0.09	0.42	-158.89
4	Distance from E6 * 0+ Density	5	331.78	1.82	0.09	0.51	-160.22
5	Distance from E6 + Depth + 0+ Density	5	332.09	2.14	0.08	0.59	-160.38
6	Distance from E6 * Depth	5	332.54	2.58	0.06	0.65	-160.6
7	River section + Mean temp + Days	5	332.92	2.97	0.05	0.7	-160.79
8	River section + Mean temp * Days	5	332.92	2.97	0.05	0.75	-160.79
9	Distance from E6 * Gravel * 1+ density + Mean temp	9	333.17	3.21	0.05	0.8	-155.39
10	Distance from E6	3	333.68	3.73	0.04	0.83	-163.58

Table A12. Parameter estimates for the selected linear model (i.e., lowest AIC score in Appendix 5, Table A11) fitted to predict effects of environmental variables on 0+ growth, data from 2008, 2011 and 2015. The 1+ density variable was ln-transformed. *** indicates a significance level of $p<0.001$.

Coefficients	Estimate	Std. Error	t-value	Pr(>|t|)
Intercept	32.6290378	2.7323648	11.942	***
Distance from E6	0.0034563	0.0011057	3.126	0.00304
1+ density	0.7527447	0.2846343	2.645	0.01108
Distance from E6 * 1+ density	-0.0008861	0.0003084	-2.874	0.00608

Appendix 6.

Restoration effects on the most supported AICc-based model fitted to predict environmental variables effect on juvenile brown trout and Atlantic salmon density and length, and parameter estimates for models including interaction.

Table A13. Parameter estimates for the selected linear model (i.e., lowest AIC score in Appendix 5, Table A1) fitted to predict effects of environmental variables and restoration effects on 0+ density, data from 2008, 2011, 2013 and 2015. Default Type of measure (intercept) is "No measure" and other levels effect have been estimated relative to this default level. The response variable and 1+ Density was ln-transformed. *** indicates a significance level of $p<0.001$.

Coefficients	Estimate	Std.Error	t-value	Pr(>|t|)
Intercept	-1.31E+02	3.15E+01	-4.158	***
Mean depth	-4.32E-01	1.09E-01	-3.958	***
Days	1.30E+00	3.04E-01	4.273	***
1+ Density	-2.75E-01	5.97E-01	-0.46	0.645929
Mean temp.	1.33E+01	2.96E+00	4.479	***
Type of measure - Riparian modifications	7.18E-01	2.48E-01	2.899	0.004242
Type of measure - Side channels	-1.79E-01	2.33E-01	-0.767	0.443964
Type of measure - Weirs	1.51E+00	3.82E-01	3.951	***
Mean depth * Days	2.53E-03	5.53E-04	4.576	***
Mean depth * 1+ Density	-1.90E-03	4.36E-03	-0.435	0.663869
Days * 1+ Density	7.26E-03	6.17E-03	1.176	0.241189
Mean depth * Mean temp.	1.05E-02	5.78E-03	1.822	0.070219
Days * Mean temp.	-1.30E-01	2.87E-02	-4.519	***

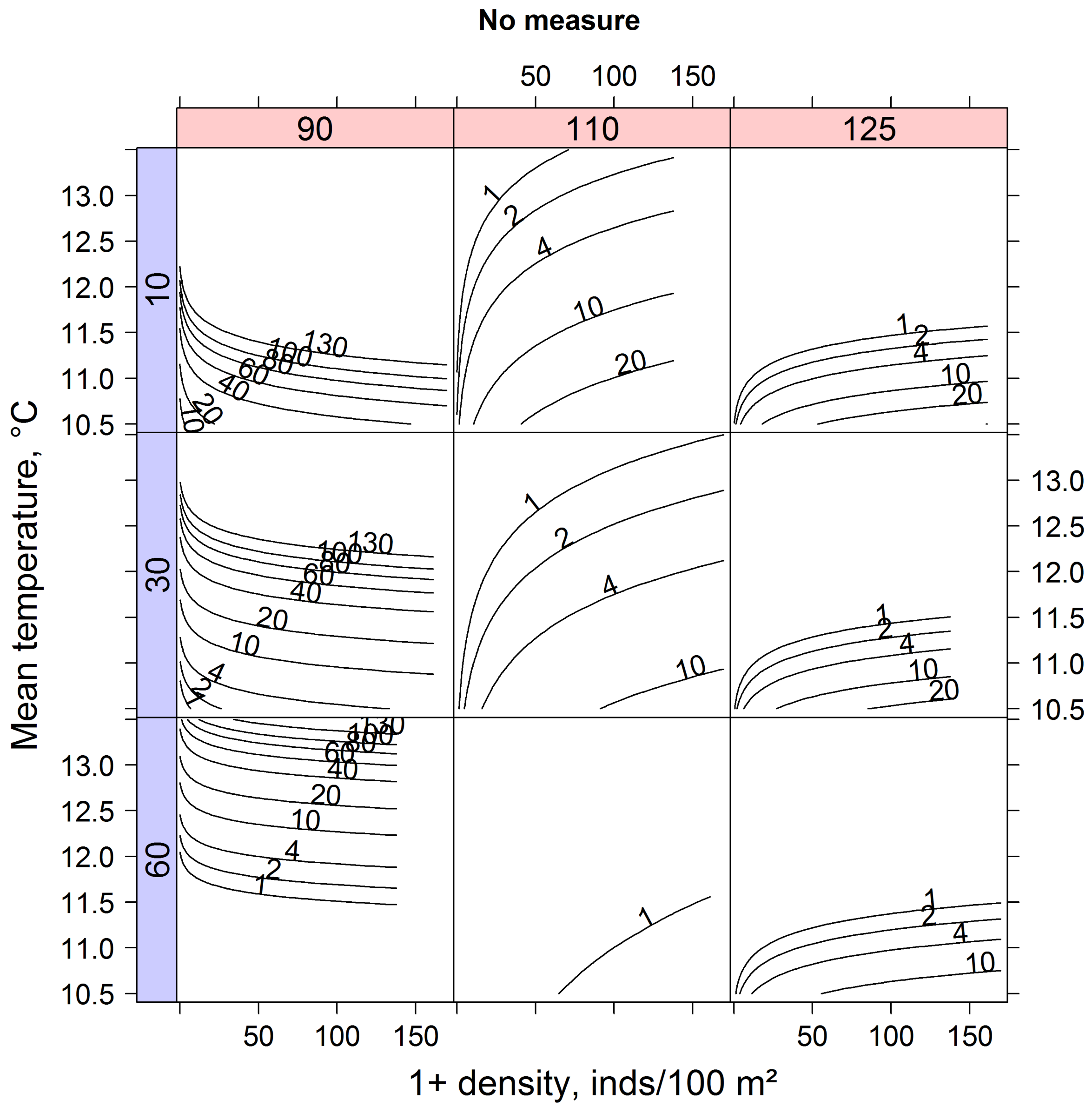


Figure A1. Prediction contour plot of the most supported 0+ density model with type of restoration measure; “No measure” for 2008, 2011, 2013 and 2015. Blue bars display mean depth (cm); red bars display duration of growth period (days).

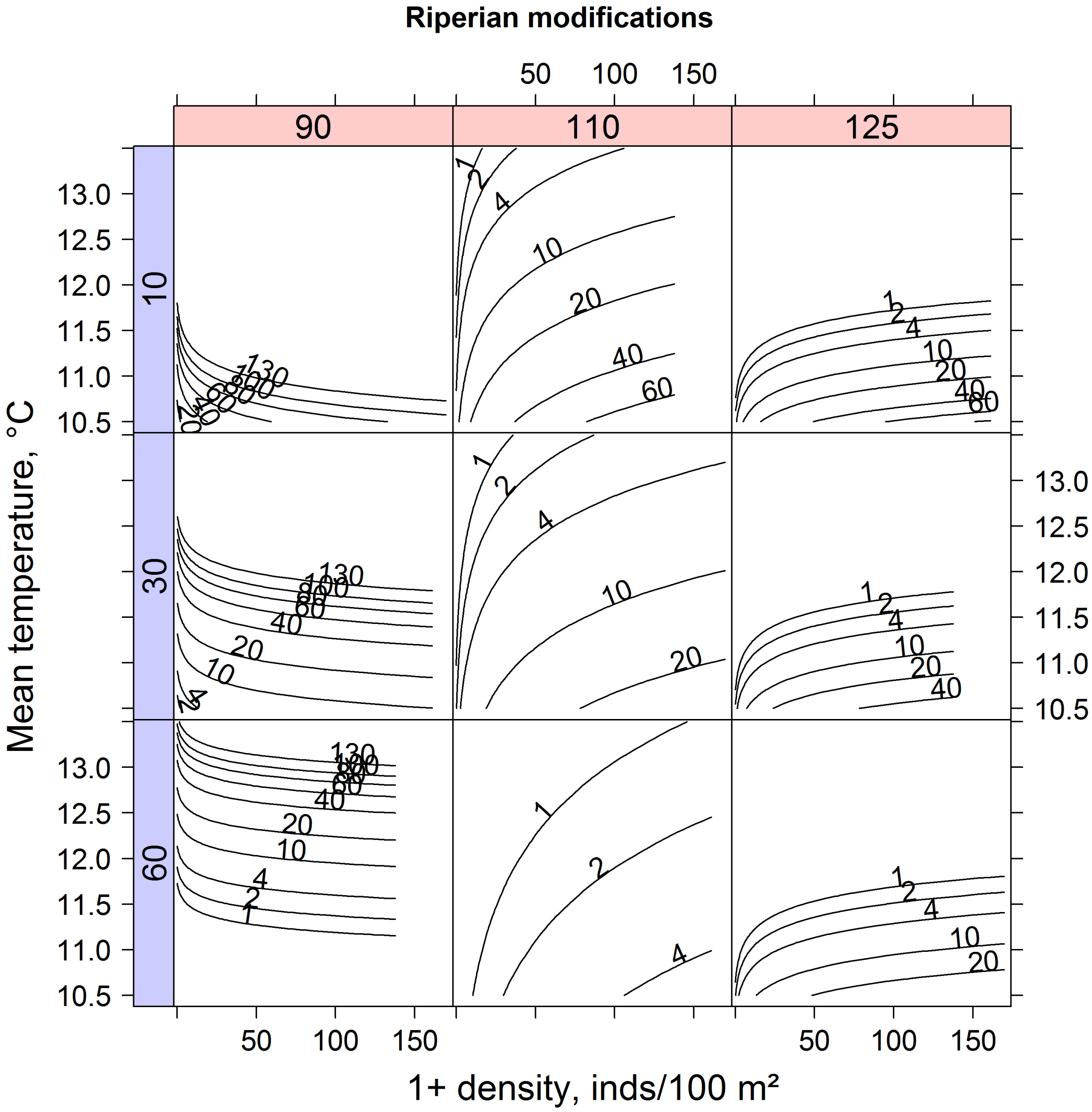


Figure A2. Prediction contour plot of the most supported 0+ density model with type of restoration measure; "Riparian modifications" for 2008, 2011, 2013 and 2015. Blue bars display mean depth (cm); red bars display duration of growth period (days).

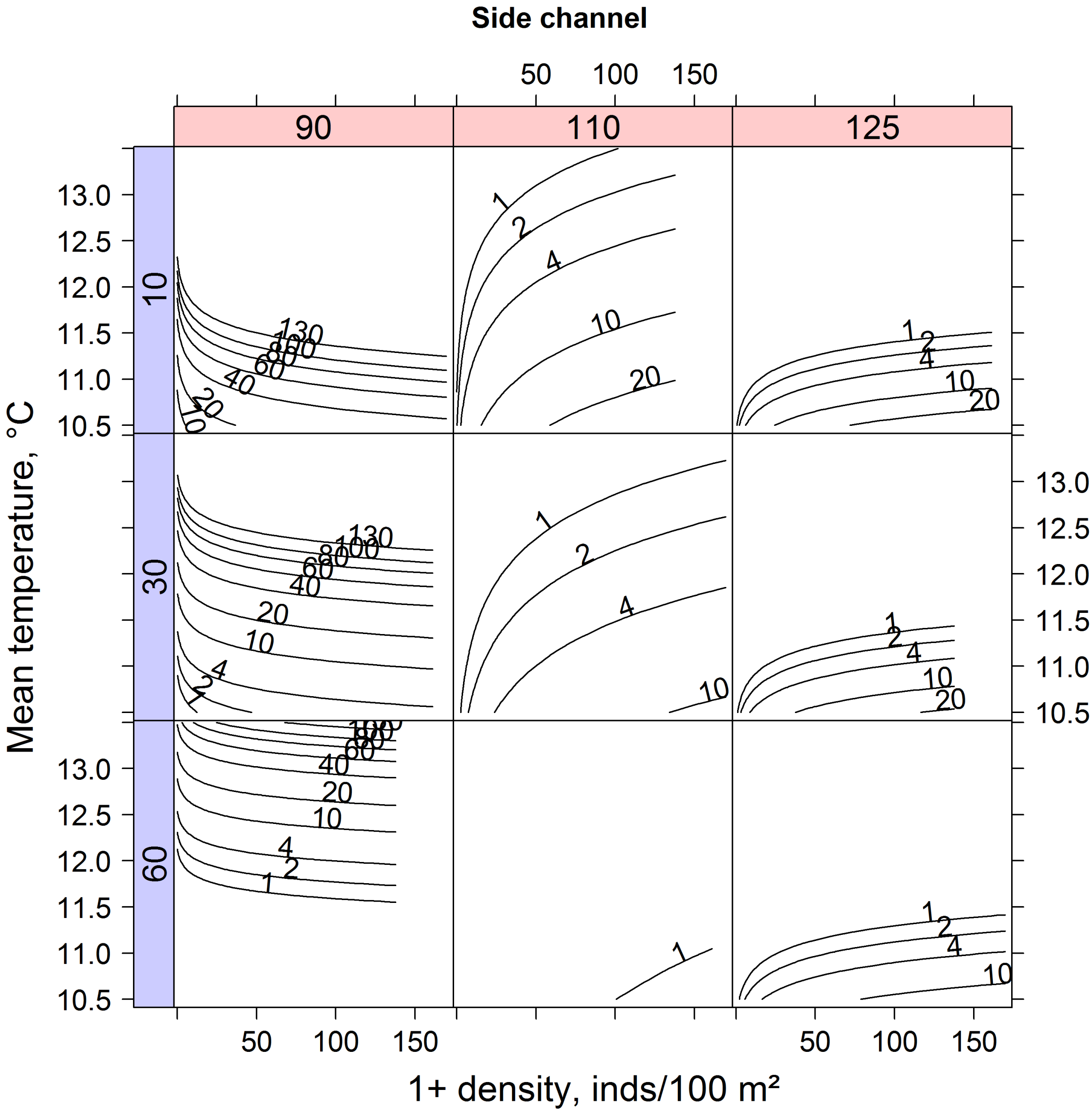


Figure A3. Prediction contour plot of the most supported 0+ density model with type of restoration measure; “Side channel” for 2008, 2011, 2013 and 2015. Blue bars display mean depth (cm); red bars display duration of growth period (days).

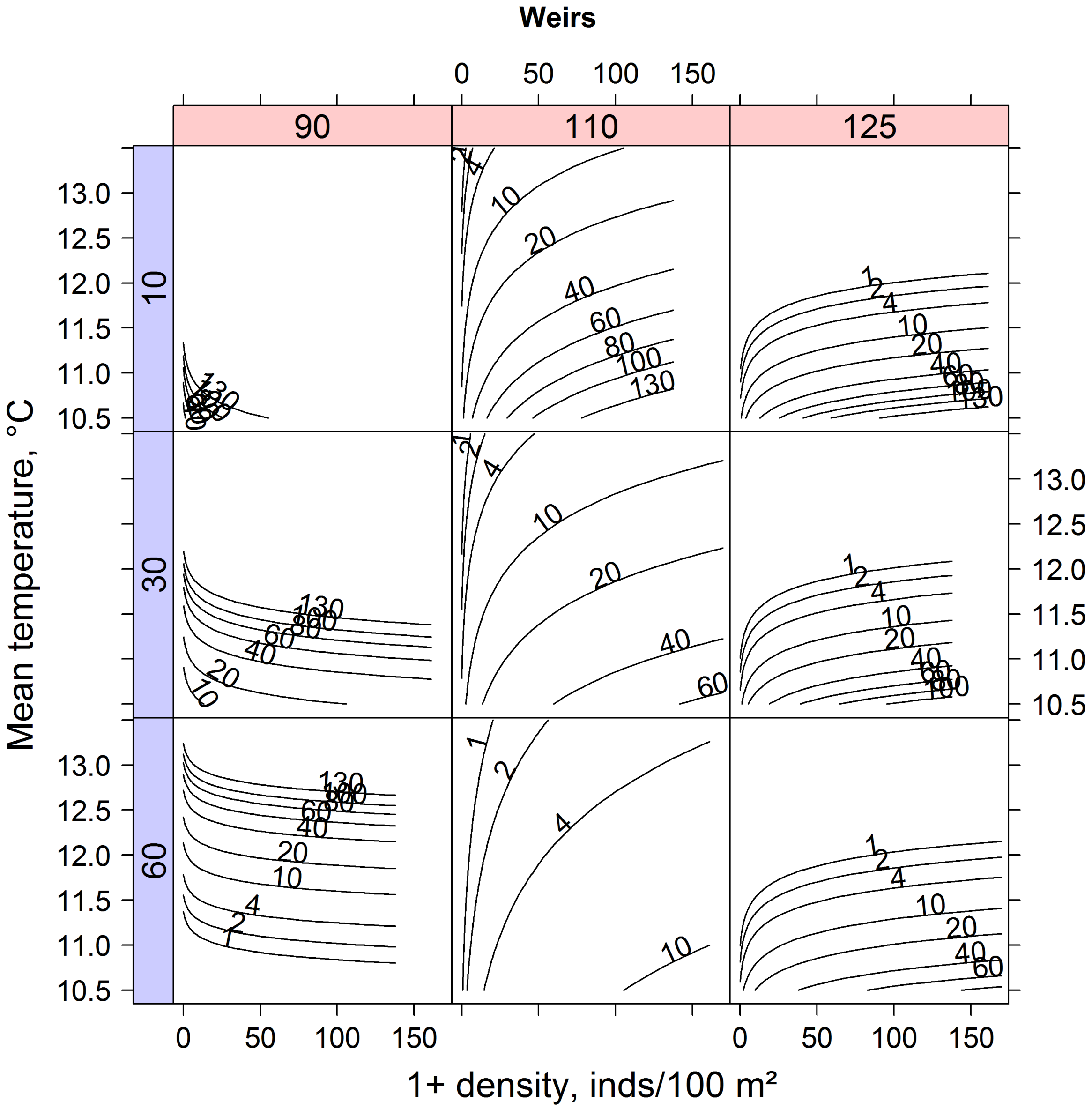


Figure A4. Prediction contour plot of the most supported 0+ density model with type of restoration measure; “Weirs” for 2008, 2011, 2013 and 2015. Blue bars display mean depth (cm); red bars display duration of growth period (days).

Table A14. Parameter estimates for the selected linear model (i.e., lowest AIC score in Appendix 5, Table A3) fitted to predict effects of environmental variables and restoration effects on 0+ density, data from 2011, 2013 and 2015. Default Type of measure (intercept) is "No measure" and other levels effect have been estimated relative to this default level. The response variable and 1+ Density was ln-transformed. *** indicates a significance level of p<0.001.

Coefficients	**Estimate**	**Std. Error**	**t-value**	**Pr(>|t|)**
Intercept	-1.31E+02	3.15E+01	-4.158	***
Moss.cat	-0.603449	0.155144	-3.89	***
Mean depth	-0.014544	0.005867	-2.479	0.014478
1+ Density	0.356952	0.084512	4.224	***
Type of measure – Riparian modifications	0.645381	0.299058	2.158	0.032791
Type of measure – Side channel	-0.823932	0.263049	-3.132	0.00215
Type of measure – Weirs	1.038247	0.393401	2.639	0.009344

Table A15. Parameter estimates for the selected linear model (i.e., lowest AIC score in Table A9) fitted to predict effects of environmental variables and restoration effects on 0+ growth, data from 2011, 2013 and 2015. Default is Lower river section and Restored. No (intercept) and other levels effect have been estimated relative to this default level. The response variable and 1+ Density was ln-transformed. *** indicates a significance level of p<0.001.

Coefficients	**Estimate**	**Std. Error**	**t-value**	**Pr(>|t|)**
Intercept	34.952	42.47303	0.823	0.410885
Upper river section	49.97802	39.71606	1.258	0.208751
Gravel	2.1661	14.00353	0.155	0.877124
1+ Density	-1.61068	0.84242	-1.912	0.056364
Mean temp	1.74738	3.49322	0.5	0.617107
Restored. Yes	0.95728	0.45724	2.094	0.036722
Upper river section * Gravel	-14.4073	12.99022	-1.109	0.267844
Upper river section * 1+ Density	-0.21605	0.21115	-1.023	0.306637
Gravel * 1+ Density	0.57998	0.24713	2.347	0.01926
Upper river section * Mean temp	-5.92176	3.27508	-1.808	0.071095
Gravel * Mean temp	-0.56328	1.1496	-0.49	0.62433
1+ Density * Mean temp	0.11164	0.06733	1.658	0.097818
Upper river section * Gravel * 1+ Density	-0.14726	0.04229	-3.483	***
Upper river section * Gravel * Mean temp	1.67771	1.06607	1.574	0.116084
Upper river section * 1+ Density * Mean temp	0.06184	0.02099	2.947	0.00334
Gravel * 1+ Density * Mean temp	-0.04086	0.01946	-2.1	0.036154

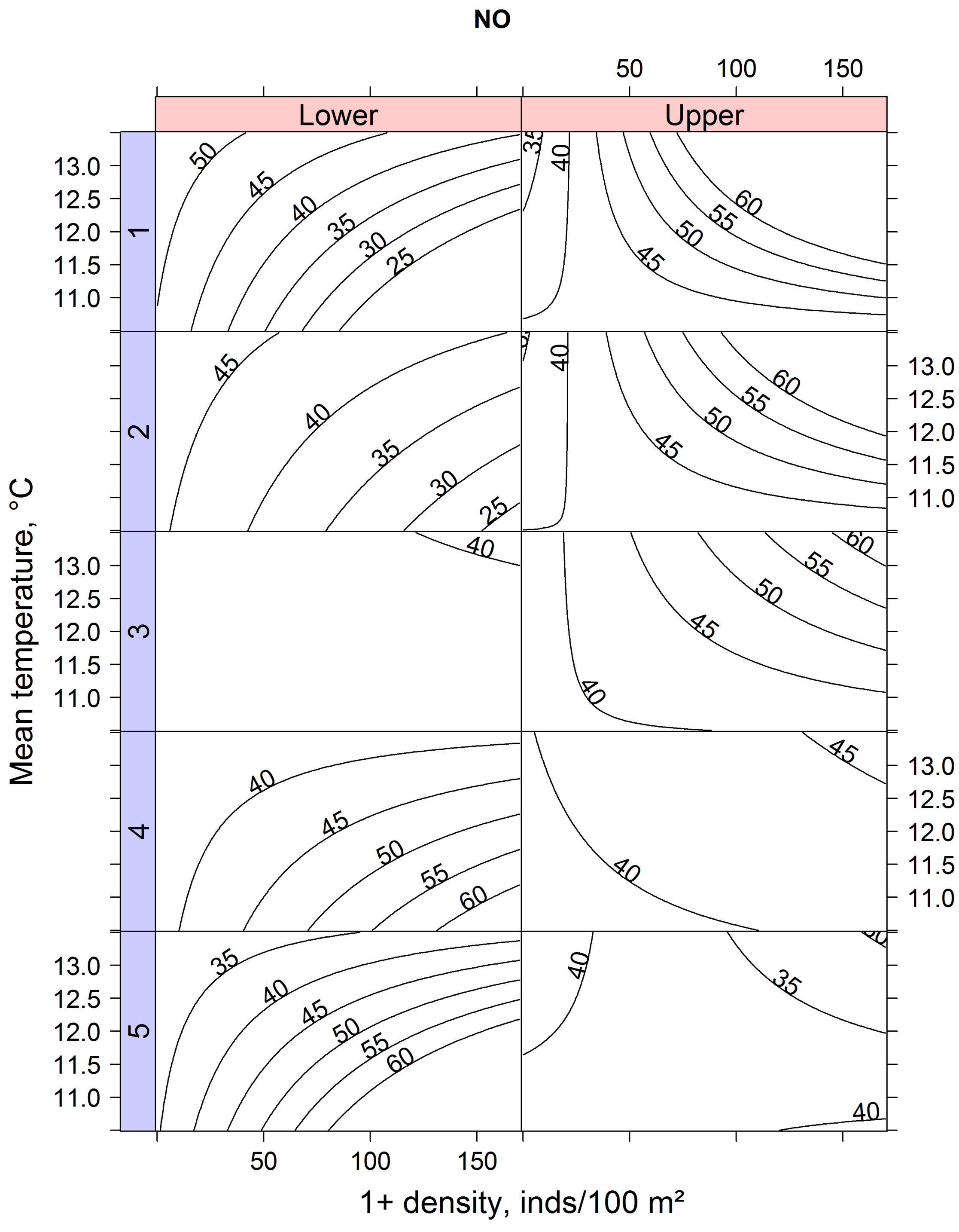


Figure A5. Prediction contour plot of the most supported 0+ length model in 2011, 2013 and 2015 with the addition; if the station is restored or not, "Not restored". Red bars display the different river sections. Blue bars display the different gravel categories; 1: 0-2 mm, 2: 2-20 mm, 3: 20-100 mm, 4: 100-250 mm, 5: >250 mm.

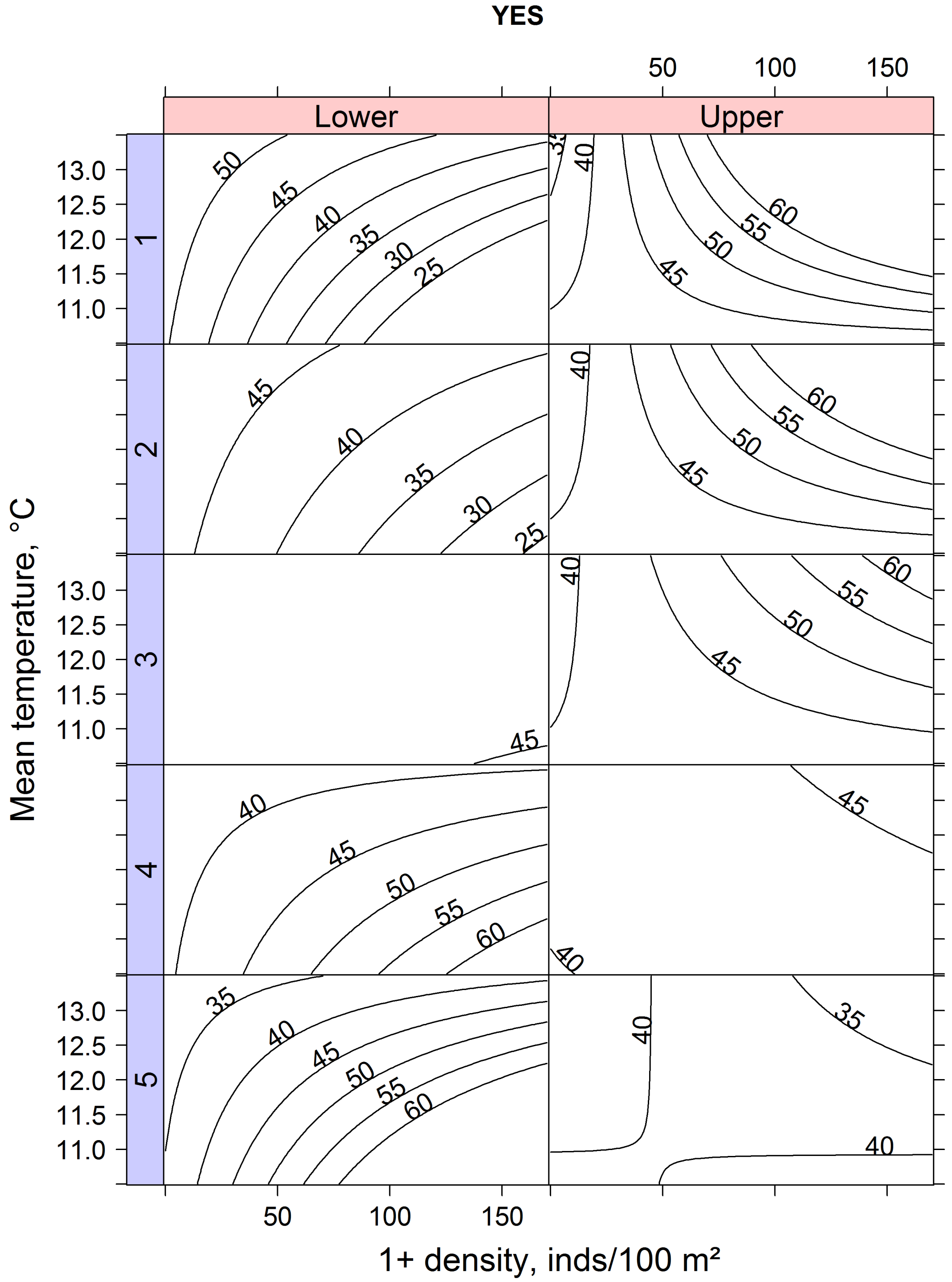


Figure A6. Prediction contour plot of the most supported 0+ length model in 2011, 2013 and 2015 with the addition; if the station is restored or not, “Restored”. Red bars display the different river sections. Blue bars display the different gravel categories; 1: 0-2 mm, 2: 2-20 mm, 3: 20-100 mm, 4: 100-250 mm, 5: >250 mm.

Appendix 7.

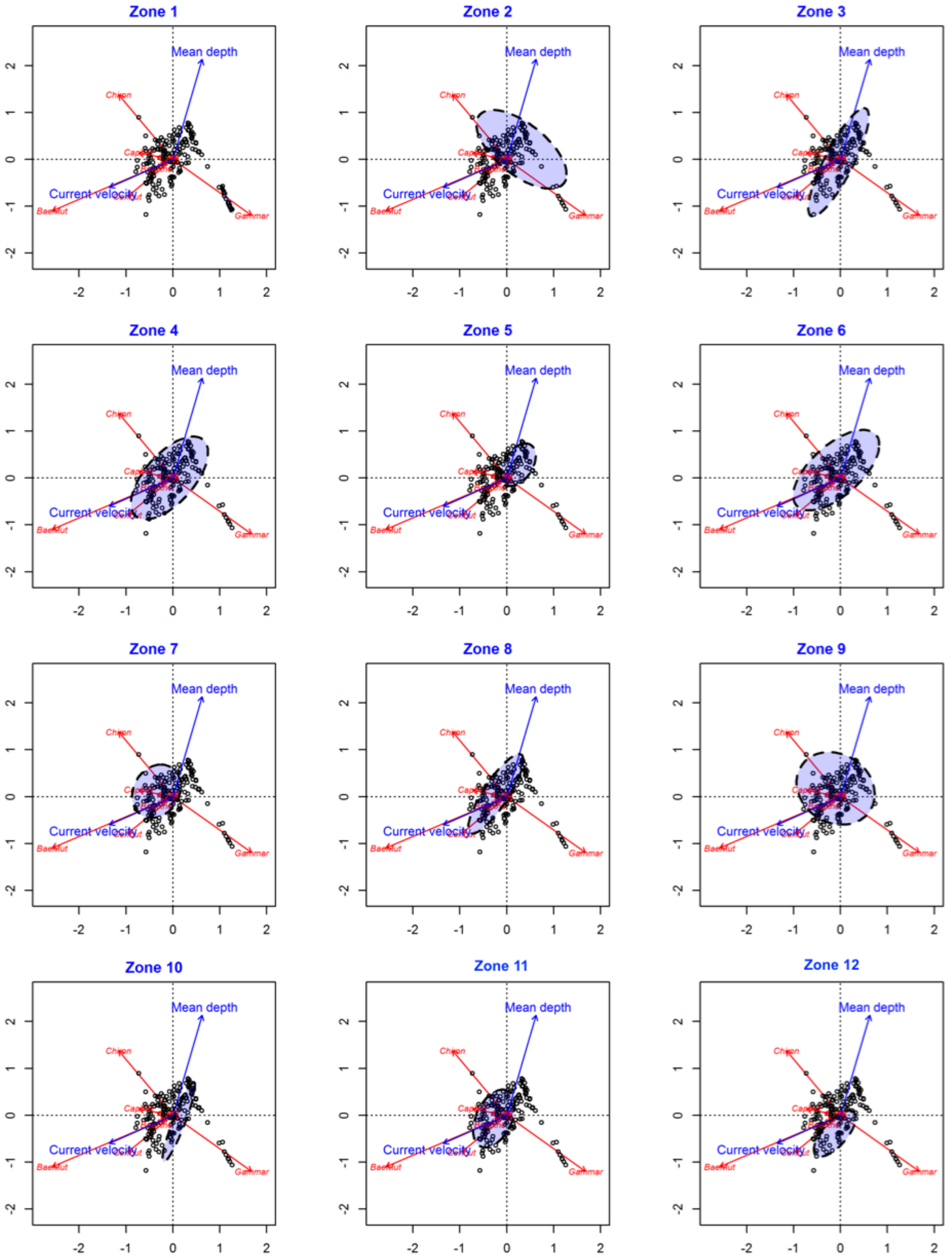


Figure A7. Biplot of the selected RDA (Table 12) where the five most influential species are shown as red vectors, continuous predictors as blue vectors and zone levels as 80% centroids (see Figure 16 for plot of remaining effects in the model).

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