Norwegian University of Life Sciences
Faculty of Environmental Science and Technology
Department of Ecology and Natural Resource Management

Master Thesis 2014
60 credits

Salmonid and Macroinvertebrate Responses to River Restoration Measures in the Channelized River Bognelv, Northern Norway.

Effekter av restaureringstiltak på laksefisk og makroinvertebrater i den kanaliserte Bognelva, Nord-Norge.

Kirsten Marie Sødal

Acknowledgements

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

First off all, I want to thank my professor and supervisor Thrond Oddvar Haugen for stepping up and making this thesis possible, and for guidance during fieldwork and writing period. I also want to thank associate professor Jonathan Edward Colman for the possibility to write this thesis, and for comments on the report. I want to thank Knut Aune Hoseth and Anders Bjordal at the local Norwegian Water Resources and Energy Directorate (NVE) office for financial support, and inputs during survey of the river. I also want to thank Arne and Anna Mikalsen for housing and fishing trip, Langfjordbotn hunting and fishing association (LJFF) for background information and Dag Petter Sødal for being my field assistant. Finally, I want to thank Terje Dønnestad for support during the writing period, and the girls in my class for making the two past years so enjoyable.

All photographs are taken by the author if not otherwise stated.

Ås, Mai 14th 2014

Kirsten Marie Sødal

Abstract

Running-water ecosystems are among the most damaged of all types of ecosystems, as humans have heavily exploited them over long periods. The pressure to restore degraded streams and rivers has increased worldwide, as the negative consequences of the degradation have become more evident. Bognelv, a river in Alta municipality, Northern Norway, was channelized between 1930 and 1990, and the salmonid fish populations were heavily reduced. Bognelv has been partly restored through several measures over the last eight years. The effects of the restoration process have been evaluated in two previous studies, in 2008 and 2011, and the raw data from these two studies have been merged with my data from 2013. Hence, three years of data have been analysed. Sampling of data has been done by electrofishing, sampling of macroinvertebrates and registration of environmental variables. The topics addressed were whether the restoration measures have increased the density of juvenile salmonid species in the river, and which environmental variables and restoration measures that have the most influence on fish density and growth, and macroinvertebrate density. An assessment of the degree of success of the restoration project was also made.

Higher densities of brown trout (*Salmo trutta*) were found in the river after restoration than before. The densities of juvenile Atlantic salmon (*Salmo salar*) and Arctic char (*Salvelinus alpinus*) have however not responded correspondingly to the restoration measures, and the densities have been low all years. Few salmon and no char were caught in 2013, and brown trout is therefore the only species analysed further.

The highest densities were found in heterogeneous habitats, and the measured environmental variables had complex effects on brown trout and macroinvertebrates. The highest densities of brown trout were found in shallow depths, with low water velocity, low levels of moss cover, high macroinvertebrate densities and at medium gravel size. The analyses indicate that cover is more important in explaining brown trout density than food availability. Mean summer temperature was found to be the most important variable for explaining brown trout growth. The highest densities of macroinvertebrates were found in habitats with coarse gravel.

When comparing restored stations with unrestored stations, the restoration measures conducted in the river where found to have positive, negative or no response on brown trout density and growth, and macroinvertebrates. However, when looking at densities and size of brown trout before and after the restoration measures, higher densities and improved growth were found. From observations during the fieldwork, higher densities of juvenile brown trout were found among boulder groups, where large woody debris was present, or at undercut banks, than in the surrounding homogenous areas. Microhabitat studies of where the fish and macroinvertebrate actually dwell are needed.

Even though it is hard to quantify effects from the various measures both at micro and station scale, thus the general increase in brown trout density and growth indicate that the sum of all measures may have produced synergistic effects that have improved ecosystem functioning. The increased brown trout population accordingly show that a full restoration of the hydraulic and geological processes is not needed to achieve biological goals. Further monitoring is needed to get a full understanding of the biological effects of the longer-term restoration process in Bognelv.

Sammendrag

Akvatiske økosystemer er blant de økosystemer som har blitt mest påvirket av menneskenes inngrep og utnyttelse. Globalt er det nå et økende ønske om å restaurere degraderte bekker og elver, ettersom de negative konsekvensene av ødeleggelsene er blitt mer kjent. Bognelva i Alta kommune i Finnmark ble kanalisert mellom 1930 og 1990, og bestandene av laksefisk ble kraftig redusert. Bognelva har nå blitt delvis restaurert, og det er gjennomført flere typer tiltak de siste åtte årene. Effektene av restaureringen har blitt undersøkt i to tidligere studier, i 2008 og 2011. Rådata fra disse to studiene er analysert på nytt sammen med mine data fra 2013, slik at datamaterialet omfatter tre år. Feltarbeidet har omfattet elektrofisking, samling av makroinvertebrater og registrering av miljøvariable. Spørsmålene som besvares er om restaureringstiltakene har økt tettheten av juvenile laksefisk i elva, hvilke miljøvariable og restaureringstiltak som har størst påvirkning på tetthet og vekst av fisk, samt på tettheten av makroinvertebrater. Den samlede måloppnåelsen til restaureringstiltakene i forhold til prosjektet er også blitt vurdert.

Etter at restaureringstiltakene ble gjennomført er det funnet klart høyere tetthet av brunørret (*Salmo trutta*) i elva. Derimot har verken laks (*Salmo salar*) eller røye (*Salvelinus alpinus*) respondert tilsvarende på restaureringstiltakene, og tetthetene av disse har vært lave alle år. Få laks og ingen røye ble fanget i 2013, og brunørret er derfor den eneste arten som er studert videre.

De høyeste tetthetene av brunørret og makroinvertebrater ble funnet i heterogene habitater, og det viste seg å være komplekse sammenhenger mellom tetthet og vekst og de målte miljøvariablene. Høyest tetthet av brunørret ble funnet i grunne områder med lav vannhastighet, lite mose, høy makroinvertebrattetthet og middels grusstørrelse. Analysene indikerer at overhengende greiner er viktigere enn mattilgang for å forklare tetthet av brunørret. Gjennomsnittlig sommertemperatur var den viktigste variabelen for å forklare vekst. De høyeste tetthetene av makroinvertebrater ble funnet i habitater med grov grus.

Når stasjoner med restaureringstiltak sammenlignes med urestaurerte stasjoner, viste de enkelte tiltakene både positiv og negativ virkning, og i noen tilfeller ingen forskjell, på tetthet og vekst for brunørret, og makroinvertebrat tetthet. Imidlertid er det samlet sett funnet klart økte tettheter og forbedret vekst for juvenil brunørret etter at restaureringsprosjektet ble satt i verk. Under feltarbeidet ble det observert klart høyere tettheter av juvenil brunørret ved steingrupper, og der det var døde greiner og trær eller undergravde elvebredder, enn i de mer homogene områdene rundt. Det er behov for mikrohabitatstudier for å undersøke hvor fisk og makroinvertebrater faktisk oppholder seg.

Selv om det er vanskelig å estimere effekten av de ulike enkelttiltakene, både på mikro og stasjonsnivå, indikerer den tydelige økningen i tetthet og vekst for brunørret at summen av alle tiltakene har produsert gjensidig forsterkende effekter, som har forbedret funksjonen til elva som økosystem. Den økte brunørretbestanden viser at en fullstendig restaurering av hydrologiske og geologiske prosesser ikke er nødvendig for å oppnå biologiske mål. Videre overvåkning behøves for å få en fullstendig forståelse av de langsiktige biologiske effektene av restaureringsprosjektet i Bognelva.

Table of contents

1.0 Introduction

1.1 Background

All over the world, there is increasing pressure on ecosystems, habitats and species, and loss of habitat is currently the largest threat for biodiversity (Hagen & Skrindo 2010; Feld et al. 2011). Running-water ecosystems are among the most damaged of all types of ecosystems, as they have been heavily exploited by humans over long periods (Sala et al. 2000; Malmquist & Rundle 2002; Lake et al. 2007; Feld et al. 2011; Pander & Geist 2013). Humans have changed rivers in order to extract water for daily needs, to make systems for irrigation, to control flooding and to build dams for energy (Eie et al. 1997; Postel & Richter 2003). In order to secure farmed areas against erosion and flooding, streams and rivers have been lowered and channelized (Kristiansen 2011). Channelization can be successful for flood control, but may have negative effects on flow characteristics for the river system, fish and other wildlife populations (Whalen et al. 2002).

Worldwide, the pressure to restore degraded streams has strengthened, as the awareness of the negative consequences has become more evident (Palmer et al. 2005), and because of the implementation of the EU Water Framework Directive (WFD) (Iversen 2011). Up to present, the planning system has not systematically integrated prevention and mitigation efforts, but with the new Nature diversity act passed by the Norwegian Parliament in 2009 and the WFD, which is implemented in Norwegian law, new goals to preserve and obtain good environmental conditions in water resources have been described (Hagen & Skrindo 2010). The WFD does not only demand protection and prevention, but also improvement and restoration where needed and possible (Iversen 2011).

Restoration ecology is an emerging field in aquatic ecology (Verdonschot et al. 2012). In restoration ecology, one essentially aspires to repair a disturbed and degraded ecosystem, area or species back to its origin (SER 2004c). The Society of Ecological Restoration (SER) has defined ecological restoration as *"Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed"* (SER 2004b). Restoration ecology is a multi-disciplinary field and contains biological, geological and physical aspects, as well as social, economic and political factors (Hagen & Skrindo 2010). The assumption that underlies many river restoration projects is that improvement of physical habitat heterogeneity and construction of inhabitable habitats will increase species richness and densities (Palmer et al. 1997; Miller et al. 2010). However, few have tested this hypothesis (Lepori et al. 2005; Roni et al. 2006; Miller et al. 2010). Iversen et al. (1993) also states the idea that if it is harmful for wildlife to destroy stream habitats, restoring them should be beneficial. In this thesis, restoration is used as a broad term, including all efforts to improve or restore aquatic habitats.

Since the 1990s, there has been an exponential increase in the number of river restoration projects (Whalen et al. 2002; Postel & Richter 2003; Bernhardt et al. 2005), and in Norway, the number of restoration projects are increasing (Hamarsland et al. 2003; DN 2009; Hagen & Skrindo 2010; Iversen 2011; Kristiansen 2011). There are surprisingly few studies on the effects of these restoration projects, but they start piling up (Shuler et al. 1994; Kondolf & Micheli 1995; Bernhardt et al. 2005; Lake et al. 2007; Vehanen et al. 2010; Feld et al. 2011). The studies reported have shown both positive, negative, varying or no response of restoration measures on density, reproduction and growth of salmonids (Johnson et al. 2005; Roni et al. 2006; Muotka & Syrjanen 2007; Weber et al. 2007; Baldigo et al. 2010; Vehanen et al. 2010; Haase et al. 2013; Lorenz et al. 2013). Despite the increasing number of studies, few actually provide evidence of how the ecological knowledge can enhance restoration success (Verdonschot et al. 2012). Even though there is no consensus on what constitutes a successful restoration project (Palmer et al. 2005; Lake et al. 2007), SER has provided a list of nine attributes to determine if restoration has been achieved, and defines recovery as "*An ecosystem has recovered - and is restored - when it contains sufficient biotic and abiotic resources to continue its development without further assistance or subsidy*" (SER 2004a). A full recovery of aquatic ecosystem is defined by Verdonschot et al. (2012, s. 11) to be "*Full recovery refers to an optimal functioning of the aquatic ecosystem under the given environmental circumstances that are not or only slightly changed by human activity*". Also, to understand the effectiveness of habitat restoration techniques are important to design successful future restoration projects (Roni 2005).

The river Bognelv, in northern Norway, is a river that is being restored and monitored. Bognelv was originally a dynamic and meandering river, with high densities of the salmonids Atlantic salmon (*Salmo salar*), brown trout (*Salmo trutta*) and Arctic char (*Salvelinus alpinus*) (Hoseth & Josefsen 2005). Between 1930 and 1990, 3.5 km of the river was channelized, which resulted in significantly reduced fish stocks (Hoseth & Josefsen 2005). The river has been restored trough several measures since 2006, implemented by The Norwegian Water Resources and Energy Directorate (NVE).

The river has earlier been the subject of two master thesis investigations, in 2008 and 2011, and some of the early effects of the restoration measures are therefore known (Schedel 2010; Austvik 2012). The aim of these studies was to reveal whether the restoration measures have increased the density of juvenile salmonid species in the river. Schedel (2010) found that restoration likely had a positive impact leading to increased populations of juvenile brown trout and salmon. Austvik (2012) also found a tendency towards increased 0+ brown trout density, which was coherent with the increase in time since restoration. It was assumed that suitable habitats and food access were improved after the restoration. Both studies concluded that opening of side channels and tributaries were the most positive restoration measures conducted. Austvik (2012) also found that macroinvertebrate densities were improved by the opening of side channels.

1.2 Aims of the study

The aim of my study is as Schedel (2010) and Austvik (2012), to [1] reveal whether the restoration measures conducted in Bognelv over the last eight years have increased the density of juvenile salmonid species in the river. Second, to [2] investigate potential environmental variables that have influenced fish density, growth and macroinvertebrate density. I will then try [3] to estimate restoration-measures-specific effects on juvenile salmonid species and the macroinvertebrate densities. Finally, I will [4] assess whether the restoration project has been successful or not, and whether Bognelv have been fully restored or not.

2.0 Materials and methods

2.1 Study area

The river Bognelv is located in the valley Bognelvdalen (Figure 1 and 2). The river originates at the county border between Troms and Finnmark County, and has its outlet in the fjord Langfjorden, west in Alta municipality (UTM 32, 7785041 N, 777617 E). Bognelv has watercourse number 211.8Z (*vann-nett.no* 2013).

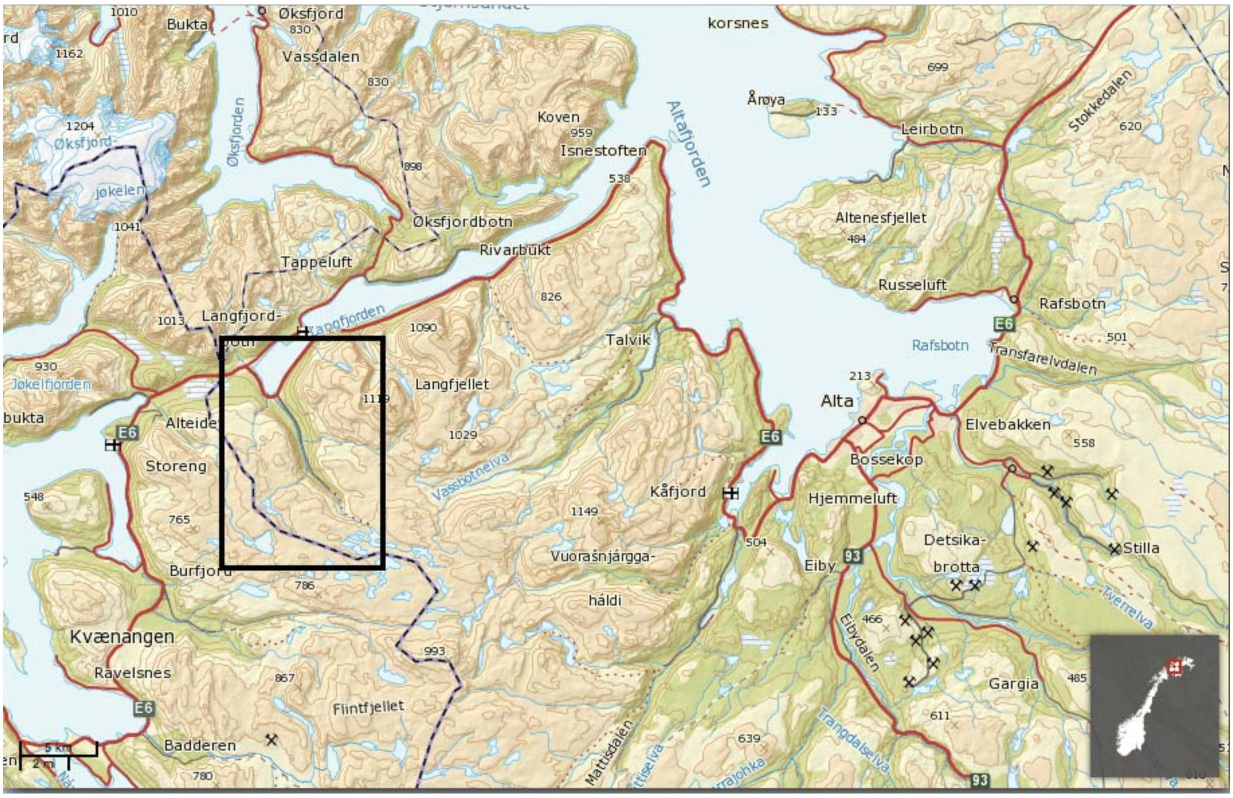


Figure 1. Location of the study area. The black square illustrates the study area Bognelvdalen, in Finnmark County, Northern Norway (www.norgeskart.no).

Figure 2. The study area covers a distance of 3.5 km. From the outlet of the river to where the river Ørplasselva drains into Bognelv (www.norgeskart.no).

All information given in chapter 2.1 and 2.2 is based on the NVE-background report written by Hoseth and Josefsen (2005). The river catchment area is 88.5 km^2, most of which lies above the tree line and has cold stable winter conditions. The spring flows dominate, as the discharge is higher in early summer. In July, the discharge is 7 m^3/s, while in August, September and October the discharge is 3 m^3/s. Normally, there is no ice drift in the river. The climate in the area has a continental character, with mildly humid conditions. The area belongs to Finnmark Sub Maritime Birch and Pine Forest Region, which is rich in all types and sizes of freshwater lakes. There are about 20 lakes in the catchment area, whereof none are larger than 1 km^2. The lakes are located between 500 and 700 meters above sea level. Most lakes are nutrient poor, but some lower lakes are nutrient rich because of the calcium-rich rocks in the area. Several of the lakes have populations of brown trout and char.

The Bognelv valley is a typical glacier-formed U-shaped valley with marine deposits, steep hillsides and a flat valley bottom. The lowest four km of the river flows through a flat area with scattered houses and sizeable agricultural activity. Birch and alder forests and a substantial presence of perennial plants dominate the bottom of the valley, and in several places it has a primeval forest character. This is a result of nutrient rich soil, and the calcareous rocks that dominate the area. By the outlet and along the riversides, there is high biodiversity, and several red listed plant and animal species exist (Strann & Frivoll 2009). The values of the area along the river have been significantly impaired by channelization, agriculture and building of the new highway (E6) near the outlet. The river was protected from hydro-electric development in 1980 (NOU 1976: 15 ; St.prp. nr. 77 (1979-80)).

2.2 The river history – channelization and restoration

2.2.1 The channelization process

Between 1930 and 1990, a total of 3.5 km of the river was channelized, from the new main road E6 up to where the river Ørplasselva drains into Bognelv (Figure 2). The reason for the channelization was to improve the conditions for agriculture along the river. From the late 1930s to the beginning of the 1950s, ten parcels of erosion control systems were built on the outside of the river bends. From 1956 to 1975, 2.1 km of the lower part of the river was channelized, straightened and lowered to further reduce the erosion. In addition, big rocks were placed along the riverbanks as erosion control. The rocks were taken from scree located near the river. Between 1980 and 1990, another 1 km in Bognelv and 0.6 km of Ørplasselva were channelized. In connection with the construction of the new highway in the beginning of 1990s, another stretch of 200 meters was channelized. Figure number 3, 4 and 5 shows how the lower part of the river looked in 1946, 1972 and 2008, before and after the channelization.

Figure 3. The lower part of Bognelv, in 1946 (Colman et al. 2010).

Figure 4. The lower part of Bognelv, in 1972 (Colman et al. 2010).

Figure 5. The lower part of Bognelv, in 2008 (www.norgeibilder.no).

2.2.2 The restoration process

NVE received the first statements of deterioration of the fish populations in 1972. The first survey of fish densities in the river was conducted in 1998, and showed low densities of all salmonid species (Saltveit & Brabrand 1999). In 2002, the hunting and fishing association in Langfjordbotn (LJFF) initiated measures to improve the river. Surveys undertaken in 2003 and 2004 concluded, as in 1998, that the densities of salmonid species were low (Dønnum & Colman 2004; Dønnum 2005).

In 2005, NVE made a report for a general restoration measures plan in Bognelv, with the goal to restore the natural dynamics and diversity of the river (Hoseth & Josefsen 2005). The intentions of the restoration measures were to improve the environment in the river without reducing the flood security. The report described eight measures. The first two measures (number 3 and 5) were implemented during fall in 2006 (Bjordal & Hoseth 2006; Hoseth & Josefsen 2006). This involved opening three side channels and the removal of a flood-control system. In 2007, measures number 4 and 6 were carried out and involved opening of the tributary Mikkelveita (Hoseth & Josefsen 2007). To further increase the natural watercourse, flood controls were improved and moved, and rocks were placed in groups from the outlet and halfway up the river. In 2009, measure number 7 was effectuated, and involved opening of an old river course and removal of several stretches of erosion control banks (Bjordal & Hoseth 2009). Also, fish access to the tributary Tverrelva was opened by removal of an obstacle. In 2012, the so far last actions were completed for measures number 3, 4 and 7, and involved reparation of a weir in Ørplasselva, removal of erosion controls, maintenance of flood control systems in several places and the placement of more rock clusters in the river (Bjordal & Hoseth 2012). Measures number 1, 2 and 8 have not yet been effectuated. See Appendix 1 for a more detailed overview of the measures conducted, and Appendix 2 for an overview of where the measures have been conducted.

Summing up, the measures done to restore the river involve opening and re-establishing the side channels and tributaries, re-creating pools and channels to improve the habitat, as well as the placement of rock clusters and the creation of weirs to increase the habitat diversity in the river.

2.3 Study species

2.3.1 Brown trout

Fish in the salmonid family are relevant indicators of water quality, ecological status and success of restoration measures (Degerman et al. 2004a; Bergan et al. 2011; Lorenz et al. 2013), and include all study species in this study. The Bognelv salmonids include brown trout, Atlantic salmon and Arctic char, hereafter referred to as brown trout, salmon and char. In 2013, there were low catches of salmon and no catches of char. Brown trout is therefore the only species included in the statistical tests.

Life history traits

Brown trout was originally restricted to Europe, but has been spread globally by humans the last 150 years (Elliott 1994; Jonsson & Jonsson 2011). The brown trout successful introduction is due to its wide range of life cycles (Elliott 1994). Brown trout can be a resident in freshwater or anadromous, using both freshwater and the ocean as habitat during its life cycle (Jonsson & Jonsson 2011). Sea trout is anadromous; the mature sea trout live and feed in the ocean, and spawn in freshwater on stone or gravel bottom in autumn or winter, preferably in a fast-flowing river (Klemetsen et al. 2003; Jonsson & Jonsson 2011). At higher latitude and altitude spawning occurs earlier, because of lower water temperature and longer egg incubation period (Klemetsen et al. 2003). The eggs hatch the subsequent spring, and for the first weeks the alevins feed on their yolk sac, often to a size of 20 mm, before they emerge from the substrate (Klemetsen et al. 2003; Jonsson & Jonsson 2011). The length of the endogenous larval period is also temperature dependent, and increases with lower temperatures (Crisp 1988; Elliott & Hurley 1998). After the alevins emerge (as parr) from the substrate, often a month after hatching, they start feeding on macroinvertebrates in the proximity of the spawning area (Jonsson & Jonsson 2011). The parr disperse as they get bigger or drift downwards in the river if they do not get a territory (Elliott 1994; Klemetsen et al. 2003). When the body length is about 15 cm, the sea trout parr transforms into smolt, and migrate to the sea in spring (Jonsson & Jonsson 2011). Sea trout have been known to return to their home river the same year as they moved to the sea (Jonsson & Jonsson 2009). Sea trout are iteroparous and can spawn every year after maturity (Jonsson & Jonsson 2011).

Habitat requirements

Habitat influences growth and survival, and to determine a stream`s carrying capacity and the density of juvenile brown trout, habitat is important (Heggenes et al. 1999). Habitat requirements are affected by several factors, and the interactions among factors are complex (Elliott 1994). There are, however, some known important habitat requirements. Brown trout require high oxygen levels and cold water (Elliott 1994; Elliott & Elliott 2010). Temperature is perhaps the most important abiotic factor as it influence the important life history traits growth and size, and hence survival and fitness (Jonsson & Jonsson 2011). The fish can sustain higher temperatures for feeding than for growth and development (Elliott & Elliott 2010; Jonsson & Jonsson 2011). The temperature tolerance changes with life stage; the egg stage has the lowest tolerance, and alevins a slightly lower tolerance than parr and smolt (Elliott & Elliott 2010; Jonsson & Jonsson 2011).

The most important requirements for the physical habitat have shown to be water depth, water velocity, streambed substrate and cover, but the requirements change with season and life stage (Elliott 1994; Heggenes et al. 1999; Jonsson & Jonsson 2011). For instance, brown trout found in bigger rivers are often located along the bank area, with the smallest and youngest parr exploiting shallower areas closer to shore than bigger older parr (Jonsson & Jonsson 2011). Incubated eggs and alevins demand high-oxygen levels, fast flowing water and a substrate with low levels of fine sediments (Jonsson & Jonsson 2011). The parr require shelter and food, and hide among and under stones, in undercut banks, among dead wood, in mosses and riparian vegetation (Beland et al. 2004). The parr prefer a stony bottom as substrate, because the stones create low-velocity stations where it can monitor macroinvertebrate drift without using much energy (Jonsson & Jonsson 2011). Parr shorter than 7 cm prefer depths between 5 and 30 cm, and riffles where the water velocity does not exceed 20 cm s^{-1} near their snouts (Heggenes et al. 1999; Jonsson & Jonsson 2011). Also, brown trout are attracted to stretches with overhead cover, as absence of cover can cause chronic stress (Pickering et al. 1987; Heggenes et al. 1999). Cover allows the fish to adopt a more risk-adverse foraging behaviour, which affects survival and abundance (Jonsson & Jonsson 2011). Cover can take forms as overhead branches, vegetation, undercut banks, high water velocity, dead wood and deep water (Boussu 1954; Crook & Robertson 1999; Klemetsen et al. 2003).

Also, food is an important factor for density and survival, and feeding is more efficient after a territory is acquired (Jonsson & Jonsson 2011). Juvenile brown trout are aggressive, support territories and compete when there are limited resources (Heggenes et al. 1999). Therefore, the population density often increases with structural complexity, as the structures give a visual shelter and decreases the aggression between close individuals (Jonsson & Jonsson 2011). The most preferred feeding stations for juvenile brown trout are close to the shelter but also in fast flowing water where the abundance of food is high (Jonsson & Jonsson 2011). The diets differ between age groups (Jonsson & Gravem 1985). Small food items like drifting zooplankton and chironomid larvae are the most important food for the 0+ age group, while surface arthropods, chironomid pupae and larger zoo benthos (Plecoptera, Trichoptera, Simuliidae) are more important for older parr (Jonsson & Gravem 1985; Jonsson 1989).

2.3.2 Macroinvertebrates

As stated earlier, macroinvertebrates are important as nourishment for brown trout, and macroinvertebrates are also relevant water-quality indicators (Degerman et al. 2004a). Macroinvertebrates are less mobile than fish, and are therefore better suited as a study species in monitoring the ecological status in the river (Bongard & Aagaard 2006). Macroinvertebrates were collected and classified to the nearest order. The orders of special interest are mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddisflies (Trichoptera), as these are predicted to be present in all undisturbed localities in Norway (Bongard & Aagaard 2006). The mayflies, stoneflies and caddisflies are termed EPT-order. The EPT-species spend most of their immature life in aquatic environment, as eggs or nymphs (Ross 1967; Anderson 1976; Hynes 1976; Brittain 1982). In Norway there are registered 45 species of mayflies, 35 species of stoneflies and 195 species of caddisflies (Ottesen 2014a; Ottesen 2014b; Semb-Johansson 2014).

2.4 Data collection

2.4.1 Preparations

In order to be able to compare results and merge data, the method for the fieldwork is based on the methodology used in the former studies done in 2008 and 2011 by Schedel (2010) and Austvik (2012). The fieldwork was undertaken in 2013 during 28th August to 6th September. Electrofishing and all other registrations and samplings were done during this period. In previous years, the sampling of macroinvertebrates and registration of environmental variables have been done in late June and early July. Electrofishing has been undertaken at the same time all three years.

Fifteen of the stations Austvik (2012) used were omitted, because there would still be enough data for statistical comparison. Two new stations in Tverrelva were added (zone 10), after inputs from NVE. In addition, two more stations were added in zone 8. Both Schedel (2010) and Austvik (2012) marked their stations with red painting on riverside stones or trees. At 27 stations, at least one mark was found, 17 of these with both marks. For 21 of the stations, the marks were not found. Some of these stations had been altered by the restoration work, and some could just not be found. At these stations a map from Austvik (2012) were used to trace the correct positions. In total, there were 50 stations; 30 in the main river, 16 in side channels and four in tributaries. Also, at six of the stations, one-pass fishing was done in the middle of the river. However, the one-pass fishing in the mid-stations is not included in the statistical analysis. All stations were located between the river outlet and 3.5 km upstream. See Appendix 3 for an overview of the station locations. Norgeskart.no was used to make the maps.

2.4.2 Electrofishing

Electrofishing was used to capture fish. This is a widely used method to estimate densities of juvenile fish in rivers (Bohlin et al. 1989; Forseth & Forsgren 2008; Bergan et al. 2011). The electrofishing gear was FA2 no.7 700/1400 volt, 35-70 Hz, pulsed DC, see Figure 6. Two persons did the electrofishing. One person carried the gear, and both were netting. In 2008 and 2011, electrofishing was conducted only along the river edges. In 2013, some stretches in the middle of the river were electro fished, because salmon are often to be found in the middle of the river where the water velocity is higher and the river is deeper (Eie et al. 1997; Heggenes & Saltveit 2007; Jonsson & Jonsson 2011).

Figure 6. Demonstration of fishing with the electrofishing gear. Photo: Dag Petter Sødal.

Electrofishing was done at all 50 stations. The stations were 15 meters long and two meters wide. Two or three passes were performed at high-to-moderate density stations, to be able to estimate the densities using removal techniques (Zippin 1956; Seber & Lecren 1967; Bohlin et al. 1989; Bergan et al. 2011). There was at least 30 minutes between each pass. The fish were stored in dark 10 litre buckets, and stored on the riverside until the fishing of the stations was finished. Different removals had different buckets. The fish were classified to species and measured to the nearest millimetre (Figure 7). The fish were thereafter released back into the same station. When fishing in the middle of the river, this was done at the same stretches as already registered stations. The purpose for this was to explore whether the fish species composition differed between mid-stream and near-shore habitats. One-pass fishing was conducted in the mid-stream habitat, but otherwise the same method was used as in other stations.

Figure 7. Photograph of a captured brown trout being measured.

2.4.3 Macroinvertebrates

Macroinvertebrates were collected at all stations. Austvik (2012) only counted the total number of macroinvertebrates, but in 2013, I also classified individuals into taxonomic order. Both years, the macroinvertebrates were sampled using a Surber-sampler (Surber 1937) (Figure 8). The sampler was placed on the riverbed, and covered an area of 0.06 m^2. The rocks in the area covered by the Surber-sampler were scrubbed with a brush. Also, bigger rocks covered by the Surber-sampler were turned and brushed. The loosened macroinvertebrates floated with the current into a net attached to the Surber-sampler. All of the material collected was put in a bucket and the macroinvertebrates were counted and classified into order.

Figure 8. Photograph of the Surber-sampler.

2.4.4 Environmental variables

See Appendix 4 for a more detailed explanation on the methods. At all stations, the canopy cover of the river and the riverbank, as well as the vegetation cover in the flood zone were assigned a category. The substrate composition was classified into five grain-size groups and given a total of 100 percent. Also, water velocity, algae cover, moss cover, depth at one and two meters, the number of large woody debris, the number of pools and the spawning ground suitability were registered. The scale of the categories used can be seen in Appendix 4. The river width was estimated at each station and given a percentage of water cover. Four temperature loggers in the main river logged the temperature every hour during the whole field period.

2.4.5 Metrological data

Metrological data was obtained from the Norwegian Meteorological Institute and their climate database “eKlima” (Norwegian Metrological Institute 2014). Air temperature data was retrieved from a weather station at Alta airport (number 93140) (UTM33, 818519E, 7785240N). This is the closest of the weather stations reporting temperatures. Precipitation and snow depths were retrieved from a weather station in Langfjordbotten (UTM33, 778300E, 778399N), called Sponesbukt (number 92910). The snow-off-day was set to be the first day without snow cover. The mean temperature in the growth period, and duration of the growth period, was calculated from the snow-off day until the first day of electrofishing. The growth season was in 2004 set to be until 15. August, as the date for the electrofishing is not stated, only month.

2.5 Brown trout age groups

During the fieldwork in 2013, a total of 608 brown trout were captured (138 0+, 277 1+ and 193 >1+). Only four salmon were captured, two 1+ and two >1+, and no char. Prior to statistical tests, the brown trout year classes (0+, 1+ and >1+) were defined for 2013, and also for 2008 and 2011 (Figure 9) based on the length distribution. The results can be seen in Table 1. Austvik (2012) revealed that the year classes set by Schedel (2010) was slightly skewed, and hence, the year classes differ from what was used in 2008. In 2011, no length group for 1+ and >1+ was decided, as there was no clear 1+ peak. In order to be able to do statistical tests, the length groups 1+ and >1+ for 2011 was set to be 58-90 mm and >91 mm. The year classes from Table 1 are used in the statistical test.

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

	Age class		
	0+	**1+**	**>1+**
2008	25-50	51-88	>89
2011	21-57	58-90	>91
2013	33-56	57-90	>91

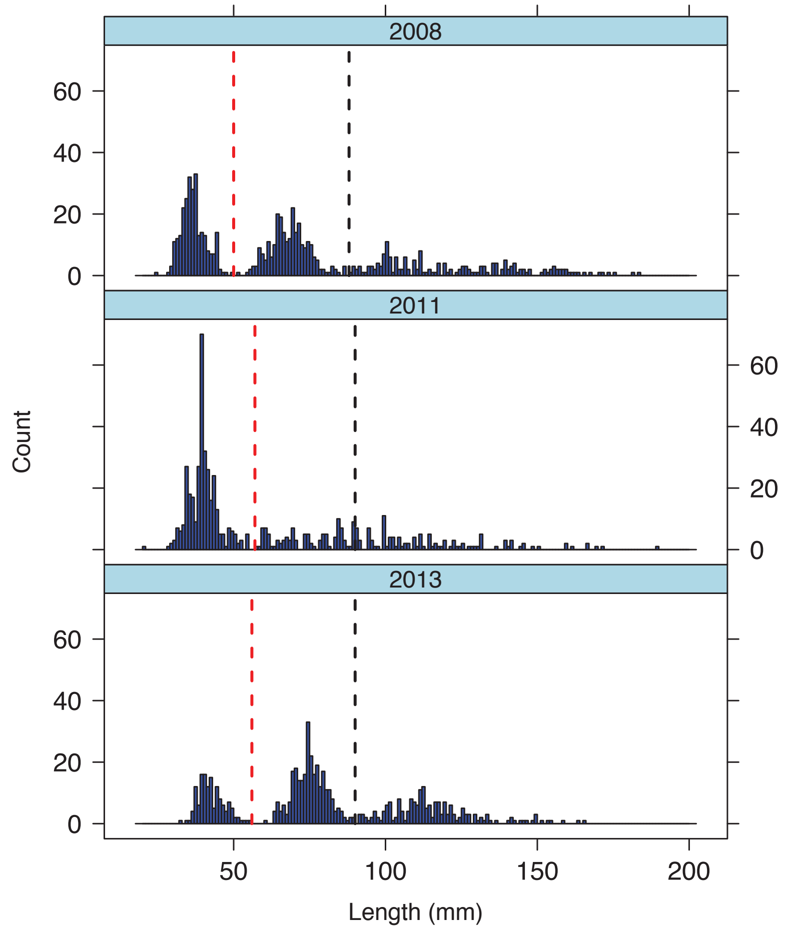


Figure 9. The histogram shows the length distribution of brown trout in 2008, 2011 and 2013. The 0+ group is below the red dotted line, the 1+ group is between the red and black dotted line, and the >1+ group is above the black dotted line.

2.6 Statistical analyses

Microsoft Excel (Microsoft Office 2011) was used for data processing and to make some graphs. However, most figures and statistics were created in R version 3.0.2 (R Development Core Team 2012). The density data was ln-transformed, and since there were zero-catches at some stations, densities were ln(X +1) transformed to avoid ln(0).

When comparing group effects on continuous response variables (e.g., density or length), ordinary one-way anova tests were undertaken. In situations with variance heterogeneity among groups, Welsh anova was used for comparison (Sokal & Rohlf 1995).

The environmental data was prepared so that the data could be used in the statistical analyses. Data from zone 1-9 was used, as data from zone 10 is only available from 2013. The environmental variables measured in 2008 were; riverbed profile and substrate, water velocity, depth, water temperature, numbers of large woody debris and overall vegetation cover. In 2011, the same environmental variables were measured as in 2013 (see chapter 2.4.4), except for numbers of large woody debris and pools. Data for numbers of pools in 2011 is missing in the excel sheet. To be able to use the gravel data collected in 2013, values from each transect was cumulated, so that each transect had a value of 100. The cumulated substrate composition data were fitted to a three-parameter Weibull function:

$$\mathrm{Pr}(x) = \mathbf{a}^{e^{-e^{(\mathrm{b}\log(x)-\log(\mathrm{c}))}}}$$

Where Pr(x) is the probability (fraction) for a given grain size x and a, b and c are parameters under estimation. Parameters were estimated in the drm package in R using the log-likelihood method. The median grain size, i.e., at the 50% prediction from the Weibull model, was derived for each station using the ED function in R. At station 17, 40 and 65 the median was set to be 1, as the values calculated by R were negative. This was probably due to the fact that the substrate at these stations was fine, and R had problems with calculating these values. Substrate data for 2008 and 2011 were given a mean value based on the mean of the category used. For depth and water velocity for all three years, a mean value was used as the measurement was different among years. When using vegetation cover for all three years, a mean of canopy and edge vegetation was used for data from 2011 and 2013. In 2008, a mean value of vegetation cover was the only measurement for canopy and vegetation. Macroinvertebrate density was multiplied to get density/m^2 in 2011 and 2013. All other environmental data were used as measured according to chapter 2.4.4 and Appendix 4.

Model selection, to find the models that most adequately describes the relationship between different predictor variables and density and growth, were performed using Akaike´s Information Criteria (AIC) (Akaike 1974). General linear models (GLM) (McCullagh & Nelder 1989) were fitted to test the environmental factors effects on density and growth. The summary function was used to get the parameter estimates and test statistics for the most supported models. P-values were considered significant at $\alpha = 0.05$. The most supported model was the one with the lowest AICc value, and it was substantially different from the other models if ΔAIC (the difference between a given candidate model and the most supported model) was below 2 (Burnham & Anderson 2002). For models involving two or more continuous predictor variables contour plots were made to graphically visualise model predictions. The model selection for density was done for two combinations of years, as more environmental variables were measured in 2011 and 2013, than in 2008. Model selection for density was carried out for both the 0+ and 1+ group. Model selection for growth was only done for 0+ growth, as I do not know the growth of 1+ the previous seasons. In the growth analyses, data sampled in 2004 was also used (Dønnum 2005), and hence the model selection for growth was done for three combinations of years, as only temperature data was available for 2004. To find the age distribution in 2004, a histogram was made, and revealed that the 0+ group was 32-50 mm. The material from 2004 included not enough data to test interactions between variables, and hence only single variables were tested for growth when model selection was done for four combinations of years. Model selection for macroinvertebrates analyses was done as for fish density and growth, but only for the years 2011 and 2013. The density data for macroinvertebrates were also ln-transformed.

To test if restoration had any effect on fish density, growth and macroinvertebrate density, all the most supported models were tested in a model selection based on AIC criteria, alone, with time since first and last restoration measure, the different measures and if the station was restored or not. Type of measure was divided in three groups, and type of measure of each station was set to be the most dominant measure. The type of measures was riparian modification, which included alteration of the riversides, side channels, which included opening of side channels and tributaries, and weirs, which included building of weirs in the river. To test if side channels had an effect on density and growth, also here a model selection based on AIC criteria was applied. The anova test and summary revealed the test statistics and the parameter estimates.

In order to model macroinvertebrate order composition (Ephemeroptera, Plecoptera, Tricoptera and Chironomidae) as function of environmental and measures variables, multinomial logit candidate models (Hosmer & Lemeshow 1989) were fitted to the macroinvertebrate composition data. This was done using the multinom-function available from the nnet-library in R. Following standard AIC model selection procedures the most supported model was selected and predictions of cumulated order-probabilities were constructed as function of the selected candidate model’s prediction variables.

3.0 Results

The structure of the results is as follows. First, an overview of the density development of the salmonid species is presented. Second, the density distribution for brown trout for zone and year are presented. Third, model selection on various environmental variable effects and interaction effects are conducted to find the most supported model structures, first on 0+ and 1+ density, thereafter on 0+ growth. The analyses are, as earlier mentioned, performed twice since more environmental variables were measured in 2011 and 2013, than in 2008. Thereafter, the effects of restoration measures on 0+ and 1+ densities and 0+ growth are estimated. Also, the effects of side channels on density and 0+ growth are estimated. Environmental variables' effects on macroinvertebrate density are explored with model selection, as well as the effects of the restoration measures. Finally, environmental variables and measured effects on mayflies, stoneflies and caddisflies (EPT-order) and Chironomidae composition are tested.

3.1 Salmonid density development between 1998 and 2013

Figure 10, 11 and 12 show the density distribution for the three salmonid species (brown trout, salmon and char) in Bognelv between 1998 and 2013. In 1998 and 2004, after the channelization and before the restoration measures, the densities of all three fish species were low. Since then, brown trout has increased in density, with some variation between the different sampling years (Figure 10). The 0+ density was lower in 2013 than in both previous years, while the 1+ density was lower in 2011 than in 2008 and 2013. The >1+ density has been relatively stable all years. The density of salmon has been low all years, with highest density in 1998, 2008 and 2011. In 2013, very few (n=4) salmon were caught (Figure 11), despite middle stretches being electro fished to investigate whether the salmon densities might have been underreported in previous years. The char density has also been low all years, and in 2013, no char were caught (Figure 12).

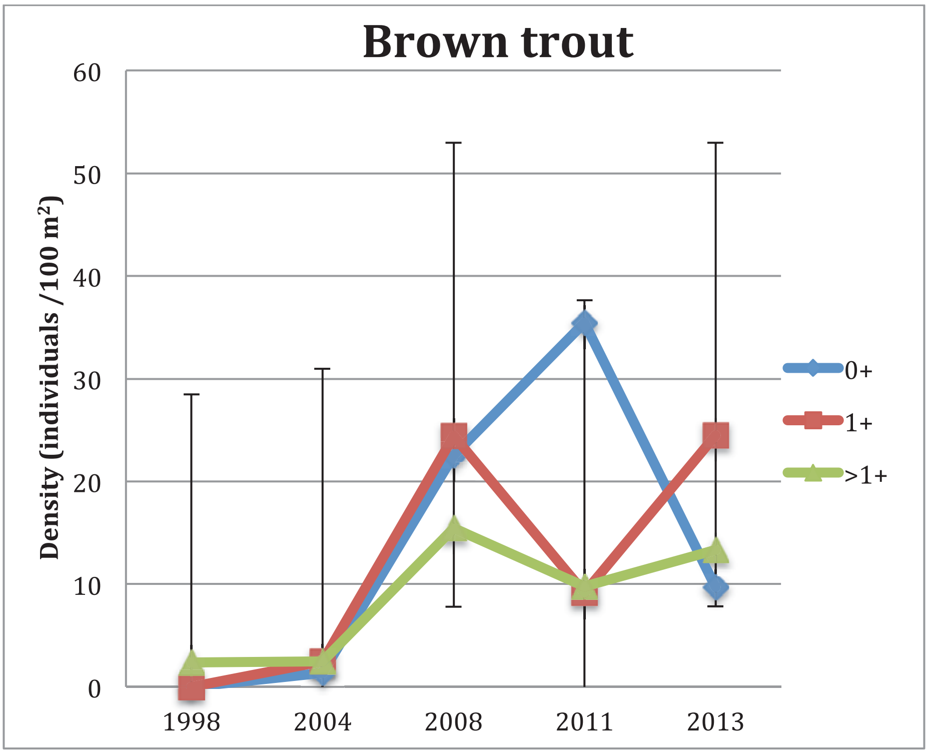


Figure 10. Density development for brown trout between 1998 and 2013. Restoration measures have been done between 2006 and 2012. The bars illustrate the standard deviation.

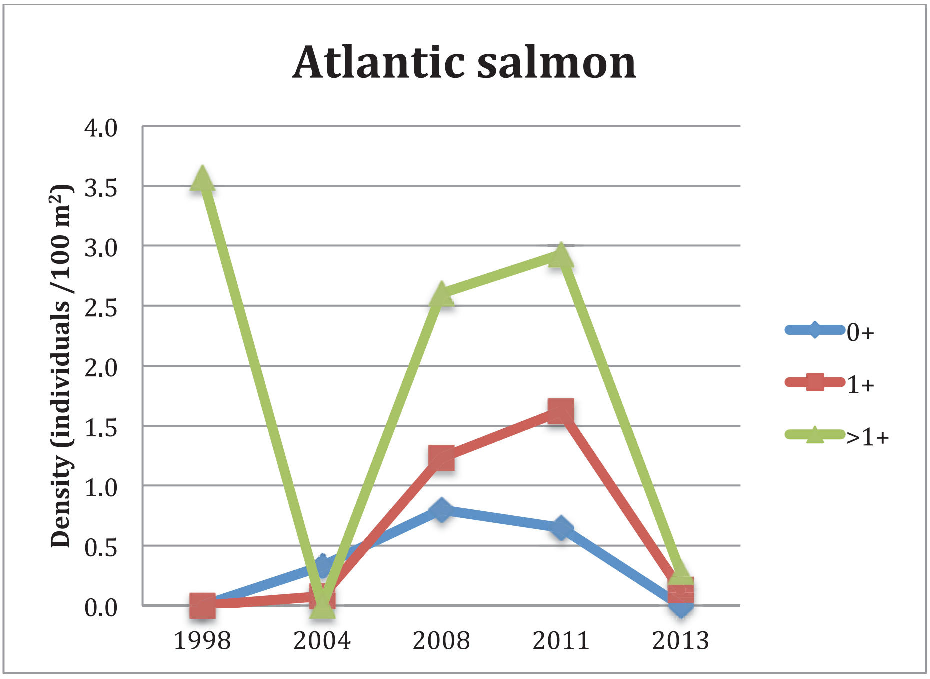


Figure 11. Density development for Atlantic salmon between 1998 and 2013. Restoration measures have been done between 2006 and 2012.

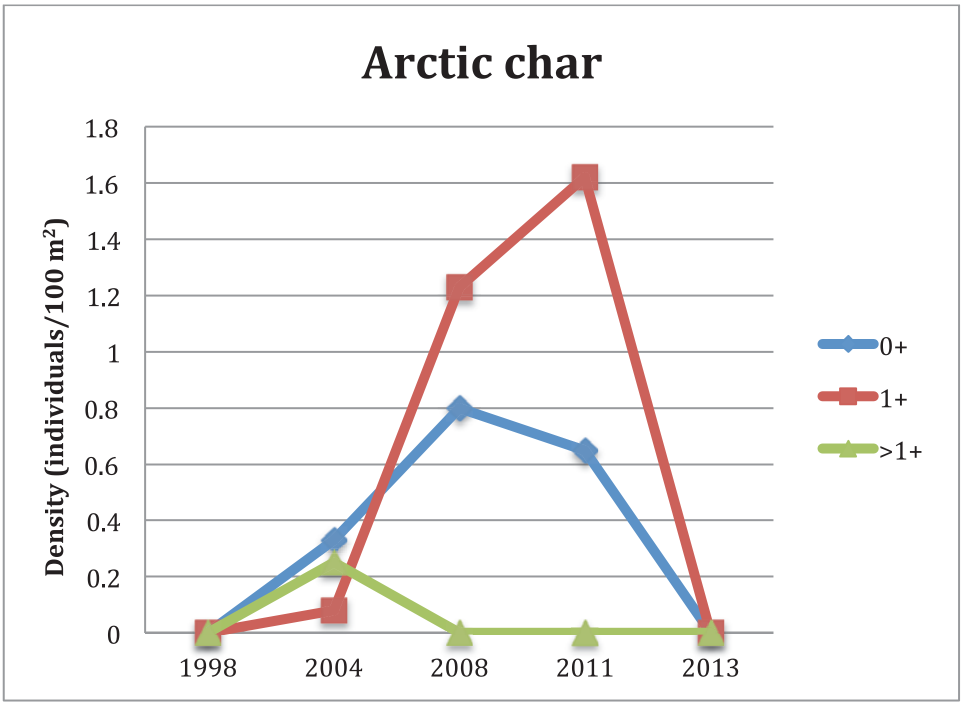


Figure 12. Density development for Arctic char between 1998 and 2013. Restoration measures have been done between 2006 and 2012.

3.2 Age-specific density distribution of brown trout among zones

A one-way Welsh anova test was conducted to look at variation among zones for the three age groups, respectively (Table 2). The tests revealed variation among zones, as can also be seen in Figure 13.

Table 2. A one-way Welsh anova test revealed differences in brown trout density among zones for all age groups. *** indicates a significance level of $p<0.001$.

Age group	F	df. Num	df. Den	p- value
0+	6.3727	9.000	20.34	***
1+	3.1707	9.000	21.0	0.0141
>1+	3.3811	9.000	22.594	0.0091

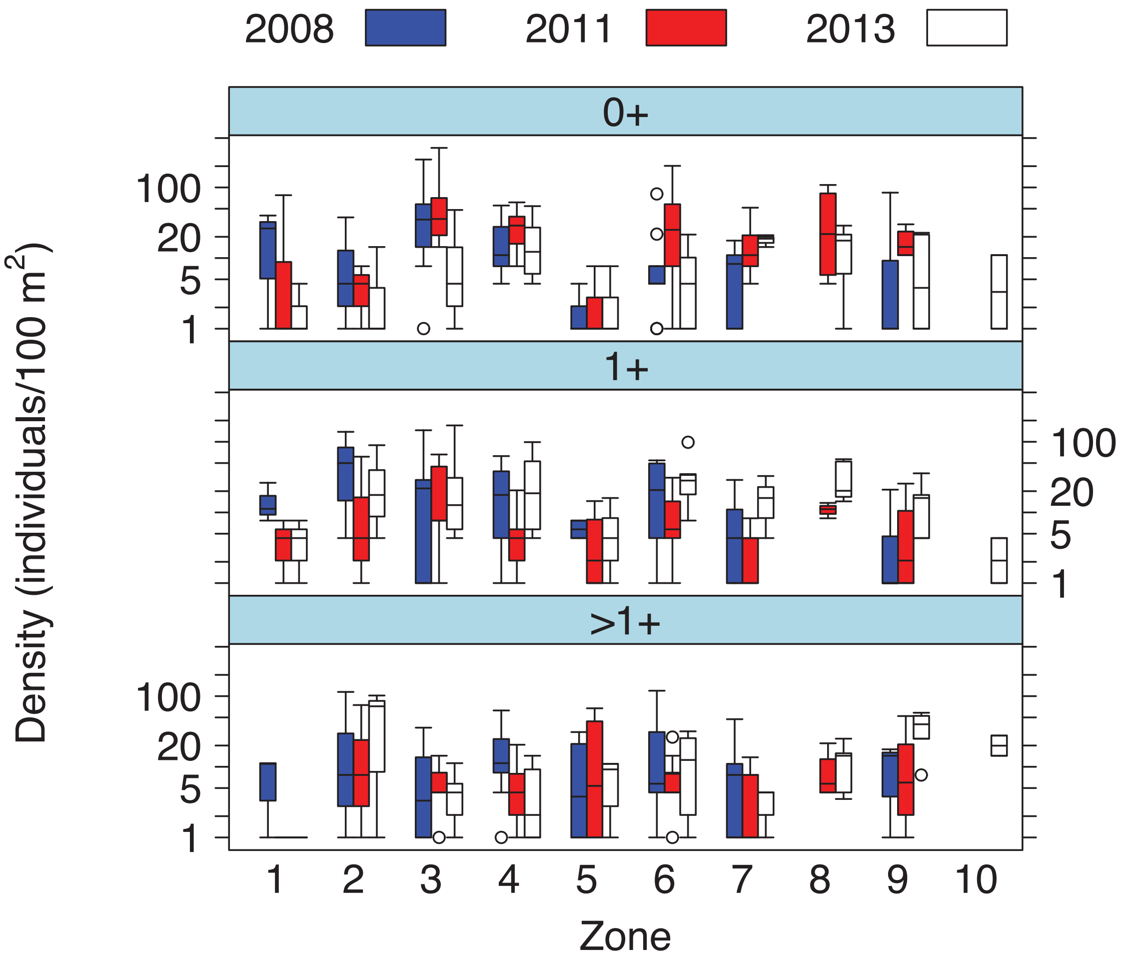


Figure 13. Boxplot of brown trout densities in 2008, 2011 and 2013, for zones 1-10, for age groups 0+, 1+ and >1+. The y-axis is on log-scale.

3.3 Environmental variables effect on brown trout density

The amount of large woody debris was only measured in 2008 and 2013. Model selection, with AIC criteria was performed and lent little support for a large woody debris effect on brown trout density. It had low support as a relevant explanatory variable for 0+ density, but it was included in the 9th most supported model for 1+, together with distance from E6 (ΔAIC=1.47). Large woody debris had in this model a positive estimate of 0.128, but with a standard deviation of 0.581, the model has little support. Also, when looking at singe parameter estimates in model selection, large woody debris has no support, and does not explain much of the differences for either 0+ or 1+ density.

3.3.1 0+ density for year 2008, 2011 and 2013

There were five models predicting 0+ density for 2008, 2011 and 2013, which all have a ΔAIC below 2 (Table 3). The most supported model included an interaction between depth and distance from E6. Depth was included in all the most supported models, and therefore constitutes an important variable for 0+ density.

Table 3. The ten most supported 0+ density models for 2008, 2011, 2013.

No	Explanatory variables	K	AICc	ΔAICc	AICcWt	Cum.Wt	LL
1	Depth * Distance from E6	5	492.37	0	0.25	0.25	-240.96
2	Velocity * Depth + Gravel	6	492.52	0.15	0.23	0.48	-239.94
3	Depth + Distance from E6	4	492.85	0.48	0.20	0.68	-242.27
4	Depth * Year	7	492.91	0.54	0.19	0.87	-239.03
5	Depth * Velocity	5	493.76	1.40	0.12	1	-241.66
6	Year + Distance from E6 * Gravel	7	501.18	8.81	0	1	-243.16
7	Year + Distance from E6	5	510.57	18.20	0	1	-250.06
8	Year + Distance from E6 + Gravel	6	511.68	19.31	0	1	-249.52
9	Distance from E6 + Velocity	4	512.98	20.61	0	1	-252.34
10	Distance from E6 * Velocity	5	513.39	21.02	0	1	-251.47

The 0+ density decreased with increasing depth (Figure 14, Table 4). For depths between 0 and 25 cm, the 0+ density decreased with increasing distance from E6. At depth larger than 25 cm, the 0+ density increased as the distance from E6 increased.

Table 4. Parameter estimates for the most supported 0+ density model for 2008, 2011 and 2013. The response variable was ln-transformed. *** indicates a significance level of $p<0.001$.

Coefficients	Estimate	SD	t value	Pr(>|t|)
Intercept	3.84E+00	4.43E-01	8.658	***
Depth	-7.75E-02	1.82E-02	-4.273	***
Distance from E6	-4.38E-04	2.61E-04	-1.678	0.0956
Depth * Distance from E6	1.88E-05	1.17E-05	1.605	0.1107

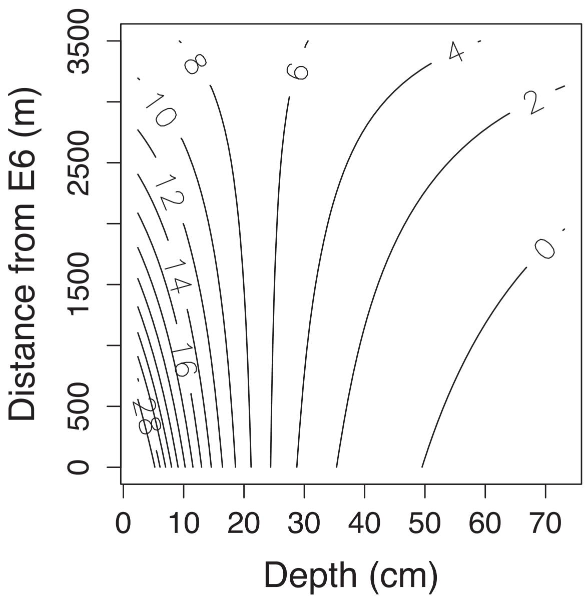


Figure 14. Prediction contour plot of the most supported 0+ density model (Table 4) for 2008, 2011 and 2013.

3.3.2 0+ density for year 2011 and 2013

There are four models explaining 0+ density for 2011 and 2013, which all have a ΔAIC below 2 (Table 5). The most supported 0+ density model included macroinvertebrate density + moss + velocity * depth. All top-four models included the same variables, except velocity in model 4, but had different interactions and additions among the variables.

Table 5. The ten most supported 0+ density models for 2011 and 2013.

No	Explanatory variables	K	AICc	ΔAICc	AICcWt	Cum.Wt	LL
1	Invertebrate density + Moss + Velocity * Depth	7	306.56	0	0.28	0.28	-145.58
2	Invertebrate density + Moss * Velocity + Depth	7	306.68	0.11	0.26	0.54	-145.64
3	Invertebrate density * Moss + Velocity * Depth	8	307.29	0.73	0.19	0.73	-144.74
4	Invertebrate density + Moss + Depth	5	308.28	1.72	0.12	0.85	-148.78
5	Invertebrate density * Moss + Depth	6	309.86	3.29	0.05	0.90	-148.41
6	Invertebrate density + Moss * Depth	6	309.92	3.36	0.05	0.95	-148.44
7	Invertebrate density + Moss * Velocity	6	311.50	4.93	0.02	0.98	-149.23
8	Invertebrate density + Moss * Velocity * Depth	10	311.90	5.34	0.02	1	-144.52
9	Invertebrate density * Moss * Depth	9	314.94	8.38	0	1	-147.32
10	Invertebrate density * Moss * Velocity * Depth	17	321.75	15.18	0	1	-139.50

The 0+ density decreased with increasing depth at water current velocities below approximately 60 cm/sec, and increased with increasing depth at velocities larger than 60 cm/sec (Figure 15, Table 6). For depths under 40 cm, the 0+ density decreased with increasing water velocity, while increased with increasing water velocity for depths over 40 cm. The 0+ density increased with increasing macroinvertebrate density and decreased with increasing moss coverage. The highest 0+ density was found at low moss cover, small depths, slow water velocity and high density of macroinvertebrates.

Table 6. Parameter estimates for the most supported 0+ density model for 2011 and 2013. The response variable was ln-transformed. *** indicates a significance level of $p<0.001$.

Coefficients	Estimate	SD	t value	Pr(>|t|)
Intercept	4.2839	0.5516	7.767	***
Invertebrate density	0.0004	0.0002	1.904	0.0604
Moss	-0.3319	0.2238	-1.483	0.1418
Velocity	-0.0440	0.0185	-2.378	0.0197
Depth	-0.0658	0.0205	-3.215	0.0019
Velocity * Depth	0.0011	0.0006	1.825	0.0717

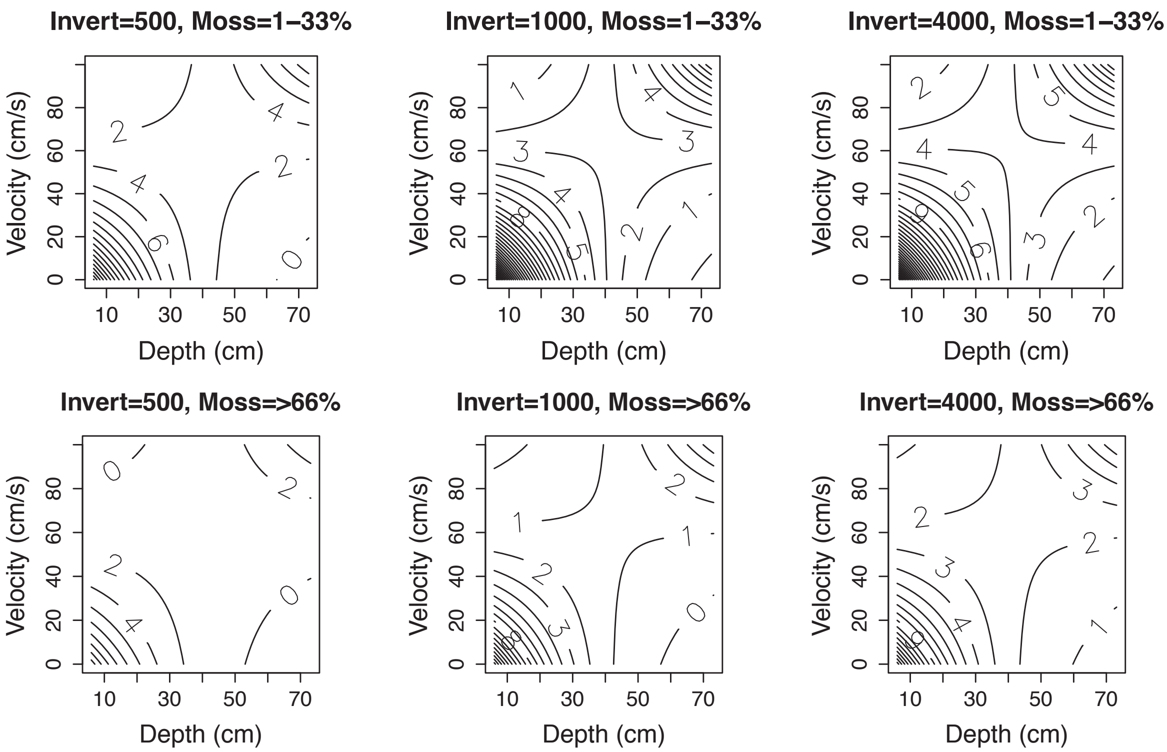


Figure 15. Prediction contour plots of the most supported 0+ density model (Table 6) for 2011 and 2013. Invert= Macroinvertebrate density (individuals/m^2).

3.3.3 1+ density for year 2008, 2011 and 2013

The most supported model for explaining differences in 1+ density for 2008, 2011 and 2013 was gravel + year * distance from E6. There was one other model with a ΔAIC value below 2 (Table 7). This model contained the same variables, but included additive effects only.

Table 7. The ten most supported 1+ density models for 2008, 2011 and 2013.

No	Explanatory variables	K	AICc	ΔAICc	AICcWt	Cum.Wt	LL
1	Gravel + Year * Distance from E6	8	471.35	0	0.55	0.55	-227.12
2	Gravel + Year + Distance from E6	6	472.34	0.99	0.34	0.89	-229.85
3	Gravel * Year + Distance from E6	8	474.59	3.23	0.11	1	-228.74
4	Depth + Distance from E6	4	484.91	13.56	0	1	-238.31
5	Water temperature + Distance from E6	4	486.26	14.90	0	1	-238.98
6	Depth * Distance from E6	5	486.96	15.61	0	1	-238.26
7	Water temperature * Distance from E6	5	487.63	16.27	0	1	-238.59
8	Distance from E6	3	488.06	16.71	0	1	-240.94
9	Vegetation + Distance from E6	4	488.23	16.88	0	1	-239.97
10	Velocity +Distance from E6	4	489.96	18.61	0	1	-240.83

Increasing gravel size had a positive effect on 1+ density (Table 8, Figure 16). For the years 2008 and 2011, distance from E6 had a negative effect on 1+ density, while for the year 2013, increasing distance had a positive effect. The densities of 1+ were lower in 2011 than in 2008 and 2013.

Table 8. Parameter estimates for the most supported 1+ density model for 2008, 2011 and 2013. The response variables were ln-transformed. *** indicates a significance level of $p<0.001$.

Coefficients	Estimate	SD	t value	Pr(>|t|)
Intercept	2.7883	0.3436	8.115	***
Gravel	0.0028	0.0011	2.462	0.0151
Year 2011	-1.3629	0.4901	-2.781	0.0062
Year 2013	-0.6184	0.4710	-1.313	0.1915
Distance from E6	-0.0005	0.0002	-2.135	0.0346
Year 2011 * Distance from E6	0.0004	0.0003	1.288	0.2001
Year 2013 * Distance from E6	0.0006	0.0003	2.294	0.0234

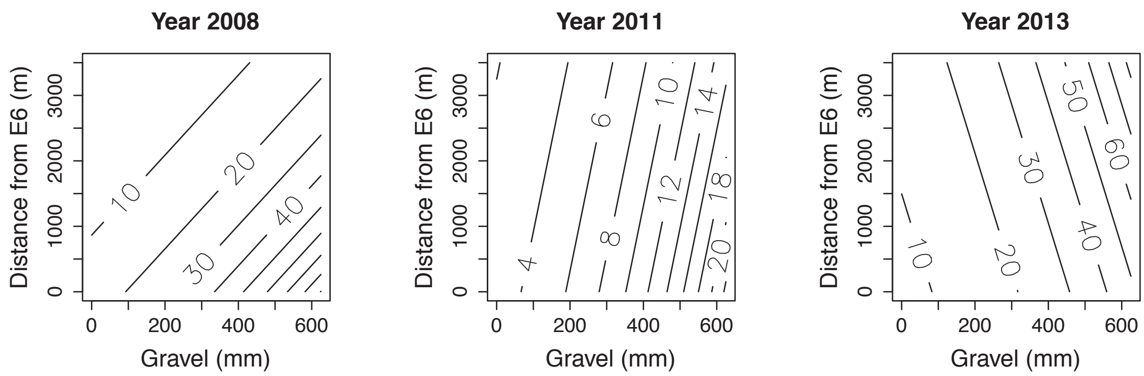


Figure 16. Prediction contour plots of the most supported 1+ density model (Table 8) for 2008, 2011 and 2013.

3.3.4 1+ density for year 2011 and 2013

The most supported model fitted to explain 1+ density for 2011 and 2013 included macroinvertebrate density + gravel * year. There were no other models with a ΔAIC value below 2 (Table 9).

Table 9. The ten most supported 1+ density models for 2011 and 2013.

No	Explanatory variables	K	AICc	ΔAICc	AICcWt	Cum.Wt	LL
1	Invertebrate density + Gravel * Year	6	276.21	0	1	1	-131.59
2	Invertebrate density + Moss + Velocity + Depth	6	289.72	13.51	0	1	-138.34
3	Invertebrate density + Moss + Depth	5	290.22	14.01	0	1	-139.74
4	Invertebrate density * Moss + Velocity + Depth	7	291.01	14.81	0	1	-137.81
5	Invertebrate density * Moss + Depth	6	291.19	14.98	0	1	-139.07
6	Invertebrate density + Moss + Velocity * Depth	7	291.96	15.75	0	1	-138.28
7	Invertebrate density + Moss * Depth	6	292.10	15.90	0	1	-139.53
8	Invertebrate density * Moss * Depth	9	293.05	16.84	0	1	-136.37
9	Invertebrate density + Moss	4	293.20	17.00	0	1	-142.36
10	Invertebrate density * Moss	5	293.82	17.61	0	1	-141.54

For 2011, the 1+ density decreased with both increasing macroinvertebrate density and gravel size (Table 10, Figure 17). For 2013, the 1+ density is almost constant with increasing macroinvertebrate density, but increased with increasing gravel size. Gravel size was the important variable for explaining the responses in 1+ density for 2013. There was higher 1+ density in 2013 than in 2011.

Table 10. Parameter estimates for the most supported 1+ density model for 2011 and 2013. The response variable was ln-transformed. *** indicates a significance level of $p<0.001$.

Coefficients	Estimate	SD	t value	Pr(>|t|)
Intercept	1.8676	0.2838	6.581	***
Invertebrate density	-0.0001	0.0002	-0.782	0.4363
Gravel	-0.0013	0.0017	-0.757	0.4513
Year 2013	0.2131	0.3944	0.540	0.5904
Gravel * Year 2013	0.0105	0.0033	3.165	0.0022

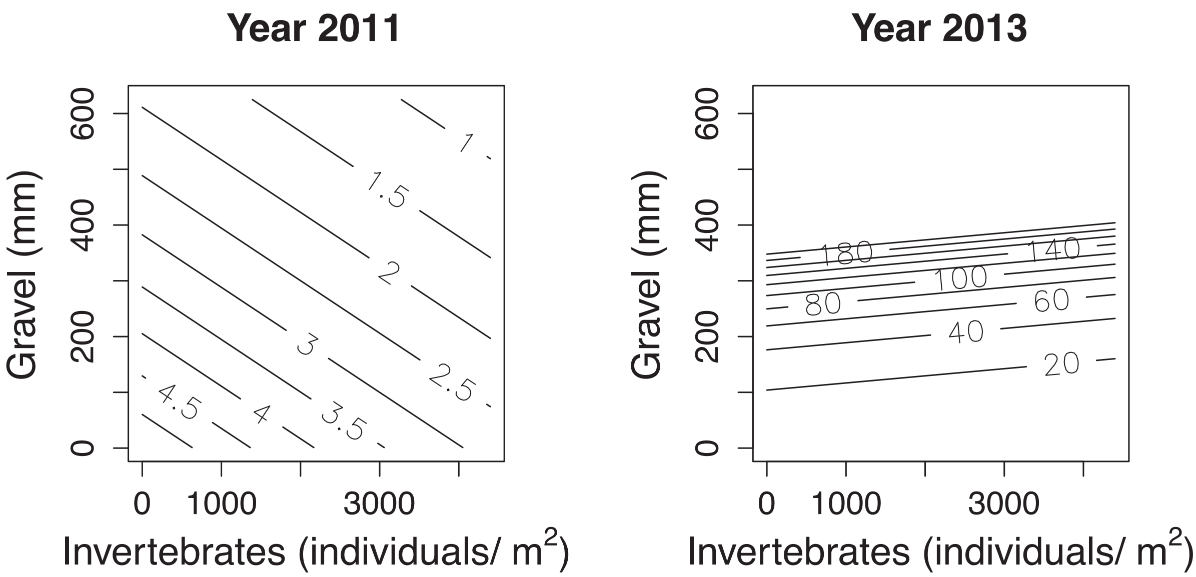


Figure 17. Prediction contour plots of the most supported 1+ density model (Table 10) for 2011 and 2013.

3.4 Environmental variables effect on brown trout growth

First, environmental variables effect on growth was tested with model selection with AIC criteria to find the most supported model to explain 0+ growth. Year was included in all the most supported models. Year in itself is not a factor that has much ecological value in explaining differences in growth, and thus, the factor year was replaced with mean summer temperature during the growth period (see chapter 2.4.5) to explore if the year effect could be adequately substituted with temperature effect on growth. The model selection was done in three separate turns, with three combinations of sample years. In 2004, only temperature and electrofishing data were available, and more environmental variables were measured in 2011 and 2013 than in 2008.

3.4.1 0+ growth for year 2004, 2008, 2011 and 2013

Mean temperature was included in the most supported model to explain 0+ growth for 2004, 2008, 2011 and 2013 (Table 11). There were no other models with a ΔAIC value below 2.

Table 11. The four most supported 0+ growth models for 2004, 2008, 2011 and 2013.

No	Explanatory variables	K	AICc	ΔAICc	AICcWt	Cum.Wt	LL
1	Mean temperature	3	4365.93	0	0.96	0.96	-2179.95
2	Duration of growth season	3	4372.08	6.15	0.04	1	-2183.02
3	0+ density	3	4498.16	132.22	0	1	-2246.06
4	1+ density	3	4506.17	140.24	0	1	-2250.07

Mean temperature had a significant positive effect on 0+ growth (Table 12, Figure 18). For each increasing degree, the 0+ length increased with 1.92 mm.

Table 12. Parameter estimates for the most supported 0+ growth model for 2004, 2008, 2011 and 2013. The response variable was ln-transformed. *** indicates a significance level of p<0.001.

Coefficients	Estimate	SD	t value	Pr(>|t|)
Intercept	17.2361	1.7876	9.642	***
Mean temperature	1.9178	0.1511	12.693	***

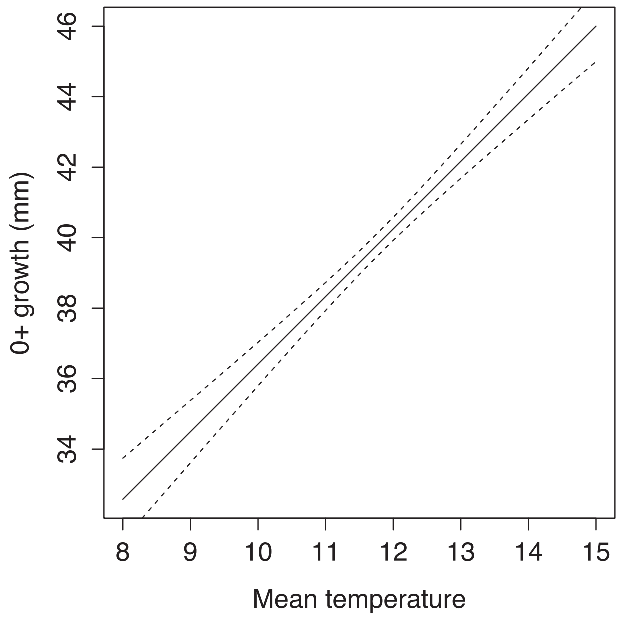


Figure 18. Prediction plot of the most supported 0+ growth model (Table 12) for 2004, 2008, 2011 and 2013.

3.4.2 0+ growth for year 2008, 2011 and 2013

The most supported model to explain 0+ growth for 2008, 2011 and 2013 was distance from E6 * gravel * 1+ density * mean temperature (Table 13). There were no other model structures with a ΔAIC below 2.

Table 13. The ten most supported 0+ growth models for 2008, 2011 and 2013.

No	Explanatory variables	K	AICc	ΔAICc	AICcWt	Cum.Wt	LL
1	Distance from E6 * Gravel * 1+ density * Mean temperature	17	4190.29	0	0.83	0.83	-2077.71
2	Distance from E6* Gravel * 0+ density * Mean temperature	17	4194.73	4.43	0.09	0.92	-2079.93
3	Distance from E6 * Gravel + 1+ density * Mean temperature	8	4195.79	5.50	0.05	0.97	-2089.8
4	Distance from E6 * Gravel + 1+ density + Mean temperature	7	4198.31	8.01	0.02	0.98	-2092.07
5	River section* Gravel * 1+ density * Mean temperature	17	4199.90	9.61	0.01	0.99	-2082.52
6	Distance from E6 * Gravel *1+ density + Mean temperature	10	4200.44	10.15	0.01	1	-2090.06
7	Distance from E6 * Gravel + 0+ density + Mean temperature	7	4202.10	11.81	0	1	-2093.97
8	Distance from E6 * Gravel * 0+ density+ Mean temperature	10	4202.88	12.59	0	1	-2091.29
9	Gravel * Zone * Mean temperature	9	4215.32	25.03	0	1	-2098.53
10	Gravel * Zone + Mean temperature	6	4217.02	26.72	0	1	-2102.45

The multi-dimensional interactions among the four predictor variables produced a complex response pattern (Table 14), as visualized in Figure 19. Some man trends are however seen. At 10 °C, the length increased with increasing gravel size. For fine gravel sizes, the length increased with increasing temperature, decreased with increasing 1+ density in the lower river sections and increased with increasing 1+ density higher up in the river. For coarse gravel, the length increased with increasing 1+ density and distance from E6, and decreased with increasing temperature.

Table 14. Parameter estimates for the most supported 0+ growth model for 2008, 2011 and 2013. The response variable was ln-transformed. *** indicates a significance level of $p<0.001$.

Coefficients	**Estimate**	**SD**	**t value**	**Pr(>|t|)**
Intercept	-2.60E+00	7.63E+00	-0.341	0.7330
Distance from E6	9.76E-03	5.93E-03	1.645	0.1004
Gravel	-9.40E-03	1.06E-01	-0.089	0.9295
1+ density	6.99E-01	2.66E-01	2.625	0.0089
Mean temperature	3.95E+00	6.73E-01	5.868	***
Distance from E6 * Gravel	-2.38E-05	5.69E-05	-0.419	0.6756
Distance from E6 * 1+ density	-5.72E-04	2.29E-04	-2.494	0.0129
Distance from E6 * 1+ density	-2.05E-03	2.91E-03	-0.706	0.4802
Distance from E6 * Mean temperature	-9.99E-04	5.03E-04	-1.986	0.0475
Gravel * Mean temperature	-3.35E-03	8.92E-03	-0.376	0.7072
1+ density * Mean temperature	-6.79E-02	2.46E-02	-2.757	0.0060
Distance from E6 * Gravel * 1+ density	3.63E-06	2.11E-06	1.718	0.0862
Distance from E6 * Gravel * Mean temperature	3.59E-06	4.71E-06	0.762	0.4461
Distance from E6 * 1+ density * Mean temperature	5.37E-05	2.01E-05	2.677	0.0076
Gravel * 1+ density * Mean temperature	2.58E-04	2.55E-04	1.011	0.3125
Distance from E6 * Gravel * 1+ density * Mean temperature	-3.41E-07	1.75E-07	-1.943	0.0524

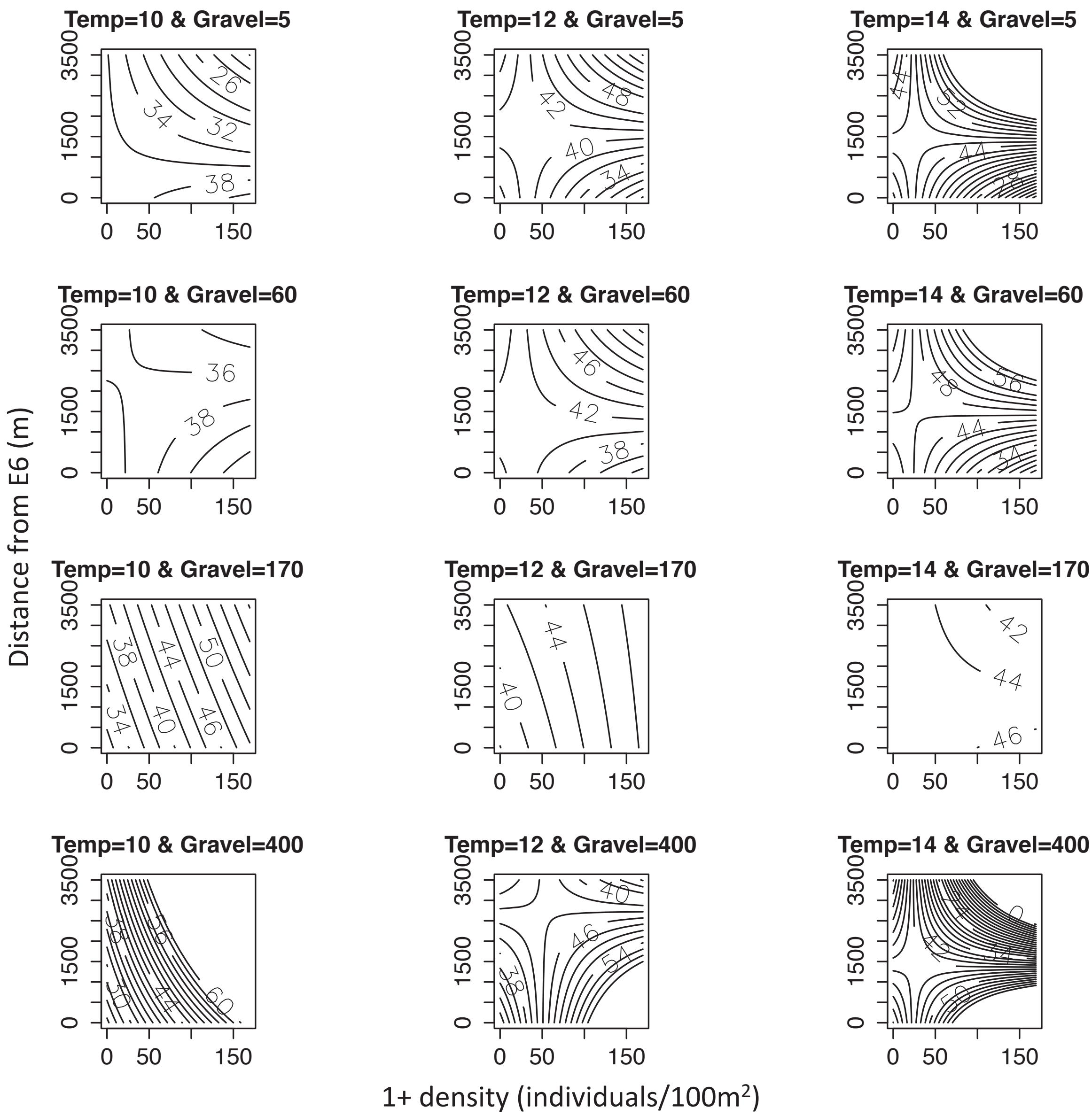


Figure 19. Prediction contour plots of the most supported 0+ growth model (Table 14) for 2008, 2011 and 2013. Temp= Mean temperature (°C). Gravel measured in mm.

3.4.3 0+ growth for year 2011 and 2013

The most supported model to explain 0+ growth for 2011 and 2013 was macroinvertebrate density * gravel * 1+ density + mean temperature (Table 15). There were no other models with a ΔAIC below 2.

Table 15. The ten most supported 0+ growth models for 2011 and 2013.

No	Explanatory variables	K	AICc	ΔAICc	AICcWt	Cum.Wt	LL
1	Invertebrate density * Gravel * 1+ density + Mean temperature	10	2703.26	0	0.88	0.88	-1341.39
2	Invertebrate density * Gravel * 1+ density * Mean temperature	17	2709.35	6.09	0.04	0.92	-1336.99
3	Invertebrate density * Gravel + 1+ density + Mean temperature	7	2709.96	6.70	0.03	0.96	-1347.86
4	Invertebrate density + Gravel * 1+ density + Mean temperature	7	2711.23	7.97	0.02	0.97	-1348.49
5	Invertebrate density * Gravel + 1+ density * Mean temperature	8	2711.97	8.71	0.01	0.98	-1347.83
6	Invertebrate density + Gravel + 1+ density + Mean temperature	6	2712.18	8.92	0.01	0.99	-1350.00
7	Invertebrate density + Gravel + 1+ density * Mean temperature	7	2714.24	10.98	0	1	-1350.00
8	Invertebrate density + Gravel * 1+ density * Mean temperature	10	2715.59	12.33	0	1	-1347.55
9	Invertebrate density * Gravel * 1+ density + Mean temperature	10	2716.44	13.18	0	1	-1347.98
10	Invertebrate density * Gravel * Mean temperature	9	2721.13	17.87	0	1	-1351.37

The interaction effects among macroinvertebrate density, gravel size and 1+ density produced a rather complex 0+ growth response (Table 16, Figure 20). The overall trends were that the 0+ growth increased with increasing temperature and decreased with increasing gravel size. For fine gravel sizes, the 0+ growth increased with increasing macroinvertebrate density. 0+ growth decreased with increasing 1+ density at low macroinvertebrate densities, but increased with increasing 1+ density at high macroinvertebrate densities. For coarse gravel, the 0+ growth decreased with both increasing macroinvertebrate density and 1+ density.

Table 16. Parameter estimates for the most supported 0+ growth model for 2011 and 2013. The response variable was ln-transformed. *** indicates a significance level of $p<0.001$.

Coefficients	Estimate	SD	t value	Pr(>|t|)
Intercept	-1.58E+00	6.07E+00	-0.261	0.7943
Invertebrate density	-5.15E-03	9.62E-04	-5.357	***
Gravel	-4.11E-02	9.82E-03	-4.19	***
1+ density	-1.40E-01	4.83E-02	-2.91	0.0038
Mean temperature	3.97E+00	4.97E-01	7.987	***
Invertebrate density * Gravel	3.21E-05	9.12E-06	3.52	***
Invertebrate density * 1+ density	1.69E-04	5.34E-05	3.166	0.0017
Gravel * 1+ density	8.63E-04	5.01E-04	1.721	0.0859
Invertebrate density * Gravel * 1+ density	-1.56E-06	5.35E-07	-2.908	0.0038

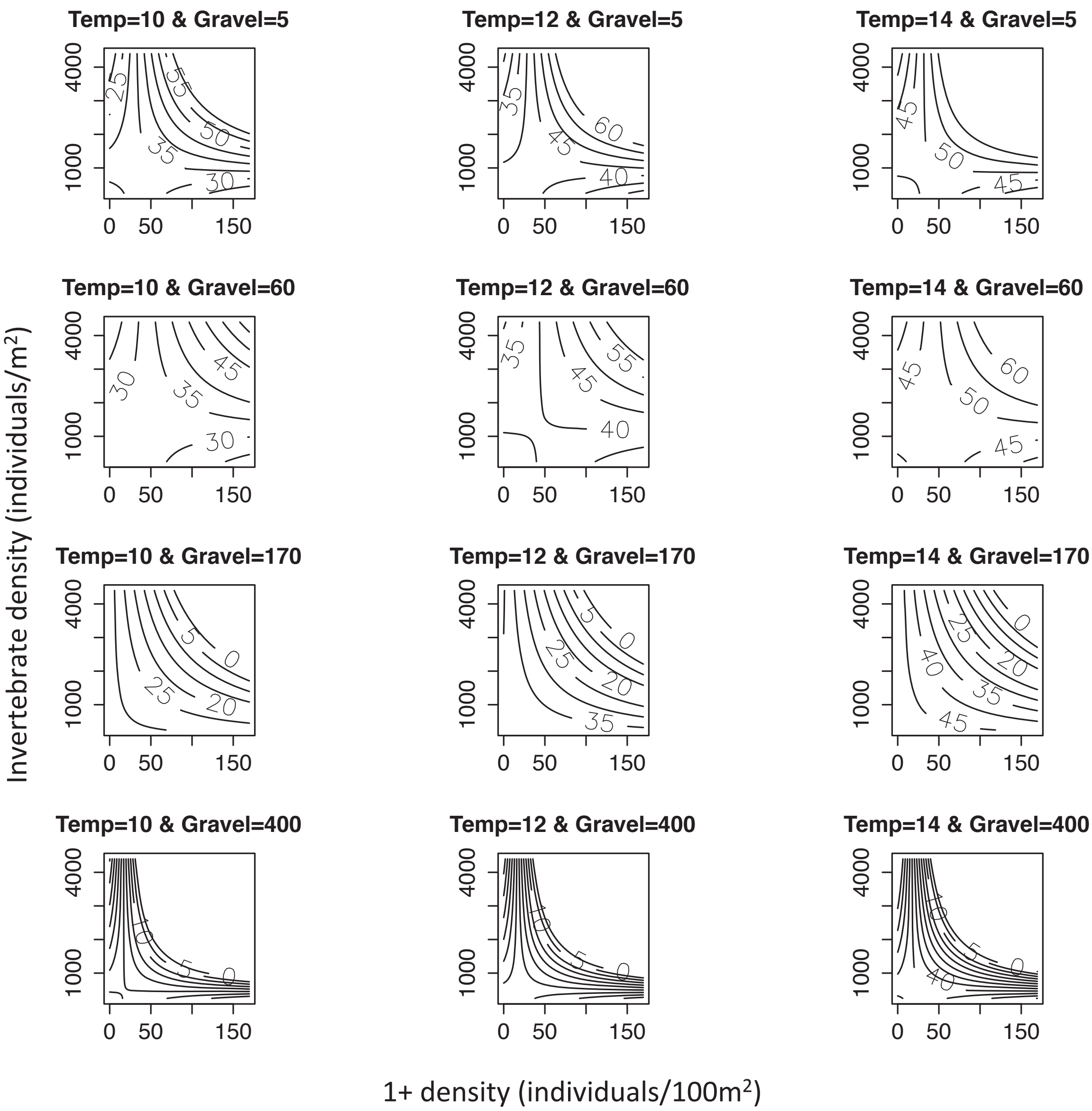


Figure 20. Prediction contour plots of the most supported 0+ growth model (Table 16) for 2011 and 2013. Temp= Mean temperature (°C). Gravel measured in mm.

3.5 Restoration measures effect on brown trout density

3.5.1 Restoration measures effect on 0+ density

There was no significant difference between 0+ density in restored and unrestored stations (p=0.67). However, there were significant differences among the effects from different types of measures (one-way anova, $F_{3,136}$=2.8186, p<0.05). The differences among the different measures were small: riparian modifications (0.46±0.33 individuals/100 m^2), side channel (-0.35±0.30 individuals/100 m^2) and weirs (1.10±0.59 individuals/100 m^2). There was no significant effect of time since first restoration measure (p=0.36). The effect of time since last restoration measure was however significant (one-way anova, $F_{1,138}$=7.041, p<0.001), with a negative effect (-0.25±0.094 individuals/100 m^2) on 0+ density with increasing time since last measure.

3.5.2 Restoration measures effect on 1+ density

There was no significant difference between 1+ density in restored and unrestored stations (p=0.98), among the different measures (p=0.87) and no effect of time since first and last restoration measure (p=0.66, p=0.95).

3.5.3 Restoration measures effect on the most supported density models

0+ density for year 2008, 2011 and 2013

The 0+ density for 2008, 2011 and 2013 was best explained if type of restoration measure was added to the most supported model presented in Table 4. The most supported model to explain 0+ density became: depth * distance from E6 + type of restoration measure. There were no other models with a ΔAIC below 2.

The trend for 0+ density is the same for depth and distance from E6 for both restored and unrestored stations (Table 17, Figure 21). 0+ density decreased with increasing depth. For depths under 30 cm, the 0+ density decreased as distance from E6 increases, while 0+ density increased with increasing distance from E6 when deeper than 30 cm. Highest 0+ density was found in stations where there have been conducted riparian modifications and created weirs. The lowest 0+ densities were found in side channels.

Table 17. Parameter estimates for the most supported 0+ density model for restoration effects on 2008, 2011 and 2013. *** indicates a significance level of p<0.001.

Coefficients	Estimate	SD	t value	Pr(>|t|)
Intercept	4.07E+00	4.35E-01	9.374	***
Depth	-8.33E-02	1.76E-02	-4.744	***
Distance from E6	-6.75E-04	2.63E-04	-2.563	0.0115
Riparian modifications	6.52E-01	3.16E-01	2.064	0.0410
Side channel	-2.80E-01	2.88E-01	-0.973	0.3324
Weirs	1.55E+00	6.13E-01	2.524	0.0128
Depth * Distance from E6	2.26E-05	1.14E-05	1.993	0.0483

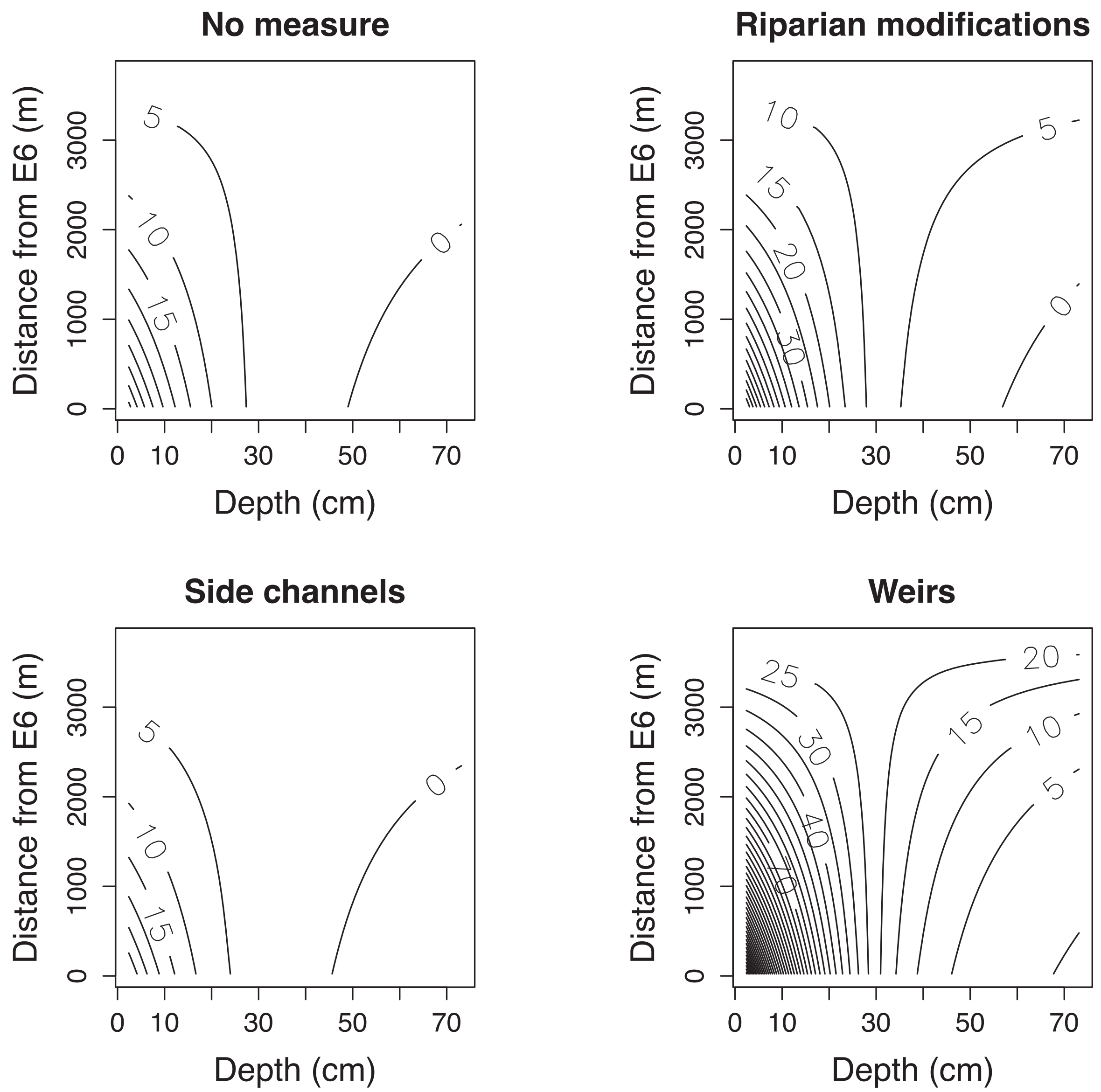


Figure 21. Prediction contour plots of the most supported 0+ density model (Table 17) with restoration effects for 2008, 2011 and 2013.

0+ density for year 2011 and 2013

The 0+ density for 2011 and 2013 was best explained if type of restoration measure was added to the model presented in Table 6. The most supported model to describe 0+ density became: macroinvertebrate density + moss + velocity * depth + type of restoration measure. There were no other models with a ΔAIC below 2. Increasing macroinvertebrate density had a positive effect on 0+ density, while increasing velocity, moss cover and depth had a negative effect on 0+ density (Table 18, Appendix 5). Highest 0+ density was found in stations where there have been conducted riparian modifications and created weirs. The lowest 0+ densities were found in side channels.

Table 18. Parameter estimates for the most supported model for restoration effects on 0+ density (2011 and 2013). The response variable was ln-transformed. *** indicates a significance level of p<0.001.

Coefficients	Estimate	SD	t value	Pr(>|t|)
Intercept	4.1844	0.5159	8.112	***
Invertebrate density	0.0003	0.0002	1.539	0.1279
Moss	-0.1423	0.2157	-0.66	0.5113
Velocity	-0.0506	0.0173	-2.917	0.0046
Depth	-0.0632	0.0197	-3.21	0.0019
Riparian modifications	0.7264	0.3583	2.027	0.0460
Side channel	-0.8010	0.3384	-2.367	0.0204
Weirs	0.7838	0.5242	1.495	0.1389
Velocity * Depth	0.0011	0.0006	1.885	0.0630

1+ density for year 2008, 2011 and 2013

The 1+ density for 2008, 2011 and 2013 was best explained without any restoration measures. There was one other model with a ΔAIC of 0.67, which is the most supported model with the addition of time since last restoration measure. The most supported model remained the same as presented in Table 8.

1+ density for year 2011 and 2013

The 1+ density for 2011 and 2013 was best explained without any restoration measures. There were two other models with a ΔAIC of 0.90 and 1.75. The models included the most supported model with the addition if the station is restored or not, and the addition of time since first restoration measure. The most supported model remained the same as presented in Table 10.

3.6 Restoration measures effect on brown trout growth

3.6.1 Restoration measures effect on 0+ growth

There was a significant difference in 0+ growth between restored and unrestored stations (One-way anova $F_{1,724}$=6.4506, p<0.013), with a small negative effect (-0.94± 0.37 mm) in the restored stations. There was also a significant difference in 0+ growth among stations with different measure (One-way anova $F_{3,722}$=3.169, p<0.03), with a small negative effect of all measures compared to unrestored stations (riparian modification (-0.60± 0.50 mm), side channel (-1.30±0.43 mm) and weirs (-0.25±0.75 mm)). Time since first and last restoration measure were not significant (p=0.25, p=0.63).

3.6.2 Restoration measures effect on the most supported 0+ growth models

0+ growth for year 2008, 2011 and 2013

The 0+ growth is best explained if type of measure is added as an interaction to the most supported model presented in Table 14. There were no models with ΔAIC below 2. The most supported model to explain 0+ growth became: distance from E6 * gravel * 1+ density * mean temperature * type of restoration measure. There are several interactions among the predictor variables in this model (Appendix 6), and therefore the model becomes complex and no clear trends are seen for the variables (Appendix 7).

0+ growth for year 2011 and 2013

The 0+ growth is best explained if time since first restoration measure is added to the model presented in Table 16. The most supported model to explain 0+ growth is now: macroinvertebrate density * gravel * 1+ density + mean temperature + time since first restoration measure. The model with interaction of time since first restoration measure had a ΔAIC of 1.18.

The overall trends were that 0+ growth increased with increasing temperature and decreased with increasing gravel size (Table 19, Appendix 8). For temperature 10°C and 12°C 0+ growth increased with increasing 1+ density and macroinvertebrate density. For temperature 14°C 0+ growth decreased with increasing 1+ density and macroinvertebrate density. There is a negative effect of time since first restoration, with 0+ growth being highest in unrestored sections.

Table 19. Parameter estimates for the most supported model for restoration effects on 0+ growth (2011 and 2013). The response variable was ln-transformed. *** indicates a significance level of p<0.001.

Coefficients	Estimate	SD	t value	Pr(>|t|)
Intercept	1.05E+00	6.07E+00	0.173	0.8627
Invertebrate density	-4.62E-03	9.68E-04	-4.768	***
Gravel	-4.06E-02	9.73E-03	-4.174	***
1+ density	-1.57E-01	4.81E-02	-3.256	0.0012
Mean temperature	3.76E+00	4.97E-01	7.573	***
Time since first restoration measure	-3.10E-01	9.94E-02	-3.116	0.0020
Invertebrate density * Gravel	3.17E-05	9.03E-06	3.513	***
Invertebrate density * 1+ density	1.79E-04	5.30E-05	3.38	***
Gravel *1+ density	1.06E-03	5.01E-04	2.122	0.0343
Invertebrate density * Gravel * 1+ density	-1.69E-06	5.32E-07	-3.171	0.0016

3.7 Side channels effect on brown trout density and growth

3.7.1 Side channels effect on density

Side channels and tributaries are both included in the term “side channel” in chapter 3.7. There was not a significant difference in 0+ density between the main channel and side channels (p=0.098). There were however significant differences between zones with and without side channels (one-way anova: $F_{1,138}$=5.2689, p<0.0322). The estimated coefficient was small (0.68±0.30), meaning an increased 0+ density in zones with side channels of 0.68 individuals per 100m^2. For both 1+ and >1+, there were no significant differences between density in the main channel and in the side channels, as well as in zones with and without side channel (p=0.43, p=0.13, p=0.40, p=0.28).

3.7.2 Side channels effect on 0+ growth

There were significant differences between the main channel and side channels for 0+ growth (one-way anova: $F_{1,724}$= 10.253, p<0.0015). However, the estimated difference coefficient was small (-1.24±0.39mm), meaning a 1.25 mm smaller 0+ size in side channels than in the main river. There were also significant differences between zones with and without side channel (one-way anova: $F_{1,724}$= 14.147, p<0.001). Again, the estimated difference coefficient was small (-1.98±0.52mm), i.e., a 2 mm smaller 0+ size in zones with side channels than without.

3.8 Macroinvertebrates

The macroinvertebrates had a small increase in density from 2011 to 2013 (0.24 ±0.21 individuals/m^2). However, the increase was not statistically significant (p=0.27).

3.8.1 Environmental variables effect on macroinvertebrate density

The most supported model to explain variation in macroinvertebrate density was suitability spawning habitat * gravel * 0+ brown trout density * year. There was no other model with ΔAIC below 2 (Table 20).

Table 20. The ten most supported models to explain variation in macroinvertebrate density.

No	Explanatory variables	K	AICc	ΔAICc	AICcWt	Cum.Wt	LL
1	Spawning suitability * Gravel * 0+ density * Year	23	202.03	0	0.93	0.93	-69.25
2	Spawning suitability * Gravel * 1+ density * Year	24	207.22	5.19	0.07	1	-69.93
3	Spawning suitability * Edge vegetation	7	227.33	25.3	0	1	-105.96
4	Spawning suitability * Year	7	228.35	26.33	0	1	-106.47
5	Spawning suitability + Velocity	5	234.14	32.11	0	1	-111.70
6	Spawning suitability + 0+ density * Year	7	235.65	33.62	0	1	-110.12
7	Spawning suitability + Velocity + Gravel	6	236.2	34.17	0	1	-111.58
8	Spawning suitability + Velocity * Gravel	7	236.32	34.3	0	1	-110.45
9	Velocity * Year	5	236.48	34.45	0	1	-112.88
10	Spawning suitability * Velocity	7	237.22	35.19	0	1	-110.90

There are several interactions among the parameter estimates for this model (Appendix 9), and therefore the model becomes complex (Figure 22). However, some trends were seen.

In 2011, for spawning category 1 and 2, and in 2013 for spawning category 2, the macroinvertebrate density increases with increasing gravel size. In 2011, for category 3, and in 2013 for spawning category 1 and 3, the macroinvertebrate density decreases with increasing gravel size. The general trend for spawning category 1 and 2 is that 0+ density has a positive effect at coarse gravel, and negative effect at fine gravel. For spawning category 3, the trend are opposite with 0+ density having a negative effect at coarse gravel, and positive effect at fine gravel.

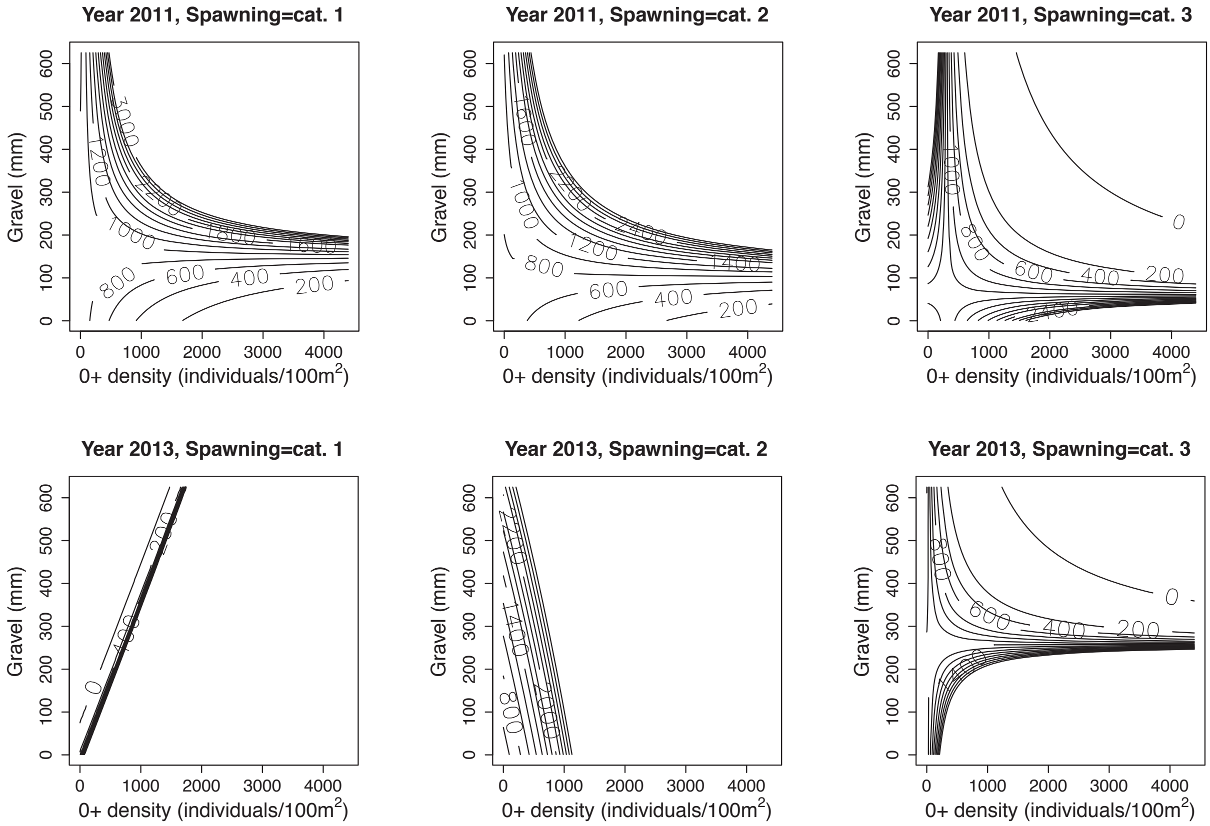


Figure 22. Prediction contour plots of the most supported model (Appendix 9) explaining the macroinvertebrate density per m^2. Spawning = Suitability spawning. Sustainability spawning category 1: bad, category 2: ok, category 3: good.

3.8.2 Restoration measures effect on macroinvertebrate density

There was no significant differences in macroinvertebrate density between restored and unrestored stations (p=0.87), among the different type of measures (p=0.07), and no effect of time since first and last restoration measure (p=0.26, p=0.34).

The macroinvertebrate density was best explained without any restoration measures, and the most supported model remained the same as presented in Appendix 9.

3.8.3 Cumulated composition of macroinvertebrate groups

The most supported model to describe the cumulated probability composition of the macroinvertebrates mayflies, stoneflies, caddisflies and Chironomidae, were type of measure * algae * edge vegetation * riverside canopy.

There are several interactions among the parameter estimates for the cumulated probability composition (Appendix 10), and therefore the model became complex (Appendix 11). Nevertheless, a few trends were seen. At measure type weirs and riverside canopy category 3 and 5, the composition of macroinvertebrates were dominated by caddisflies and mayflies, in contrast to most of the other figures where caddisflies were scarce. A trend towards more mayflies in restored versus unrestored sites was also seen.

4.0 Discussion

Channelization of rivers are known to have negative effects on flow characteristics, fish and other wildlife populations (Whalen et al. 2002). Channelization increases the water velocity, which makes erosion stronger on the bottom of the river, and results in a more unstable and sterile bottom material (Kristiansen 2011). This will eventually deteriorate the living conditions for fish and invertebrates (Kristiansen 2011). Lack of suitable habitats in streams and rivers is thought to limit fish abundance, growth and survival, and several restoration measures have been conducted in the river Bognelv the last eight years to improve the habitats for salmonid fish. Bognelv was channelized to improve the conditions for agriculture along the river. In contrast to other river channelization, the agriculture did not expand fully towards the river, and this has made Bognelv a river possible to restore, as a number of side channels are intact, and there are buffer zones along most of the river. In addition, most of the landowners have been positive to the realization of the restoration process.

4.1 Density development of the salmonid species between 1998 and 2013

The first aim of my study was to reveal whether the restoration measures done in Bognelv over the last eight years have increased the density of juvenile salmonid species in the river compared to densities found in 1998 and 2004. The restoration measures have increased the brown trout density considerably, but the densities of salmon and char have been low throughout all sampling years. Thus, the restoration measures in Bognelv seem only to have had a positive effect on the brown trout density. There has however been a decrease in the 0+ density of brown trout in 2013. There is no clear reason why there is a decrease, but salmonid populations are known to fluctuate naturally (Bohlin 1977; Bergan et al. 2011). Some suggested reasons are that ice drift in May 2013, which scoured the riverbank, can have had a negative influence on the 0+ density (Rødmyr 2014). However, the effect of this is uncertain, as the 1+ density seems not to be affected, and most of the scouring occurred upstream of the study area. In 2013, both age classes 1+ and >1+ were strong. However, they were also strong in 2008, and this can therefore not explain the decrease in 0+ density. Other explanations are that there was a high discharge in the river at the sampling period in 2013, and that this could have increased possible habitats, and thereby reduce the density at the sampling stations. It seems like long-term monitoring is needed to detect natural fluctuation, as well as to distinguish the natural fluctuations from other influences.

The salmon density has been low all years, with a decrease in 2013 compared to the two previous sampling years. One explanation can be that salmon were not classified correctly. The ruling view for describing segregation between salmon and brown trout has been thought to be that habitat use by salmon is restricted through interspecific competition with the more aggressive brown trout (Heggenes et al. 1999; Armstrong et al. 2003). However, Berg et al. (2013) found that habitat use by salmon was not affected by the occurrence of brown trout. However, they found that brown trout occurred more often in shallow habitat when salmon was present. This may explain the higher densities of brown trout found in shallow waters. In addition, salmon is also known to be more flexible and can inhabit more fast-flowing areas than brown trout (Eie et al. 1997; Heggenes & Dokk 2001; Heggenes & Saltveit 2007; Jonsson & Jonsson 2011). Therefore, some middle stretches were electro fished in 2013, but few salmon were caught. To be able to electro fish in the middle of the river, the most fast flowing and deeper areas were not chosen. Heggenes and Saltveit (2007) found more salmon by direct underwater observations than with electrofishing. In order to get a better picture of the salmon density, other sampling measures and sampling at more suitable habitats is probably needed.

The density of char has been low all sampling years, and in 2013 no char were caught. The density of char has decreased in northern Norway the last decade (Svenning et al. 2012), and the low catches in the river are therefore not surprising. Char are often found in slow flowing, deep habitats and lake systems (Halvorsen et al. 1997; Klemetsen et al. 2003), which is probably caused by competitive exclusion by salmon and brown trout, which occupies the stream habitats (Halvorsen et al. 1997). Char are found in several of the lakes in the catchment area to Bognelv (Hoseth & Josefsen 2005). In a case study of the three salmon species in the river Halselva, only a few kilometres from Bognelv, higher densities of char were observed by direct underwater observations (Heggenes & Saltveit 2007). To determine whether char have disappeared from Bognelv, more studies are needed in habitats where char normally occur. The easiest and most reliable way of gaining knowledge about the stock size of mature char in rivers are by establishment of fish traps and registration of the fish trapped (Svenning et al. 2012).

4.2 Environmental variables explaining brown trout density and growth

The second aim of this study was to investigate which of the environmental variables, collected in 2008, 2011 and 2013, that can best explain the variation in fish density, growth and macroinvertebrate density. The most important environmental variables for brown trout are discussed in this chapter, while the most important environmental variables for macroinvertebrates are discussed in section 4.4.1.

4.2.1 The sampling design effects on environmental variables

The results have been analysed in two parallel sessions, as the datasets for all years were not equal. For all density- and growth models looking at the three last sampling years, distance from the main road (E6) was included as predictor in all models, and seems to be important. When only looking at data from 2011 and 2013, distance from E6 is not included in any of the most supported models, and the importance of this river-gradient variable in explaining density and growth is therefore uncertain. However, there is a clear trend of decreasing 0+ density at shallow depths upwards in the river. Distance from E6 is not a variable that has much ecological value, but is probably an indicator of another process that changes upwards in the river. Macroinvertebrate density was only measured in 2011 and 2013, and is included in all the most supported models. Macroinvertebrate density therefore seems to be an important variable in explaining fish density and growth – which is in accordance with findings in (Bowlby & Roff 1986b; Jensen 1990; Kilgour & Barton 1999; Imre et al. 2004). Furthermore, moss was only measured in 2011 and 2013, and is included in the most supported model to best explain 0+ growth for these two years. The environmental variables not measured in 2008 seem to be important, and this illustrates the importance of bringing in holistic perspectives when designing ecosystem-functioning studies like the present one.

4.2.2 The most important environmental variables explaining brown trout density

Water depth, water velocity, cover of moss, and macroinvertebrate density were found to be the most important environmental variables explaining 0+ density. Water depth is considered the most important variable for brown trout (Heggenes et al. 1999). Depth was in both combinations of years, found to be an important environmental variable, and the 0+ density decreased as the depth increased. This is in accordance with the literature that brown trout parr are abundant in shallow waters and that preferred depth increases with fish size (Bohlin 1977; Egglishaw & Shackley 1982; Maki-Petays et al. 1997; Jonsson & Jonsson 2011). The 0+ density should however, in accordance with Heggenes (1995), increase to a certain depth and thereafter decrease as the depth increases. Increasing water velocity had a negative effect on 0+ density when shallower than 40 cm, while a positive effect when deeper than 40 cm. Small brown trout can often be found in riffles with moderate water velocities up to 10 cm/s, and small brown trout are rarely found in habitats were the current exceeds 20 cm/s (Heggenes et al. 1999). Young parr need slow-flowing water to hold positions and be able to feed successfully (Armstrong & Nislow 2006). However, in accordance with Heggenes (1995), there should be a bell-shaped response curve, with an increase in 0+ density up to about 20 cm/s and thereafter a decreasing density as the water velocity increases. The increase in density for higher velocities at deep waters is not in accordance with the literature, and the findings in this study are therefore difficult to explain. Brown trout are attracted to cover, and aquatic vegetation and moss act as cover (Boussu 1954; Heggenes et al. 1999). An increase in the present cover of moss in the river had a negative effect on 0+ density, which is in contrast to studies done by Boussu (1954) and Heggenes and Saltveit (2002), who found that moss cover had a positive effect on 0+ density. However, Heggenes and Saltveit (2002) state that little is known about how moss affects habitat quality and that presence of moss leads to sand accumulation, and thereby can reduce habitat heterogeneity. Moss cover consequently affects the bottom structure and hydraulics near the bottom, and this may be the reason why moss in Bognelv seems to have a negative effect on 0+ density. Macroinvertebrate density has a small positive effect on 0+ density, which is in accordance with other studies (Bowlby & Roff 1986b; Kilgour & Barton 1999; Bridcut 2000; Imre et al. 2004).

Gravel and macroinvertebrate density were found to be the most important environmental variables explaining 1+ density. A year effect was also found, and this can probably be attributed to the low density found in 2011. Brown trout prefer streams with a stony bottom, but can also utilise finer bottom substrates (Heggenes 1988; Heggenes 1995; Heggenes et al. 1999). Gravel was found in both combinations of years to be an important environmental variable for 1+ density. Gravel size was found to have a positive effect on 1+ density for all years, except for a small negative effect on 1+ density in 2011, when only looking at 2011 and 2013. However, in accordance with Heggenes (1995), there should be a peak, with increasing density between substrate from sand to stone, and then a decrease in density from bigger stones to boulders. Why this peak was not found in the statistical analyses could be because of the sampling design, or that this trend is not obvious in Bognelv. The increasing density with increasing gravel size is as expected, as increasing gravel size decreases the water velocity near the bottom and creates more suitable low-flow habitats, where the parr can monitor macroinvertebrate drift without spending too much energy (Heggenes et al. 1999). Maridet et al. (1992) found that the macroinvertebrate abundance and diversity increased with the complexity of the substrate. Also, a coarse bottom provides the young parr with shelter from predators, and also functions as visual isolations between individuals and consequently decreases the aggression between close individuals (Kalleberg 1958). Too coarse gravel on the other hand gives little shelter and the water velocity becomes too fast for the parr to stay without spending too much energy (Jonsson & Jonsson 2011). Increasing macroinvertebrate density had an insignificant negative effect on 1+ density in 2011 while a small, insignificant positive effect in 2013. The results from 2013 are as expected, as increasing macroinvertebrate density has a positive effect on fish density (Bowlby & Roff 1986b; Kilgour & Barton 1999; Imre et al. 2004). The results from 2011 are unexpected as food availability often is a limiting factor. However, low densities of 1+ brown trout were captured in 2011. The results could also have been different if density of the different macroinvertebrate groups had been used, as stoneflies and caddisflies are known to be more important for older parr (Jonsson & Gravem 1985; Jonsson 1989).

4.2.3 The most important environmental variables explaining brown trout growth

For 0+ growth, mean temperature was included in all the most supported models for all three combinations of years, and is therefore assumed to be an important environmental variable. Also, macroinvertebrate density, gravel and 1+ density were found to be important environmental variables. Mean temperature had a significant positive effect on 0+ growth, with an increase of 1.9 to 4 mm for each degree the temperature increases. Temperature is one of the most important environmental variables affecting growth (Spigarelli et al. 1982; Lobon-Cervia & Mortensen 2005; Elliott 2009; Baerum et al. 2013), and the results are therefore not unexpected. Mean temperatures are measurements of air temperature. Water temperature is found to increase as an s-shaped curve with increasing air temperature (Mohseni & Stefan 1999), and hence air temperature can be used to predict water temperatures. Temperature loggers in the river measured water temperature during the field period. The temperature from these loggers correlated with the air temperature data from the weather station (see section 2.4.5). Air temperature data obtained for the whole growth period for four years were used in the statistical analyses. Water temperature affects the metabolism and the efficiency of energy transformation, and is hence important in regulating growth (Elliott 1976). Growth is among the most important life history variables, as it affects the survival rate, age and size at smolting and reproductive success (Jonsson & Jonsson 2011). Jensen (1990) found that the growth rates of brown trout were less when temperature was decreasing in autumn, than at the same temperatures when temperature was increasing in spring. Jensen (1990) further states that the seasonal growth pattern can be a consequence of food availability. The growth season in northern Norway is short, and the highest densities of macroinvertebrates are found in first half of summer (Jensen 1990). Macroinvertebrate density was found to be an important variable in the model selection. Increasing macroinvertebrate density had a positive effect on 0+ growth at fine gravel sizes, but a negative effect on 0+ growth at coarse gravel. 0+ brown trout prefer coarse gravel, but at too coarse substrate, there will be unfavourable habitats. To see more clear trends of macroinvertebrates on 0+ growth, macroinvertebrate density should be monitored earlier or several times during the growth season, as growth and mean temperature are a measure on the entire growth season.

Increasing gravel size had both positive and negative effects on 0+ growth. Finer substrates are associated with lower prey ability, more aggression and higher risk of injuries (Suttle et al. 2004), and hence, increasing gravel should be assumed to be positive. For three years, 1+ density had a negative effect on 0+ growth at fine gravel sizes, but a positive effect at coarse gravel. For two years, 1+ density had a positive effect on 0+ growth at fine gravel sizes and high macroinvertebrate densities, a negative effect at fine gravel and low macroinvertebrate densities, and a negative effect at coarse gravel. According to Jenkins et al. (1999), there should be a clear negative effect of 1+ density on 0+ growth, and the negative effects seen is as expected. When 0+ and 1+ brown trout compete for territories, the 1+ dominate the 0+, and hence, 0+ individuals get the habitats not occupied by older fish (Bohlin 1977). The positive effects found are opposite of what is expected, but may be a result of habitat exclusion (i.e., interactive segregation).

4.2.4 Other environmental variables explaining brown trout density and growth

Other environmental variables that did not get included in the most supported models were canopy cover, vegetation cover and algae cover. These variables are known to have an effect on density and growth, and the reason why they were not included may be because of the sampling design, or that other environmental variables are more important in explaining fish density and growth in the river. Large woody debris (LWD) and pools were not variables supported by the model selection, as LWD was only counted in 2008 and 2013 and the numbers of pools were only counted in 2013. However, these are also known to be important environmental factors (Bremset & Berg 1997; Degerman et al. 2004b).

Canopy cover of the river and the riverbank and vegetation cover in the flood zone was not included in any of the most supported models. However, brown trout are generally attracted to stretches with overhead cover, as higher densities are found in sections with cover than without (Boussu 1954; Heggenes et al. 1999). Both benthic macroinvertebrates and brown trout are found to have higher densities in clear-cut sites than in shaded old-growth and second-growth sites (Murphy et al. 1981). Food quality in streams is strongly linked to algal production, which is higher in clear-cut sites (Hawkins et al. 1982). There were lower brown trout densities and less overhead cover in restored versus unrestored stations. Trees have been uprooted together with the embankments in Bognelv. This may indicate that cover is more important in explaining brown trout density in Bognelv than food availability. Also, inputs of leaves, other litter and large wood from the terrestrial vegetation are important organic matter sources in rivers (Wallace et al. 1995). Algae were not included in any of the most supported models for brown trout density and growth. Periphytic algae are however a major food source for many macroinvertebrates (Hawkins et al. 1982; Rutherford et al. 1997; Brönmark & Hansson 2008), and are hence important for brown trout density and growth. Water flow is important in determining growth, as it can change the quality of the habitat at high and low flows (Elliott et al. 1997; Lobon-Cervia & Mortensen 2005). Water flow has not been measured, and can therefore not be used to explain the differences in growth.

Presence of dead wood in rivers is known to be profitable for the production of salmonid species (Johnson et al. 2005; Fox & Bolton 2007). It increases the surface areas for the growth of prey species (Crook & Robertson 1999), and Milner and Gloyne-Phillips (2005) showed that woody debris was an important habitat for several macroinvertebrate taxa. Woody debris give shelter for fish as it decreases the water velocity, function as overhead cover, and decreases the visual contact between fish (Crook & Robertson 1999). Analysis was conducted for the two sampling years LWD levels were measured. In my results LWD did not have much effect for explaining density, but observations from the fieldwork showed that fish were often caught in the woody debris, when present. This is not expressed in the statistical tests, as mean values of LWD and fish density was used for each station. There was however not much dead wood or trees in the river. In the restored patches, the uprooted trees have not been removed, but remain on the top of the riverbank. However, some LWD is present as a consequent of the restoration measures. As the spring flooding and meandering probably will drag some trees from the riverbank into the river, even more LWD will be present in the river. Furthermore, as the river continues to recover, trees and other plants will get the chance to grow in the riparian buffer zone along the banks (Haberstock et al. 2000; Opperman & Merenlender 2004). This will in time increase the levels of woody debris in the river. However, recruitment of wood to streams can take decades to recover after clearance of the river edge (Meleason & Hall 2005).

In larger rivers, pools are preferred habitat for both small parr and larger fish (Bremset & Berg 1997; Heggenes et al. 1999). Bremset and Berg (1997) found that parr density and growth was higher in pools than in riffles. Small individuals stay near the riverbed and riverbank, and the distance increases as the fish get larger (Bremset & Berg 1999). Possible explanations for the increased density and growth are that dominant larger parr move into the pools as they get older, or that there are better conditions in the pools that give the pool-dwelling fish an energetic advantage (Bremset & Berg 1997). If pools had been sampled several years and analysed, highest densities should be assumed to be higher in stations with pools than without.

4.2.5 Diurnal and seasonal variations

The habitat preferences and behaviour of salmonid species varies between seasons, and there is also known to be diurnal migration (Heggenes et al. 1999; Heggenes & Dokk 2001; Heggenes & Saltveit 2007). A stronger preference for cover, shelter in the streambed, and deeper waters are found in winter than in summer (Heggenes et al. 1999). During nights, all fish are found closer to the bottom and at coarser gravel than during daytime (Heggenes &

Saltveit 2007). This further illustrates that complex and heterogeneous habitats are important to maintain suitable habitats all year. Suitable winter habitats are probably available in Bognelv since there are strong year classes of older fish.

4.3 Restoration measures explaining brown trout density and growth

The third aim of the study was to estimate restoration–measures-specific effects, measured in 2008, 2011 and 2013, on juvenile salmonid species and the macroinvertebrate density. The restoration measures affecting brown trout are discussed in this chapter, while the restoration measures affecting macroinvertebrates are discussed in section 4.4.2.

Several of the environmental factors explaining brown trout density and growth are similar, and hence restoration effects on density and growth will be discussed together. Furthermore, no restoration measures were designed to improve conditions for one or the other of these. No significant differences in brown trout density were found between restored and unrestored stations for all three age groups and sampling years. This is in accordance with Lepori et al. (2005), who found little evidence that restoration of structural heterogeneity in streams increased the biotic diversity. Even though no significant differences were found between restored and unrestored stations, there has been a clear trend of increasing brown trout density after the restoration measures began. A significant difference in 0+ growth between restored and unrestored stations was found, with lower growth in the restored stations. However, the 0+ growth has increased all sampling years, and indicates better growing conditions for the young brown trout. The river is a continuum habitat, and Bognelv has been altered and restored several places. It may therefore be difficult to see the effect of actions at one specific site, as the effects could be found throughout in the river. As such, enhanced ecosystem functioning may have resulted from the measures even though local effects from each measure action were not estimable or separable in statistical tests. Synergies among upstream and further downstream measures may yield enhanced ecosystem functioning that favours brown trout production.

When adding the types of restoration measures and time since first and last restoration measure to the most supported environmental variables, some other trends are seen. 0+ density is best explained if type of measure is added to the most supported model. For 0+ density there was a significant difference among the different types of measures, with weirs and riparian modifications having higher densities, and side channels lower densities, compared to unrestored stations. For 1+ density there was no significant difference among the measures, and the density was best explained without any restoration effects added to the most supported model. This may indicate that 1+ brown trout have a better mobility to disperse, and hence are not so vulnerable to environmental changes. 0+ growth is best explained (for 2008, 2011 and 2013) if type of measure is added to the most supported model. There was a significant difference in 0+ growth among stations with different measures. However, the model is complex and no trends were evident. According to section 3.6.1, lower 0+ growth is found in restored compared to unrestored stations. Roni et al. (2008) reviewed the effectiveness of stream rehabilitation techniques in 345 papers. The results indicated that the most effective techniques to improve habitat and increase fish abundance was reconnection of isolated habitats, rehabilitation of floodplains and placement of in-stream structures. Rehabilitation of floodplains contains, among other things, reconnection of existing floodplain habitats, levee breaching and re-meandering, which all have been done in Bognelv. Reconnection of isolated habitats and reconnection of existing floodplain habitats has been done in Bognelv by opening of side channels. However, lower densities are found in side channels compared to unrestored stations (see the last paragraph in this section for a discussion on side channels as a restoration measure). Levee breaching and re-meandering are restoration measures done in Bognelv under the names riparian modification and weirs. Both restoration measures were found to be positive for 0+ density compared to stations without any measures. Removals of levee along the riversides allow the channel to naturally recover its former sinuosity, and are becoming more common (Roni et al. 2008). Building of weirs have in other studies been found to increase water covered areal and possible habitats for brown trout (Arnekleiv et al. 2006). Re-meandering was not done as an action in Bognelv, but the river is now allowed several places to meander. Re-meandering is one of the most widely used approaches for river restoration (Kondolf 2006), as it increases the total stream length and hence increases possible habitats for brown trout (Iversen et al. 1993).

In-stream habitat enhancement is widespread (Roni et al. 2002), and were found by Roni et al. (2008) to be an effective technique. Feld et al. (2011) found that introduction of large woody debris, boulders and gravel were the most common restoration measures, but that the effects often were swamped by larger-scale effects. Placement of in-stream structures has been done in Bognelv, and several boulders have been laid out in the river (Figure 23). Also, some large woody debris is found. See chapter 4.2.4 for a discussion on LWD as a measure in the restoration process. When electro fishing in stations with boulders, almost all fish were caught around the boulders and not in the surrounding homogenous areas (Figure 23). Boulder structures have previously shown to have a positive effect on fish density (Shuler et al. 1994). Boulders increase the diversity in water velocity and substrate, and hence provide more locations and heterogeneity that are favourable for brown trout (Shuler et al. 1994). The boulders will probably change in composition as flows will alter them, but probably some of the functions of the clusters will remain. Also, in stations with variable cover, more fish were caught in the structures than without. For instance, more fish were caught in areas where trees were laying in the rivers and in undercut banks, than in areas with no cover (Figure 24). This is in accordance with what Boussu (1954) found. This is however not displayed in the statistical test, as the mean of the environmental variables were used for each station. Also, at stations with still water and fine substrate, no or little fish were caught. The most important message is that there is higher density in heterogeneous habitats, especially with possible cover. There is probably enough food in the river, and therefore the habitat is the limiting factor that can be seen because of the density dependent factors.

Figure 23. Photograph of boulder structures in Bognelv.

Figure 24. Photograph of an undercut bank in a side channel in Bognelv.

No significant effect of time since first restoration measure was found on neither 0+ nor 1+ densities. The effect of time since last restoration measure was however significant for 0+ density, with a small negative effect on density from time since last measure. This is in contrast to the trend Austvik (2012) found of increasing 0+ density with time since restoration. However, this trend was not statistically significant, and the trend is not obvious. The small negative effect on density with increasing time since last measure found in 2013 is opposite of what is expected, as the density is expected to increase as the river recovers (Palmer et al. 1997; Miller et al. 2010). The explanation is probably the low 0+ density found in 2013. No time effect was found to be significant for 0+ growth. However, for 2011 and 2013, 0+ growth was actually best explained if time since first restoration measure was added with the most important environmental variables. A significant negative effect of time since first restoration was found, with 0+ growth being highest in unrestored sections. This indicates that there are probably more favourable growth conditions in unrestored versus restored stations, and that the negative effects increases with time. The growth has however increased after the restoration process started in 2004 (32-50 mm) to 2013 (33-56 mm), and the negative effect is unexpected. Both density and growth are therefore found to have a positive response to the restoration measures. However, full recovery of rivers after restoration measures may take centuries (Rutherford et al. 1997; Meleason & Hall 2005; Davies-Colley et al. 2009), and monitoring of the river is therefore needed in the future to detect not only direct effects but also major indirect effects on the overall ecosystem (Feld et al. 2011).

No significant difference in density between the main river and the side channels were found for any of the age groups. However, significant differences among zones with and without side channels were found, with higher 0+ densities in zones holding side channels than without. This can be an indicator of higher 0+ densities in side channels and subsequent dispersal into the main river. Significant decreases in 0+ growth in side channels compared to the main river and in zones with side channels indicate a negative relationship between density and growth, which is not unexpected (Jenkins et al. 1999; Lobon-Cervia 2007). Lower densities were found in side channels compared to unrestored stations. However, reconnection of side channels to the main channel is beneficial because it increases the area of physical habitat, as also found by Roni et al. (2008). Habersack and Nachtnebel (1995) found a positive effect on juvenile fish density in side channels, and Schedel (2010) found higher densities of 0+ brown trout in 2008 in the side channels than in the main river. No significant effect of increased density in side channels were found in 2011 (Austvik 2012). In 2011, the river was unusually dry. Fish may in dry periods migrate from dry side channels to deeper refugees in the main river (Magoulick & Kobza 2003), and this could be why Austvik (2012) did not see the same results as Schedel (2010). In 2013, the overall 0+ density was low, and possible explanations have been proposed earlier. However, from my observations, high density of fish was observed several places in the side channels. Places with high fish density had higher water velocity, adequate spawning gravel and undercut banks. Several of the places with low observations had still water and silt as substrate, which is not a suitable habitat for young brown trout (Ciutti et al. 2004; Suttle et al. 2004). The low densities in 2013 may be because of the poor habitats several places in the side channels.

4.4 Macroinvertebrates

4.4.1 The most important environmental variables explaining macroinvertebrate density

The aims of the study considering macroinvertebrates were to investigate which of the environmental variables had the highest explanatory effects, and to estimate restoration-measures-specific effects. The environmental variables found to have the most influence on macroinvertebrate density was suitability spawning category (which is a measure of water velocity and substrate, see Appendix 4), substrate and 0+ density. A year effect was also included in the model, and is probably a result of the increase in macroinvertebrate density from 2011 to 2013. The increase is however not significant, but indicates a better food access, as the 0+ brown trout growth has also increased. The results of the densities could however be biased, as macroinvertebrates have been collected at different times the two years. In 2011, the macroinvertebrates were collected in June and July, while in 2013 they were collected in August and September. Species richness are known to vary seasonally (Arnekleiv 1985). Mayflies and stoneflies are known, in Norway, to hatch between April and August/ September (Hynes 1976; *Artsinformasjon* 2014). There should therefore be assumed higher density in summer, and hence highest macroinvertebrate density in 2011. This is not the case, and the findings of increased macroinvertebrate density in 2013 seem correct.

No clear trends of spawning category were found for explaining macroinvertebrate density. However, the right size of spawning gravel and suitable water velocity is known to be important in sustaining high densities of macroinvertebrates Garcia et al. (2012). Garcia et al. (2012) states that water velocity is the primary characteristic variable, as it influence substrate characteristics. Macroinvertebrate density is found to be highest with stable riverbed conditions and at low hydraulic stress (Rempel et al. 1999; Nakano & Nakamura 2006), but different macroinvertebrate species inhabit different habitats (Garcia et al. 2012). A trend towards increased macroinvertebrate density with increasing gravel size was found for the poorest spawning categories. This is in accordance with Friberg et al. (1998), who found that substrate are an important factor, as a coarse and stony substrate is important to sustain densities of stone-dwelling macroinvertebrates. The findings illustrate that at too fine gravel, increasing gravel size had a positive effect. A top-down effect by brown trout on macroinvertebrate density has been described in the literature (Bowlby & Roff 1986a; Schofield et al. 1988; Wiseman et al. 1993), however Culp (1986), found no top-down effect by coho salmon on macroinvertebrate density. There may be a top-down effect as 0+ density is included in the model. Trends of both increasing and decreasing macroinvertebrate density with increasing 0+ density was found, and hence, the relationship between 0+ brown trout and macroinvertebrates is uncertain. Also, 0+ density could be included in the model because brown trout and macroinvertebrates prefer some of the same habitat qualities.

4.4.2 Restoration measures explaining macroinvertebrate density

There were no significant differences between restored and unrestored stations on macroinvertebrate density. The lack of significant differences between restored and unrestored stations is similar to findings by Friberg et al. (1998), who found that the overall density and diversity of macroinvertebrates was similar between restored and unrestored stretches. A meta-study by Miller et al. (2010) found that increasing habitat heterogeneity had a positive effect on macroinvertebrate diversity, but that an increase in density was negligible.

In this study, no effects of type of measure were found, compared to the unrestored stations. However, addition of groynes is known to have a positive effect on macroinvertebrate richness and density (Nakano & Nakamura 2006), and Miller et al. (2010) found that boulder additions and channel reconfigurations had a positive, yet variable response, on macroinvertebrate density. A groyne is an in-stream structure, usually made of wood, stone or concrete, with the purpose of transportation enhancement, bank protection and manipulation of the current (Nakano & Nakamura 2006). Additions of large woody debris have been found to have the most positive effect on macroinvertebrate richness and density (Milner & Gloyne-Phillips 2005; Miller et al. 2010). Higher densities and richness are found in shallow habitats along the river edges, with low hydraulic stress and stable riverbed conditions (Rempel et al. 1999; Nakano & Nakamura 2006). This indicates that large woody debris or other groynes can stabilize the riverbed and create suitable microhabitats for macroinvertebrate colonization (Nakano & Nakamura 2006). Garcia et al. (2012) found variable effects of re-meandering, even thought they state that meanders produces complex favourable high biodiversity habitats. Restoration of side channels should be assumed to have a positive effect on macroinvertebrate density, as the river is allowed to meander and there are complex and variable habitats. Several places in the side channels in Bognelv, there were still or almost still water, and the sampling of invertebrates did not function satisfactory. Ciutti et al. (2004) found that macroinvertebrates tended to prefer substrate with a prevalence of gravel and substrata where the current speed was higher. Schoen et al. (2013) also found in a study that density of macroinvertebrates was five times greater on wood than the sandy streambed, and the average richness being twice as great. However, in stations with higher water velocity in the side channel, high densities of macroinvertebrates were captured.

No significant effect of time since first and last restoration measure was found for macroinvertebrate density. The lack of a time effect of the restoration measures can be because macroinvertebrates have a high resilience, and are found to recover fast after restoration measures (Reice 1985; Friberg et al. 1998). Also, macroinvertebrate density was best explained without any restoration effects added to the most supported model.

4.4.3 Cumulated composition of macroinvertebrate groups

The multinomial model to explain the cumulated composition of the EPT-orders and Chironomidae became complex. This is not unexpected as the EPT-species and Chironomidae show a wide range of diversity in habitat and food preferences, and critical limits for pollution and water quality (Hynes 1976; Mackay & Wiggins 1979; Brittain 1982; Pinder 1986; Bongard & Aagaard 2006). The macroinvertebrates were only sampled to order, which is too broad a classification in order to use defined indexes (Bongard & Aagaard 2006). However, some trends were seen, and the environmental variables affecting macroinvertebrate composition will be discussed. The dominance of caddisflies and mayflies at weirs at canopy category 3 and 5 must be explained by the fact that species in this order are better at colonising this type of habitat. The trend towards more mayflies in restored versus unrestored sites may be explained by the fact that mayflies are known to be among the first macroinvertebrates to colonise virgin habitats (Ladle et al. 1980). No trends of algae, edge vegetation and riparian canopy on the macroinvertebrate composition were found. However, all three environmental variables are found to be important food sources for macroinvertebrates. The periphytic algae can be utilised directly, and leafs from the edge vegetation and canopy are an important source of organic matter in rivers (Wallace et al. 1995). Most mayflies are herbivores, and feed on detritus and periphytic algae (Brittain 1982). Caddisflies are opportunistic, and utilizes both coarse and fine dead organic matter, algae, moss and aquatic vegetation (Mackay & Wiggins 1979). Most families of stoneflies are herbivores, and feed mainly on dead and decaying plant material, and relatively little on algae, moss and other live plants (Hynes 1976). Chironomidae is known to have a varied diet (Pinder 1986). Chironomidae is known to be an important food source for 0+ brown trout, while stoneflies and caddisflies are more important for older parr (Jonsson & Gravem 1985; Jonsson 1989). As no trends are seen, the link between macroinvertebrate order and brown trout density will not be discussed further.

4.5 Evaluation of the restoration project

The fourth and final question to be address is whether the restoration project has been successful, and if Bognelv has been fully restored.

4.5.1 Evaluation

The restoration success of a project depends on the goals set to be achieved (Ruiz‐Jaen & Aide 2005). It is often difficult to decide on the success of a restoration project, since the original state of the ecosystem typically is unclear. In addition, a habitat is a dynamic system, so the aim of habitat restoration is always changing (Samaritani et al. 2011).

In Bognelv, the restoration goals for the Norwegian Water Resources and Energy Directorate (NVE) has been to improve the watercourse environment without reducing the flood security, and to make the watercourse more attractive for the general and local public (Hoseth & Josefsen 2005). The hunting and fishing association in the area have proposed three goals; to get back an acceptable fish stock in the watercourse, increase the recreational opportunities, and increase possible business opportunities (Rødmyr & Rapp 2013). Previous ecological states in Bognelv are known to some extent. The aerial photograph from 1946 (Figure 3) shows the original state of Bognelv, before any channelization measures, and the river thrived with salmonid fish in this period (Dønnum & Colman 2004). Density data from electrofishing in 1998 and 2004 (Saltveit & Brabrand 1999; Dønnum 2005) and an aerial photograph from 1972 (Figure 4) act as controls for the before-situation, i.e., before launching the restoration measures. In this study, I have also used control stations to test differences between restored and unrestored stations at the current stage for the river. The control sites for the restoration measures in the river have been the six lowermost stations and stations that have not been altered directly. The three lowermost stations are influenced by tidewater and are generally poor habitats for brown trout, and should in a new study not be included as control sites. Most goals set by NVE and the local hunting and fishing association have been achieved, as the watercourse environment has been improved without reducing the flood security and recreational opportunities have increased. As there has been a clear increase of the brown trout density since before the restoration, the goal to get back an acceptable fish stock in the river seems to be achieved. The production of juvenile brown trout has increased considerably, and some bigger brown trout were also spotted during electrofishing. To date, there have been little interest of fishing in Bognelv, the catches have been small, and people below age 18 undertake most of the fishing (Rødmyr & Rapp 2013). People under age 18 are not obligated to register their catches, and the catch statistics are therefore deficient, and were not obtained. However, based on the production, there must be a considerable amount of spawning brown trout in the river. The hunting and fishing association drafted the goal of displaying business opportunities, as they have made a contract with the local camping site to sell fishing licenses (Rødmyr & Rapp 2013). They hope that a further increase in fish density and increased recreation possibilities will lead to a higher income for the local community (Rødmyr & Rapp 2013).

Even though there is no consensus on what constitutes a successful restoration project (Palmer et al. 2005; Lake et al. 2007), according to the list of nine attributes and the definition sited in the introduction by The Society of Ecological Restoration (SER), Bognelv is recovering. It seems that Bognelv is not a river for which full restoration is achievable, by the definition sited in the introduction by Verdonschot et al. (2012). The channelized sections of the river are still present, and will not be removed. However, the river is now allowed to meander in some places, and this can in time change the river dynamics. Despite not achieving a full restoration, the increase in brown trout density has shown that a full restoration of the hydraulic and geological processes is not needed to achieve biological goals. However, monitoring over a longer period of time is needed to get a full picture of the further development of the ecological status in the river.

4.5.2 Suggestions for improved measures

The side channels need a higher and more stable water flow, as there are aggregations of silt several places in the side channels. The flow of water into many of the side channels has been a problem since their re-opening, and several measures have been done to improve the inflow of water (pers. comm. Anders Bjordal). Further improvements at the inflows of the side channels, to increase the water flow, are needed to make a greater part of the sections in the side channels work as suitable habitats for brown trout. The aggregation of fine sediments comprise short-term consequence of the restoration work, and will be reduced as no further measures are planned over the next years. However, the aggregations of the sediments could be mechanically removed to accelerate the process. Also, as recovery is known to take decades (Rutherford et al. 1997; Meleason & Hall 2005; Davies-Colley et al. 2009), I will, as Austvik (2012), suggest that planting of riparian vegetation could be beneficial for the recovery of the system. However, natural recovery of riparian vegetation is thought to be an effective and low-cost strategy (Roni et al. 2008), and monitoring to see if planting is necessary is needed.

4.5.3 Source of errors

Summing up earlier comments, it is clear that there are some error sources in this study. The 2×15 m stations used do not show microhabitat effects, as the mean of density and growth, and environmental variables are used. This can yield biased results. The station area sampled may also be too small, as some zone effects were found, with higher densities in zones with side channels than without. The environmental variables are on a quite rough scale, and this may be too broad to see the real effects. In addition, three different persons have sampled the environmental variables, and the registration can therefore be inconsistent, even though the same categories have been used each year. The Surber-sampler did not function properly in areas with slow water velocity, and hence other methods for sampling of invertebrates should be done in these areas. The results from the statistical analysis, which partly differs from the literature, could be explained because of the low data amount sampled at these habitats. E.g. odd results at boulders and high water velocity may be explained by the fact that little electrofishing was done in these types of habitats or that the catch probability is low. Even though electrofishing has been undertaken in midsections in the river, the most fast flowing areas were not chosen due to difficulties with the methods in these areas. Also, as char are found in the slower and deeper habitats (Halvorsen et al. 1997; Klemetsen et al. 2003), it is clear that the electrofishing was not undertaken in areas where salmon and char mainly dwell. The persons doing the actual electrofishing, weather, turbulence and coincidence affect the catch probability (Forseth & Forsgren 2008). Fish that are being electroshocked, but do not emerge from their hiding places will not be counted, and hence is a source of error. To be able to estimate the densities using removal techniques, two or three passes was therefore performed at high-to-moderate density stations, in accordance with among others Bohlin et al. (1989). However, at low densities and low catch probability, the population estimates give uncertain estimates (Forseth & Forsgren 2008). There were more statistically significant effects explaining growth, than densities. This may partly be explained by the fact that a higher numbers of observation usually provide more significant effects due to higher statistical power (Sokal & Rohlf 1995). Growth is evaluated on individual level, while density is evaluated on station level, and hence growth has higher numbers of observations.

4.6 Suggestions for further surveys

A possible new master thesis could be undertaken in about five years. By this time, the system will have had time to start to naturally recover. Macroinvertebrates should be sampled according to national standards (e.g. Bongard and Aagaard (2006)), to be able to use diversity indexes. The composition for the EPT-orders shows great variation between different measures and environmental variables. This could be studied further in a new master thesis, as well as the macroinvertebrates effect as food source for brown trout. Also, microhabitat studies on both brown trout and macroinvertebrates habitat preferences and restoration measures could be done, as this study had too big a scale to be able to see the microhabitat effects. There should be undertaken studies of salmon and char in areas where these species actually occur. This can be done e.g. by visual observation (Heggenes & Saltveit 2007), modified electrofishing (Forseth & Forsgren 2008), or, for large/mature individuals, by establishment of fish traps and registration of the fish trapped (Svenning et al. 2012).

Other factors that are important to consider when designing restoration projects are climate change and fish farming. Climate change and increasing temperature is an important factor in restoring salmonid rivers, as mean water temperature is found to increase as an s-shaped curve with increasing air temperature (Mohseni & Stefan 1999; van Vliet et al. 2011). Also, temperature is sensitive to changes in water flow, and discharge are expected to change with increasing temperature (van Vliet et al. 2011). Bolscher et al. (2013) asked the question *"Can the reintroduction of the salmon in the Rhine fail as a result of climate change?"* They found a significant risk that the project would fail, due increasing water temperatures. In Bognelv, the temperature will most likely not exceed the salmonid requirements for growth, since it is far north. However, an increase in temperature can have effects on other flora and fauna, increased sea temperature and new types of diseases, but the effects are unclear (Vitenskapelig råd for lakseforvaltning 2011). Densities of brown trout and salmon are thought to increase as consequents of better growth condition and higher food availability (Norges forskningsråd 2013b; Norges forskningsråd 2013a). The opposite is assumed for char densities, as increasing temperature will result in less ice cover and more nutrients, and hence brown trout will outcompete char if sympatric (Norges forskningsråd 2013b). This illustrates the importance of designing restoration projects, where changing climate and increasing temperature is a part of the design, as several rivers and streams will be thermally unsuitable for fish (Mohseni et al. 2003).

Salmon farming is significant in Langfjorden (Cermaq Norway AS 2014), and the hunting and fishing association is concerned about how the fish farming influences the fish stock in Bognelv (Rødmyr & Rapp 2013). Escaped farmed salmon and sea lice (*Lepeophtheirus salmonis*) are thought to be the most important de-stabilising factors affecting salmon (Vitenskapelig råd for lakseforvaltning 2013). Escaped farmed salmon can have negative ecological and genetic effects on wild salmonid populations, while sea lice may be a stressor affecting other anadromous salmonids (Vitenskapelig råd for lakseforvaltning 2013). In intensive farming areas, sea lice are found to give population effects by reducing the drift of mature salmonids from the ocean, and hence reduce the stocks in the rivers (Vitenskapelig råd for lakseforvaltning 2012). In addition, several of the fish farm locations in Langfjorden have had outbreaks of fish diseases (Fish.no 2011; Mattilsynet 2013). One mature salmonid fish was caught, with a sea louse, during the fieldwork. The effects of climate change, escaped farmed salmon, sea lice and diseases on the wild population of the salmonids in Bognelv are uncertain. The stressors may have an effect, and the effects could be further analysed in a new thesis. (Bolscher et al. 2013)

In addition, the fishing and hunting association is concerned about mink (*Mustela vison*) and European otter (*Lutra lutra*) which have been observed along Bognelv, illegal net fishing in the fjord and illegal fishing in the river, as well as pollution damage from a possible dumping of tunnel mass in the fjord (Rødmyr & Rapp 2013). However, these problems will not be further analysed as they are beyond the scope of this thesis.

5.0 Conclusions

The first aim of my study was to reveal whether the restoration measures done in Bognelv over the last eight years have increased the density of juvenile salmonid species in the river compared to densities found in 1998 and 2004. The restoration measures have clearly increased the density of juvenile brown trout, as also found by Schedel (2010) and Austvik (2012). The decrease in 0+ brown trout density in 2013 is probably caused by natural fluctuations. The densities of salmon and char have however not responded to the restoration measures, and have been low all years.

The second aim of my study was to investigate which of the environmental variables that had the most influence on fish density, growth and macroinvertebrate density. Several environmental variables were found to influence density and growth, and the interactions between the environmental variables were complex. The highest densities of 0+ brown trout was found in shallow habitats with slow water velocity, low levels of moss cover and high levels of macroinvertebrates. The highest densities of 1+ brown trout were found in habitats with coarse gravel. Mean summer temperature had the most effect on 0+ growth rates. Highest densities of macroinvertebrates were found at coarse gravel. The composition between the different macroinvertebrate orders showed great variation with environmental variables.

The third aim of the study was to estimate restoration–measures-specific effects on juvenile salmonid species and the macroinvertebrate density. From the analyses, the restoration measures conducted in the river where found to have positive, negative or no effect on brown trout density and growth, and macroinvertebrate density when compared to unrestored stations. However, higher densities and improved size of brown trout are found after the restoration measures. As Bognelv has been altered and restored several places, it may be difficult to see the effect of single measures at one specific site. As such, enhanced ecosystem functioning may have resulted from the measures even though local effects from each specific measure were not estimable or separable in the statistical tests. Synergies among upstream and further downstream measures may yield enhanced ecosystem functioning that favours brown trout production. From observations during the fieldwork, higher densities were found among boulder groups, where large woody debris was present or at undercut banks, than in the surrounding homogenous areas.

The fourth and final question is whether the restoration project has been successful, and if Bognelv has been fully restored. The obvious increased density and growth of juvenile brown trout after the restoration measures compared to the situation before, shows that the restoration project have been quite successful for brown trout. The increased density shows that a full restoration of the hydraulic and geological processes is not needed to achieve valuable biological goals. The measures in the river were finished in 2012, and the river will now get time to fully recover. Further monitoring is needed to get a full understanding of the biological effects of the longer-term restoration process in Bognelv.

6.0 References

Akaike, H. (1974). A new look at the statistical model identification. *IEEE Transactions on Automatic Control*, 19 (6): 716-723.

Anderson, N. H. (1976). The distribution and biology of the Oregon Trichoptera. *Technical Bulletin*, 134. Corvallis: Agricultural Experiment Station, Oregon State University. 152 pp.

Armstrong, J. D., Kemp, P. S., Kennedy, G. J. A., Ladle, M. & Milner, N. J. (2003). Habitat requirements of Atlantic salmon and brown trout in rivers and streams. *Fisheries Research*, 62 (2): 143-170.

Armstrong, J. D. & Nislow, K. H. (2006). Critical habitat during the transition from maternal provisioning in freshwater fish, with emphasis on Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*). *Journal of Zoology*, 269 (4): 403-413.

Arnekleiv, J. V. (1985). Seasonal variability in diversity and species richness of Ephemeropteran and Plecopteran communities in a boreal stream. *Norwegian Journal of Entomology*, 32 (1): 1-6.

Arnekleiv, J. V., Raddum, G. G., Sandnæs, T. O., Fjellheim, A. & Fergus, T. (2006). Evaluering av terskler som avbøtende tiltak i et utvalg vassdrag i Midt- og Vest-Norge, 2006:3. Oslo: Norges vassdrags- og energidirektorat. 83 pp.

Artsinformasjon. (2014). Available at: http://www.miljolare.no/data/ut/art/artsinfo/?or_id=65,1803,314,68,334,1193,1189,46,433,54,325,706,1287,70,53,26,466,429,770,359,32,49,914,133,125,144,318,147,208,172,578,138,132,452,50,556,2094,2136,2148,2123 (accessed: 31.03.2014).

Austvik, K. L. (2012). *Let the river live. Cascade-effects of restoration in Bognelv*. Ås: Norwegian University for Life Sceinces, Department of Nature Conservation. 21 pp.

Baerum, K. M., Haugen, T. O., Kiffney, P., Olsen, E. M. & Vollestad, L. A. (2013). Interacting effects of temperature and density on individual growth performance in a wild population of brown trout. *Freshwater Biology*, 58 (7): 1329-1339.

Baldigo, B. P., Ernst, A. G., Warren, D. R. & Miller, S. J. (2010). Variable responses of fish assemblages, habitat, and stability to natural-channel-design restoration in Catskill Mountain streams. *Transactions of the American Fisheries Society*, 139 (2): 449-467.

Beland, K. F., Trial, J. G. & Kocik, J. F. (2004). Use of riffle and run habitats with aquatic vegetation by juvenile Atlantic salmon. *North American Journal of Fisheries Management*, 24 (2): 525-533.

Berg, O. K., Bremset, G., Puffer, M. & Hanssen, K. (2013). Selective segregation in intraspecific competition between juvenile Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*). *Ecology of Freshwater Fish*: 1-12.

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

Bernhardt, E. S., Palmer, M. A., Allan, J. D., Alexander, G., Barnas, K., Brooks, S., Carr, J., Clayton, S., Dahm, C., Follstad-Shah, J., et al. (2005). Synthesizing U.S. river restoration efforts. *Science*, 308 (5722): 636-637.

Bjordal, A. & Hoseth, K. A. (2006). Rapport Bognelva. Tiltakene i Bognelva utført høsten 2006. Utførte tiltak. Narvik: Norges vassdrags- og energidirektorat. 6 pp.

Bjordal, A. & Hoseth, K. A. (2009). Tiltak i vassdrag. Miljøtiltak i Bognelva, tiltak 7. Detaljplan. Narvik: Norges vassdrags- og energidirektorat. 16 pp.

Bjordal, A. & Hoseth, K. A. (2012). Rapport Bognelva. Miljøtiltak 2012. Utførte miljøtiltak høsten 2012. Narvik: Norges vassdrags- og energidirektorat. 13 pp.

Bohlin, T. (1977). Habitat selection and intercohort competition of juvenile sea-trout *Salmo trutta*. *Oikos*, 29 (1): 112-117.

Bohlin, T., Hamrin, S., Heggberget, T. G., Rasmussen, G. & Saltveit, S. J. (1989). Electrofishing - Theory and practice with special emphasis on salmonids. *Hydrobiologia*, 173 (1): 9-43.

Bolscher, T., van Slobbe, E., van Vliet, M. T. H. & Werners, S. E. (2013). Adaptation turning points in river restoration? The Rhine salmon case. *Sustainability*, 5 (6): 2288-2304.

Bongard, T. & Aagaard, K. (2006). BIOKLASS. Klassifisering av økologisk status i norske vannforekomster – elver. Forslag til bunndyrindeks for definisjon av Vanndirektivets fem nivåer for økologisk status, 113. Trondheim: Norsk institutt for naturforskning. 22 pp.
Boussu, M. F. (1954). Relationship between trout populations and cover on a small stream. *Journal of Wildlife Management*, 18 (2): 229-239.
Bowlby, J. N. & Roff, J. C. (1986a). Trophic structure in southern Ontario streams. *Ecology*, 67 (6): 1670-1679.
Bowlby, J. N. & Roff, J. C. (1986b). Trout biomass and habitat relationships in southern Ontario streams. *Transactions of the American Fisheries Society*, 115 (4): 503-514.
Bremset, G. & Berg, O. K. (1997). Density, size-at-age, and distribution of young Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) in deep river pools. *Canadian Journal of Fisheries and Aquatic Sciences*, 54 (12): 2827-2836.
Bremset, G. & Berg, O. K. (1999). Three-dimensional microhabitat use by young pool-dwelling Atlantic salmon and brown trout. *Animal Behaviour*, 58: 1047-1059.
Bridcut, E. E. (2000). A study of terrestrial and aerial macroinvertebrates on river banks and their contribution to drifting fauna and salmonid diets in a Scottish catchment. *Hydrobiologia*, 427 (1-3): 83-100.
Brittain, J. E. (1982). Biology of mayflies. *Annual Review of Entomology*, 27: 119-47.
Brönmark, C. & Hansson, L.-A. (2008). *The biology of lakes and ponds*. 2nd ed. New York: Oxford University Press Inc.
Burnham, K. P. & Anderson, D. R. (2002). *Model selection and multimodel inference. A practical information-theoretic approach*. 2nd ed. New York: Springer. Available at: http://www.mun.ca/biology/quant/ModelSelectionMultimodelInference.pdf (accessed: 03.02.2014).
Cermaq Norway AS. (2014). *Cermaq Norway's locations*. Available at: http://www.cermaq.com/portal/wps/wcm/connect/msno-content-en/mainstream-norway/about-us/our-locations/ (accessed: 22.04.1014).
Ciutti, F., Cappelletti, C., Monauni, C. & Siligardi, M. (2004). Influence of substrate composition and current velocity on macroinvertebrates in a semi-artificial system. *Journal of Freshwater Ecology*, 19 (3): 455-460.
Colman, J. E., Hoseth, K. A. & Dønnum, B. O. (2010). Restaurering av Bognelva, Langfjordbotn. In Hagen, D. & Skrindo, A. B. (eds). *Restaurering av natur i Norge - et inblikk i fagfeltet, fagmiljøer og pågående aktivitet*. Trondheim: Norsk institutt for naturforskning. 83-87 pp.
Crisp, D. T. (1988). Prediction, from temperature, of eyeing, hatching and swim-up times for salmonid embryos. *Freshwater Biology*, 19 (1): 41-48.
Crook, D. A. & Robertson, A. I. (1999). Relationships between riverine fish and woody debris: implications for lowland rivers. *Marine and Freshwater Research*, 50 (8): 941-953.
Culp, J. M. (1986). Experimental evidence that stream macroinvertebrate community structure is unaffected by different densities of Coho salmon fry. *Journal of the North American Benthological Society*, 5 (2): 140-149.
Davies-Colley, R. J., Meleason, M. A., Hall, G. M. J. & Rutherford, J. C. (2009). Modelling the time course of shade, temperature, and wood recovery in streams with riparian forest restoration. *New Zealand Journal of Marine and Freshwater Research*, 43 (3): 673-688.
Degerman, E., Henrikson, L., Lingdell, P.-E. & Weibull, H. (2004a). Indikatorer på naturvärde i skogsvattendrag - mossor, bottenfauna, fisk och biotopegenskaper: Väldsnaturfonden WWF. 19 pp.
Degerman, E., Sers, B., Törnblom, J. & Angelstam, P. (2004b). Large woody debris and brown trout in small forest streams – Towards targets for assessment and management of riparian landscapes. *Ecological Bulletins*, 51 (233-239).
Direktoratet for naturforvaltning. (2009). Bestandsutvikling hos sjøørret og forslag til forvaltningstiltak. *Notat*, 2009:1: Trondheim. 32 pp.
Dønnum, B. O. & Colman, J. (2004). Oppsummering av feltbefaring i Bognelva i Alta kommune, Finnmark med forslag til videre arbeid. 14 pp.
Dønnum, B. O. (2005). Bognelva – Oppsummering av elfiske august 2004. 11 pp.

Egglishaw, H. J. & Shackley, P. E. (1982). Influence of water depth on dispersion of juvenile salmonids, *Salmo salar* L. and *S. trutta* L., in a Scottish stream. *Journal of Fish Biology*, 21: 141-155.

Eie, J. A., Brittain, J. E. & Eie, J. A. (1997). Biotope adjustments measures in Norwegian watercourses. Oslo: The Norwegian Water Resources and Energy Administration. 76 pp.

Elliott, J. M. (1976). The energetics of feeding, metabolism and growth of brown trout (*Salmo trutta* L.) in relation to body weight, water temperature and ration size. *Journal of Animal Ecology*, 45 (3): 923-948.

Elliott, J. M. (1994). *Quantitative ecology and the brown trout*. Oxford Series in Ecology and Evolution. Oxford: Oxford University Press.

Elliott, J. M., Hurley, M. A. & Elliott, J. A. (1997). Variable effects of droughts on the density of a sea-trout *Salmo trutta* population over 30 years. *Journal of Applied Ecology*, 34 (5): 1229-1238.

Elliott, J. M. & Hurley, M. A. (1998). An individual-based model for predicting the emergence period of sea trout fry in a lake district stream. *Journal of Fish Biology*, 53 (2): 414-433.

Elliott, J. M. (2009). Validation and implications of a growth model for brown trout, *Salmo trutta*, using long-term data from a small stream in north-west England. *Freshwater Biology*, 54 (11): 2263-2275.

Elliott, J. M. & Elliott, J. A. (2010). Temperature requirements of Atlantic salmon *Salmo salar*, brown trout *Salmo trutta* and Arctic charr *Salvelinus alpinus*: Predicting the effects of climate change. *Journal of Fish Biology*, 77 (8): 1793-1817.

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

Fish.no. (2011). *Bekrefter ILA i Langfjorden i Alta*. Available at: http://www.fish.no/oppdrett/4677-bekrefter-ila-i-langfjorden-i-alta.html (accessed: 22.04.2013).

Forseth, T. & Forsgren, E. (2008). El-fiskemetodikk. Gamle problemer og nye utfordringer. *NINA Rapport*, 488. Trondheim: Norsk institutt for naturforskning. 74 pp.

Fox, M. & Bolton, S. (2007). A regional and geomorphic reference for quantities and volumes of instream wood in unmanaged forested basins of Washington state. *North American Journal of Fisheries Management*, 27 (1): 342-359.

Friberg, N., Kronvang, B., Hansen, H. O. & Svendsen, L. M. (1998). Long-term, habitat-specific response of a macroinvertebrate community to river restoration. *Aquatic Conservation-Marine and Freshwater Ecosystems*, 8 (1): 87-99.

Garcia, X. F., Schnauder, I. & Pusch, M. T. (2012). Complex hydromorphology of meanders can support benthic invertebrate diversity in rivers. *Hydrobiologia*, 685 (1): 49-68.

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

Habersack, H. & Nachtnebel, H. P. (1995). Short-term effects of local river restoration on morpology, flow field, substrate and biota. *Regulated Rivers-Research & Management*, 10: 291-301.

Haberstock, A. E., Nichols, H. G., DesMeules, M. P., Wright, J., Christensen, J. M. & Hudnut, D. H. (2000). Method to identify effective riparian buffer widths for Atlantic salmon habitat protection. *Journal of the American Water Resources Association*, 36 (6): 1271-1286.

Hagen, D. & Skrindo, A. B. (2010). Restaurering av natur i Norge- et inblikk i fagfeltet, fagmiljøer og pågående aktivitet. *NINA Temahefte*, 42. Trondheim: Norsk institutt for naturforskning. 109 pp.

Halvorsen, M., Jørgensen, L. & Amundsen, P. A. (1997). Habitat utilization of juvenile Atlantic salmon (*Salmo salar* L.), brown trout (*Salmo trutta* L.) and Arctic charr (*Salvelinus alpinus* (L.)) in two lakes in Northern Norway. *Ecology of Freshwater Fish*, 6 (2): 67-77.

Hamarsland, A. T., Hoseth, K. A. & L'Abée-Lund, J. H. (2003). Program for miljøtiltak i vassdrag, 11. Oslo: Norges vassdrags- og energidirektorat. 33 pp.

Hawkins, C. P., Murphy, M. L. & Anderson, N. H. (1982). Effects of canopy, substrate composition, and gradient on the structure of macroinvertebrate communities in cascade range streams of Oregon. *Ecology*, 63 (6): 1840-1856.

Heggenes, J. (1988). Substrate preferences of brown trout fry (*Salmo trutta*) m artificial stream channels. *Canadian Journal of Fisheries and Aquatic Sciences*, 45 (10): 1801-1806.
Heggenes, J. (1995). Habitatvalg og vandringer hos ørret og laks i rennende vann. In Borgstrom, R., Jonsson, B. & L'Abée-Lund, J. H. (eds) *Ferskvannsfisk. Økologi, kultivering og utnytting*, pp. 17-28. Trondheim: Norges forskningsråd.
Heggenes, J., Bagliniere, J. L. & Cunjak, R. A. (1999). Spatial niche variability for young Atlantic salmon (*Salmo salar*) and brown trout (*S. trutta)* in heterogeneous streams. *Ecology of Freshwater Fish*, 8 (1): 1-21.
Heggenes, J. & Dokk, J. G. (2001). Contrasting temperatures, waterflows, and light: Seasonal habitat selection by young Atlantic salmon and brown trout in a boreonemoral river. *Regulated Rivers-Research & Management*, 17 (6): 623-635.
Heggenes, J. & Saltveit, S. J. (2002). Effect of aquatic mosses on juvenile fish density and habitat use in the regulated river Suldalslagen, Western Norway. *River Research and Applications*, 18 (3): 249-264.
Heggenes, J. & Saltveit, S. J. (2007). Summer stream habitat partitioning by sympatric Arctic charr, Atlantic salmon and brown trout in two sub-arctic rivers. *Journal of Fish Biology*, 71: 1069-1081.
Hoseth, K. A. & Josefsen, A. (2005). Tiltak i vassdrag. Miljøplan for Bognelva. Helhetlig plan. Narvik: Norges vassdrags- og energidirektorat. 37 pp.
Hoseth, K. A. & Josefsen, A. (2006). Tiltak i vassdrag. Miljøtiltak i Bognelva: deltiltak 3 og 5. Detaljplan. Narvik: Norges vassdrags- og energidirektorat. 22 pp.
Hoseth, K. A. & Josefsen, A. (2007). Tiltak i vassdrag. Miljøtiltak i Bognelva, tiltak 4 og 6 samt steingrupper. Detaljplan. Narvik: Norges vassdrags- og energidirektorat. 22 pp.
Hosmer, D. W. & Lemeshow, S. (1989). *Applied Logistic Regression*. New York: John Wiley & Sons, Inc.
Hynes, H. B. N. (1976). Biology of Plecoptera. *Annual Review of Entomology*, 21: 135-153.
Imre, I., Grant, J. W. A. & Keeley, E. R. (2004). The effect of food abundance on territory size and population density of juvenile steelhead trout (*Oncorhynchus mykiss*). *Oecologia*, 138 (3): 371-378.
Iversen, A. (2011). Økt fokus på vassdragsrestaurering i Europa. *Vann*, 46 (2): 177-183.
Iversen, T. M., Kronvang, B., Madsen, B. L., Markmann, P. & Nielsen, M. B. (1993). Re-establishment of Danish streams: Restoration and maintainance measures. *Aquatic Conservation-Marine and Freshwater Ecosystems*, 3: 73-92.
Jenkins, T. M., Diehl, S., Kratz, K. W. & Cooper, S. D. (1999). Effects of population density on individual growth of brown trout in streams. *Ecology*, 80 (3): 941-956.
Jensen, A. J. (1990). Growth of young migratory brown trout *Salmo trutta* correlated with water temperature in Norwegian rivers. *Journal of Animal Ecology*, 59 (2): 603-614.
Johnson, S. L., Rodgers, J. D., Solazzi, M. F. & Nickelson, T. E. (2005). Effects of an increase in large wood on abundance and survival of juvenile salmonids (*Oncorhynchus spp*.) in an Oregon coastal stream. *Canadian Journal of Fisheries and Aquatic Sciences*, 62 (2): 412-424.
Jonsson, B. & Gravem, F. R. (1985). Use of space and food by resident and migrant brown trout, *Salmo trutta*. *Environmental Biology of Fishes*, 14 (4): 281-293.
Jonsson, B. (1989). Life history and habitat use of Norwegian brown trout (*Salmo trutta*). *Freshwater Biology*, 21: 71-86.
Jonsson, B. & Jonsson, N. (2009). Migratory timing, marine survival and growth of anadromous brown trout *Salmo trutta* in the river Imsa, Norway. *Journal of Fish Biology*, 74 (3): 621-638.
Jonsson, B. & Jonsson, N. (2011). *Ecology of Atlantic salmon and brown trout. Habitat as a template for life histories*. Fish and fisheries series, vol. 33. The Netherlands: Springer.
Kalleberg, H. (1958). Observations in a stream tank of territoriality and competition in juvenile salmon and trout (*Salmo salar* L. and S. *trutta* L.). *Institute of Freshwater Research Drottningholm*, 39: 55–98.
Kilgour, B. W. & Barton, D. R. (1999). Associations between stream fish and benthos across environmental gradients in southern Ontario, Canada. *Freshwater Biology*, 41 (3): 553-566.
Klemetsen, A., Amundsen, P.-A., Dempson, J. B., Jonsson, B., O´Connell, M. F. & Mortensen, E. (2003). Atlantic salmon *Salmo salar* L., brown trout *Salmo trutta* L. and Arctic charr

Salvelinus alpinus (L.): A review of aspects of their life histories. *Ecology of Freshwater Fish*, 12: 1-59.
Kondolf, G. M. & Micheli, E. R. (1995). Evaluating stream restoration projects. *Environmental Management*, 19 (1): 1-15.
Kondolf, G. M. (2006). River restoration and meanders. *Ecology and Society*, 11 (2).
Kristiansen, G. (2011). Miljøtiltak i vassdrag med erfaringer fra Nord-Norge. *Vann*, 46 (2): 192-201.
Ladle, M., Welton, J. S. & Bass, J. A. B. (1980). Invertebrate colonisation of the gravel substratum of an experimental recirculating channel. *Holarctic Ecology*, 3: 116-123.
Lake, P. S., Bond, N. & Reich, P. (2007). Linking ecological theory with stream restoration. *Freshwater Biology*, 52 (4): 597-615.
Lepori, F., Palm, D., Brannas, E. & Malmqvist, B. (2005). Does restoration of structural heterogeneity in streams enhance fish and macroinvertebrate diversity? *Ecological Applications*, 15 (6): 2060-2071.
Lobon-Cervia, J. & Mortensen, E. (2005). Population size in stream-living juveniles of lake-migratory brown trout *Salmo trutta* L.: The importance of stream discharge and temperature. *Ecology of Freshwater Fish*, 14 (4): 394-401.
Lobon-Cervia, J. (2007). Density-dependent growth in stream-living brown trout Salmo trutta L. *Functional Ecology*, 21 (1): 117-124.
Lorenz, A. W., Stoll, S., Sundermann, A. & Haase, P. (2013). Do adult and YOY fish benefit from river restoration measures? *Ecological Engineering*, 61: 174-181.
Mackay, R. J. & Wiggins, G. B. (1979). Ecological diversity in Trichoptera. *Annual Review of Entomology*, 24: 185-208.
Magoulick, D. D. & Kobza, R. M. (2003). The role of refugia for fishes during drought: A review and synthesis. *Freshwater Biology*, 48 (7): 1186-1198.
Maki-Petays, A., Muotka, T., Huusko, A., Tikkanen, P. & Kreivi, P. (1997). Seasonal changes in habitat use and preference by juvenile brown trout, *Salmo trutta*, in a northern boreal river. *Canadian Journal of Fisheries and Aquatic Sciences*, 54 (3): 520-530.
Malmquist, B. & Rundle, S. (2002). Threats to the running water ecosystems of the world. *Environmental Conservation*, 29 (2): 134-153.
Maridet, L., Wasson, J.-G. & Philippe, M. (1992). Vertical distribution of fauna in the bed sediment of three running water sites: Influence of physical and trophic factors. *Regulated Rivers: Research & Management*, 7 (1): 45-55.
Mattilsynet. (2013). *Pancreassykdom (PD) påvist på oppdrettsanlegg i Rivarbukt i Langfjorden*. Available at: http://www.mattilsynet.no/fisk_og_akvakultur/fiskehelse/fiske_og_skjellsykdommer/pd/pancreassykdom_pd_paavist_paa_oppdrettsanlegg_i_rivarbukt_i_langfjorden.10327 (accessed: 22.04.2013).
McCullagh, P. & Nelder, J. A. (1989). *Generalized Linear Models*. 2nd ed. London: Chapman & Hall. 511 pp.
Meleason, M. A. & Hall, G. M. J. (2005). Managing plantation forests to provide short- to long-term supplies of wood to streams: A simulation study using New Zealands pine plantations. *Environmental Management*, 36 (2): 258-271.
Miller, S. W., Budy, P. & Schmidt, J. C. (2010). Quantifying macroinvertebrate responses to in-stream habitat restoration: Applications of meta-analysis to river restoration. *Restoration Ecology*, 18 (1): 8-19.
Milner, A. M. & Gloyne-Phillips, I. T. (2005). The role of riparian vegetation and woody debris in the development of macroinvertebrate assemblages in streams. *River Research and Applications*, 21 (4): 403-420.
Mohseni, O. & Stefan, H. G. (1999). Stream temperature/ air temperature relationship: A physical interpretation. *Journal of Hydrology*, 218 (3-4): 128-141.
Mohseni, O., Stefan, H. G. & Eaton, J. G. (2003). Global warming and potential changes in fish habitat in U.S. streams. *Climatic change*, 59: 389-409.
Muotka, T. & Syrjanen, J. (2007). Changes in habitat structure, benthic invertebrate diversity, trout populations and ecosystem processes in restored forest streams: A boreal perspective. *Freshwater Biology*, 52 (4): 724-737.

Murphy, M. L., Hawkins, C. P. & Anderson, N. H. (1981). Effects of canopy modification and accumulated sediment on stream communities. *Transactions of the American Fisheries Society*, 110 (4): 469-478.
Nakano, D. & Nakamura, F. (2006). Responses of macroinvertebrate communities to river restoration in a channelized segment of the Shibetsu river, northern Japan. *River Research and Applications*, 22 (6): 681-689.
Norges forskningsråd. (2013a). Klimaendringer gir mer villaks. *NORKLIMA*. Oslo: Norges forskningsråd. 2 pp.
Norges forskningsråd. (2013b). Mer ørret, mindre røye. *NORKLIMA*. Oslo: Norges forskningsråd. 2 pp.
Norwegian Metrological Institute. (2014). *eKlima*. Available at: http://sharki.oslo.dnmi.no/portal/page?_pageid=73,39035,73_39049&_dad=portal&_schema=PORTAL (accessed: 21.01.2014).
NOU 1976: 15. *Verneplan for vassdrag*.
Opperman, J. J. & Merenlender, A. M. (2004). The effectiveness of riparian restoration for improving instream fish habitat in four hardwood-dominated California streams. *North American Journal of Fisheries Management*, 24 (3): 822-834.
Ottesen, P. S. (2014a). *Steinfluer*. Available at: http://snl.no/steinfluer (accessed: 29.04.2014).
Ottesen, P. S. (2014b). *Vårfluer*. Available at: http://snl.no/v%C3%A5rfluer (accessed: 29.04.2014).
Palmer, M. A., Ambrose, R. F. & Poff, N. L. (1997). Ecological theory and community restoration ecology. *Restoration Ecology*, 5 (4): 291-300.
Palmer, M. A., Bernhardt, E. S., Allan, J. D., Lake, P. S., Alexander, G., Brooks, S., Carr, J., Clayton, S., Dahm, C. N., Follstad Shah, J., et al. (2005). Standards for ecologically successful river restoration. *Journal of Applied Ecology*, 42 (2): 208-217.
Pander, J. & Geist, J. (2013). Ecological indicators for stream restoration success. *Ecological Indicators*, 30: 106-118.
Pickering, A. D., Griffiths, R. & Pottinger, T. G. (1987). A comparison of the effects of overhead cover on the growth, survival and haematology of juvenile Atlantic salmon, *Salmo salar* L., brown trout, *Salmo trutta* L., and rainbow trout, *Salmo gairdneri* Richardson. *Aquaculture*, 66 (2): 109-124.
Pinder, L. C. V. (1986). Biology of freswater Chironomidae. *Annual Review of Entomology*, 31: 1-31.
Postel, S. & Richter, B. (2003). *Rivers for life: Managing water for people and nature*. Washington, DC: Island Press. 243 pp.
R Development Core Team. (2012). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.
Reice, S. R. (1985). Experimental disturbance and the maintenance of species diversity in a stream community. *Oecologia*, 67 (1): 90-97.
Rempel, L. L., Richardson, J. S. & Healey, M. C. (1999). Flow refugia for benthic macroinvertebrates during flooding of a large river. *Journal of the North American Benthological Society*, 18 (1): 34-48.
Roni, P., Beechie, T. J., Bilby, R. E., Leonetti, F. E., Pollock, M. M. & Pess, G. R. (2002). A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific northwest watersheds. *North American Journal of Fisheries Management*, 22 (1): 1-20.
Roni, P. (2005). Overview and background. In Roni, P. (ed.) *Monitoring stream and watershed restoration*, pp. 1-12. Bethesda, Maryland: American Fisheries Society.
Roni, P., Bennett, T., Morley, S., Pess, G. R., Hanson, K., Van Slyke, D. & Olmstead, P. (2006). Rehabilitation of bedrock stream channels: The effects of boulder weir placement on aquatic habitat and biota. *River Research and Applications*, 22 (9): 967-980.
Roni, P., Hanson, K. & Beechie, T. (2008). Global review of the physical and biological effectiveness of stream habitat rehabilitation techniques. *North American Journal of Fisheries Management*, 28 (3): 856-890.
Ross, H. H. (1967). The evolution and past dispersal of the Trichoptera. *Annual Review of Entomology*, 12: 169-206.
Ruiz-Jaen, M. C. & Aide, T. M. (2005). Restoration success: How is it being measured? *Restoration Ecology*, 13 (3): 569-577.

Rutherford, J. C., Davies-Colley, R. J., Quinn, J. M., Stroud, M. J. & Cooper, A. B. (1997). Stream shade: Towards a restoration strategy. New Zealand: Department of Conservation. 69 pp.
Rødmyr, O. & Rapp, K. (2013). Driftsplan for Bognelva: Langfjordbotn jeger- og fiskeforening. 13 pp.
Rødmyr, O. (2014). *Bognelva* (e-mail 27.01.2014).
Sala, O. E., Chapin, F. S., Armesto, J. J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L. F., Jackson, R. B. & Kinzig, A. (2000). Global biodiversity scenarios for the year 2100. *Science*, 287 (5459): 1770-1774.
Saltveit, S. J. & Brabrand, Å. (1999). Vurdering av behov for lakseterskel i Bognelva, Finnmark. *Notat*, 1999:1. Oslo: Laboratorium for ferskvannsøkologi og innlandsfiske (LFI), Zoologisk Museum, Universitetet i Oslo. 7 pp.
Samaritani, E., Shrestha, J., Fournier, B., Frossard, E., Gillet, F., Guenat, C., Niklaus, P. A., Pasquale, N., Tockner, K., Mitchell, E. A. D., et al. (2011). Heterogeneity of soil carbon pools and fluxes in a channelized and a restored floodplain section (Thur River, Switzerland). *Hydrology and Earth System Sciences*, 15 (6): 1757-1769.
Schedel, J. B. t. (2010). *River restoration and habitat improvements in the sub-arctic river Bognelva – Effects on anadromous fish*. Ås: Norwegian University of Life Sciences, Department of Nature Conservation. 27 pp.
Schoen, J., Merten, E. & Wellnitz, T. (2013). Current velocity as a factor in determining macroinvertebrate assemblages on wood surfaces. *Journal of Freshwater Ecology*, 28 (2): 271-275.
Schofield, K., Townsend, C. R. & Hildrew, A. G. (1988). Predation and the prey community of a headwater stream. *Freshwater Biology*, 20 (1): 85-95.
Seber, G. A. F. & Lecren, E. D. (1967). Estimating population parameters from catches large relative to the population. *Journal of Animal Ecology*, 36 (3): 631-643.
Semb-Johansson, A. (2014). *Døgnfluer*. Available at: http://snl.no/d%C3%B8gnfluer (accessed: 29.04.2014).
Shuler, S. W., Nehring, R. B. & Fausch, K. D. (1994). Diel habitat selection by brown trout in the Rio Grande river, Colorado, after placement of boulder structures. *North American Journal of Fisheries Management*, 14 (1): 99-111.
Society of Ecological Restoration International Science & Working group. (2004a). *Attributes of restored ecosystems.* The SER international primer on ecological restoration. Available at: http://www.ser.org/resources/resources-detail-view/ser-international-primer-on-ecological-restoration#4 (accessed: 04.11.2013).
Society of Ecological Restoration International Science & Working group. (2004b). *Definition of ecological restoration.* The SER international primer on ecological restoration. Available at: http://www.ser.org/resources/resources-detail-view/ser-international-primer-on-ecological-restoration#3 (accessed: 04.11.2013).
Society of Ecological Restoration International Science & Working group. (2004c). *Overwiev.* The SER international primer on ecological restoration. Available at: http://www.ser.org/resources/resources-detail-view/ser-international-primer-on-ecological-restoration#2 (accessed: 04.11.2013).
Sokal, R. R. & Rohlf, F. J. (1995). *Biometry*. 3rd ed. New York: W. H. Freeman and Company.
Spigarelli, S. A., Thommes, M. M. & Prepejchal, W. (1982). Feeding, growth, and fat deposition by brown trout in constant and fluctuating temperatures. *Transactions of the American Fisheries Society*, 111 (2): 199-209.
St.prp. nr. 77 (1979-80). *Verneplan II for vassdrag*.
Strann, K.-B. & Frivoll, V. (2009). Naturfaglige undersøkelser i utvalgte områder i Altaelva, Bognelva og Reisaelva. *NINA Minirapport*, 254. Tromsø: Norsk institutt for naturforskning. 22 pp.
Surber, E. W. (1937). Rainbow trout and bottom fauna production in one mile of stream. *Transactions of the American Fisheries Society*, 66 (1): 193-202.
Suttle, K. B., Power, M. E., Levine, J. M. & McNeely, C. (2004). How fine sediment in riverbeds impairs growth and survival of juvenile salmonids. *Ecological Applications*, 14 (4): 969-974.
Svenning, M.-A., Falkegård, M. & Hanssen, Ø. K. (2012). Sjørøya i Nord-Norge – en fallende dronning? *NINA Rapport*, 780. Tromsø: Norsk institutt for naturforskning. 61 pp.

van Vliet, M. T. H., Ludwig, F., Zwolsman, J. J. G., Weedon, G. P. & Kabat, P. (2011). Global river temperatures and sensitivity to atmospheric warming and changes in river flow. *Water Resources Research*, 47: 1-19.
vann-nett.no. (2013). Available at: http://vann-nett.no/portal/SearchWaterbody.aspx?q=Bognelv&cat=All (accessed: 08.10.2013).
Vehanen, T., Huusko, A., Maki-Petays, A., Louhi, P., Mykra, H. & Muotka, T. (2010). Effects of habitat rehabilitation on brown trout (*Salmo trutta*) in boreal forest streams. *Freshwater Biology*, 55 (10): 2200-2214.
Verdonschot, P. F. M., Spears, B. M., Feld, C. K., Brucet, S., Keizer-Vlek, H., Borja, A., Elliott, M., Kernan, M. & Johnson, R. K. (2012). A comparative review of recovery processes in rivers, lakes, estuarine and coastal waters. *Hydrobiologia*, 704 (1): 453-474.
Vitenskapelig råd for lakseforvaltning. (2011). Prognoser for lakseinnsig, regnbueørret og klimaendringer: utfordringer for forvaltningen, nr. 2. Trondheim: Vitenskapelig råd for lakseforvaltning. 45 pp.
Vitenskapelig råd for lakseforvaltning. (2012). Lakselus og effekter på vill laksefisk – fra individuell respons til bestandseffekter, nr. 3. Trondheim: Vitenskapelig råd for lakseforvaltning. 56 pp.
Vitenskapelig råd for lakseforvaltning. (2013). Status for norske laksebestander i 2013, nr. 5. Trondheim: Vitenskapelig råd for lakseforvaltning. 136 pp.
Wallace, J. B., Whiles, M. R., Eggert, S., Cuffney, T. F., Lugthart, G. H. & Chung, K. (1995). Long-term dynamics of coarse particulate organic-matter in 3 Appalachian Mountain streams. *Journal of the North American Benthological Society*, 14 (2): 217-232.
Weber, C., Peter, A. & Zanini, F. (2007). Spatio-temporal analysis of fish and their habitat: A case study on a highly degraded Swiss river system prior to extensive rehabilitation. *Aquatic Sciences*, 69 (1): 162-172.
Whalen, P. J., Toth, L. A., Koebel, J. W. & Strayer, P. K. (2002). Kissimmee River restoration: a case study. *Water Science and Technology*, 45 (11): 55-62.
Wiseman, S. W., Cooper, S. D. & Dudley, T. L. (1993). The effects of trout on epibenthic odonate naiads in stream pools. *Freshwater Biology*, 30 (1): 133-145.
Zippin, C. (1956). An evaluation of the removal method of estimating animal populations. *Biometrics*, 12 (2): 163-189.

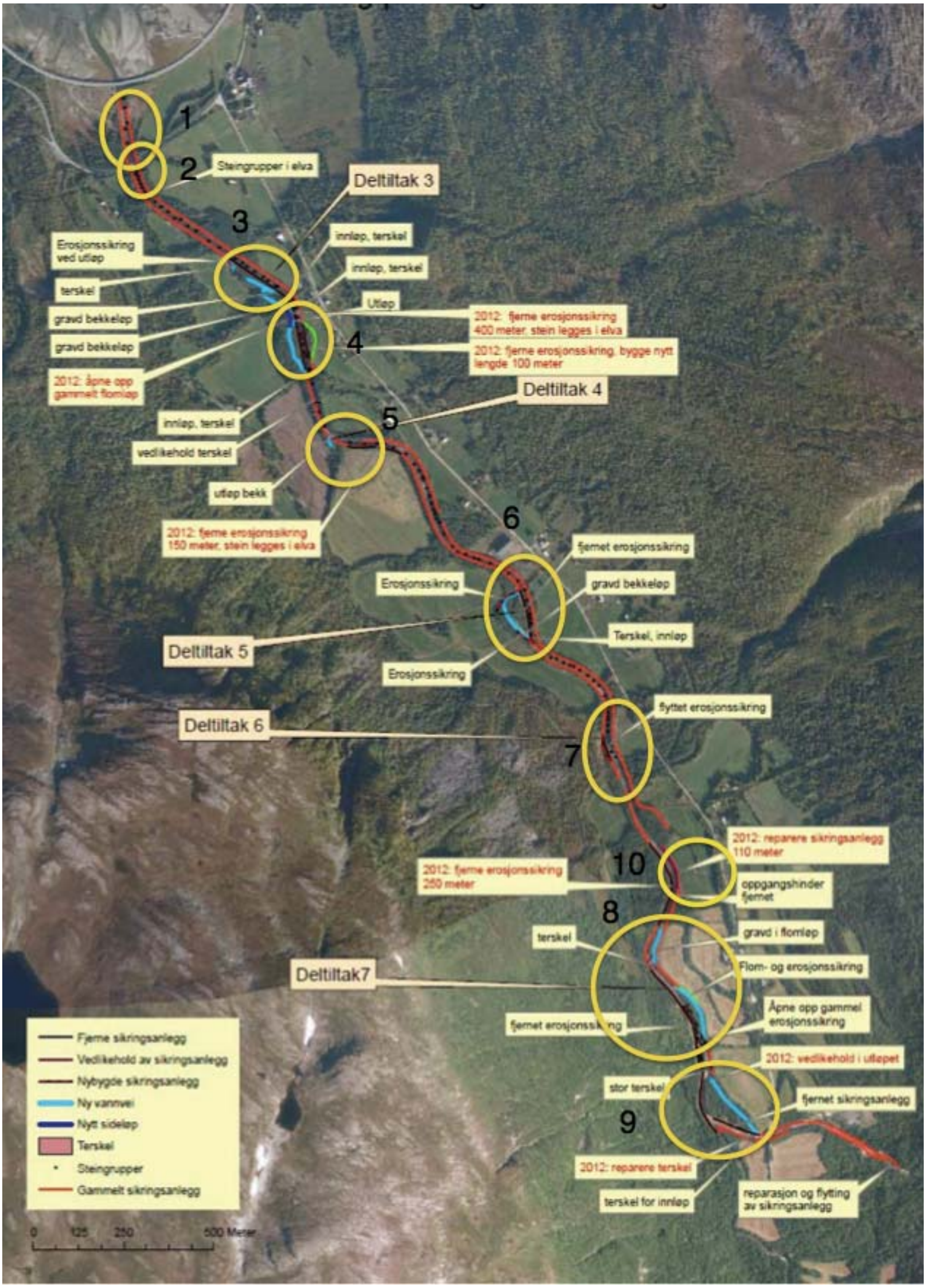
Appendices

Appendix 1. Summary of all restoration measures done in Bognelv between 2006 and 2012.

Zone	2006 Measure 3 and 5	2007 Measure 4 and 6	2009 Measure 7	2012 Measure 3,4 and 7
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
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
5		- Opening of the tributary Mikkelveita - Two weirs were improved and repaired.		
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.			
7		- Relocation and improvement of flood protection - Split a big rock into several pieces.	- Relocation of flood protection systems.	

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.	
9			- Maintenance of a weir. - Removal of erosion control systems. - Opening of the original river course for Øverpasselva. - Construction of a weir to get water into the original river course.	- Repairing of a weir in Øverpasselva - 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 2. Map of zones (1-10) and all restoration measures done in Bognelv between 2006 and 2012. Background map from Bjordal & Hoseth (2012).



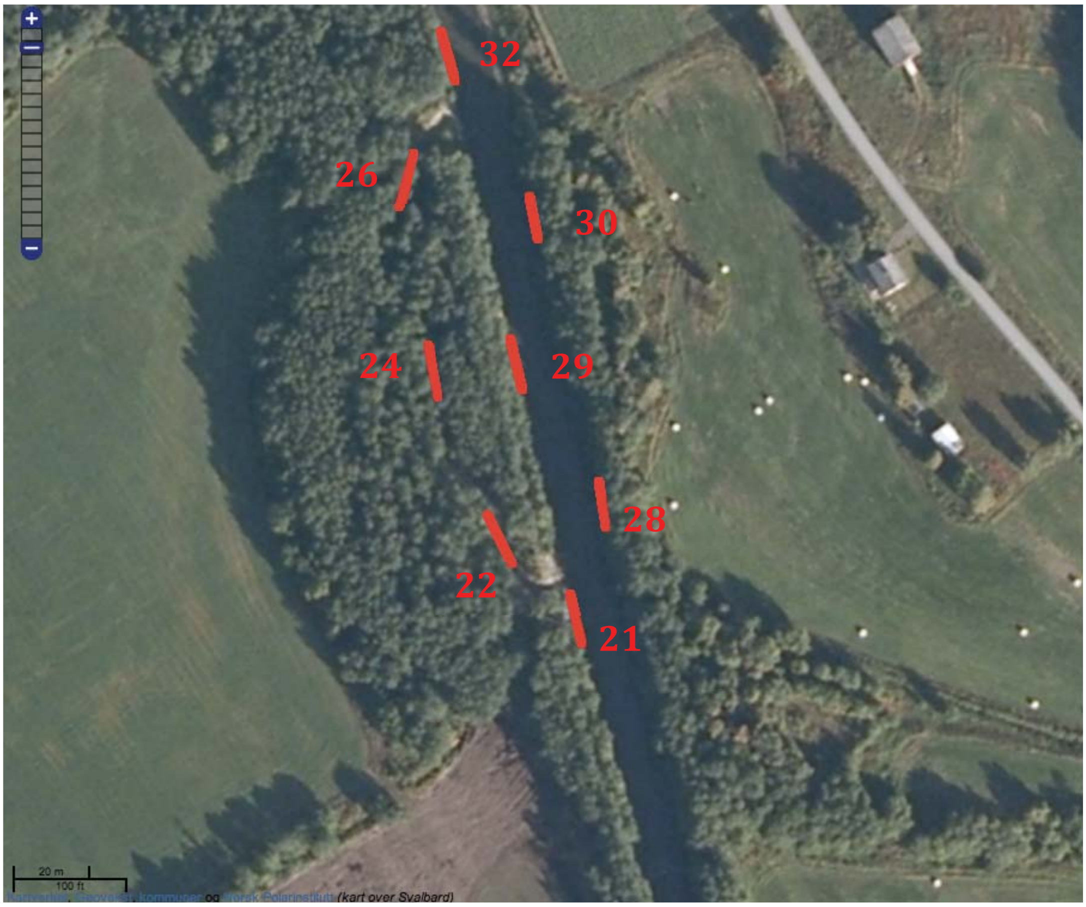
Appendix 3. Aerial photos of station locations for each zone, with coordinates. Aerial photographs from www.norgeibilder.no, taken in 2008.

Zone 1: Station 50, 51 and 52.

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.

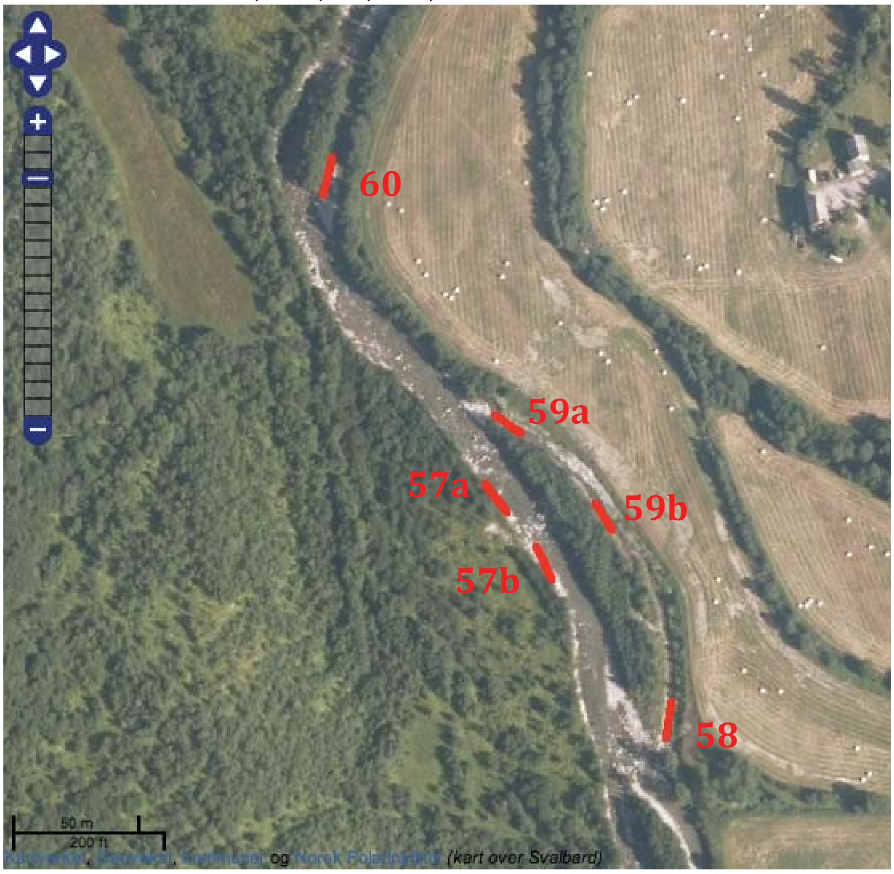


Zone 5: Station 17, 18, 19 and 20.

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 62.

Zone 10: Station 64 and 65.

Coordinates			
Zone	**Station**	**UTM Zone34 East**	**UTM Zone34 North**
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

Appendix 4. Methods for sampling of fish, macroinvertebrates and environmental variables.

The sampling of macroinvertebrates, canopy cover and riverside vegetation, substrate composition, water velocity, depth, algae and moss cover was measured at 0, 5, 10 and 15 meter at each station. The transects were 10 cm wide and two meters long. I used the same categories as Austvik did in 2012.

Fish
At each station the number, size and species of fish were registered. The stations were 15 meters long, and 2 meters wide. There were also, on some of the stations, conducted electrofishing in the middle of the river. The stations in the middle were also 15x2 meter.

Macroinvertebrates
A surber-sampler was placed on the river bottom, covering an area of 0.06 m2. A brush was used on the stones in the topmost layer. The loosened macroinvertebrates were captured in the Surber- sampler and emptied in a bucket. This was carried out at the four transects. I counted the number of macroinvertebrates, and classified them to group. The groups registered were Plecoptera, Trichoptera, Ephemeroptera, Chironomidae, Tipulidae, Hydrachnidia and Oligochaeta.

Cover of branches (canopy)
River: Percent cover of branches measured from the edge of the riverbank and 2 meters out 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 on the top 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 gravel in the riverbed were classified into five categories. The categories were given a percentage after how big part the category constitutes of the total.
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
Measurements on water velocity were obtained by visual estimates. 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 the streams that were narrower than 2 meters, the depth was measured at 1 meter and in the middle.

Algae
Measurements of mean percentage cover of algae were obtained for each station. Biofilm and small periphytic algae covering the substrate were classified as algae.
Category 1: 0%, category 2: 1-33%, category 3: 34-66%, category 4: >66%.

Moss
Measurements of mean percentage cover of moss were obtained for each station. Moss and threadlike algae were classified as moss.
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 the branch 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.

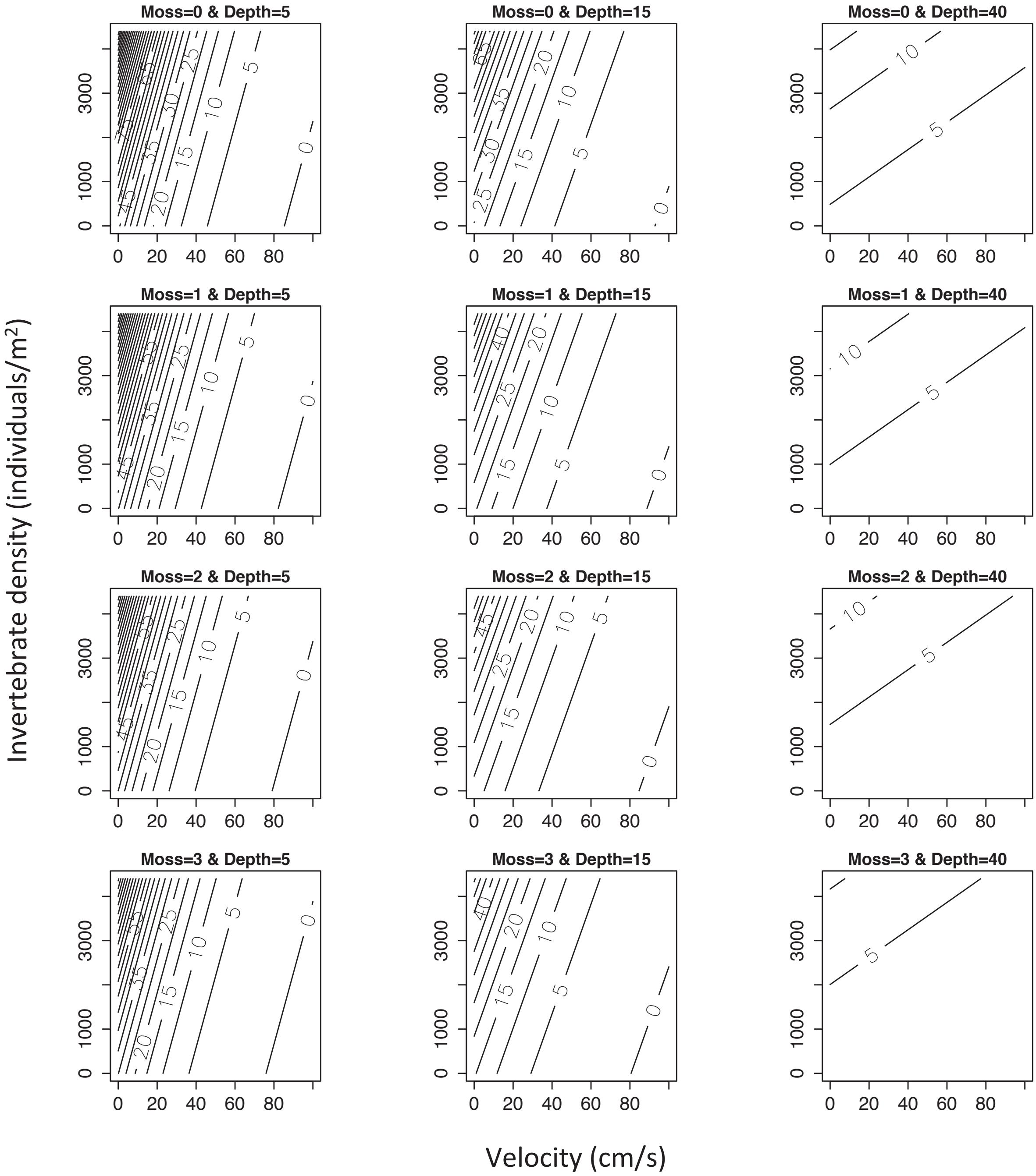
Water temperature
Water temperature is derived from four temperature loggers that laid the main river under the whole field period. The temperature of the river was logged every hour.

Spawning habitat
The spawning habitat was classified into three categories: good (category 3), ok (category 2), and bad (category 1). This was based on substrate composition and water velocity.

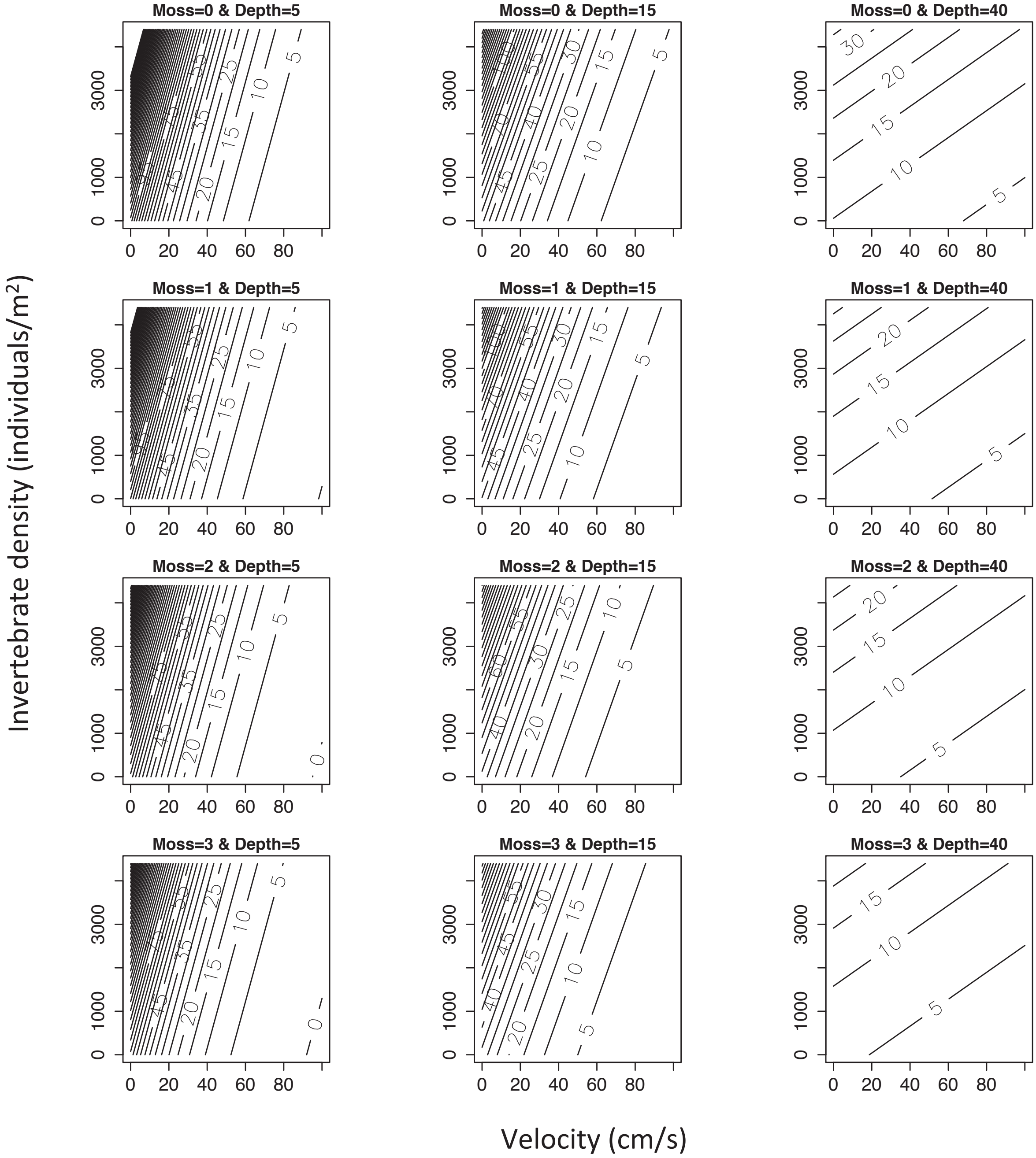
Additional
The width of the river and the area covered by water were measured for each station. The distance from the new E6 was measured from the lowest point at each station using a measurement tool in norgeskart.no

Appendix 5. Figure of the most supported 0+ density model, with type of measure. For 2011 and 2013.

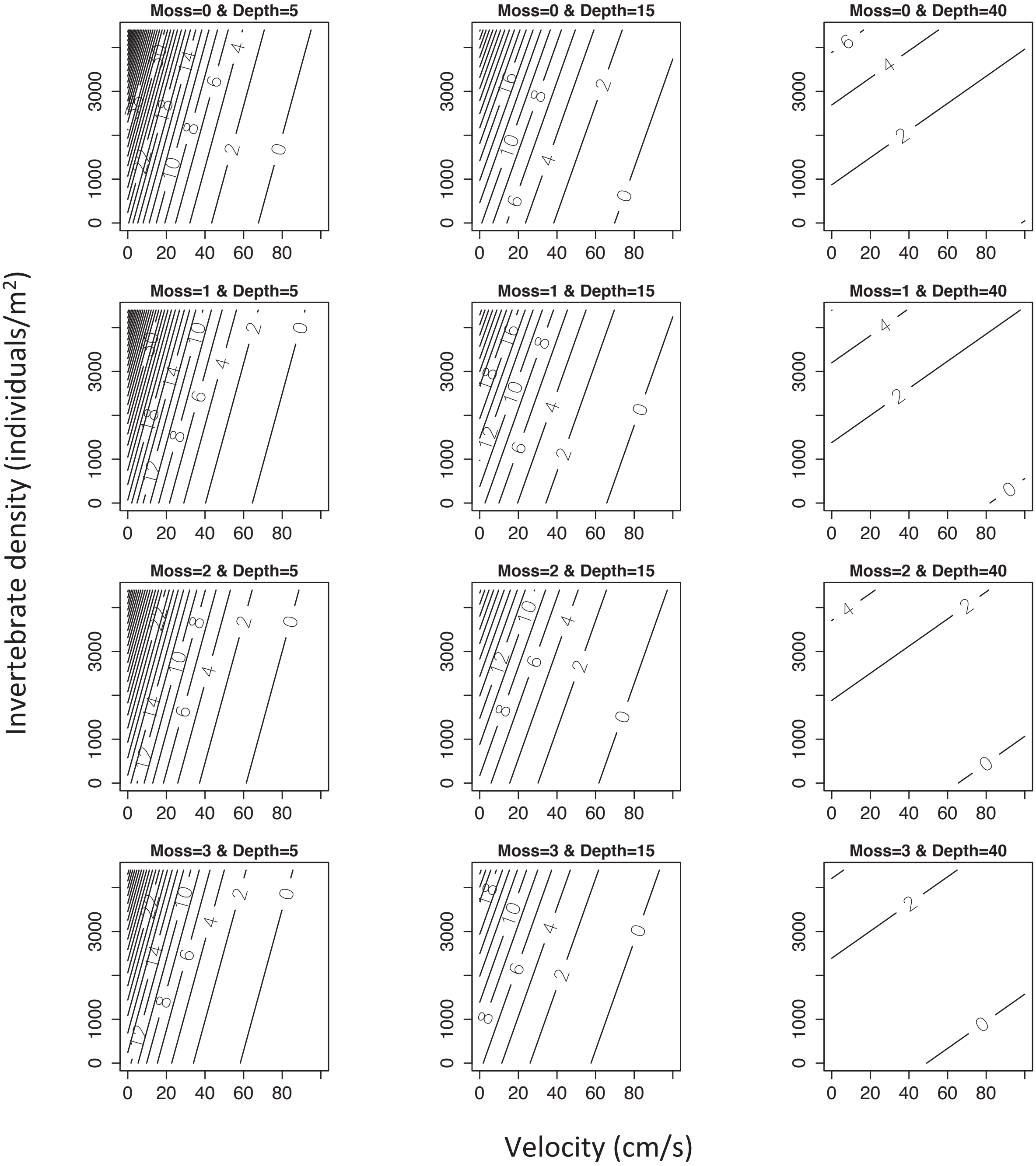
No measure



Riparian modifications



Side channels



Weirs

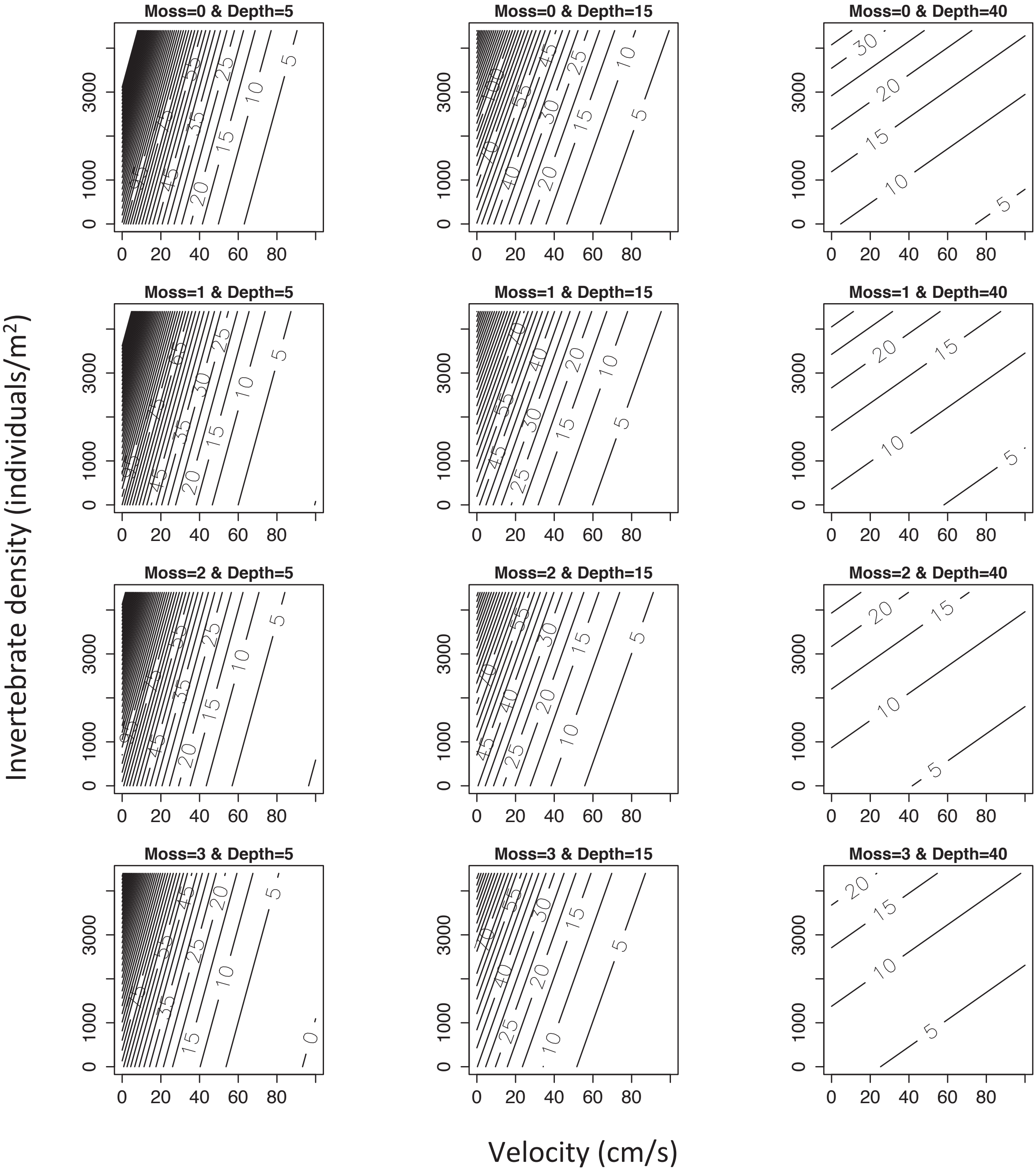


Figure A1. Prediction contour plots of the most supported 0+ density model (Table 18), with type of restoration measure, for 2011 and 2013.

Appendix 6. Parameter table of the most supported 0+ growth model, with type of measure. For 2008, 2011 and 2013.

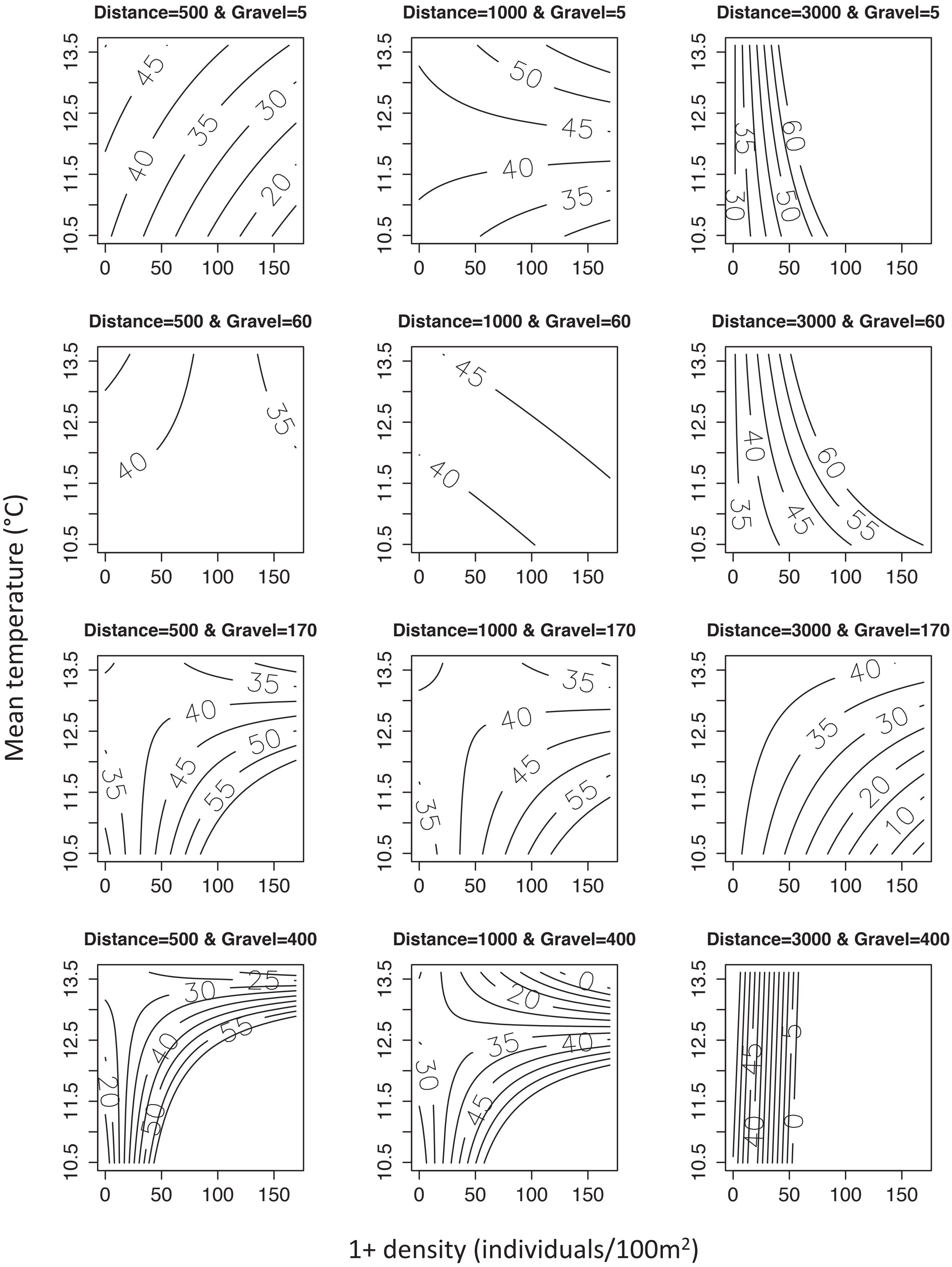
Table A1. Parameter estimates for the most supported 1+ density model with restoration effects, for 2008, 2011 and 2013. Nine of the interactions are not defined because of singularities. The response variable was ln-transformed

Coefficients	Estimate	SD	t value	Pr(>|t|)
Intercept	6.88E+00	1.91E+01	3.61E-01	7.18E-01
Distance from E6	8.30E-03	2.33E-02	3.55E-01	7.23E-01
Gravel	-1.70E-01	2.83E-01	-5.99E-01	5.49E-01
1+ density	-4.25E-01	1.01E+00	-4.23E-01	6.72E-01
Mean temperature	3.52E+00	1.59E+00	2.21E+00	2.72E-02
Riparian modifications	-1.28E+02	1.16E+02	-1.11E+00	2.67E-01
Side channel	6.59E+01	6.50E+01	1.01E+00	3.11E-01
Weirs	-1.58E+02	8.01E+02	-1.97E-01	8.44E-01
Distance from E6 * Gravel	5.79E-05	3.00E-04	2.02E-01	8.40E-01
Distance from E6 * 1+ density	-2.00E-04	1.00E-03	-1.94E-01	8.46E-01
Gravel * 1+ density	1.71E-02	1.37E-02	1.25E+00	2.12E-01
Distance from E6 * Mean temperature	-1.30E-03	2.00E-03	-6.44E-01	5.20E-01
Gravel * Mean temperature	6.00E-03	2.31E-02	2.57E-01	7.97E-01
1+ density * Mean temperature	1.13E-02	8.27E-02	1.37E-01	8.91E-01
Distance from E6 * Riparian modifications	5.59E-02	5.23E-02	1.07E+00	2.85E-01
Distance from E6 * Side channel	-6.10E-02	5.25E-02	-1.16E+00	2.45E-01
Distance from E6 * Weirs	4.44E-02	2.20E-01	2.02E-01	8.40E-01
Gravel * Riparian modifications	3.28E-01	9.05E-01	3.63E-01	7.17E-01
Gravel * Side channel	-2.36E+00	2.04E+00	-1.16E+00	2.47E-01
Gravel * Weirs	1.05E+00	4.80E+00	2.18E-01	8.28E-01
1+ density * Riparian modifications	7.01E+00	9.77E+00	7.18E-01	4.73E-01
1+ density * Side channel	-6.09E+00	5.53E+00	-1.10E+00	2.71E-01
1+ density * Weirs	2.36E-01	5.54E+00	4.30E-02	9.66E-01
Mean temperature * Riparian modifications	8.24E+00	8.66E+00	9.52E-01	3.42E-01
Mean temperature * Side channel	-7.08E+00	6.11E+00	-1.16E+00	2.47E-01
Mean temperature * Weirs	5.14E-01	4.50E+00	1.14E-01	9.09E-01
Distance from E6 * Gravel * 1+ density	-5.74E-06	9.97E-06	-5.75E-01	5.65E-01
Distance from E6 * Gravel * Mean temperature	3.26E-07	2.38E-05	1.40E-02	9.89E-01
Distance from E6 * 1+ density * Mean temperature	4.06E-05	8.54E-05	4.75E-01	6.35E-01
Gravel * 1+ density * Mean temperature	-1.20E-03	1.10E-03	-1.07E+00	2.84E-01
Distance from E6 * Gravel * Riparian modifications	-2.00E-04	5.00E-04	-3.28E-01	7.43E-01
Distance from E6 * Gravel * Side channel	7.00E-04	1.00E-03	6.71E-01	5.03E-01
Distance from E6 * Gravel * Weirs	-3.00E-04	1.30E-03	-2.45E-01	8.06E-01
Distance from E6 * 1+ density * Riparian modifications	-3.20E-03	4.30E-03	-7.37E-01	4.62E-01
Distance from E6 * 1+ density * Side channel	5.80E-03	3.60E-03	1.61E+00	1.07E-01
Distance from E6 * 1+ density * Weirs	-5.87E-05	1.60E-03	-3.60E-02	9.71E-01
Gravel * 1+ density * Riparian modifications	-5.30E-02	8.43E-02	-6.28E-01	5.30E-01
Gravel * 1+ density * Side channel	5.30E-02	1.20E-01	4.42E-01	6.59E-01
Gravel * 1+ density * Weirs	NA	NA	NA	NA

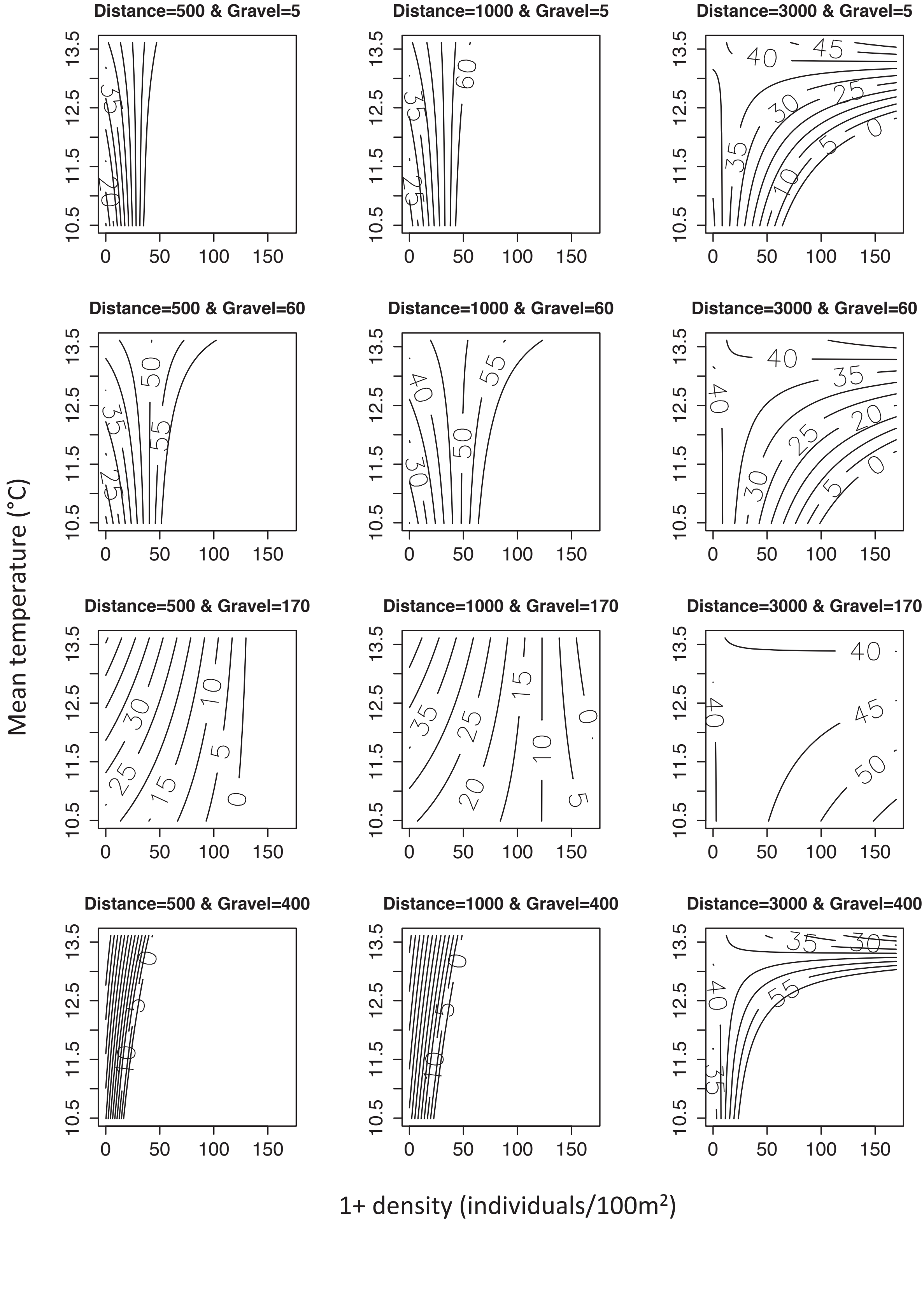
Distance from E6 * Mean temperature * Riparian modifications	-3.50E-03	4.10E-03	-8.40E-01	4.01E-01
Distance from E6 * Mean temperature * Side channel	6.40E-03	4.90E-03	1.31E+00	1.90E-01
Distance from E6 * Mean temperature * Weirs	NA	NA	NA	NA
Gravel * Mean temperature * Riparian modifications	-1.14E-02	7.11E-02	-1.61E-01	8.73E-01
Gravel * Mean temperature * Side channel	2.09E-01	1.81E-01	1.16E+00	2.47E-01
Gravel * Mean temperature * Weirs	NA	NA	NA	NA
1+ density * Mean temperature * Riparian modifications	-4.55E-01	7.18E-01	-6.34E-01	5.26E-01
1+ density * Mean temperature * Side channel	5.95E-01	5.23E-01	1.14E+00	2.55E-01
1+ density * Mean temperature * Weirs	NA	NA	NA	NA
Distance from E6 * Gravel * 1+ density * Mean temperature	2.75E-07	8.16E-07	3.37E-01	7.36E-01
Distance from E6 * Gravel * 1+ density * Riparian modifications	2.56E-05	3.34E-05	7.65E-01	4.45E-01
Distance from E6 * Gravel * 1+ density * Side channel	-1.95E-05	5.56E-05	-3.51E-01	7.26E-01
Distance from E6 * Gravel * 1+ density * Weirs	NA	NA	NA	NA
Distance from E6 * Gravel * Mean temperature * Riparian modifications	6.36E-06	4.43E-05	1.44E-01	8.86E-01
Distance from E6 * Gravel * Mean temperature * Side channel	-7.39E-05	9.40E-05	-7.86E-01	4.32E-01
Distance from E6 * Gravel * Mean temperature * Weirs	NA	NA	NA	NA
Distance from E6 * 1+ density * Mean temperature * Riparian modifications	2.00E-04	3.00E-04	6.18E-01	5.37E-01
Distance from E6 * 1+ density * Mean temperature * Side channel	-5.00E-04	3.00E-04	-1.62E+00	1.07E-01
Distance from E6 * 1+ density * Mean temperature * Weirs	NA	NA	NA	NA
Gravel * 1+ density * Mean temperature * Riparian modifications	3.40E-03	6.20E-03	5.42E-01	5.88E-01
Gravel * 1+ density * Mean temperature * Side channel	-6.20E-03	1.10E-02	-5.62E-01	5.75E-01
Gravel * 1+ density * Mean temperature * Weirs	NA	NA	NA	NA
Distance from E6 * Gravel * 1+ density * Mean temperature * Riparian modifications	-1.60E-06	2.48E-06	-6.46E-01	5.19E-01
Distance from E6 * Gravel * 1+ density * Mean temperature * Side channel	2.86E-06	5.20E-06	5.50E-01	5.83E-01
Distance from E6 * Gravel * 1+ density * Mean temperature * Weirs	NA	NA	NA	NA

Appendix 7. Figure of the most supported 0+ growth model, with type of measure. For 2008, 2011 and 2013.

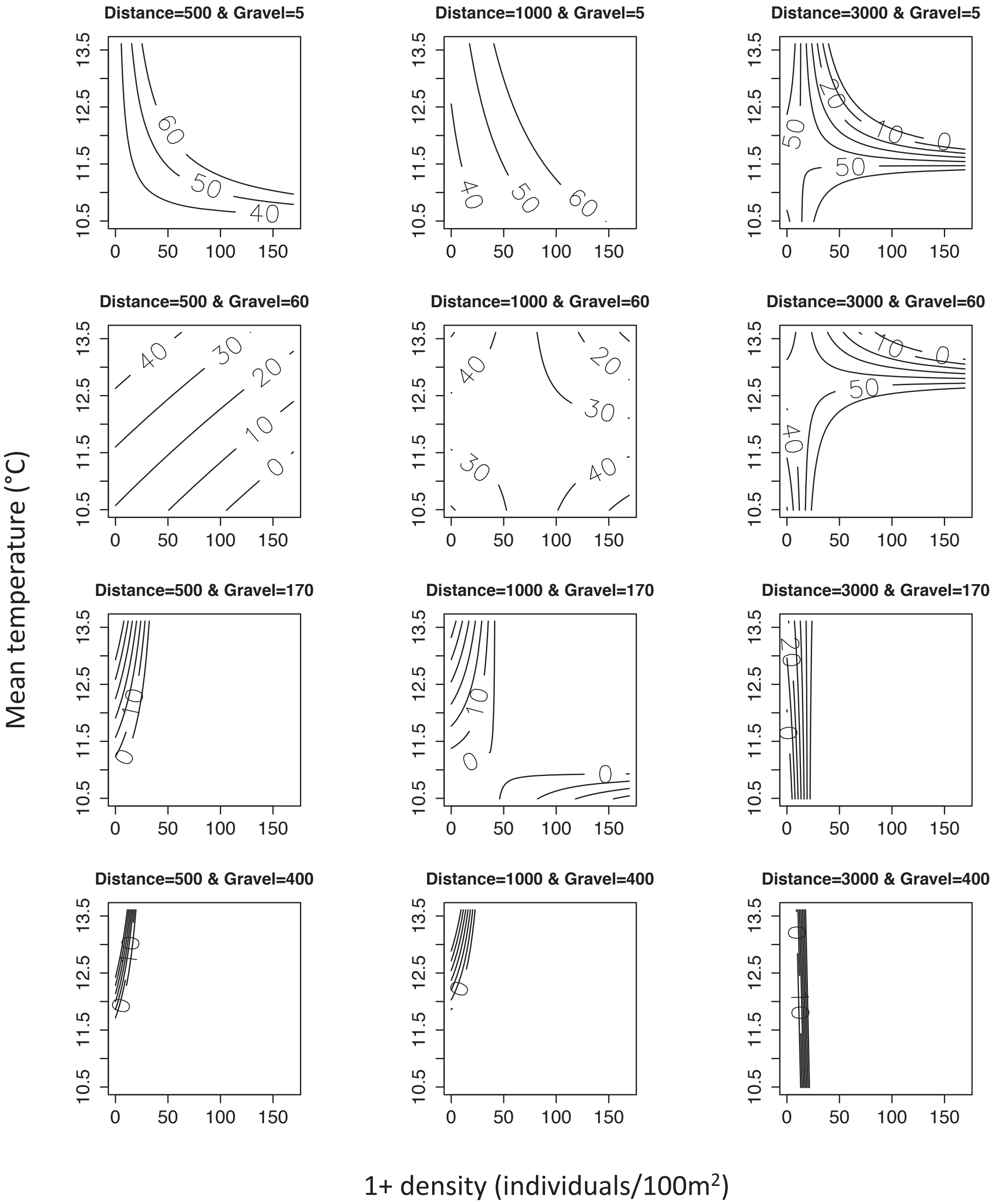
No measure



Riparian modifications



Side channels



Weirs

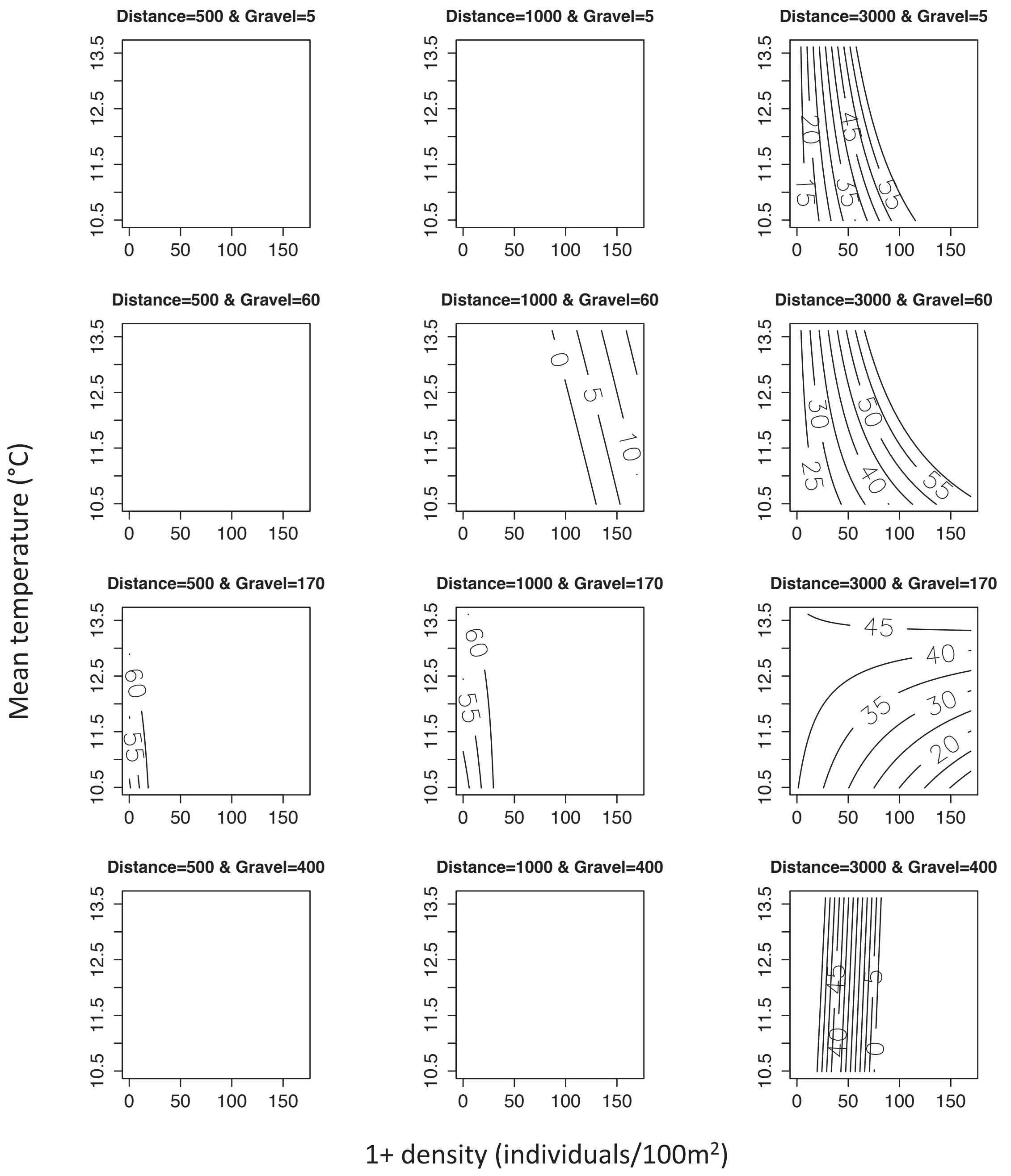
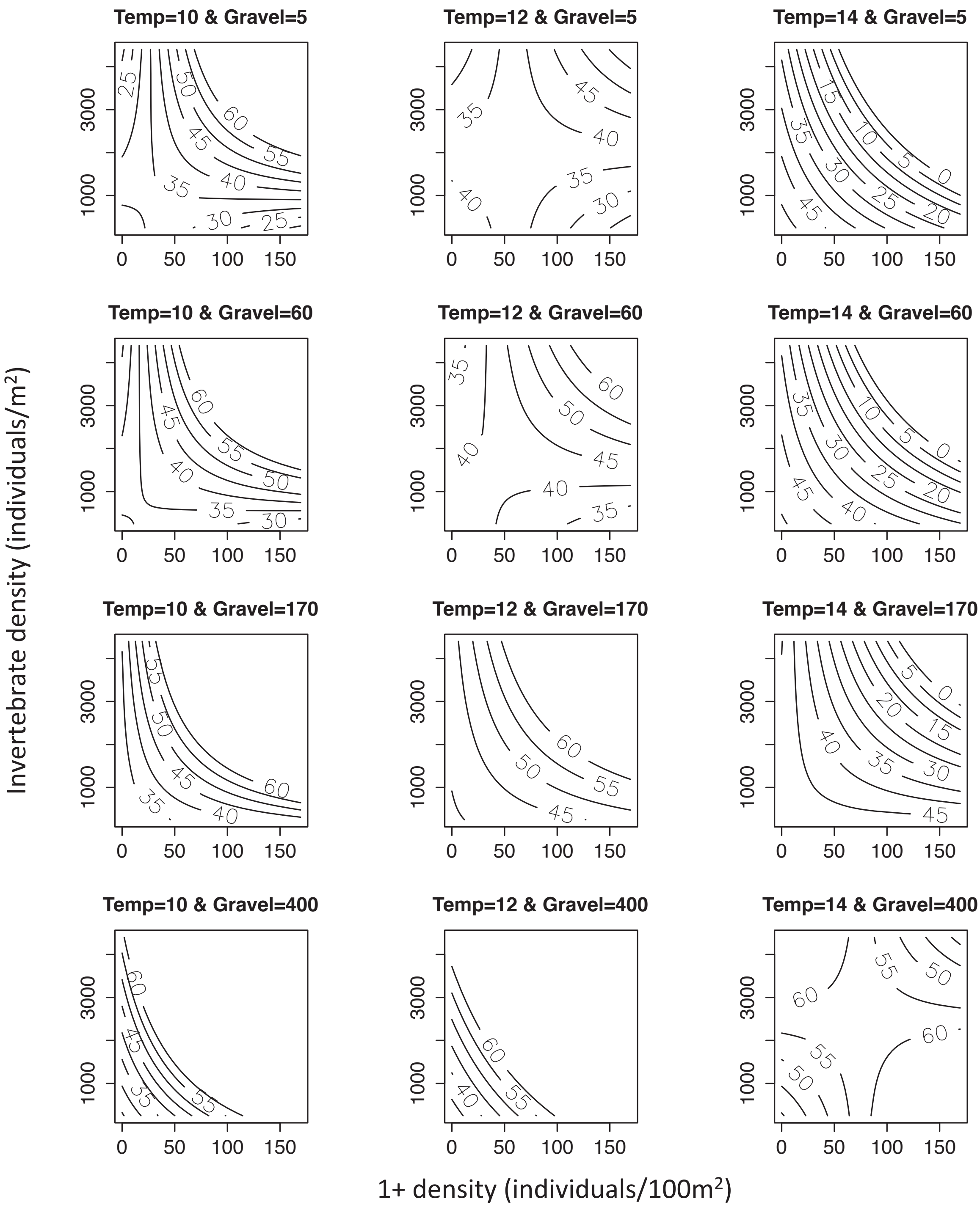


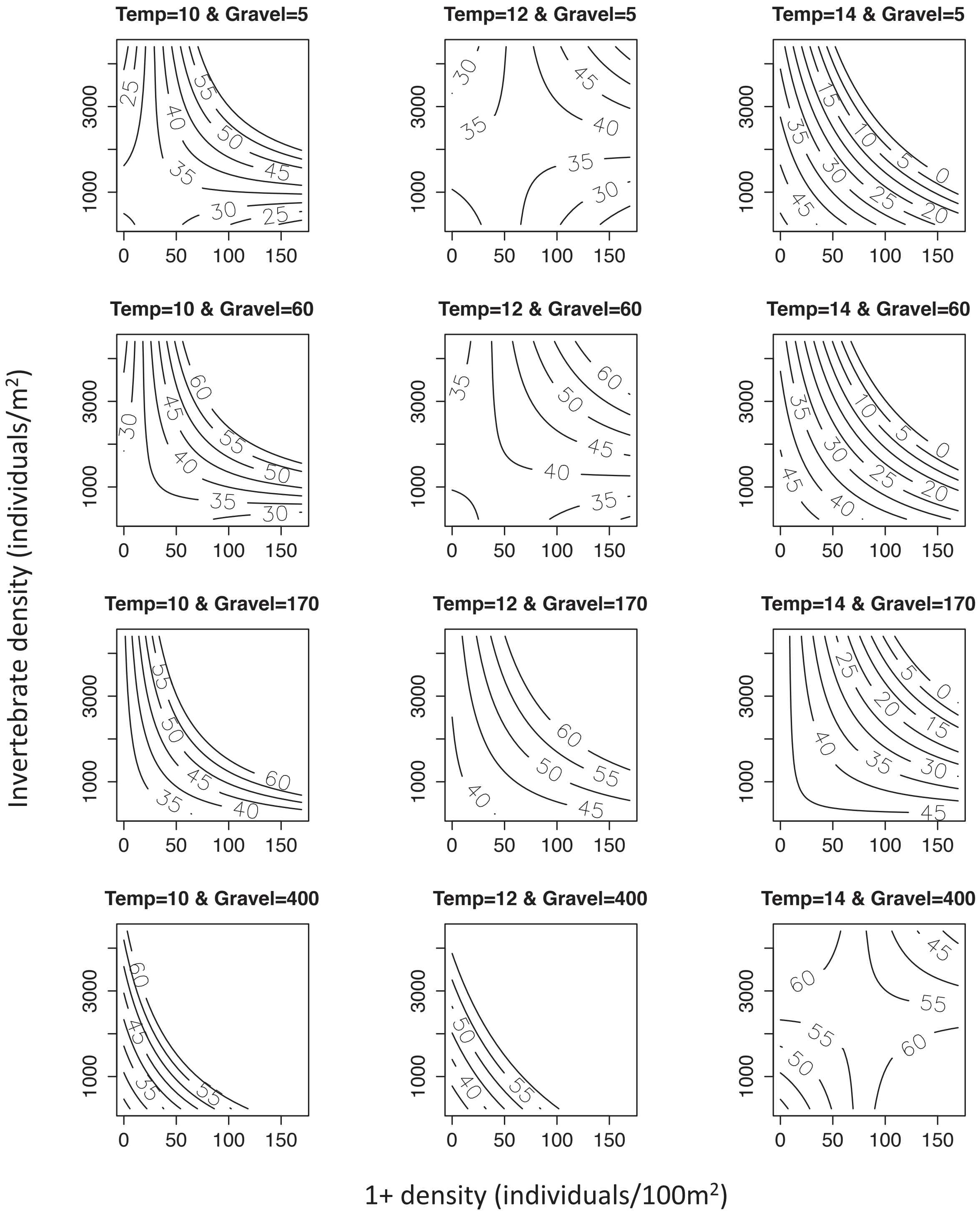
Figure A2. Prediction contour plots of the most supported 0+ density model (Table A1), with the different restoration measures, for 2008, 2011 and 2013.

Appendix 8. Figure of the most supported 0+ growth model, with time since first restoration measure. For 2011 and 2013.

Channelized sections



Four years since first restoration measure



Seven years since first restoration measure

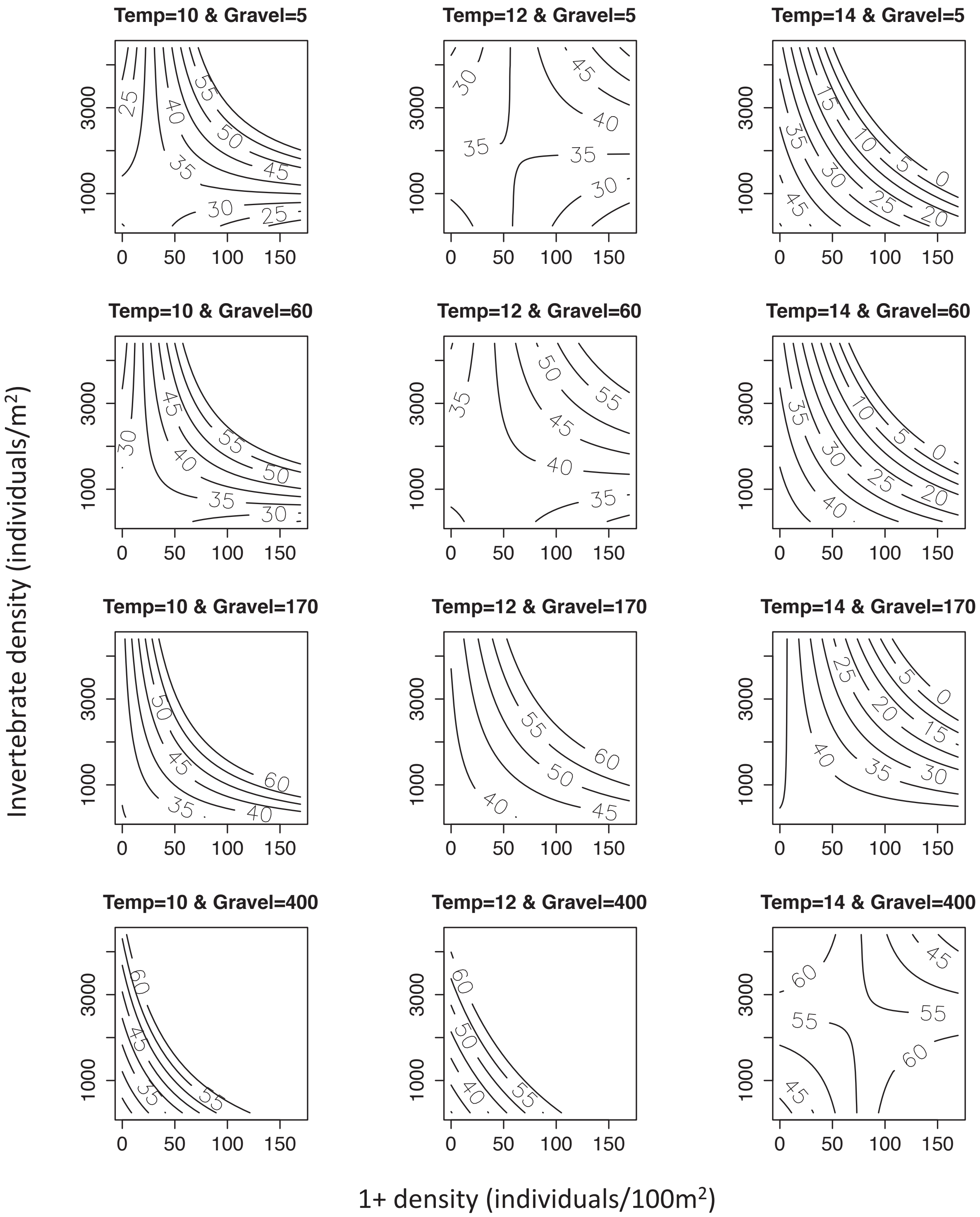


Figure A3. Prediction contour plot of the most supported 0+ growth model (Table 19), with time since first restoration measures, for 2011 and 2013.

Appendix 9. Parameter table for the most supported model explaining macroinvertebrate density.

Table A2. Parameter estimates for the most supported model explaining macroinvertebrate density. The response variable was ln-transformed. *** indicates a significance level of p>0.001. Two of the interactions are not defined because of singularities. Sustainability spawning category 1: bad, category 2: ok, category 3: good.

Coefficients	Estimate	SD	t value	Pr(>|t|)
Intercept	6.8250	0.2768	24.6530	***
Suitability spawning (cat.2)	-0.2460	0.5073	-0.4850	0.6294
Suitability spawning (cat.3)	0.1282	2.1400	0.0600	0.9524
Gravel	-0.0003	0.0012	-0.2410	0.8105
0+ density	-0.0111	0.0095	-1.1690	0.2466
Year 2013	-0.9789	0.4635	-2.1120	0.0385
Suitability spawning (cat.2) * Gravel	0.0008	0.0057	0.1440	0.8860
Suitability spawning (cat.3) * Gravel	0.0037	0.0310	0.1180	0.9065
Suitability spawning (cat.2) * 0+ density	0.0052	0.0126	0.4130	0.6813
Suitability spawning (cat.3) * 0+ density	0.0192	0.0314	0.6100	0.5438
Gravel * 0+ density	0.0001	0.0001	1.2060	0.2321
Suitability spawning (cat.2) * Year 2013	0.6459	0.7305	0.8840	0.3798
Suitability spawning (cat.3) * Year 2013	1.1530	2.1040	0.5480	0.5857
Gravel * Year 2013	-0.0782	0.0100	-7.8140	***
0+ density * Year 2013	0.3595	0.0615	5.8490	***
Suitability spawning (cat.2) * Gravel * 0+ density	0.0000	0.0001	-0.1090	0.9132
Suitability spawning (cat.3) * Gravel * 0+ density	-0.0002	0.0005	-0.4220	0.6744
Suitability spawning (cat.2) * Gravel * Year 2013	0.0800	0.0128	6.2390	***
Suitability spawning (cat.3) * Gravel * Year 2013	0.0752	0.0318	2.3650	0.0210
Suitability spawning (cat.2) * 0+ density * Year 2013	-0.3347	0.0468	-7.1450	***
Suitability spawning (cat.3) * 0+ density * Year 2013	-0.3167	0.0518	-6.1130	***
Gravel * 0+ density * Year 2013	-0.0001	0.0004	-0.1480	0.8825
Suitability spawning (cat.2) * Gravel * 0+ density * Year 2013	NA	NA	NA	NA
Suitability spawning (cat.3) * Gravel * 0+ density * Year 2013	NA	NA	NA	NA

Appendix 10. Parameter table for the multinomial EPT-species and Chironomidae model.

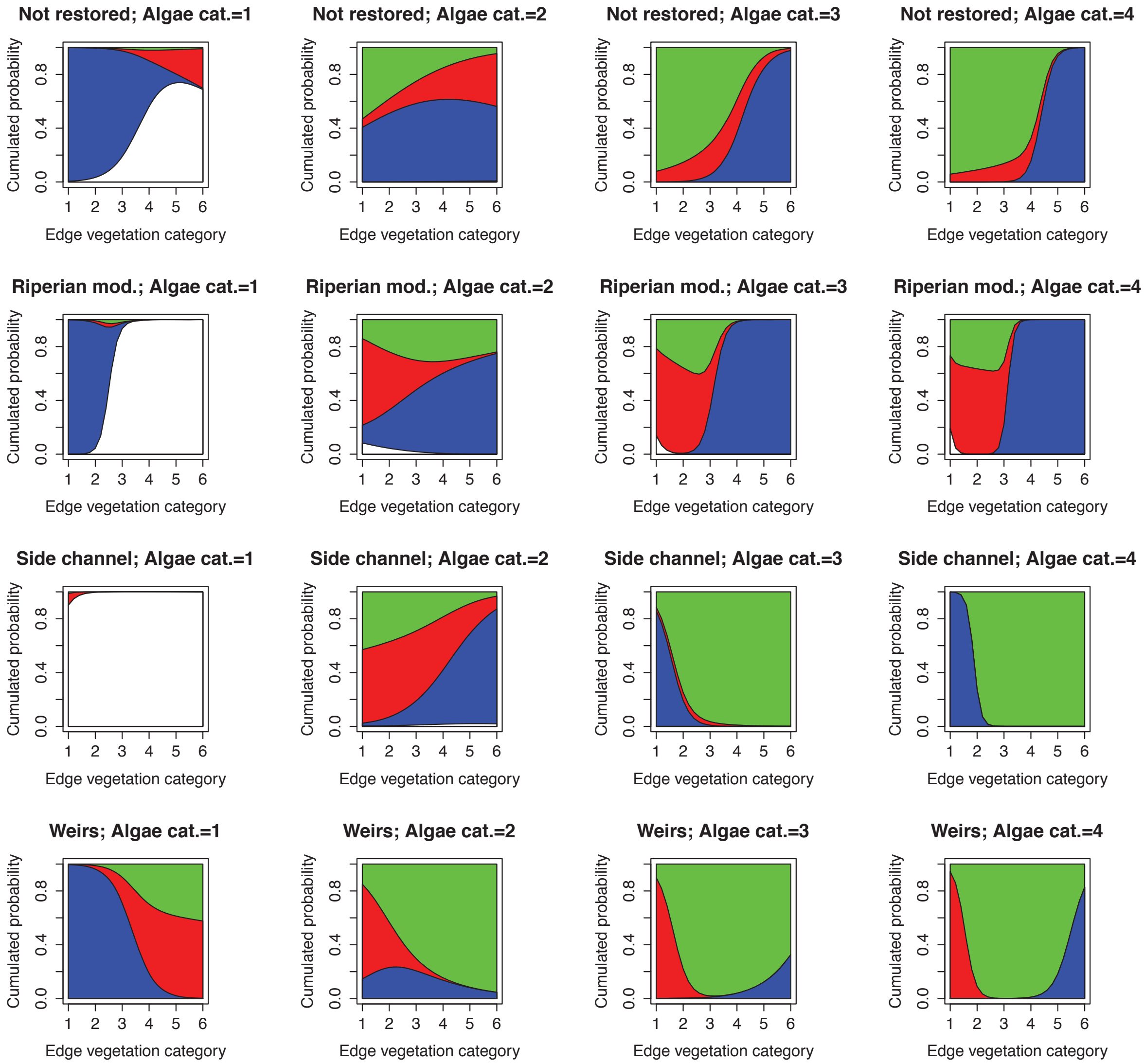
Table A3. Coefficients and standard deviation parameters, to describe the cumulated composition of the EPT- species and Chironomidae, for the most supported multinomial model. Caddisflies were not included in the parameters, as few were counted.

	Coefficients			SD		
	Chironomidae	Mayflies	Stoneflies	Chironomidae	Mayflies	Stoneflies
Intercept	14.4364	-9.2295	-4.8227	1.9151	2.0538	1.7846
Riparian modifications	28.5214	0.7986	-15.0445	0.8314	0.8832	0.8771
Side channel	-37.1146	10.3555	9.4582	1.6298	1.8321	1.5976
Weirs	1.3245	1.9466	1.2589	0.1212	0.1746	0.1194
Edge vegetation	-5.5574	-0.3299	-2.0009	1.2688	1.2990	1.2693
Algae	-3.8840	7.0540	6.8466	1.3977	1.5208	1.4228
Canopy riverside	-6.6283	-3.5777	-5.2268	2.9137	2.9931	2.9373
Riparian modifications * Edge vegetation	-13.4315	-3.3050	2.4986	1.2121	1.2713	1.3902
Side channel * Edge vegetation	3.0336	-10.2909	-13.5065	1.2922	1.3455	1.3241
Weirs * Edge vegetation	1.4978	1.8601	1.9110	0.0650	0.1028	0.0656
Riparian modifications * Algae	-19.6280	-2.9403	1.3812	1.6094	1.6218	1.6344
Side channel * Algae	14.6526	-4.6580	-7.0494	1.8218	1.8627	1.7712
Weirs* Algae	2.9892	3.8114	2.7769	0.2102	0.3041	0.2084
Edge vegetation * Algae	2.5969	0.0834	0.3411	0.7273	0.7423	0.7281
Riparian modifications * Canopy riverside	-4.4187	22.4734	31.5413	0.9882	1.0955	1.1097
Side channel * Canopy riverside	0.4747	-1.8662	-4.6976	1.6319	1.4098	1.3399
Weirs * Canopy riverside	0.3533	1.0851	0.2981	0.1240	0.1795	0.1210
Edge vegetation * Canopy riverside	2.1034	1.5311	1.9453	0.4150	0.4880	0.4278
Algae * Canopy riverside	3.2568	1.5399	1.8684	1.8290	1.8600	1.8382
Riparian modifications * Edge vegetation * Algae	8.1687	2.1989	0.5364	0.8283	0.8444	0.8541
Side channels * Edge vegetation * Algae	-0.9602	4.6322	6.9764	0.6689	0.6973	0.6720
Weirs * Edge vegetation * Algae	4.3560	3.3930	4.8580	0.2425	0.3632	0.2339
Riparian modifications * Edge vegetation * Canopy riverside	3.0580	-5.3150	-8.1731	0.9449	0.9585	0.9567
Side channels * Edge vegetation	2.4305	3.2318	5.0537	0.6746	0.6403	0.6094

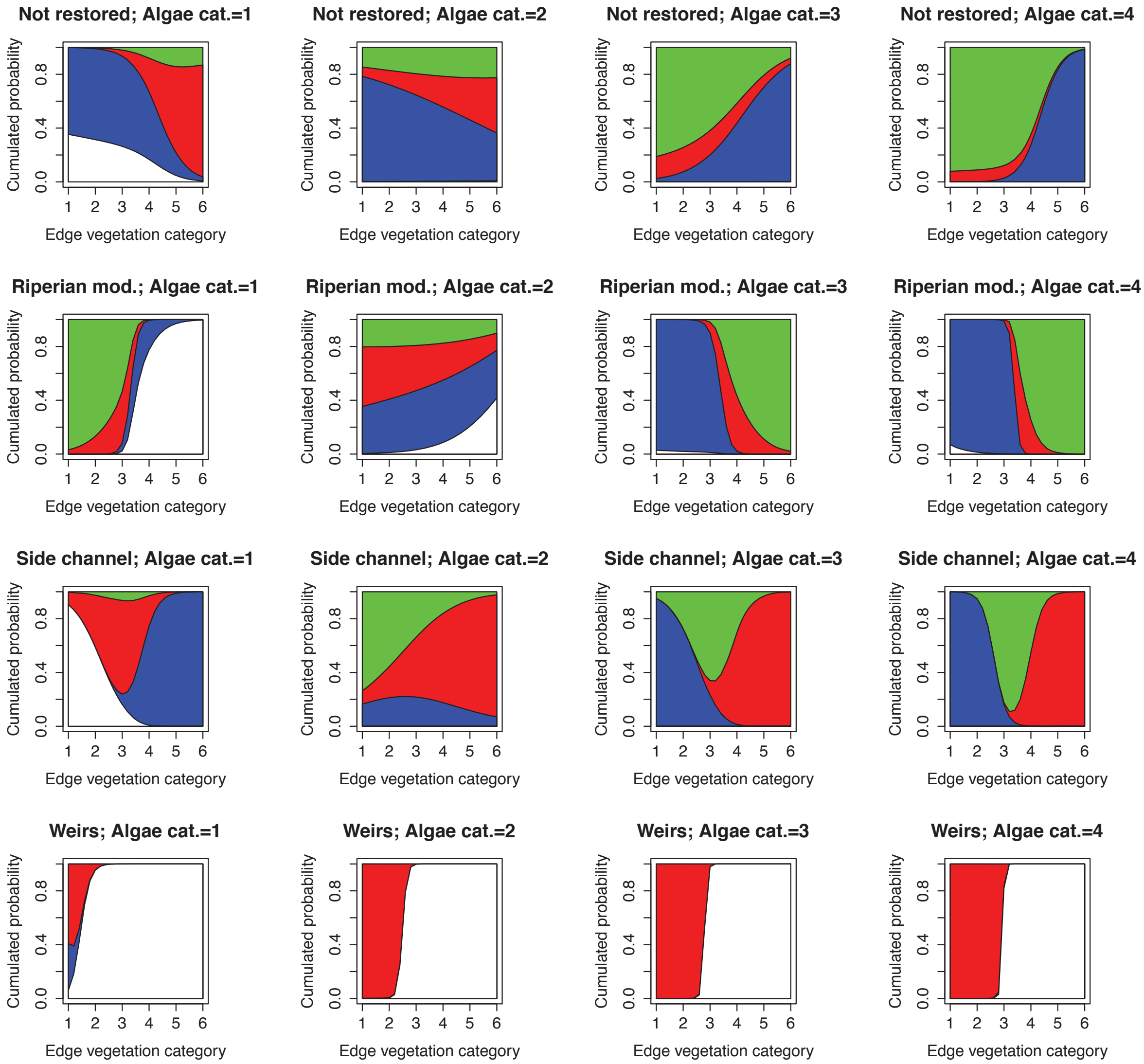
* Canopy riverside						
Weirs * Edge vegetation * Canopy riverside	-2.3873	-1.5861	-1.9322	0.0811	0.1116	0.0850
Riparian modifications * Algae * Canopy riverside	3.8410	-9.9755	-13.6273	0.7397	0.7610	0.7700
Side channel * Algae * Canopy riverside	1.3479	1.3430	4.0633	1.6513	1.4901	1.4808
Weirs * Algae * Canopy riverside	1.3247	2.2957	0.8972	0.2741	0.4053	0.2694
Edge vegetation * Algae * Canopy riverside	-1.0619	-0.7234	-0.7827	0.2694	0.2982	0.2741
Riparian modifications * Edge vegetation * Algae * Canopy riverside	-2.0966	2.2644	3.3436	0.4886	0.4952	0.4882
Side channel * Edge vegetation * Algae * Canopy riverside	-1.4204	-1.4468	-2.7494	0.7004	0.6759	0.6706
Weirs * Edge vegetation * Algae * Canopy riverside	-2.3019	-2.6699	-2.6607	0.0720	0.0969	0.0724

Appendix 11. Figure of the multinomial EPT-species and Chironomidae model

Canopy riverside = category 1.



Canopy riverside = category 3.



Canopy riverside = category 5.

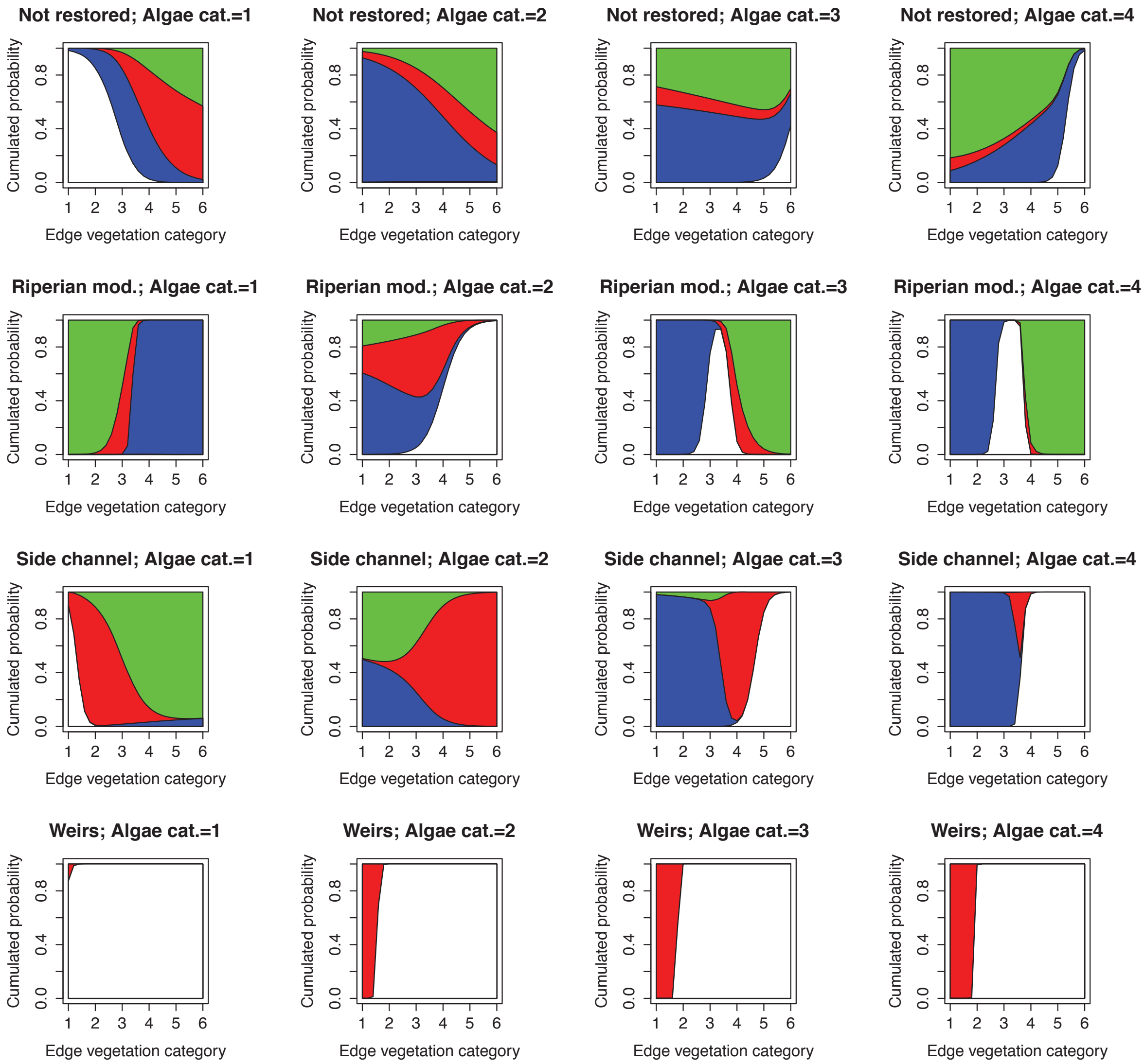


Figure A4. The cumulative probability composition of the most supported multinomial model (Table A3) for EPT-species and Chironomidae. Red is mayflies, green is stoneflies, white is caddisflies, and blue is Chironomidae. Riparian mod. = Riparian modifications. Algae cat. = Algae category.

Norwegian University
of Life Sciences

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