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Do juvenile densities in the river Bognelv experience density dependency after river restoration and do the reopened side channel function as suitable nursing areas for juvenile brown trout (*Salmo* trutta)

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Preface

This master thesis is written at Faculty of Environmental Science and Natural Management at the Norwegian University of Life Sciences. This is a 60 credits thesis and the final part of my master degree in Nature management.

I wish to thank my supervisors, Thrond Haugen for help with motivation, statistics, license and documentation from the government to do the project and writing prosses, and Jonathan Colman for help with choosing a project, motivation, ideas, the writing prosses and logistics considering the fieldwork, despite difficulties considering the corona situation. Further, Maja Bernhoff needs an acknowledgment for her contribution to my fieldwork and as a good friend. In addition, I wish to thank Ivar Mikalsen and his family for their hospitality when lending me their house and I wish to thank Ole Magnus Rapp for his hospitality for borrowing his cabin at Altafjord camping. Additionally, I wish to thank Finnmark county for founding resources, and Anders Bjørdal at The Norwegian Water Resources and Energy Directorate for unbar the information in Bognelv. Many other have also contributed to this thesis; like my family, friends and fellow students and employs at Norwegian University of Life Sciences. I wish to thank them all, and especially Benjamin, my brother Magnus, my sisters Emma, my friends Ida and Viktoria, my friends and fellow students Tonje and Eleanor. Thanks for taking my crap. I believe its in its place considering the corona situation.

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Abstract

The are still uncertainties today about the biological effectiveness considering river restoration practise, despite the long history contributing to the amount of literature and founding resources found on this topic. This highlights the important for investigation to understand why. A restoration project that is still ongoing is the project in river Bognelv in Northern Norway. Bognelv was canalized to favour agricultural land use and flood control and restoration in favour of salmonids started in 2006. Several master theses have studied Bognelv. Their main findings were an increase in the brown trout population and that measure side channel are the most responsive measure conducted in Bognelv.

This master thesis is an extension of the research conducted in Bognelv. The theory is that side channels in Bognelv are function as suitable nursing areas for juvenile brown trout. This thesis is testing if the abundance of brown trout has increased since before restoration, and the theory about suitable nursing areas for juvenile brown trout. This was done by comparing side channel against main channel in the analysis.

The abundance of brown trout has increased since before restoration, but a stabilization is appearing. There was no detected density dependent survival in either measures. It appears that side channel is more adapted as a nursing area when analysing the environmental data. There was no foundation on comparison between side channel and main channel when looking at the survival probability due to the lack of estimated parameter. It appears that dispersal in main channel are occurring with low densities, which indicates that the environmental conditions in main channel are poor and not favoured by juvenile brown trout. Lastly, the recapture probability is probably influenced by the drought episode. Generally, side channel appears more adapted as a suitable nursing area, but the representativity are compromised due to drought.

Why no density dependence occurred emphasise the importance of continuing the research in Bognelv. Perhaps other life stadium in brown trout life cycle should be studied for knowing the reason why no density dependent survival occurred.

Sammendrag

Det eksister ennå usikkerheter rundt den biologiske effektivitet rundt elverestaurering, til tross for mengden litteratur og finansiering som eksister oppgjennom historien. Dette setter lys på viktigheten forskning har for å forstå hvorfor det er slik. Et restaurerings prosjekt som pågår er prosjektet i Bognelv i Nord-Norge. Bognelv ble kanalisert i favør for landbruk og flom demping, og startet restaurering med tanke på laksefisk i 2006. Flere masteroppgaver har studert Bognelv. Felles funn for alle masteroppgaver er en økning i ørret populasjonen, og at sidekanaler viser seg å være det mest responsive tiltaket utført i Bognelv.

Denne masteroppgaven er en utvidelse av forskningen som er utført i Bognelv. Generelt er teorien er at sidekanaler i Bognelv skal fungere som egnete oppfostringsområder for ungfisk av ørret. Denne masteroppgaven tester om det er en økning i ørret populasjonen sett i forhold til før restaurering startet, og om teorien om egnete oppfostringsområder for ungfisk er overførbar. Dette ble gjort med å sammenligne sidekanaler opp mot hovedløpet i analysene.

Mengden ørret har økt siden før restaurering startet, men det ser ut til at det er en stabilisering av populasjonen. Det ble ikke funnet noen tetthetsavhengig overlevelse i noen av tiltakene. Det ser ut til at sidekanaler er mer tilpasset om egnet oppfostringsområde for ungfisk når en analyserer miljø dataene. Det er ikke mulig å sammenligne sidekanaler og hovedløp når en ser på overlevelses sannsynligheten på grunn av manglende estimert parameter. Det ser ut til at forflytting skjer ved lave tettheter i hovedløpet, noe som indikerer at habitatet i hovedløpet er lite favorisert av ungfisk. Tilslutt, er nok gjenfangst sannsynligheten påvirket av tørke episoden som rådde. Generelt virker det som at sidekanalene er mer tilpasset som egnet oppfostringsområdet for ungfisk, men representativiteten er svekket på grunn av tørke episoden.

Hvorfor ingen tetthetsavhengighet forekommer, understreker viktigheten av å fortsette forskingen i Bognelv. Mulig andre livs stadier i ørretens livssyklus burde bli studert for å forstå hvorfor ingen tetthetsavhengig overlevelse oppsto.

1. INNHOLD

1 INTRODUCTION

Loss and degradation of habitat and ecosystem worldwide is a great problem, and in order to ensure the habitat diversity and biodiversity scientists, politicians, managers and stakeholders are all contributing to restoration of lost or degraded habitat and ecosystems (Perimack and Sher, 2016). River restoration is one of the oldest forms of ecological restoration and dates back hundreds of years (Roni, 2019). River restoration is a management process which focuses on the rehabilitation of degraded river ecosystems (including hydrologic, geomorphic, biological and ecological processes) caused by human activities (Benayas, 2009, Wohl et al., 2005, Wohl et al., 2015). Wohl et al. (2005, 2015) stated that river restoration, as most nature management projects, is a social process were science is involved to varying degrees. This means that river restoration involves input from managers, politicians, stakeholders and scientists. There is a lack of long-term monitoring of restoration projects worldwide. This is often due to the lack of delegating monitoring responsibilities in restoration projects, as well as the lack of established usable and robust methodology for monitoring the pre- and post-restoration effects (Wohl et al., 2005). There are still uncertainties today about the biological effectiveness of river restoration projects (Stewart et al., 2009, Wohl et al., 2015, Roni, 2019) despite the long history of economic investments in monitoring projects and literature contributions on the topic of river restoration.

Salmonids have attained particular attention when it comes to restoration and habitat improvement (Roni, 2019), mostly because of their economic value, especially in Norway (Miljødirektoratet, 2020). In Sweden, Nilsson et. al. (2017) investigated the abiotic and biotic responses before and after the restoration had taken place in the canalized Vindel river, and used salmonids as one of the indicators. They did not detect any biotic response and argued that the reasons for this was that the study was short-term. Bernhardt and Palmer (2011) discuss this topic of study period. They highlight and question today’s restoration practice. They state that short-term studies often lack documentation of the desired response, because such responses are often not easy to detect after a short period (Bernhardt and Palmer, 2011). However, long-term studies where responses on the salmonid abundance after restoration measures are detected do exists (White et al., 2011, Pierce et al., 2013, Louhi et al., 2016). In order to gain knowledge about the success of the restoration project, one needs to set clear measurable goals and ensure long-term studies to evaluated the success, as most river systems and restoration project differs greatly (Wohl et al., 2005, 2015).

In Norway river restoration started in the 1900s. Mostly biotope adjusting measures in regulated watercourses meant for power production were implemented then to ensure fish production, erosion control and ecological processes (Hagen and Skrindo, 2010). A study that is still ongoing, is the restoration project of the river Bognelv in Northern Norway. This project started as a pioneer project for The Norwegian Water Resources and Energy Directorate in 2005 (Hoseth and Josefsen, 2005). During 1950s and 60s, Bognelv was canalized to favour agricultural land use and flood control (Hoseth and Josefsen, 2005). This resulted in a decrease in salmonid abundance (including brown trout (*Salmo trutta*), Atlantic salmon (*Salmo salar*) and Artic charr (*Salvelinus alpinus*)), and restoration measures have been implemented to improve this situation (Hoseth, 2008b, Hoseth, 2008a, Hoseth, 2010, Hoseth, 2013, Bjordal, 2019). They created pools and stone groups in the main channel, and some of the erosion prevention constructions from the canalization was removed. Some of the previous main channel closed by the canalization was reopened as side channels. Generally, the river is still mostly straight, but with reopened side channels and supposedly improved erosion and sediment transport.

Previous master theses have studied Bognelv and measured juvenile densities in restored and unrestored areas (Schedel, 2010, Austvik, 2012, Sødal, 2014, Nordhov and Paulsen, 2016). Schedel (2010) found that the most positive restoration measure conducted in Bognelv was the reopened side channels and tributaries, and the abundance of salmonids had increased compared to before restoration. In addition, Austvik (2012) found that there was a tendency of increasing densities since before restoration and that the results indicated that side channels were important structures in the system. Furthermore, Sødal (2014) found that the highest densities were found in the most diverse habitat, but did not detect differences in densities between side channels and main channel. In addition Sødal (2014) detected fluctuations in 0+ densities as a result of density dependence. Lastly, Nordhov and Paulsen found that the highest densities were found in areas with weirs and riparian vegetation and lower in the side channels and tributaries compared to the main channel. Common for all previous theses was the consistent, positive increase in overall brown trout juvenile density after restoration measures were implemented.

Keystone approaches are well discussed in the field of restoration, and represent structures or objects that provide causal elements to the success of a study (Wohl et al., 2015). In this restoration project, side channels, pools and stone groups are such keystones. Pools and stone groups are meant to provide more water velocity variance in the system, while side channels are meant to be production sites or "hot-spots" for juvenile fish. In a study from Finland, Louhi et. al. (2016) detected that the restored areas had an increased density of juveniles compared to unrestored areas. They stated that the increase was not significant, and one reasons explaining this was that the area where the river is located was unproductive. Either way, Roni (2019) debated if the increasing fish densities are a product of increased survival or a concentration of fish, hence "hot-spots". He stated that no study is looking at multiple sections of a river, and concluded that it appears that restoration might influence different sections differently. Such density "hot-spots" might be created in Bognelv with the re-opening of side channels, and function on the foundation that juvenile brown trout are territorial (Elliott, 1990, Elliott, 2002). The basis of this is that side channels are meant to be suitable nursing areas for juvenile brown trout and then contribute to other parts in the river through dispersal. Such side channels need to provide shelter from predation and drought, stable food resources and suitable spawning sites (Jonsson and Jonsson, 2011). When the carrying capacity in the side channels peaks, intraspecific competition between juveniles (as a result of the juveniles' territorial behaviour) will result in dispersal from the side channel to main channel in order to ensure individual survival (Elliott, 1990).

Bognelv has since the first restoration measure were implemented in 2005 had time to settle, while also new measures have been implemented almost every other year until 2019. This provided an interesting system to study, and test where in the river salmonid abundance (brown trout in particular) increased. This is the first aim of this master thesis. Sødal (2014) stated that partially restoration could be enough to achieve the biological goal of increasing fish abundance, and it makes it interesting to study if this applies to side channels as "hot-spots" in Bognelv. Furthermore, this master thesis is a continuation of the research in Bognelv focusing on brown trout, but not a direct follow-up study from previous years. The specific theory this master thesis is testing is that the side channel should provide suitable nursing habitat for brown trout. In order to test if side channels are providing suitable nursing habitat for juvenile brown trout, I compared the juvenile densities and environmental variables from earlier studies, tested the probability of dispersal, survival and recapture in the reopened side channels and compared this to the dispersal, survival and recapture probability in the main channel. Several hypotheses were drafted and presented in table 1. Lastly, the second aim with this master thesis was to contribute new knowledge about whether side channels provide suitable nursing habitat for juvenile brown trout and if partially restoration is enough to ensure biological goals as Sødal (2014) claimed.

Table 1 Hypotheses for this study from the river Bognelv.

The hypotheses for this thesis were:
1. If the abundance of brown trout is at or above the system's carrying capacity, one should detect a negative correlation between 0+ and 1+ densities of juvenile brown trout (i.e., density dependence).
2. One are detecting differences between type of measure when comparing the environmental variables, and a tendency of favourable habitat condition are more noticeable in the side channels compared to other measures, as they are meant to provide suitable nursing habitat for brown trout.
3. A lower survival rate are occurring in the side channels compared to the main channel if the side channels function as nursing areas due to density dependence.
4. If dispersal occurs, it should be driven by densities as density contributes to more competition of food resources and lower survival.
5. Lastly, if side channels are meant to be a nursing habitat, one should expect lower recapture probabilities of tagged individuals in the side channels than in the main channel, as higher densities are expected that in turn drive higher dispersal frequencies.

2 MATERIAL AND METHOD

2.1 STUDY SPECIES, BROWN TROUT (*SALMO TRUTTA*)

Brown trout is a widely distributed species, native in Europe, western Asia, and North Africa (Jonsson and Matzow, 1979, Elliott, 1994, Klemetsen et al., 2003). The species is much studied over time, and the biology of the species and distribution are well described by many researchers. For general information about the species see (Elliott, 1994, Klemetsen et al., 2003, Jonsson and Jonsson, 2011).

In their different life stages, brown trout shift habitat and food preferences (Jonsson and Jonsson, 2011). To ensure growth and survival, brown trout generally move and shift habitat as they grow and changes from egg to fry, fry to parr, and so on. Several factors contribute to these shifts in habitat. Importantly, the density dependent-survival in juvenile brown trout are the main regulator of the population density throughout the life-stages (Elliott, 1987, Elliott, 1990, Elliott, 1993, Elliott, 1994, Elliott, 2002, Jonsson and Jonsson, 2011). Normally for an ecosystem that is in balance or at it carrying capacity, a tendency for juveniles from the year before would affect the survival of the juveniles this year by supressing the emerging fry. This is a well establish theory from Elliott (1994). Many factors contribute to this tendency, like egg densities, the intraspecific competition that arise when eggs hatch, and the density of juveniles from earlier years. Importantly, this results in fluctuations in densities between years (Elliott, 1993, Elliott, 1994, Elliott, 2002). This is what I expected to occur in the side channels compared to other parts in the river if the theory that side channels are suitable nursing habitat applies.

Furthermore, a suitable nursing habitat as the side channels in this master thesis are meant to provide, should consist of shelter, pools, suitable spawning substrate, stable food resources, suitable water temperature and velocities. These factors contribute to suitable nursing areas (Elliott, 1994, Jonsson and Jonsson, 2011), and I expected to find more of these environmental variables in side channels compared to other parts of the river. There should be more variability in the side channels, including more shelter in forms of large woody debris, lower water velocities, more pools and more than in the main channel.

Organisms that are mobile are expected to choose the most profitable habitat that ensures the best probability of survival and growth, and for brown trout, growth largely depends on food consumption and temperature (Nevoux et al., 2019). Food consumption will be strongly correlated with food abundance, competition and the relationship between these. Brown trout appear to favour a dispersal that meets their energy requirements, and therefore individuals should adjust usage of available habitat and move to a more productive habitats accordingly (Nevoux et al., 2019). As Nevoux et. Al. (2019) stated in some system, lakes can provide better survival probability and migration from river to lake occurs because habitat providing better feeding opportunities are selected. The same applies for dispersal from tributaries to main channels. Survival rates are affected by many factors, including age, size, sex, density, availability of resources such as food and space, environmental factors such as temperature and oxygen concentration, parasites and diseases, abundance of predators, including human (Elliott, 1993). An important and interesting factor in this study could be reduced survival rates through density dependent survival. Therefore, since side channels in this study are meant to provide suitable nursing habitat, I expected that dispersal from side channel to main channel would be driven by density, as high densities provide lower survival rates and more competition for food. The concentration of fish should reduce the resources in the habitat located in the side channels. If this is the case for this study and dispersal is driven by density I further expected that the survival in the side channels would be lower than in the main channel.

Furthermore, based on many fish one can mark during the sampling round the recapture probability is a product of the amount of marked fish versus the recapture proportion of the marked fish. Therefore, as higher densities were expected in the side channel and the marked fish are experiencing density dependent survival, the recapture probability should be lower in the side channel compared to the main channel.

2.2 STUDY AREA

This study was conducted in the river Bognelv in Langfjordbotn, Alta municipality, Finnmark county in Norway (Figure 1). The river has its outlet in the fjord Langfjordbotn, a side fjord of Altafjorden. The catchment is 88,5 square kilometres, and most of this is above the tree line. This results in large discharge in the last part of June because of the accumulation of snow during the winter season (Hoseth and Josefsen, 2005). Bognelvdalen valley, where the river

Bognelv flows through, is a rich and productive valley. The lowest part of the valley is characterized as a floodplain area with swamps, flood channels and other open water surfaces (Hoseth and Josefsen, 2005).

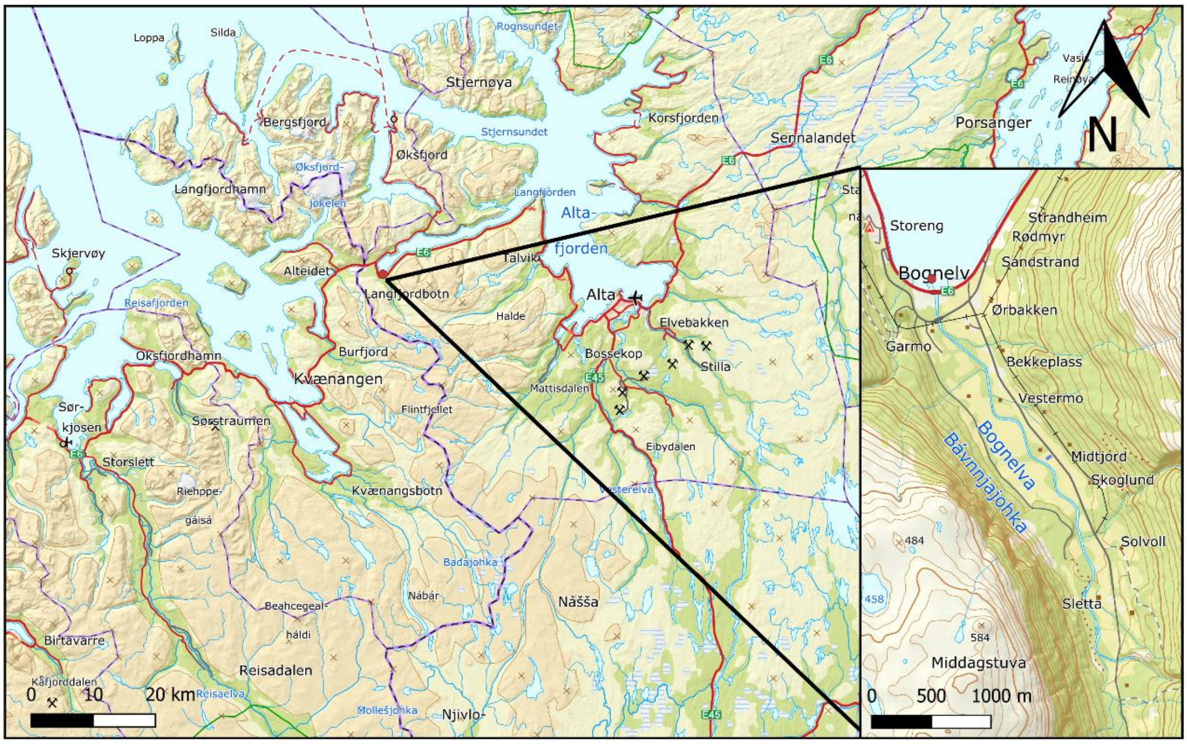


Figure 1 Map over the location of the study system.

Since the 1930s and until the 1990s, the river was canalized in favour of erosion control for the surrounding agricultural land. The meandering river (Figure 2) with pools, ox-bow lakes, and floodplain areas was straightened out (Figure 3) and an erosion prevention solution consisting of rock filling was constructed (Hoseth and Josefsen, 2005). A more homogenic, fast flowing river was created, and the locals experienced a decline in salmonid abundance present in the river system (Hoseth and Josefsen, 2005).

Figure 2 River Bognelv, in 1946. To the right is the outlet in to the fjord Langfjordbotn. (Hoseth and Josefsen, 2005)

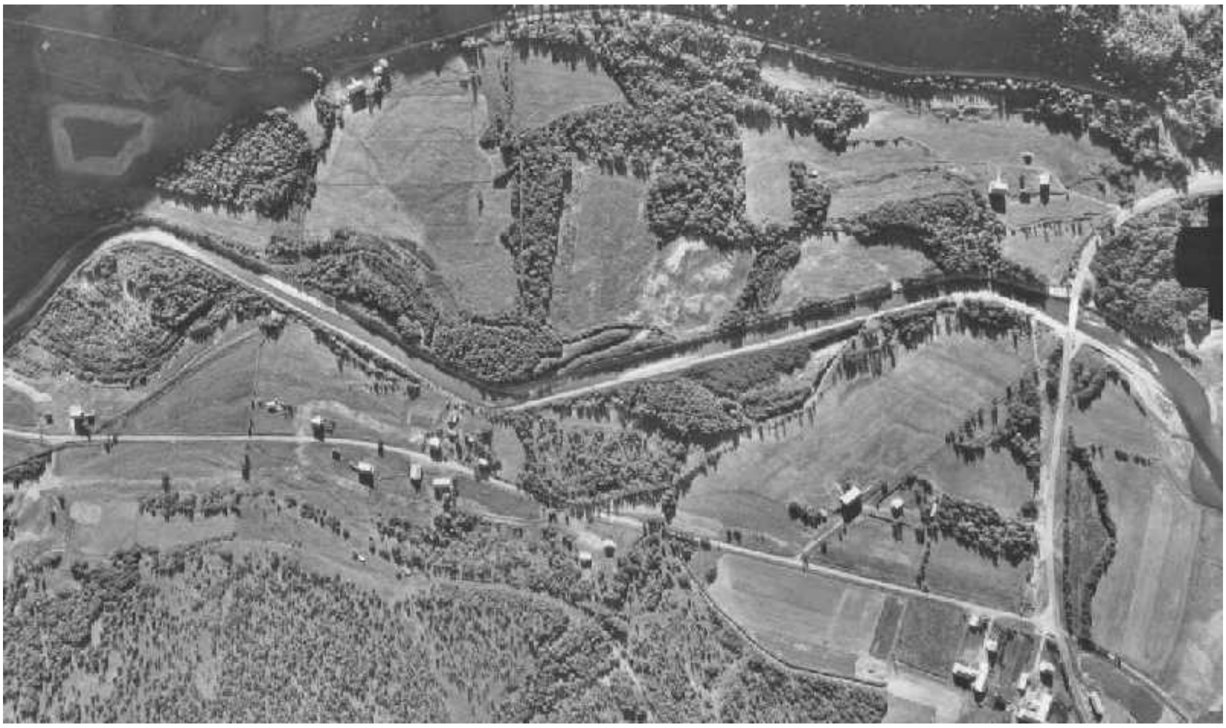


Figure 3 River Bognelv in 1972. To the right is the outlet into the fjord Langfjordbotn. (Hoseth and Josefsen, 2005)

As a pioneer project by The Norwegian Water Resources and Energy Directive in collaboration with the locals and local authorities, restoration of the river began in 2006 and continues to this day (Hoseth and Josefsen, 2005, Bjordal, 2019). Restoration measures conducted in the river have focused on preserving and improving several interests, such as agricultural land, juvenile fish density, recreation values and aesthetics (Hoseth and Josefsen, 2005). To summarize the conducted measures applied; the main river is still left straightened in the lower parts of the river (but with more riffles), the creation of pools with constructed weirs, and the introduction of rock clutches. The erosion prevention solution consisting of rock filling is still present in parts of the river to prevent erosion of agricultural land. Old water ways from before the canalization are now open as side channels, and some side tributaries are now accessible for fish (Hoseth, 2008a, Hoseth, 2008b, Hoseth, 2010, Hoseth, 2013). More detailed summary of the conducted measures is found in Appendix 1.

2.3 STUDY SITES

2.3.1 Station selection

The fieldwork was conducted on four separate trips (17th June to 19th June, 2th September to 6th September 14th October to 19th October, and lastly the 6th and 7th November). This study is not a direct follow-up of previous master theses written on this river (Schedel, 2010, Austvik, 2012, Sødal, 2014, Nordhov and Paulsen, 2016). New stations (see figure 4) were created with a length of 50 meters and a width of 2 meter. Four stations were placed in the main river (HL1, HL2, HL3, HL4), five stations in a side channel (SL1, SL2, SL3A, SL3B, SL4) and two in side tributary (SE1, SE2). Some of the new stations overlapped with older stations from the previous studies (HL1 with station 28, SL1 with station 7 and 8, SL2 with station 59b and SL3A with station 40).

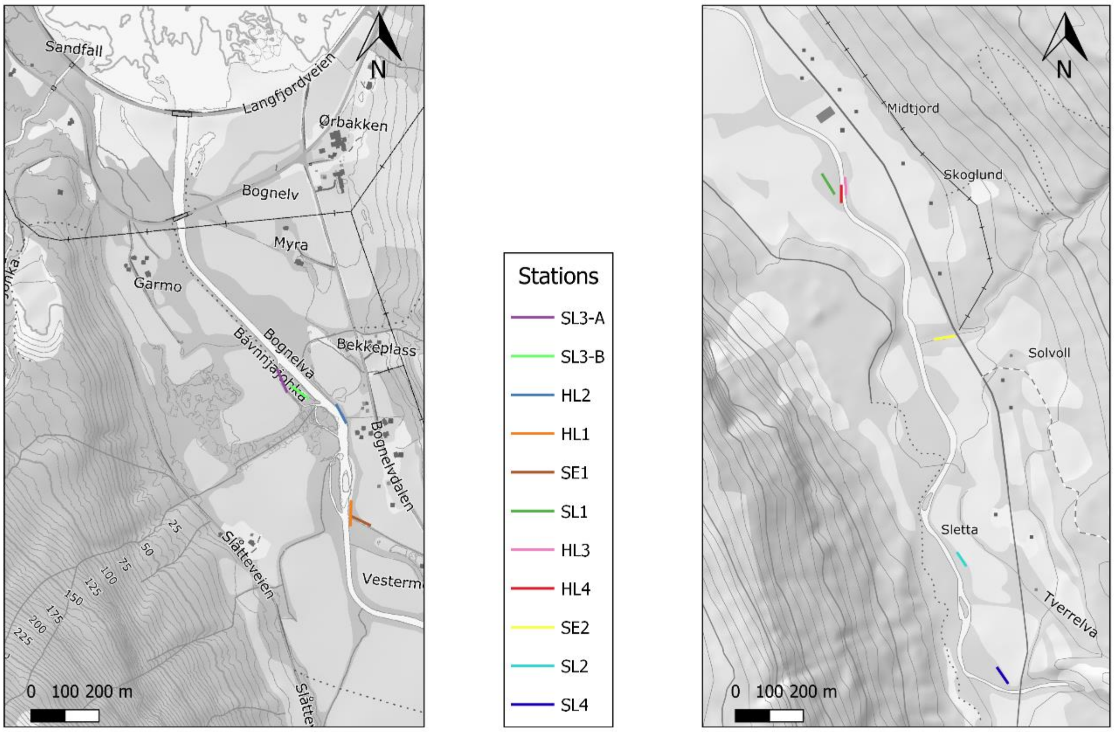


Figure 4 Map over the selected stations

The focal point of the examined restoration measures in this study were the side channels, tributaries and pools/removal of the erosion prevention in the main river. Additionally, two stations in the main river with an intact erosion prevention of rock fillings were added as a reference (Station HL2 and HL3).

Station SL3-B and SE2 dried out the last tree sampling rounds. Only station SE1 was dried during the second sampling round. These stations (SL3-B, SE1 and SE2) will therefore not be part of any further analysis in this thesis, because of the mentioned drought episodes.

2.3.2 PIT telemetry

Passive Integrated Transponder (PIT) is a very useful marking technology for wild animals (Gibbons and Andrews, 2004). This is the same technology that is used in ID-marking of household animals such as cats, dogs and horses. A PIT-tag is an electronic microchip encased in biocompatible glass (Gibbons and Andrews, 2004). The concept of marking wildlife is not new; tagging and color-codes have been used for decades to reveal information on migrations patterns and population levels of game and commercial species (Gibbons and Andrews, 2004). The term “passive” means that the chip is dormant until it gets activated by an electromagnetic antenna. Antennas can be short-range handheld scanners or long-range copper cable loops deployed at strategic sites were tagged animals are likely to pass. Each PIT-tag has a unique code, and therefore one can identify the tagged individuals. The code is unmistakable, but in situations where many tags arrive at the same antenna at the same time, code collisions may create so-called ghost detections (Gibbons and Andrews, 2004).

In this study, one stationary antenna (Oregon Single Antenna Reader, ORSR - https://www.oregonrfid.com/products/hdx-long-range-readers/next-generation-single-antenna-reader/) was placed right above the old E6 road bridge (seen from the outlet from the fjord Langfjordbotn). After the first battery change took place this, stationary antenna did not function correctly. For most of the time, the antenna was not active, resulting in few detections of data from the tagged fish swimming out of the river system. This source of data was therefore excluded from further analysis.

For the last sampling round, a portable antenna with GPS tracking (Oregon RFID Mobile Reader kit, https://www.oregonrfid.com/products/hdx-long-range-readers/mobile-reader-kit/) was used to scan the river. Side channels and the main river were scanned. An additional GPS (GARMIN etrex 10) was used to track routes in the watercourse, and the tracking route from this sampling round can be seen in figure 5. Some parts of the river were left out when scanning the river, due to safety purposes. This explains the left out parts in figure 5, some parts of the river were too slippery and had too thin ice. The detections from last sampling round are found in Appendix 2

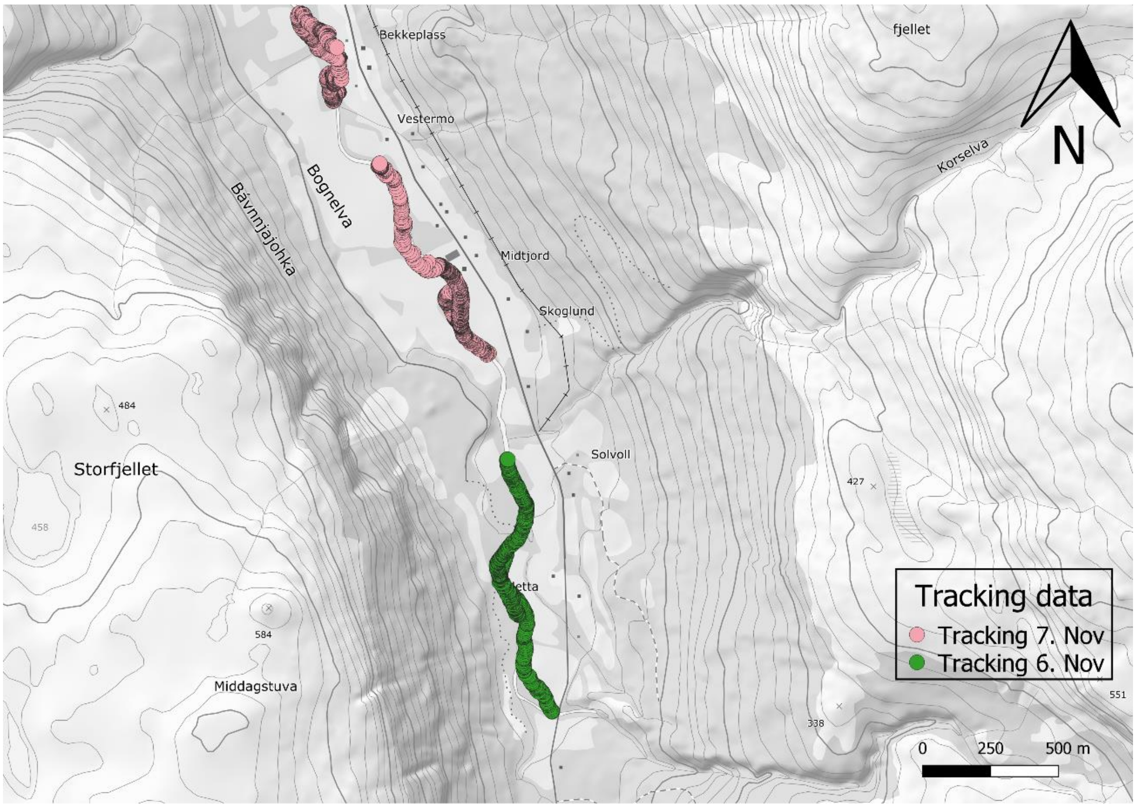


Figure 5 Tracking data from the handheld GPS from sampling round four, when the portable PIT-antenna were used.

2.3.3 Environmental variables

At each station, a number of environmental variables were registered. Each station was divided into five cross-transects, were transect 1 and 5 were located at the start and end of the stations. For all transect, variables such as substrate, depth, water velocity, cover of canopy in river, flood area and riverbank, mosses, algae, number of pools and large woody debris were registered with a category/value based on percentage cover, size, speed, distance, number or quality. The same method was used in previous master theses (Austvik, 2012, Sødal, 2014, Nordhov and Paulsen, 2016), but variables such as temperature and spawning habitat were not included. The method is described in detail in Appendix 3.

2.4 CAPTURE AND HANDLING

2.4.1 Electro fishing and the removal method

The sampling of fish was done with portable backpack electrofishing gear (GeOmega FA-4 generator produced by Terik Technology). Electro fishing is a common method used for sampling riverine fish (Forseth and Forsgren, 2008). The aim is to catch fish, record individual data and release them with minimal harm (Bohlin et al., 1989). The likelihood of catch increases with the size of the fish and water conductivity, but decreases with depth and water discharge. Other factors that affect catchability is visibility of shocked individuals for the researcher to catch with their dip net. Factors such as turbulence in the water surface and/or reflections from the sun will impact visibility (Forseth and Forsgren, 2008). Also, behaviour of the fish will impact their catchability (e.g., some hide when approached by the researchers, other flee). Lastly, the substrate or habitat in the stream can also impact of the catchability (Forseth and Forsgren, 2008). In the field, one person operates the electrofishing gear and another assistant walks behind with an additional dip net and place the captured fish in a bucket. The person operating the electrofishing gear sends electrical impulses at an interval of 5 to 10 seconds before moving a couple of meters and make a new pulse, and so on (Forseth and Forsgren, 2008, Bohlin et al., 1989).

For the first sampling round in June, the stations were only fished once, since it was too early to estimate juvenile densities (0+ still in gravel or too small to shock). Therefore, it was not necessary to do a three-pass fishing of all the stations. For the second sampling round, in September, all stations were fished up to three times. The method used was the removal method done with a three-pass system (Forseth and Forsgren, 2008). This method is based on three assumption. Firstly, the population is closed with no immigration or emigration during the sampling. Secondly, catchability is identical for all individuals, and thirdly, catchability is equal among removal passes (Bohlin et al., 1989). The pause between passes was 30 minutes. At one station, station HL3, only two passes where collected due to low catches in the first (n=9) and second pass (n=4). For the third sampling round in October, the stations were only fished one time to sample recaptures for earlier PIT-tagging and tagging new individuals.

2.4.2 Handling and tagging

The sampled fish had their body length measured (fork length, mm), were weighed (0.1 g, MyWeight®i1200), counted, and lastly, tagged if the size criteria for tagging were met. The sampled fish were released back into the same station they were caught from, after recovering from handling and tagging. Catches from the first and second passes in September (three-pass fishing) were stored between passes, and after three passes, they were all measured, weighed and counted. Some fish from first- and second-pass groups were tagged if they met the size criteria for inserting a tag. Individuals from third-pass groups were not tagged to reduce additional harm as they had been subjected to electric shocking episodes over a rather short time span. Recaptures were detected by using the handheld scanner and were recorded in the logbook. All individuals were released back into the station they were caught from, after handling and, for some, being tagged. The third sampling round in October, focused on catching and tagging new individuals as well as counting recaptures, following same procedures as in previous rounds.

In the field, PIT-tags were surgically inserted into the body cavity of the fish. The fish was anaesthetized with benzocaine, with a concentration of 2 – 3 mL (BENZOAK® VET 200 mg/mL) per 10 L of water. The PIT-tags were sterilized with alcohol before soaked in chlorhexidine and then inserted through a tinny incision (not more than necessary, depending on the size of the tag) in the skin and popped through the peritoneum. Two sizes of PIT-tags were used. The smallest tag, at 12 mm length, was used for fish larger than 6 cm but smaller than 12 cm, and the largest tag at 23 mm length was used for fish larger than 12 cm. Mainly 1st pass captures were tagged. At stations with relatively few individuals larger than 12 cm captured in the 1st pass, captures larger than 12 cm in other passes were tagged as well. Every fish that got a PIT-tag inserted was scanned before being put in a bucket of water to wake up from the anaesthesia. To ensure minimal harm to the fish when stored in the bucket, before and after tagging, replacement of water was done rapidly to ensure enough oxygen saturated water was available to prevent suffocation among the fish.

2.5 DATA PROCESSING AND QUANTITATIVE ANALYSES

2.5.1 Population size and catchability – The removal method

The method used in this study for estimation of juvenile density and catchability is described in detail in Bohlin et al. (1989). Only catches from the second sampling round (2th September to 6th September) were used to estimate juvenile density and catchability for the different stations, as well as total juvenile density.

2.5.2 Mark-recapture analyses

When testing hypothesis 3, 4 and 5 (table 1), a simple chi-squared test (package MASS in R) was conducted to quantify whether dispersal occurred or not outside the station where the individuals were marked before entering more complex analyses.

The analysis of the recapture data was processed through the software Mark version 9 (White and Burnham, 1999). The software Mark provides several types of re-encounter data. In this study, a multi-state approach was used by fitting Conditional Arnason-Schwarz models (CAS) that reflected the study's design of detecting movement between the side channels and main channel, e.g., constituting states of interest (Lebreton et al., 1992, White and Burnham, 1999). CAS models, as mark-recapture models in general, are based on the presumption that marked animals are later re-encountered either by catching them alive or by visual recognition. In this study, recaptures from sampling round two and three were caught alive. While recaptures from sampling round four were re-encountered for from the portable PIT-antenna (Oregon RFID Mobile Reader kit, https://www.oregonrfid.com/products/hdx-long-range-readers/mobile-reader-kit/). In this case, each "recapture" (re-encountered by the portable PIT-antenna) is assumed as having survived if the PIT-marked fish is re-encountered in the watercourse and not on land/ dried area. If recaptures were found within the station where it was originally marked, each catch was classified as "1", while recaptures that were caught outside the original station from where they were originally marked were classified as "2". If the fish was not re-encountered for their recapture history, they got a "0". Example of a re-encounter history: 1102. This means that the fish was tagged in occasion 1, on the second occasion re-encountered in the same station as originally tagged, not seen on the third occasion, and for last occasion, it was found outside the station where it was originally marked.

The parameterization of the multi-state model deployed can be visualized in a fate diagram (see figure 6). This fate diagram visualizes the probability for survival, dispersal and recapture for one tagged individual throughout 3 occasions (k, k+1, k+2). CAS models estimate three parameters. Psi (ψ) which is the probability of movement or dispersal, survival probability (S) and recapture probability (p).

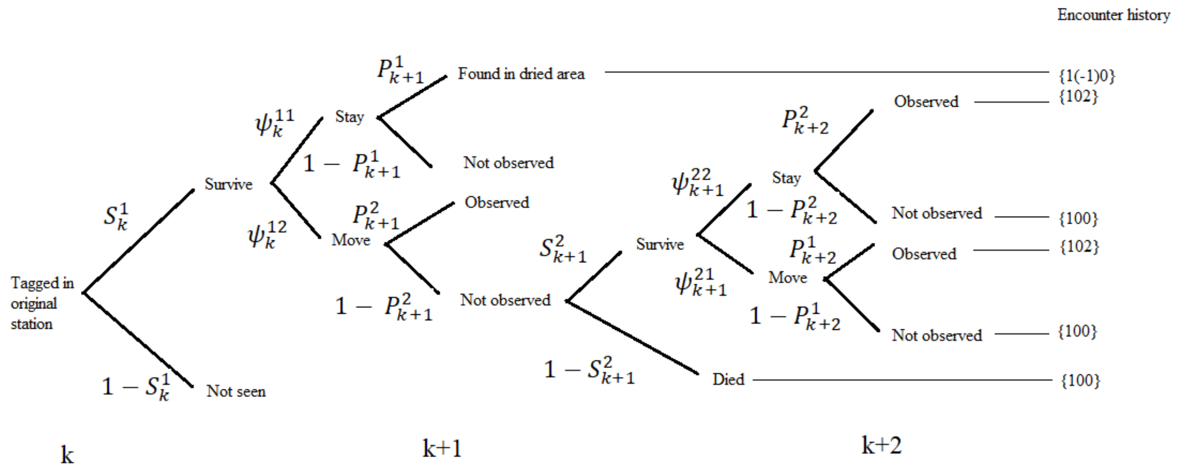


Figure 6 The fate diagram, with the different re-encounter history for an individual when using CAS model (Conditional Arnason-Schwars). S is the survival probability, psi (ψ) is the probability of movement, while p is the probability of recapture.

The parameters were fitted using the maximum likelihood method. These parameters can be estimated to be constant or time dependent for all occasions and stations. Either way, for a more relevant perspective (ecological perspective) the parameters were estimated as function of fixed effects (side channel vs. main river) and covariates of interest (juvenile density and fish fork length).

Using MARK, I fitted different candidate models when combining covariates and factors of interest into the model. In order to find the candidate model(s) that attained highest support in the data (e.g., that most efficiently balanced parameter estimate bias and precision), I used Akaike's information criterion (AIC) (White and Burnham, 1999). Some parameters of the candidate models were fixed. The survival probability for the fish that had moved to other places in the river was fixed to 1, since this data only has one occasion due to the sampling method (i.e., movement could only be confirmed by a re-encounter, hence, the fish had to be alive). This means that the survival for the moved fish would be 1 either way. In addition, the recapture probability for station SL4 was fixed, as there was no recapture to analyse from station SL4. Furthermore, the dispersal from the original marked station to outside the original station at the first occasion was also fixed at zero, as there was no collection of density distribution due to early sampling. Lastly, the dispersal of movement from outside the original station to the original station was also fixed at zero, as these types of data did not exist in my data set.

2.5.3 Other statistical analysis

Program R, version 3.6.3 (R Developing Core Team 2020), was used for data processing, statistical analysis and visual representation of the data and statistical result.

To test the negative density dependent correlation between age classes and year, the age classes (0+, 1+, >1+) per year were defined from the different length interval between years. The age distribution and length intervals were set to best fit the visual representation of length distribution for the data in 2019, the same method as earlier study in Bognelv has used (Schedel, 2010, Austvik, 2012, Sødal, 2014, Nordhov and Paulsen, 2016).

ZIP – Zero-inflated Poisson models (package pcsl in R, e.g, (Wagh and Kamalja., 2017)) were used when fitting models exploring how fish density data was affected by type of restoration measure, since the density data showed an excess of 0 observations after transforming data on to a logarithmic scale, which is not expected in count data when data should be Poisson distributed (log-normally distributed). This tendency occurred in two analysis with different subsets of the sampling data; data from 2008 to 2019 and data from 2013 to 2019 (figure 7 and 8). The creation of two subsets for analysis are a result of the lack of environmental variables, that first collected in 2013 and onwards. To justify the use of ZIP models, a Vuong test (package MASS in R) was conducted to compare the ZIP approach with density models fitted using a Poisson model and a negative binomial model approach (fitted as generalized linear models, GLM (McCullagh and Nelder, 1989)). Both models showed significant p-values and indicated that Zero-inflated Poisson models were the best fit since it explained most of the observed variation.

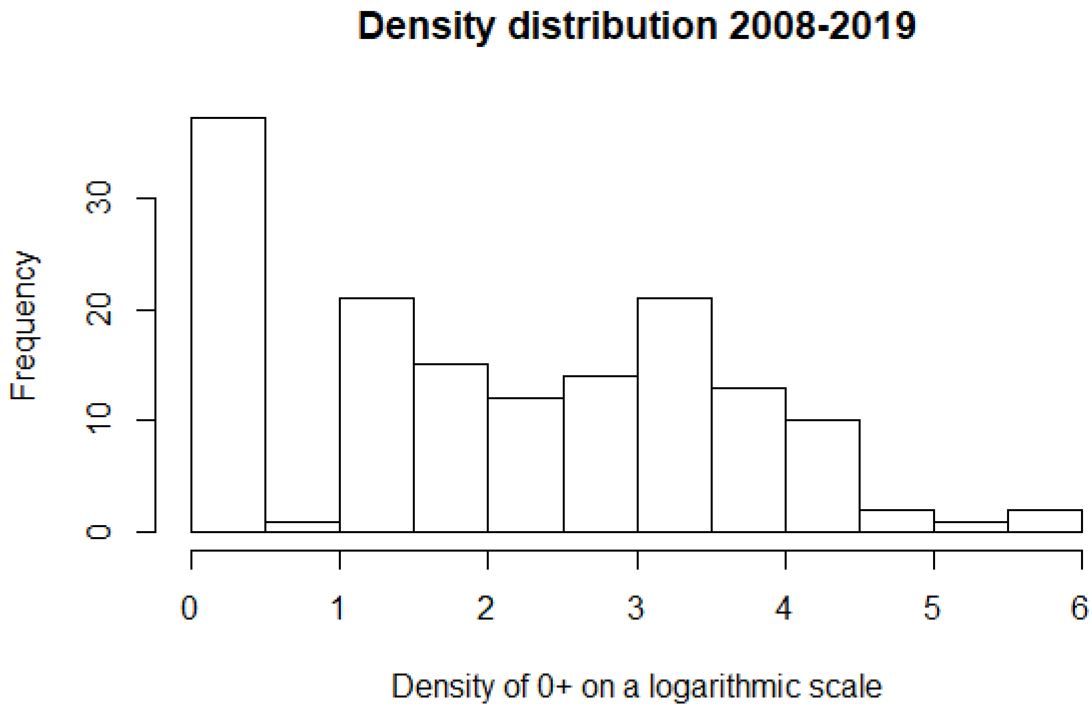


Figure 7 The density distribution from 2008 to 2019 log transformed. As seen in this figure an excessive tendency of 0 observation is occurring.

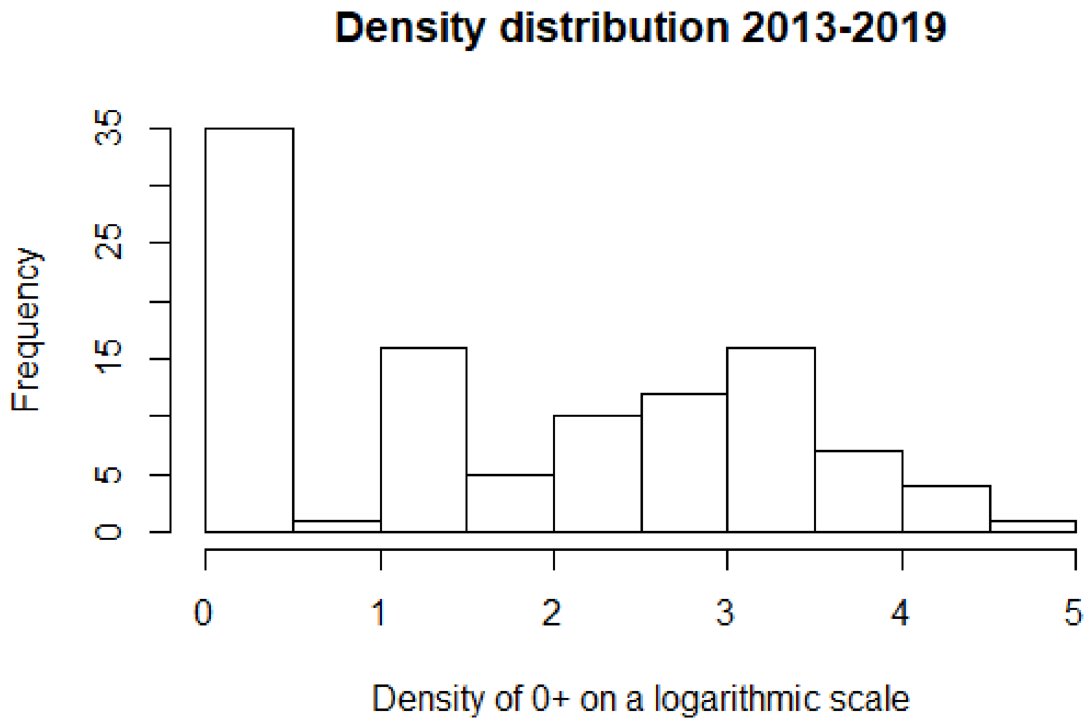


Figure 8 The density distribution from 2013 to 2019 log transformed. As seen in this figure an excessive tendency of 0 observation is occurring.

ZIP models are based on a zero-inflated probability distribution which allows for frequent zero-valued observations (Lambert, 1992), like in my case. ZIP models consist of two sub-models, simply two models combined to explain the tendency observed by adding probability to the regression. Model one looks for an explanation for why a tendency of 0 observations occurred. The second model of the ZIP-models looks for an explanation for the data which is non-0 observations, which is the same as normal Poisson regression (Lambert, 1992). The first model of the ZIP-models, were probability of 0 observations are corrected for, looks like this:

$$Pr(y_j = 0) = \pi + (1 - \pi)e - \lambda$$

The second model of the ZIP-models (Poisson regression) looks like this:

$$Pr(y_j = h_i) = (1 - \pi)\frac{\lambda^{h_i}e^{-\lambda}}{h_i}, \qquad h_i \geq 1$$

The outcome (response) variable y_j can have all non-negative values. The expected Poisson count is λ, and π is the probability of additional 0 values, apart from what is expected from the Poisson distribution (h_i). Both models can be modelled as generalized linear models, but the first model is modelled with a logit-link and the second model is modelled as an ordinary Poisson model with log-link function (Lambert, 1992).

Principal component analysis (PCA), or multivariate analysis (package vegan in R) were used to analyses the explanation in density distribution of age class 0+ and 1+ combined with the environmental variables (First axis length =1.27, meaning PCA can be used since value is less than 3 (Morris, 2015)). The environmental data had to be scale transformed (Z escalated) to best fit the environmental data due to the categorical sampling (see Appendix 4). PCA consists of principal components (PC1, PC2 and so on)(Pearson, 1901), which are uncorrelated variables fitted to the data and plotted in a three-dimensional plot to best describe the tendency occurring. This method increases the interpretation and reduces los of information (Jolliffe and Cadima, 2016). Furthermore, in order to figure out if the observed environmental variables are a product of type of measure, candidate models consisting of an intercept model and an environmental model were conducted.

For both ZIP models and PCA, candidate models were fitted. The selection of the candidate models was done with Akaike information criterion (AIC) (package AICcmodavg in R). This selection applies for both the analyses done in R and program Mark. The candidate model with lowest the AIC value (AICc, an n-corrected version of AIC) compared to other models in the same analysis were selected, as the lowest AIC value has the highest AIC support (ΔAICc) (Burnham and Anderson, 2002, White and Cooch, 2019). The selected model has most support in the data under the principle of parsimony, i.e., it is the model that most efficiently balance parameter estimate bias and precision.

3 RESULTS

3.1 AGE DISTRIBUTION

3.1.1 Length based age assignments

The length intervals are shown in figure 8. There is a difference between stations, and generally a tendency of high amounts of fish in age class 0+ and 1+ appears in station SL3A in side channel. In other stations in the main channel, like station HL4 there is no detected fish of age class 0+. Generally low catches are caught in main channel.

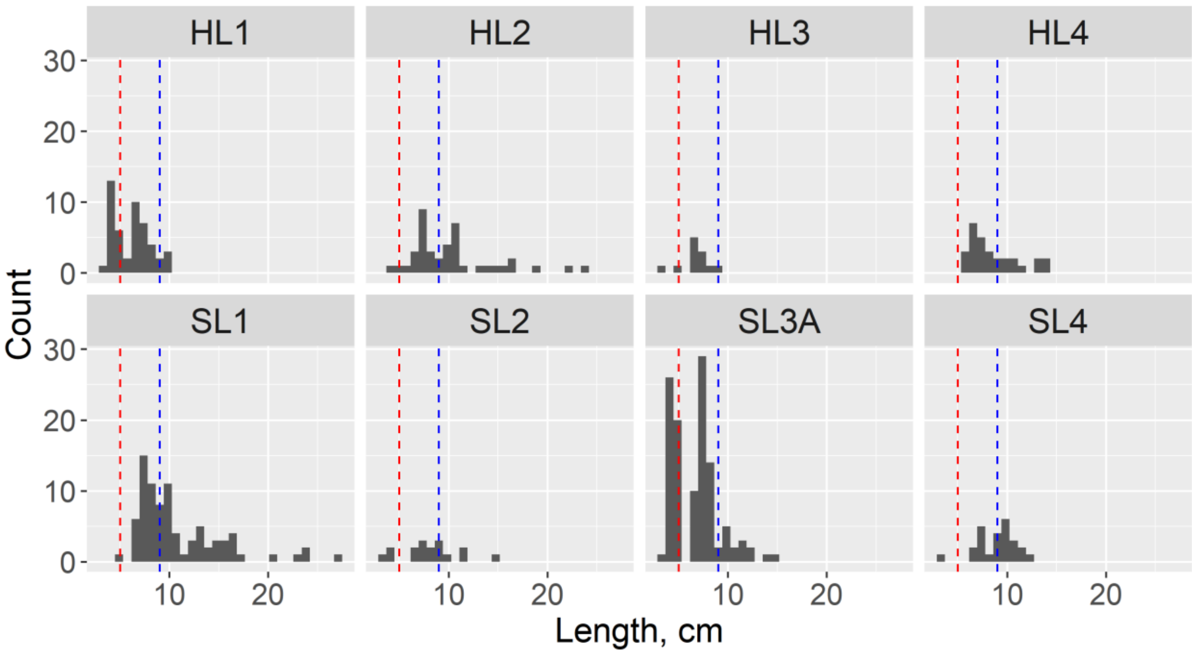


Figure 9: The age distribution and age classes in the different stations in river Bognelv, 2019.The line that separate age class 0+ and 1+ was set to 5 cm (red dashed line), and the line that separate age class 1+ and >1+ was set to 9 cm (blue dashed line).

3.1.2 Annual age distribution

Table 2 shows the different length interval between years and the age distribution from the sampled fish for each year are shown below in figure 9. The are generally sampled more fish before 2019, but the age distribution are generally even between years. 2011 is noticeable as a peak year of age class 0+, while 2019 appears as a poor year for age class 0+. In 2011 it appears that age class 1+ were influenced by the peak year for age class 0+.

Table 2: The length interval per year in river Bognelv. The length intervals are a result of the visual representation of length distribution from the sampled fish.

	Age classes		
Years	0+	1+	>1+
2008	25-50	51-88	>88
2011	21-57	58-90	>90
2013	33-56	57-90	>90
2015	31-57	58-88	>88
2019	25-50	51-90	>90

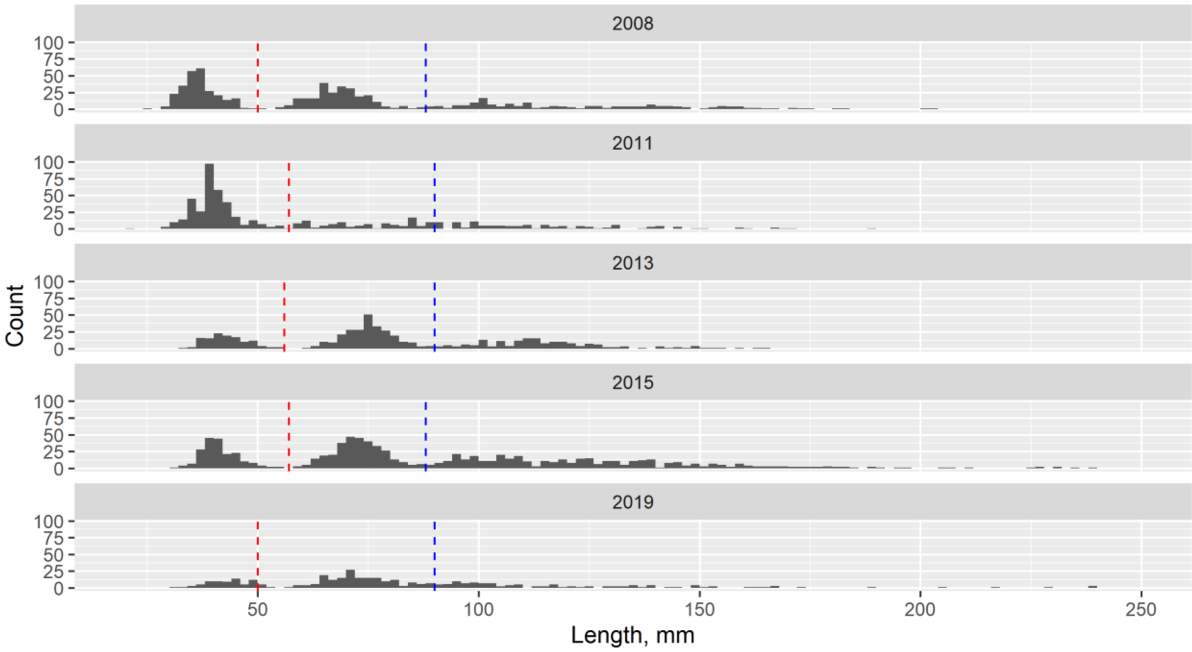


Figure 10: The age distribution form each year in river Bognelv. The dashed line both red and blue is representing the age class distinguish between age class 0+, 1+, and >1+. To the left to the red dashed line is age class 0+. In between the red and blue dashed line is age class 1+, and to the right to the blue dashed line is age class >1+.

3.2 ANALYSIS OF THE JUVENILE DENSITY DATA

The density distribution for each year and age class with confidence intervals are found in figure 10. The density before restoration (1998 and 2004) are lower than juvenile densities after restoration (2008, 2011, 2013, 2015 and 2019). In addition, the recruitment for 0+ in year 2013 and 2019 was lower than 2008, 2011 and 2015. The highest mean recruitment of 0+ after restoration was found in 2011, and the lowest mean recruitment of 0+ after restoration was found in year 2019. After the peak in recruitment of 0+ in 2011, the mean densities of 0+ has been below 20 individuals per 100 m^2.

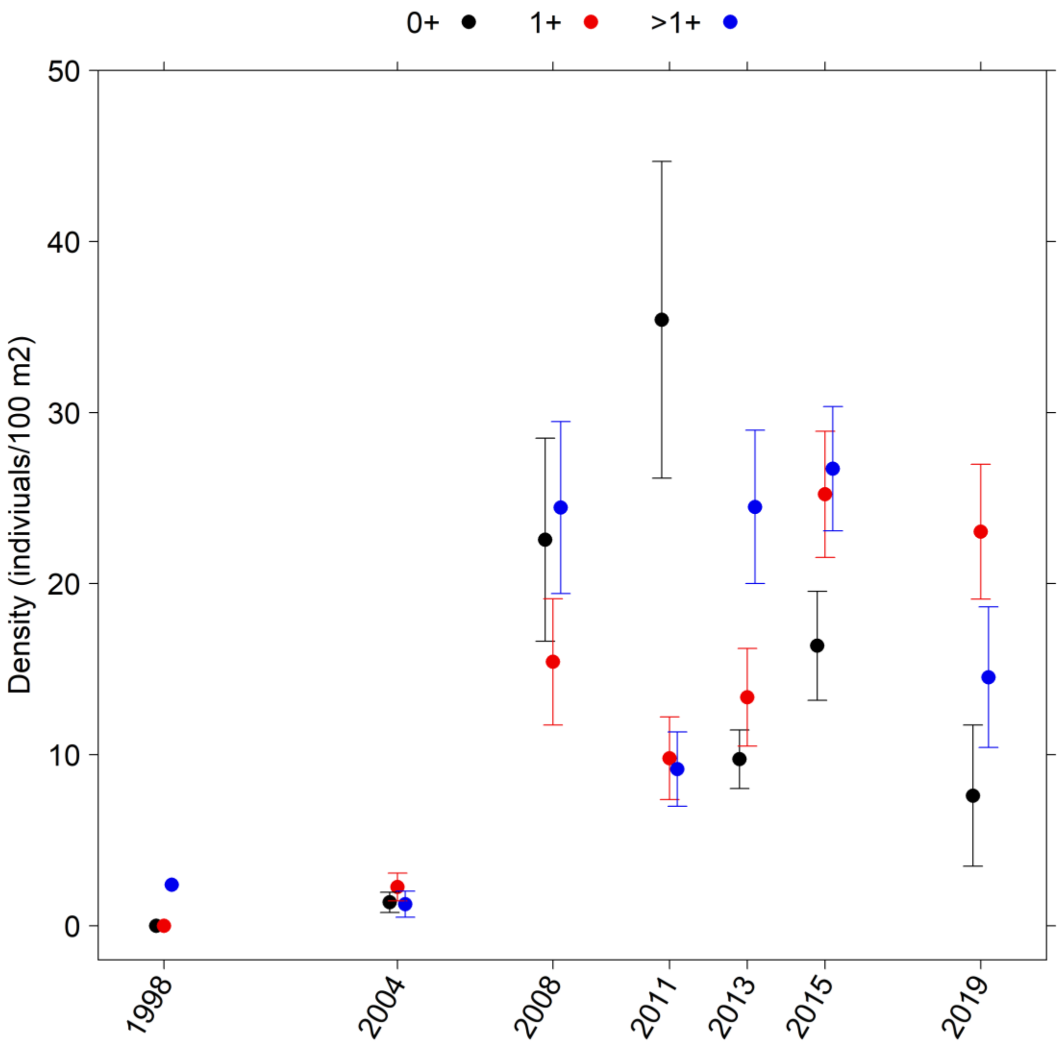


Figure 11: Juvenile densities (individuals per 100 m^2) with standard deviation before and after restoration in river Bognelv.

3.2.1 Juvenile density from 1998 to 2019

Model selection amongst the candidate ZIP-models (table 3) fitted to the 0+ density data revealed that the candidate with zero-inflation part contained measure and year as predictors and the count part with measure and year as predictors (table 3). The model attained AICc-values that were 58.57 AICc-units lower than the second-most supported candidate (table 3). The prediction from the Poisson regression from the selected candidate model (first model mention in table 3) are plotted in figure 11. The selected models estimate is found in table 4. The predictions from the Poisson regression of the ZIP model showed that the predicted 0+

density is generally increasing with increasing 1+ density for measure pools (with a relatively steep slope) and riparian modifications (less steep slope than pools). Furthermore, the predicted 0+ density for restoration measure side channel is increasing (much less than for pools and riparian modifications), and the slop for measure side channel partly flattens out with increasing 1+ density. For channelized sites, an increase of the predicted 0+ density is occurring, but the intercept is much lower compared to the other restoration measures. The predicted 0+ density for channelized sites is flattening with increasing 1+ densities.

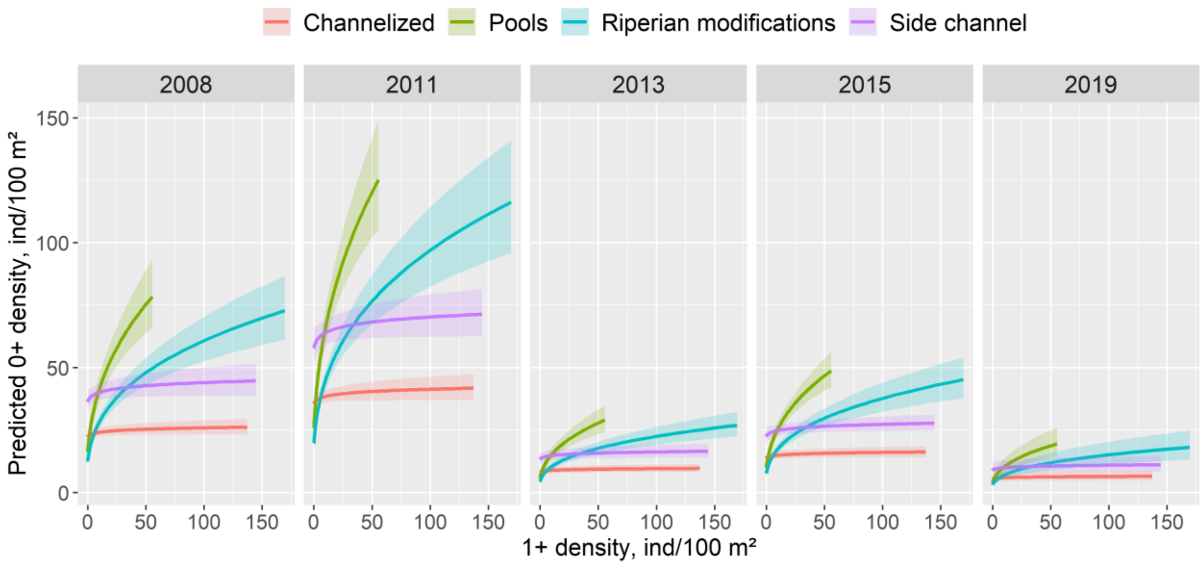


Figure 12 The predicted 0+ densities from the selected model (table 4), per year and restoration measure are plotted against 1+ densities from year 2008 to 2019.

Table 4 Predicted estimate for the count model (Poisson) with log link for the selected ZIP-model.

Count model coefficients (poisson with log link):				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	3.113819	0.061860	50.337	< 2e-16
log.density1plus	0.029001	0.019475	1.489	0.1364
MeasureCoarsePools	-0.292708	0.141856	-2.063	0.0391
MeasureCoarseRiperian modifications	-0.411760	0.098004	-4.201	2.65e-05
MeasureCoarseSide channel	0.465852	0.082111	5.673	1.40e-08
Year2011	0.450980	0.042778	10.542	< 2e-16
Year2013	-0.946933	0.057653	-16.425	< 2e-16
Year2015	-0.469036	0.052738	-8.894	< 2e-16
Year2019	-1.379391	0.137046	-10.065	< 2e-16
log.density1plus:MeasureCoarsePools	0.349541	0.049078	7.122	1.06e-12
log.density1plus:MeasureCoarseRiperian modifications	0.260818	0.034899	7.474	7.80e-14
log.density1plus:MeasureCoarseSide channel	0.009744	0.029067	0.335	0.7375

Table 3 Model selection based on AICc.

	K	AICc	ΔAICc	AICcWt	Cum.Wt	LL
log(density.one + 1) * MeasureCoarse + Year | log(density.one + 1) + MeasureCoarse + Year	21	5346.24	0	1	1	-2599.54
log(density.one + 1) * Year + MeasureCoarse | log(density.one + 1) + MeasureCoarse + Year	22	5304.81	58.57	0	1	-2627.56
log(density.one + 1) + Year + MeasureCoarse | log(density.one + 1) + MeasureCoarse + Year	18	5342.39	96.14	0	1	-2651.32
log(density.one + 1) + Year + MeasureCoarse | log(density.one + 1) + MeasureCoarse	14	5346.26	100.01	0	1	-2658
log(density.one + 1) + Year + MeasureCoarse | log(density.one + 1) + Year	15	5350.48	104.24	0	1	-2658.94
log(density.one + 1) + Year + MeasureCoarse | MeasureCoarse	13	5354.65	108.4	0	1	-2663.35
log(density.one + 1) + Year + MeasureCoarse | log(density.one + 1)	11	5355.55	109.3	0	1	-2666.08
log(density.one + 1) + Year + MeasureCoarse | 1	10	5365.65	119.4	0	1	-2672.24
log(density.one + 1) + Year + MeasureCoarse | Year	14	5369.17	122.92	0	1	-2669.45
log(density.one + 1) * Year | log(density.one + 1) + MeasureCoarse + Year	19	5472.08	225.83	0	1	-2714.94
log(density.one + 1) + Year | log(density.one + 1) + MeasureCoarse + Year	15	5499.43	253.19	0	1	-2733.42
log(density.one + 1) * MeasureCoarse | log(density.one + 1) + MeasureCoarse + Year	17	6067.92	821.68	0	1	-3015.29
log(density.one + 1) | log(density.one + 1) + MeasureCoarse + Year	11	6114.22	867.97	0	1	-3045.41

Additionally, the probability prediction of the ZIP model (figure 12 and the estimate for the model are found in table 5) is generally showing that with an increased density of 1+, the probability of not finding individuals of 0+ at the site is decreasing. Variances between years and restoration measures occurs, but it is generally predicted that it is more likely to find individuals of 0+ in pools and riparian modifications than in side channel and channelized sites.

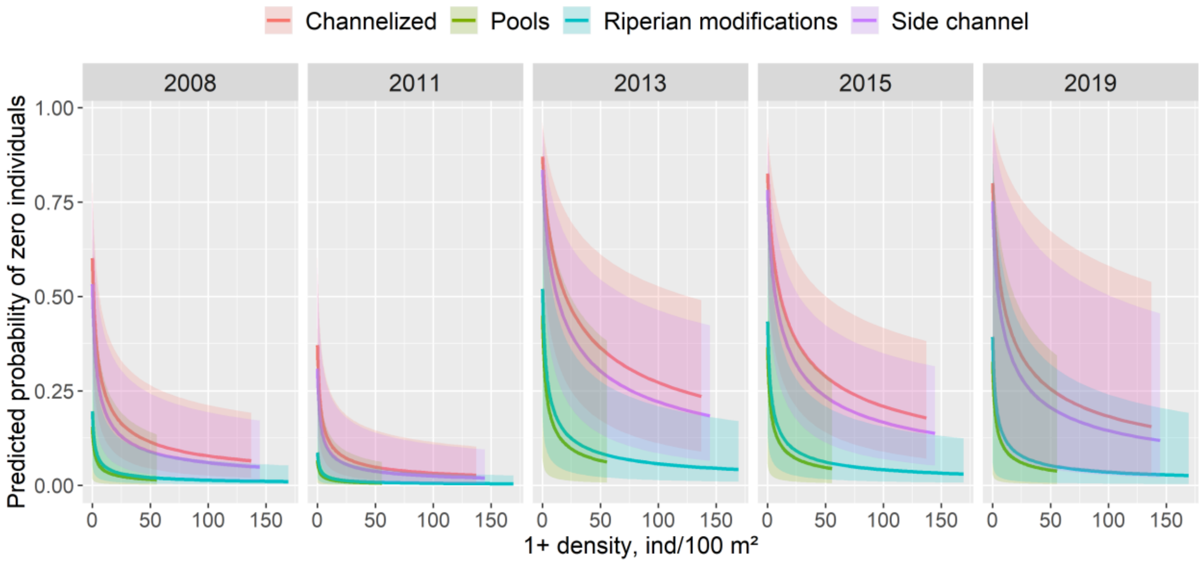


Figure 13 The predicted probability of finding 0+ plotted for the selected model (table 5), against 1+ densities for each restoration measure and from year 2008 to 2019.

Table 5 Predicted estimate for the zero model (binomial) with logit link for the selected ZIP-model.

Zero-inflation model coefficients (binomial with logit link):				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	0.34167	0.47966	0.712	0.47627
log.density1plus	-0.55394	0.14100	-3.929	8.55e-05
MeasureCoarsePools	-2.10953	1.08969	-1.936	0.05288
MeasureCoarseRiperian modifications	-1.78570	0.67028	-2.664	0.00772
MeasureCoarseSide channel	-0.05524	0.39732	-0.139	0.88943
Year2011	-0.98981	0.57842	-1.711	0.08704
Year2013	0.78844	0.51074	1.544	0.12265
Year2015	0.90009	0.52767	1.706	0.08805
Year2019	0.68269	0.96778	0.705	0.48055

3.2.2 Principal component analysis of the environmental variables

In the unconstrained PCA fitted to explore covariations among environmental variables for all sites, the first axis (PCA1) explained 25,3 % of the observed variation, while the second axis (PCA2) explained 23,6 % of the observed variation. Both first axis and second axis together explained 48.9 % of the observed variation (see table 6).

Table 6 The importance of the components in the Principle Component Analysis.

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Eigenvalue	2.0245	1.8890	1.1957	0.9540	0.79047	0.51364	0.37586	0.25675
Proportion Explained	0.2531	0.2361	0.1495	0.1192	0.09881	0.06421	0.04698	0.03209
Cumulative Proportion	0.2531	0.4892	0.6387	0.7579	0.85672	0.92092	0.96791	1.00000

In the biplot (figure 13), large woody debris (number of dead wood) has a negative PC1 score as well as it is negative correlated with both water velocity (Velocity) and substrate category (Substrate), where both have a positive PC1 score and are relatively close to each outer. With increasing velocities and increasing substrate the amount of large woody debris decreases. Furthermore, the number of pools decreases with increasing depth (Average depth), as this is negatively correlated. Number of pools has a negative PC1 score and depth have a positive PC1 score. In addition, the vegetation variables (Canopy cover in riverbank, Canopy cover in river and edge vegetation) have no direct correlation with other environmental variables. Edge vegetation and large woody debris is relatively close to each other, but edge vegetation has a positive PC2 score, while large woody debris have a negative PC2 score. An overview of the different PC1 and PC2 score for the different variables is found in table 7.

Table 7 Variable scores from the unconstrained Principle Component Analysis.

	PC1	PC2	PC3	PC4	PC5	PC6
Canopy cover in river	-1.49627	0.5988	-0.24347	0.7234	-0.13070	0.240773
Canopy cover in riverbank	-1.43537	0.9714	-0.06098	0.3583	-0.20147	0.042223
Edge vegetation	-1.00211	0.1991	0.70448	-0.7780	1.16709	-0.365247
Velocity	0.60523	1.3960	0.21432	0.6545	0.28900	-0.646845
Substrate	1.22952	0.9229	-0.52279	0.3891	0.46177	-0.003451
Average depth	0.05493	1.0523	-1.07765	-0.8563	0.35027	0.639357
Number of dead wood	-0.52787	-0.6405	-1.49559	-0.1621	-0.04992	-0.857723
Number of pools	-0.09973	-1.1458	-0.37020	0.9618	1.03736	0.374040

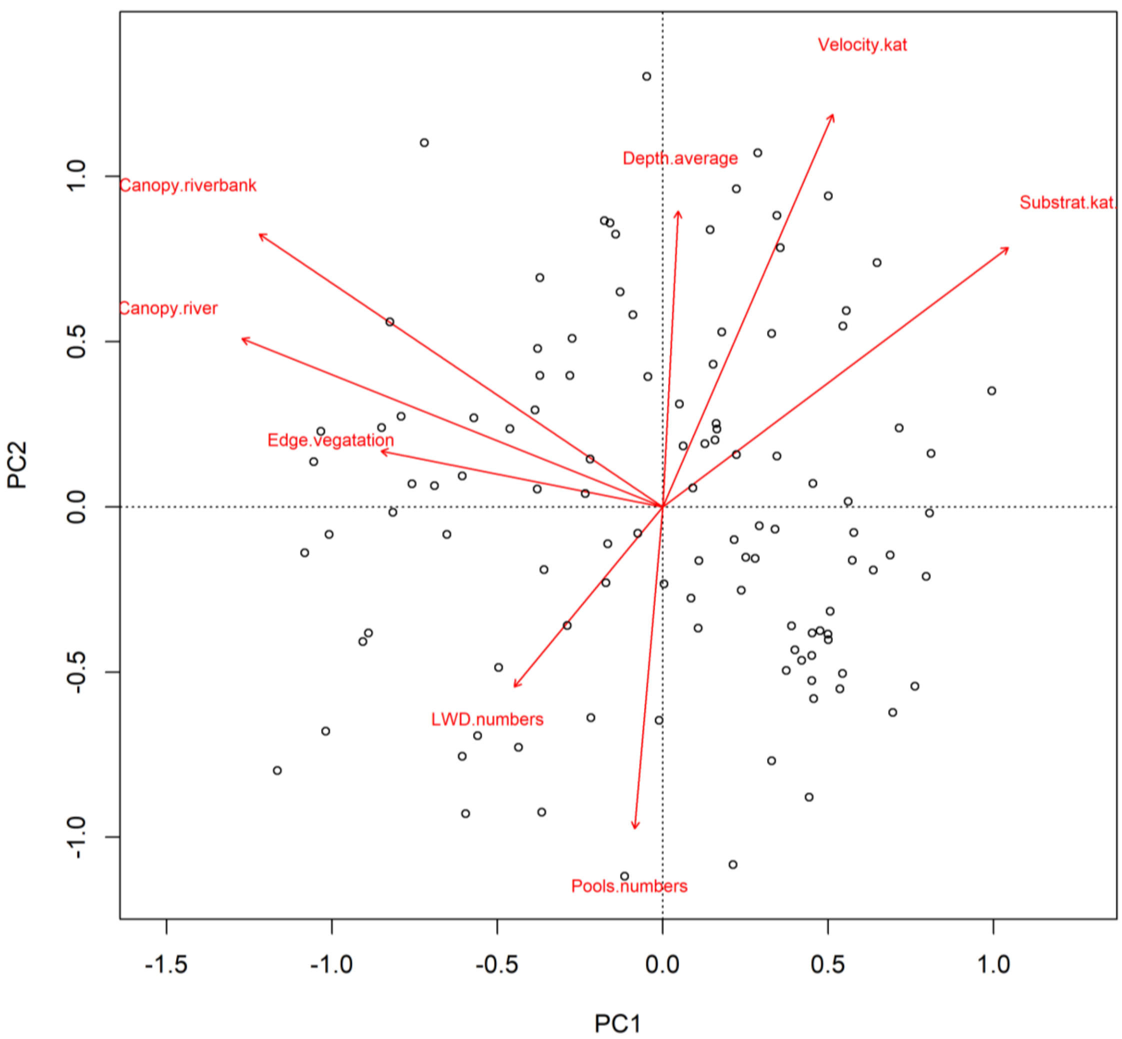


Figure 14 Biplot of PCA of total amount registered environmental variation.

The constrained PCA, fitted to explore effects of measurement type on environmental variables, showed that 16.4% of the observed environmental variation can be explained through the type of restoration measure (table 8, figure 14). There was a considerable overlap between the different measures. In measure side channel, there was a large association with vegetation variables (Canopy cover in riverbank, Canopy cover in river and edge vegetation) and large woody debris. In contrast pools are more associated with large depth and higher velocity, and not an increased number of pools.

Table 8 Partial R^2 and effect p-value for the RDA fitted to explain the variation in restoration type in Bognelv. The model explains 16.4 % of the variation.

Effect	**R^2**	**Pr(<r)**
Measure	0.1643	0.001

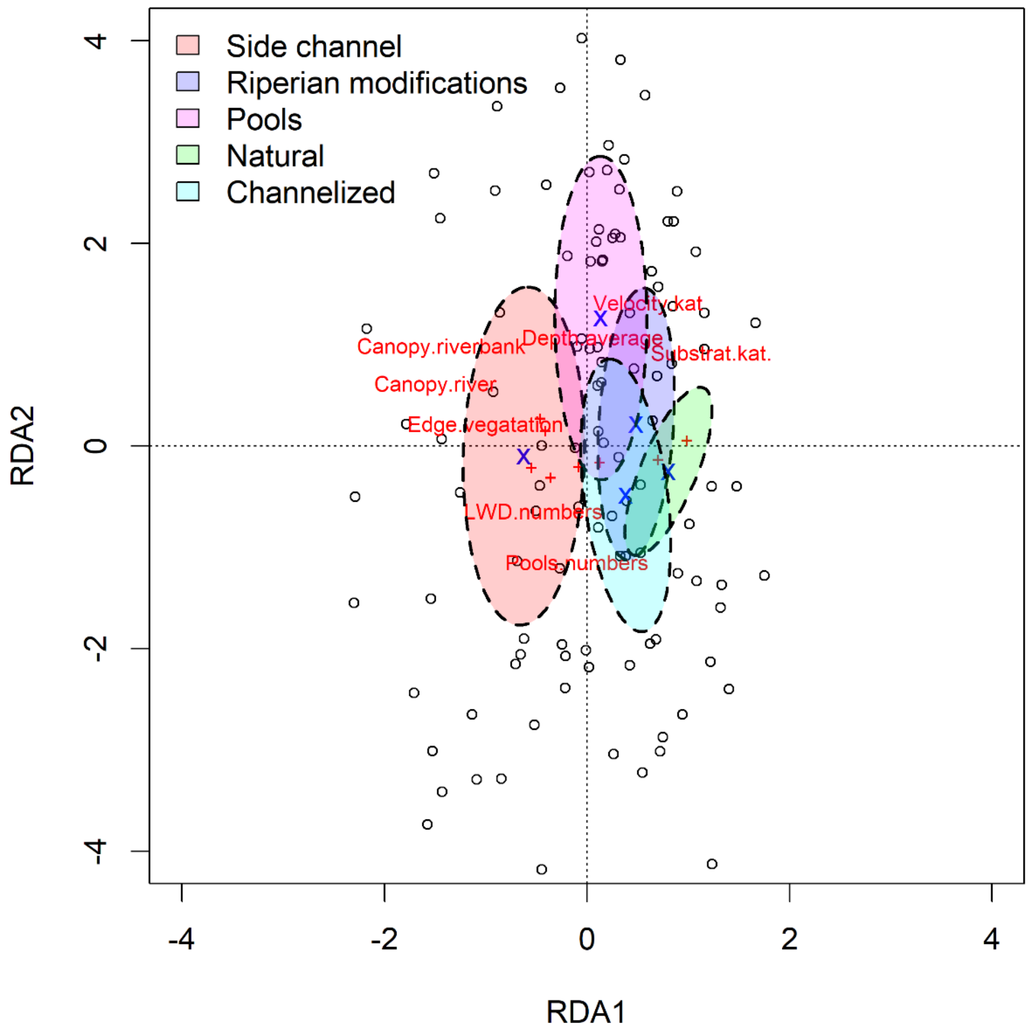


Figure 15 Biplot of the selected RDA where the blue X are the mean for each measure type and ellipse are showing the confidence interval for type of measure.

3.2.3 Environmental effects on juvenile densities

Model selection of ZIP candidate models (table 10) fitted the 0+ density data, yielded a top candidate model with year, measure, and PC3 as predictors for the zero-part of the model and year, measure, PC2 and PC3 for the count part (table 10, table 12).

Table 12. Model selection based on AICc.

	K	AICc	ΔAICc	AICcWt	Cum.Wt	LL
log(density.one + 1) + Year + MeasureCoarse + PC2 + PC3 | log(density.one + 1) + MeasureCoarse + Year + PC3	17	1124.31	0	0.46	0.46	-541.71
log(density.one + 1) + Year + MeasureCoarse + PC3 | log(density.one + 1) + MeasureCoarse + Year + PC3	16	1125.48	1.17	0.25	0.71	-543.72
log(density.one + 1) + Year + MeasureCoarse + PC1 + PC2 + PC3 | log(density.one + 1) + MeasureCoarse + Year + PC3	18	1127.07	2.76	0.11	0.83	-541.65
log(density.one + 1) + Year + MeasureCoarse + PC1 + PC3 | log(density.one + 1) + MeasureCoarse + Year + PC3	17	1127.32	3.02	0.1	0.93	-543.22
log(density.one + 1) + Year + MeasureCoarse + PC1 + PC2 + PC3 | log(density.one + 1) + MeasureCoarse + Year + PC2 + PC3	19	1129.73	5.42	0.03	0.96	-541.5
log(density.one + 1) + Year + MeasureCoarse + PC1 + PC2 + PC3 | log(density.one + 1) + MeasureCoarse + Year + PC1 + PC3	19	1130	5.69	0.03	0.98	-541.63
log(density.one + 1) + Year + MeasureCoarse + PC1 + PC2 + PC3 | log(density.one + 1) + MeasureCoarse + Year + PC1 + PC2 + PC3	20	1132.75	8.44	0.01	0.99	-541.49
log(density.one + 1) + Year + MeasureCoarse + PC1 + PC2 + PC3 | log(density.one + 1) + MeasureCoarse + Year	17	1133.16	8.85	0.01	1	-546.14
log(density.one + 1) + Year + MeasureCoarse + PC1 + PC2 + PC3 | log(density.one + 1) + MeasureCoarse + Year + PC2	18	1135.93	11.63	0	1	-546.08
log(density.one + 1) + Year + MeasureCoarse + PC1 + PC2 + PC3 | log(density.one + 1) + MeasureCoarse + Year + PC1	18	1136.04	11.74	0	1	-546.13
log(density.one + 1) + Year + MeasureCoarse + PC2 | log(density.one + 1) + MeasureCoarse + Year + PC3	26	1138.59	14.28	0	1	-550.27
log(density.one + 1) + Year + MeasureCoarse + PC1 + PC2 + PC3 | log(density.one + 1) + MeasureCoarse + Year + PC1 + PC2	19	1138.89	14.58	0	1	-546.08
log(density.one + 1) + Year + MeasureCoarse + PC1 + PC2 | log(density.one + 1) + MeasureCoarse + Year + PC3	17	1141.4	17.1	0	1	-550.26
log(density.one + 1) + Year + MeasureCoarse + PC1 | log(density.one + 1) + MeasureCoarse + Year + PC3	16	1141.8	17.5	0	1	-551.88

Table 11 Predicted estimates for the zero model (binominal) with logit link from the selected ZIP-model.

Zero-inflation model coefficients with logit link				
	Estimate	**Std. Error**	**Z value**	**Pr(<|z|)**
(Intercept)	2.20436	0.79737	2.765	0.005700
log.density1plus	-0.95858	0.24989	-3.836	0.000125
MeasureCoarsePools	-2.10289	1.18358	-1.777	0.075614
MeasureCoarseRiperian modifications	-2.52703	1.14696	-2.203	0.027578
MeasureCoarseSide channel	0.05914	0.56143	0.105	0.916104
Year2015	0.16509	0.54017	0.306	0.759891
Year2019	-1.19559	1.19007	-1.005	0.315070
PC3	-1.63878	0.63773	-2.570	0.010179

In the zero-inflation part of the selected ZIP-model predicted PC3 and 1+ density to have a negative effect on the probability of not finding 0+ (figure 15). Furthermore, the same model predicted that at any combination of 1+ density and PC3, the probability of not catching 0+ was lowest in pools and riparian modification stations and for 2019. As number of large woody debris and depth loaded negatively to PC3 axis (table 7), these two variables have a positive effect on the probability for not catching 0+.

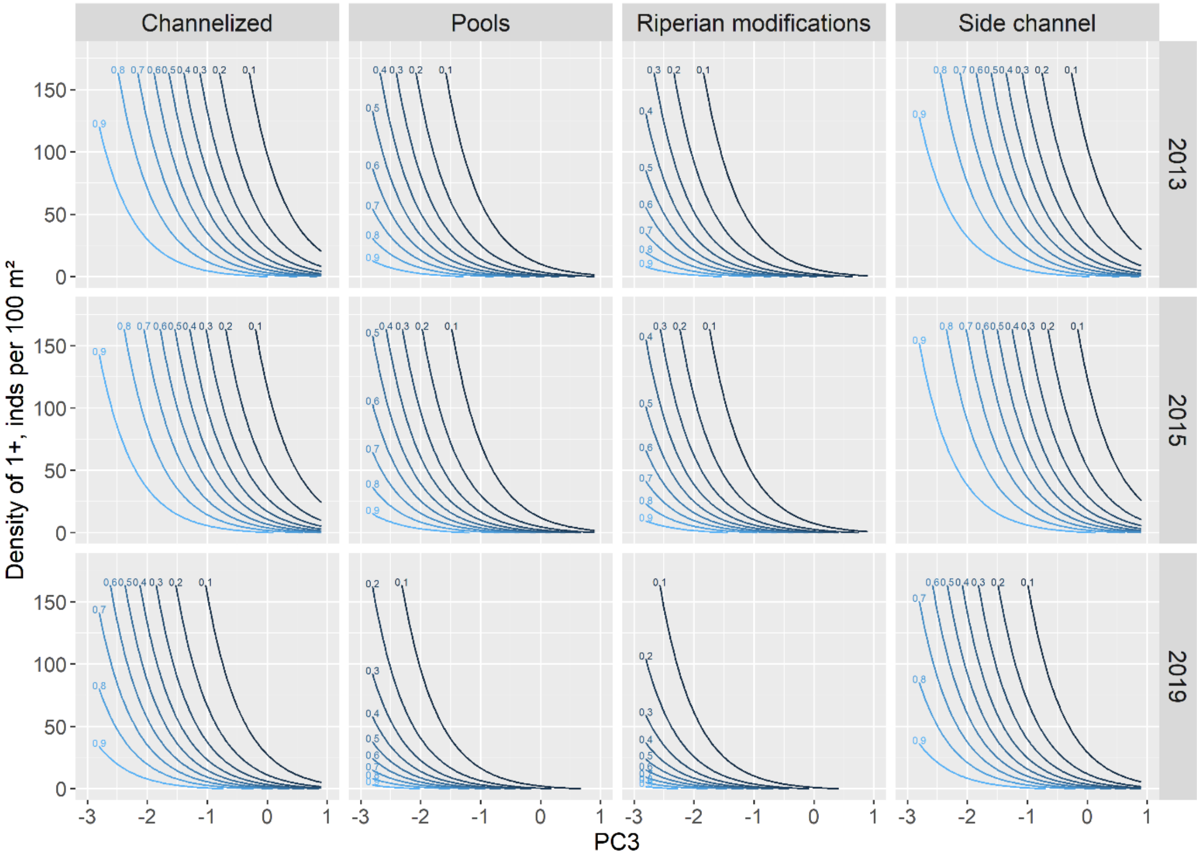


Figure 15 Contour plot of probability of not catching 0+ as function PC3, 1+ density, type of restoration measures and year. Predictions were made from the selected ZIP-model presented in table 12. Contour lines represent predicted probabilities at given levels, as indicated by numbers on top of the contour line (and different colours).

The selected ZIP-model predicted PC2 and PC3 to have a negativ effect on 0+ density for all measure levels. The model estimated highest mean 0+ density in pools and riperian modifications (figure 16). Based on PC-scores provided in table 7, number of large woody debris and dept are the environmental variables that load most heavilly, and important, negatively so, to the PC3-axis, and therefore is suggested to have a positive effect on 0+ density. Likewise, number of pools loads most heacily, and negatively, to the PC2-axis and is therefore suggested by the model to have a positiv effect on 0+ density. Regarding the PC2 effect, water velocity and depth load positively to PC2, and they are therefor suggest to have a negative effect on 0+ density. Further, the model predicted highest density in pools and riperian modification for year 2015, and generelly there are predicted highest density in pools and riperian modification for all years.

Table 12 Predicted estimate for the count model (Poisson) with log link from the selected ZIP-model.

Count model coefficients with log link				
	Estimate	**Std. Error**	**Z value**	**Pr(<|z|)**
(Intercept)	1.98441	0.13473	14.729	< 2e-16
log.density1plus	0.04320	0.03192	1.353	0.17595
Year2015	0.57249	0.06880	8.321	< 2e-16
Year2019	-0.41804	0.16152	-2.588	0.00965
MeasureCoarsePools	0.95801	0.10068	9.516	< 2e-16
MeasureCoarseRiperian modifications	1.06256	0.09136	11.630	< 2e-16
MeasureCoarseSide channel	0.04884	0.10093	0.484	0.62845
PC2	-0.14714	0.07378	-1.994	0.04613
PC3	-0.32559	0.07765	-4.193	2.75e-05

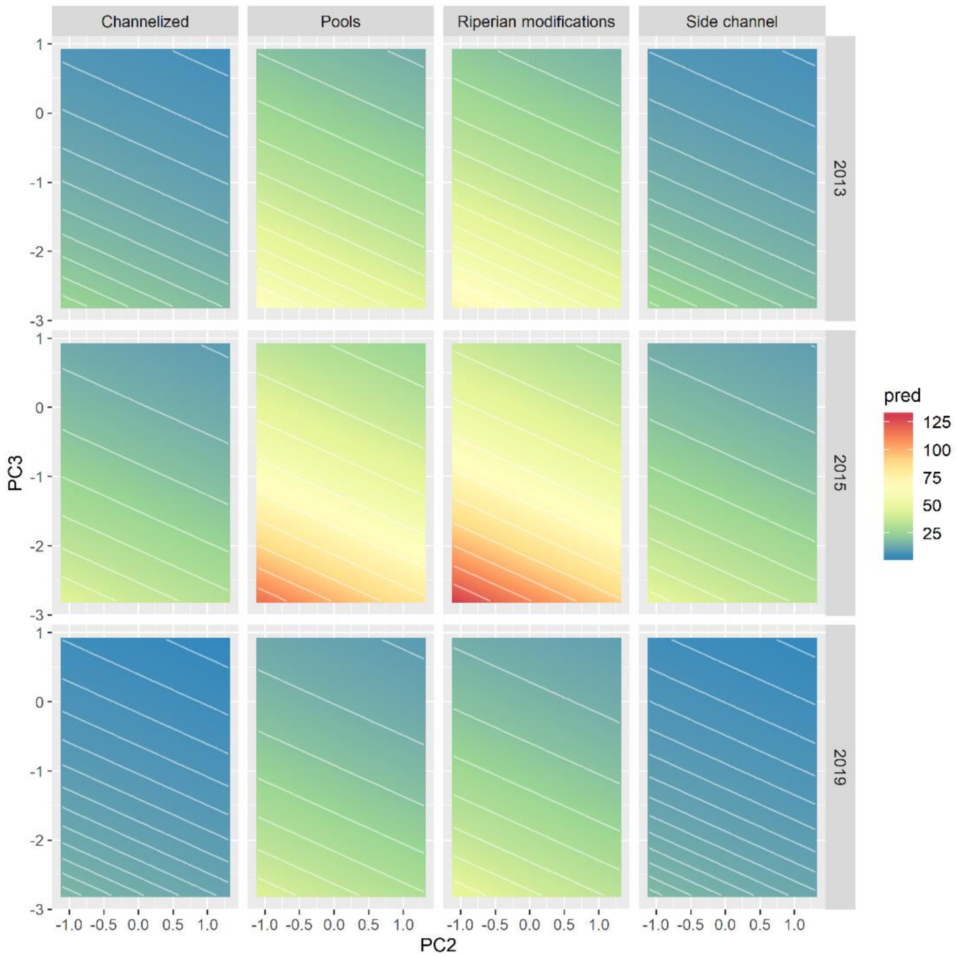


Figure 16 The predicted contour plot of fish density and the effect of PC2 and PC3 for each type of restoration measure and between years. Generally, a negative PC2 and PC3 results in a higher predicted mean fish density.

3.3 ANALYSES OF THE RECAPTURE DATA

The chi-squared test indicated that there was a significant (X-squared = 237.67, df = 1, p-value < 2.2e-16) difference between fish that move and fish that stays in the original marked station and indicated that dispersal occurs.

Further, the selected CAS candidate model attained an AICc-value that was 0.6 units lower than the second-most supported model (table 13, Appendix 5). Based on real estimates (Appendix 6) for the selected candidate model the survival probability for tagged fish in main channel station was 100 percent, and for side channel 83,3 percent per month. The was little support in the data that individual length influenced survival, dispersal or recapture probability (table 13). Density had a negative effect on dispersal from main channel stations.

The beta estimate indicates that Mark had some difficulties with estimating some of the parameters, and this is also reflected in the parameter estimate table for the selected model (table 14). The selected model had 17 parameters, but only 11 parameters were estimated. Five of these parameters are fixed (see chapter 2.5.2). The parameter that was not estimated is the survival probability for individuals that stayed in the main channel, but lack of convergence is most likely due to the real value being close to 1.

Table 13 Model selection metrics for candidate CAS models. S = Survival probability. P = Recapture probability. Phi = The probability of dispersal. HL= Station in main channel, SL= Station in the side channel. (.) = Constant over time, (1-2) = Movement from the original station were the individual were marked and recaptured outside the station. (t) = Time dependent parameter and only data from recapture occasion 2-4 (Time (months) between occasion 2-3 and 3-4). L = The individual covariate length. Zone = Each station.

Model	AICc	ΔAICc	AICc Weights	Model Likelihood	Num. Par	Deviance	-2log(L)
S(Move(.)vsStay(SLvsHL))p(zone)psi(HL(density)SL(.))(1->2,)	368.9815	0	0.20479	1	11	346.1271	346.1271
S(Move(.)vsStay(.))p(zone)psi(HL(density)SL(.))(1->2,)	369.6359	0.6544	0.14764	0.7209	11	346.7816	346.7816
S(Move(.)vsStay(HLvsSL))p(zone)psi(HLvsSL(1->2)(t)	369.9246	0.9431	0.1278	0.624	14	340.5521	340.5521
S(Move(.)vsStay(SLvsHL))p(zone+L)psi(HL(density)SL(.))))(1->2,)	370.1327	1.1512	0.11517	0.5624	12	345.1198	345.1198
S(Move(.)vsStay(SLvsHL))p(zone)psi(HL(density)SL(L))))(1->2,)	370.7476	1.7661	0.08469	0.4135	12	345.7346	345.7346
S(Move(.)vsStay(SLvsHL))p(zone)psi(HL(density) SL (density))(1->2,)	371.1263	2.1448	0.07008	0.3422	12	346.1133	346.1133
S(Move(.)vsStay(L))p(zone)psi(HL(density)SL(.))))(1->2,)	371.3253	2.3438	0.06344	0.3098	12	346.3123	346.3123
S(Move(.)vsStay(SLvsHL))p(zone)psi(HLvsSL +density)))(1->2,)	371.6821	2.7006	0.05307	0.2591	11	348.8277	348.8277
S(Move(.)vsStay(SLvsHL))p(zone+L)psi(HL(density)SL(L))(1->2,)	371.9454	2.9639	0.04653	0.2272	13	344.7598	344.7598
S(Move(.)vsStay(SLvsHL))p(zone)psi(density)))(1->2,)	374.0757	5.0942	0.01604	0.0783	10	353.366	353.366

Table 14 Beta estimate (logit-scale) for the selected candidate model. S = Survival probability. P = Recapture probability. Phi = The probability of dispersal. HL= Station in main channel, SL= Station in the side channel. (.) = Constant over time, HL1 – HL4 = Each station in the main channel. SL1 – SL4 = Each station in the side channel. (1-2) = Movement from the original station were the individual were marked and recaptured outside the station. (t) = Time dependent parameter and only data from recapture occasion 2-4 (Time (months) between occasion 2-3 and 3-4). D = Density. (2-1) = Movement to the original station were the individual were marked from outside the station. Fixed = Fixed parameters see chapter 2.5.2 for the explanation.

Probability type	**Parameter**	**Beta**	**SE**	**LCI**	**UCI**	
S	**Stay HL(.)**	18.56	6230.53	-12193.29	12230.41	
S	**Stay SL(.)**	1.61	1.39	-1.11	4.34	
S	**Move(.)**	0.00	0.00	0.00	0.00	Fixed
P	**Stay HL1**	-2.80	0.73	-4.23	-1.37	
P	**Stay HL2**	-4.17	1.01	-6.15	-2.20	
P	**Stay HL3**	-0.69	0.46	-1.60	0.21	
P	**Stay HL4**	-1.13	0.36	-1.84	-0.41	
P	**Stay SL1**	-1.71	0.47	-2.63	-0.79	
P	**Stay SL2**	-2.02	0.84	-3.68	-0.36	
P	**Stay SL3A**	-2.26	0.58	-3.40	-1.12	
P	**Stay SL4**	0.00	0.00	0.00	0.00	Fixed
Phi	**Move HL (1-2)(.)**	0.00	0.00	0.00	0.00	Fixed
Phi	**Move HL(1-2)(t)**	0.37	0.95	-1.49	2.23	
Phi	**Move (1-2)(t) D.**	-0.20	0.10	-0.41	0.01	
Phi	**Move SL (1-2)(.)**	0.00	0.00	0.00	0.00	Fixed
Phi	**Move SL (1-2)(t)**	-0.57	0.35	-1.26	0.12	
Phi	**Move (2-1)(.)**	0.00	0.00	0.00	0.00	Fixed

The selected CAS model suggested that density only influenced dispersal in the main channel and a tendency of dispersal that decrease with increasing densities (figure 17). In contrast, the probability of dispersal for side channels was estimated constant, but on a generally higher probability level (~0.35 pr month) than for main channel individuals (range: 0-0.39).

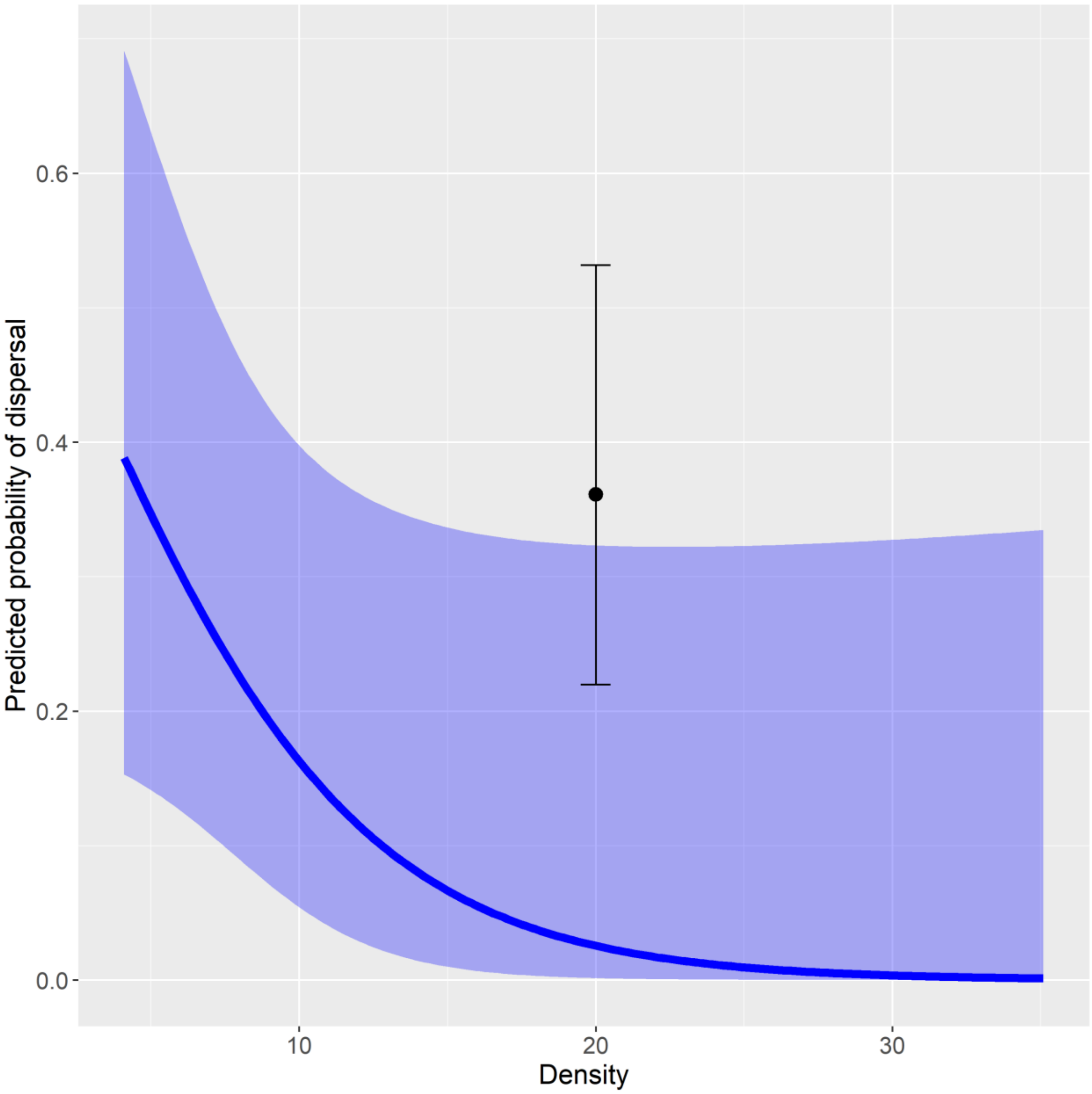


Figure 16 The predicted probability of dispersal for the selected model. The blue line is the predicted probability of dispersal with confidence interval for station in main channel while the point with confidence interval is the predicted probability of dispersal for side channel (which is not dependent on density).

The predicted probability of recapture varied between stations (figure 18). Station HL3 had the highest recapture probability, but in general no differences were estimated between stations. There was little support in the data that the recapture probability was lower in the side channels compared to the main channel, but it may look like that side channels had an overall a stabile recapture probability compared to main channel.

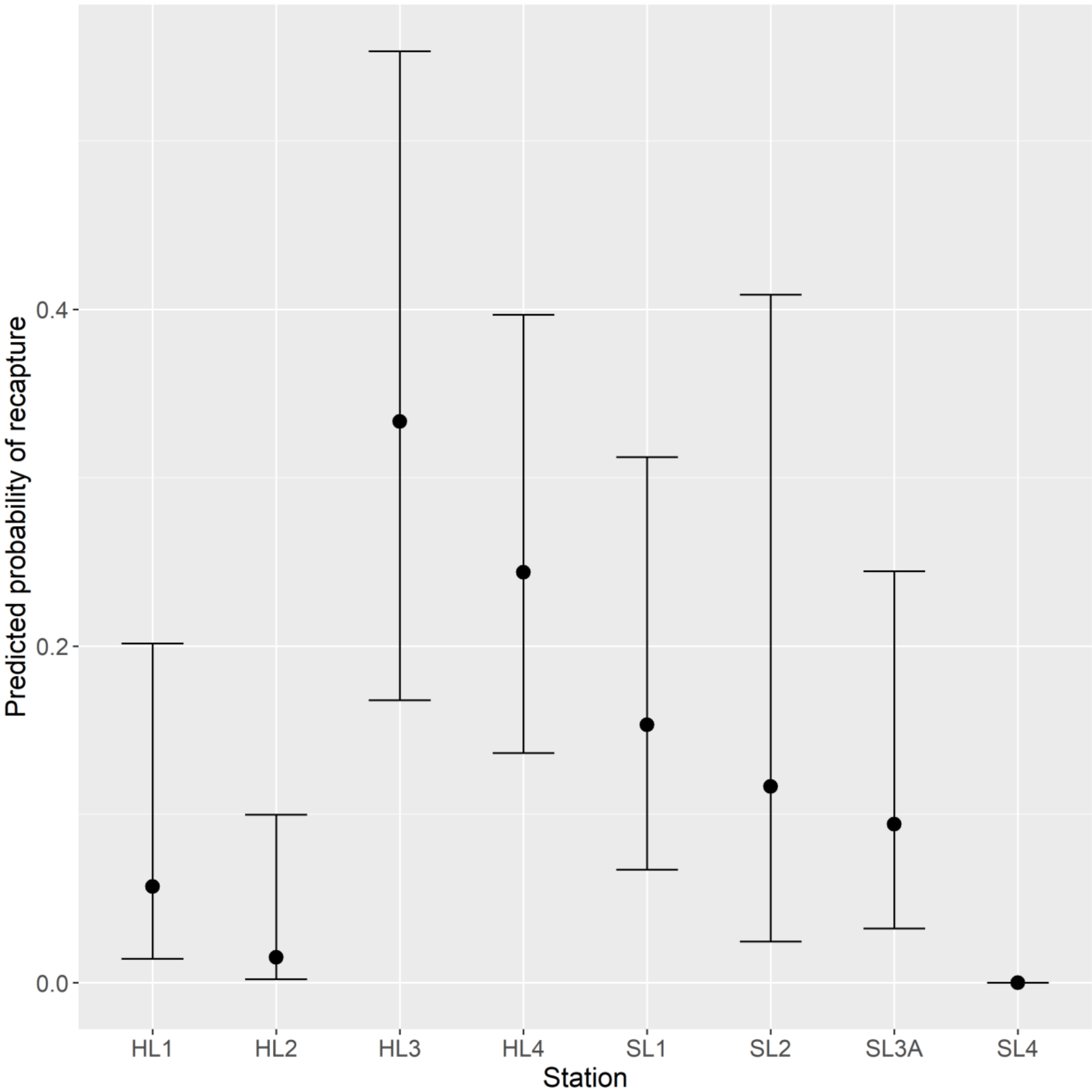


Figure 17 The predicted probability of recapture for each station in Bognelv for the selected model.

4 DISCUSSION

4.1 DISCUSSING THE FINDING AND HYPOTHESIS

Overall, I did not find a pattern that indicated a supressing of the age class 0+ by the present of age class 1+ in this study as hypothesized. The exists difference between type of measure when comparing the environmental variables, but the overlap is quite large. There were predicted highest densities in pools and riparian modification, and not side channel yet side channel is dominated by large woody debris. Further, the dispersal in main channel are negative influenced by density. As hypothesized, the survival probability in the side channel were lower compared to main channel, but difficulties with the estimation in main channel appeared. Lastly, the recapture probability is not influenced by density dependence.

4.1.1 Evidence of density dependence?

I found no evidence that Bognelv is experiencing density dependency. The most important factor influencing and regulating brown trout populations is density dependencies (Elliott, 1990, Jonsson and Jonsson, 2011) a factor not restricted to a type of habitat or geographically region (Grossman and Simon, 2019). Restoration as a treatment is in itself a disturbance that could lead to temporary declines in populations (bottleneck effects) (Nilsson et al., 2015, Nilsson et al., 2017). In the period of 15 years since first restoration measures were implemented in Bognelv, I expected that the brown trout population would have reached its carrying capacity and effects of density dependence should arise. I found no general pattern indicating supressing of age class 0+ by the presence of age class 1+. Furthermore, the probability of finding age class 0+ increased with an increasing density of age class 1+, indicating that the brown trout population is not experiencing density dependency. It may look as though a stabilization of juvenile densities is occurring (figure 10). Either way, this weakens my hypothesis about density dependence for all measures and not only side channel. This means that there is room for more juveniles in the river. The carrying capacity has the ability to fluctuate with the amount of degradation and rehabilitation influencing the size of a population (Lee, 2020). Thus, it does not depend on whether the habitat is good or poor. The population will always adapt to what the habitat can offer. Either way, there are several theoretically explanations for this unexpected result in my analysis, despite the observed stabilization.

Firstly, the limit for conducting measures or maintenance is low in Bognelv. Last maintenance was conducted the same time as the fieldwork was conducted. Stressors are highly important in conservation of biodiversity (Reid et al., 2019). My result can partly be explained similarly to what Nilsson et. al. (2017) detected in their study. They did not find positive biotic response in their study of salmonids and argued that this could be a result of other stressors. They argued that the study time is important because restoration is a disturbance itself. At this point, Bognelv has had very little time to settle when there is a continuation of measures and maintenance of the restored sites. This might mean that the disturbance created by maintenance could impact the brown trout population in a negative manner, resulting in that the population not reaching the carrying capacity. Lastly, the continuation of maintenances almost every other year might explain the stabilization occurring in juvenile densities that density dependence cannot account for.

Secondly, not only stressors and disturbance can influence the population of brown trout in Bognelv. Having no evidence of density dependence in this study could be accounted for by the smolt emigration, adult populations, fertility or hatching success of eggs of brown trout present in Bognelv. These parts of the brown trout life cycle are not studied in Bognelv. Either way, as density dependence is a result of the territorial behaviour of juvenile brown trout, this in turn is dependent on the hatching success, fertility success of the eggs, smolt emigration and the reproductive adult populations of brown trout (Elliott, 1990, Elliott, 1994). All these factors are important for determining how many individual juveniles of age class 0+ emerge from the gravel, which again influences the present of age class 1+. Importantly, if some stadium of the life cycles is compromised or non-existent, it will affect the juvenile population sampled and analysed.

Restoration and habitat improvement in the favour of salmonids has been ongoing for decades, and a tendency of focusing on only one stadium of the life cycle has been highlighted before (Wohl et al., 2005). Salmonids problematize river restoration, as they often are anadromous. This could limit the effect of restoration effort in the river system. As Wohl et. al. (2005) said: “why invest heavily in salmonid spawning and rearing habitat enhancement in a coastal catchment if the main source of mortality is in the coastal lagoon downstream?”. This applies to all parts of planning restoration, and specially Bognelv, as the system is restored with the goal of making suitable nursing habitat for juveniles with the aim to increase the overall abundance of salmonids. Many factors can contribute to increased mortality rates both the in limnological and marine environment. Mortality rates are affected by age, size, sex, survivor density, availability of resources such as food and space, environmental factors such as temperature and oxygen concentration, parasites and diseases, abundance of predators, including fishermen and more (Elliott, 1993). There are some known problems in Norwegian fjord systems that could apply to the population of brown trout in Bognelv. Parasites, such as sea lice (*Lepeophtheirus salmonis),* are a known and increasing problem in Norwegian fjord systems as an negative consequence of fish farming (Søvik, 2015). Sea lice as an ectoparasite increases the mortality rate in smolt and adult brown trout (Søvik, 2015). In Hardanger, Norway, Skaala et. al. (2014) detected increased mortality among the brown trout population with increased amount of sea lice in different part of the smolt emigration. As both Langfjordbotn and Alta fjord has farming locations in their fjord system it will not be unlikely that sea lice are influencing the survival of smolt and adult brown trout, as Skaala et. al. (2014) detected in their study. This cloud again effect that the carrying capacity is not reached as this will determent who many individuals that return to their natal river for spawning. Still there are several factor that need to be for filled before this problem could arise as it is generally concluded that the probability of sea lice as a threat in Northern Norway is small due to low water temperature and low intensity in the farming locations (Anon, 2012). But as the climate change and the temperature in the fjord systems rises or that the in intensity in the farming location increases and increased resistance to delousing substance, this cloud affect the brown trout population in Bognelv.

Furthermore, overexploitation is a great problem for the conservation of biodiversity (Perimack and Sher, 2016). In Norway, fishing with gillnets that reduces the free waterway in sea or fjord is illegal, unless the gillnet is immediately retrieved after placement (Klima og miljødepartementet, 1993). These types of gillnet are not selective enough and are able to harm populations that do not need regulations. Positively, the activity of reducing the illegal sea gillnet fishing has increased (Miljødirektoratet, 2019a, Miljødirektoratet, 2019b). Either way, this is still a major problem in Norwegian fjords and coastal areas, and are time consuming as well as expensive to get rid of/ control. Overexploitation in coastal areas or in fjord systems is a problem the adult population and post-smolt face and is a factor contributing to increased mortally in their marine environment. This could be a reason for why the carrying capacity is not reached as it potentially culls the adult population and thus the number of spawners.

Importantly the hatching success of eggs is crucial for how much juveniles emerges from the gravel (Jonsson and Jonsson, 2011). Bognelv is known for low water velocities during the winter session as well as high velocities during the flooding period in, approximately, June (Hoseth and Josefsen, 2005). The demand for suitable spawning gravel providing stable oxygen concentration and temperature during the incubation time is well investigated (Jonsson and Jonsson, 2011). This may not be ensured enough in the restored sites in Bognelv. If side channels have too low volume of water and low water velocities, there are risks of drying out or freezing to the river bottom during winter. This does not ensure suitable conditions for hatching success. Again, this is not studied in Bognelv and yet could be a reason why the carrying capacity is not reached.

Lastly, if one stadium in the life cycle is compromised or experiencing difficulties this will affect the entire population of brown trout. This needs further investigation if the side channel appears to be suitable nursing areas for juvenile brown trout.

4.1.2 Are the habitat conditions in side channels more favourable then others for juvenile brown trout?

I found perhaps very ambiguous results considering the habitat conditions. Side channel was dominated by large woody debris, but it was predicted highest density in pools and riparian modification. The widespread failure reported for many restoration projects highlights the need to understand why it occurs and how to make restoration more effective (Wohl et al., 2015). Since a lot of time and resources have been spent on Bognelv, it was surprising that only 16.4 percent of the observed environmental variation cloud be explained by restorations measures. The overlap between the different measures is quite large. Importantly, the predicted probability of finding high densities were found for pools and not side channel as expected. Either way, side channel should stand out in a way that contributes to more juveniles. This is partly secured. My result that side channel was dominated by large woody debris are a good indicator that side channels are more adapted to juveniles. Nilsson et. al. (2015) found in their study that large woody debris were the in-stream structure that had the most success when restoring salmonid habitat. The positive effect large woody debris has on juvenile brown trout is generally well-established (Lehane et al., 2002, Vehanen et al., 2010, Antón et al., 2011, Howson et al., 2012, Louhi et al., 2016, Nilsson et al., 2017). This indicates that side channels, in this study, are clearly more adapted for juveniles compared to other measures. Generally, the success with a restoration project is the habitat heterogeneity one provides the stream (Stewart et al., 2009). Large woody debris contributes to securing habitat heterogeneity in Bognelv, which give juveniles the ability to find more shelter and food compared to other measures.

In contrast, pools, that I found to have the highest densities predicted densities, are not dominated by large woody debris. Pools was dominated by more depth and high velocities compared to side channels. These types of habitat conditions are not usually what juveniles in other rivers have been found to favours (Armstrong et al., 2003, Jonsson and Jonsson, 2011). When conducting the fieldwork in the second sampling round, parts of the selected stations were dried out due to drought. Pools are crucial during drought, as they provide a water column that can ensure lower temperatures and therefore enough oxygen for survival (Elliott, 2000). The drought could be the reasons for why I found higher predicted densities in pools, and not in side channels. It is hard to reject or support my hypothesis based on these findings do to the fact that the drought made an unusual situation and might not represent the normality for Bognelv.

4.1.3 What affects the survival probability estimation in these analyses?

I found that the survival probability in main channel were higher than in the side channel. Still, the survival probability in the main channel were perhaps not estimated correctly. Problems with estimating the survival probability in Mark often occurrs when the survival probability is close to about 100 percent (White and Cooch, 2019). Additionally, low sample size could affect the estimation. Often with larger sample sizes, there is a smaller chance of random sampling errors, and the optimum sampling size is dependent on the parameter of the phenomenon studied (Marshall, 1996). There is limitations when it comes to sampling size, and very large datasets would be unnecessary since the sampling error is inversely proportional to the square root of the sample size (Marshall, 1996). Most likely, the non-estimated survival probability in main channel is a result of random sampling error cause by a small sampling size. That the survival probability in the main channel is closer to 100 percent is highly unlikely as the main channels are both measure pools and channelized in these analyses. In addition, the most dominated environmental variables in main channel both for measure pools and channelized is high water velocities. Bognelv was restored with the aim of securing suitable nursing areas for juvenile because of the high velocities that occurred before restoration (Hoseth and Josefsen, 2005). Lastly, the drought could have influenced the water velocities in main channel, which again cloud explain the estimation problem. Either way, there is no foundation for comparison between side channel and main channel as there is too many factors in consideration and lastly, this is the first survival estimate from Bognelv and no reference values exists. This makes it hard to reject or support the hypothesis that the survival probability in side channels are lower than in the main channel. Lastly, no density dependency was found that could have explained the hypothesized differences in the survival probability between side channel and main channel. Further, although data from 2019 in this thesis can not be compared with each outer, this is still data that can be used in future studies.

4.1.4 Evidence for that dispersal is density dependent?

This study found that dispersal in main channel occurred with low densities. It is expected that mobile organism moves in effort of ensuring survival and growth or reproduction. This is to meet their energy requirements and further growth (Nevoux et al., 2019). Density dependence, intraspecific competition, makes it more difficult for individuals to survive (Elliott, 1987). Elliott (1987) observed a tendency for migration from areas of high density to those of low density in his study. This was expected to be seen in Bognelv, that migration from side channels to other areas would occur due to density dependency. This was not the case for Bognelv. Surprisingly, these findings could indicate that main channel is a poor area for juveniles, as density dependency was absent and dispersal appeared to increase with lower densities. Most likely, this is a result of the environmental conditions found in the main channel. Fornaroli et. al. (2016) found in their study that the factor that limits the densities of trout were water velocity, substrate characteristics and refugia availability. Importantly, Fornaroli et. al. (2016) highlight that high velocities provided a less suitable habitat regardless of other physical characteristics. In addition, hydrological variability in structuring brown trout populations is well established (Tissot et al., 2017), and could explain the tendency occurring in the main channel. As mention, Bognelv is only partially restored to ensure agricultural land use and flood control, meaning Bognelv is still quite straight (Hoseth and Josefsen, 2005). Some in-stream structures in Bognelv, such as pools, weirs and stone groups were manmade in order to ensure lower velocities. This could mean that the observed velocities are enough for juvenile to disperse out of this habitat, and that the in-stream structures in the main channel have had a limited effect. Generally, my result indicate that the environmental conditions are still a problem that in the main channel, as dispersal appears to occur with low densities. There is a leakage of individuals in this river, both from side channels and main channels (figure 17). Leakage in side channels could partly be explained by the smolt emigration but how much cannot be accounted for because the stationary antenna stop functioning. Lastly, there is little evidence that the dispersal occurred are density dependent as hypothesized.

4.1.5 The recapture probability might be influenced

I found that the recapture probability between stations in side channels and main channel varied quite. Different behavioural phenotypes could have different roles and effects on the ecosystem (Näslund et al., 2018). Salmonid populations consist commonly of different behavioural types which are characterized by different activity patterns (Näslund et al., 2018). Interesting, Näslund et. al. (2018) found that behavioural in brown trout influenced recapture probability. Size had a slightly positive effect on recapture probability for passive fish but a clear negative effect on active fish. This could apply for the recapture probability shown in the side channels in Bognelv. As mention earlier, there was a period of drought when conducting fieldwork, and the vital function pools haves in periods of serious drought is known (Elliott, 2000). This drought could have influenced the recapture probability through fish that have a passive behaviour being forced to become active in order to ensure survival. Recapture probability was likely influenced by the drought and differed from normal conditions. In addition, the drought can increase mortality which further influences the recapture probability (Elliott, 1990). The fact that side channels seem to have a lower recapture probability and the mention drought, it is hard to find support for my hypothesis. Lastly, as no density dependency was found, there is little support that my hypothesis should be true. Either way, as the drought makes an unusual situation for Bognelv and probably does represent the normal condition, there is too little information to ether reject or support the hypothesis.

4.2 HAS THE ABUNDANCE OF BROWN TROUT IN BOGNELV INCREASED SINCE RESTORATION BEGAN AND DO SIDE CHANNELS FUNCTION AS SUITABLE NURSING HABITAT?

Sødal (2014) claimed that partial restoration could ensure biological goals, while Nilsson et. al. (2015) claimed that if their study had been fully restored perhaps a biological response could have been detected. Importantly, restoration and nature management is a combination of politics and science (Wohl et al., 2005). This will automatically set some ground rules for how to define a goal. The focus towards river restoration outside the river corridor has begun to set root, but still there is a high proportion of restoration projects that do not achieve significant improvements in river function (Wohl et al., 2015). Central is the process of identifying restoration goals based on an appropriate model of ecosystem response and the recovery of biotic community composition (Wohl et al., 2015). This is highly problematic in the Norwegian management system, as the Norwegian system is based on hearings of all involved parties (Justis og beredskapsdepartementet, 1970). Bognelv has set little root outside the river corridor due to different interest like flood control, agricultural land use and recreation values (Hoseth and Josefsen, 2005, Hoseth, 2010, Hoseth, 2013, Bjordal, 2019). The management system and the different interest in Bognelv limit Bognelv to partial restoration, and a full restoration is unlikely to take place. Therefore, maintenance and evaluation of measures is necessary to ensure biological goals. One goal in Bognelv, which is the first aim in this thesis, has been to ensure sustainable populations of salmonids, and it appears that this is partly reached. Brown trout population in Bognelv has increased since before restoration (Schedel, 2010, Austvik, 2012, Sødal, 2014, Nordhov and Paulsen, 2016), but my result show that there is room for more fish. It appears that the juvenile densities are stabilizing, yet with no density dependency detected. This raises some questions which is touch upon the second aim in this thesis. Are side channels suitable nursing areas for juvenile brown trout and have side channels achieved their purpose as a restoration measure?

Why does it seem like the juvenile densities are stabilizing despite no density dependency? Side channels are dominated by large woody debris and vegetation variables in these analyses, and side channels are clearly more adapted as nursing areas compared to other measures. In addition, it is not possible to interpret the survival probability, as it is highly unlikely that the main channel has a survival probability of 100 percent. Furthermore, dispersal due to density dependence is nonexisting, and recapture probability is not representative for a normal situation. Representativity is crucial for the generalization of a population (Marshall, 1996). When the drought makes an unusual situation in Bognelv, the representativity is not secured, problematizing the conclusion. Generally, there is an increase in the abundance of brown trout, but these results do not give a good indication if side channels are functioning properly. Importantly, side channels are not the only measure conducted, meaning side channel combined with other measures can be the reason for this increase together. The result from the dispersal analysis are perhaps a good indicator of why other measures are important, as main channel in these analyses can be interpret as unsuitable for juveniles. Dispersal in main channel increases with low densities could be explained though unsuitable abiotic conditions at the sampling moment. This highlights the importance of habitat heterogeneity (Einum et al., 2007, Nilsson et al., 2017) that gives the opportunities of seeking shelter in other parts in the river system. This evidence that dispersal increases with low densities in the main channel will perhaps emphasize the importance of side channels. If this tendency of dispersal in the main channel represent the normality due to harsh condition all year around, side channels would then be the only explanation of why the abundance of brown trout has increased since restoration. Lastly, side channels do appear to be suitable nursing areas. This is either way a good indication that side channel function to a certain extent, but the drought made it difficult to conclude this for sure, as no density dependence was reached and that the exist several uncertainties concerning the results.

4.3 SOURCE OF ERROR

This study has some weaknesses. First there is no data from before channelization which makes it impossible to know what the reference situation was like in Bognelv before major impact. It makes it difficult to strive for a natural condition as this information will never exist. In addition, the data for this thesis was analysed with data from earlier years. Much less data was collected from 2019 than from earlier years. PIT-tagging of fish is time consuming and a selection of how many stations were necessary to make sure fieldwork did not take too much time compared to other parts of this thesis. This could affect the result since no density dependence was detected. If data from 2019 were larger and more representative compared to earlier years, perhaps the results would have been different.

Furthermore, only four occasion from capture-recapture data were collected as time became an issue. Issues with the last scanning also appeared. In November ice and snow accumulated in the river and safety concerns to scan certain parts of the river appeared. Originally, a last scanning was planned to be performed in January, but ice, snow and temperature were not allowed for safe field work to conduct the last scanning. Only four occasion that Mark had to prosses were not enough to detect certain phenomena (etc. size specific dispersal) expected to be seen, and estimations done by Mark were often not accounted for (Lebreton et al., 1992). Furthermore, survival probability can not account for individuals that disperse outside the river system (smolt emigration) as the stationary antenna was defective. This affect the survival probability estimates, as all individuals are assumed re-encounter or not re-encounter for by Mark. Lastly, PIT-tagging is selective, as a certain size criterion must be achieved before inserting a tag. This affects the ability to fit size-dependent survival models, recapture probability and dispersal only to age class 1+ or older. Age class 0+ are too small to tag and the importance of age class 0+ on population regulation (density dependence) in brown trout has not been studied.

4.4 SUGGESTIONS TO FURTHER RESEARCH

As no density dependency was found, this should be investigated further. It would also be interesting to investigate the spawning sites, egg densities, hatching success as well as the adult population. Furthermore, as PIT-tagging has now been introduced to Bognelv, this project should be continued and monitor the change over time and quantify if general differences between side channel and main channel exists. Bognelv will unlikely be fully restored, and to secure the brown trout population, this project should still investigate the effects on brown trout. Lastly, perhaps Atlantic salmon and Artic charr should get some attention and investigate why these species do not respond as well as brown trout to restoration, and perhaps ensure populations of all three salmonids.

5 CONCLUSION

This study can conclude with that there is an increase in the abundance of brown trout since the restoration began, which was the first aim with this thesis. Importantly, the brown trout population in Bognelv has not reached its carrying capacity. I did not find evidence of density dependency in any investigate stations. The second aim with this thesis were to conclude if side channels were function as suitable nursing area for juvenile brown trout. This is hard to conclude for sure as several expectations were not for filled due to no detected density dependency and the drought made an unusual situation. Lastly, side channels are more adapted as nursing area compared to other measures and is a good indication that side channel function to a certain extent.

6 References

ANON 2012. Lakselus og effekter på vill laksefisk - fra individuell respons til bestandseffekter. Temarapport fra Vitenskaplig råd for lakseforvaltning nr 3, 56 s. Trondheim, Norway.

ANTÓN, A., ELOSEGI, A., GARCÍA-ARBERAS, L., DÍEZ, J. & RALLO, A. 2011. Restoration of dead wood in Basque stream channels: effects on brown trout population. *Ecology of Freshwater Fish,* 20**,** 461-471.

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**,** 143-170.

AUSTVIK, K. L. 2012. *LET THE RIVER LIVE -CASCADE-EFFECTS OF RESTORATION IN BOGNELV.* Master, Norwegian University of Life Sciences.

BENAYAS, J. M. R., NEWTON, A.C., DIAZ A., M. BULLOCK, J.M. 2009. Enhancement of Biodiversity and Ecosystem Services by Ecological Restoration: A Meta-Analysis. *SCIENCE,* 325**,** 1121-1124.

BERNHARDT, E. S. & PALMER, M. A. 2011. River restoration: the fuzzy logic of repairing reaches to reverse catchment scale degradation. *Ecological Applications,* 21**,** 1926-1931.

BJORDAL, A. 2019. Tiltaksplan Bognelv - justering av Oladammen. *In:* DIRECTIVE, T. N. W. R. A. E. (ed.).

BOHLIN, T., HAMRIN, S., HEGGBERGET, T. G., RASMUSSEN, G. & SALTVEIT, S. J. 1989. ELECTROFISHING - THEORY AND PRACTICE WITH SPECIAL EMPHASIS ON SALMONIDS. *Hydrobiologia,* 173**,** 9-43.

BURNHAM, K. P. & ANDERSON, D. R. 2002. *Model Selection and Multimodel Inference. A Practical Information - Theoretic Approach,* New York, Springer.

EINUM, S., NISLOW, K. H., REYNOLDS, J. D. & SUTHERLAND, W. J. 2007. Predicting population responses to restoration of breeding habitat in Atlantic salmon. 45**,** 930-938.

ELLIOTT, J. 2000. Pools as refugia for brown trout during two summer droughts: trout responses to thermal and oxygen stress. 56**,** 938-948.

ELLIOTT, J. M. 1987. Population Regulation in Contrasting Populations of Trout Salmo trutta in Two Lake District Streams. *The Journal of Animal Ecology,* 56**,** 83.

ELLIOTT, J. M. 1990. Mechanisms Responsible for Population Regulation in Young Migratory Trout, Salmo trutta. III. The Role of Territorial Behaviour. 59**,** 803.

ELLIOTT, J. M. 1993. The pattern of natural mortality throughout the life cycle in contrasting populations of brown trout, Salmo trutta L. *Fisheries Research,* 17**,** 123-136.

ELLIOTT, J. M. 1994. *Quantitative ecology and the brown trout,* Oxford, Oxford University Press.

ELLIOTT, J. M. 2002. Shadow competition in wild juvenile sea-trout. 61**,** 1268-1281.

FORNAROLI, R., CABRINI, R., SARTORI, L., MARAZZI, F., CANOBBIO, S. & MEZZANOTTE, V. 2016. Optimal flow for brown trout: Habitat – prey optimization. *Science of The Total Environment,* 566-567**,** 1568-1578.

FORSETH, T. & FORSGREN, E. 2008. El-fiskemetodikk - Gamle problemer og nye utfordringer. Trondheim, Norway: Norwegian Insitute for Nature Research.

GIBBONS, J. W. & ANDREWS, K. M. 2004. PIT tagging: Simple technology at its best. *Bioscience,* 54**,** 447-454.

GROSSMAN, G. D. & SIMON, T. N. 2019. Density-dependent effects on salmonid populations: A review. *Ecology of Freshwater Fish*.

HAGEN, D. & SKRINDO, A. B. 2010. Restaurering av natur i Norge – et innblikk i fagfeltet, fagmiljøer og pågående aktivitet Throndheim, Norge: Norsk Insitutt for Naturforskning.

HOSETH, K. A. 2008a. Rapport Bognelv. Tiltak utført i Bognelva høsten 2008. Utførte tiltak. *In:* DIRECTIVE, T. N. W. R. A. E. (ed.).

HOSETH, K. A. 2008b. Rapport Bognelva. Tiltakene i Bognelva utført høsten 2007. *In:* DIREKTIVE, T. N. W. R. A. E. (ed.).

HOSETH, K. A. 2010. Rapport Bognelva. Vedlikeholdstiltak 2010. Utførte vedlikeholdstiltak august 2010. *In:* DIRECTIVE, T. N. W. R. A. E. (ed.).

HOSETH, K. A. 2013. Rapport Bognelva, Miljøtiltak 2012. Utførte miljøtiltak høsten 2012. *In:* DIRECTIVE, T. N. W. R. A. E. (ed.).

HOSETH, K. A. & JOSEFSEN, A. 2005. Tiltak i vassdrag, Miljøplan for Bognelva, Helhetlig plan.

HOWSON, T. J., ROBSON, B. J., MATTHEWS, T. G. & MITCHELL, B. D. 2012. Size and quantity of woody debris affects fish assemblages in a sediment-disturbed lowland river. *Ecological Engineering,* 40**,** 144-152.

JOLLIFFE, I. T. & CADIMA, J. 2016. Principal component analysis: a review and recent developments. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences,* 374**,** 20150202.

JONSSON, B. & JONSSON, N. 2011. *Ecology of Atlantic Salmon and Brown Trout: Habitat as a template for life histories,* Dordrecht, Springer Netherlands, Dordrecht.

JONSSON, B. & MATZOW, D. 1979. *Fisk i vann og vassdrag : om økologien til aure, røyr og laks,* Oslo, Aschehoug.

JUSTIS OG BEREDSKAPSDEPARTEMENTET 1970. Forvaltningsloven.

KLEMETSEN, A., AMUNDSEN, P. A., DEMPSON, J. B., JONSSON, B., JONSSON, N., 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.

KLIMA OG MILJØDEPARTEMENTET 1993. Lov om laksefisk og innlandsfisk mv. (lakse- og innlandsfiskloven). Klima- og miljødepartementet.

LAMBERT, D. 1992. Zero-Inflated Poisson Regression, with an Application to Defects in Manufacturing. *Technometrics,* 34**,** 1.

LEBRETON, J.-D., BURNHAM, K. P., CLOBERT, J. & ANDERSON, D. R. 1992. Modeling Survival and Testing Biological Hypotheses Using Marked Animals: A Unified Approach with Case Studies. *Ecological Monographs,* 62**,** 67-118.

LEE, A. M. 2020. *Bereevne - økologi* [Online]. Store Norsk Leksikon. Available: https://snl.no/bereevne_-_%C3%B8kologi [Accessed 27.04 2020].

LEHANE, B. M., GILLER, P. S., O'HALLORAN, J., SMITH, C. & MURPHY, J. 2002. Experimental provision of large woody debris in streams as a trout management technique. 12**,** 289-311.

LOUHI, P., VEHANEN, T., HUUSKO, A., MÄKI-PETÄYS, A. & MUOTKA, T. 2016. Long-term monitoring reveals the success of salmonid habitat restoration. *Can. J. Fish. Aquat. Sci.,* 73**,** 1733-1741.

MARSHALL, M. N. 1996. Sampling for qualitative research. *Family Practice,* 13**,** 522-526.

MCCULLAGH, P. & NELDER, J. A. 1989. *Generalized linear models,* London, Chapman and Hall.

MILJØDIREKTORATET. 2019a. *Kampen mot ulovlig laksefiske intensiveres* [Online]. Miljødirektoratet. Available: https://www.miljodirektoratet.no/aktuelt/nyheter/2019/april-2019/intensiverer-kampen-mot-ulovlig-laksefiske/ [Accessed 29.04 2020].

MILJØDIREKTORATET. 2019b. *Lakseoppsynet avdekker færre ulovligheter* [Online]. Miljødirektoratet. Available: https://www.miljodirektoratet.no/aktuelt/nyheter/2019/juli-2019/lakseoppsynet-avdekker-farre-ulovligheter/ [Accessed 29.04 2020].

MILJØDIREKTORATET. 2020. *Laksefiske i Norge* [Online]. Miljødirektoratet. Available: http://tema.miljodirektoratet.no/no/Tema/Arter-og-naturtyper/Villaksportalen/Laksefiske-i-Norge/ [Accessed 05.02 2020].

MORRIS, C. 2015. Multivariate Analysis of Ecological Data Using Canoco 5, 2nd Edition.

NEVOUX, M., FINSTAD, B., DAVIDSEN, J. G., FINLAY, R., JOSSET, Q., POOLE, R., HÖJESJÖ, J., AARESTRUP, K., PERSSON, L., TOLVANEN, O. & JONSSON, B. 2019. Environmental influences on life history strategies in partially anadromous brown trout (Salmo trutta , Salmonidae). *Fish and Fisheries*.

NILSSON, C., POLVI, L. E., GARDESTRÖM, J., HASSELQUIST, E. M., LIND, L. & SARNEEL, J. M. 2015. Riparian and in-stream restoration of boreal streams and rivers: success or failure? *Ecohydrology,* 8**,** 753-764.

NILSSON, C., SARNEEL, J. M., PALM, D., GARDESTRÖM, J., PILOTTO, F., POLVI, L. E., LIND, L., HOLMQVIST, D. & LUNDQVIST, H. 2017. How Do Biota Respond to Additional Physical Restoration of Restored Streams? *Ecosystems,* 20**,** 144-162.

NORDHOV, P. F. R. & PAULSEN, S. M. 2016. *River Restoration in Bognelv, Northern Norway Salmonid and Macroinvertebrate Responses to Restoration Measures.* Master, Norwegian University of Life Sciences.

NÄSLUND, J., WENGSTRÖM, N., WAHLQVIST, F., ALDVÉN, D., ZÁVORKA, L. & HÖJESJÖ, J. 2018. Behavioral type, in interaction with body size, affects the recapture rate of brown trout Salmo trutta juveniles in their nursery stream. *Integrative Zoology,* 13**,** 604-611.

PEARSON, K. 1901. LIII. On lines and planes of closest fit to systems of points in space. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science,* 2**,** 559-572.

PERIMACK, R. B. & SHER, A. A. 2016. *An Introduction to Conservation Biology,* Massachusetts, USA, Sinauer Associates, Inc. Publishers.

PIERCE, R., PODNER, C. & CARIM, K. 2013. Response of Wild Trout to Stream Restoration over Two Decades in the Blackfoot River Basin, Montana. *Transactions of the American Fisheries Society,* 142**,** 68-81.

REID, A. J., CARLSON, A. K., CREED, I. F., ELIASON, E. J., GELL, P. A., JOHNSON, P. T. J., KIDD, K. A., MACCORMACK, T. J., OLDEN, J. D., ORMEROD, S. J., SMOL, J. P., TAYLOR, W. W., TOCKNER, K., VERMAIRE, J. C., DUDGEON, D. & COOKE, S. J. 2019. Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological Reviews,* 94**,** 849-873.

RONI, P. 2019. Does River Restoration Increase Fish Abundance and Survival or Concentrate Fish? The Effects of Project Scale, Location, and Fish Life History. *Fisheries,* 44**,** 7-19.

SCHEDEL, J. B. 2010. *River restoration and habitat improvements in the sub-arctic river Bognelva – effects on anadromous fish.* Master, Norwegian University of Life Sciences.

SKAALA, Ø., KÅLÅS, S. & BORGSTRØM, R. 2014. Evidence of salmon lice-induced mortality of anadromous brown trout (Salmo trutta) in the Hardangerfjord, Norway. *Marine Biology Research,* 10**,** 279-288.

STEWART, G. B., BAYLISS, H. R., SHOWLER, D. A., SUTHERLAND, W. J. & PULLIN, A. S. 2009. Effectiveness of engineered in-stream structure mitigation measures to increase salmonid abundance: a systematic review. 19**,** 931-941.

SØDAL, K. M. 2014. *Salmonid and Macroinvertebrate Responses to River Restoration Measures in the Channelized River Bognelv, Northern Norway.* Master, Norwegian University of Life Sciences.

SØVIK, G. 2015. *Lakselus* [Online]. Store Norske Leksikon. Available: https://snl.no/lakselus [Accessed 29.04 2020].

TISSOT, L., BRET, V., CAPRA, H., BARAN, P. & GOURAUD, V. 2017. Main potential drivers of trout population dynamics in bypassed stream sections. *Ecology of Freshwater Fish,* 26**,** 336-346.

VEHANEN, T., HUUSKO, A., MÄKI-PETÄYS, A., LOUHI, P., MYKRÄ, H. & MUOTKA, T. 2010. APPLIED ISSUES: Effects of habitat rehabilitation on brown trout (Salmo trutta) in boreal forest streams. 55**,** 2200-2214.

WAGH, Y. S. & KAMALJA., K. K. 2017. Zero-inflated models and estimation in zero-inflated Poisson distribution. Communications in Statistics - Simulation and Computation:1-18. *Communications in Statistics - Simulation and Computation,* 47.

WHITE, G. C. & BURNHAM, K. P. 1999. Program MARK: survival estimation from populations of marked animals. *Bird Study,* 1**,** 120-139.

WHITE, G. C. & COOCH, E. G. 2019. *Program Mark - A Gentle Introduction*.

WHITE, S. L., GOWAN, C., FAUSCH, K. D., HARRIS, J. G. & SAUNDERS, W. C. 2011. Response of trout populations in five Colorado streams two decades after habitat manipulation. *Canadian Journal of Fisheries and Aquatic Sciences,* 68**,** 2057-2063.

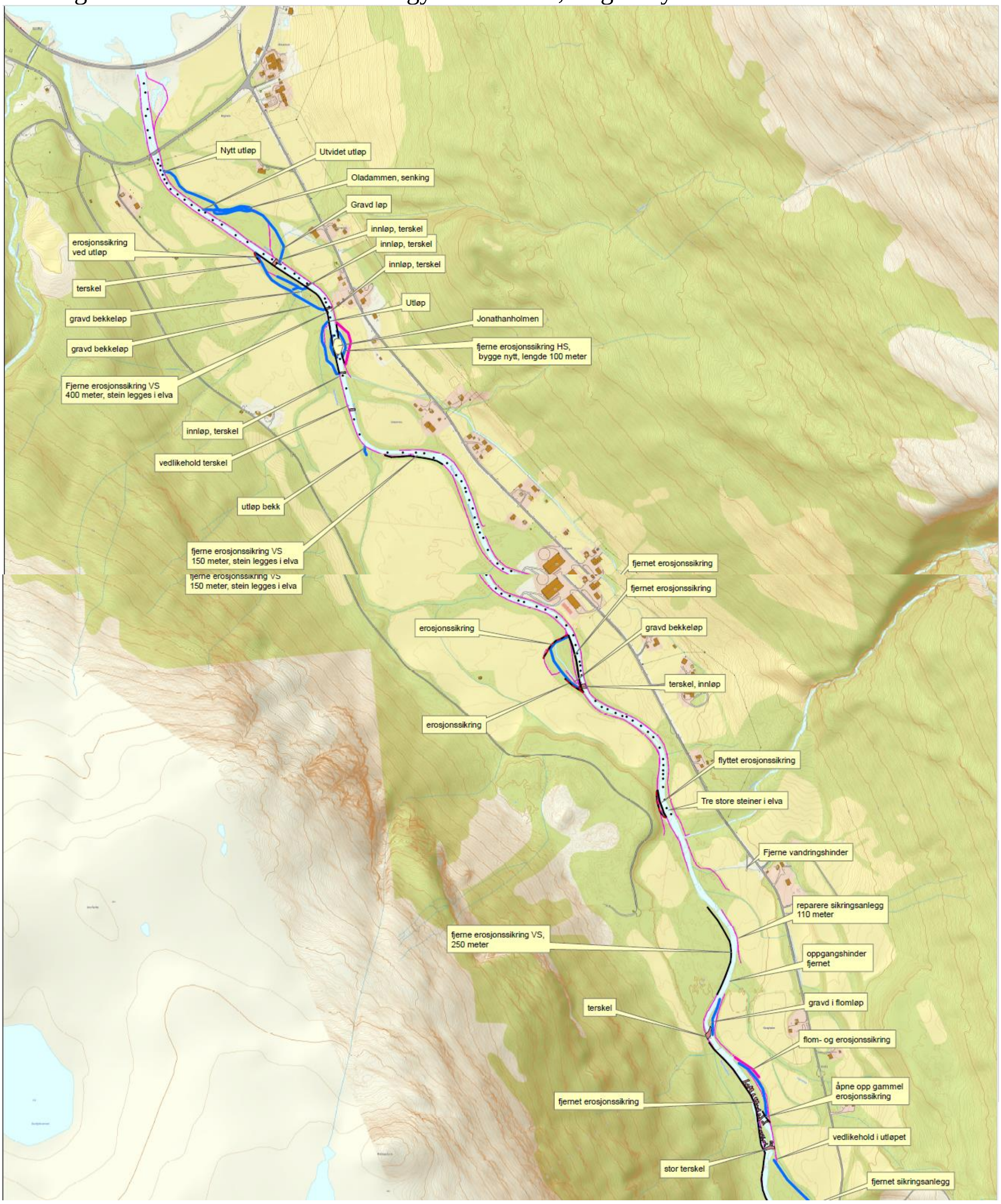
WOHL, E., ANGERMEIER, P. L., BLEDSOE, B., KONDOLF, G. M., MACDONNELL, L., MERRITT, D. M., PALMER, M. A., LEROY POFF, N. & TARBOTON, D. 2005. River Restoration. *WATER RESOURCES RESEARCH,* 41.

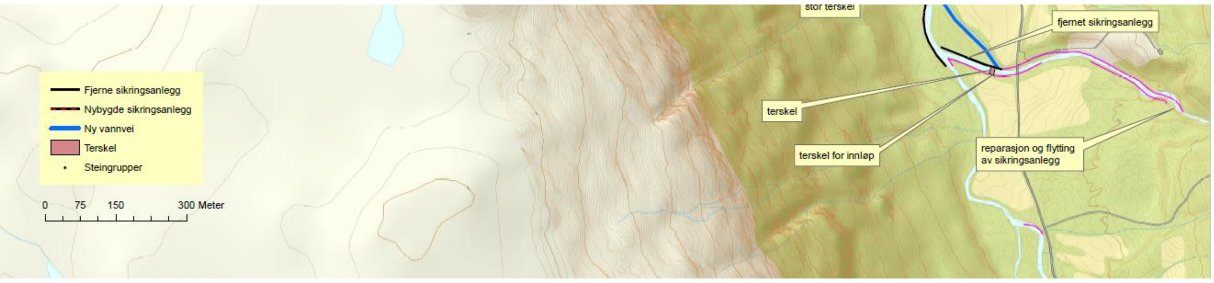
WOHL, E., LANE, S. N. & WILCOX, A. C. 2015. The science and practice of river restoration. *Water Resources Research,* 51**,** 5974-5997.

7 APPENDICES

7.1 APPENDIX 1

Map over restoration measures conducted in Bognelv. Regained from Anders Bjørdal at The Norwegian Water Resources and Energy Directorate, originally as a PDF.

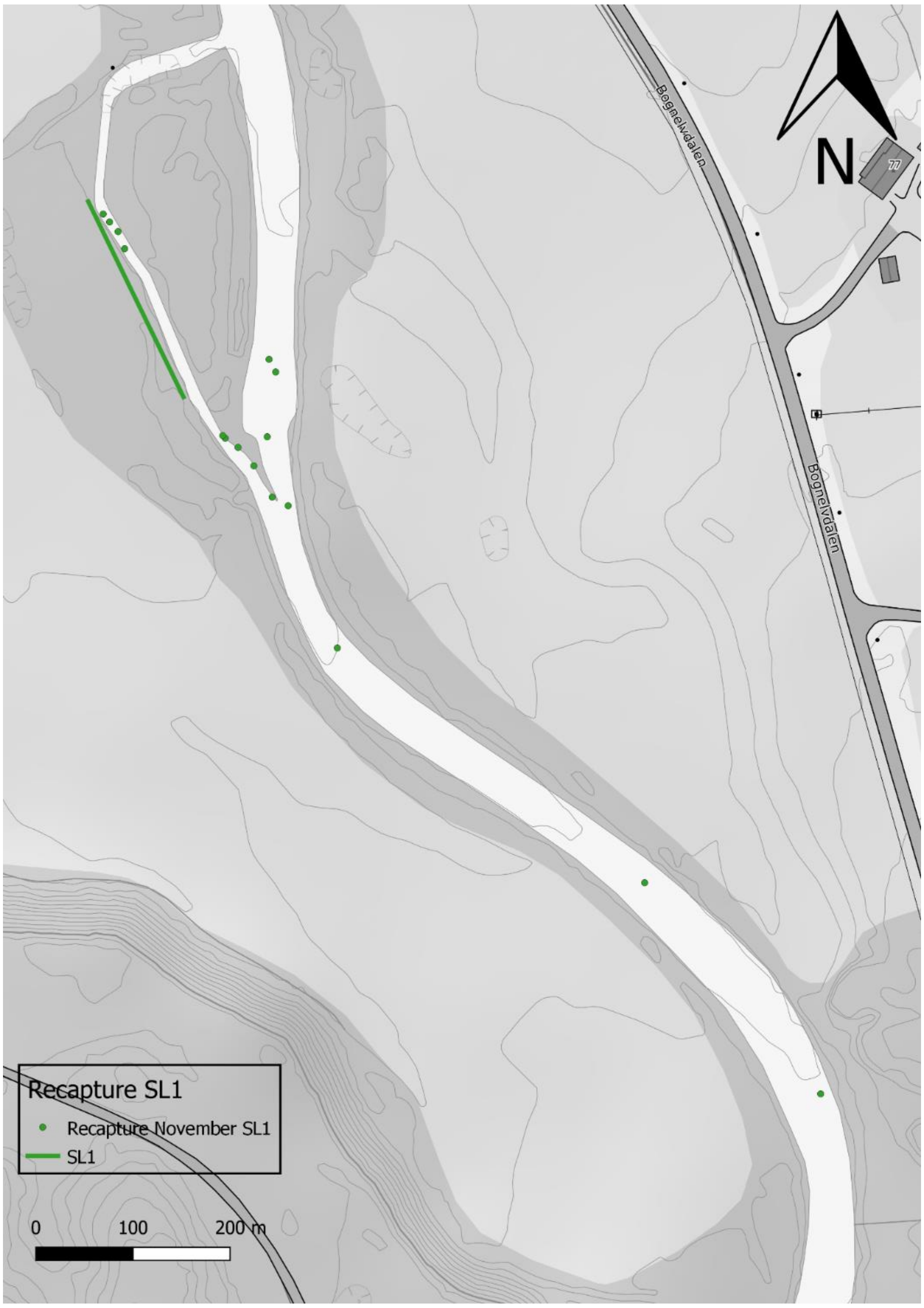




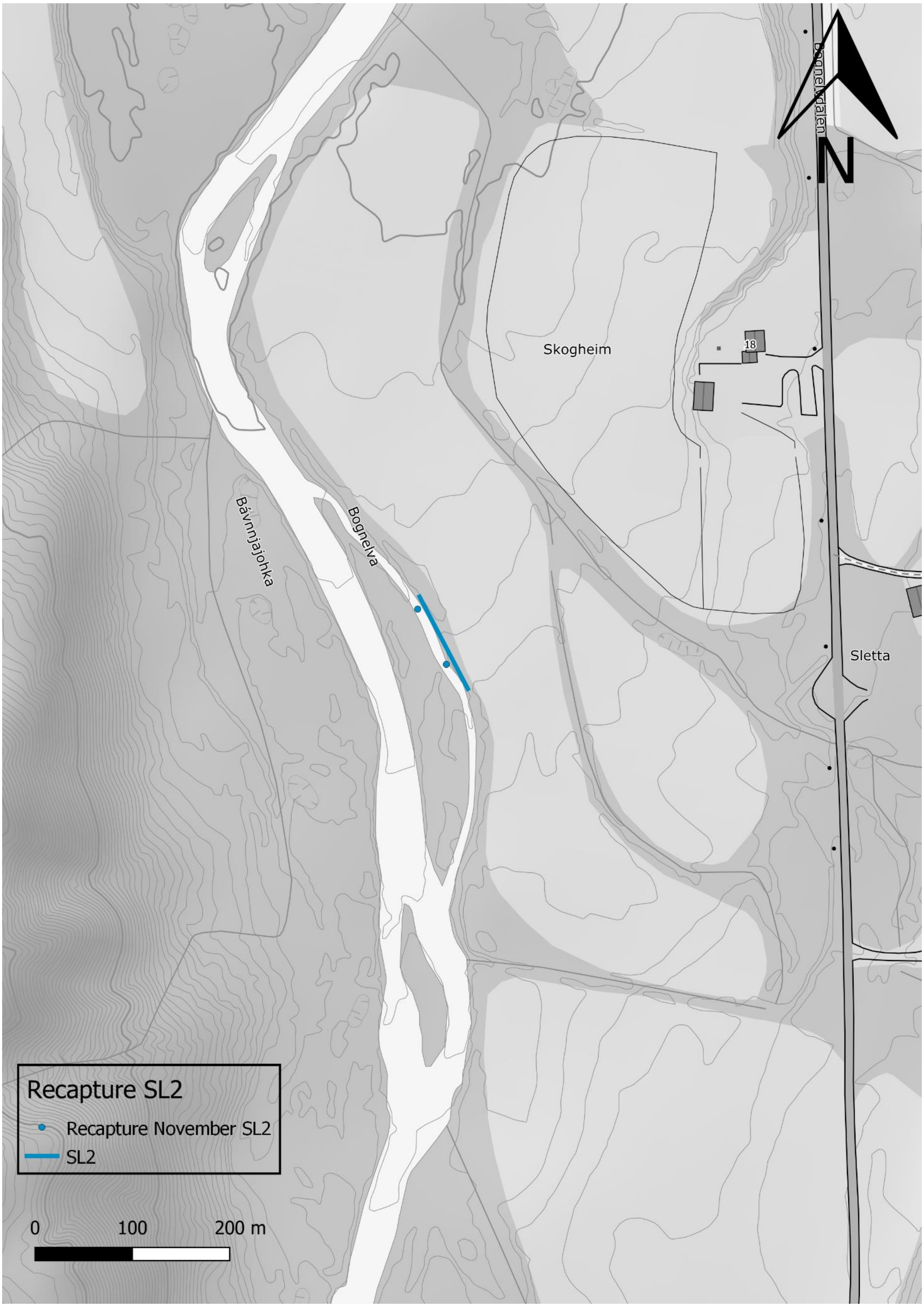
7.2 APPENDIX 2

Maps over the recaptured fish from the last sampling round done with the portable antenna.

Detections and movement in Station SL1

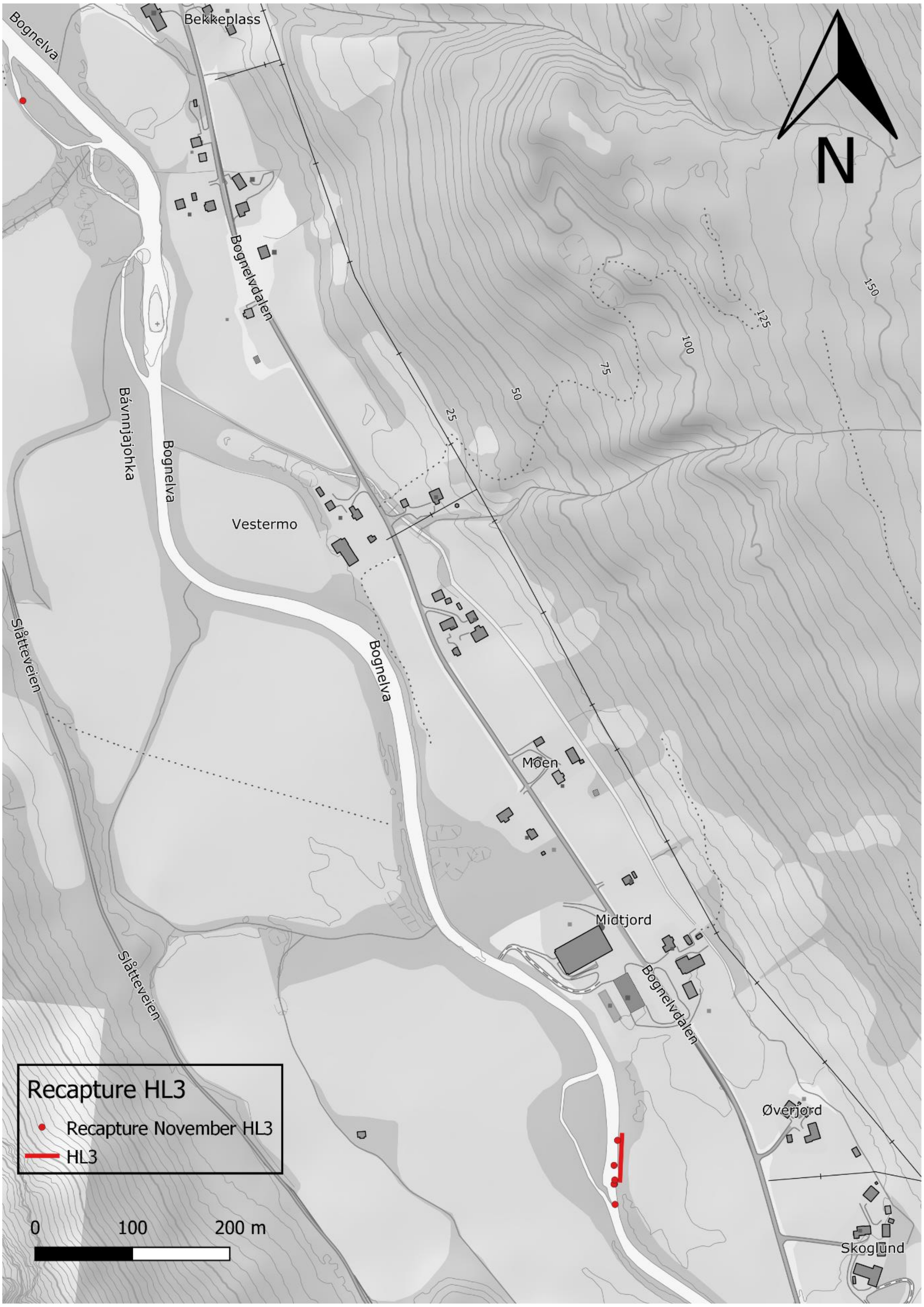


Detections and movement in Station SL2

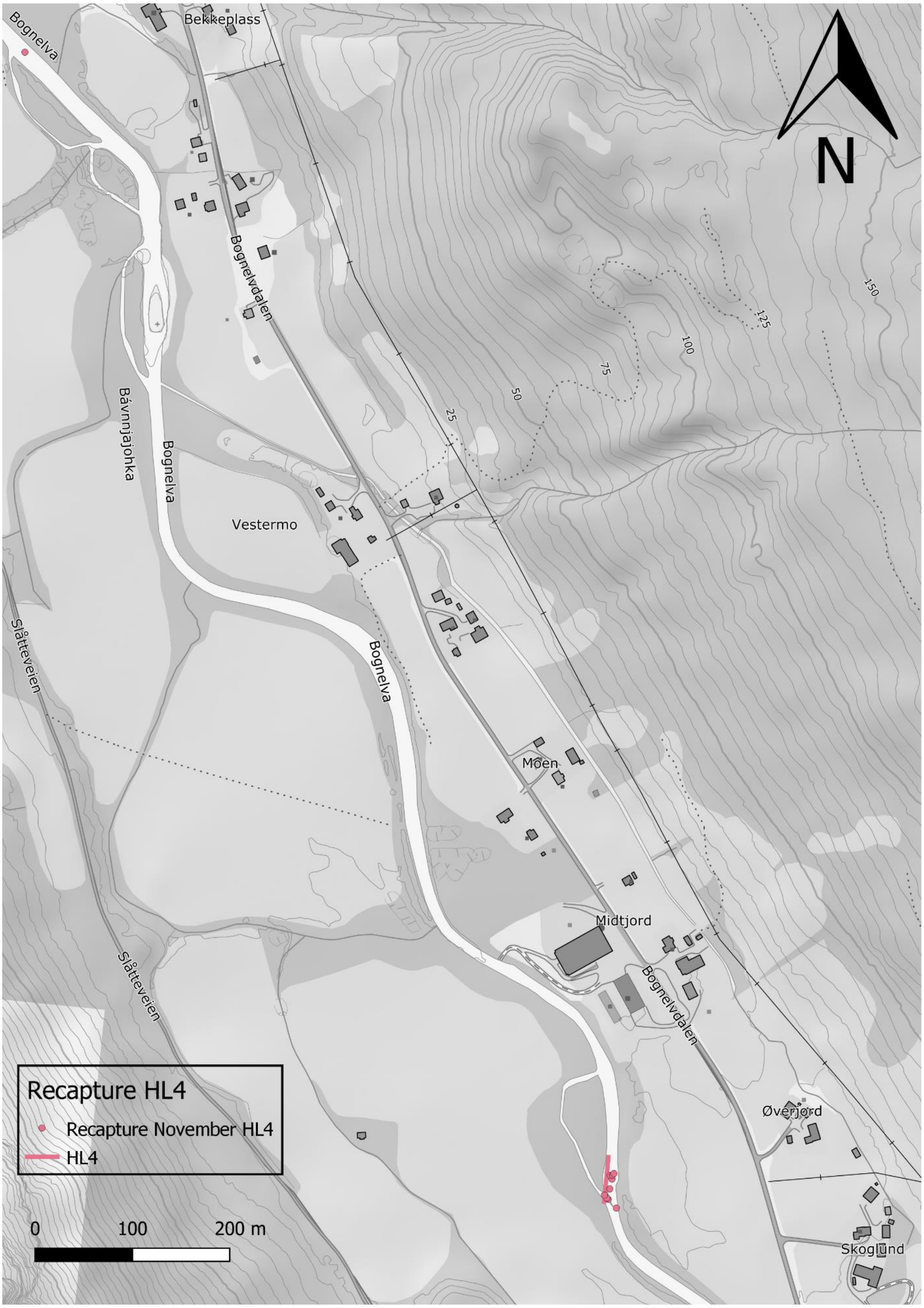


Detections and movement in Station SL3a

Detections and movement in Station HL3



Detections and movement in Station HL4



7.3 APPENDIX 3

Method for measuring environmental variables

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 in cm at all five transects at 0, 25, 50, 75 and 100 precent at each transect.

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 and larger than 2 square meters. The number of pools were counted.

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.

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 Qgis.

7.4 APPENDIX 4

Scale transformed PCA

```
Detrended correspondence analysis with 26 segments.
Rescaling of axes with 4 iterations.

                  DCA1    DCA2    DCA3     DCA4
Eigenvalues     0.1875 0.06831 0.03514 0.030004
Decorana values 0.2724 0.06008 0.02418 0.007785
Axis lengths    1.2768 1.11094 0.80670 0.726358
```

7.5 APPENDIX 5

Candidate models from CAS analysis from program Mark.

Table A2 Candidate models from CAS analysis. S = Survival probability. P = Recapture probability. Phi = The probability of dispersal. HL= Station in main channel, SL= Station in the side channel. (.) = Constant over time, (1-2) = Movement from the original station were the individual were marked and recaptured outside the station. (t) = Time dependent parameter and only data from recapture occasion 2-4 (Time (months) between occasion 2-3 and 3-4). L = The individual covariate length. Zone = Each station.

Model	AICc	Δ AICc	AICc Weights	Model Likelihood				
S(Move(.)vsStay(SLvsHL))p(zone)psi(HL(density)SL(.))))(1->2,)	368.9815	0	0.20479	1	11	346.1271	346.1271	20:03:30:10:55:19
S(Move(.)vsStay(.))p(zone)psi(HL(density)SL(.))))(1->2,)	369.6359	0.6544	0.14764	0.7209	11	346.7816	346.7816	20:04:02:10:21:55
S(Move(.)vsStay(HLvsSL))p(zone)psi(HLvsSL(1->2)(t)	369.9246	0.9431	0.1278	0.624	14	340.5521	340.5521	20:02:14:09:23:31
S(Move(.)vsStay(SLvsHL))p(zone+L)psi(HL(density)SL(.))))(1->2,)	370.1327	1.1512	0.11517	0.5624	12	345.1198	345.1198	20:04:02:09:26:40
S(Move(.)vsStay(SLvsHL))p(zone)psi(HL(density)SL(stL))))(1->2,)	370.7476	1.7661	0.08469	0.4135	12	345.7346	345.7346	20:04:02:09:22:14
S(Move(.)vsStay(SLvsHL))p(zone)psi(HL(density) SL (density))(1->2,)	371.1263	2.1448	0.07008	0.3422	12	346.1133	346.1133	20:03:30:10:36:09
S(Move(.)vsStay(L))p(zone)psi(HL(density)SL(.))))(1->2,)	371.3253	2.3438	0.06344	0.3098	12	346.3123	346.3123	20:03:30:10:59:54
S(Move(.)vsStay(SLvsHL))p(zone)psi(HLvsSL +density)))(1->2,)	371.6821	2.7006	0.05307	0.2591	11	348.8277	348.8277	20:03:30:10:41:49
S(Move(.)vsStay(SLvsHL))p(zone+L)psi(HL(density)SL(L))))(1->2,)	371.9454	2.9639	0.04653	0.2272	13	344.7598	344.7598	20:04:02:09:25:18
S(Move(.)vsStay(SLvsHL))p(zone)psi(density)))(1->2,)	374.0757	5.0942	0.01604	0.0783	10	353.366	353.366	20:03:30:10:42:40
S(Move(.)vsStay(SLvsHL))p(zone)psi(HL(.) SL (.,siste(L))(1->2,)	374.1152	5.1337	0.01572	0.0768	11	351.2608	351.2608	20:03:30:10:11:26
S(Move(.)vsStay(SLvsHL))p(zone)psi(HL(.) SL (L)(1->2,)	374.5541	5.5726	0.01263	0.0617	11	351.6997	351.6997	20:03:30:10:08:59
S(MovevsStay)p(zone)psi(.)	375.5763	6.5948	0.00757	0.037	10	354.8666	354.8666	20:02:13:14:15:19
S(Move(.)vsStay(HLvsSL)(t))p(zone)psi(HLvsSL(1->2)(t)	375.9873	7.0058	0.00617	0.0301	17	339.9675	339.9675	20:02:14:09:20:54

S(Move(.)vsStay(SLvsHL*density))p(zone)psi(HL(density)SL(.))(1->2,)	376.6299	7.6484	0.00447	0.0218	11	353.7755	353.7755	20:04:02:11:05:20
S(Move(.)vsStay(SL(density)HL(.))p(zone)psi(HL(density)SL(.))(1->2,)	376.6299	7.6484	0.00447	0.0218	11	353.7755	353.7755	20:04:02:11:13:15
Check Par. Cnt. S(Move(.)vsStay(SLvsHL))p(zone)psi(HL(L) SL (L)(1->2,)	376.7032	7.7217	0.00431	0.021	12	351.6902	351.6902	20:03:30:10:07:28
S(Move(.)vsStay(HLvsSL))p(zone)psi(HLvsSL(1->2)	376.9649	7.9834	0.00378	0.0185	12	351.9519	351.9519	20:02:13:14:37:54
S(Move(.)vsStay(HLvsSL))p(zone)psi(.)	377.0489	8.0674	0.00363	0.0177	11	354.1946	354.1946	20:02:13:14:35:34
S(.)p(zone)psi(.)	377.7209	8.7394	0.00259	0.0126	11	354.8666	354.8666	20:02:13:14:09:39
Check Par. Cnt. S(Move(L)vsStay(HLvsSL +L))p(zone)psi(HLvsSL(1->2)(t)	378.2563	9.2748	0.00198	0.0097	18	339.9914	339.9914	20:03:30:09:58:05
S(Move(.)vsStay(HL(density)SL(.)))p(zone)psi(HL(density)SL(.))(1->2,)	379.2153	10.2338	0.00123	0.006	11	356.3609	356.3609	20:04:02:11:11:41
S(MovevsStay(t))p(zone)psi(.)	379.3429	10.3614	0.00115	0.0056	12	354.3299	354.3299	20:02:13:14:22:38
S(Move(t)vsStay(t))p(zone)psi(.)	381.1104	12.1289	0.00048	0.0023	13	353.9247	353.9247	20:02:13:14:25:44
Check Par. Cnt. S(Move(.)vsStay(density))p(zone)psi(HL(density)SL(.))(1->2,)	381.3739	12.3924	0.00042	0.0021	12	356.3609	356.3609	20:04:02:11:09:12
S(Move(.)vsStay(HLvsSL)(t))p(zone)psi(HLvsSL(1->2)	383.3279	14.3464	0.00016	0.0008	15	351.7542	351.7542	20:02:14:09:15:55

7.6 APPENDIX 6

Real estimate for the selected candidate model in Mark.

Table A3 Real estimate for the selected candidate model in Mark. S = Survival probability. P = Recapture probability. Phi = The probability of dispersal. (1-2) = Movement from the original station were the individual were marked and recaptured outside the station. (2-1) = Movement to the original station were the individual were marked from outside the station. Fixed = Fixed parameters see chapter 2.5.2 for the explanation.

Real Function Parameters of S(Move(.)vsStay(SLvsHL))p(zone)psi(HL(density)SL(.))))(1->2,)					
			95% Confidence Interval		
Parameter	**Estimate**	**Standard Error**	**Lower**	**Upper**	
--------------------------	--------------	--------------	--------------	--------------	
1:S 1:stay	**1.0000000**	**0.5425951E-04**	**0.9998936**	**1.0001063**	
2:S 1:stay	**0.8338894**	**0.1928956**	**0.2467565**	**0.9871678**	
3:S 2:move	**1.0000000**	**0.0000000**	**1.0000000**	**1.0000000**	**Fixed**
4:p 1:stay	**0.0571429**	**0.0392347**	**0.0143342**	**0.2016440**	
5:p 1:stay	**0.0151515**	**0.0150363**	**0.0021302**	**0.0998073**	
6:p 1:stay	**0.3333334**	**0.1028689**	**0.1679187**	**0.5533356**	
7:p 1:stay	**0.2439024**	**0.0670664**	**0.1365552**	**0.3968511**	
8:p 1:stay	**0.1532068**	**0.0609151**	**0.0672350**	**0.3123026**	
9:p 1:stay	**0.1165760**	**0.0870298**	**0.0245643**	**0.4087980**	
10:p 1:stay	**0.0942162**	**0.0494358**	**0.0323391**	**0.2445652**	
11:p 1:stay	**0.0000000**	**0.0000000**	**0.0000000**	**0.0000000**	**Fixed**
12:Psi 1 to 2	**0.0000000**	**0.0000000**	**0.0000000**	**0.0000000**	**Fixed**
13:Psi 1 to 2	**0.0368961**	**0.0459681**	**0.0030259**	**0.3259455**	
14:Psi 1 to 2	**0.0368961**	**0.0459681**	**0.0030259**	**0.3259455**	
15:Psi 1 to 2	**0.0012848**	**0.0039072**	**0.3291820E-05**	**0.3345581**	
16:Psi 1 to 2	**0.0012848**	**0.0039072**	**0.3291820E-05**	**0.3345581**	
17:Psi 1 to 2	**0.3874696**	**0.1520533**	**0.1526891**	**0.6894911**	
18:Psi 1 to 2	**0.3874696**	**0.1520533**	**0.1526891**	**0.6894911**	
19:Psi 1 to 2	**0.0645034**	**0.0613253**	**0.0093196**	**0.3357162**	

20:Psi 1 to 2	**0.0645034**	**0.0613253**	**0.0093196**	**0.3357162**	
21:Psi 1 to 2	**0.0000000**	**0.0000000**	**0.0000000**	**0.0000000**	**Fixed**
22:Psi 1 to 2	**0.3612290**	**0.0820805**	**0.2197282**	**0.5317530**	
23:Psi 1 to 2	**0.3612290**	**0.0820805**	**0.2197282**	**0.5317530**	
24:Psi 1 to 2	**0.3612290**	**0.0820805**	**0.2197282**	**0.5317530**	
25:Psi 1 to 2	**0.3612290**	**0.0820805**	**0.2197282**	**0.5317530**	
26:Psi 1 to 2	**0.3612290**	**0.0820805**	**0.2197282**	**0.5317530**	
27:Psi 1 to 2	**0.3612290**	**0.0820805**	**0.2197282**	**0.5317530**	
28:Psi 1 to 2	**0.3612290**	**0.0820805**	**0.2197282**	**0.5317530**	
29:Psi 1 to 2	**0.3612290**	**0.0820805**	**0.2197282**	**0.5317530**	
30:Psi 2 to 1	**0.0000000**	**0.0000000**	**0.0000000**	**0.0000000**	**Fixed**

7.7 APPENDIX 7

Coordinates for stations 2019.

Table A4 Coordinated for stations 2019.

	Start nedstrøms		**Slutt oppstrøms**		
Stasjon:	Punkt N	Punkt Ø	Punkt N	Punkt Ø	Type tiltak
SL1	70*00.511'	022*19.161'	70*00.482'	022*19.224'	Sideløp
SL2	69*59.907'	022*19.759'	69*59.888'	022*19.793'	Sideløp
SL3-A	70*01.067'	022*18.157'	70*01.042'	022*18.195'	Sideløp
SL3-B	70*01.049'	022*18.210'	70*01.036'	022*18.268'	Sideløp
SE1	70*00.900'	022*18.452'	70*00.891'	022*18.518	Sideelv
SE2	70*00.248'	022*19.681'	70*00.252'	022*19.764'	Hovedløp kulp
HL1	70*00.917'	022*18.447'	70*00.889'	022*18.452'	Hovedløp referanse
HL2- ref	70*01.030'	022*18.372'	70*01.012'	022*18.419'	Hovedløp referanse
HL3- ref	70*00.504'	022*19.276'	70*00.481'	022*19.276'	Hovedløp kulp
HL4	70*00.493'	022*19.257'	70*00.470'	022*19.255'	Sideelv
SL4	69*59.724'	022*19.934'	69*59.701'	022*19.977'	Sideløp

7.8 APPENDIX 8

Photos from the fieldwork

Figure A19 Station SE2 during the first field trip

Figure A18 Station SE2 during the second field trip

Figure A20 Station SE1 the first field trip

Figure A21 Station SE1 the second field trip

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