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NINA Report

Salmon smolt migration in Tana/Teno and effects of the fish fence in 2025

Karl Ø. Gjelland, Panu Orell, Finn Økland, Henrik Baktoft, Mikko Kytökorpi, Sigurd Domaas, Narve Johansen, Riina Huusko, Nicolas Pohjanheimo, Jaakko Erkinaro

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Salmon smolt tracking in Tana/Teno, 2025

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Smolt traps in Utsjoki © Panu Orell

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Abstract

Gjelland, K.Ø., Orell, P., Økland, F., Baktoft, H., Kytökorpi, M., Domaas, S., Johansen, N.S., Huusko, R., Pohjanheimo, N., & Erkinaro, J. 2026. Salmon smolt tracking in Tana/Teno, 2025. NINA Report 2719. Norwegian Institute for Nature Research.

The present study investigated Atlantic salmon smolt survival and migration behaviour during the smolt run in the Tana watercourse in 2025, using acoustic telemetry. The main aims were to 1) assess the migration survival during the smolt migration in the River Tana main stem, and 2) assess if the presence of a migration barrier for ascending adult fish influenced the smolt behaviour and survival at the barrier site. The intention with the fish barrier was to catch and remove pink salmon, while native salmon should be sorted out and released on the upstream side of the fence. The barrier was composed of a fixed fence with vertical bars, with enough space between the bars for the smolts to pass freely through. Catch chambers (traps) for ascending adult fish were installed at two sections in the fence. The fence and traps were installed at Seida, 4 km downstream of Tana bru (34 km from the sea). 195 smolts were caught, tagged and released in Utsjoki, close to the confluence with the River Tana main stem (109 km from the sea). Of these, 97 were tagged with a transmitter including a predation sensor. An array of receivers was then used to detect passing smolts at locations 104, 58, 42, 34, and 16 km from the sea (locations Viđgaveaisavu, Polmak, Skiippagurra, Seida and Rustefielbma, respectively). In addition, two manual tracking surveys were conducted to locate tags from smolts that did not make it all the way downstream to Rustefielbma. The detection data were treated by survival analyses to assess smolt survival (i.e. number of tagged smolts reaching the receiver sites) and loss rates (i.e. the rate of tagged smolts lost per km between the receiver sites).

Loss of tagged smolt during the first 4 km was large (72 smolt), but may have been influenced by several factors such as misinterpretation of smolt state (i.e. the fish was not undertaking smolt migration), discontinued migration due to the tagging and handling, mortality due to handling effects, or tag failure shortly after tagging. We have therefore based our survival estimates on the number of smolts passing Viđgaveaisavu, located 4 km downstream of the tagging site. From Viđgaveaisavu down to Rustefielbma (89 km) the survival estimate was 4.9%, corresponding to a mean instantaneous loss rate of 3.2% km^{-1}. On a more detailed scale, the losses fell from 12.6% km^{-1} between Utsjoki and Viđgaveaisavu to lower levels for the next 47 km (1.7-2.2% km^{-1} to Polmak, depending on estimation method), whereafter it increased to higher levels again to Seida (9% km^{-1}), before falling to lower levels downstream of Seida towards Rustefielbma. In addition to the high loss rate as measured by arrivals at Seida, additive losses near the fence at Seida further increased the losses in the area. The overall survival estimate of 4.9% is a conservative estimate since it is prone to be biased low for several reasons, such as indirect tagging effects (e.g. discontinued migration, reduced shoal cohesion and/or reduced predator evasion capability) and/or early tag malfunction. Hence the survival estimate should be regarded as an indication of generally low migration success rather than accurate estimate of survival during smolt migration in Tana. However, these factors cannot explain the pattern of increased loss rate in the fence area, which contrasted the lower loss rate estimated for this area in an earlier study. The predation sensor were activated in 4 out of 10 sensor tags detected during manual tracking surveys, indicating that 40% of the losses were caused by predation. However, the losses caused by predation were likely higher for two reasons; 1) the predation sensor may have failed to identify the predation event, and 2) tags from smolts predated by birds or mink may have been shed on land and become unavailable for detection by our surveys.

When arriving the fence area the smolt temporarily interrupted the downstream migration and started swimming along the fence, likely searching for larger openings in the fence than provided by the space between the bars. Half of the smolts that arrived at the fence spent more than two hours at the fence site. It is unlikely that smolt retention on the scale of a few hours will deplete the smolt's energy reserves. However, the retention will increase the probability of predator encounter and the short-term energy expenditure towards exhaustion, potentially reducing the predator evasion capability. We found indications of increased losses in the fence area, but the

estimate of potentially fence-related extra losses is uncertain due to a low number of tagged smolts observed in this area. Furthermore, comparing loss rates between years with and without the fence would substantially improve our ability to assess its impact on smolt survival.

In summary, the smolt survival during downstream migration in the river Tana were found to be very low. Tagging effects and tag performance may have biased survival estimates low, but could not explain the increase in smolt losses in the lower river section. The presence of the fence associated with the fish trap at Seida temporarily halted the smolt migration on the scale of hours. The smolt losses were high in the fence area (up to 25%, 4 out of 16 smolt that reached the area) and likely influenced by the presence of the fish fence, but the relatively low number that reached the area reduce the confidence in the accuracy of the loss percentage.

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Sammendrag

Gjelland, K.Ø., Orell, P., Økland, F., Baktoft, H., Kytökorpi, M., Domaas, S., Johansen, N.S., Huusko, R., Pohjanheimo, N., & Erkinaro, J. 2026. Salmon smolt tracking in Tana/Teno, 2025. NINA Rapport 2719. Norsk institutt for naturforskning.

I dette studiet ble akustisk telemetri brukt til å undersøke overlevelse og vandringsatferd hos laksesmolt ved smoltutvandringa i Tanavassdraget i 2025. Hovedmåla var å 1) vurdere overlevelsen under utvandringa i Tanaelva, og 2) vurdere om smoltens atferd og overlevelse ble påvirka av gjerder og fiskefelle retta mot oppvandrende voksen fisk. Hensikten med fiskefella var å fange og fjerne pukkellaks, mens stedegen laks skulle sorteres ut og slippes oppstrøms gjerdet. Denne vandringsbarrieren besto av et fast gjerde med vertikale stag, med tilstrekkelig mellomrom mellom stagene til at smolten kunne passere fritt gjennom. Det ble installert to fangstkamre for oppvandrende voksen fisk i gjerdet. Fellesystemet ble installert ved Seida, 4 km nedstrøms Tana bru (34 km fra sjøen). Totalt ble 195 smolt fanga, merka og sluppet ut i Utsjoki, like ovenfor samløpet med Tanaelva (109 km fra sjøen). Av disse ble 97 merka med en sender med predasjonssensor. Et nettverk av akustiske mottakere ble plassert på lokaliteter 104, 58, 42, 34 og 16 km fra havet (henholdsvis Viđgaveaisavu, Polmak, Skiippagurra, Seida og Rustefielbma). I tillegg ble det padlet ned elva i to omganger med en mottaker på slep for å registrere merker fra smolt som ikke kom seg helt nedstrøms til Rustefielbma. Deteksjonsdata ble behandla med overlevelsesanalyser for å vurdere smoltoverlevelse. Antall merka smolt registrert ved mottakerlokalitetene ble brukt som en proxy for overlevelse, og tapsrater beregna som andelen merka smolt tapt per km mellom mottakerlokalitetene.

Tapa de første 4 km var høye (72 smolt fra Utsjoki til Viđgaveaisavu), men disse tapa kan ha vært påvirka av metodiske faktorer som for eksempel feiltolking av smoltstatus (altså at den merka fisken ikke var på vandring) eller at den har avbrutt vandring som følge av fangst og håndtering, eller at merkefunksjon har opphørt kort tid etter merking. Vi ekskluderte derfor disse første 4 km fra estimata, og antok at estimert overlevelse på 4,9 % fra Viđgaveaisavu ned til Rustefielbma er mer representativ for smoltoverlevelsen fra Utsjoki til Rustefielbma. Dette tilsvarer en gjennomsnittlig tapsrate på 3.2 % km^{-1}. På en mer detaljert skala var tapsraten lavere fra neste 47 km til Polmak (1,7-2.2 % km^{-1}, avhengig av estimeringsmetode), hvoretter den økte til høyere nivåer igjen til Seida (9 % km^{-1}), før den falt til lavere nivåer nedstrøms Seida mot Rustefielbma. Utover dette var det ytterligere tap området rundt fiskefella. Overlevelsesestimatet på 4,9 % til Rustefielbma er trolig noe for lavt av flere årsaker, for eksempel indirekte merkeeffekter (merka smolt bestemmer seg for ikke å starte utvandring, redusert stimtilhørighet og/eller redusert evne til å unnvike predatorer) og/eller funksjonsfeil i merket kort tid etter merking. Overlevelsesestimatet bør derfor betraktes som en indikasjon på generelt lav overlevelse snarere enn et nøyaktig tall for overlevelse ved smoltutvandringen i Tana. Disse faktorene forklarer likevel ikke det økte tapet av merka smolt i og nær felleområdet. Tapsraten i 2025 står i klar kontrast til den betydelig lavere raten som ble estimert for samme strekning i 2021. Basert på sensordata ble predasjon estimert til å forårsake 40 % av smolttapa, men det reelle tapet av merka fisk forårsaka av predasjon var sannsynligvis betydelig høyere av to grunner; 1) predasjonssensoren kan ha feila i å identifisere predasjon, og 2) merker fra smolt spist av fugl eller mink kan ha havnet på land og dermed vært utilgjengelige for deteksjon i våre undersøkelser.

Ved ankomst fellegjerdet ved Seida avbrøt smolten vandringa nedstrøms og begynte å svømme langs gjerdet. Dette tyder på at den var på leting etter større åpninger enn mellomrommet mellom gjerdestaga. Omtrent halvparten av smolten som ankom gjerdet oppholdt seg i området i mer enn to timer. Det er lite sannsynlig at en tilbakeholdelse av smolt på en skala av timer vil tappe smolten for energireserver. Men de høye svømmehastighetene som kreves for å svømme mot strømmen foran gjerdet kan føre til utmattelse på denne tidsskalaen, og dermed svekke evnen til å unngå predasjon. Kombinert med økt risiko for å møte predatorer som en følge av tilbakeholdelse ved gjerdet, kan dette medføre vesentlig økning i predasjonsrisiko. Vi fant indikasjoner på økt tap av merka smolt i felleområdet, men anslaget for eventuelle tilleggstap knyttet til gjerdet er usikkert på grunn av et lavt antall merkede smolt observert i dette området. En sammenligning

av tapsrater mellom år med og uten felle vil derfor kunne gi et bedre grunnlag for å vurdere effekten på smoltoverlevelsen.

Oppsummert var overlevelsen ved smoltutvandring i Tanaelva svært lav. Anslaget for overlevelse for merka smolt er trolig for lavt sammenligna med umerka smolt, på grunn av håndteringsrelaterte adferdsendringer og dødelighet, samt mulig merkesvikt kort tid etter merking. Men disse effektene kunne ikke forklare økt tapsrate langt nede i vassdraget. Predasjon var sannsynligvis viktigste dødsårsak. Fiskefella ved Seida førte til at smolten stoppa utvandringa midlertidig, for de fleste i noen timer. Smolttapa i felleområdet var høye (inntil 25%, 4 av 16 smolt som nådde området) og trolig påvirka av fiskefella, men det relativt lave antallet smolt som nådde felleområdet gjør at det hefter usikkerhet rundt omfanget av tapa ved fella.

Contents

Foreword

The Atlantic salmon stocks in the Tana watercourse have been in decline for many years. This study of Atlantic smolt seaward migration in the river Tana was a result of concern for the smolt survival, a concern shared by LUKE, NINA, and the Norwegian Environmental Agency, as well as many others. We thank the Norwegian Environmental Agency, LUKE, and NINA for contributing with financial support. Furthermore, we thank Tanavassdragets fiskeforvaltning and the Norwegian Veterinary Institute for help during field work.

Tromsø, January 2026

Karl Øystein Gjelland

Research Scientist, project leader

1 Introduction

The Atlantic salmon stocks in the Tana watercourse have been declining over the recent couple of decades, to the extent that the stock status is now critically low for all stocks (Anon. 2026). Thus, the river has been closed for salmon fishing since 2021. The reasons for the decline are complex, likely involving climate change, reduced sea survival, and too high fishing pressure. Stressors related to the pink salmon invasion and the related removal program in the river may further add to the difficulty of the Atlantic salmon stock recovery in Tana. Once at a low level, populations can be difficult to rebuild to their former status (Falkegård et al. 2023).

Pink salmon (*Oncorhynchus gorbuscha*) is an anadromous salmonid non-native to the Atlantic Ocean and the Barents Sea, introduced to the region by Russian stocking programs in the latter half of the twentieth century (Sandlund et al. 2019). As a result, pink salmon has been caught in Norwegian rivers and fjords since 1960, but from 2017 numbers entering Norwegian rivers have dramatically increased (Staveley et al. 2025). This increase has been evident in Tana as well (Erkinaro et al. 2026). As a non-native species classified as very high risk by Artsdatabanken, a large-scale pink salmon removal program has been introduced in the region (Thorstad et al. 2025). The purpose of the program is to reduce the number of pink salmon entering the rivers and to limit the growth of pink salmon populations. This should be done with as little harm as possible to native fish populations. The main method used in the program is establishment of fish traps in the lower river sections, as close as possible to the sea. The traps are operated by closing off the river cross-section by fences and catching up-migrating fish in dedicated in-fence chambers. While the traps should enable pink salmon removal, adult native fish should be allowed to pass either by manual or automatic sorting methods. The extent to which such barriers hampers native salmonid spawning migration probably vary between rivers as well as between trap types, but there is little information available to quantify the effects of fish traps on the spawning migration success of native salmonids.

Even less is known about how Atlantic salmon smolts navigate adult fish barriers during their seaward migration. Monitoring at the trap site during the fence operation in River Tana in 2023 documented that smolts hesitated to pass the fence, even though smolts were able to physically pass the trap without harm. However, the delay caused by the trap could not be quantified due to lack of individual tracking (Domaas et al. 2024). Adding to the concern, the return of one sea-winter Atlantic salmon to River Utsjoki during summer 2024 indicated the lowest recorded survival of a smolt cohort (2023) ever of the Utsjoki system. Thus, to inform effective pink salmon mitigation that avoids harm to native smolts, it is crucial to assess to what extent trap operations affect smolt migration and survival. The pink salmon fence is not the only concern for the survival of smolts during the seaward migration in the River Tana. Recent studies have shown that juvenile Atlantic salmon, in particular smolts, are more important in the diet of pike during the smolt migration period than at other times of the year (Svenning et al. 2020, 2023, 2026). A pilot study in 2021 using radiotelemetry showed a low migration success from a large headwater tributary of the Tana, Kárášjohka, to the sea (Gjelland et al. 2024), adding to the concern that predation may be a severe constraint on seaward migration survival for Atlantic smolts in the Tana watercourse.

The Norwegian Environment Agency planned to install a new cross-river fence and trap for pink salmon removal at Seida in the lower part of River Tana. In accordance with the recommendations from the Tana Monitoring and Research Group (Anon. 2025), we proposed a study to investigate the migration success and the behaviour of Atlantic salmon smolts during the trap operation period. The aim was to answer the following questions:

1. Is smolt migration delayed at the trap site? If so, which percentage of smolts are being delayed, and for how long?
2. Is there increased predation on smolts near the fence?
3. What is the smolt survival from Utsjoki to the fence site, and from the fence site to the sea?

4. How important is predation for lowering the survival?
5. How is the swimming behaviour close to the trap fences compared to the time used passing the various receiver sites? Can the swimming behaviour in this area be used to evaluate fence influence on smolts, and to suggest mitigation measures?

The proposed study was designed to measure smolt survival from the River Utsjoki to the sea, but also to obtain detailed information on how the smolts behave at the adult fish barrier.

2 Methods

2.1 Environmental data

The water discharge in the Tana river fell from slightly above 250 $m^3 s^{-1}$ in 23 June to about 100 $m^3 s^{-1}$ in late July, before an increase to about 150 $m^3 s^{-1}$ at the end of the tracking experiment in early August 2025 (Figure 1). Thus, neither particularly heavy nor low discharge conditions were experienced during the experiments. The water temperatures during the capture and tagging period (23. June – 8. July) were below 15 °C, and varied between 15 and 20 °C from 12 July till the end of the project in early August (Figure 1)

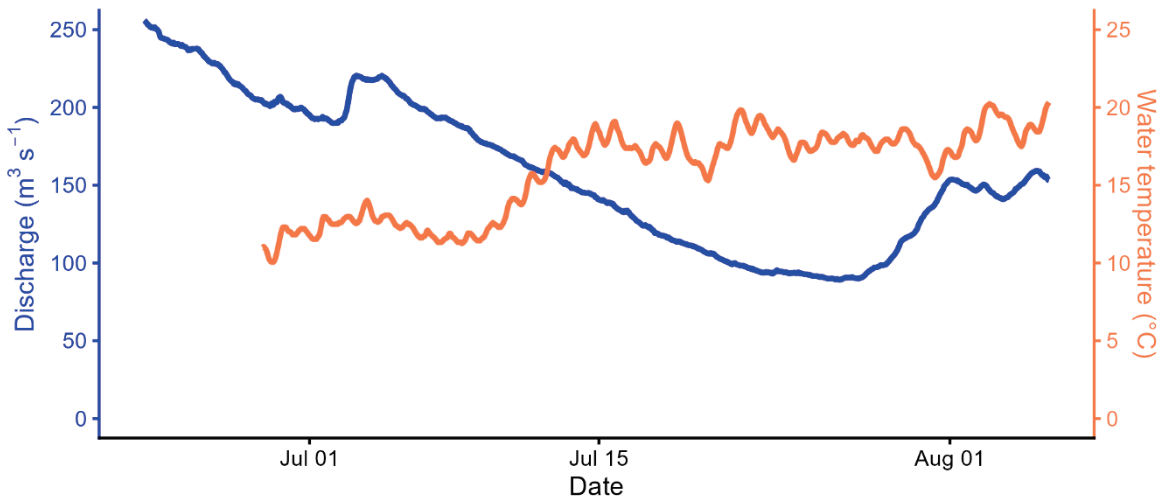


Figure 1. Discharge and water temperature in the river Tana during the study period in 2025. The discharge data was downloaded from www.sildre.nve.no, whereas the water temperature was recorded at 15 minute intervals by a temperature logger deployed with one of the receivers at Seida. The temperature logger was deployed from 28 June

2.2 Acoustic receiver design

The study was designed to study the smolt migration from the outlet of the River Utsjoki, a major tributary to the Tana emptying to the mid-part of the mainstem, down to the Tanafjorden (Figure 3) by means of acoustic telemetry. A 180 kHz system was used, combining a high residency signal protocol (HR, high transmission rate) for 2D positioning near the fence and a PPM protocol (lower transmission rate) for logging smolt passage (1D) at selected locations along the river. The Innovasea V5-1x transmitters (4.3 x 5.7 x 12.7 mm, 0.66 g) were used, with 5 s transmission interval for the HR protocol and a random burst interval between 30-50 s for the PPM protocol. In addition to the Innovasea 180 kHz system, a pilot study using the JSATS system (416.7 kHz, tag transmission interval 5 s) was done to evaluate the feasibility of using this system in the Tana river.

Prior to tagging any smolts, the systems were thoroughly tested in order to evaluate the detection probability by range. The observed ranges were shorter than expected. Whereas the observed detection ranges during range tests could reach 200 m, the HR and PPM systems had few detections at >100 m range. In general, the PPM system had higher detection probability than the other systems on short range (< 70 m), but the detection probability on ranges >100 m were very low for all systems, and decreased range at high water currents. Hence the original plan using two receivers at each 1D location was abandoned and replaced by a design of 3-8 receivers at each 1D location (Figure 3). The detection probability at any receiver site was a combination of the detection probability on each of the receivers at the location, and the total detection efficiency at each site was modelled in the migration and survival analyses. The HR receivers at Seida were placed in a dense array just up- and downstream to the pink salmon fence at Seida, to ensure good tracking probability in this area (Figure 3). The JSATS receivers were used only just upstream to the fence, as there were not enough of them to cover other areas (Figure 3). The receiver positions were recorded by a Trimble Gx7-device with a CPOS-subscription from Kartverket (GNSS accuracy at cm level).

2.3 Capture and tagging of smolts

Smolt capture and tagging were carried out by a trained and experienced research team from LUKE. The smolt were caught in River Utsjoki, just upstream to the confluence with the River Tana main stem, using two funnel traps (Figure 4a). The traps were checked and emptied during the morning and evening, if this was not doable the traps were kept closed to avoid capture of fish. Captured smolts were held in sheltered keepnets until the tagging procedure started, either the day of capture or up to two days after trap check. Prior to tagging , the fish were anesthetised in a 40 mg/L solution of Benzoak, weighed (g), and measured for total length (mm). The fish were scored for smoltification according to an index score 1-4, with score 4 representing a smolt with no parr marks, complete silvering and pigmentation only along fins. Only fish with a smolt index of 3 or 4 were used for tagging (apart from 1 fish with smolt index 2). Fish accepted for tagging based on smoltification index and size were then surgically implanted with an acoustic tag into the peritoneal cavity. The incision for the tag was closed with one stitch (suture: Resolon, 5-0/DS 16). The surgery was performed with the smolt held in a cradle with circulating anaesthetic bath of 15 mg/L solution of Benzoak. This was done inside a tent at the riverbank to keep the fish in shade to protect fish skin and eyes from the sun and the anaesthetic bath from heating in the sun (Figure 4b). The tagged smolt were released into a recovery bath with clean river water. After recovery, the smolts were transferred to a keepnet in the river, from where they were released between 19:00 and 20:00 in the evening. The smolt releases included both tagged and non-tagged fish, with batch sizes between 25-100 fish. The release location was just downstream of the traps at the catch location. All handling and tagging were conducted according to the Finnish regulations for treatment and welfare of animals (permit ESAVI/10501/2025. The average length and weight of the tagged smolts was 160.1 mm (127-204 mm, sd = 11.9 mm), the mean weight was 28.8 g (16.9-55.9 g, sd = 6.3 g), and the mean smolt index was 3.5. The final smolt run estimate from the video monitoring carried out by LUKE in Utsjoki is not ready yet, but the raw counts (not adjusted for coverage etc.) indicated that the capture, tagging and release were mostly done within the first half of the smolt run period (Figure 2).

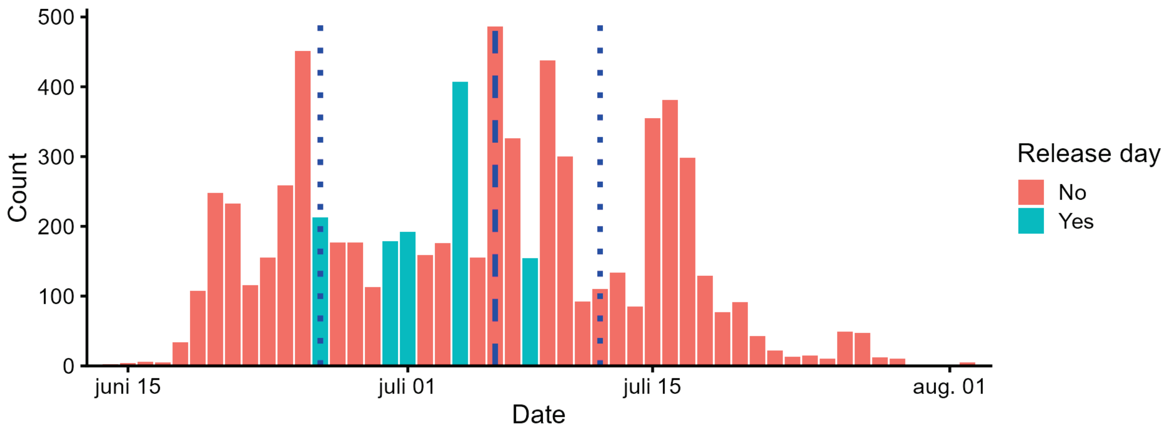


Figure 2. The daily raw counts of the smolt run in Utsjoki, as counted in the video monitoring records. The days of tagged smolt release in Utsjoki are indicated by column colour. The blue vertical dashed line gives the day of median (50%) cumulative smolt run, whereas the blue vertical dotted lines gives the dates of 25 and 75% cumulative smolt run, respectively.

In total, 98 smolts were tagged and released with Innovasea V5 tags without a predation sensor, and 97 smolts with Innovasea V5D tags with a predation sensor. The predation tag changes signal if the sensor is exposed to the stomach acid of a predator. In addition, 20 smolts were tagged and released with Lotek Pin tags and 22 with ATS SS410 tags. Both these tags are small JSATS tags (15 x 3.2 mm, 0.21 g). Lastly, 16 smolts were tagged and released with ATS SS300p (JSATS), tags containing a pressure sensor for registering depth (17,5 x 6,2 x 3,1 mm, 0.58 g). For an overview of smolt sizes by tag model, see Table 1. As we did not have JSATS receivers between Utsjoki and Seida, an attempt was made on 7 July to transport tagged smolts from Utsjoki for release at Tana bru. The transport was made with the smolts kept in oxygenated bags (max 5 in each bag). However, 7 of the 20 tagged and transported smolts did either die or not recover properly from the transport and were hence given a humane endpoint and removed from the study. For this reason, no transport was attempted for the remaining JSATS-tagged smolts. For an overview of smolt releases by date, tag and release site, see

Table 2.

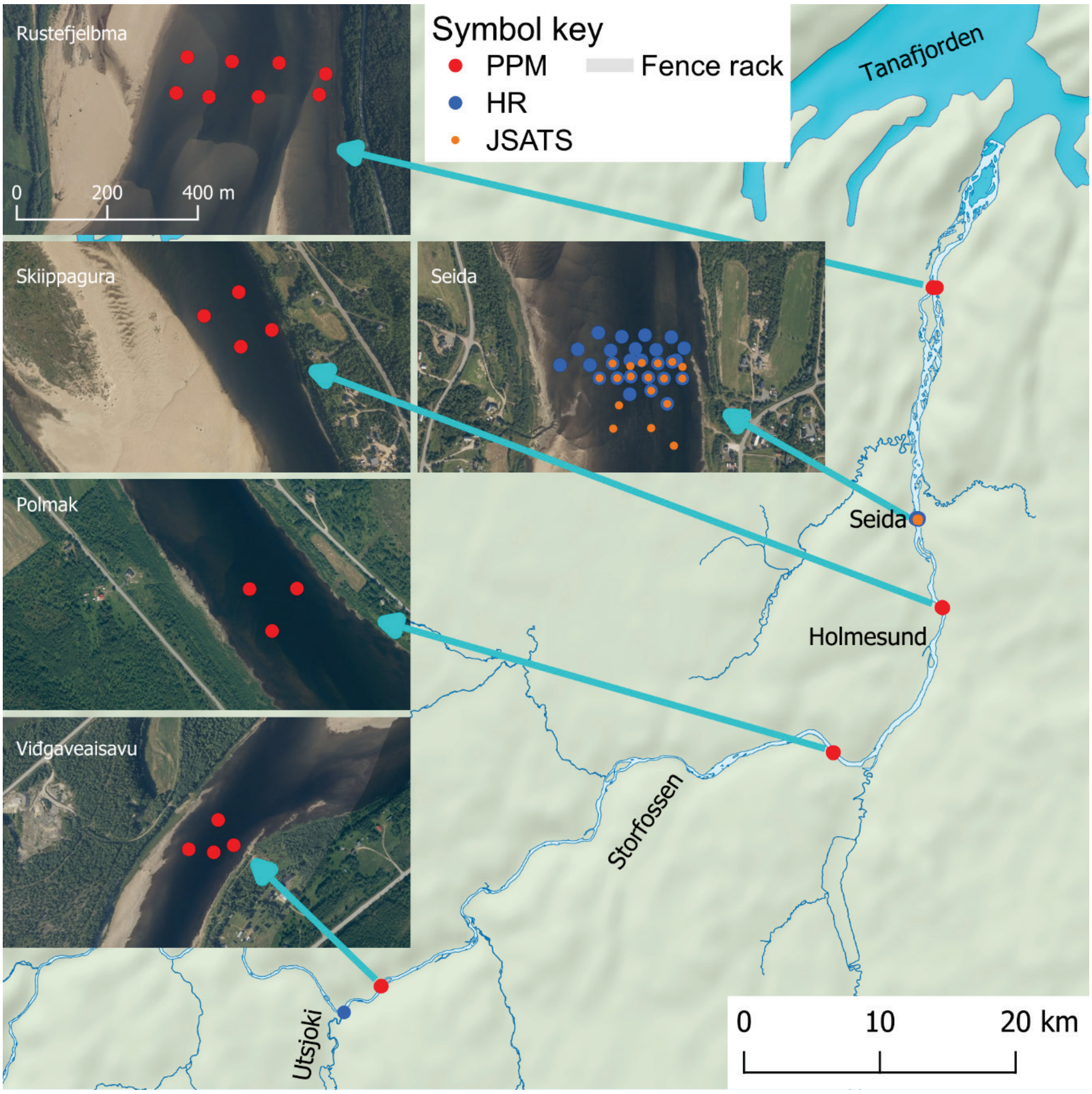


Figure 3. Receiver locations along the Tana river. The PPM receivers were used for 1D tracking (smolts passing by) at 4 locations up- and downstream to the fence. The HR receivers (26) were all used for 2D positioning near the fence at Seida, apart from one used at the smolt release location. PPM receivers could detect only PPM signals, whereas HR receiver could detect both HR and PPM signals. The JSATS receivers (3 ATS SR3017 and 15 Lotek WHS 4350) were all used just upstream to the fence for 2D positioning, with the exception of one, which was used at the release location in Utsjoki.

Table 1. Overview of smolt sizes tagged with the different tag models.

Tag model	N	Length ± SD (mm)	Weight ± SD (g)
Innovasea V5	98	161.0 ± 10.8	29.0 ± 5.7
Innovasea V5D	97	161.1 ± 13.4	29.4 ± 7.3
Lotek Pin	20	154.8 ± 7.4	26.5 ± 3.4
ATS SS410	22	150.8 ± 7.6	24.1 ± 3.8
ATS SS300p	16	168.3 ± 8.4	33.3 ± 3.9

Table 2. Overview of number of tagged smolts (N) by release date, with mean length, tag model and release site. Lotek Pin tags and ATS SS410 tags are grouped together, as these tags were identical in size. A varying number of non-tagged fish was released together with the tagged smolts at each release, but the exact numbers of non-tagged fish in each release is not available.

Date	N	Length (mm)	V5	V5D	Pin/SS410	SS300p	Release site
2025-06-26	50	168.5	25	25	0	0	Utsjoki
2025-06-30	50	161.6	25	25	0	0	Utsjoki
2025-07-01	50	154.2	25	25	0	0	Utsjoki
2025-07-04	45	159.7	23	22	0	0	Utsjoki
2025-07-07	13	157.5	0	0	7	6	Tana bru
2025-07-08	45	156.9	0	0	35	10	Utsjoki

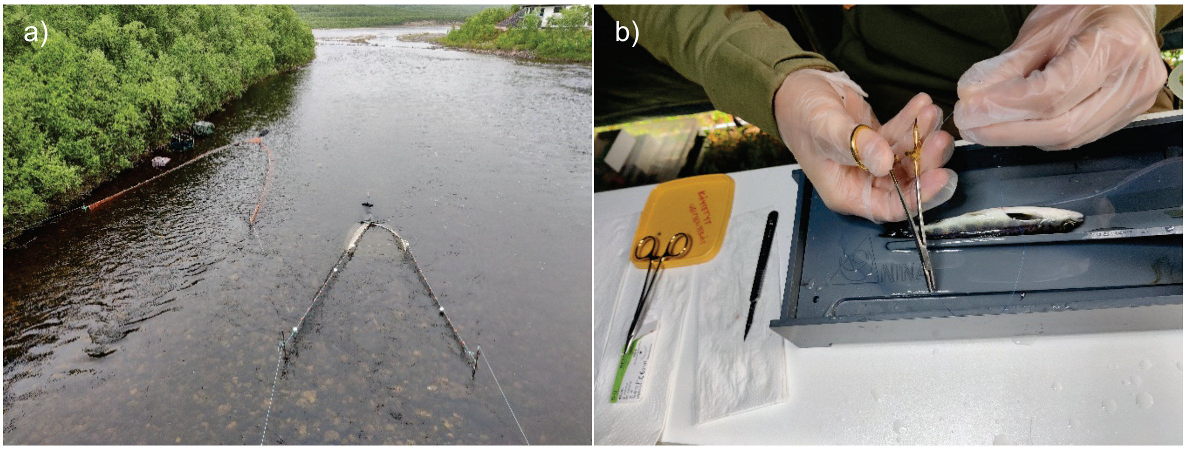


Figure 4. Traps for catching smolts (a), located just downstream to the bridge in Utsjoki. The confluence with the Tana river main stem can be seen in the background. During the tagging procedure, the smolts were shaded and held in a cradle with a circulating anaesthetic bath (b) to enhance breathing and keep negative effects of the tagging procedure as low as possible. Photos: Panu Orell.

2.4 Manual tracking

For the purpose of locating tags from smolts that did not make it to Rustefielbma, two manual tracking surveys were performed. The first was done 24 July with two teams á two packrafts. One team did the stretch from Utsjoki to upstream side of Storfossen, the other team did from Storfossen camping to Holmesund (Figure 3). The second manual tracking survey was performed by a team of four packrafts over three days from 2-4 August. The stretch from Utsjoki to the upstream side of Storfossen was done the first day, from the downstream side of Storfossen to Seida the second day, and from Seida to Rustefielbma the third day (Figure 3). When doing these manual tracking surveys, the packrafts were paddling in parallel in order to cover the river cross-section as much as possible. Each packraft were equipped with a GPS logging location by time and were towing a Innovasea 180 kHz Vr2W receiver suspended from a buoy behind the packraft (Figure 5).

2.5 Receiver data downloads

The receivers were downloaded by the relevant software from the different manufacturers (Innovasea: Fathom, Lotek: WHShost, ATS: Trident). After download, all detection data were managed in R v 4.5.0 (R Core Team 2025), including linear time drift corrections. As support for the fish trap management team at Seida, 2-3 of the HR2 receivers at the fence were downloaded two times a week, in order to check if smolts were gathering for longer time on the upstream side of the fence.. The field study was ended 5 August, when receiver retrieval started and the final receiver data download initiated.

Figure 5. Manual tracking survey with three out of 4 packrafts in parallel (a), each with a receiver suspended from a buoy towed behind the packraft (b). Photos: K. Ø. Gjelland

2.6 Detection data filtering

The probability of false positives in the detection data varied by code protocols and receiver type, hence the data were filtered separately by each receiver type. All data from each tag code was scrutinized separately to check for consistency in detection pattern. For the 180 kHz tags, removing detections containing sensor data from tag codes that did not have a sensor, as well as removing detections lacking sensor data from sensor tag codes, were sufficient to obtain a reliable dataset with consistent detection pattern among receivers in the same area. The JSATS codes have a higher probability of false positives, in particular for the Lotek WHS4350 receivers. Hence a requirement for tag presence was set to at least two detections on a receiver within a minute, these two detections should fit with the transmission interval of the tag. Furthermore, at least 4 such detections should be recorded within a 10-minute period on the same receiver, and at least 2 receivers should have such accepted detection pattern within the 10-minute period.

2.7 Migration analyses

As a first simple approach, point estimates of the detection efficiency at each receiver site was estimated by mark-recapture methods using the acoustic smolt detections (Perry et al. 2012). At each of the receiver sites Viđgaveaisavu, Polmak, Skiippagurra, and Seida (Figure 3), detection efficiency was calculated by considering how many tags was detected at the site as well as how many tags were not detected at the site but on downstream sites using the Cormack-Jolly-Seber (CJS) method (Perry et al. 2012). This method cannot be used for estimating detection efficiency at the most downstream location, since we cannot know how many tagged individuals passed undetected. Hence, the detection probability estimate at Rustefielbma were obtained by dividing the receiver array into two subarrays; the upstream and downstream lines, each consisting of four receivers (Figure 3), and then calculating the combined detection probability by the dual array model (Perry et al. 2012).

The survival of a smolt to a given site was inferred by the detection of the acoustic tag at that site, i.e. the smolt was assumed to have arrived to the site, whereas the loss of a smolt was inferred by the lack on any detection further downstream from the last detection. Due to detection probabilities less than 1 at several sites, the number of tagged smolts that reached a receiver site was modelled based on the number of smolts reaching the receiver site, and the receiver efficiency. A simple estimate of how many fish reached each receiver site was obtained by dividing the number of detected smolts at the site by the point estimate of receiver efficiency. This way of calculating survival depends on the number of lost tags between the receiver sites, whether the tag was detected or not during manual tracking surveys. As other factors than mortality may contribute to estimated smolt losses (e.g. tag failure, tag loss, tagged fish not initiating smolt migration), the survival estimates should be viewed as minimum survival estimates. The survival *S* was calculated as the proportion of tagged smolts that reached a receiver site. The instantaneous loss rate was calculated as $\frac{log(N_j)-log(N_i)}{D}$, where N_i is the estimated number of smolts reaching receiver site *i*, N_j is the estimated number of smolts reaching the receiver site *j* (typically the next downstream), and *D* is the distance (km) between the receiver sites.

2.8 Survival analysis

To obtain estimates of survival including uncertainty, we fitted a Bayesian state–space survival model with a hierarchical detection process to the smolt detections. Individual receivers within each of the five locations were analyzed as separate units each contributing to the overall detection probability at the location. The model separates the biological process governing survival from the observation process governing detection and allows incorporation of confirmed losses, i.e. tags detected during the manual tracking.

Survival and state process

Survival probability ϕ_t was estimated for each interval between receiver locations and assigned a uniform prior between 0 and 1. For each individual smolt, survival outcomes between locations were modelled as Bernoulli trials and treated as observed when losses was known, and as latent otherwise. All individuals were assumed to be alive at tagging and release. An individual's state (alive/lost) on each occasion depended on its state at the previous occasion and its survival outcome, such that a loss was permanent once it occurred. Importantly, because detection at a given location was assumed to only be possible when an individual was alive, any detection at a location further downstream implies that the individual must have been alive at all earlier locations.

Detection process

Detection was modelled at the level of the individual receivers. Detection probabilities varied among receivers and were modelled hierarchically on the logit scale with a shared mean and variance. Observations were modelled as Bernoulli trials, with detection possible only when an individual was alive.

Estimated losses and cumulative survival

For each location, we calculated overall instantaneous smolt loss rate (i.e. loss per river kilometer) and the overall cumulative survival of a random smolt (i.e. probability of a random smolt surviving the downstream migration) assuming tagged smolt truly represented the overall smolt population. These metrics were calculated using the posterior samples from the model.

Key assumptions

The model allows for river stretch-varying survival; allows for imperfect detection but assumes zero false positives; loss is assumed to be permanent once it occurs, and all smolts were assumed to be alive when tagged and released. Furthermore, the model assumes that losses occurs between the receiver sites, not at the receiver sites.

2.9 Swimming trajectory estimates

At Seida, 2D swimming trajectory estimates were obtained using the algorithm Yet Another Positioning Solver (YAPS, Baktoft et al. 2017). This method requires accurate synchronization of the receiver clocks. Clock synchronization was done by postprocessing the detection data in the R-package yaps (v. 2.0), using sync signals transmitted by internal receiver transmitters every 30 s. After syncing all detection data at Seida to the same receiver clock, accurate swimming trajectories of present tagged smolt could be estimated by means of multilateration in the yaps package (Baktoft et al. 2017).

3 Results

3.1 Smolt migration and survival

The count of tagged smolts detected at the fixed receiver sites declined rapidly from Viđgaveaisavu to Rustefielbma (Figure 6). The detection probability was high at all sites except Polmak, hence the count estimates adjusted for the detection probability was similar to the observed counts (Figure 6).

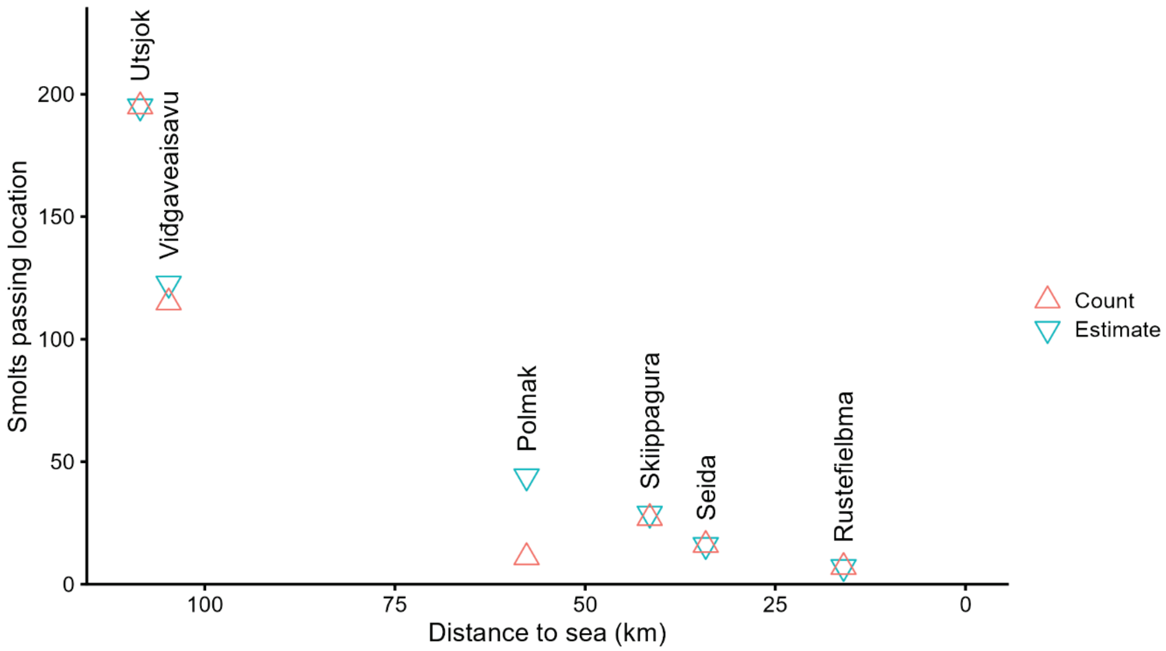


Figure 6. The count of tagged smolts detected at each logger location from Utsjok to Rustefielbma. Green symbols give counts adjusted for Cormack-Jolly-Seber detection probability estimates at each site.

The hierarchical Bayesian state-space survival analysis revealed a high estimated instantaneous loss rate for the first 4 km from Utsjoki to Viđgaveaisavu, then a much lower loss rate between Viđgaveaisavu and Polmak, after which the estimated loss rate again increased with a top between Skiippagurra and Seida (Figure 7). These arrival analyses did not include other information, such that one smolt was lost to predation after first detection at the Rustefielbma receivers, nor one smolt tag that were found upstream to Viđgaveaisavu during manual tracking surveys, although this smolt had been detected on the Viđgaveaisavu receiver site. Overall, the Bayesian estimate of cumulative survival from Utsjoki to Rustefielbma was as low as 2.5% (Figure 7b), or by count of detected smolts 3.6% (3.1% when including the one that suffered predation at Rustefielbma). As the high instantaneous loss rate (12.6 and 12.4% km^{-1} for the Bayesian and CJS methods, respectively) estimated for the first 4 km may have been influenced by methodological issues such as misidentification of smolt status and other factors, we used the estimated arrival counts to calculate survival rates relative to the arrival estimates at Viđgaveaisavu (Table 3). The Bayesian and CJS models were in close agreement on the survival and loss rate estimates for most stretches, with the largest difference in loss rate between Polmak and Skiippagurra due to the lower detection probability at Polmak. These analyses was based on the tagged individuals detected at each fixed receiver site, hence arrivals, and the Bayesian analysis supported by tags found between the fixed receiver sites during the manual tracking surveys. To include information about losses at the receiver sites, the estimated arrival counts subtracted by the smolt known or assumed to be lost at the Viđgaveaisavu, Seida and Rustefielbma were used to calculate survival and loss rates for smolt successfully departing each location (Table 3, see Chapter 3.2 for losses at Seida). After such adjustment, the estimated survival from Viđgaveaisavu to Rustefielbma was 4.9% (overall mean instantaneous loss rate of 3.2% km^{-1}).

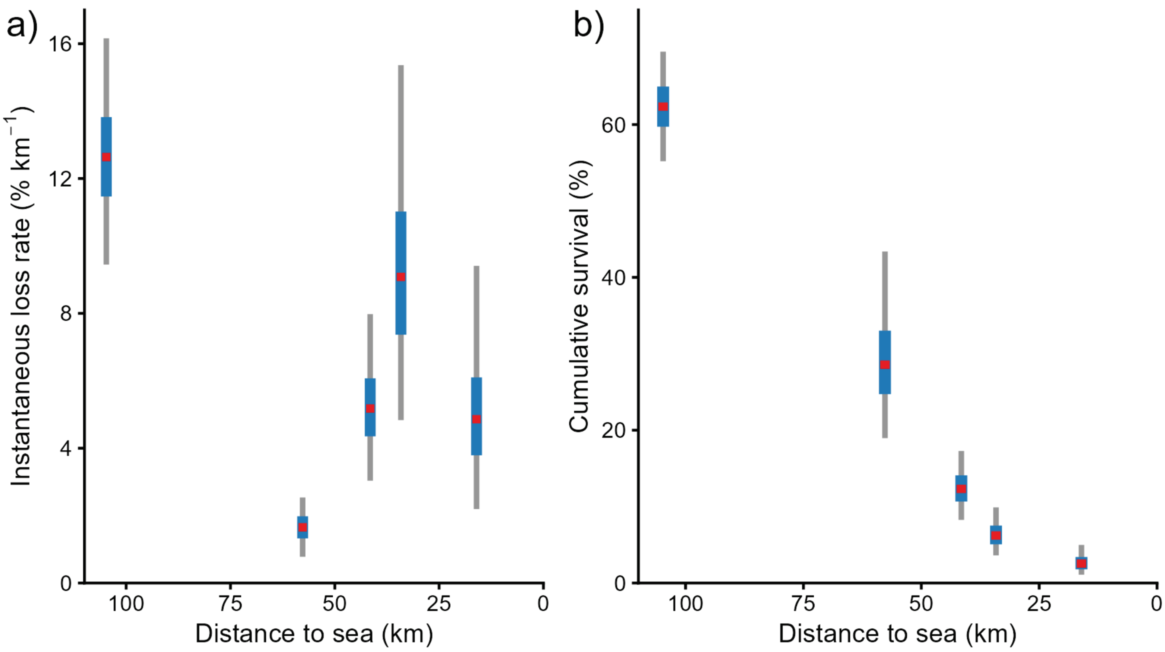


Figure 7. Results from the hierarchical Bayesian state-space survival model. a) Instantaneous loss rate per kilometer, b) cumulative survival from Viđgaveaisavu to Rustefielbma. Red dots show the 50% credible point estimate, blue boxes show the 25-75% credible interval, and the grey whiskers stretches to the lower 2.5% and the upper 97.5% credible intervals.

Table 3. Table showing the Bayesian state-space model 50% credible estimates for survival (%) and loss rate (% km^{-1}), as well as the corresponding Cormack-Jolly-Seber (CJS) estimates. The numbers shown are based on the estimated numbers arrived at each receiver location from Viđgaveaisavu to the downstream receiver sites (arrival), or by the arrival estimates adjusted for the number of smolts lost at the receiver location, when ignoring the losses from Utsjoki to Viđgaveaisavu.

Model	Type	Parameter	Polmak	Skiippagurra	Seida	Rustefielbma
Bayesian	Arrival	Survival	45.8	19.8	10.0	4.1
CJS	Arrival	Survival	35.9	23.5	13.0	5.7
CJS	Departure	Survival	36.2	23.7	9.9	4.9
Bayesian	Arrival	Loss rate	1.7	5.2	9.1	4.9
CJS	Arrival	Loss rate	2.2	2.6	8.0	4.6
CJS	Departure	Loss rate	2.2	2.6	11.9	3.8

3.1.1 Manual tracking surveys

Due to small variations in the transmission interval of the Innovasea tags, the expected tag life varied from 38-45 days for these tags. The expected tag life is given as period of time at least 95% of the tags are expected to be transmitting. Taking activation date of the individual transmitters into account, the cumulative numbers of tags still transmitting at a given date indicated that nearly all tags were still transmitting at the time of the manual surveys (Figure 8).

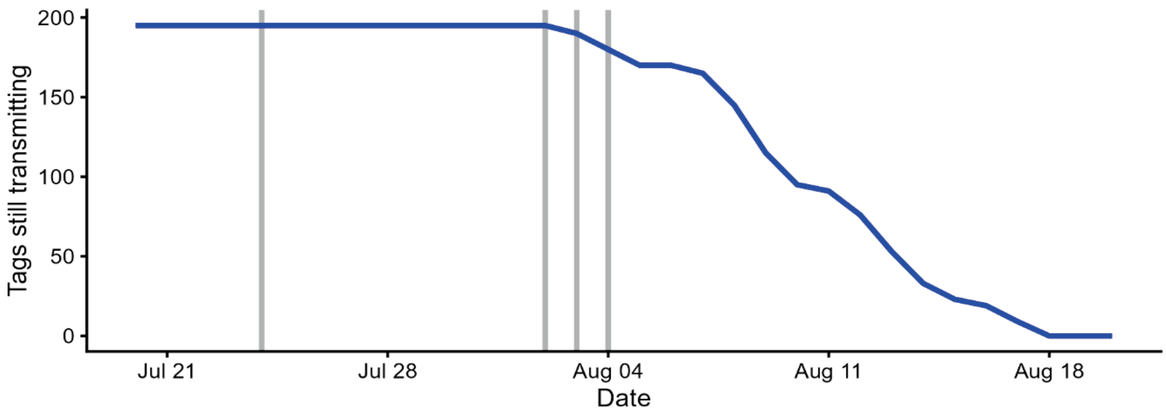


Figure 8. Blue curve: the number of Innovasea tags expected to still be transmitting at a given date. Vertical grey lines: the dates of manual surveys.

During the first manual tracking surveys (24 July, two packrafts in parallel), a total of 13 tags were detected. During the second survey (2-4 August, four packrafts in parallel), a total of 19 tags were detected. Four of these were detected at stretches not included in the first survey; one just downstream to Storfossen but upstream to Storfossen camping, one at Homesund just downstream to the end of the first survey, one between Skiippagurra and Seida, and one just downstream to the receiver line at Rustefielbma (Figure 9). For the first and second surveys combined, a total of 20 unique tags were detected (Figure 9, Figure 10). The locations of tags detected during both the first and the second survey were highly similar, and it was concluded that the tags likely was not moved between the surveys. The location of detections for all detected smolts can be seen in Figure A1. Detection history for all tags detected at the fixed receiver sites and / or manual tracking surveys, excluding the release location. The fixed receiver sites (Viđgaveaisavu, Polmak, Skiippagurra, Seida, and Rustefielbma from left to right) are indicated with a grey background vertical line.Figure A1.

Although tags were detected from the very first to the very last part of the manual tracking surveys, there seemed to be a “hotspot” between Vetsijoki/Veahčajohka and Sirbmá, and also from downstream Storfossen to upper Båteng (Figure 9, Figure 10). Of the estimated losses from one site to the next, 1%, 18%, 20%, 8%, and 11% of the tags were recovered (detected) for the stretch to Viđgaveaisavu, Polmak, Skiippagurra, Seida, and Rustefielbma, respectively, during the manual tracking surveys.

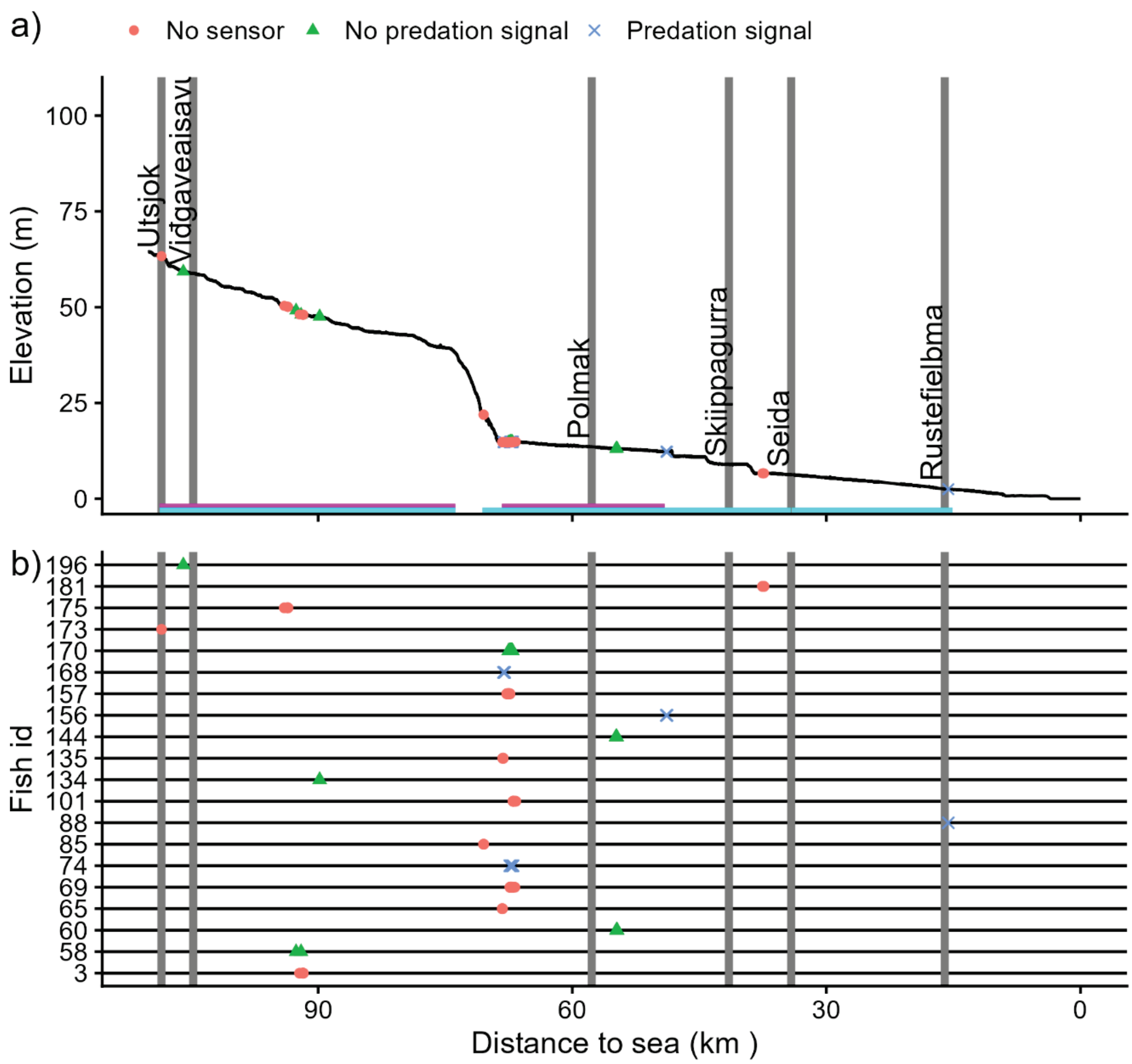


Figure 9. Coloured symbols: Tags detected during the manual tracking surveys by paddling down the Tana river towing receivers behind the kayaks. Location along the river is shown as river distance to the sea. Vertical grey lines shows the release location (Utsjoki) as well as the fixed receiver locations. The magenta-coloured and cyan-coloured horizontal lines indicate stretches paddled during the first and second survey, respectively. a) tag locations plotted on the river elevation profile (black curve), b) tag locations for each representative fish id.

Among the 20 tags detected in these manual surveys, 10 were tags with a predation sensor. Out of these, four tags emitted a predation signal (Figure 11). The sensor data indicated that the sensor was triggered 5.9, 20.1, 6.3, 7.2 days after release for fish id 74, 88, 156 and 168, respectively (Figure 11). Three suffered predation before 12 July, the fourth on 20 July. The latter had migrated all the way to Rustefielbma before the predation event, with the loggers at Rustefielbma detecting the tag both before and after the predation sensor was triggered. This tag (fish id 88) was detected a couple of hundred meters downstream to the fixed receiver site during the last manual tracking survey. Another tag (fish id 196) was detected on Viđgaveaisavu fixed receivers shortly after release. However, this tag was detected a couple of hundred meters upstream to Viđgaveaisavu during manual tracking (Figure 10).

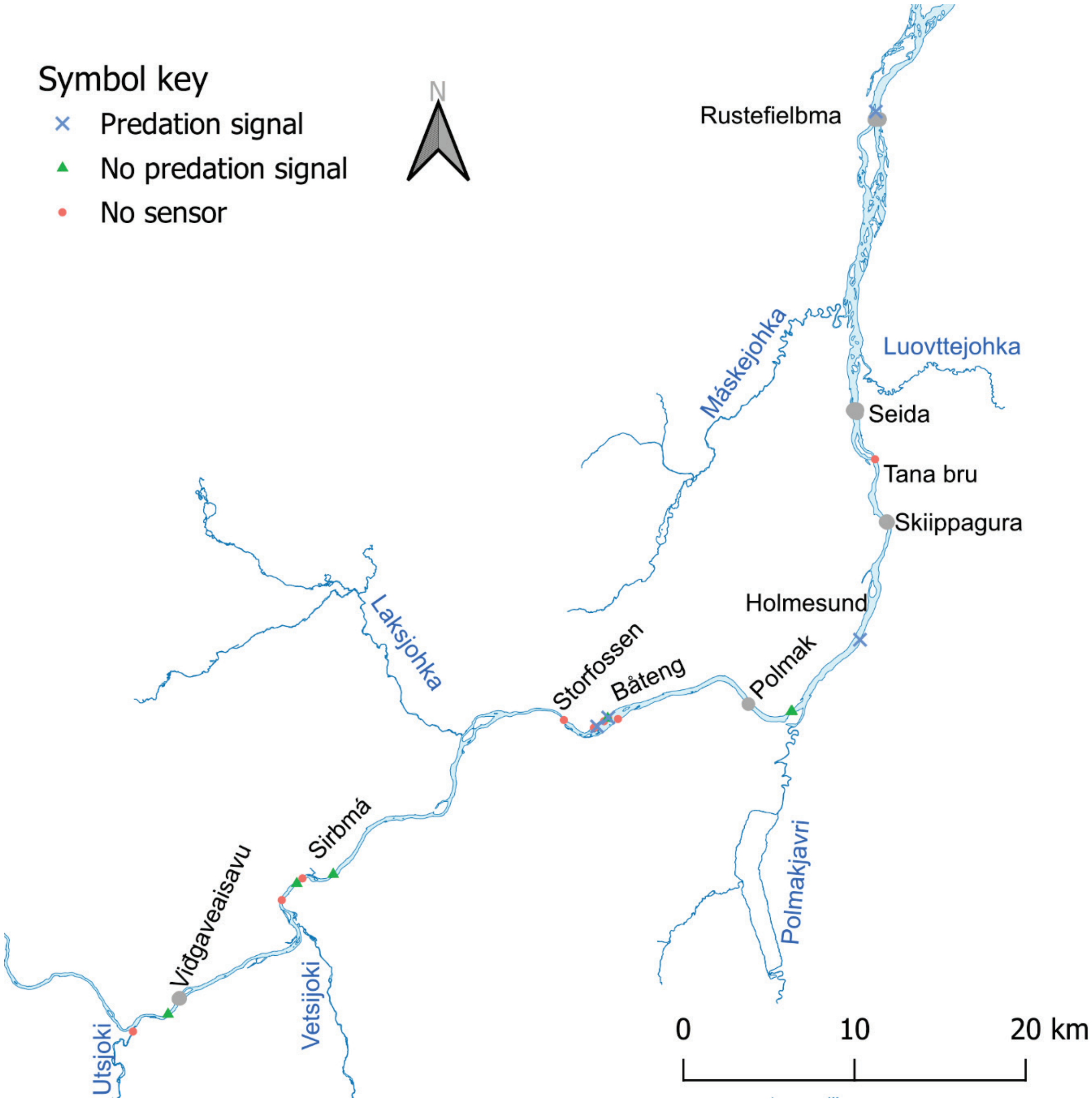


Figure 10. Map of the Tana watercourse from Utsjoki to the sea. Coloured symbols: location of the tags detected during manual tracking surveys. Grey symbols: location of the fixed receiver sites.

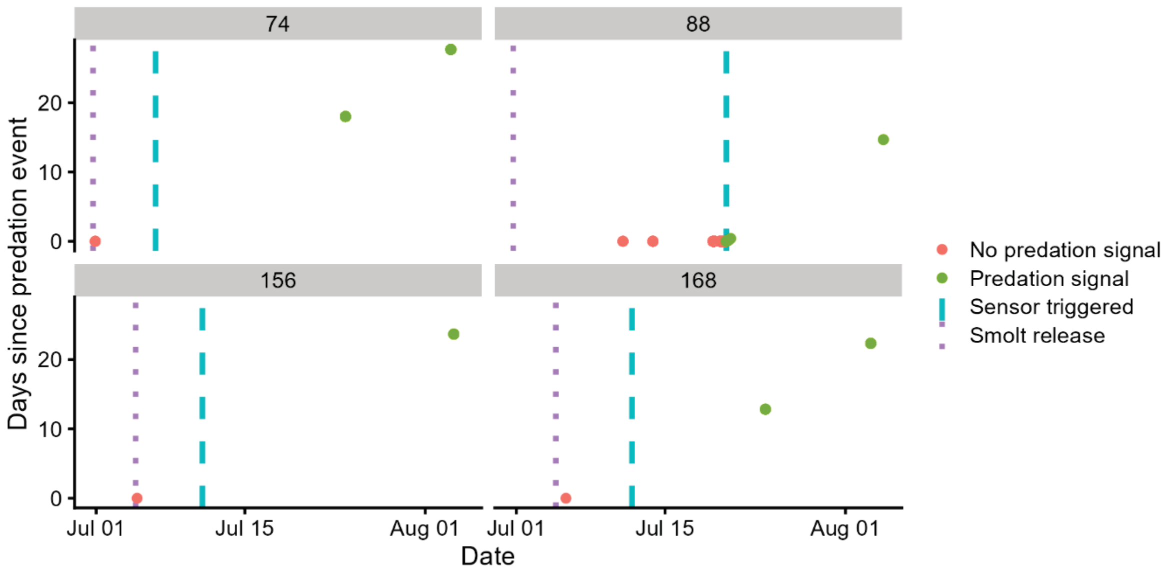


Figure 11. Detection history for the four smolts where the predation sensor was activated. Dots indicate detections by date, with the y-axis indicating days passed since the predation event. Dot colour indicates if the predation sensor was activated or not. The vertical dotted line indicate release time, the vertical dashed line indicate the time of the predation event

3.1.2 Migration speed, travel time and shoal cohesion

For the four releases of smolts with Innovasea tags, 115 smolts were detected at the Viđgaveaisavu receivers. The fastest smolts spent less than 3 hours on the 3.8 km long stretch (Table 4), and many smolts made this stretch in just a few hours (Figure 12). But for three of the releases, median travel time for this stretch was about one day or more. There was no clear indication that smolts arriving among the first to the location had better survival probability than smolts arriving later (Figure 12). None of the 9 smolts that were observed for more than three hours at the receiver site at Viđgaveaisavu reached any of the other downstream fixed receiver locations. The shoal cohesion with the smolts released together was evaluated by comparing arrival time at the first fixed receiver site, Viđgaveaisavu. The arrival times indicated that even though a few seemed to arrive at the Viđgaveaisavu location within a short time interval, most arrived at separate times indicating that the smolts did not stick together with the group they were released together with (Figure 12).

For the smolts that made it from Utsjoki to Seida, 16 tagged with Innovasea tags and 2 tagged with JSATS tags, the median travel time from Utsjoki to Seida was 5.9 days (interquartile range 4.9 – 11.2 days), corresponding to migration speeds of respectively 12.7 km day^{-1} (15.2 – 6.7 km day^{-1}). There was no indication that early migrating smolts migrated faster than later migrants (Figure 13). Most of the tagged smolts reached Seida after the fence were mostly finished, but before it was completely closed by the trap installations (12th July).

Table 4. Summary of migration speed and time from Utsjoki to Viđgaveaisavu (3.8 km river distance). N = number of tagged and released smolts at Utsjoki, n = number of smolts detected at Viđgaveaisavu.

			Travel speed (m s^{-1})		Travel speed (body lengths s^{-1})		Travel time (hours)	
Release group	N	n	Fastest	Median	Fastest	Median	Fastest	Median
26.06.2025	50	19	0.22	0.023	1.28	0.13	4.73	45.98
30.06.2025	50	33	0.68	0.036	4.32	0.23	1.52	28.79
01.07.2025	50	35	0.21	0.045	1.38	0.30	4.95	23.24
04.07.2025	45	28	0.37	0.151	2.43	0.91	2.81	6.95

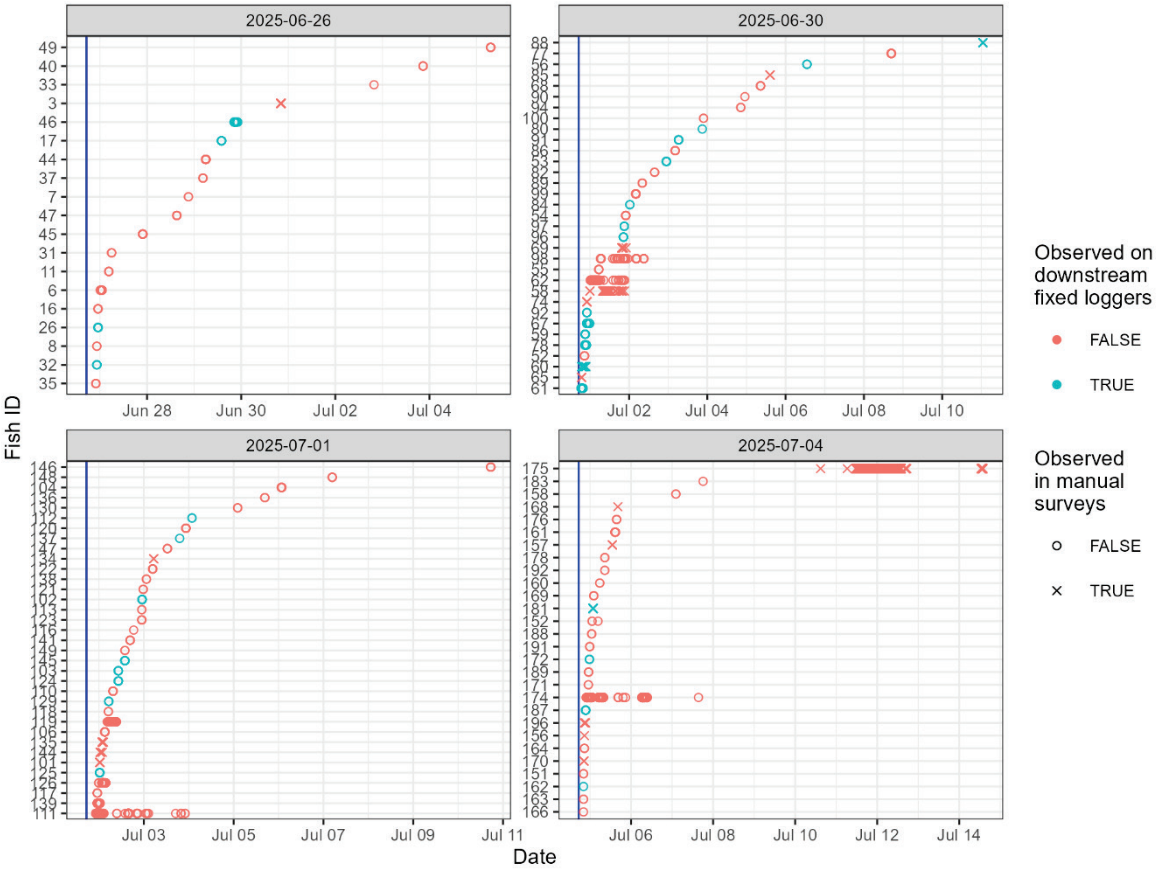


Figure 12. Arrival time of tagged smolts at the receivers at Viđgaveaisavu, faceted by release. The number of tagged smolts in each release was 50, except in the last where 45 tagged smolts were released. Symbol colour indicate if the smolt was detected at one or more of the downstream fixed receiver sites, symbol shape indicate if the tag was detected during the manual tracking surveys. The blue vertical line indicates release time.

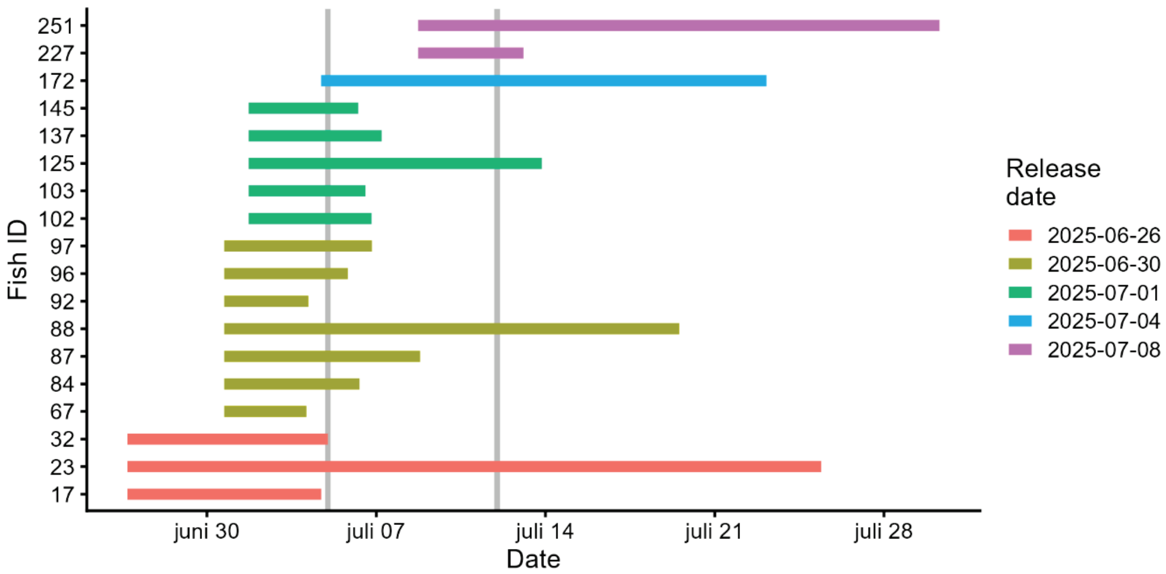


Figure 13. Figure with horizontal coloured bars indicating the travel time from release in Utsjoki to detection at Seida, including Innovasea tags and JSATS tags. Gray vertical lines indicate the time of closing the fence at Seida by installing trap 1 and trap 2. Most smolts arrived before the last trap was installed.

The survival from Usjoki to Seida varied for the different release groups, being 6, 14, 10, 2.2 and 4.4% for the releases 26 June, 30 June, 1 July, 4 July, and 8 July, respectively. From Utsjoki to Rustefielbma the corresponding numbers were 2, 6, 6, and 0% (8 July excluded, since there were no JSATS receivers at Rustefielbma.

3.1.3 Smolt size and migration success

We found no indication that smolt length influenced which smolts were detected at the first receiver site (Viđgaveaisavu) (Figure 14). Although there seemed to be a slight tendency that larger smolts had a higher probability of reaching Seida or Rustefielbma, this was anyhow a weak effect that did not pass a statistical test (glm with binomial family).

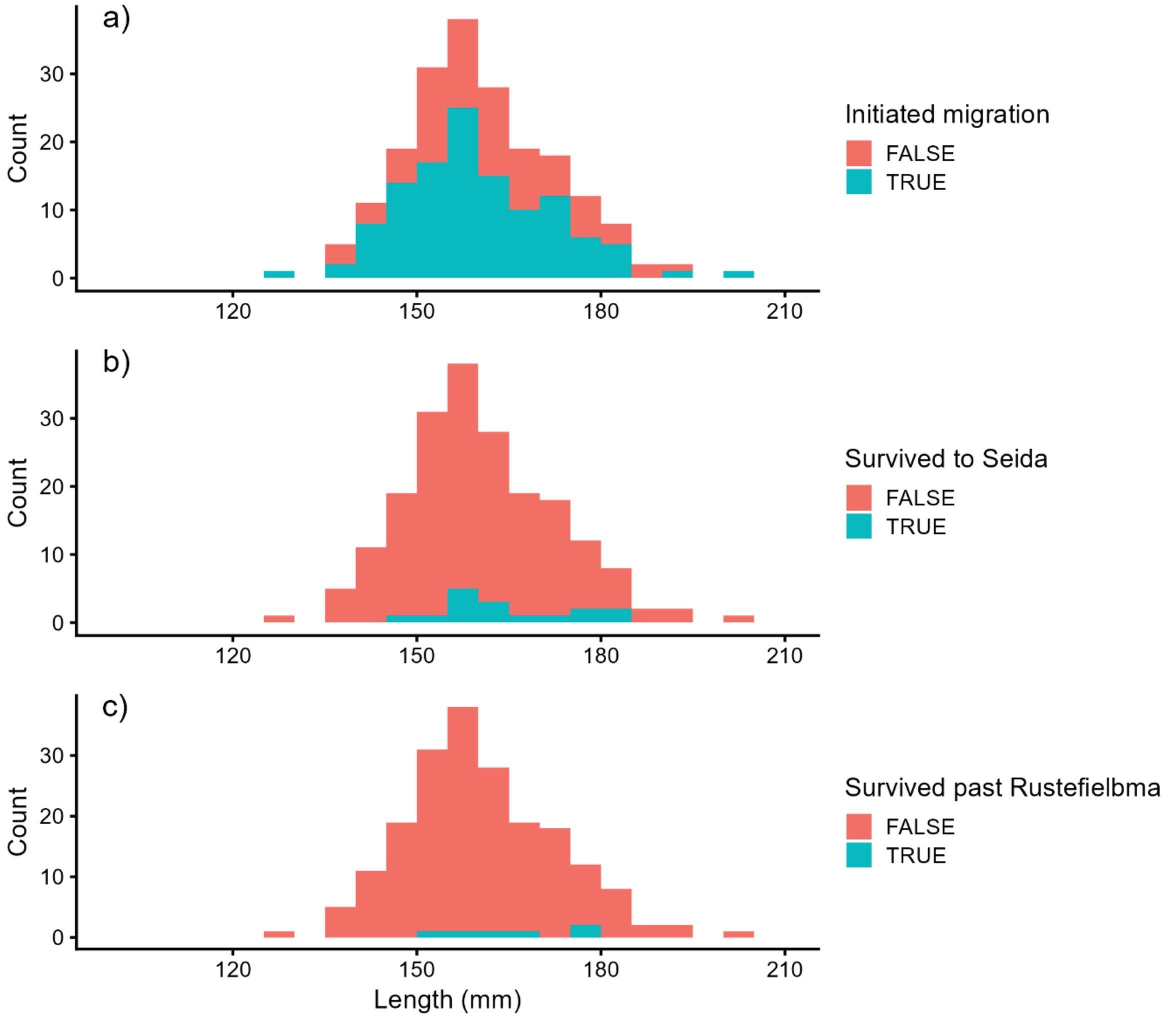


Figure 14. Smolt size distribution, with fill colour indicating which a) initiated migration (i.e. were detected at Viđgaveaisavu), b) reached the Seida receivers, and c) reached and survived past the Rustefielbma receivers.

3.2 Behaviour at the fence site

The median observation time at the fence site (time from first to last detection) was 123 minutes (16 Innovasea tags and 4 JSATS tags), with interquartile range 51-229 minutes, and range 16 minutes to 54.2 hours (ignoring one tag observed for 31 days, apparently dropped to the bottom just upstream to the fence). When near the fence, smolts typically swam along the fence, often back and forth for some time. See the Appendix for figures of the swimming trajectories of each individual, e.g. Figure A2. Based on swimming trajectories and/or detection patterns, it was judged that 3 smolts did not cross the fence, whereas one smolt passed the fence and moved downstream, but reappeared on the downstream side of the fence an hour later. This one was considered a potential predation loss, as well as the three not crossing the fence. Several pike were caught at the fence by people working as trap operators, the stomach content of some of these pike were investigated and revealed smolt predation. The traps did not come into position until 5 and 12 July, and the fence did therefore have relatively large openings at the trap locations in the fence. Most of the smolts arrived before both traps were into position, and a few of the smolts seemed to pass the fence at the trap locations before closure. As the fate downstream to the fence could not be evaluated for JSATS-tagged fish due to lack of receivers, the potential loss of 3-4 out of 16 smolts tagged with Innovasea tags could be seen as an additive (extra) loss of 12-25% caused by predators aggregating at the fence. Acknowledging the small number of smolts arriving to the area, as well as that there could be some mortality in the area also without the fence, these numbers are indicative of extra losses rather than precise estimates. These losses were included when calculating the survival and loss rates for site departure (Table 3).

4 Discussion

The results from the present study indicate that very few of the tagged Atlantic salmon smolts fulfilled the downstream migration from Utsjoki to Rustefielbma in 2025, a river stretch of about 92.5 km. The overall survival estimate of 4.9% (excluding losses the first 4 km stretch) is lower than the estimated return rates of 1SW salmon to Utsjoki in most of the earlier years (Anon. et al. 2026, the return rate is given as a proxy for the survival of smolt in one year to returning one sea winter, 1SW, salmon the next year). We expect a large marine mortality in addition to the freshwater mortality, and therefore the overall survival from outmigration from Utsjoki to return as 1SW salmon to be much smaller than the survival from Utsjoki to Rustefielbma. Hence, the estimated overall survival seems incomparable to earlier survival estimates, including the radio telemetry study in 2021 where the estimated survival from Iešjohka to Rustefielbma was 11%, also classified as very low (Gjelland et al. 2024). Apart from 2023, earlier survival estimates are from years without any fish trap.

Estimated smolt survival in 2023 was very low, with only a 0.8% return rate of 1SW salmon to Utsjoki in 2024, and it has been suggested that the salmon trap may have contributed to the reduced survival of the smolt run (Anon. 2025). In the present study, losses were found near the fence, and the fence did halt the migration for some time for most smolts observed at the fence. However, the results in this study indicate that the fence was not likely to be the main driver for large smolt losses, as much of the losses occurred before the smolt reached the fence. Although some of the initial losses indicate a methodological issue for the first stretch from Utsjoki to Viđgaveaisavu, the data further downstream are quite consistent, and we do not have indications that methodological issues were the driver of the large losses observed further downstream. In the following, we will go more into detail about the findings.

4.1 Survival during downstream migration

The reasons for the large losses during smolt migration from Utsjoki to Rustefielbma are not unequivocal. The manual tracking surveys were performed with the intention of locating tags from smolts that did not make it to the sea, i.e. tags that were not detected as passing the fixed receiver sites. The inclusion of predation sensors were intended to identify the percentage lost to predation, and the manual surveys were therefore necessary to get information on the fate of the smolts that apparently did not fulfil the migration down the Tana river. However, the relatively low number of detected tags during the manual tracking surveys, compared to the high losses of smolt during the migration, leaves some room for speculations. Several factors may have the potential to contribute to the uncertainty of the fate of the smolts that apparently did not make the journey: 1) reliability of the tag and tag battery life, 2) reliability of the predation sensor, 3) detection probability at fixed receivers, 4) detection probability during the manual surveys, 5) How representative the tracked smolts are for the population of non-tagged smolts.

<u>Tag reliability and battery life</u>

An important factor potentially contributing to the uncertainty of the results is tag reliability and longevity. Due to financial constraints, we did not set aside tags for testing tag life, hence we have no data indicating to what degree we can trust the specifications given by the tag producers. However, the migration speed of smolts that made it to Seida suggested that the typical migration time was much shorter than the expected tag life, hence the tag life should have been very far off from the expectations if this was to contribute to the low migration success. We do know that the tags observed during the first manual tracking survey were also detected during the last tracking survey (i.e. 27-39 days after tagging), with the exception of one out of thirteen. Also, one tag by the fence was observed to the end of the study period. Thus, we have some data that indicate that tag life lasted as expected, and that tag malfunction was not an issue well into the study period. If many tags should have stopped much earlier, this must have been due to tag malfunctioning soon after tagging, rather than too short tag longevity in general. The high loss rate from Utsjoki to Viđgaveaisavu, combined with the very low tag recovery (1%) of many tags at this short stretch (4 km), could be an indication that such early tag malfunctioning occurred. From experience, if an acoustic tag malfunction this typically occur shortly after tag initialization (<1 day). Later tag malfunctioning is unlikely in our data, as that would contradict the tag recoveries between first and second manual tracking surveys. Moreover, it would require a decreasing, increasing and then decreasing pattern of tag malfunctioning if it was to explain the tag loss rate pattern further downstream.

Predation sensor

The reliability of the predation sensor can be questioned. Both tags with and without a predation sensor will continue to transmit signals after the predation event, both when in the predator and after being shed from the predator. It is not the reliability of the tag transmission we question, but the reliability of the sensor correctly identifying a predation event. As the tags detected during the two manual tracking surveys did apparently not move between the surveys, we think that the smolts that carried these were most likely dead. It does not seem reasonable to think that the smolts would initiate migration and then stop some half-way down the watercourse to stay there. Recent diet studies in pike have shown that smolt make up an important part of pike diet during the smolt migration period, likely causing the loss of Atlantic salmon smolts at the scale of hundreds of thousands in the Tana watercourse (Svenning et al. 2026). Inference from this indicate that predation must be an important factor for smolt mortality during migration down the watercourse. Although a published study co-authored by a tag manufacturer employee indicated a high predation sensor reliability (Halfyard et al. 2017), a study testing the same kind of tags with predation sensors bought from the shelf as in our study indicated a sensor reliability of only 50% (Lennox et al. 2021). A similar predation sensor reliability applied to our study would indicate that predation was the cause of 80% rather than 40% (4 out of 10) of the smolt losses. The numbers of detected tags with predation sensors during the manual tracking surveys were however small, and thus the inference on the importance of predation based on the predation sensor data is anyway weak. The relatively many tags detected during manual tracking surveys in an area known for pike predation on smolts may, on the other hand, indicate that predation was an important factor for the high smolt losses during the migration study. Other potential important predators are mergansers, loons, mink, and brown trout, but it was not a purpose of this study to identify predator species. Pink salmon was not regarded as a potential predator, since pink salmon on their spawning migration entirely stops feeding when in freshwater (Quinn 2005, Diaz et al. 2023).

Detection probability at fixed receivers

The initial range testing before the experiment start revealed poorer detection performance than expected. This challenge was met with a revised receiver array design involving shorter distance between the receivers, and the detection analyses involving different ways of estimating detection probabilities (the “traditional” Cormack-Jolly-Seber method (Perry et al. 2012), the dual subarray method (Perry et al. 2012), and the Bayesian state-space model all gave similar estimate of detection probabilities at each receiver site. With the exception of the Polmak site, the combined detection probability was > 90% at all sites. Moreover, the water discharged decreased from the first to the last tagged smolt release, which should lead to an expectation of higher detection probability for smolts in the last release as compared to earlier releases. The survival estimates for the separate release groups did not match such a pattern. Hence, our survival estimates seem not to be affected by detection range, and we have no indication that many tagged smolts with functional tags migrated to the sea undetected.

Detection probability during manual tracking

During the manual tracking surveys, the detection probability of tags from smolts that did not make it to the sea have several components. Acoustic tags in air will not be detected by the acoustic receivers. Hence, tags from smolts that suffered predation from birds or mink could be shed on land and go undetected, as could tags shed from predatory fish during high water level at locations that become dry during lower water levels. It is also likely that some tags, if dropped into the bottom substrate by a predator, are bypassed without detection during manual tracking due to acoustic “shadowing” and sound attenuation. This effect is likely to be strongest in highly heterogeneous habitats with lots of larger stones, blocks and rapids, such as the Storfossen area. The result of these different factors is that we may expect a recovery of less than 100% of the tags that were lost between two receiver sites.

There was seemingly a couple of tag hotspots along the migration route, one between Vetsijoki and Sirbmá, and also from downstream Storfossen to upper Båteng. This could be indicative of predation hotspots. We cannot know if this pattern was solely due to predation/mortality patterns, or if substrate conditions were better for detecting tags in these areas. Moreover, Storfossen was not surveyed during the manual tracking, and the stretch from Storfossen to Storfossen camping (upper Båteng) is characterised by lots of boulders and rapids, with poor detection probability. Hence, parts of a potentially important predation area are known to have poor detection coverage during the manual tracking. Having said this, the Storfossen to upper Båteng area has been an important catch area for pike, whose diet have revealed a high prevalence of smolts during the smolt migration period (Svenning et al. 2026). Hence, we believe that these areas are indeed areas of increased predation risk.

Representativity of tagged smolts

When doing tagging experiments, we strive to get information on individual behaviour and fate while keeping the effects of the tagging and handling procedures as low as possible, in order to secure samples that are representative of the population. In the current experiments, water temperature was considered adequate for tagging, the tagging procedure involved a careful surgery with the smolt in an aeriated anaesthetic bath, and a post-surgery monitoring to ensure the recovery of healthy tagged smolts. The capture of smolts with the fish traps used may have forced the smolt to swim against the current for a substantial amount of time (up to 12 hours), but we do not have current measurements and cannot quantify this effect. No significant mortality or indisposition were observed when the traps were emptied or later when smolts were kept in keepnets. There is therefore little support that the high migration losses could be caused by mortality induced by the capture method.

The capture, tagging and release all occurred well into the smolt run period in Utsjoki, but still mainly before 50% of the smolts had passed the video monitoring location close to the capture location. The tagged smolts were apparently healthy at release and were released in groups of 50-100 smolts (including non-tagged smolts) to ensure the possibility for the smolts to shoal. It has been shown that smolts released in periods of high smolt run have higher return rates, indicative of larger shoals giving better protection towards predation (Hvidsten & Johnsen 1993). Neither we nor Hvidtsten & Johnsen (1993) could control the actual shoal size joined by individual smolts, and the results of Hvidtsten & Johnsen (1993) could maybe reflect a predator swamping effect rather than a shoal size effect per se. We found that many of the tagged and released smolts did not migrate with the group they were released together with. We do still anticipate that tagged and released smolts will join smolt shoals when migrating, though not necessarily the group they are released together with. It is possible that the tagged smolts will less effectively join shoals of appropriate size and thus become easier targets for a predator and contribute to overestimation of loss rates. The different survival observed for the different release groups was not associated with the smolt run in Utsjoki for the release day nor the following day, but it could be associated with the smolt run in the Tana main stem for the days following the release day, with higher smolt run numbers being associated with predator swamping and higher smolt survival (Hvidsten & Johnsen 1993). But a pattern with low survival for smolt released at days with low main stem smolt run and higher survival for smolt released at times with high main stem smolt migration, would lead to a mean survival estimate being biased low if not weighed for the total smolt run at release time for each released group. Since we do not know the smolt run numbers by day in Tana main stem, we could not do such weighing in our analyses. Although handled and tagged fish were healthy at release, it is possible that the tagged smolts were more vulnerable to predation by mechanisms such as reduced shoal coherence and/or reduced predator evasion capability. Such effects will imply some degree of overestimation of the migration losses for the general population. But the predation risk must be still be significant for such effects to result in high loss rate, and the high loss rates from our study should rather be interpreted as indications of high predation losses than accurate measures of the general smolt losses during the smolt migration in Tana.

<u>Implications for the interpretation of the survival analysis</u>

For the first stretch from Utsjoki to Viđgaveaisavu, we anticipate that the loss rate is overestimated as compared to the true mortality for non-tagged and non-handled fish. This could occur if some fish were erroneously classified as migrating smolt, halted migration as a consequence of the capture and tagging procedure, or died post-release as a consequence of the tagging procedure. Moreover, early tag malfunction appears as a likely candidate explaining parts of the losses. Anyhow, it is reasonable to assume that smolts that passed Viđgaveaisavu were healthy fish that had initiated their migration. Downstream to Viđgaveaisavu, potential tag malfunctioning may have biased survival estimates low, but is unlikely to cause the pattern of increased loss rates in the lower parts. If we consider survival estimates from Viđgaveaisavu to Rustefielbma, the survival is still as low as 4.9% (acknowledging the mortality of one smolt at Rustefielbma), or 6% if we consider the release groups with highest survival estimates. The predation sensor data indicate that 40% of the losses was due to predation. But the predation tag recoveries were low, moreover the predation sensor may have failed to identify predation. In addition, the tag from smolts lost to bird or mink predation may have ended up on land, unavailable to detection by our surveys. These factors will lead to underestimation of predation losses, hence the percentage of losses caused by predation was likely substantially higher than 40%.

4.2 Behaviour and losses at the fence site

Although the smolts could physically pass between the bars at any point along the fence, they typically responded to the fence by swimming along it. Of the 17 smolts that we were able to get a swimming trajectory for, only one seemed to swim directly past the fence. The rest did either not reach the fence (2) or swam along the fence for a shorter or longer time. The time spent in the fence area, as presented in the Results, is likely underestimated compared to what would have been observed if the fence had been fully closed at smolt arrival, as some smolts apparently passed at the trap locations before the traps were installed. Others probably passed in the boxes intended for downstream migration of kelts. In the presence of predators, the back-and-forth movements of smolts in the fence area will increase the predator encounter rate. Likewise, the presence of the fence may increase predator densities of pike, sea trout and salmon kelts when the movements of these are impeded by the fence. In turn, this will also contribute to increased predator-prey encounters for the migrating smolts. Piscivorous birds were also present in the area, particularly mergansers and red-breasted loon, although the extent to which their presence is influenced by the fence is unknown. Increased predator encounter rates are expected to result in increased predation mortality. In addition, with a water current of about 0.8 m s^{-1} just upstream to the fence, holding position against the current will require a sustained swimming speed of 5 body lengths s^{-1} for a smolt of mean size in the present study, and even higher swimming speed to move along the fence. Such high swimming speeds is in the range of critical swimming speed (Remen et al. 2016) or the maximum swimming speed a smolt can sustain for more than 200 minutes (Hvas et al. 2017), and therefore exhaustive. Exhaustion will reduce the predator evasion capability during a predator attack. Overall, increased predation is a likely consequence of the fence installation. On the other hand, the smolt retention time caused by the fence was for the most smolts on the scale of hours rather than days, and it is unlikely that this has a major impact on the overall energy reserves for the smolt. Hence, we do not expect a significant increase in smolt mortality caused by energy depletion as a consequence of retention at the Seida fences.

The loss of 3-4 smolts in the fence area may indicate a substantial additive smolt mortality caused by the presence of the fence, but the low numbers of smolts that reached the fence implies that the proportion of smolt that is lost due to the fence installation is uncertain. In a telemetry study investigating smolt migration from Iešjohka to Rustefielbma the loss rates dropped to less than 1% km^{-1} downstream to Polmak (Gjelland et al. 2024). In the present study loss rates decreased to 1.7% km^{-1} towards Polmak but thereafter increased to 9% km^{-1} from Skiippagurra to the Seida fence site, or as much as 12% km^{-1} if accounting for smolts inferred not to have departed further downstream from Seida. Hence, the loss pattern in the fence area was very different as compared to 2021. Except for the stretches from Utsjoki to Viđgaveaisavu and from Skiippagurra to Seida, the observed loss rates were within the range 0.3-7% km^{-1} reported in other studies of Atlantic salmon smolt downstream migration (median 2.3% km^{-1}, reviewed by Thorstad et al. 2012). Whereas the high loss rate from Utsjoki likely were influenced by methodological issues such as smolt identification, tagging effects and potentially early tag malfunctions, these factors are unlikely to explain the exceptionally high loss rates towards and including the Seida area

4.3 Conclusions

The present telemetry study revealed extremely high smolt losses during the 2025 smolt migration from Utsjoki to Rustefielbma in the Tana watercourse. The overall survival from Utsjoki to Rustefielbma was estimated at 3.1%, but several methodological factors likely contributed to underestimation of the survival for the first 4 km stretch to Viđgaveaisavu. A more representative survival estimate for the study is the 4.9% survival from Viđgaveaisavu to Rustefielbma (mean instantaneous loss rate of 3.2% km^{-1}). Some release groups had higher (6%) survival estimates, if these releases were associated with larger smolt runs for the relevant release date, this would be a more representative survival estimate. Moreover, if handling and tagging makes the smolt more vulnerable to predation through effects such as reduced shoaling and/or reduced predator evasion capability, the loss rate will be overestimated. Hence, the low survival estimates should rather be interpreted as indications of low general survival and potentially high predation mortality, than accurate figures of survival. The use of predation sensors in tagged smolts indicated that 40% of the losses were due to the predation. However, other studies have revealed that these sensors have a high rate of false negatives in identifying predation events. Moreover, predators such as birds and mink may shed the smolt tag on land and unavailable to detection by our surveys, further biasing low the estimated proportion lost to predation. We argue that a major part of the losses were due to predation, although insufficient data are available to quantify this precisely. The pattern of increased loss rate towards and including the Seida trap site was unlikely to be explained by methodological effects and hence represented increased smolt losses at the population level. We found clear evidence that the fences associated with the fish trap temporarily interrupted smolt migration. Although smolts were physically able to swim between the bars anywhere along the fence, the typical behavioural response was to swim along the fence, potentially searching for larger openings. Half of the smolts arriving at the fence spent more than two hours at the fence site, increasing predator encounter rates and the energy expenditure towards exhaustion. These factors likely contributed to considerable additive losses in the fence area, with up to 25% extra mortality near the fence (4 out of 16 smolts). However, it must be emphasised that the true effect of the fence on smolt losses can only be assessed by comparing loss rates along the river stretches in years with a fence installation to years without a fence.

5 References

Anon. 2025. Status of the Tana/Teno River salmon populations in 2024. Report from the Tana/Teno Monitoring and Research Group nr 1/2025. https://brage.nina.no/nina-xmlui/handle/11250/3175356

Anon. 2026. Status of the Tana/Teno River salmon populations in 2025. Report from the Tana/Teno Monitoring and Research Group nr 1/2026. https://jukuri.luke.fi/handle/11111/103692

Bærum, K. M., Silva, A. T., Baktoft, H., Gjelland, K. Ø., Økland, F., & Forseth, T. 2024. Predicting fine-scale downstream migratory movement of Atlantic salmon smolt (*Salmo salar*) in front of a hydropower plant. Scientific Reports, 14(1), 30778. https://doi.org/10.1038/s41598-024-80972-4

Diaz Pauli, B., Berntsen, H. H., Thorstad, E. B., Homrum, E. ì, Lusseau, S. M., Wennevik, V., & Utne, K. R. 2023. Geographic distribution, abundance, diet, and body size of invasive pink salmon (*Oncorhynchus gorbuscha*) in the Norwegian and Barents Seas, and in Norwegian rivers. ICES Journal of Marine Science, 80: 76–90. https://doi.org/10.1093/icesjms/fsac224

Domaas, S., Orell, P., Kytökorpi, M., Myklebost, M. R., Erkinaro, J., & Gjelland, K. Ø. 2024. Evaluation of fish trap and guiding fence efficiency in the River Tana in 2023. In *57* (No. 2387). Norwegian Institute for Nature Research (NINA). https://brage.nina.no/nina-xmlui/handle/11250/3108000

Erkinaro, J., Orell, P., Fossøy, F., Kytökorpi, M., Gjelland, K.Ø., Johansen, N., Domaas, S, Kuusela, J., Fagard, P., Frøiland, E. & Falkegård, M. 2026. Rapid increase in abundance and distribution of invasive pink salmon (*Oncorhynchus gorbuscha*) within a diverse, large Barents Sea catchment. Journal of Fish Biology, in press. https://doi.org/10.1111/jfb.70348

Falkegård, M., Lennox, R. J., Thorstad, E. B., Einum, S., Fiske, P., Garmo, Ø. A., Garseth, Å. H., Skoglund, H., Solberg, M. F., Utne, K. R., Vollset, K. W., Vøllestad, L. A., Wennevik, V., & Forseth, T. 2023. Predation of Atlantic salmon across ontogenetic stages and impacts on populations. Canadian Journal of Fisheries and Aquatic Sciences, *80*(10), 1696–1713. https://doi.org/10.1139/cjfas-2023-0029

Gjelland, K. Ø., Baktoft, H., Økland, F., Hedger, R. D., & Forseth, T. 2014. Automatisk posisjonering av akustisk merket smolt i tre dimensjoner – utprøving og evaluering i Mandalsvassdraget. NINA Rapport 1072, Norsk institutt for naturforskning (in Norwegian). https://hdl.handle.net/11250/2372267

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 Rapport 2396. Norwegian Institute for Nature Research. https://brage.nina.no/nina-xmlui/handle/11250/3123078

Halfyard, E. A., Webber, D., Del Papa, J., Leadley, T., Kessel, S. T., Colborne, S. F., & Fisk, A. T. 2017. Evaluation of an acoustic telemetry transmitter designed to identify predation events. Methods in Ecology and Evolution, 8(9), 1063–1071. https://doi.org/10.1111/2041-210X.12726

Hvas, M., & Oppedal, F. (2017). Sustained swimming capacity of Atlantic salmon. Aquaculture Environment Interactions, 9, 361–369.https://doi.org/10.3354/aei00239

Hvidsten, N. A., & Johnsen, B. O. 1993. Increased recapture rate of adult Atlantic salmon released as smolts into large shoals of wild smolts in the river Orkla, Norway. North American Journal of Fisheries Management, 13(2), 272–276. https://doi.org/10.1577/1548-8675(1993)013%253C0272:IRROAA%253E2.3.CO;2

Lennox, R. J., Nilsen, C. I., Nash, A., Hanssen, E. M., Johannesen, H. L., Berhe, S., Barlaup, B., & Wiik Vollset, K. 2021. Laboratory and field experimental validation of two different predation sensors for instrumenting acoustic transmitters in fisheries research. Fisheries, 46(11), 565–573. https://doi.org/10.1002/fsh.10669

Orell, P., Erkinaro, J., Svenning, M. A., Davidsen, J. G., & Niemelä, E. 2007. Synchrony in the downstream migration of smolts and upstream migration of adult Atlantic salmon in the subarctic River Utsjoki. Journal of Fish Biology, 71(6), 1735–1750. https://doi.org/10.1111/j.1095-8649.2007.01641.x

Quinn, T. P. 2005. The behavior and ecology of Pacific salmon and trout. Bethesda, Md. American Fisheries Society, 378 pp.

Remen, M., Solstorm, F., Bui, S., Klebert, P., Vågseth, T., Solstorm, D., Hvas, M., & Oppedal, F. 2016. Critical swimming speed in groups of Atlantic salmon *Salmo salar*. Aquaculture Environment Interactions, 8, 659–664. https://doi.org/10.3354/aei00207

Sandlund, O.T., H.H. Berntsen, P. Fiske, J. Kuusela, R. Muladal, E. Niemelä, I. Uglem, T. Forseth, T.A. Mo, E.B. Thorstad, and A.V. Zubchenko 2019. Pink salmon in Norway: the reluctant invader. Biological Invasions, 21, 1033–1054. https://doi.org/10.1007/s10530-018-1904-z

Shorgan, M. B., Raby, G. D., Fedus, A. L., Howell, B. E., Haniford, L. S. E., Howitt, L. C., Klinard, N. V., Matley, J. K., Brownscombe, J. W., Cooke, S. J., & Fisk, A. T. 2025. Effects of surgical implantation of electronic tags in fishes: A review and meta-analysis. Reviews in Fish Biology and Fisheries, 36(1), 14. https://doi.org/10.1007/s11160-025-10020-5

Shorgan, M. B., Reid, H. B., Ivanova, S. V., Fisk, A. T., Cooke, S. J., & Raby, G. D. 2025. Validation of a new acoustic telemetry transmitter for the study of predation events in small fishes. Journal of Fish Biology, 106(5), 1531–1539. https://doi.org/10.1111/jfb.15827

Silva, A. T., Bærum, K. M., Hedger, R. D., Baktoft, H., Fjeldstad, H.-P., Gjelland, K. Ø., Økland, F., & Forseth, T. 2020. The effects of hydrodynamics on the three-dimensional downstream migratory movement of Atlantic salmon. Science of The Total Environment, 705, 135773. https://doi.org/10.1016/j.scitotenv.2019.135773

Staveley, T.A.B., Ahlbeck Bergendahl, I., Bárðarson, H., Berntsen, H.H., Eliasen, K. Erkinaro, J., Nygaard, R., Sivebæk, F. & Thorstad, E.B. 2025. Status and future perspectives of pink salmon in the Nordic region. Boreal Environmental Research 30: 149–162. https://doi.org/10.60910/ber2025.wt02-y377

Svenning, M.-A., Domaas, S., Johansen, N. S., & Borgstrøm, R. 2023. Alders- og størrelsesfordeling, vekst, dødelighet og diett hos gjedde og ørret i Tanavassdraget basert på fiske i 2021. Nina Rapport 2298. Norsk institutt for naturforskning. https://hdl.handle.net/11250/3095119

Svenning, M.-A., Johansen, N. S., & Borgstrøm, R. 2020. Predasjon på laksunger i Tana. Med hovedvekt på diett hos gjedde og sjøørret. NINA Rapport 1648. Norsk Institutt for naturforskning (in Norwegian). https://hdl.handle.net/11250/2671932

Svenning, M.-A. & Borgstrøm, R. 2026. Gjedda i Tanavassdraget. Estimert konsum av laksesmolt. NINA Rapport 2641. Norsk institutt for naturforskning (in Norwegian). https://hdl.handle.net/11250/5361672

Thorstad, E. B., Whoriskey, F., Uglem, I., Moore, A., Rikardsen, A. H., & Finstad, B. 2012. A critical life stage of the Atlantic salmon *Salmo salar*: Behaviour and survival during the smolt and initial post-smolt migration. Journal of Fish Biology, 81(2), 500–542. https://doi.org/10.1111/j.1095-8649.2012.03370.x

Thorstad, E. B., Frøiland, E., Fagard, P., Kvaal, M., Lehne, C. K., Liberg, E., Sandodden, R., Skaala, Ø. & Vatne, T. 2025. Assessing the extraordinary measures used to counteract invasion of pink salmon into the North Atlantic. Management of Biological Invasions, 16(2), 465-487. https://doi.org/10.3391/mbi.2025.16.2.09

Szabo-Meszaros, M., Forseth, T., Baktoft, H., Fjeldstad, H.-P., Silva, A. T., Gjelland, K. Ø., Økland, F., Uglem, I., & Alfredsen, K. 2019. Modelling mitigation measures for smolt migration at dammed river sections. Ecohydrology, 12(7), e2131. https://doi.org/10.1002/eco.2131

Szabo-Meszaros, M., Silva, A. T., Bærum, K. M., Baktoft, H., Alfredsen, K., Hedger, R. D., Økland, F., Gjelland, K. Ø., Fjeldstad, H.-P., Calles, O., & Forseth, T. 2021. Validation of a swimming direction model for the downstream migration of Atlantic salmon smolts. Water, 13(9), Article 9. https://doi.org/10.3390/w13091230

Vollset, K. W., Berhe, S., Barlaup, B. T., Åtland, Å., Isaksen, T. E., Wiers, T., Landro, Y., Normann, E. S., & Lennox, R. J. 2025. High level of predation of Atlantic salmon smolt during marine migration. Marine Ecology, 46(1), e12864. https://doi.org/10.1111/maec.12864

6 Appendix

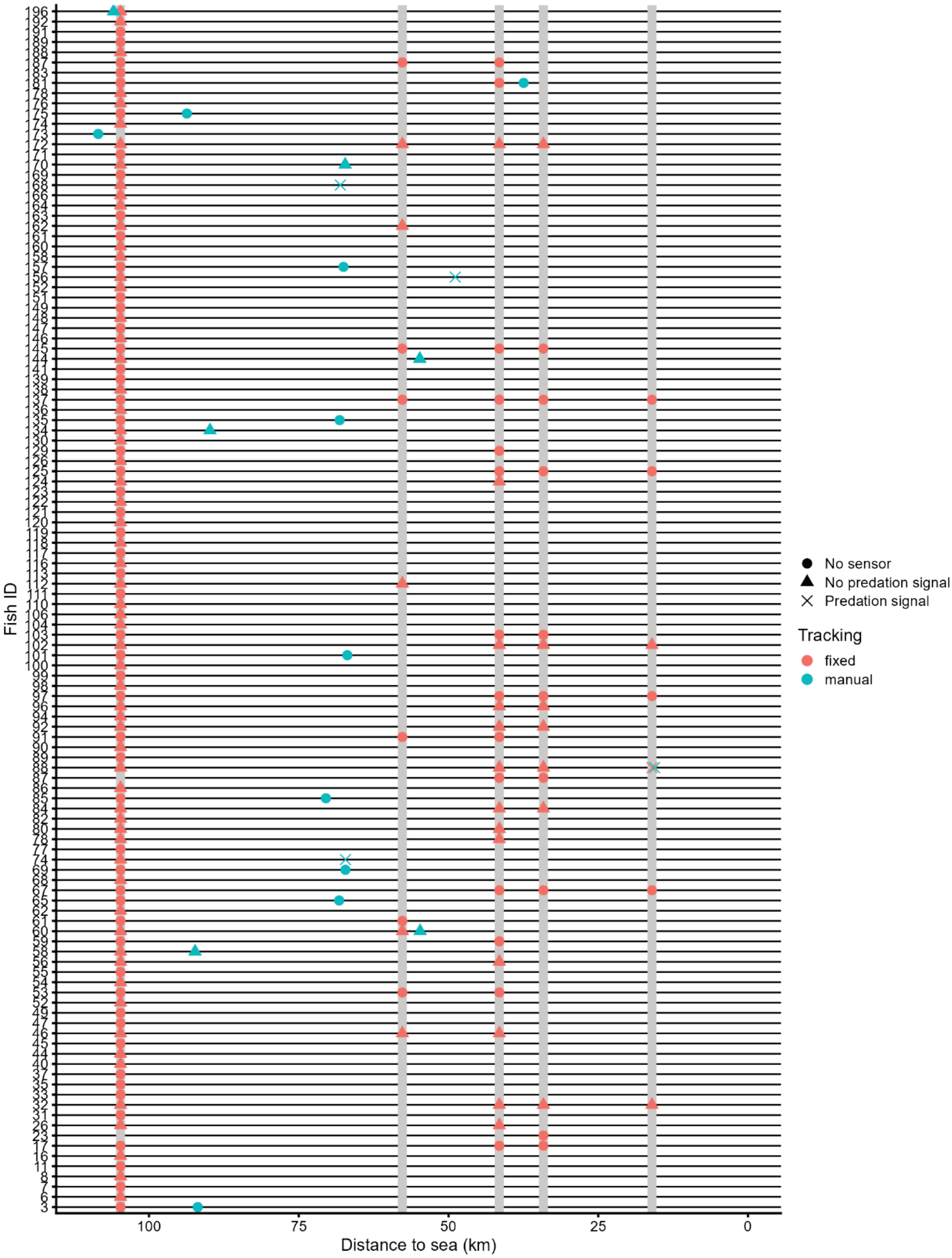


Figure A1. Detection history for all tags detected at the fixed receiver sites and / or manual tracking surveys, excluding the release location. The fixed receiver sites (Viđgaveaisavu, Polmak, Skiippagurra, Seida, and Rustefielbma from left to right) are indicated with a grey background vertical line.

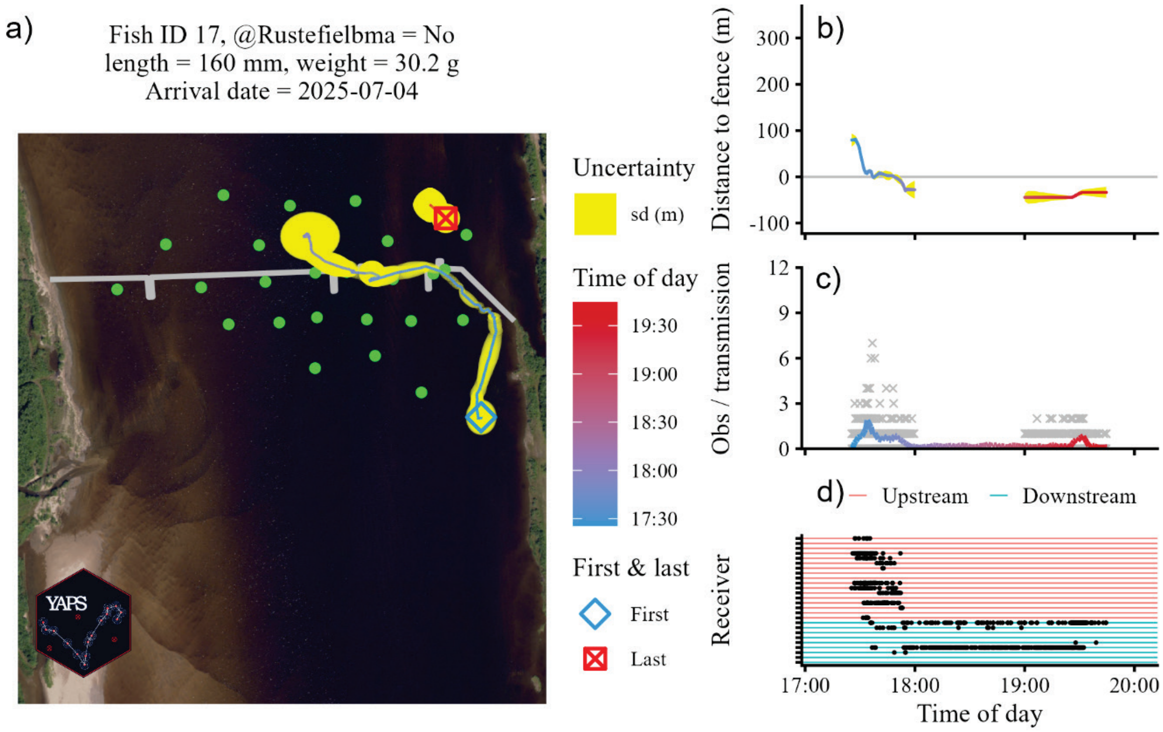
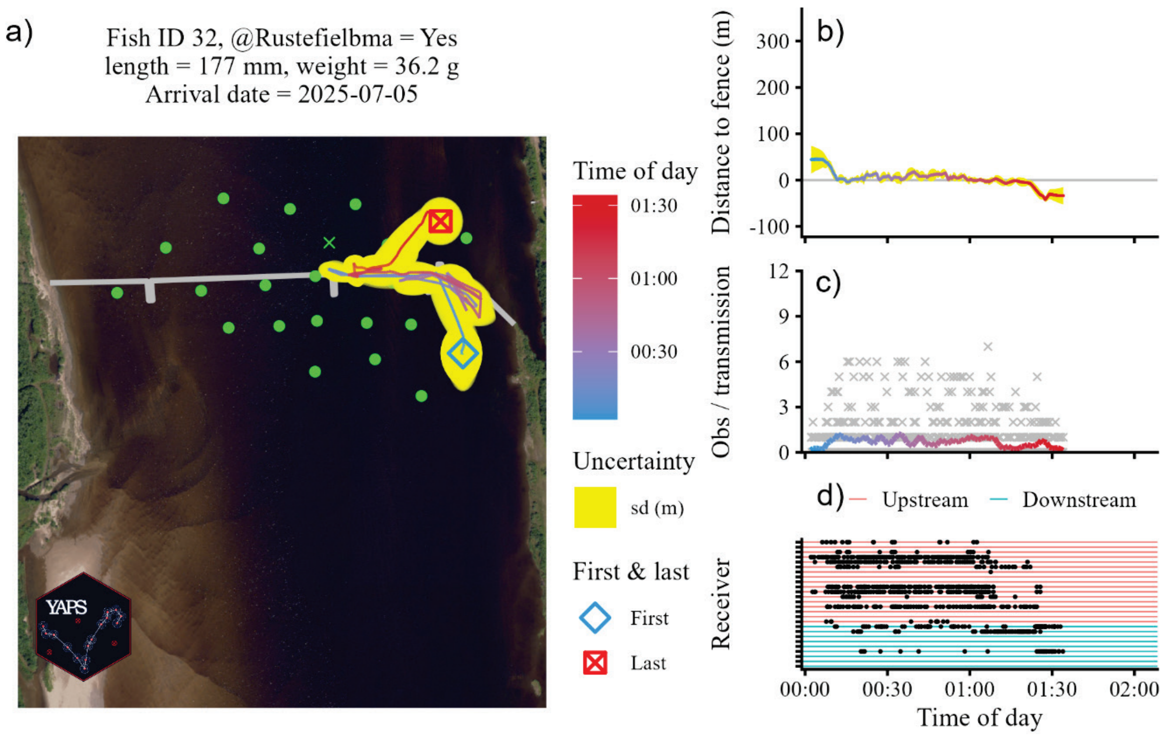
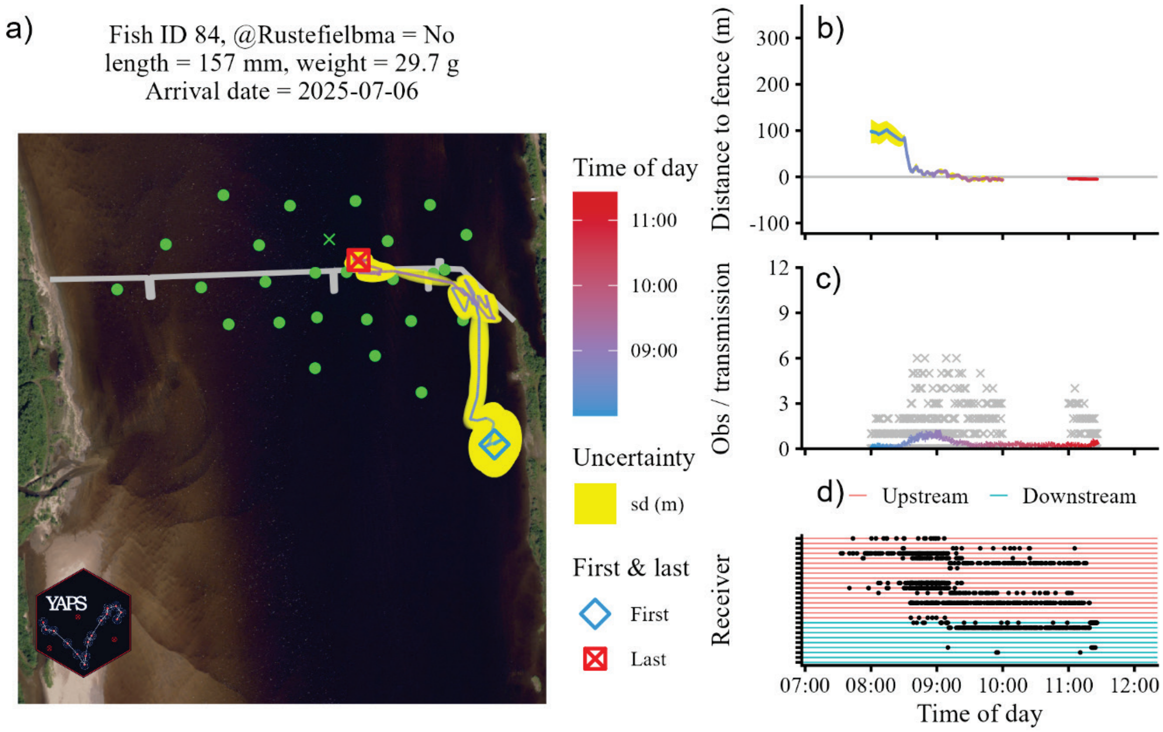
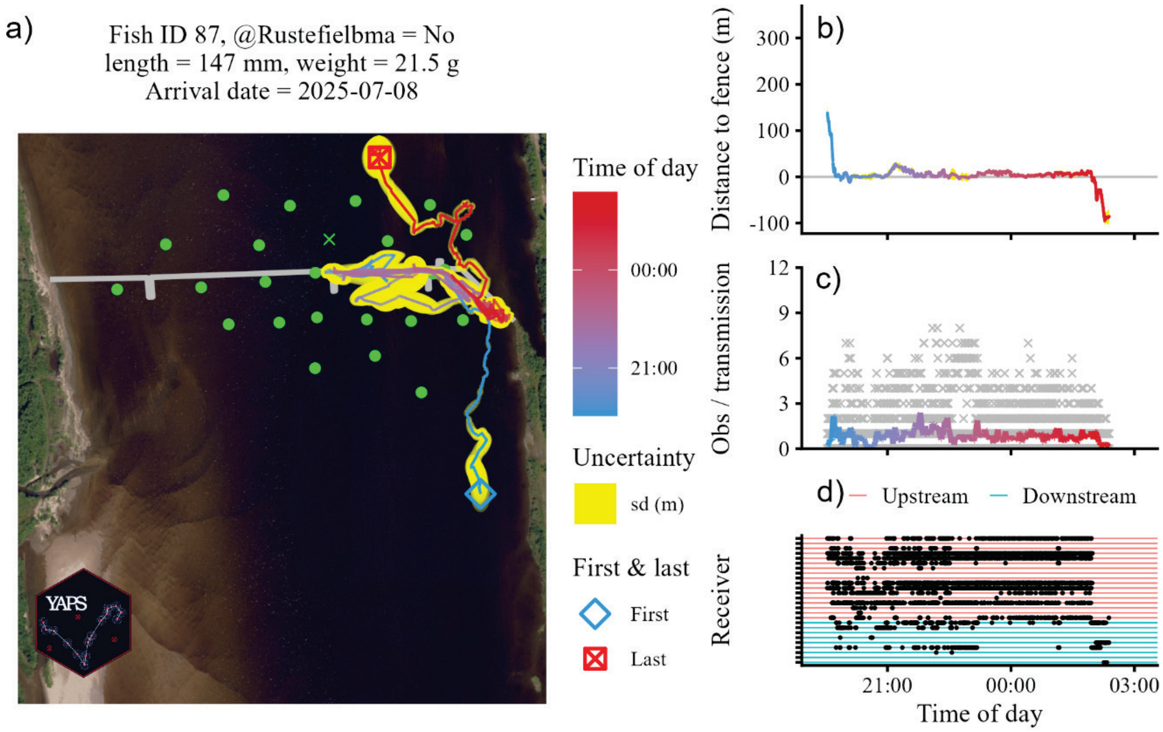
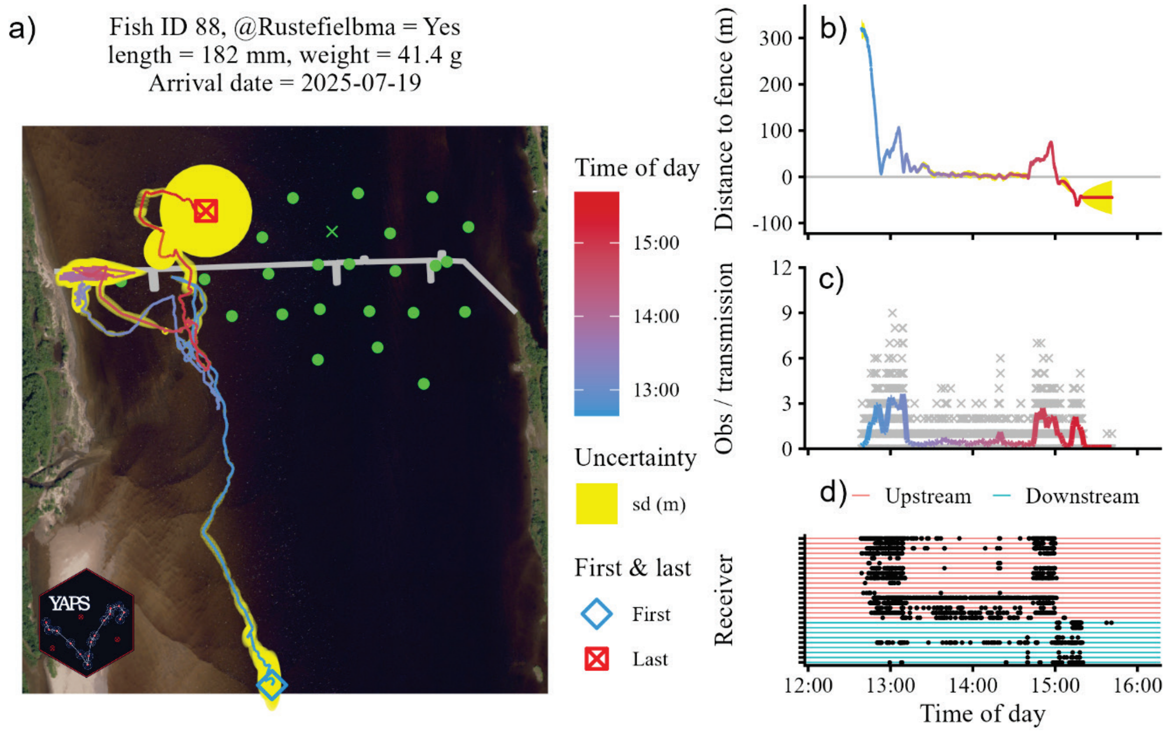


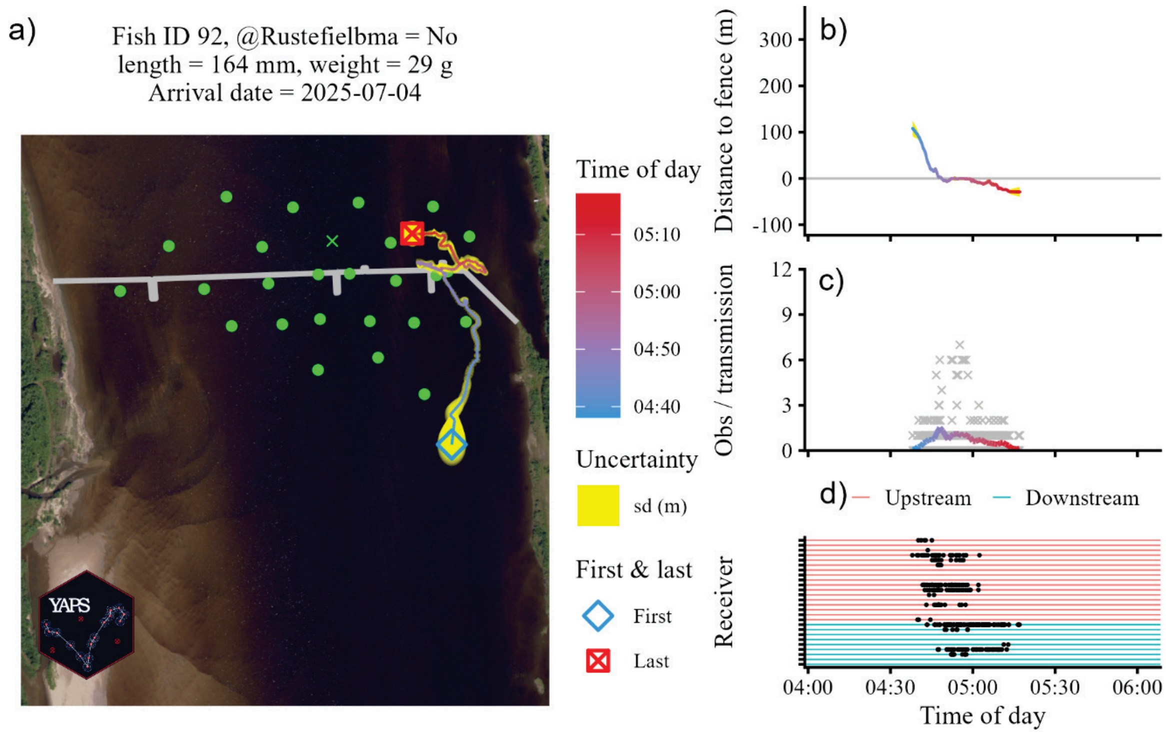
Figure A2. a) River Tana at Seida, with the fence indicated by the grey line and receivers by green dots (lost receivers / non-functioning receivers indicated by a green x). The text above the aerial photo indicates fish id, if the smolt were later detected at Rustefielbma, as well as the smolt length and weight. The smolt swimming trajectory estimates is indicated by the coloured line; the yellow fill colour indicate a position error estimate. b) distance to the fence by time. Positive values are upstream to the fence; negative values are downstream to the fence. c) the count of detections of each transmission (grey points), with a 3-minute rolling smooth indicated by the coloured line. d) detections at receivers by time, indicated by black symbols on background colour indicating receivers upstream (red) or downstream (green) to the fence, respectively. The following figures all have the same figure explanation. Note that fish id's 198, 206 and 251 were tagged with JSATS tags, hence there were no receivers downstream to the fence for detection of these tags.

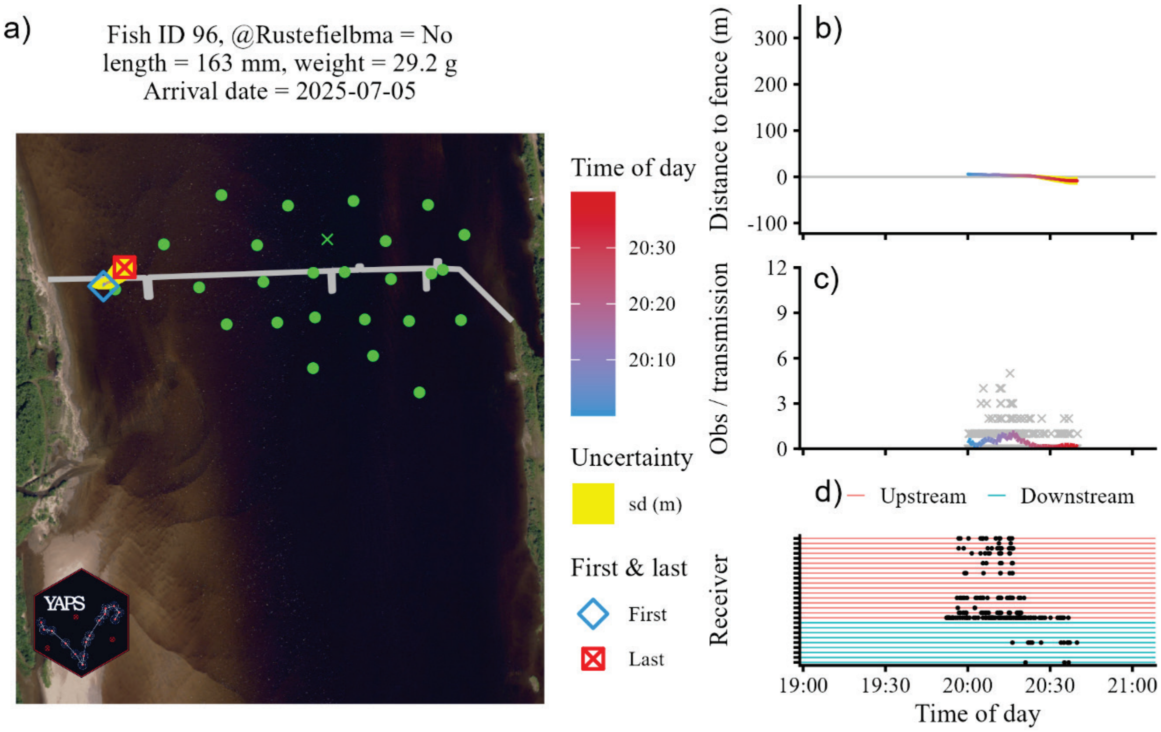


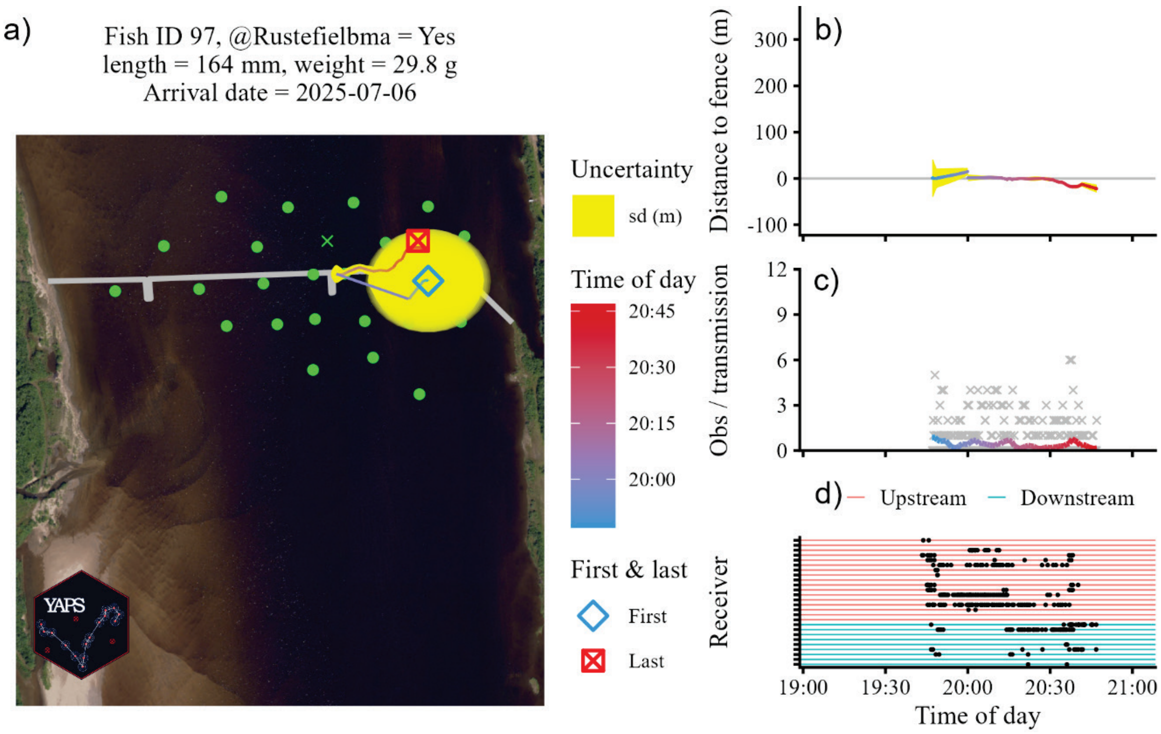

a)
Fish ID 84, @Rustefielbma = No
length = 157 mm, weight = 29.7 g
Arrival date = 2025-07-06
YAPS
Time of day
11:00
10:00
09:00
Uncertainty
sd (m)
First & last
First
Last
b)
Distance to fence (m)
300
200
100
0
-100
c)
Obs / transmission
12
9
6
3
0
d)
Upstream
Downstream
Receiver
07:00
08:00
09:00
10:00
11:00
12:00
Time of day

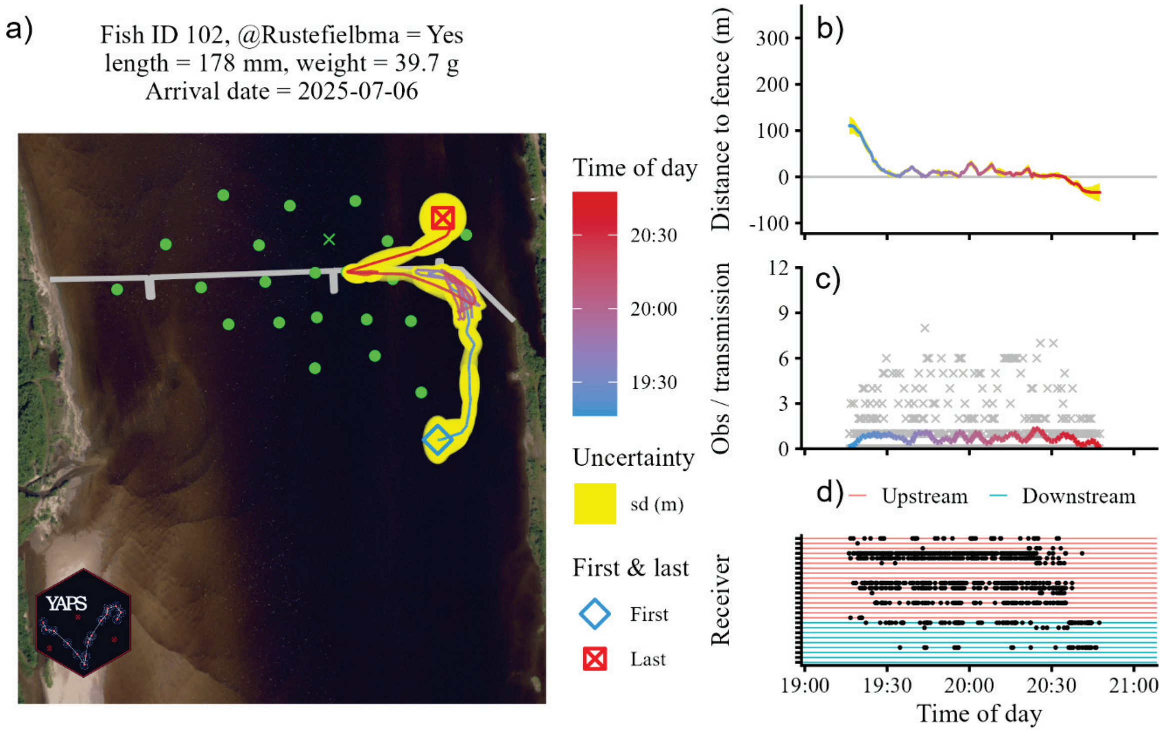

a)
Fish ID 87, @Rustefielbma = No
length = 147 mm, weight = 21.5 g
Arrival date = 2025-07-08
YAPS
Time of day
00:00
21:00
Uncertainty
sd (m)
First & last
First
Last
b)
Distance to fence (m)
300
200
100
0
-100
c)
Obs / transmission
12
9
6
3
0
d)
Upstream
Downstream
Receiver
21:00
00:00
03:00
Time of day

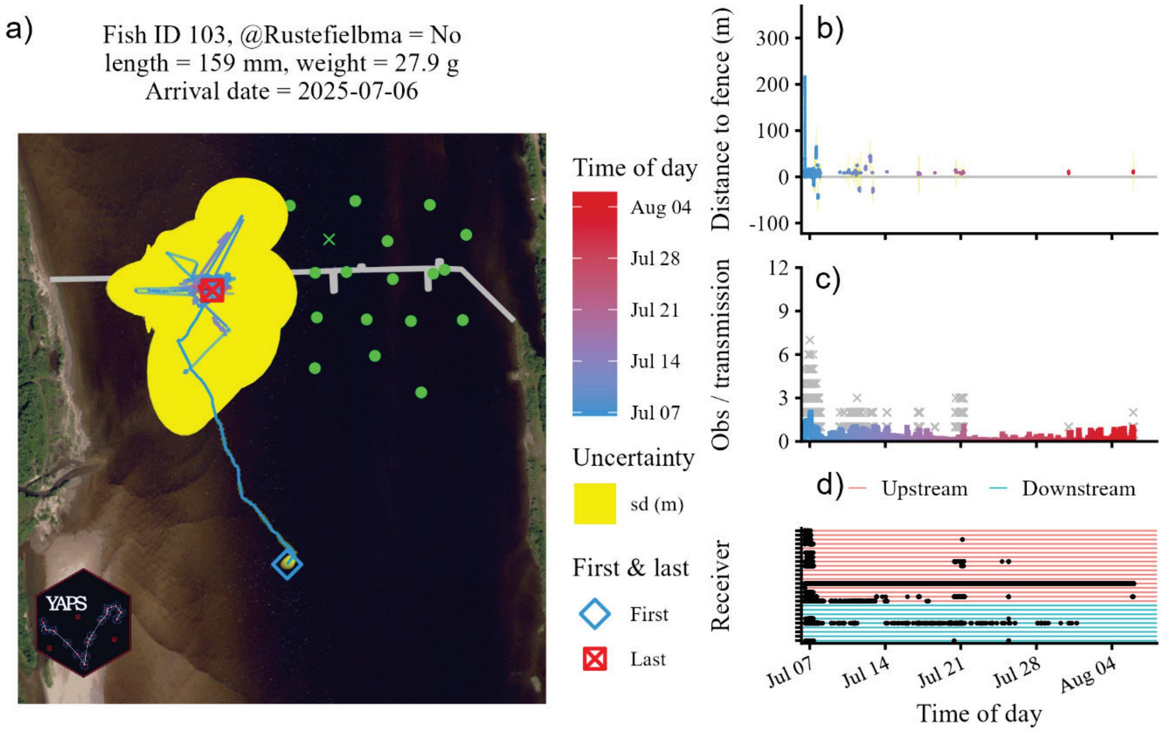

a)
Fish ID 88, @Rustefielbma = Yes
length = 182 mm, weight = 41.4 g
Arrival date = 2025-07-19
YAPS
Time of day
15:00
14:00
13:00
Uncertainty
sd (m)
First & last
First
Last
b)
Distance to fence (m)
300
200
100
0
-100
c)
Obs / transmission
12
9
6
3
0
d)
Upstream
Downstream
Receiver
12:00
13:00
14:00
15:00
16:00
Time of day

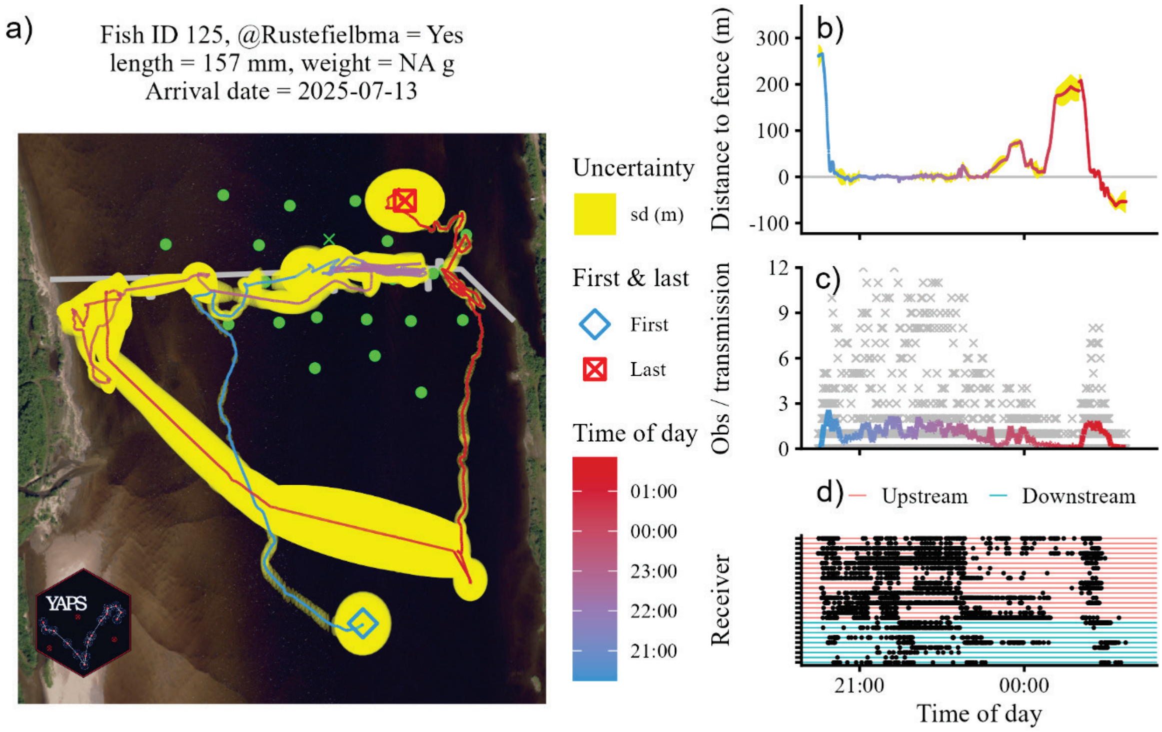

a)
Fish ID 92, @Rustefielbma = No
length = 164 mm, weight = 29 g
Arrival date = 2025-07-04
YAPS
Time of day
05:10
05:00
04:50
04:40
Uncertainty
sd (m)
First & last
First
Last
b)
Distance to fence (m)
300
200
100
0
-100
c)
Obs / transmission
12
9
6
3
0
d)
Upstream
Downstream
Receiver
04:00
04:30
05:00
05:30
06:00
Time of day

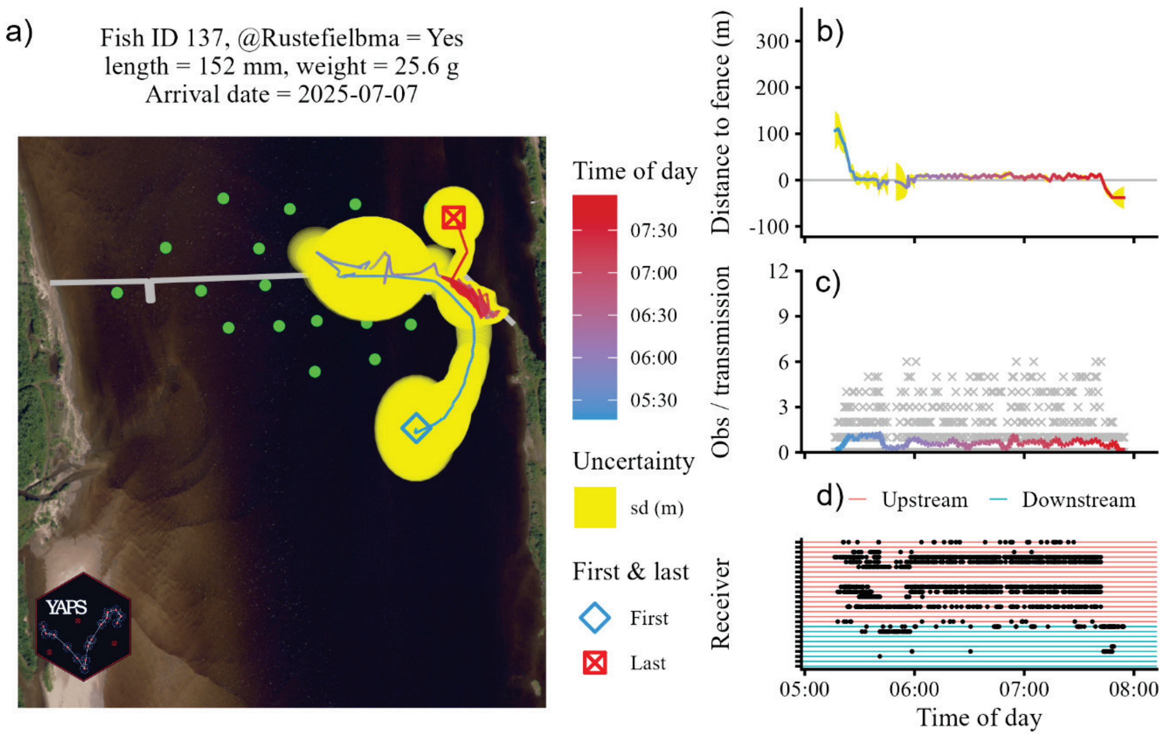

a)
Fish ID 96, @Rustefielbma = No
length = 163 mm, weight = 29.2 g
Arrival date = 2025-07-05
YAPS
Time of day
20:30
20:20
20:10
Uncertainty
sd (m)
First & last
First
Last
b)
Distance to fence (m)
300
200
100
0
-100
c)
Obs / transmission
12
9
6
3
0
d)
Upstream
Downstream
Receiver
19:00
19:30
20:00
20:30
21:00
Time of day

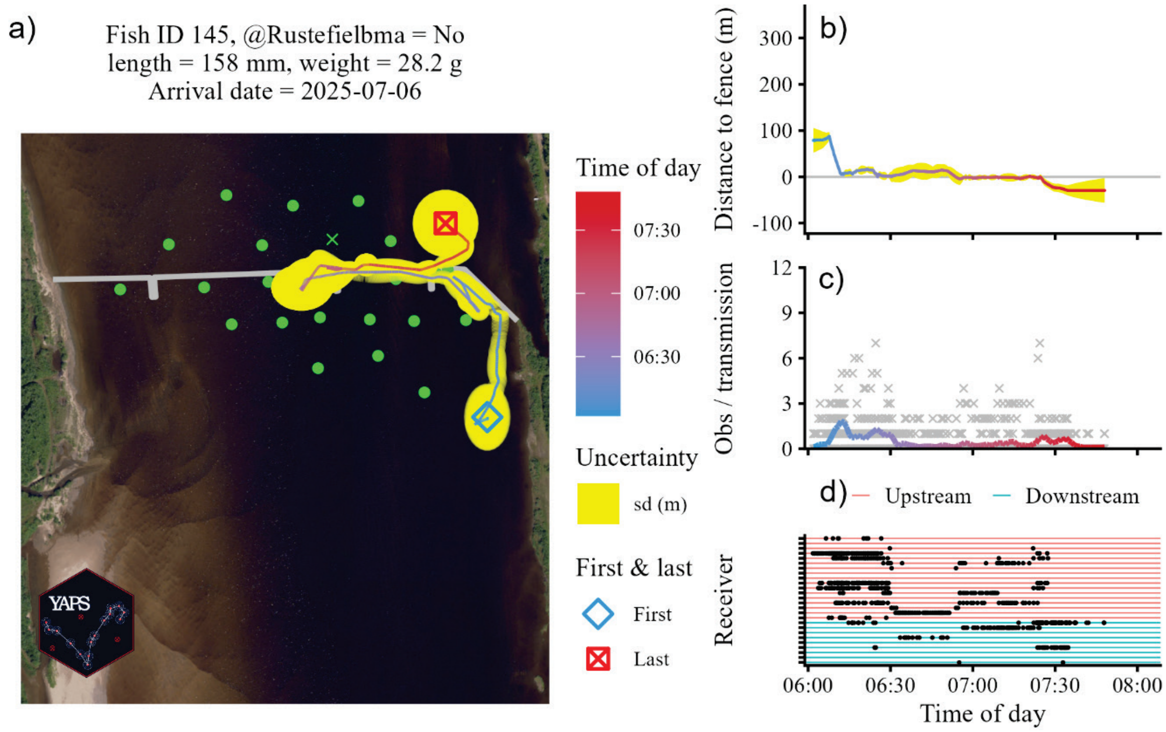

a)
Fish ID 97, @Rustefielbma = Yes
length = 164 mm, weight = 29.8 g
Arrival date = 2025-07-06
YAPS
Uncertainty
sd (m)
Time of day
20:45
20:30
20:15
20:00
First & last
First
Last
b)
Distance to fence (m)
300
200
100
0
-100
c)
Obs / transmission
12
9
6
3
0
d)
Upstream
Downstream
Receiver
19:00
19:30
20:00
20:30
21:00
Time of day

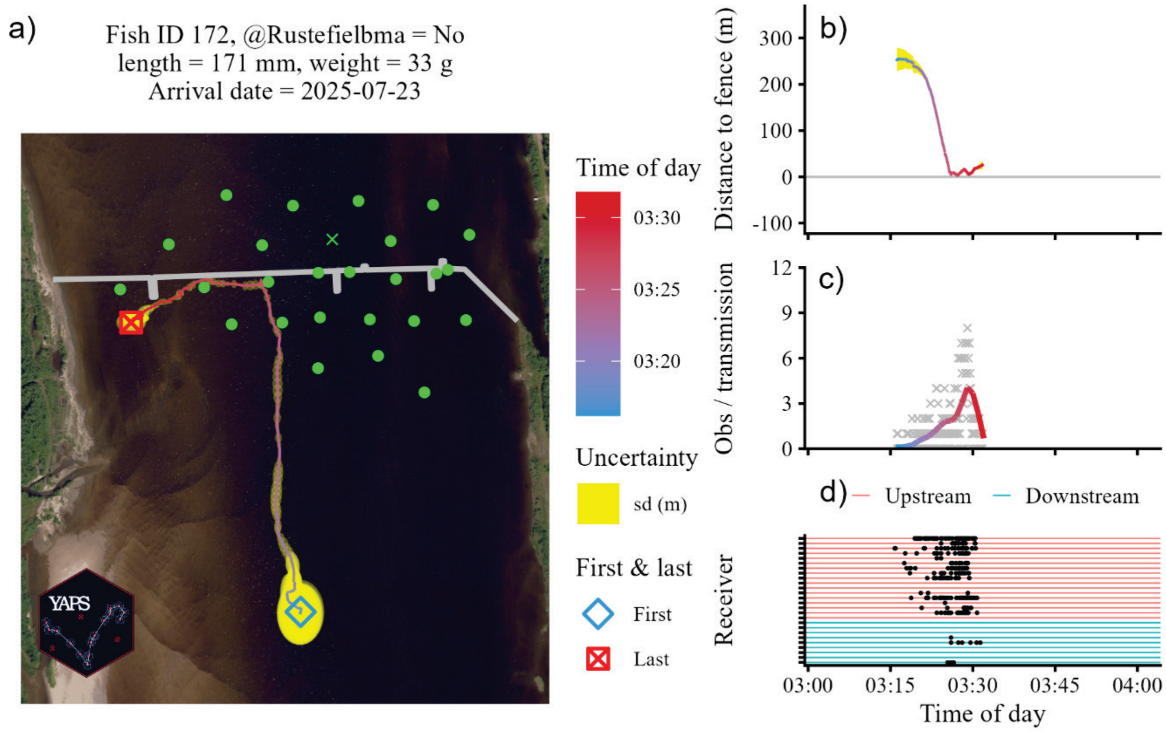

a)
Fish ID 102, @Rustefielbma = Yes
length = 178 mm, weight = 39.7 g
Arrival date = 2025-07-06
YAPS
Time of day
20:30
20:00
19:30
Uncertainty
sd (m)
First & last
First
Last
b)
Distance to fence (m)
300
200
100
0
-100
c)
Obs / transmission
12
9
6
3
0
d)
Upstream
Downstream
Receiver
19:00
19:30
20:00
20:30
21:00
Time of day

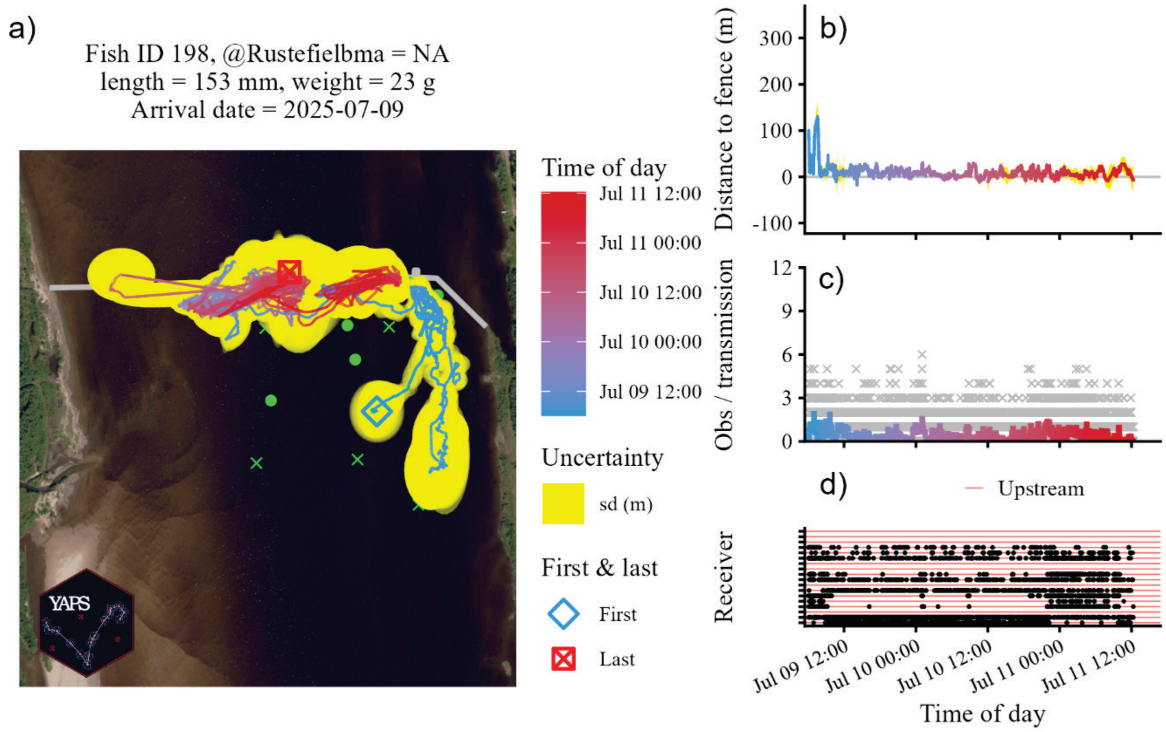

a)
Fish ID 103, @Rustefielbma = No
length = 159 mm, weight = 27.9 g
Arrival date = 2025-07-06
YAPS
Time of day
Aug 04
Jul 28
Jul 21
Jul 14
Jul 07
Uncertainty
sd (m)
First & last
First
Last
b)
Distance to fence (m)
300
200
100
0
-100
c)
Obs / transmission
12
9
6
3
0
d)
Upstream
Downstream
Receiver
Jul 07
Jul 14
Jul 21
Jul 28
Aug 04
Time of day

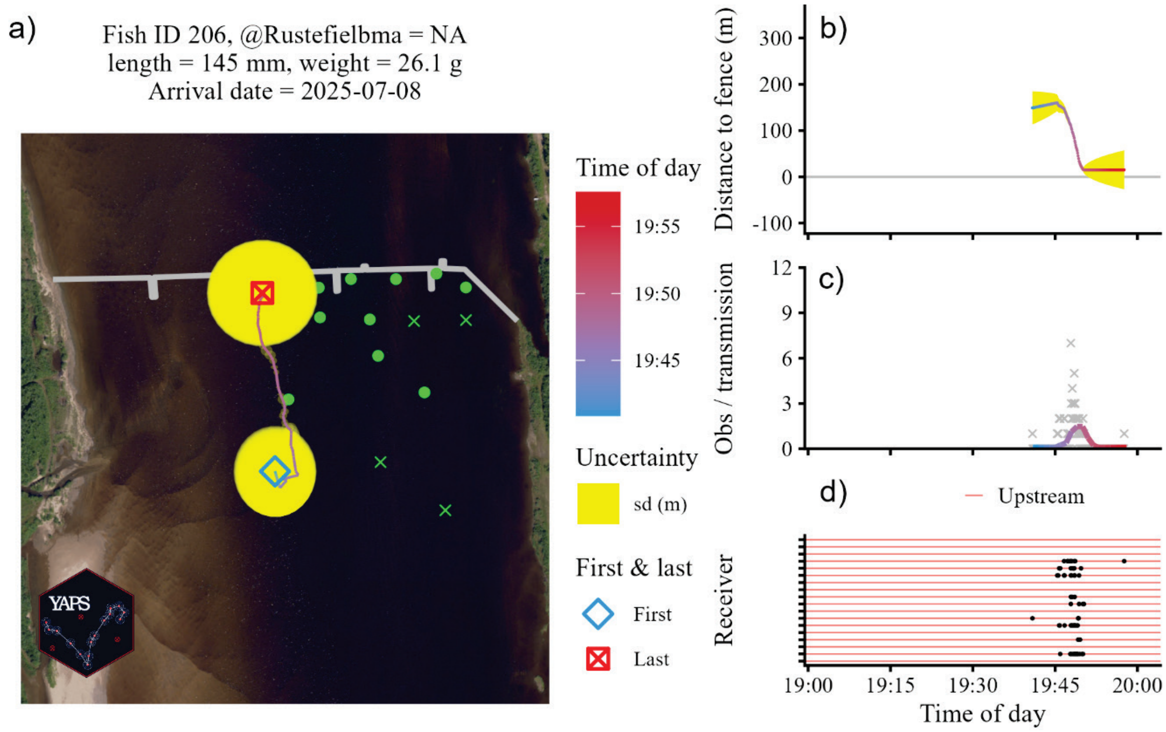

a)
Fish ID 125, @Rustefielbma = Yes
length = 157 mm, weight = NA g
Arrival date = 2025-07-13
YAPS
Uncertainty
sd (m)
First & last
First
Last
Time of day
01:00
00:00
23:00
22:00
21:00
b)
Distance to fence (m)
300
200
100
0
-100
c)
Obs / transmission
12
9
6
3
0
d)
Upstream
Downstream
Receiver
21:00
00:00
Time of day

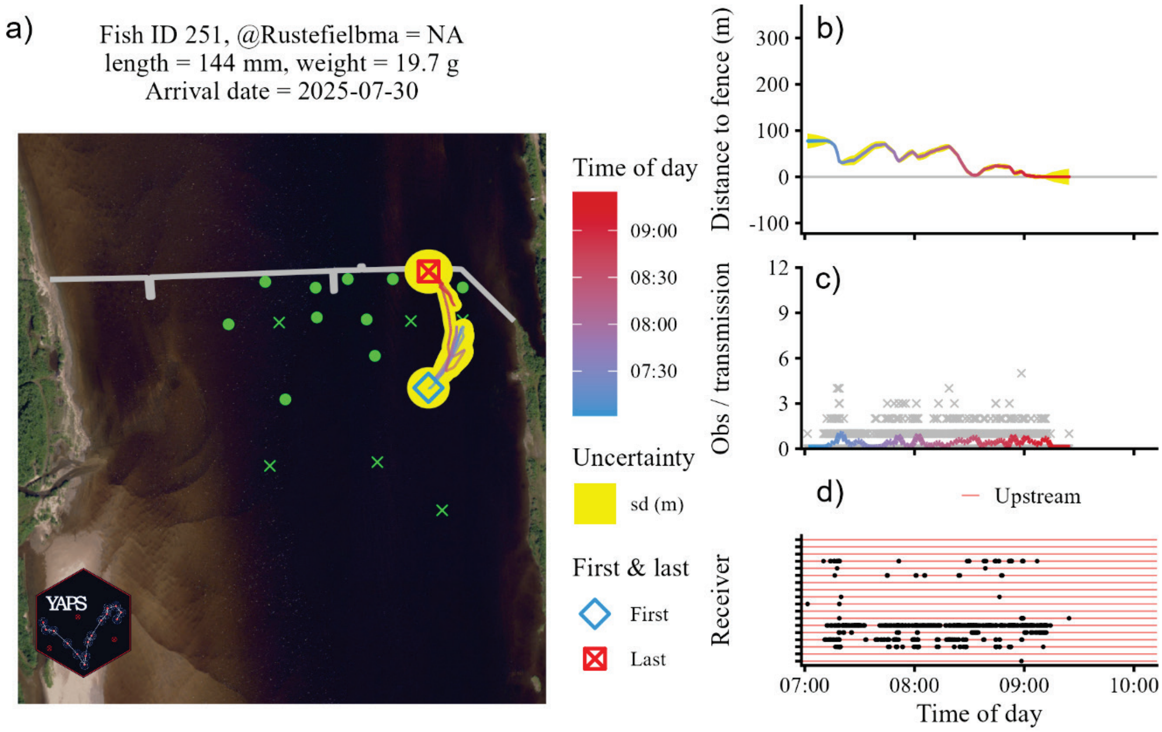

a)
Fish ID 137, @Rustefielbma = Yes
length = 152 mm, weight = 25.6 g
Arrival date = 2025-07-07
YAPS
Time of day
07:30
07:00
06:30
06:00
05:30
Uncertainty
sd (m)
First & last
First
Last
b)
Distance to fence (m)
300
200
100
0
-100
c)
Obs / transmission
12
9
6
3
0
d)
Upstream
Downstream
Receiver
05:00
06:00
07:00
08:00
Time of day


a)
Fish ID 145, @Rustefielbma = No
length = 158 mm, weight = 28.2 g
Arrival date = 2025-07-06
YAPS
Time of day
07:30
07:00
06:30
Uncertainty
sd (m)
First & last
First
Last
b)
Distance to fence (m)
300
200
100
0
-100
c)
Obs / transmission
12
9
6
3
0
d)
Upstream
Downstream
Receiver
06:00
06:30
07:00
07:30
08:00
Time of day


a)
Fish ID 172, @Rustefielbma = No
length = 171 mm, weight = 33 g
Arrival date = 2025-07-23
YAPS
Time of day
03:30
03:25
03:20
Uncertainty
sd (m)
First & last
First
Last
b)
Distance to fence (m)
300
200
100
0
-100
c)
Obs / transmission
12
9
6
3
0
d)
Upstream
Downstream
Receiver
03:00
03:15
03:30
03:45
04:00
Time of day


a)
Fish ID 198, @Rustefielbma = NA
length = 153 mm, weight = 23 g
Arrival date = 2025-07-09
YAPS
Time of day
Jul 11 12:00
Jul 11 00:00
Jul 10 12:00
Jul 10 00:00
Jul 09 12:00
Uncertainty
sd (m)
First & last
First
Last
b)
Distance to fence (m)
300
200
100
0
-100
c)
Obs / transmission
12
9
6
3
0
d)
Upstream
Receiver
Jul 09 12:00
Jul 10 00:00
Jul 10 12:00
Jul 11 00:00
Jul 11 12:00
Time of day


a)
Fish ID 206, @Rustefielbma = NA
length = 145 mm, weight = 26.1 g
Arrival date = 2025-07-08
YAPS
Time of day
19:55
19:50
19:45
Uncertainty
sd (m)
First & last
First
Last
b)
Distance to fence (m)
300
200
100
0
-100
c)
Obs / transmission
12
9
6
3
0
d)
Upstream
Receiver
19:00
19:15
19:30
19:45
20:00
Time of day


a)
Fish ID 251, @Rustefielbma = NA
length = 144 mm, weight = 19.7 g
Arrival date = 2025-07-30
YAPS
Time of day
09:00
08:30
08:00
07:30
Uncertainty
sd (m)
First & last
First
Last
b)
Distance to fence (m)
300
200
100
0
-100
c)
Obs / transmission
12
9
6
3
0
d)
Upstream
Receiver
07:00
08:00
09:00
10:00
Time of day

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2719

NINA Report

The Norwegian Institute for Nature Research, NINA,
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NINA was established in 1988. The headquarters are located in Trondheim, with branches in Tromsø, Lillehammer, Bergen and Oslo. In addition, NINA owns and runs the aquatic research station for wild fish at Ims in Rogaland and the arctic fox breeding center at Oppdal.

NINA's activities include research, environmental impact assessments, environmental monitoring, counselling and evaluation. NINA's scientists come from a wide range of disciplinary backgrounds that include biologists, geographers, geneticists, social scientists, sociologists and more. We have a broad-based expertise on the genetic, population, species, ecosystem and landscape level, in terrestrial, freshwater and coastal marine ecosystems.

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