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Evaluation and use of a monitoring method to estimate Atlantic salmon spawning run

An assessment of the use ARIS sonar in combination with Timespace underwater video in Máskejohka, a tributary of the River Tana

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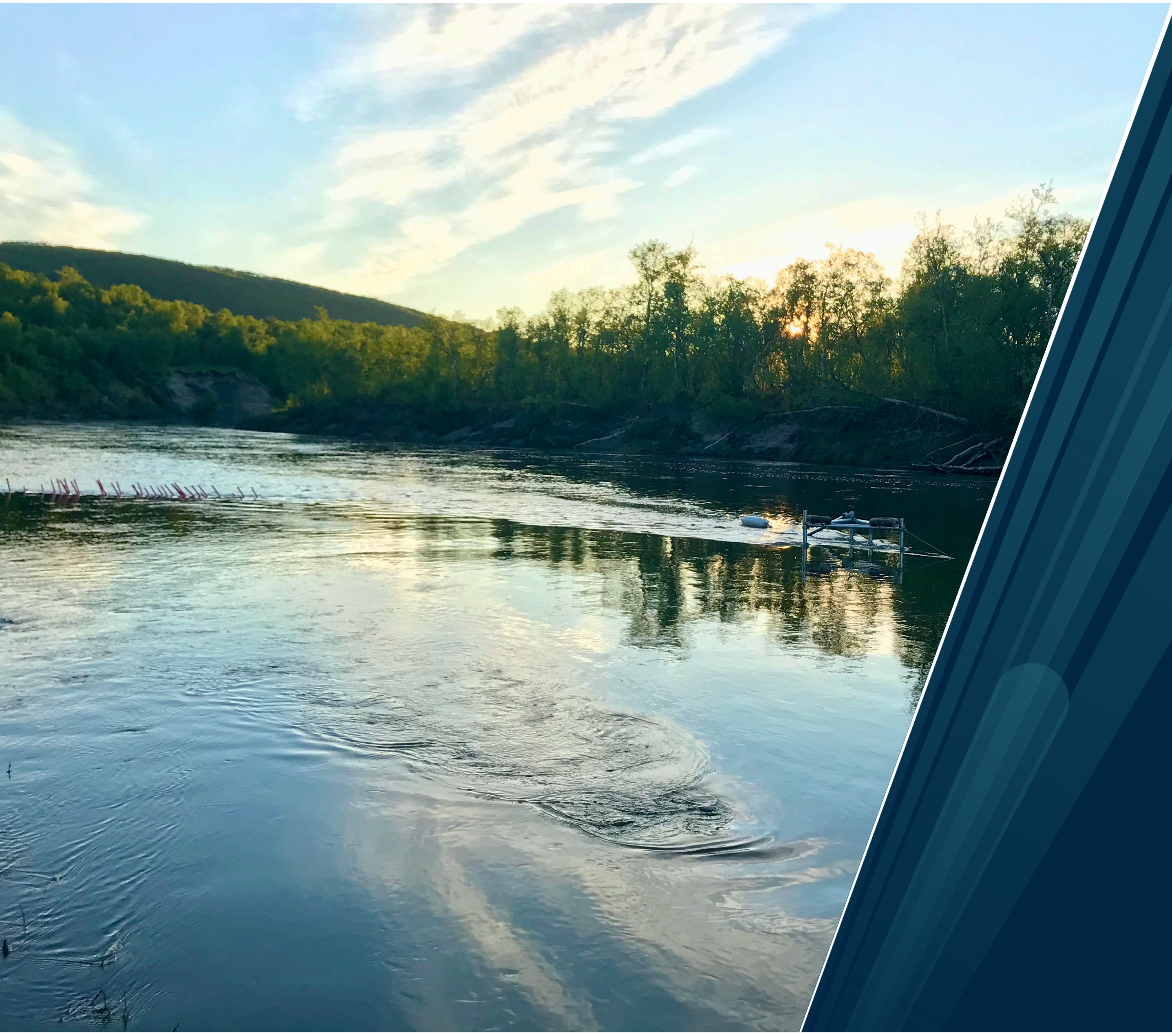
BIO-3950 Master's thesis in Biology, June 2021



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Acknowledgments

Of all of those I must thank for contributing to my master thesis, First I must thank my supervisors Karl Øystein Gjelland, Morten Falkegård, Eva Bonsak Thorstad and Rune Knudsen. I want to thank them for fantastic supervision through a rough year of fieldwork, analyzing and writing during a pandemic that have affected us all. Thanks for all the rapid responds and good advice.

All of those contributing to the field work in Máskejohka, Karl Øystein for supervising the whole project along with Narve Stubbraaten Johansen. Crister Höök for allowing us to install our equipment so close to his farm, and for rental of electric power, river boat and transport. Stein-Arnulf Hansen for rent of his caravan and his assistance during the fieldwork. And to all those others who contributed to the fieldwork; Iver Boine, Sigurd Domaas, Mina Gjelland and my father Sverre Kimo Pedersen.

I want to thank the science group I got to be a part of during my two years at The University of Tromsø, the Freshwater Ecology group. Thanks for interesting courses, inspiring professors, all new acquaintances, and all the social events.

I want to thank my fellow students, Vegar, Atle, Eivind, Malin, Mathilda, Katrine and Adrian for making my two years at UiT amazing.

At last, I want to thank my partner, Leif Henrik, along with friends and family for supporting me through the writing of this master thesis.

Abstract

ARIS sonar and Timespace video cameras were used to estimate spawning run and migration pattern of Atlantic salmon in Máskejohka, a tributary belonging to the River Tana. Máskejohka has not been monitored before and needs more detailed information about the stock size and its migration pattern, after several years with declining Atlantic salmon catch. Data for the first weeks of the migration period was hampered by an extreme spring flood, and the total sonar data coverage for the period (31.05.2020-15.09.2020) was 78%. Fish ≥ 45 cm were divided into the following length classes, based on measurements from the sonar data: 45-55 cm, 55-67 cm, 67-89 cm and > 89 cm. Only fish ≥ 45 cm was included, due to minimum Atlantic salmon size. Fish species were subjectively identified with sonar data based on size and behavior before confirming or refuting species with video recordings. Using video-identified species, the probability of a target being an Atlantic salmon was estimated by binomial regression using length as predictor. Estimation of total Atlantic salmon run was then completed using the regression model to estimate the proportion of Atlantic salmon among the targets observed on video. For the period with missing data, the potential run was estimated based on development from week to week from catch statistics from the previous years. Results from the sonar and video analyses were compared to catch statistics from Máskejohka to calculate the size of the spawning stock. The total number of fish registered by the sonar was 1810, 1270 upstream and 539 downstream. A total of 110 Atlantic salmon 75 grayling, 16 trout, 2 whitefish, 2 pike and one pink salmon during the period of 16 days (30.07.2020-14.08.2020) were observed on the video recordings. Grayling dominated the smallest size group between 45-55 cm, while the size group 55-67 cm was dominated by Atlantic salmon. Trout was present in both the smallest length classes. The larger size classes of 67-89 cm and > 89 cm contained only Atlantic salmon. Atlantic salmon and sea trout often swam fast past the sonar window and in the center of the river channel, while grayling and smaller trout used more time passing the sonar window and swam often closer to the guiding fences. Both total catch and catch per unit effort were lower in 2020 than four previous years, which demonstrate a need for better monitoring and recovery of the Máskejohka Atlantic salmon stock. A minimum of 747 Atlantic salmon migrated up Máskejohka during the study period, most of them were smaller Atlantic salmon. The larger Atlantic salmon migrated in the late spring and early summer. Including the missing run estimates, a total of 531 Atlantic salmon migrated up Máskejohka in 2020. After accounting for catches, the spawning target attainment was between 39 and 71%.

1 Introduction

The Atlantic salmon, *Salmo salar,* is an anadromous fish belonging to the Salmonidae family, living in temperate and subarctic waters in the North Atlantic Ocean (Thorstad et al., 2011). Atlantic salmon has been essential for the settlement along northern rivers, where it, as an outfield resource, historically has been an important household provision. Petroglyphs carved into stone in Alta and Tana demonstrate the value of Atlantic salmon for thousands of years back in time (Solbakk, 2018; Gjerde, 2019). More recently, Atlantic salmon has been an important resource for commercial and recreational fisheries (Hindar et al., 2011).

Atlantic salmon is anadromous, spawning in freshwater and undertaking a long feeding migration into the sea. This migration between freshwater and seawater environments poses a challenge for Atlantic salmon management (Rikardsen et al., 2008). Anadromy is a strategy often used by salmonid species such as Atlantic salmon, brown trout *Salmo trutta* and Arctic charr *Salvelinus alpinus* (Santaquiteria et al., 2016). It is an adapted behavior which utilizes the available recourses from different habitats during its life span to increase its fitness (Lucas & Baras, 2001). The Atlantic salmon spawn in the late autumn, however, the Atlantic salmon starts their migration several months before the spawning (Klemetsen et al., 2003; Thorstad et al., 2008). Multi-sea-winter (MSW) salmon that have spent more than one winter at sea start their spawning run up their home river earlier than the one-sea-winter(1SW) grilse (Jonsson et al., 1990; Borgstrøm et al., 2010). The Atlantic salmon migrate up and through the estuary when river conditions are suitable, with factors such as water temperature, light, water discharge and water chemistry affecting run timing (Banks, 1969; Jonsson, 1991; Thorstad et al., 1998).

Populations of Atlantic salmon has declined dramatically since the 1970s in the approximately 2 000 Atlantic salmon rivers found on both sides of the Atlantic Ocean (Chaput, 2012; ICES, 2020). The North Atlantic Salmon Conservation Organization (NASCO) was established in 1984 after years with declining Atlantic salmon stocks, and the NASCO members are obligated to adopt a precautionary approach to Atlantic salmon management (NASCO, 2014; Anon, 2019). Larger river systems often contain several genetically different stocks of Atlantic salmon, depending on the size and structure the river (Heggberget et al., 1986; Hess et al., 2014; Vähä et al., 2017). Atlantic salmon has a strong homing behavior, which means that they return to the river and tributary where it grew up. This homing behavior provides the base for assessing genetic stock structuring both among and within rivers (Klemetsen et al., 2003; Vähä et al., 2007). In recognition of this genetic structure separating Atlantic salmon stocks, NASCO has established management guidelines stating that the Atlantic salmon management should be stock-specific, based on conservation limits and management targets, and that any actions affecting Atlantic salmon stocks should be preceded by a clear assessment of the possible action outcomes (with variation and uncertainty) and a plan for possible mitigating actions (NASCO, 2014; Anon, 2019). Smaller rivers and tributaries often have stocks of less Atlantic salmon, which are more vulnerable to impact factors such as fishing, and this should be considered when managed (Chaput, 2004). Stock-specific monitoring of Atlantic salmon affected by a mixed-stock fishery within a river may allow for targeted harvesting of healthy stocks, while vulnerable stocks can be protected, and the effectiveness of local management plans can be evaluated continuously (Cowx & Fraser, 2003; Crozier et al., 2004; Branch & Hilborn, 2010). A well-designed monitoring program is thus a necessity for sustainable harvest of Atlantic salmon stocks.

Hydroacoustic methods (sonars and echosounders) of monitoring migration of salmonids have been used since the 1960s to quantify populations by counting. Since then, the reliability of the technology have improved and today sonars are a frequently used monitoring tool all over the world (Cook et al., 2019; Ghobrial, 2019). Sonars, often called imaging sonars when used in river applications, are often preferred methods due to being non-invasive and a quantitative way of monitoring fish stocks independent of light and visual conditions (Foote, 2009). This is especially the case in rivers with visibility limitations due to colored water, for instance during high-water periods (Cook et al., 2019). Fish species identification remains the most significant limitation of sonar. This have been somewhat mitigated by the use of higher frequencies and improved image quality, which makes it easier to observe both the morphology and swimming behavior of individual fish and, from this, potentially infer fish species (Martignac et al., 2015; Ghobrial, 2019). The most common approach to identify species is to place underwater video cameras within the sonar window, which allows for species information when the water visibility is sufficient. Sonars can be used in wide rivers, but sonar images become less detailed with increasing distance, making it more difficult to identify and measure individual fish. However, relatively small sonar windows can be constructed in rivers with the placement of guiding fences or nets that guides the fish into a manageable sonar window and ensures that the study objects passes in front of the sonar (Helminen et al., 2020). The most suitable period and location to monitor the adult stock of Atlantic salmon is during spawning run at a narrow location within a river.

Monitoring by quantifying Atlantic salmon stocks has been a requirement in Norway for the last decades. Norway has more than 400 watercourses with genetically distinct stocks of Atlantic salmon, with a 50% general decline in pre-fishery abundance of Atlantic salmon since the 1980s (Forseth et al., 2017; Anon, 2020b). There are regional differences within Norway and, disregarding Atlantic salmon from the large River Tana (Deatnu in Sámi, Teno in Finnish), the other Atlantic salmon rivers in northern Norway have seen a 9% increase in returning Atlantic salmon since 1989. In contrast, the River Tana has declined 68% since 1989 (Anon, 2020b). The River Tana, on the border between Norway and Finland, with the largest potential for Atlantic salmon production of Atlantic salmon in Norway with at least 28 genetically distinct stock of Atlantic salmon (Vähä et al., 2017; Erkinaro et al., 2019). The Atlantic salmon stocks in River Tana and its tributaries have been declining over the last two decades, with the last couple of years seeing the lowest recorded catches (Anon, 2020a). The Atlantic salmon fisheries are regulated through a joint agreement between the countries and a new agreement between the countries was ratified and implemented in 2017 (Anon, 2018). An overall aim of this agreement was to arrest the Atlantic salmon stock decline and initiate stock recovery by reducing the overall river exploitation rate by 30% (Anon, 2019).

The decrease of Atlantic salmon production in River Tana and its tributaries has demanded action from the management because of its high cultural and economic value for the local people. Monitoring has been an important part of quantifying and mapping the different status of the River Tana Atlantic salmon stocks complex. Sonar monitoring, where fish are counted have been used for several years at various locations within the River Tana system. Dual-frequency Identification Sonar (DIDSON) and underwater video cameras were used to estimate spawning run in one of the upper tributaries to Tana, Kárášjohka, as early as 2010. This pilot study documented that the run size of Atlantic salmon were lower than needed to fulfill the spawning target for Kárášjohka in 2010 (Lilja et al., 2011). The Kárášjohka-monitoring have been continued annually since 2017, along with similar monitoring projects in the tributaries Iešjohka (Johansen, 2020), Anárjohka, Vetsijohka and in the main River Tana (Anon, 2020a).

The Máskejohka is the lowermost tributary to the River Tana on the Norwegian side. The Atlantic salmon stock in this tributary has never been monitored before. The annual status evaluation of this tributary done by the Norwegian-Finnish Monitoring and Research Group is solely based on catch statistics and a coarse estimate of the river exploitation rate. The overall aim of this thesis is to estimate the spawning run size of Atlantic salmon in Máskejohka and combine this with upstream catch statistics to establish a new monitoring-based estimate of exploitation. I will use the counting data to establish temporal patterns in the Atlantic salmon migration of different size classes (especially contrasting the migration of 1SW grilse and MSW salmon, as the majority of female Atlantic salmon belongs to the latter group). I expect it to be a diurnal difference in migration timing before and after nights starts darkening in August.

There are other fish species present in Máskejohka and I expect that Atlantic salmon and European grayling *Thymallus thymallus* are the dominating species in this area, along with the presence of some brown trout and maybe presence of other stationary species. I also expect that small Atlantic salmon, brown trout (both anadroumus and stationary) and grayling are overlapping in size class 45-55 cm, but that they can be separated by behavior. Sea trout will probably be difficult to separate from Atlantic salmon by behavior due to similar migration pattern and morphology (Gurney et al., 2014). The aim is to separate Atlantic salmon from stationary fish. To do this, I will identify the fish species with sonar data and describe their swimming behavior. Afterwards, I will video-identify the registered fish and correlate the species that could be identified wrong from sonar data. This will give an estimate of which fish species pass the sonar and their size. I will evaluate these methods used (sonar and underwater video camera) to monitor Atlantic salmon run and mapping of the species composition. From the data collected, I will estimate the 2020 spawning stock of Atlantic salmon in Máskejohka.

2 Materials and methods

2.1 Study location

The sub-Arctic River Tana (70°N,28°E) is one of the largest and most productive Atlantic salmon rivers in both countries it is shared between, Norway and Finland. River Tana has about 1 100 km available for Atlantic salmon in the entire watercourse (Falkegård, 2014). The total catchment area is 16 386 km^2, where most of it (70%) is located in Norway along with the estuary that drains into the Tana fjord (Davidsen et al., 2005; Lilja et al., 2011). The river is shared between the municipalities Tana, Karasjok and Kautokeino within Norway, and Utsjoki within Finland. There are several variously sized tributaries within the river system, most of which have genetically distinct stocks of Atlantic salmon (Vähä et al., 2017; Erkinaro et al., 2019). The whole Tana river system has the largest spawning target of all Atlantic salmon rivers in Norway (Hindar et al., 2007).

The River Máskejohka (70°21´N, 27°25´E) is located on the western side of the Tana, approximately 28 km upstream from the main river estuary (Anon, 2019). The precipitation field of Máskejohka is 602 km^2 with an annual inflow of 319 mill m^3 (Kartverket, 2021), this makes Máskejohka a middle-sized river. Máskejohka has three tributaries; Ciikojohka, Geasis and Uvjalátnjá with varying length and bottom profiles (Berg, 1964)(Figure 1). Máskejohka origins in the lakes Máskejávri and Máskeluobbal. Ciikojohka flows into Máskejávri from the south. Uvjalátnjá flows into Geasis from the south, while Geasis further flows from the west into Máskeluobbal, which is north of Máskejávri (Falkegård et al., 2014).

The main Máskejohka, starting at Máskeluobbal, has a 30 km stretch available for Atlantic salmon. Ciikojohka has 11 km until the migration stop by a larger waterfall, Geasis has 7 km until its waterfall and Uvjalátnjá 7 km, in total are 55 km available for Atlantic salmon within the Máskejohka river system (Anon, 2019).

At the latitude of Máskejohka it is approximately two months of midnight sun from middle of May until the end of July, however, the study lasted until middle of September when the night gets dark. The river is usually ice-free from early-to mid-May until November-December. Most of the river is surrounded by forest, mainly consisting of birch *Betula pubescens* and *Betula pubescens ssp. czerepanovii*, rowan *Sorbus aucuparia* ssp., several species of *Salix* and some presence of pine *Pinus sylvestris*.

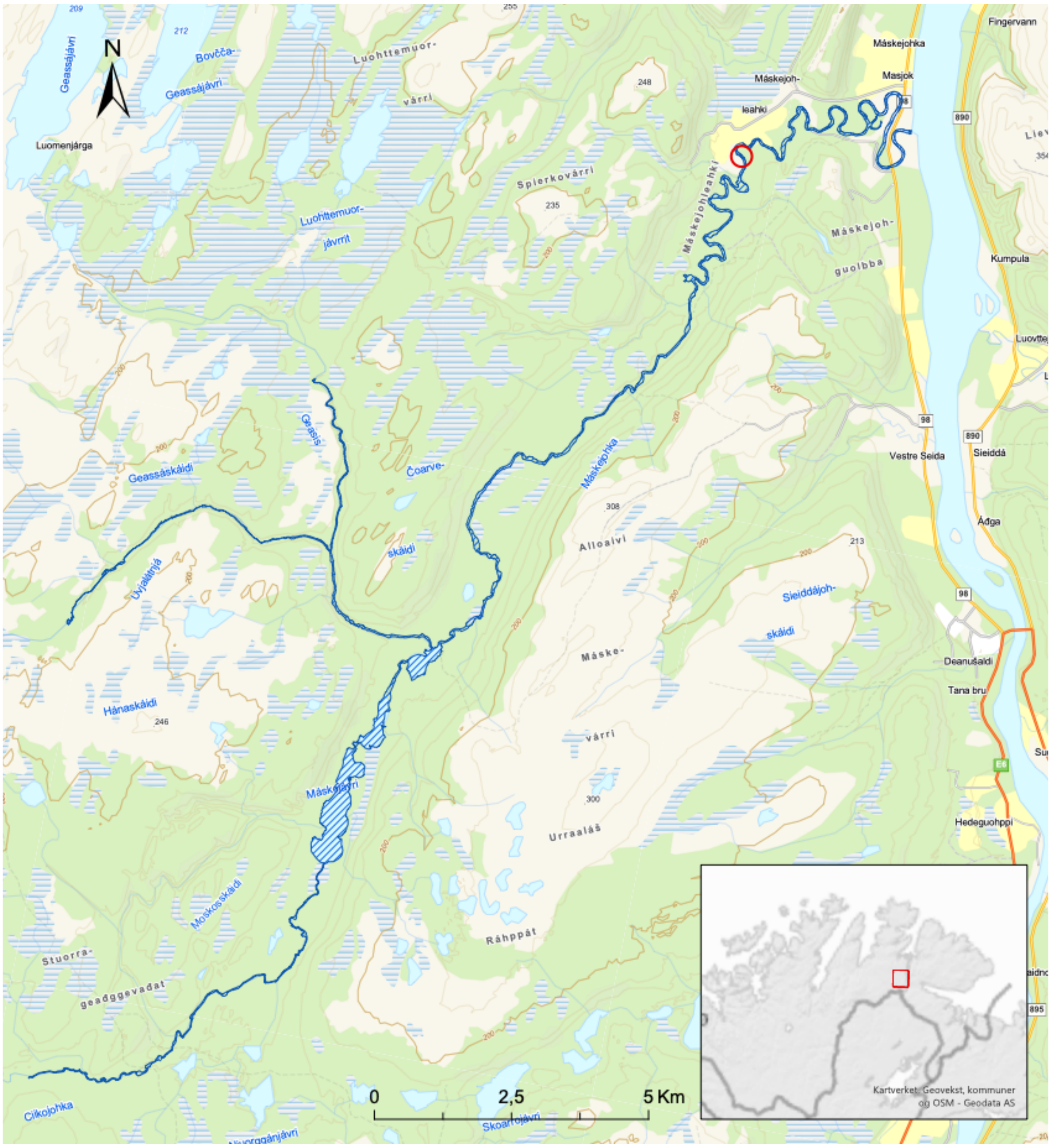

Figure 1. Map of Máskejohka with tributaries. Stretches of Máskejohka watercourse available for Atlantic salmon are marked in blue. A red ring marks the sonar location. Cartographer: L. H. Halvari.

The sonar location was 9.3 km upstream from the river mouth of Máskejohka in the lower slow-flowing meandering part of the river with deep channel (Figure 2). This sonar location was preferred due to lower disturbance from the closest roads and to be able to connect by power via a local farm. Moreover, the river stretch between the River Tana stem and the study site is dominated by mud and clay. There are no suitable spawning sites for Atlantic salmon in this area which is therefore classified as a non-productive area with 0 eggs m^{-2} in the Máskejohka spawning target calculation (Falkegård et al., 2014).

This lower part of Máskejohka does not have any permanent natural or unnatural barriers that could cause individual Atlantic salmon to mill in the area (Thorstad et al., 2008). The river mouth of Máskejohka contains sand and shifts direction annually and splits into plural river mouths and can become too shallow for larger Atlantic salmon to pass in dry low-water periods (Berg, 1964). Most of the upstream migrating Atlantic salmon will have passed during the study period, however, snorkeling was still performed below the sonar in the start of September to check the number of Atlantic salmon below the sonar location.

The bottom profile at the study site was optimal for sonar location with small gravel and mud. No larger rocks or trees were interfering with the horizontal path of the acoustic beam or creating any turbulent flow at the site.

Figure 2. Aerial photo of sonar location, with the river flowing from south to north. The arrows are pointing the direction of the river flow. The fan shaped symbol indicates the sonar window in the river. Power was rented from the farm on the picture. Map: www.kartverket.no

2.1.1 Fish species

The fish species inhabiting Máskejohka has not been thoroughly mapped, but the catch statistics include Atlantic salmon, brown trout, European grayling, pink salmon *Oncorhynchus gorbuscha,* northern pike *Esox lucius* and whitefish *Coregonus lavaretus*. Atlantic salmon, pink salmon, trout, and grayling are known for choosing running water as habitat (Northcote, 1995; Riley et al., 2009; Vøllestad, 2019c). Grayling is a common fish species in both the main river Tana and the tributary Máskejohka. It is native in Europe, inhabiting freshwater streams and lakes (Swatdipong et al., 2009). Grayling has long been a popular fish for angling, especially in Finland and England (Ingram et al., 2000; Koskinen et al., 2001). Brown trout is also a common species in River Tana watercourse, however, few trout are reported caught in Máskejohka (Johansen, 2018). Still, I expected trout to be observed in Máskejohka during the study period. I also expected presence of pike, whitefish or anadromous charr. However, there are few catch reports of species other than Atlantic salmon (Fortuna, 2021), since these other species are not a target by the Máskejohka anglers.

The main study object is the Atlantic salmon because it is the main target in the Máskejohka fishery. Máskejohka has its own genetic stock of Atlantic salmon different from the rest of the watercourse, different in various plasticity of life history, within both migration and spawning pattern (Klemetsen et al., 2003; Vähä et al., 2017; Erkinaro et al., 2019). The stock in Máskejohka has a mixture of sea-age-groups, it has mostly 1-3SW, but also a some 4SW (Anon, 2019; Erkinaro et al., 2019). The average weight of an Atlantic salmon caught in Máskejohka between 2016-2012 was 3.4 kg and the average weight of a female Atlantic salmon in Máskejohka was 4.2 kg. The spawning target for Máskejohka is 3 155 148 eggs, corresponding to a total female biomass of 1 521 kg (Falkegård et al., 2014). The spawning target is the number of eggs needed to ensure that a Atlantic salmon stock reaches its production potential (Forseth et al., 2013). To fulfill the spawning target for Máskejohka, about 372 female Atlantic salmon of average weight are needed. The upstream migration in Máskejohka normally starts in week 22-23, but based on the catch statistics, the majority of the upstream migration occurs in weeks 25-34 (Falkegård, 2014).

2.2 Imaging sonar

The main equipment in this study was an Adaptive Resolution Imaging Sonar Explorer (ARIS) 1200 (hereafter called sonar) from Sound Metrics, which is a further development from the DIDSON sonar, with higher resolution and more information (SoundMetrics; Ghobrial, 2019). The sonar made images across the river by sending out 48 narrow sound beams in the shape of a fan (Figure 3). Each of these sound beams were 0.6° wide, overall, it created a view of 28° across the river. Objects, including fish passing the sonar, created echoes that are sent back to the sonar. The number of sound beams sent back to the sonar depended on the fish size, a larger fish gives echoes from more beams. The longer distance from the sonar, the wider the sound beam, and the lower the resolution, which translates to less accurate size measurements with increasing distance. The sonar view across the river had a data resolution of 512 segments, and the length of the segment depended on the length of the sonar view, which varied thought the season with water level.

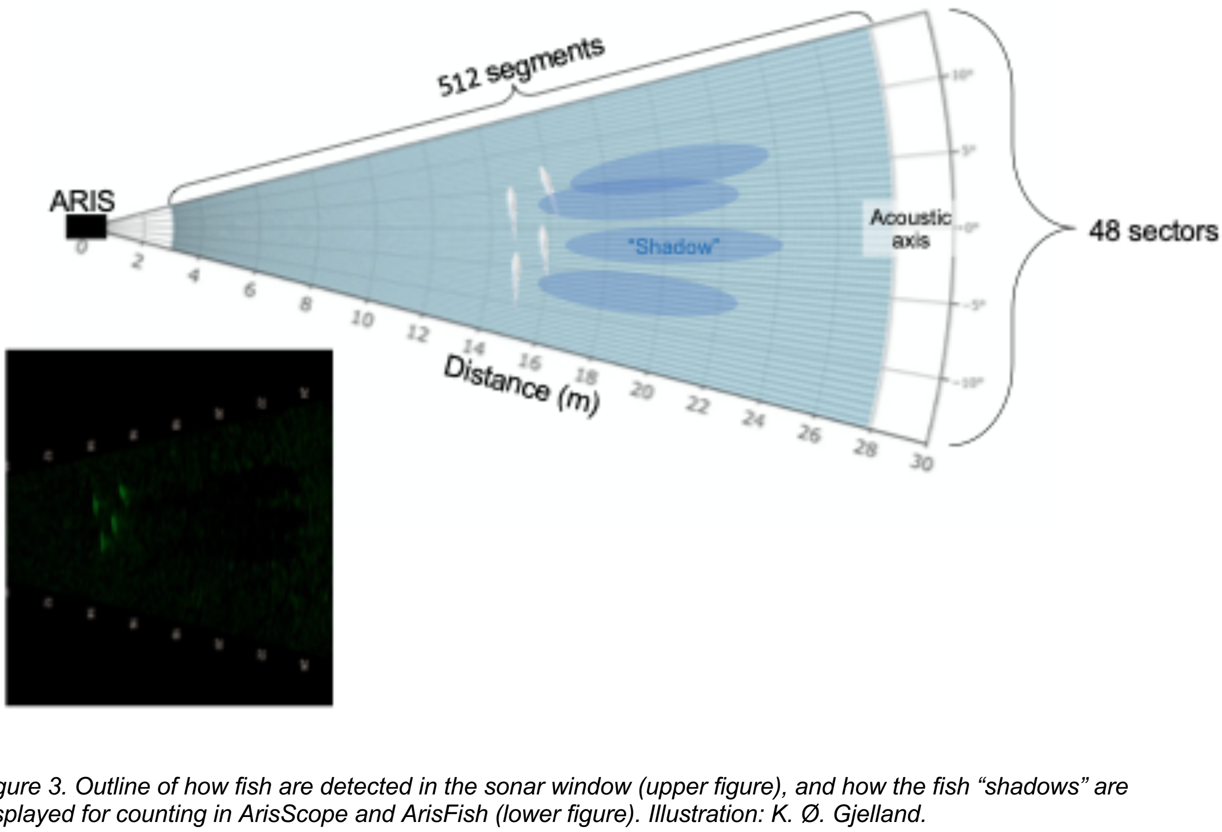

Figure 3. Outline of how fish are detected in the sonar window (upper figure), and how the fish "shadows" are displayed for counting in ArisScope and ArisFish (lower figure). Illustration: K. Ø. Gjelland.

The sonar view was only split by sound beams in the horizontal plane and not in the vertical plane, hence there is no information about fish depth, whether it was close to the bottom or close to the surface. However, the vertical view can be concentrated from 14º to 8º or 3º. All these options were tested, and a lens with a vertical view of 8º was chosen because of the clear image for later review. High frequency mode of 1.2 MHz was used through most of the season, when the conditions were optimal with shorter sonar distance and less flood disturbance. Low frequency mode of 0.7 MHz was used in the spring when the sonar distance was at the longest and the flood created disturbances. The program collecting data was ArisScope, which was programmed to make new data files separated by time and date starting at the top of the hour. Transmission rate was 7-9 echograms per second. The data material collected from the sonar was saved for later review at a local server and sent over via internet to servers at the Norwegian Institute for Nature Research (NINA).

The placement of the sonar and data collection started on the 31st of May 2020. Electric power, a riverboat, a caravan, and assistance were rented from the local farm. The sonar was installed by the river beach and placed out in the river between three metal poles with weights to hold the sonar steady. At normal summer water levels, the river is about 25 m wide at the study location. With the higher water level on the site during the installation the sonar initially had a 25 m view to the opposite shore. With guiding fences narrowing the fish passage (Figure 4), this window was later adjusted as water levels sank during the summer. Red air-filled road signs anchored by chains to the bottom was used to narrow the fish passage to get a more exact data and shorter sonar view. This is a relatively maintenance-free solution, in contrast to other earlier studies that have often used nets (e.g. from the traditional weir fisheries) to narrow the fish passage. These nets need to be cleaned often to remain functional and trees will get stuck (Johansen, 2020).

Figure 4. Placement of sonar in Máskejohka. Red guiding fences from both shores narrows the fish passage. Photo: N. S. Johansen.

All the data equipment and was installed in a caravan closer to the farm and further up in the terrain to avoid possible flood damage and easier access to electric power from the farm via the caravan to the sonar. Inside the caravan, was a field computer to control the sonar (via ArisScope), and this computer was also controlled via internet with the program TeamViewer.

Whilst installing the sonar, the water level of Máskejohka was rapidly increasing due to high air temperatures and melting of unusually high amounts of snow. Placement of the guiding fences proved difficult as water velocity increased with the increasing waters level and fallen trees started drifting downstream. The water level continued to increase after the placement of the sonar and guiding fences, and by 7th of June the sonar was covered by trees blocking the view. The flood peak occurred on 8th of June with 2 345 m^3/s at the measure station at Polmak in the main River Tana. There is no discharge monitoring in Máskejohka, but locals could confirm a flood peak on 8th of June. Discharge could also be extracted from modelled runoff data on a 1 km grid from senorge.no and integrated for the Máskejohka watercourse (Figure 5). The resulting discharge values likely reflects the temporal discharge pattern, although the 2020 flood peak must have been underestimated compared to the previous years (pers med. K. Ø. Gjelland). This is because the water level in the river was record high in 2020, and much higher than in the previous years, as measured by the maximum water level at the site during the flood (pers med, C. Höök).

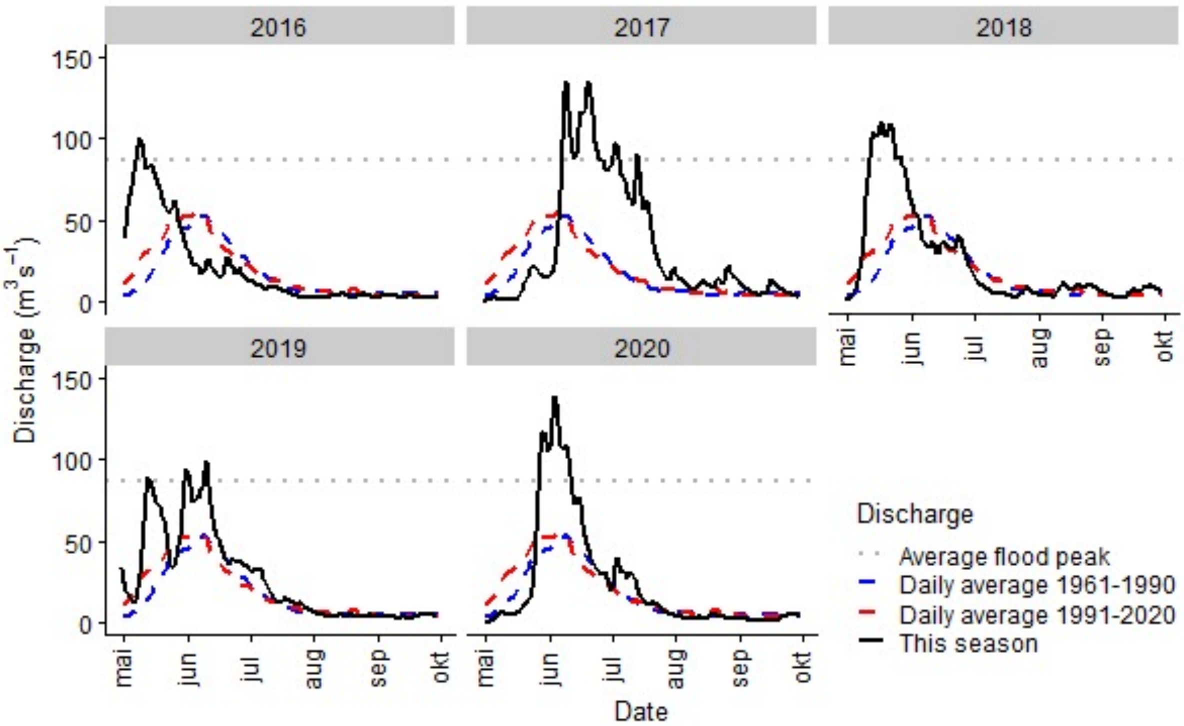

Figure 5. Discharge pattern in Máskejohka during the summer season in the years 2016-2021, as modelled from gridded runoff data from senorge.no. The discharge pattern for each year is compared to the daily average for the period 1961-1990 and 1991-2020, and the average maximum flood peak for the period 1961-1990 (very similar to 1991-2020) is also shown. The timing of the start of the flood peak for 2020 is correct, but the flood peak is severly underestimated as compared to the other years, because the water level was record high in 2020 and much higher than during spring flood in previous years (pers. med. landovner Christer Höök) with the maximum peak occuring 5 days later than in the discharge estimate (8th as compared to 3rd June). The discharge pattern from runoff estimates vary considerably in timing between the years, consistent with field observations. Figure made by K. Ø. Gjelland.

Precipitation (mm) data were collected from the closest weather station with exact measurement. There was little precipitation in the spring during the installment, so the precipitation did not contribute to the spring flood. The precipitation was little until a heavy rainfall in early July, thereafter rainfalls occurred evenly with some short rain periods during the rest of the study period (see Appendix Figure 1).

The flood in Tana lasted for several weeks, and it was not possible to safely work again at the sonar location until week 25. During 21st and 22nd of June (week 25) the field team were back at the sonar location; at that time the water flow was 471 m^3s^{-1} at Polmak and estimated from runoff to 39 m^3s^{-1} in Máskejohka. The flood had severely affected the sonar, which was covered by trees and debris, all of which obstructed the sound beam and had made the data unusable for almost three weeks. The equipment was still undamaged and functioning. The sonar view was cleared from trees during the field work and the sonar moved further out in the river due to lower water level in Máskejohka. The guiding fences were also moved further out to limit the sonar view, and the view became decreased to 19 m to opposite shore. Sonar and guiding fences were again moved further into the river 30th of July (week 31) due to lower water level and had then a view of 17 m ahead to the opposite shore.

The study period ended 15th of September (week 38), the sonar and guiding fences were dismantled and removed from the study location. The study period from 31st of May until 15th of September had a sonar data coverage by 78%. However, after 21st of June the coverage until end of study period was 92%. The weeks of 26, 27, 32, 34, 35 and 37 had 100% data coverage. There were shorter periods with data loss in weeks 30 and 36 due to some software failures of ArisScope and local power loss in the area (Figure 6).

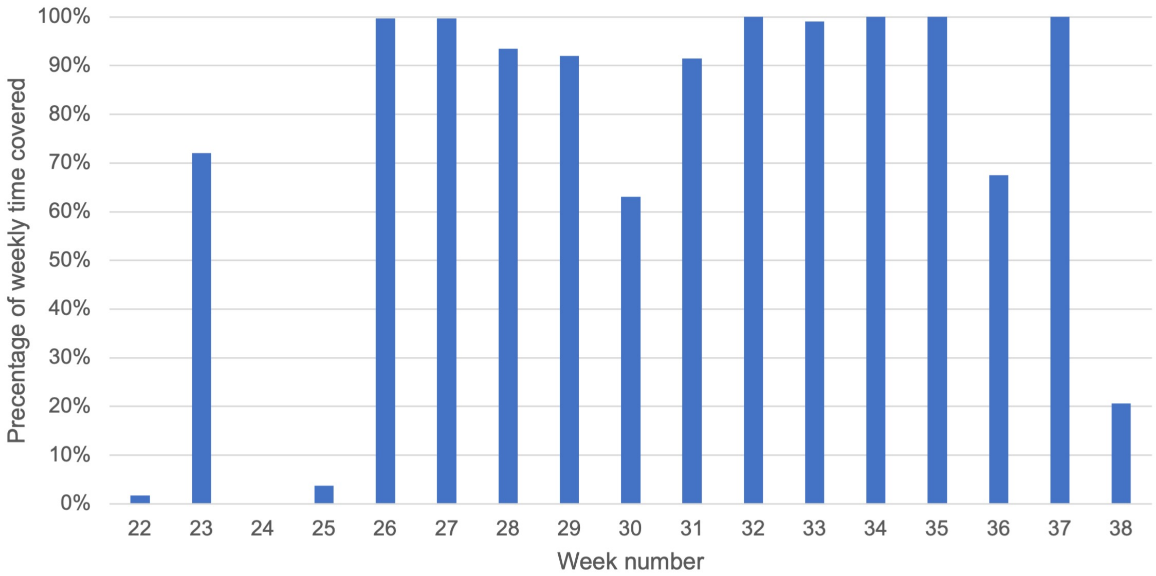

Figure 6. Overview of the weekly percentage of time covered with sonar during the study period (31.05.-15.09.)

2.3 Processing of sonar data

The collected data from ArisScope were analyzed in the program ArisFish version 2.6.3 from Sound Metrics (based in Bellevue, Washington), where we looked through data collected from the study period. The ARIS data (hereafter called sonar data) were processed with SMC Adaptive filter parameter to update background in response to changes happening and stabilizing the background to only show objects in motion. Thereafter the view was changed to a classic DIDSON format for analyzing, with a light green palette for better contrast. A background filter removed the background noise for better observation of the contrast from moving objects. These views were toggled to both see the contrast of the fish and to observe the shadow of the fish in the background substation. Each file was played back to detect possible migrating fish. I did most of the playback of sonar data myself, with some assistance from my supervisors. After reviewing sonar data from the entire study period, I completed an extra review of the sonar data that overlapped in time with underwater video data. Within this data the species were subjectively identified by length and behavior. Fish within the length group 45-55 cm could be Atlantic salmon, trout, and grayling, but the length and behavior may separate them. Other species could also be present within this length group, but they are expected to be few.

2.3.1 Body length measurement

When a fish was detected with body length, I froze the frame to manually mark the fish and measure the fish from nose to caudal fin for each individual. Length data along with migration direction and distance from sonar were automatically saved in Excel files for later review. Only fish ≥ 45 cm length were included due to representative minimum Atlantic salmon size. Measurement of fish were completed at least three times on each individual to get a representative average measure of the fish. The fish were also measured at different places in the sonar window to increase the precision of the length measurement. Manual measurement of fish length has shown to be more accurate than the software-automated values (Boswell et al., 2008; Gurney et al., 2014; Helminen et al., 2020). Studies on length measurement with ARIS and DIDSON sonar has proven to be accurate on distances up to 21 meters (Burwen et al., 2010; Cook et al., 2019; Helminen et al., 2020). However, some studies has shown that smaller fish (< 57 cm) tend to be overestimated compared to their true length, while larger fish (> 57 cm) became underestimated in length (Daroux et al., 2019). Therefore, it its recommended to measure the length of the fish more than once and at different places in the sonar window.

2.3.2 Fish behavior

I expected to observe difference in behavior between grayling and the *Salmo* species. Grayling was expected to spend longer time swimming past the sonar window due to foraging in the area. And since grayling is stationary in the river, I expected it not to fear the guiding fences and therefore swim closer to them. While both Atlantic salmon and sea trout were on a migration past the sonar. I expected that they would use less time swimming past the sonar window, and swim further away from the guiding fences because they may fear them. Stationary trout could probably act more like a grayling and forage in the area, but they will probably be smaller than sea trout. After a subjective identification of species from sonar data in ArisFish, I started the review of the underwater video recordings to confirm or refute the species classification from sonar data. Fish were only identified in ArisFish to species such as

Atlantic salmon, grayling, and trout. The time use within the sonar window was calculated in seconds to check for differences between species. The behavior of fish was used to subjectively identify species in ArisFish, based on use of space and time within the sonar window. I also noted the closest and furthest location from the sonar (m) of the fish, to easier observe the fish on underwater camera later.

2.4 Underwater video camera

The underwater camera system in use was Timespace PCLink Suite version 1.9.1 (15/05/2018) which allow both live view and playback of video records from the river. The underwater video cameras were installed 30th of July. The installment of the underwater cameras had been postponed two times earlier due to a dirt avalanche that happened early in the spring flood that gave Máskejohka high turbidity until the end of July. When the visibility in Máskejohka was finally clearer, we installed four underwater cameras on a line on the bottom across the river. All four cameras were installed with a 90° view against the current, anchored 20 cm above the bottom strapped on pipes with weight and again anchored onto the sonar to avoid drifting downstream. All the cameras were connected to a box on the shore with connection to power. This box had a screen available for live stream from the underwater cameras, and the availability to control the cameras. Camera 1 was 2.8 m from the sonar, camera 2 at 6.4 m, camera 3 at 8.5 m and camera 4 at 11.5 m. The four cameras had varying view. On the second day of recording camera number 1 changed its angle to downstream and not against the next camera, camera 1 had few observations. Camera 2 had a good view against camera 3, camera 3 had a good view, but could not view the backside of camera 4. Camera 4 had a good view against the guiding fence from the opposite shore. Camera 4 had varying light, due to the close shore making a shadow for the camera. The cameras were dismantled and removed from Máskejohka on 14th of August. The underwater video cameras had no missing data during its period in the river. The data from the underwater video cameras were used to confirm species identity from sonar data, and to get an overview of the species composition in this part of the river.

2.4.1 Fish species recognition

Fish species were identified by underwater video camera. The underwater video data was in black and white color. Species were separated by their morphology and phenotypic characteristics (such as body shape, fin placement and size, silvery appearance, and spots). Atlantic salmon, trout, grayling, pink salmon, and whitefish can be silvery in color (Figure 7).

Both Atlantic salmon and trout becomes darker in color and males of both species develop a more hook formed under jaw closer to the spawning period (Jonsson, 1987; Pethon, 1998; Hansen, 2000).

Atlantic salmon can be similar in morphology to sea trout (Vøllestad, 2019b). However, Atlantic salmons differ from sea trout having a more streamlined shape with fewer spots below the lateral line, and especially fewer on the head (Pethon, 1998). Atlantic salmon has a concave caudal fin with a slim caudal peduncle and the upper part of the jaw does not reach further back than the rear of the eye. The morphology of Atlantic salmon and its differences from trout reveal that Atlantic salmon is more adapted for longer ocean migration and a life in strong currents within rivers (Jonsson & Jonsson, 2011).

The larger trout, especially the sea trout can be highly similar to Atlantic salmon (Pethon, 1998). Trout changes its phenotypic characteristics to adapt to its habitat (Jonsson, 1987). The sea trout is normally more round and thicker with more spots below the lateral line than Atlantic salmon (Jonsson & Jonsson, 2011). The caudal fin is square or convex with a broader caudal peduncle, the head has more spots and the upper jaw reaches further past the rear of the eye (Jonsson, 2000).

The grayling has a slim body shape with a tall and colorful dorsal fin which can lay high or low (Borgstrøm, 1987). On the silvery sides it has recognizable stripes and the scales of the grayling is larger than other Salmonids and it has a smaller mouth (Ingram et al., 2000). The caudal fin is very concave compared to other Salmonids (Borgstrøm, 1987; Vøllestad, 2019a).

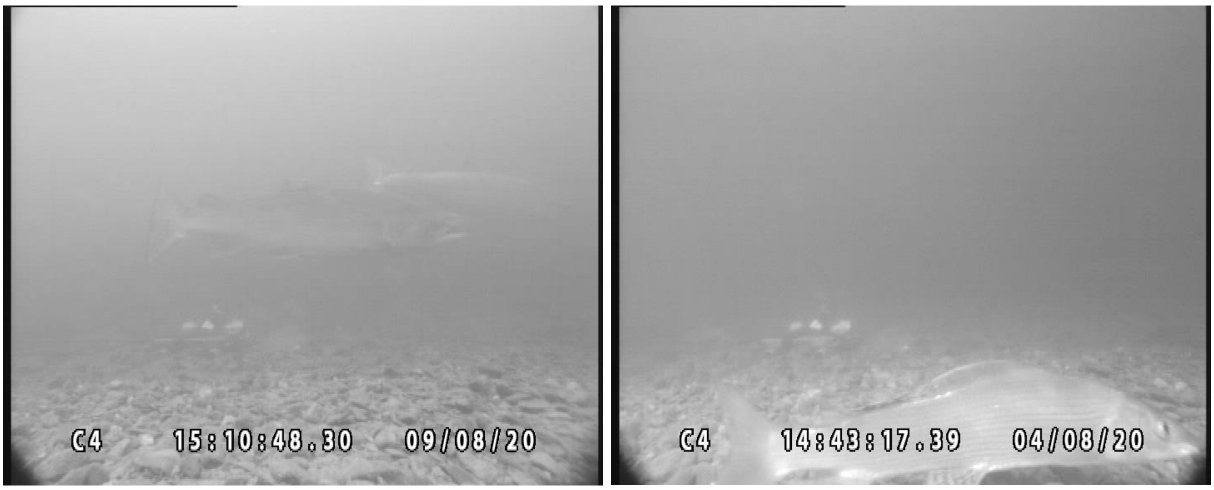

Figure 7. Observation of Atlantic salmon (left) and grayling (right) from the video monitoring.

2.5 Snorkeling

Before the removal of the sonar, on 1st of September, a team of three divers, including myself, snorkeled from 300 m above the sonar and 5.2 km downstream to observe if there were any salmonids or other species in these areas at this time. The stretch is slow-flowing meandering which is 10-20 m wide and has 0 eggs m^2 in Atlantic salmon production (Falkegård et al., 2014). Therefore, I expected few or no Atlantic salmon below the sonar this late in the season. The method of snorkeling for estimating the density of spawning stock and species composition is a valid method, but is limited by the experience of the team and by habitat characteristics, with a higher accuracy in pools than then turbulent flows (Orell et al., 2011). This team had experience from river snorkeling, free diving, and regular diving. We snorkeled side by side downstream the river and met up every ten-fifteen minutes to consult and note observations. The snorkeling ended about 4.1 km before the river mouth since the last kilometers is very slow-flowing and only contains sand bottom, and the probability of observing Atlantic salmon on this stretch is not any higher than the snorkeled stretch (Falkegård et al., 2014).

2.6 Sonar and video analysis

The data material from both sonar and underwater video were processed in Excel and analyzed in R studio (version 1.4.1103). A combination of upstream-migrating fish counts and catch statistics has been an established method in the assessment of Atlantic salmon stocks with sonar within the River Tana watercourse (Anon, 2020a).

The sonar registered fish were grouped into size categories corresponding to the weight classes used in the Norwegian Atlantic salmon catch statistics. The weight classes were: < 3 kg, 3-7 kg, and > 7 kg. Since all sonar registrations only contain length measures, an equation was needed to convert body lengths into estimated weights. The following equation have been established for converting body length into weights by the Norwegian-Finnish Monitoring and Research Group:

$$\text{Weight} = 0.0000112 * \text{length(cm)}^{2.971}$$

This equation is based on a total of approximately 24 000 Atlantic salmon with length and weight measures caught in the years 2006-2012 (Anon, 2012). Based on the equation, the following fish body lengths correspond to the weight classes above: < 67 cm, 67-89 cm and > 89 cm. Of the 24 000 Atlantic salmon, no individual was smaller than 45 cm, and 45 cm was therefore selected as a lower cutoff point for potential Atlantic salmon in the sonar analysis. Therefore, I also used 45 cm as a lower body length limit for Atlantic salmon.

The two biggest size classes above were expected to only contain Atlantic salmon, while the smallest length class was expected to contain Atlantic salmon, grayling, trout, and smaller proportions of other species. The proportion of grayling was expected to be especially pronounced for fish < 55 cm, which is the maximum size for grayling in Máskejohka, and the size class < 67 cm was therefore frequently separated into two sub-groups: 45-55 cm and 55-67 cm.

The second kind of size class is what is normally used in Norwegian catch statistics, are called weight classes, and where the two smaller size classes in the previous categorization are assembled. This size categorization was used with data only containing Atlantic salmon. The weight classes used were: > 3 kg (45-67) 3-7 kg (67-89 cm) and > 7 kg (> 89 cm). Migration data were also split between before and after 15^{th} of August to check for migration difference with and without dark hours around midnight.

Estimation of the minimum run of Atlantic salmon of sonar registered fish were completed by using binomial regression in R studio. The probability of a registered fish to be an Atlantic salmon is based on the sonar-measured length of the video identified fish. With the amount of data available and based on the probability of an Atlantic salmon with length as a predictor, Atlantic salmon run was estimated per week. Catch and sold fishing license statistics from 2020 in Máskejohka were collected and used to estimate catch per unit effort (CPUE), this data came from the local management (Johansen & Domaas, 2021). Catch statistics were used to compare with estimated Atlantic salmon run. When calculating CPUE, only day fishing licenses were included, because they are the only ones with reports of days without catch (zero catch), as well as daily catch. CPUE was calculated per week by dividing the catch number by the number of sold day fishing licenses for the corresponding week. Catch statistics also show how much of the net upstream migration have been caught and had to be subtracted from the spawning run before estimating the spawning stock of 2020.

$$CPUE = \frac{Number\ of\ fish\ caught}{Sold\ day\ fishing\ licenses}$$

3 Results

3.1 Sonar data

In total, 1 810 fish were registered during the study period. Of these, 1 270 migrated upstream and 539 downstream (Figure 8). The net upstream number was therefore 731 fish. A total of 202 fish migrated upstream the first week after reinstalling of the sonar after the flood impacts. The downstream migration of fish was low until week 29. Week 37 had both high upstream and downstream migration of fish, however, most of these were fish < 55 cm, and most of them were probably other species than Atlantic salmon. Most of the larger fish > 3 kg migrated upstream within the weeks 26-29. An unknown number of larger Atlantic salmon likely migrated during the weeks 23-25, which was the period with missing data. Most of the downstream migration were fish within length class 45-55 cm (70%) and were likely mostly grayling milling around in the area.

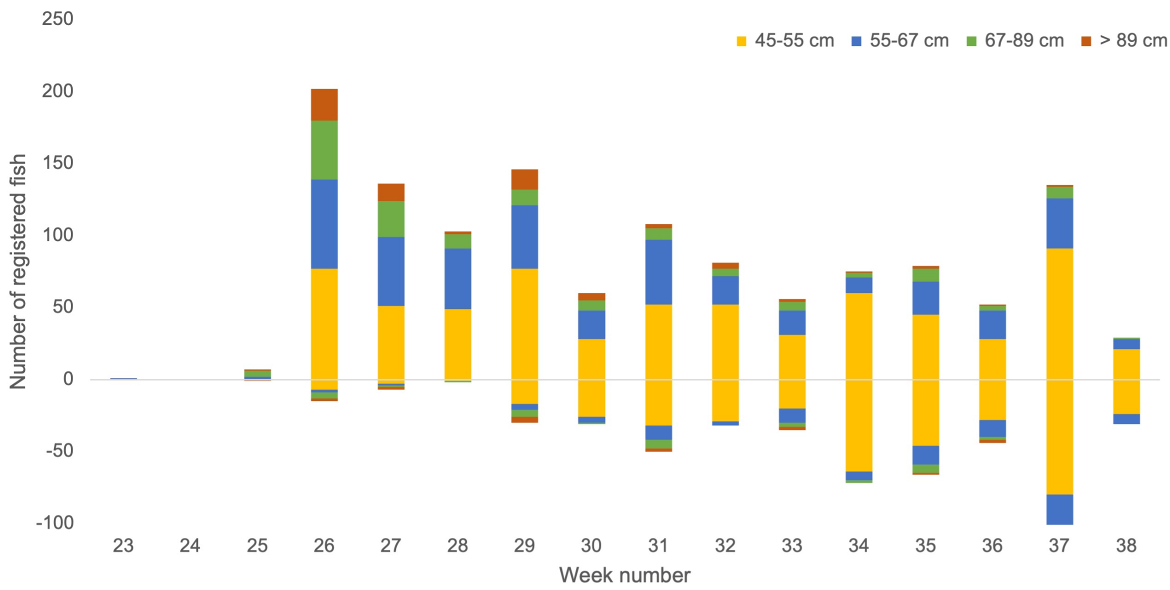

Figure 8. The weekly upstream (positive numbers) and downstream (negative numbers) migration of all fish species combined divided into different length classes, during the study period (31.05.2020-15.09.2020).

The largest registered fish, and that is most probably an Atlantic salmon, was 118 cm in length (corresponding to 16.1 kg). It migrated upstream 17th of July when there were not any underwater video cameras at the study site. The largest Atlantic salmon caught in Máskejohka in 2016-2020 was 18 kg, the largest caught in 2020 was 9.5 kg.

3.1.1 Diel fish migration

At these latitudes, it was light during the night entire June and July, however from mid-August every night became than the previous night. Therefore, diel data for fish migration was split between before and after 15th of August. The upstream migration had oscillations every 4-5 hours before 15th of August when the nights started darkening (Figure 9). The downstream migration was evenly distributed during the diel cycle before 15th of August, but with a lower downstream migration between 10 and 22, and with especially low downstream migration at the hours 03, 10 and 18. The downstream migrations was clearly dominated by fish in the smallest length class, 45-55 cm, and might have been dominated by grayling.

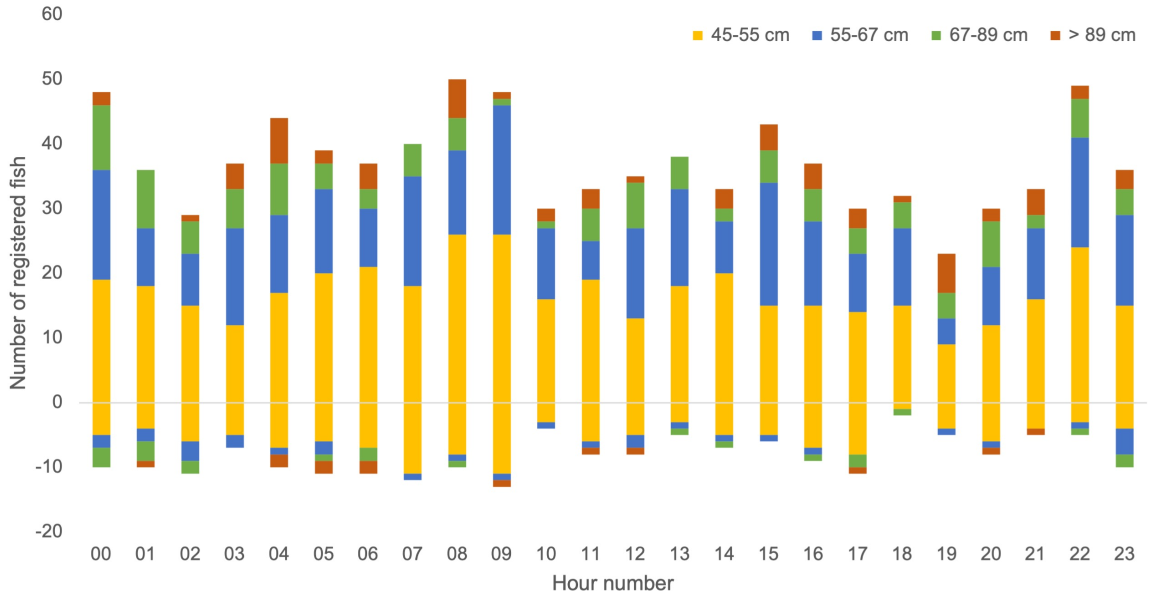

Figure 9. Upstream (positive numbers) and downstream (negative numbers) migrations of all fish species combined divided into different length classes and hour numbers, from the study period ***before*** *15th of August (31.05.2020-15.08.2020).*

The downstream migration after 15th of August was no longer evenly distributed through the days (Figure 10). Most of the downstream migration took place during the hours after midnight, with a top at hour 03. During the rest of the day, the downstream migration was quite level with fewer migrations. The upstream migration after 15th of August had similar pattern as before 15th of August, however, a larger proportion migrated during the night. The number of migrations upstream decreased after the nights started darkening by mid-August, and the amount of data after the 15th of August is smaller than before the 15th. After the 15th of August, among the fish < 55 cm, almost as many migrated downstream (243) as upstream (249). Among the fish > 89 cm, five fish migrated upstream and seven downstream, after the 15th of August.

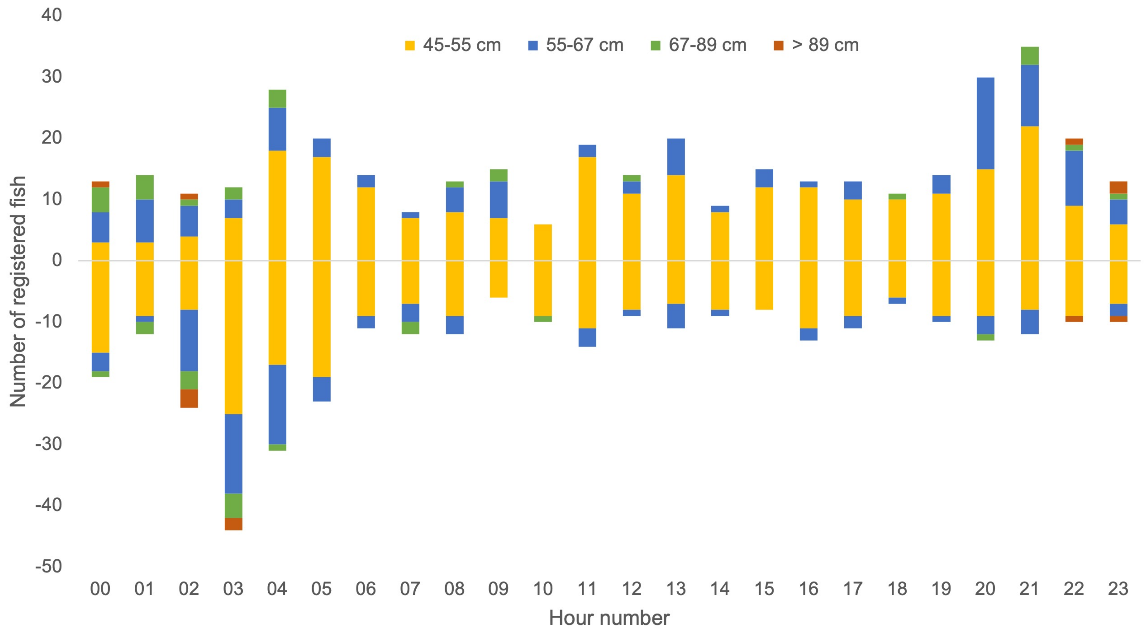

*Figure 10. Upstream (positive numbers) and downstream (negative numbers) migrations of all fish species combined divided into different length classes and hour numbers, during the study period **after** 15th of August (15.08.2020-15.09.2020).*

The average number of movements up- or downstream past the sonar was significantly higher during nights (from 20 in the evening to 8 in the morning) than days after 15.08.2020 (1.14 ± 0.16 movements per hour, day: 0.73 ± 0.02; t = -3.26, p = 0.004). No such differences were detected before 15.08.2020 (night: 0.86 ± 0.01, day: 0.79 ± 0.03; t = -1.17, p = 0.25).

3.2 Species identification with sonar and video

There were 242 registrations on sonar in the period the four underwater cameras were operative. Out of these, 210 (87%) were observed on at least one underwater video camera, and all except 2 (0.9%) were identified to species. During the records of underwater video several fish species were observed, and an otter, which was removed from the dataset. All the fish that were observed on video were also observed with the sonar.

Based on the 242 sonar registrations during the video period, camera 1 was expected to have 21 observations of fish, which would represent 9% of all the fish expected to be observed on all four cameras. Camera 2 was expected observe 102 fish (43%), camera 3 to have 102 fish (43%) and camera 4 to have 14 fish (6%). Three sonar registrations were closer to land than camera 1 and were not expected to be observed on any cameras. Video observations showed that camera 1 had five (2%) fish observed, camera 2 had 87 (41%), camera 3 had 102 (49%), and camera 4 had 16 (8%). Camera 2 and 3 in the center of the river channel, had 90% of the camera observations, and those observations were dominated by Atlantic salmon (57%) and grayling (32%) (Figure 11). Cameras 2 and 3 were expected to have almost all the observations. Camera 1 was expected to have more observations than camera 4, however, the opposite occurred with more observations on camera 4 than 1. Camera 1 had few observations, most probably due to its downstream angle, however, Atlantic salmon, pink salmon and pike were observed on camera 1. Camera 4 had only observations of grayling and trout, this camera was close to the guiding fence from the opposite shore. This area had varying light conditions and probably missed on some sonar registered grayling and stationary trout. The two trout observed on camera 4, they were 45 and 45.9 cm in length and probably were stationary trout.

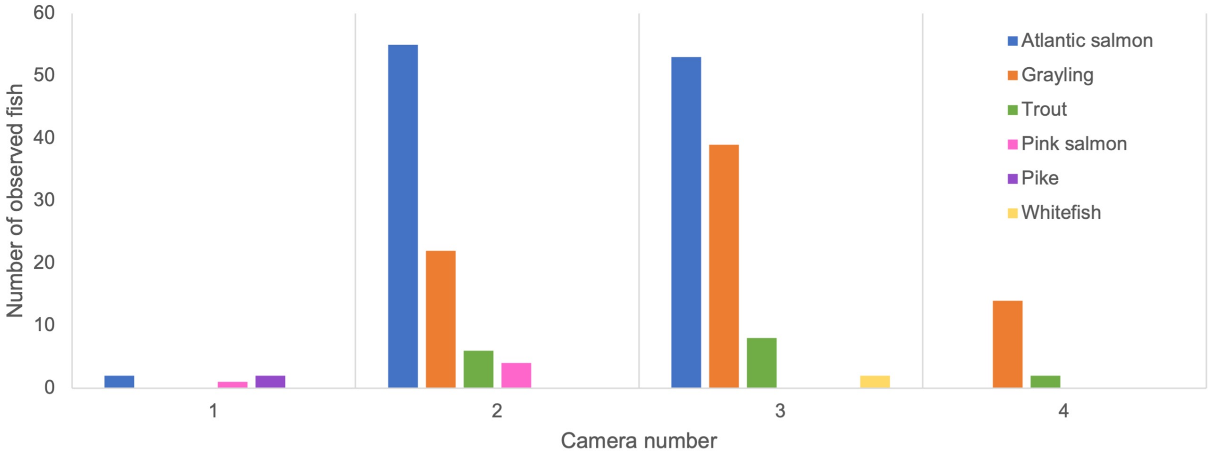

Figure 11. Distribution of fish species on the four different cameras during the video recordings (30.07.2020-14.08.2020). Both upstream and downstream migration are combined.

Migrating Atlantic salmon were observed in the video material every day of the video period, with daily numbers varying between 1 and 21 (Figure 12). The highest migration was observed on August 9-10, when 36 Atlantic salmon migrated after a heavy rainfall. Sixteen of these were MSW salmon larger than 67 cm.

Very few grayling were observed on video when Atlantic salmon migration numbers where at its highest. This was also observed on the hourly migration numbers (See Appendix Figure 2), where grayling dominated during the day (06-21) and Atlantic salmon during the night (22-05). Trout had an even presence during the video period, with video presence on 9 of the 16 days of video material.

A single pink salmon was observed on video migrating upstream on 11th of August, and three days later it migrated down again and stayed around the sonar for a while. It acted aggressively around the cameras for almost one hour before it swam downstream.

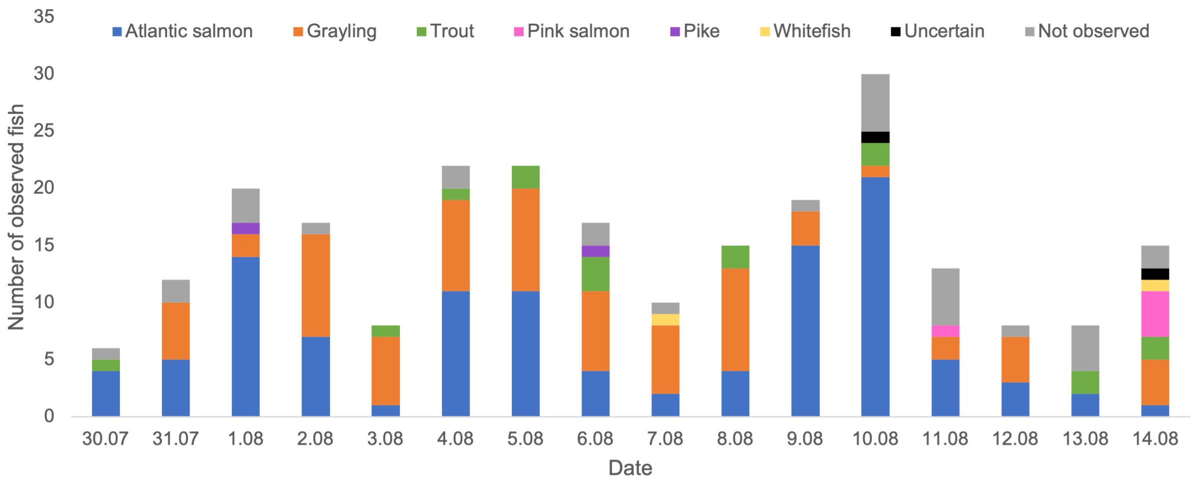

Figure 12. Distribution of fish species on each date during the video recordings period (30.07.2020-14.08.2020). Both upstream and downstream migration are combined.

The Atlantic salmon size distribution from the video recordings demonstrated a clear dominance of small salmon < 3 kg (Figure 13). Atlantic salmon between 3-7 kg were observed during the first days and last week of the video period. Atlantic salmon > 7 kg were only observed on four out of the 16 days with video material. The first and last days of video recordings were only half days of recording.

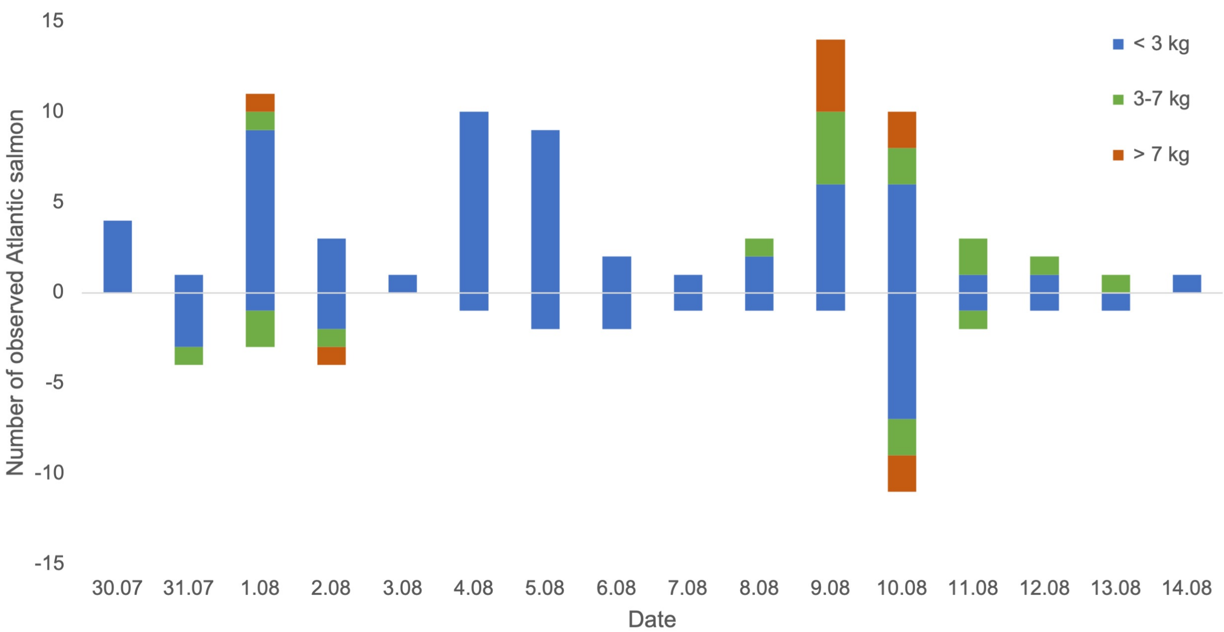

Figure 13. Distribution of weight classes of Atlantic salmon both upstream (positive numbers) and downstream (negative numbers) during the video recordings (30.07.2020-14.08.2020).

The video observed species showed a difference in both size (body length) and behavior. The latter was most pronounced for upstream migrating fish, whereas behavioral differences between species were difficult to find for downstream migrating fish. When fish swam downstream, almost all swam fast and straight downstream in the center of the river channel. Among the 242 sonar registered fish during the video period; 192 fish were attempted classified to species, 126 of these were labeled Atlantic salmon, 57 grayling, and 9 as trout. The remaining 50 fish had movement patterns that were difficult to identify, the majority of them (44) swam downstream, and 6 upstream.

After review of the underwater camera recordings, 210 fish were identified by video, of which 110 were Atlantic salmon, 75 grayling, 16 trout, 2 pike, 2 whitefish and one pink salmon (which swam past and around the sonar and video cameras several times). Thirty of the 242 sonar registered fish that migrated during the video recording period, were not observed on any cameras.

A total of 163 sonar observations between 45 and 67 cm were labeled to species and 141 of these could subsequently be checked with video (Figure 14). Of these 141 fish recorded both by the sonar and on video, 113 (80%) were identified correctly and 28 (20%) were wrong. There were more grayling and trout confirmed on video recordings than expected from sonar data, and less Atlantic salmon confirmed on video than expected from sonar data.

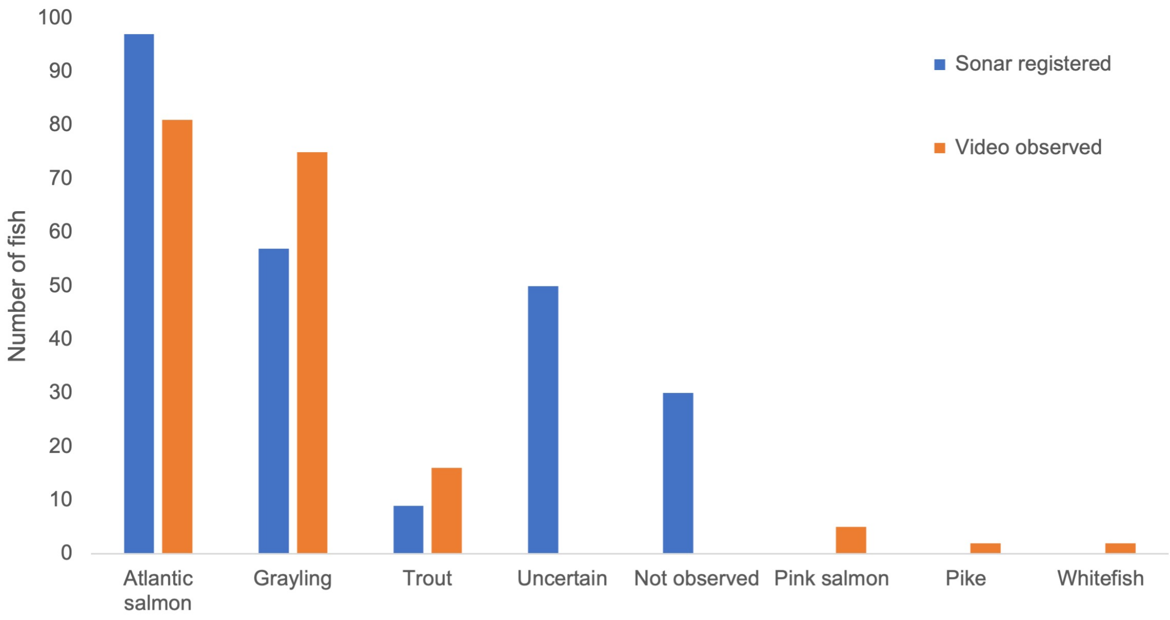

Figure 14. Species identification differences between sonar and video material. The uncertain are sonar fish that could not be identified with sonar data. Not observed are fish not observed on any underwater video cameras but were registered on sonar.

3.2.1 Species and lengths

All fish larger than 67 cm observed on video were Atlantic salmon, meaning that other species were only observed within the length classes smaller than 67 cm. During the entire study period, the length class of 67-89 cm contained a total of 177 sonar registered fish both upstream and downstream, while length class > 89 cm contained 90 fish both upstream and downstream.

The lowest proportions of Atlantic salmon were observed in the length class 45-55 cm. Atlantic salmon constituted 34% of the upstream moving fish and 24% of the downstream moving fish in this length class (Figure 15). Atlantic salmon constituted 79% of the upstream and 84% downstream moving fish in the length class 55-67 cm (Figure 16).

Grayling dominated both among the upstream and downstream moving fish in the length class 45-55 cm, with 54% and 64%. The largest registered and video observed grayling was 54 cm in length. Therefore, no grayling appeared in length class 55-67 cm.

Trout appeared in both length classes 45-55 cm and 55-67 cm. Trout represented 8% of both the upstream and downstream moving fish in length class 45-55 cm Trout represented a larger part of the upstream moving fish in length class 55-67 cm by 13%, and again 8% among the downstream moving fish. The largest trout observed and measured was 65.3 cm.

Whitefish appeared only in length class 45-55 cm with only two observations. The two observations of pike fitted into length class 55-67 cm.

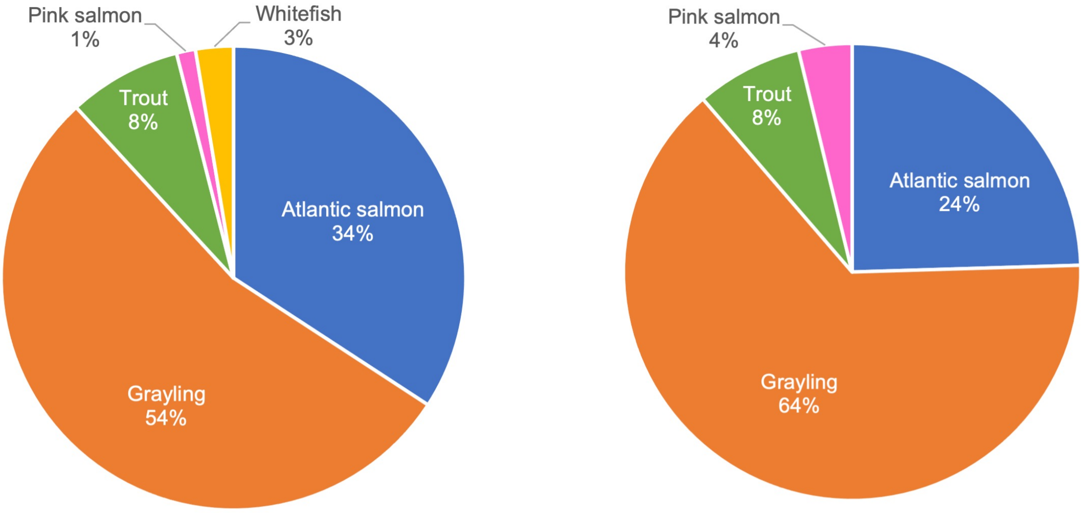

Figure 15. Species composition in percentage in length class 45-55 cm split between upstream (left) and downstream moving fish (right) during the video recordings (30.07-14.08.2020). Length class 45-55 cm contains 129 video observed fish, 76 upstream and 53 upstream.

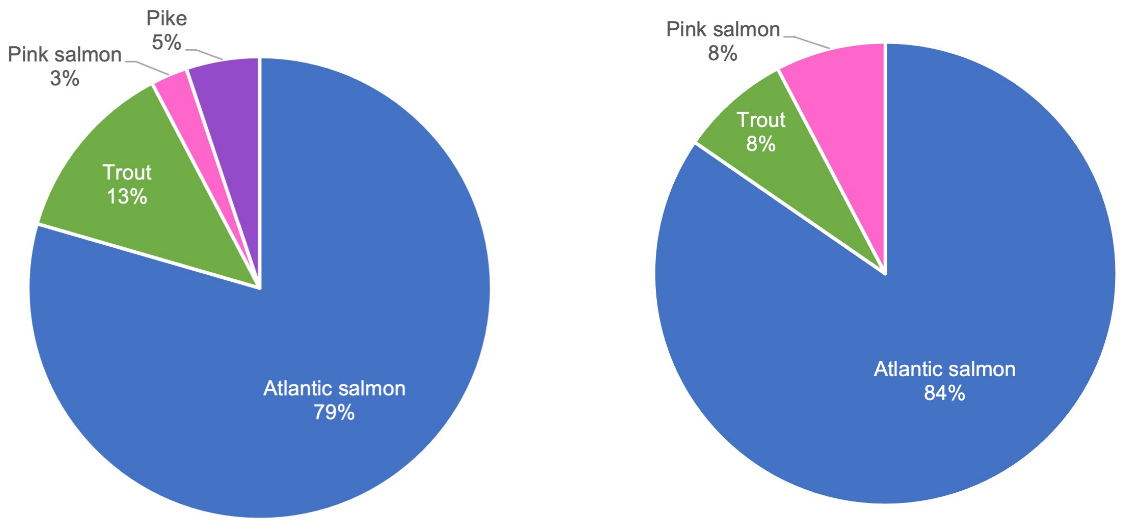

Figure 16. Species composition in percentage in length class 55-67 cm split between upstream (left) and downstream (right) moving fish during the video recordings (30.07.2020-14.08.2020). Length class 55-67 cm contains 52 video observed fish, 13 upstream and 39 downstream.

The average length measures of video observed fish species gave a clear difference between Atlantic salmon and grayling (Figure 17). The average length of Atlantic salmon was 63 cm, trout 52 cm, and grayling 48 cm. The single male pink salmon was observed and measured five times with an average length of 55 cm (length class 45-55 cm). The average length of the two pikes was 61 cm, while the average length of the two whitefish was 48 cm. This few observations of pink salmon, pike and whitefish may not give a representative image of the average length.

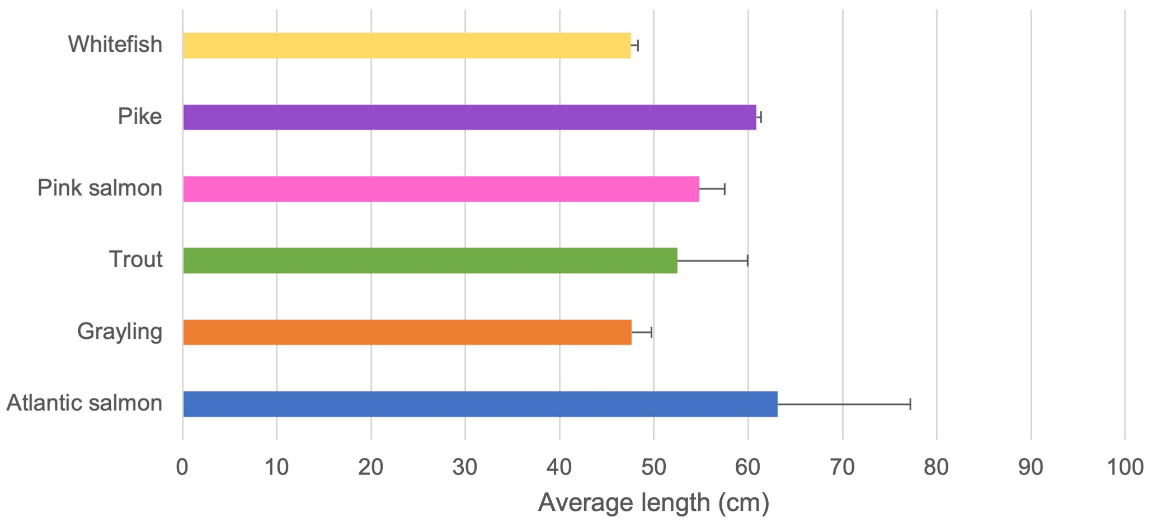

Figure 17. Average length of video observed fish passing the sonar and underwater video cameras during the video recordings (30.07.2020-14.08.2020). Both upstream and downstream migration are combined. Standard deviation is included.

3.2.2 Behavior

Atlantic salmon observed on video recordings migrated both upstream and downstream in the middle of the water column and in the center of the river channel, while grayling was more often closer to the bottom and closer to the opposite shore (Figure 18). Grayling, trout, pink salmon, and pike did not seem to fear the cameras or guiding fences and often swam close. When swimming face-down downstream, Atlantic salmon, trout, grayling, and whitefish all had similar behavior, but the video revealed that grayling were closer to the bottom. Atlantic salmon, trout, and grayling were observed moving downstream while facing both upstream and downstream. Few fish were sonar registered swimming closer to the sonar than 4 m, these few were not observed on any cameras.

Among the 30 fish not observed on any video cameras, these fish were moving about 1-6, 10-11 and 14-15 meters from the sonar. Most of the "not observed" fish (43%; 13 fish) were in the first 6 meters from the sonar, this was probably due to the switched angle of camera 1. Less "not observed" were in the center of the river channel between 7-10 meters from the sonar (23%; 7 fish), and from 11-15 meters (33%; 10 fish). Twenty-two of the fish that were not observed on video cameras were labeled to species based on sonar, 50% (11 fish) were labeled Atlantic salmon, 45.5% (10 fish) grayling, and 4.5% (1 fish) trout.

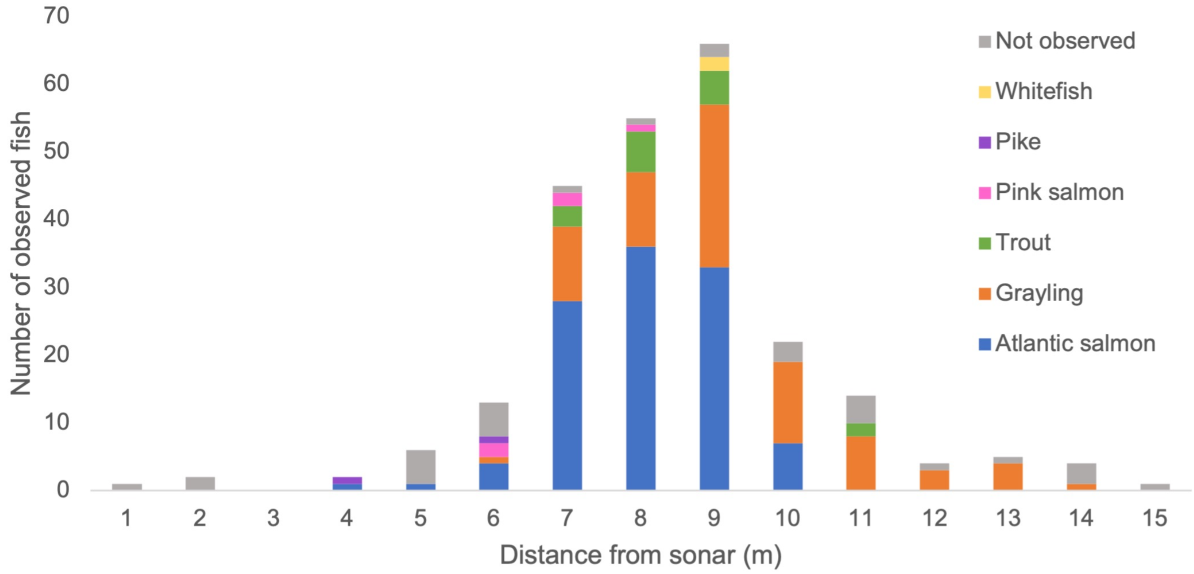

Figure 18. Distribution in distance from the sonar (m) of video observed fish and the "not observed" during the video recordings (30.07.2020-14.08.2020). Both upstream and downstream migration are combined. The distance from the sonar to the opposite shore was 17 meters.

Atlantic salmon and grayling had differences in use of distance from the sonar while swimming past the sonar. Atlantic salmon preferred to swim in the center of the river channel between 4-10 meters from the sonar, while grayling was observed mainly from 7-14 meters from the sonar. The proportion of Atlantic salmon among both Atlantic salmon and grayling at different distances from the sonar indicated a clear difference in distance from the sonar between the species during the video recordings (Figure 19). Over 50% of the fish were Atlantic salmon between 4 and 9 meters, dropping from 100% at 4-5 meters, over 70 to 80% at 6-8 meters and under 60% at 9 meters. The majority of the fish observed from 10 meters and towards the opposite shore were grayling.

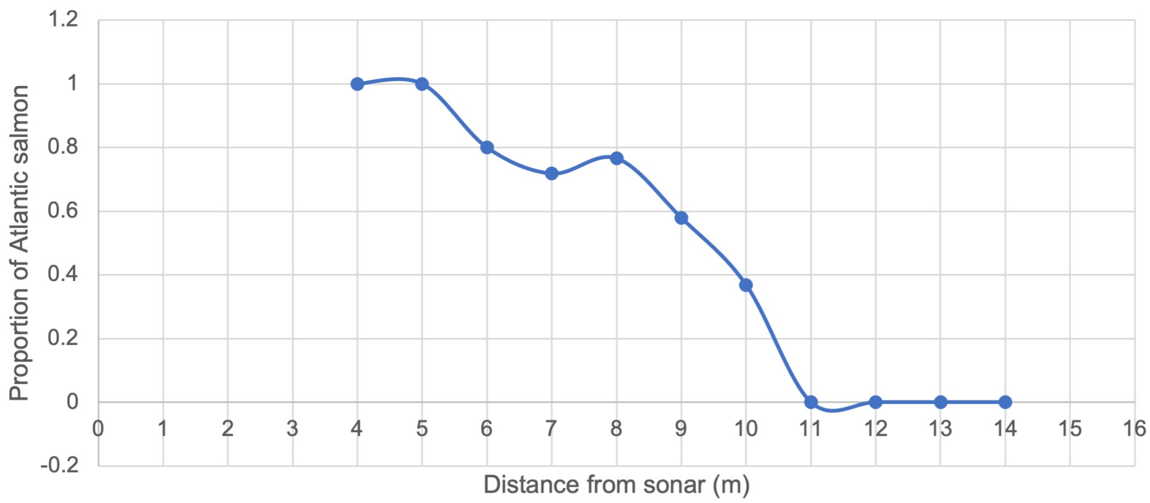

Figure 19. Proportion of Atlantic salmon among both Atlantic salmon and grayling observations on underwater video camera distributed on distance from sonar (m) during the video recordings (30.07.2020-14.08.2020).

The time spent swimming past the sonar window varied greatly between the species, especially between anadromous and stationary species (Figure 20). Whereas Atlantic salmon almost always migrated fast past the sonar, in less than 30 seconds, grayling was often observed feeding while moving upstream and therefore used more time passing the sonar. On average, Atlantic salmon spent 19 seconds moving upstream and 17 seconds downstream. Comparative numbers for grayling were 83 seconds upstream and 29 downstream. The swimming behavior of trout was similar to Atlantic salmon, spending on average 18 seconds upstream and 20 seconds downstream. There were only two observations each of whitefish and pike, all upstream. Whitefish used 15 seconds upstream and pike used 24 seconds upstream. The single male pink salmon did not only migrate past the sonar, but was milling around the cameras and acted aggressively, the measured time use probably was not representative for pink salmon.

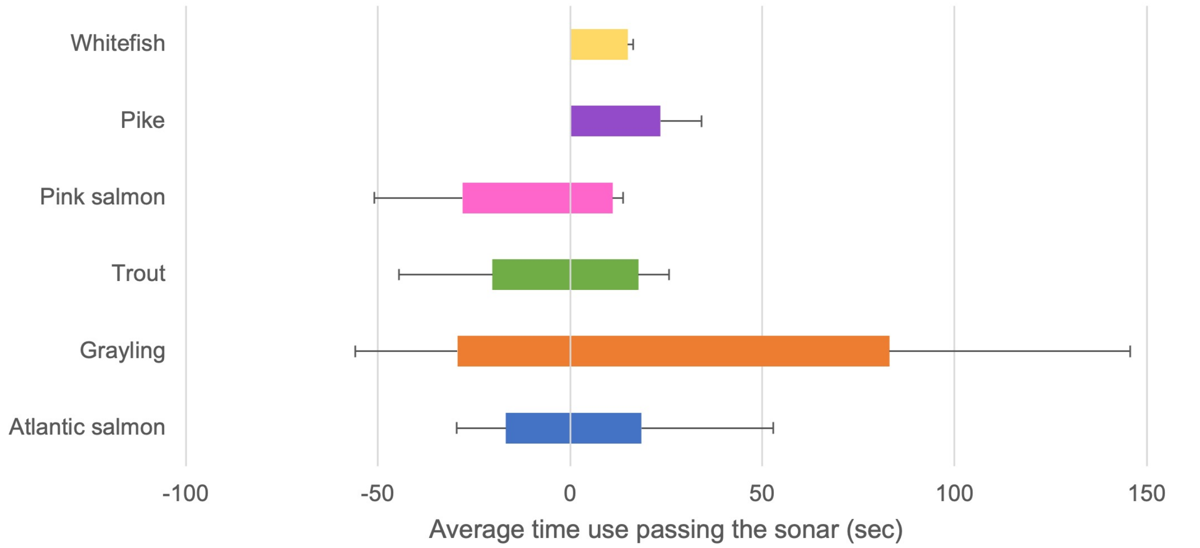

Figure 20. Average time use in seconds of video observed fish passing the sonar and underwater video cameras during the video recordings (30.07.2020-14.08.2020). Both upstream (positive numbers) and downstream (negative numbers) migration are combined. Standard deviation is included.

3.3 Snorkeling

Very few fish and few species were observed during snorkeling of the 5.5 km stretch from just above the sonar location and downstream. We observed only 3 Atlantic salmon, 3 trout and 22 grayling on this stretch. Atlantic salmon were only observed in the lower part of the snorkeling stretch, in an area with more gravel, and some known fishing spots.

3.4 Catch statistics

The number of Atlantic salmon caught in Máskejohka has varied along with varying fishing restrictions (Table 1). However, there has never been any bag limit or limited size of Atlantic salmon allowed to catch in Máskejohka. The price of day fishing license in Máskejohka was 450 NOK in 2016-2019, and 500 NOK in 2020. Locals can buy a season license for the entire watercourse at 700 NOK or restricted to their municipality for 450 NOK (TF, 2021).

Table 1. Overview of the fishing periods in Máskejohka from 2016-2020 for local and tourist fishing. (TF, 2021).

Year	Locals	Tourists
2016	20.05 – 31.08 (Monday – Sunday)	01.06 – 10.08 (Monday – Sunday)
2017-2018	01.06 – 10.08 (Tuesday – Sunday)	17.06 – 31.07 (Tuesday – Sunday)
2019 - 2020	1.06 – 20.08 (Monday – Sunday)	10.06 – 10.08 (Monday – Sunday) Limited to 350 day fishing licenses

The catch data was included to demonstrate the declining catch of Atlantic salmon in Máskejohka and was used to compare with estimated Atlantic salmon run for 2020. The catches have been reduced from 469 Atlantic salmon caught in 2016, 282 in 2017, 281 in 2018, 219 in 2019 and 136 in 2020 (Johansen & Domaas, 2021) (Figure 21). The 2020 catch of Atlantic salmon represent only 50% of the catches from 2018 and 2017, and only 29% of the 2016 catch. Year 2016 had both an early start and late ending of the fishing season both for locals and tourists. Still, 2016 had a higher weekly catch most of the weeks. The season of 2017 was like 2020 with a high spring flood and a late start of the fishing season. However, the weekly Atlantic salmon caught in 2017 was higher than in 2020 throughout almost the entire season. Both 2018 and 2019 had a normal spring flood, despite this, catches were much lower in 2019 than 2018. The week with the highest catch in most of the years was week 28, which is in early July, with variation from week 26 to 30. The season of 2016 had its peak in week 28 with 75 Atlantic salmon caught during that week.

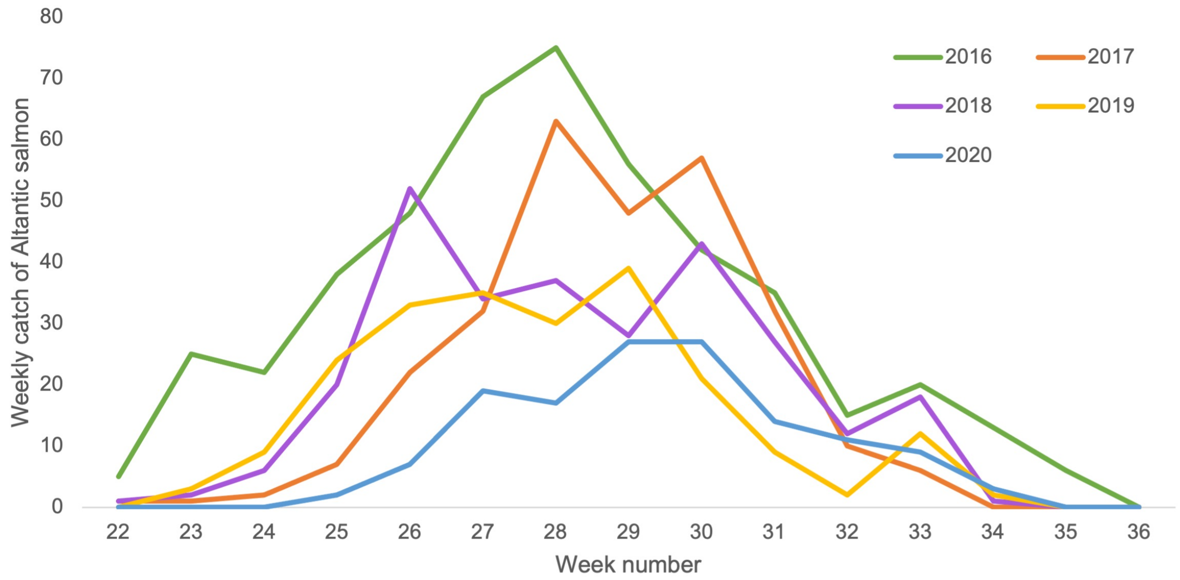

Figure 21. Weekly catch of Atlantic salmon in Máskejohka in the years 2016-2020. Catch data from (Johansen & Domaas, 2021).

Catch per unit effort (CPUE) has been calculated for each year from 2016 to 2020 for the day fishing licenses for each week of Atlantic salmon catch in Máskejohka (Figure 22). Total CPUE for each season for Atlantic salmon fishing in the last five years started with 0.47 in 2016, 0.29 in 2017, 0.48 in 2018, 0.33 in 2019 and to the lowest for these years, 0.25 in 2020. The CPUE was evenly lower in 2020 compared to all previous year in Máskejohka, however, 2020 had the highest CPUE in the last week of 32 within those years. The high CPUE in week 32 may be due to a postponed fishing season due to the large spring flood.

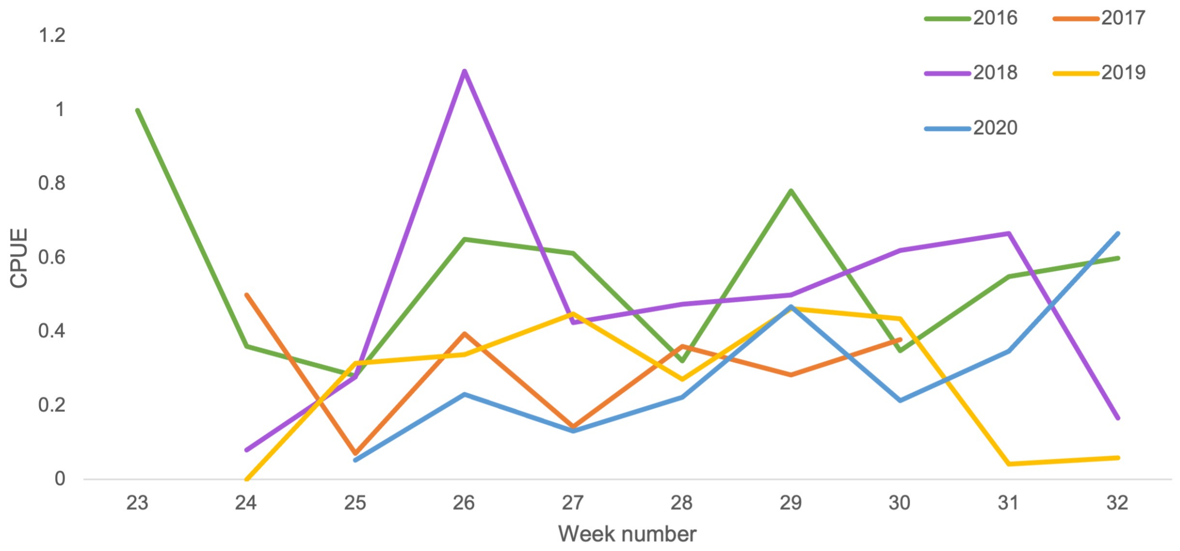

Figure 22. Catch per unit effort (CPUE) in the year 2016-2020 in Máskejohka on a weekly basis. These numbers were calculated based only on catches from day fishing licenses. Catch data from (Johansen & Domaas, 2021).

The cumulative run of estimated Atlantic salmon run in 2020 and catch of Atlantic salmon in Máskejohka had a slow start in 2020 until the weeks 25-26 (Figure 23). There was a time lag between the run and the catch of Atlantic salmon. The cumulative catch crossed the cumulative run in week 32, where there also was the highest CPUE in Máskejohka in 2020. This was also the last week of fishing in 2020, still the migration continued until September. The cumulative number of migrated Atlantic salmon almost flattened from the middle of August.

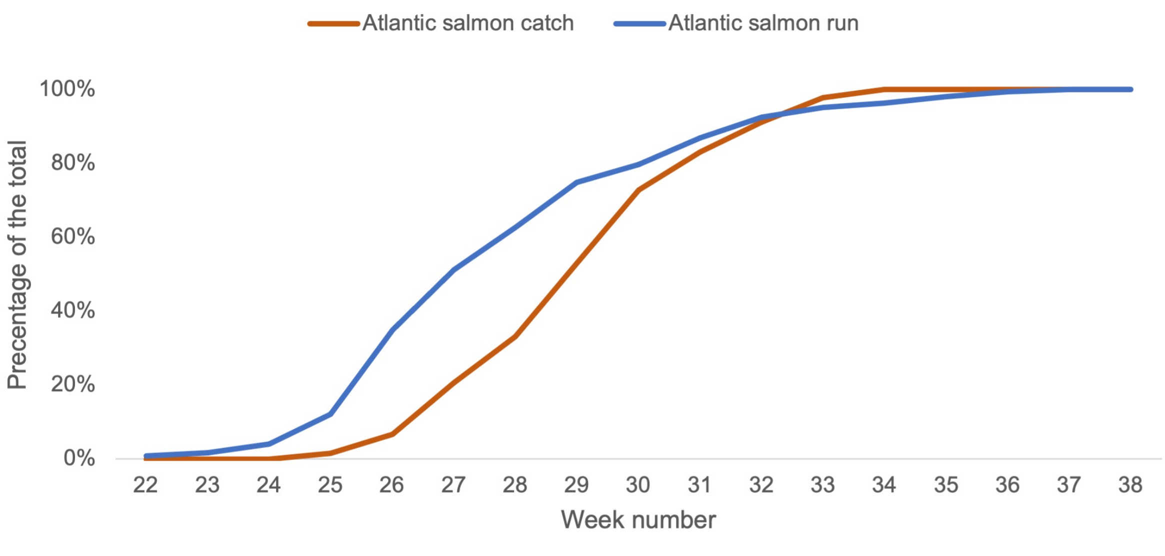

Figure 23. Cumulative estimated Atlantic salmon run (with spring estimations) and cumulative catch statistics of Atlantic salmon from the same year (2020) in Máskejohka on weekly basis demonstrated in percentage of the total. Catch data from (Johansen & Domaas, 2021).

3.5 Atlantic salmon spawning run estimation

When estimated with a binomial regression a minimum of 474 Atlantic salmon migrated upstream Máskejohka based on the sonar data from started at 21st of June until 15th of September. Only one possible Atlantic salmon was observed during the early study week before the flood caused loss of possible spawning run for a period. Grilse dominated the monitored spawning run in Máskejohka in 2020 (Figure 24). Most of the larger Atlantic salmon > 7 kg migrated in the late spring and early summer, only a few individuals were observed after week 32. Atlantic salmon of the middle size group (3-7 kg) also migrated predominantly in late spring and early summer, but individuals from this group continued to be observed later in the summer and fall.

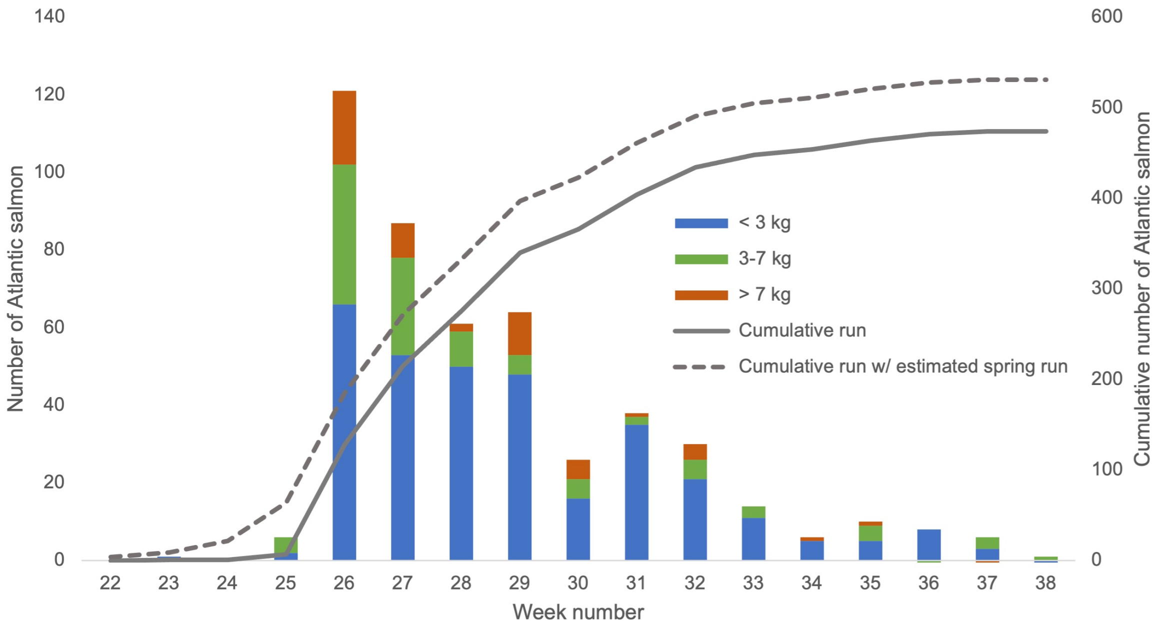

Figure 24. Weekly run of the different size classes of estimated Atlantic salmon run from sonar data during the study period (31.05.2020-15.09.2020). Along with minimum estimated cumulative spawning run (grey line) and same data including estimations of spawning run during the obstructed sonar period (dashed grey line).

According to the sonar data, a minimum of 474 Atlantic salmon migrated up Máskejohka. The early spring run with missing data was estimated to 64 Atlantic salmon. Accounting for the potential run during the missing data period, 531 Atlantic salmon migrated up Máskejohka in 2020.

Based on the catch statistics from Máskejohka for 2016-2020, 26 of the 64 estimated Atlantic salmon would be females. According to the 2020 catch statistics, 41% of the catch were females with an average weight of 4.8 kg. Average weight of males was 2.1 kg. The female proportion of the Máskejohka catch has varied between 35-49% in 2016-2020.

The female biomass needed to fulfill the Máskejohka production potential is between 1 100 and 2 000 kg. With an average weight of 4.8 kg, between 229 and 417 female Atlantic salmon would be needed to meet the spawning target. Based on the estimated run of 531 Atlantic salmon and a female proportion of 41%, the total run of females in 2020 would be 218 Atlantic salmon.

A total of 136 Atlantic salmon were caught in Máskejohka in 2020. A female proportion of 41% means that 56 females were caught, none of them were reported released back into the river. Subtracting the catch from the estimated run size gives a spawning stock of 162 females with biomass of 778 kg. The spawning target attainment would then be between 39 and 71% of the total female biomass needed, thus the spawning target for the Atlantic salmon stock in Máskejohka was not fulfilled in 2020.

4 Discussion

The methods of sonar and underwater video have been beneficial for underwater surveillance of aquatic creatures, especially due to its non-invasive technology. The methods are used by research organizations all over the world as a tool to preserve their endangered species. The method is not fail-proof, but is always under development for better surveillance (Ghobrial, 2019). The anadrome migration of Atlantic salmon gives the opportunity to monitor this species non-invasively, which is important now when the abundance of Atlantic salmon has been declining in the North Atlantic Ocean (Anon, 2020b). Monitoring by sonar has become an established method in monitoring Atlantic salmon stocks in Norway (Anon, 2020a). Especially the stocks of Atlantic salmon belonging to River Tana have been experiencing a huge decline in production and homing, and the need of monitoring has never been bigger.

This registration of the Atlantic salmon spawning run was the first in Máskejohka with sonar, as well as with video. The method of using sonar and video was well suited for monitoring Atlantic salmon spawning run in Máskejohka. The decision of sonar location was challenging but appeared to be excellent. The sonar covered the entire fish passage across the river by use of guiding fences and probably did not miss any passing Atlantic salmon. This was supported by the video material, as Atlantic salmon migrated in the center of the river channel. As expected, the location was not a milling place for Atlantic salmon with lots of up and down movement, which was also confirmed by the video material. The decision of sonar location within a study river may be difficult and complicated. The location should not be a milling place for the study object, and no other elements that would disturb within the sonar window. The connection to power is also important, either via solar panel or close civilization. The solar power may be unstable, while close civilization may disturb the project. The possibility to install the sonar close to a trusted farmer further away from the rest of the civilization appeared to work very well.

Unusual natural conditions made this study more difficult than it would be in most years. An extraordinary harsh spring flood inundated the whole floodplain of the river valley and caused large amounts of debris to accumulate on the sonar, which delayed the onset of data collection. Similar issues have occurred at other sonar projects, with debris covering the sonars and guiding nets, making the fieldwork more time consuming and complicated (English & Roias, 2020). The Máskejohka discharge increased heavily in the days following during the installation of the sonar and guiding fences, inundating the floodplain, causing avalanches that resulted in high turbidity and uprooting several larger trees that floated downstream (personal and local observations). The dirt avalanches and the formation of new river channels aggravated water turbidity and made it impossible to use underwater video cameras even after the sonar started working efficiently.

Despite the difficulties, the sonar data collection covered most likely the most important spawning migration period of Atlantic salmon in 2020 by 78% of the study period. The catch statistics show that only two Atlantic salmon were caught in Máskejohka before the sonar were cleaned and realigned, a very low catch compared to the two previous years with normal spring floods. And only one possible Atlantic salmon was observed before the sonar became covered by debris in the first study week. This may indicate that only a limited number of Atlantic salmon entered Máskejohka under these harsh flood conditions. However, fishing is also difficult during such flood events, and a low catch does not necessarily confirm a low spawning run of Atlantic salmon. Both high and low water temperatures may affect the upstream migration of Atlantic salmon, that might have delayed the fish migration, especially when low temperatures from ice and snow melting coincide with spring flood (Thorstad et al., 2008). The harsh conditions might have delayed the upstream migration of Atlantic salmon in the first half of June, until the river started calming down in the third week of June. I would however recommend installing sonar soon after the study river is ice-free to cover most of the spawning run. Amount of snow and weather forecast will signal the size of the spring flood.

Despite calming down, discharge continued to be unusually high well into July. But dry conditions in the late summer in August (personal observations) led to low water levels in the river mouth of Máskejohka. When the water levels are low Atlantic salmon will gather in sand pools in the River Tana main stem just below the Máskejohka river mouth (Berg, 1964). Low water levels, especially in smaller rivers, may delay the upstream migration for shorter periods depending on the flow development, affecting the larger MSW salmon the most (Jonsson, 1991). Local river guards have noted observations of Atlantic salmon following river boats up the river mouth of Máskejohka during low water periods. An increased migration of mid- and large-sized Atlantic salmon were observed after a large rainfall in mid-August, migration was very low in the days preceding the rain. The tide can have an effect on the upstream migration where the majority of Atlantic salmon migrate up during the hours of highest tide (Karppinen et al., 2004), whereas studies in Tana has shown low tide effect on upstream migration (Erkinaro et al., 1999). Local fishers in the lower part of River Tana experience an affect from the tide on their fisheries, that more Atlantic salmon runs upstream with the high tide (pers med. S. K. Pedersen). The tide effect was however not investigated in this thesis.

The species composition at the counting site largely followed expectations with a clear dominance of Atlantic salmon and grayling. The main surprise was the number of sea trout at the study location during the video period. Local knowledge and personal experience from fishing indicates that sea trout are relatively rare in Máskejohka, and few trout are reported caught in Máskejohka in catch statistics. However, this can be due to trout not being the main target when fishing in Máskejohka. Trout was observed and measured with length between 45 and 65.3 cm The larger trout observed were probably sea trout on spawning run in Máskejohka, while the smaller trout could be stationary trout. The observations of whitefish and pike in the video recordings were also expected. Pike was observed moving downstream with only two observations close to the sonar and is probably not abundant at the study location due to habitat characteristics of the area. The observation of a pink salmon was not expected, as the pink salmon have a two year life cycle where they migrate up rivers and spawn every second year (Sandlund et al., 2019), and the Russian introduced pink salmon that we have in Norwegian rivers spawn in odd years (Mo et al., 2018).

Separating by size gives a clear image of the size differences between the fish species present in Máskejohka. The proportion of Atlantic salmon increased with length, and within length > 67 cm was only Atlantic salmon observed. Grayling was only observed < 55 cm and dominated that length class. Due to a season with grilse of smaller size, it was important to separate Atlantic salmon and grayling within the smallest length class of 45-55 cm (Fortuna, 2021). Atlantic salmon was observed in small sizes down to 45.1 cm. However, the grilse run were lesser in number during the 2020 season (Anon, 2020a). The length class of 45-55 cm proved useful to separate grayling from Atlantic salmon. The average length of the different species confirmed again a clear difference between the species. However, they will always overlap in the length class < 67 cm.

Behavior difference between species was highly visible, especially between anadromous fish and stationary fish. Atlantic salmon and sea trout swam straight forward, in the center of the river channel and used normally less than 30 seconds to pass the sonar window upstream. This behavior is probably due to that they are on a migration route and not feeding while they are on spawning migration (Bardonnet & Bagliniere, 2000; Johansen et al., 2011). However, evidence of freshwater feeding exists in the neighboring tributary, Lákšjohka, but were not found in Máskejohka (Johansen, 2001). Still, little is known about feeding while on spawning migration.

Grayling in average spent longer time swimming past the sonar window compared to anadromous fish, but they could also swim as fast as an anadromous fish downstream. There was however observed a difference between anadromous fish and stationary fish where in the water column they swam. Atlantic salmon and sea trout were observed swimming in the center of the water column, while grayling often swam close to the bottom. If further development of sonar equipment includes positioning of the fish in the water column, it would be easier to species identify fish with only sonar data. Studies involving sockeye salmon and chinook salmon showed a difference in spatial use when migrating upstream. Sockeye salmon swam near the bottom and closer to the shores where it was shallower, while chinook salmon swam in the deeper center of the river channel in water with higher velocity (Holmes et al., 2006).

At the latitude of Tana, during the midnight sun period, the Atlantic salmon, both adults and smolts, do not show any clear migration pattern with respect to the time of the day according to (Karppinen et al., 2004). With increasing levels of darkness in August, the sonar data show that fish migration up and down past the sonar were more concentrated towards evenings and nights. After 15th of August, migration of fish of all sizes happened primarily during the night between 2 and 5 pm. The Atlantic salmon in Máskejohka migrated more at night (See Appendix Figure 2). The opposite migration pattern has been observed of Atlantic salmon while migration through a fish pass in Scotland, where the migration was reduced during darkness (Gowans et al., 2003). The opposite salmon behavior was also discovered of migration of sockeye salmon in a Pacific river, where almost all salmon migrated during daylight, in contrast from other Pacific rivers (English & Roias, 2020). In mid-August grayling were almost absent during the time when larger Atlantic salmon were in the area. (See Appendix Figure 2). This may be due to grayling fearing larger Atlantic salmon, or that grayling is more active during daylight. When grayling are threatened it swims away and does not hide (Nykänen et al., 2001). However, most of the registrations in Máskejohka during the night after 15th of August and after video recordings were ended, were smaller fish, and most likely grayling. Several shoals of smaller fish, with some individuals larger than 45 cm, were observed on sonar during the two last weeks of the study period (in September). These shoals may be grayling on fall migration, earlier grayling have been observed in shoals entering tributaries in the early fall (pers med. Falkegård). This may be the reason for high migration numbers in week 37. Grayling is known to form shoals outside the spawning season, for protection from predators (Nykänen et al., 2001).

Separating Atlantic salmon and sea trout with sonar was difficult, this makes the use of underwater video cameras an important supplement, especially when establishing first time monitoring sites. Species composition proportions from catch statistics would not be representable, since most anglers target Atlantic salmon while fishing. There is often also little incentive to report any catch of trout or other species than Atlantic salmon. The differences in size and swimming behavior were sufficient to separate anadromous fish (Atlantic salmon, brown trout) from stationary fish (grayling) in the sonar data. This is however, with a certain error rate depending on the experience of the observer. This was my first-time processing and analyzing sonar data. Among the sonar registered fish > 55 cm, 80% of the fish were identified correct. I believe that the error rate of 20% could be declined with even more experience. It is recommended to use the same technicians that are trained to both do the fieldwork and to process the sonar data (English & Roias, 2020).

The opportunity to map the species composition with the non-invasive underwater cameras next to the sonar is a better method than gillnets, especially if mapping an endangered species. However, is not a matter of course, due to the light limitations. It was possible in Máskejohka because it was enough light though the video recordings to identify species. The species composition may vary during the day (See Appendix Figure 2), it is therefore important to have a diel data coverage at the study site. Gillnets were used to map the species composition in a Pacific river as a contribution of the DIDSON and ARIS sonars (English & Roias, 2020). Use of underwater camera earlier in the season and for a longer period could provide a wider understanding of the species composition and would give a more representative species composition with possible seasonal variations. Especially during odd year seasons with pink salmon entering Norwegian rivers, due to that pink salmon overlap in size and behavior with Atlantic salmon and trout, and may be difficult to separate from our anadromous fish (Vøllestad, 2019c). The need for underwater cameras to map the species composition and to separate species depends on the species precent and the size differences between the species inhabiting the study area. In my study the camera approved very useful, especially for the estimation of Atlantic salmon run, by using length as a predictor for probability of a fish being an Atlantic salmon among the other fish.

Very few Atlantic salmon were observed while snorkeling the Máskejohka downstream of the sonar. Based on the snorkeling, it was concluded that upstream migration had mostly ended and that the stretch between the main stem of River Tana and the sonar location is of little importance for spawning. This supports the classification of the lowermost Máskejohka as a low production area for Atlantic salmon below the sonar location (Falkegård et al., 2014). According to locals in Máskejohka, there is only one possible spawning location in the lower part of Máskejohka (at a spot called Ávggostnjárga), however, we did not observe any Atlantic salmon in that location during the snorkeling. Snorkeling as a method might be an important supplement to sonar and video in cases where there are significant production areas below the counting site, in these cases snorkeling counts will be necessary to assess the complete spawning stock size. Snorkeling to observe fish species- and densities has proven as a valid method (Orell et al., 2011).

Both the total catch of Atlantic salmon and the catch per unit effort (CPUE) was lower in Máskejohka in 2020 compared to the four previous years. This may partly be explained by the harsh spring flood and continuous high water levels well into July, however, the spring flood in 2017 was almost as harsh as in 2020 and in both years. It took a while until Máskejohka reached a normal summer water levels, environmental conditions should therefore have affected the 2017 and 2020 catches in a similar way. The number of day fishing licenses has declined in the later years, but the CPUE was still lower in 2020 than the previous years. From personal conversations with anglers who used to fish in Máskejohka, several have told they quit fishing there due to experiencing low CPUE when fishing in Máskejohka and that they have therefore moved on to fish in other Atlantic salmon rivers in Finnmark. I have also seen less and less anglers in Máskejohka during the nine last years of working as a river ranger in River Tana. However, catch data alone is not a reliable predictor of stock abundance of Atlantic salmon (Hendry et al., 2007). The effort of fishing is only calculated of day fishing licenses, while locals buy season licenses, and do not have to report for days without catch. If a local angler fish for several days without catching anything, does it not show in any statistics. If an angler buys a day fishing license, we do not know how much time the angler spends fishing, how skilled the angler is or how the river conditions are affecting the chance of catch. However, CPUE is the only predictor we have about the fishing pressure, which should give a signal about a declining fish abundance.

A combination of sonar, video and catch data was used to estimate the spawning stock size of Máskejohka. This spawning stock calculation included an estimate of the spring period when sonar data were missing. The spawning target of Máskejohka indicates that between 229 and 417 female Atlantic salmon are needed to reach the Atlantic salmon production potential. The estimated female run size in Máskejohka was below the lower limit of the spawning target, indicating that there was no sustainable surplus available for exploitation within this tributary in 2020. According to the ICES, catch of Atlantic salmon should not be allowed when the conservation limit is not achieved (ICES, 2020). If the spawning targets are not fulfilled, the consequences may be a river closed for fishing for several years to recover the Atlantic salmon stock. In its latest report, the Tana Monitoring and Research Group estimated the 2020 spawning stock size in Máskejohka to be within the range from 580 to 1 000 kg, with approximately 750 kg as the most likely value (Anon, 2020a). This estimate was based on the 2020 catch statistics and an estimate of the exploitation rate of Máskejohka Atlantic salmon fishery and was close to the spawning stock estimate from this thesis (778 kg).

An earlier study, based on River Tana catch statistics, indicate that most of the female MSW salmon, migrated up their rivers earlier than the male MSW salmon (Niemelä et al., 2006). A 4-year study counting migrating Atlantic salmon with video cameras in the River Ohcejohka, a tributary further up in the Tana river system, found that early migration consisted mainly of large MSW salmon which experienced a higher exploitation rate compared to the smaller grilse that ascended later in the summer (Borgstrøm et al., 2010). The observed spawning run data confirmed the migration of larger fish earlier in the season also in Máskejohka. Grilse belonging to Máskejohka has been confirmed to enter fresh water in the early July (Vähä et al., 2011). Most female Atlantic salmon in Máskejohka are relatively large, approximately two thirds of the females are 2SW Atlantic salmon (Falkegård et al., 2014) and three quarters of the Atlantic salmon larger than 3 kg are females (Anon, 2020a). Given the early migration of larger Atlantic salmon, the larger females in Máskejohka may therefore be exposed to a higher exploitation rate than smaller males. The high pressure on early migrating Atlantic salmon can, potentially reach unsustainable levels and the current situation for Máskejohka indicates that this has been the case. The latest evaluation recommends initiating a stock recovery program for the Máskejohka Atlantic salmon stock (Anon, 2020a). Historically, the fishing regulation in Máskejohka has contained no measures aimed at sparing large females. This in contrast to many other Norwegian rivers where larger females are either subject to very strict quotas or even supposed to be released alive, especially in the rivers that have been struggling with fulfilling their spawning targets. Some rivers also postpone the start of the fishing season to let the larger female Atlantic salmon migrate before the exposure from fishing. Introduction of regulations on fishery has shown to increase the number of Atlantic salmon spawning in other salmon rivers (Aprahamian et al., 2006).

More years of monitoring the spawning run of Atlantic salmon may detect run size variations of Atlantic salmon ascending the river (Anon, 2020b). The run size of Ohcejohka varied from 1 297 fish in 2004 to 6 664 fish in 2006, and the largest variation appeared within the grilse and smaller MSW salmon (Borgstrøm et al., 2010). This thesis provides the first count-based estimate of the fishing pressure and the spawning stock size within Máskejohka, but further counts are needed to demonstrate the relation between run size, number of fishing licenses and the resulting exploitation pressure. This is especially important given the current stock development within River Tana. During the spring of 2021, following recommendations from the Tana Monitoring and Research Group, Norway and Finland decided to ban all Atlantic salmon fisheries in River Tana for the 2021 fishing season. The current decision is that this is a one-year ban only, and a decision for 2022 will be made based on the next status report from the Tana Monitoring and Research Group. Given the need for a stock recovery in Máskejohka, mitigating measures need to be taken to ensure reduced fishing mortality of larger females, and I would recommend the local management to use quotas and release demand on female Atlantic salmon above 4 kg when Máskejohka reopens for fishing. The weight limit of 5 kg for female Atlantic salmon is a custom limit in Norwegian rivers, and the average weight of a female Atlantic salmon in Máskejohka 2016-2020 was 4.8 kg. River Tana has had a recommendation to release Atlantic salmon above 80 cm, corresponding to 5 kg.

In conclusion, this study has contributed to further development of sonar monitoring of fish and will work as a comparable project for other monitoring projects with sonar. The estimated Atlantic salmon run numbers will contribute the local management with the river fishery management. This study supports the hypothesis of Atlantic salmon and grayling being the dominating fish species in the study area. Along with support of the hypothesis of that it is possible to separate anadromous fish from stationary fish with only sonar data, with an error rate of 20% by a first-time observer. The hypothesis of being a diurnal difference in migration was confirmed with difference in migration numbers between day and night before and after mid-August. With higher migration numbers during the nights and from diel migrations during the video recordings Atlantic salmon dominated during the night. For future research, I recommend further sonar monitoring in Máskejohka and in other rivers with lacking reliable numbers of spawning migration. However, I recommend using supplement of video and snorkeling in a first-time monitored river, numbers of video and snorkeling can be used in later years as predictors.

Appendix

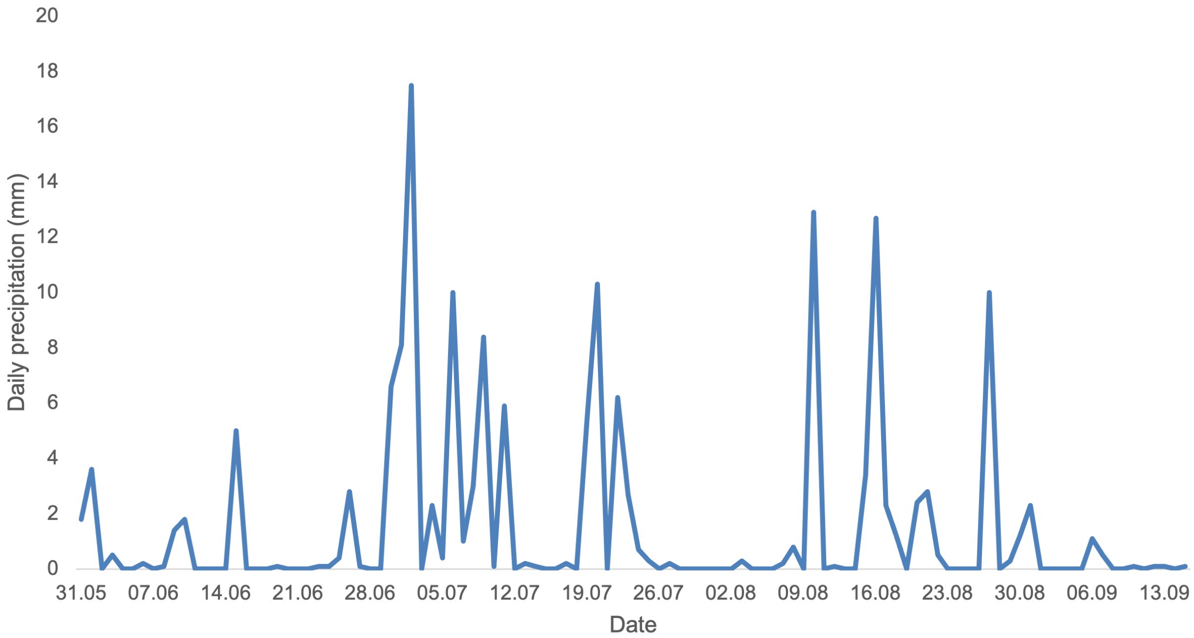

Figure 1. Daily precipitation (mm) at Tana bru weather station during the study period (31.05.2020-15.09.2020). These numbers may not correctly represent the precipitation for the precipitation field of Máskejohka.

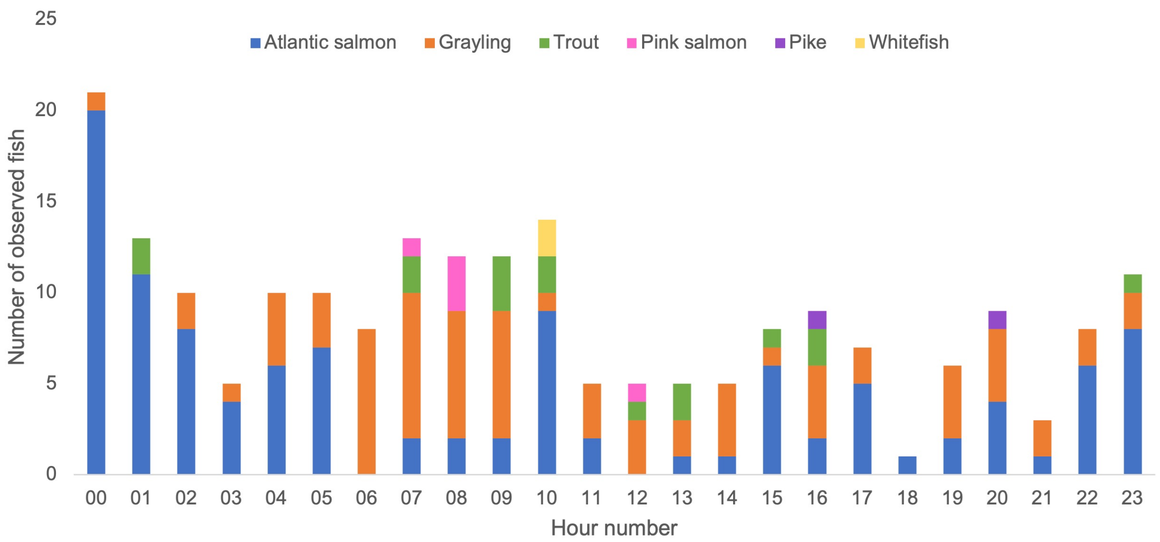

Figure 2. Hour number distribution of species passing the sonar and video cameras during the video recordings (30.07.2020-14.08.2020). This is both upstream and downstream migration combined.

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