Norwegian University
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Faculty of Environmental Sciences and Natural Resource Management

# The effects of riparian vegetation on density, survival, and in-stream movement patterns of juvenile brown trout (*Salmo trutta*) in tributaries to the river Gausa, Norway

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Ecology

# Preface

This thesis marks the end of my six years of studies at the Norwegian University of Life Sciences (NMBU). The thesis is a part of the research project SABICAS, which aims to increase knowledge regarding the usage of nature based solutions along rivers and streams without economical losses. I would like to thank all involved for allowing me to participate in the project, as well as for financial support. A special thanks goes to Leonard Sandin, who has been my supervisor at the Norwegian Institute for Nature Research. I would also like to thank the Norwegian Water Association for their financial contribution.

I would like to thank my main supervisor at NMBU, Professor Thrond Haugen for invaluable help with fieldwork, statistics, and feedback during the writing process. I would also like to thank Louise Chavarie and Jon Museth for their time reviewing my text. Furthermore, I would like to thank Mathias Brink Kjeldgaard, Kåre-Jørgen Ingerø Bøe, Sverre Fjeldstad and Camille Jane E. Fredriksen for assistance during fieldwork. Fellow students Kåre-Jørgen Ingerø Bøe and Emma Helen Berg also deserve a huge thank you for all hours spent discussing my text structure and results. Last but not least, I want to express my deep gratitude to my (at the time pregnant) girlfriend Tuva, who has been of great support throughout the entire process.

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# Abstract

Loss of riparian vegetation along rivers and streams due to human activities lead to significant changes in aquatic environments. Many fish species, including the brown trout (*Salmo trutta*), utilize rivers and streams throughout their life cycle and may therefore be exposed to these changes. Thus, this study examined how riparian vegetation influences the density, survival, and movement patterns of juvenile brown trout.

During the summer of 2023, 15 electro-fishing stations were selected across four tributary streams in the Gausa watershed, Innlandet, Norway. Electro-fishing was conducted in June and September, with the aim of tagging fish with Passive Integrated Transponders (PIT-tags) and estimating the density of young-of-the-year (0+) and older age classes (>0+) of brown trout. At all electro-stations, riparian vegetation and other environmental covariates were assessed to further be linked with the estimated densities. Manual antenna PIT-scanning was conducted five times in all tributaries between July and November 2023 to establish detection histories to further estimate survival probability and record potential movements. Riparian vegetation and habitat types were also mapped along the scanned stretches. The relationship between riparian vegetation and 0+ density, >0+ density, survival probability, movement probability, and in-stream movement distances were then examined. Covariates were included in all analyses to isolate the riparian effects. Riparian effects on juvenile densities were assessed using linear models, considering riparian conditions and other environmental variables related to stream habitat. Additionally, the >0+ density was included as a density-dependent factor in the analysis of 0+ density. The riparian effects on apparent survival probability was estimated using a Cormack-Jolly-Seber model structure, modelled as a function of the detection histories, standardized fish lengths, the average riparian conditions, standardized water discharge of the corresponding tributaries, and seasons. Two analyses were conducted for addressing riparian effects on in-stream movement patterns: “movement probability” and “movement distances”. Prior to analyzing movement probability, individuals’ positions in the stream, along with their previous documented positions, were linked to corresponding on-site riparian conditions. Movement probability was then assessed through logistic linear regression, as a function of corresponding riparian conditions, habitat type, individual total length, and season. Movement distances were analyzed using linear models with the same covariates as in the analysis of movement probability, along with the average riparian conditions of the corresponding tributaries.

Riparian shading on the water surface, riparian buffer width, the presence of larger trees, and overhanging canopy cover were found to have a negative effect on 0+ density. Overhanging non-woody vegetation had a weak positive correlation, while no notable effects were found of upstream vegetation. Riparian vegetation was not found to have an effect on >0+ density. The negative effects of extensive riparian vegetation on 0+ fish density can possibly be explained by reduced light influx and autochthonous production in the presence of riparian cover. 0+ individuals are known to have higher food requirements when compared to >0+ and has previously been shown to prefer aquatic invertebrates as a food source. Stretches of low riparian cover could consequently be favored. The absent effect on >0+ suggests that older age classes are evenly distributed across sections of varying riparian conditions, thus being less affected by the riparian effects. This could possibly be a result of older age classes favoring riparian cover and allochthonous terrestrial invertebrates. A negative correlation between riparian vegetation and survival probability was found when the extent of riparian vegetation was adjusted for seasonal variations. Survival probability was consequently found to be lower in summer than in autumn, post-senescence. The negative effect of riparian vegetation on survival probability aligned with the negative correlation found for 0+ density. As the young-of-the-year age class were likely the highest represented among the tagged individuals, the observed negative riparian effect on survival probability might be in support of that stretches with extensive riparian vegetation seemingly may provide poorer growth conditions for 0+. However, as the variable representing the riparian effects was adjusted for seasonal variations, other factors that vary with season may also have influenced the survival probability. A major flood in mid-August and subsequent decreasing water flow through the autumn may have played a central role, decreasing survival probability during summer. No correlations were found between riparian vegetation and movement patterns. Both movement probability and movement distances were best explained by seasonal differences, with longer movement distances during summer and higher movement probabilities during autumn. These findings might be explained by the observed variations in water discharge throughout the study period, and align with the findings on survival probability, suggesting seasonal differences. The high water levels and mid-august flooding event may have caused fish dislocations, explaining the elevated movement distances during summer. The elevated movement probability during autumn might be explained by the reduced water levels potentially leading to increased competition for remaining habitat, resulting in an increase in small scale movements.

The findings of this study suggest that various aspects of riparian vegetation may have different impacts on different age classes of brown trout. This underscores the importance of processing a comprehensive understanding of riparian vegetation in fish management. The study also sheds light on the effect of water flow and flooding on juvenile brown trout ecology.

# Sammendrag

Tap av kantvegetasjon langs elver og bekker som følge av menneskelig påvirkning fører til betydelige endringer i det akvatiske miljøet. Mange fiskearter, deriblant ørreten (*Salmo trutta*), utnytter elver og bekker gjennom sin livssyklus, og vil dermed kunne eksponeres for disse endringene. I dette studiet ble det undersøkt hvordan kantvegetasjon påvirker tetthet, overlevelse og bevegelsesmønstre hos yngel og ungfisk av ørret.

Sommeren 2023 ble det plukket ut 15 el-fiskestasjoner fordelt på fire bekker i Gausavassdraget, Innlandet, Norge. El-fiske ble gjennomført i juni og september, der målet var å merke fisk med Passive Integrated Transponders (PIT-merker), samt estimere tetthet av yngel (0+) og ungfisk (>0+). Ved alle el-fiske-stasjoner ble kantvegetasjon og øvrige miljøvariabler kartlagt for å sammenholdes med de registrerte tetthetene. Søk etter fisk med PIT-skanner ble gjort i alle bekker fem ganger i perioden juli-november 2023 for å opparbeide deteksjonshistorikk for estimat på overlevelsesannsynlighet, samt for å registrere eventuelle forflytninger. Kantvegetasjon og habitattype ble i den forbindelse også kartlagt langs strekningene som ble skannet. Videre ble det gjort separate analyser for å se på sammenhengen mellom kantvegetasjon og 0+ tetthet, >0+ tetthet, overlevelsesannsynlighet, bevegelsesannsynlighet og bevegelsesdistanser. Kofaktorer ble inkludert i alle modeller for å bedre kunne isolere kantsoneeffektene. Tettheter av 0+ og >0+ ble analysert ved lineære modeller, der kantvegetasjon og andre miljøvariabler knyttet til bekkehabitat var inkludert. >0+ tetthet ble også inkludert som prediktorvariabel i analysen på 0+ tetthet, som en tetthetsavhengig faktor. Kantsoneeffekter på overlevelsesannsynlighet ble analysert gjennom en Cormack-Jolly-Seber modellstruktur, som en funksjon av deteksjonshistorikk, standardiserte fiskelengder, gjennomsnittlig kantsonetilstand og standardisert vannføring i hver bekk, samt sesong. Det ble gjort to analyser for å redegjøre for kantsoneeffekter på bevegelsesmønstre: «bevegelsesannsynlighet» og «bevegelsesdistanse». Før analysen av bevegelsesannsynlighet ble individene sine posisjoner i bekken, samt forrige observerte posisjon koblet sammen med korresponderende kantsonetilstander. Effekten av kantvegetasjon på bevegelsesannsynlighet ble deretter analysert gjennom en logistisk lineær regresjon, som en funksjon av kantsonetilstand, habitattype, individuelle totallengder, samt sesong. Kantvegetasjonens effekt på bevegelsesdistanse ble analysert gjennom lineære modeller, som en funksjon av gjennomsnittlig kantsonetilstand i hver bekk, samt med de samme kovariatene som ble brukt i analysen for bevegelsesannsynlighet.

Utbredt kantvegetasjon, målt som skygge på vannoverflaten, kantsonebredde, samt tilstedeværelsen av større trær og overhengende kronedekke, ble funnet til å ha en negativ effekt på 0+ tetthet. Overhengende ikke-veddannende vegetasjon hadde en svak positiv korrelasjon, mens det ikke ble funnet nevneverdige effekter av oppstrøms vegetasjon. Det ble ikke funnet noen effekt av kantvegetasjon på >0+ tetthet. De negative effektene av utbredt kantvegetasjon på 0+ fisketetthet kan trolig forklares av redusert lystilgang

og redusert autokton produksjon. 0+ er kjent for å ha et større matbehov sammenlignet med >0+, og er tidligere vist til å i større grad foretrekke akvatiske evertebrater. Dette kan ha resultert i at de større grad oppholder seg på strekninger uten utbredt kantvegetasjon. Den fraværende effekten på >0+ antyder at eldre aldersgrupper er mer jevnt fordelt på tvers av kantsonetilstand, og at de i mindre grad er berørt av kantsoneeffekten. Det er tidligere vist at >0+ i større grad foretrekker skjul, og at de i større grad utnytter alloktont tilførte terrestriele evertebrater, noe som kan forklare de observasjonene i dette studiet. Videre ble det funnet tendenser til en negativ korrelasjon mellom kantvegetasjon og overlevelsesannsynlighet når kantvegetasjonens tilstand var justert for sesongvariasjoner. Overlevelsesannsynligheten ble følgelig funnet til å være lavere om sommeren enn om høsten, etter lauvfall. Den negative effekten av kantvegetasjon på overlevelsesannsynlighet samsvarer med den negative assosiasjonen funnet for 0+ tetthet, og støttes av at 0+ trolig var høyest representert blant de merkede individene. Funnet støtter følgelig oppunder at strekninger med utbredt kantvegetasjon tilsynelatende kan gi dårligere vekstforutsetninger for yngel. Siden variabelen som representerte kantsoneeffekt i analysen var justert for sesongvariasjoner, kan trolig andre faktorer som varierer med sesong ha gitt utslag på resultatene. En stor flom i midten av august og påfølgende synkende vannføring gjennom høsten kan trolig ha spilt en sentral rolle. Det ble ikke funnet direkte korrelasjoner mellom kantvegetasjon og bevegelsesmønstre, da både bevegelsessannsynlighet og bevegelsesdistanser var best forklart av sesong. Disse funnene samsvarer med den observerte utviklingen i vannføring gjennom studieperioden, samt funnene ved overlevelsesannsynlighet. Høy vannstand, flom og lav overlevelse på sommeren er trolig knyttet til lange bevegelsesdistanser og mulig utvasking av fisk. Høyere bevegelsessannsynlighet om høsten er trolig knyttet til at den reduserte vannstanden kan ha gitt økt konkurranse om gjenværende habitat.

Funnene i dette studiet antyder at aspekter ved kantvegetasjon kan ha forskjellig innvirkning på aldersklasser av ørret, og fremmer viktigheten av å ha et helhetlig bilde i fiskeforvaltningen. Studiet belyser i tillegg effekten av vannføring og flom på ung ørret.

# Table of content

# 1. Introduction

The rapid loss of biodiversity on our planet stands as a major concern, addressing the need for comprehensive understanding and efficient conservation measures. "The global assessment report on biodiversity and ecosystem services" from IPBES (2019) underscored that human pressure poses a significant threat to both aquatic and terrestrial environments. The riparian zones, which link aquatic and terrestrial environments, stands out as one of the most threatened ecosystems (Dosskey et al., 2010; Singh et al., 2021). Through the intensification of agriculture and urbanization, humans have drastically altered land adjacent to freshwater ecosystems (Vörösmarty et al., 2010). This alteration has resulted in substantial losses of riparian vegetation (Dudgeon et al., 2006), particularly in small rivers and streams (Gregory et al., 1991).

The loss of riparian vegetation has profound effects on the ecological functions of aquatic ecosystems (Pusey & Arthington, 2003). Riparian vegetation plays a crucial role in regulation of light influx into the water, which in turn affects thermal conditions, biochemical processes and the prerequisites for autochthonous production (Broadmeadow et al., 2011; Knight & Bottorff, 1984). Rivers and streams are fed with allochthonous inputs from adjacent lands. In this context, riparian vegetation plays an important role as a supplier of plant litter and terrestrial invertebrates (Wallace et al., 1997), as well as performing as a filtering system preventing nutrients and environmental toxins from entering in the water (Burken & Schnoor, 1999; Paterson & Schnoor, 1992; Peterjohn & Correll, 1984; Roca & Vallejo, 1995; Valley, 1986). Additionally, the roots of the riparian vegetation binds the soil and prevent erosion, keeping soil particles from clogging cavities in the stream bed substrate (Gregory et al., 1991; Knight & Bottorff, 1984). As changes in riparian conditions influence the environmental characteristics of rivers and streams, there is a pronounced potential to drastically affect the species that utilize these habitats (Crenshaw et al., 2002; Knight & Bottorff, 1984; Pace et al., 1999).

The brown trout (*Salmo trutta*) hatch and live as juveniles in small rivers and streams (Jonsson et al., 2011), and may therefore be vulnerable to alterations in riparian conditions. When the young-of-the-year cohort (0+) emerge from the substrate in early spring, the number of individuals is often substantially higher than the carrying capacity (Jonsson et al., 2011). The carrying capacity can be defined as the largest population size that can be sustained indefinitely by the environment (Bowman & Hacker, 2021). Limited resources and increasingly overlapping habitat preferences throughout the summer can induce juveniles, both the 0+ and the older age classes (>0+) to display aggressive and territorial behavior, resulting in high levels of intraspecific competition (Bohlin, 1977; Elliott, 1990). If 0+ individuals are forced out of their territory, they search for alternative habitat (Bachman, 1984; Hesthagen, 1988). These movements are associated with high energetic costs and are linked to high mortality rates (Elliott, 1990; Milner et al., 1979). During this phase, which is referred to as the critical period, the 0+ density declines until it matches the carrying capacity of the stream (Jonsson et al., 2011).

The density of older age classes, substrate composition, shelter availabilities, water velocities and chemical characteristics have been shown to be important factors determining the density of 0+ at the end of the critical period (Jonsson et al., 2011; Nordwall et al., 2001). As riparian vegetation plays a critical role in shaping the aquatic environmental conditions (Pusey & Arthington, 2003), several studies have examined its influence on the population dynamics of salmonid juveniles, such as the brown trout (Sievers et al., 2017).

While numerous studies has reported positive impacts of riparian vegetation on juvenile brown trout density (Boussu, 1954; Jentoft, 1998; Teixeira-de Mello et al., 2016; Wesche et al., 1987), the occurrence of both non-existing and negative effects have been described on several occasions (Dbowski & Radtkc, 1998; McCormick & Harrison, 2011; O'grady, 1993; Riley et al., 2009; Sievers et al., 2017). Such mixed results has also been observed for other salmonid species (Bilby & Bisson, 1992; Hawkins et al., 1983; Hunt, 1976; Johansen et al., 2005; Kawaguchi & Nakano, 2001; Murphy et al., 1986; Wootton, 2012). Consequently, the relationship between riparian vegetation and juvenile brown trout density have been described as complex (Sievers et al., 2017), highlighting the necessity of further research for a better understanding. Despite having considerable knowledge of the intraspecific interaction effects and their influence on brown trout juvenile densities, survival and movement patterns (Bachman, 1984; Hesthagen, 1988; Milner et al., 1979; Nordwall et al., 2001), to our knowledge, no known studies have directly linked the conditions of the riparian vegetation to survival, as well as to how it affects the in-stream movements.

Thus, the aim of this study is to increase knowledge regarding the interplay between riparian vegetation and juvenile brown trout, examining the effects on density, survival, and in-stream movement patterns. By utilizing the variation in riparian cover along and between tributaries of the Gausa watercourse (Norway), the following research questions (Q) and predictions (P) were made:

Q1: Does the condition of riparian vegetation stand out as an important explanatory factor regarding density and survival probabilities of juvenile brown trout, and if so, how does it influence these aspects?

P1: Riparian vegetation stand out as an important explanatory factor, exhibiting a positive effect on density and survival probabilities of juvenile brown trout.

Q2: Does the condition of riparian vegetation stand out as an important explanatory factor regarding in-stream movement patterns of juvenile brown trout, and how does riparian vegetation affect these patterns?

P2: Riparian vegetation stand out as an important explanatory factor and reduce the extent of movements of juvenile brown trout.

# 2. Materials and methods

## 2.1. Study system

The study was conducted within tributaries of the Gausa watercourse in Innlandet county in South-Eastern Norway (Figure 1). The catchment area covers 932 $km^2$ and has an annual runoff of ca. 463 million $m^3$ (Kraabøl & Arnekleiv, 1993). The river feeds into the river Gudbrandsdalslågen just north of the lake Mjøsa (Figure 1). Gausa, with its 72 kilometers of length, was historically considered to be among the best fishing rivers in Norway (Grøndahl et al., 2022). There are seven fish species present in the watercourse. Brown trout and minnow (*Phoxinus phoxinus*) can be found in the entire system, while the distribution of pike (*Esox Lucius*), perch (*Perca fluviatilis*), grayling (*Thymallus thymallus*), European brook lamprey (*Lampetra planeri*) and alpine bullhead (*Cottus poecilopus*) is restricted to the lower sections (Kraabøl & Arnekleiv, 1993). The lower 23 kilometers of the watercourse act as important spawning and nursing areas for a large-grown potamodromous and piscivorous form of brown trout originating from lake Mjøsa (Figure 1) (Kraabøl & Arnekleiv, 1998). However, over the years, rapid increases in water discharge has led to implementation of numerous flood prevention measures such as canalization, ditching, and stabilization of riverbanks (Kraabøl & Arnekleiv, 1998). Intensive agriculture are also practiced in the catchment area (Myrvold & Dervo, 2019). Collectively, this can induce potential for loss of riparian vegetation and degradation of brown trout habitats within tributary streams.

Four tributaries within the watercourse were selected for the study: Djupa, Sagåa, Finna and Rauda (Figure 1). All four tributaries originate from the forest-dominated heights surrounding the valley of Gausdal and are characterized as steep and with course substrate in their upstream sections. The downstream sections, selected for this study, are characterized by finer substrate and varying cover of deciduous riparian vegetation as the tributaries partly run through intensively driven agricultural lands. Juvenile brown trout are known to be present in the four tributaries (Kraabøl & Arnekleiv, 1998; The County Governor of Innlandet, 2022), which all sustain the piscivorous ecotype (Figure 1) (Kraabøl & Arnekleiv, 1993).

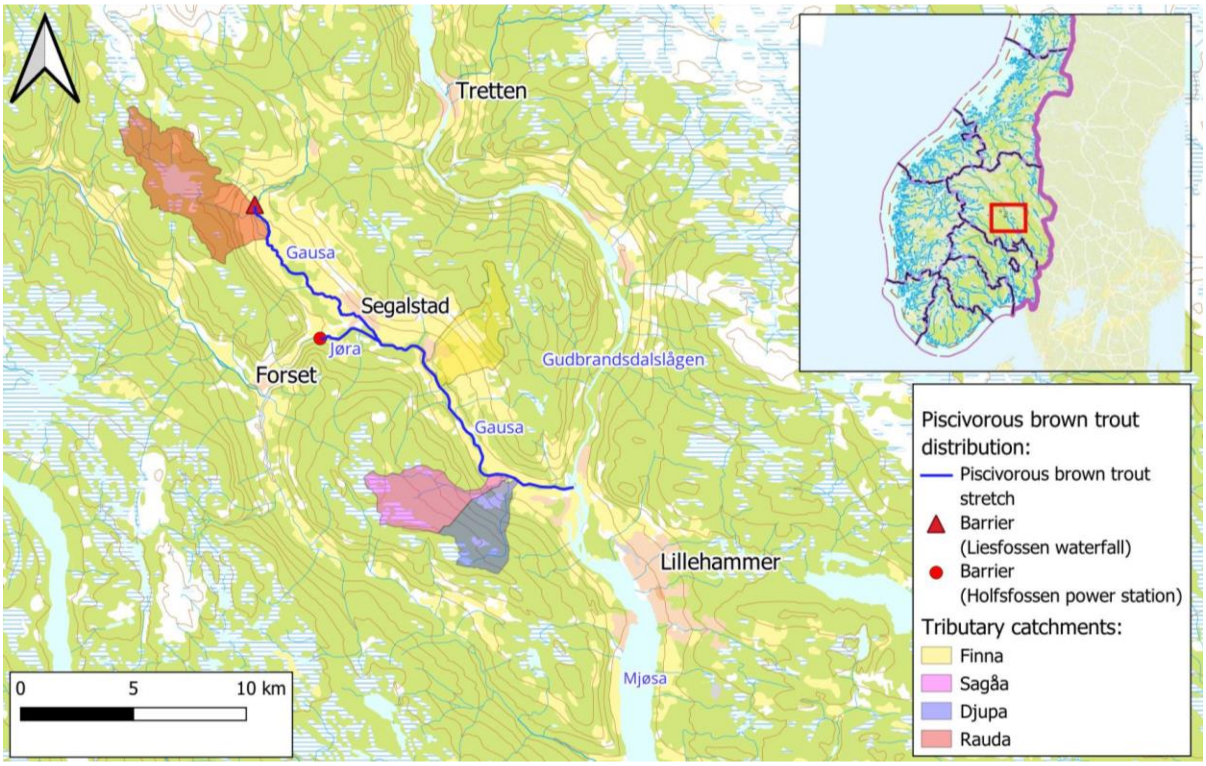


**Figure 1.** *The studied tributaries are located within the Gausa watercourse in Norway (colored polygons). A potamodromous and piscivorous form of brown trout utilize the lower 23 kilometers of the watercourse as spawning and nursing areas (blue lines). Liesfossen waterfall and Holsfossen powerplant act as migration barriers (red shapes).*

## 2.2. Data collection

### 2.2.1. Electro-fishing stations

In the four tributaries, a total of 15 electro-fishing stations were distributed with varying conditions of riparian vegetation (Table 1), following the guidelines provided by Bohlin (1989). The number of established stations varied between the tributaries due to their differences in riparian characteristics and length of fish-bearing habitat.

**Table 1.** *A total of 15 electro-fishing stations were included in the study. The station names correspond to the first letter of the tributary names followed by a station number. Station 1 is located the closest to Gausa, while station 5 is located most upstream in the tributary. At station 5 in Rauda (R5), no PIT-tagging was conducted (*).*

| Tributary | | | |
|---|---|---|---|
| Djupa | Sagåa | Finna | Rauda |
| D1 | S1 | F1 | R1 |
| D2 | S2 | F2 | R2 |
| | S3 | F3 | R3 |
| | S4 | F4 | R4 |
| | | | R5* |

### 2.2.1. Habitat data collection

To assess variables influencing juvenile densities and evaluate the effects of riparian conditions, habitat assessments were conducted within each electro-fishing station. The assessments included both in-stream habitat characteristics and riparian conditions. In-stream habitat characteristics were assessed to better isolate the effects of riparian vegetation.

Within each station, cross-sectional transects were drawn at the downstream end (0 %), at 25 %, 50 %, 75 % and at the upstream end (100 %). At each transect, the width, water depth, substrate composition, shelter availability, moss cover and benthic algae cover were measured. The fraction with overhanging riverbanks, number of pools and amount of dead wood were measured and counted throughout the station as a whole. Water depth was measured at 10 %, 25 %, 50 %, 75 % and at 90 % of the stream's cross-section at each transect. Substrate composition was assessed as the relative distribution among the following five size categories: “0-2 mm”, “2-20 mm”, “20-100 mm”, “100-250 mm” and “>250 mm”. Assessment of moss and benthic algae cover was measured and categorized as follow: 0 %, 1-33 %, 34-66 % or >66 % cover. Shelter availability was measured following the methodology of Forseth & Harby (2013), counting the number of cavities within a quadrat of 50 x 50 cm randomly placed within each transect using a plastic hose with a diameter of 13 mm. The hose, which had markings indicating the length intervals 2-5 cm, 5-10 cm and >10 cm, was pushed between the substrate to find cavities within the three categories. The fraction with overhanging riverbanks was quantified as the stretches containing undercut riverbanks reaching more than 10 cm over the water surface. Measurements were done on both sides of the stream.

For the assessment of riparian conditions, the variables “vegetation composition”, “riparian buffer width”, “fraction with overhanging trees”, “fraction with overhanging non-woody vegetation”, “surface shadow”, and “vegetation composition the next 100 meters upstream” were evaluated following the concept described by Harding (2009). Each assessed variable was assigned a score ranging from one (poor) to five (excellent), based on predetermined conditions (Table 2). The evaluation of “vegetation composition”, “surface shadow”, and “vegetation composition the next 100 meters upstream” were done visually. “Vegetation composition” and “vegetation composition the next 100 meters upstream” refers to the dominating vegetation type of the riparian zone within the electro-fishing station, and within the next 100 meters upstream of the electro-fishing station respectively. The riparian buffer width was measured at both ends, and at the center of the station before the mean width was calculated. For "fraction with overhanging trees" and "fraction with overhanging non-woody vegetation," the proportion containing vegetation extending more than ten cm over the water surface were recorded. All variables were measured on both sides of the stream.

To link riparian conditions to survival and in-stream movement patterns, the “vegetation composition”, “riparian buffer width”, and “surface shadow” were quantified along the entire stretch of the stream where manual antenna PIT-scanning was to be performed (Appendix A-1; A-5; A-9; A-13). Starting at the tributary’s outlet to the river Gausa, the three variables were assessed with the same score-based criteria as for the assessments done within the electro-fishing stations (Table 2). A geo-reference was set when the score of one of the assessed variables changed on one or both sides using a Garmin etrex 30x GPS. This was repeated on the whole stretch, establishing sections of different riparian conditions. To qualify as a section, the riparian conditions had to be homogeneous over a stretch exceeding two meters. Riparian conditions along the PIT-scanned stretches were quantified during the period from June 27th to June 29th, 2023.

**Table 2.** *Riparian conditions were assessed according a score system ranging from one to five, based on the methods of Harding (2009). A low score indicates poor conditions. All variables were assessed within stations, while vegetation composition, riparian buffer width and surface shadow were also assessed along the PIT-scanned stretches of the tributaries.*

| Attributes | Scores 1 | Scores 2 | Scores 3 | Scores 4 | Scores 5 |
|---|---|---|---|---|---|
| Vegetation composition | Little/ no vegetation | Non-woody vegetation | Trees (<2m) | Trees (2-10m) | Trees (>10m) |
| Riparian buffer width | <1m | 1-5m | 5-15m | 15-30m | >30m |
| Surface shadows | <10% shading | 10-25% shading | 25-50% shading | 50-80% shading | >80% shading |
| Fraction of overhanging trees | <10% of station length | 10-25% of station length | 25-50% of station length | 50-80% of station length | >80% of station length |
| Fraction of overhanging non-woody vegetation | <10% of station length | 10-25% of station length | 25-50% of station length | 50-80% of station length | >80% of station length |
| Vegetation composition next 100 meters upstream | Little/ no vegetation | Non-woody vegetation | Trees (<2m) | Trees (2-10m) | Trees (>10m) |

Habitat types were assessed along the PIT-scanned stretches as covariables to clarify potential variations in survival probabilities and movement patterns not explained by riparian vegetation. The assessment of habitat types followed the same method as with riparian conditions. The streams were divided into the three categories “riffle”, “run” and “pool”, following the protocol of Jowett (1993). To qualify as a mesohabitat, the habitat type had to be dominant on the stretch. Riffles and runs had to be more than two meters long, and pools had to be larger than two-meter square. Habitat types in Djupa, Sagåa and Rauda were assessed from June 10th to June 13th, 2023, while Finna was assessed on October 04th, 2023.

Standardized water discharge throughout the studied period was used as a predictor in the analysis of survival probability (Figure 2; Appendix B-8). For the tributary Rauda, water discharge data for the entire period was accessible through the hydropower plant at Rausjøen, upstream of the study area. For the remaining three tributaries, water discharge estimates were obtained from the runoff modeling tool Nevina (NVE, 2022) at The Norwegian Water Resources and Energy Directorate (NVE). Precipitation and snow depth data from nearby metrological stations were obtained through the Norwegian centre for climate services (NORWEGIAN CENTRE FOR CLIMATE SERVICES, 2023). Precipitation data were obtained from the station at Follebu (SN13030). Snow depth data were obtained from the station at Øvrehagen (SN13060) since no data were available at Follebu. Snow depth was converted to snow melt by using the reduction in snow depth between days. During the modelling in Nevina, a climate surcharge of 0 % was used. After estimating water discharge, the data were standardized at stream level (mean=0 (±1 SD)).

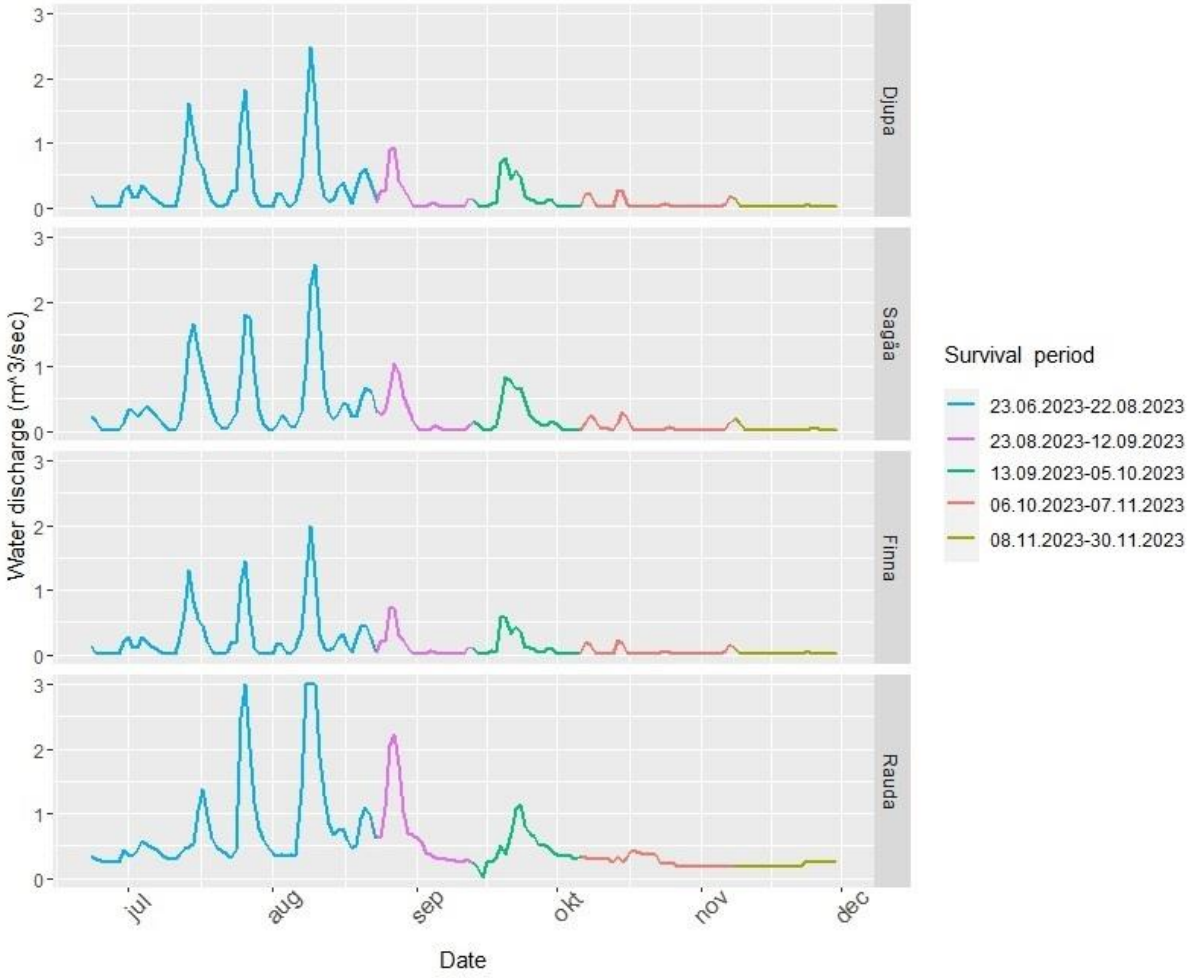


**Figure 2.** *Water discharges were estimated for all tributaries in the period from June 23rd to November 30th, 2023. The colored lines mark the different survival periods. Maximum water discharge visualized in the plot is 3 m$^3$/second to optimize resolution outside of flood events. The water discharge in Rauda exceeded this value at four occasions: July 26th with 3.62 m$^3$/second, August 8th with 5.12 m$^3$/second, August 9th with 9.77 m$^3$/second and August 10th with 4.17 m$^3$/second.*

### 2.2.3. Electro-fishing and PIT-tagging

Fish sampling was conducted by electro-fishing in June and September 2023, and followed the methods described by Bohlin et al. (1989). While electro-fishing for estimation of juvenile densities were done in all stations, tagging of fish with Passive Integrated Transponders (PIT-tags) was done in all except for

R5 in Rauda. For the electro-fishing, a Geomega FA-55 (Terik Technology, Levanger, Norway) was used. The fishing was always carried out in an upstream direction, and the entire area of each station was thoroughly traversed. During the June session, one capture round was conducted to perform PIT-tagging procedure. The electro-fishing during the September session, aimed at providing estimates of juvenile brown trout densities, consisted of three capture rounds following the removal method described by Zippin (1958). To allow the remaining individuals within the station to return to their initial conditions, a 30-minute gap was always included before the next capture to facilitate equal catchability at each round (Bohlin et al., 1989). If the catch from round two did not exceed three individuals, the electro-fishing was stopped prior to the third round.

The total length was registered for all individuals and fish larger than or equal to 65 millimeters (mm) caught during the first capture round were PIT-tagged (Figure 3a; Table 4) (Forseth & Forsgren, 2009). The PIT-tags used in this study were Oregon RFID HDX ISO 11784/11785 compliant ICAR-registered animal tags. Four different versions of these tags were used, depending on the size of the fish (see Table 3 for details). Permission for the PIT-tagging was granted by the Norwegian Food Safety Authority (FOTS ID 30313). The PIT-tagging procedures required the fish to undergo anesthesia. Each fish (>65 mm) was placed in a bucket containing 10 liters of water and 4 milliliters of anesthetic benzocaine (*Optomease Vet 200 mg/ml*). After one to two minutes in the bucket, it was assessed whether the fish was ready for the tagging procedure by checking the fish's response to spinal reflex stimulation at the peduncle. If the fish did not respond to the stimulus, it was ready to be tagged. Using a scalpel, an incision of 2-5 mm was made between the lower end of right-side pelvic fin and the centerline of the ventral region. A PIT-tag, previously rinsed with isotonic chlorhexidine to prevent infections, was then inserted into the incision (Figure 3b). The fish' unique PIT-ID was then scanned with an Oregon RFID EasyTracer I FDX/HDX PIT-reader. The remaining benzocaine on the gill surfaces was removed by gently pushing the fish back and forth in clean water to reduce the morality of tagged fish. The fish from each capture round were placed into separate containers downstream of the electro-fishing station for monitoring until all three capture rounds were completed. The fish were monitored until they were ready to be released back into the stream and were then placed back in separate locations where the water velocity was low and where there was shelter from predators.

**Table 3.** *Four different PIT-tags were used during tagging of juvenile brown trout. The type of tag inserted depended on the fish size. TL (mm) is total length of fish, measured from the snout end to the tip of the tail. The detection distance varied among PIT-tag types.*

| Total length (mm) | Tag name | Tag dimentions (mm) | Tag weight (g) | Detection distance (cm) |
|---|---|---|---|---|
| 65-84 (89) | 12 mm HDX+ PIT Tag | 12.0 x 2.12 | 0.11 | 35 |
| 85-130 | 14 mm HDX+ PIT Tag | 14 x 3 | 0.23 | 41 |
| 90-130 | 16 mm HDX+ PIT Tag | 16 x 3 | 0.25 | 50 |
| >130 | 23 mm HDX+ PIT Tag | 23 x 3.65 | 0.58 | 67 |

**Table 4.** *PIT-tagging was conducted on all fish equal to or larger than 65 millimeters of total length. Different sized PIT-tags were inserted depending on the fish total length. The table reveals the number of individuals tagged with each PIT-tag variant in each tributary in June and September.*

|  | Tag size | Djupa | Sagåa | Finna | Rauda |
|---|---|---|---|---|---|
| June | 12 mm | 1 | 20 | 8 | 16 |
|  | 14 mm |  | 1 | 12 | 9 |
|  | 16 mm |  |  |  |  |
|  | 23 mm | 1 |  |  | 2 |
|  | Total | 2 | 21 | 20 | 27 |
| September | 12 mm | 6 | 6 | 54 | 16 |
|  | 14 mm |  |  |  |  |
|  | 16 mm | 4 | 5 | 10 | 15 |
|  | 23 mm | 1 |  | 2 | 10 |
|  | Recaptures |  | 1 | 4 | 6 |
|  | Total | 11 | 12 | 70 | 47 |

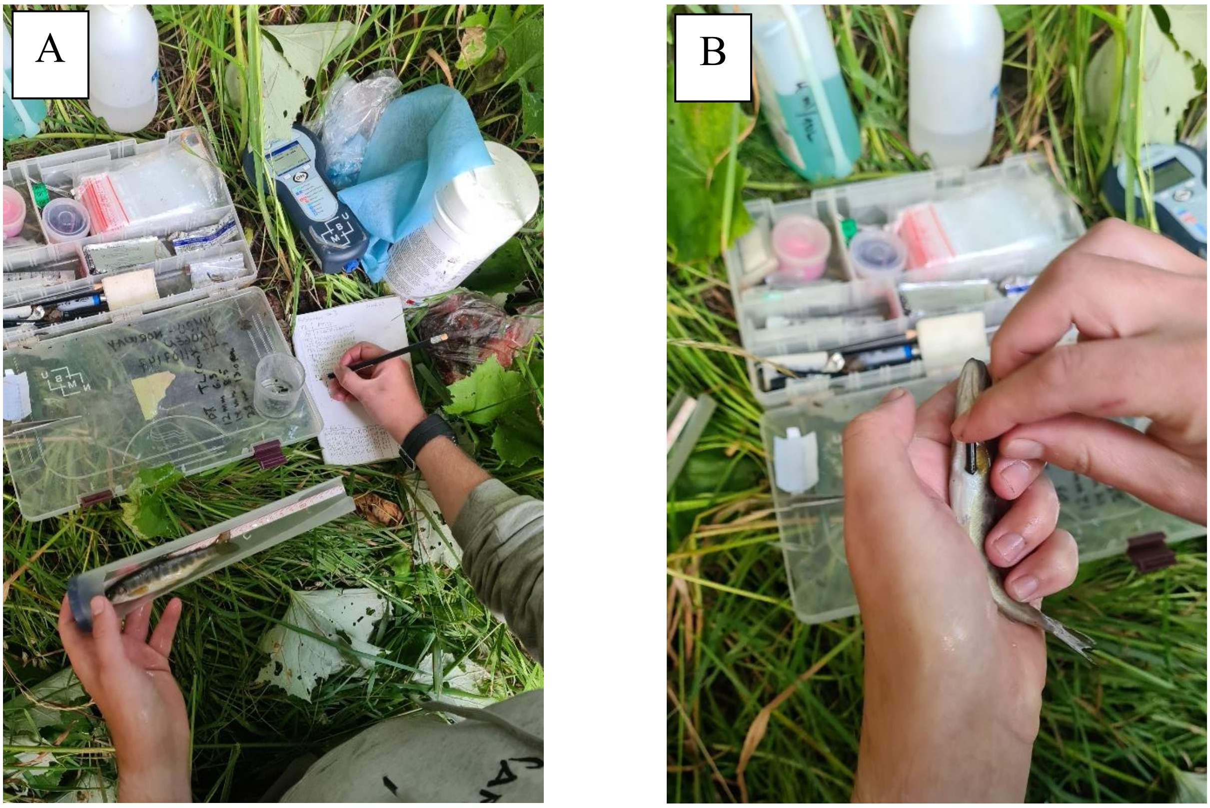


**Figure 3. A:** *All fish were measured for total length.* ***B:*** *PIT-tags were inserted into all individuals equal to or larger than 65 millimeters of total length. The PIT-tag was inserted between the lower end of the right-side pelvic fin and the centerline of the ventral region. Photos: Tuva Løken Frøvoll.*

### 2.2.4. Manual PIT-scanning

Five rounds of manual PIT-scanning were carried out with an Oregon RFID HDX Single Antenna PIT Tag Reader kit between June and November 2023 (Table 5). The PIT tag reader kit consists of a handheld antenna and a backpack with an ORSR Long Range HDX PIT Tag Reader, powered by a rechargeable battery (Figure 4a; 4b). When the antenna is in close proximity of a PIT-tag, the tag sends the unique PIT-ID to the transceiver, which is then stored together with the time of detection, as well as the GNSS coordinates (O'Donnell et al., 2010). The GNSS receiver has an accuracy of 1.5 meters when it is in contact with the required number of satellites (Oregon RFID, 2021).

The PIT scanning was conducted in an upstream direction, from the mouth of the river Gausa and up to 100 meters upstream of the uppermost fish tagging station (Appendix A-1; A-5; A-9; A-13). During the scan, the antenna was moved over the surface of the water in an oscillating motion. To detect the smallest tags (12 mm HDX+ PIT Tag) as well as fish hiding in deeper pools and within the substrate, the antenna was systematically lowered into the water in deeper areas. The GNSS system on the scanner has proven to be unreliable if it does not have contact with enough satellites (Thrond Haugen, personal communication, 2023). A handheld Garmin etrex 30x GPS was therefore used as a backup to establish geo-references when detecting fish.

**Table 5.** *Five rounds of manual antenna PIT-scanning was conducted from July to November 2023. Each round resulted in detections of PIT-tagged individuals.*

| Manual PIT-scanning | Detections | | | |
|---|---|---|---|---|
| | Djupa | Sagåa | Finna | Rauda |
| 19th-20th of July | | | 1 | 2 |
| 21th-22th of August | | 2 | 1 | 1 |
| 4th-5th of October | 5 | 3 | 28 | 11 |
| 6th-7th of November | 2 | 6 | 23 | 17 |
| 29th-30th of November | 1 | 6 | 12 | 15 |
| Total | 8 | 17 | 65 | 46 |

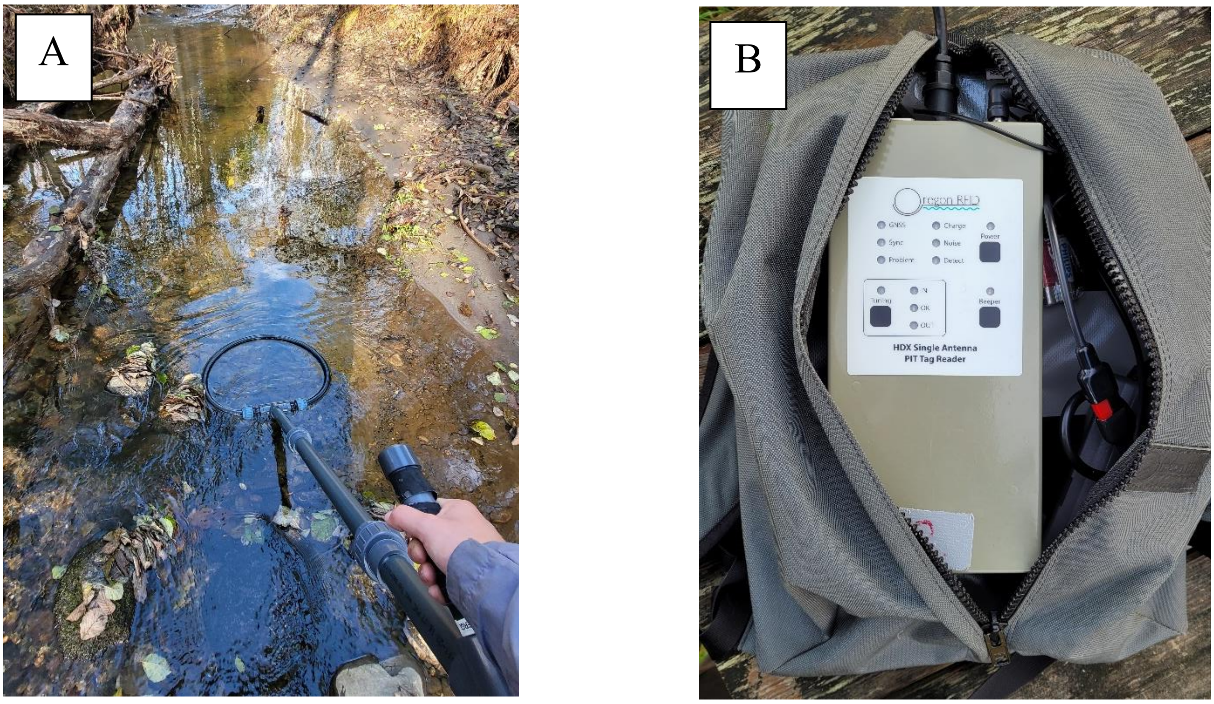


**Figure 4.** ***A:*** *Manual PIT-scanning was conducted using an Oregon RFID HDX Single Antenna PIT Tag Reader kit.* ***B:*** *The receiver was kept in a backpack with a rechargeable battery. Photos: Ole Eivind Ovnan Fjeldstad.*

## 2.3. Statistical analysis

Processing of data was done using the software R (R Core Team, 2024) with R-studio, version 2023.09.1 (RStudio Team, 2024). Extraction of GPS data was performed using the software BaseCamp, version 4.7.5 (Garmin Ltd., 2024). PIT-telemetry data were extracted using the software CoolTerm version 2.0.1 (Meier, 2024). Production of maps, as well as further processing of georeferenced data was performed in QGIS, version 3.32 Lima (QGIS Development Team, 2024). Map layers were acquired from Kartverket (kartverket.no). Analyses were conducted in R-studio and program MARK version 10.x. (White & Burnham, 1999). All statistical testing was conducted using a significance level alpha = 0.05. All plots were made in R-studio using the R-package "Ggplot2" (Wickham et al., 2016).

### 2.3.1. Analyzing the effects of riparian vegetation on juvenile density

#### Habitat data

Processing of in-station habitat data involved calculating the mean values for all variables. When calculating the mean values for shelter availability, different sized cavities were weighted differently. Following the methods from Forseth & Harby (2013), the category 2-5 cm were not weighted, whereas cavities within the category 5-10 cm were weighted with factor two, and cavities within the category >10 cm were weighted with factor three. The geometric midpoint of each substrate category was used to calculate the mean substrate size. Regarding moss and algae cover, the median value within each category was used to determine the mean cover percentage. Thus, 16 %, 59 %, and 83 % were used. The values for the habitat characteristics variable "overhanging riverbanks", as well as the riparian condition variables "fraction of overhanging trees" and "fraction of overhanging non-woody vegetation" were averaged using both sides and then converted it into a percentage of the station's length. The values of the left and right sides were averaged for the in-station riparian condition variables "vegetation composition", "riparian buffer width", and "vegetation composition next 100 meters upstream".

Each electro-fishing station in the dataset were represented by multiple in-stream habitat characteristics and riparian conditions variables, which could possibly result in complex models. As there were also indications of correlations among several of the variables within the two variable groups (Appendix B-2; B-6), ordination analyses were conducted. By conducting ordination analyses, the dimensionality in the dataset was reduced while simultaneously preserving the relative relationships between the variables by transforming the assessed variables into linear combinations (Palmer, 2004). A Detrended Correspondence Analysis (DCA) was conducted to determine the type of ordination analysis that was going to be used for the in-stream habitat variables. The correct type of ordination analysis is determined by the length of the first axis in the DCA. The length of the first axis was 1.37, which indicated that Principal Component Analysis (PCA) should be used for the further analysis (Lepš & Šmilauer, 2003). Using the R-package "vegan" (Oksanen et al., 2019), a PCA containing the variables "mean shelter availability", "mean depth", "mean substrate size", "mean algae cover", "mean moss cover", "dead wood", "number of pools", and "fraction with overhanging riverbanks" was then carried out on these variables scaled to mean=0 and SD=1. The station scores, i.e. the weighted sums of the in-stream habitat variable loadings across the principal components PC1, PC2, and PC3 at each electro-fishing station, were entered the dataset as covariates representing proxy variables for the in-stream habitat data (Appendix B-3), allowing for investigating the relationship between habitat characteristics and juvenile densities. Biplots were constructed to visualize how the specific variables loaded on the principal components.

Since the in-station riparian condition variables were ordinal categories, a copula-based ordination analysis with factor scoring was used (Popovic et al., 2018a). Copula-based ordination was done using the R-package “EcoCopula” (Popovic et al., 2018b). The variables included in the ordination were “vegetation composition”, “riparian buffer width”, “fraction of overhanging trees”, “fraction of overhanging non-woody vegetation”, “surface shadow”, and “vegetation composition next 100 meters upstream”. The station scores, i.e. the weighted sums of the riparian condition variable loadings across the two factors Factor1 and Factor2 at each electro-fishing station (Appendix B-7), were entered the dataset as proxy variables for the riparian conditions data. A biplot was created to visualize the loading of specific variables on the factors.

### Juvenile brown trout density data

The density of the age classes 0+, 1+ and >1+ was estimated for each station. Histograms of length distributions were used to determine boundaries between the age classes, and thereby decide the catch within each age class for each electro-fishing round. The histograms showed multi-peaked distributions, where each peak represented an age class. Fixed boundaries were set midway between the peaks, founding the assumption that all individuals within an age class had total lengths within the given length intervals. Juvenile densities were estimated using the R-package “FSA” (Ogle & Ogle, 2017). The "removal" command uses the Zippin method (Zippin, 1958), and provides an estimate of the density of the three separate age classes within a station. The densities were then converted to density per 100 $m^2$.

At station D1, the density estimate was considered biased because 20 fish were caught in the first round, 12 in the second round and 19 in the third round. This resulted in an artificially high density estimate and gave a large standard error. To remedy to the erroneous estimate, the order of the catch in the station was changed: round 1: 20 fish, round 2: 19 fish, round 3: 12 fish (Thrond Oddvar Haugen, personal communication, 2023).

## Model selection

Linear models were constructed, incorporating both density-dependent and density independent factors. Two separate analyses were carried out: one to determine the predictors of 0+ density and one to determine the predictors of >0+ density (Figure 4). The conceptual framework for the models was outlined as follows:

*Density of 0+ = Effects of in-stream habitat characteristics + >0+ density + Effects of riparian conditions*

*Density of >0+ = Effects of in-stream habitat characteristics + Effects of riparian conditions*

Model selection was carried out following a forward stepwise procedure (Bursac et al., 2008). In the initial step, the effects of in-stream habitat characteristics were incorporated into the model structure via station-specific principal component scores derived from the previously described PCA (Appendix B-4). This was done to overcome multicollinearity issues pertinent to habitat characteristics data (Appendix B-3), an approach named principal component regression analysis (Jolliffe & Jolliffe, 1986). The density of >0+ was included as a predictor in the model structure for analysis of 0+ density, considering the anticipated impact of inter-cohort competition (Bohlin, 1977). The most supported model was taken forward for inclusion of riparian effects through the factor scorings generated in the copula-based ordination analysis, following the same rationale as for the in-stream variable PCA (Figure 5; Appendix B-7). Akaike's Information Criterion corrected for small sample sizes (AICc) was used for model selection (Symonds & Moussalli, 2011).Candidate models with a ΔAICc below two were considered to have empirical support (Burnham & Anderson, 2002). AICc was available through R-package "AICcmodavg" (Mazerolle & Mazerolle, 2017).

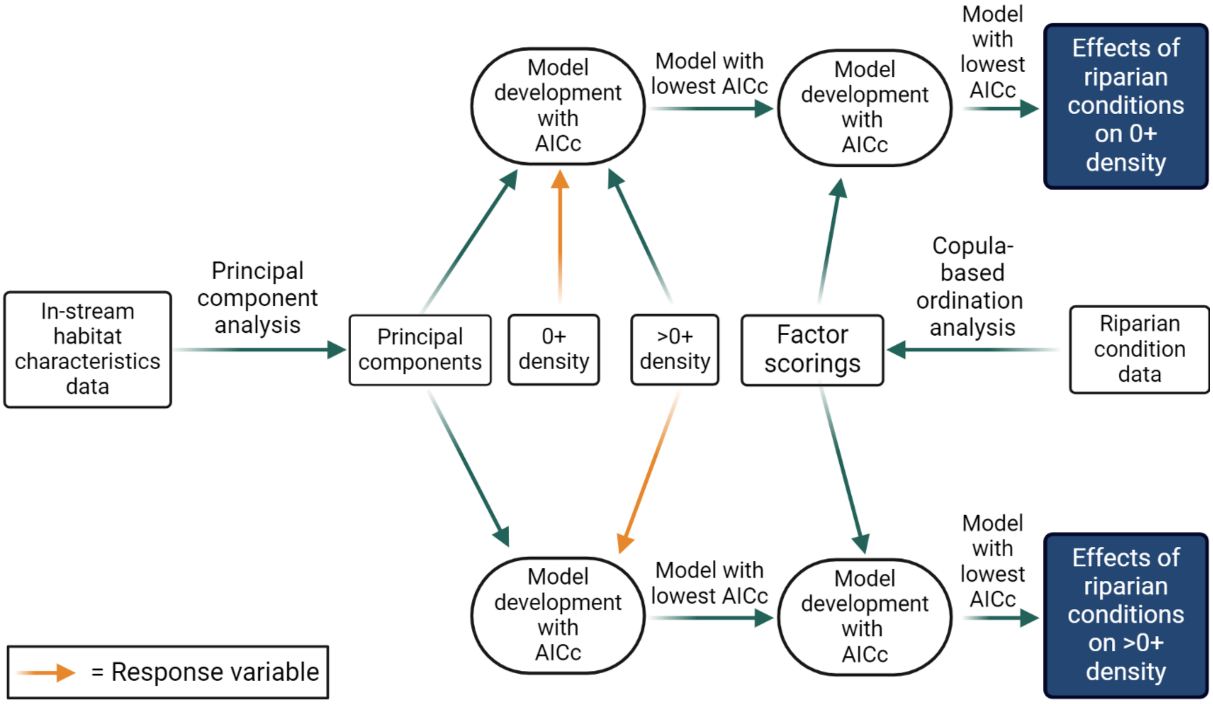


**Figure 5.** *Ordination analyses were conducted on the assessed in-stream habitat and riparian condition variables. The station scores were then used as predictor variables in linear regressions. >0+ density was included as a predictor in 0+ analysis. Model selection was done with AICc. The upper section visualize procedures for analyses of 0+ density, while the lower section represent analyses of >0+ density. The figure was made in BioRender.com.*

### 2.3.2. Analyzing the effects of riparian vegetation on survival probability

#### Habitat data

As the analysis of survival probability included a stream-effect, riparian conditions data were required to be adjusted to stream-level. To adjust to a stream-level, as well as to reduce the complexity in the data, a riparian condition index score (RCI-score) was calculated as the mean score of “vegetation composition”, “surface shadow”, and “riparian buffer width” along the entire PIT-scanning stretches, providing an overall riparian conditions variable for each tributary (Table 6). The RCI-score was weighted on the section lengths, which was found using the function “Shortest path (point to layer)” in QGIS.

**Table 6.** *A riparian condition index score (RCI-score) for each tributary were calculated as the mean of the three assessed variables riparian composition, riparian buffer width, and surface shadow.*

| Tributary | Riparian composition | Riparian buffer width | Surface shadow | RCI-score |
|---|---|---|---|---|
| Djupa | 2.43 | 2.37 | 1.89 | 2.23 |
| Sagåa | 3.96 | 3.12 | 4.14 | 3.74 |
| Finna | 3.24 | 3.24 | 3.51 | 3.32 |
| Rauda | 3.33 | 2.43 | 3.45 | 3.06 |

### Apparent survival (φ) and recapture probability (*p*)

A detection history was constructed for each individual (Lebreton et al., 1992), together with standardized fish lengths (mean=0 (±1 SD)), separated into their respective tributaries. The detection histories consisted of binomial data. A "1" was set on the respective detection occasion when the individual was detected, and a “0” was set when the individual was not detected (Figure 6). Due to the few individuals encountered during the scanning rounds in July and August, these were merged into one occasion. The period from 23rd of June to 30th of November 2023 was thus divided into six detection occasions and five survival periods, with period one to three representing summer survival and period four and five representing autumn survival (Figure 7). The detection histories were exported as an IMP-file to be used during the estimation of apparent survival (φ) and recapture probability (*p*).

Apparent survival (φ) and recapture probability (*p*) were estimated using a joint likelihood function through a Cormack-Jolly-Seber (CJS) model structure (Figure 6; Figure 8) in program MARK (White & Burnham, 1999). Detection histories, mean RCI-scores, standardized water discharge and standardized fish total lengths were used in the CJS model structure and ran through model selection with AICc, available through a built-in function in program MARK (White & Burnham, 1999). The RCI-score were also included as seasonal effect, setting its values to zero during the autumn survival period (period four and five; Figure 7 and Figure 8). This was done to illustrate senescence of vegetation in the autumn survival period. The term apparent survival (φ) is used as the CJS model structure cannot distinguish between migrated and dead fish (Pledger et al., 2003). Apparent survival thus captures fish that at the moment are "dead to the system".

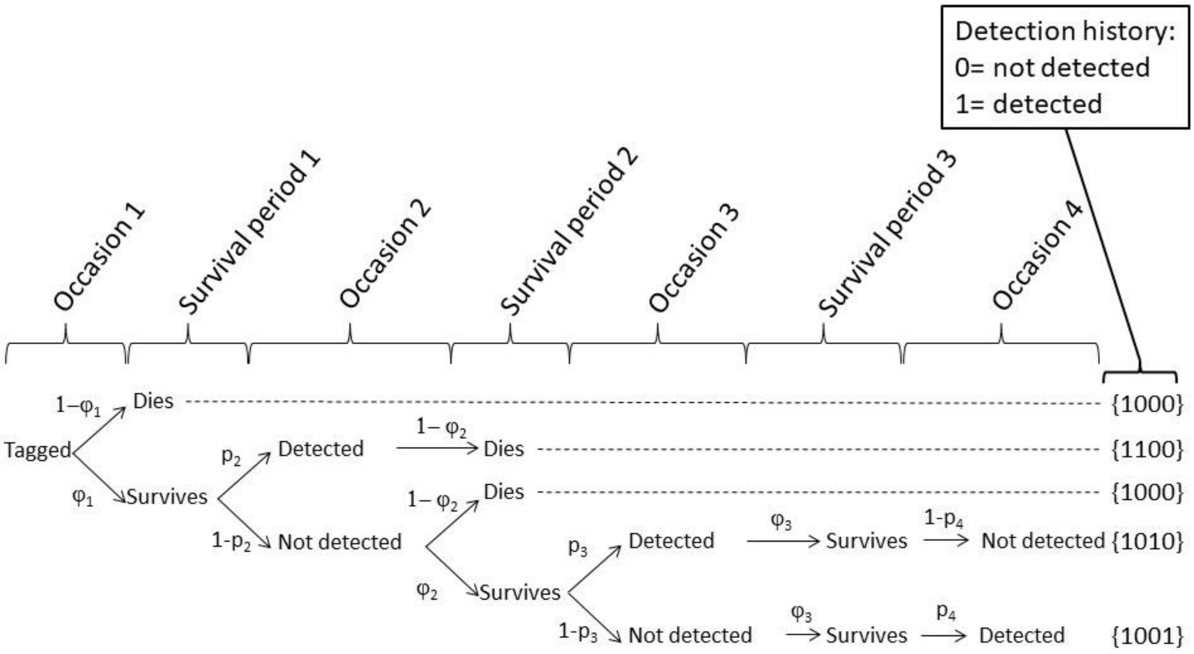


**Figure 6.** *A fate diagram illustrates the* ***concept*** *of detection histories. Fate diagrams are made up of occasions and survival periods. φ is apparent survival and p is recapture probability. A 0 represent an occasion when the individual is not detected, while a 1 represent the detection of the individual. The fate diagram is based on a Cormack-Jolly-Seber model structure.*

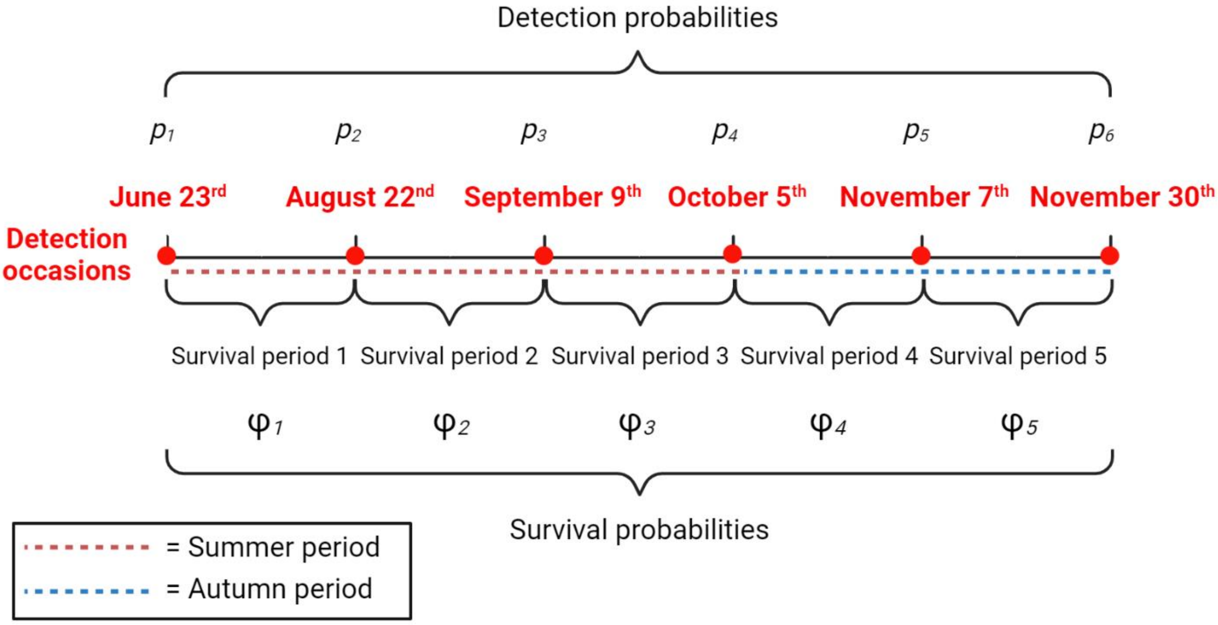


**Figure 7.** *A parameterization of the Cormack-Jolly-Seber model in the current study. The study contained six encounter rounds and five survival periods throughout the summer (red) and autumn (blue) of 2023. Since encounter probability estimates are dependent on data from earlier encounter rounds, $p_1$ could not be estimated. $p_x$ is recapture probability at occasion x. $\varphi_x$ is apparent survival in round x. The red numbers mark the dates of detection occasions and boundaries between survival periods. The figure was made in BioRender.com.*

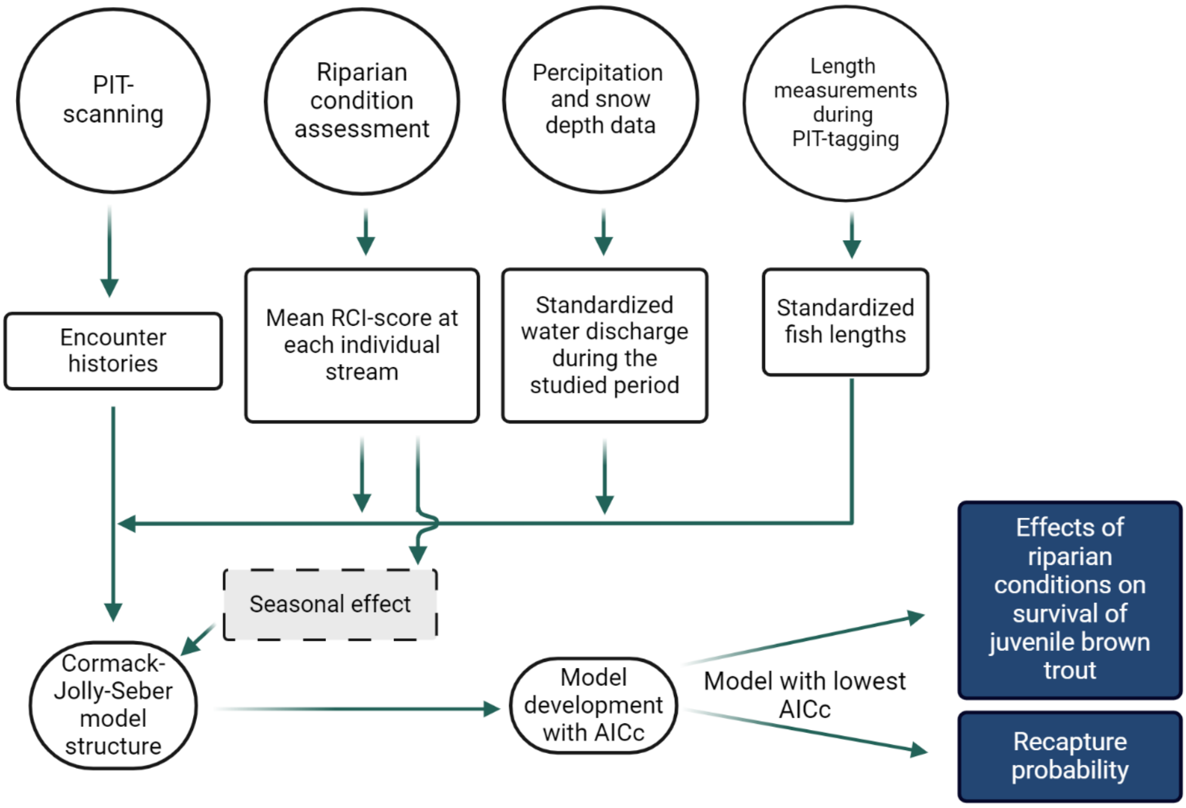


**Figure 8.** *Encounter histories, a riparian condition index score (RCI-score) based on the scores of three assessed variables related to riparian conditions, standardized waterflow and standardized fish lengths were inserted in a Cormack-Jolly-Seber model structure in program MARK to estimate survival probability (apparent survival) and recapture probability. The RCI-score was also seasonally adjusted to represent senescence of riparian vegetation. Model selection was done with AICc. The figure was made in BioRender.com.*

### 2.3.3. Analyzing the effects of riparian vegetation on in-stream movement patterns

For the analyses of in-stream movement patterns, the RCI-score of all separate sections within the PIT-scanning stretches were converted into a binomial variable. A threshold of 2.5 was therefore set to distinguish between sections of poorly developed and highly developed riparian vegetation. Using the function "Numerical digitize" in QGIS, all detections were converted in a shape file. Each detection was then linked to the habitat type and the binomial RCI-score at the detection site. Since the exact positions of release within the stations after PIT-tagging were not documented, the dominant habitat type and dominant riparian conditions within the respective electro-fishing stations were used. After linking the PIT-telemetry data to the environmental data, the movements of each tagged individual between the six occasions were mapped. For each detection, it was decided whether the individual had remained stationary or not, establishing a binomial response variable for the analysis of movement probability. In cases of movement, the distance moved was measured to establish the response variable "distance moved" for the movement distance analysis. Since the exact position for release after PIT-tagging in

June and September were not available, the movement distance from the tagging occasion to the first PIT-scanning occasion was set from the center of the electro-fishing station. For a movement to be registered, the fish had to move more than five meters to encompass the accuracy bias of the GNSS system in the PIT-scanning equipment. For all detections, the variables “riparian conditions at pre-movement position” and “mesohabitat type pre-movement position” were generated.

To determine the effects on movement probability, logistic linear regressions were conducted, using the binomial variable “movement” as the response variable. Analysis of movement distances were conducted with linear models on the response variable “distance moved”, using exclusively non-stationary individuals (n=107) (Figure 9). AICc was used for model selection, as described in section 2.3.2. Movement distances were expected to be time dependent as movements across longer distances typically require more time. Initially, it was considered to include time as an offset in the candidate models. However, plots showed that movements over longer distances occurred within short timespans (Appendix D-4). Consequently, the effect of time was omitted from the final candidate models. As some individuals were detected at several occasions, not all detections within the dataset could be considered independent (Harrison et al., 2018). To account for individual non-independent movement or individual redundancy, mixed models accounting for PIT-ID were adapted using the R-package lme4 (Bates, 2010). However, backward elimination revealed that mixed models had low support from AICc, leading to the retention of the original candidate models (Bursac et al., 2008).

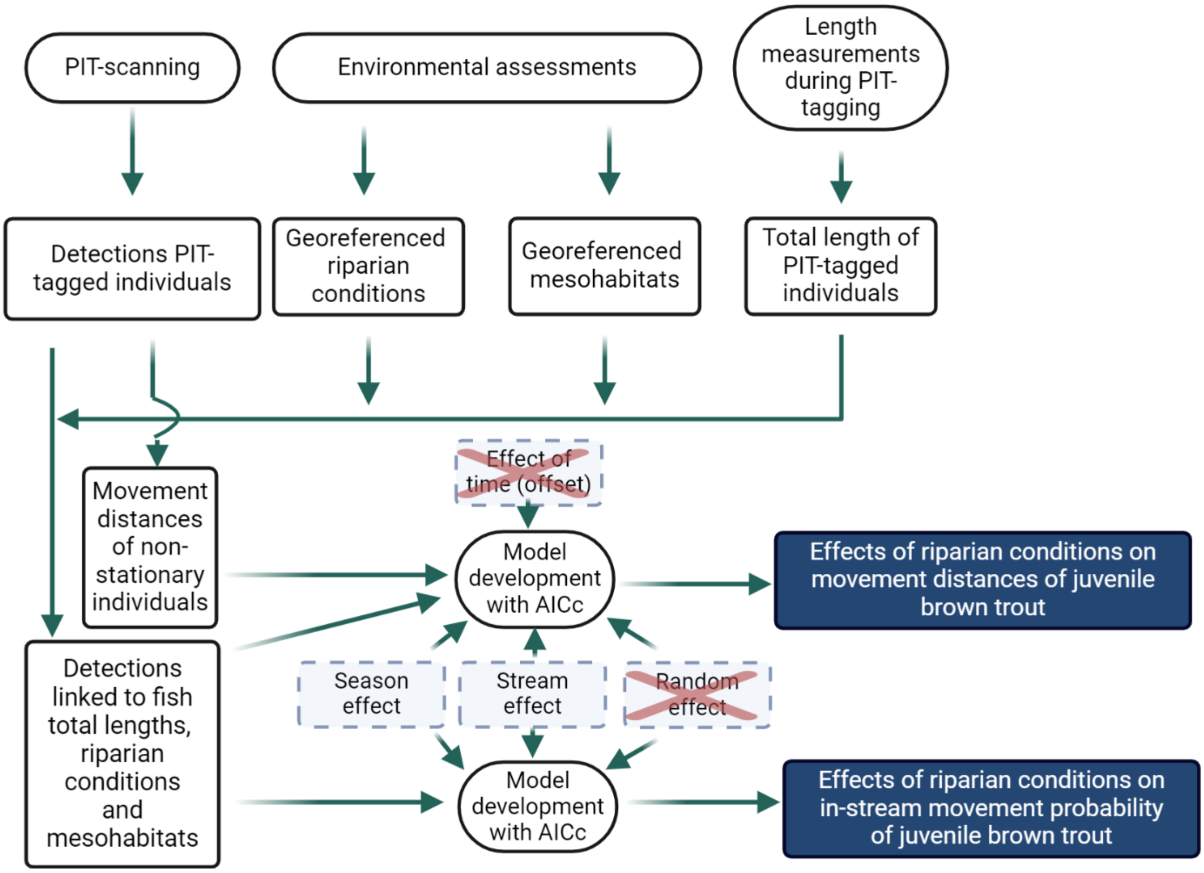


**Figure 9.** *The positions of individual PIT-tag detections and georeferenced riparian conditions were included in regression models to investigate the riparian effects on movement probability and movement distances. Georeferenced mesohabitats and individual total lengths were included as covariables. Model selection was one with AICc. Seasonal effects and stream effects were included in the models. A random effect and the effect of time were not supported, and thus left out of the final candidate models. The figure was made in BioRender.com.*

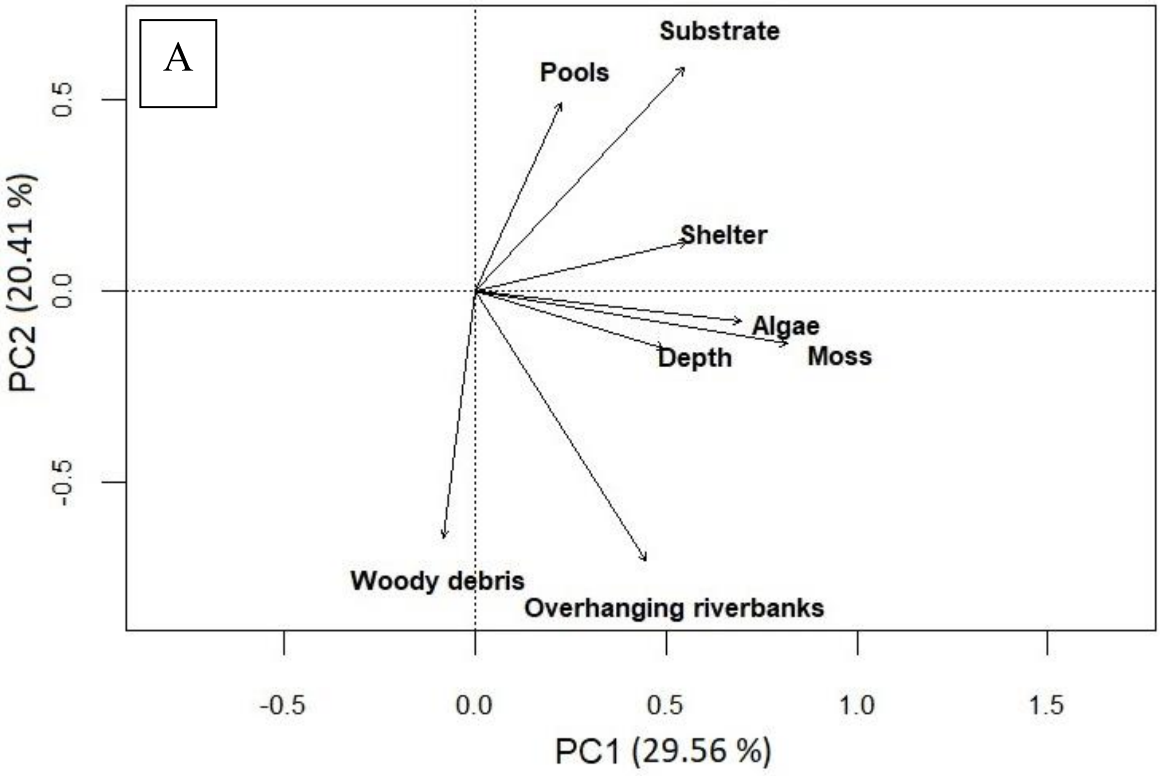
# 3. Results

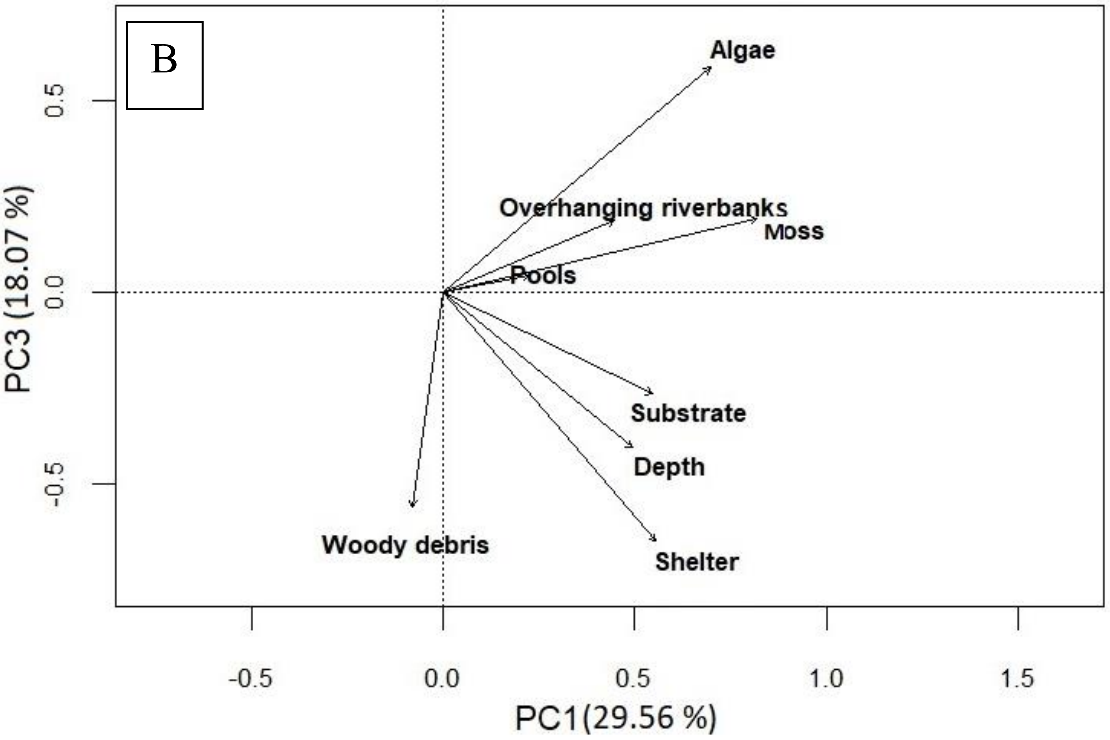
## 3.1. Effects of riparian conditions on juvenile brown trout density

### 3.1.1. Ordination of habitat data

**Principal component analysis of in-stream habitat**

The PCA analysis showed that the cumulative variation explained by PC1, PC2 and PC3 is 68.04 %. PC1 explained 29.56 % of the total variance and had all variables except for dead woody debris having an impact on positive values. Moss cover was the variable with the highest positive loading. For PC2, which explained 20.41 % of the variance, substrate size was the variable with the highest positive loading while overhanging riverbanks had the highest negative loading. PC3 explained 18.07 % of the variation and had algae cover as the variable with the highest positive loading. The highest negative loading for PC3 was shelter availability (Figure 10; Appendix B-3; Appendix B-5).





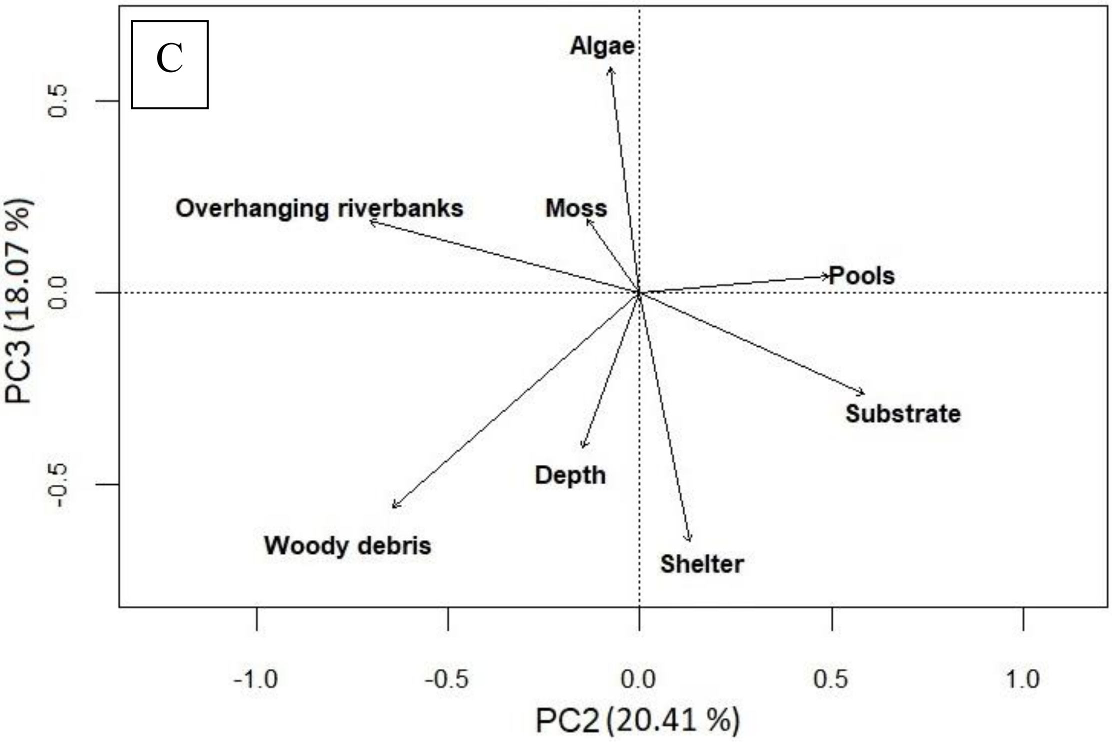


**Figure 10.** *Figure 10A shows PC1 and PC2, figure 10B shows PC1 and PC3, and figure 10C shows PC2 and PC3. Variables are defined as follows: algae is algae cover, moss is moss cover, substrate is substrate size. The vector of each variable included in the PCA were displayed in biplots.*

### Copula-based ordination of in-station riparian condition assessments

For Factor1, all assessed variables had an impact on positive values except for the fraction of overhanging non-woody vegetation, which had a marginal negative score. The variables with the highest score on positive values were surface shadow, riparian buffer width, and fraction of overhanging trees, while the score of vegetation composition next 100 meters upstream was found to be marginally positive. For Factor2, all variables except for fraction of non-woody overhanging vegetation had an impact on positive values (Figure 11; Appendix B-9).

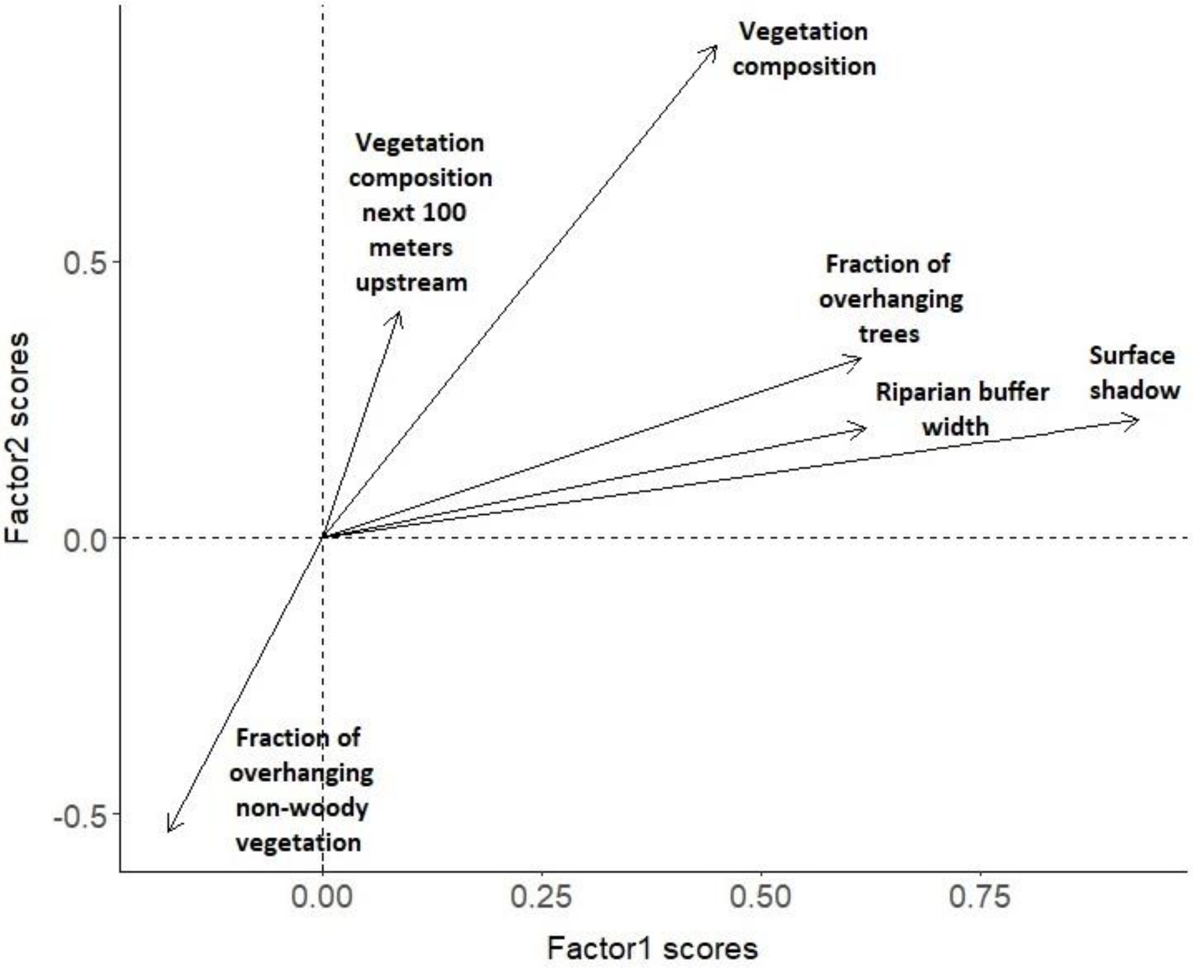


**Figure 11.** *The impact of variables included in the copula-based ordination on the factor axes are presented in a biplot.*

### 3.1.3. Catch-, age, and length distributions

During the density fishing in September, a total of 760 brown trout were caught in the four tributaries (Appendix C-1). Brown trout were caught at all stations. The total length varied from 37 to 207 mm, and the mean total length in the tributaries was 65.2 mm (±22.5 mm SD). The 0+ age class dominated at all stations in all streams. Occurrence of the 1+ age class was found at all stations except for station one in Sagåa. Occurrence of the >1+ age class was found at both stations in Djupa, at station 3 in Finna, and at stations 2-5 in Rauda (Figure 12).

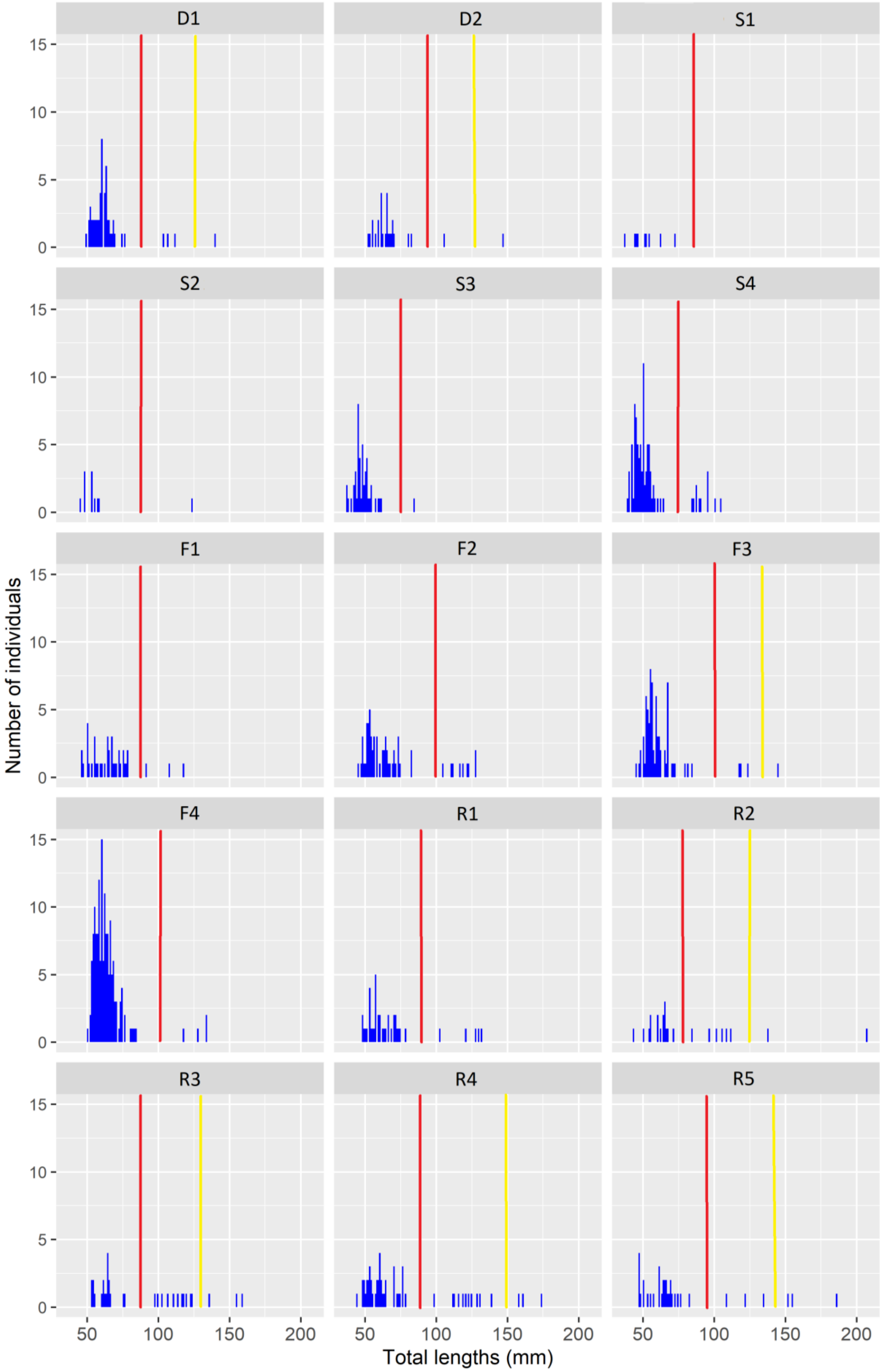

D1
D2
S1
S2
S3
S4
F1
F2
F3
F4
R1
R2
R3
R4
R5
Number of individuals
0
5
10
15
50
100
150
200
Total lengths (mm)

**Figure 12.** *Length distributions were used to determine densities of each age class. The red lines delineate the assumed maximum length of 0+. The yellow lines delineate the assumed maximum length of 1+ (See details in Appendix C-2 for the specific boundaries). All individuals on the right side of the red line (1+ and >1+) are grouped as >0+ in the analysis of juvenile densities. D1 and D2 represent the electro-fishing stations in Djupa, S1–S4 represent the stations in Sagåa, F1-F4 represent the stations in Finna, and R1-R5 represent the stations in Rauda. Station 1 was located the furthest downstream in all tributaries.*

### 3.1.4. Juvenile brown trout densities

The density of the 0+ varied from six to 151 individuals per 100 m$^2$, the density of 1+ varied from zero to 11 individuals per 100 m$^2$ and the density of >1+ varied from zero to three individuals per 100 m$^2$. The highest density of 0+ was found at station F4, with 151 individuals per 100 m$^2$. The lowest density of 0+ was found at station S1 with six individuals per 100 m$^2$. The uncertainty surrounding the estimates were greatest for the 0+ age class (Figure 13; Appendix C-1).

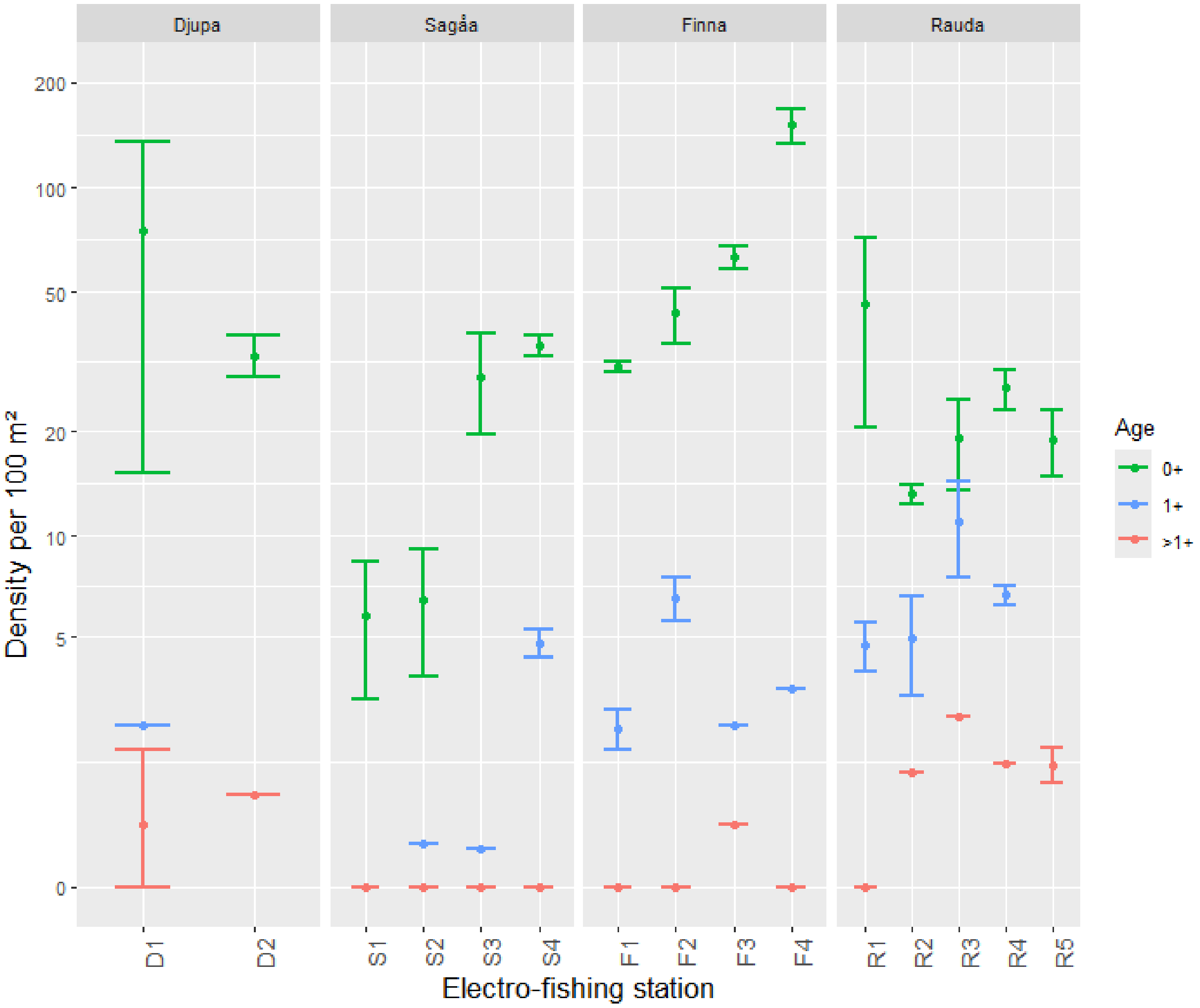


**Figure 13.** *Juvenile brown trout densities per 100 m$^2$ varied among the electro-fishing stations. Acronyms correspond as follows: D is Djupa, S is Sagåa, F is Finna, and R is Rauda. Station 1 in each stream was located furthest downstream in all tributaries. Vertical lines represent the 95% confidence intervals. Y-axis is shown in log-scale.*

### 3.1.5. Predictors for 0+ density

The model receiving the highest support from AICc indicated that the inclusion of >0+ density, PC1 from the in-stream habitat assessments, and Factor1 from the riparian conditions assessments as variables with additive effects best explained the variation in 0+ density (Table 7; $F_{3.11} = 8.17$, $R^2 = 0.69$).

**Table 7.** *The model selection contained the ten candidate models best explaining the variation in 0+ density (see Appendix D-1 for full list). PC1, PC2 and PC3 were measures of in-stream habitat. Density of >0+ ($N_{>0+}$) was included in all models as it was assumed that intercohort competition would affect the density of 0+. Factor1 and Factor2 were output variables generated in the copula-based ordination, representing riparian conditions. AICc parameters are presented as follows: K is the number of parameters in the model, ΔAICc is the difference in AICc value compared to the top model, AICcWt is the weight of AICc support within the models, and LL is the Log likelihood.*

| Model | K | AICc | ΔAICc | ModelLik | AICcWt | LL |
|---|---|---|---|---|---|---|
| $N_{>0+}$+PC1 +Factor1 | 5 | 32.495 | 0 | 1 | 0.794 | -7.914 |
| $N_{>0+}$*Factor1+PC1 | 6 | 37.994 | 5.5 | 0.064 | 0.051 | -7.747 |
| $N_{>0+}$+PC1*Factor1 | 6 | 38.279 | 5.784 | 0.055 | 0.044 | -7.89 |
| $N_{>0+}$+PC1 +Factor1+Factor2 | 6 | 38.312 | 5.818 | 0.055 | 0.043 | -7.906 |
| $N_{>0+}$+PC1 | 4 | 39.302 | 6.807 | 0.033 | 0.026 | -13.651 |
| $N_{>0+}$+PC1+PC3 | 5 | 40.678 | 8.183 | 0.017 | 0.013 | -12.005 |
| $N_{>0+}$+PC3 | 4 | 41.502 | 9.007 | 0.011 | 0.009 | -14.751 |
| $N_{>0+}$*PC1 | 5 | 42.649 | 10.155 | 0.006 | 0.005 | -12.991 |
| $N_{>0+}$+PC2 | 4 | 43.209 | 10.714 | 0.005 | 0.004 | -15.604 |
| $N_{>0+}$+PC1+PC2 | 5 | 43.518 | 11.023 | 0.004 | 0.003 | -13.426 |

#### The effect of >0+ density, in-stream habitat characteristics and riparian conditions on 0+ density

According to the model with the most AICc support, variables with an impact on positive values of Factor1 were negatively correlated with 0+ density (Table 8; Figure 14). Surface shadows, riparian buffer width, and the fraction of overhanging trees stood out having an impact on high positive values of Factor1, signaling a substantial negative effect on 0+ density. Vegetation composition had an intermediate negative effect, while vegetation composition the next 100 meters upstream showed a tendency of having a low influence on 0+ density. Fraction of overhanging non-woody vegetation was the only variable with a tendency of an impact on weak negative values of Factor1, and thus a weak positive effect on 0+ density (Table 8; Figure 11; Figure 14). Variables with an impact on positive values of PC1 from the in-stream habitat characteristics were negatively correlated with 0+ density (Table 8; Figure 14). Moss cover and algae cover had a highly negative influence on 0+ density, while an intermediate negative effect was found of shelter availability, substrate size, depth, and overhanging riverbanks. Number of pools had a low negative effect on 0+ density, while no effect was found of dead woody debris (Table 8; Figure 10; Figure 14). According to the model, there was also a tendency of 0+ being positively correlated to >0+ density (Table 8; Figure 14).

**Table 8.** *Parameter estimates and corresponding effect test are showed for the model with the most support from AICc. PC1 represented in-station habitat characteristics. Factor1 was the output variable from the copula-based ordination and represent riparian conditions. SE is the standard error of the estimate, Df represents the degrees of freedom, SS is the sum squared, F equals to the F-value, and p is the p-value.*

| **Parameter estimates** | | | **ANOVA table** | | | |
|---|---|---|---|---|---|---|
| **Parameter** | **Estimate** | **SE** | **Df** | **SS** | **F** | **P** |
| Intercept | 2.058 | 0.343 | | | | |
| $N_{>0+}$ | 0.720 | 0.220 | 1 | 1.008 | 4.426 | 0.059. |
| PC1 | -0.788 | 0.199 | 1 | 1.721 | 7.555 | 0.018* |
| Factor1 | -0.562 | 0.157 | 1 | 2.916 | 12.803 | 0.004** |

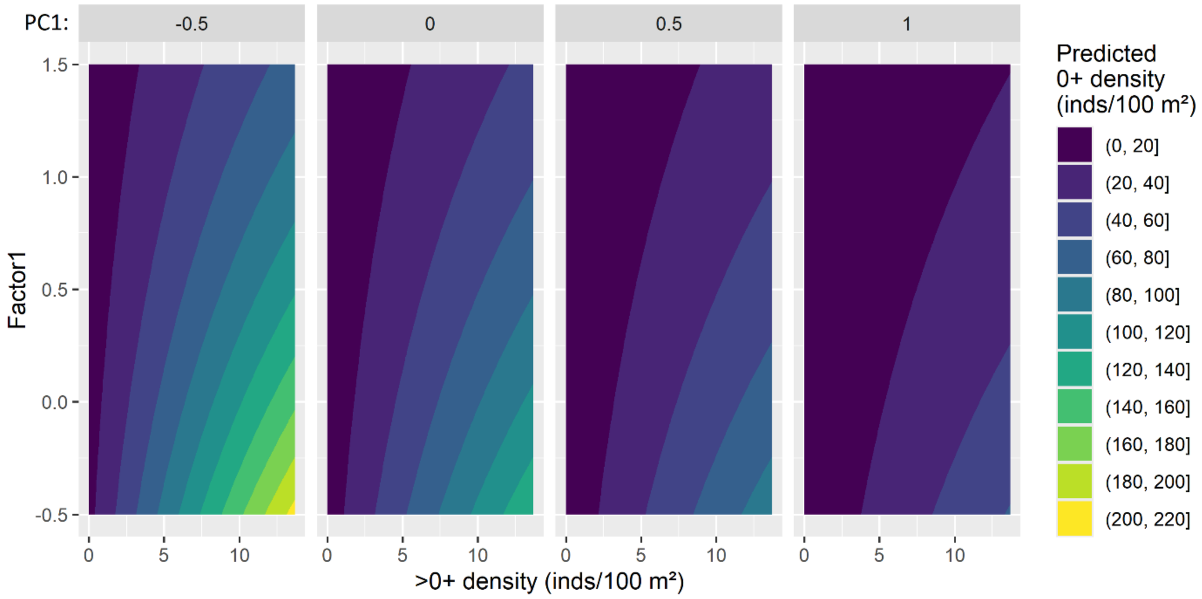


**Figure 14.** *The model with the most support within AICc suggested that 0+ density was negatively correlated with in-stream habitat characteristics (PC1), as well as riparian conditions (Factor1). Consequently, variables which attained positive scores in the ordinations had a negative effect on 0+ density. A tendency was found of 0+ density being positively correlated to >0+ density, indicating higher densities of the young-of-the-year age class when older age classes are more numerous. The colored areas in the plot represent the density of 0+. The X-axis shows the >0+ density. The Y-axis represent Factor1 from the riparian condition assessments. The prediction plot visualizes the effects at four values of PC1 to encompass the range of the in-stream habitat: -0.5, 0, 0.5 and 1.*

### 3.1.6. Predictors for >0+ density

The model receiving the highest AICc support indicated that PC1 best explained the variation in >0+ density (Table 9; $F_{1.13} = 7.03$, $R^2 = 0.35$), which suggest that variables related to in-stream habitat characteristics stood out as explanatory factors contrary to riparian conditions represented as Factor1 and Factor2.

**Table 9**. *The model selection included the ten candidate models best explaining the variation in >0+ density (see Appendix D-2 for full list). PC1, PC2, and PC3 are represented in-station habitat characteristics. Factor1 and Factor2 characterized riparian conditions. AICc parameters are defined as follows: K is the number of parameters in the model, ΔAICc is the difference in AICc value compared to the top model, AICcWt is the weight of AICc support within the models, and LL is the Log likelihood.*

| Model | K | AICc | ΔAICc | ModelLik | AICcWt | LL |
|---|---|---|---|---|---|---|
| PC1 | 3 | 33.360 | 0.000 | 1.000 | 0.441 | -12.589 |
| PC1+Factor1 | 4 | 35.878 | 2.517 | 0.284 | 0.125 | -11.939 |
| PC1*Factor2 | 5 | 35.976 | 2.616 | 0.270 | 0.119 | -9.655 |
| PC1+PC3 | 4 | 36.927 | 3.567 | 0.168 | 0.074 | -12.464 |
| PC1+PC2 | 4 | 37.050 | 3.690 | 0.158 | 0.070 | -12.525 |
| PC1+Factor2 | 4 | 37.104 | 3.744 | 0.154 | 0.068 | -12.552 |
| Factor2 | 3 | 39.421 | 6.060 | 0.048 | 0.021 | -15.620 |
| PC3 | 3 | 39.682 | 6.322 | 0.042 | 0.019 | -15.750 |
| PC2 | 3 | 39.762 | 6.401 | 0.041 | 0.018 | -15.790 |
| Factor1 | 3 | 39.827 | 6.467 | 0.039 | 0.017 | -15.823 |

### The effect of in-stream habitat characteristics

Variables with an impact on positive values of PC1 were positively correlated with >0+ density (Table 10; Figure 15). Among the in-stream habitat variables from PC1, moss cover and algae cover stood out with a clear positive impact on >0+ density. Shelter availability, substrate size, depth, and overhanging riverbanks had an intermediate positive impact on >0+ density, while the number of pools had a weak positive effect on >0+ density. No mentionable effect was found of dead woody debris (Figure 10).

**Table 10.** *Parameter estimates and corresponding effect test are showed for the model attaining the most support from AICc. PC1 represented the in-station habitat characteristics (with influence from high to low: moss cover, algae cover, shelter availability, substrate size, depth, overhanging riverbanks, number of pools, dead woody debris). SE is the standard error of the estimate, Df represents the degrees of freedom, SS is the sum squared, F equals to the F-value, and P is the p-value.*

| **Parameter estimates** | | | **ANOVA table** | | | |
|---|---|---|---|---|---|---|
| **Parameter** | **Estimate** | **SE** | **Df** | **SS** | **F** | **P** |
| Intercept | 1.455 | 0.155 | | | | |
| PC1 | 0.490 | 0.185 | 1 | 2.544 | 7.03 | 0.019 * |

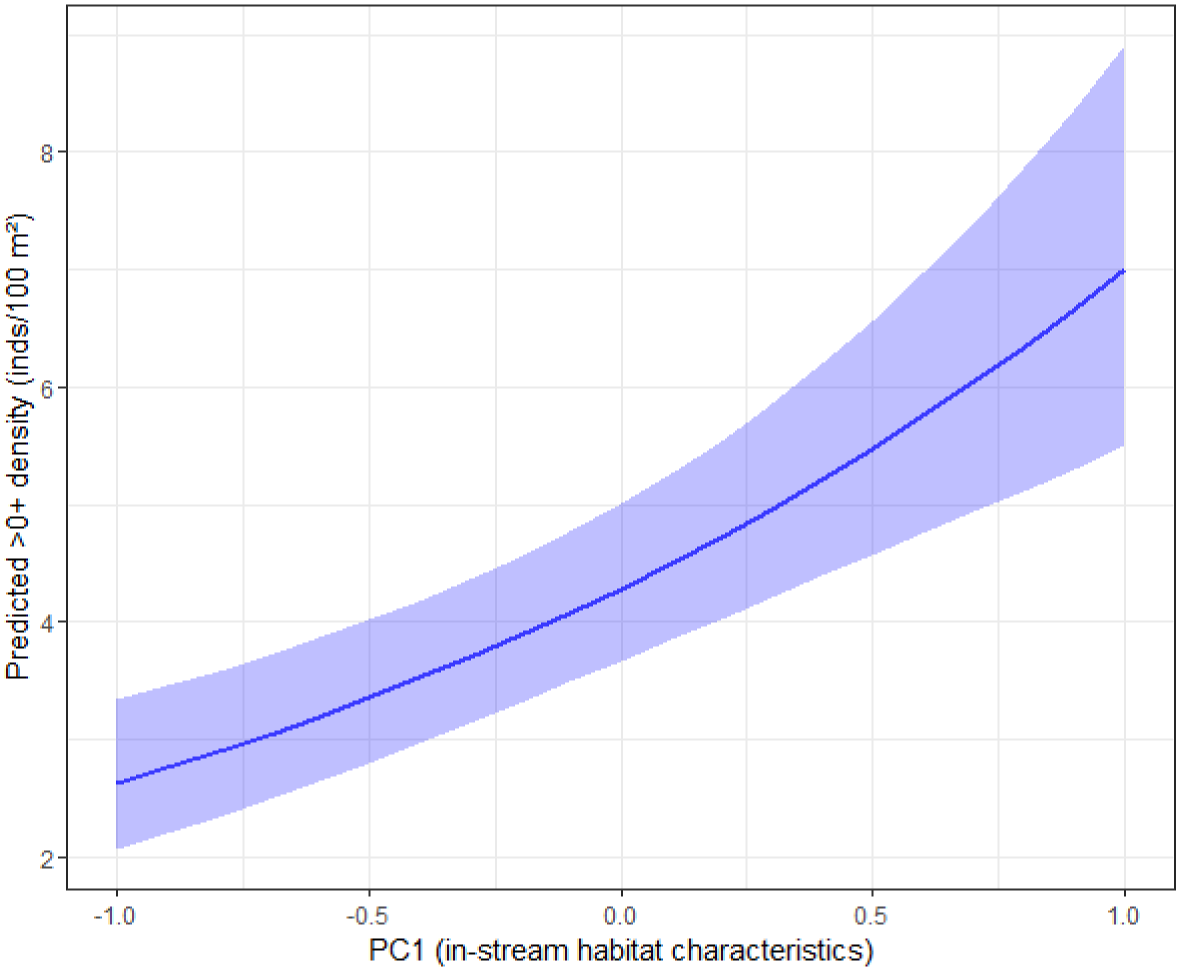


**Figure 15.** *The model with the most support in AICc suggested that PC1, representing in-stream habitat variables, positively impacted >0+ density. The variables with the greatest contribution to the effect was moss cover and algae cover, while shelter availability, substrate size, depth, and overhanging riverbanks had an intermediate influence. The shaded areas represent the 95% confidence intervals.*

## 3.2. Effects of riparian conditions on juvenile brown trout survival probability

### Predictors for apparent survival (φ) and recapture probability (p)

The model receiving the highest support from AICc indicated that the inclusion of the stream effect, total length (standardized), water discharge (standardized) and a seasonally adjusted RCI-score best explained apparent survival (φ), and that the stream effect, total length (standardized), and water discharge (standardized) best explained the recapture probability (*p*). For the variables explaining apparent survival (φ), the model supported interactive effects between the stream effect, total length (standardized), and water discharge (standardized). For recapture probability (*p*), an interaction was favored between the stream effect and total length (standardized) (Table 11).

**Table 11.** *The model selection included candidate models for apparent survival ($\varphi$) and recapture probability ($p$) for juvenile brown trout in the tributaries (see Appendix D-3 for full list). "Stream" represented the stream effect, stL represented standardized fish length, stWD is the standardized water discharge, stWD_VAR is the standardized water discharge variation, RCI represented the riparian condition index score, and summer is survival period one, two, and three. AICc parameters are described as follows: K is the number of parameters in the model, ΔAICc is the difference in AICc value compared to the model with the most support in the data, AICc.Wt is the weight of AICc support within the models. -2log(L) is the log likelihood.*

| Model | K | AICc | ΔAICc | ModelLik | AICcWt | -2log(L) |
|---|---|---|---|---|---|---|
| Phi(stream*stL*stWD+(RCI\|summer)) p(stream*stL+stWD) | 22 | 648.194 | 0.000 | 1.000 | 0.981 | 600.680 |
| Phi(stream*stL*stWD+RCI) p(stream*stL+stWD) | 21 | 657.887 | 9.693 | 0.008 | 0.008 | 612.690 |
| Phi(stream*stL+stWD+RCI) p(stream*stL+stWD) | 18 | 658.159 | 9.965 | 0.007 | 0.007 | 619.816 |
| Phi(stream*stL*stWD+RCI) p(stream*stL*stWD) | 24 | 660.199 | 12.005 | 0.003 | 0.002 | 608.003 |
| Phi(stream*stL*stWD+RCI) p(stream*stL) | 19 | 663.310 | 15.116 | 0.001 | 0.001 | 622.699 |
| Phi(stream*stL*stWD_VAR) p(stream*stL) | 19 | 665.344 | 17.150 | 0.000 | 0.000 | 624.733 |
| Phi(stream*stL+stWD*RCI) p(stream*stL) | 17 | 668.720 | 20.526 | 0.000 | 0.000 | 632.631 |
| Phi(stream*stL+RCI) p(stream*stL) | 16 | 669.023 | 20.829 | 0.000 | 0.000 | 635.172 |
| phi(stream)p(stream) | 8 | 678.340 | 30.146 | 0.000 | 0.000 | 661.863 |

The selected model predicted apparent survival to decrease with increasing RCI-score. For example, the apparent survival of an individual of average total length at average water discharge would drop from 75 % at a score of 2.5 to 37 % at a score of 3.5 (Figure 16). When representing the summer period and set to zero during the autumn period, the RCI-score resulted in a drop in apparent survival during summer compared to autumn (Table 12; Figure 17). Water discharge appeared to have a positive effect on apparent survival but differed among tributaries and seasons (Table 12). The positive influence of water discharge occurred at lower water levels during autumn (Figure 17). No clear effect was found for the total length of the fish among the tributaries (Table 12; Figure 17). The model found that the recapture probability ($p$) was positively correlated to total length in Sagåa and Rauda, while negative correlations were found in Djupa and Finna. Water discharge was negatively correlated to recapture probability inn all tributaries (Table 12; Figure 18).

**Table 12.** *Beta estimates for the CJS candidate model that received the most support from AICc. Parameters are described as follows: φ is the apparent survival, p is the recapture probability, SE is the standard error, LCI is the lower confidence interval, and UCI is the upper confidence interval.*

| Parameter | Term | Estimate | SE | LCI | UCI |
|---|---|---|---|---|---|
| φ | Intercept, stream effect (Rauda) | 5.217 | 1.558 | 2.163 | 8.271 |
| φ | Stream effect, Djupa | 3.332 | 4.144 | -4.790 | 11.455 |
| φ | Stream effect, Sagåa | 1.325 | 0.649 | 0.053 | 2.597 |
| φ | Stream effect, Finna | -1.409 | 0.552 | -2.490 | -0.328 |
| φ | Slope, fish length (Rauda) | 0.019 | 0.271 | -0.512 | 0.550 |
| φ | Fish length, Djupa | -0.710 | 1.040 | -2.748 | 1.328 |
| φ | Fish length, Sagåa | -0.303 | 0.886 | -2.040 | 1.434 |
| φ | Fish length, Finna | -0.320 | 0.374 | -1.053 | 0.414 |
| φ | Slope, water discharge (Rauda) | 6.669 | 3.036 | 0.718 | 12.619 |
| φ | Water discharge, Djupa | 13.314 | 9.774 | -5.843 | 32.471 |
| φ | Water discharge, Sagåa | -4.300 | 5.978 | -16.018 | 7.417 |
| φ | Water discharge, Finna | 1.725 | 2.689 | -3.547 | 6.996 |
| φ | Slope, Riparian condition index \| summer | -1.640 | 0.497 | -2.614 | -0.666 |
| *p* | Intercept, stream effect (Rauda) | -0.665 | 0.331 | -1.314 | -0.017 |
| *p* | Stream effect, Djupa | -0.127 | 0.728 | -1.553 | 1.299 |
| *p* | Stream effect, Sagåa | -0.598 | 0.564 | -1.704 | 0.508 |
| *p* | Stream effect, Finna | 1.348 | 0.482 | 0.403 | 2.293 |
| *p* | Slope, fish length (Rauda) | 0.518 | 0.355 | -0.179 | 1.214 |
| *p* | Fish length, Djupa | -1.081 | 0.790 | -2.630 | 0.467 |
| *p* | Fish length, Sagåa | 0.019 | 0.763 | -1.476 | 1.514 |
| *p* | Fish length, Finna | -0.683 | 0.564 | -1.789 | 0.422 |
| *p* | Slope (water discharge) | -2.630 | 0.585 | -3.777 | -1.483 |

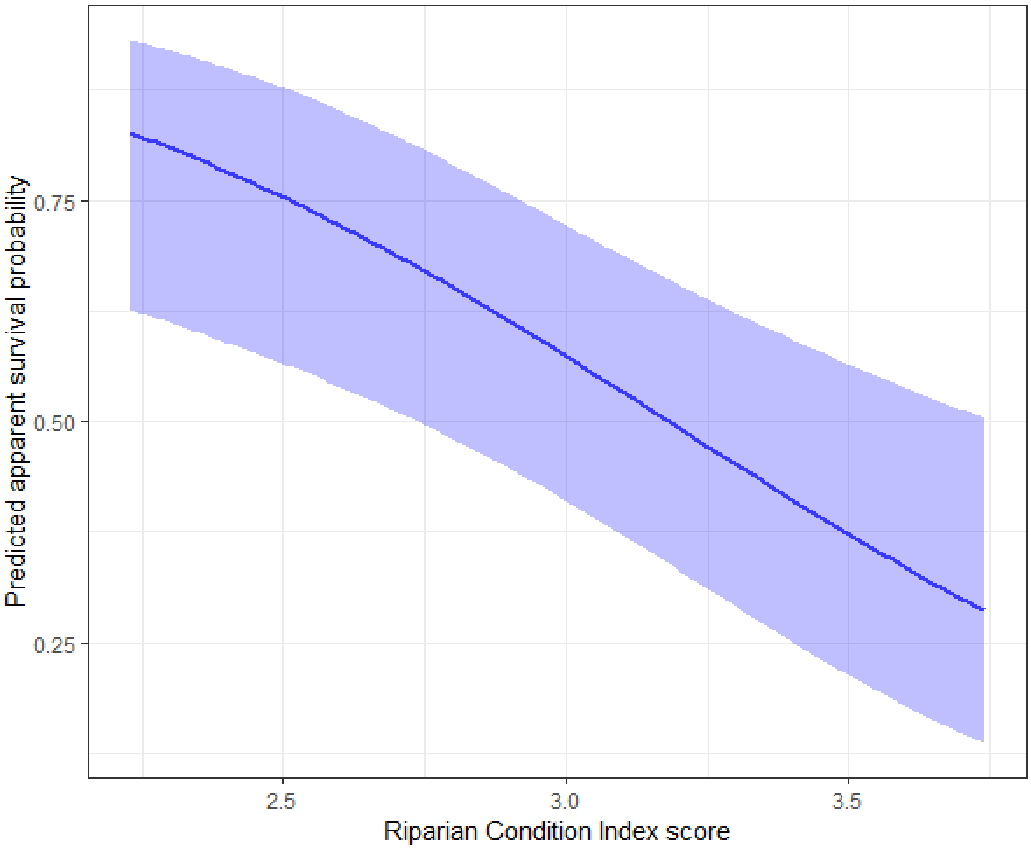


**Figure 16.** *The additive effect of the riparian condition index score (RCI-score) on apparent survival of juvenile brown trout was plotted. The RCI-score was set to 0 during the autumn survival period. The effect shown in the figure applies to an individual of mean length (88 mm) and at mean water discharge. Shaded areas represent the 95 % confidence intervals.*

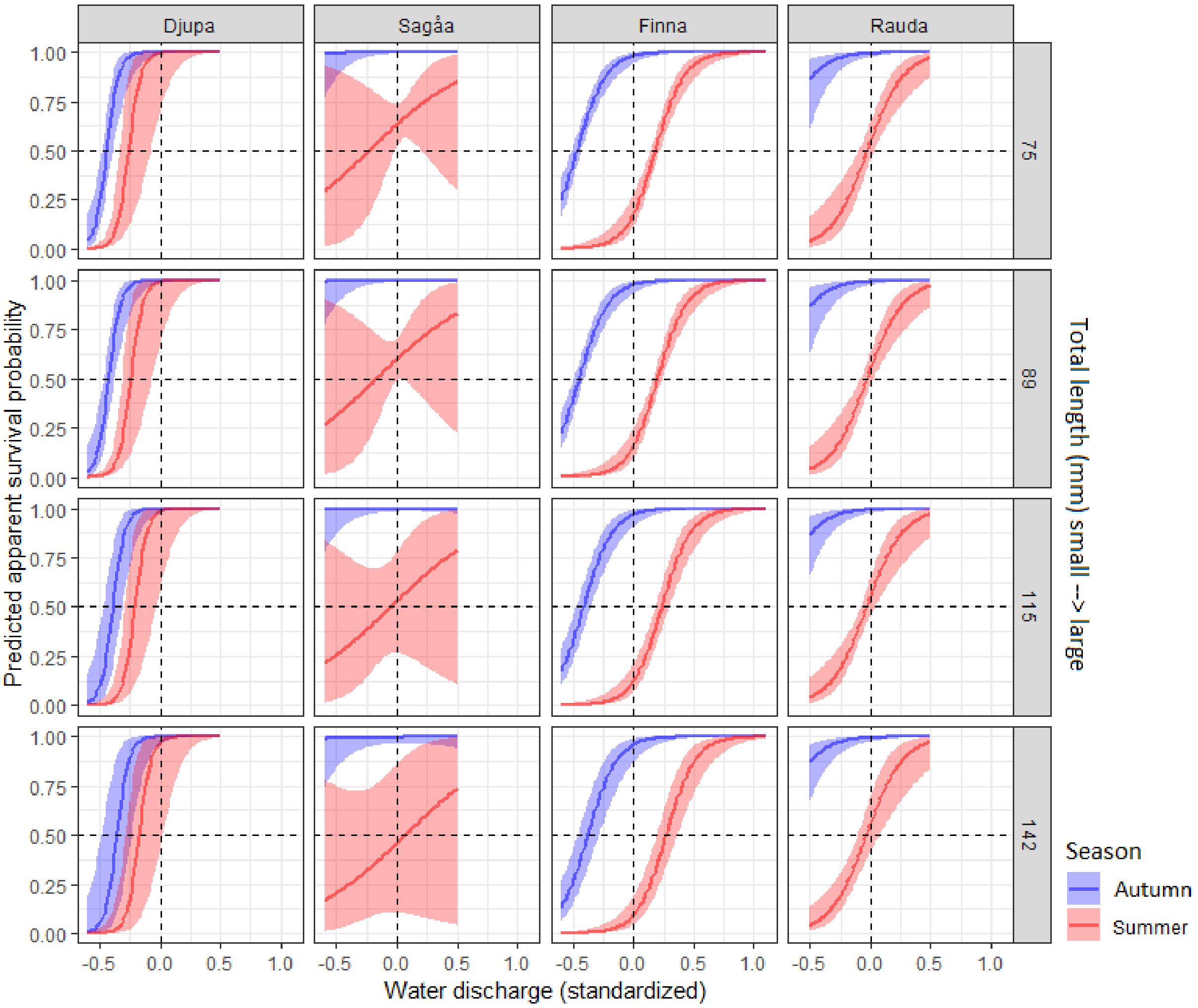


**Figure 17.** *The predicted apparent survival probability (monthly) of juvenile brown trout is shown in all tributaries at different water discharges and fish lengths, during summer and autumn periods. Water discharge was standardized to mean = 0 (± 1). To increase readability in the figure, the shaded areas represent the standard error. Dashed lines were included to increase comparability between the subplots.*

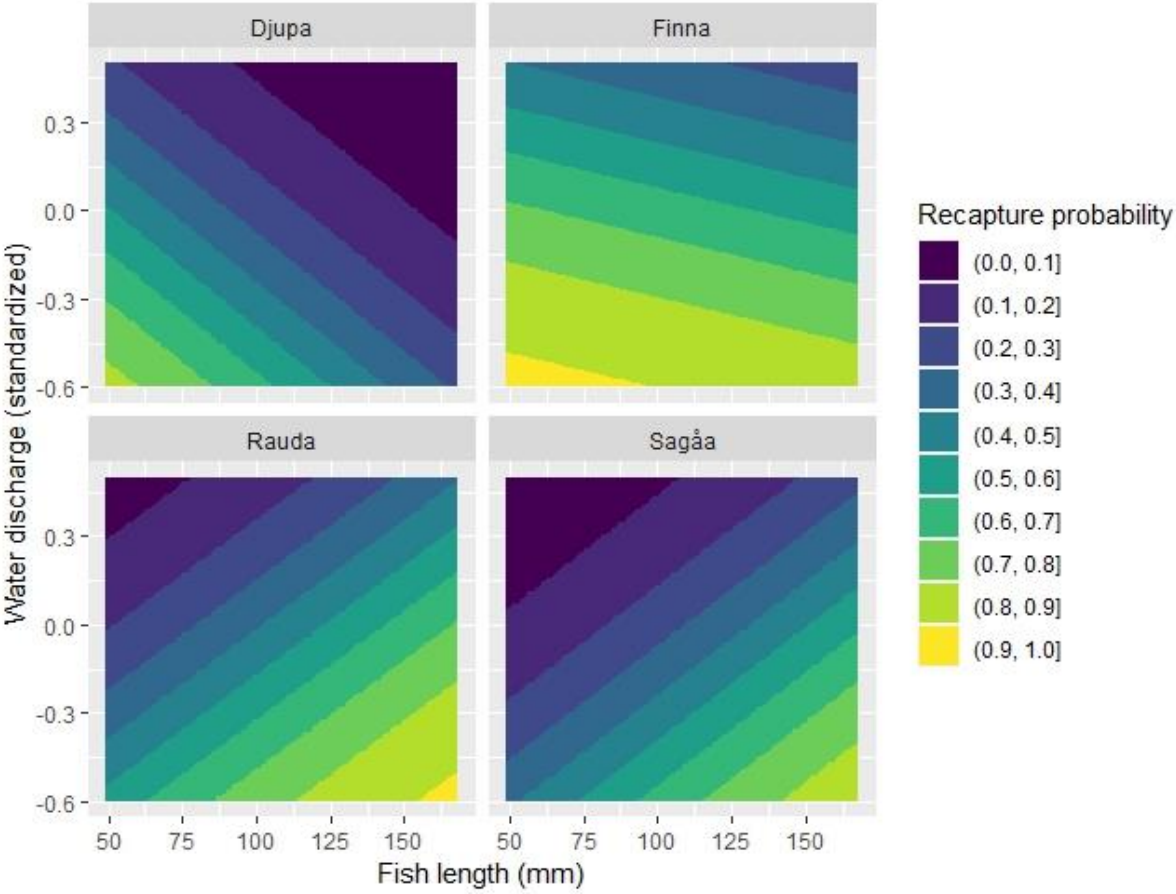


**Figure 18.** *The predicted recapture probability are visualized in a contour plot as a product of water discharge and fish length. High recapture probability is marked in yellow. Low recapture probability is marked in dark blue.*

## 3.3. Effects of riparian conditions on in-stream movement patterns of juvenile brown trout

### 3.3.1. Predictors for movement probabilities

The model receiving the highest support from AICc indicated that the seasonal effect and total length, with additive effects, best explained the variation in movement probability (Table 13).

**Table 13.** *The model selection contained candidate models adapted for analysis of movement probability. RCP represented riparian condition at pre-movement position, MP was mesohabitat at pre-movement position, and TL was fish total length (mm). The variable season distinguished between survival periods one to three, and four and five. AICc parameters are presented as follows: K is the number of parameters in the model, ΔAICc is the difference in AICc value compared to the top model, AICcWt is the weight of AICc support within the models, and LL is the log likelihood.*

| Model | K | AICc | ΔAICc | ModelLik | AICcWt | LL |
|---|---|---|---|---|---|---|
| season + TL | 3 | 162.375 | 0.000 | 1.000 | 0.699 | -78.100 |
| season * TL | 4 | 164.398 | 2.023 | 0.364 | 0.254 | -78.052 |
| season | 2 | 169.212 | 6.837 | 0.033 | 0.023 | -82.564 |
| season + Exit_rip_qual | 3 | 170.749 | 8.374 | 0.015 | 0.011 | -82.290 |
| season + stream | 5 | 171.474 | 9.099 | 0.011 | 0.007 | -80.523 |
| season + Exit_meso_type | 4 | 172.947 | 10.572 | 0.005 | 0.004 | -82.331 |
| TL | 2 | 174.226 | 11.851 | 0.003 | 0.002 | -85.070 |
| 1 | 1 | 180.738 | 18.363 | 0.000 | 0.000 | -89.355 |
| Exit_rip_qual | 2 | 182.332 | 19.957 | 0.000 | 0.000 | -89.124 |
| stream | 4 | 182.873 | 20.498 | 0.000 | 0.000 | -87.294 |
| Exit_meso_type | 3 | 183.754 | 21.379 | 0.000 | 0.000 | -88.793 |

#### The effects of total length and seasons

Movement probabilities were found to be higher during the autumn periods. The fish total lengths had a negative effect on movement probability, indicating higher tendencies of movements for smaller individuals during both seasons (Table 14; Figure 19).

**Table 14.** *Parameter estimates and corresponding analysis of deviance table are showed for the model with the most support from AICc. SeasonAutumn represented survival period four and five and TL represented the fish total length (mm). SE represents the standard error of the estimate, Df equals to degrees of freedom, deviance is the measure of discrepancy between observed and predicted outcomes, Resid.Dev is the residual deviance (deviance of the fitted model after accounting for the degrees of freedom used in estimating the model parameters), and P represents the p-value.*

| Parameter estimates | | | Analysis of Deviance Table | | | | |
|---|---|---|---|---|---|---|---|
| **Parameter** | **Estimate** | **SE** | **Effect** | **Df** | **Deviance** | **Resid. Dev** | **P** |
| Intercept | 0.428 | 0.846 | NULL | | | 173.43 | 0.059. |
| seasonAutumn | 2.040 | 0.579 | season | 1 | 13.377 | 160.06 | <0.001*** |
| TL | -0.015 | 0.008 | TL | 1 | 3.857 | 156.2 | 0.049* |

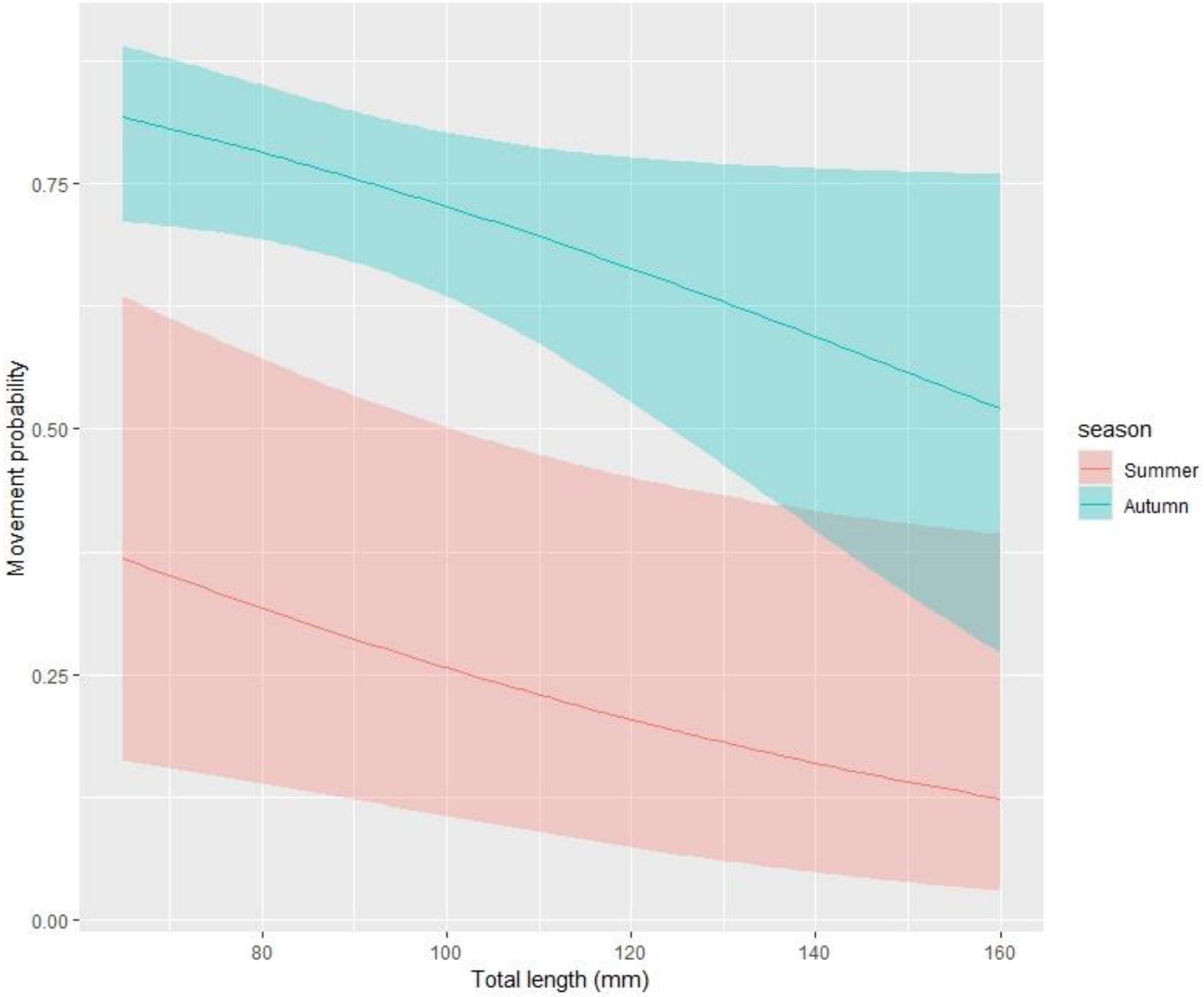


**Figure 19.** *The model with the most support from AICc showed a size dependent difference in movement probability of juvenile brown trout between summer and autumn seasons. The prediction plot displayed movement probability at total lengths from 65 to 160 mm during summer (red) and autumn (blue). Shaded areas represent 95 % confidence intervals.*

### 3.3.2. Predictors for movement distances

The candidate model with the most support in AICc showed that the seasonal effect and total length, with additive effects, best explained the variation in movement distances of moving individuals (Table 15; $F_{2,95} = 4.23$, $R^2 = 0.082$).

**Table 15.** *The model selection included ten candidate models to best explain the variation in movement distances for non-stationary individuals (see Appendix D-5 for full list). RCI-score_stream represented the riparian condition index score of the corresponding tributary, RCP was the riparian condition at pre-movement position, MP was the mesohabitat at pre-movement position, and TL represented the fish total length (mm). The variable season distinguished between survival periods one to three, and four and five. AICc parameters are presented as follows: K is the number of parameters in the model, ΔAICc is the difference in AICc value compared to the top model, AICc.Wt is the weight of AICc support within the models, and LL represents Log likelihood.*

| Model | K | AICc | ΔAICc | ModelLik | AICcWt | LL |
|---|---|---|---|---|---|---|
| TL+season | 4 | 336.010 | 0.000 | 1.000 | 0.688 | -163.790 |
| TL*season | 5 | 338.194 | 2.184 | 0.336 | 0.231 | -163.771 |
| TL | 3 | 342.167 | 6.157 | 0.046 | 0.032 | -167.956 |
| TL+RCI_score_stream | 4 | 343.336 | 7.326 | 0.026 | 0.018 | -167.453 |
| TL+RCP | 4 | 344.187 | 8.177 | 0.017 | 0.012 | -167.878 |
| TL+MP | 5 | 344.487 | 8.477 | 0.014 | 0.010 | -166.918 |
| TL*RCI_score_stream | 5 | 345.318 | 9.308 | 0.010 | 0.007 | -167.333 |
| TL+stream | 6 | 346.648 | 10.638 | 0.005 | 0.003 | -166.863 |
| TL*stream | 9 | 352.620 | 16.610 | 0.000 | 0.000 | -166.287 |
| season | 3 | 356.425 | 20.415 | 0.000 | 0.000 | -175.090 |

### The effects of total length and seasons

Movement distances of non-stationary individuals were higher during the summer period. No effect was found of the fish total length (Table 16, Figure 20).

**Table 16.** *Parameter estimates and corresponding effect test was showed for the model with the most support from AICc. TL represented total length (mm) and seasonSummer represented summer period (survival period one to three). SE is the standard error of the estimate, Df represents the degrees of freedom, SS is the sum squared, F equals to the F-value, and P is the p-value.*

| **Parameter estimates** | | | **ANOVA table** | | | |
|---|---|---|---|---|---|---|
| **Parameter** | **Estimate** | **SE** | **Df** | **SS** | **F** | **P** |
| Intercept | 2.918 | 0.501 | | | | |
| TL | 0.002 | 0.006 | 1 | 0.076 | 0.044 | 0.833 |
| seasonSummer | 1.743 | 0.600 | 1 | 14.406 | 8.43 | 0.004** |

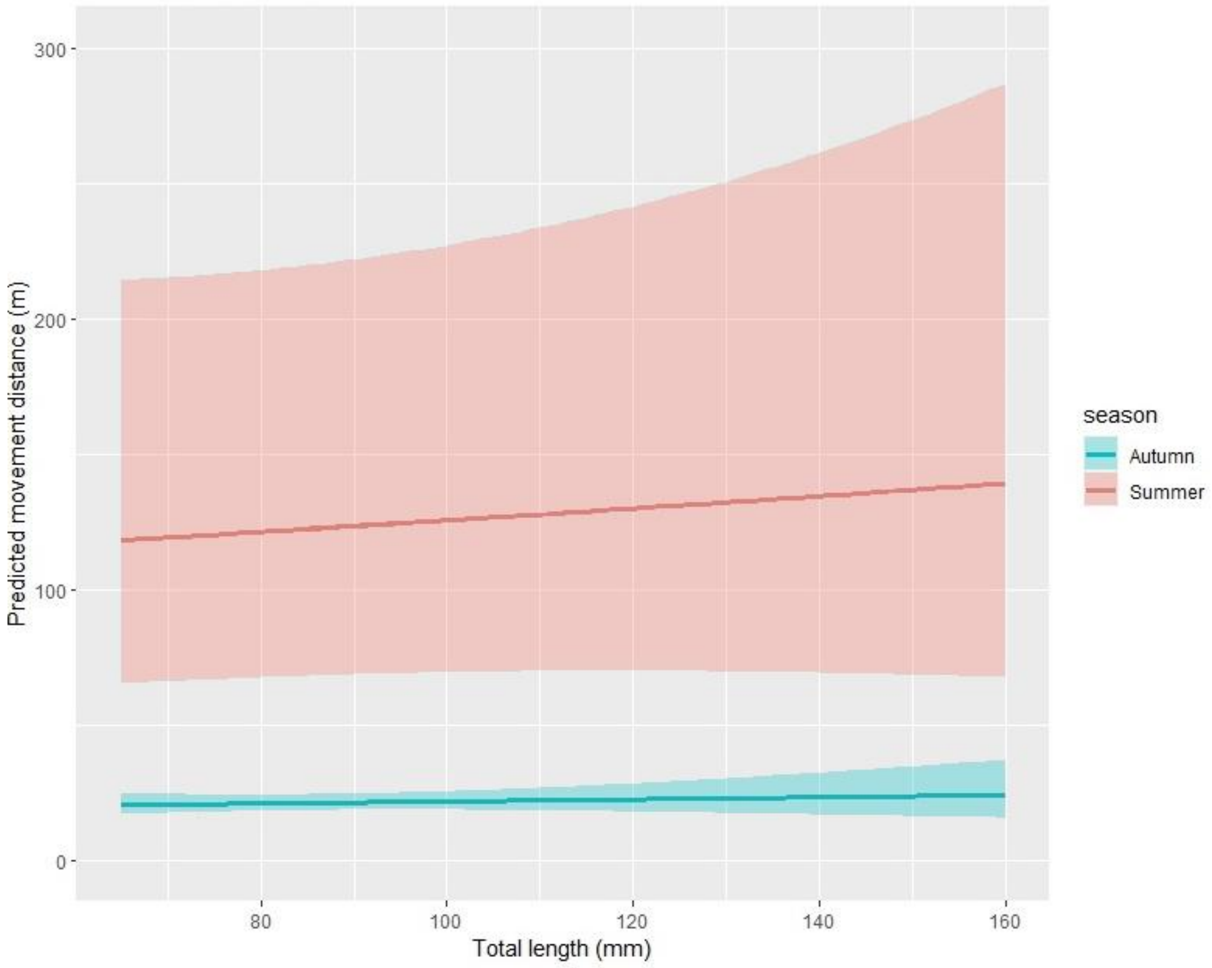


**Figure 20.** *According to the model with the most support from AICc, there was a significant difference in movement distances of juvenile brown trout between summer and autumn periods. The plot visualizes the predicted movement distance (m) as a function of total length (mm) and season. The summer period consisted of survival period one to three, and the autumn period consisted of survival period four and five. Shaded areas represent the standard error.*

# 4. Discussion

## 4.1. Main findings

This study aimed to enhance knowledge of the interplay between riparian vegetation and the density, survival, and in-stream movement patterns of juvenile brown trout in tributaries to the river Gausa, Innlandet, Norway. The 0+ density was found to have a highly negative association with surface shadows, riparian buffer width, and overhanging trees. While on-site vegetation composition had an intermediate negative influence, overhanging non-woody vegetation was the only assessed variable that seemingly had a positive influence on 0+ density. Upstream vegetation composition had no clear influence. Several aspects of in-stream habitat characteristics were also associated with reduced densities of the 0+ age class. The cover of moss and algae were found to have a highly negative association with 0+ density. Substrate size, shelter availability, depth, and overhanging riverbanks were found to have intermediate negative effects, while the number of pools had a low negative influence on 0+ density. Woody debris was not found to have a noteworthy influence. Further on, the 0+ density was found to increase with a higher density of the >0+ age classes. Contrarily, the density of >0+ was found to be positively affected by the mentioned in-stream habitat characteristics, while no effect of the riparian conditions was found. Regarding survival probability, the results suggested a negative riparian effect when accounting for senescence of the riparian vegetation. No direct effects of riparian vegetation were found for in-stream movement patterns. Movement probabilities were found to be significantly higher during autumn, but movement distances peaked during summer.

## 4.2. Effects of riparian conditions on juvenile brown trout density

Different aspects of the riparian vegetation were found to have varying effects on 0+ density, with most factors exhibiting negative influence. Some of the riparian aspects assessed within each electro-fishing station were linked together (Figure 11; Appendix B-6). These being vegetation composition, overhanging trees, riparian buffer width, and surface shadows, which all may affect the brown trout carrying capacity of the streams through their potential influence on light influx, autochthonous production, and allochthonous inputs (Gregory et al., 1991; Riley et al., 2009). The negative association found between surface shadows and 0+ density align with the findings of several studies (McCormick & Harrison, 2011; O'grady, 1993; Riley et al., 2009). A possible explanation is that light limitations in forested sections of the tributaries negatively affects productivity, resulting in trophic cascade effects (McCormick & Harrison, 2011; Riley et al., 2009). Light influx is recognized to be a limiting factor for autochthonous production in streams due to its influence on primary production, which in turn affects the composition and density of aquatic invertebrates (Kiffney et al., 2004), the primary food source for the 0+ brown trout (Elliott, 1994; Johnson & McKenna Jr, 2015; Skoglund & Barlaup, 2006). Lower food availabilities in sections of extensive riparian cover could consequently result in lower 0+ densities (Riley et al., 2009). The uniform distribution of >0+ among stations with extensive and limited riparian vegetation could potentially be a result of older age classes having different food preferences than 0+, to a larger extent utilizing allochthonous terrestrial invertebrates (Elliott, 1967; Sánchez-Hernández & Cobo, 2016). Consequently, older age classes could be affected differently by riparian conditions compared to the 0+ age class. The observed differences in riparian effects between the age classes in the current study could also be related to a tradeoff between reduced predation risk and foraging benefits (Railsback & Harvey, 2002). Specifically, the 0+ age class may favor food resources in sections with limited riparian vegetation, while the older age classes may, to some extent, prioritize shelter from predators under the riparian canopy (Heggenes, 1988; Riley et al., 2009). The 0+ age class has previously been documented to have higher needs in terms of feeding and growing, when compared to older age classes (Grant & Noakes, 1987). Additionally, previous studies have documented larger grown brown trout to favor sections containing overhead cover, demonstrating shelter as a higher priority resource of >0+ individuals (Heggenes, 1988; Maki-Petäys et al., 1997; Wesche et al., 1987). However, it is likely that the trends found in the current study stem from a combination of differing food preferences and the tradeoff between food availability and cover availability.

Spatial niche selection of juvenile brown trout is indeed known to be structured by fish size (Heggenes et al., 1999). Thus, an alternative explanation to the observed differences in riparian effects among age classes could be competitive exclusion (Höjesjö, 2017). The habitat usage of the 0+ age class have previously been documented to change in the absence of older age classes (Kaspersson et al., 2012), indicating that the frequently observed usage of shallow, low cover, low velocity, and fine substrate habitat types could be a result of competitive exclusion rather than preferences (Heggenes et al., 1999; Höjesjö, 2017; Maki-Petäys et al., 1997). As the 0+ density in the current study was found to be negatively associated with in-stream habitat characteristics acknowledged to be important in terms of the juvenile brown trout habitat niche selection, while the opposite pattern was found for >0+ age classes, the findings could align with the narrative of intraspecific competition causing competitive exclusion in the tributaries (Bohlin, 1977; Fausch & White, 1981; Heggenes et al., 1999; Höjesjö, 2017; McCormick & Harrison, 2011). As cover is recognized as an important element for spatial niche selection (Bagliniere & Champigneulle, 1982; Maki-Petäys et al., 1997; Wesche et al., 1987), and since overhanging riparian vegetation has been observed to be preferred by larger grown brown trout (Heggenes, 1988), the significant negative riparian effect on the 0+ age class and the uniform distribution of >0+ could suggest that competitive exclusion is also occurring for shelter resources in sections of extensive riparian vegetation.

Opposite to the effects of extensive riparian cover, overhanging non-woody vegetation seemed to be associated with higher densities of the 0+ age class. To my knowledge, no other studies have done a direct assessment of how overhanging non-woody vegetation affects the density of juvenile brown trout. However, several studies evaluating the impact of riparian grazing have found higher salmonid densities in non-grazed stretches compared to grazed stretches, indicating the importance of non-woody vegetation as a habitat element (Sievers et al., 2017; Summers et al., 2005). Although not statistically tested in the current study, evidence were found that overhanging non-woody vegetation seemingly had a higher presence in sections with less extensive riparian cover (Appendix B-5; B-6). Consequently, the positive association with 0+ density may possibly be due to the non-woody vegetation providing an extent of overhead cover in stretches of limited woody vegetation, acting as an important habitat component in sections of high food availability for the 0+ age class (Kiffney et al., 2004; Skoglund & Barlaup, 2006).

As a part of the in-stream habitat characteristics, dead woody debris seemed to not have an influence on either 0+ or >0+ density. Dead woody debris are seen as an important habitat characteristic as it provides both shelter for fish and serves as important habitats for periphytic algae and macroinvertebrates (Golladay & Sinsabaugh, 1991; Jähnig et al., 2009; Milner & Gloyne-Phillips, 2005). Contrary to the current findings, several studies have quantified dead woody debris to have a positive impact juvenile salmonid abundance (Degerman et al., 2004; Roni & Quinn, 2001; Thompson et al., 2018). However, the influence of dead woody debris has also been found to vary greatly among river types and fish communities (Crook & Robertson, 1999; Kail et al., 2007). Bretzel et al. (2024), which found no correlation between dead woody debris and juvenile salmonids in a steep and oligotrophic Norwegian river, argued that woody debris may have a greater influence in streams of low structural richness and low shelter availability. The substrate in steep and structural rich streams could provide a substantial proportion of the shelter required by the juvenile salmonids, resulting in dead woody debris having a less vital role as a habitat element (Bretzel et al., 2024). As course streambed substrate was found to dominate in several electro-fishing stations in the current study (Appendix B-1), the absence of correlation could be a result of the substrate providing the required structural richness for juvenile brown trout.

The tendency of the density of 0+ being positively correlated with >0+ density was unexpected as density dependent competition is known to occur among age classes, resulting in elevated mortality rates for the 0+ age class (Bohlin, 1977; Nordwall et al., 2001). The positive correlation may be in support of physical segregation as a result of differences in food and habitat preferences as described above, allowing for coexistence within the electro-stations, or that the carrying capacity is not exceeded during the study period (Hayes et al., 2010; Lobon-Cervia, 2008). Lund (2020) and Pedersen (2021) documented positive correlations between 0+ and >0+ densities in studies on anadromous brown trout in Verdal, Norway. Early emigration because of high competition for preferable winter habitat was discussed as a possible explanation. During winter, the juvenile brown trout prefers habitats of low water velocity and submerged overhead cover such as cobbles or woody debris, often present along the riverbanks (Cunjak & Power, 1986; Griffith & Smith, 1993; Maki-Petäys et al., 1997). If such habitats are scarce due to the low water discharge, high intraspecific competition and early emigration may occur, reducing the densities of older age classes the following year (Armstrong & Griffiths, 2001).

The characteristics of the dataset and methodological weaknesses may also have influenced the findings on the effects of riparian conditions on juvenile brown trout density. In addition to being restricted to one year of data, overall low catches of >0+ may have caused poor accuracy and precision in the density estimates of older cohorts, as well as providing a low ability to test for differences among stations. The density estimates may have been affected by methodological weaknesses related to the electro-fishing procedures. Although procedures followed the method described by Bohlin et al. (1989), three persons carried the electro-fishing device. Differences in technique and experience may have influenced catchability. Variations in the quantity of woody debris and differences in substrate size may also have resulted in different conditions for catchability across the electro-fishing stations, as individuals could have become trapped among structures when electrified. Fine sediments and poor visibility at certain stations may also have led to decreased catchability (Bohlin et al., 1989). The transect-based assessments of in-stream habitat might be seen as a weakness of the study design, as they might not have captured all microhabitats important for the juvenile brown trout. Additionally, variations in the assessed variables were averaged during the data analysis, potentially masking their true impact on the brown trout density. Further on, surface shadows within the electro-fishing stations were assessed at different times of the day. As the position of the sun changed throughout the day, so did the shaded areas on the water surface. A station assessed during morning hours could thus have a totally different light influx during afternoon.

### 4.3. Effects of riparian conditions on juvenile brown trout survival probability

When considered as a seasonal effect, riparian conditions seemed to have a negative impact on survival probability of juvenile brown trout, with increased survival during autumn, post-senescence of the riparian vegetation. The 0+ are expected to be the dominating age class in brown trout nursery streams (as indicated by the data; see table 3, 4, and 5). The decrease in survival probability with highly developed riparian conditions could thus align with the negative association between riparian vegetation and 0+ density seen in this study, as well as in other studies (McCormick & Harrison, 2011; O'grady, 1993; Riley et al., 2009). The observed tendency could consequently be in support of the assumption stated above, that extensive riparian vegetation provide poor conditions regarding food productivity (Kiffney et al., 2004; McCormick & Harrison, 2011; Riley et al., 2009), lowering survival probabilities for the 0+ age class as food requirements are not met (Grant & Noakes, 1987).

The transition from summer to autumn involves multiple concurrent processes that might have caused the observed changes in survival probability, explained by the seasonally adjusted riparian conditions in this study (Heggenes & Saltveit, 1990; Lobón-Cerviá & Mortensen, 2005). One should therefore exercise caution discussing whether the increased survival probability during autumn is caused by the senescence of riparian vegetation or other seasonal effects. Previous studies on salmonids have revealed diverse relationships between apparent survival and seasonality, with higher survival rates during the summer (Letcher et al., 2002; Lund et al., 2003; Mitro & Zale, 2002), consistent survival throughout the year (Carlson et al., 2008; Elliott, 1993; Lund et al., 2003), or even higher during the autumn and winter season (Carlson & Letcher, 2003). One possible explanation for the elevated autumn survival probability detected in the current study could be related to changes in behavioral strategies throughout seasons. As water temperatures drop and the metabolism of the brown trout decrease, the juveniles spend more time sheltered within the streambed substrate (Elliott, 1976; Heggenes & Saltveit, 1990), transitioning from a diurnal activity pattern during the summer to a more nocturnal activity pattern in the autumn and winter (Eriksson, 1978; Heggenes et al., 1993). Such a behavioral shift could potentially lead to reduced exposure to predators (Johnsson et al., 2004; Penaluna et al., 2016), thereby increasing survival probability.

Another potential explanation for the elevated survival probability observed during autumn could be that events of excessive water discharges during the summer period reduced the juvenile brown trout densities in the tributaries, resulting in an increase in survival probability afterward (Hayes et al., 2010). During the summer survival period, a major flooding occurred mid-August (Figure 2). Previous studies has documented similar events to cause elevated mortality rates, reducing juvenile salmonid densities significantly (Allen, 1951; Elwood & Waters, 1969; Hayes et al., 2010), potentially lowering the post-flood density to a level lower than the carrying capacity (Hayes et al., 2010). Such environmental events could thus result in reduced intraspecific competition and increase the survival probability of the remaining individuals (Hayes et al., 2010; Jonsson et al., 2011). The flooding event in mid-August could thus explain both the low survival probability during the summer period, and the following increased survival during the autumn period. Yet, water discharge was found to exhibit a significant positive influence on survival probability across all tributaries during both summer and autumn periods. Several studies on salmonids have documented positive effects of water discharge (McKernan et al., 1950; Scarnecchia, 1978; Smoker, 1955). A possible explanation could be that less habitat is generally available at lower water discharge. This could have led to overlapping habitat use among age classes, resulting in increased intraspecific competition and lower survival probability (Elliott, 1994; Greenberg, 1992). It is conceivable that these dynamics only applies during regular variations in water levels and not during floods (Hall & Knight, 1981; Hayes et al., 2010).

The widely acknowledged “bigger is better” hypothesis implies that survival probability increases with total length, as larger individuals are better equipped of resisting starvation and at tolerating physical extremes (Carlson & Letcher, 2003; Einum & Fleming, 1999; Smith & Griffith, 1994; Sogard, 1997). However, survival probability has also both been found to be consistent across sizes (Carlson et al., 2008; Lund et al., 2003) and negatively correlated with size in other studies (Carlson et al., 2004; Carlson et al., 2008), implying that the “bigger is better” hypothesis is not always correct. In the current study, no clear sign of length-specific survival was found. Previous studies has argued that the extent of length-specific survival varies among years (Good et al., 2001; Hendry et al., 2003; Quinn & Peterson, 1996), a variation that is not accounted for in the current study.

Several methodological weaknesses could potentially have affected the findings on juvenile brown trout survival probability in this study. During PIT-scanning in July and August, high water discharge reduced the efficiency of PIT-scanning, potentially affecting recapture probabilities (O'Donnell et al., 2010). When submerged, navigating the antenna of the PIT-scanner proved to be challenging. At several occurrences, the antenna could not reach the stream bed of the deepest pools, possibly missing out on individuals sheltering within the substrate. Additionally, for security reasons, certain shorter sections of the tributaries could not be scanned during these scanning occasions. Consequently, the high water discharge was likely to reduce the recapture probability. The presence of surface ice at sections of the tributaries during "PIT-scanning occasion 6" at the end of November may also have influenced recapture probabilities, affecting the estimates for apparent survival. Another weakness possibly affecting the results is the uncertainty of whether the detected fish were alive. The combination of high turbidity and course substrate in sections of the tributaries made it difficult to assess whether the detected individuals were dead or alive, possibly causing an overestimation of survival. There are also potential biases related to the assessment method and utilization of riparian conditions and mesohabitats along the PIT-scanning stretches. It is debatable whether the assessments of riparian conditions and mesohabitats are representative for the entire studied period as characteristics could have changed throughout the studied period. All assessments of riparian conditions, as well as most assessments of mesohabitats were conducted in the end of June. Following the major flooding event in mid-August, much of the non-woody vegetation was washed away, and in several locations, the geomorphology of the stream beds changed. The utilization of the RCI-score, representing the average riparian conditions for the entire tributaries rather than specific sites of individual detections, raises concerns about its applicability. Local conditions and variations within stretches might play a more crucial role in influencing habitat suitability for juvenile brown trout than the average conditions of the tributaries alone.

The most substantial bias in the analysis of survival probability is that the CJS model structure cannot provide insight into the true survival probability. The model structure is based on detections of individuals, and the mortality reflected in the estimates includes individuals that have left the tributaries. Therefore, the model structures estimate of survival probability, apparent survival, is influenced by movement patterns. For the observed differences in survival probability among seasons to reflect true survival, the fish must exhibit the same movement patterns during both the summer and autumn periods. With differing movement patterns, increased survival probability during autumn could imply a reduction in long-distance movements extending out of the tributary systems, rendering fewer individuals "dead to the system".

## 4.4. Effects of riparian conditions on in-stream movement patterns

If riparian vegetation act as a limiting factor for juvenile brown trout abundance, as supported by the findings with 0+ density and juvenile survival probability, movement patterns could potentially be affected as non-dominant individuals are forced to leave their home ranges (Höjesjö, 2017). Riparian conditions were however not found to act as an important explanatory factor for either movement probability or movement distances. A potential riparian effect on juvenile brown trout movement patterns can, though, not be completely ruled out as a substantial proportion of the undetected individuals recorded as "dead to the system" may have left the tributary systems in long-range movements.

Movement patterns seemed to vary with seasons, with movement distances being higher during summer, and movement probabilities being higher during autumn. The increased movement distances during the summer period are likely to be related to the mid-August flooding event, triggering displacement of juvenile brown trout (Hayes et al., 2010). Consequently, these findings strengthen the idea of reduced survival probability during summer being a result of flooding rather than riparian vegetation. Hesthagen (1988), which found most individual movements during summer to be restricted to 45 meters, argued that movement probabilities could increase with decreasing water discharge, as preferable habitats was reduced and intraspecific competition intensified. As water discharges decreased between September and November in the current study, an increase in intraspecific competition could thus possibly explain the increase in short-scale movements during the autumn period.

The observed tendencies could also be a result of a methodological weakness and presence of predators. No PIT-scanning were performed immediately after PIT-tagging, resulting in uncertain initial positions regarding the movements of the first survival period after tagging. This may have resulted in both false movements and false stationarity. Mink (*Neovison vison*) and common merganser (*Mergus merganser*) were observed in the studied tributaries during PIT-scanning (Ole Eivind Ovnan Fjeldstad, personal observations, 2023). The presence of these species, which is both known to consume fish (Brzeziński, 2008; Stokke, 2018), may indicate occurrence of predation. Detected movements could thus be a consequence of predators moving the PIT-tags via excretion, potentially weakening the credibility of the findings.

## 4.5. Further research and recommendations

Cyclical variations in density and dominance relationships among age classes are commonly observed (Nordwall et al., 2001), and could potentially lead to great variations in density estimates between years. Historical electrofishing data from 2012 to 2021 (Appendix A-4; A-8; A-12; A-16) have documented significant variations in density in the studied tributaries (The County Governor of Innlandet, 2022). Thus, the detected variation in density in the historical data signals the need for multiple years of data to confidently assess how riparian vegetation affects 0+ density. Additionally, it is noteworthy that the current study only provides a slight insight into riparian effects on density at a certain point during late summer. It is known that juvenile brown trout have different habitat preferences among seasons (Vehanen et al., 2000), whereas they predominantly utilize shelters with overhead cover to a greater extent during winter (Cunjak & Power, 1987; Griffith & Smith, 1993; Heggenes & Saltveit, 1990). Riparian effects could therefore change throughout the year, making it hard to conclude whether riparian vegetation has a persistent negative impact on the 0+ density. Future studies on the relationship between riparian vegetation and juvenile brown trout density should therefore focus on different seasons, quantifying eventual differences throughout and among year.

In future studies, substantial changes can be made both in data collection and statistical analyses regarding survival probability and in-stream movement patterns. The evaluation of riparian conditions and mesohabitats along the PIT-scanning stretches in the current study has proved to be time-consuming and extensive. Future studies should consider whether these assessments can be assessed upon detections of individuals during PIT-scanning. This approach would allow for monitoring changes in riparian conditions and streambed morphology throughout the seasons. The detection-based assessments could further be included in the models as individual covariates and thus provide predictor variables at finer resolution compared to the RCI-score representing the tributary average conditions in the current study. Additionally, to enhance the variation explained in models related to apparent survival and in-stream movement patterns, adjustments to the set of predictor variables could be considered. Both water temperature and water velocities have previously been shown to affect juvenile brown trout behavior and fitness (Elliott & Elliott, 2010; Jonsson & Jonsson, 2017) and should thereby be prioritized. Stationary antenna PIT-scanners should also be implemented in the tributary outlets to quantify the extent of emigration from the tributaries, providing further insight into true survival probability.

Although included in the analyses of juvenile densities in the current study, no clear effect was found of upstream riparian conditions for either 0+ or >0+. The lack of association could possibly be a consequence of the course resolution of the variable, as it was an estimate of the average vegetation composition the next 100 meters upstream of the electro-fishing stations. Riparian conditions are known to affect downstream riverine ecosystems as the vegetation provide allochthonous input and regulate nutrient concentrations and water temperatures (Gregory et al., 1991). Future studies should consider multiple quality aspects of upstream riparian conditions, as well as to examine how the effects are influenced when assessed at different geographic scales.

# 5. Conclusion

While the 0+ age class seems to utilize stretches without riparian cover during late summer, >0+ age classes were found to be evenly distributed regardless of riparian conditions. The findings suggest physical segregation between age classes, indicating tradeoffs in habitat preferences and resource use or the presence of competitive exclusion in the tributaries. Survival probability was found to be lower in tributaries of higher developed riparian vegetation, but the evaluation riparian conditions founded substantial uncertainty to whether the observed effects are caused by riparian vegetation. Variations in water discharge throughout the studied seasons provided an empirically strong alternative explanation for the observed differences in survival probability. The initial prediction, stating that riparian vegetation conditions were to act as an explanatory factor with positive effects on juvenile brown trout densities and survival probabilities in the tributaries, were thus not supported. Riparian conditions were not found to affect in-stream movement probabilities. Both movement probability and movement distances differed significantly between seasons, with movement probabilities being higher during autumn, whereas movement distances were higher during summer. With movement patterns being closely linked to survival, variations in water discharge are likely to be the main driver behind the seasonal variations in in-stream movement patterns. The initial prediction, which suggested reduced movement activities in stretches containing riparian vegetation, was not supported by the findings. The analyses conducted in this study, however, were composed of variables of low resolution, which likely influenced the results. Coupled with the extensive weaknesses and substantial potential for improving methods, more studies should be conducted to validate the findings. The flooding event occurring in mid-August and differentiating water discharges throughout study period are also likely to have affected the results, further emphasizing the need of multiple years of studies.

### Implications for management

The findings related to juvenile densities in tributaries of the Gausa watercourse indicated that the different age classes may utilize stream sections with dissimilar riparian conditions. In future fish management efforts, strategies should consequently be aimed at promoting habitat diversity to accommodate all age classes. Thus, targeted habitat restoration projects pointed towards enhancing recruitment of the piscivorous brown trout population of the lake Mjøsa should focus on creating a variety of habitat types beneficial to different life stages. This emphasizes the importance of having a holistic perspective during fish management. The study also highlights the significance of water discharge as an influencing factor for juvenile brown trout in the tributaries. As of the indications of flooding resulting in higher mortality and displacement of fish, measures to reduce water velocities may be important to ensure a stable recruitment of brown trout in the Gausa watercourse as the frequency of flood events are likely to increase in near future (Madsen et al., 2014).

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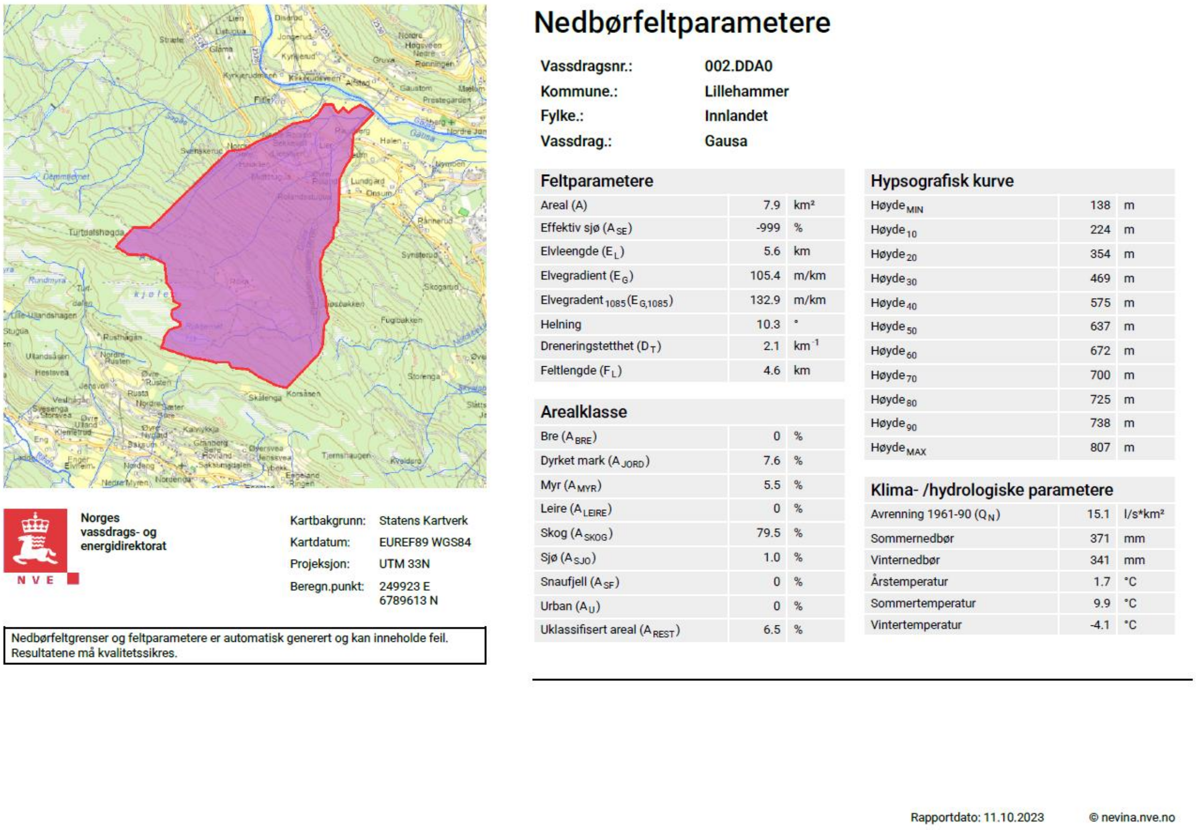
# 7. Appendices

## Appendix A: Tributaries

### Djupa

**Appendix A-1.** *Two electro-fishing stations were established in the lower sections of the tributary Djupa (orange). PIT-scanning was performed on a stretch reaching from the outlet to the river Gausa, and up to 100 meters upstream electro-fishing station D2 (dotted blue line). A historical electro-fishing station is present immediately upstream the outlet (red point).*



**Norges vassdrags- og energidirektorat**

| | |
|---|---|
| Kartbakgrunn: | Statens Kartverk |
| Kartdatum: | EUREF89 WGS84 |
| Projeksjon: | UTM 33N |
| Beregn.punkt: | 249923 E<br>6789613 N |

Nedbørfeltgrenser og feltparametere er automatisk generert og kan inneholde feil. Resultatene må kvalitetssikres.

## Nedbørfeltparametere

| | |
|---|---|
| **Vassdragsnr.:** | **002.DDA0** |
| **Kommune.:** | **Lillehammer** |
| **Fylke.:** | **Innlandet** |
| **Vassdrag.:** | **Gausa** |

| Feltparametere | | |
|---|---|---|
| Areal (A) | 7.9 | km² |
| Effektiv sjø ($A_{SE}$) | -999 | % |
| Elvleengde ($E_L$) | 5.6 | km |
| Elvegradient ($E_G$) | 105.4 | m/km |
| Elvegradent$_{1085}$ ($E_{G,1085}$) | 132.9 | m/km |
| Helning | 10.3 | ° |
| Dreneringstetthet ($D_T$) | 2.1 | km$^{-1}$ |
| Feltlengde ($F_L$) | 4.6 | km |

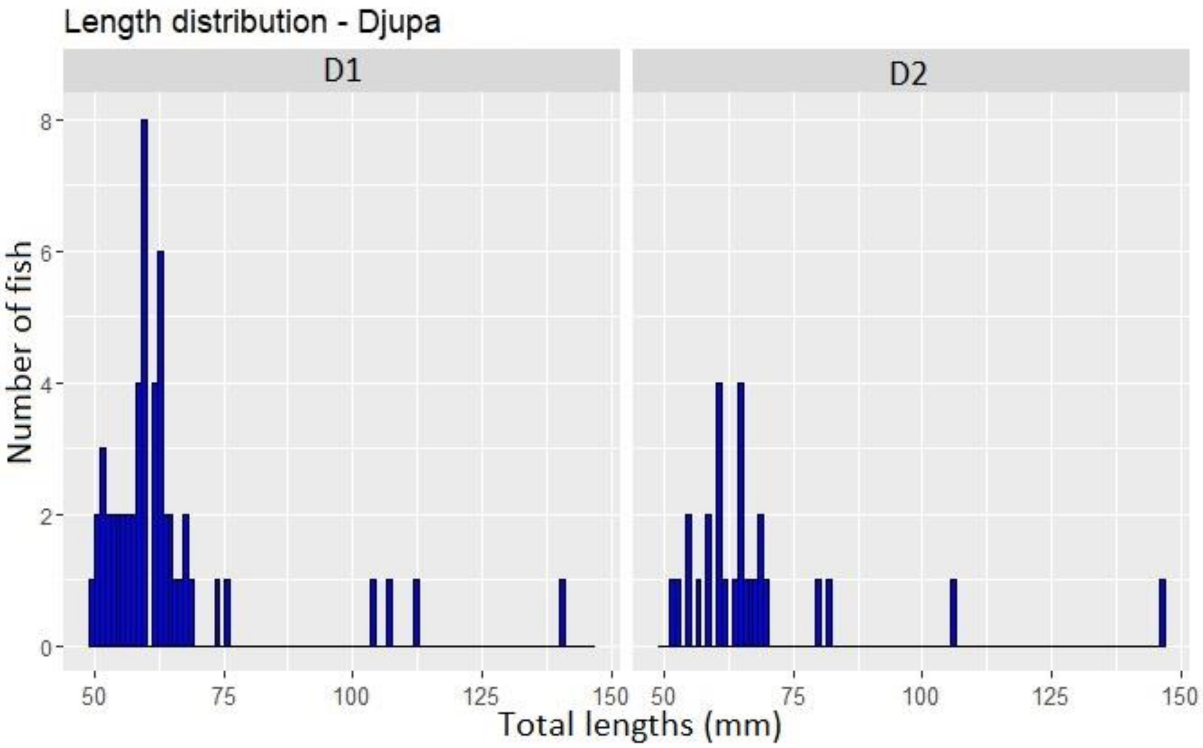
| Arealklasse | | |
|---|---|---|
| Bre ($A_{BRE}$) | 0 | % |
| Dyrket mark ($A_{JORD}$) | 7.6 | % |
| Myr ($A_{MYR}$) | 5.5 | % |
| Leire ($A_{LEIRE}$) | 0 | % |
| Skog ($A_{SKOG}$) | 79.5 | % |
| Sjø ($A_{SJO}$) | 1.0 | % |
| Snaufjell ($A_{SF}$) | 0 | % |
| Urban ($A_U$) | 0 | % |
| Uklassifisert areal ($A_{REST}$) | 6.5 | % |

| Hypsografisk kurve | | |
|---|---|---|
| Høyde$_{MIN}$ | 138 | m |
| Høyde$_{10}$ | 224 | m |
| Høyde$_{20}$ | 354 | m |
| Høyde$_{30}$ | 469 | m |
| Høyde$_{40}$ | 575 | m |
| Høyde$_{50}$ | 637 | m |
| Høyde$_{60}$ | 672 | m |
| Høyde$_{70}$ | 700 | m |
| Høyde$_{80}$ | 725 | m |
| Høyde$_{90}$ | 738 | m |
| Høyde$_{MAX}$ | 807 | m |

| Klima- /hydrologiske parametere | | |
|---|---|---|
| Avrenning 1961-90 ($Q_N$) | 15.1 | l/s*km² |
| Sommernedbør | 371 | mm |
| Vinternedbør | 341 | mm |
| Årstemperatur | 1.7 | °C |
| Sommertemperatur | 9.9 | °C |
| Vintertemperatur | -4.1 | °C |

Rapportdato: 11.10.2023 © nevina.nve.no

**Appendix A-2.** *Precipitation parameters in the watershed of Djupa were acquired from the modeling software NEVINA, provided by The Norwegian Water Resources and Energy Directorate (NVE).*

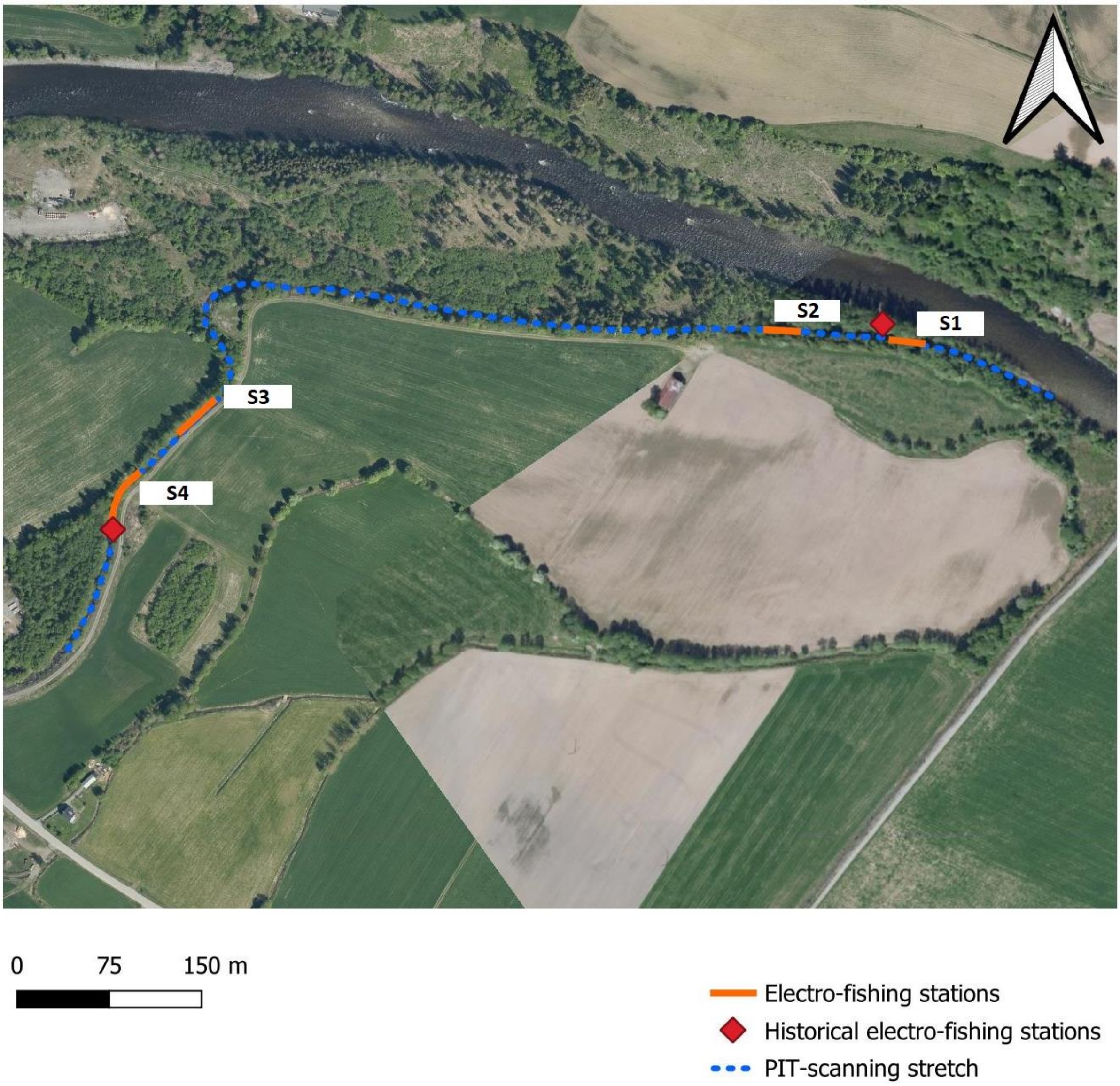


**Appendix A-3.** *Length distributions were used to set boundaries, separating the caught juveniles into age classes. The figure shows the length distributions in the electro-fishing stations of Djupa.*

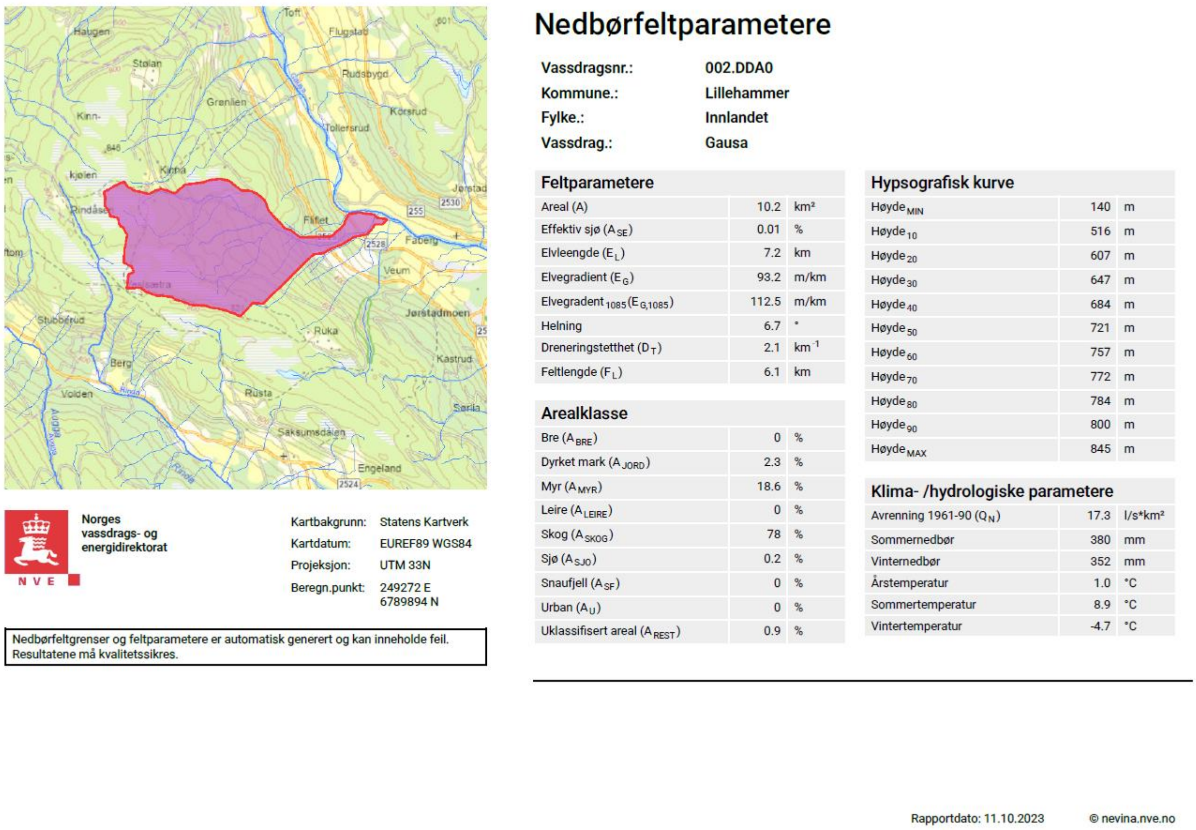
**Appendix A-4.** *In 2020 and 2021, on the behalf of The County Governor of Innlandet, electro-fishing was carried out near the outlet of Djupa to provide density estimates for juvenile brown trout (The County Governor of Innlandet, 2022).*

| Year | 0+ (ind/100 m$^2$) | >0+ (ind/100 m$^2$) |
|---|---|---|
| 2020 | 45.1 | 15.4 |
| 2021 | 17.8 | 3 |

**Sagåa:**



**Appendix A-5.** *Four electro-fishing stations were established in the lower sections of the tributary Sagåa (orange). PIT-scanning was performed on a stretch reaching from the outlet to the river Gausa, and up to 100 meters upstream electro-fishing station S4 (dotted blue line). Two historical electro-fishing station is present within the studied section of the tributary (red points).*



Norges
vassdrags- og
energidirektorat

NVE

| | |
|---|---|
| Kartbakgrunn: | Statens Kartverk |
| Kartdatum: | EUREF89 WGS84 |
| Projeksjon: | UTM 33N |
| Beregn.punkt: | 249272 E<br>6789894 N |

Nedbørfeltgrenser og feltparametere er automatisk generert og kan inneholde feil. Resultatene må kvalitetssikres.

## Nedbørfeltparametere

| | |
|---|---|
| **Vassdragsnr.:** | 002.DDA0 |
| **Kommune.:** | Lillehammer |
| **Fylke.:** | Innlandet |
| **Vassdrag.:** | Gausa |

### Feltparametere

| | | |
|---|---|---|
| Areal (A) | 10.2 | km² |
| Effektiv sjø ($A_{SE}$) | 0.01 | % |
| Elvleengde ($E_L$) | 7.2 | km |
| Elvegradient ($E_G$) | 93.2 | m/km |
| Elvegradient$_{1085}$ ($E_{G,1085}$) | 112.5 | m/km |
| Helning | 6.7 | ° |
| Dreneringstetthet ($D_T$) | 2.1 | km$^{-1}$ |
| Feltlengde ($F_L$) | 6.1 | km |

### Arealklasse

| | | |
|---|---|---|
| Bre ($A_{BRE}$) | 0 | % |
| Dyrket mark ($A_{JORD}$) | 2.3 | % |
| Myr ($A_{MYR}$) | 18.6 | % |
| Leire ($A_{LEIRE}$) | 0 | % |
| Skog ($A_{SKOG}$) | 78 | % |
| Sjø ($A_{SJO}$) | 0.2 | % |
| Snaufjell ($A_{SF}$) | 0 | % |
| Urban ($A_U$) | 0 | % |
| Uklassifisert areal ($A_{REST}$) | 0.9 | % |

### Hypsografisk kurve

| | | |
|---|---|---|
| Høyde$_{MIN}$ | 140 | m |
| Høyde$_{10}$ | 516 | m |
| Høyde$_{20}$ | 607 | m |
| Høyde$_{30}$ | 647 | m |
| Høyde$_{40}$ | 684 | m |
| Høyde$_{50}$ | 721 | m |
| Høyde$_{60}$ | 757 | m |
| Høyde$_{70}$ | 772 | m |
| Høyde$_{80}$ | 784 | m |
| Høyde$_{90}$ | 800 | m |
| Høyde$_{MAX}$ | 845 | m |

### Klima- /hydrologiske parametere

| | | |
|---|---|---|
| Avrenning 1961-90 ($Q_N$) | 17.3 | l/s*km² |
| Sommernedbør | 380 | mm |
| Vinternedbør | 352 | mm |
| Årstemperatur | 1.0 | °C |
| Sommertemperatur | 8.9 | °C |
| Vintertemperatur | -4.7 | °C |

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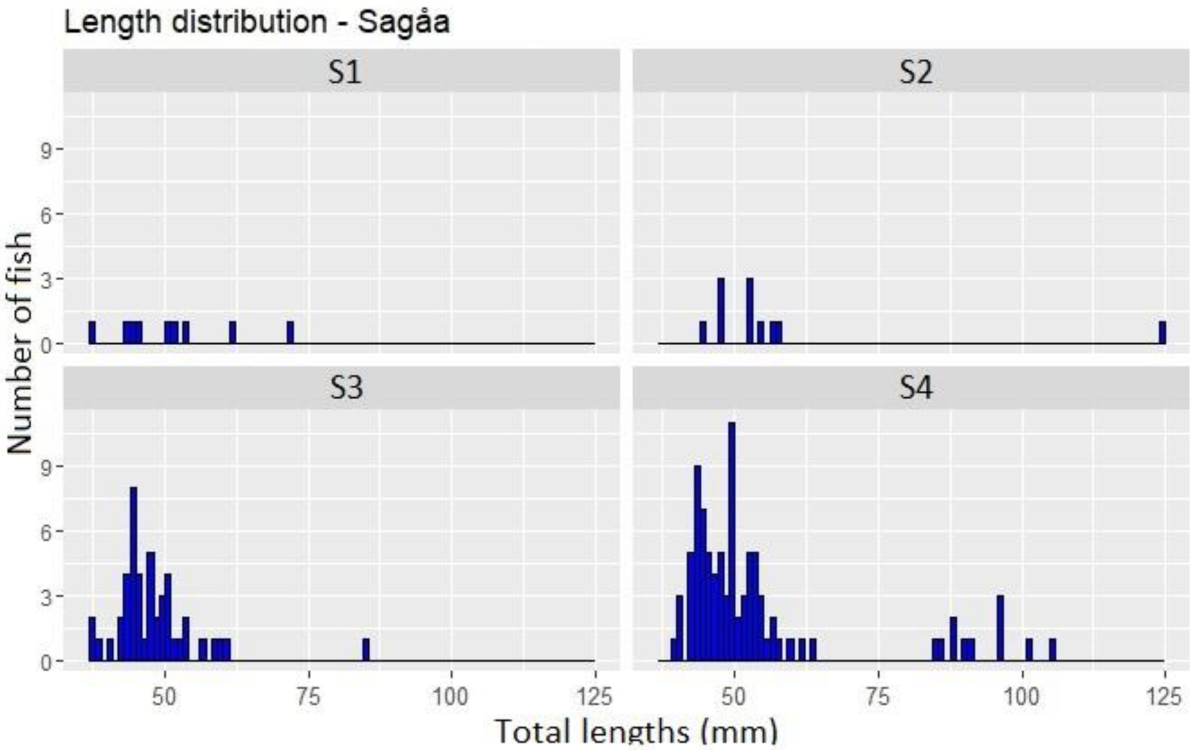
**Appendix A-6.** *Precipitation parameters in the watershed of Sagåa were acquired from the modeling software NEVINA, provided by The Norwegian Water Resources and Energy Directorate (NVE).*

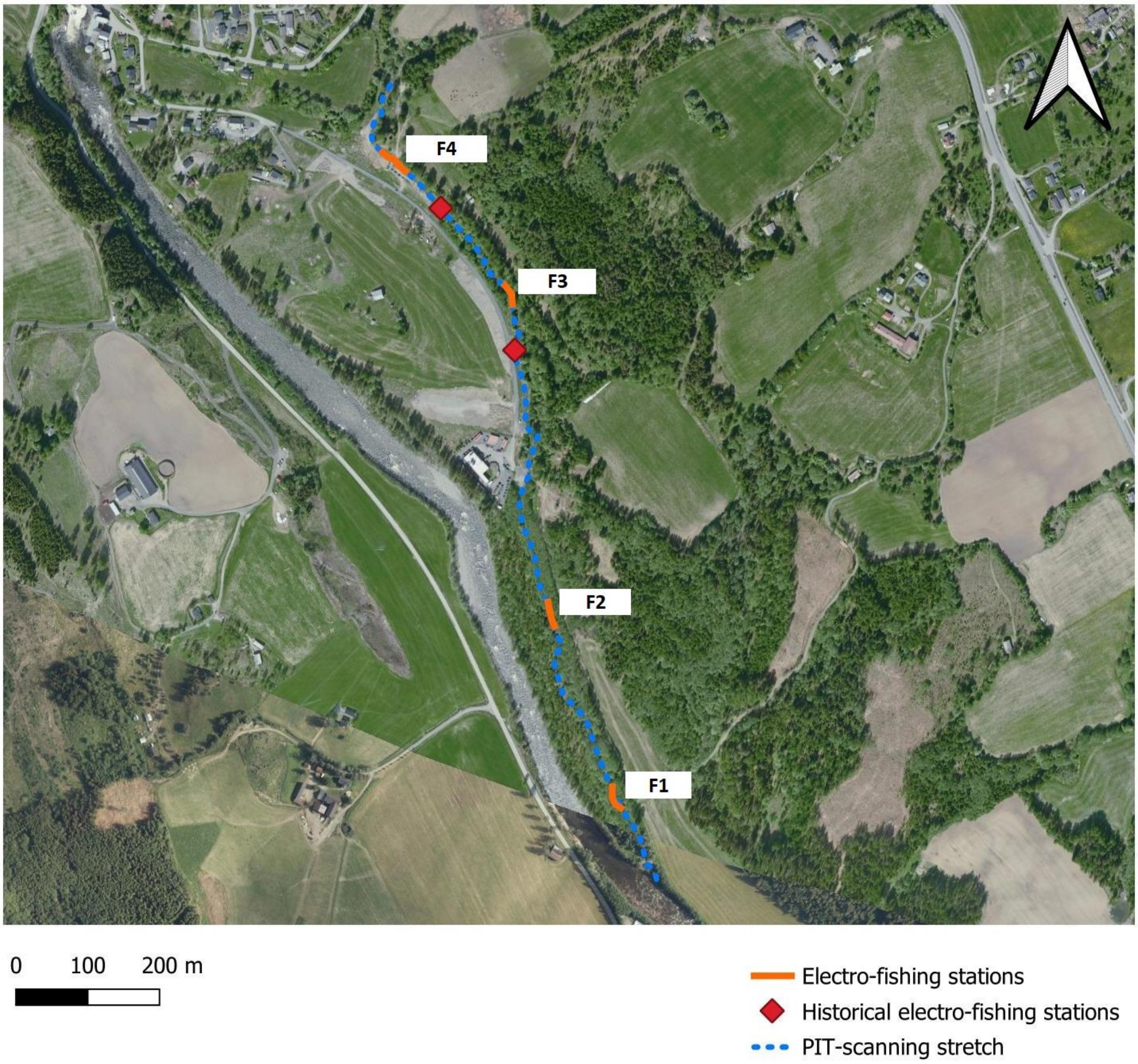


**Appendix A-7.** *Length distributions were used to set boundaries, separating the caught juveniles into age classes. The figure shows the length distributions in the electro-fishing stations of Sagåa.*

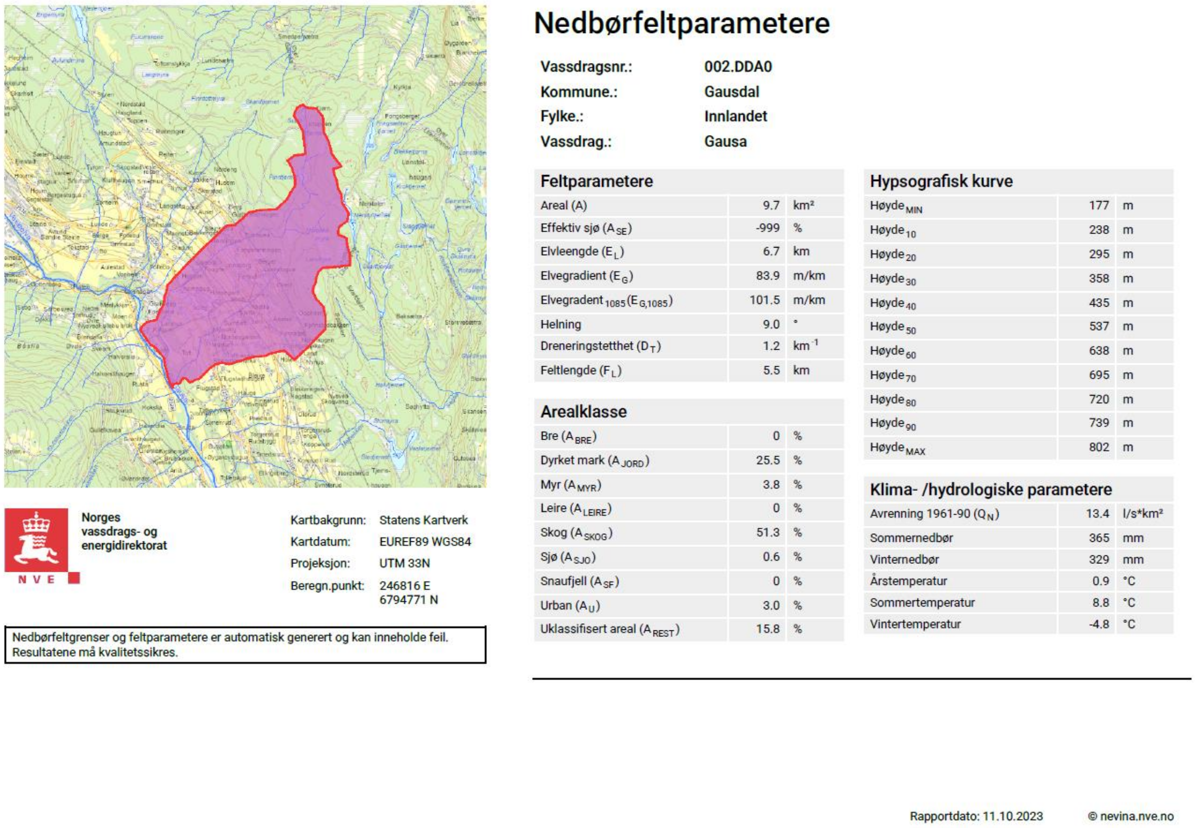
**Appendix A-8.** *In 2015 - 2020, on the behalf of The County Governor of Innlandet, electro-fishing was carried out in two stations in Sagåa to provide density estimates for juvenile brown trout (The County Governor of Innlandet, 2022).*

| | Station 1 | | Station 2 | |
|---|---|---|---|---|
| Year | 0+ (ind/100 m$^2$) | >0+ (ind/100 m$^2$) | 0+ (ind/100 m$^2$) | >0+ (ind/100 m$^2$) |
| 2015 | 5 | 0 | 48.2 | 0 |
| 2016 | 44.5 | 2 | 122.9 | 17.4 |
| 2017 | 0 | 0.8 | 72.8 | 10.2 |
| 2020 | 52.9 | 0 | 93.7 | 18.2 |

## Finna:



**Appendix A-9.** *Four electro-fishing stations were established in the lower sections of the tributary Finna (orange). PIT-scanning was performed on a stretch reaching from the outlet to the river Gausa, and up to 100 meters upstream electro-fishing station F4 (dotted blue line). Two historical electro-fishing station is present within the studied section of the tributary (red points).*



## Nedbørfeltparametere

| | |
|---|---|
| Vassdragsnr.: | 002.DDA0 |
| Kommune.: | Gausdal |
| Fylke.: | Innlandet |
| Vassdrag.: | Gausa |

**Norges vassdrags- og energidirektorat**

NVE

| | |
|---|---|
| Kartbakgrunn: | Statens Kartverk |
| Kartdatum: | EUREF89 WGS84 |
| Projeksjon: | UTM 33N |
| Beregn.punkt: | 246816 E<br>6794771 N |

Nedbørfeltgrenser og feltparametere er automatisk generert og kan inneholde feil. Resultatene må kvalitetssikres.

| Feltparametere | | |
|---|---|---|
| Areal (A) | 9.7 | km² |
| Effektiv sjø ($A_{SE}$) | -999 | % |
| Elvleengde ($E_L$) | 6.7 | km |
| Elvegradient ($E_G$) | 83.9 | m/km |
| Elvegradient$_{1085}$ ($E_{G,1085}$) | 101.5 | m/km |
| Helning | 9.0 | ° |
| Dreneringstetthet ($D_T$) | 1.2 | km$^{-1}$ |
| Feltlengde ($F_L$) | 5.5 | km |

| Arealklasse | | |
|---|---|---|
| Bre ($A_{BRE}$) | 0 | % |
| Dyrket mark ($A_{JORD}$) | 25.5 | % |
| Myr ($A_{MYR}$) | 3.8 | % |
| Leire ($A_{LEIRE}$) | 0 | % |
| Skog ($A_{SKOG}$) | 51.3 | % |
| Sjø ($A_{SJO}$) | 0.6 | % |
| Snaufjell ($A_{SF}$) | 0 | % |
| Urban ($A_U$) | 3.0 | % |
| Uklassifisert areal ($A_{REST}$) | 15.8 | % |

| Hypsografisk kurve | | |
|---|---|---|
| Høyde$_{MIN}$ | 177 | m |
| Høyde$_{10}$ | 238 | m |
| Høyde$_{20}$ | 295 | m |
| Høyde$_{30}$ | 358 | m |
| Høyde$_{40}$ | 435 | m |
| Høyde$_{50}$ | 537 | m |
| Høyde$_{60}$ | 638 | m |
| Høyde$_{70}$ | 695 | m |
| Høyde$_{80}$ | 720 | m |
| Høyde$_{90}$ | 739 | m |
| Høyde$_{MAX}$ | 802 | m |

| Klima- /hydrologiske parametere | | |
|---|---|---|
| Avrenning 1961-90 ($Q_N$) | 13.4 | l/s*km² |
| Sommernedbør | 365 | mm |
| Vinternedbør | 329 | mm |
| Årstemperatur | 0.9 | °C |
| Sommertemperatur | 8.8 | °C |
| Vintertemperatur | -4.8 | °C |

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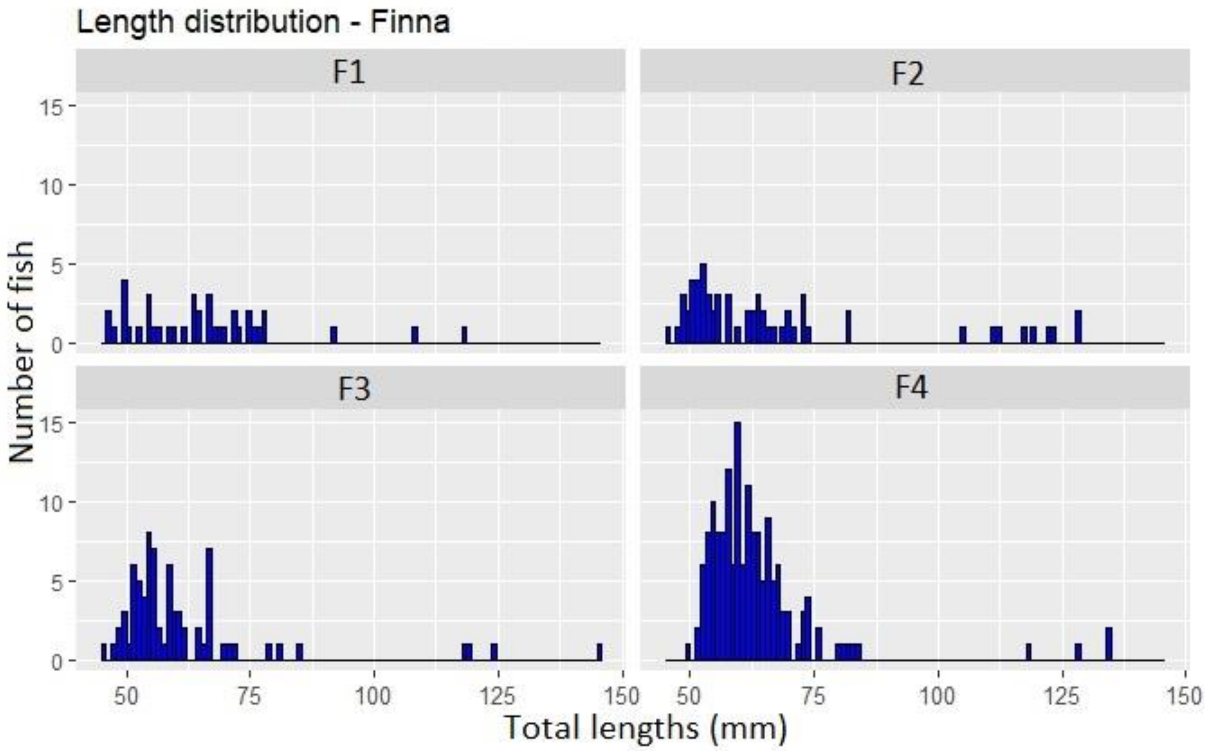
**Appendix A-10.** *Precipitation parameters in the watershed of Finna were acquired from the modeling software NEVINA, provided by The Norwegian Water Resources and Energy Directorate (NVE).*



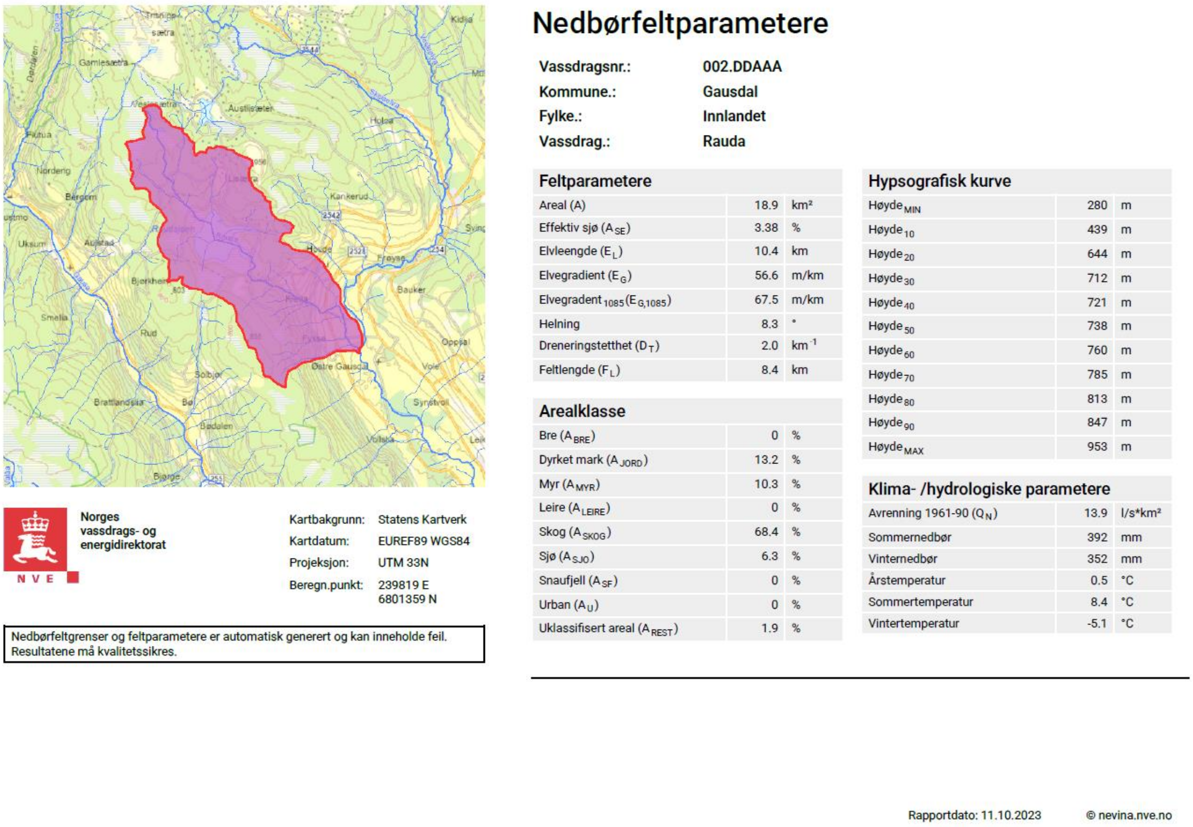
**Appendix A-11.** *Length distributions were used to set boundaries, separating the caught juveniles into age classes. The figure shows the length distributions in the electro-fishing stations of Finna.*

**Appendix A-12.** *In 2015 - 2017, on the behalf of The County Governor of Innlandet, electro-fishing was carried out in Finna to provide density estimates for juvenile brown trout (The County Governor of Innlandet, 2022).*

| | Station 1 | | Station 2 | |
|---|---|---|---|---|
| Year | 0+ (ind/100 m$^2$) | >0+ (ind/100 m$^2$) | 0+ (ind/100 m$^2$) | >0+ (ind/100 m$^2$) |
| 2015 | 33.3 | 0 | 3.5 | 1.4 |
| 2016 | | | 38.4 | 13.1 |
| 2017 | 0 | 3.2 | 13.4 | 6.3 |

**Rauda:**

**Appendix A-13.** *Five electro-fishing stations were established in the lower sections of the tributary Rauda (orange). PIT-scanning was performed on a stretch reaching from the outlet to the river Gausa, and up to 100 meters upstream electro-fishing station R4 (dotted blue line). Two historical electro-fishing station is present within the studied section of the tributary (red points). At electro-fishing station R5, electro-fishing was done only to determine fish density.*



Norges
vassdrags- og
energidirektorat

NVE

Kartbakgrunn: Statens Kartverk
Kartdatum: EUREF89 WGS84
Projeksjon: UTM 33N
Beregn.punkt: 239819 E
6801359 N

Nedbørfeltgrenser og feltparametere er automatisk generert og kan inneholde feil.
Resultatene må kvalitetssikres.

## Nedbørfeltparametere

| | |
|---|---|
| **Vassdragsnr.:** | **002.DDAAA** |
| **Kommune.:** | **Gausdal** |
| **Fylke.:** | **Innlandet** |
| **Vassdrag.:** | **Rauda** |

### Feltparametere

| | | |
|---|---|---|
| Areal (A) | 18.9 | km² |
| Effektiv sjø ($A_{SE}$) | 3.38 | % |
| Elvleengde ($E_L$) | 10.4 | km |
| Elvegradient ($E_G$) | 56.6 | m/km |
| Elvegradient$_{1085}$ ($E_{G,1085}$) | 67.5 | m/km |
| Helning | 8.3 | ° |
| Dreneringstetthet ($D_T$) | 2.0 | km$^{-1}$ |
| Feltlengde ($F_L$) | 8.4 | km |

### Arealklasse

| | | |
|---|---|---|
| Bre ($A_{BRE}$) | 0 | % |
| Dyrket mark ($A_{JORD}$) | 13.2 | % |
| Myr ($A_{MYR}$) | 10.3 | % |
| Leire ($A_{LEIRE}$) | 0 | % |
| Skog ($A_{SKOG}$) | 68.4 | % |
| Sjø ($A_{SJO}$) | 6.3 | % |
| Snaufjell ($A_{SF}$) | 0 | % |
| Urban ($A_U$) | 0 | % |
| Uklassifisert areal ($A_{REST}$) | 1.9 | % |

### Hypsografisk kurve

| | | |
|---|---|---|
| Høyde$_{MIN}$ | 280 | m |
| Høyde$_{10}$ | 439 | m |
| Høyde$_{20}$ | 644 | m |
| Høyde$_{30}$ | 712 | m |
| Høyde$_{40}$ | 721 | m |
| Høyde$_{50}$ | 738 | m |
| Høyde$_{60}$ | 760 | m |
| Høyde$_{70}$ | 785 | m |
| Høyde$_{80}$ | 813 | m |
| Høyde$_{90}$ | 847 | m |
| Høyde$_{MAX}$ | 953 | m |

### Klima- /hydrologiske parametere

| | | |
|---|---|---|
| Avrenning 1961-90 ($Q_N$) | 13.9 | l/s*km² |
| Sommernedbør | 392 | mm |
| Vinternedbør | 352 | mm |
| Årstemperatur | 0.5 | °C |
| Sommertemperatur | 8.4 | °C |
| Vintertemperatur | -5.1 | °C |

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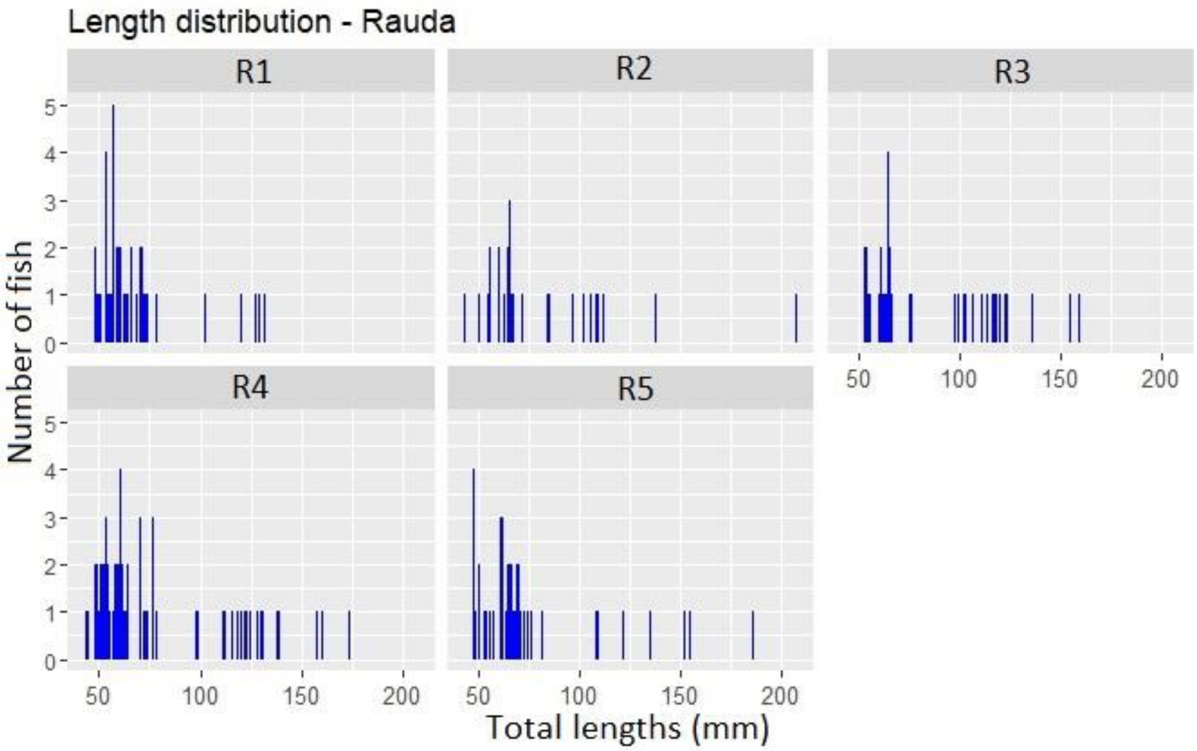
**Appendix A-14.** *Precipitation parameters in the watershed of Rauda acquired from the modeling software NEVINA, provided by The Norwegian Water Resources and Energy Directorate (NVE).*



**Appendix A-15.** *Length distributions were used to set boundaries, separating the caught juveniles into age classes. The figure shows the length distributions in the electro-fishing stations of Rauda.*

**Appendix A-16.** *In 2012 - 2022, on the behalf of The County Governor of Innlandet, electro-fishing was carried out at two stations in Rauda (at Fykse and Likveine) to provide density estimates for juvenile brown trout (The County Governor of Innlandet, 2022).*

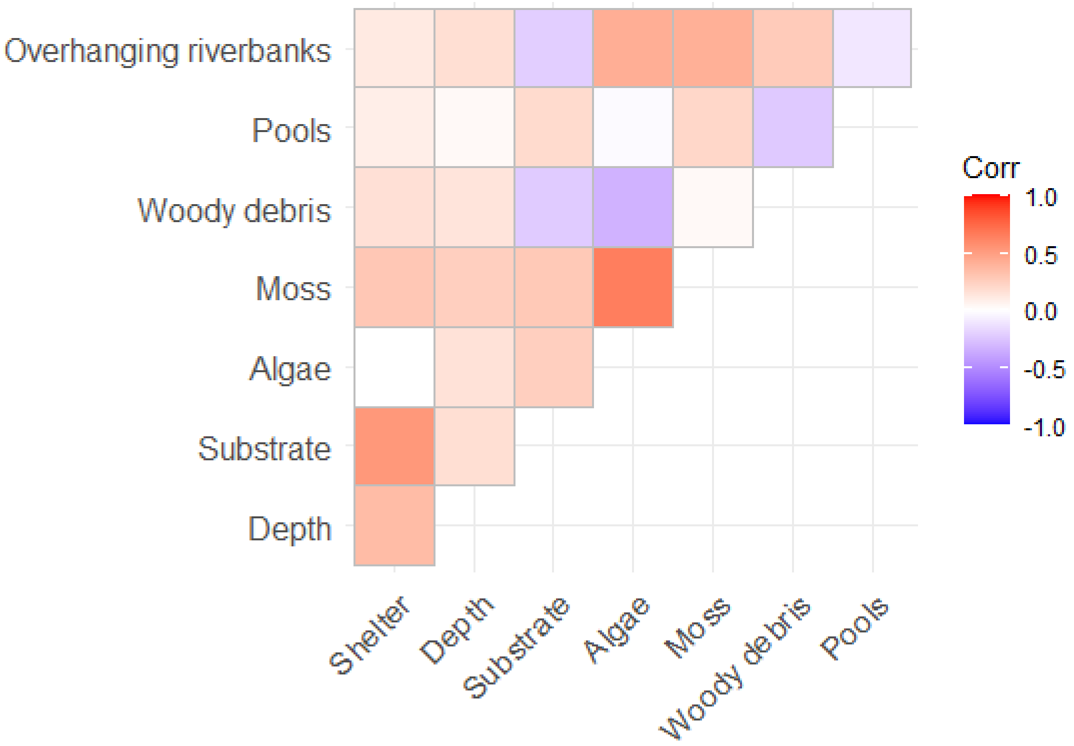
| | Fykse | | Likveine | |
|---|---|---|---|---|
| Year | 0+ (ind/100 m$^2$) | >0+ (ind/100 m$^2$) | 0+ (ind/100 m$^2$) | >0+ (ind/100 m$^2$) |
| 2012 | 20 | 2.2 | 8.9 | 3.2 |
| 2013 | 12.3 | 1.8 | 4.4 | 0 |
| 2014 | 10.1 | 4.4 | 3.7 | 1.3 |
| 2015 | 27.2 | 2.2 | 16.3 | 3 |
| 2016 | 16.7 | 0 | 5.6 | 1.3 |
| 2017 | 18.2 | 2 | 22.5 | 0 |
| 2018 | 3.6 | 0 | 8.5 | 0 |
| 2019 | 9.5 | 0 | 9.9 | 1.8 |
| 2020 | 6.7 | 1.6 | 15.6 | 0 |
| 2021 | 6.7 | 8.1 | 21.6 | 1 |
| 2022 | 2.4 | 0 | 0 | 0 |

# Appendix B: Environmental assessments

## In-stream habitat assessments

**Appendix B-1.** *At each electro-fishing station, several in-stream habitat characteristics variables were assessed. The variables were later included in a Principal Component Analysis (PCA) to act as a covariables in the analyses of juvenile brown trout densities.*

| Tributary | Station | Width (m) | Shelter availability (n) | Depth (m) | Substrate size (mm) | Algae cover (%) | Moss cover (%) | Dead woody debris (n) | Pools (n) | Overhanging riverbank (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Djupa | D1 | 2.92 | 6 | 0.07 | 115 | 9.6 | 0 | 0 | 1 | 0.0 |
| Djupa | D1 | 2.26 | 14.2 | 0.12 | 372 | 6.4 | 0 | 4 | 4 | 0.0 |
| Sagåa | S1 | 5.32 | 3 | 0.24 | 170 | 0 | 0 | 11 | 4 | 6.2 |
| Sagåa | S2 | 5.52 | 4 | 0.18 | 136 | 0 | 16 | 12 | 2 | 1.6 |
| Sagåa | S3 | 5.26 | 12.2 | 0.18 | 216 | 0 | 0 | 6 | 0 | 4.1 |
| Sagåa | S4 | 5.21 | 12.4 | 0.15 | 219 | 20 | 12.8 | 1 | 9 | 0.0 |
| Finna | F1 | 2.85 | 1.8 | 0.13 | 17 | 0 | 0 | 13 | 4 | 35.4 |
| Finna | F2 | 3.38 | 20.8 | 0.15 | 159 | 9.6 | 13.2 | 26 | 2 | 35.6 |
| Finna | F3 | 3.31 | 2.6 | 0.14 | 24 | 0 | 0 | 17 | 2 | 16.9 |
| Finna | F4 | 2.97 | 6.4 | 0.20 | 98 | 29.6 | 6.4 | 1 | 3 | 0.0 |
| Rauda | R1 | 4.14 | 15.4 | 0.22 | 258 | 49.8 | 12.8 | 12 | 0 | 19.5 |
| Rauda | R2 | 4.22 | 21.8 | 0.28 | 158 | 0 | 3.2 | 9 | 3 | 24.3 |
| Rauda | R3 | 5.72 | 34.4 | 0.21 | 231 | 6.4 | 12.8 | 9 | 4 | 20.8 |
| Rauda | R4 | 5.08 | 12.8 | 0.20 | 277 | 43.2 | 22.8 | 7 | 5 | 32.3 |
| Rauda | R5 | 4.96 | 5.4 | 0.17 | 126 | 50 | 16 | 0 | 2 | 58.8 |



**Appendix B-2.** *A correlation matrix was made to get an indication of the correlation between the assessed in-stream habitat variables. Red color indicates a positive correlation, while blue color indicates a negative correlation.*

**Appendix B-3.** *The eigenvalue, proportion explained, and cumulative proportion explained by the principal components from the PCA on in-stream habitat variables.*

| **Importance of principal components:** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 | PC7 | PC8 |
| Eigenvalue | 2.3649 | 1.6332 | 1.4453 | 0.8997 | 0.73258 | 0.48016 | 0.29915 | 0.14501 |
| Proportion Explained | 0.2956 | 0.2041 | 0.1807 | 0.1125 | 0.09157 | 0.06002 | 0.03739 | 0.01813 |
| Cumulative Proportion | 0.2956 | 0.4997 | 0.6804 | 0.7929 | 0.88447 | 0.94449 | 0.98188 | 1 |

**Appendix B-4.** *The station loadings on the principal components, calculated as the weighted sums of variable scores at each electro-fishing station, were included as a proxy predictor variable for the in-stream habitat variables in the linear regressions of juvenile densities.*

| Station | PC1 | PC2 | PC3 |
|---|---|---|---|
| D1 | -0.928 | 0.447 | 0.234 |
| D2 | 0.084 | 1.650 | 0.438 |
| S1 | -0.744 | 0.263 | 0.037 |
| S2 | -0.467 | 0.072 | 0.359 |
| S3 | -0.325 | 1.238 | 0.286 |
| S4 | 0.181 | 0.292 | 0.082 |
| F1 | -1.328 | -1.025 | -0.317 |
| F2 | 0.405 | -0.106 | -0.489 |
| F3 | -1.230 | -0.719 | -0.452 |
| F4 | -0.161 | 0.102 | 0.521 |
| R1 | 1.274 | 0.497 | 1.224 |
| R2 | 0.221 | -0.021 | -1.501 |
| R3 | 1.266 | 0.100 | -2.022 |
| R4 | 1.391 | -1.051 | 0.500 |
| R5 | 0.360 | -1.737 | 1.099 |

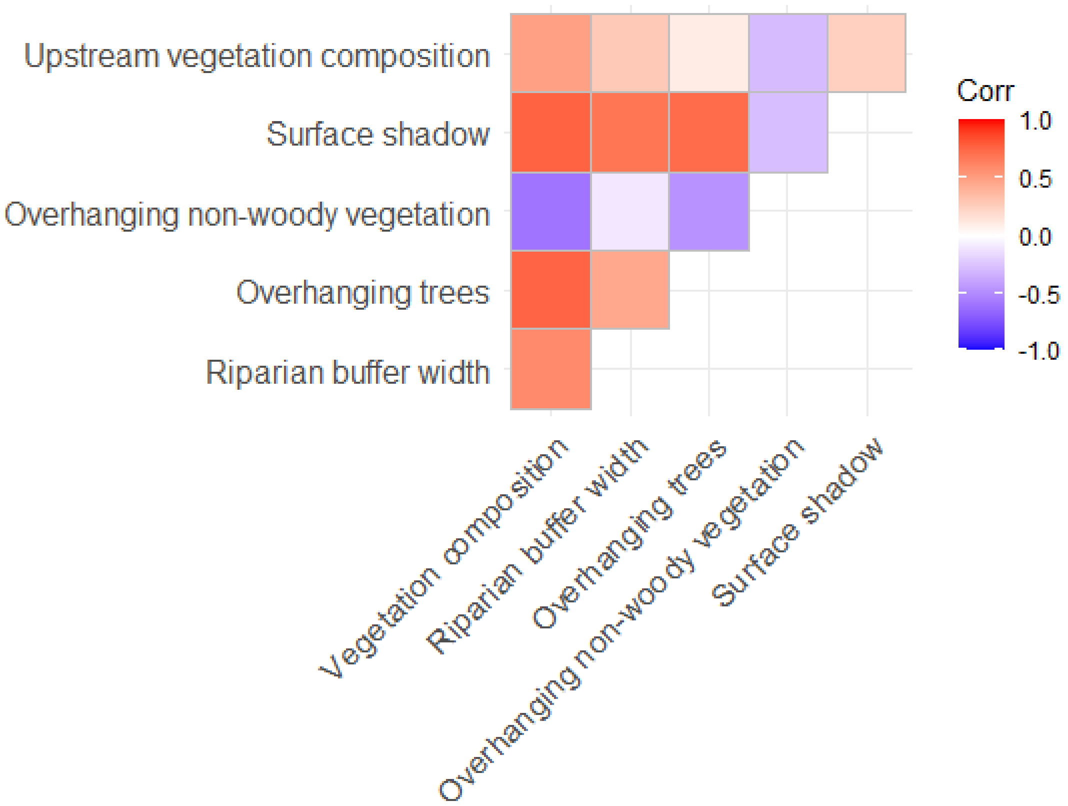
**Appendix B-5.** *All in-stream habitat characteristics variables included in the principal component analysis (PCA) are presented with associated loadings for PC1, PC2, and PC3.*

| Variable | PC1 | PC2 | PC3 |
|---|---|---|---|
| Moss cover | 0.962 | -0.162 | 0.227 |
| Algae cover | 0.819 | -0.091 | 0.689 |
| Shelter availability | 0.653 | 0.151 | -0.762 |
| Substrate size | 0.643 | 0.688 | -0.311 |
| Depth | 0.581 | -0.175 | -0.476 |
| Overhanging riverbanks | 0.525 | -0.829 | 0.219 |
| Number of pools | 0.265 | 0.581 | 0.052 |
| Dead woody debris | -0.095 | -0.758 | -0.657 |

## Riparian conditions assessments

**Appendix B-6.** *At all stations, a score ranging from one (poor) to five (excellent) was given for all assessed riparian condition variables. The variables later underwent a copula-based ordination analysis with factor scoring to reduce the complexity in the data.*

| Tributary | Station | Vegetation composition | Riparian buffer width | Overhanging trees | Overhanging non-woody vegetation | Surface shadow | Vegetation composition 100 m upstream |
|---|---|---|---|---|---|---|---|
| Djupa | D1 | 2.5 | 2 | 2 | 2 | 2 | 2 |
| Djupa | D2 | 4 | 3 | 4 | 1 | 3 | 4.5 |
| Sagåa | S1 | 5 | 3 | 4 | 1 | 3 | 5 |
| Sagåa | S2 | 5 | 4 | 5 | 1 | 4 | 3.5 |
| Sagåa | S3 | 3 | 1.5 | 4 | 3 | 2 | 3.5 |
| Sagåa | S4 | 5 | 2 | 4 | 1 | 5 | 5 |
| Finna | F1 | 4.5 | 4.5 | 5 | 2 | 5 | 4 |
| Finna | F2 | 5 | 4 | 3 | 1 | 4 | 4 |
| Finna | F3 | 5 | 4 | 4 | 4 | 5 | 4 |
| Finna | F4 | 3 | 1 | 1 | 2 | 1 | 5 |
| Rauda | R1 | 2.5 | 2 | 2 | 2 | 1 | 4 |
| Rauda | R2 | 4 | 3 | 4 | 1 | 5 | 4 |
| Rauda | R3 | 5 | 3.5 | 3 | 1 | 3 | 5 |
| Rauda | R4 | 2.5 | 4.5 | 1 | 4 | 3 | 5 |
| Rauda | R5 | 1 | 1 | 1 | 4 | 1 | 2.5 |



**Appendix B-7.** *A correlation matrix was made to get an indication of the correlation between the assessed riparian condition variables. Red color indicates a positive correlation, while blue color indicates a negative correlation.*

**Appendix B-8.** *The station loadings on the factor axes, calculated as the weighted sums of variable scores at each electro-fishing station through the copula-based ordination analysis, were included as a proxy predictor variable for the assessed variables in the linear regressions of juvenile densities.*

| Station | Factor1 | Factor2 |
|---|---|---|
| D1 | -0.473 | -0.860 |
| D2 | -0.153 | 2.218 |
| S1 | -0.244 | 1.112 |
| S2 | 0.841 | 0.641 |
| S3 | -1.261 | 0.068 |
| S4 | -0.200 | 1.269 |
| F1 | 1.390 | -0.450 |
| F2 | 0.910 | 0.497 |
| F3 | 1.357 | 0.115 |
| F4 | -1.273 | 0.046 |
| R1 | -0.735 | -0.695 |
| R2 | 0.499 | 0.042 |
| R3 | 0.007 | 0.984 |
| R4 | 0.369 | -1.232 |
| R5 | -1.044 | -1.654 |

**Appendix B-9.** *The riparian condition variables included in the copula-based ordination attained scores for Factor1 and Factor2.*

| Variable | Factor1 | Factor2 |
|---|---|---|
| Surface shadow | 0.910 | 0.196 |
| Riparian buffer width | 0.625 | 0.189 |
| Fraction of overhanging trees | 0.633 | 0.296 |
| Vegetation composition | 0.476 | 0.876 |
| Vegetation composition next 100 meters upstream | 0.072 | 0.423 |
| Fraction of overhanging non-woody vegetation | -0.195 | -0.513 |

## Water discharge

**Appendix B-10.** *Water discharges (meanQ; m3/second) for each survival period was estimated for the tributaries Djupa, Sagåa, and Finna. Discharge data in Rauda was obtained from Rausjøen Powerplant. The mean standardized water discharge (stMeanQ) was then calculated for use in the analysis of survival probability. MaxQ and minQ is maximum and minimum discharge for each survival period respectively. stMaxQ and stMinQ is standardized maximum and minimum water discharge respectively. diffQ is the difference in water discharge between stMaxQ and stMinQ.*

| Period | Tributary | meanQ | maxQ | minQ | stMeanQ | stMaxQ | stMinQ | diffQ |
|---|---|---|---|---|---|---|---|---|
| 1 | Djupa | 0.377 | 2.630 | 0.000 | 0.451 | 6.711 | -0.596 | 6.711 |
| 2 | Djupa | 0.172 | 0.980 | 0.000 | -0.117 | 2.127 | -0.596 | 2.127 |
| 3 | Djupa | 0.176 | 0.800 | 0.000 | -0.108 | 1.627 | -0.596 | 1.627 |
| 4 | Djupa | 0.048 | 0.310 | 0.000 | -0.461 | 0.265 | -0.596 | 0.265 |
| 5 | Djupa | 0.018 | 0.150 | 0.000 | -0.547 | -0.179 | -0.596 | -0.179 |
| 1 | Sagaa | 0.481 | 2.590 | 0.000 | 0.486 | 5.509 | -0.660 | 5.509 |
| 2 | Sagaa | 0.237 | 1.070 | 0.000 | -0.096 | 1.889 | -0.660 | 1.889 |
| 3 | Sagaa | 0.234 | 0.840 | 0.000 | -0.103 | 1.341 | -0.660 | 1.341 |
| 4 | Sagaa | 0.055 | 0.290 | 0.000 | -0.528 | 0.031 | -0.660 | 0.031 |
| 5 | Sagaa | 0.029 | 0.210 | 0.000 | -0.590 | -0.160 | -0.660 | -0.160 |
| 1 | Finna | 0.459 | 2.540 | 0.000 | 1.035 | 8.371 | -0.583 | 8.371 |
| 2 | Finna | 0.215 | 1.140 | 0.000 | 0.175 | 3.435 | -0.583 | 3.435 |
| 3 | Finna | 0.219 | 0.930 | 0.000 | 0.189 | 2.695 | -0.583 | 2.695 |
| 4 | Finna | 0.055 | 0.320 | 0.000 | -0.391 | 0.545 | -0.583 | 0.545 |
| 5 | Finna | 0.013 | 0.110 | 0.000 | -0.536 | -0.196 | -0.583 | -0.196 |
| 1 | Rauda | 0.973 | 9.770 | 0.250 | 0.479 | 11.214 | -0.403 | 10.909 |
| 2 | Rauda | 0.717 | 2.230 | 0.260 | 0.166 | 2.013 | -0.391 | 1.696 |
| 3 | Rauda | 0.473 | 1.140 | 0.010 | -0.131 | 0.683 | -0.696 | 0.671 |
| 4 | Rauda | 0.270 | 0.440 | 0.190 | -0.378 | -0.171 | -0.476 | -0.403 |
| 5 | Rauda | 0.208 | 0.260 | 0.180 | -0.454 | -0.391 | -0.488 | -0.610 |

# Appendix C: Catch

**Appendix C-1.** *The density fishing consisted of three capture rounds. Density estimates were made for the age classes 0+, 1+ and >1+, of which the latter two were later merged as >0+. Density SE represents the standard error of the density estimates. Catchability SE represents the standard error of the estimated catchability. 0+ represents the young-of-the-year age class, 1+ is the one year olds, while >1+ is fish at two years or older.*

| Tributary | Station | Age | Round 1 | Round 2 | Round 3 | Density/100 m$^2$) | Density SE | Catchability | Catchability SE |
|---|---|---|---|---|---|---|---|---|---|
| Djupa | D1 | 0+ | 20 | 19 | 12 | 75.26 | 30.67 | 0.25 | 0.13 |
| Djupa | D2 | 0+ | 16 | 6 | 3 | 35.60 | 4.65 | 0.51 | 0.14 |
| Sagåa | S1 | 0+ | 4 | 4 | 1 | 9.83 | 11.90 | 0.21 | 0.33 |
| Sagåa | S2 | 0+ | 7 | 3 |  | 6.43 | 1.37 | 0.67 | 0.25 |
| Sagåa | S3 | 0+ | 20 | 19 | 6 | 28.78 | 4.72 | 0.41 | 0.12 |
| Sagåa | S4 | 0+ | 53 | 17 | 8 | 35.25 | 1.18 | 0.65 | 0.06 |
| Finna | F1 | 0+ | 29 | 7 | 1 | 30.62 | 0.50 | 0.80 | 0.07 |
| Finna | F2 | 0+ | 32 | 11 | 10 | 43.61 | 4.02 | 0.50 | 0.09 |
| Finna | F3 | 0+ | 45 | 21 | 5 | 63.16 | 2.36 | 0.64 | 0.07 |
| Finna | F4 | 0+ | 89 | 41 | 25 | 150.97 | 8.70 | 0.49 | 0.06 |
| Rauda | R1 | 0+ | 17 | 9 | 9 | 46.24 | 13.11 | 0.34 | 0.14 |
| Rauda | R2 | 0+ | 14 | 2 |  | 13.19 | 0.46 | 0.89 | 0.09 |
| Rauda | R3 | 0+ | 10 | 6 | 3 | 26.41 | 13.19 | 0.29 | 0.21 |
| Rauda | R4 | 0+ | 26 | 10 | 5 | 26.65 | 1.79 | 0.59 | 0.09 |
| Rauda | R5 | 0+ | 17 | 7 | 5 | 20.16 | 3.20 | 0.46 | 0.14 |
| Djupa | D1 | 1+ | 3 | 0 | 0 | 2.54 | 0.00 | 1.00 | 0.00 |
| Djupa | D2 | 1+ | 1 | 0 | 0 | 1.27 | 0.00 | 1.00 | 0.00 |
| Sagåa | S1 | 1+ | 0 | 0 | 0 | 0.00 | 0.00 |  |  |
| Sagåa | S2 | 1+ | 1 | 0 |  | 0.58 | 0.00 | 1.00 | 0.00 |
| Sagåa | S3 | 1+ | 1 | 0 | 0 | 0.51 | 0.00 | 1.00 | 0.00 |
| Sagåa | S4 | 1+ | 8 | 2 | 1 | 4.79 | 0.34 | 0.69 | 0.16 |
| Finna | F1 | 1+ | 2 | 1 | 0 | 2.49 | 0.22 | 0.75 | 0.27 |
| Finna | F2 | 1+ | 6 | 2 | 1 | 6.54 | 0.50 | 0.69 | 0.17 |
| Finna | F3 | 1+ | 3 | 0 | 0 | 2.56 | 0.00 | 1.00 | 0.00 |
| Finna | F4 | 1+ | 4 | 0 | 0 | 3.39 | 0.00 | 1.00 | 0.00 |
| Rauda | R1 | 1+ | 3 | 2 | 0 | 4.72 | 0.42 | 0.71 | 0.22 |
| Rauda | R2 | 1+ | 4 | 2 |  | 4.95 | 0.87 | 0.75 | 0.26 |
| Rauda | R3 | 1+ | 7 | 2 | 2 | 10.93 | 1.73 | 0.55 | 0.19 |
| Rauda | R4 | 1+ | 8 | 3 | 0 | 6.66 | 0.23 | 0.79 | 0.13 |
| Rauda | R5 | 1+ | 2 | 1 | 0 | 1.78 | 0.42 | 0.60 | 0.35 |
| Djupa | D1 | >1+ | 0 | 1 | 0 | 0.85 | 0.62 | 0.50 | 0.73 |
| Djupa | D2 | >1+ | 1 | 0 | 0 | 1.27 | 0.00 | 1.00 | 0.00 |
| Sagåa | S1 | >1+ | 0 | 0 | 0 | 0.00 | 0.00 |  |  |
| Sagåa | S2 | >1+ | 0 | 0 |  | 0.00 | 0.00 |  |  |
| Sagåa | S3 | >1+ | 0 | 0 | 0 | 0.00 | 0.00 |  |  |
| Sagåa | S4 | >1+ | 0 | 0 | 0 | 0.00 | 0.00 |  |  |
| Finna | F1 | >1+ | 0 | 0 | 0 | 0.00 | 0.00 |  |  |
| Finna | F2 | >1+ | 0 | 0 | 0 | 0.00 | 0.00 |  |  |
| Finna | F3 | >1+ | 1 | 0 | 0 | 0.85 | 0.00 | 1.00 |  |
| Finna | F4 | >1+ | 0 | 0 | 0 | 0.00 | 0.00 |  |  |
| Rauda | R1 | >1+ | 0 | 0 | 0 | 0.00 | 0.00 |  |  |
| Rauda | R2 | >1+ | 2 | 0 |  | 1.65 | 0.00 | 1.00 |  |
| Rauda | R3 | >1+ | 3 | 0 | 0 | 2.73 | 0.00 | 1.00 |  |
| Rauda | R4 | >1+ | 3 | 0 | 0 | 1.82 | 0.00 | 1.00 |  |
| Rauda | R5 | >1+ | 2 | 1 | 0 | 1.78 | 0.16 | 0.75 | 0.23 |

## Cohort boundaries:

**Appendix C-2.** *Based on the length distribution of the catch within each electro-fishing station in September, boundaries were set distinguishing between the 0+, 1+ and >1+ age classes. 0+ represents the young-of-the-year age class, 1+ is the one year olds, while >1+ is fish at two years or older.*

| | Age class boundaries (TL (mm)) | | |
|---|---|---|---|
| Station | 0+ | 1+ | >1+ |
| D1 | <88 | 88-125 | >125 |
| D2 | <92 | 92-125 | >125 |
| S1 | <76 | 76-125 | >125 |
| S2 | <88 | 88-135 | >135 |
| S3 | <75 | 75-125 | >125 |
| S4 | <75 | 75-125 | >125 |
| F1 | <85 | 85-125 | >125 |
| F2 | <92 | 92-135 | >135 |
| F3 | <100 | 100-135 | >135 |
| F4 | <100 | 100-135 | >135 |
| R1 | <90 | 90-145 | >145 |
| R2 | <78 | 78-125 | >125 |
| R3 | <85 | 85-120 | >120 |
| R4 | <90 | 90-145 | >145 |
| R5 | <95 | 95-145 | >145 |

# Appendix D: Quantitative analysis

## Analysis of density

**Appendix D-1.** *Complete model selection table containing all candidate models for analysis of 0+ density.*

| Modnames | K | AICc | ΔAICc | ModelLik | AICcWt | LL |
|---|---|---|---|---|---|---|
| log(olderTHnull+1)+PC1 +Factor1 | 5 | 32.495 | 0.000 | 1.000 | 0.794 | -7.914 |
| log(olderTHnull+1)*Factor1+PC1 | 6 | 37.994 | 5.500 | 0.064 | 0.051 | -7.747 |
| log(olderTHnull+1)+PC1*Factor1 | 6 | 38.279 | 5.784 | 0.055 | 0.044 | -7.890 |
| log(olderTHnull+1)+PC1 +Factor1+Factor2 | 6 | 38.312 | 5.818 | 0.055 | 0.043 | -7.906 |
| log(olderTHnull+1)+PC1 | 4 | 39.302 | 6.807 | 0.033 | 0.026 | -13.651 |
| log(olderTHnull+1)+PC1+PC3 | 5 | 40.678 | 8.183 | 0.017 | 0.013 | -12.005 |
| log(olderTHnull+1)+PC3 | 4 | 41.502 | 9.007 | 0.011 | 0.009 | -14.751 |
| log(olderTHnull+1)*PC1 | 5 | 42.649 | 10.155 | 0.006 | 0.005 | -12.991 |
| log(olderTHnull+1)+PC2 | 4 | 43.209 | 10.714 | 0.005 | 0.004 | -15.604 |
| log(olderTHnull+1)+PC1+PC2 | 5 | 43.518 | 11.023 | 0.004 | 0.003 | -13.426 |
| log(olderTHnull+1)+PC1 +Factor2 | 5 | 43.690 | 11.195 | 0.004 | 0.003 | -13.512 |
| log(olderTHnull+1)+PC1 +Factor1*Factor2 | 7 | 45.804 | 13.309 | 0.001 | 0.001 | -7.902 |
| log(olderTHnull+1)+PC2+PC3 | 5 | 45.897 | 13.403 | 0.001 | 0.001 | -14.615 |
| log(olderTHnull+1)+PC1+PC2+PC3 | 6 | 45.911 | 13.416 | 0.001 | 0.001 | -11.706 |
| log(olderTHnull+1)*PC3 | 5 | 45.996 | 13.501 | 0.001 | 0.001 | -14.665 |
| log(olderTHnull+1)*PC2 | 5 | 47.196 | 14.701 | 0.001 | 0.001 | -15.264 |

**Appendix D-2.** *Complete model selection table containing all candidate models for analysis of >0+ density.*

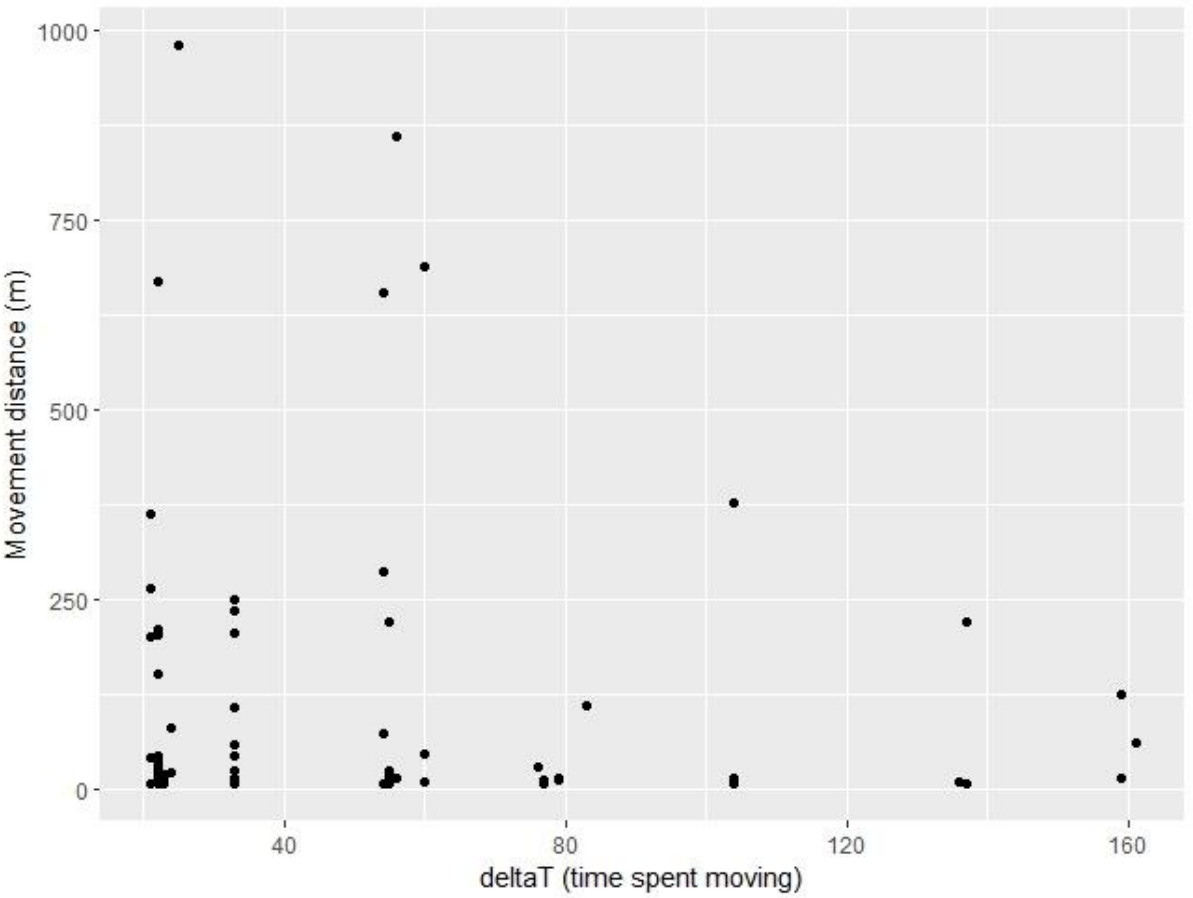
| Model | K | AICc | ΔAICc | ModelLik | AICcWt | LL |
|---|---|---|---|---|---|---|
| PC1 | 3 | 33.360 | 0.000 | 1.000 | 0.441 | -12.589 |
| PC1+Factor1 | 4 | 35.878 | 2.517 | 0.284 | 0.125 | -11.939 |
| PC1*Factor2 | 5 | 35.976 | 2.616 | 0.270 | 0.119 | -9.655 |
| PC1+PC3 | 4 | 36.927 | 3.567 | 0.168 | 0.074 | -12.464 |
| PC1+PC2 | 4 | 37.050 | 3.690 | 0.158 | 0.070 | -12.525 |
| PC1+Factor2 | 4 | 37.104 | 3.744 | 0.154 | 0.068 | -12.552 |
| Factor2 | 3 | 39.421 | 6.060 | 0.048 | 0.021 | -15.620 |
| PC3 | 3 | 39.682 | 6.322 | 0.042 | 0.019 | -15.750 |
| PC2 | 3 | 39.762 | 6.401 | 0.041 | 0.018 | -15.790 |
| Factor1 | 3 | 39.827 | 6.467 | 0.039 | 0.017 | -15.823 |
| PC1*Factor1 | 5 | 40.524 | 7.164 | 0.028 | 0.012 | -11.929 |
| PC1+PC2+PC3 | 5 | 41.464 | 8.103 | 0.017 | 0.008 | -12.398 |
| Factor1+Factor2 | 4 | 43.173 | 9.813 | 0.007 | 0.003 | -15.587 |
| PC2+PC3 | 4 | 43.416 | 10.056 | 0.007 | 0.003 | -15.708 |
| Factor1*Factor2 | 5 | 47.775 | 14.415 | 0.001 | 0.000 | -15.554 |

## Analysis of survival probability

**Appendix D-3.** *Complete model selection table containing all adapted candidate models for analysis of survival probability, including those where all parameters could not be estimated (as indicated by similar AICc values).*

| Model | K | AICc | ΔAICc | ModelLik | AICcWt | -2log(L) |
|---|---|---|---|---|---|---|
| Phi(stream*stL*stWD+(RCI\|summer)) p(stream*stL+stWD) | 22 | 648.194 | 0.000 | 1.000 | 0.981 | 600.680 |
| Phi(stream*stL*stWD+RCI) p(stream*stL+stWD) | 21 | 657.887 | 9.693 | 0.008 | 0.008 | 612.690 |
| Phi(stream*stL+stWD+RCI) p(stream*stL+stWD) | 18 | 658.159 | 9.965 | 0.007 | 0.007 | 619.816 |
| Phi(stream*stL*stWD+RCI) p(stream*stL*stWD) | 24 | 660.199 | 12.005 | 0.003 | 0.002 | 608.003 |
| Phi(stream*stL*stWD) p(stream*stL) | 19 | 663.310 | 15.116 | 0.001 | 0.001 | 622.699 |
| Phi(stream*stL*stWD+RCI) p(stream*stL) | 19 | 663.310 | 15.116 | 0.001 | 0.001 | 622.699 |
| Phi(stream*stL*stWD+RCI) p(stream*stL*kantInd) | 19 | 663.310 | 15.116 | 0.001 | 0.001 | 622.699 |
| Phi(stream*stL*stWD*RCI) p(stream*stL) | 19 | 663.310 | 15.116 | 0.001 | 0.001 | 622.699 |
| Phi(stream*stL*stWD_VAR) p(stream*stL) | 19 | 665.344 | 17.150 | 0.000 | 0.000 | 624.733 |
| Phi(stream*stL+stWD) p(stream*stL) | 17 | 668.720 | 20.526 | 0.000 | 0.000 | 632.631 |
| Phi(stream*stL+stWD+RCI) p(stream*stL) | 17 | 668.720 | 20.526 | 0.000 | 0.000 | 632.631 |
| Phi(stream*stL+stWD*RCI) p(stream*stL) | 17 | 668.720 | 20.526 | 0.000 | 0.000 | 632.631 |
| Phi(stream*stL) p(stream*stL) | 16 | 669.023 | 20.829 | 0.000 | 0.000 | 635.172 |
| Phi(stream*stL+RCI) p(stream*stL) | 16 | 669.023 | 20.829 | 0.000 | 0.000 | 635.172 |
| Phi(stream*stL*RCI) p(stream*stL) | 16 | 669.023 | 20.829 | 0.000 | 0.000 | 635.172 |
| phi(stream)p(stream) | 8 | 678.340 | 30.146 | 0.000 | 0.000 | 661.863 |

## Analysis of in-stream movement patterns



**Appendix D-4.** *Movement distance as a function of deltaT (time spent on movement). The plot shows that long distance movements can occur in short timespans. DeltaT was thus not included in modeling.*

**Appendix D-5.** *Complete model selection table containing all candidate models for the analysis of movement distances.*

| Model | K | AICc | ΔAICc | ModelLik | AICcWt | LL |
|---|---|---|---|---|---|---|
| TL+season | 4 | 336.010 | 0.000 | 1.000 | 0.688 | -163.790 |
| TL*season | 5 | 338.194 | 2.184 | 0.336 | 0.231 | -163.771 |
| TL | 3 | 342.167 | 6.157 | 0.046 | 0.032 | -167.956 |
| TL+RCI_score_stream | 4 | 343.336 | 7.326 | 0.026 | 0.018 | -167.453 |
| TL+RCP | 4 | 344.187 | 8.177 | 0.017 | 0.012 | -167.878 |
| TL+MP | 5 | 344.487 | 8.477 | 0.014 | 0.010 | -166.918 |
| TL*RCI_score_stream | 5 | 345.318 | 9.308 | 0.010 | 0.007 | -167.333 |
| TL+stream | 6 | 346.648 | 10.638 | 0.005 | 0.003 | -166.863 |
| TL*stream | 9 | 352.620 | 16.610 | 0.000 | 0.000 | -166.287 |
| season | 3 | 356.425 | 20.415 | 0.000 | 0.000 | -175.090 |
| RCP | 3 | 361.588 | 25.577 | 0.000 | 0.000 | -177.671 |
| RCI_score_stream | 3 | 363.262 | 27.252 | 0.000 | 0.000 | -178.509 |
| MP | 4 | 363.641 | 27.631 | 0.000 | 0.000 | -177.614 |
| stream | 5 | 367.166 | 31.156 | 0.000 | 0.000 | -178.270 |

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