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NINA Report

# Downstream migration success of Atlantic salmon smolts in River Tana

## A telemetry study in 2021

Karl Øystein Gjelland, Narve S. Johansen, Panu Orell, Mikko Kytökorpi, Sire Grønmo, Tobias Holter

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# Downstream migration success of Atlantic salmon smolts in River Tana, 2021

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Smoltfelle i Kárášjohka © NINA

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# Abstract

Gjelland, K.Ø., Johansen, N.S., Orell, P., Kytökorpi, M., Grønmo, S. & Holter, T. 2024. Downstream migration success of Atlantic salmon smolts in River Tana, 2021. NINA Report 2396. Norwegian Institute for Nature Research.

Several of the salmon stocks in the Tana watercourse have had a severe decline over the last two decades. The status of the stocks in the upper headwaters are currently very low. This has caused the Finnish and Norwegian management to agree on closing all Atlantic salmon fishery in the Tana watercourse and the Tana fjord from 2021. There is a concern that that predation on out-migrating smolt may have a much stronger impact on population growth when the population is small as compared to when the population is large. This may hinder the expected salmon population recovery during the fishing moratorium. There is a pressure to have predator culling on smolt eaters such as the northern pike and the sea trout. The effect of such potential measure is not known, as the effect of predation itself on Atlantic salmon population growth is not known.

The pattern and survival of the freshwater phase of the smolt migration have not yet been studied. The aim of this study was to investigate migration pattern and survival of radio tagged smolts, and to identify bottle necks on the 240 km long route from the tagging site to the ocean. To achieve this, we planned to tag 100 smolts, and track them on a network of 22 fixed radio receivers as they migrate down the watercourse.

The smolt migration is normally at its peak between mid-June and mid-July in the Tana watercourse. The smolt trap was initially placed in the small tributary Geaimmejohka on 22nd of June. No salmon smolts were caught there until the 28th of June, and the trap was then moved to the much larger tributary Kárášjohka. From 3rd – 7th of July the trap was fishing successfully, and a total of 65 salmon parr/smolts were caught, and 27 smolts (14.3 cm length, standard deviation ± 8.2 cm) were tagged and released. During the first days of July there was a heat wave in Finnmark, and water temperature rose above 20°C already the 4th of July. The water temperature led to high stress, and mortality during smolt catch and handling. The tagging was therefore ended long before we reached the goal of 100 tagged smolts.

Only 3 of 27 tagged smolts reached the sea. 18 of the 21 smolts that migrated at least 3 km, became stationary later and were categorized as dead by predation based on the detection pattern in the tracking history. There was no clear relationship between smolt length and survival. Neither was there a clear relationship between smolt length and observed migration distance, although there was a weak tendency for larger individuals to make it farther.

Smolt migration speed as measured by travel time and distance between fixed radiologgers varied between 3.7 and 75 km/day. The migration speed varied consistently over the different parts of the migration route, although there was considerable individual variation. Moreover, there was a clear relationship between migration speed in the headwaters and how far the individuals made it along the migration route. All three individuals that made it to the sea had among the highest early migration speed.

The mortality rate in the headwater/tributary Kárášjohka was much higher than in the Tana River. The predation risk may truly be higher in this area if predator density is higher. To some extent this may also be a result of smolts being more vulnerable just after release, as the handling stress may lead to reduced avoidance capabilities.

In conclusion, the Atlantic smolt survival during migration from the Kárášjohka / Iešjohka confluence towards the sea was low. The low survival can at least partly be attributed to predation, but stress associated with high water temperatures during catching and tagging of the smolts caused some direct and indirect mortality. The survival rates found in this study are therefore underestimates or minimum estimates for out-migrating smolts in the watercourse. On the other hand, if we consider smolts that were able to migrate more than 30 km as healthy, the survival was still very low (25 %).

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# Sammendrag


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Over de siste to tiårene har flere av laksebestandene i Tanavassdraget hatt en negativ utvikling, og statusen for bestandene i de store tilløpselvene har de siste årene vært ned mot 20 % av gytebestandsmålet. Fra 2021 har norske og finske forvaltningsmyndigheter derfor stengt laksefisket i vassdraget. Det er en bekymring for at predasjon på utvandrende smolt har mye større effekt på bestanden når bestandsstørrelsen er liten, og det er fryktet at predasjonspresset skal hindre den forventede veksten i bestanden som følge av fredningen. Det er derfor et lokalt press på å drive predasjonskontroll, med målrettet uttak av fiskespisere som gjedde og (sjø-) ørret.

Utvandringsmønster og overlevelse til utvandrende smolt gjennom ferskvannsfasen i vassdraget er ikke tidligere studert. Målet med dette studiet var å undersøke overlevelse og vandringshastighet til radiomerket smolt, samt å vurdere om det finnes flaskehalser langs den 240 km lange utvandringsruta hvor smolten er spesielt sårbar for predasjon. For å gjøre dette var målet å merke 100 smolt, samt å følge de ved hjelp av manuell peiling og et nett med 20 faste loggestasjoner.

Smoltutgangen fra Tanavassdraget foregår grovt sett fra midt i juni til midt i juli, men med flere ukers forskyvning mellom år. Smoltfella ble først rigget opp i den lille sideelva Geaimmejohka 22. juni, og var aktiv der frem til 28. juni. Ettersom det ikke lyktes å fange smolt der ble fella flyttet til en ny lokalitet like nedstrøms samløpet av de to store tilløpselvene Iešjohka og Kárášjohka 3. juli. Frem til 7. juli ble 65 laksesmolt/parr fanget, og 27 smolt (14.3 cm, standardavvik ± 8.2 cm) ble gjenutsatt med radiomerke operert inn i bukhulen. I løpet av merkeperioden kom det en varmebølge til Karasjok, og vanntemperaturen økte til over 20 °C allerede 4. juli. Varmen førte til at fangst og merking ble avsluttet før målet om 100 merka smolt var nådd.

Kun tre av 27 merka smolt nådde sjøen. Skjebnen til den merka smolten ble delt i 5 kategorier, ettersom noen forble i området etter utsetting, eller radiosignalene forsvant. 21 smolt migrerte minimum 3 km før merkene ble stasjonære, og 18 av disse ble senere vurdert som død ved predasjon. Det var ingen klar sammenheng mellom smoltstørrelse og overlevelse, men en tendens til at større smolt nådde lenger ned i vassdraget. Vandringshastigheten varierte betydelig mellom individene og på ulike elvestrekninger (3.7 - 75 km/dag). Smolten som holdt høyest hastighet øverst på undersøkt strekning hadde større sjanse for å nå havet.

Dødeligheten var mye høyere innledningsvis, i den nedre del av Kárášjohka, enn i Tanaelva. Strekningen i Karasjohka kan være spesielt utsatt på grunn av høyere tetthet av predatorer, men lav overlevelse på denne strekningen skyldes i noen grad kombinasjonen av merkeeffekter kombinert med stress som følge av høy vanntemperatur.

Vi konkluderer med at det var lav smoltoverlevelse fra samløpet mellom Iešjohka og Kárášjohka til Tanafjorden (240 km) i 2021. Predasjon er trolig en viktig faktor for å redusere overlevelsen til laksesmolten langs denne elvestrekningen. Men stress som følge av høy vanntemperatur vanntemperaturen under fangst og merking resulterte også i merkeeffekter som økte dødeligheten både direkte og indirekte. Overlevelsesestimatene fra dette studiet må derfor anses for å være underestimat eller minimumsestimat for utvandrende smolt i Tana. Imidlertid hadde selv smolt som overlevde de første 30 km, og derfor må ansees som lite påvirket av håndteringen, svært lav overlevelse (25 %).

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# Contents

# Foreword

This project was initiated by the Norwegian Environmental Agency as an effort to increase the knowledge of smolt migration patterns in the Tana watercourse, as well as the understanding of potential predation impact on this. Due to a seasonal temperature development pattern departing from the normal for the Tana watercourse, the field part of the project had to be terminated prematurely. Thes result from this work thus has a lower generality and predictive power than aimed at when designing the project. We still believe that the work has generated more knowledge about the smolt migration in Tana. It has also provided valuable knowledge for future smolt tracking projects in Tana and other northern rivers. We thank the Norwegian Environmental Agency for commissioning the tracking study to NINA. We also want to thank Jan Gunnar Jensås at NINA for his help and guidance with setting up and running the smolt trap.

Tromsø, 18. februar 2024

Karl Øystein Gjelland

Project leader

# 1 Introduction

The Atlantic salmon is an iconic species with long importance for subsistence fishery, but also for economically valuable sport fishing tourism, recreational fishery, as well as a symbol for healthy nature. Atlantic salmon spawns in rivers with sea access, the progeny lives the first years in the river before it becomes a smolt (15-50 g) and migrates to the ocean to feed there for 1-4 years. Upon return for spawning, the salmon has grown to 1-20 kg, and is a very popular fishing target. Many of the salmon stocks in the Tana watercourse have been declining in the recent decades, to such a degree that the spawning stock for some of the salmon populations are currently at only 20 % of the spawning target (Anon 2020), and by 2023 11 out of 13 evaluated areas had less than 40% probability of reaching the spawning target and no exploitable surplus (Anon, 2024). This is very dramatic and has caused the Finnish and Norwegian management to agree on closing all Atlantic salmon fishery in the Tana watercourse and the Tana fjord in 2021-2023 (Anon, 2024). The reasons for the decline are debated; fishing toll undoubtedly plays an important role, and varying survival during ocean migration may also contribute. However, there might be reasons to believe that predation on outmigrating smolt may have a much stronger impact on population growth when the population is small as compared to when the population is large (Ward & Hvidsten 2011, Pavlová & Berec 2012, Neuenhoff et al. 2019, Vitenskapelig råd for lakseforvaltning 2022). There is therefore a pressure to start predator culling, but the effects of such potential measures are not known, as the effect of predation itself on Atlantic salmon population growth in the Tana watercourse is not known.

Diet investigations has shown that salmon smolt make a significant fraction of the diet of Northern pike and sea trout during the time of smolt migration (Svenning et al. 2020, 2023). The survival rates of out-migrating smolts are not known though, since neither the predator population sizes, nor the smolt stock size are known. This project aimed at addressing smolt survival during migration along the Tana main river stem, from upstream Karasjok all the way to the sea (approx. 240 km). In order to do this, we aimed to tag 100 smolts with radio tags, and track them on a network of 22 fixed radio receivers as they migrated down the watercourse. In addition, manual tracking were done between the fixed receiver stations in the upper part of the migration route. Smolts that didn't make it to the sea were by study design assumed to be lost by predation. The study may aid in identifying locations were smolts are particularly vulnerable to predation, as well as provide data on the general survival and migration characteristics of Atlantic salmon smolt while migrating down the Tana river.

# 2 Material & methods

## 2.1 Radio telemetry receivers

This study took benefit of sharing radio telemetry receivers (radiologgers) capacity with two other projects; one tracking pike tagged in Iešjohka, and one tracking pink salmon tagged in the lower reach of river Tana. Tagged fish were registered by Lotek SRX1200-D2 at 22 fixed radiologger locations (Figure 1), and/or by manual tracking using Lotek SRX1200-MD2 with a handheld antenna. The array of fixed receivers was deployed from 23 June till 12 September 2021. Manual tracking for smolts were done by boat on the river stretch between Jergul (Iešjohka) and the Kárášjohka / Anárjohka confluence on 15 July, 26 July, and 25 August.

## 2.2 Smolt tagging

The initial plan was to catch, tag and release 100 smolts in Geaimmejohka (Figure 1). This is a relatively small tributary known to be used by Atlantic salmon for spawning and juvenile recruitment. The river has adequate flow conditions for using a funnel trap for catching the fish. The smolt run period in river Tana is normally in from around June 20$^{th}$ till mid-July, later than in salmon rivers further south (Davidsen et al. 2005, Orell et al. 2007, 2011, Rikstad & Niemelä 2009). The funnel trap was deployed in Geaimmejohka on 22 June 2021, covering the full river width (Figure 2). The trap was checked in the morning and evening until 28 June. Two juvenile brown trout were caught, however no Atlantic salmon smolts were caught at this location. It was then decided to move the trap to the area downstream to the Iešjohka / Kárášjohka confluence. At this location, only approx. 1/3 of the river width was covered (Figure 3). Smolt catching was resumed by 3 July. However, water temperature was rapidly rising, passing 20 °C on 4 July and 23 °C by 6 July. This caused relatively high stress levels to the smolts, and it was decided to stop catching and tagging on 7 July due to the high temperatures. By then, 65 Atlantic salmon juveniles, 6 brown trout juveniles, 1 grayling and 1 pike had been caught in the trap. The pike was killed and had 1 smolt in the stomach and might have been feeding in the trap.

Of the 65 caught Atlantic salmon juveniles, 24 was considered parr and released without any further handling. The remaining smolts were either tagged and released, released without tagging, or they died at some point during the captivity period (Table 1).

*Table 1. Overview of the caught juvenile Atlantic salmon and whether they were tagged or not.*

*Tabell 1. Oversikt over fangst av lakseparr/smolt, og hvorvidt de ble merket eller ikke.*

| Action | Count | Mean length (mm) | Length std.dev. (mm) |
|---|---|---|---|
| Tagged and released smolt | 27 | 143 | 8.2 |
| Not tagged, released smolt | 5 | 137 | 17.3 |
| Smolt died during captivity | 9 | 150 | 7.2 |
| Parr, released | 24 | | |
| Sum | 65 | | |

Smolts were tagged with Lotek Freshwater Nanotag model NTF-2-1 (9.6 x 3 x 5 mm, 0.3 g) inserted into the abdomen by surgery. The 18 cm long Teflon covered tag antenna was protruded through the abdominal skin with the help of a 1 mm diameter hollow needle. After tag insertion, the surgery opening was closed by two stitches. Prior to the surgery, smolts were anaesthetized in a bath with a solution of 20 ml Benzoac / 100 l water (2-3 minutes), and during the surgery the fish was kept in a bath with circulating solution of 10 ml Benzoac / 100 l water (2-3 minutes). The smolt was transferred to a recovery tank immediately after the surgery was finished and were held in a basket with good water flow in the river for 12 hours before release.

## 2.3 Fate classification

Due to the patterns of radiotransmitter detections, we chose to classify the fate of individual tagged and released smolts into five different groups. The fate assigned to a smolt depended on the time and location of smolt detections on fixed automatic radiologgers and manual tracking history (Table 2).

*Table 2. Fate classes with criteria for the fate assessment.*

*Tabell 2. Utfallet/skjebnen til de 27 merka smoltene ble klassifisert i 5 kategorier.*

| Fate class | Criteria |
|---|---|
| Predation/parr | An individual that moved slightly upstream and may have been a parr due to weak smolt characters, or it might have been taken by a predator and moved upstream |
| Dead/predation | Individuals that were observed in the vicinity of the release area throughout the study and may have died or been predated before full recovery. |
| Bird/failure | Individuals not seen on automatic loggers nor manual tracking since shortly after release. May be caused either by bird predation or tag failure. |
| Predation | Individuals that initiated downstream migration, but where the tag subsequently either became stationary upstream to the Kárášjohka / Anárjohka confluence as verified by manual tracking, or disappeared between the Kárášjohka / Anárjohka confluence and Tana bru, assumedly caused by predation after a migration distance of 3-140 km. |
| Sea | Individuals that made it to the sea |

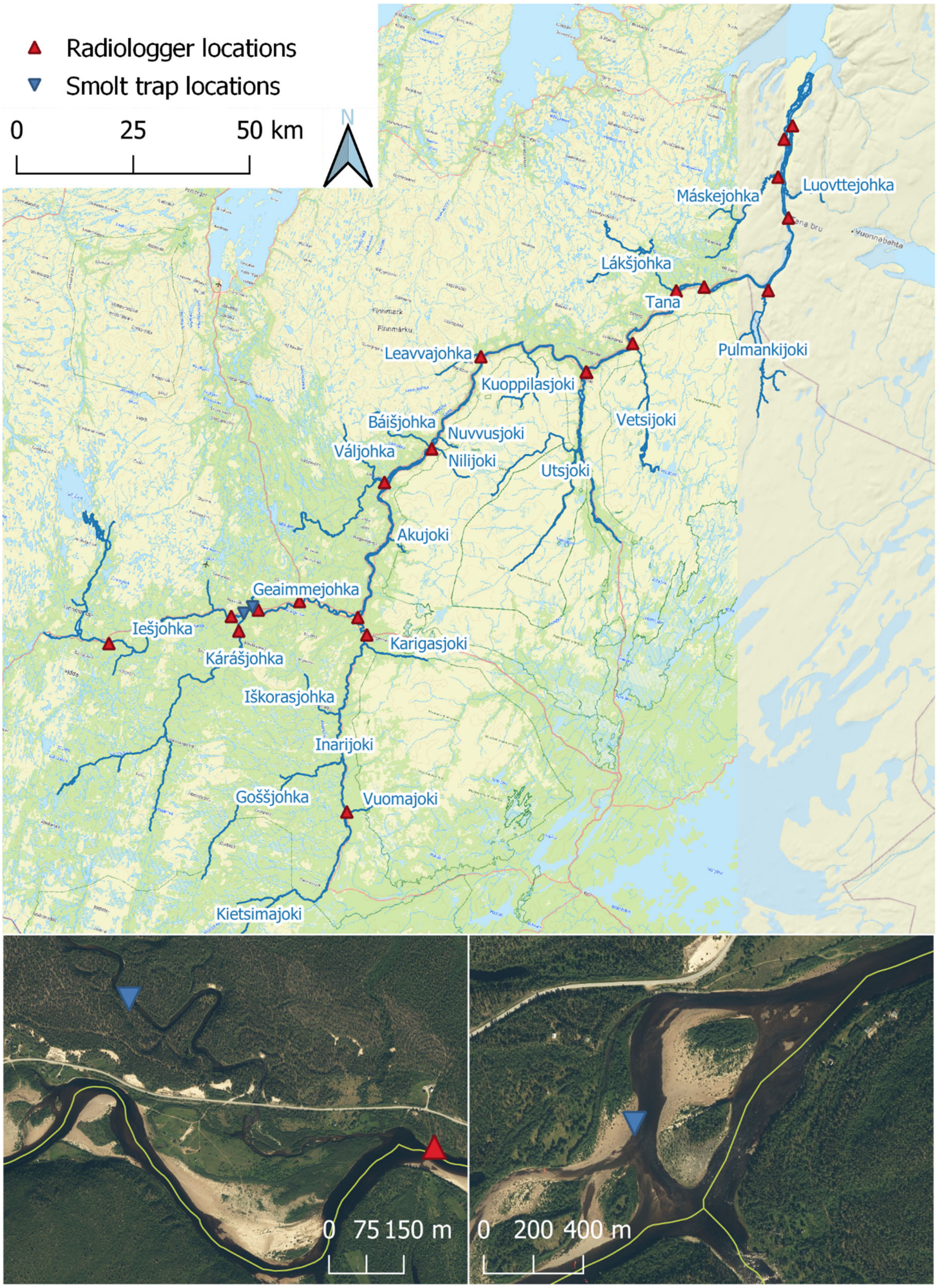


*Figure 1. Top: Map overview of Tana watercourse with main stem and tributaries indicated by deep blue. Radiologger and smolt trap locations are indicated by triangles. Lower left: Smolt trap was first located in Geaimmejohka, indicated by blue triangle. Lower right: Smolt trap was moved to 200 m downstream of the Iešjohka/Kárášjohka confluence.*

*Figur 1. Øverst: Kart over Tanavassdraget med de viktigste sideelvene markert med mørkeblått. Radiologger- og smoltfellelokaliteter er merket med trekanter. Nede til venstre: Smoltfella var først plassert i Geaimmejohka, merket med blå trekant. Nede til høyre: Smoltfella ble flyttet til en lokalitet 200 m nedstrøms samløpet mellom Iešjohka/Kárášjohka*

*Figure 2. Jan Gunnar checks the smolt trap in Geaimmejohka. Foto: Tobias Holter, NINA.*

*Figur 2. Jan Gunnar røkter smoltfella i Geaimmejohka. Foto: Tobias Holter, NINA.*

*Figure 3. The smolt trap deployed downstream to the Iešjohka / Kárášjohka confluence. Foto: Tobias Holter, NINA.*

*Figur 3. Smoltfella rigget opp nedstrøms samløpet mellom Iešjohka / Kárášjohka. Foto: Tobias Holter, NINA.*

# 3 Results

## 3.1 Overall survival

The overall survival amongst tagged and released Atlantic salmon smolts was apparently very low, and only three out of 27 tagged smolts reached the sea. There was no clear relationship between smolt length and survival (Figure 4a). Neither was there a clear relationship between smolt length and observed migration distance, although there was a weak tendency for larger individuals to make it farther (Figure 4b). This tendency was, however, far from statistically significant ($p = 0.48$). Apparently, smaller individual thus hade similar probabilities to make it as far as larger individuals.

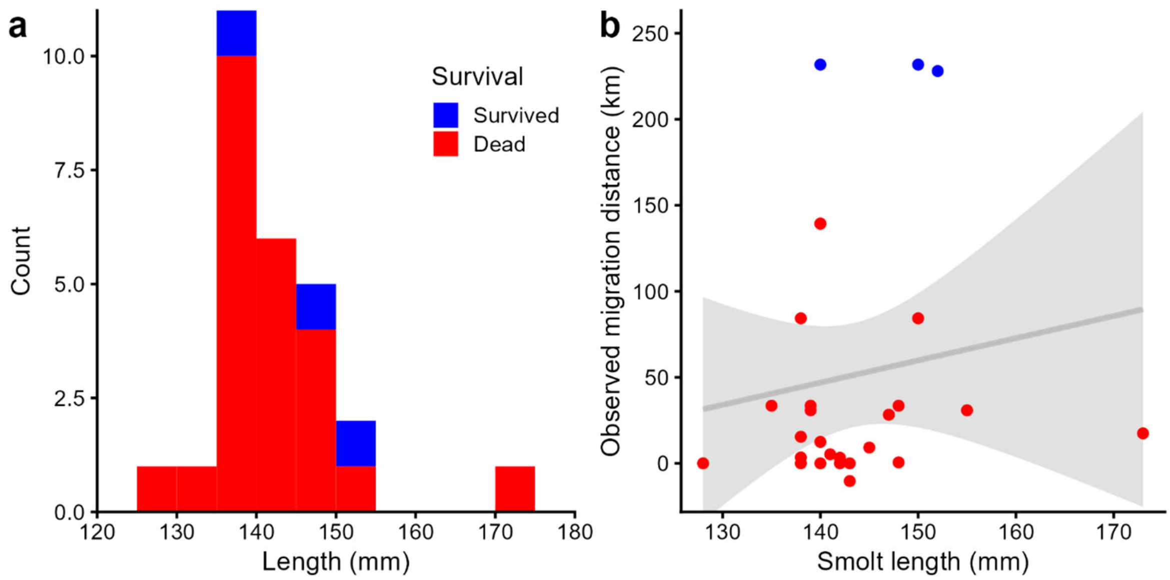


*Figure 4. a) Length distribution (grouped in 5-mm intervals) of tagged and released smolts, colour indicate survival. b) Migration distance as a function of smolt lengths. Symbols indicates individual length and travel distance, grey line indicates relationship by linear regression with 95 % confidence interval indicated by grey shaded area. There was a tendency for surviving smolts to be larger, but smolt length had no significant effect on smolt survival nor observed migration distance.*

*Figur 4. a) Lengdefordeling (i 5 mm intervaller) av merket og gjenutsatt smolt. Fargen angir overlevelse. b) Migrasjonsstrekning som en funksjon av smoltlengde. Symbolene angir individuell lengde og tilbakelagt distanse. Den grå linja indikerer sammenhengen med en lineær regresjon med 95 % konfidensintervall illustrert som grått areal rundt linja. Det var en tendens til at smolten som overlevde utvandringen var noe større, men det var ikke en signifikant sammenheng mellom smoltstørrelse og overlevelse, eller observert tilbakelagt distanse.*

Of the 24 individuals that did not make it to the sea, 18 were classified as lost to predation (Figure 5). These had an observed migration distance of between 3 and 140 km. Three individuals were detected by manual receiver on the day of release, but never since neither on manual tracking nor on fixed radiologgers. These may either have been removed from the river by bird predation, or the tag may have malfunctioned shortly after release. Two tags were registered close to the release site on several later manual tracking occasions, these smolts may have died as a result of a poor recovery, or they may have been taken by a predator at the site. One 140 mm smolt with weak smolt characters moved 0.6 km upstream, this might not have initiated migration (potentially a parr), or it may have been taken by a predator that later moved upstream.

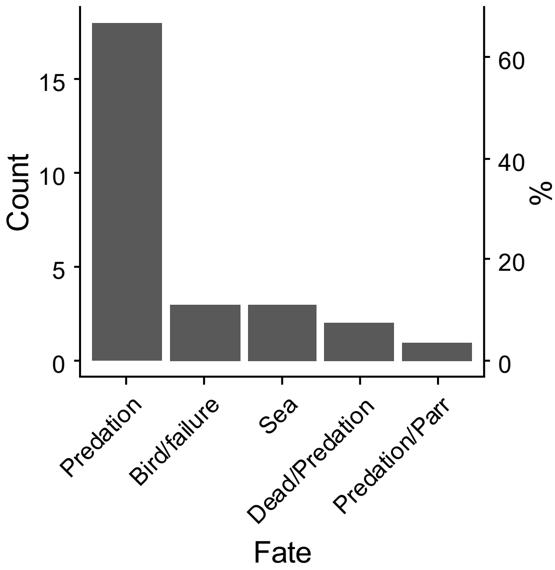


*Figure 5. Distribution of fates among the 27 tagged and released smolts, sorted by number in each class. The "Bird/failure" class indicates tags that disappeared from the study shortly after release, either due to bird predation or due to tag failure. Individuals classified as "Dead/Predation" was observed in the vicinity of the release area throughout the study and may have died or been predated before full recovery. See the Methods chapter for full explanation of the fate classification.*

*Figur 5. Fordelingen av utfallet/skjebnen til de 27 merkede smoltene fordelt på antall innen de ulike klassene. Klassen som er kalt «Bird/failure» beskriver individ som forsvant kort tid etter gjenutsetting, enten på grunn av predasjon fra fugl, eller feil ved merket. Individene i klassen «Dead/predation» ble registrert i nærheten av fellelokaliteten i lengre tid etter gjenutsetting. Disse kan ha dødd, eller blitt spist før de hadde kommet seg fullstendig etter fangst og merking. Se metodekapittelet for full gjennomgang av klassifiseringen.*

## 3.2 Mortality rate

If we look at the mortality rate as a function of the distance from the release site to the sea, there was a clear pattern of high mortality rate on the first 15 km river stretch, somewhat lower mortality rate further downstream to the Kárášjohka / Anárjohka confluence, and much lower mortality rate below the Kárášjohka / Anárjohka confluence (Figure 6).

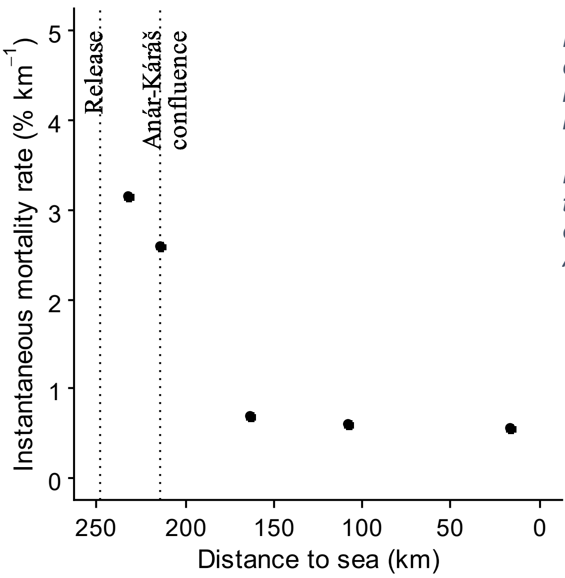


*Figure 6. Instantaneous mortality rate as a function of distance to sea. Mortality rate per river km was higher in Kárášjohka than in Tana mainstem (after the Kárášjohka-Anárjohka confluence).*

*Figur 6. Dødelighetsrate som en funksjon av avstand til havet. Dødelighetsraten var høyere i Kárášjohka enn i Tanaelva (etter samløpet mellom Kárášjohka-Anárjohka)*

## 3.3 Migration speed

Smolt migration speed as measured by travel time and distance between fixed radiologgers varied between 3.7 and 75 km/day. Individual mean migration speed varied between 9.1 and 59 km/day. The migration speed varied consistently over the different parts of the migration route, although there was considerable individual variation (Figure 7a). Moreover, there was a clear relationship between early migration speed (between the river outlets of Geaimmejohka and Ravdujohka) and how far the individuals made it along the migration route (Figure 7b). All three individuals that made it to the sea had among the highest early migration speeds (Figure 7b).

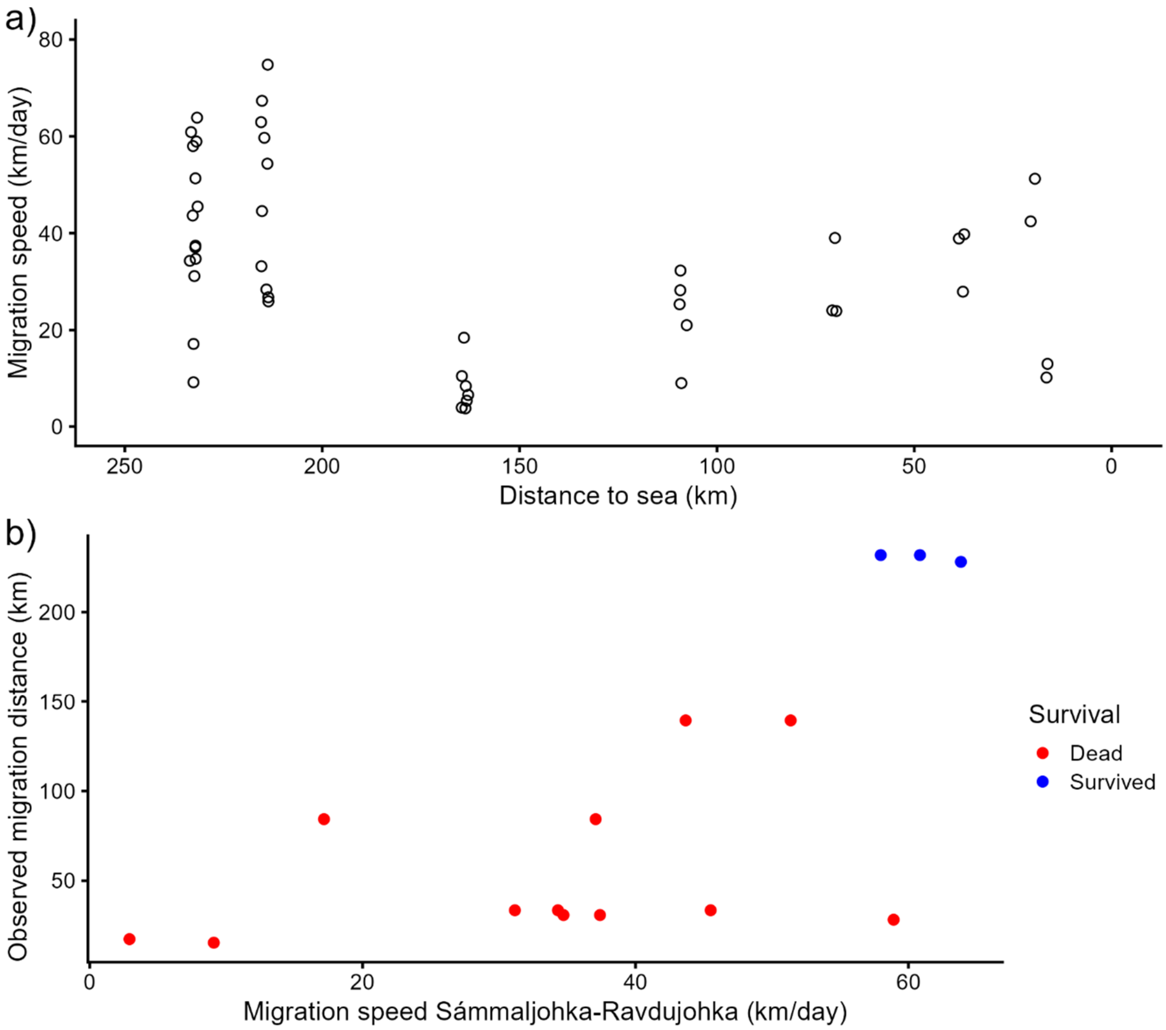


*Figure 7. a) Individual migration speed between fixed loggers along different parts of the migration route. Points are slightly jittered along the x-axis to enhance the visibility of overlapping points. b) Maximum observed migration distance as a function of the migration speed between Sámmaljohka (close to Geaimmejohka river outlet))) and Ravdujohka outlet (close to Karasjok town). Symbols indicates individual migration speed and observed migration distance, grey line indicates relationship by linear regression with 95 % confidence interval indicated by grey shaded area. This relationship was statistically significant (P = 0.006, adjusted $r^2$=0.42).*

*Figur 7. a) Individuell migrasjonshastighet mellom faste loggestasjoner på ruta ned til havet. Punktene er justert noe for å få synliggjort også overlappende punkter. b) Maksimal observert migrasjonsdistanse som en funksjon av migrasjonshastigheten på strekningen mellom de to øverste faste loggestasjonene (Sámmaljohka og Ravdujohka). Symbolene viser individuell migrasjonshastighet og observert migrasjonsavstand. Den grå linja indikerer sammenhengen med en lineær regresjon med 95 % konfidensintervall illustrert som grått areal rundt linja. Sammenhengen var statistisk signifikant (P = 0.006, justert $r^2$=0.42).*

# 4 Discussion

This smolt tracking study has revealed some new insight into the characteristics of the Atlantic smolt migration patterns from the confluence between Kárášjohka and Iešjohka down to the Tana fjord. It was, however, very unfortunate that the water temperatures got too high. This caused extra stress to the smolts during handling and captivity, inevitably causing increased mortality among handled smolts. This was seen as a high mortality before and after the handling process, before the smolts were ready for release. Thus, we cannot exclude that the handling stress and tagging effects also caused increased mortality after release, although the tagged individuals had apparently fully recovered upon release. Such increased mortality may be direct as death caused by increased stress, or indirect by increased vulnerability to predators due to reduced predator avoidance capabilities. As a consequence, the mortality estimates found in this study are evaluated as higher than they would have been for non-handled smolts. Other studies using similar methods has found much better general survival for smolts tagged with radio transmitters (e.g. Havn et al. 2018, 2020), indicating that the high water temperatures experienced in this study had a negative effect on overall survival of the tagged fish.

There are several other factors that may have increased the predation risk for the tagged individuals in this study. Firstly, the tagged smolts were released in much smaller groups than the number of smolts in a typical smolt shoal. Thus, each tagged smolt had less protection by shoaling than non-caught smolts, as smolt swimming alone or with only few individuals are easier targets for a predator (Furey et al. 2016). Secondly, the tagged smolts probably were caught in the "tail" of the smolt run. In a diet survey of pike and trout in the Tana watercourse as well as in Kárášjohka in 2021, the highest portion of salmon in the stomachs were found in smolts caught in mid-June. Smolts were also found in trout-stomach as late as the first week of July (Svenning et al. 2023). Smolts from the tail of the smolt run probably have lesser chance of linking up with other smolt groups and may generally have lower survival probability than earlier migrating smolts (Blackwell et al. 1998). Furthermore, the recession of the spring flood resulted in lesser river cross-sectional area and clearer water, factors which may increase the encounter rates with predators (Mazur & Beauchamp 2003, Turesson & Brönmark 2007). In combination, these factors likely increased the predation risk for the studied tagged smolts as compared to earlier migrating smolt.

Although there are thus reasons to assume that the mortality rate estimated in this study are higher than the real average mortality for out-migrating smolts in Tana, there is evidence that predation on Atlantic salmon smolts is an important mortality factor in the Tana watercourse. Diet investigations of pike and brown trout has revealed a considerable proportion of smolts in the diet of these piscivorous predators (Svenning mfl. 2020, 2023). Moreover, 14 out of 41 smolts caught in this study had wounds or marks indicative of predator attack. Some of these (3) were caught together with a pike in the funnel trap, which may have caused such marks. However, the other 11 must have got the marks before getting into the trap. This indicates that predator attacks are indeed highly prevalent for out-migrating smolts in the river.

Initially, one would expect larger smolts to have better evading capabilities from predators than smaller smolts. Although we found a tendency for such a pattern, it was not very clear. The small sample size of 27 tagged smolts has limited statistical power to reveal the relationship. However, some predators may select for larger prey, and it may be that prey shoal numbers and predator swamping are much more important survival factors than smolt size during the freshwater phase of the smolt migration (Furey et al. 2016). This may be in contrast to the marine phase, where it seems to be clear that size and growth rate is important for survival probability of anadromous salmonids during their first sea migration (Holtby et al. 1990, Jensen et al. 2018).

Downstream to the Kárášjohka/Anárjohka confluence the mortality estimates of 0.5-0.7% $km^{-1}$ were almost the double of the mortality estimates of 0.3-0.4% $km^{-1}$ in free-flowing sections of the upper Tornionjoki and Kemijoki rivers (Huusko et al. 2018). The mortality rates above the confluence (2.6-3.1% $km^{-1}$) was many times higher than these estimates. This shows that the smolt mortality rates observed in this study were higher to much higher than in other larger rivers in the region where comparable data exists. The higher mortality rates along the upper parts of the migration route could be indicative of several different effects. Firstly, the predation risk may be truly higher in this area if predator density is higher, leading to higher predation mortality. Secondly, the river is much larger downstream of the Kárášjohka / Anárjohka confluence, giving a larger river cross-section and deeper water for the smolts to travel in. This may both reduce the ratio of adequate pike habitat to water volume (a dilution effect), and also increase the distance that the smolt may be able to detect and react to the predator. Thirdly, smolt numbers increase as more tributaries flows into the river, especially from river Anárjohka. This will aid the potential for joining larger shoals, which in turn may reduce the individual predation risk (Furey et al. 2016, 2021). Last, but not least, the individuals with most reduced avoidance capabilities as a result of the handling stress was presumably most vulnerable to predation and lost early, whereas the healthiest ones that were able to avoid predators along the upper migration route, were also better fit to avoid predators on the lower migration route.

Although there was a considerable individual variation in migration speed, as well as varying migration speed along different parts of the migration route, a high early migration speed clearly increased the chances of reaching the sea. Of the four smolts with highest migration speed down to Karasjok, three reached the sea. Smolts swimming with a high migration speed will spend shorter time on a given distance, thus reducing the time exposed to predators and enhancing the survival. As the migration occurs during the midnight sun season, there is likely no difference in predation risk between daytime and night-time, making a fast migration beneficial. Individuals with the slowest migration speed may, on the other hand, be indicative of poor performing individuals, potentially as a consequence of the high temperatures and handling stress. Twelve individuals travelled more than 30 km, all of these had a mean migration speed of 25 km/day or more.

## 4.1 Conclusion

Predation was an important factor strongly reducing the Atlantic smolt survival during migration from the Kárášjohka / Iešjohka confluence towards the sea. High water temperatures during catching and tagging of the smolts lead to elevated stress, causing direct mortality and likely also indirect mortality due to higher susceptibility to predation. The mortality rates found in this study are therefore assumed to be higher than the true mortality rates of out-migrating smolts in the watercourse. On the other hand, if we consider smolts that were able to migrate more than 30 km as healthy, the survival was still very low (25 %). Mortality rates was highest between the Kárášjohka / Iešjohka confluence and the Kárášjohka / Anárjohka confluence, indicating higher predation pressure in this area ass compared to further downstream. However, this could also result from the least fit individuals. A clear relationship between early migration speed and observed migration distance indicated that individuals moving fast had higher survival.

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