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Evaluation of fish trap and guiding fence efficiency in the River Tana in 2023

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COVER PICTURE
The fish trap with guiding fences in the eastern river channel, with Seidaholmen in the background. ©Karl Øystein Gjelland

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Abstract

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. NINA Report 2387. Norwegian Institute for Nature Research.

Pink salmon (*Oncorhynchus gorbuscha*) is an anadromous species which spawns in rivers and whose fry migrate to sea shortly after emergence from the gravel. It is native to the Pacific Ocean but was repeatedly translocated to the White Sea during the latter half of the 20th century. Pink salmon has a strict 2-year life cycle, and odd-year populations have in recent years become invasive in the Eastern Atlantic. In the River Tana/Teno, a large Norwegian-Finnish watercourse and one of the world's most important rivers for Atlantic salmon (*Salmo salar*), the spawning run was estimated at more than 50 000 pink salmon in 2021.The Norwegian Environmental Agency therefore decided to install a large trap-fence system in the river in 2023 to remove as much pink salmon as possible whilst letting native salmonids through.

The Norwegian Institute for Nature Research (NINA) in co-operation with Natural Resources Institute Finland (Luke) was given the task to monitor how the ascending and descending fish responded to the trap and guiding fences. A suite of sonars, camera systems with and without artificial intelligence (AI) capable of recognising fish, snorkelling, and drones were used for the fish monitoring. The results were compared to sonar counts of migrating fish further upstream in the watercourse.

A rapid build-up in fish numbers and activity was seen in the area immediately downstream to the trap following the trap installation. However, after a short dip, increasing numbers of fish passing the Polmak fish counting station (about 20 km upstream the trap) indicated that the guiding fences were "leaking" fish. Daily numbers of migrating fish observed in the western channel at Seidaholmen corresponded well to daily numbers observed at Polmak, indicating that this was the main route for fish bypassing the trap. During the trap operation period, at least 108 700 fish migrated past Polmak, most of these pink salmon. Whilst there was such a large trap bypass migration, the trap catch numbers were moderate 7 666 (6.6% catch efficiency). This large discrepancy made it clear that: 1) both pink salmon and native migratory fish species showed a low willingness to enter the trap, and 2) the flexible fences used in both channels were not capable of stopping the pink salmon from migrating further up the River Tana. However, it was evident that native salmonids were held back from their normal upstream migration for some time, and it is not known to what extent this may have had negative consequences for the following migration and spawning period. Better entrance positioning and more trap entrances is needed to improve the willingness to enter the trap and bypass solutions.

Some kelts were observed holding positions on the upstream side of the fences, but none used the downstream migration openings. Smolt schools swam back and forth along the upstream side of the fence and only used the downstream migration solutions to a limited extent. It is not known for how long kelts and smolts were held back. The Tana/Teno Atlantic salmon populations are considered as vulnerable populations. Successful return of native anadromous spawners as well as good smolt and kelt survival are all critical to population recovery. It is not known if these factors were negatively influenced by the trap with flexible fences in 2023, but future solutions with fixed fences have potential for significant negative effects. In the case of future use of in-river fish traps aimed to eliminate pink salmon, uttermost care must be taken to reduce the impact on the native salmonids. There is a large knowledge gap about realized trap effects on native salmonids. Further studies are thus needed to investigate trap and guiding fence effects on e.g. individual holding times and mortality risk, as well as migration behaviour and spawning success.

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Sammendrag

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. NINA Rapport 2387. Norsk institutt for naturforskning.

Pukkellaks (*Oncorhynchus gorbuscha*) er en anadrom fiskeart som gyter i elv mens yngelen drar på beitevandring i havet straks etter at den kommer opp av gytegropen. Opprinnelig utbredelsesområde er i Stillehavet, men den ble gjentatte ganger introdusert til Kvitsjøen i andre halvdel av 1900-tallet. Pukkellaks har en streng toårig livssyklus fra den selv blir lagt som egg til den returnerer fra havet for å gyte. Generasjoner som gyter i oddetallsår har hatt en kraftig økning i Øst-Atlanteren i de senere år og arten er blitt en invasjonsart. I Tanavassdraget, et av verdens viktigste laksevassdrag, ble det i 2021 registrert mer enn 50 000 pukkellaks. Miljødirektoratet bestemte seg derfor for å installere en fiskefelle i Tanaelva i 2023 for å fjerne så mye pukkellaks som mulig mens lokale fiskearter skulle slippes forbi. Norsk institutt for naturforskning (NINA) fikk i samarbeid med det Finske Naturressursinstituttet (Luke) i oppdrag å overvåke hvordan oppvandrende og nedvandrende fisk ble påvirket av fella og ledegjerdene. For å gjennomføre dette ble det brukt et arsenal av sonarer, videokameraer med og uten innebygd kunstig intelligens, observasjon ved snorkling og filming med drone. Resultatene fra overvåkingen ble sammenlignet med resultater fra sonarovervåking lenger oppe i vassdraget.

En rask økning i fiskemengde og aktivitet ble observert nedstrøms fella og ledegjerdene like etter at disse kom på plass. Fiskeoppgangen forbi Polmak (20 km oppstrøms fella) ble redusert i noen dager, men tok seg deretter kraftig opp. Dette indikerte at ledegjerdene til fella ikke holdt igjen all fisk. Daglige tall fra sonar- og videoovervåking for oppvandring i det vestre elveløpet ved Seidaholmen var i godt samsvar med daglige tall for oppvandring ved Polmak, og indikerte at det var i det vestre elveløpet det meste av fisk passerte fella. I perioden fella var i bruk passerte det minst 108 700 oppvandrende fisk forbi Polmak, de fleste av disse var pukkellaks. I samme perioden ble det kun fanget 7 666 fisk i fella, noe som gir en fangsteffektivitet på 6,6 %. Denne store skjevheten indikerte at 1) pukkellaks og stedegne arter var lite villige til å gå inn i fella, og 2) de fleksible plastikkrørgjerdene som ble brukt i vestre og delvis østre løp ikke hindret pukkellaks fra å vandre videre opp i vassdraget. Det var likevel klart at atlanterhavslaks ble holdt tilbake fra sin naturlige oppvandring i noe tid, men det er ikke kjent i hvor stor grad dette hadde negative konsekvenser for påfølgende gytesuksess. Flere og bedre plasserte felleinnganger er nødvendig for å sikre at oppvandrende laks og andre stedegne fiskearter vil gå inn i fella, og dermed bli sluppet gjennom.

Støinger ble observert på oversiden av ledegjerdene, men ingen ble observert i nedvandringsåpningene. Smoltstimer ble observert svømmende fram og tilbake langs ledegjerdet, og disse brukte i noen, men liten grad nedvandringsåpningen. Det er ukjent hvor lenge vinterstøinger og smolt ble holdt tilbake av ledegjerdet. Å sperre en elv med fiskefelle har stort potensiale for negativ påvirkning, men vi vet lite om de faktiske effektene. Oppkonsentrasjon av smolt ovenfor gjerdet kan tiltrekke seg predatorer og dermed øke smoltdødeligheten her. Laksebestandene i Tanavassdraget er sårbare bestander. Suksessfull gyting, samt god overlevelse og vekst hos smolt og støinger er alle sentrale faktorer for å bygge opp igjen laksestammene. Hvorvidt disse faktorene ble negativt påvirket av fella med fleksible ledegjerder i 2023 er ukjent, men fremtidige løsninger basert på faste ledegjerder har vesentlig skadepotensiale. Dersom det igjen skal bygges fiskefelle i Tanavassdraget, må det derfor legges stor vekt på gode løsninger som sikrer minimal påvirkning på vandringen til stedlige arter. Det er en stor kunnskapsmangel om fellepåvirkning på stedegne arter, og studier av felle og ledegjerders påvirkning på blant annet oppholdstid, overlevelse, vandringsadferd og gytesukksess er nødvendig.

Contents

Foreword

Non-native species are in general unwanted in nature management, and especially so if an alien species becomes invasive. The non-native pink salmon has been present along the Barents Sea coast for several decades after the first introduction to the White Sea, but in the recent years there has been a dramatic increase in pink salmon numbers. The management of invasive species is, however, a challenging task, and efforts to control the pink salmon population growth is not any exception to this. Pink salmon has in a few decades gained a wide geographical occurrence distribution, but very little is known as to which extent the pink salmon coming to rivers along the Norwegian coast was reared in the White Sea area or if they are the result of pink salmon spawning in Norwegian rivers. Whereas pink salmon stocking is ended in the White Sea and Kola area, the pink salmon is seen as a resource in Russia. It seems unlikely that there will be taken any measure to reduce pink salmon population growth by Russian management. The Norwegian authorities can take measures to reduce pink salmon spawning success in Norwegian rivers (and Finnish for the Tana/Teno watercourse), and such efforts was taken in many rivers in Troms and Finnmark counties the summer of 2023. The most widely used method was installation of fish traps in the rivers, with the aim of removing all or as much as possible pink salmon, while releasing native salmonids caught in the trap back to the rivers. The largest pink salmon run was expected for River Tana/Teno, but in Norway there is no experience with building and operating fish traps in such big rivers. The Norwegian Environmental Agency (Miljødirektoratet) therefore decided to run an evaluation study, focusing on how the trap and guiding fences influenced the migration of native salmonids. NINA and Luke have for many years studied and monitored salmonid populations in the Tana/Teno watercourse, and we thank the agency for commissioning the trap evaluation study to NINA and Luke in cooperation. We are also grateful to Joachim Henriksen, who provided drone footage from the trap and guiding fence areas for us to use in our analyses.

Tromsø, 12. December 2023

Karl Øystein Gjelland, senior scientist

Project leader

1 Introduction

Pink salmon (*Oncorhynchus gorbuscha*) is native to the northern parts of the Pacific Ocean but has recently become an invasive species to Europe (Diaz Pauli et al. 2023). Pink salmon has the shortest life cycle of any salmonid species, with a strict two-year life cycle from spawning of one generation to spawning by their progeny. As with most other *Oncorhynchus* species, pink salmon is semelparous. This means it spawns only once during its lifetime and dies shortly after spawning. This causes strictly separated odd- and even year pink salmon populations, with no interbreeding between the populations.

Pink salmon was introduced to Europe by Russians who started stocking them to the White Sea area in the late 1950s, with the first returns of adult spawners occurring in 1960. This year, large catches of pink salmon were reported both from the White Sea as well as from the Finnmark coast, with more sporadic catches further south on the Norwegian coast (Berg 1961). Stocking continued for many but not all years until 2000 (Zubschenko et al. 2004 in Niemelä et al. 2016), with tens of millions of fertilized eggs being transferred from the Pacific during the period 1959-1964, and smaller numbers in most years until 1989. A part of the stocking program was based on returning pink salmon bred in the White Sea, hence stocking from successful survivors in the White Sea area took place and may have included both second, third, fourth generations and so on. Successful pink salmon smolt outmigration was documented in river Neiden already in 1976 (Bjerknes 1977), but it is unknown whether spawning populations in Norwegian rivers have been self-sustaining in any way. Successful natural establishment of odd-year pink salmon occurred in White Sea rivers in the 1980's (Gordeeva et al. 2015) whereafter the species have spread out to both east and west from the White Sea (Armstrong et al. 2018; Diaz Pauli et al. 2023; Lennox et al. 2023, Sandlund et al. 2019, Skóra et al. 2023a,b). In 2017, there was a large increase in both the distribution and abundance of pink salmon throughout large areas in western Europe (Sandlund et al. 2019, Diaz Pauli et al. 2023). During the recent years the most dramatical increase in pink salmon numbers have been observed in Northern Norway, including the large River Tana.

In 2017 registered catches of pink salmon from rivers across Norway far exceeded what had been considered normal catches in previous years, but the registered catch of 6 549 pink salmon (Berntsen et al. 2020) was in retrospect trivial to the catches registered in both 2019 and 2021. From 2017 to 2019, there was a threefold increase in total registered catches in Norway. This growth continued, with a remarkable seven-and-a-half-fold increase from 2019 to 2021, resulting in a combined registered catch (both at sea and in rivers) of over 150,000 pink salmon in Norway. (Statistics Norway 2022a, 2022b).

As a non-native species, pink salmon is unwanted in Norwegian nature and its invasive risk category has been defined as "very high" by Artsdatabanken (Forsgren et al. 2023). There are considerable concerns that large numbers of pink salmon in the north may cause even larger returns in the next generation, and that pink salmon may proliferate to salmon rivers further south. Therefore, actions have been implemented to remove and decrease pink salmon spawning in Northern Norway. Although efforts to remove pink salmon on spawning grounds started already in 2007 (Muladal 2010), such efforts were relatively limited for many years. But in 2021, over 100 000 pink salmon were caught due to extraordinary efforts with the use of homemade traps, nets, and seines in rivers in Troms and Finnmark (County Governor of Troms and Finnmark, 2022).

In the Tana River (Norway's second largest river, catchment area 16 377 km^2, mean annual discharge 197 m^{3}s^{-1}) in Northern Norway (70% of catchment) and Finland (30% of catchment), pink salmon has been included in the catch reports since 1974. Except of the years 1981, 1982 and 1984, catches of pink salmon have been reported annually. Although the variation has been large, mean annual reported catch was 446 kg in odd years during the period 1989-2007

(Sandlund et al. 2019), which translates to 200-300 pink salmon assuming a mean weight of 1.5-2 kg. Parallel with the observations of increased nationwide catches of pink salmon across Norway in 2017 significant increase in catch was also seen in the River Tana (Johansen 2018). With the introduction of the sonar monitoring station in Polmak (Anon. 2023 p.18-19) in 2018 it became possible to monitor and make estimates of ascending pink salmon numbers in the Tana watercourse. These estimates showed a dramatic development suggesting a tenfold increase with estimates growing from just below 5 000 in 2019 to 50 000 in 2021 (Anon. 2021). Given this trend in population growth, there was a concern that the influx of pink salmon into the Tana watercourse in 2023 might escalate to as much as 500,000 individuals.

As a measure to minimize pink salmon spawning population size in the Tana system, Miljødirektoratet (the Norwegian Environmental Agency) decided to install a large trap-fence system to the lower reaches of the Tana River in 2023. This trap and associated fences were installed at Seidaholmen just downstream to Tana bru and covered the river cross-section from shore to shore. The overall aim of using this system was to catch and remove most pink salmon ascending the Tana River and at the same time let the descending and ascending native species pass and continue their migration. The task of constructing and running the Seidaholmen trap-fence system were given to the Norwegian Veterinary Institute in cooperation with Miljødirektoratet.

Constructing and running a trap system in a large river with high numbers of migrating fish is a complicated task, and this was the first time such an operation was run in Norway. Miljødirektoratet therefore decided to have a study aimed to assist the trap operation and evaluate trap effects on the migration of native fish. This task was given to the Norwegian Institute for Nature Research (NINA) in co-operation with Natural Resources Institute Finland (Luke). Whilst the experiences in trap operation and fish handling at the trap will be documented in a separate report (Sandodden et al. 2023), this report presents results from the monitoring system developed for the evaluation of fish behaviour and migration patterns near the trap and associated guiding fences. This includes both down- and up-migration, as well as trapping efficiency. Some recommendations for future fish traps and monitoring needs are given based on the influence on native fish species. Potential ecological effects of pink salmon on native species were beyond the scope of this work.

2 Methods and monitoring sites

The Tana/Teno river (Norwegian/Finnish) is a Norwegian-Finnish watercourse, partially forming the border between the two countries, with a watershed area of 16 377 km^2. The mean annual discharge at the lower reaches (Polmak nye (234.18.0) measuring station; sildre.nve.no) of the river is approx. 197 m^{3}s^{-1}. The Tana system is one of the most important Atlantic salmon (*Salmo salar*) rivers in the world and has about 1 200 km of river available for salmon, 211 km in the Tana mainstem and approx. 1 000 km in larger and smaller tributaries throughout the watershed (**Figure 1**).

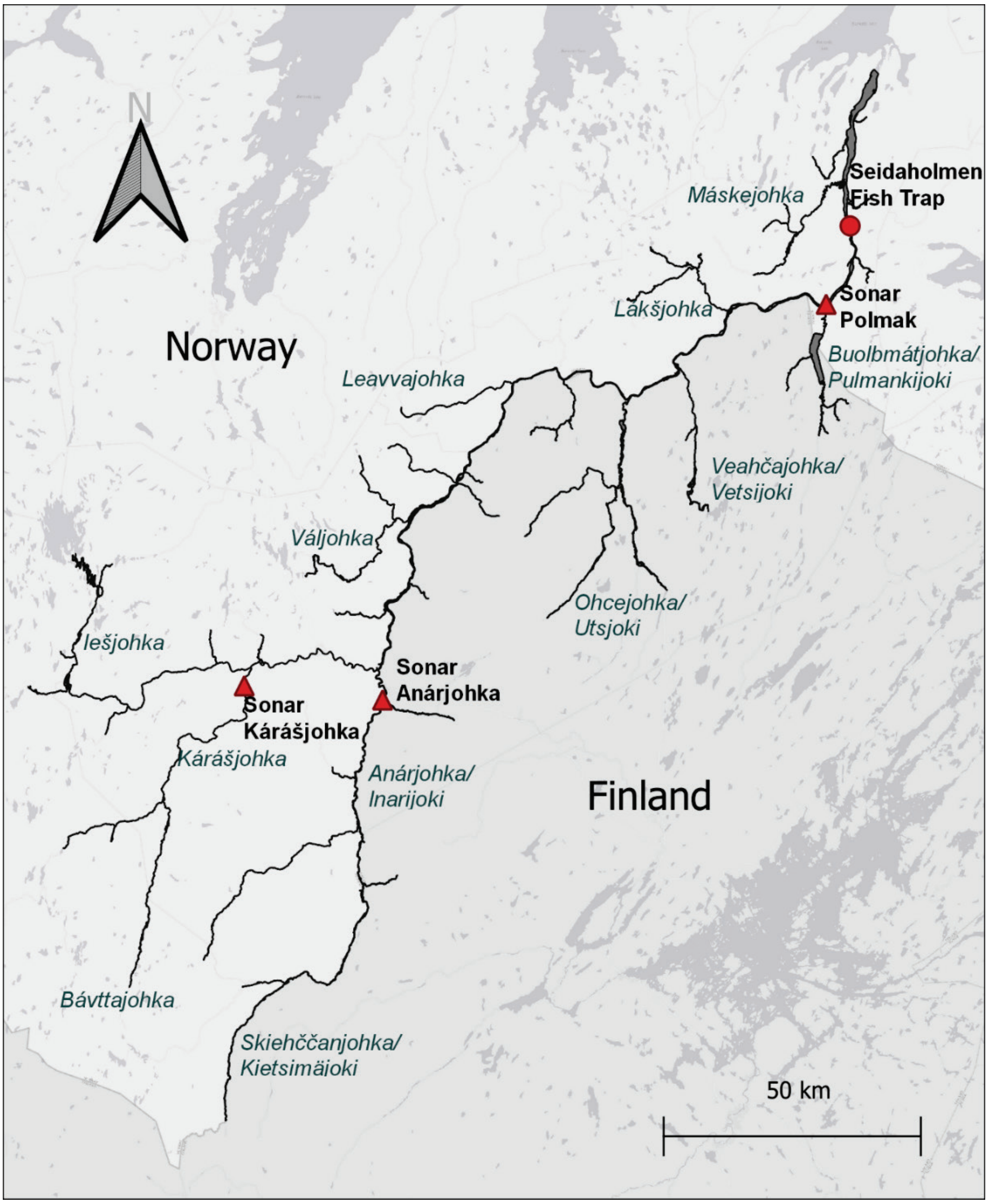

Figure 1. *Estimated adult salmon distribution area in the Tana/Teno watercourse with the largest tributaries named. The Tana/Teno starts where Kárášjohka meets Anárjohka and drains in the Tana fjord in the north, making up 211 km of the total available river stretch of about 1 200 km. The filled circle marks the location of the fish trap during the summer of 2023. The filled triangles*

mark the location of sonar monitoring stations. The Polmak location monitors the Tana/Teno main stem.

The Tana/Teno watercourse had a relatively early spring in 2023 with a discharge peak of 1 630 m^3s^{-1} on May 18th followed by a very dry summer with water discharge levels below the 25th percentile through most of June and July (**Figure 2**). Three summer spates occurred in late July and August. The Tana/Teno watercourse has a long-term median flood value of 1 720 m^3s^{-1} but has a large variation in flood peak discharge levels. Over the last six years (2018-2023) flood peaks have ranged from 860 m^3s^{-1} (2019) to 2 345 m^3s^{-1} (2020). As well as variation in flood peak values, the timing of the flood peaks have also varied greatly between years. Over the last six years the flood peak has occurred from May 15th (2019) to June 8th (2020); typically, higher peak floods coincide with later timing in the spring, and earlier spring floods typically result in lower peak levels.

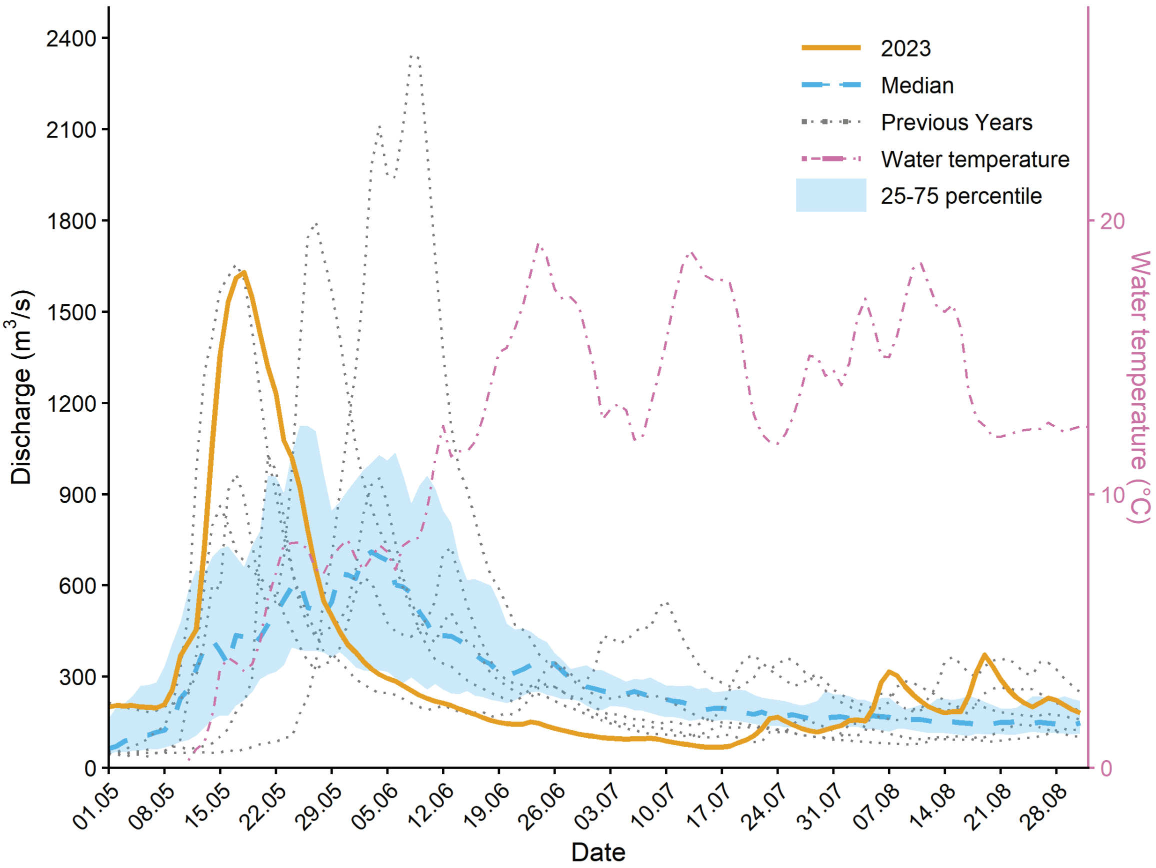

***Figure 2.** Water discharge (solid line) as measured at The Norwegian Water Resources and Energy Directorate's (NVE) Polmak nye (234.18.0) measuring station in Tana in the period 01.05-31.08.2023. Dashed line represents the 50th percentile whilst the coloured area below and above it represents the 25th-75th percentile water discharge measured at this station on the given days. The dotted lines represent the measured water discharge on the given days in the years 2018-2022. Dash-dotted line shows water temperature at the same measuring station in 2023.*

2.1 Trap-fence structures and monitoring overview

Miljødirektoratet (the Norwegian Environmental Agency) decided that the pink salmon (*Oncorhynchus gorbuscha*) trap-fence system was to be installed at Seidaholmen in Tana bru approx. 35 km upstream from the river mouth. At Seidaholmen the river runs in two separate channels, on the eastern and western side of the island (**Figure 3**). The trap-fence evaluation and monitoring activities were concentrated to three main locations (**Figure 3**): 1) the area downstream and around the trap-fence structure in the eastern river channel, 2) the area around the fence in the western river channel and 3) the southern part of the western river channel. In addition to the forementioned areas the sonar monitoring site at the Buolbmát/Polmak (Anon. 2023 p.18-19) by the Natural Resources Institute Finland (Luke) had a key role in the evaluation program (**Figure 3,** location a).

The eastern channel fence structure (**Figure 3**, location 1) consisted of a rigid wood and aluminium fence (hereafter called rigid fence) and a short section (approx. 20 m) of flexible fence on the western end of the rigid fence (**Figure 4**) (see Sandodden et al. 2023 for a detailed description of the fences). The trap entrance (tunnel opening) was located approx. 1/3 river-width distance from the eastern shore (**Figure 3**, trap opening). The construction of the fence structure was completed on June 28th, with the tunnel and trap cages completed the morning after. However, it quickly became evident that the initial setup of the entrance tunnel and trapping facility was unsatisfactory. Consequently, the tunnel, along with the trap cages were relocated almost two meters upstream and positioned more into the current on the 4th and 5th of July. In the western channel (**Figure 3,** location 2) the flexible fence was installed on June 22nd with small adjustments the following days.

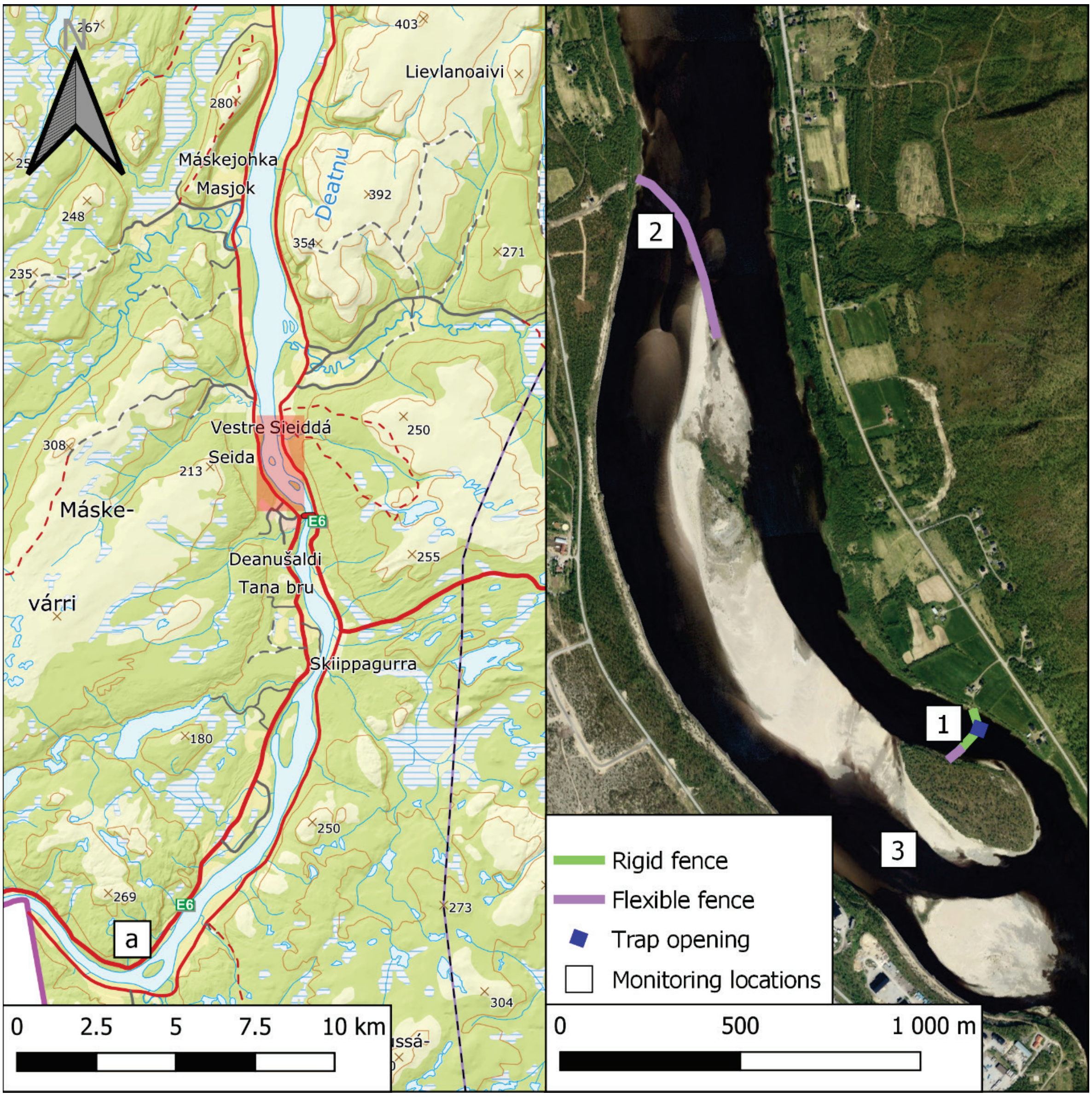

Figure 3. *Map on the left: The River Tana fish trap installation area in Tana (red filled rectangle), a) Luke's sonar counting site with video supplement at Polmak/Buolbmát. Orthophoto on the right: The trap-fence system (solid lines) and monitoring locations (white squares) around the Seidaholmen/Sieiddásuolu (Seidaholmen is the long island dividing the river into an eastern and a western channel), 1) location monitored using ARIS and DIDSON, FRS cameras, and Seavision cameras in different combinations and times throughout the period from pre-trap operation to end of trap operation, 2) location monitored using FRS camera, Timespace and Seavision cameras, and 3) Location monitored with DIDSON and FRS. See* ***Chapter 2.2*** *for information on monitoring equipment.*

Figure 4. *The eastern channel trap-fence system. The eastern channel trap-fence system consisted of a solid wooden structure supporting aluminium frames with aluminium tubes (top picture) and a short section (approx. 20 m) of flexible fence (bottom picture) on the western side of the fence. The bottom picture also shows the initial downstream migration solution in the eastern channel that was closed on the 30th of June, whilst the top picture shows the second downstream migration solution which was opened at different times throughout the trap operation period. Top photo was taken June 27th, 2023, and the bottom picture June 29th, 2023. Photos: S. Domaas, NINA.*

The eastern channel has three deeper runs across its cross section, one closer to the eastern riverbank, a second halfway across the channel, and the third and deepest one towards the western bank (**Figure 5**). A bypass opening in the eastern fence to enable upstream migration of salmon and sea trout was located close to the western end of the aluminium fence in the deepest channel (**Figure 5**, yellow rectangle). This opening was used on regular basis between July 3rd and August 14th.

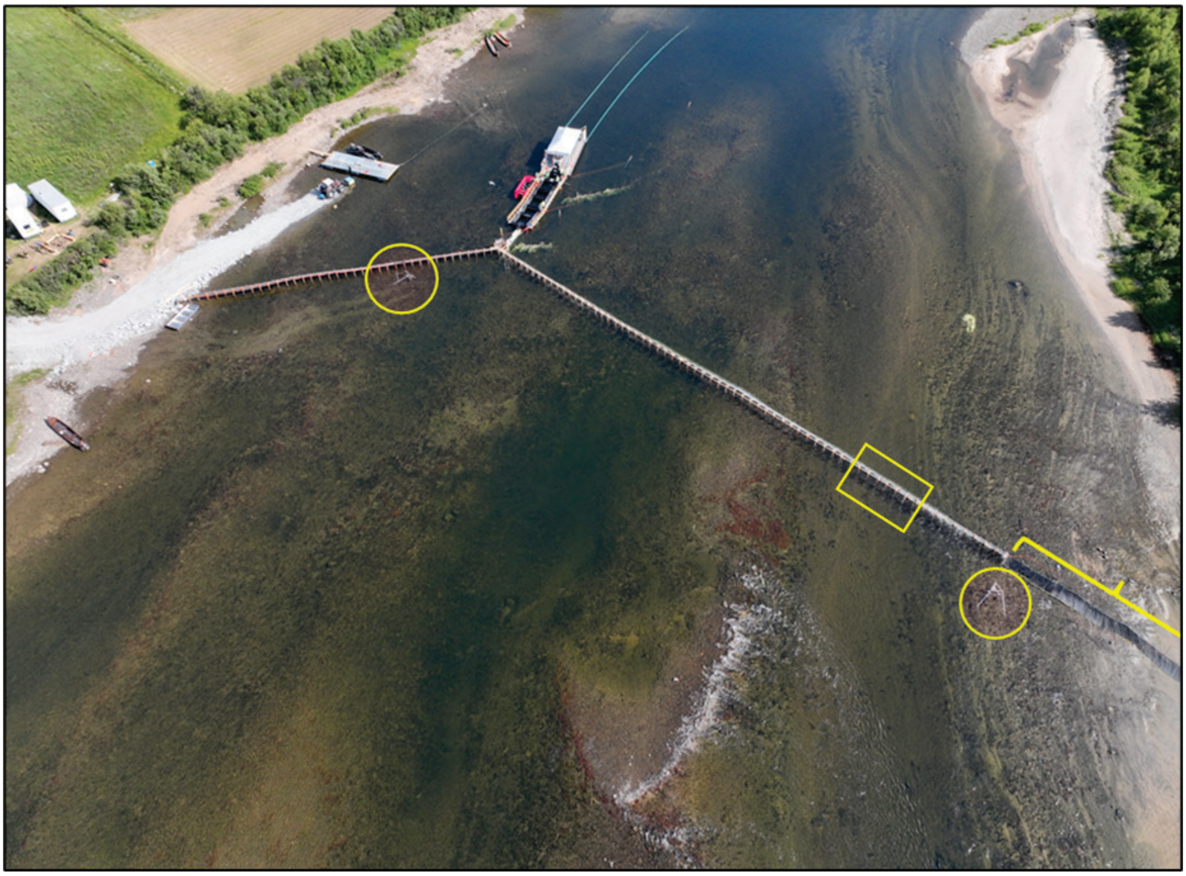

Figure 5. *Drone photo taken of the trap-fence system (facing upstream) in the eastern channel on July 11th, 2023. Here the three deeper runs are visible as darker parts downstream of the trap-fence, one very close to the bank on the left-hand side, the second in the middle of the photo and the third on the right-hand side of the photo just left of where the flexible fence starts (black fence seen extending out of the photo on the right, indicated by yellow bracket extended out of the photo). In addition, both sonars used during this study, the ARIS unit on the left and the DIDSON unit on the right, both highlighted with yellow circles, are indicated. The yellow rectangle marks the bypass location in the fence. Photo: Joachim Henriksen, Tana.*

In the western channel a 500-600 meter long flexible fence, like the one in the eastern channel but with approx. 60 mm. spacing between the plastic pipes, was installed, spanning across the whole channel (**Figure 6**). The area at the western channel fence was characterized by sandy bottom and relatively shallow and even depths. An opening intended as a downstream migration solution, like the one in the flexible fence in the eastern channel, was created close to the western shoreline.

Figure 6. *Drone photo taken from the north end on the Seidaholmen looking south towards Tana bru on July 28th. In the downstream part of the western channel (to the right) the black flexible fence is visible spanning from the sand banks on the island to the stone banks on western shore. Photo: Joachim Henriksen, Tana.*

2.2 Monitoring equipment

In this study two types of sonars from the same manufacturer (Sound Metrics Corp.) were used: an ARIS explorer 1200[1] and a DIDSON 300m[(2)]. For further information on the use of sonars in the Tana, and the workings of the ARIS, see Domaas et al. (2024) (Norwegian only). The sonars will from here on mostly be referred to as ARIS and DIDSON.

For this study a total of eight Seavision SV-AQV130 underwater cameras[3] capable of 4K recording supplied with lights[4] were used with two NoVus NHDR-4308-H2 eight channel digital video recorders (DVR)[5]. Four Seavision cameras were paired to each NoVus DVR. These two camera sets, á 4 cameras, are from here on referred to as Seavision set 1 or set 2. An additional four underwater cameras capable of 720p recording were used with a Timespace X300 four channel DVR[6]. The four cameras used with the Timespace DVR are from here on referred to as Timespace.

The sonars and video cameras mentioned above required manual data analyses, and due to the large amount of data gathered throughout the monitoring period and limited resources, all data have not been analysed. In addition to the sonars and traditional underwater cameras, three Fish

1 http://www.soundmetrics.com/products/ARIS-sonars/ARIS-explorer-1200
2 http://www.soundmetrics.com/Products/DIDSON-Sonars/DIDSON-300m
3 https://www.seavision.no/_files/ugd/a4979a_ec7ccc4048684c188bb9407c7068b18b.pdf
4 https://www.seavision.no/lys
5 https://www.novuscctv.com/en/products/5327/NHDR-4308-H2
6 https://www.tspace.co.uk/timespace_x300.asp

Research System[7] (FRS) cameras capable of autonomous fish recognition by use of artificial intelligence (AI) were used. To separate the three FRS cameras, they are from here on referred to as FRS 1, FRS 2 or FRS 3. The FRS camera consists of a 3MP machine vision camera which is run by a microcomputer with an AI accelerator chip for edge computing. The FRS camera has proven reliable in a large variety of conditions in rivers and fjords across Norway. It is made from robust materials and has an anti-fouling system that ensured clean lenses through the project period. The cameras have integrated custom lights that can be dimmed and programmed to the user's needs. In addition, it has a pressure and temperature sensor. The AI machine vision runs directly on the camera to reduce the amount of bandwidth / data usage. The AI was trained before installation by annotating thousands of fish images taken under a large variety of conditions. The dataset consisted of 50 000 annotated images, and the algorithms were trained on a powerful server. The resulting algorithm (or program) from those images is small in size and works well on a microcomputer. The machine vision is constantly being tuned and updated with new images, and the algorithms are updated remotely.

Joachim Henriksen, a private person living in the area, made video recordings using a DJI Mini 3 Pro drone on some days when weather conditions allowed the use of a drone. The drone footage gave a top-down view of the trap and surrounding area, which under good lighting conditions with little wind, was suitable to identify fish. Henriksen helpfully made his drone footage available for our use in this report.

2.3 Monitoring at the trap-fence in the eastern channel

Monitoring in the eastern channel around the trap-fence structure was done using an ARIS, a DIDSON, two FRS cameras, two Seavision camera sets and systematic diving along the fence and in the area immediately downstream the fence (0-200 meters). In addition, drone footage from the area downstream the trap and fence taken by Joachim Henriksen on June 30th (1 min 3 s) and July 11th (6 min 20 s) was available.

The monitoring at the trap-fence was active and equipment was moved frequently throughout the monitoring period to cover the areas found most relevant at the time (**Figure 7**). The monitoring was focused on (but not limited to) five main areas: 1) The area downstream the fence along the eastern bank, 2) the flexible fence and the area surrounding it, 3) the deepest run downstream the western part of the fence (visible in **Figure 5**), 4) the trap entrance and the surrounding area (ARIS visible in **Figure 5**), and 5) the bypass opening in the western part of the fence (location of opening marked in **Figure 5**).

In addition to the monitoring effort described above, frequent snorkelling in the area was done to gather information on species composition and identify if fish were aggregating in certain areas. Systematic snorkelling of the three deeper runs of the eastern channel was (most often) conducted by two snorkellers drifting on a line close to each other with the snorkeller on the right covering the right sector and vice versa. Only fish close enough to be identified to species were counted, this meant that results from snorkelling was heavily dependent on visibility, which varied from about five meters at the clearest to less than two meters at the murkiest. Drifting in the two easternmost runs was conducted from the fence until the snorkeller ran aground in the shallow areas located downstream the fence, typically 50-100 meters. Drifting in the westernmost, and deepest run was conducted from the fence until 200 meters downstream where the snorkeller would swim ashore.

A downstream migration opening was initially created in the section of the flexible fence (**Figure 7**, area 2), close to the western shore but that was quickly closed (June 30th) in fear of pink

[7] https://www.mohntechnology.no/product/fish-research-system-frs/

salmon using it to bypass the trap. However, visual observations of smolts shoals swimming along the upstream side of the fences indicated that a downstream migration opening was needed. Therefore, an alternative opening was made close to the eastern bank (upstream to area 1 in **Figure 7**) by removing the aluminium poles from one of the aluminium frames in the rigid fence, see photo in **Figure 4**. This opening was opened and closed throughout the trap operation period and was considered to be a less likely migration route for pink salmon. Monitoring of this opening was not prioritized, in favour of monitoring areas further west in the channel with much higher pink salmon and Atlantic salmon densities and activity.

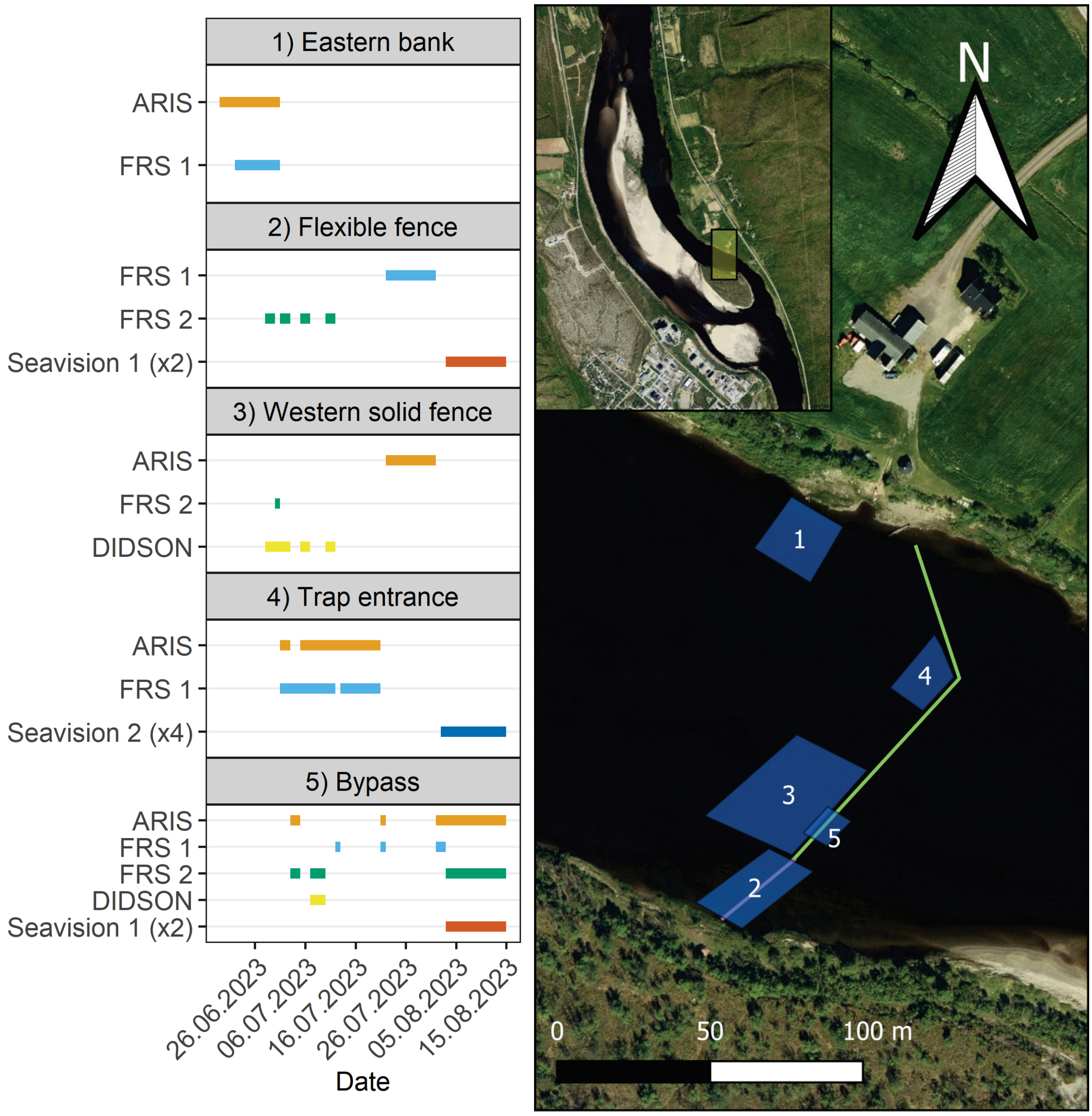

Figure 7. *Composed overview of the monitoring efforts in the eastern channel trap-fence area of the River Tana (Eastern side of Seidaholmen/Sieiddásuolu in Tana). In the left figure we see a timeline showing when and which areas different monitoring equipment was monitoring, with the number in each panel heading corresponding to the number in the blue-shades monitoring areas on the aerial photo to the right. Each Seavision set was comprised of one recorder and*

four underwater cameras, the numbers in the parenthesis behind Seavision represents the number of underwater cameras installed in the different areas.

2.3.1 Activity measurement at the site

Due to the nature of the area (particularly its size) and the behaviour of the fish, a 'traditional' monitoring with sonar, i.e., counting migrating fish as they swim past the location, was not always a suitable method. For these cases, the relative abundance and activity in the area was used to make an abundance/activity index. The index was based on hourly activity as seen on the sonar echogram, and classified into five categories, where *1* meant *very little* activity and *5* meant *a lot* of activity (**Figure 8**). The *mean daily abundance/activity* was estimated by calculating the mean abundance/activity from every fourth hour of the day (i.e., six hours a day). Comparing daily mean abundance/activity estimates between days within an analysed period is a good way to show change in abundance/activity over time, but comparing between different analysed periods, and particularly locations, might not be comparable due to e.g., different movement patterns, sonar range etc.

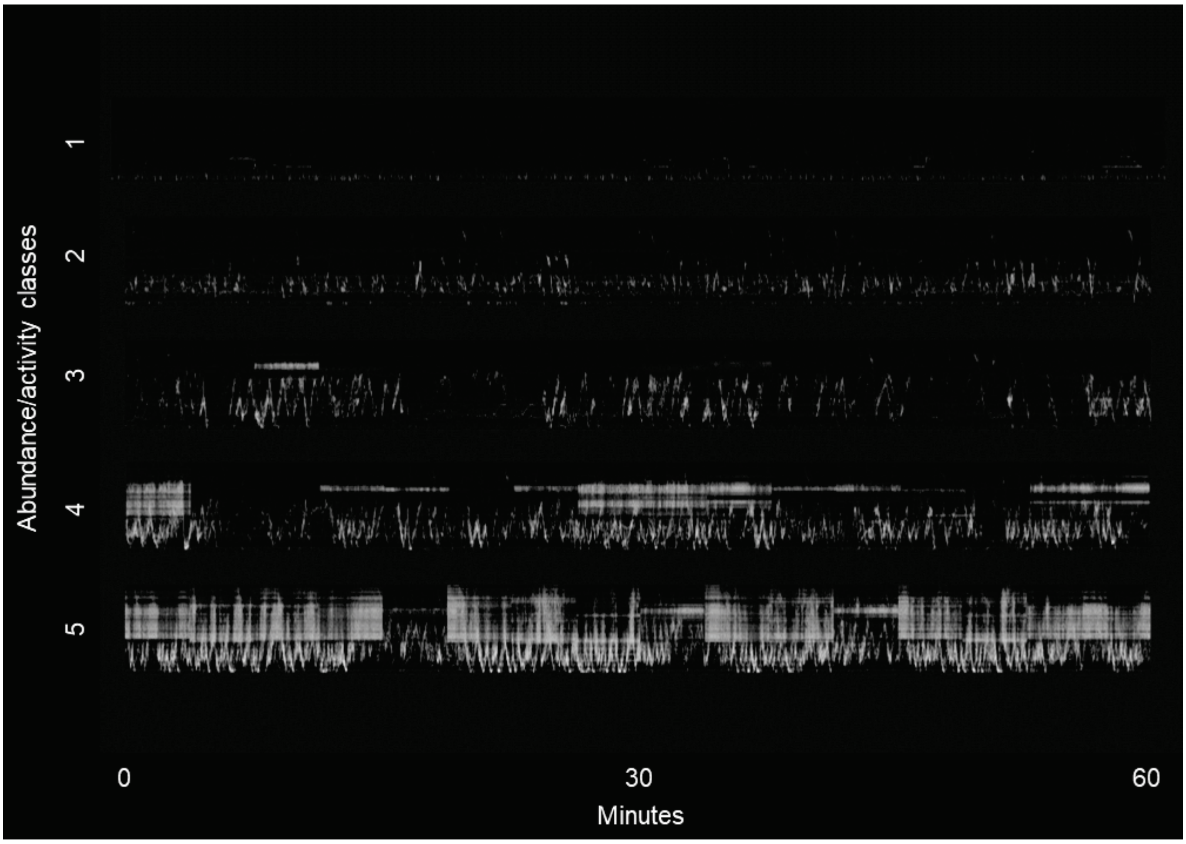

Figure 8. *Five, one-hour long echograms illustrating what classifies as the five abundance/activity classes (y-axis) used for making the abundance/activity index. The top echogram represents "very little" activity (abundance/activity class 1), and the bottom echogram represents "a lot" of activity (abundance/activity class 5). In each echogram the y-axis represents the distance from the sonar and the x-axis is time. The white streaks seen in the echograms are primarily fish, meaning more white streaks in the echogram = a higher abundance/activity of fish in the area.*

2.4 Monitoring at the fence in western channel

Monitoring at the western channel fence was done using an FRS camera, the Timespace camera set and one Seavision set as well as occasional diving along the fence. In addition, the drone footage made available by Joachim Henriksen was used. The FRS-camera was installed at the opening intended as a downstream migration solution to monitor the migration of smolts, kelts and other native species, as well as uncovering whether pink salmon would take advantage of the opening and ascend through it. The Timespace and Seavision cameras were installed upstream along the flexible fence to uncover whether pink salmon would swim through it. The cameras were installed 20, 28, 32, 38, 53, 71, 82 and 94 meters from the shore (relative to the water levels on July 10th) (**Figure 9**). The FRS-camera was installed on June 22nd and removed on the August 14th, the Timespace set was installed on July 10th and removed on August 14th, and the Seavision set was installed on July 20th and removed on August 2nd.

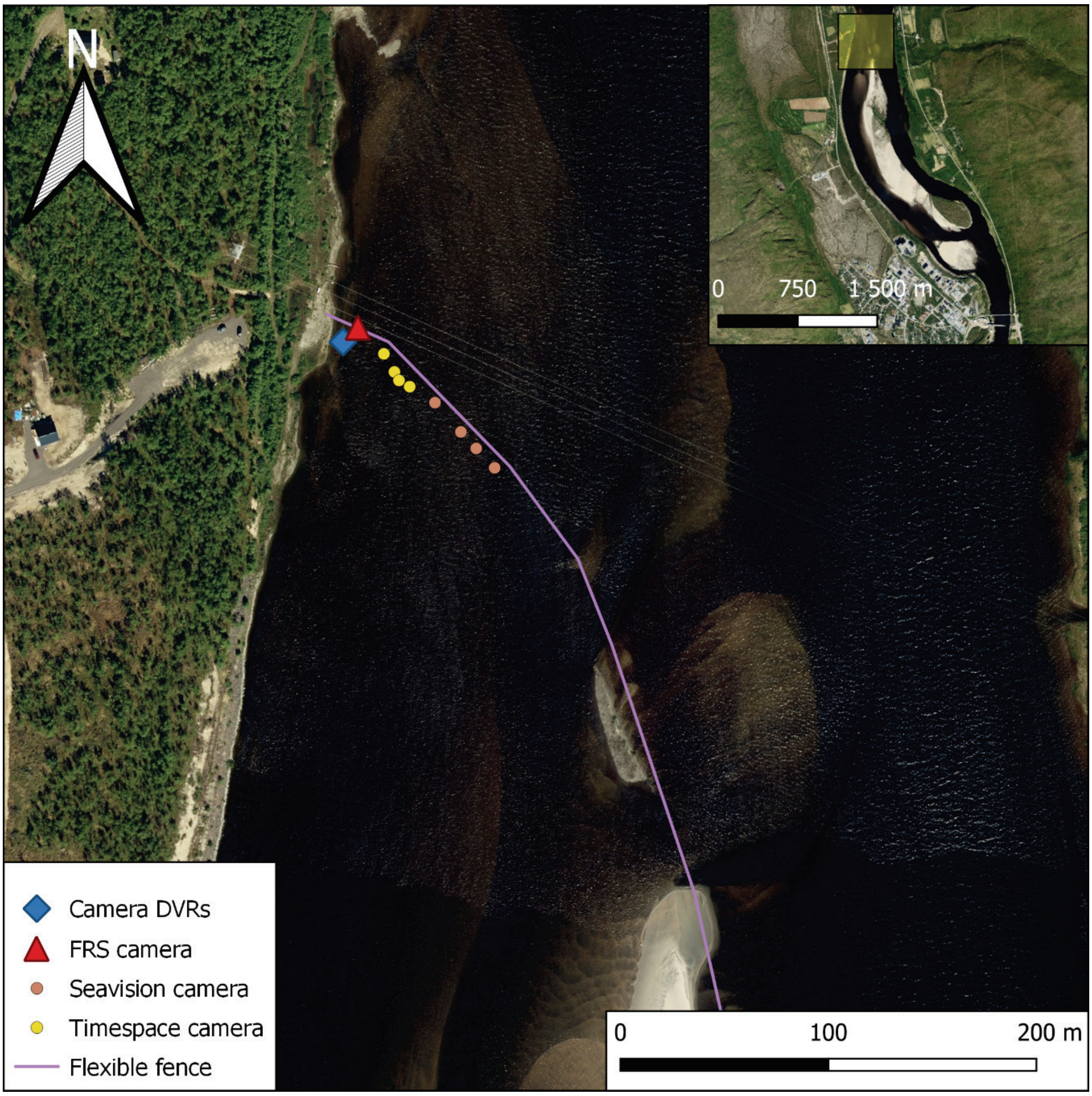

***Figure 9.** Orthophoto of the area north of Seidaholmen/Sieiddásuolu in Tana. The solid line represents the approximate placement of the flexible fence made to guide fish into the eastern river channel. The filled triangle represents the approximate placement of the migration opening and*

the FRS camera monitoring it. The filled diamond (being overlapped by the triangle) marks the position of the box where the DVRs were installed, and the filled circles marks the position of the eight underwater cameras installed in the area.

Drone footage was available from certain days from June 30th to July 28th (**Table 1**).

Table 1. *Dates and length of available drone videos from the fence area in the western channel.*

Date	30.06	3.07	7.07	8.07	9.07	10.07	11.07	12.07	17.07	20.07	23.07	27.07	28.07
Length (m:s)	02:13	01:53	03:39	01:03	13:37	14:24	04:48	03:54	01:59	18:52	02:34	08:23	05:24

2.5 Monitoring of ascending fish in the western channel

To get relative numbers and species distribution of up-migrating fish that had passed the flexible fence in the western channel, a DIDSON was used together with an FRS camera at the upstream end of the western channel (**Figure 10**). Both the DIDSON and the FRS-camera were installed in the period July 12th to August 14th.

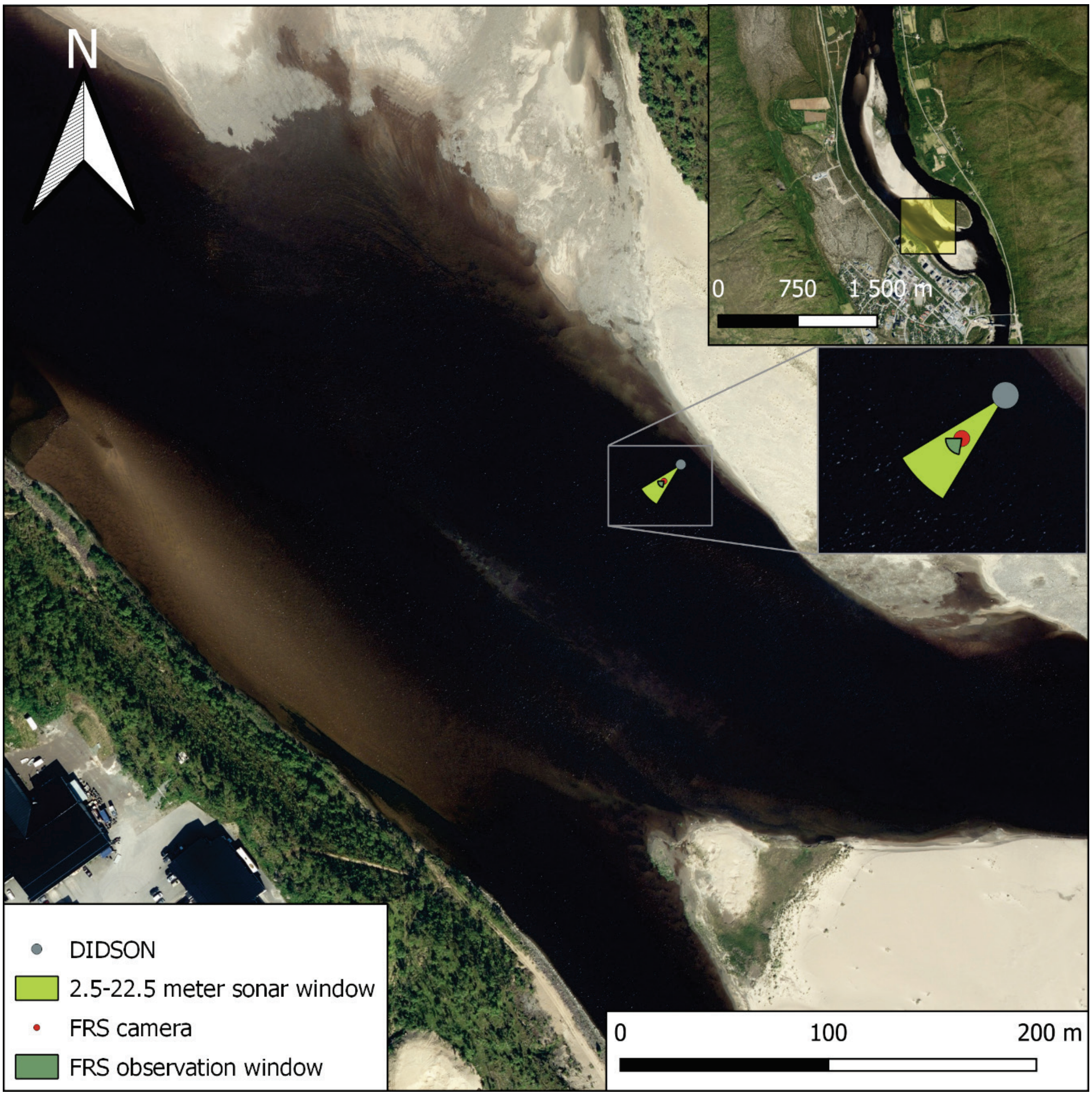

Figure 10. *Orthophoto of the chosen location for monitoring ascending fish in the western river channel at Seidaholmen/Sieiddásuolu in Tana. The location of the DIDSON sonar with its range (2.5–22.5 meters), as well as the FRS camera are marked and illustrated as according to the legend (bottom left corner). The range of the FRS-camera is unknown, as we don't know exactly how far from the lens the AI is capable of recognizing fish.*

2.6 Operational support

One of the goals with the monitoring was to provide operational support for the trap managers, e.g. by notifying the trap managers if there was a lot of fish approaching the trap. The operational support was given by daily dialogues with the present daily leader at the administration office at the trap site. Some feedback was also provided by email. An interim report describing the monitoring results as per July 25th was delivered on July 27th, 2023.

3 Results

3.1 Downstream migration

3.1.1 Smolts

The opening intended for downstream migration at the downstream end of the guiding fence in the western river channel was kept open throughout the trap operation period, whereas the original opening in the eastern channel (see **Figure 4**, bottom photo) was closed on June 30th. Data from June 22nd to July 18th from the FRS camera used to monitor migration through the western channel opening (**Figure 11**) was analysed. No smolt migration data was gathered from the eastern channel primary opening before it was closed and no resources were used to monitor the secondary opening (see **Figure 4**, top photo) in the periods it was open.

In the western channel, a total of 6 078 Atlantic salmon smolts were observed on the FRS camera upstream the opening during the period 22.06-18.07. Of these, 1 265 smolts (21%) were observed descending through the opening, whereas 79% of the observed smolts continued swimming back and forth upstream the flexible fence. Hence, some of these may have been counted several times. All approaching smolts came swimming along the fence. No smolts were observed swimming between the sticks outside the opening, but only the immediate area around the opening was monitored. The most intensive migration occurred on June 24th with a total of 1 658 observations, with 356 smolts descending through the opening (**Figure 12**). Albeit being a large watercourse with varying migration routes and lengths depending on spawning site, the observed smolt migration peak period was rather narrow. As much as 75 % of the observed smolts migrated through the opening in the period from the 24th to the 29th of June. Based on the smolt migration pattern from Utsjoki (video monitoring), the trap operation with guiding fences and downstream migration openings covered most of the smolt migration window. As well as showing a rather narrow migration peak within the analysed period, the smolt surprisingly showed a preference to migrate through the opening during night (**Figure 13**), even though there was midnight sun throughout the whole monitoring period.

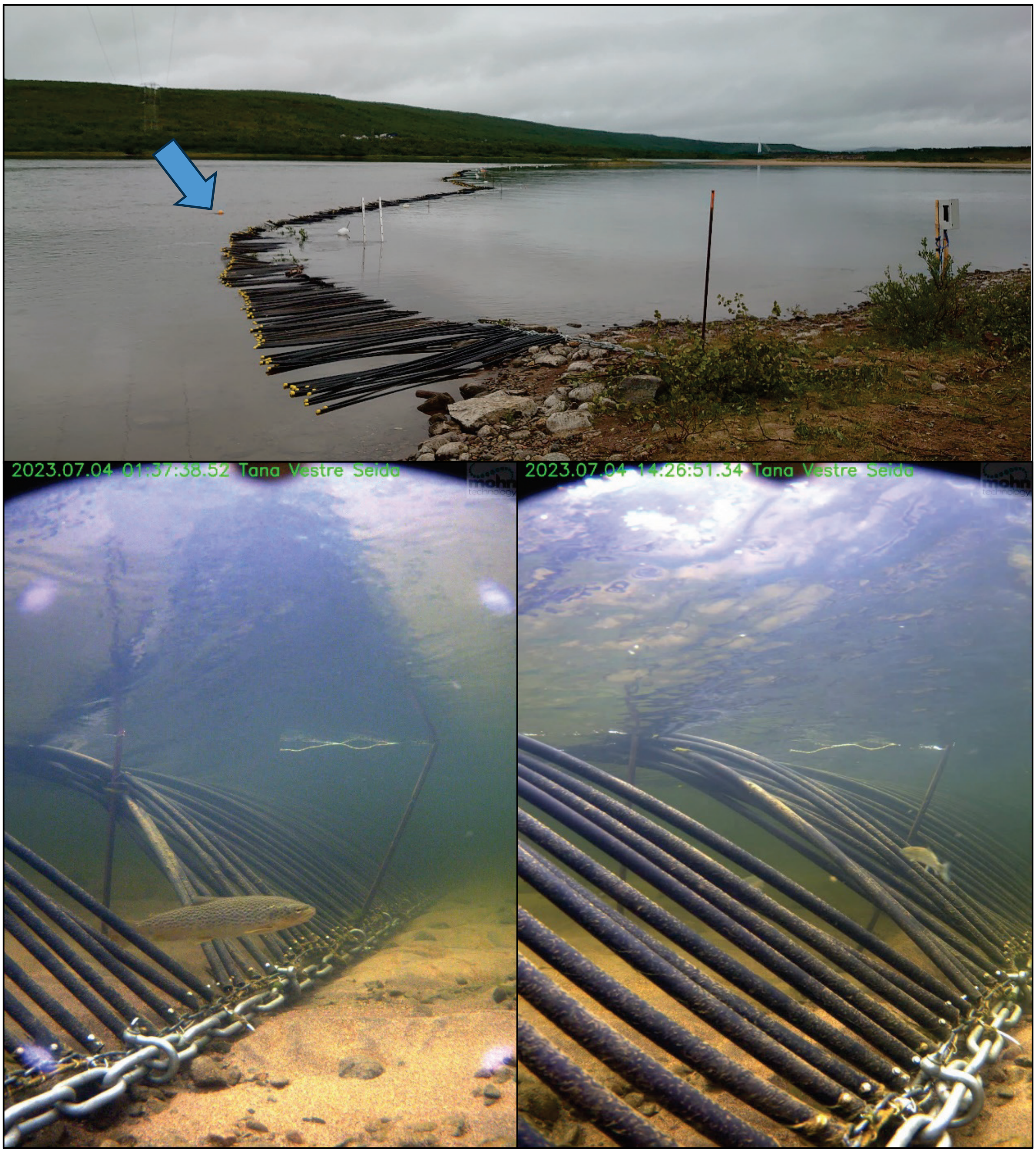

Figure 11. *The downstream migration solution in the western channel. The top picture shows the flexible fence spanning across the western channel at the northern end of Seidaholmen. The downstream migration solution can be seen as a larger gap/opening in the flexible fence (indicated by the blue arrow). The bottom two pictures are taken by the underwater FRS camera installed at the location to monitor both ascending (left picture: example of a brown trout (Salmo trutta) ascending on July 7th, 01:37) and descending (right picture: example of a smolt descending on July 7th, 14:26) fish through the migration solution. Top photo: S. Domaas, NINA. Bottom photos: Mohn Technology.*

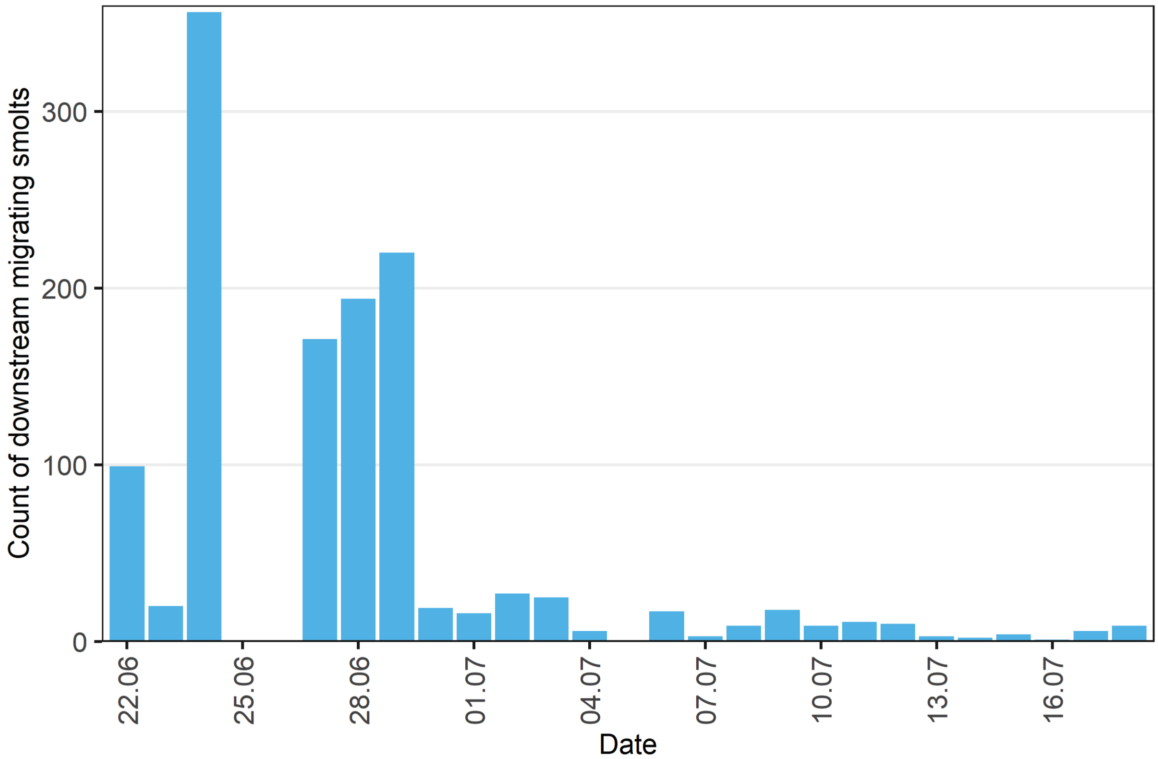

Figure 12. *Count of registered smolts migrating downstream through the opening in the flexible fence in the western river channel in the period 22.06-18.07.2023. There is reason to believe that the FRS system did not work as it should on June 25th as no videos from that date were saved. On June 26th however, multiple videos were saved and smolts were registered above the fence, but none were recorded going through the opening.*

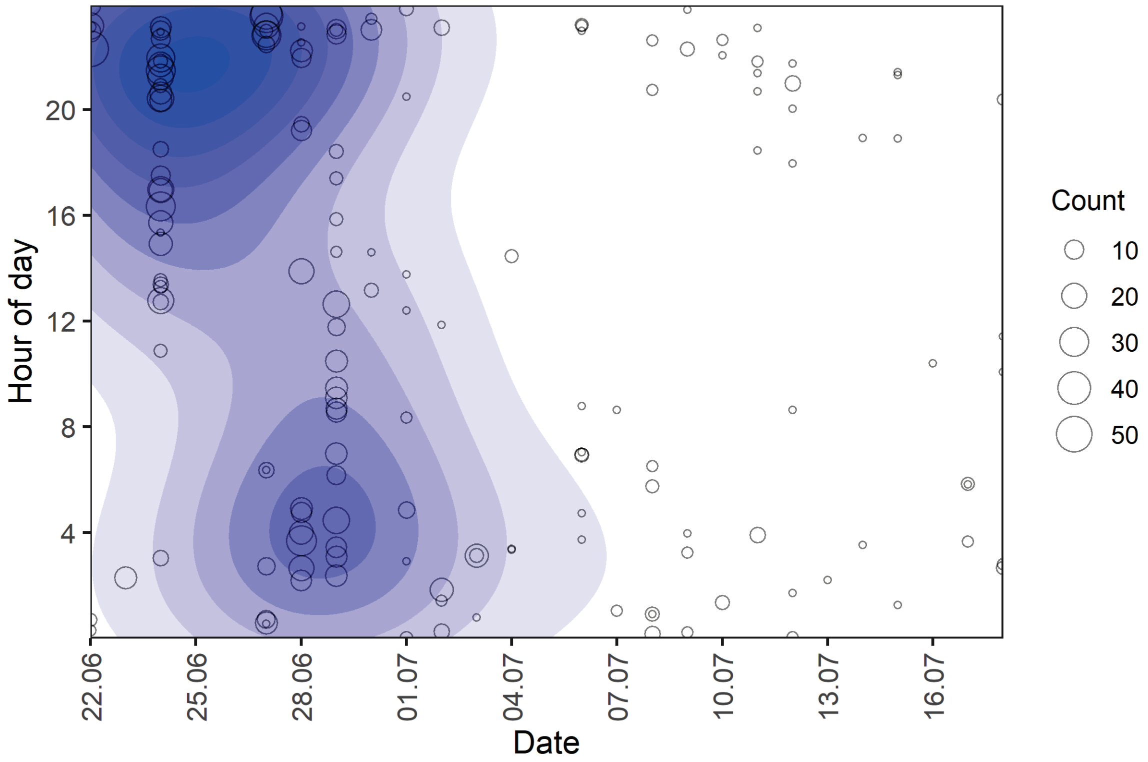

Figure 13. *Plot showing date and time of when smolts were observed migrating down through the opening (open circles, size represents number of smolts) in the flexible fence in the western river channel in the monitored period (22.06.-18.07.) in 2023. The darker the background colour, the higher preference for migrating down through the opening at the given date and time.*

3.1.2 Kelts

Unlike the smolts, not a single kelt was recorded migrating down through the migration opening in the western channel flexible fence. Some kelts (7) were however observed on the FRS camera close to the opening during the period 22.06-18.07, and a few more fish tails potentially belonging to kelts were also observed on this camera. The spatial and temporal coverage of the drone footage was better on the downstream side compared to the upstream side of the flexible fence, but no large kelt gatherings were observed upstream to the fence. Groups of 4-12 fish in kelt size were observed upstream the fence throughout the observation period, though (**Figure 14**). On July 28th the number of fish holding upstream the fence had increased to over 20, but some of these were pink salmon. Overall, kelts were observed on camera (FRS, Timespace, Seavision and/or drone) in all of the three main monitor locations (see **Figure 3**) throughout most of the monitoring period, with the latest observation being as late as August 5th (**Figure 14**). Towards the end of July, some of the observed kelts had considerable amounts of fungus infection.

3.1.3 Other species

During the period 22.06-18.07, other species such as grayling (*Thymallus thymallus*) (198 observations), brown trout (*Salmo trutta*) (24), European flounder (*Platichtys flesus*) (15), whitefish (*Coregonus lavaretus*) (10), pink salmon (10), and stickleback (*Gasterosteidae*) (2) were also observed by the FRS-camera at the opening intended as a downstream migration solution. Of 171 larger graylings, 18 passed downstream, 10 upstream and 143 did not pass through the opening during this period. Of 16 non-juvenile trout, 2 passed upstream and 3 downstream, whereas 11 did not move through. None of the whitefish were observed passing through this

opening. Two pink salmon were observed passing downstream through the opening, none observed passing upstream through the opening during the period 22.06-18.07.
The data gathered after 18.07 (thousands of video clips) has not been systematically analysed, but contains hundreds of pink salmon video clips, quite a few video clips of grayling and trout, and at least one of an Arctic charr moving downstream through the opening.

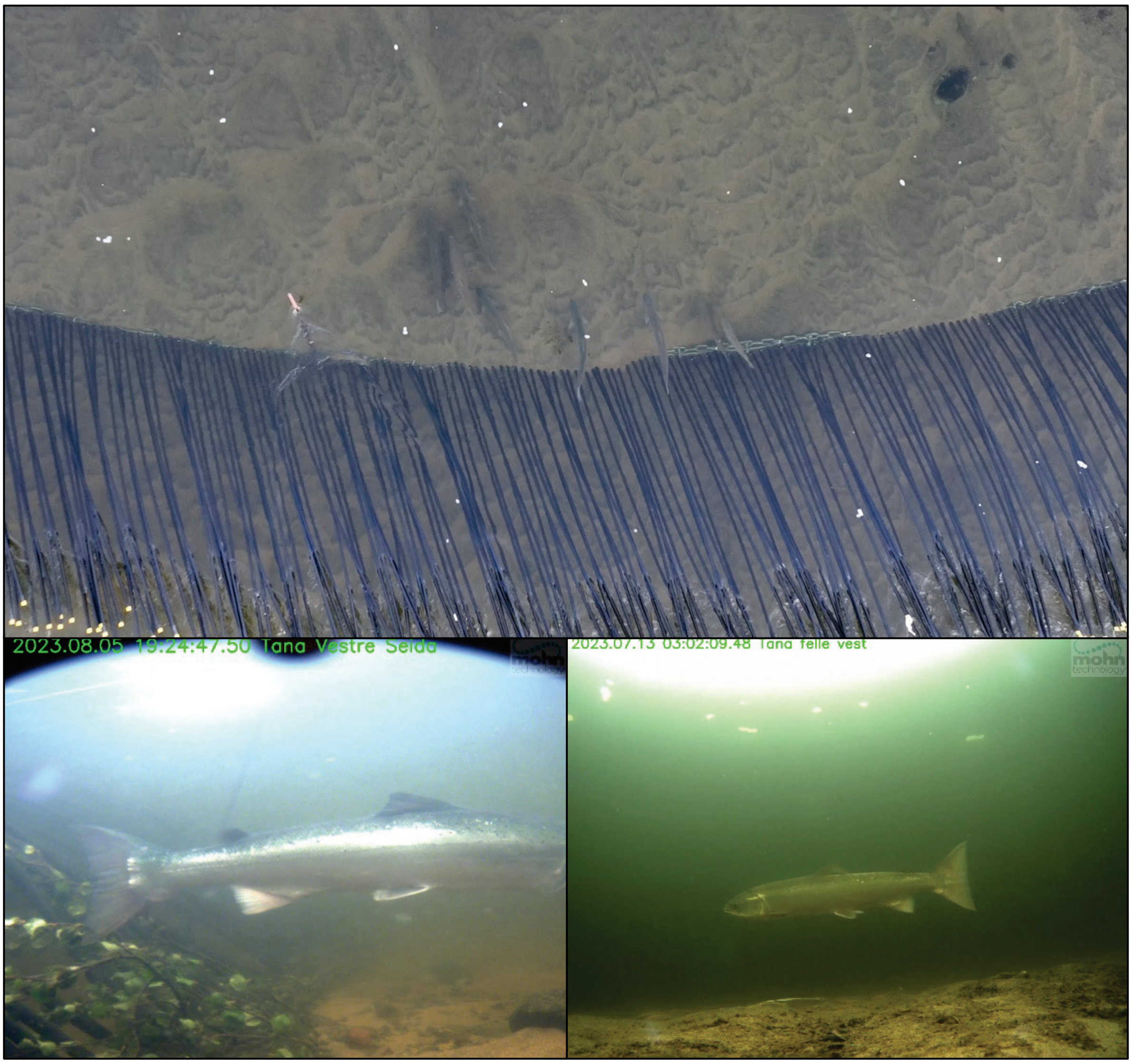

Figure 14. *Top photo: Drone footage showing eight salmon upstream the flexible fence in the western channel on July 8th, 2023. Except for maybe one, all these salmon show typical characteristics of kelts – being thin. Bottom left: A salmon believed to be a kelt observed in conjunction with the down migration solution in the western channel flexible fence on the night of August 5th, 2023. Bottom right: A salmon believed to be a kelt in the northern monitor location in the western channel (location 3,* ***Figure 3****) on July 13th, 2023. Top photo: Joachim Henriksen, Tana. Bottom photos: Mohn Technology.*

3.2 Ascending fish approaching the eastern fence and trap

3.2.1 General observations

The numbers of fish gathering downstream the eastern fence (**Figure 3**, monitoring location 1) varied throughout the monitoring period. Exact fish numbers could not be quantified because of smaller and larger schools of fish moving frequently back and forth along and below the fence and further downstream. However, an increase in estimated *mean daily abundance/activity* (see **chapter 2.3.1**) in area 1 (see **Figure 7**) was seen in the period from the 26th to the 30th of June. On both June 26th and 27th the estimates for the *mean daily abundance/activity* were very low. On the 28th the hourly abundance/activity levels varied from 1 to 4, and the estimated *mean daily abundance/activity* increased to 2.33. On the 29th and 30th the abundance/activity subsided, and the estimated *mean daily abundance/activity* lowered to 1.67 for both days (**Figure 15**).

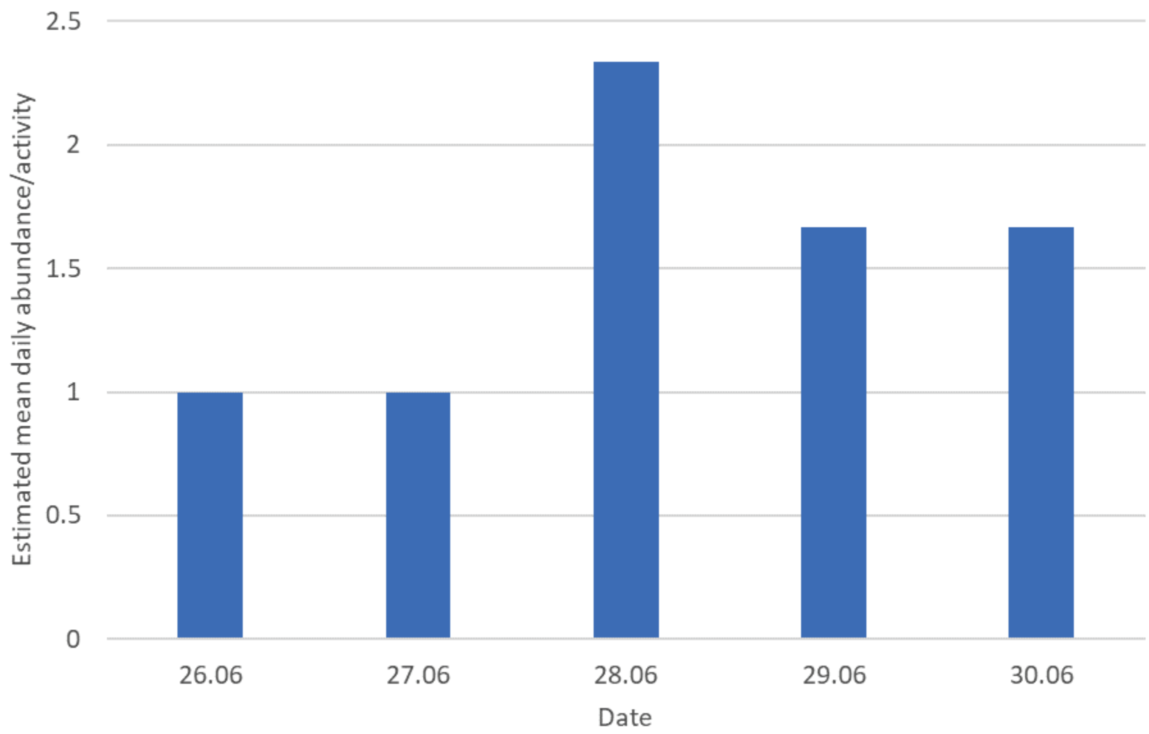

***Figure 15.** Estimated mean daily abundance/activity (see **Chapter 2.3.1**) in area 1 below the trap in the eastern channel (see **Figure 7**) in the period 26.06-30.06.2023.*

The estimated *mean daily abundance/activity* in area 4 (see **Figure 7**) in the period 05.07-21.07.2023 varied between days (**Figure 16**), and the days with the highest activity were July 11th, 13th, and 18th.Throughout the period, there were also significant differences in observed abundance/activity between hours within the same days.

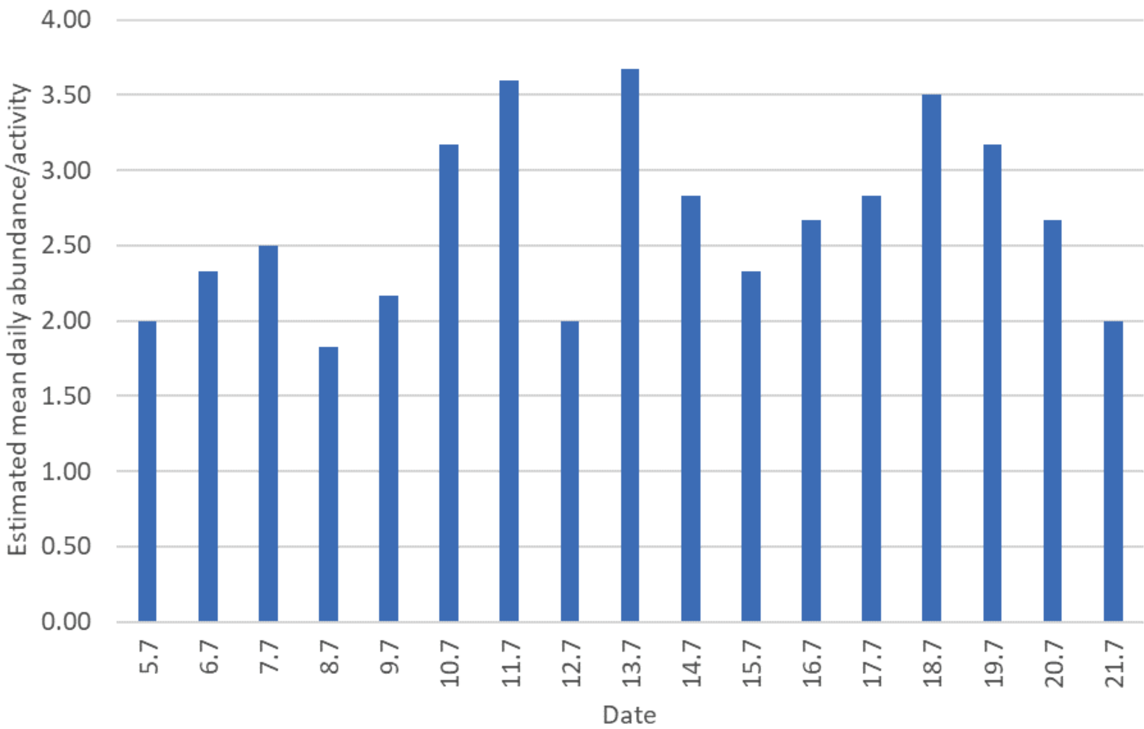

Figure 16. *Estimated mean daily abundance/activity (see **Chapter 2.3.1**) in area 4 below the trap tunnel in the eastern channel (see **Figure 7**) in the period 05.07-21.07.2023.*

3.2.2 Fish behaviour at the trap entrance

Judging from the observed activity downstream the trap it was clear that the trap-fence system was creating a holdup for fish migrating upstream. By looking at the ARIS sonar data from the trap entrance (**Figure 7**, area 4), it became clear that the fish would not enter the trap as both smaller and larger schools were observed moving towards the trap entrance tunnel without entering it.

The sonar data showed that during the most intensive migration peak below the eastern fence (10^{th}-15^{th} of July), schools of fish would swim towards the fence and trap opening, but when reaching it turned back and retreated. Schools were also observed approaching the tunnel entrance from the western side, swimming along the fence, but these also turned away and retreated when reaching the tunnel entrance. As the number of fish increased in the ARIS observation area, the more frequent were the back-and-forth movements immediately downstream to the fence and trap.

By a closer inspection (FRS camera data) of fish behaviour around the tunnel we saw at least two patterns of movement pre tunnel adjustment (4^{th} and 5^{th} of July). One observed pattern was where schools would move towards the tunnel area from the west close under the fence, but when reaching the tunnel turned downstream and swam out of the entrance area (**Figure 17**). The other pattern was schools approaching the tunnel from downstream, but rather than entering the tunnel, congregated in the corner formed at the right side of the tunnel where the tunnel met the fence, before swimming out of the trap entrance area to the west (**Figure 18**).

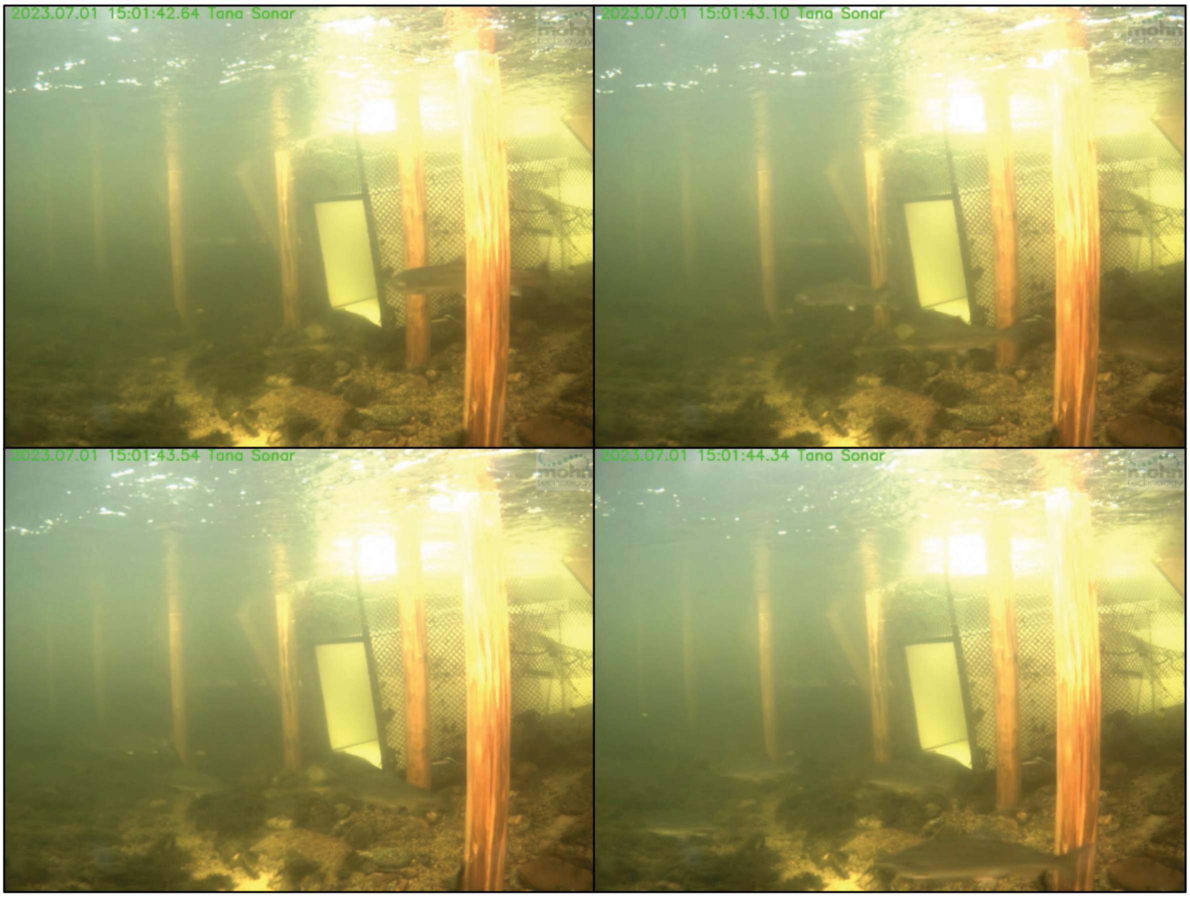

Figure 17. *Sequential series of pictures (from top left to bottom right) showing a school of pink salmon approaching the tunnel from the west. The school was swimming along the fence approaching the tunnel before heading downstream as they met the tunnel. Pictures are taken on July 1st, 2023, pre tunnel adjustment (4th and 5th of July). Pictures: Mohn Technology.*

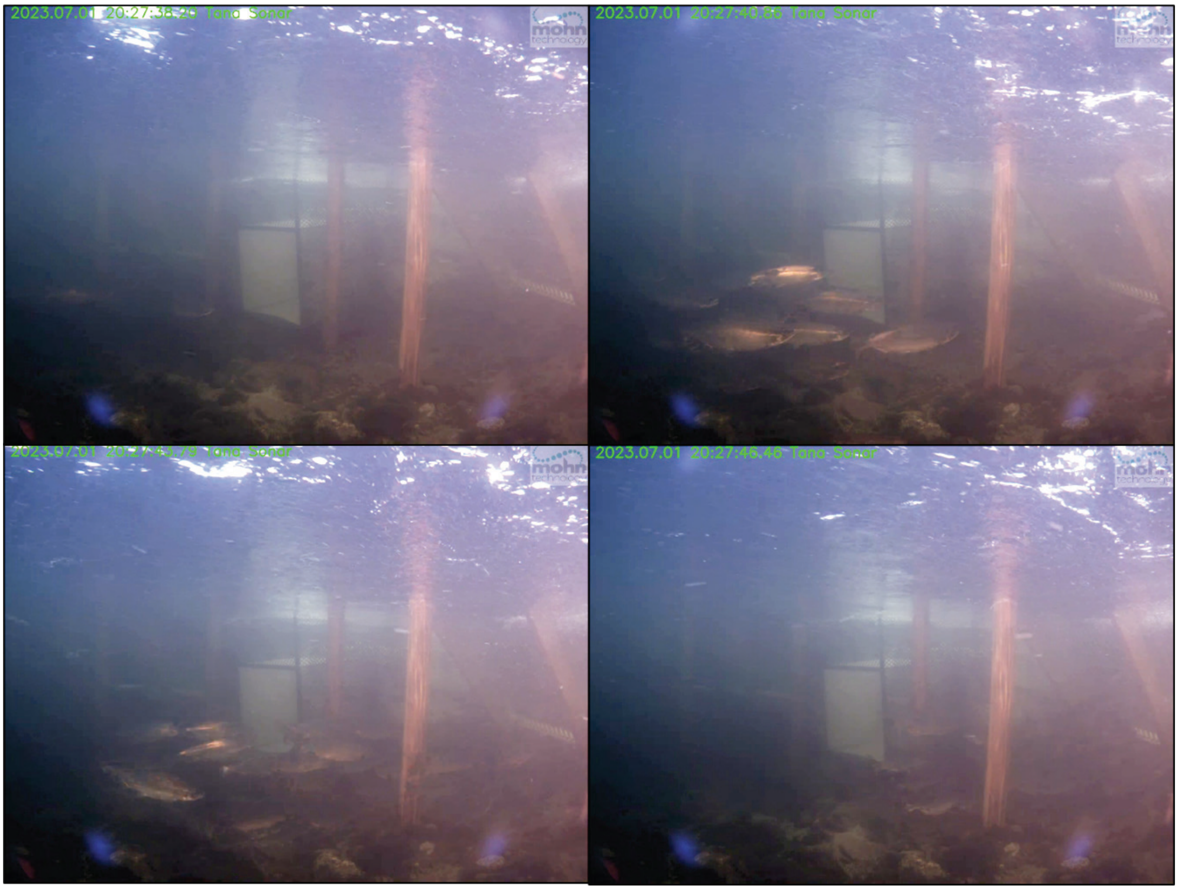

Figure 18. *Sequential series of pictures (from top left to bottom right) showing how a school of fish approaching the trap from directly downstream, rather than entering the tunnel, went into to the corner formed on the right side of the tunnel where they met the fence. Pictures are taken on July 1st, 2023, pre tunnel adjustment (4th and 5th of July). Pictures: Mohn Technology.*

After the tunnel adjustment (4th and 5th of July) schools were observed behaving a lot of the same as pre-tunnel adjustment. However, rather than being lead away from the tunnel entrance when approaching from the west, or aggregating in the corner when approaching from downstream, fish would swim up to the tunnel entrance and scatter before swimming downstream out of the tunnel entrance area (**Figure 19**).

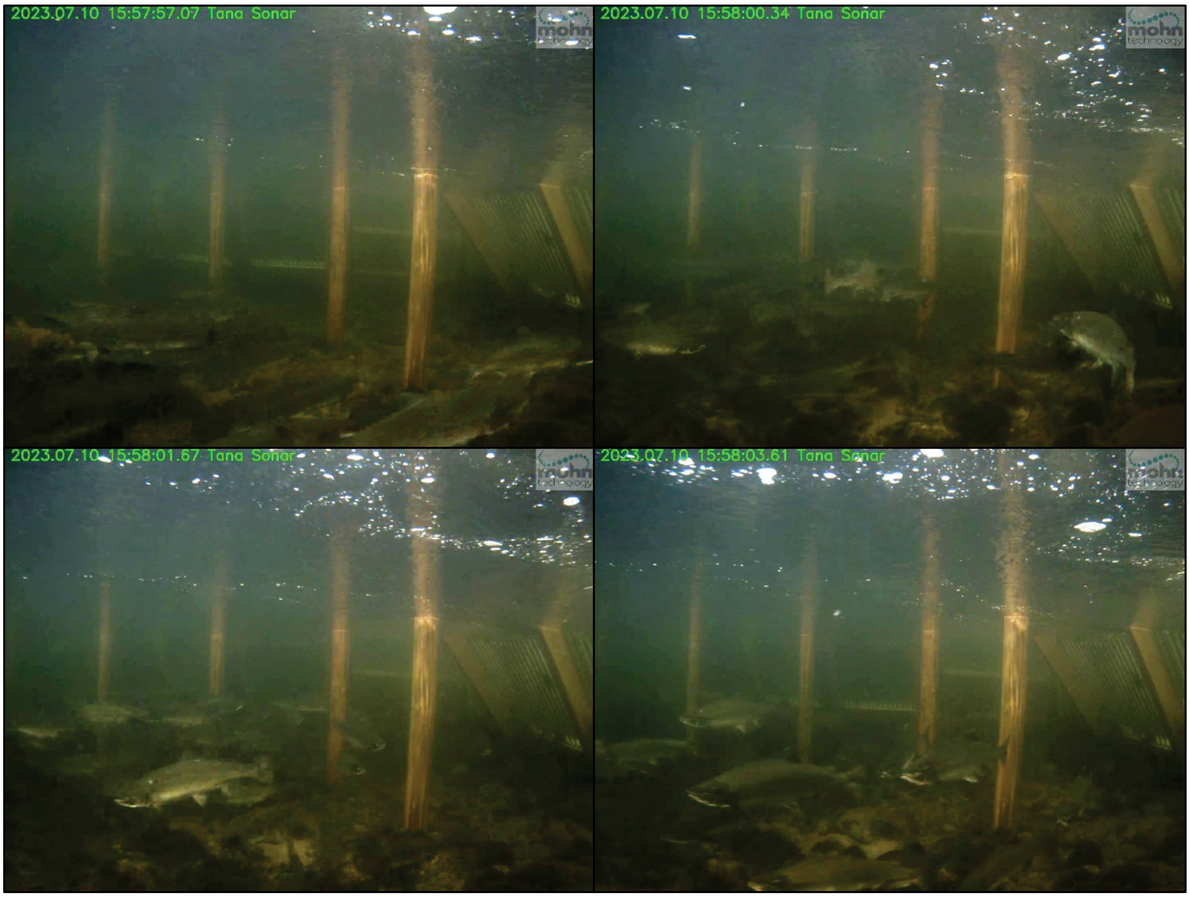

Figure 19. *Sequential series of pictures (from top left to bottom right) showing how a school of fish approaching the trap from directly downstream, and rather than entering the tunnel, they scatter in all directions before swimming downstream again. Pictures are taken on July 10th, 2023, post tunnel adjustment (4th and 5th of July). Pictures: Mohn Technology.*

3.2.3 Snorkelling counts below eastern trap-fence structure

Snorkelling counts below the eastern fence revealed indications of species-specific distribution and preferences in area use. With only a few exceptions, the westernmost run was the run where most fish were observed, and this run had the highest proportion of Atlantic salmon (**Table 2**). The easternmost run had the lowest overall observations of fish but had the highest observed proportions of pink salmon. In the middle run, the distribution between the two species were more even. When snorkelling the westernmost channel, it was also quite clear that pink salmon were dominating in the first 20-50 meters immediately downstream the fence whilst Atlantic salmon were dominating in the remaining 200 meters that were frequently dived. Schools exclusively consisting of pink salmon were rarely observed, as there almost always was one or more Atlantic salmon mixed in.

Table 2. *Overview of snorkelling results from diving downstream the trap in the period 03.07-21.07.2023. *Not dived because of fishermen fishing in the run (>180 meters downstream the trap). The three runs are the three deeper channels found in the area downstream of the trap (see **Figure 5**). The numbers are not perfectly standardized, since the visibility (water transparency) varied throughout the period and to some extent within the observation area. The number of snorkellers also varied, normally two or three repeating drifting in each channel.*

	Eastern run		**Middle run**		**Western run**		**Sum**	
Date	Atlantic salmon	Pink salmon	Atlantic salmon	Pink salmon	Atlantic salmon	Pink salmon	Atlantic salmon	Pink salmon
03.07	3	10	30	30	250	50	283	90
05.07	0	0	8	20	180	20	188	40
07.07	0	4	46	13	110	25	156	42
08.07	0	0	1	24	130	1	131	25
10.07	0	93	0	10	60	167	60	270
11.07	0	0	0	11	*	*	0	11
12.07	0	0	10	2	133	61	143	63
14.07	1	7	5	1	46	21	52	29
17.07	0	0	1	1	8	18	9	19
20.07	1	11	14	0	45	2	60	13
21.07	0	0	6	2	49	5	55	7

Whilst snorkelling gave information on the number of observed fish downstream the trap, the counts were limited by visibility and relatively low spatial coverage of the total area downstream the trap. Taking these limitations into consideration, high fish counts below the trap indicates that there were high numbers of fish in the area, but on the other hand low counts wouldn't necessarily mean that there were low numbers of fish in the area. This is evident when comparing the snorkelling results with drone footage from the same days, e.g., July 11th, at least 152 fish can be seen in the middle channel whereas only 11 pink salmon were counted during the snorkelling.

Snorkelling along the fence revealed individuals of both pink salmon and Atlantic salmon seeking migration routes (openings) along the fence (**Figure 20**) as well as standing still below the fence. The snorkelling also revealed the presence of other species than just Atlantic salmon and pink salmon. During snorkelling, grayling, European flounder and brown trout were observed, and maybe the most interesting observation were pure schools of whitefish close under the fence (**Figure 21**).

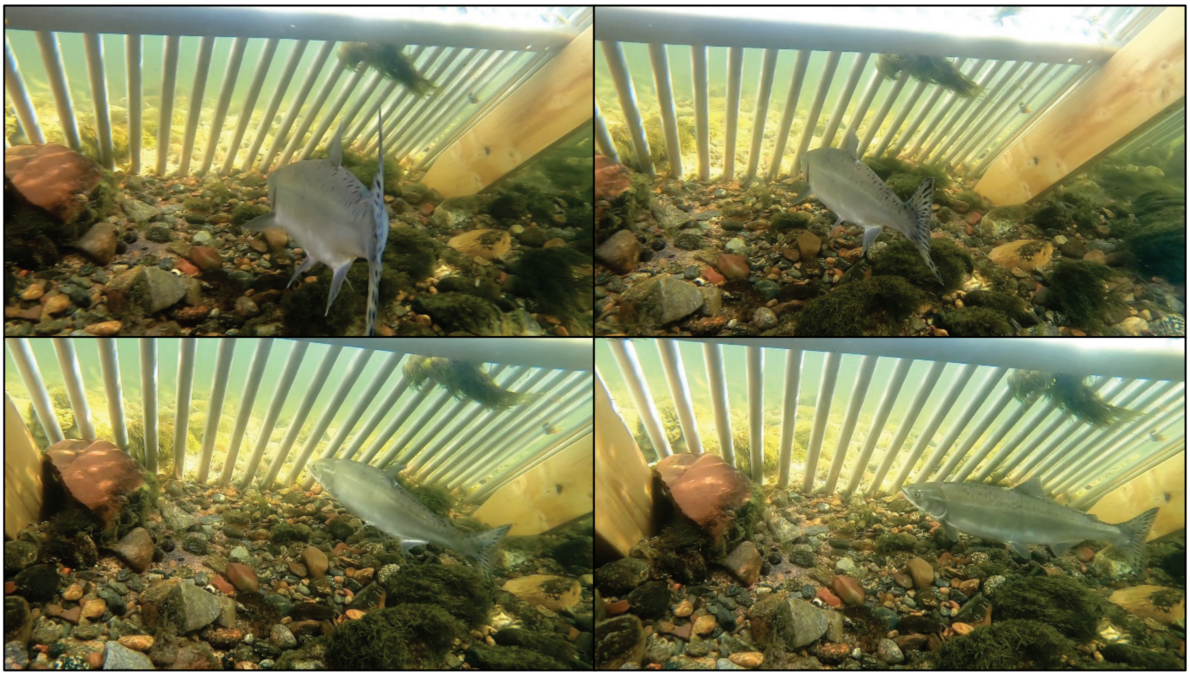

Figure 20. *Sequential series of pictures (from top left to bottom right) showing a pink salmon approaching and "prodding" the fence with its nose realizing the gap is too narrow. Pictures are taken on July 11th, 2023. Pictures: S. Domaas, NINA.*

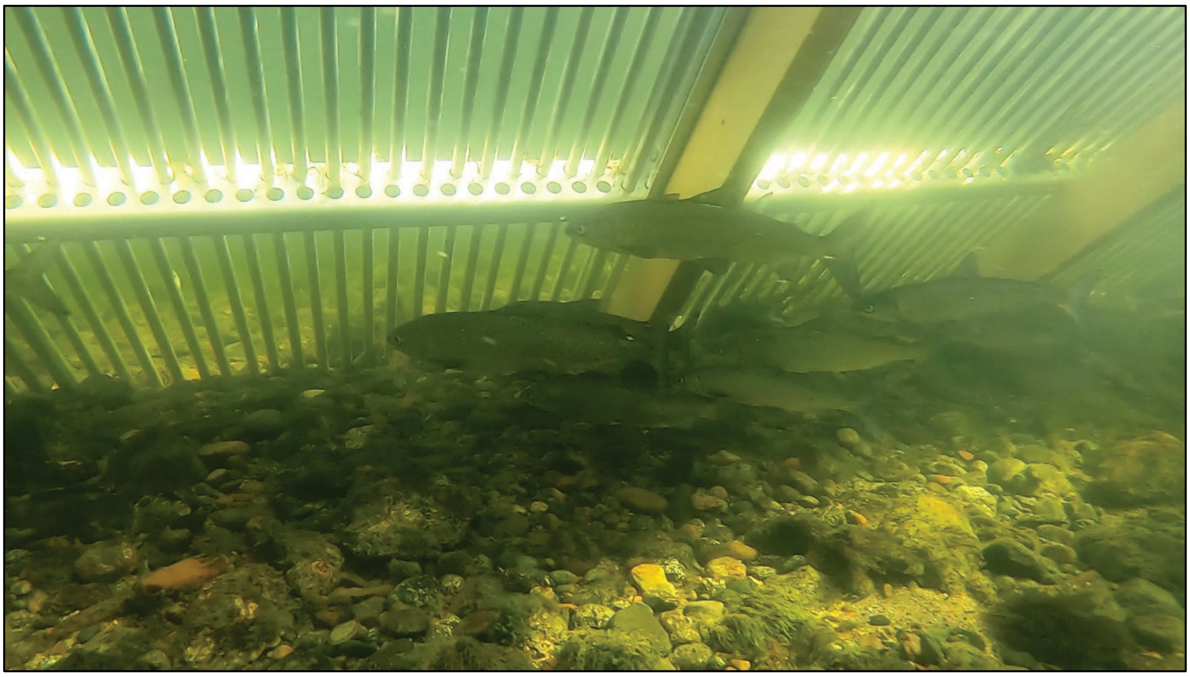

Figure 21. *A school of 12-15 whitefish observed under the trap on July 11th, 2023. Photo: S. Domaas, NINA.*

3.2.4 Fish behaviour at the flexible fence section in the eastern channel

Mixed schools with both pink salmon and Atlantic salmon were observed downstream the flexible fence section in the eastern channel, but not as frequent as below the solid fence section. This may likely be due to the flexible fence being in a shallower area close to the riverbank. Pink salmon were however observed swimming through the flexible fence (**Figure 22**) on multiple occasions during the periods the flexible fence section was monitored (**Figure 7**, area 2).

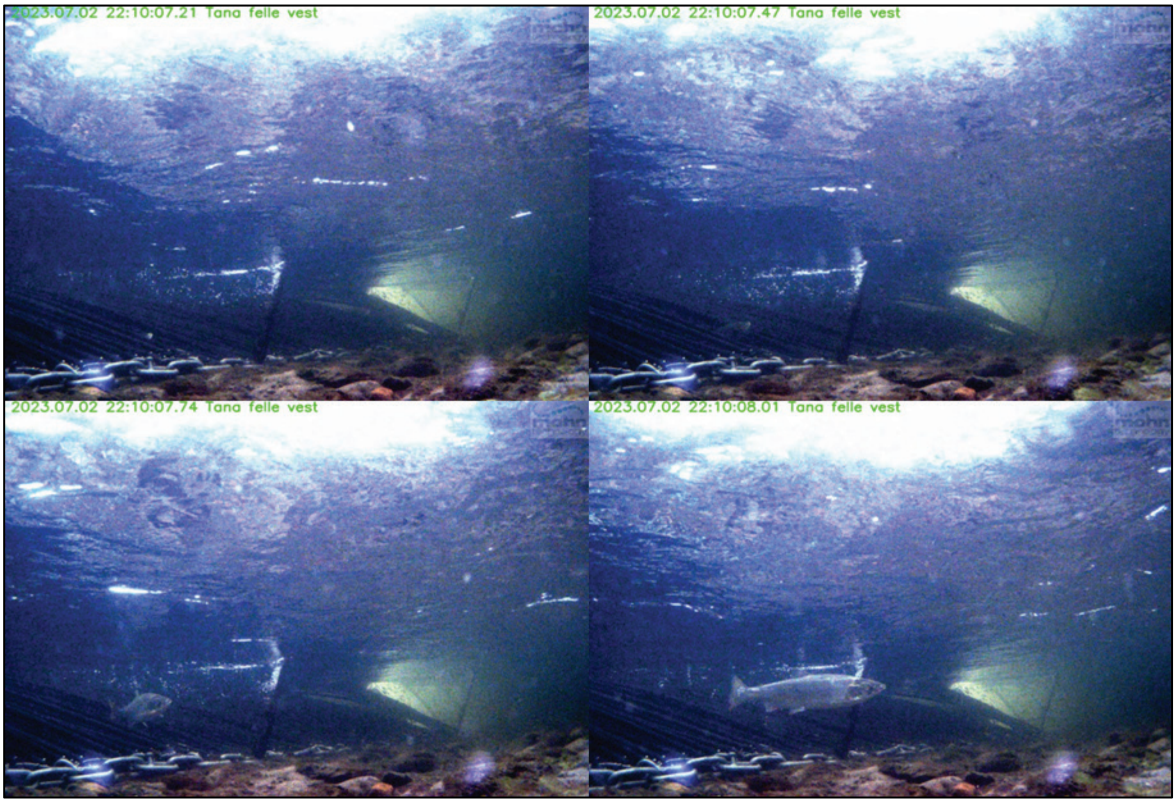

Figure 22. *Sequential series of pictures (from top left to bottom right) showing a pink salmon forcing its way through the flexible fence located in the eastern channel on July 2nd, 2023. The rigid fence can be seen in the background as a 'brighter' section in the continuation of the flexible fence. Pictures: Mohn Technology.*

3.2.5 Fish behaviour at bypass openings

As seen in **Table 3** the bypass opening was opened frequently throughout the whole trap operation period. In addition to the bypass opening there was an opening around the trap tunnel entrance whilst it was being adjusted on the 4th and 5th of July. The opening around the tunnel was monitored with an FRS-camera, and 32 fish were counted swimming up through the opening whilst one fish was counted going down during the period from 17:17 on the 4th to 08:15 the following morning. Six of the fish were identified as pink salmon, and judging from the size, schooling, and swimming behaviour of the remainder of the observations, they were likely pink salmon as well.

Table 3. *Overview of bypass periods, number of segments the opening consisted of (the number of aluminium frames removed, eventually from how many frames the aluminium tubes were removed from), used monitoring equipment to register passing fish, and analysis progress (percentage of the period analysed) on the respective monitoring equipment. NA = Not used/installed at location. The 30th and 31st of July and parts of the 1st of August was not monitored due to not knowing about the opening.*

Date	From	To	Segments	Sonar	FRS	Seavision
3.07	19:50	00:00	3	100 %	100 %	NA
4.07	00:00	18:00	3	100 %	100 %	NA
7.07	17:45	00:00	3	100 %	100 %	NA
8.07	00:00	17:00	3	100 %	100 %	NA
12.07	17:00	23:00	1	NA	100 %	NA
21.07	19:30	00:00	2	50 %	100 %	NA
22.07	00:00	09:00	2	50 %	100 %	NA
30.07	09:00	21:00	2	NA	NA	NA
31.07	09:00	21:00	2	NA	NA	NA
1.08	09:00	21:30	2	52 %	0 %	NA
2.08	08:40	21:30	2	97 %	0 %	0 %
3.08	09:00	22:10	2	65 %	0 %	0 %
4.08	09:10	22:10	2	100 %	0 %	0 %
5.08	09:00	22:20	2	0 %	0 %	0 %
6.08	14:20	22:10	2	100 %	0 %	0 %
7.08	12:30	22:30	2	0 %	0 %	0 %
8.08			0	0 %	0 %	0 %
9.08	17:20	00:00	2	0 %	0 %	0 %
10.08	00:00	09:30	2	5 %	0 %	0 %
11.08	12:30	22:30	2	0 %	0 %	0 %
12.08	09:00	21:00	2	0 %	0 %	0 %
13.08	09:00	21:00	2	0 %	0 %	0 %
14.08	09:00	21:00	2	0 %	0 %	0 %

3.2.5.1 3rd-4th and 7th-8th of July bypass

During the period from 19:50 on the 3rd to 18:00 on the 4th of July, and the period from 17:45 on the 7th of July to 17:00 on the 8th of July, three sections of the trap were completely removed as seen in **Figure 23**.

Figure 23. *The bypass opening made by removing three sections of the fence for the bypass of Atlantic salmon and other native species on the 3rd and 4th of July 2023. On the picture we see the tail of a pink salmon and an Atlantic salmon following closely behind. Photo: Mohn Technology.*

From the 3rd to the 4th, a total of 965 fish were counted migrating up through the bypass opening, whilst on the 7th to the 8th 986 fish were counted migrating up and 65 migrating down. Common for both periods seem to be that fish preferred to go through the opening during late evening/early night (**Figure 24**).

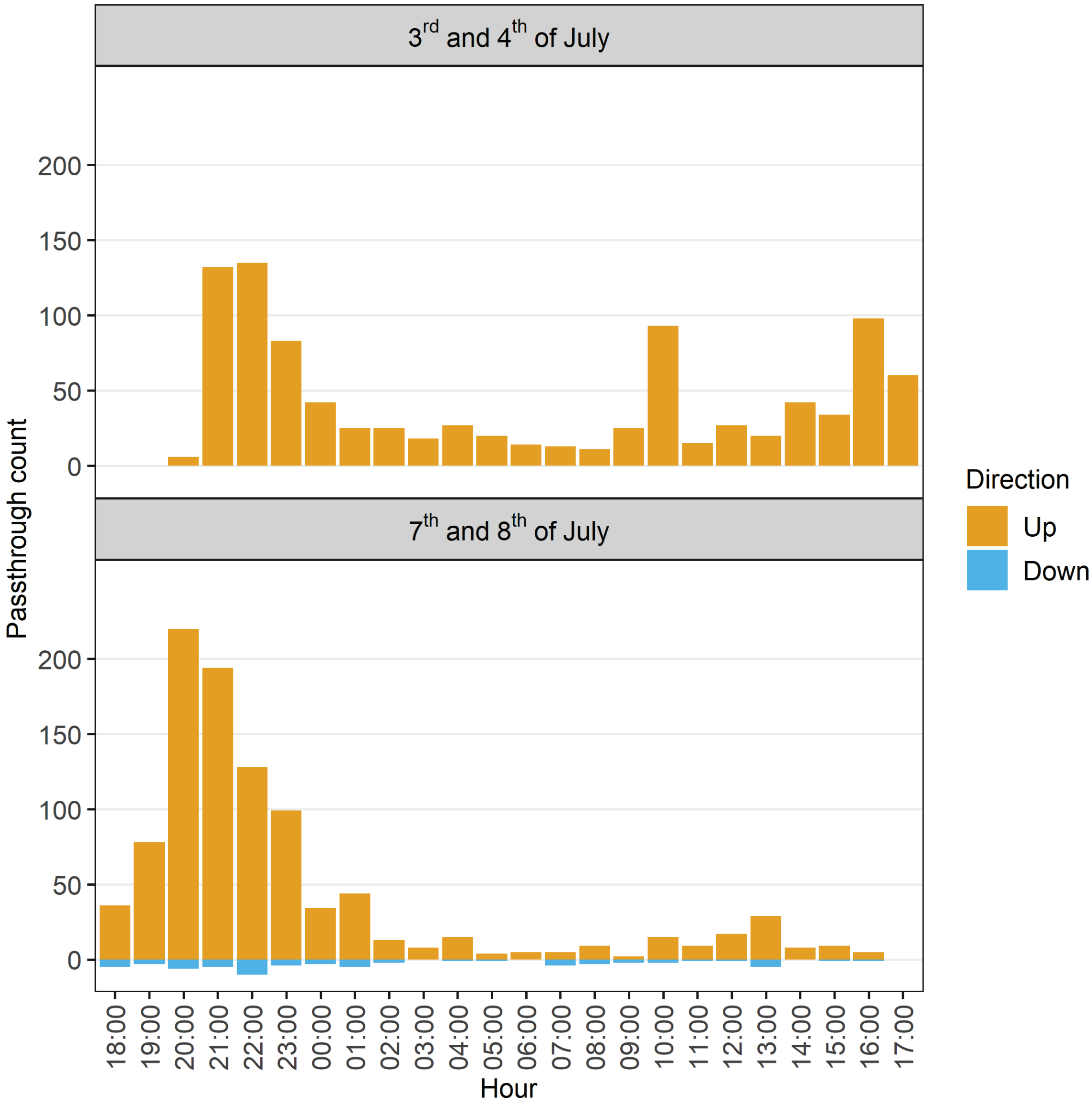

***Figure 24.** Overview of hourly counts through the bypass opening on the 3rd-4th and 7th-8th of July 2023. X-axis: hour of the day (be aware of the date change at 00:00 and its placement on the axis). Y-axis: counts of up (above 0) and down (below 0) migrating fish. In the first period only upstream migrating fish were included in the count. The highest number of down migrating fish counted in a single hour in the second period was ten.*

Although the intention of the bypass opening was to let Atlantic salmon and sea trout pass the trap, the species distribution of the fish passing the trap suggests that as much as 69 % of the fish passing in the first period (3rd-4th of July) were pink salmon, whilst Atlantic salmon and other species accounted for 29 % and 2 % respectively. The same numbers for the second period (7th-8th of July) was very similar with values of 65, 32 and 3 % respectively. And although fish were observed swimming through the bypass opening, it was evident that most Atlantic salmon held back when reaching the fence structure rather than swimming straight through the bypass opening (**Figure 25**).

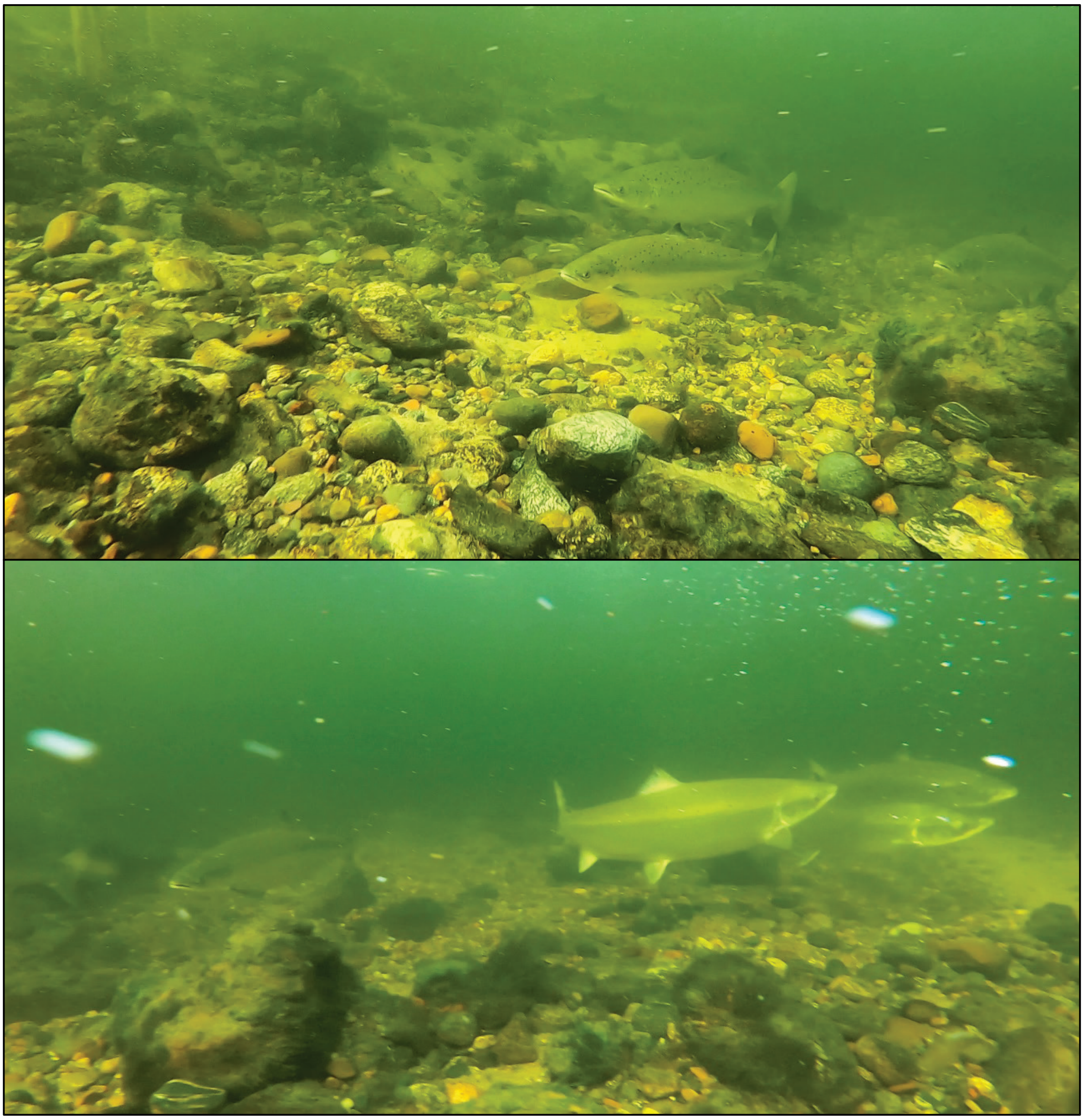

***Figure 25.** Pictures showing a gathering of Atlantic salmon directly downstream of the bypass opening on July 8th, 2023. Pictures: S. Domaas, NINA.*

3.2.5.2 The 12th of July bypass

During July 12th the aluminium poles from one section were removed to create the bypass opening as seen in **Figure 26**. This period was monitored using an FRS camera, giving a count of 53 fish migrating up (unable to identify to species due to challenging light conditions), 4 fish migrating down where two of them were whitefish, and 28 fish swimming upstream the fence (three pink salmon, ten graylings and one whitefish, and the rest unidentified).

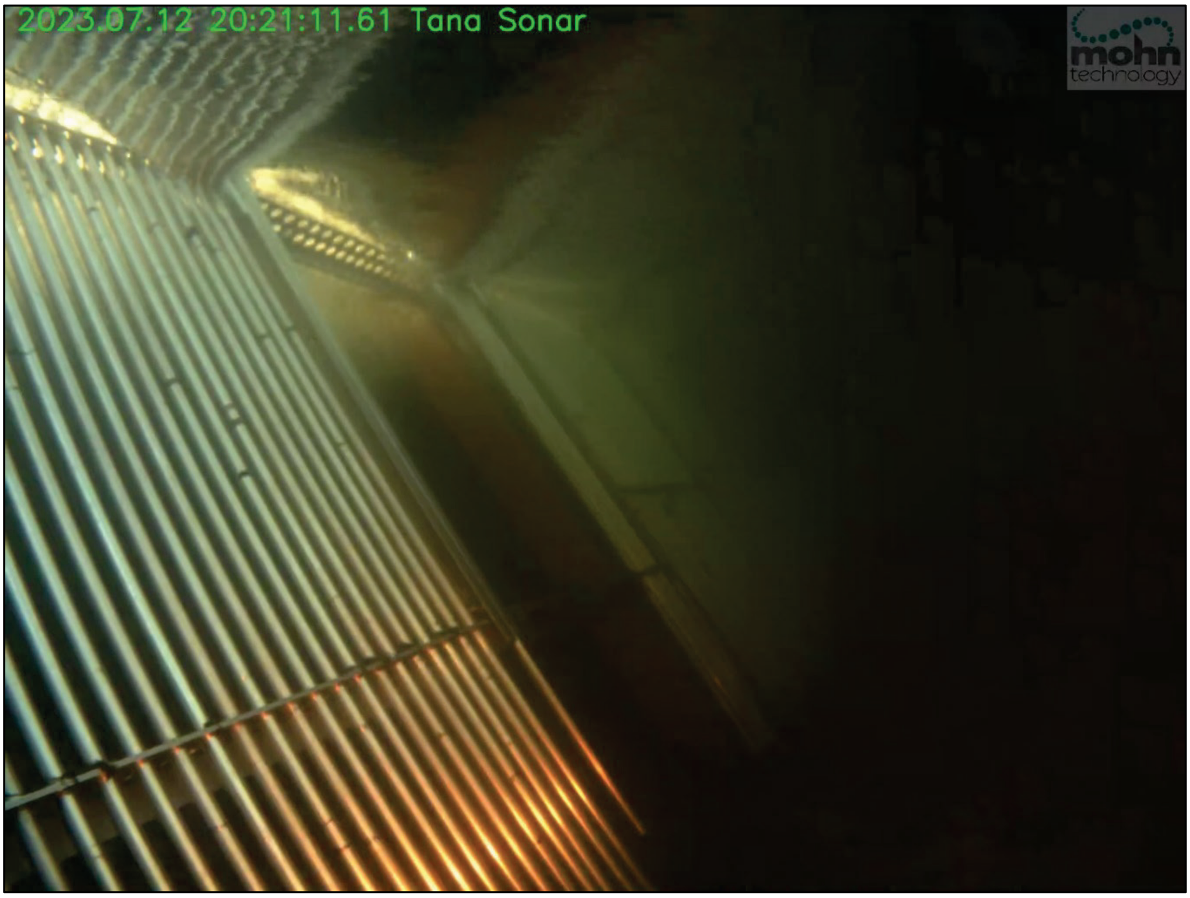

Figure 26. *The bypass opening made by removing the aluminium poles from one section of the fence for the bypass of Atlantic salmon and other native species on July 12th, 2023. Photo: Mohn Technology.*

3.2.5.3 The 21st and 22nd of July bypass

During the period from 19:30 on July 21st to 09:00 on July 22nd, aluminium poles from two sections were removed to create an opening as seen in **Figure 27.** Sonar data from every other hour from the bypass period gives an estimate of net up migration of 20 fish, whereas the FRS data gives a species distribution of 57 % pink salmon, 29 % Atlantic salmon and 14 % trout. From the sonar data we can see fish of all size classes below the fence, and whilst smaller fish swum through the opening, the bigger fish were more reluctant and did not. Further analysis revealed that 88% of the fish swum under the frame whilst the rest swum through it.

Figure 27. The bypass opening created by removing the aluminium poles from two aluminium frames for the bypass of Atlantic salmon and other native species on July 21st and 22nd, 2023. Photo: Mohn Technology.

3.2.5.4 The August openings

Onwards from July 30th two segments of the fence were opened almost daily for variable periods, mainly from 9 to 21 (**Table 3**). Sonar data from August 1st to 4th as well as August 6th was analysed, giving a total of 2 195 fish migrating up and 113 fish migrating down. The daily counts varied from 212 (August 6th) to 703 (August 3rd) fish, and variations were also seen between hours.(**Figure 28**). In the hour before, or in the same hour as the bypass opening was opened, it was clear that fish had accumulated downstream the fence (**Figure 29**). The sonar data also showed that the immediate response to the workers nearing the opening was for fish to clear the area (also visible in **Figure 29**). When fish were passing, large, tight schools were observed to pass through the opening. Larger individual fish, presumably salmon were also passing through (i.e., **Figure 30**), but these larger individuals were most often observed standing still or moving back and forth below the fence without going through the bypass opening. In August the number of downstream passing fish increased. These fish were mainly small sized and presumably stationary grayling or pink salmon.

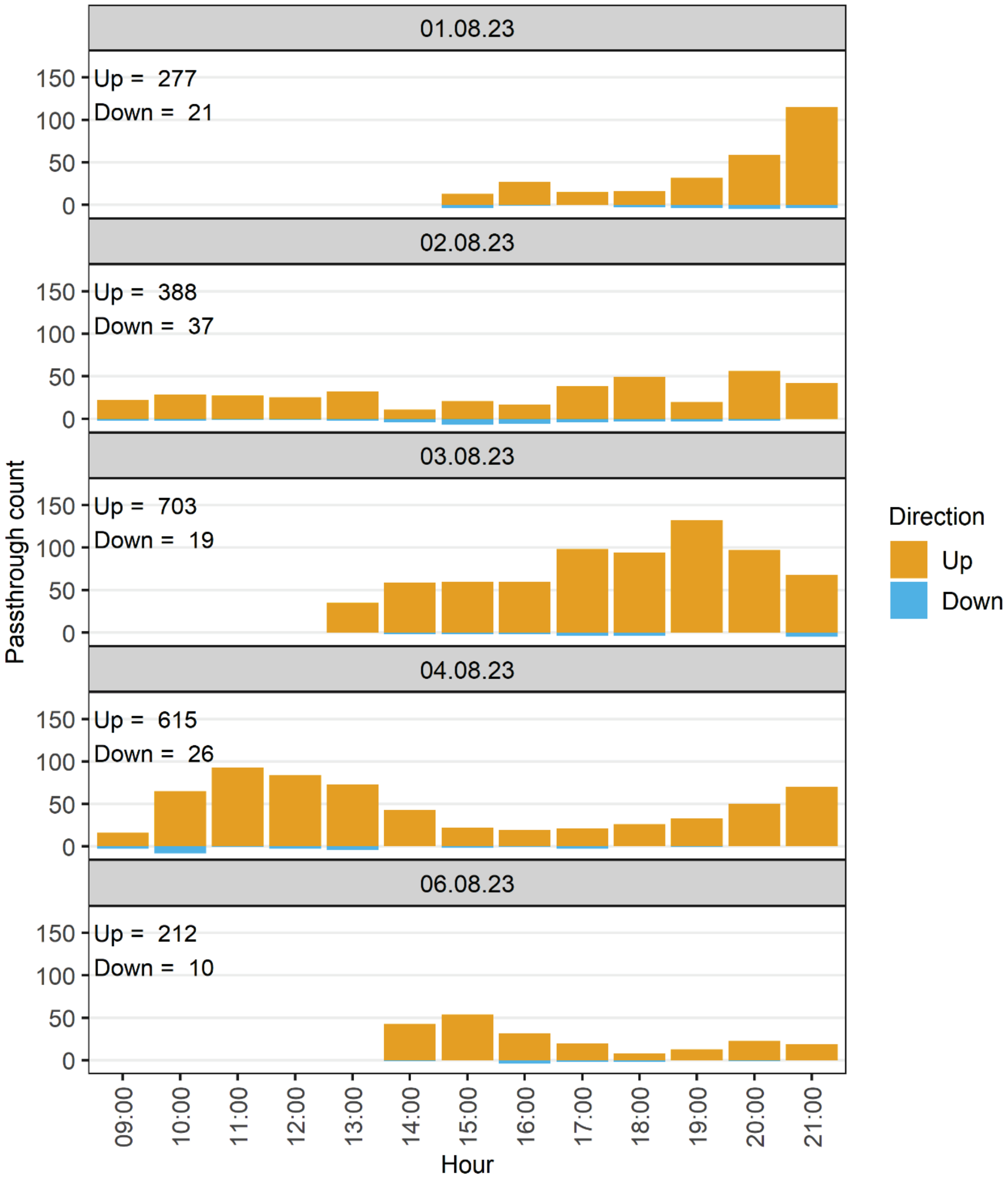

Figure 28. *Overview of hourly counts through the eastern fence bypass opening on the given dates (header). X-axis: hour of the day. Y-axis: counts of up (above 0) and down (below 0) migrating fish. 'Up' and 'Down' gives the total counts for the given dates.*

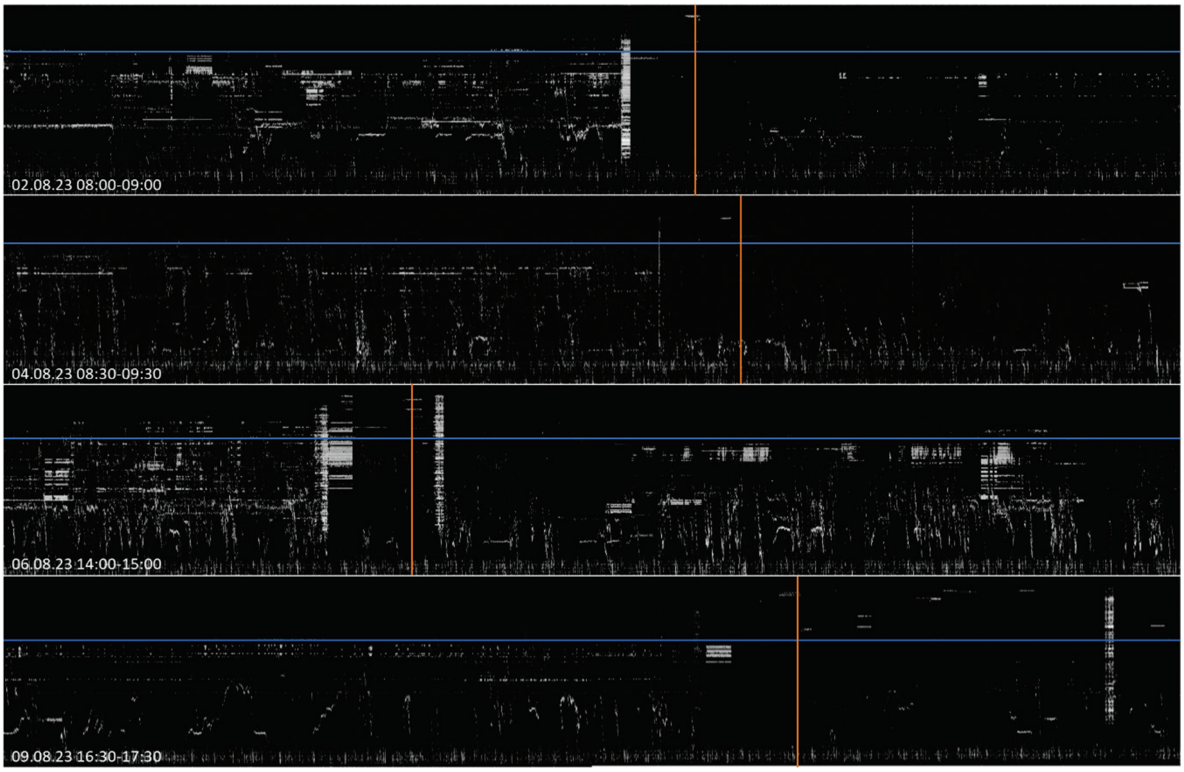

Figure 29. *Sonar (ARIS) echograms from the area below the bypass opening in the period immediately before and after the bypass opening was opened on the 2nd, 4th, 6th and 9th of August (lower left corner of echograms). In each echogram the y-axis represents the distance from the sonar and the x-axis represents time (each echogram is 60 minutes long). Blue horizontal lines indicate the 10-meter distance from the ARIS, which is the distance from the ARIS to the bypass opening. The orange vertical lines represent the approximate time the opening was completely open (all aluminium poles removed from the two sections). The white streaks seen in the echograms are primarily fish, meaning more white streaks in the echogram = a higher abundance/activity of fish in the area. The abundance or activity of fish in the area decreased in the period immediately after personnel from the trap operation team came to open the bypass opening.*

Figure 30. *Sequential series of pictures (from top left to bottom right) showing a large salmon, measured to 98 cm on the sonar, making its way through the bypass opening on August 5th, 2023. As we can see, the aluminium frame did pose as a challenge, requiring some agile swimming from the larger salmon to pass under it.*

3.3 Ascending fish in the western river channel

3.3.1 Fish numbers and behaviour at the flexible fence

Large amounts of fish in all size classes were observed downstream to the western fence on multiple occasions. The first drone footage was made on June 30th, and is not comprehensive for the area. At least 70-100 fish, many of them too large to be pink salmon, can be discerned in the videos. Next drone footage was made on July 4rd, this time also covering only parts of the river channel width. Still, more than 125 fish, many of them large, were seen downstream to the fence. Drone footage from July 7th cover areas very close to the fence, and reveals more than 150 fish. On July 9th, 400-500 fish could be seen on a larger overview of the flexible fence and the downstream area (**Figure 31**). For the next days no overview of the area were available, but 200-300 fish could be seen close to the fence on July 12th. By July 17th, numbers close to the downstream side of the fence were 50-100, and by July 20th numbers close to the fence were apparently 30-50 fish, but higher water level and poorer water transparency made counting more difficult. Similar numbers were observed on July 27th and 28th, which were the last days with drone footage available.

Although the area coverage was only partial for most of these days, the numbers reveals a pattern of increasing fish numbers from Jun 30th to July 9th downstream to the flexible fence in the western river channel, whereafter the fish numbers in the area decreased. Fish numbers on the downstream side were always many times as high as numbers on the upstream side, indicating a hold-back effect. As observed for the eastern river channel, fish were observed holding position both close to, and far downstream to the flexible fence. The observed holding behaviour was every now and then broken up by highly active swimming, potentially as a result of aggressive behaviour. Some fish with wounds were observed, but we cannot know if these were acquired before the fish arrived the area. Moreover, both fish schools and single fish were observed searching along the fence, apparently looking for bypass opportunities. Although this rarely led to fish intrusion through the fence, it sometimes did (**Figure 32**). The share of large fish (thus not pink salmon) was higher in the beginning and end of the period with drone footage than at the peak of fish abundance around July 9th-12th, potentially indicating that pink salmon left the area faster than Atlantic salmon. On July 20th and July 23th 19 fish were observed on the Seavision cameras swimming through the flexible fence each day. Some additional fish were observed coming into the video frame from a direction suggesting that they also swam through the fence, although the fence itself was not visible at this angle. If each of the camera covered approx. 2-3 m, the four camera together covered around 5% of the river channel width of about 200 m at the flexible fence. Scaling fish numbers observed traversing the fence up to full river width reveals a daily fence traversal by fish on the scale of 400 fish for each of these two dates, but we don't know how representative the observe numbers were for the other parts of the flexible fence.

Figure 31. *Drone footage showing hundreds of fish gathered downstream to the flexible fence in the western river channel at the northern end of the Seidaholmen, on July 9th, 2023. Blue arrows indicate flow direction in the pictures. The fish are visible as darker lines against the bright sand. In the big photo we can roughly 300 fish, many of these relatively close to the fence, but as indicated by the zoomed in picture showing the (approximate) area in top left corner of the big photo, there were many fish concentrated into small areas further downstream as well. Another large concentration of more than 100 fish was also found further west in this video. The counting of fish in parts of the picture area was made in more zoomed-in videos. Photos: Joachim Henriksen, Tana.*

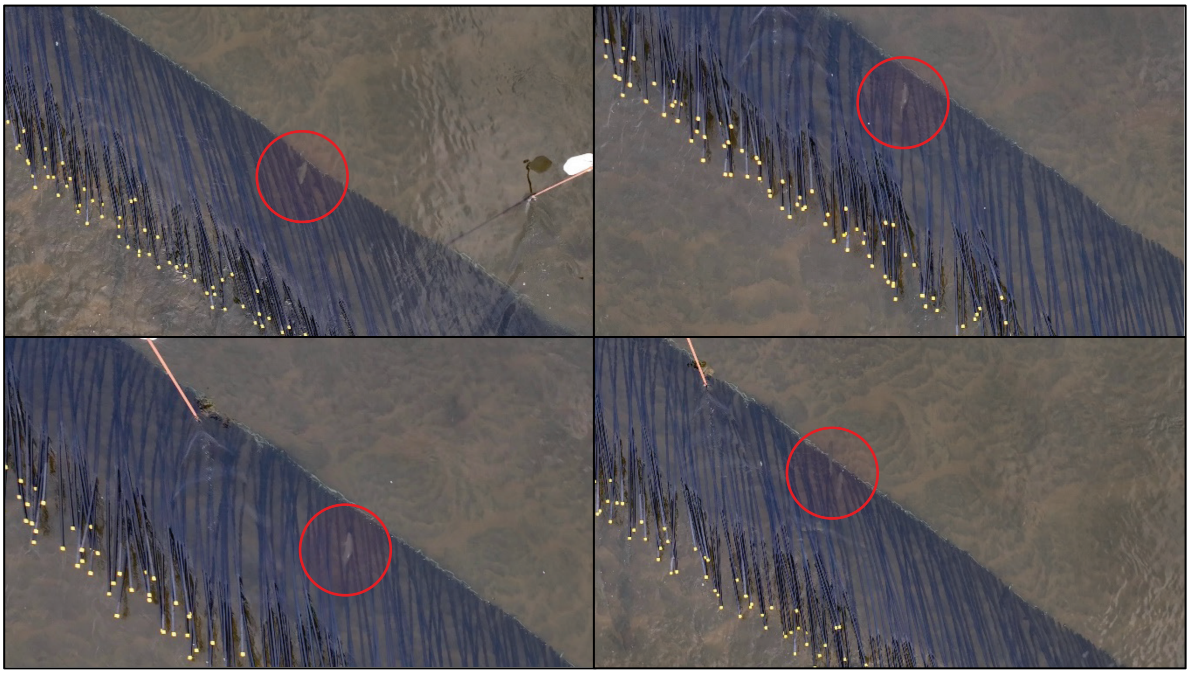

Figure 32. *Drone footage, from top left to bottom right, showing a total of five fish (circled), possibly pink salmon, swimming through the flexible fence spanning the western channel at Seidaholmen within a 15 second time window on July 11th, 2023. Photo: Joachim Henriksen, Tana.*

3.3.2 Migration up the western channel

The monitoring done with the DIDSON and an FRS camera in the southern end of the western channel (see **Figure 10**) revealed considerable numbers of fish migrating up the western river channel. These fish must have passed the flexible fence further downstream in the western channel, which indicates that the western channel flexible fence was heavily leaking. During the peak migration days (12.07-14.7.2023), just after installing the monitoring equipment, thousands of fish were counted migrating up past the location (**Figure 33**). Migration activity, however, decreased quickly within a few days, with a net up migration estimate of 1 548 fish on July 15th and a daily net up migration average of just 140 fish from July 16th to July 25th.

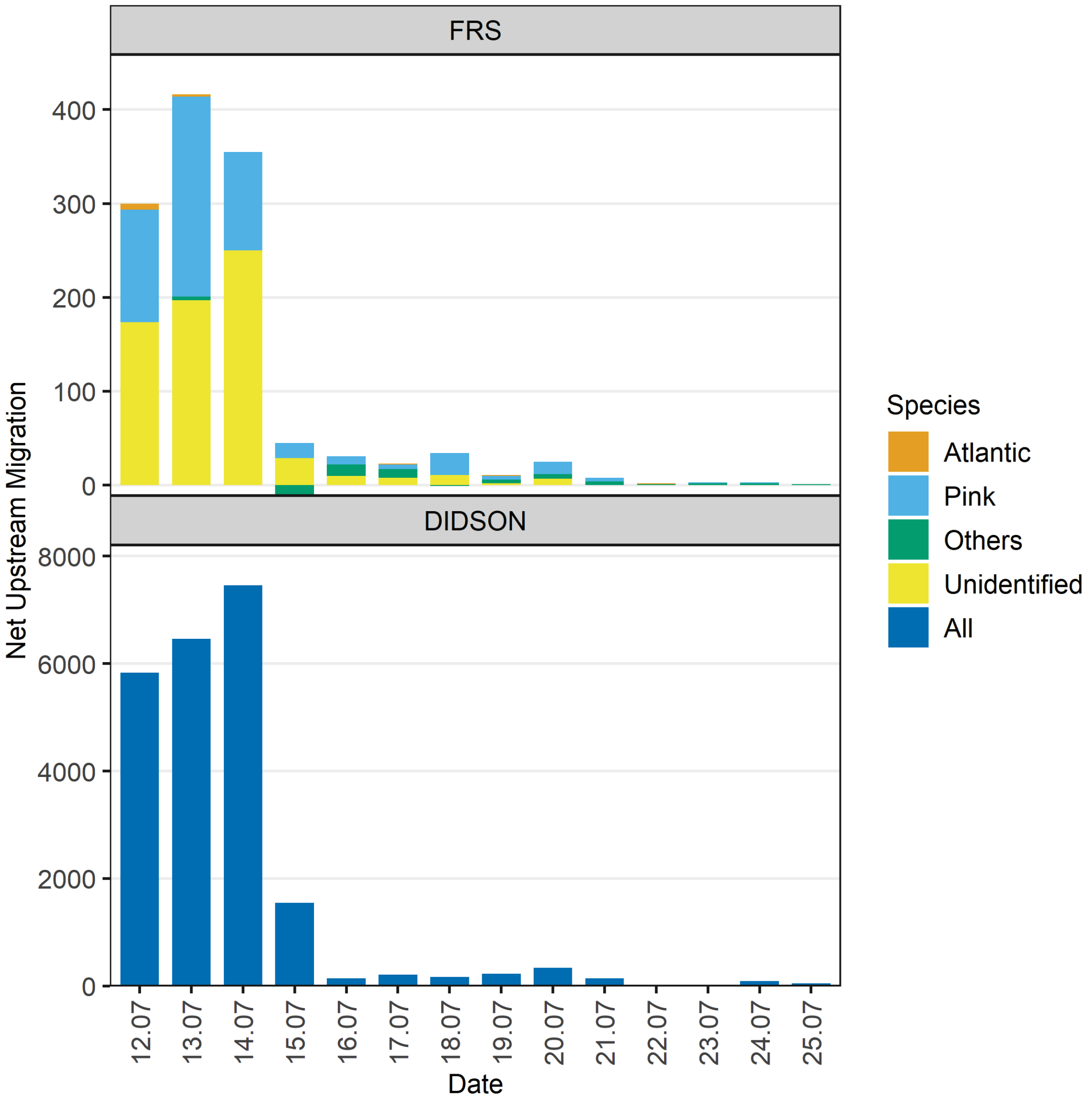

Figure 33. *Net ascending fish counts by the FRS camera (upper graph) and the DIDSON sonar (lower graph) in the western channel (west of Seidaholmen) during the period 12.07-25.07.2023. Following days are estimates based on counts with partial temporal coverage: July 12th FRS and DIDSON 15%, July 13th DIDSON 50% (11:27-24:00), July 15th DIDSON 67% (all even hours and the four first odd hours of the day), July 19th DIDSON 88 % (all even hours and the first nine odd hours), July 20th-22nd DIDSON 50% (all even hours), and July 23rd DIDSON 25% (00:00-02:50 and 21:05-24:00). Be aware of different scales on the y-axis on the two graphs. On July 15th there was a net-downstream movement of 11 fish in the 'other' category registered on the FRS-camera, whilst it on July 18th was a net-downstream movement of one fish in the same category, on all other days the net-upstream migration was zero or higher for all categories.*

Further, the species data gathered with the FRS-camera suggests a species distribution of 90 % pink salmon, 2 % Atlantic salmon, and 8 % other species, in the period July 12th to July 25th. That means that for every Atlantic salmon identified throughout the analysed period, on average, 44 pink salmon were identified migrating up past the monitor location. However, there is an uncertainty in whether the species distribution among the species-identified observations are representative for the sonar observations.

Also, worth keeping in mind, is that the above-mentioned fish numbers are based on what passed within the 20-meter-long sonar window, meaning that the DIDSON, at most, covered about 1/4 of the western channel's width, which at the lowest discharge levels was about 80 meters. At slightly higher discharge levels the small island that was there during the lowest discharges became flooded, and the total width of the western channel increased to approx. 220 meters, meaning the sonar would cover less than 1/10 of the channel width. Even a conservative spatial upscaling of four times would mean a quadrupling of the sonar counts, giving an estimate in the order of 91 000 ascending fish, or 82 000 pink salmon during the monitoring period.

3.4 Ascending fish numbers at Polmak, Anárjohka and Kárášjohka

3.4.1 Polmak

Sonar monitoring of ascending fish numbers have been conducted since 2018 in Polmak by Luke (Anon. 2023), approx. 55 km from the river mouth and 20 km upstream from the Seidaholmen trapping site. The count in 2023 was performed in good environmental conditions in the period from May 30th to August 31st. For species discrimination purposes four underwater cameras were also used in the sonar window in the period from May 31st to August 31st.

The run estimate of ≥ 40 cm fish was 142 000 individuals based on sonar counts (**Figure 34**), before school density correction (see further below). The majority (92%) of fish belonged to size groups 40-50 cm and 50-65 cm. The first peak in up-migrating fish was observed in late-June, the highest peak during the period from July 10th to July 15th, and the last peak in early August (**Figure 34**).

Based on the sonar counts and species proportions from the video data, the run size of Atlantic salmon at Polmak was estimated (preliminary estimate, analyses have not been fully completed) to be approx. 19 000 individuals and the run size of pink salmon approx. 120 000 individuals. The first pink salmon were observed in Polmak on June 18th, but their numbers started to increase on June 23rd.

In the case of the pink salmon the video data revealed a significant underestimation of pink salmon numbers from sonar data. This underestimation was caused by pink salmon swimming in large and dense schools that were not possible to count precisely from the sonar images (**Figure 35**). When using school size correction factor derived from the underwater video data combined with synchronous sonar data analyses, the pink salmon run estimate past Polmak was in the order of 170 000 individuals in 2023.

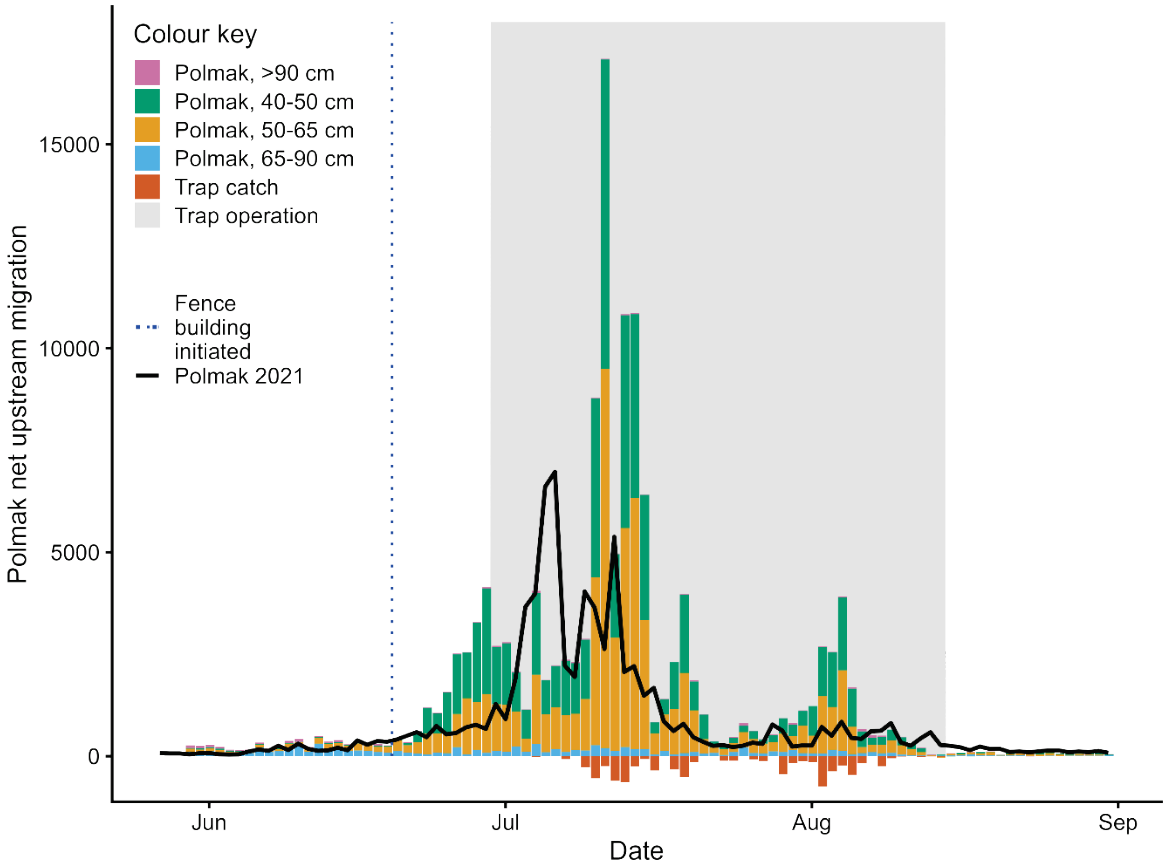

Figure 34. *Daily counts (net upstream) of fish in four size categories based on the Polmak sonar monitoring 30.5.-31.8.2023, combined with daily trap catches at Seidaholmen as negative counts. For comparison, daily counts at the Polmak sonar from 2021 (all size groups >45 cm) is shown with a black line. The start of the fence building at Seidaholmen is indicated by the blue vertical dotted line, and the grey-shaded area indicates the period of trap operation.*

Figure 35. *Still image from an underwater camera installed to Polmak sonar counting window indicating pink salmon schooling behaviour. The schools were large and dense compared to schools of Atlantic salmon. Photo: Panu Orell.*

3.4.2 Comparison between Polmak and Seidaholmen, western channel

Results from several of the different monitoring methods can be compared to evaluate how well the estimates agree. The FRS-camera in the western channel at Seidaholmen (**Figure 10**) had a very low range, probably between 1-2 m for the AI to recognize fish. For the sonar, the 20-meter sonar window (range: 2.5-22.5 m) was much higher. Still, there was a very strong correlation between the FRS counts and the sonar counts (**Figure 36a)**. Linear regression (R^2 = 0.96) indicated a highly significant relationship for the regression slope ($P_{slope=0}$ <<0.001). We don't know how much time pink salmon and Atlantic salmon spend on the 20 km migration from Seidaholmen to Polmak, but it is very clear that the Polmak sonar counts correlate to the Seidaholmen western channel sonar counts for the corresponding dates (**Figure 36b**). Linear regression also indicates a highly significant relationship between the Seidaholmen western channel sonar counts and the Polmak sonar counts (R^2 = 0.80, $P_{slope=0}$ << 0.001). Assuming that the migrating fish spread randomly across the river channel cross-section, as supported by the strong relationship between FRS counts and sonar counts with very different observation range, the daily counts from the 20 m sonar window were multiplied by 4 to scale up to net daily upstream migration estimates. This revealed a close to 1:1 relationship between the Seidaholmen western channel migration estimates and the Polmak estimates for most dates (**Figure 36c**). This indicates that the high number of migrating fish observed at Polmak passed Seidaholmen through the flexible fence in the northern end of the western channel.

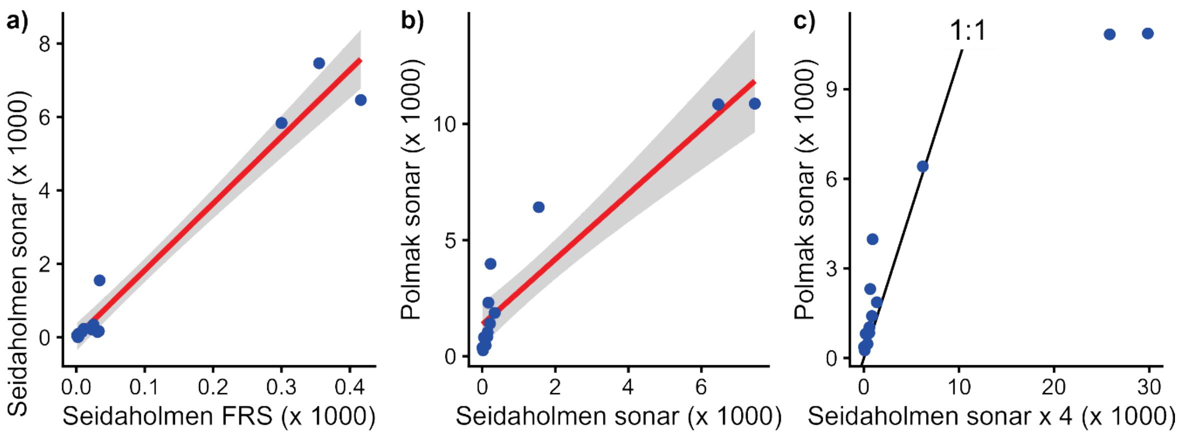

Figure 36. *Comparison of FRS to DIDSON sonar in the Seidaholmen western channel (a) and DIDSON sonar in the Seidaholmen western channel with Polmak sonar (b and c) for the period 12.07-25.07.2023.* ***a)*** *Comparison between daily net upstream migration estimates at Seidaholmen as assessed by the FRS-camera and by the DIDSON sonar. Blue dots represent daily estimates, numbers in thousands. Red line indicates linear regression line with 95 % confidence interval indicated by grey shading.* ***b)*** *Comparison between daily net upstream counts as assessed by the DIDSON sonar in the Seidaholmen western channel with net upstream migration assessed by sonar at Polmak. Blue dots represent daily estimates, numbers in thousands. Red line indicates linear regression line with 95 % confidence interval indicated by grey shading.* ***c)*** *Same figure as in b, but with Seidaholmen net daily upstream migration estimates obtained by daily counts multiplied by 4 to scale up from 20 m analysis range to 80 m river channel width. The black line indicates line of unity, i.e., the numbers observed at Polmak would be the same as the numbers observed at Seidaholmen, western channel.*

3.4.3 Kárášjohka and Anárjohka

The net upstream migration in the Kárášjohka and Anárjohka tributaries was assessed by sonar monitoring combined with underwater video for species discrimination. The species composition difference between the two tributaries was large (**Figure 37**). Whilst there was a strong dominance of Atlantic salmon and few pink salmon in Kárášjohka, there were much more pinks, as well as more individuals from other species, in Anárjohka. The first pink salmon appeared in Anárjohka on June 23rd, and in Kárášjohka on July 1st. In Kárášjohka, a total of 370 pink salmon passed the sonar counting site on upstream migration, but there was some traffic back and forth and some may have been counted several times as the net upstream counts for pink salmon was 133. However, quite a few pink salmon heading downstream were observed during August, presumably many of these had already spawned. The pink salmon counts in Anárjohka were more than tenfold higher than Kárášjohka, with a gross upstream migrating pink salmon count of 4 759. Again, there was substantial fish movement up- and downstream at the monitoring site, resulting in a net upstream count of 3 805 pink salmon. Some of the downstream migrating pink salmon were clearly spent and dying.

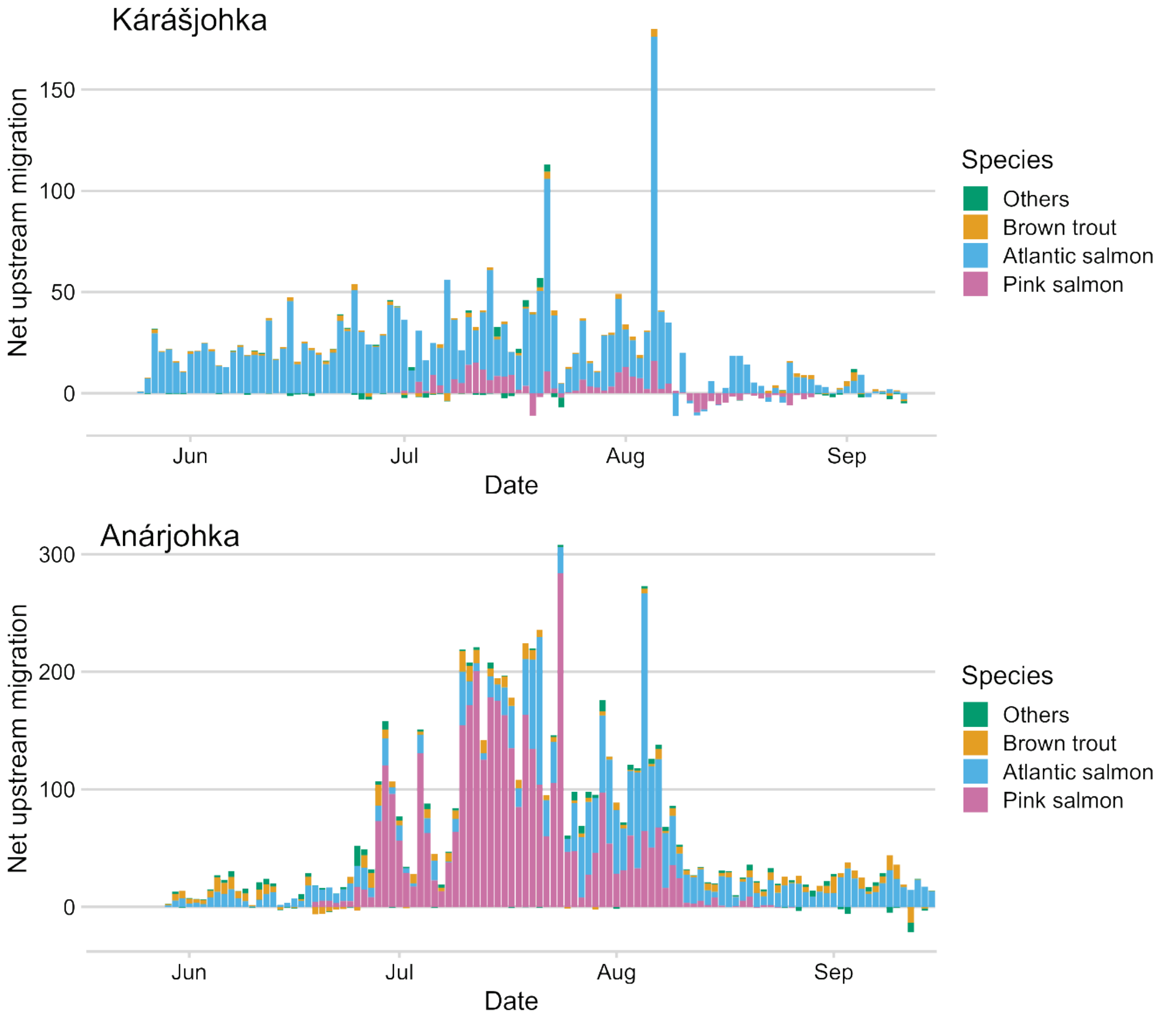

Figure 37. *Net daily upstream migration at the monitoring localities in Kárášjohka and Anárjohka, 2023. The species proportions were assessed using 4 underwater video cameras at each monitoring locality. Counts of downstream migrating salmon and brown trout >45 cm before July 1st were removed before calculating net upstream migration, as these were considered to be kelts ("støing") and hence could mask the counts of early migrating spawners. Further details and results from the Kárášjohka and Anárjohka 2023 monitoring sites will be given in a separate report (see also Domaas et al. 2024).*

As observed in Polmak, there was a reduction in daily counts of upstream migrating fish both in Kárášjohka and Anárjohka in early July, with a following large increase in fish numbers by mid-July dominated by pink salmon (**Figure 37**). Few Atlantic salmon reached Anárjohka and Kárášjohka during the first half of July (**Figure 37**, **Figure 38** and **Figure 39**).The cumulative upstream migration to Kárášjohka and Anárjohka by Atlantic salmon ≥65 cm in July and August is shown in **Figure 39**, compared to previous year as well as to water discharge measured at Polmak. June is excluded, since salmon reaching Anárjohka and Kárášjohka by June had passed Seidaholmen before the trap interception. Fish ≥65 cm are almost exclusively Atlantic salmon (Domaas et a. 2024), smaller fish were excluded in order to avoid uncertainties about the species composition. The cumulative upstream migration of Atlantic salmon in the first half of July was the lowest observed in any of the monitoring years, the same goes for the water discharge levels in first half of July (**Figure 39**).

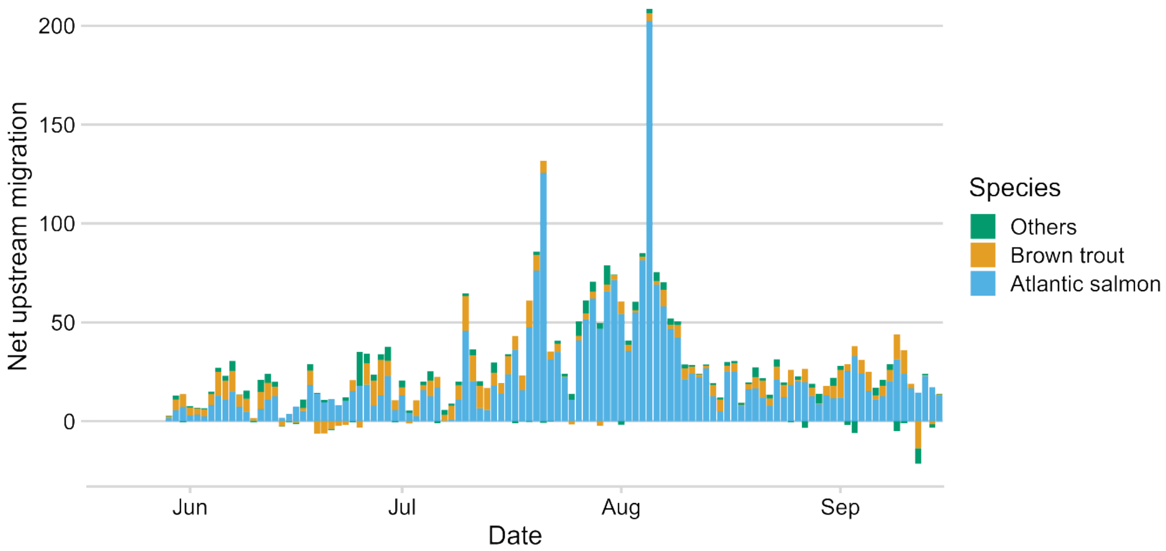

Figure 38. *Same counts as in* ***Figure 37*** *(Anárjohka) but excluding pink salmon to better see the pattern of other fish migration.*

3.5 Fish trap catch efficiency

Our observations show that a much higher number of fish passed Seidaholmen in the western channel than were caught in the trap. Some fish also passed through the flexible fence in the eastern channel, as well as through the bypass openings in the rigid fence opened to let Atlantic salmon and trout pass upstream. After initial modifications of the trap entrance, the trap was in operation from July 5th to August 14th. During this period, a total of 7 666 fish were caught in the trap. During the corresponding period, the net upstream migration estimate (without school size correction) at the Polmak monitoring site was 108 700. This gives a trap catch efficiency of at most 6.6%. The river between Seidaholmen and the Polmak monitoring site has multiple spawning sites (Johansen et al. 2021) where an unknown fraction of pink salmon that passed Seidaholmen likely spawned. During a helicopter survey at this stretch 29th of July, at least 750 pink salmon were observed in this river section (Pierre Fagard, TF, pers. Comm.). Some additional pink salmon may have ascended Polmak river, however we do not have indications that a large fraction of the pink salmon that passed the fences at Seidaholmen spawned downstream to

Polmakholmen. The largest pink salmon aggregations were observed in the Sirbmá area and on the river stretch between Utsjoki and Borsejohka.

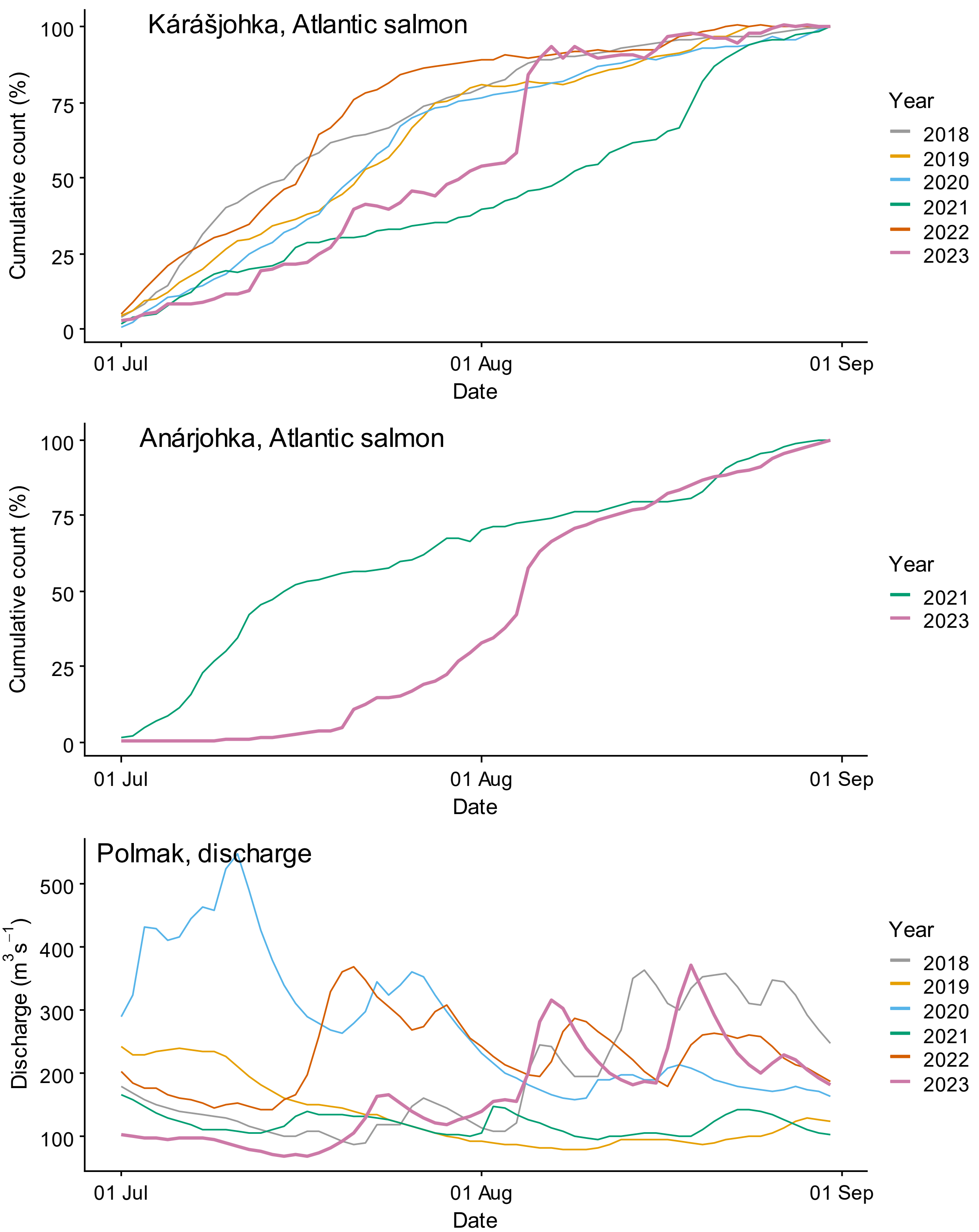

***Figure 39**. Cumulative counts of Atlantic salmon ≥65 cm length in Kárášjohka, years 2018-2023 (upper), Anárjohka years 2021 and 2023 (middle), compared to daily mean discharge at Polmak (lower) in the period from 1. July to 1. September.*

4 Discussion

4.1 Downstream migration

The installation of guiding fences both in the eastern and western channels had an immediate effect on smolt migration behaviour. Smolts were observed swimming along the aluminium fence already during the installation, although the spacing between the aluminium bars was sufficient to let smolt through unharmed. In the western channel, schools were observed swimming along the fence shortly after the fence was completed and in front of the FRS-camera installed in the opening made for downstream migration. Moreover, observations from the different monitoring surveys conducted at Seidaholmen trap-fence system and other on-site observations clearly indicated that the Seidaholmen fence systems slowed down the downstream migrations of both smolts and kelts that had not passed before the fence installation. The alternative hypothesis would be that these fish would stop in the area anyway, which we are not aware of any support for. Whereas smolt schools swam relatively close to the fence and were frequently observed on the FRS-camera for the downstream migration solution, kelts seemed to keep somewhat more distance to the fence. Whereas the tail of a kelt was seen every now and then by the FRS-camera at the opening for downstream migration, kelts were not observed moving through this opening in the fence.

Smolts, on the other hand, were observed to pass through the opening intended for downstream migration. But many schools passed back and forth along the fence for quite some time, seemingly rather cautious and hesitating to pass through it. As soon as one smolt decided to swim through, the rest of the group usually followed. The overall low numbers of fish passing through the opening for downstream migration indicate that most smolts and kelts likely have passed Seidaholmen trough the fences elsewhere. Both smolts and kelts would be able to swim trough the flexible fences without harm.

Delays caused by human-made structures during downstream migration can cause significant problems to fish (Aarestrup & Koed 2003, Marschall et al. 2011, Thorstad et al. 2012). Firstly, timing of smolt migration is likely evolved to ensure that the fish reach its marine feeding grounds at optimal times when suitable food resources are readily available and environmental conditions are favourable (McCormick et al. 1998). Delays in arrival can result in reduced growth and elevated mortality rates. Secondly, the extended time spent in rivers increases the energy expenditure of fish and may expose fish to predation which increases their mortality rates. Mortality rates can increase significantly if predators aggregate in areas where downstream migration is delayed (Cheng et al. 2022), a phenomenon also seen e.g. at hydropower bypasses in the River Rhine (pers. Comm. Oliver Selz, Federal Office for the Environment, Switzerland). We do not know for how long the smolts were held back by the fences, but find no reason to assume that the smolt shoals would have stopped in the area if there was no fence. An accumulation of smolts at the fence may attract a range of predators. The kelts and brown trout observed just upstream to the fence are two obvious threats, but other predators such as loons, mergansers and gulls were also observed foraging in the area. Predation from naturally occurring predators may not be a problem in an Atlantic salmon population that reaches its spawning target, but predation mortality may make it difficult to rebuild a salmon population that has come to a low or critically low level, as is the case for most Atlantic salmon populations in the Tana watercourse (Anon. 2023, Vitenskapelig råd for lakseforvaltning 2022). Factors that increase predation will make it even more difficult to rebuild the population. Predation on downstream migrating smolt may be an important factor limiting recruitment in the Tana salmon populations (Gjelland et al. 2024, Svenning et al. 2020, 2023).

For energetic reasons, it may be very unfavourable for kelts to be held back in the river (Baktoft et al. 2020). Kelts may show high swimming activity and swim far away from the fence or weir in search for a bypass opportunity (Baktoft et al. 2020), thus the number of kelts observed close by the fence may not reflect the number of kelts held back from their downstream migration. Prolonged freshwater stay may make the kelts more vulnerable to *Saprolegnia parasitica* infection, a fungus-like organism in freshwaters that may be lethal to salmon and have caused declines in many wild salmonid populations (van West 2006). Seawater entrance would inhibit further growth of this pathogen (van West 2006). Increased stress levels may reduce the sea survival for kelts (Bordeleau et al. 2018), but we don't know how the stress levels of kelts are influenced by the fences. In the Tana system kelts migrate earlier in the season than smolts, and although there may be considerable year-to-year variation, their downstream migration is mostly over by late June (Niemelä et al. 2000). Considering the period of the trap operation, a large fraction of kelts had thus likely migrated past the trapping site before the trap was operational. Kelts may therefore to a larger extent than smolts have escaped the trap interception in 2023. But for the ones who had not, the observations of kelts holding upstream the fences indicate that the trap was a migration hindrance delaying their return to the sea. Smolts on the other hand normally migrate between mid-June and late-July (Orell et al. 2007, Rikstad & Niemelä 2009), coinciding with the Seidaholmen fence and trap operation period. Therefore, a larger fraction of migrating smolts than kelts were delayed by the fences. The extent of delay may also have varied between the groups as well as between individuals.

To which extent the downstream migration by smolt and kelts will be intercepted by a trap operation in future applications will thus depend the time of the trap installation, factors initiating the smolt and kelt downstream migrations as well as the trap design, Overall, the poor status of salmon populations in the Tana system makes the Atlantic salmon highly vulnerable to any increased predation or other kinds of mortality (Vitenskapelig råd for lakseforvaltning 2022).

4.2 Upstream migration

As with the downstream migration the Seidaholmen trap-fence system clearly delayed and at least temporarily stopped the upstream migrations of fish. This phenomenon has been observed at many man-made structures even in sites that do not seem to be physically difficult for salmon to pass (Thorstad et al. 2008 and references therein). Rather large quantities of fish were observed accumulating below the fences shortly after the installation of the trap-fence systems. This was documented by several methods below the eastern fence, where most of the monitoring was done, but also by drone footage in the western run. Schools of fish were observed roaming upstream, downstream and sideways, and even pushing against the rigid fence likely seeking for a way upstream. Pink salmon dominated in numbers, but the Atlantic salmon were counted in the hundreds in the eastern channel already on July 3rd. Although Atlantic salmon mostly preferred to keep somewhat more distance to the trap, and pink salmon were more frequently observed in shallower areas, there was no clear segregation between Atlantic salmon and pink salmon schools. The pink salmon seemed more agile and were at times frenetically swimming around. Still, they were very reluctant to enter the fish trap, and Atlantic salmon extremely rarely did so. These observations lead to the decisions to make a bypass opening in the rigid fence, that were kept open for periods, to give the Atlantic salmon a chance to pass upstream.

We do not have data on individual holding times. But the many fish observed holding quite far downstream to the trap indicates that the fish preferred to retreat some distance away from the trap, or potentially hesitating to approach. One explanation could be fish avoiding the substantial noise produced by the metal tubes and other metal structures in the trap in the eastern channel. Noise may be stressful to fish (e.g. de Jong et al. 2020) and sound deterrents are used many places to guide fish (e.g. Jesus et al. 2021). We do not know which sound frequencies the metal structures generated, but if some was in a frequency that resonates with the swim bladder it could be unpleasant for the fish to approach. The trap also had quite some influence on the flow and turbulence conditions. On the other hand, the flow conditions seemed to be one important factor explaining how the fish approached the eastern fence. The deepest channel led fish to the western side of the eastern channel, quite far away from the trap entrance, and this was where most of the fish, in particular Atlantic salmon, approached the fence. This was also the area where the bypass opening was made. What was the most important proximate que for deterring fish from entering the trap remains an open question. Fish were observe holding positions quite far downstream to the fence also in the western river channel, however the investigated area here did not stretch many hundred meters below the fence as in the eastern run.

Drone footage revealed large gatherings of fish downstream the guiding fences, often in accordance with the snorkellers observations. But we also experienced situations when relatively few fish were observed by the snorkeller, but numerous fish were observed by the drone. This illustrates the challenge of the typically low visibility range in the River Tana. In both underwater video and drone footage fish were observed forcing their way through the flexible guiding fences both in the western and eastern river channels. This showed us that although the guiding fences had a clear guiding effect as revealed by underwater video and diving, they were not sufficient to hold back all fish. They also largely failed in guiding the fish over to the eastern channel as intended, since a lot of the fish chose to hold below the western fence and eventually forced its way through. Due to the lack of individual-based data we don't know the typical hold-back time for the different species, nor the proportion of fish that never passed. But the high numbers of migrating fish passing Polmak sonar site indicates that most fish made it through the flexible fence in the western channel, at times also helped by the bypass opening made in the eastern fence. Holes made by the water flow under the flexible fence anchoring chain could also be a potential bypass route, but we do not have any footage showing that this happened. The flexible guiding fence thus has some benefits and some pitfalls; it makes much less noise than the aluminium fence, it does not catch debris etc, and it guides fish. Also, it does not harm fish swimming through. The fact that fish can force their way through is obviously also the reason it fails in confining the fish to the downstream side. The observations made in this study however indicate that the flexible fence works well as a guiding fence for the purpose of leading fish towards the centre of the river channels, as it is used for the sonar monitoring locations in the Tana tributaries (e.g., Domaas et al. 2024).

The large increase in fish numbers downstream to the fences in early July was seen both in the eastern and western run and indicates that fish ascending rates from the sea were higher than the rate at which fish passed the fences through the deliberately made bypass openings and through the flexible fences. On the other hand, fish numbers downstream to the western fence decreased after July 12th, and during the following days large numbers of fish were observed migrating up the western channel. This wave of migrants seemed not to be correlated to any changes in water discharge, but likely reflects a migration peak from the sea. To which extent this migration peak was delayed at the trap and fences is difficult to say, but the highest migration peak at Polmak appeared later in 2023 than in 2021 when there was no trap and fences. Two migration peaks observed at Polmak around the 20th of July and early August in 2023 coincided with increases in water discharge. It might well be that fish that had been reluctant to pass the fences found it easier to do so at higher water discharge, but this remains speculations. These two peaks were seen as migration peaks by Atlantic salmon in both Kárášjohka and Anárjohka.

The effects caused by the delays below the Seidaholmen trap-fence system for salmon and trout are largely unknown but there are several potential problems (see e.g. Thorstad et al. 2008). In the Tana system different salmon populations have their own temporal migration patterns indicating local adaptations (Vähä et al. 2011). These adaptations are probably advantageous for salmon enabling them to migrate during optimal environmental conditions and to arrive at proper times to spawning grounds. In addition, entry to small tributaries (very shallow river mouths) from the Tana main stem is often dependent on suitable water levels which may occur within a narrow temporal window (Vähä et al. 2011). A delay early in the migration may at worst hinder entry to such small tributaries. Discharge dependent passage of certain riffles and waterfalls have been observed in other rivers too (Thorstad et al. 2008 and references therein). Warm water during the active migration, which was the case in Tana in 2023, may cause additional energetic cost to migratory fish, especially if migration is delayed. This potential effect is largest for the head-water populations with long migration distances. It also can't be ruled out that some of the up-stream migrating salmon turns back at obstacles and migrate to other rivers to spawn (Croze 2005, Thorstad et al. 2008). Individuals often differ in boldness and other behavioural traits, so-called behavioural syndromes, may have had evolutionary advantages (Sih et al. 2004). Such differences are likely to lead to differences in delay time for migrating Atlantic salmon about to travers a manmade structure such as the trap and fences. Thus, we might expect that some individuals experienced short delays, whereas others were delayed much longer.

Sea migrating trout use the lower reaches of the Tana main stem as its overwintering (both non-maturing and maturing individuals) area and migrations between river and the feeding grounds at the Tana mouth/Tanafjorden are frequent between spring and autumn (Orell et al. 2017). Catch statistics from the river stretch between Tana bru and the Norwegian-Finnish border (Nuorgam, Finland) shows that the upstream migration for both non-maturing and maturing individuals starts around mid-July and increases throughout August (Niemelä 2016). The Seidaholmen trap-fence was situated within the overwintering area and would have been necessary to pass for migrating sea trout ascending further up the watercourse. It is thus reasonable to assume that the Seidaholmen trap-fence has caused changes and delays to sea trout migrations, both up-stream and downstream. If so, these delays may cause similar effects to sea trout as they may cause to salmon. However, sea trout observations were much more sparse than Atlantic salmon observations in the analysed data. Very little data from August have been analysed, it is likely that we would have observed more sea trou in August. In the drone footage it is generally very difficult to separate sea trout from similarly sized Atlantic salmon or pink salmon. We observed several sea trout swimming through the flexible fence in upstream direction, and we observed one dead sea trout drifting towards the flexible fence from the upstream side. However, our analysed data are too limited to draw strong conclusions on sea trout reactions to the guiding fences.

4.2.1 Trapping efficiency

The fish trap at Seidaholmen in 2023 had a very low pink salmon catch efficiency, based on the counts of fish (Polmak sonar) that bypassed the trap. The trapping efficiency was even lower for Atlantic salmon and sea trout, which is very problematic, as these fish should swim rapidly into the trap to be quickly released upstream. The two most important factors causing low catch efficiency were 1) the fish were very reluctant to enter the trap, likely as a consequence of a non-optimal trap entrance placement and flow conditions at the entrance itself, and 2) the flexible fences were not capable of holding fish. None of these factors are trivial with obvious quick-fixes, and the adoption of one solution with some benefits will very often have other negative aspects. We will come back to this in the Recommendations-section (**Chapter 4.5**).

4.3 Potential ecological impacts

The ecological risks from the pink salmon invasion are treated elsewhere (see e.g. Sandlund et al. 2019, Hindar et al. 2020, Forsgren et al. 2023) and will not be discussed here. The return of adult spawners is important not only to start the next generation of anadromous fish, but it also brings nutrient-rich matter from the marine system to nutrient-poor rivers, headwaters and coastal ecosystems (e.g. Schindler et al. 2003, McLennan et al. 2019, Bernthal et al. 2022). Constraining the unhindered migration of fish in rivers through the installation of barriers disrupts river connectivity, directly contradicting the overarching objective of most fish ecologists, namely the enhancement of river connectivity. Physical structures hindering unrestricted migration can exert significant impacts on both local and migratory fish populations (Thorstad et al. 2008). In this case this is *per se* the goal of the barrier for one of the species, the pink salmon. However, the ecological consequences of such pervasive management actions may be difficult to foresee, especially for already vulnerable populations such as the many threatened Atlantic salmon populations in the Tana watercourse. We have pointed to the risks associated with delays in out-migration both for smolts and kelts and upstream migration of adult fish. As the flexible fence did not work well for the purpose of holding and guiding the fish to the trap, another solution will be warranted. Using more robust solutions, as in traps in other rivers in the region, is likely to result in more fish with sores and abrases from pushing towards the fence. For the fish caught at the Seidaholmen trap during the summer of 2023 a wound frequency of 15% was reported, but it was not known to which extent these wounds were acquired before or after trap entrance (Sandodden et al. 2023). Such wounds can lead to *Saprolegnia* infection challenges in freshwater and diffusion balance challenges in the sea. Such effects may result from physical contact with the trap installation or weirs but may also result from aggressive behaviour among stressed fish in front of the fences. Immune responses required to handle wounds comes in addition to the other energetic challenges associated with the spawning migration. Not all fish will incur problems, but it is important to consider the effects of these challenges on top of the many challenges Atlantic salmon and other anadromous salmonids face. For other fish species frequently observed in the area, such as arctic grayling and whitefish, we know very little about their local ecology and habitat use and hence effect of the fence/trap.

4.4 Operational support

The operational support provided by the monitoring in this trap evaluation project proved highly important. The support rapidly identified that the trap entrance protruding downstream from the v-shaped guiding fence caused fish not to enter the trap at all. This was followed up by the trap management by moving the trap entrance upstream to the end of the v-shape, a modification that improved the function to some extent. However, the continued monitoring showed large amounts of Atlantic salmon downstream to the fences not willing to enter the trap. The operational support team therefore recommended to make an opening in the guiding fence to let these salmon through for continued spawning migration. The recommendations were followed up by the trap management, by making openings in the rigid fence for irregular periods. The Environmental Agency also wanted the operational support to give “early warning” about high fish numbers approaching the trap, for the trap operators to be aware of increased workload at the trap. However, as the number of fish entering the trap continued to be low compared to the amount of fish observed downstream to the trap and bypassing the trap, the monitoring had little value as an indicator of the amount of fish entering the trap.

The high numbers of fish surpassing the fence in the western run was also communicated to the trap management in the interim report, which was followed up by various efforts to improve the fence. However, these efforts seemed not to hinder the fish in traversing the fence in the western run.

Overall, the monitoring and operational support worked well for evaluation of the trap and fences, whereas the poor willingness of fish to enter the trap made the numbers observed downstream to the trap a poor indicator of the number of fish entering the trap. The further actions that would be needed to make the trap function better and more efficient would involve major measures like large reconstructions of the trap-fence structures, which was out of the scope for the summer of 2023.

Due to the number of people involved and complexity of the operation of the trap, e.g. the daily leader of the trap operation varied at any given day, we see a need for an administration plan and communication protocol between the actors before a project like this is to be carried out again.

4.5 Recommendations

4.5.1 Trap-fence system development

As indicated above, a major concern regarding future use and development of the trap in the River Tana is the consequences for descending smolts and kelts as well as for ascending native spawners. A precautionary approach should be used in all management actions at the current salmon stock status in the Tana with salmon fisheries totally closed. If a trap is once again installed, there must be developed better downstream migrations solutions to aid the free and relatively undisturbed outmigration of smolts and kelts. We recommend developing a system with many downstream migration solutions in order to avoid concentrations of smolts and kelts in front of a single or a few routes; two or three of such openings will likely not suffice. Similarly, the nature of a varying flow situation throughout the summer combined with the large scale of the river necessitates a trap with several intakes/traps for upstream migrating fish. A solution with four or more trap entrances will be helpful in several ways; it creates several entrance opportunities for the fish, each that can be favourable for different flow conditions and different species/size groups, it can reduce the traffic necessary per entrance, giving a better potential for AI-guided automated sorting and native fish release without handling. Having multiple trap entrances not only provides alternative options for ascending fish but also serves as a reliable backup in case one trap fails or requires closure for repairs, ensuring a more resilient and effective system. A central consideration must be to ensure good flow conditions through the entrances, to make them attractive and to motivate fish to enter them. Local resources were involved in the planning of the first trap in Tana, having these onboard during planning of potential future traps will be central to succsess. Local fishermen with long experience in catching Atlantic salmon with weir traps have a good understanding of how salmon use the river flow and should be consulted for advice on exact entrance locations. Getting the native fish to pass the trap and fences without delay and harm must have highest priority. The opportunity to pass a flexible fence will probably not be part of a future trap solution; what to do if the native fish won't pass through the migration solutions must be planned together with monitoring and action thresholds as part of a comprehensive risk analysis.

4.5.2 Monitoring program

The current monitoring and evaluation of the trap-fence system was planned shortly prior to when the operation commenced. Consequently, we uncovered areas of improvement regarding coordination and a need for an operational support protocol, e.g. the construction of the trap and guiding fences lacked coordination with monitoring actions. For upcoming trap operations, we suggest integrating monitoring from the initial planning stages. This proactive approach will not only enhance the effectiveness of the trap operation but also contribute to a more comprehensive evaluation of its impact on fish populations.

The use of cameras is essential for species identification, and cameras were also highly valuable for evaluating fish behaviour at the fences. The sonar covers a much large water volume than cameras and can be used for fish counting and fish length measurement. Snorkelling was also very informative for information on fish distribution in the area, but we admittedly also underestimated fish presence at times due too poor water visibility. Whilst we didn't initially plan for the use of a drone ourselves, the invaluable drone footage generously shared by Joachim Henriksen from Tana provided us with highly beneficial observations and information. As the other methods, drones have some limitations with poor water transparency, especially at higher water levels, wind that create a rough scattering water surface, and also relatively short operation time. But the benefits of the bird's-eye view were very well illustrated during the periods with low water flow, good light conditions and calm weather conditions with no or little wind.

The current study and monitoring design had a significant limitation: a lack of information on individual behaviour. Whilst we almost consistently observed fish in front of the trap and guiding fences, we have no way to tell whether these are any of the same individuals observed 30 minutes, 4 hours, or 2 days ago, etc. Furthermore, we were unable to determine if fish that approached the trap in the eastern channel and then returned downstream, continued to try the western channel or if those in the western channel never ventured up the eastern channel. Moreover, we don't know if spawners gave up and returned to the sea to seek spawning opportunities in other rivers. This is an issue in most, if not all, rivers with migration barriers, i.e. the full-scale pink salmon traps used extensively in Norwegian rivers in 2023. The duration of the time smolts needed to pass the fence and the extent of their mortality risk in the area also remains unknown. Therefore, future trap monitoring studies should prioritize the inclusion of individual fish tracking through telemetry methods. Such an experiment should encompass a diverse array of fish from various sources, including downstream migrating smolts and kelts, as well as upstream migrating pink salmon and native salmonids.

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