Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Natural Sciences
Department of Biology

Rasmus Rødne Lange

Comparing migratory behavior and habitat use during seaward migration of Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) post-smolts in and outside the protected national salmon fjord Beiarfjorden.

Master's thesis in Ocean Resources (MSOCEAN)
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ABSTRACT

Seaward migration constitutes a vulnerable part in the life history of Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) smolts. In addition to an already high mortality rate for first time migrants during the early stages of the fjord entry, anthropogenic activities pose further risk to local salmonid populations. Protection and development of Norway's most important salmon populations was implemented as a preventive measure by the Norwegian government. Beiarfjorden, Nordland, became one of 29 nationally protected salmon fjord in 2007, excluding this fjord from fish farm activities in a direct sense. Fish farms can, however, be found in fjord sections outside this protected area. In order to map migratory behavior and habitat use of wild populations of Atlantic Salmon and brown trout post-smolts in Beiarfjorden and connecting fjord sections, acoustic telemetry was used to track tagged fish. A total of 108 Atlantic salmon (length = 142 ± 10 mm) and 142 brown trout (length = 174 ± 36 mm) were caught and tagged during spring and summer of 2022 and 2023.

The present study found that Atlantic salmon post-smolts almost exclusively (88%) used the northern exit, Nordfjorden, when leaving the fjord complex, as opposed to the southwestern exit. For the brown trout post-smolts, 94% stayed inside the protected Beiarfjorden. Brown trout post-smolts had a continuous temporal presence in the fjord complex from May to September, with a reduced number of detections in July, suggesting habitat use in unmonitored sections in central parts of Beiarfjorden during this month. In 2023, mean estuary entry date for brown trout post smolts were June 15, ranging from May 15 to August 20, while Atlantic salmon post-smolts had a mean entry date of 3 June, ranging from May 14 to July 13. The Atlantic salmon post-smolts increased their swimming speed from a mean speed of 0.64 body lengths per second (0.32 km/h) in Beiarfjorden, to 1.76 body lengths per second (0.87 km/h) in Nordfjorden, with an average fjord residency time of 113 hours (range = 11 – 1278 hours) in Beiarfjorden, and 27 hours (range = 7 – 195 hours) in Nordfjorden. Presence of Atlantic salmon post-smolts in Nordfjorden was detected from May 16 to August 17, 2023. The short residency of Atlantic salmon post-smolts in Nordfjorden, in addition to the sedentary behavior of brown trout post-smolts in Beiarfjorden, indicates a reduced exposure to fish farms, highlighting the importance of the national salmon protection in Beiarn.

SAMMENDRAG

Sjøvandringen utgjør en sårbar del av livshistorien i smoltfasen hos atlanterhavslaks (*Salmo salar*) og brunørret (*Salmo trutta*). I tillegg til en allerede høy dødelighet for førstegangsvandrere i de tidlige stadiene av sjøfasen, utgjør antropogene aktiviteter ytterligere risiko for de lokale laksefiskbestandene. Vern av Norges viktigste laksebestander ble iverksatt som et forebyggende tiltak av norske myndigheter. Beiarfjorden, Nordland, ble en av 29 nasjonalt vernede laksefjorder i 2007, noe som ekskluderte denne fjorden fra oppdrettsvirksomhet i direkte forstand. Oppdrettsanlegg finnes imidlertid i fjordseksjoner utenfor dette verneområdet. Akustisk telemetri ble brukt for å spore merkde fisk for å kartlegge vandringsatferd og habitatbruk av ville bestander av atlanterhavslaks og brunørret postsmolt i Beiarfjorden og fjordkomplekset utenfor. Totalt 108 atlanterhavslaks (lengde = 142 ± 10 mm) og 142 brunørret (lengde = 174 ± 36 mm) ble fanget og merket gjennom våren og sommeren 2022 og 2023.

Denne studien fant at atlanterhavslaks postsmolt nesten utelukkende (88 %) brukte det nordlige fjordløpet (Nordfjorden) under utvandringen, i motsetning til det sydvestlige fjordløpet. For brunørret holdt 94 % seg inne i Beiarfjorden. Videre hadde de en kontinuerlig tilstedeværelse i denne vernede fjordseksjonen fra mai til september, med et redusert antall deteksjoner i juli, noe som tyder på bruk av habitater i uovervåkede seksjoner av Beiarfjorden i denne måneden. I 2023 var gjennomsnittlig dato for vandring til elvemunningen for brunørret 15. juni (fra 15. mai til 20. august), mens det for atlanterhavslaksen var en gjennomsnittlig dato estimert til 3. juni (fra 14. mai til 13. juli). Atlanterhavslaksen økte svømmehastigheten fra en gjennomsnittshastighet på 0.64 kroppslengder per sekund (0.32 km/t) i Beiarfjorden, til 1.76 kroppslengder per sekund (0.87 km/t) i Nordfjorden, med en gjennomsnittlig oppholdstid på 113 timer (variasjonsbredde = 11 – 1278 timer) i Beiarfjorden, og 27 timer (variasjonsbredde = 7 – 195 timer) i Nordfjorden. Tilstedeværelse av atlanterhavslaks postsmolt i Nordfjorden ble påvist å vare fra 16. mai til 17. august i 2023. Den korte oppholdstiden til atlanterhavslaks postsmolt i Nordfjorden, i tillegg til den mer stasjonære adferden til brunørret postsmolt i Beiarfjorden, indikerer en redusert eksponering fra lokal oppdrettsnæring, og understreker viktigheten av det nasjonale laksevernet i Beiarn.

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1 INTRODUCTION

Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) are salmonids originating from the same genus, thus sharing a number of similarities. Perhaps one of the most spectacular common features of these freshwater species are their ability to migrate to sea to feed, later returning back to their freshwater home grounds to spawn (Jonsson & Jonsson, 2011d). In preparation for a marine migration, Atlantic salmon and brown trout undergo a physiological and behavioral change better suited for marine life, called smoltification (Thorstad *et al.*, 2012). During this phase the salmonids are called smolts, while they enter the post-smolt stage as soon as they enter the marine environment. This pre-requisite for seaward migration is hormonally governed, and triggered by water temperature and photoperiod (Jonsson & Jonsson, 2011d). Both species possess the ability of becoming anadromous migrants, but the spatial and temporal scale of this migration varies greatly between Atlantic salmon and brown trout. While Atlantic salmon post-smolts migrate to the North Atlantic Ocean to feed, brown trout post-smolts seldom migrate more than 100 km away from their home river (Jonsson & Jonsson, 2006; Jonsson & Jonsson, 2011a).

A predominant factor in the marine migration is the change in food availability between habitats (Gross *et al.*, 1988). Better feeding opportunities in the marine habitat alongside substantially reduced intraspecific competition provides a potential for an increased growth, which in turn has a positive impact on gonadal production and reproductive success (Jonsson & Jonsson, 2011b). However, these benefits do come with a high inherent cost, as energy expenditure will increase for anadromous populations, and the mortality risk due to predation and disease is high in the post-smolt phase, especially during the early part of the marine migration (Thorstad *et al.*, 2007; Jonsson & Jonsson, 2011b; Flaten *et al.*, 2016; Halttunen *et al.*, 2018; Kristensen *et al.*, 2018). While Atlantic salmon in large part are obligate migrants, brown trout are more facultative in their migration, and hence allow for environmental factors to influence the proportion of the population migrating seawards, to a larger extent. If marine residency, compared to the freshwater habitat, no longer offer improved growth, or mortality becomes higher than the gain from increased fecundity, the amount of brown trout that resorts to anadromy is likely to decline (Halttunen *et al.*, 2018; Eldøy *et al.*, 2020).

Anthropogenic activities are posing challenges for wild anadromous populations, with early marine life stages being particularly susceptible to the impacts of open net pen salmon aquaculture, with this type of fish farming being potential sources of pathogens transmitted between farmed stock and wild fish populations (Thorstad *et al.*, 2015). The introduction of Atlantic salmon open net pen farming increases the abundance of the ectoparasite salmon louse (*Lepeophtheirus salmonis*), which feeds on the mucus, skin, and muscle of the host (Thorstad *et al.*, 2015; Eldøy *et al.*, 2020). An infestation could cause osmoregulatory issues and decreased disease resistance, negatively impacting growth, and potentially contribute to mortalities in the long run (Thorstad *et al.*, 2015; Serra-Llinares *et al.*, 2020). The presence of salmon lice in areas with salmon farming is higher compared to locations without (Bjørn *et al.*, 2001; Bjørn *et al.*, 2011), and since Beiarfjorden has no outlet without fish farms present, this is a viable concern.

For wild brown trout, an increase in salmon lice infestation pressure could result in shorter marine residency and reduced marine habitat use (Bjørn *et al.*, 2001), potentially reducing the seaward migrating part of the population over time (Halttunen *et al.*, 2018; Serra-Llinares *et al.*, 2018; Serra-Llinares *et al.*, 2020). With Atlantic salmon having to swim through fjord sections used for fish farming in order to get to the open ocean, time spent in these sections will be decisive in the pathogen exposure risk. Unlike brown trout, Atlantic salmon do not have the practical capability of returning to freshwater if infested by a high amount of salmon lice (Sivertsgård *et al.*, 2007), making the progression rate out to the open ocean very important.

With coastal zones being of great importance for anadromous salmonids, but also particularly vulnerable to human intervention, the Norwegian government designated a total of 29 fjords in an effort to better protect the most important Atlantic salmon populations in the country. The national salmon fjord protection entails protection against anthropogenic interventions with potential negative effects on their wild salmon stocks, and populations in these areas are expected to have a reduced presence of salmon lice (DKMD, 2006; Steinkjer, 2021; Davidsen *et al.*, 2022). Beiarfjorden ultimately became a nationally protected salmon fjord in 2007, preventing fish farming in this fjord, in addition to the connected fjord section, Holmsundfjorden. Although this protection was aimed at Atlantic salmon, brown trout effectively got a reduced aquacultural impact in the areas under this protection. However, Nordfjorden and Morsdalsfjorden, being the northern and southwestern exit route out of the fjord complex outside Beiarfjorden, are not subject to the national salmon protection. With overlapping spatial use between brown trout and fish farming in these fjord sections, the effect of this protected zone on the wild brown trout population should be questioned, as they are a separate species with a different life history than Atlantic salmon (Sortland *et al.*, 2024). Reports addressing the condition of brown trout populations in Norway have assessed that aquaculture continues to be of moderate impact in Beiarn (Anon, 2019; 2022), and with both Atlantic salmon and brown trout being of substantial economic, social and cultural importance for many people (Pennell & Prouzet, 2009; Liu *et al.*, 2019), further insight into these species' use of the fjord systems and the dangers they my face as post-smolts should therefore be properly investigated.

Tracking studies on adult Atlantic salmon and brown trout in Beiarfjorden indicate that the national salmon protection largely protects smaller sized adult brown trout, while larger individuals are more exposed to pathogens from fish farming, owed to their increased spatial use within the fjords (Nilsen, 2021; Steinkjer, 2021; Davidsen *et al.*, 2022). Moreover, the protection does little to protect Atlantic salmon kelts (individuals that have spawned at least once) during their seaward migration, but limited residency in Nordfjorden reduces the chances of infestation (Nilsen, 2021; Davidsen *et al.*, 2022). Nilsen (2021) and Steinkjer (2021) both suggested focused conservation strategies, treating Atlantic salmon Brown trout as different species in need of different management actions. Corresponding knowledge does not exist for salmonid post-smolts in Beiarfjorden, however, and considering that the transition from fresh to salt water is a more vulnerable phase for smolts than for adult salmonids (Davidsen *et al.*, 2022), increased knowledge of this life stage could be an important contribution in future protective assessments made.

With the overarching research goal of mapping migratory behavior and habitat use of wild populations of brown trout and Atlantic salmon post-smolts in Beiarfjorden and the fjord complex outside the fjord, the following hypotheses were tested: *1) Atlantic salmon post-smolts use the northern exit in the fjord complex outside Beiarfjorden*, *2) brown trout post-smolts keep within the confines of Beiarfjorden,* and *3) Atlantic salmon post-smolts have a higher swimming speed in the fjord complex outside than in Beiarfjorden*. During the summers of 2022 and 2023, acoustic telemetry was used to track tagged Atlantic salmon and brown trout, in order to compare migratory behavior and habitat use between the two species.

2 MATERIALS AND METHODS

2.1 STUDY AREA

Studying the seaward migration of brown trout and Atlantic salmon, a large research area was monitored, and included Beiarelva, Beiarfjorden, Nordfjorden, Holmsundfjorden and Morsdalsfjoden (figure 1). The study area hence spanned from the municipality of Beiarn, through Gildeskål and up to the southern end of Bodø municipality, all situated in Nordland County, Norway. While Nordfjorden often is referred to as the northern exit later in the text, Holmsundfjorden and Morsdalsfjorden constitute the southwestern exit. The study took place during two summer seasons, from June 4 to October 5, 2022 and from May 8 to September 27, 2023.

2.1.1 BEIARELVA

Beiarelva is a river starting northeast of Svartisen, at the upper parts of Beiardalen, and stretches all the way to the estuary close to Tverrvika, in Beiarn municipality (figure 1). The total length of the river is approximately 54 kilometers, with the lower 7 km affected by the tides. The anadromous stretch spans approximately 25 km upwards from the point of no tidal influence (Davidsen *et al.*, 2020). Larger tributaries often used by salmonids in Beiarelva are Tollåga and Gjeddåga, both of which fish were caught and tagged in this project. Water regulation and rotenone treatment of the water due to presence of the ectoparasite *Gyrodactulus salaris* during the mid-1990s put restrictions on fishing for many years, with Beiarelva not being declared healthy again until 2001 (Davidsen *et al.*, 2020). The river was defined as a national salmon river in 2007, alongside the now nationally protected fjord, Beiarfjorden.

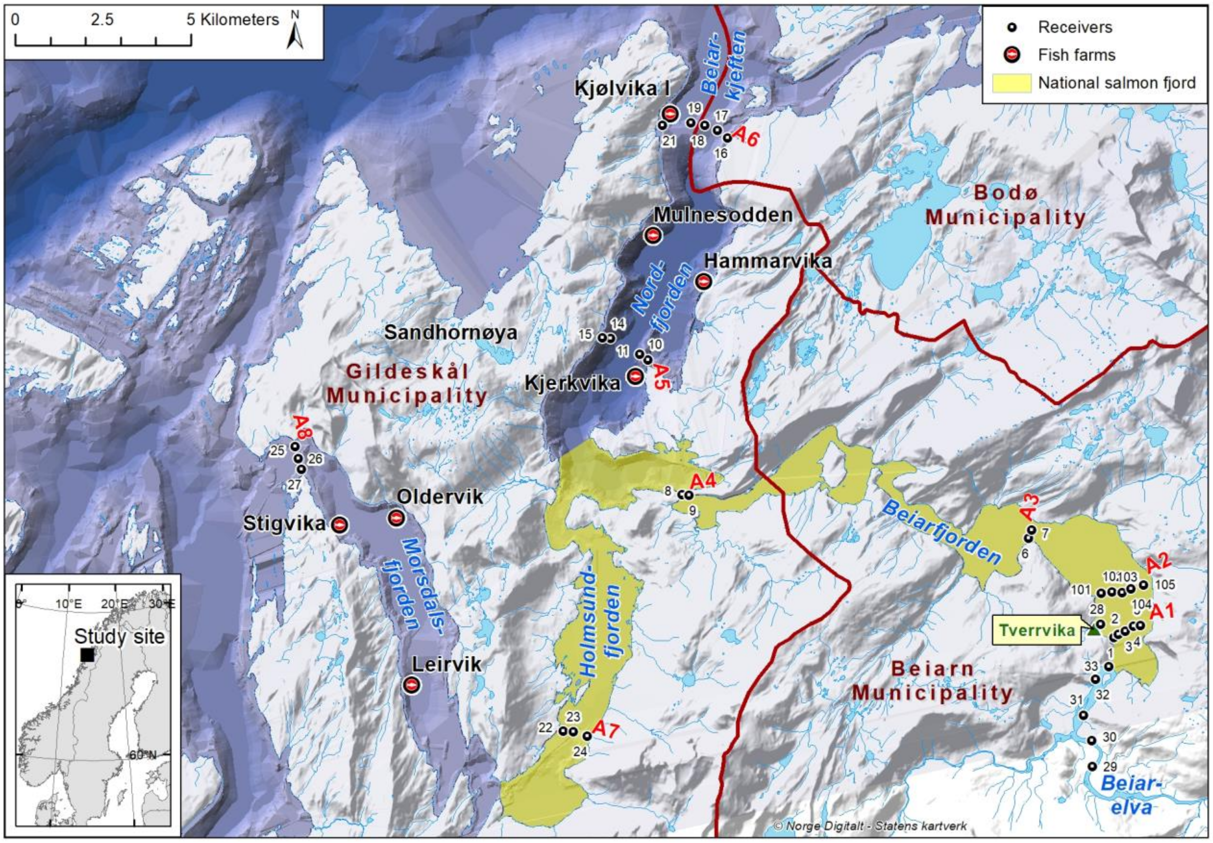

***Figure 1**: Study area with indication of deployed acoustic receivers (⊙), locations for open net-pen Atlantic salmon aquaculture (⊖) and the protected national salmon fjord ( )*

2.1.2 BEIARFJORDEN & SANDHORNØYA

Due to Beiarfjorden becoming a national salmon fjord in 2007, no fish farms are found in this section of the fjord (Davidsen *et al.*, 2022). The fjord stretches 19 km in length, from the mouth of Beiarelva, all the way out to Sandhornøya, making two distinct fjord exits (figure 1). The fjord has varying depths, with several sections going down to 160 meters (barentswatch.no). The island is separated from the mainland by Nordfjorden, Holmsundfjorden and Mordsdalsfjorden. Sandhornøya encompasses an area of more than 100 km^2, and its highest peak reaches 993 above sea level. Seven fish farms are located within the confines of the study area, but additional fish farms are surrounding the north and western sides of the island (not given on the map).

2.1.3 NORTHERN FJORD EXIT

Nordfjorden, also referred to as the northern exit, extends northward from Beiarfjorden up to Beiarkjeften, and runs along the northwestern side of Sandhornøya (figure 1). Nordfjorden reaches 13 km in length, and with this fjord not being part of the national salmon protection zone, while also having good enough conditions for aquaculture, four fish farm locations are found here: Kjølvika I, Mulnesodden, Hammarvika and Kjerkvika. Kjølvika was only active during the winter of 2022/2023 (barentswatch.no). Nordfjorden constitutes the deepest fjord section in study area, with depths down towards 400 meters (barentswatch.no) (Nilsen, 2021).

2.1.4 SOUTHWESTERN FJORD EXIT

Holmsundfjorden, being the first section of the southwestern fjord exit, is included as a part of the national salmon fjord and marks the southern end of the protected area (figure 1), adding 13 km of fjord to the national salmon protestation. No fish farm locations zre found in Holmsundfjorden. This part of the study area can generally be described as shallow and quite narrow compared to that of the other fjord sections (Nilsen, 2021), with depths generally well under 100 meters (barentswatch.no). Morsdalsfjorden, pointing northwest from the southern end of Holmsundfjorden, is the continuation of the southwestern exit from Beiarfjorden. This fjord section is not a part of the national salmon fjord, and three fish farm locations can be found here: Leirvik, Oldervik and Stigvika, though Oldervik was not in use during the study period (barentswatch.no). The length of the fjord is 11 km, and while the general depth in this fjord is considerably deeper than Holmsundfjorden, it is not to the same extent as Nordfjorden, only having depths down towards 150 meters in some sections (barentswatch.no).

2.2 DATA COLLECTION – ACOUSTIC TELEMETRY

2.2.1 CAPTURE AND TAGGING

Fish capture and tagging was conducted during three separate fieldwork events, using two different approaches. Capture and tagging in 2022 took place from June 4 to July 7, with smolt-traps being the sole capture method used this year. First fieldwork session of 2023 was conducted during a short available time window, where waterflow in Beiarelva was very low, allowing for electrofishing (figure 2). This capturing method was used from May 8 to 10. The second fieldwork event went on from May 22 to June 15, and because of mostly high waterflow in the river, smolt-traps was used exclusively in this period. The traps were set up in the estuary east of Tverrvika (figure 1),

Previous observations in the field in combination with calculated smolt lengths from scales (Davidsen *et al.*, 2022), have indicated smolts lengths in the water course ranging from 111 – 198 mm for Atlantic salmon and 103 – 254 mm for brown trout. However, to keep a low tag to body mass percentage to reduce the tagging effect (Doogan *et al.*, 2023), a minimum length of 130 mm was set for both Atlantic salmon and brown trout. Further, based on the estimates of variance and standard deviation done by Davidsen et al. (2022), an upper limit of 200 mm was set for Atlantic salmon post-smolts and 260 mm for brown trout post-smolts.

After capture by electrofishing or trapping, fish was held in a holding tank (either a net in the river, or a ventilated tank on land by Tvervika) until tagging (1-4 days). Before tagging smolts were anaesthetized using Benzoak Vet. (15-20mL/100L) for 4-5 minutes. The fish was then measured in total length (mm) and body mass (g), before being placed on the operating table with a tube inserted to the mouth to allow water flow over the gills, or alternatively had gills submerged when tagging predominantly larger sized salmonid post-smolts. An 10-15 mm incision was performed with a scalpel into the abdominal cavity, anterior of left pelvic fin, ventral side up. The acoustic tag was then inserted in direction towards the pelvic fin, and the incision was closed with two interrupted suture knots (Resolon suture 5-0), followed by recovery and release. Length of the recovery time given varied, but usually the fish would be held in a recovery tank for 30-45 minutes after the procedure. Tanks were always covered with a tarp to reduce stress. During electrofishing, all smolts were released close to the catch site in the river, while smolts trapped in the river mouth were released in Tverrvika (figure 1). In 2022, five Atlantic salmon and 28 brown trout post-smolts were caught, and in 2023, an additional 103 and 114 were captured, respectively (table 1). Proceedings were done in accordance with a permission (22/41685) from the Norwegian Food and Safety Authority.

Table 1: Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) sample size (n). Total number of fish caught in 2022 and 2023. TL: total length. m: body mass. SD: standard deviation.

2022	**n**	**TL (mm)**			**m (g)**		
Species	**Total**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**
Salmo salar	5	**15.9**	1.2	14.2 - 17.5	**31**	9	23 - 45
Salmo trutta	28	**17.4**	3.5	13.0 - 25.6	**49**	37	15 - 164
2023	**N**	**TL (mm)**			**m (g)**		
Species	**Total**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**
Salmo salar	103	**14.1**	1.0	13.0 - 19.6	**22**	4	17 - 48
Salmo trutta	114	**17.4**	3.6	13.0 - 25.8	**51**	35	18 - 160

2.2.2 TRANSMITTERS

The acoustic transmitters used in this project, hereby referred to as tags, are transmitting sound signals, which in turn can be detected by receivers. The tags used were two versions of the standard ID transmitters from Thelma Biotel AS (table 2), as well as tags with temperature sensors in addition to ID. Of the 250 tags utilized in 2022 and 2023, 120 were type T-LP6, 96 were type ID-MP6, and 34 were type ID-LP6.

Table 2: Acoustic transmitter specifications for the tags used. The tags provided either the ID of the fish (ID) or a combination of ID and the temperature of the fish (T). The power level in the tags differed between low (LP) or medium (MP). Diameter of all tags were 6.3 mm.

Tag Type	Length (mm)	Est. Battery Life	Power Output (dB)	Interval (sec)	Body mass (Air/Water)	Protocol	Frequency
ID-LP6	15.5	4.1 months	137	30-90	1.2/0.7 g	R64K	69/71
T-LP6	18.5	3.1 months	137	30-90	1.3/0.8 g	S64K	69/71
ID-MP6	18.5	2.3 months	139	30-90	2.0/1.0 g	R64K	69

2.2.3 RECEIVERS

A total of 37 receiver stations (Thelma biotel models TBR800R, TBR800 or TBR700L) were used to monitor the study area (figure 1). Eight arrays of receivers were deployed, with A1-A4 in Beiarfjorden (15 km distance), A5-A6 in Nordfjorden (13 km distance), and A7-A8 in Holmsundfjorden and Morsdalsfjorden (24 km distance). A singular station deployed the settlement Tverrvika is not included in an array, and henceforth referred to simply as Tverrvika station. However, stations adjacent to the estuary (namely A1, A2 and Tverrvika station) are 1 km apart, and often complied and referred to as the estuary stations.

For most stations with depths shallower than 100 m, a single receiver was deployed app. 30 m below water surface. At greater depths, an acoustic receiver with a release function (Vemco model VR2-AR or AAR-RLD and Thelma biotel model TBR800R) were deployed at the bottom and the receiver detecting tagged fish attached to a rope so it was located app. 30 below water surface. All receivers in the fjord were moored with a 40 kg anchor, 14 mm rope and two trawl floats. In the lower part of the river, TBR700L were attached to concrete blocks and chained to the shore.

2.2.4 RECEIVER PERFORMANCE

Receiver performance was estimated to check the reliability of the detections in the fjord complex. Using Atlantic salmon post-smolts detected along the outermost array (A6) in Nordfjorden (n = 26), registrations were then backtracked through the remaining arrays based on the fish IDs detected at array A6 (figure 1). The estuary stations (A1, A2 and Tverrvika) had a receiver performance of 96 % (n = 25). Varying receiver performance was found in the remaining arrays, with A3 at 73 % (n = 19), A4 at 92 % (n = 24) and A5 at 85 % (n = 22). Array A1 and array A2 were not included separately in these estimates, as array A1 was located closer to the estuary than the release site by Tverrvika, and array A2 were deployed on May 22, 2023, excluding detections from fish tagged and released prior to deployment. As there were only two Atlantic salmon that traversed the southwestern exit (A7-A8), these were excluded in favor of unmixed detection percentages along the northern exit.

2.2.5 RETRIEVING DATA

All receivers were downloaded using the Comport software (thelmabiotel.com) during the period of October 3 to 5, 2022, and September 25 to 27, 2023. Using acoustic telemetry, two main types of errors tend to occur: sound pollution and signal collision. The former can occur when sound from a different source than a tag is interpreted as a transmitter signal by a receiver. Sound pollution rarely register as existing IDs, and are usually a negligible issue during filtration (Steinkjer, 2021). The latter is the result of two or more tag signals overlapping, creating a new and possibly existing ID (Pincock, 2012; Nilsen, 2021; Steinkjer, 2021). Signal collisions are more common, however, and while filtration can remove a significant number of errors, a complete removal of all false detections would be unlikely (Pincock, 2012). A mediating measure taken in this study was that for periods with a total of more than 1000 detections and/or three or more detections of false transmitter IDs on a single receiver within 24 hours, a filter requiring at least two valid detections within 60 minutes from a transmitter ID of a tagged fish to pass as accepted detections for further analyses. Unfiltered registrations for Atlantic salmon and brown trout in total were 801 934. After initial filtration, this number was reduced 793 337 registrations (98.9 % of initial detections), with 42 % coming from Atlantic salmon.

2.3 ENVIRONMENTAL VARIABLES

Temperature and water flow (figure 2) measured during the smolt run in 2023 at the bridge Selfors bru about 11 km upstream from the estuary of Beiarelva was accessed through sildre.nve.no. Temperatures during fieldwork events were found to be 11.3 ^{o}C (range = 11.1 – 11.7 ^{o}C) during May 8-10, and 11.9 ^{o}C (range = 11.4 – 12.7 ^{o}C) during May 22 – June 15. Water flow in the river was found to be 25.8 m^3/s (range = 6.9 – 59.0 m^3/s) and 81.8 m^3/s (range = 35.5 – 203.1 m^3/s), respectively.

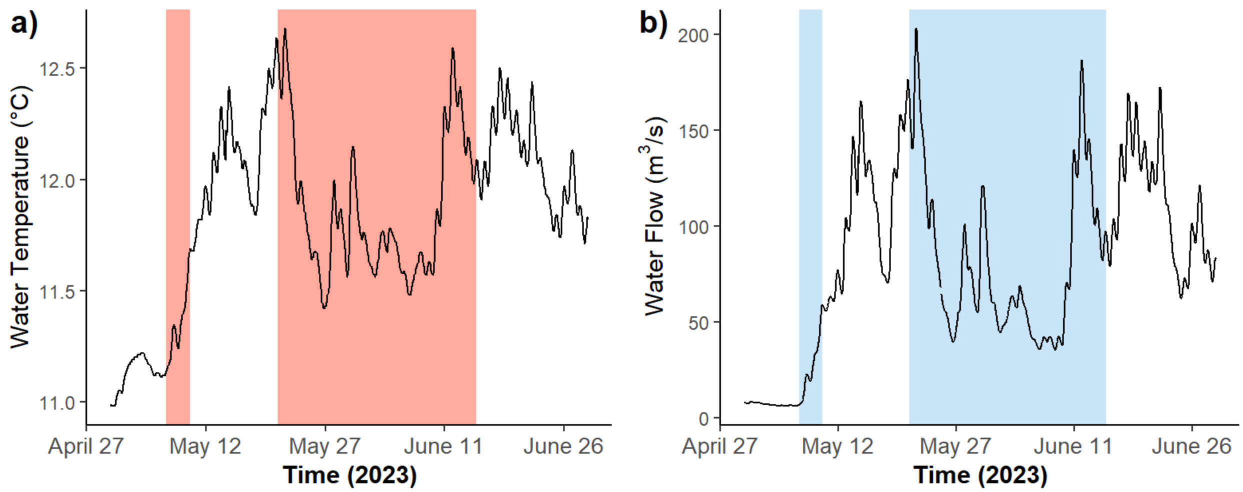

Figure 2*: Water temperature and water flow measured at Selfors bru, Beiarn municipality (Nordland). Data is collected for the months of May and June 2023 (from sildre.nve.no), showing a) water temperatures (◦C) and b) water flow (m^3/s). Colored sections indicate fieldwork events in 2023, with first stay from May 8 to 10, and second stay from May 22 to June 15.*

2.4 DATA ANALYSES

2.4.1 DATA FILTRATION

A comprehensive filtration process was necessary in order to work with the detection data collected. In addition to the initial filtration of raw data, IDs of tagged fish without detections, IDs with only false registrations, and IDs detected at only one singular station was removed. Fish presumed dead (n = 13) based on persistent stationary records was also removed from the sample. This secondary filtration adjusted the sample size to 81 Atlantic salmon, and 104 brown trout post-smolts. Detections from nearby stations were grouped, with the arrays in the fjord making up the lines A1-A8 (figure 1). Additionally, the river stations were grouped to form the cluster River, combining detections from station 29-33. As the majority of fish in this project were tagged and released by Tverrvika (figure 1), station 28 gathered a lot of initial registrations, and hence, was not grouped with any other stations. An additional round of filtration was necessary for the travelling speed data. This subsample demanded detections by the estuary and the outlet of Beiarfjorden (A4), or from the outlet to either of the fjord exits (A6 or A8). As the distances between stations in Tverrvika, array A1 and A2 varied with less 1 km, all 11 stations were clustered, indicated as A1 in figure 7.

2.4.2 FULTON'S CONDITION FACTOR

The condition factor for a fish shows the relationship between length and body mass of the individual or group. This relationship is usually described through an exponential function (Le Cren, 1951),

$$W = a * L^b \tag{1}$$

with W being the body mass (g), L being the length (cm), a is a constant, and b usually being an exponent between 2.5 and 4, depending on the species in question. When looking at fish considered to go through isometric growth, somewhat keeping the same shape throughout its lifetime, b can be set to 3. This seems to generally apply to salmonids (Svenning & Christensen, 1996), even though cases where length-body mass relationships often have been proved not to fit the cube law well (Le Cren, 1951). Although a particularly young life stage is being studied in this thesis, which arguably could warrant another exponent, b = 3 will be used here, to better follow up previous reports and papers from this study area. Alternatives to this exponent will be referred to later in the text using the same term (b).

By adding the exponent for b = 3 as well as substituting a = k / 100 in formula (1), Fulton's condition factor can be derived (Fulton, 1902; 1904),

$$K = 100 * \frac{W}{L^3} = 100 * \frac{Body\ Mass\ (g)}{Body\ Length\ (cm)^{\ 3}} \qquad (2)$$

with body mass in wet weight measured in grams (g) and body length in total length (TL) measured in centimeters (cm), keeping measurements in line with previous data collected in the study area. With body mass and length measurements being independent of detection data, all available data were used in the calculations (figure 3).

Looking at the differences between the condition factors for the two species, the Shapiro-Wilk test was used to look for normal distributions within the groups. Moreover, Levene's test was used to test for equal variances. While Atlantic salmon showed a normal distribution (Shapiro-Wilk test, $p > 0.05$), brown trout did not ($p < 0.05$). This, in addition to a significant result from the Levene test (Levene's test, $p < 0.05$), indicating unequal variances, set the grounds for choosing a non-parametric test, opting for the Wilcoxon Rank Sum Test. This decision was based on the classic t-test assuming a normal distribution and homogenous variances, which these data don't seem to have. A Wilcoxon Rank Sum Test was also used checking for intraspecific differences between years.

2.4.3 STATISTICAL ANALYSES

Statistical analyses were done using R Version 4.3.1 (R Core Team, 2023) through RStudio (R Studio, 2023). Multiple packages from *tidyverse*, which is a large collection of packages dealing with presentation and transformation of data, have been used in these analyses (Wickham *et al.*, 2019). The package *ggplot2* and S*cales* has been used for all plots (Wickham, 2016; Seidel, 2022). The R package *stringr* was used in order to handle data formatted as text strings (Wickham, 2022). Additionally, *dplyr* was used, which adds crucial functions used in this project, having helped substantially in the manipulation and analyses of data used, making maneuvers such as selections, groupings, filtrations, mutations and summarizations easier and more intuitive (Hadley Wickham, 2023). The package *tidyr* have been used too, tidying the data so that columns forms variables, rows constitute observations, and tables form observational units (Girlich, 2023). Finally, the package *lubridate* was used to a great extent, as it was important in handling several aspects of the date and time data used (Wickham, 2011a).

The package *ggpubr* compliments tidyverse, while not actually being a part of it, as it simplifies the process of combining and making plot combinations (Kassambara, 2023). The dunn.test was used for non-parametric analysis (Dinno, 2024). On a wider scale, the Companion to Applied Regression package, or *car*, was used, as it holds many different functions enabling further analytical support for standard regression models, as well as diagnostic plots (Weisberg, 2019). MuMIn, or Multi-Model Inference, was used to compare different models made, to better choose the right fit based on AIC values, through the function *dredge* (Barton, 2023). *openxlsx* was used to move tables to Excel in an easy manner (Walker, 2023), and lastly, *plyr* was used in part for e.g., splitting and combining data (Wickham, 2011b).

Statistical analyses were applied to the presence data at different arrays in the fjord, to find statistical support in addition to seeing if any other parameters were involved in these trends. Model selection for the most appropriate GLM was found for figure 5, through the use of a global model including all available parameters in the table as predictor variables (location, species, length, body mass and condition factor), including the interaction between array and species, was used. All available sub-models were explored, and a subset of the best models was chosen through a delta AICc of less than 4, with the model selection supporting multiple alternative models of equal fit (Anderson *et al.*, 2001). A conditional average from the averaged model summary was then used. With the majority of the data not having a normal distribution, analyses conducted used the non-parametric Wilcoxon rank-sum test, which is comparing two independent samples. Additionally, a Kruskal-Wallis rank sum test was used when analyzing the travelling speed of Atlantic salmon, as this required a non-parametric test for more than two samples. This was then followed by a Dunn’s test.

3 RESULTS

3.1 LENGTH-BODY MASS RELATIONSHIP

Due to the low sample size in 2022, data from 2022 and 2023 were merged into one dataset in order to increase the overall sample. For Atlantic salmon smolts, there was a small, but significant difference in length between years (T-test, $p < 0.05$), while this was not the case for the brown trout ($p > 0.05$). Considering the particularly small sample size of Atlantic salmon from 2022 ($n = 5$), the result of this analysis was less reliable compared to brown trout from 2022 ($n = 28$), and it was concluded that merging the two years would not have consequences for the overall findings or conclusions. Analyzes conducted where one of the year groups are separate, this will be specified in the text.

Total length and body mass measurements from the samples of Atlantic salmon and brown trout post-smolts from 2022 and 2023 showed that mean total length and body mass of brown trout was larger than Atlantic salmon (table 1). Intraspecific variance was also higher in brown trout (figure 3). Regression line from the log-transformed length and body mass parameters showed that brown trout post-smolts ($b_t = 2.96$) also were heavier per unit body mass than Atlantic salmon post-smolts ($b_s = 2.43$). Atlantic salmon post-smolts having $b < 2.5$ suggests an allometric growth for the group rather than an isometric growth (formula 1).

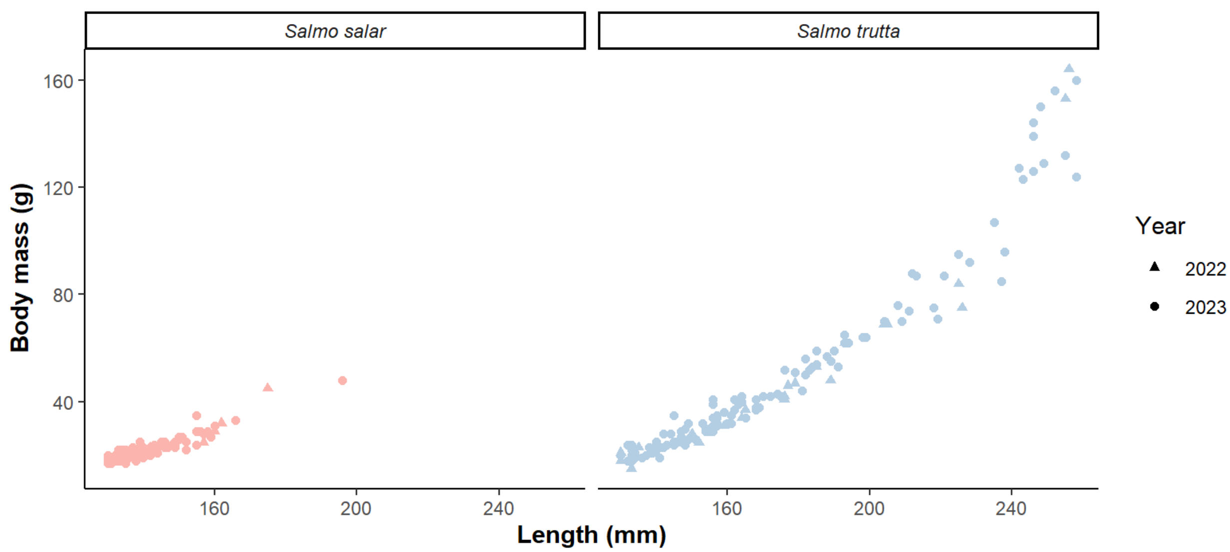

***Figure 3**: Total length (mm) and body mass (g) of Atlantic salmon (Salmo salar) and brown trout (Salmo trutta) from 2022 (▲) and 2023 (●).*

3.2 FULTON'S CONDITION FACTOR

Fulton's condition factor for Atlantic salmon and brown trout was estimated using exponent $b = 3$ (formula 2), finding a higher overall condition factor for brown trout (Wilcoxon rank-sum test, $p < 0.001$). Mean condition factors (K) were calculated to be 0.78 ($n = 108$, SD = ± 0.06, range = 0.63-0.94) for Atlantic salmon, and 0.84 ($n = 142$, SD = ± 0.09, range = 0.64-1.15) for brown trout post-smolts (figure 4). No intraspecific difference was found between the groups of 2022 and 2023 for Atlantic salmon post-smolts (Wilcoxon rank-sum test, p > 0.05), and variance was small compared to brown trout. A significant result was found in brown trout post-smolts, with a condition factor indicating a slightly more conditioned sample in 2023 (Wilcoxon rank-sum test, $p < 0.05$).

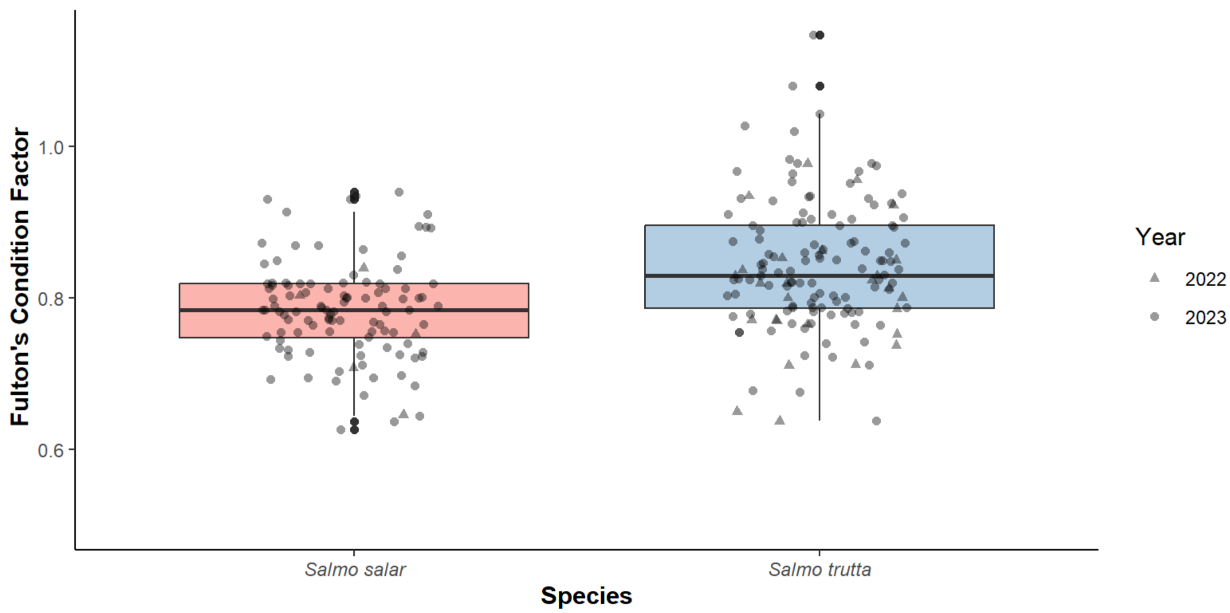

***Figure 4**: Fulton's condition factor (K) for Atlantic salmon (Salmo salar) and brown trout (Salmo trutta) from 2022 (▲) and 2023 (●), using 3 as exponent, assuming an isometric growth. Salmo salar (n = 108), Salmo trutta (n = 142).*

3.3 AREA USE

Of 108 tagged Atlantic salmon and 142 tagged brown trout tagged, 75% (*n* = 81) and 73% (*n* = 104), respectively, were used to study the area use. In the estuary and in Beiarfjorden (A1-A3), there was a big interspecific overlap in area use (figure 5). Further out, at the outermost point of Beiarfjorden (A4) and along Nordfjorden (A5 and A6), a comprehensive difference in area use was found. Only six (5.8 %) brown trout post-smolts were detected swimming past array A4, and only four of these (3.8%) ventured out to any of the arrays in other fjord sections (A5-A8). As opposed to the brown trout, the Atlantic salmon post-smolts had fairly even detection rates across all arrays in Beiarfjorden (A1-A4). The detection rate decreased further out in the fjord complex, with the highest number of detections being in Nordfjorden (A5-A6).

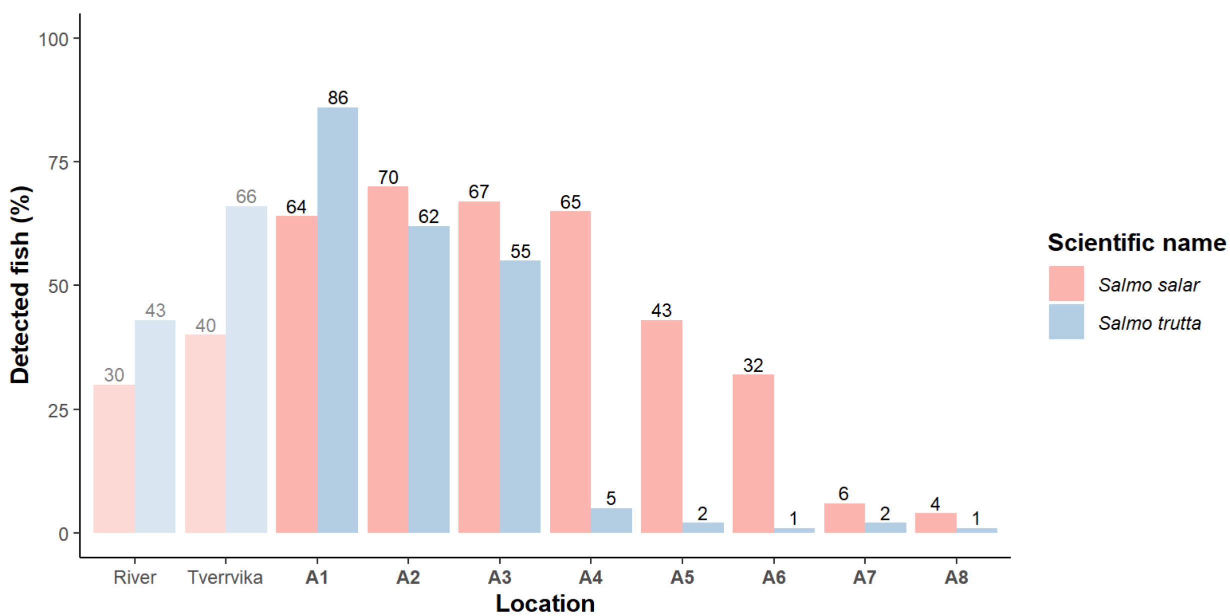

Figure 5*: Detections of Atlantic salmon (Salmo salar) and brown trout (Salmo trutta) at the different arrays (A1-A8) in bold, as well as River (Station 29-33) and Tverrvika (Station 28) in a more transparent coloring. Box plot displaying detections of individual fish presence, showing the number of detections in percentage (%). Total sample size for each species being n = 81 and n = 104, respectively. Data from 2022 and 2023.*

Generalized linear regression was used to model the differences in area use between Atlantic salmon and brown trout post-smolts, and if individual differences were correlated to condition factor, total body length, species, body mass or the interaction term location:species. These variables were included in a global model, where only the sub-models with the best fit (Δ AICc < 4) were included (table 3). The conditional model averaging, estimated through a model averaged summary, gave highly significant negative differences between baseline values (Atlantic salmon at array A1) and arrays A6, A7 and A8 (Model averaging, $p < 0.001$), In addition to a significant difference to A5 ($p < 0.01$). Significant difference was found in brown trout compared to baseline ($p < 0.05$), also evident the plot (figure 5). Strongly significant negative differences were found between species at arrays A3 - A6 ($p < 0.001$), and particularly for the latter three arrays. Additionally, array A2 and A7 ($p < 0.01$), and array A8 ($p < 0.05$), had significant differences in detection percentage. No significant correlation was found for presence and length, body mass or condition factor, but as shown above, the interaction term estimated multiple significant differences between species presence at arrays further out in the fjord complex, in particular. Species, location, and the interaction between these two variables were of highest importance in this model average, being the only term codes consistently present at all sub-models used.

Table 3: Model selection for the detections of Atlantic salmon and brown trout post-smolts in Beiarfjorden, Nordland. A generalized linear model was used with presence/absence data as a response variable, with combinations of the following parameters: location (1), condition factor (2), length (3), species (4), body mass (5) and the interaction term location:species (6). Sub-models included were filtered based on a Δ AICc value < 4.

	Term Codes:	df	Log likelihood	AICc	Delta AICc	AICc Weight
Model 1	1, 2, –, 4, 5, 6	22	-811.59	1667.74	0.00	0.31
Model 2	1, –, –, 4, 5, 6	21	-812.91	1668.32	0.58	0.23
Model 3	1, 2, 3, 4, –, 6	22	-812.01	1668.57	0.82	0.20
Model 4	1, –, 3, 4, 5, 6	22	-812.32	1669.19	1.45	0.15
Model 5	1, 2, 3, 4, 5, 6	23	-811.59	1669.79	2.05	0.11

Atlantic salmon and brown trout post-smolts had a spatial and temporal overlap from the estuary out to array A3 during the month of June (figure 6 b-e). For Atlantic salmon post-smolts, the detections in both Beiarfjorden and the fjord complex outside were highest during this month. There were only few detections in June and July, and no detections during September. Brown trout had a comparatively constant presence during June to September in inner Beiarfjorden, seeing only a small drop in detections in July, while arrays outside Beiarfjorden, from array A4 onwards, only getting a few sporadic detections (figure 6 f-j). Brown trout post-smolts had an estuary entry date estimated to mid-June (*n* = 78, mean date = June 15, range = May 15 – August 20, 2023), and Atlantic salmon post-smolts had a mean entry date closer to the start of June (*n* = 75, mean date = June 3, range = May 14 – July 13, 2023). Atlantic salmon were present in Nordfjorden from May 16 to August 17, 2023.

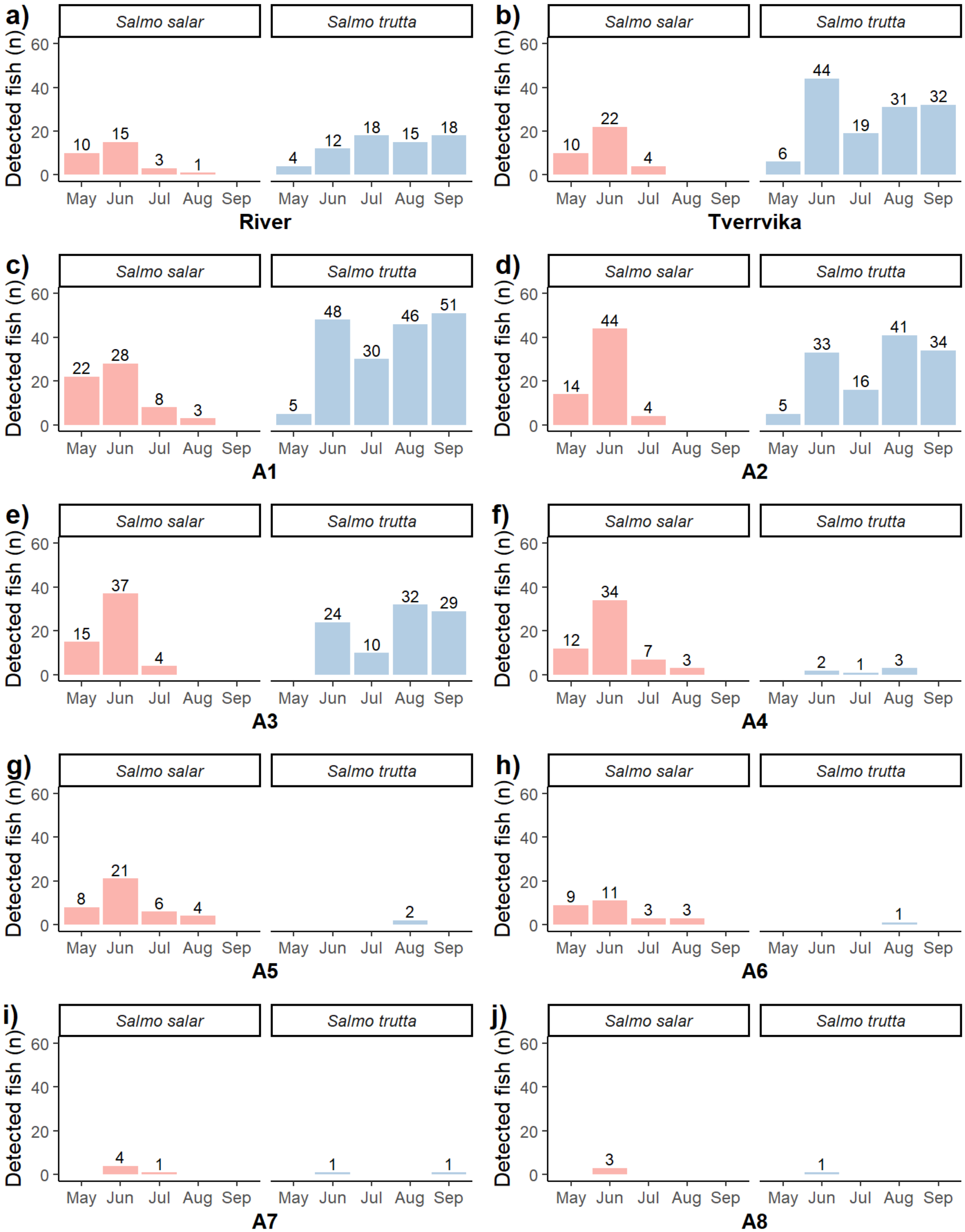

***Figure 6**: Number of detected individuals (n) of Atlantic salmon (Salmo salar) and brown trout (Salmo trutta) from May – September (2022 and 2023) at the different locations (a – j).*

3.4 TRAVELLING SPEED ANALYSES

Atlantic salmon post-smolts had an increasing progression through the fjord complex. On average, 113 hours (*n* = 50, distance = 15 km, range = 11 – 1278 hours) were used in Beiarfjorden, compared to the 27 hours (*n* = 21, distance = 13 km, range = 7 – 195 hours) though the northern fjord exit, and 49 hours (*n* = 3, distance = 24 km, range = 34 - 57 hours) in the southwestern fjord exit. This corresponds with the travelling speed estimates (figure 7) of 0.64 BL/sec (range = 0.02 - 2.87 BL/sec) in Beiarfjorden, 1.76 BL/sec (range = 0.1 - 3.73 BL/sec) along the northern fjord exit, and 1.02 BL/sec along the southwestern fjord exit (range = 0.84 - 1.34 BL/sec). Concurrently, migration speed was estimated in km/h (table 4).

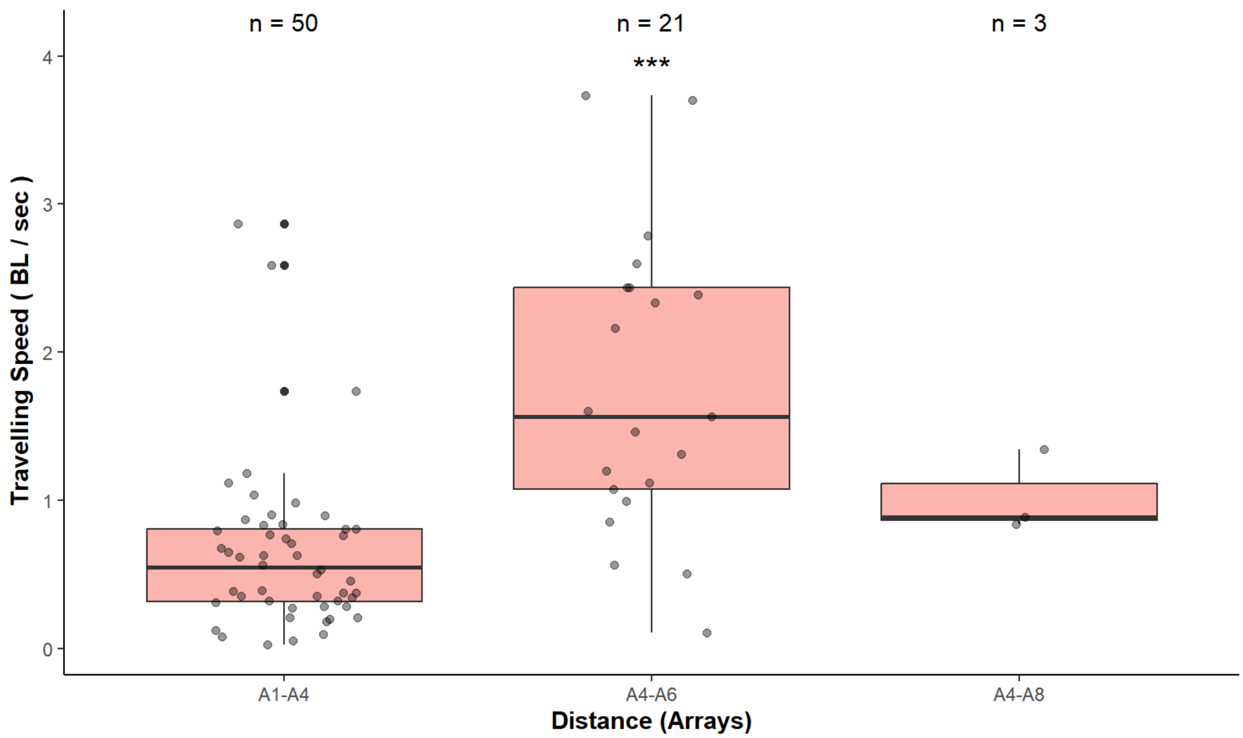

Figure 7*: Travelling speed (BL/sec) in different sections of the fjord for Atlantic salmon (Salmo salar), with median speed for each stretch is 0.55 (A1-A4), 1.56 (A4-A6) and 0.89 (A4-A8). A highly significant positive difference in speed was found for stretch A4-A6 compared to baseline values (A1-A4), indicated by ***.*

There was a significant positive difference between the three distance groups and their travelling speeds (Kruskal-Wallis rank sum test, $p < 0.001$). Further testing reinforced this indication by a highly significant difference in the groups A1-A4 and A4-A6 specifically (Dunn's test, $p < 0.001$).

Table 4: Travelling speed in different sections of the fjord for the Atlantic salmon post-smolts, showing all available data for each section shown in BL/sec and km/h, including standard deviation and range for each group. Gr. 1: includes all fish detected through at least one of the three distance groups. Gr. 2: includes only fish detected at A1-A4, in addition to one of the two additional distances.

Group 1	**n**	**BL/sec**			**km/**		
Distance	**Total**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**
A1-A4	50	**0.64**	0.55	0.02 - 2.87	**0.32**	0.27	0.01 - 1.39
A4-A6	21	**1.76**	1.00	0.10 - 3.73	**0.87**	0.46	0.07 - 1.75
A4-A8	3	**1.02**	0.28	0.84 - 1.34	**0.52**	0.17	0.42 - 0.72
Group 2	**n**	**BL/sec**			**km/**		
Distance	**Total**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**
A1-A4	23	**0.62**	0.58	0.02 - 2.87	**0.32**	0.28	0.01 - 1.39
A4-A6	20	**1.66**	0.91	0.10 - 3.70	**0.82**	0.43	0.07 - 1.73
A4-A8	3	**1.02**	0.28	0.84 - 1.34	**0.52**	0.17	0.42 - 0.72

Since brown trout in general did not reside in the fjord complex outside Beiarfjorden, travelling speeds were not calculated for the small sample of brown trout post-smolts migrating to Nordfjorden, Holmsundfjorden and Morsdalsfjorden (table 5). Mean total length and body mass were larger for brown trout post-smolts observed in the outer fjord complexes ($n = 4$) compared to those that stayed in Beiarfjorden ($n = 100$). However, the difference was not significant (total body length: Wilcoxon rank-sum test, $p > 0.05$, body mass: $p > 0.05$, nor condition factor: $p > 0.05$), most likely due to a low sample size.

Table 5: brown trout post-smolts and their respective mean total body length, body mass and condition factor for the group travelling outside Beiarfjorden (A5-A8), and those staying within the fjord (A1-A4).

	n	**TL (mm)**			**m (g)**			**K**		
	Total	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**
A5-A8	**4**	**213**	51	145 - 255	**99**	63	25 - 153	**0.88**	0.08	0.81 - 0.98
A1-A4	**100**	**177**	34	132 - 258	**52**	33	15 - 164	**0.83**	0.08	0.64 - 1.15

4 DISCUSSION

This study compared the seaward migration of Atlantic salmon and brown trout post-smolts in and outside the protected national salmon fjord Beiarfjorden. Atlantic salmon post-smolts were found to use the northern exit in the fjord complex outside Beiarfjorden. Of the 29 tagged Atlantic salmon post-smolts detected at the outermost arrays in the fjord complex, 88 % were detected in the northern exit point, with only a few (*n* = 3) individuals using the alternate southwestern exit. Brown trout post-smolts, on the other hand, mostly stayed within the confines of Beiarfjorden and 94 % of brown trout post-smolts did not get detected any further than the middle section of Beiarfjorden. Additionally, Atlantic salmon post-smolts had a higher swimming speed in the fjord complex outside than inside Beiarfjorden, almost doubling the progression rate through Nordfjorden (13 km) compared to Beiarfjorden (19 km).

That the majority of Atlantic salmon post-smolts used Nordfjorden during the seaward migration is consistent with the hypothesis of Atlantic salmon post-smolts using the northern exit in favor of the southwestern exit, and corresponds well with previous findings of adult Atlantic salmon kelts exclusively using this migratory route (Nilsen, 2021; Davidsen *et al.*, 2022). This observation indicates a behavioral pattern that already is preset during the migration and further correlates with the existing notion of salmonids having preferred migratory paths (Kristensen *et al.*, 2018).

The proportion of brown trout post-smolts residing within Beiarfjorden were larger than expected based on previous work on brown trout veterans from the same fjord (Nilsen, 2021; Davidsen *et al.*, 2022), and only 12 % (*n* =16) of the tagged trout kept within the protected area of the fjord (Steinkjer, 2021). Similar behavior, that brown trout post-smolts don't migrate far away from their home river, have been observed at other locations as well (Atencio *et al.*, 2021), and is in line with typical brown trout post-smolt behavior (Jonsson & Jonsson, 2011c). The observations done by Atencio *et al.* (2021) suggested that the behavioral difference between life stages of post-smolt and veteran brown trout migrants were not that different form each other. However, the novel findings from Beiarfjorden suggest that brown trout post-smolts stay closer to the river mouth to a larger extent than brown trout veterans (Nilsen, 2021).

A gradual decline in detections further out in the fjord complex was observed for Atlantic salmon. While 69 % of tagged salmon post-smolts were present by the outlet of Beiarfjorden, 54% were detected beyond this point, and by the Nordfjord and Morsdalsfjord outlet, only 36% were detected.

Nordfjorden, being the most common exit to the ocean, had gaps along the station lines. This, in combination with an increased swimming speed, and smaller tags with a lower power output compared to the ones used in previous studies in Beiarfjorden, can explain the decrease in observed detentions to some extent. While brown trout have been recorded to migrate predominantly close to shore, Atlantic salmon typically use the middle sections of the fjord to a larger extent (Thorstad *et al.*, 2007; Davidsen *et al.*, 2009; Thorstad *et al.*, 2012), making the loss of two receiver stations in the mid-section of the inner array in Nordfjorden, and yet another station in the outermost array in the fjord, viable reasons for tag signals not being picked up. The results from estimated receiver performance gave relatively good detection rates, with the lowest detection percentage being 73%, in the mid-section of Beiarfjorden. Measurements from previous years suggest a potential for a halocline and thermocline present in this section of the fjord (Nilsen, 2021; Davidsen *et al.*, 2022), which could limit the range of the tags based on the environmental circumstances (thelmabiotel.com). This test did not account for the reliability of the reference array at the outermost section of Nordfjorden, however, as the probability of fish passing though undetected is possible. Nevertheless, the lack of detection data along the northern and southwestern exit cannot be explained by this alone, and mortality probably constitute a notable proportion of the data lost, as the beginning of the marine phase is affiliated with the lowest survival rates (Davidsen *et al.*, 2009). A similar loss is probably the case for brown trout as well, and although a reduced number of detections for the species during the month of July most likely is due to temporary occupation of zones outside receiver range, there are, in all likelihood, also losses along the way in the form of mortalities.

Across all locations within the study area, most Atlantic salmon post-smolts were detected in June. This observation correlates well with progression rate, using 113 hours in Beiarfjorden and 27 hours in Nordfjorden on average. Observing gradually fewer detections in the months after is within what would be expected from the species at this altitude (Davidsen *et al.*, 2022). However, for the month of May, it is important to note that only 66% of Atlantic salmon and 37% of brown trout post-smolts were tagged, looking the total sample of tagged fish. Moreover, 21% and 38% of these salmonids, respectively, were tagged within the last week of this month. No fish were tagged prior to June in 2022. This bias is particularly evident in brown trout, with May having the overall lowest number detections for each location. With tagged brown trout post-smolts primarily staying in Beiarfjorden, the most notable change in detections beyond May was a reduced detection rate in

July. A likely explanation for the drop in detections would be the increased use of habitable zones between arrays. The hypothesis of brown trout post-smolts spending more time in Beiarfjorden than in the fjord complex outside, are nonetheless corroborated by these observations.

In 2023, the mean date for tagged Atlantic salmon post-smolts entering the estuary were June 3, ranging from May 14 – July 13, while mean estuary entry time for tagged brown trout post-smolts were June 15, ranging from May 15 – August 20. This indicates a difference in estuary entry of almost two weeks between the species. Even though there are some limitations in the dataset as some smolts were kept in the tank for up to 4 days before release, the difference in range between the species indicates a more comprised seaward migration for Atlantic salmon post-smolts.

The Atlantic salmon post-smolts increased their progression rate during the outward migration with higher swimming speeds in Nordfjorden than in Beiarfjorden, Hence, the exposure to potential negative impacts from fish farms in Nordfjorden were limited in time, with the post-smolts using a mean time of just over one day in this fjord section compared to the almost five days spent in Beiarfjorden on average. Although the number of Atlantic salmon migrating through the southwestern exit was too small to hold any significant statistical power, it did show a tendency of speed increase compared to the travelling speed in Beiarfjorden and is supported by the speed increase evident in the northern exit. The finding that Atlantic salmon post-smolts increase their travelling speed when getting closer to open sea is similar to previous observations (Davidsen *et al.*, 2009). Despite the reduced sample size for Nordfjorden compared to Beiarfjorden, the findings do suggest that the hypothesized increase in swimming speed from Beiarfjorden to the outer fjord complexes is present. Atlantic salmon post-smolt swimming speeds in this fjord system compared to observations in other fjords indicate a moderate travelling speed found in this study. Observations on wild and hatchery reared Atlantic salmon post-smolts by Thorstad et al. (2007) indicates comparable travelling speeds in Romsdalsfjorden (Møre & Romsdal County) to the recorded speeds in Beiarfjorden, while the travelling speed found in Nordfjorden more than doubled the numbers found in this study. On the other hand, the progression rate in Nordfjorden did not compare to the estimated speeds found in Altafjorden, with subsequent fjord sections seeing higher numbers than Nordfjorden (Davidsen *et al.*, 2009). Food abundance could potentially be a factor contributing to these differences, but without any data on feed intensity, this suggestion remains speculative. Nilsen (2021) fund that the travelling speed of kelts in Beiarfjorden and

Nordfjorden were a lot higher than that of the post-smolts in this study, but adjusting for total body length, the travelling speed was greater for post-smolts in both fjord sections, with more than three times the speed found in Nordfjorden. Another study from Romsdalsfjorden found travelling speeds of Atlantic salmon post-smolts during a short-term monitoring of 14 hours to have similar migratory speeds between what was found in Beiarfjorden and Nordfjorden (Thorstad *et al.*, 2004). The same was evident in both wild and hatchery-reared post-smolts monitored in Eresfjorden, in Møre & Romsdal County (Økland *et al.*, 2006). These comparisons demonstrated in a better way the practicality of using BL/sec as a unit of measure, as the hatchery-reared post-smolts were significantly larger than the smolts tagged in this study (263 mm, range = 226–300 mm), yet the sample (n = 5) had recognizable speed estimates. These studies also demonstrated relatively large fluctuations in range in speed, even with smaller sample sizes used. Furthermore, the study factored in water currents, which was not done in this thesis. A weak but seemingly directional current in Nordfjorden based on assessments from barentswatch.no, repeatedly showed ocean currents of 0.1 - 0.3 knots towards the fjord exit, which would be of interest to investigate further.

The initial intent of the national salmon protection was to protect Atlantic salmon from the ramifications of fish farming, with brown trout not being a part of this intended protection (DKMD, 2006; Steinkjer, 2021; Davidsen *et al.*, 2022). However, the protection might still be of value for populations of brown trout residing closer to the coast (Bjørn *et al.*, 2011; Serra-Llinares *et al.*, 2014), and for the brown trout post-smolts residing in Beiarfjorden, observations seem to suggest this. Atlantic salmon will, in all likelihood, experience a reduced pathogen pressure during the days spent in Beiarfjorden. However, salmon lice can be found in elevated numbers within 30 km of fish farms, and can even extend further (Thorstad *et al.*, 2015), which would mean that even with the protection in place, Bareiarfjorden might have higher levels of the ectoparasite. However, if ocean currents mostly move northwards in Nordfjorden, this could potentially limit the spread of pathogens from fish farms in this fjord section to Beiarfjorden.

Nevertheless, Atlantic salmon post-smolts usually face a high mortality rate when entering a marine environment (Davidsen *et al.*, 2009; Thorstad *et al.*, 2012; Doogan *et al.*, 2023; English *et al.*, 2023). First time migrants of anadromous brown trout sees similar fates (Thorstad *et al.*, 2007), and predation is often a large contributor to the mortalities during early marine migration (Doogan *et al.*, 2023). Mortality in salmonids has not been a focal point in this project, as reliable and concise numbers were difficult to estimate. However, a minimum of five Atlantic salmon and eight brown trout were assumed dead based on persistent stationary positionings, and if fish with insufficient data are to be assumed dead too, this would add another 14 and 37 IDs, respectively. As mortalities are highly plausible during the fjord migration, an in-depth estimate of mortality rates throughout the migration from these data would be an interesting next step. However, such an analysis would be biased by the varying lifespan of tags used in this study as it causes uncertainty as to whether a fish has actually died, or the battery simply have run its course. An important and potentially additive factor to data loss and mortality is the interventions imposed on the fish during the many steps of a tagging process. All salmonids included in this project was caught either actively, by electrofishing, or passively, through smolt traps. No mortality was linked to electrofishing in a direct sense, as all caught fish with the right length were tagged and released after seeing a return to normal swimming behavior. The use of smolt traps saw some casualties however, with two instances of fish caught in the net arm of one of the traps, in addition to potentially lethal crowning for some fish in the trap itself. Catchment method, handling between tanks, as well as the tagging procedure itself, could have culminated in mortalities through long term effects, but no tagged salmonids were released before showing normal swimming behavior first. Mediating efforts were put in place to minimize strain on the fish, such as aerated water in tanks used for prolonged holding, cover over the tanks to limit visual stimuli, minimized handling, time to recover, and well thought out setup for an efficient tagging process. A certain risk will always be involved in release after a tagging procedure, and an elevated risk is assumed for estuary release, as potential predators are most abundant in the fjords (Davidsen *et al.*, 2009). Previous studies have indicated that Atlantic cod (*Gadus morhua*) aggregate in the estuary (Davidsen pers com.). However, the large influx of fresh water in the area surrounding Tverrvika might limit the proportion of predators, at least in the uppermost part of the water column, in addition to giving the post-smolts a better starting point after tagging regarding osmoregulation. Nevertheless, smolts are particularly sensitive to the proceedings involved in capture and tagging, and this invasive step could potentially have caused mortalities (Jonsson & Jonsson, 2011a), as well as tags potentially being lost due to tag expulsion (Lawrence *et al.*, 2023).

5 CONCLUSION

In conclusion, the present study demonstrates a strong preference in migratory route for Atlantic salmon post-smolts, further reinforcing the existing notion that the species use Nordjorden as a primary fjord exit. Furthermore, it was shown that brown trout post-smolts, as opposite to the Atlantic salmon post-smolts, mainly resided in Beiarfjorden during the summer season. This sedentary behavior of brown trout post-smolts limits the exposure to local fish farms, while Atlantic salmon post-smolts, on the other hand, are compelled to migrate through several fish farm locations. However, as the travelling speed outside Beiarfjoden increased, potential negative interactions with the open net pen salmon production in Nordfjorden were reduced. The findings emphasize the importance of the national salmon fjords protecting salmonid post-smolts, but also suggests that further studies should be conducted on the use of Nordfjorden by Atlantic salmon post-smolts, as well as details surrounding the use of Beiarfjorden by brown trout post-smolts.

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