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Facilitating migration for anadromous salmonids through restoration and compensation; challenges and opportunities

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Environment and Natural Resources

Acknowledgements

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(All photos are taken by author unless otherwise specified)

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Summary

Many of the rivers that flow into the inner part of the Oslo fjord have for a long time been subjected to habitat change done to facilitate a growing human population with all the requirements that follow. This has led to severe loss of essential habitats for spawning, nursery areas and feeding grounds for the anadromous fish populations in the fjord. Reclaiming and/or restoring areas that were barred by human activities, or making new areas available to compensate for human-induced habitat loss, is one of the goals in the new “Oslo fjord rescue plan” from the Ministry of Climate and Environment. The removal of the Bjørumssaga dam in the river Isielva and a possible fish ladder in the river Lysakerelva are good examples of ecological restoration and compensation of migration barriers, respectively. This thesis aimed to estimate smolt production for these two rivers, assess consequences the initiatives would have on the local trout population, explore the potential above the migration barriers for the anadromous species and to look at positive and negative aspects of “removing” the barriers.

Fish data was sampled using electrofishing and PIT telemetry with a portable backpack reader, and habitat characterization was done according to the a method developed by Ulrich Pulg. Population density and smolt production were based on instantaneous mortality rates and the estimated 0+ densities, as the mark-recapture data logging failed. This rendered very large instantaneous death rates, which resulted in annual mortality rates of 74 % to 80 %. Adjusted mortality rates were used to estimate the smolt production of the two rivers.

The salmon smolt production estimates based on adjusted mortality rates were very high in Lysakerelva (20.7 ind./100 m^2) and high in Isielva (15.9 ind./100 m^2) compared to the smolt production estimates given for the 80 National Salmon Watercourses in 2007. The trout smolt production estimates in Lysakerelva (3.3 ind./100 m^2) and Isielva (1.2 ind./100 m^2) were much lower. There were some indications of phenotypic differences between both the rivers and stations, both salmon and trout 0+ were in general longer in Lysakerelva than Isielva, and there were differences in length above and below migration barriers. This was especially noticeable between areas with and without salmon presence, and there was a strong indication that the presence of salmon suppressed the local trout population. Due to hatchery efforts, the smolt production potential above the migration barriers was already realised for salmon in the river stretches where the alevins/parr are released. This could be replaced by natural spawning in Lysakerelva, but not in Isielva, as the fish do not reach the migration barrier every year, and thus, would not use the stetches above this either in those years. Allowing anadromous populations past the barriers could benefit salmon sport angling, but at the cost of accessible year-round angling on local river trout. Presently, the barriers act as an

insurance in case the downstream stretch becomes contaminated by pathogens or parasites like e.g. *Gyrodactylus salaris,* and would no longer be effective if the migration barriers were removed.

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Introduction

Some of the first post glacial freshwater fish immigrants to settle in Norway followed the sea ice edge across the ocean. They could feed and grow in sea water and use the rivers as spawning- and nursery areas. As the land lifted, some of the previously anadromous areas became inaccessible, and separated the populations in genetically different sub-populations. Two of the earliest immigrants were the salmonids Atlantic salmon (*Salmo salar*) and brown- or sea trout (*Salmo trutta*), and we look at them as native species to Norway. I will hereby refer to the species as salmon and trout. During their juvenile stage in freshwater, both can use the same habitats and they co-exists in many of our waterways. After migrating to sea, as smolts, the habitat and area use is very different in the two species; salmon being an ocean-dwelling species, whereas trout is a fjord- and coastal species. How they coexist during their juvenile stage in freshwater depends both on the competition and morphological differentiation. The salmon is better adapted for higher water currents, and uses less of their time actively feeding in the water column, but the trout is more aggressive. Thus, the realized niche of salmon parr is restricted in slow-flowing and of trout in fast flowing areas due to competitive superiority from the other. Without the competition of the other (allopathy), they can expand their use of the freshwater areas (Jonsson, 2011).

Both salmonids are important, both from an ecological and an anthropocentric point of view. They cause top-down interactions on smaller fish or fish eggs, insects and macroinvertebrates as well as providing an important food source to larger fish, birds, otter (*Lutra lutra*) and mink (*Neovison vison*) (Jonsson, 2011). From a human utilitarian point of view, salmonids are important for recreational, cultural and provisioning values (Piccolo, 2018) and, especially in later years, as a gene pool used in the aquaculture breeding process. Atlantic salmon is also one of the most pollution sensitive species we have in Norway, making it an excellent indicator species for contamination (Jonsson, 2011). Last, but not least, the salmonids should be valued for their own intrinsic value.

Historically, many of the rivers that flow into the inner part of the Oslo fjord have been subjected to channelization, flood protection and infrastructure projects like dams and culverts. This has been done to facilitate intensive industry located nearby the rivers and a growing population with all requirements that follow (Anonymous, 2020). Habitat change is one of the main challenges for the trout in the Oslo fjord area (Finstad, 2011). This has led to severe loss of essential habitats for spawning, nursery areas and feeding grounds before migrating to the sea (Jonsson, 2011), and there is a strong political interest in strengthening the population of *salmon and trout* in the fjord. One of the goals in a new “Oslo fjord rescue plan” is to map negative contributions in rivers and streams where sea trout historically spawned, and plan mitigating actions (Anonymous, 2021a). One of the most direct contributions is to make larger areas available, either by reclaiming and/or restoring areas that were barred by human activities like dams or culverts, or by mitigating actions making new areas available to compensate for human-induced habitat loss in other nearby locations.

The removal of the Bjørumssaga dam in the river Isielva and establishing a possible fish ladder in the river Lysakerelva are good examples of ecological restoration and compensation, respectively. Both systems are located in densely populated areas and bear visible marks of earlier human activities. The old dam in Isielva is an absolute migration barrier, separating the upstream and downstream populations. This dam is also in very bad condition, holding back years of collected fine sediment and posing a potential danger, both to humans and to the ecosystem below if it collapses. The new highway, E16, will be built above the Bjørumssaga dam (Figure 2) and as a mitigating action for the negative impact the building phase will pose upon the river ecosystem, a safe removal of both the dam and the fine sediments is planned, thus restoring natural migration into the upper reaches of Isielva for salmon and trout (Merkesdal, 2020). In the Lysaker area, both Oslo and Bærum municipality envision the Lilleaker area below the Fåbrofossen waterfall (Fåbrofossen) as a new city district (Figure 2). To maintain good ecological status according to the European water framework directive's requirements, specific milestone goals are under development in the new zoning plan (J. Hovland, 2011). There are, however, many strong actors in play connected to the development of new urban infrastructure, as the Lilleaker area is close to the capital and located in one of Norway's best real estate areas. Short-term economic gain can easily overshadow the long-term value a healthy river with a harvestable fish stock represents, and it is important that the isolated gain obtained by creating a fish ladder at Fåbrofossen does not give a green-card to destroy the areas below the waterfall. It is also important to understand other potential effects upstream Fåbrofossen that this new migration passage for salmon and sea trout incur for, among other things, the resident trout population.

The precautionary principle in §9 in the Nature Diversity Act should be paramount to secure urban areas with high biodiversity in the future. It is therefore essential that educated decisions are made based on the current ecological status, bearing in mind the additional adverse effects of habitat loss and climate change when larger anthropogenic actions are planned. The aim of this master thesis is to be a small contribution in the large task it is to improve the knowledge of the fish populations above and below the migration barriers in both Isielva and Lysakerelva, so the best decisions can be made.

This thesis will focus on four topics. The first is to estimate the production of smolt in the different river stretches and investigate whether the stretches segregate for specific phenotypes. The second is to evaluate if the presence of salmon affects the trout population in areas where the two species co-exists, and evaluate the strength of inter- and intra-specific interactions between the two salmonid populations that live upstream and downstream the migration barriers. This will be assessed from individual growth and population density data in the different river sections and can be sampled because salmon alevins or pre-fed parr are hatched and released in the upper sections each year and interact with the resident, non-anadromous trout population. The third topic is to explore the potential for the anadromous salmonid populations above the migration barrier in Isieleva and Lysakerelva, and the last topic is considering positive and negative impacts of improving migration though restoration or compensation in Isielva and Lysakerelva, respectively.

Methods

Study species

This study focuses on the anadrome fish species trout and salmon. Salmo species are highly variable, and they often live in isolated systems supporting few competing fish species. In such environments, different morphs of the same species can exploit different habitats and specialize on different food items such as zooplankton, zoobenthos and smaller fish (Jonsson, 2011). In streams and rivers, salmon and trout segregate partly in habitat by depth, water velocity and abundance of overhead cover. Although the species are phenotypically similar, morphological adaptations make young salmon better able to exploit swift water than trout. Thus, the two segregate partly in nursery rearing habitat, as they use different parts of rivers and lakes with respect to depth, distance from the shore and substrate. With increasing age and size, the parr typically move from the nursery area where they hatch and start feeding in a spectrum of habitats: from small streams to large rivers, lakes and estuaries. If there are suitable, brackish feeding habitats outside their river of origin, they can move to these areas already as pre-smolts. After being transformed to smolts (smolting), the young can also feed in the ocean. Smoltification normally occurs between age 1 and 8, with a population mean between 2 to 4 years for salmon, and between age 1 and 9 with a population mean between 2 to 4 years for trout. While trout seldom leave estuarine and coastal areas, salmon move to feeding areas in the North Atlantic Ocean (Jonsson, 2011).

The trout population in both Isielva and Lysakerelva is divided into two populations. One population is anadromous and share the same habitat as the salmon, the other is geographically separated by a migration barrier and form an isolated resident population.

Study area

The watersheds for the two study rivers are located in the Oslo region in Norway and represent two of the main waterways running into in the inner Oslo fjord. The lower parts of both the Lysakerelva and Isielva are located in densely populated areas, however, large parts of the Isielva and Lysakerelva watershed is located in the Nordmarka and Krokskogen forests. The sampling stations in both rivers were located both upstream and downstream the first complete migration barrier for returning anadromous fish (Figure 1).

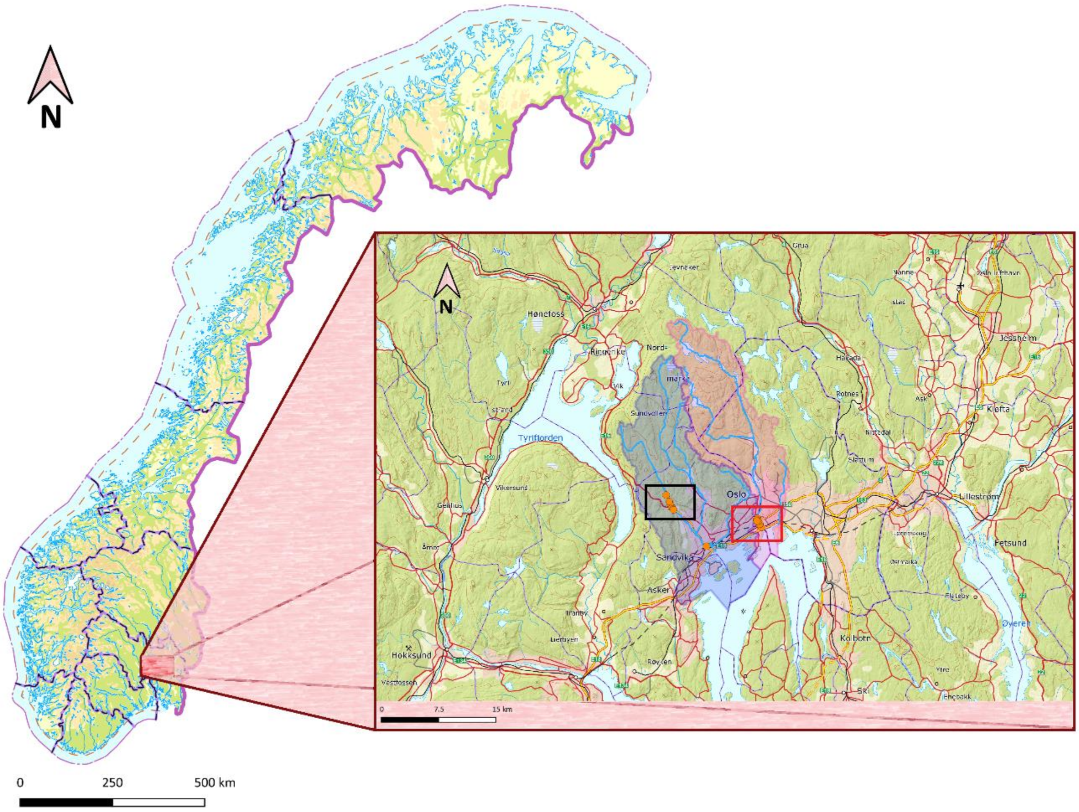

Figure 1: The study areas is located in Bærum and Oslo municipalities in Norway. The Lysakerelva watershed is marked in red with Lysakerelva stations pinpointed in the red square. The Sandvikselva watershed is marked in blue, with Isielva stations pinpointed in the black square (Kartverket, 2021).

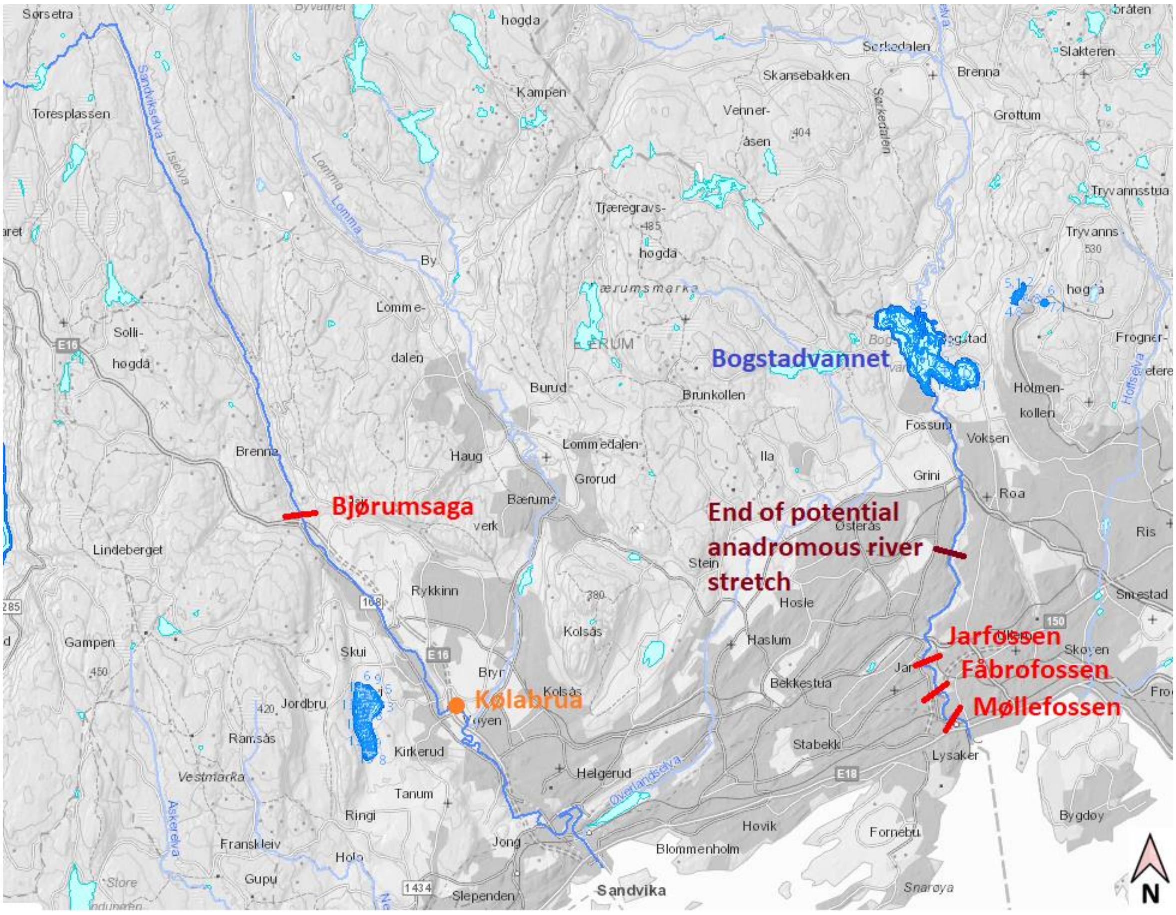

Figure 2: Map showing migration barriers and potential anadromous river stretch above the barriers (NVE, 2021). If the river stretch above the last wandering barrier is limited, this is marked with "end of anadromous river stretch". Situation today: Fåbrofossen marks the end of the anadromous stretch in Lysakerelva and Bjørumssaga marks the end of the anadromous stretch in Isielva, although salmon does not pass Kølabruholen every year (Rosseland, 1962).

Lysakerelva watershed

Lysakerelva is the lower part of the Sørkedal watershed and marks the border between Oslo and Bærum municipalities. The total watershed is 178 km^2, where 5.8 km^2 is the urban area through which Lysakerelva is located. The length of the river from the lake Bogstadvannet (Figure 2) to Lysaker fjord is 9,34 km, with a mean water flow of 4,2 m^3/sec . Five species of fish are found in the river; brown trout, salmon, European flounder (*Platichthys flesus*), European minnow (*Phoxinus phoxinus*) and lamprey (*Hyperoartia*). Invertebrates of interest to this master thesis, freshwater pearl mussel (*Margaritifera margaritifera*) are also registered in the lower reaches (S. J. Saltveit, 2014).

According to Vann-nett (Vann-nett, 2020), the ecological status in Lysakerelva was scored moderate based on an evaluation of salmonid juvenile densities in 2018. The benthic invertebrate- and phytobenthos communities were classified as good and high ecological status, respectively, and the chemical quality of the water classified as good despite occurrence of a large degree of diffuse run-off from urban areas (Vann-nett, 2020).

Lysakerelva marks the boundary between Oslo and Bærum, and the zoning plan is managed by VPOR, a cooperation between the urban development organizations in both municipalities. The area above Fåbrofossen remains pristine in several stretches due to a challenging topography along the riverside (Figure 3). The area below Fåbrofossen presently consists of old industrial buildings owned by the real estate developer Mustad Eiendom, see Figure 4 (DARK+ADEPT, 2014; J. Hovland, 2011). A more thorough description of each station can be found in Appendix I. Each year, salmon alevins or pre-fed parr are released in the area between Jarfossen and Fåbrofossen waterfalls (Dalen, 2021) (Table 1).

Table 1: Release date, life stage and number of released salmon between the Jarfossen and Fåbrofossen waterfalls.

Release date	Life stage	Number of individuals
14.05.2018	Pre-fed parr	20 000
08.05.2019	Pre-fed parr	20 000
09.04.2020	Alevins	5 000

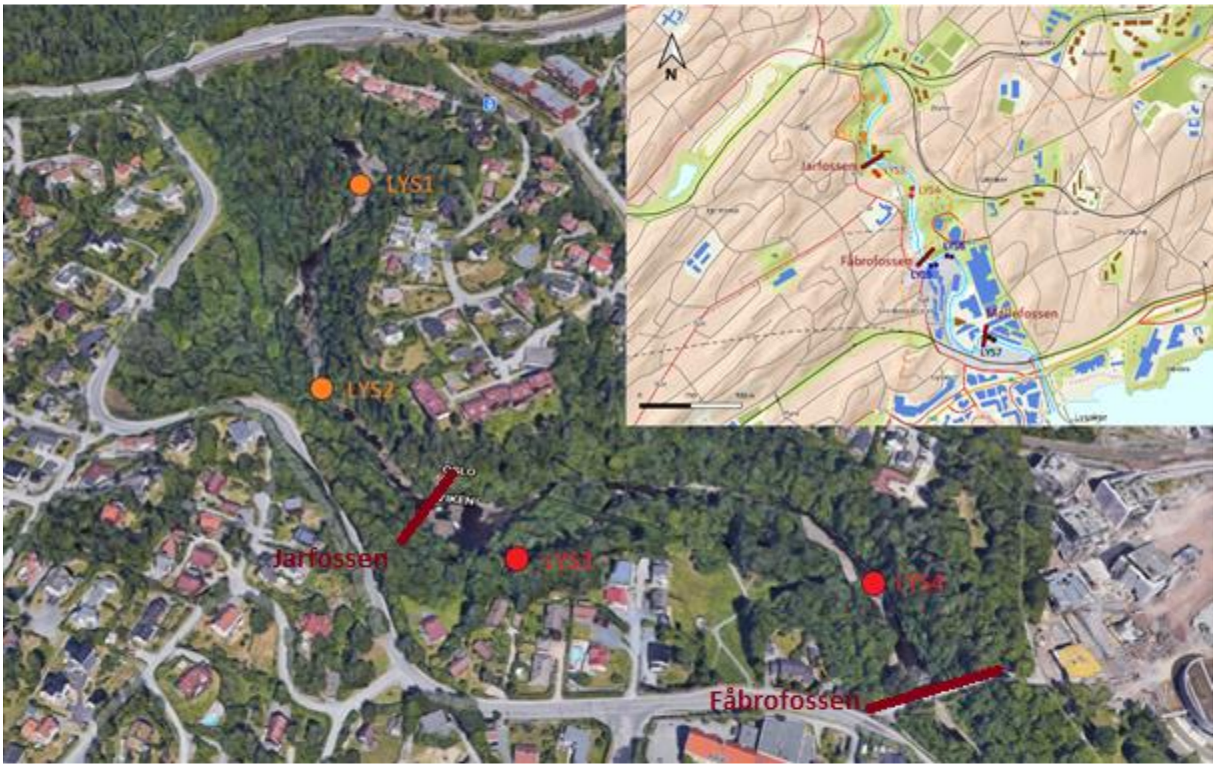

Figure 3: The stations above the Fåbrofossen waterfall migration barrier (Google, 2021; Kartverket, 2021). Between station LYS2 and LYS3 is the Jarfossen waterfall which today acts as an upwards migration barrier. Stations above Jarfossen waterfall are marked in orange making the upper river stretch, stations located between the Jarfossen waterfall and the Fåbrofossen waterfall are marked in red which is the middle river stretch.

Figure 4: The stations below the Fåbrofossen waterfall migration barrier making the lower river stretch (Google 2021, Kartverket 2021). Between station LYS6 and LYS7 is the Møllefossen waterfall where there is a fish ladder. Stations between the Fåbrofossen waterfall and Møllefossen waterfall are marked in blue, the last station, LYS7, is in the tidal river zone and marked in black.

Sandvikselva watershed

The Sandvikselva watershed is 226 km^2, where approximately 50 km^2 in the lower parts is heavily influenced by human activity consisting of densely populated areas, agriculture and E16, the main highway from Oslo to Bergen (Kartverket, 2021). This study has four stations in Kjaglielva, with a watershed of 33.8 km^2 in the middle of the Krokskogen forest area, including the Djupedalen and Kjaglidalen nature reserves (Vann-nett, 2020). In the lower part of this stretch, the dam of an old saw mill from 1855 acts as a migration barrier for spawning anadrome fish (A. Mohus, 2020). Below the crossing of the E16 highway, Kjaglielva meets Rustanbekken tributary and forms Isielva where three of the stations are located. Local speech and common information sources use the name Isielva for the river stretch that NVE names the Kjaglielva. This thesis will follow the local names, with upper and lower stretches of Isielva divided by Rustanbekken and/or the Bjørumsaga migration barrier (Figure 1).

The upper stretch of Isielva has good chemical status according to the water framework directive (Vann-nett, 2020), and has a native resident trout population. In addition, 400 000 salmon alevins from the local hatchery are released each year in the area above the Bjørumssaga dam/migration barrier (Merkesdal, 2020). The lower stretch of Isielva has poor chemical status, with diffuse run-off from urban areas and point run-off from refuse stations as the main contributors. In addition, pollution from diffuse transport and infrastructure flows in from Rustanbekken, which runs alongside E16. Ecological status for Rustanbekken is not available (Vann-nett, 2020). There are four stations located upstream and three stations located downstream the Bjørumssaga dam/migration barrier. ISI2 to ISI7 are the same stations as Elina Lungrin used in her master thesis in 2020 (Lundgrin, 2020), which enables a comparison of densities and ecological status for these sites. As ISI2 and ISI3 are similar, the station ISI1 was added to provide a comparison to ISI4 above the migration barrier.

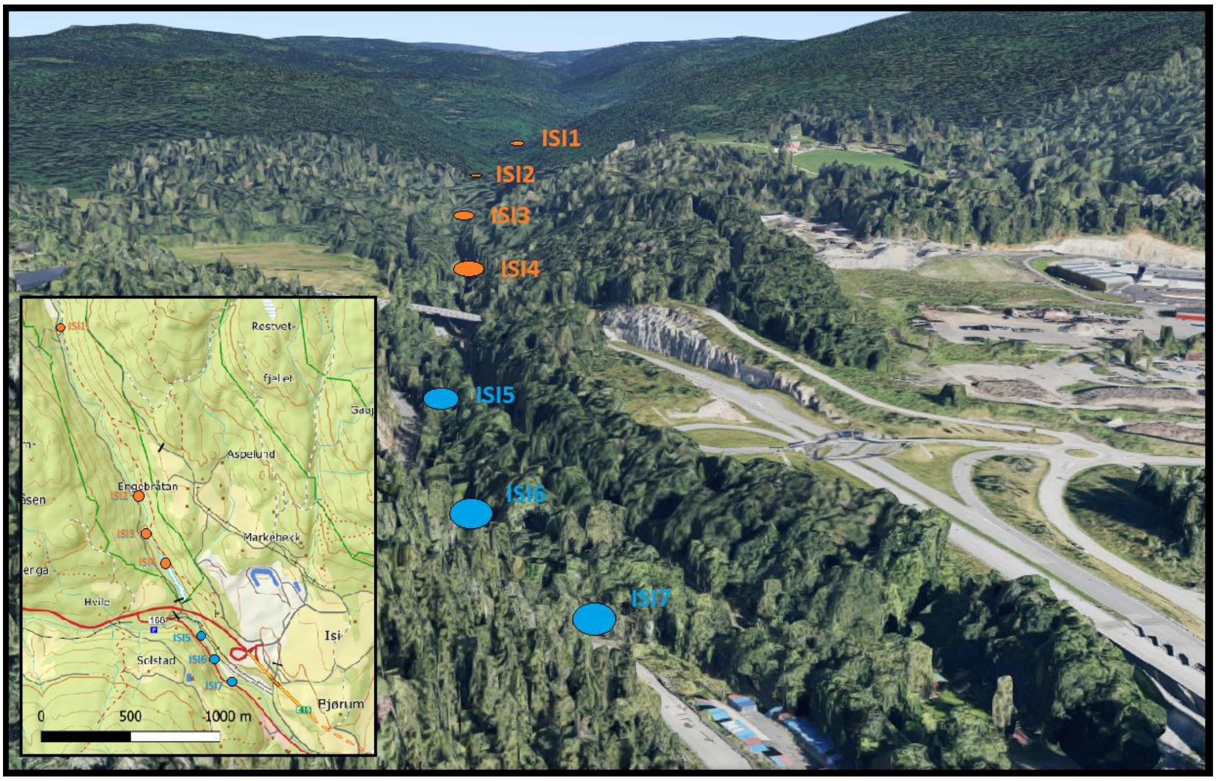

Figure 5: Stations in Isielva stretch above and below the Bjørumssaga dam/migration barrier (Google, 2021; Kartverket, 2021). Stations above the barrier are marked in orange. Stations below are marked in blue. Below the migration barrier and above station ISI3 is the outlet of the Rustanbekken tributary which runs alongside the E16.

Habitat characterization

The Pulg method

Due to difficult conditions from the middle of September until December, habitat characterization was done by visually dividing the stations into mesohabitat types and evaluating the quality of the river stretch morphology, substrate and cover after the form in *Appendix II – Evaluation form for habitat characterization*. Verification of the method can be found in *Appendix III – Verification of the Pulg method*.

There are four mesohabitat types; 1) spawning area, dominated by gravel banks, other substrates were divided in two categories depending on gradient and dominating water velocity; 2) fast run with gradient above 0.3 % and water surface velocity above 0.3 m/s and 3) slow run with gradient below 0.3 % and water surface velocity below 0.3 m/s. There are no differentiation between a slow run and a pool (Ulrich Pulg, 2011). The last mesohabitat type is 4) culvert, which is not applicable for the river stretches in question.

After the mesohabitat type is defined, morphology, substrate and cover were categorized on a scale from 1 to 4 according to quality. Beside water chemistry and temperature, these traits are essential for the fish production capacity in a river, and the sum value of the traits can indicate the general quality of the habitat according to Table 2. It is important to notice that the habitat quality of the Pulg method is based upon the habitat requirements of sea trout, and is not a measure of the habitat quality in general (Ulrich Pulg, 2011).

Table 2: Habitat quality after the Pulg method.

Sum	Habitat quality
12 – 11	Excellent
10 – 9	Good
8 – 7	Moderate
6 – 5	Poor
4 – 3	Very poor

Estimation of suitable areas

Visual assessment was used to estimate the suitable area available for the alevins and parr in May 2021. The river was divided into similar mesohabitat stretches with approximately the same percentage of suitable area. The upper and lower boundary coordinates were marked with a handheld GPS(Garmin etrex 30) . The waypoints were imported into QGIS 3.10.12-A and polygons following each river stretch level were made. The riverbank at lower water levels was chosen as this provides the most conservative estimate of smolt production, and are most similar to the conditions during the electrofishing in September 2020. The percentage of suitable area was added as an attribute to the polygons, and the total available area and percentage of suitable areas in square meters were calculated.

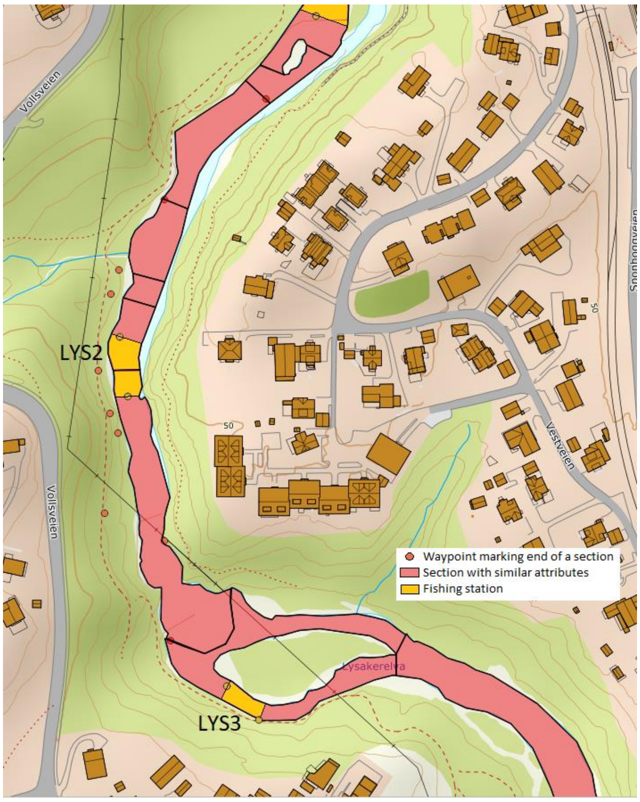

Figure 6: River segments representing different percentage of suitable area for 0+ and 1+ salmonids. This illustration is from the river section between the river tunnel at Jar to the Jarfossen waterfall.

As Isielva has suitable habitat without migration barriers many kilometres upstream of the upper station, a limit was set at the upper boundary of this station for the density calculation. A rough estimate of the area above was considered when calculating the total production capacity of the river, but time did not allow a more thorough investigation.

Table 3: Sections separated with migration barriers. Each section can contain several mapped river segments.

River	River stretch	Comment	Length in [m]
Lysaker	LYS_upper	Between the river tunnel at Jar to the Jarfossen waterfall	461
Lysaker	LYS_middle	Between the Jarfossen waterfall to the Fåbro waterfall	635
Lysaker	LYS_lower	Between the Fåbro waterfall to the Møllefossen waterfall	910
Lysaker	LYS_lower	Below the Møllefossen waterfall to the end of station LYS7	48
Isi	ISI_upper	Between the upstream border of station ISI1 to the Bjørumssaga migration barrier	1810
Isi	ISI_lower	Below the Bjørumssaga migration barrier to the downstream border of station ISI7	602

Data sampling

Fish data was sampled using electrofishing and PIT telemetry with a portable backpack reader (ORMR Single Antenna PIT Tag Reader). There was one electrofishing round only due to too high water discharge in the river from late September until the river froze. This also inhibited a traditional habitat characterization, as it was impossible to gather the data in a safe way. PIT scanning was performed under very difficult conditions in February, when a thick ice layer made too large a distance between the antenna and the tagged fish, and again in April 2021, when the data logging turned out to be defective.

Electrofishing

Electrofishing is used in quantitative investigations of fish populations in running water. The possibility of using electricity for fishing is due to the fact that aquatic organisms are immobilized (electronarcosis) when the body voltage from nose to tail exceeds a certain value. In the outer rim of the electric field, fish will show a fright response effect when trying to escape the anode. As the anode gets closer, fish will be attracted and start to swim towards it. Very close to the anode, where the electric field is strongest, fish will be subjected to galvanonarcosis and get immobilized (Bohlin et al., 1989a).

Effectiveness of electrofishing depends on several factors, where the conductivity of the water, the water flow, turbidity, access with gear and temperature are of the most important abiotic factors. Species, life history choices and individual differences are biotic factors affecting catchability. The skill of the operator is important, as stress associated with capture, handling, and fish release and additional procedures as anaesthetization, tag attachment and carrying of the tag affects the behaviour and survival of fish (Bohlin et al., 1989b). All stations were fished during the same water temperature, flow and weather conditions, changing only with daily air temperature variations around the same mean temperature. The abiotic factor with the largest impact on catchability was light condition. Some sampling rounds were conducted early in the morning with “bothersome” light reflection on the surface making fish harder to spot, while some stations were sampled after sunset with diminishing light. In addition, some stations were fished by different people due to time shortage caused by a forecasted weather change.

The electro-sampling operation was performed by one person handling the apparatus and a hand net and one or two persons carrying hand nets and a bucket. This was done to ensure security working in an electric field in water and effectiveness of catching and handling as many fish as possible. Sampling was always carried out in an upstream direction. In Norway, when using the removal method, it is common to have a 20 minute break in-between sampling sessions as a compromise between catchability and migration in and out of the area (Forseth, 2009). This was not done here, as each sampling round took approximately one hour, hence, the lower part of the station already had more than 20 minutes before we finished the round. The apparatus used in Isielva and most of Lysakerelva was a FA4, Terik model. In station LYS2 and LYS5, an apparatus of FA-55 was used. Both gave a current of approximately 0.7 ampere.

Figure 7: Electro-sampling gear consisting of a DC transformer, a battery, a cathode and a hand held anode. The transformer and the battery are rigged onto a backpack and the cathode trails downstream in the river while in use.

PIT telemetry

To estimate survival, migration past obstacles, migration velocity and when tagged fish migrate to and from feeding grounds and habitat preference, a PIT (Passive Integrated Transponder) tag was inserted into the peritoneal cavity. Permission from Mattilsynet was given to ensure correct handling when marking live animals to minimize negative effects (FOTS id: 24316). PIT telemetry is used to identify and follow individuals, typically as they migrate in and out of rivers or over artificial barriers such as dams (Network, 2019).

A PIT tag is an electronic microchip encased in biocompatible glass that varies in size according to the length of the fish. The tags used in this thesis were relatively small 12 mm, medium 14 mm and large 23 mm. The glass casing protects the electronic components and prevents tissue irritation. The implication of the term passive is that the tag is dormant until activated by an antenna. If a PIT tag is present, the reader generates a close-range, electromagnetic field that immediately activates the tag, which transmits a radio signal providing its number. This unique alphanumeric code permits a tagged individual to be distinguished from every other tag, whether on a population or global scale. The process is analogous to scanning barcodes in a grocery store (Gibbons, 2004).

A portable backpack reader of type Oregon RFID with a handheld coil antennae was used to retrace the fish. When a fish was registered, the location was logged on a GPS. At the beginning of each fishing round, a test PIT tag was scanned to mark the starting point and to align the clock with the GPS. The range of the smallest PIT tags is approximately 0.5 meters.

Figure 8: Retracing fish in Lysakerelva in February, 2021. Photo taken by Reidar Martinsen.

Handling and tagging

Each station was electro-sampled three rounds back-to-back, and fish from each round were stored separately. After the third round, all fish were counted, measured for total length with a tape band (Figure 10) and the species were identified. As there were many fish sampled each round in all stations, they could not be kept in buckets due to lack of oxygen supply. Dark baskets allowing water to flow through were placed downstream the station before fishing, and large rocks were placed in the bottom to provide both stability for the baskets and shelter for the fish to minimize stress. The lid of the basked was marked to differentiate between the rounds, and held down by a rock, both to provide less stressful environment for the fish and to inhibit the larger fish to escape.

Figure 9: Dark baskets allowing a constant supply of oxygen rich water to pass through were used to store the fish between sampling rounds.

Figure 10: Length was determined using a measuring tape glued to half a cylinder. Here a salmon parr is measured in ISI1 station.

Fish sampled in round 1 in Lysakerelva were marked with a PIT tag (Figure 11). Fish were sedated in a separate box containing benzocaine (30 mg L^{-1}). An oxygenizer ensured that the water in the sedation box always contained enough oxygen. Fish are fully sedated when they no longer twitch when pinched in the tail muscles. The three sizes of PIT tags corresponded to different fork lengths of the fish; small tags for fish between 6 and 8 cm, medium tags for fish between 8 and 12.5 cm and large tags for fish above 12.5 cm. PIT tags of all sizes were ready in a small container filled with chlorhexidine. To streamline the process, some small and medium sized PIT tags and a scalpel were laid ready in chlorhexidine in the lid of the small container. This ensured that the scalpel was always disinfected, and that time was not wasted trying to find the right tag. A small cut was made next to the bend of the leading edge of the left pectoral fin in resting position, and a PIT tag was slipped into the abdomen. The unique tag number was registered with the reader Datatracer FDX/HDX TARIC: 85423990, before the fish was released into a recovery basket. After tagging, when fish showed signs of normal behaviour, they were released back into the river. Minimizing stress and ensuring release of a completely recovered fish is important, both from an animal welfare point of view as well as from a research point of view, as it affects the results if survival of the fish is reduced drastically.

Figure 11: Mobile operating room. Fish were sedated using benzocaine (30 mg L^{-1}) in the box to the left. Oxygen was provided by an oxygenizer. Three different sizes of PIT tags and a scalpel were sterilized in chlorhexidine and ready to use.

Ecological classification

Presently, there exists no local quality norm for the two study sites, meaning that there is no set reference condition to compare against, or set limit values of the reproduction rate, harvesting potential or genetic variation of the populations. Hence, the national classification norm for salmon populations cannot be used (miljødepartementet, 2013). To classify the study areas, biological quality based upon a density limit table for smaller rivers and creeks in non-mountainous areas was used (vanndirektivet, 2018). This table does not cover the *Lysaker and Isi rivers*, as the watershed areas in both are greater than 10 km^2, however, an indication of the ecological state of the sites can be provided, further allowing for a comparison with the results in Isielva found by Elina Lundgrin in 2020. (Lundgrin, 2020) reported densities per 100 m^2 per station (LYS2 to LYS7). To compare the results, these densities were used to calculate the expected production over the suitable area found in *Estimation of suitable area*, then the production for each river section was summed up and scaled back to production per 100 m^2.

There are different density limits for different population structures and habitat classes. The habitat class is rated from 1 to 3, where habitat class 1 is less suitable habitat with no spawning grounds or shelter for parr on the site, habitat class 2 covers areas with moderate spawning opportunities and some shelter and habitat class 3 is well suited areas for spawning with enough shelter for parr (vanndirektivet, 2018). All stations in both rivers were set as habitat class 3, based on the Pulg approach, as shelter was not been measured for the stations. However, looking at the river stretches, the lower part of Lysakerelva is dominated by a deep, slow-flowing area between the stations LYS6 and LYS7, hence habitat class 2 is used. Below the migration barriers in both rivers, the population is classified as anadromous and sympatric, above the barriers the population is stationary and sympatric due to the overlap with the European minnow, see Appendix IV – Class limits for ecological state.

Size distributions

Based on the peaks from a size distribution plot, different age groups can be determined. According to Rosseland this renders quite trustworthy estimates as the salmonids in Sandvikselva grow very quickly. (Rosseland, 1962). The age limit line from another station in the same river section was used when it was difficult to determine an age limit line from the data at the station in question. The age limits for all stations can be found in *Appendix VI – Age group limits*.

Quantitative analysis

The statistical analyses used to estimate the density of juvenile salmonids in the different river stretches were performed in the software programs R and Microsoft EXCEL. The densities and catchability of each age group were found using the removal method (Zippin, 1958), which made the foundation data for the instantaneous mortality rate estimated by using catch curves (Robson DS, 1961). The use of linear modelling gave the production capacity of the river stretches.

The removal method

The removal method is one of the most common approaches to estimate population size in small areas. The case of three removals was used, as this is shown to rend good estimates of the population size. To use the method, three assumptions have to be fulfilled (Bohlin et al., 1989b);

1. The population is closed
2. Equal catchability for all individuals
3. Equal catchability among the removals

All of these assumptions will be broken to certain degree, as electro-sampling in field involves genetically different individuals of an unknown population which are free to migrate in and out of the chosen station, and that the electro-sampler was not skilled, which may have resulted in a difference in efficiency in-between the removals. This is however minimized by using the same persons throughout the removals as far as possible, and sampling each round as close in time as recommended.

Density calculations were done using the FSA (Fisheries Stock Assessment) package in R++, choosing the Zippin method. As standard large-sample normal distribution theory is used in the computation method, the standard-error formula will yield a confidence interval of 95 % for populations of size 200 with less than 90 % of the population captured. When the population is between 50 to 200 individuals, the confidence interval is approximately 90 % (Zippin, 1958).

As the precision of the three-catch removal method tolerates populations down to 50 individuals with a first catch yield above 25 individuals, the standard error estimate will be doubtful for catches below these limits. However, the catchability of larger populations of the same species in the same river may be used, which can render quite good precision if the catchability is reasonably constant (Bohlin et al., 1989b). In these cases, the catchability of the nearest similar station was used or a mean value of the stations in the same river stretch if there were no obvious similarities between the stations, see Appendix VIII – Changed catchabilities. In the cases where the yield was below 50 individuals for all stations, the catchability given by the Zippin method was kept for all stations in that age group, as this was deemed a better estimate than to use the catchability from another river or species.

Mortality rate

To determine the mortality rates, the catchCurve function in the FSA package in R was applied to the catchability-adjusted population estimate from the removal method. The function fits a linear model to the user-defined descending limb of a catch curve (Anonymous, 2021b). The catchCurve function requires at least three input values to make a model fit, and some of the stations have significantly lower numbers of 0+ than 1+ and >1+, or are missing some of the age groups. To get enough data points, the populations were divided between age groups 0+, 1+, >1+ and old, i.e. above 16 [cm] for salmon and 20 [cm] for trout. Adding the age group old was necessary to be able to estimate the instantaneous death rate, Z, for the stations where no 0+ were caught, however exact age of the individuals in the group is unknown, which will affect the results.

Adding more datapoints will give a more robust model, but it is not unproblematic. Adding zero-catches for the older age groups will thether the fit to an imaginary point, which significantly affects the fit when there are only two or three other input values. From a mortality rate perspective, this can be acceptable if the zero-catch for the old age group is placed far out on the x-axis representing age. However, as there is no information of the real age of this group, this approach was deemed to give more uncertainty to the fit even if the standard error decreases for a four point fit compared to a three point fit. The standard error of the fitted line is a precision measure which provides the average distance that the data points fall from the regression line. Based on regression line plots and standard error estimates, the cases with negative Z value were removed as they are unbiological, and cases with a standard error above 1 were removed as they render a confidence interval which is too large to implement in further analyses. The regression models from the catchCurve analyse in R are found in Appendix VII – Regression models from catchCurve.

As the mortality calculations for the individual stations differ to a large degree between stations, a larger dataset was formed representing river segments separated with migration barriers. Hence, the model represents the separated populations of the river. This was done by merging data from the stations belonging to each segment, which formed five segments: Isi upper and lower and Lysaker upper, middle and lower. The instantaneous mortality rate was calculated for these sections, and used to estimate the production capacity.

Model selection

To analyse correlates of 0+ density and 0+ growth, linear modelling was applied to the two response variables for both species. To explore the combined effects from inter- and intra-specific interactions and abiotic environmental variables, candidate models using densities of 0+ and 1+ along with groups of relevant predictors like habitat quality metrics were made. The habitat quality measures used in the analysis were the results from the Pulg method, see *Appendix III – Verification of the Pulg method*. Interaction candidate models were used to account for dependencies between the variables like synergy effects, but other than that, additive models were used.

Model selection was based on Akaike's information criteria (AIC), and the model with the lowest AIC value was chosen, as this is the model that demonstrates the minimum loss of information relative to reality. As the model complexity increases with plural predictor factors, a penalty factor is added which increases with increased use of predictor factors. More predictor factors render a better fit, however, the noise created by the uncertainty of estimating these predictors will at some point render an unprecise model with a large risk of spurious effects. The penalty factor renders a trade-off between model fit and parameter precision (Anderson, 2010).

To get a picture of how different factors correlated with the salmonid yearlings in the systems, several models were made; models looking for inter-cohort or interspecific density effects, additive and interaction models accounting for density correlations and river effects, additive and interaction models accounting for density correlations and species, additive models looking at the influence of density correlations and habitat quality, and a model accounting for the additive effect of density correlations, species and habitat quality. Interspecific correlations as a predictor variable were not included for the 0+ density of salmonids response variable, as this includes both species. For 0+ density of salmon and 0+ density of trout, 27 linear regression models were made (Table 4). To explore how different factors impact total length, the linear candidate models in Table 5 were used.

A linear regression was conducted for all models and an inspection of residuals was done to verify that the fitted models had homogenous residual variance. As count variables are known to be Poisson-distributed, thus log-normally distributed, the densities was log-transformed for a better fit, see Appendix XI – Model diagnostics. In addition, if the lowest AIC scores and weighted AIC values are very similar, a comparison of the residuals can be done to determine the best model fit, see *Comparison of the models* under Appendix XI – Model diagnostics.

Table 4: Candidate models used to explore effects on 0+ density of salmon and 0+ density of trout. The variable "Section" is the same as river stretch.

Model	0+ density of salmon	0+ density of trout
1	$Dens_{1+\ salmon}$	$Dens_{1+\ trout}$
2 & 3	$Dens_{1+\ salmon}$ [+,*] $Dens_{1+\ trout}$	$Dens_{1+\ trout}$ [+,*] $Dens_{1+\ salmon}$
4 & 5	$Dens_{1+\ salmon}$ [+,*] River	$Dens_{1+\ trout}$ [+,*] River
6	$Dens_{1+\ salmon}$ + $Dens_{1+\ trout}$ + River	$Dens_{1+\ trout}$ + $Dens_{1+\ salmon}$ + River
7 & 8	$Dens_{1+\ salmon}$ [+,*] Habitat quality	$Dens_{1+\ trout}$ [+,*] Habitat quality
9	$Dens_{1+\ salmon}$ + $Dens_{1+\ trout}$ + Habitat quality	$Dens_{1+\ trout}$ + $Dens_{1+\ salmon}$ + Habitat quality
10	$Dens_{1+\ salmon}$ + River + Habitat quality	$Dens_{1+\ trout}$ + River + Habitat quality
11 & 12	$Dens_{0+\ trout}$ [+,*] River	$Dens_{0+\ salmon}$ [+,*] River
13 & 14	$Dens_{0+\ trout}$ [+,*] Habitat quality	$Dens_{0+\ salmon}$ [+,*] Habitat quality
15 & 16	$Dens_{0+\ trout}$ + River + Habitat quality	$Dens_{0+\ salmon}$ + River + Habitat quality
17 & 18	$Dens_{1+\ trout}$ [+,*] River	$Dens_{1+\ salmon}$ [+,*] River
19 & 20	$Dens_{1+\ trout}$ [+,*] Habitat quality	$Dens_{1+\ salmon}$ [+,*] Habitat quality
21 & 22	$Dens_{1+\ trout}$ + River + Habitat quality	$Dens_{1+\ salmon}$ + River + Habitat quality
23	Section	Section
24 & 25	$Dens_{1+\ salmon}$ [+,*] Section	$Dens_{1+\ salmon}$ [+,*] Section
26	River	River
27	Habitat quality	Habitat quality

Table 5: Candidate linear models fitted to explore effects on 0+ body length.

Model	Total length salmon [cm]	Total length trout [cm]
1	Station	Station
2	Habitat.quality	Habitat.quality
3	Section	Section
4	$Dens_{0+\ trout}$	$Dens_{0+\ trout}$
5	$Dens_{0+\ salmon}$	$Dens_{0+\ salmon}$
6	$Dens_{1+\ trout}$	$Dens_{1+\ trout}$
7	$Dens_{1+\ salmon}$	$Dens_{1+\ salmon}$
8	$Dens_{0+\ salmon}$ * River	$Dens_{0+\ salmon}$ * River
9	$Dens_{0+\ salmon}$ + River	$Dens_{0+\ salmon}$ + River
10	$Dens_{1+\ salmon}$ * River	$Dens_{1+\ salmon}$ * River
11	$Dens_{1+\ salmon}$ * Section	$Dens_{1+\ salmon}$ * Section

Estimation of smolt production

The production capacity of Lysakerelva and Isielva were estimated using the calculated densities from the river stations and the instantaneous mortality rates from the river sections. There are no data for the rivers estimating the mean smolt age or the percentage of individuals that smolt, hence it was assumed that all individuals should smolt after their second winter. Integrating the instantaneous rate of change in a cohort over time gives the following formula:

$$(I) \qquad N_t = N_0 * e^{-Zt}$$

Where *t* is the time, N_t is the estimated density per 100 m^2 of the specified time, N_0 is the density per 100 m^2 of the 0+ age group and *Z* is the instantaneous mortality rate. The density was scaled up to the size of each river segment found in *Estimation of suitable area*. The river segments located between stations used the density estimates from the most similar station in the same river stretch. As there were no 0+ salmon in the river stretch between the Jarfossen and Fåbrofossen waterfalls, the 1+ density was used as N_1. See *Appendix IX – Estimated densities and production capacity* for the assumptions taken for each river stretch. As the river stretches are divided in an anadrome and non-anadrome part, the production capacity for these stretches was also calculated separately for comparative purposes.

Results

Habitat characterization

The habitat quality in Lysakerelva ranged from Good to Excellent, where the largest difference between the scores consisted of cover/shadow (Table 6). Broader stations like LYSI, or where the footpath coincides with the riverbank along LYS3, generally had less coverage which is reflected in the scores. The exception to this was station LYS6, where coverage was good, but the morphology and substate scored less than average. A more detailed description of each stations is found in *Station description* under *Appendix I – Habitat descriptions*.

Table 6: Sum score and habitat quality assignment for the stations in Lysakerelva

	Mesohabitat type			Habitat			Habitat quality	Habitat quality
Stasjon	Spawning ar	Fast run	Slow run	Morphology	Substrate	Cover		
LYS1	x	x		4	4	1	9	Good
LYS2		x		4	3	3	10	Good
LYS3		x		3	4	2	9	Good
LYS4		x		4	4	3	11	Excellent
LYS5	x	x		4	4	3	11	Excellent
LYS6		x		3	3	4	10	Good
LYS7		x		4	4	2	10	Good

In Isielva, the Pulg scores ranged from Moderate to Excellent, where ISI6 and ISI7 differed from the rest with lower scores (Table 7). Common for these stations was a road running along the eastern riverbank, affecting the morphology score for both stations and the cover score for ISI7, which is more exposed to the roadside than ISI6.

Table 7: Sum score and habitat quality for the stations in Isielva

	Mesohabitat type			Habitat			Habitat quality	Habitat quality
Stasjon	Spawning ar	Fast run	Slow run	Morphology	Substrate	Cover		
ISI1		x		4	4	3	11	Excellent
ISI2		x		4	3	4	11	Excellent
ISI3		x		4	3	4	11	Excellent
ISI4		x		4	4	3	11	Excellent
ISI5		x		4	3	4	11	Excellent
ISI6		x		3	3	4	10	Good
ISI7		x		3	3	2	8	Moderate

Size distributions

Size distributions among stations varied, especially regarding 0+ and 1+ densities (Figure 12). Looking at the salmon size distributions in Lysakerelva, LYS3 and LYS4 stand out with no 0+ individuals and a distinct 1+ age group. There was only one older individual in the LYS3 station. The 1+ below Fåbrofossen had a smaller length range with lower size limits than above the waterfall. LYS5 had a very clear multimodal size distribution with a clear 0+ peak at 5 cm. The distribution in LYS7 was also near normal, with individuals ranging from 0+ to old, but too few individuals were found at LYS6 to produce clear age-related peaks. For trout, stations LYS1 and LYS4 stood out with high numbers of 0+, while stations LYS6 and LYS7 had no 0+ catches. The other stations showed a more random spread. In Isielva, the length range between the age groups was quite similar, however, stations ISI1, ISI4 and ISI7 stand out with higher densities of 0+ than for the other stations for both salmon and trout. There was no 0+ trout found at station ISI2 and ISI6.

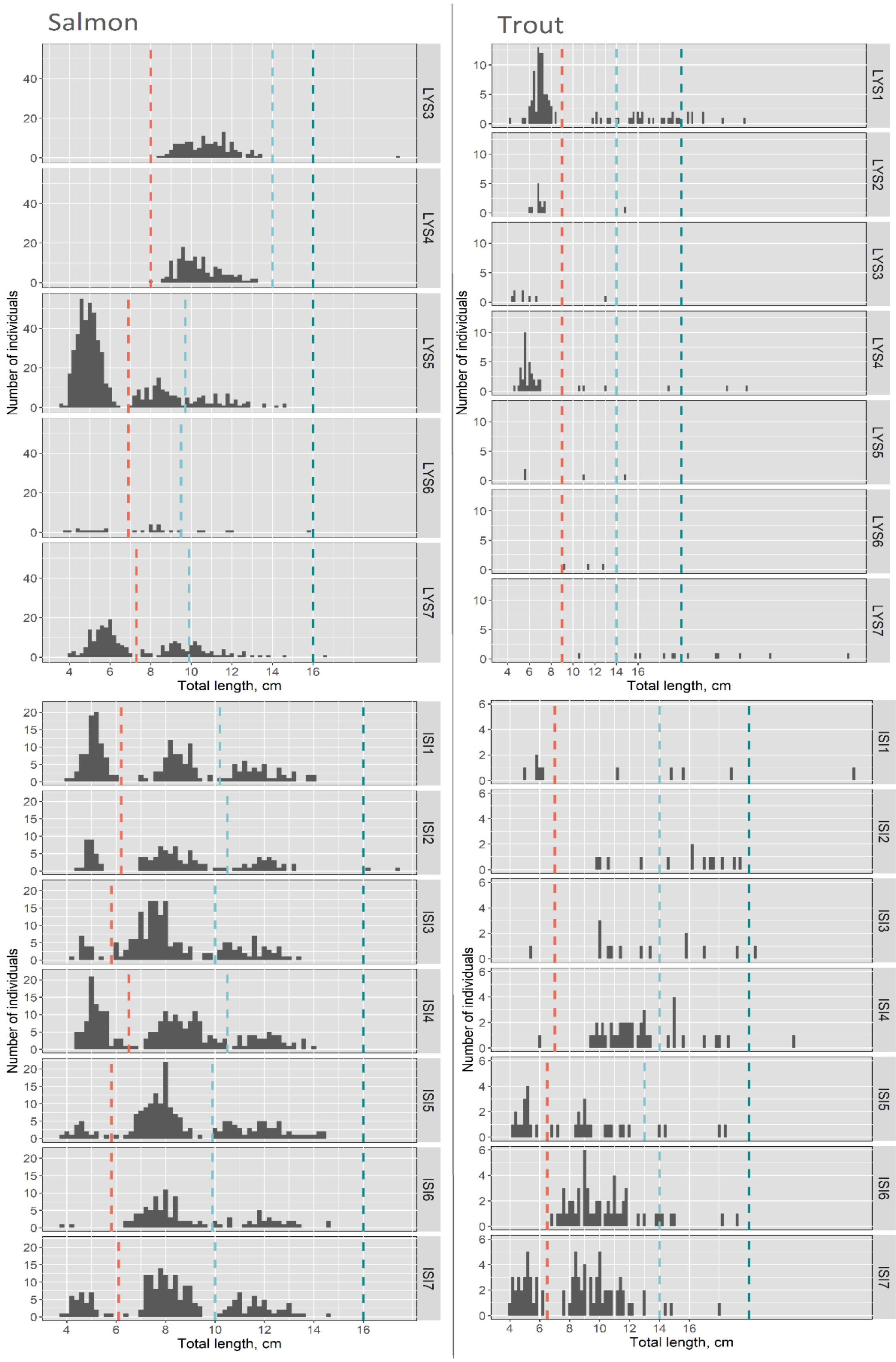

Figure 12: Size distribution plot showing the number of individuals caught in the electrofishing round in September 2020 plotted according to total length in cm. The vertical lines separate the different age groups; red separate 0+ and 1+, light blue separate 1+ from >1+ and teal separate >1+ from old.

Population density

Salmon densities were higher than trout densities where the species coexisted (Figure 13,Table 8). For salmon, the 1+ density was distinctly larger than for the other age groups in stations ISI3, ISI5 and ISI6. For trout, the differences between stations were generally smaller, but there was a clear dominance of 0+ in stations ISI7 and LYS1. In station ISI7, the salmon and trout densities follow the same curve across the age groups.

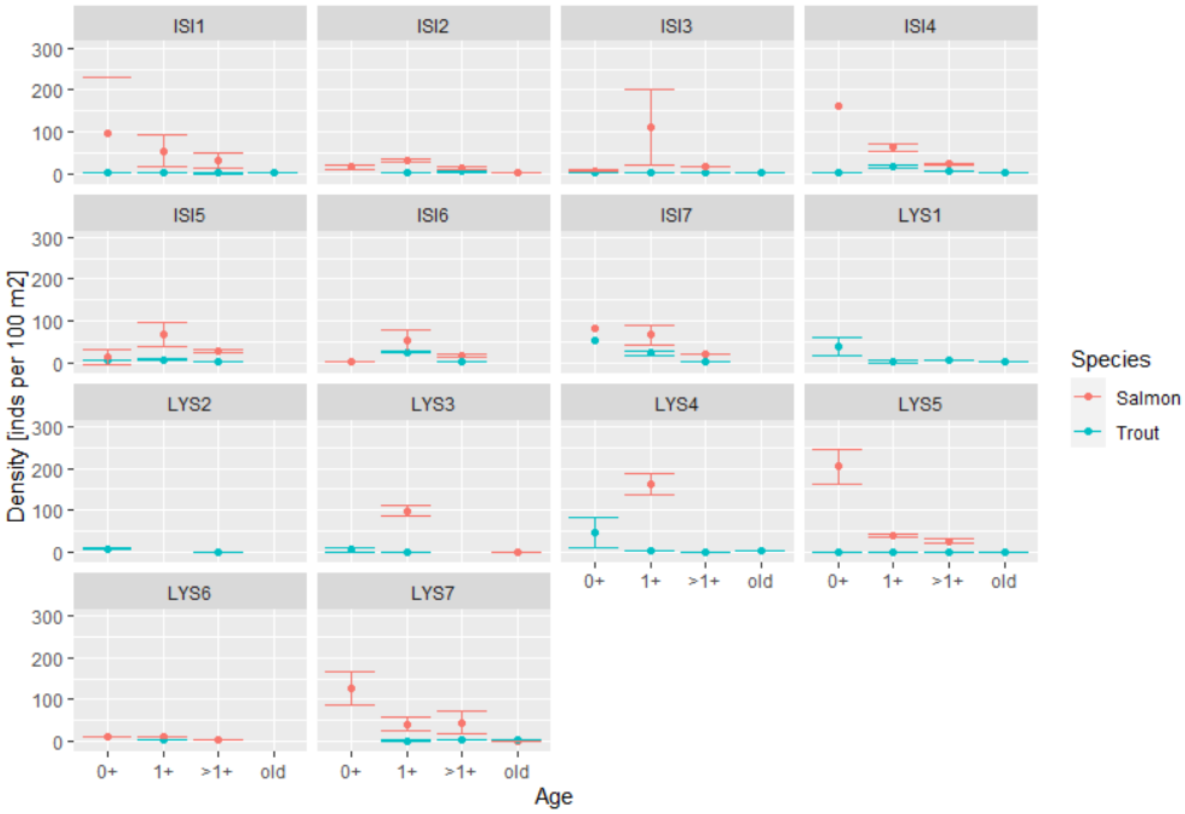

Figure 13: Density estimates (individuals per 100 m^2) with 95% confidence interval per station and age group for salmon and trout.

Table 8: Density estimates (individuals per 100 m^2) per station and age group for salmon and trout.

Station	Species	0+	1+	>1+	old
ISI1	Salmon	98.0	50.7	21.8	0.4
ISI2	Salmon	40.2	32.1	13.0	1.4
ISI3	Salmon	20.4	112.4	18.1	0.4
ISI4	Salmon	161.0	63.4	23.2	0.5
ISI5	Salmon	23.8	68.8	27.2	0.4
ISI6	Salmon	3.7	54.4	17.9	0.5
ISI7	Salmon	45.1	66.9	21.6	0.4
LYS3	Salmon	0.6	101.1	0.6	1.3
LYS4	Salmon	0.9	161.5	0.0	0.0
LYS5	Salmon	205.6	40.6	23.4	0.4
LYS6	Salmon	15.6	15.7	5.2	0.8

LYS7	Salmon	126.5	46.7	31.5	1.3
ISI1	Trout	2.9	1.0	2.0	0.9
ISI2	Trout	0.5	2.6	4.9	0.5
ISI3	Trout	0.8	3.8	1.9	0.7
ISI4	Trout	1.1	18.1	5.7	1.0
ISI5	Trout	5.9	8.0	2.0	0.4
ISI6	Trout	0.5	26.1	3.6	0.5
ISI7	Trout	53.9	23.8	1.6	0.4
LYS1	Trout	38.4	3.1	6.7	2.7
LYS2	Trout	13.4	0.0	0.0	0.0
LYS3	Trout	8.1	1.6	0.6	0.6
LYS4	Trout	50.3	5.0	1.8	2.6
LYS5	Trout	1.6	0.7	0.8	0.7
LYS6	Trout	0.8	3.4	0.8	0.8
LYS7	Trout	0.0	2.0	4.3	4.6

Mortality estimates

The mean 0+ to >1+/old instantaneous mortality rate (Figure 14) varied between 0.55 and 1.41 for salmon in Lysakerelva and 0.37 and 1.10 in Isielva. For trout, this varied between 0.36 and 1.27 in Lysakerelva and 0.08 and 1.74 in Isielva. The mean mortality rate values for each river section are found in Table 9 and Figure 15. Common for all stations with a very large confidence interval was very few 0+ individuals, which greatly affected the regression line, as this is based upon three to four data points. Stations with negative instantaneous mortality rate were removed. This is visualized in Figure 30 to Figure 31 under Appendix VII – Regression models from catchCurve.

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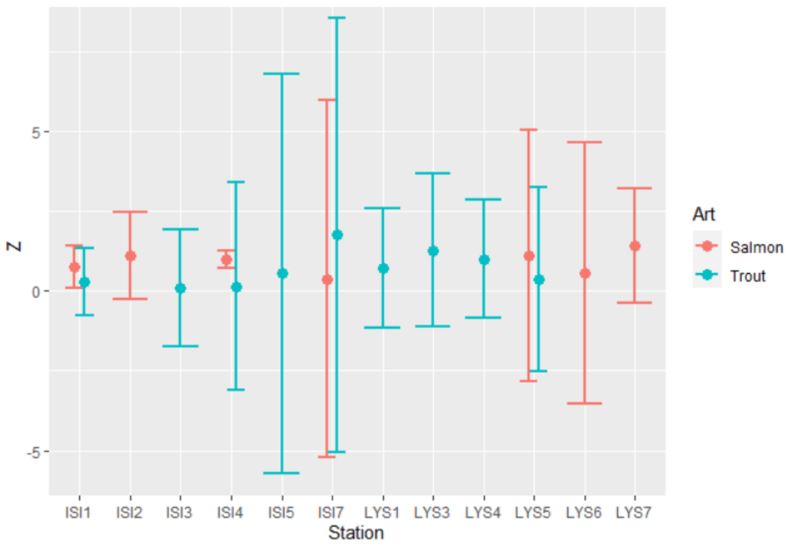

Figure 14: Species-specific estimates of mortality with 95% confidence interval plotted per station.

Table 9: Species- and section-specific estimates of the yearly death rate, A, in percent and the instantaneous rate of mortality, Z, with 95% confidence interval given by the lower limit LCL and the upper limit UCL.

River stretch	Species	A [%]	Z	LCL	UCL
LYS_lower	Salmon	80.4	1.63	-0.15	3.41
ISI_upper	Salmon	78.7	1.54	-0.68	3.77
ISI_lower	Salmon	73.6	1.33	-2	4.66
LYS_upper	Trout	53.6	0.77	-1.19	2.73
LYS_middle	Trout	61.8	0.96	-0.69	2.61
ISI_upper	Trout	18.8	0.21	-1.87	2.28
ISI_lower	Trout	76.0	1.43	0.75	2.1

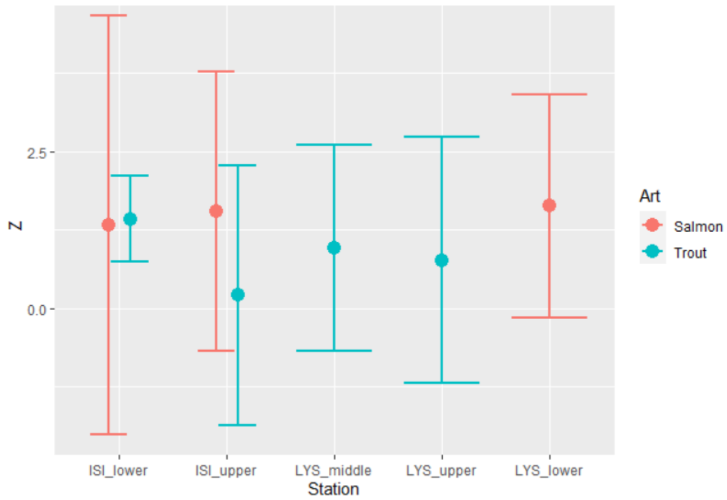

Figure 15: Species-specific estimates of mortality with 95% confidence interval plotted per river section.

Smolt production

As the instantaneous death rate was in a range of 1.3 to 1.6 for Lysakerelva below the migration barrier and the entire Isielva except the upper stretch for trout, the smolt production estimates for Isielva and the lower stretch of Lysakerelva were very conservative. The salmon density for the middle stretch of Lysakerelva stands out, with an estimated production capacity of 24.3 smolt per 100 m^2. This river stretch also contains the largest smolt estimate for trout of 4.9 smolt per 100 m^2. In Isielva, the upper stretch provided the largest production capacity estimated at 3.4 smolt per 100 m^2, while the trout smolt density was largest for the lower stretch at 1.0 smolt per 100 m^2.

Table 10: Production capacity in total and above and below the migration barrier in the Lysaker and Isi rivers.

River stretch	Species	Smolt density per 100 m^2
Lysaker upper	Salmon	-
	Trout	2.8
Lysaker middle	Salmon	24.3
	Trout	4.9
Lysaker lower	Salmon	0.6
	Trout	0.1
Lysakerelva total	Salmon	10.2
	Trout	2.2
Isi upper	Salmon	3.4
	Trout	0.9
Isi lower	Salmon	1.6
	Trout	1.0
Isielva total	Salmon	3.0
	Trout	0.9

Ecological status

The ecological status is "Excellent" for the upper stretch of Lysakerelva, and the entire Isielva. The lower stretch of Lysakerelva have "Good" status.

Table 11: Ecological classification based on salmon and trout density per 100 m^2 above and below the migration barrier.

River	Salmonid density per 100 m^2	Ecological state
Lysaker above migration barrier *Stream or lake living sympatric, habitat class 3*	186.5	Excellent
Lysaker below migration barrier *Anadrome sympatric, habitat class 2*	17.4	Good
Isi upper *Stream or lake living sympatric, habitat class 3*	98.0	Excellent
Isi lower *Anadrome sympatric, habitat class 3*	52.9	Excellent

Factors affecting 0+ densities

0+ density of salmon

The candidate model "Section" with river stretches as the sole predictor variable got the most AIC-support in the data. This model obtained 30 % of the support amongst all candidate models, and the second most supported model, with salmon 1+ density as the only predictor variable, attained 18 % of the AIC support. The third most supported model with trout 0+ density as the only predictor variable attained 14 % of the AIC support. The remainder candidate models all had ΔAIC values higher than 2 and got less than 10 % of the AIC support. Table 12 below shows only the models with an AIC weight above 0.01. As the AIC score of the second and third ranked model were very similar, a model diagnostic was done which concluded that "$Dens_{1+\ salmon}$" was the model explaining most effectively the variation in 0+ salmon density, see *Appendix XI – Model diagnostics*. The most supported model consisted of a strictly abiotic prediction factor and the two next models consists of biotic prediction factors. Models including plural prediction factors had a higher AIC score and do not have substantial support. The parameter estimates of the two most supported models (Table 13,Table 14) and a prediction plot of the second most supported model (Figure 16) are shown below.

Table 12: AIC table showing different linear models with 0+ density of salmon as the response factor, ΔAIC is the difference between the AIC score and the lowest AIC score in the analyse, AICcWt is the weight of evidence in favour of the best model and Cum.Wt is the cumulative weighted score. R^2 = 0.71.

Models	**AICc**	**ΔAICc**	**AICcWt**	**Cum.Wt**
Section	50.36	0	0.3	0.3
$Dens_{1+\ salmon}$	51.42	1.06	0.18	0.48
$Dens_{0+\ trout}$	51.94	1.58	0.14	0.62
Habitat quality	53.4	3.04	0.07	0.69
River	53.47	3.11	0.06	0.75
$Dens_{1+\ trout}$	53.88	3.52	0.05	0.8
$Dens_{0+\ trout}$ * Habitat quality	54.95	4.58	0.03	0.83
$Dens_{1+\ salmon}$ + River	54.97	4.61	0.03	0.86
$Dens_{1+\ salmon}$ + Habitat quality	55.17	4.81	0.03	0.89
$Dens_{0+\ trout}$ + River	56.03	5.67	0.02	0.91
$Dens_{1+\ salmon}$ + $Dens_{1+\ trout}$	56.06	5.69	0.02	0.93

Table 13: Parameter estimates of the most supported model "Section", p=0.016, multiple R-squared=0.7, ISI_upper has a more positive effect on salmon 0+ density than ISI_lower. LYS_lower had the most positive effect on salmon 0+ of all the sections and LYS_middle had the least positive effect on salmon 0+ density.

Coefficients	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	2.8615	0.6063	4.72	0.0015
ISI_upper	1.254	0.8021	1.563	0.1566
LYS_lower	1.4688	0.8574	1.713	0.1251
LYS_middle	-2.3021	0.9587	-2.401	0.0431

Table 14: Parameter estimates of the second most supported model "Dens$_{1+ salmon}$", p=0.14, multiple R-squared=0.2, salmon 1+ density has a strong negative effect on salmon 0+ density, especially for lower densities of 1+ salmon.

Coefficients	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	8.3737	3.2295	2.593	0.0268
Dens$_{1+ salmon}$	-1.2529	0.7841	-1.598	0.1411

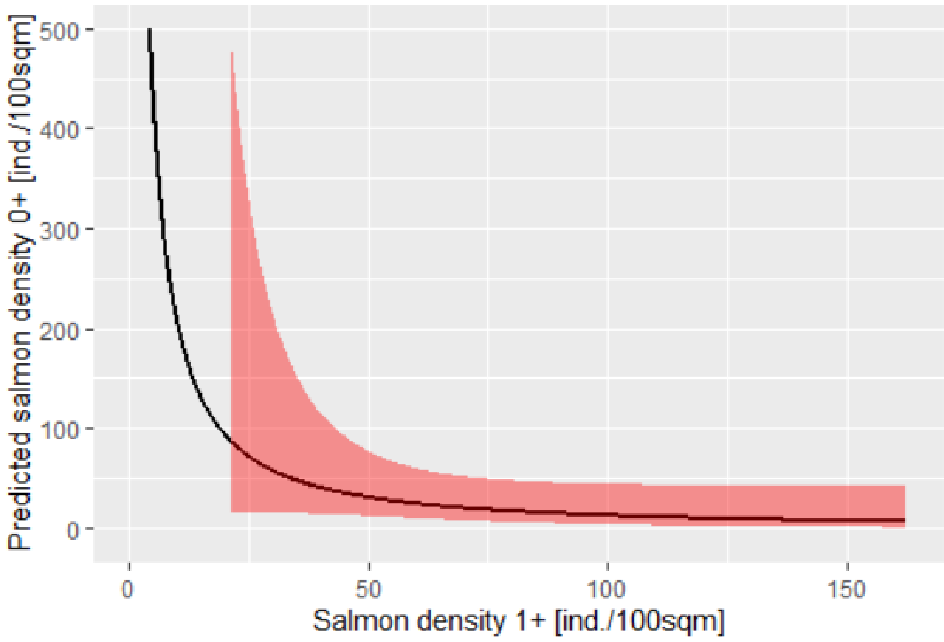

Figure 16: Prediction plot of the second most supported model "Dens$_{1+ salmon}$" with a 95 % confidence interval. Salmon 1+ density has a negative effect on salmon 0+ density.

0+ density of trout

The candidate model with salmon 1+ density as the sole predictor variable got the most AIC-support in the data. This model obtained 34 % of the support amongst all candidate models, and the second most supported model, an additive model with salmon 1+ density and habitat quality as predictor variables, attained 18 % of the AIC support. The third most supported model with habitat quality as the only predictor variable attained 11 % of the AIC support, although with a ΔAIC values higher than 2. The remainder candidate models all had ΔAIC values higher than 2 and got less than 10 % of the AIC support. Table 15 below shows only the models with an AIC weight above 0.01. The most supported model consists of a strictly abiotic prediction factor and the two next models consists of biotic prediction factors. Models including plural prediction factors had a higher AIC score and do not have substantial support. The parameter estimates of the two most supported models (Table 16, Table 17) and a prediction plot of the most supported model (Figure 17) are shown below.

Table 15: AIC table showing different linear models with 0+ density of trout as the response factor, ΔAIC is the difference between the AIC score and the lowest AIC score in the analyse, AICcWt is the weight of evidence in favour of the best model and Cum.Wt is the cumulative weighted score.

Models	**AICc**	**ΔAICc**	**AICcWt**	**Cum.Wt**
$Dens_{1+\ salmon}$	44.66	0	0.34	0.34
$Dens_{1+\ salmon}$ + Habitat quality	45.9	1.24	0.18	0.52
Habitat quality	46.99	2.33	0.11	0.62
$Dens_{0+\ salmon}$	47.01	2.35	0.1	0.73
$Dens_{1+\ trout}$	48.47	3.81	0.05	0.78
$Dens_{1+\ trout}$ + $Dens_{1+\ salmon}$	48.96	4.3	0.04	0.82
$Dens_{1+\ salmon}$ + River	49.13	4.46	0.04	0.85
$Dens_{0+\ salmon}$ + Habitat quality	49.16	4.5	0.04	0.89
Section	50.14	5.48	0.02	0.91

Table 16: Parameter estimates of the most supported model "$Dens_{1+\ salmon}$", p=0.06, multiple R-squared=0.3, salmon 1+ density has a slightly positive effect on salmon 0+ density.

Coefficients	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	-3.7634	2.4369	-1.544	0.154
$Dens_{1+\ salmon}$	1.2723	0.5916	2.151	0.057

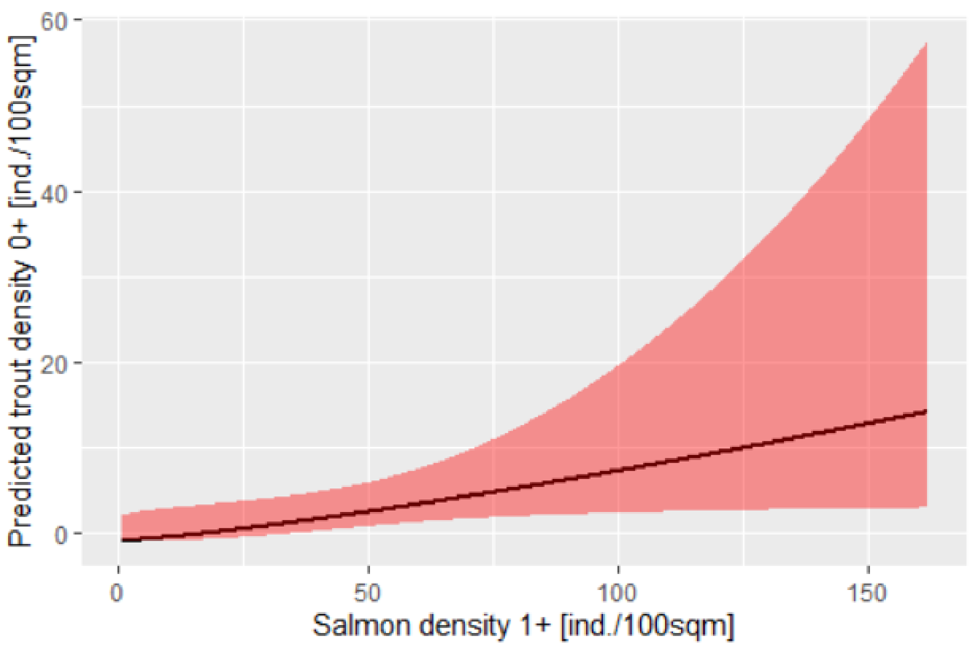

Figure 17: Prediction plot of the most supported model "Dens1+ salmon", salmon 1+ density has a slightly positive effect on salmon 0+ density.

Table 17: Parameter estimates of the second most supported model "Dens$_{1+ salmon}$ + Habitat quality", p=0.05, multiple R-squared=0.5, salmon 1+ density has a positive effect on trout 0+ density. Habitat quality has a less positive effect compared to the intercept.

Coefficients	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	2.0958	4.0373	0.519	0.6162
Dens$_{1+ salmon}$	1.2764	0.5396	2.365	0.0422
Habitat quality	-0.5686	0.3271	-1.738	0.1161

Correlates of 0+ growth

Total length of salmon 0+

The candidate model "Station" as the sole predictor variable got the most AIC-support in the data. This model obtained 100 % of the support amongst all candidate models. The remainder candidate models all had ΔAIC values higher than 2 without AIC support. Common for the most supported models in the analyse are the abiotic aspect. The models with least support have entirely biotic prediction factors. The parameter estimates of the most supported model (Table 19) are shown below.

Table 18: AIC table showing different linear models with total length of salmon as the response factor, ΔAIC is the difference between the AIC score and the lowest AIC score in the analyse, AICcWt is the weight of evidence in favour of the best model and Cum.Wt is the cumulative weighted score.

Models	**AICc**	**ΔAICc**	**AICcWt**	**Cum.Wt**
Station	1181.26	0	1	1
Dens$_{0+ salmon}$ * River	1269.03	87.77	0	1
Dens$_{1+ salmon}$ * Section	1304.63	123.37	0	1
Dens$_{1+ salmon}$ * River	1328.33	147.07	0	1
Section	1366.75	185.49	0	1
Dens$_{0+ trout}$	1375.8	194.54	0	1
Dens$_{0+ salmon}$ + River	1382.13	200.87	0	1
Habitat.quality	1390.29	209.03	0	1
Dens$_{1+ trout}$	1396.44	215.18	0	1
Dens$_{1+ salmon}$	1397.76	216.5	0	1
Dens$_{0+ salmon}$	1398.19	216.93	0	1

Table 19: Parameter estimates of the most supported model "Stations", p=2.2e^{-16}, multiple R-squared=0.2, stations ISI4 and LYS7 has a more positive effect on the length than ISI1 (intercept), while the rest of the stations has a less positive effect on the length than ISI1. Station LYS1 to LYS4 are missing as there was not found any 0+ salmon in these stations.

Coefficients	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	5.14756	0.05653	91.056	< 2e-16
ISI2	-0.12904	0.11359	-1.136	0.25628
ISI3	-0.36521	0.13642	-2.677	0.00759
ISI4	0.09024	0.07995	1.129	2.59e-01
ISI5	-0.51072	0.13034	-3.918	9.71e-05

ISI6	-1.04756	0.36637	-2.859	4.36e-03
ISI7	-0.41899	0.10336	-4.054	5.55e-05
LYS5	-0.18366	0.06242	-2.942	0.00336
LYS6	-0.17256	0.15822	-1.091	2.76e-01
LYS7	0.56705	0.07219	7.855	1.35e-14

Total length of trout 0+

The candidate model "Section" with river stretches as the sole predictor variable got the most AIC-support in the data. This model obtained 34 % of the support amongst all candidate models, and the second most supported model, an integration model with salmon 0+ density and river as predictor variables, attained 24 % of the AIC support. The third most supported model with salmon 1+ density and section as predictor variables attained 21 % of the AIC support. The remainder candidate models all had ΔAIC values higher than 2 and got less than 10 % of the AIC support. Table 20 below shows only the models with an AIC weight above 0. There were no clear pattern dividing the most supported models from the least supported models in the table, however models containing trout densities got little support. The parameter estimates of the three most supported models (Table 21, Table 22, Table 23) and a prediction plot of the most supported model (Figure 18) are shown below.

Table 20: AIC table showing different linear models with total length of trout as the response factor, ΔAIC is the difference between the AIC score and the lowest AIC score in the analyse, AICcWt is the weight of evidence in favour of the best model and Cum.Wt is the cumulative weighted score.

Models	AICc	ΔAICc	AICcWt	Cum.Wt
Section	173.28	0	0.34	0.34
$Dens_{0+\ salmon}$ * River	173.99	0.71	0.24	0.57
$Dens_{1+\ salmon}$ * Section	174.19	0.92	0.21	0.78
Station	176.45	3.17	0.07	0.85
$Dens_{1+\ salmon}$	176.69	3.41	0.06	0.91
$Dens_{1+\ salmon}$ * River	177.09	3.81	0.05	0.96
$Dens_{0+\ salmon}$ + River	177.8	4.52	0.04	1

Table 21: Parameter estimates of the most supported model "Section", $p=2.2e^{-16}$, multiple R-squared=0.6, ISI_upper has a more positive effect on trout length than ISI_lower (intercept). LYS_upper had the most positive effect on trout length of all the sections. LYS_middle had a slightly more positive effect on trout length than LYS_lower.

Coefficients	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	5.07143	0.09588	52.891	< 2e-16
ISI_upper	0.7	0.25369	2.759	0.00641
LYS_lower	0.57857	0.44974	1.286	2.00e-01
LYS_middle	0.70662	0.13643	5.18	6.04e-07
LYS_upper	1.90385	0.11633	16.366	< 2e-16

*Table 22: A parameter estimates done on the second most supported model "$Dens_{0+\ salmon}$ * River", $p=2.2e^{-16}$, multiple R-squared=0.2, there is a slight negative impact on trout length by the salmon 0+ density in Lysakerelva and positive impact by the 0+ salmon density in Isielva. For low salmon 0+ densities the trout length in Lysakerelva is larger than in Isielva.*

Coefficients	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	4.761381	0.17287	27.543	< 2e-16
$Dens_{0+\ salmon}$	0.008863	0.003243	2.733	0.00759
Lysakerelva	1.017089	0.196893	5.166	1.48e-06
$Dens_{0+\ salmon}$: Lysakerelva	-0.009479	0.003877	-2.445	1.65e-02

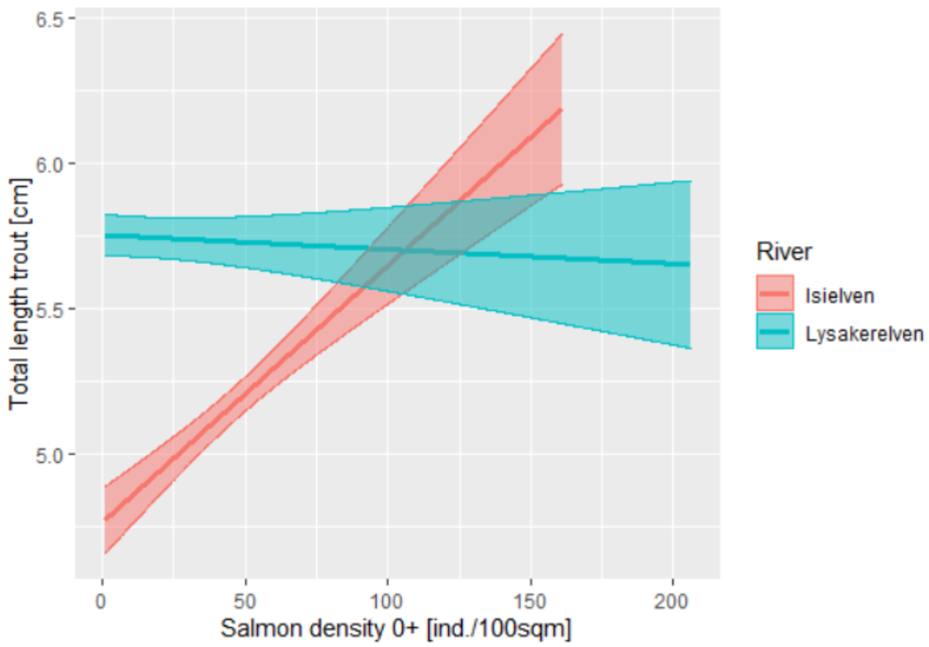

Figure 18: Prediction plots with 95% confidence interval showing the interaction effects of 0+ salmon density and river site upon the total length of trout. There is a slight negative impact on trout length by the salmon 0+ density in Lysakerelva and positive impact by the 0+ salmon density in Isielva. For low salmon 0+ densities the trout length in Lysakerelva is larger than in Isielva.

Table 23: Parameter estimates of the third most supported model "Section", $p=1.4e^{-5}$, multiple R-squared=0.3. For low salmon 1+ densities ISI_upper has a more positive effect on trout length than ISI_lower (intercept) and LYS_middle had a less positive effect on trout length than LYS_lower. Salmon 1+ densities has a stronger negative impact on trout length in ISI_upper than in ISI_lower and a stronger negative impact on trout length in LYS_middle than in LYS_lower. The largest negative effects of increasing salmon 1+ densities of all the river stretches are in LYS_middle.

Coefficients	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	9.68053	6.91401	1.4	0.165
oneAS	-0.06822	0.10232	-0.667	0.507
SectionISI_upper	-3.64149	6.9473	-0.524	6.02e-01
SectionLYS_lower	-1.25751	2.78684	-0.451	6.53e-01
SectionLYS_middle	-5.30071	6.9416	-0.764	4.47e-01
oneAS:SectionISI_upper	0.06386	0.10286	0.621	5.36e-01
oneAS:SectionLYS_middle	0.07747	0.1024	0.756	4.51e-01

Detections of marked individuals

The first detection round with a portable PIT-antenna was performed during 19th and 20th of February. Due to a thick layer of ice, only the open parts of the river could be scanned. No re-captures were found between the Jar waterfall and the Fåbrofossen waterfall, where almost the entire river was covered in ice creating shelter for the fish, and too thick for the signals to reach trough, see Figure 8. Station LYS5 were scanned both days and none of the detections from the 19th of February were registered the 20th of February. Due to a contamination episode with unknown pollution into the river, a scan was done in station LYS7 the 9th of March to estimate whether the contamination had caused acute damage. LYS5 was scanned as a control. The contamination turned out to be tunnel wash water causing no documented short-term damage. 14 tagged individuals were detected in LYS7, where five were the same individuals as found the 19th of February. LYS5 were now ice-free and 27 individuals were scanned, of which nine had been detected in the earlier rounds. The last scans were performed in late March with a new apparatus. The logging was glitchy, most of the data is missing and the results from this round should not be fully trusted.

Table 24: Overview over detections scanned with a hand-held PIT antennae.

Date	Tag registration place	Individuals detected	Species	All individuals marked at station	Comment
19.02.2021	LYS7	14	Salmon and 1 trout	LYS7	
19.02.2021 & 20.02.2021	Extended LYS5	7 & 6	All salmon	LYS5	
09.03.2021	LYS7	14	All salmon	LYS7	5 re-captures from 19.02
09.03.2021	LYS5	6	All salmon	LYS5 & LYS6	One upstream migration from LYS6
09.03.2021	LYS5	27	All salmon	LYS4, LYS5 & LYS6	- 9 re-captures from 19.02 & 20.02 - one upstream and one downstream migration.
22.03.2021 & 23.03.2021	LYS1 Below LYS1 Above Fåbro LYS5	4 1 4 4	Trout Trout Salmon Salmon	LYS1 LYS2 LYS4 LYS5	- No comment - Migrated upstream - Migrated downstream - All caught twice earlier

Discussion

The results showed clear variations in species-specific densities and growth above and below the migration barriers in both rivers. Habitat quality and ecological status varied a bit throughout the river stretch, but it was the differences in the population structure and interactions between salmon and trout upstream and downstream the barriers that distinguished the sections.

Looking at the smolt production of the rivers based on the data from 2020, the potential salmon smolt production was 10.2 salmon smolts and 2.2 trout smolts per 100 m^2 in Lysakerelva, and 3.0 salmon smolts and 0.9 trout smolts per 100 m^2 in Isielva. Both population density and smolt production were based on instantaneous mortality rates and the estimated 0+ densities. The original plan was to use mark-recapture data to estimate the instantaneous mortality rate as this is a more robust method that also would have allowed for size-specific rates and separation of migration, survival and catchability processes (Lebreton et al., 1992). However, as the logging was faulty catch curves were used to estimate mortality. This method sets strong limitations to the dataset to get physically reasonable results. Only stations with a higher number of 0+ than 1+ can be used, and as there are three to four datapoints the regression line is very case sensitive. The morphological differences between the stations may select stronger for one of the age groups, which can render too high or too low instantaneous mortality rates. In addition, this method does not differentiate between mortality and migration. As many of the instantaneous mortality rates were relatively large, this can render an artificially low population density and smolt production when analysing each station isolated. To mitigate for this, and to minimize the migration effects, the smolt densities and smolt production were based on the instantaneous mortality rates from different river stretches comprising of both types of stations, however, this also rendered very large, but not unrealistically large, instantaneous mortality rates.

Comparing the smolt production estimates to the NINA (The Norwegian Institute for Nature Research) report estimating smolt densities in 80 Norwegian rivers (Hindar, 2007), the estimate in Lysakerelva is neither very low or very high. The salmon smolt production in Isielva, however, were at the same level as rivers with the lowest smolt estimates in the report, all located above the polar circle. For a river with a middle to long growing season and a lowland watershed near the coast, it is very low. The annual death rate calculated for the smolt estimation is 80 % in Lysakerelva and 79 % above and 74 % below the migration barrier in Isielva. NINA estimated the potential salmon smolt production based on the survival from egg to smolt of 10 % the first year and 50 % the years after (Hindar, 2007). A large part of the natural mortality occurs during the first summer from the alevin to the early parr stage when exogenous feeding starts (Jonsson, 2011). As the electrofishing occurred in late September, the annual mortality of the 0+ parr in both Lysakerelva and Isielva should be nearer the annual mortality rate used for older fish in the NINA report. Assuming a 50 % annual mortality all-over, the estimated smolt production increased to 20.7 salmon smolts and 3.3 trout smolts per 100 m^2 in Lysakerelva and 15.9 salmon smolts and 1.2 trout smolts per 100 m^2 in Isielva. The updated estimated salmon smolt density in Lysakerelva is equal to the highest smolt density estimates registered in the NINA report.

For Isielva, older smolt production estimates exists. Rosseland (1962) reports an estimate of 1890 smolts from Bjørumssaga and 9 km upstream based on the mean values per meter from 6 stations of 30 meters each. The length from station ISI1 to Bjørumssaga is 1.8 km. Downscaling the number to the last 1.8 km of the river stretch, assuming an even distribution, renders 378 smolts, giving 1.9 smolt per 100 m^2. Rosseland discussed that countings from the years after the electrofishing session indicated that the numbers were too large. At the time, between 25 000 to 30 000 individuals were released each year and the difference in counted smolts could be linked to the varying number of released salmon (Rosseland, 1962). 1.9 smolt per 100 m^2 is less than the smolt estimate from the upper Isielva river stretch of 3.4 smolt per 100 m^2, but they are comparable. Using the annual mortality rates from the NINA report (Hindar, 2007) renders a production potential of 18.8 smolts per 100 m^2. Looking at survival from release in the river through their first summer, Rosseland (1962) reports 22 140 individuals. Downscaling this to the last 1.8 km river stretch renders 4428 individuals. Assuming that 30 000 salmon were released that year gives a survival of 74 %. Assuming that the first critical feeding phase had past and applying a survival rate of 50 % to the next year, gives a total survival rate from release to 1+ of 37 %. It is not clear from the report if the released fish are alevins or pre-fed parr, however, according to the hatchery manager (Merkesdal, 2020), the hatchery has always been run the same way and it is therefore reasonable that the released fish were alevins. If so, the survival rate is very high. The 0+ density in the same stretch was 14 980 individuals for September 2020. 400 000 alevins were released, which correlates to 80 000 individuals in the lower 1.8 km river stretch. This gives a survival rate from late May to September of 19 %. Assuming a further survival rate of 50 %, results in 7490 1+ next year, which is 9 % of the released alevins. Those numbers fit well with what was presented in Hindar (2007). Looking at production of salmonids, Lundgrin (2020) found in early November 2019 20.7 individuals per 100 m^2 in the upper stretch of Isielva and 26.4 individuals per 100 m^2 in the lower stretch. The fishing was carried out at low temperatures which could decrease catchability significantly (Lundgrin, 2020). This is in accordance with the results from September 2020 with significantly higher salmonid densities; 98.0 individuals 100 m^2 in the upper stretch and 52.9 individuals per 100 m^2 in the lower stretch. Both the smolt production and density estimate from 2020 are higher than what has been documented in these river stretches before, however, a longer timeline is needed to evaluate if the results from 2020 are within the mean estimates for the river or if this was a very productive year.

The inter- and intraspecific interactions between the two salmonid populations were evaluated by looking at the density interactions. Looking at 0+ salmon, the effects from 1+ salmon was by far the most negative, followed by 0+ trout and at last 1+ trout. Here, the intraspecific intercohort competition is the most important negative contributor to 0+ density, followed by intracohort competition from both trout and salmon. Looking at trout 0+ density, both salmon and trout 1+ had a positive effect, and salmon 0+ had a negative effect. The availability of slow flowing habitats is critical for the survival of the newly emerged parr during the first months (Armstrong & Nislow, 2006) due to their poor ability to hold position and feed successfully in fast-moving water. In larger streams, juvenile trout are typically located along the bank areas, although large individuals often exploit deep, slow-flowing pool areas. Compared with the trout, the salmon parr use a wider range of depths and water velocities and exploit deeper areas as well as stretches with faster current velocities farther from shore (Sweka & Mackey, 2010). Although the species are phenotypically similar, morphological adaptations make young salmon better able to exploit swift water than trout. Thus, the two segregate partly in nursery rearing habitat as they use different parts of rivers with respect to depth, distance from the shore and substrate (Jonsson, 2011). This segregation increases when comparing 0+ trout to 1+ salmon. As juvenile salmonids feed to a large extent on drifting and epibenthic invertebrates which is positively correlated with current velocity (Keeley & Grant, 1995), there will be more to gain for 1+ salmons by using a habitat that does not fully overlap with trout 0+. If there are strong intercohort competition between the salmon age groups, a strong 1+ group can restrain the 0+ group. Even though trout are very aggressive (Kalleberg, 1958) and can through interference constrain the salmon use of slow flowing river stretches, a weaker 0+ salmon group renders less competition for the 0+ trout. Although data from one year is not enough to do more than speculations of the interactions between the species and age groups, there are indications of salmon dominance in the studied river stretches, where the intercohort competition seems stronger than interspecific competition for salmon and intracohort, interspecific competition seems stronger than intraspecific competition for trout.

In addition to salmon and trout, the European minnow also contributes to the interspecific competition in all river stretches. The European minnow can live in shoals which may comprise a hundred or more fish of all age groups, they inhabits flowing waters and pools where the current is gentle and the bottom substratum consists preferably of stones and gravel, although they may use habitats with silt or sand bottom (Frost, 1943). European minnow often occur at very high densities in nursery streams for brown trout (Museth, 2002), and food competition with young trout (1+, >1+)

and predation by European minnows on 0+ trout may both potentially reduce trout recruitment (Museth et al., 2007). The impact of European minnow on salmon populations is not known, however the European minnow is not likely to compete strongly with salmon in fast flowing areas, but will probably have greater success in slow-flowing river sections (Museth et al., 2007). 11 % of the total catch in Lysakerelva and 0 % in Isielva were European minnow. As the aim was fishing for salmonids, this percentage is underestimated as many European minnows were not netted. They were caught strictly in stations with shallow areas and slowing current or areas with fine sediments, the first which coincides with salmonid nursery habitat. It is therefore reason to believe that there are European minnow – salmonid interactions, and that these may cause a more negative contribution on the trout 0+ density due to habitat preference overlap.

As the use of different habitats results in dissimilar growth rates, mortality rates and associated life history traits (Jonsson, 2011), 0+ length was coupled against different prediction factors to see if the different river stretches segregate for specific phenotypes. Looking at 0+ salmon, the individuals in the upper stretch of Isielva were a bit longer than in the lower stretch. A comparison cannot be done in Lysakerelva due to missing data in the middle stretch of the river, but the 0+ salmon lengths were generally higher in Lysakerelva. It was the same for trout; the upper stretch of Isielva rendered a bit longer 0+ individuals than the lower stretch, and the individuals were generally shorter in Isielva than in Lysakerelva. In Lysakerelva, however, there was a strong difference between the upper stretch, which had markedly longer individuals, and the middle and lower stretches. This is also the only river stretch where the trout population did not experience sympatry with salmon. The models including spatial prediction factors like river- and station effects got most support from the AIC analyse, but the Pulg habitat score did not get much support. According to Finstad et al. (2007) densities and growth of Atlantic salmon parr are highly influenced by shelter availability. The Pulg method does not reflect specific current velocity, water depth, substrate structure or shelter opportunities, all of which are major habitat variables influencing the habitat use of stream-living salmonids (Jonsson, 2011). These traits are reflected both in the river- and station variables. This may indicate that the habitat above the migration barriers are better suited for 0+ salmonids as more energy can be used on growth. The length is also dependent on interspecific competition, as clearly demonstrated in the upper stretch in Lysakerelva where the individuals were markedly longer, probably due to less competition in the absence of salmon.

To look more into how the presence of salmon affects the trout population, the trout 0+ lengths were coupled against salmon densities. Due to detections of very few individuals below the Fåbrofossen waterfall, and only in station LYS5, data from this section does not render trustworthy results. In Isielva, however, there is a strong positive effect between increasing salmon 0+ density and 0+ trout length. This positive effect is slightly lower in the upper stretch of the river where the percentage of salmon is larger. Looking at 0+ trout length coupled with salmon 1+ density the picture changes. Increasing salmon 1+ density has a positive effect on the trout 0+ length in Lysakerelva and a strong negative effect in Isielva. Looking at the sections in Isielva, increasing salmon 1+ density has stronger negative effects on the trout 0+ length in the lower section of the river. In the middle section of Lysakerelva the increasing salmon 1+ density has a weak positive correlation. As increasing 1+ salmon density has a negative effect on the 0+ salmon density, this makes sense. Growth depends upon a positive energy budget and the habitat use is expected to maximize their net energy intake-rate, balancing foraging opportunities, behavioural costs and shelter (Jenkins & Keeley, 2010). Densities and growth of salmon parr are highly influenced by shelter availability, and the strength of density-dependent population regulation, measured as carrying capacity, has been found to increase with decreasing number of shelters (Finstad et al., 2007; Finstad et al., 2009; Jonsson, 2011). Since increasing salmon 0+ density has positive effects on the trout length but negative effect on the 0+ trout density, it may indicate that Isielva has reached its salmonid production carrying capacity, where salmon presence supresses the trout population. As only the strongest trout individuals survive, which correlates to length, increasing salmon 0+ density may translate to a positive length effect on 0+ trout. Comparing the catch in the different river stretches shows that while trout constituted of 10 % of the catch above and 26 % below the migration barrier in Isielva, it was the opposite in Lysakerelva, with 13 % above and 2 % below the Fåbrofossen waterfall. In addition, there was a lot of European minnow in the anadromous stretch, most probably due to a much finer substratum in the deeper, slow-flowing parts. In the upper stretch of Lysakerelva the ratio trout to European minnow was 75 to 25 %. The strong salmon presence in all stretches where the species co-exists, indicates a habitat template that suits salmon much better than trout in both rivers, especially in Lysakerelva. By removing the migration barrier, one may expect conditions more similar to the anadromous river stretches for the trout populations, i.e. upstream the barrier trout 0+ density would increase and 0+ length decrease in Isielva and trout 0+ density would drastically decrease in Lysakerelva.

The competition between the species can be different in the river stretches where the salmon population consists of released hatchery individuals. In hatcheries, salmonid eggs are often incubated at elevated water temperature to induce early hatching and a prolonged first-growing season. This gives the young fish a size advantage over similar-aged wild conspecifics, if liberated in nature. This size advantage can influence the outcome of social encounters, with effects on life history characters (Jonsson, 2011), as discussed above. The alevins released in Isielva have experienced conditions as close as possible to the river substratum and air temperature, and are released before they start exogeneous feeding (Merkesdal, 2020), and the interspecific competition is not very different above and below the migration barrier. The picture is different in the middle stretch of the Lysaker river, where the released parr in both 2018 and 2019 were pre-fed, which could give them a size advantage. In 2020, the hatchery salmon were alevins, fewer in numbers and released in early April. Looking at the trout catch data, there are very few individuals in the 1+ and >1+ age groups which have competed with the pre-fed hatchery salmon, there are however a much better 0+ group indicating that the absence of 20 000 pre-fed salmon parr had a strong positive effect on the trout population. Allowing natural spawning of anadromous salmonids in these areas might shift the ratio in favour of trout in Isielva as both anadromous salmon and trout would spawn. In Lysakerelva, natural spawning could enhance the number of salmon alevins in the river stretch, which would increase the competition with trout. This could affect the ratios in the populations below the migration barriers as well, as parr have a tendency to migrate downstream before they smolt (Jonsson, 2011). That would shift the ratios even more towards trout in Isielva and salmon in Lysakerelva.

Anadromous populations use the river as a spawning and nursery area before they emigrate to the sea for feeding, hence the population depends largely of habitats well suited for this purpose. Looking at the river stretches above the migration barriers, they consist in Lysakerelva of 64 % and in Isielva of 95 % well suited habitat for salmonid 0+ and 1+ age group of good to excellent habitat quality. The potential for salmon in the upper stretch of Lysakerelva can be estimated using the mean value of expected 0+ density in the anadromous river stretch and the survival rate from Hindar (2007). This renders a salmon smolt production of 15.7 smolts per 100 m^2 in the upper river stretch. Above the upper river stretch there is an additional 2 km of the Lysaker river that is available. Assuming a similar number in this river stretch, the area above the Jarfossen waterfall may produce 2759 salmon smolt. Using the same number on the middle stretch renders a salmon smolt production of 24.6 smolts per 100 m^2, a total of 2888 individuals. That is less than the estimated production in the middle stretch of 62.0 smolts per 100 m^2, indicating that the mean value of expected 0+ density in the anadromous river stretch is a conservative estimate for the potential above the Fåbrofossen migration barrier. In Isielva, a river stretch of about 15 km is available above the migration barrier. Using the mean value of expected 0+ density from below the migration barrier render a smolt production estimate of 5.5 salmon smolts per 100 m^2 and 0.9 trout smolts per 100 m^2. This is a much lower estimate for salmon but a slightly better estimate for trout. As the salmon population above the wandering hinder is significant and habitat quality and morphology is different above and below the wandering hinder, the smolt estimates from the upper river stretch are probably “most correct”. This renders a smolt production estimate of 18.8 salmon smolts and 0.3

trout smolt per 100 m^2, giving 31 209 salmon individuals and 565 trout individuals for the whole river stretch.

Removal of the migration barriers in Isielva and Lysakerelva can have both positive and negative effects. New areas will open to the anadromous populations which have experienced a large net loss of habitat due to human activities the last few hundreds of years. There is a large production potential above the migration barriers in both rivers, but most of the area except the upper part of Lysakerelva is already utilized through releasing salmon alevins or smolts from hatcheries. The salmon alevins are made from parents caught while merging towards the spawning grounds in each river without a sorting selecting for specific traits. The parentage of the alevins released in Isielva are tested to avoid genetics from hybrids and farmed fish (Dalen, 2021; Merkesdal, 2020). Without the effort from the hatcheries, the removal of the migration barriers might be essential to the anadromous populations. However, according to Rosseland (1962), salmon rarely passes Kølabruhølen 4 km downstream station ISI7, but trout usually use the entire available river stretch. He estimates a yearly return of 210 salmon and 3900 trout spawners with an addition of fish passing outside the fishladder at the Møllefossen waterfall at Franzefoss. That the spawners do not reach Bjørumssaga each year is backed by Morten Merkesdal (Merkesdal, 2020). This is not a problem in the stretch below Fåbrofossen, hence, a fish ladder here could be more profitable for the anadromous population than removing the old sawmill dam at Bjørumssaga. Allowing anadromous fish past Fåbrofossen will result in two selection processes; first the fish ladder will select for a particular range of phenotypes, then the Jarfossen waterfall will select for potentially others. Looking at the length of the spawners caught in the fish ladder in the Møllefossen migration barrier in Sandvikselva from 2015 to 2020, there is a mean length of salmon of 65 cm and of trout of 45 cm (Merkesdal, 2021). Transferring this to Lysakerelva, the Jarfossen waterfall might select only for the largest salmon as they are strong enough to leap up the main drop. As previously discussed, there are strong indications that salmon presence suppresses the trout population. Allowing anadromous fish to pass Fåbrofossen will most probably diminish the local, resident trout population. From an angling perspective, this will render a very different picture, as a larger part of the river stretch will allow salmon sport angling in the fall at the expense of all-year fishing for trout. This can result in both an increase of recruitment for fishing as salmon are a charismatic creature which fascinates, or a decrease of recruitment as fishing might become less available for everyone. The freshwater pearl mussel depends on trout during the larval life stage (Österling, 2014). A lower trout density in Lysakerelva may negatively affect recruitment of freshwater pearl mussel, however, Österling (2014) found that freshwater pearl mussel parasite suitability was higher on migratory than on resident host fish and lower mussel encapsulation and growth on resident hosts results in reduced recruitment for the freshwater mussels. As their study systems had previously been anadromous river stretches barred by human activities (Österling, 2014), their findings are not necessarily applicable to the freshwater mussels in Lysakerelva which are adapted to the resident trout, and it is reason to believe that the freshwater mussels will be negatively affected by removing the migration barrier. The anadromous migration barriers are also acting as an insurance if the rivers should be contaminated by *Gyrodactylus salaris* from the nearby Drammensvassdraget watercourse. If the anadromous area had to be treated, it would quickly be recolonized from the upper stretches. In addition, a large quantity of the anadromous gene pool would be saved, as hatchery alevins are presently released upstream the barrier most years. If the barriers are removed before Drammensvassdraget is treated, this insurance will disappear. Lastly, as the Bjørumssaga dam is in very bad condition, a safe removal of this will remove the risk of dam breach and downstream clogging by fine sediment.

Conclusion

The salmon smolt production estimates based on the adjusted mortality rates were very high in Lysakerelva and high in Isielva compared to the smolt production estimates given for the 80 National Salmon Watercourses in 2007. The smolt production was estimated to be higher above the migration barrier in both rivers. For trout, the smolt production estimates were much lower. In Lysakerelva, the highest smolt estimates were the upper river stretch, followed by the middle river stretch. The smolt estimate in the lower river stretch were extremely low. It was the opposite in Isielva, with a markedly low smolt production estimate above the migration barrier and a much better estimate below.

There were some indications of phenotypic differences between both the rivers and stations. Both salmon and trout 0+ were in general longer in Lysakerelva than Isielva. Looking at salmon 0+ length, the individuals above the migration barrier in Isielva were a bit longer than the individuals below the barrier. A comparison cannot be done in Lysakerelva as no salmon 0+ were found above the migration barrier. Trout length reflected the same tendencies in Isielva, however in Lysakerelva individuals in the upper river stretch were noticeably longer compared to the middle and lower river stretches.

The strong salmon presence in all stretches where the species co-exists, indicates a habitat template that suits salmon much better than trout in both rivers. Looking at the trout 0+ density in middle stretch in Lysakerelva, the absence released pre-fed salmon parr in 2020 had a strong positive effect on the population. In addition, both the length and estimated smolt density of trout 0+ were noticeably higher in the upper river stretch in Lysakerelva where trout is sympatric with European minnow, but not with salmon.

Looking at the areas above the migration barriers and the estimated smolt production these could render, there is a large potential for the anadromous salmonid populations in both rivers. For salmon, a lot of this potential is already realised by the release of alevins in the whole area that would be made available in Isielva and in the middle section of Lysakerelva. The potential in the upper section of Lysakerelva is not yet realised, and would be made accessible to larger individuals that manage to pass the Jarfossen waterfall. As it is only salmon alevins that are released in the river stretches, there is an unused potential for anadromous trout if natural spawning replaces the hatchery contribution.

Removal of the migration barrier in Lysakerelva will allow the anadromous populations access to large spawning areas of good quality in the middle river stretch. Only the largest individuals are thought to be able to pass the Jarfossen waterfall, which may select for salmon in the upper stretch and would most probably diminish the local trout population, as seen in the middle stretch of the river. This could also potentially negatively affect the freshwater pearl mussel in the upper river stretches. Allowing anadromous fish up Fåbrofossen will allow more salmon sport angling in a larger stretch of the river in one of the most urban locations in Norway, but it could also render fishing less available as it would reduce the local trout population. As the anadromous population does not reach the wandering barrier in Isielva every year, a removal of this will not necessarily enhance smolt production, especially if natural spawning replaces the hatchery contribution. This could however be positive for the trout population, as there would be less competition from salmon. Today the migration barriers also act as an insurance if the downstream part should be contaminated by Gyrodactylus salaris. This would disappear if the migration barriers were removed before Drammensvassdraget is treated.

Further work

To better understand the interactions in the river, mark-recapture data should be gathered in several rounds. This would render a better estimate of the instantaneous mortality rate as migration would be considered. This would also allow an investigation of migration patterns and which habitat is used throughout the year. Classical habitat characterization should be performed in all stations with special focus on shelter availability, and new linear models should be run with data from the PCA analysis. New electrofishing and marking rounds should be performed to see how the population evolves over time and to look for effects of intercohort competition. During the fishing rounds European minnow could also be counted and measured as it has habitat and dietary overlap with trout.

To get a better picture of the percentage that smoltify and at what age, two antennas should be installed in parallel in the estuary zone below station LYS7 to register in- and outward migration to the fjord. A camera counting fish installed in the fish ladder at Møllefossen would contribute to an estimation of smolt production from the river each year. Both of these initiatives are planned.

The long term effects on the local trout population of avoiding release of hatchery salmon 0+ should be studied. This would only be possible through a pause of the salmon release in the middle stretch of Lysakerelva, but it could give valuable information on the recovery and resilience of the local trout population. It looks like the local trout populations has responded positively on the absence of 0+ salmon alevins in 2020, and such a study could verify this. A study comparing the upper river stretch to the middle river stretch over several years to see how the populations evolve over time.

As the freshwater pearl mussel is a threatened species, a comparison of the encystment of the larvae on trout above and below the migration barrier should be studied to verify if the population would be negatively or positively affected by a fishladder in Fåbrofossen.

This report found signals of correlation between the ordination analysis from a classical habitat characterization and the Pulg method. This should be explored further with a larger dataset.

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Appendix I – Habitat descriptions

The electrofishing in Lysakerelva was performed as effectively as possible due to a forecasted weather change that moved forward in time. Fishing all stations under equal conditions were prioritized against a third sampling round in stations with noticeably low catch.

It was observed thread algae, see below figure, especially in the upper part of the river from station LYS1 to LYS3. The smell of sewage came and went while sampling the upper stations, even after a long period of dry weather.

Figure 19: Thread algae photographed at station LYS2 indicates a nutrition rich environment. It was also a noticeable sewage odour in both station LYS1 and LYS2.

Station description

Station	Date	Length [m]	Mean witdth [m]	Area [m2]	Weather condition	Temp air [degC]	Electrofisher	Hand net	Comment
LYS1	19.09.2020	25	15	337	Sunny	16	MI	Torbjørn, Rebecca	Inexperienced help, could affect catchability and identification of smaller fish. Clear smell of sewage.
LYS2	19.09.2020	20	6	157	Clear		Veronica	Elina	A lot of thread algae and almost no fish.
LYS3	20.09.2020	18	7	157	Clear		MI/Elina	Anne	Only the river run at the western side were fished. Inexperienced hand net operator. Change of electrofisher after the first sampling round to allow PIT marking in parallel. No European minnow found, maybe doe to coarser substratum .
LYS4	22.09.2020	21	6	115	Cloudy	16	MI	Amund	
LYS5	22.09.2020	27	9	273	Sunny	16	Veronica	Elina	Shallow station with very many small individuals.
LYS6	22.09.2020	20	6	120	Sunny		MI	Amund	
LYS7	23.09.2020	25	6	151	Rain	17	Thrond	E, A, MI	A lot of surface reflexion made the fish harder to spot.
ISI1	14.09.2020	30	7,5	225	Sunny	16	Thrond	E, MI	
ISI2	16.09.2020	26	8,2	213	Sunny	14	MI	A	
ISI3	16.09.2020	30	8,9	267	Sunny		MI	A, E	Darkness fell when counting the fish, mobile light was used.
ISI4	17.09.2020	28	7	196	Sunny	16	MI	E	
ISI5	18.09.2020	25	10,2	255	Sunny	12	MI	A	A lot of surface reflexion made the fish harder to spot.
ISI6	18.09.2020	25	7,9	198	Sunny	16	MI	A	
ISI7	18.09.2020	27	9,1	246	Sunny	15	Veronica (1) Amund (2&3)	Amund Elina&MI	Change of electrofisher after first sampling round. The last sampling round was fished using head lights.

Photos

Figure 20: Jarfossen waterfall upstream of station LYS3.

Figure 21: Station LYS3 seen from above.

Figure 22: station LYS4 seen from below.

Figure 23: Station LYS5 seen from above

Figure 24: Station LYS6 seen from below

Figure 25: the Møllefossen dam and station LYS7 seen from below.

Appendix II – Evaluation form for habitat characterization

Table 25: Evaluation form for habitat characterization (Ulrich Pulg, 2011)

Mesohabitat type	Traits	Estimating habitat quality
Spawning area • Spawning gravel dominates the substrate	Morphology	1 bad: v ≈ 0,1 m/s or v ≈ 1 m/s, d ≈ 5 cm
		2 less suited: v ≈ 0,1-0,2 m/s or v ≈ 0,8-1 m/s, d ≈ 5 cm
		3 good: v ≈ 0,2-0,8 m/s, d ≈ 5-10 cm
		4 excellent: v ≈ 0,2-0,8 m/s, d > 10 cm
	Substrate	1 little: cover 0-25 %
		2 middle: cover 25-50 %
		3 much: cover 50-75 %
		4 dense: cover 75 – 100 %
	Cover and dead wood	1 little: cover 0-25 %
		2 middle: cover 25-50 %
		3 much: cover 50-75 %
		4 dense: cover 75 – 100 %
Fast run • Less spawning gravel • Dominating water velocities > 0,3 m/s • Gradient > 0,3 %	Morphology	1 Channelling with permanent fortification without cavities: shelter and cavities of <50% of the area
		2 Channelling with stones or low morphological diversity - shelter and cavities of <50% of the area
		3 Channelling with stones or low morphological diversity - shelter and cavities of 50-100 % of the area
		4 High morphological diversity, natural river banks, shelter and cavities of 5050-100 % of the area
	Substrate	1 bad : only bedrock
		2 middle: boulders and pebbles
		3 good: boulders, gravel and pebbles/trees
		4 excellent: boulders, pebbles, trees and patches of spawning gravel
	Cover and dead wood	1 little: cover 0-25 %
		2 middle: cover 25-50 %
		3 much: cover 50-75 %
		4 dense: cover 75 – 100 %
Slow run • Less spawning gravel • Dominating water velocities < 0,3 m/s • Gradient < 0,3 %	Morphology	1 Channelling with permanent fortification without cavities: shelter and cavities of <50% of the area
		2 Channelling with stones or low morphological diversity - shelter and cavities of <50% of the area
		3 Channelling with stones or low morphological diversity - shelter and cavities of 50-100 % of the area
		4 High morphological diversity, natural river banks, shelter and cavities of 5050-100 % of the area
	Substrate	1 bad : only fine sediment or bedrock
		2 middle: fine sediment and pebbles/blocks/rock/gravel/trees

		3 good: fine sediment and pebbles/blocks/rock/gravel/trees
		4 excellent: fine sediment and pebbles and gravel and blocks/trees
	Cover and dead wood	1 little: cover 0-25 %
		2 middle: cover 25-50 %
		3 much: cover 50-75 %
		4 dense: cover 75 – 100 %
Culvert • Closed river	Evaluated in the same manner as slow or fast run depending on type	

F = fine sediment [< 1 mm]

Appendix III – Verification of the Pulg method

In order to check for coherence between Pulg's habitat scores and detailed habitat character measurements, linear regressions were fitted between the habitat quality sum from the Pulg method against each one of the first three principal components from a PCA analysis done on detailed habitat characterization data in two locations. The detailed characterizations were: list. The PC1-PC3 explained x % of the habitat variation. As the Pulg method is used on river stretches instead of transects, the mean value of the river transects for each station were used for comparison in the classical approach. In Isielva, classical habitat characterization were performed for the stations ISI2 to ISI7 during the fall of 2019 (Lundgrin, 2020) and compared to Pulg characterization done for this master thesis during the spring 2021. For the river Årungselva, classical habitat characterization was done during the fall of 2020 by Amund Dahle and compared to Pulg characterization done for this master thesis during the spring 2021.

For both the Isi- and Årungselva rivers PC3 is a distinctly better fit than the other two, with an R-square of respectively 36% and 65% against a range of R-squares between 1% and 4%. PC3 explaines 11,7% of the variation in Isielva and 12,9% in the Årungselva river. A combination of the datasets from the Isi and Årungselva rivers also renders PC3 as the best fit, however with a R-square of 0,9 compared to R-squares of 0,2 and 0,03, none of which are statistically significant.

To further check the combination dataset analyse, a parameter estimation on the linear regression were done in R, see Figure 26. The R^2 is 0.094, which is to say that the model explains only 9.4 % of the data variability, however, the $\sqrt{R^2}$ is 0.30 which is a considerable correlation. The p-value of PC3 is 0.36, which gives a 36% chance that it is not meaningful for the regression, and the correlation coefficient is -0-31. In conclusion there are no strong indices that the Pulg method is a good representation of a classical habitat characterization, however as the analyse gives signals of correlation, the Pulg method scores will be used as a variable in the linear regression analysis in this master thesis.

```
Residuals:
    Min      1Q  Median      3Q     Max 
-2.1140 -0.4945  0.3313  0.8605  1.3573 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  10.0909     0.3694  27.315 5.73e-10 ***
PC3          -0.9160     0.9491  -0.965     0.36    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.225 on 9 degrees of freedom
Multiple R-squared:  0.09378,	Adjusted R-squared:  -0.006909 
F-statistic: 0.9314 on 1 and 9 DF,  p-value: 0.3597
```

Figure 26: Parameter estimation of model “PC3" with Pulg as the response variable. The correlation coefficient between Pulg and PC3 is -0.306.

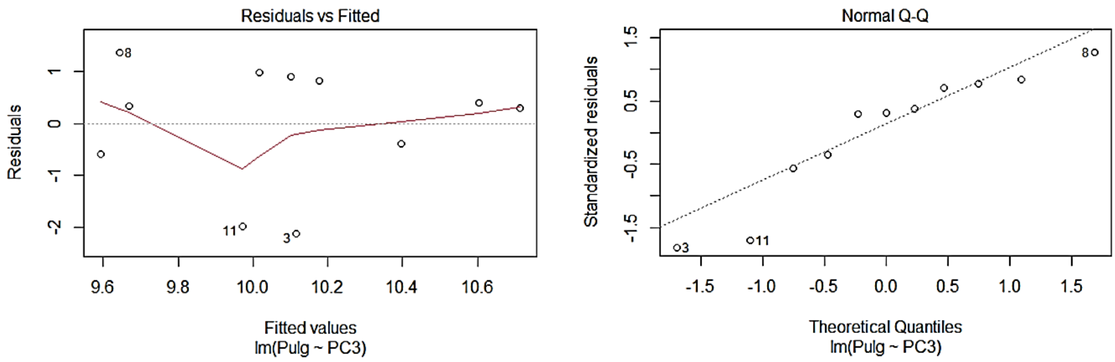


Figure 27: Model diagnostics of model “PC3" with Pulg as the response variable. No transformation of the variable is needed.

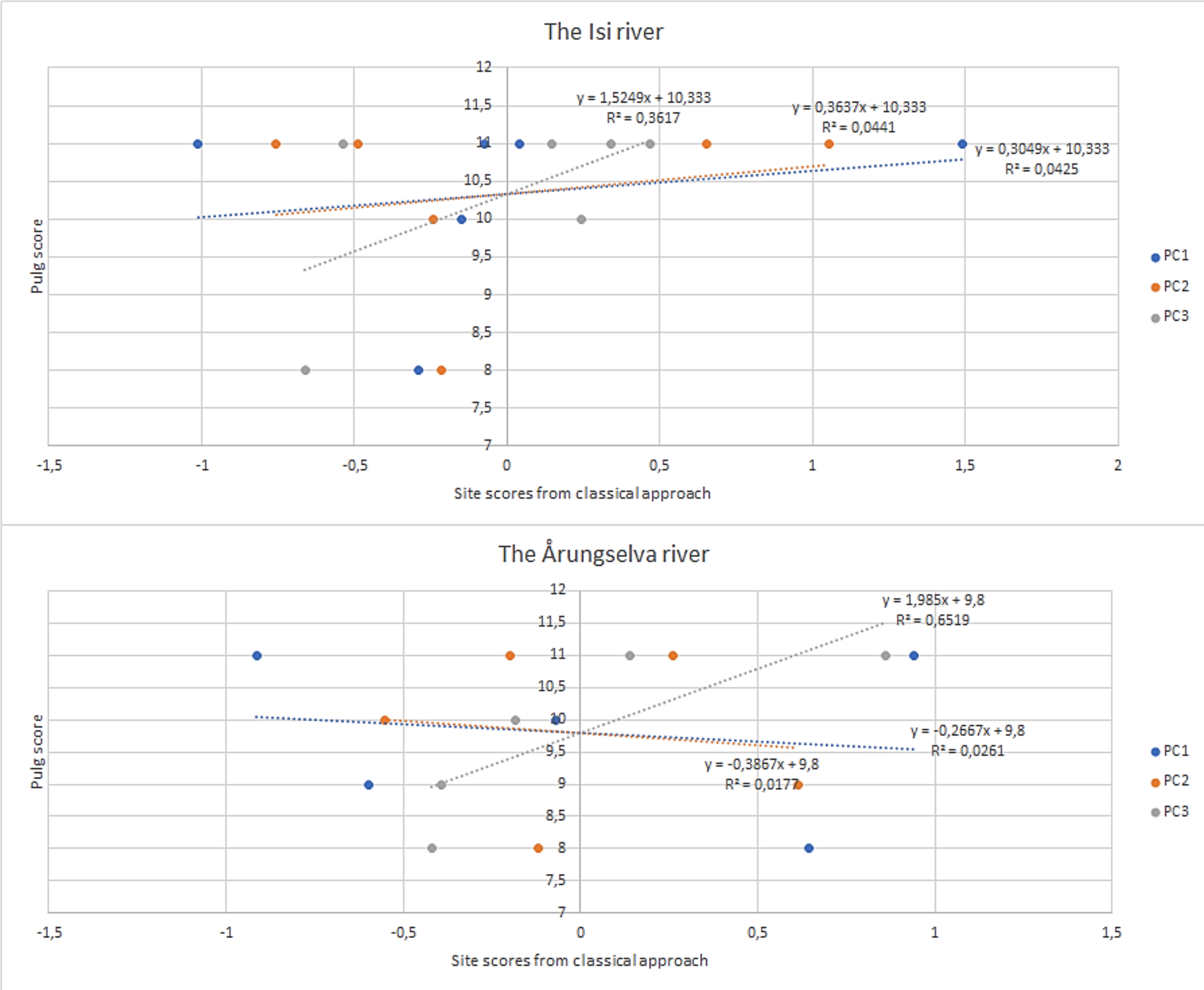


Figure 28: Comparison of Pulg and classical habitat characterization for the Isi and Årungselva rivers

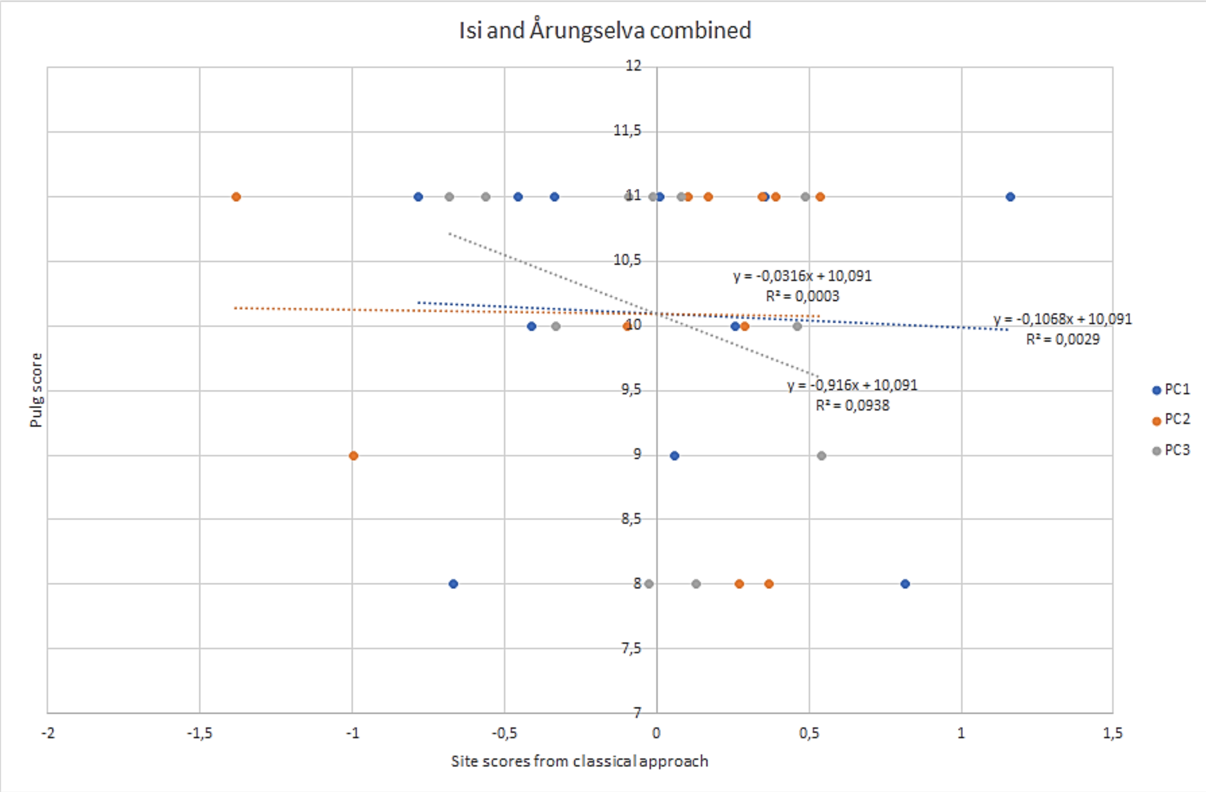


Figure 29: Comparison of Pulg and classical habitat characterization for the Isi and Årungselva rivers combined in a large dataset.

Appendix IV – Class limits for ecological state

Table 26: Class limits for ecological state in smaller rivers and creeks in non-mountainous areas (6.15 (vanndirektivet, 2018))

Population	Excellent	Good	Moderate	Poor	Very poor
Anadrome, habitat not described	>70	69-53	52-35	34-18	<18
Anadrome, habitat class 2	>49	49-37	36-25	25-12	<12
Anadrome, habitat class 3	>81	81-61	60-41	40-20	<20
Anadrome sympatric, habitat not described	>19	18-15	14-10	9-5	<5
Anadrome sympatric, habitat class 2		≥5	≤4		
Anadrome sympatric, habitat class 3	>25	24-19	18-13	12-6	<6
Stream or lake living allopatric, habitat not described	>58	58-44	43-29	28-15	<15
Stream or lake living allopatric, habitat class 1	>34	34-26	25-17	16-9	<8
Stream or lake living allopatric, habitat class 2	>55	55-41	40-28	27-14	<14
Stream or lake living allopatric, habitat class 3	>67	67-50	50-34	33-17	<17
Stream or lake living sympatric, habitat not described	>10	10-8	8-6	5-3	<3
Stream or lake living sympatric, habitat class 2		≥2	<2		
Stream or lake living sympatric, habitat class 3	>14	14-11	10-7	6-4	<4

Appendix V – Catch summary tables

Table 27: Summary table from electrofishing in Lysakerelva.

Stasjon	Runde	Laks	%	Ørret	%	Ørekyt	%	Flyndre	%	Ål	%	Totalt
LYS1	Runde 1	0	0 %	60	67 %	30	33 %					90
	Runde 2	0	0 %	30	77 %	9	23 %					39
	Runde 3	0	0 %	32	84 %	6	16 %					38
	Totalt	0	0 %	122	73 %	45	27 %					167
LYS2	Runde 1	0	0 %	6	100 %	0	0 %					6
	Runde 2	0	0 %	7	100 %	0	0 %					7
	Runde 3	0		0		0						0
	Totalt	0	0 %	13	100 %	0	0 %					13
LYS3	Runde 1	79	98 %	2	2 %	0	0 %					81
	Runde 2	29	88 %	4	12 %	0	0 %					33
	Runde 3	26	93 %	2	7 %	0	0 %					28
	Totalt	134	94 %	8	6 %	0	0 %					142
LYS4	Runde 1	79	64 %	21	17 %	23	19 %					123
	Runde 2	48	72 %	9	13 %	10	15 %					67
	Runde 3	25	54 %	10	22 %	11	24 %					46
	Totalt	152	64 %	40	17 %	44	19 %					236
LYS5	Runde 1	253	97 %	4	2 %	3	1 %					260
	Runde 2	172	98 %	1	1 %	2	1 %					175
	Runde 3	103	98 %	0	0 %	2	2 %					105
	Totalt	528	98 %	5	1 %	7	1 %					540
LYS6	Runde 1	25	32 %	3	4 %	49	64 %					77
	Runde 2	6	23 %	0	0 %	20	77 %					26
	Runde 3	0		0		0						0
	Totalt	31	30 %	3	3 %	69	67 %					103
LYS7	Runde 1	95	90 %	8	8 %	0	0 %	3	3 %	0	0 %	106
	Runde 2	86	91 %	4	4 %	0	0 %	3	3 %	1	1 %	94
	Runde 3	42	89 %	1	2 %	0	0 %	4	9 %	0	0 %	47
	Totalt	223	90 %	13	5 %	0	0 %	10	4 %	1	0 %	247
Totalt Lysaker		**1068**	**74 %**	**204**	**14 %**	**165**	**11 %**	**10**	**1 %**	**1**	**0 %**	**1448**

Table 28: Summary table from electrofishing in Isielva.

Stasjon	Runde	Laks	%	Ørret	%	Ørekyt	%	Totalt
ISI1	Runde 1	78	95 %	4	5 %	0	0 %	82
	Runde 2	69	95 %	4	5 %	0	0 %	73
	Runde 3	50	96 %	2	4 %	0	0 %	52
	Totalt	197	95 %	10	5 %	0	0 %	207
ISI2	Runde 1	70	89 %	9	11 %	0	0 %	79
	Runde 2	28	90 %	3	10 %	0	0 %	31
	Runde 3	18	95 %	1	5 %	0	0 %	19
	Totalt	116	90 %	13	10 %	0	0 %	129
ISI3	Runde 1	93	92 %	8	8 %	0	0 %	101
	Runde 2	64	91 %	6	9 %	0	0 %	70
	Runde 3	36	100 %	0	0 %	0	0 %	36
	Totalt	193	93 %	14	7 %	0	0 %	207
ISI4	Runde 1	117	81 %	27	19 %	0	0 %	144
	Runde 2	68	89 %	8	11 %	0	0 %	76
	Runde 3	47	87 %	7	13 %	0	0 %	54
	Totalt	232	85 %	42	15 %	0	0 %	274
ISI5	Runde 1	95	81 %	23	19 %	0	0 %	118
	Runde 2	53	87 %	8	13 %	0	0 %	61
	Runde 3	43	91 %	4	9 %	0	0 %	47
	Totalt	191	85 %	35	15 %	0	0 %	226
ISI6	Runde 1	51	58 %	37	42 %	0	0 %	88
	Runde 2	31	72 %	12	28 %	0	0 %	43
	Runde 3	22	81 %	5	19 %	0	0 %	27
	Totalt	104	66 %	54	34 %	0	0 %	158
ISI7	Runde 1	100	73 %	37	27 %	0	0 %	137
	Runde 2	57	66 %	29	34 %	0	0 %	86
	Runde 3	40	73 %	15	27 %	0	0 %	55
	Totalt	197	71 %	81	29 %	0	0 %	278
Totalt Isielva		**1230**	**83 %**	**249**	**17 %**	**0**	**0 %**	**1479**

Appendix VI – Age group limits

Table 29: Age group limits; L_0 divides 0+ from 1+, L_1 divides 1+ from >1+ and L_2 divides >1+ from old.

River	Station	Species	L_0	L_1	L_2
Lysaker	LYS1	Salmon			
Lysaker	LYS2	Salmon			
Lysaker	LYS3	Salmon	8	14	16
Lysaker	LYS4	Salmon	8	14	16
Lysaker	LYS5	Salmon	6.9	9.7	16
Lysaker	LYS6	Salmon	6.9	9.5	16
Lysaker	LYS7	Salmon	7.3	9.9	16
Lysaker	LYS1	Trout	9	14	20
Lysaker	LYS2	Trout	9	14	20
Lysaker	LYS3	Trout	9	14	20
Lysaker	LYS4	Trout	9	14	20
Lysaker	LYS5	Trout	9	14	20
Lysaker	LYS6	Trout	9	14	20
Lysaker	LYS7	Trout	9	14	20
Isi	ISI1	Salmon	6.2	10.2	16
Isi	ISI2	Salmon	6.2	10.5	16
Isi	ISI3	Salmon	5.8	10	16
Isi	ISI4	Salmon	6.5	10.5	16
Isi	ISI5	Salmon	5.8	9.9	16
Isi	ISI6	Salmon	5.8	9.9	16
Isi	ISI7	Salmon	6.1	10	16
Isi	ISI1	Trout	7	14	20
Isi	ISI2	Trout	7	14	20
Isi	ISI3	Trout	7	14	20
Isi	ISI4	Trout	7	14	20
Isi	ISI5	Trout	6.5	13	20
Isi	ISI6	Trout	6.5	14	20
Isi	ISI7	Trout	6.5	14	20

Appendix VII – Regression models from catchCurve

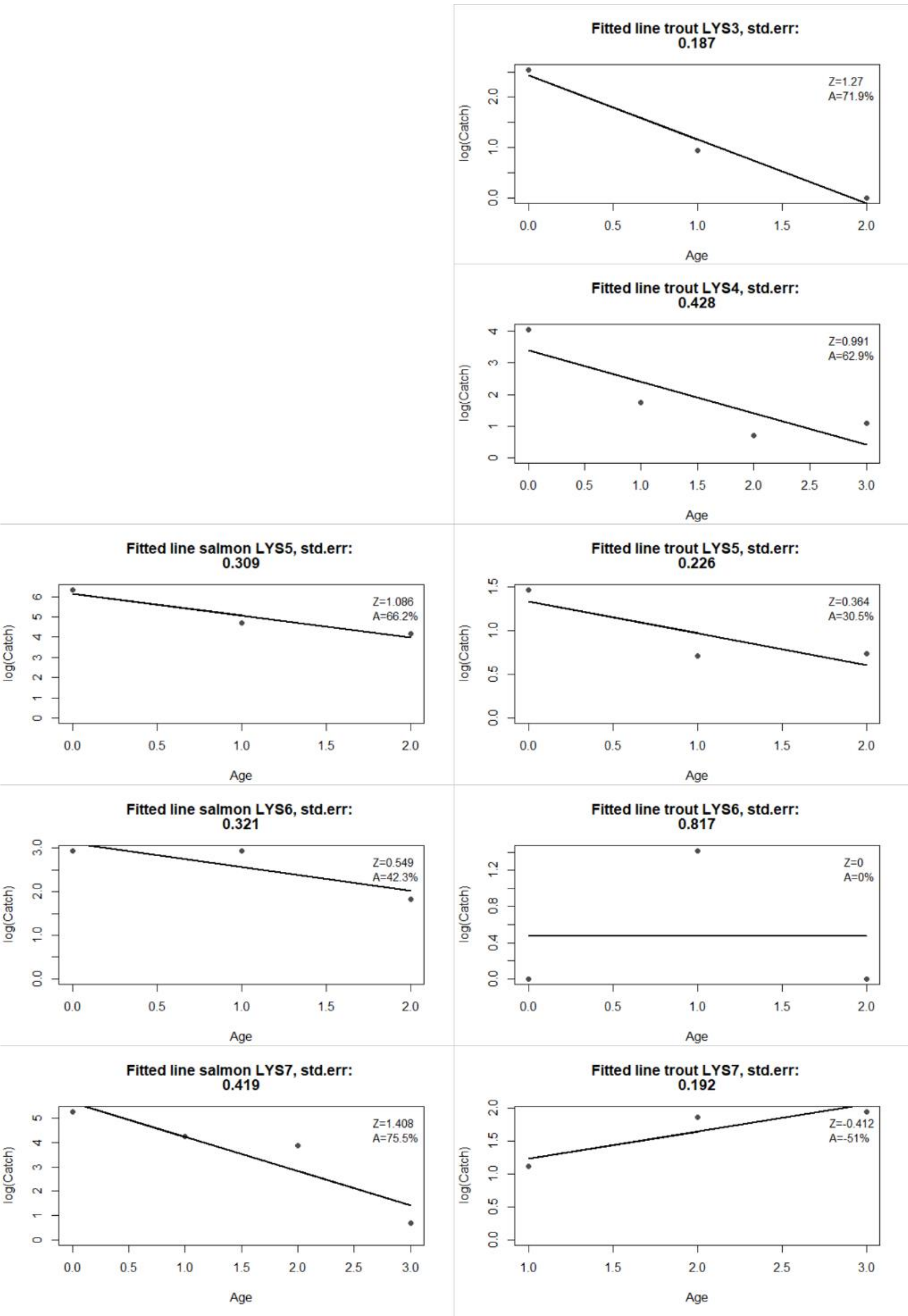
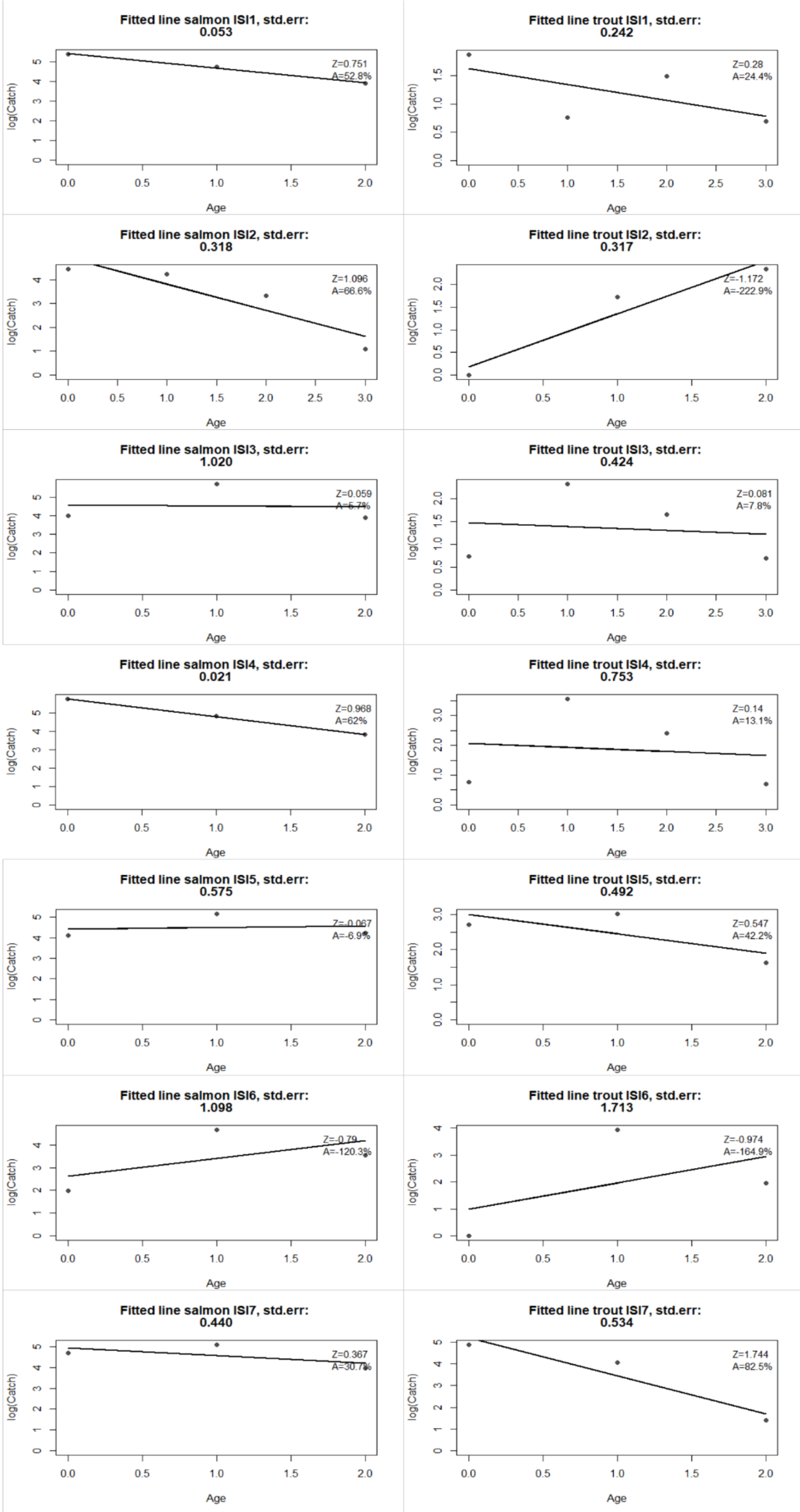


Figure 30: Regression model from catchCurve with the standard error plotted for trout and salmon in Lysakerelva.



Fitted line salmon ISI1, std.err: 0.053
Z=0.751
A=52.8%
Fitted line trout ISI1, std.err: 0.242
Z=0.28
A=24.4%
Fitted line salmon ISI2, std.err: 0.318
Z=1.096
A=66.6%
Fitted line trout ISI2, std.err: 0.317
Z=-1.172
A=-222.9%
Fitted line salmon ISI3, std.err: 1.020
Z=0.059
A=5.7%
Fitted line trout ISI3, std.err: 0.424
Z=0.081
A=7.8%
Fitted line salmon ISI4, std.err: 0.021
Z=0.968
A=62%
Fitted line trout ISI4, std.err: 0.753
Z=0.14
A=13.1%
Fitted line salmon ISI5, std.err: 0.575
Fitted line trout ISI5, std.err: 0.492
Z=0.547
A=42.2%
Fitted line salmon ISI6, std.err: 1.098
A=-120.3%
Fitted line trout ISI6, std.err: 1.713
Z=-0.974
A=-164.9%
Fitted line salmon ISI7, std.err: 0.440
Z=0.367
Fitted line trout ISI7, std.err: 0.534
Z=1.744
A=82.5%
log(Catch)
Age

Figure 31: Regression model from catchCurve with the standard error plotted for trout and salmon in Isielva

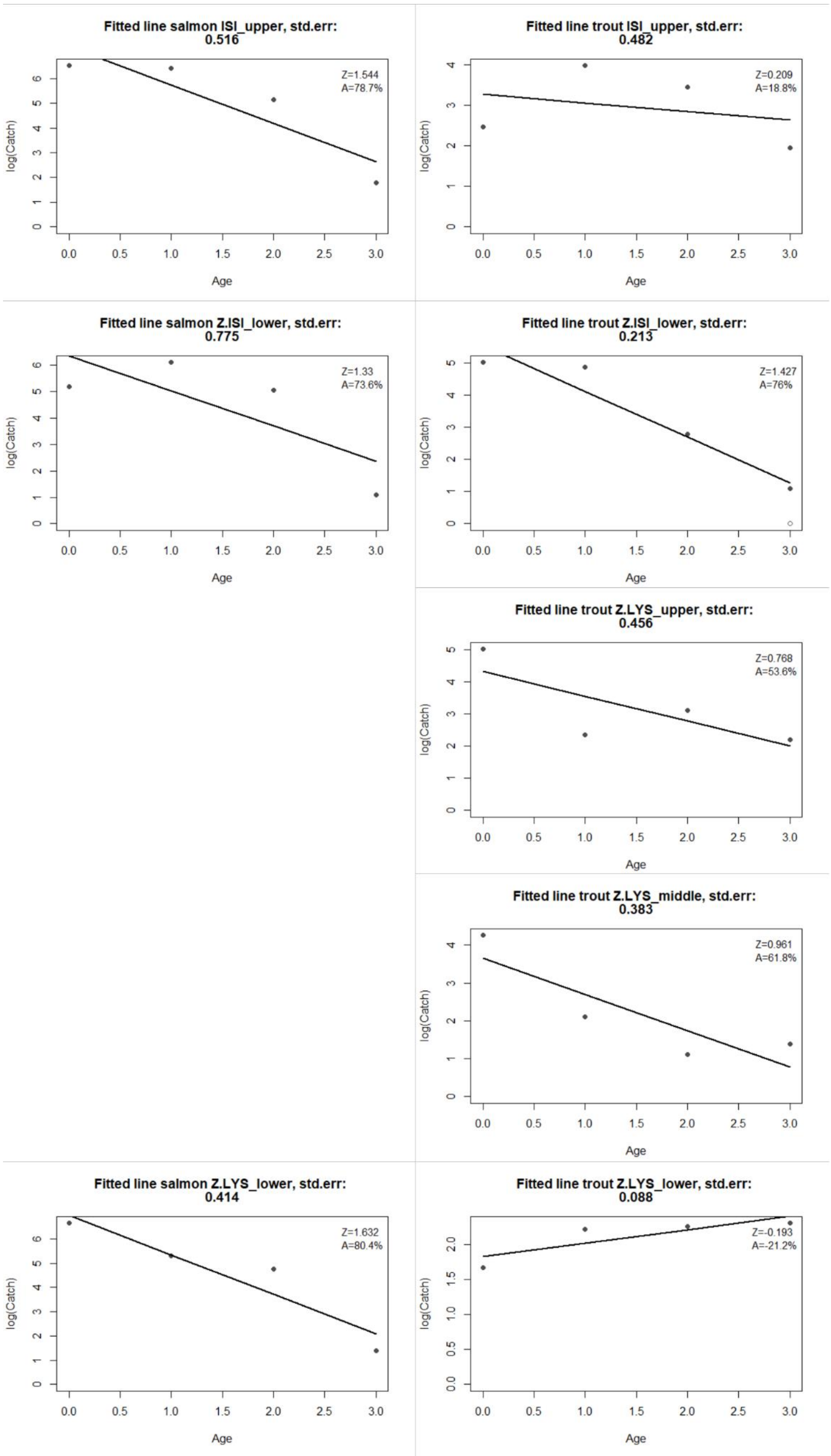


Figure 32: Regression model from catchCurve with the standard error plotted for trout and salmon in the river sections.

Appendix VIII – Changed catchabilities

Station	Species	Age	Catchability	Comment
ISI2	L	0+	0.1200803	Mean value of ISI1 and ISI4
ISI3	L	0+	0.1200803	Mean value of ISI1 and ISI4
ISI5	L	0+	0.1200803	Mean value of ISI1 and ISI4
ISI6	L	0+	0.1200803	Mean value of ISI1 and ISI4
ISI7	L	0+	0.1200803	Mean value of ISI1 and ISI4
LYS6	L	0+	0.31245459	Mean value of LYS5 and LYS7, i.e the mean value of the lower stations
LYS6	L	1+	0.39865132	Mean value of LYS5 and LYS7, i.e the mean value of the lower stations
ISI1	L	>1+	0.71399595	Mean value of ISI3 and ISI4, i.e the mean value of the upper stations
ISI2	L	>1+	0.71399595	Mean value of ISI3 and ISI4, i.e the mean value of the upper stations
ISI6	L	>1+	0.59259259	Mean value of ISI5 and ISI7, i.e the mean value of the lower stations
LYS2	Ø	0+	0.26279863	Same as LYS1
LYS3	Ø	0+	0.26279863	Same as LYS1
LYS4	Ø	0+	0.26279863	Same as LYS1
LYS5	Ø	0+	0.26279863	Same as LYS1
LYS6	Ø	0+	0.26279863	Same as LYS1
ISI1	Ø	1+	0.4950495	Same as ISI7: over 50 individuals and more than 25 caught the first round, i.e better than ISI6
ISI2	Ø	1+	0.4950495	Same as ISI7: over 50 individuals and more than 25 caught the first round, i.e better than ISI6
ISI3	Ø	1+	0.4950495	Same as ISI7: over 50 individuals and more than 25 caught the first round, i.e better than ISI6
ISI4	Ø	1+	0.4950495	Same as ISI7: over 50 individuals and more than 25 caught the first round, i.e better than ISI6
ISI5	Ø	1+	0.4950495	Same as ISI7: over 50 individuals and more than 25 caught the first round, i.e better than ISI6

Appendix IX – Estimated densities and production capacity

Table 30: Density and production estimation

LYSAKER RIVER				**Total salmon smolt production pr.100sqm:**	**22**			**Total trout smolt production pr.100sqm:**	**2**					
Name	Suitabl habitat	Area	Suitabl area	Comment	Expected 0+ salmon pr. 100 sqm	Expected 0+ trout pr. 100 sqm	Z salmon per segment	Expected 0+ salmon per segment	Expected 1+ salmon per segment	Expected salmn smolt pr segment	Z trout per segment	Expected 0+ trout per segment	Expected 1+ trout per segment	Expected trout smolt pr segment
H1	45	1492	672	Density for LYS1 is chosen as		38,38					0,77	257,78	119,59	55,48
H2	100	1093	1093	Station LYS1 included in segment		38,38					0,77	419,69	194,70	90,32
H3	50	447	224	Density for LYS1 is chosen		38,38					0,77	85,84	39,82	18,47
H4	30	1207	362	Density for LYS1 is chosen		38,38					0,77	138,95	64,46	29,90
H5	50	815	408	Density for LYS1 is chosen		38,38					0,77	156,43	72,57	33,66
H6	15	225	34	Density for LYS1 is chosen		38,38					0,77	12,98	6,02	2,79
H7	65	588	382	Station LYS2 included in segment		13,39					0,77	51,16	23,73	11,01
H8	0	2844	0	Jarfossen waterfalls										
H9	100	2528	2528	Station LYS3 included in segment		8,06	0,58		2554,54	1424,37	0,96	203,74	77,92	29,80
H10	70	4223	2956	Station LYS4 included in segment		50,33	0,58		4774,57	2662,23	0,96	1487,61	568,93	217,59
H11	75	2035	1527	Dens. LYS4 represents the segment better		50,33	0,58		2465,85	1374,92	0,96	768,28	293,83	112,37
H12	100	2955	2955	Dens. LYS4 represents the segment better		50,33	0,58		4773,11	2661,42	0,96	1487,16	568,76	217,52
H13	0	1661	0	Fåbrofossen waterfall										
H14	100	1060	1060	Station LYS5 included in segment	205,61	1,59	1,63	2178,57	426,11	83,34	0,36	16,83	11,70	8,13
H15	20	1680	336	Station LYS6 included in segment	15,65	0,83	1,63	52,59	10,29	2,01	0,36	2,80	1,95	0,94
H16	0	12390	0	Deep, slow run ending in the Møllefossen waterfall										
H17	20	801	160	Station LYS7 included in segment	126,46	0,00	1,63	202,61	39,63	7,75	0,36	0,00	3,26	2,26
Sum		**38045**	**14695**					**2433,77**	**15044,09**	**8216,05**		**5089,24**	**2047,22**	**830,26**

ISI RIVER				**Total salmon smolt production pr.100sqm:**	**11**			**Total trout smolt production pr.100sqm:**	**1**					
Name	Suitabl habitat	Area	Suitabl area	Comment	Expected 0+ salmon pr. 100 sqm	Expected 0+ trout pr. 100 sqm	Z salmon per segment	Expected 0+ salmon per segment	Expected 1+ salmon per segment	Expected salmn smolt pr segment	Z trout per segment	Expected 0+ trout per segment	Expected 1+ trout per segment	Expected trout smolt pr segment
H1	100	6384	6384	ISI1	98,00	2,88	1,54	6256,20	1335,49	285,08	0,21	183,89	149,24	121,11
H2	90	6155	5539	ISI2	40,20	0,47	1,54	2226,99	475,39	101,48	0,21	25,98	21,08	17,11
H3	90	2875	2588	ISI3	20,35	0,79	1,54	526,63	112,42	24,00	0,21	20,32	16,49	13,38
H4	100	3709	3709	ISI4	160,97	1,11	1,54	5970,28	1274,45	272,05	0,21	41,16	33,40	27,11
H5	0	815	0	Bjørumssaga wandering hinder and the area just above										
H6	90	2948	2653	ISI5	23,77	5,93	1,33	630,65	166,73	44,08	1,43	157,44	37,78	9,06
H7	90	1307	1176	ISI6	3,68	0,51	1,33	43,33	11,46	3,03	1,43	5,96	1,43	0,34
H8	100	1470	1470	ISI7	45,10	53,93	1,33	662,92	175,26	46,34	1,43	792,61	190,18	45,63
Sum		**79639**	**39770**					**21184,52**	**19071,30**	**9086,56**		**6336,22**	**2513,72**	**1075,34**

Appendix X – Re-captures

Table 31: Table showing re-captures, where the individual was marked and where it was caught. Individuals caught several times are colour coded with a unique colour.

Date	Tag registration	Tag_ID	Station where the fish was marked	Comment
19.02.2121	LYS5	A0000000939000002224549	LYS5	
19.02.2121	LYS5	A0000000939000002224721	LYS5	
19.02.2121	LYS5	A0000000900228000531287	LYS5	
19.02.2121	LYS5	A0000000900226001154735	LYS5	
19.02.2121	LYS5	A0000000939000002224723	LYS5	
19.02.2121	LYS5	A0000000939000002224716	LYS5	
19.02.2121	LYS5	A0000000900228000531288	LYS5	
19.02.2121	LYS7	A0000000900226001155407	LYS7	
19.02.2121	LYS7	A0000000900226001155492	LYS7	
19.02.2121	LYS7	A0000000900226001155419	LYS7	
19.02.2121	LYS7	A0000000900228000642791	LYS7	
19.02.2121	LYS7	A0000000900228000642793	LYS7	
19.02.2121	LYS7	A0000000900226001155413	LYS7	
19.02.2121	LYS7	A0000000900226001155462	LYS7	
19.02.2121	LYS7	A0000000900226001155465	LYS7	
19.02.2121	LYS7	A0000000900226001155424	LYS7	
19.02.2121	LYS7	A0000000900226001155496	LYS7	
19.02.2121	LYS7	A0000000900226001155494	LYS7	
19.02.2121	LYS7	A0000000900226001155486	LYS7	
19.02.2121	LYS7	A0000000900226001155449	LYS7	
19.02.2121	LYS7	A0000000900226001155476	LYS7	
20.02.2121	LYS5	A0000000939000002224602	LYS5	
20.02.2121	LYS5	A0000000900226001155193	LYS5	
20.02.2121	LYS5	A0000000939000002224511	LYS5	
20.02.2121	LYS5	A0000000939000002224690	LYS6	Migrated upstream
20.02.2121	LYS5	A0000000900226001154728	LYS5	
20.02.2121	LYS5	A0000000939000002224683	LYS5	
09.03.2121	LYS7	A0000000900226001155490	LYS7	
09.03.2121	LYS7	A0000000900226001155454	LYS7	
09.03.2121	LYS7	A0000000900226001155475	LYS7	
09.03.2121	LYS7	A0000000900226001155492	LYS7	Caught earlier
09.03.2121	LYS7	A0000000900226001155426	LYS7	
09.03.2121	LYS7	A0000000900228000642793	LYS7	Caught earlier
09.03.2121	LYS7	A0000000900226001155405	LYS7	
09.03.2121	LYS7	A0000000900226001155447	LYS7	
09.03.2121	LYS7	A0000000900226001155478	LYS7	
09.03.2121	LYS7	A0000000900226001155480	LYS7	
09.03.2121	LYS7	A0000000900226001155413	LYS7	Caught earlier
09.03.2121	LYS7	A0000000900226001155462	LYS7	Caught earlier
09.03.2121	LYS7	A0000000900226001155468	LYS7	
09.03.2121	LYS7	A0000000900226001155486	LYS7	Caught earlier
09.03.2121	LYS5	A0000000939000002224551	LYS5	
09.03.2121	LYS5	A0000000939000002224520	LYS5	
09.03.2121	LYS5	A0000000939000002224743	LYS5	
09.03.2121	LYS5	A0000000900226001154735	LYS5	Caught earlier
09.03.2121	LYS5	A0000000939000002224723	LYS5	Caught earlier
09.03.2121	LYS5	A0000000939000002224578	LYS5	
09.03.2121	LYS5	A0000000900226001154717	LYS5	
09.03.2121	LYS5	A0000000939000002224535	LYS5	
09.03.2121	LYS5	A0000000939000002224537	LYS5	
09.03.2121	LYS5	A0000000900228000531288	LYS5	Caught earlier
09.03.2121	LYS5	A0000000939000002224721	LYS5	Caught earlier

09.03.2121	LYS5	A0000000900228000531287	LYS5	Caught earlier
09.03.2121	LYS5	A0000000900226001154761	LYS5	
09.03.2121	LYS5	A0000000939000002224650	LYS5	
09.03.2121	LYS5	A0000000939000002224686	LYS5	
09.03.2121	LYS5	A0000000900226001154795	LYS5	
09.03.2121	LYS5	A0000000939000002224685	LYS5	
09.03.2121	LYS5	A0000000939000002224644	LYS5	
09.03.2121	LYS5	A0000000939000002224581	LYS4	Migrated downstream
09.03.2121	LYS5	A0000000939000002224716	LYS5	Caught earlier
09.03.2121	LYS5	A0000000939000002224511	LYS5	Caught earlier
09.03.2121	LYS5	A0000000939000002224602	LYS5	Caught earlier
09.03.2121	LYS5	A0000000939000002224542	LYS5	
09.03.2121	LYS5	A0000000939000002224690	LYS6	Caught earlier, stayed in LYS5
09.03.2121	LYS5	A0000000900226001154723	LYS5	
09.03.2121	LYS5	A0000000939000002224555	LYS5	
09.03.2121	LYS5	A0000000939000002224724	LYS6	Migrated upstream
22.03.2121	LYS1	A0000000939000002224016	LYS1	
22.03.2121	LYS1	A0000000900228000642858	LYS1	
22.03.2121	LYS1	A0000000939000002224097	LYS1	
22.03.2121	LYS1	A0000000939000002224174	LYS1	
22.03.2121	LYS1	A0000000939000002224081	#I/T	Annen tag
22.03.2121	Between LYS1 and LYS2	A0000000939000002224149	LYS2	Migrated upstream
23.03.2121	Just above the Fåbro waterfall	A0000000939000002224624	LYS4	Migrated downstream
23.03.2121	Just above the Fåbro waterfall	A0000000939000002224505	LYS4	Migrated downstream
23.03.2121	Just above the Fåbro waterfall	A0000000939000002224538	LYS4	Migrated downstream
23.03.2121	Just above the Fåbro waterfall	A0000000939000002224737	LYS4	Migrated downstream
23.03.2121	LYS5	A0000000939000002224520	LYS5	Caught earlier
23.03.2121	LYS5	A0000000939000002224602	LYS5	Caught twice earlier
23.03.2121	LYS5	A0000000939000002224511	LYS5	Caught twice earlier
23.03.2121	LYS5	A0000000900228000531288	LYS5	Caught twice earlier

Appendix XI – Model diagnostics

0+ density of salmonids

The model with the best fit was found to be "$Dens_{1+}$ + Species". However, looking at the residuals in Figure 33, they are scattered over a large span, with a skewed trend line. This deviation is seen more clearly plotting the standardised residuals. Looking at the Cook's Distance plot it is clear that many of the data points do not follow a pattern, which shows that the model is a bad fit and the variable should be transformed. A log-transformation was done on the density variable, which rendered the residuals shown in Figure 34. The residuals are scattered in a range from -3 to 3 about an almost horizontal line. This is also shown in the standardized residual plot where the data points have a good fit to the line. There is still some clatter in the Cook's distance plot, but it is much better than the untransformed model, and the conclusion were to continue with the log-transformed model.

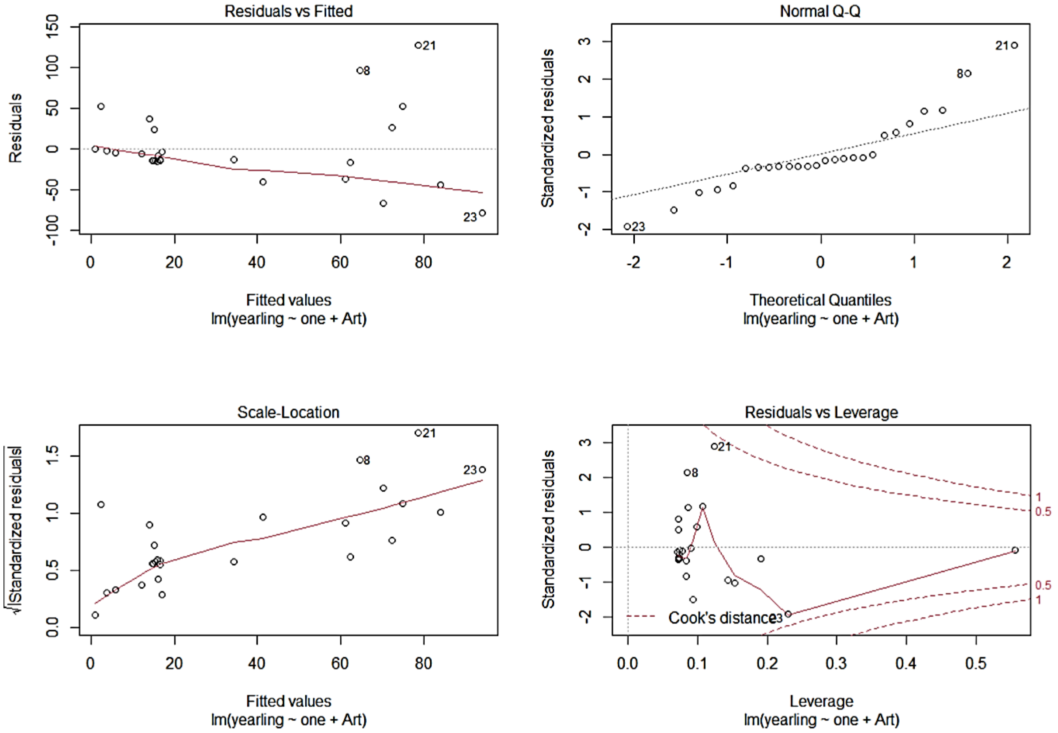


Figure 33: Model diagnostics of model "Dens1+ + Species" with 0+ density as the response variable. A transformation of the variables is needed.

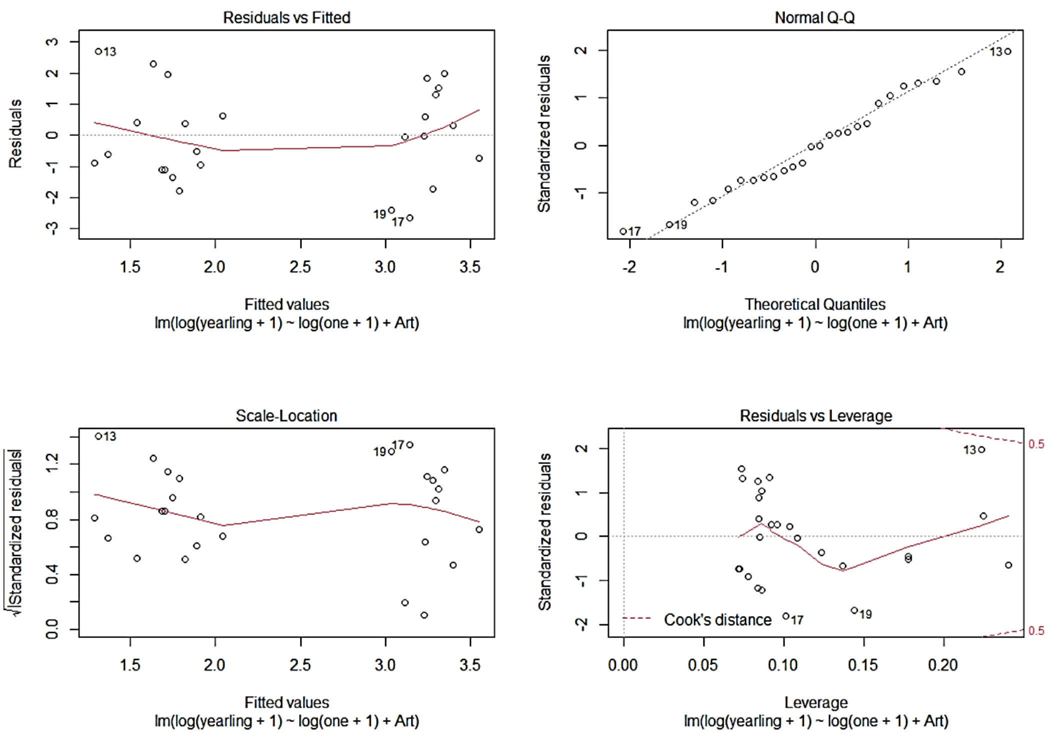


Figure 34: Model diagnostics of model “Dens1+ + Species” with 0+ density as the response variable. Further transformation of the variables is not needed, and the model can be used.

Comparison of the models “Dens$_{1+}$ + Species” and “Dens$_{1+}$ * Species”

Comparing Figure 34 above and Figure 35 below one can see that the residuals in the interaction model “Dens$_{1+}$ * Species” have a larger spread with a line far from horizontal. This is mirrored in the standardized plot. In addition the Cook’s distance plot for the interaction model is worse than for the additive model. Hence, the additive model is the best fit, even if the AIC scores are close to equal.

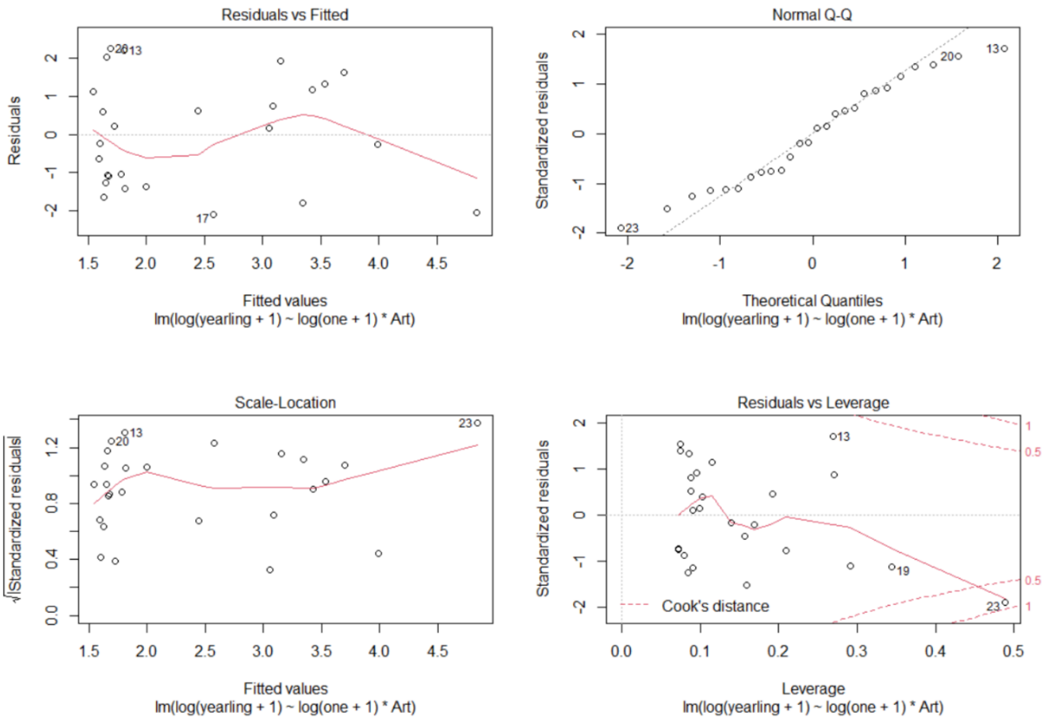


*Figure 35: Model diagnostics of the interaction model “Dens1+ * Species” with 0+ density as the response variable.*

0+ density of salmon as response factor

“Density”

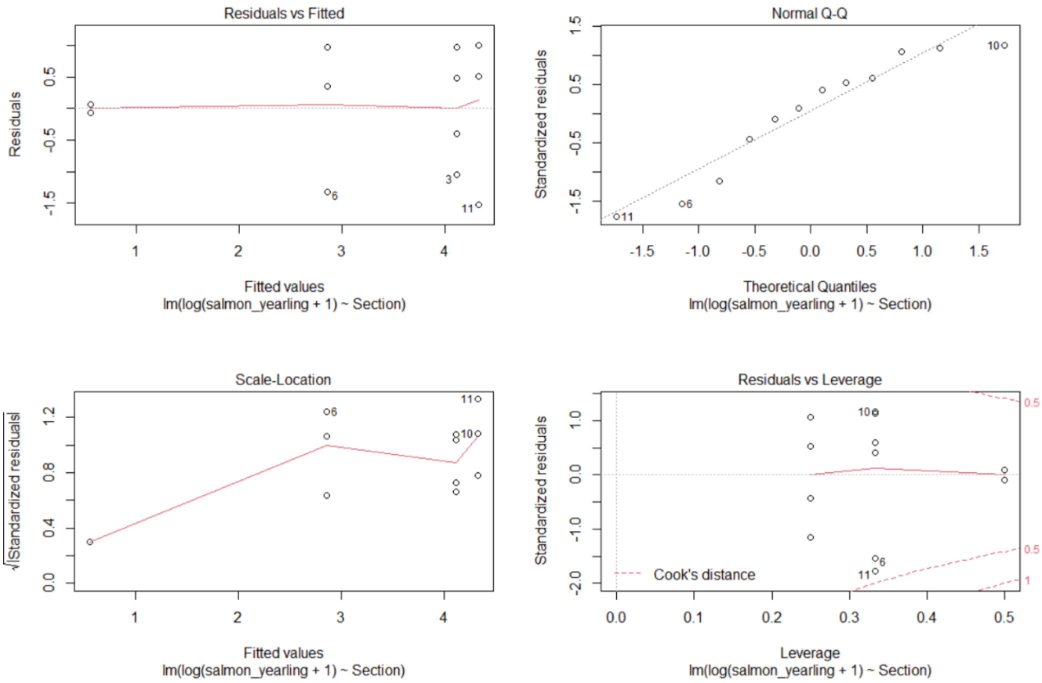


Figure 36: Model diagnostics of model “Section” with 0+ density salmon as the response variable.

“$Dens_{1+\ salmon}$”

Comparing Figure 37 and Figure 38 below the standardized residuals in the “$Dens_{1+\ trout}$” model follow the line more closely than for the “$Dens_{1+\ salmon}$” model. In addition the Cook’s distance plot is better for the “$Dens_{1+\ trout}$” model. However, they are still so similar that the larger weight score of the AIC weight for the “$Dens_{1+\ salmon}$” model is deemed the critical value, and is the model chosen for further analysis.

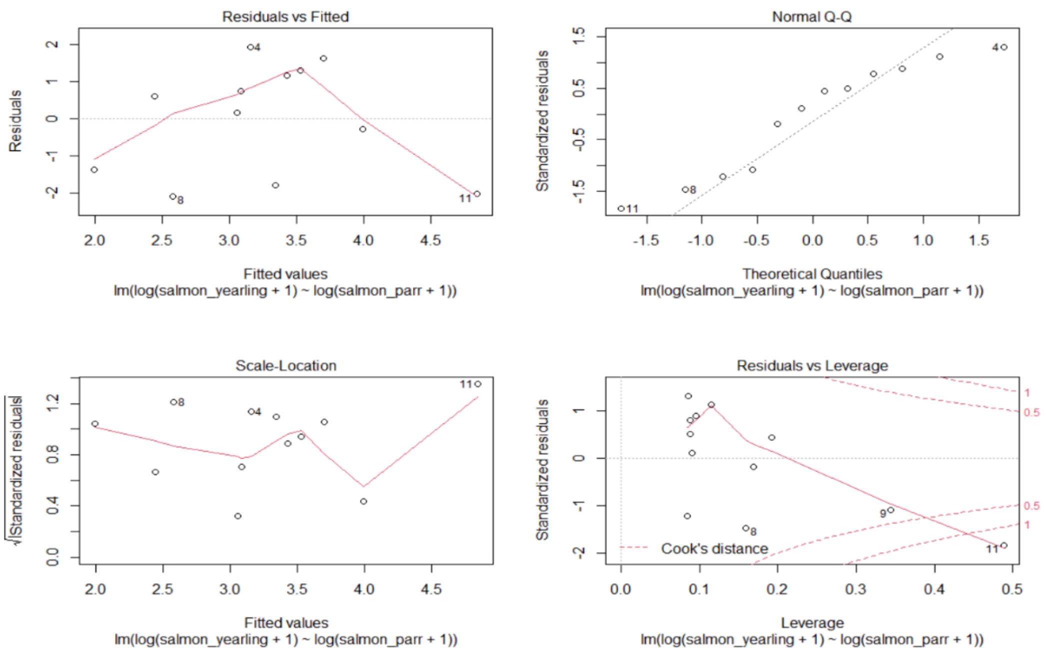


Figure 37: Model diagnostics of the interaction model “$Dens_{1+\ salmon}$” with 0+ density salmon as the response variable.

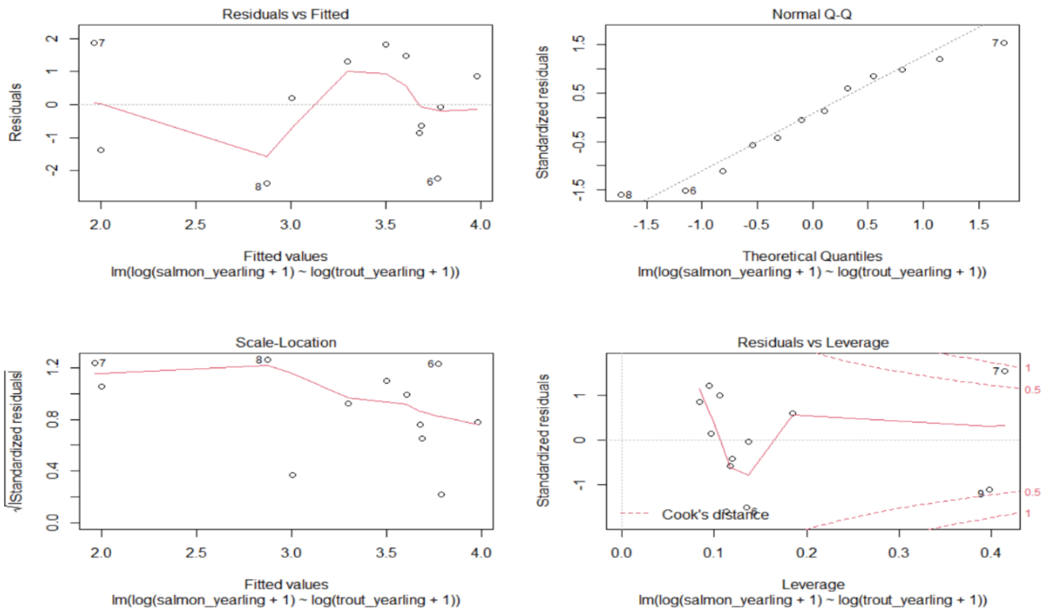


Figure 38: Model diagnostics of the interaction model “$Dens_{0+\ trout}$” with 0+ density salmon as the response variable.

0+ density of trout as response factor

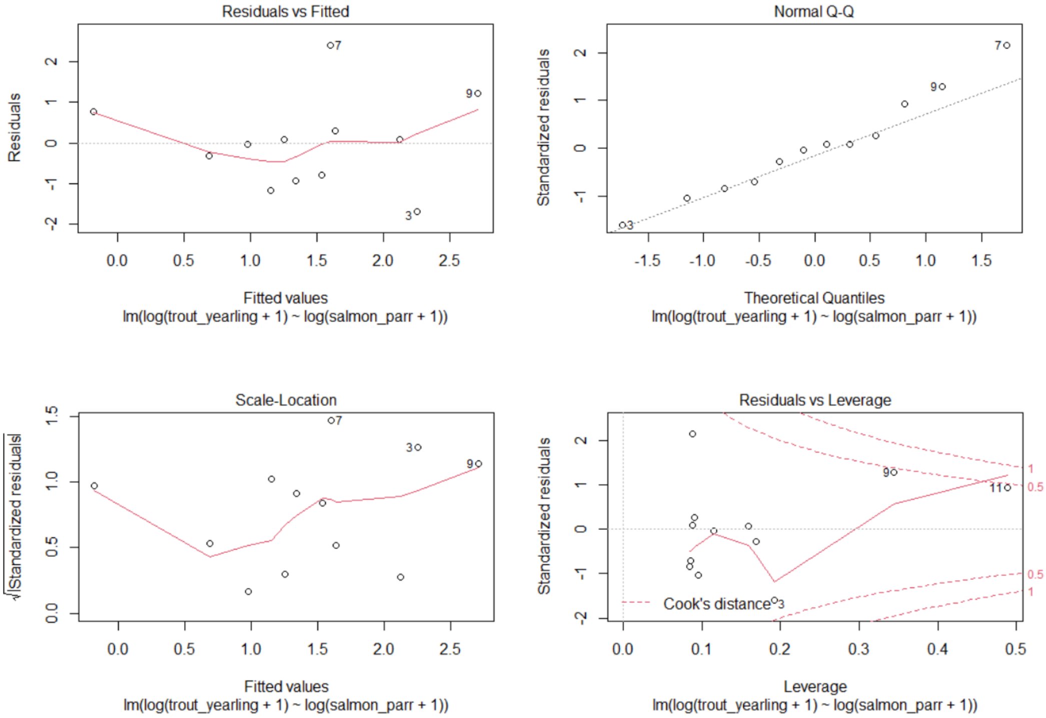


Figure 39: Model diagnostics of the model "Dens$_{1+ salmon}$" with 0+ density trout as the response variable.

Density dependent growth with total length as the response factor

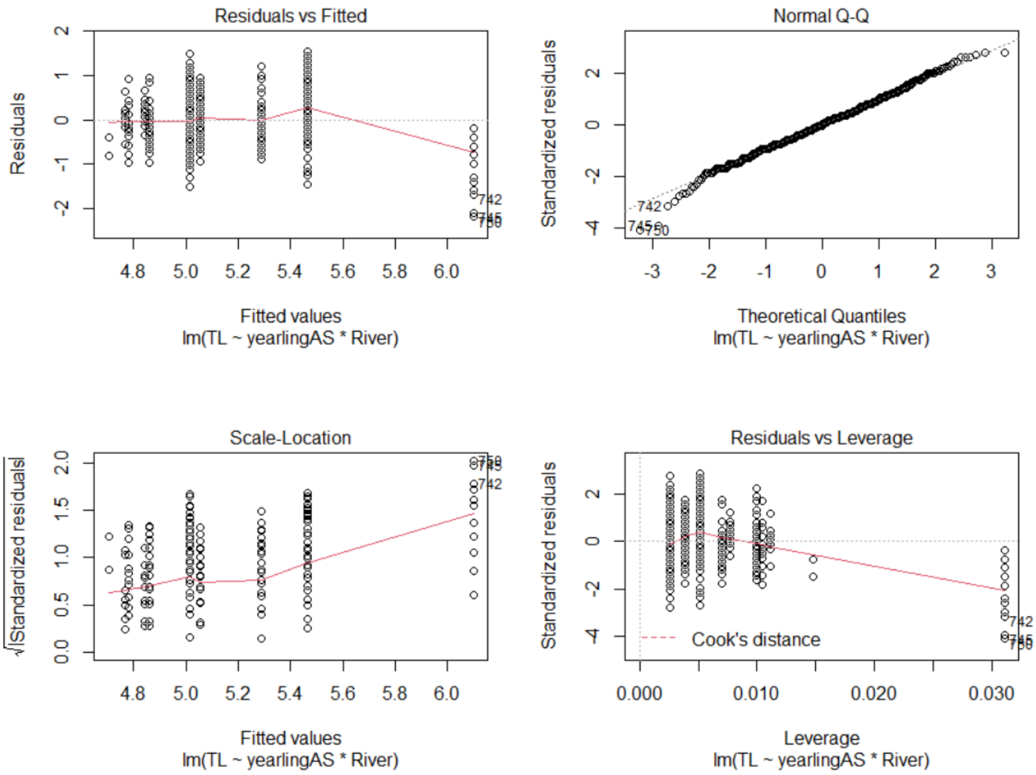


Figure 40: Model diagnostics of the model "Dens$_{0+\ salmon}$" with total length of salmon as the response variable.

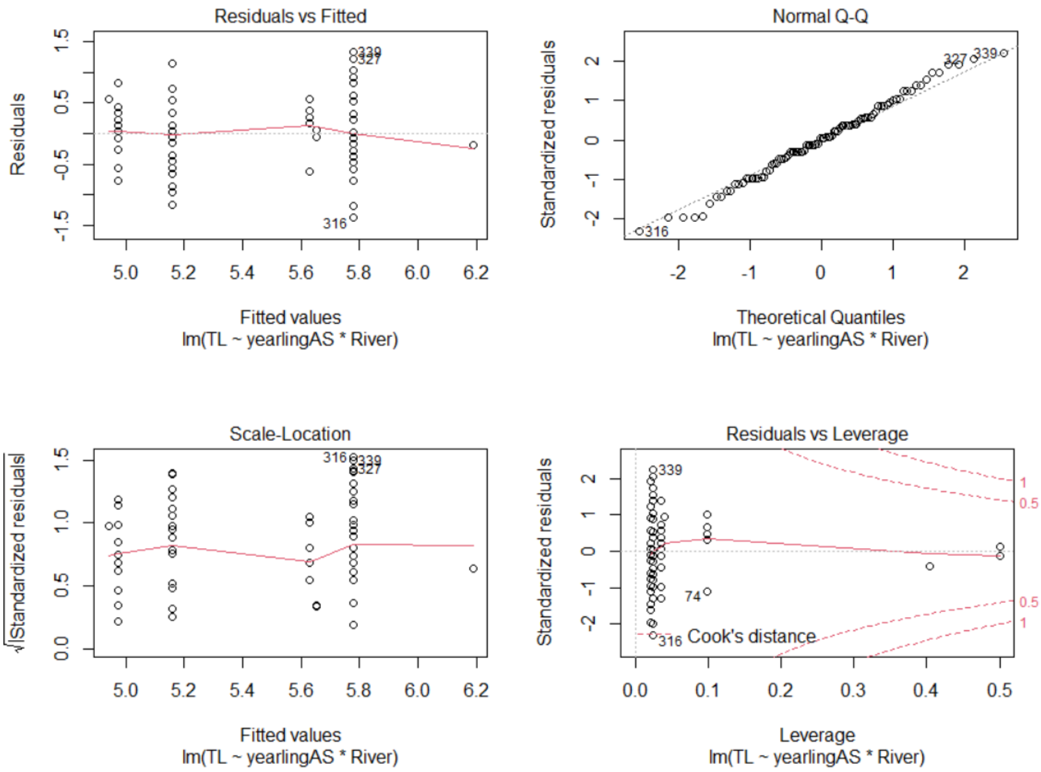


Figure 41:Model diagnostics of the model "Dens$_{0+\ salmon}$" with total length of trout as the response variable.

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