Master's thesis

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Department of Biology

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The effect of surveillance fishing on migrated distance of Atlantic salmon (*Salmo salar* L.) during the spawning period

Master's thesis in Natural Science with Teacher Education
Supervisor: Jan Grimsrud Davidsen
Co-supervisor: Robert Lennox
June 2022

NTNU
Kunnskap for en bedre verden

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Abstract

Atlantic salmon (*Salmo salar* L.) have been subject to an increasing number of threats over the last decades, which have led to declining populations and even some populations being extirpated. One of the greatest threats is the presence of escaped farmed salmon at the spawning grounds in the native rivers. The farmed salmon can successfully interbreed with the wild salmon, which has been shown to cause significant genetic outbreeding effects to the wild populations. In the effort to handle this problem, designated surveillance fishing surveys can be performed to estimate the proportion of farmed salmon represented in the spawning stock. These surveys take place after the recreational fishing period, and therefore closer upon spawning. The effect of being caught and released (C&R) has been shown to alter the short-term behaviour of salmon after release, but no long-term effects have been identified. However, the fact that surveillance fisheries are conducted much closer upon spawning could lead to behavioural effects that influence the reproductive success of the C&R salmon. To test this, the migrated distance of Atlantic salmon caught in the river Orkla (n = 74) were tracked by use of radiotelemetry. One group was tagged during the regular fishing season in the summer, while one was tagged during the autumn surveillance fishing. The results showed that the summer and autumn group of salmon moved on average respectively 11.9 kilometres and 12.6 kilometres (median; 6.5 and 7.8 kilometres) in total accumulated absolute distance, and 0.75 kilometres and 0.70 kilometres per day during the period 11 October – 31 October 2021. This indicate that there were no long-term effects from surveillance fishing. Long downstream movements (>10 kilometres) between two consecutive tracking days were observed in ten different Atlantic salmon (16%), where four of the individuals were C&R late in the surveillance period. Stressors from C&R too close upon the spawning period could have caused these long downstream movements and possible no participation in the spawning. Based on this observation, it is suggested that surveillance fishing should be stopped more than two weeks before the assumed spawning period, to provide a sufficiently long period for recovery after C&R. The total mortality of wild Atlantic salmon from surveillance fishing was 9.3%, which must be considered a significant negative consequence of these surveys. The proportion of farmed salmon captured was 8.3% of all captured salmon, which is defined as a medium proportion based on government standards. Out of the tagged salmon, 18% entered one of many tributaries to Orkla river during the tracking period, which indicate that surveillance fishing should also be conducted in these smaller watercourses to get a best possible estimation of the proportion of farmed salmon represented in the spawning stock.

Sammendrag

Atlantisk laks (*Salmo salar* L.) har blitt utsatt for et økende antall trusler de siste tiårene, noe som har ført til synkende bestander og til og med utryddelse av enkelte bestander. En av de største truslene er tilstedeværelse av rømt oppdrettslaks ved gyteplassene i elvene. Oppdrettslaksen kan gyte sammen med villaksen, noe som kan forårsake betydelige genetiske effekter for de ville bestandene. I arbeidet med å håndtere dette problemet kan vi utføre egne undersøkelser, som overvåkingsfiske, for å estimere mengden oppdrettslaks i gytebestanden. Disse undersøkelsene blir utført etter sportsfiskeperioden, og derfor nærmere gyting. Effekten av å bli fanget og satt ut har vist seg å endre kortsiktig atferd til laks etter utsetting, mens langtidseffekter ikke har blitt påvist. Det faktum at overvåkingsfiske utføres mye nærmere gyting kan føre til atferdseffekter som påvirker reproduksjonssuksessen til laksen. I denne studien undersøkte jeg den migrerte avstanden til atlantisk laks fanget i Orkla (n = 74) i perioden 11 oktober til 31 oktober 2021 ved hjelp av radiotelemetri. Laksen ble delt inn i to grupper, de fanget på sommeren (kontroll), og de fanget på høsten under overvåkningsfisket (eksperiment). Sommer- og høstgruppen av laks beveget seg henholdsvis i gjennomsnitt 11,9 kilometer og 12,6 kilometer (median; 6,5 og 7,8 kilometer) totalt, og 0.75 kilometer og 0.70 kilometer per dag i perioden 11 oktober – 31 oktober 2021, noe som ikke indikerer langtidseffekter fra overvåkingsfisket. Lange nedstrøms bevegelser over 10 kilometer mellom peileintervallet på 2 dager ble observert hos 10 forskjellige atlantiske lakser (16 %), hvor fire individer ble fanget sent i overvåkingsperioden. Disse resultatene kan indikere en effekt fra overvåkingsfiske, der fisken var for utmattet fra fang og slipp til å delta i gytingen. Fra denne observasjonen bør overvåkingsfisket stanses mer enn to uker før antatt gyteperiode, for å gi fisken en tilstrekkelig lang periode for restitusjon etter fang og slipp. Den totale dødeligheten av vill atlantisk laks fra overvåkingsfiske var 9,3 %, noe som må anses som en alvorlig negativ konsekvens av disse undersøkelsene. Den estimerte andelen oppdrettslaks i elva fra denne studien var 8,3 %, hvor all oppdrettslaks ble korrekt identifisert og avlivet. Av den merkede laksen gikk 18 % opp i en av mange sideelver til Orkla i løpet av peileperioden, noe som tilsier at det også bør drives overvåkingsfiske i disse mindre vassdragene for å estimere mengden oppdrettslaks representert i gytebestanden på en mest mulig representativ måte.

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1 Introduction

Atlantic salmon (*Salmo salar* L. 1758) is a salmonid species that is indigenous to temperate, subarctic, and Arctic coastal regions of the Atlantic Ocean (Aas et al., 2010, p.12). The species is considered as an important game fish and gourmet food (Shelton, 2014). However, the Atlantic salmon (hereafter referred to as salmon) populations have declined in numbers and range, and some have been extirpated (Dadswell et al., 2022), but due to its high economic value that has resulted in intensive farming and global expansion of its non-native distribution, the species is highly abundant along the Norwegian coastline (Gross, 1998). The farmed salmon is a result of an artificial selection that has led to increased growth rate, age at maturity, and fat content, and has reduced egg size, genetic diversity, and stamina compared to wild salmon (Gross, 1998). Although these differences make wild and farmed salmon distinct, they can still spawn together and produce reproductive offspring (Skaala et al., 2012).

When salmon escapes from aquaculture facilities, they can aggregate with wild salmon at marine feeding areas and join the migration into fresh water (Hansen & Jacobsen, 2003). The abundance of farmed salmon in Norwegian rivers is typically 3-9% in the summer and 2-14% in autumn (during spawning) (Thorstad et al., 2021). One of the greatest threats to the wild salmon populations is this presence of escaped farmed salmon at the spawning grounds (Bolstad et al., 2021; Forseth et al., 2017; Wringe et al., 2018). Interbreeding with farmed salmon have been shown to alter age and size at maturation in wild salmon populations (Bolstad et al., 2021), and hybrid development rates are often mismatched to prevailing environmental conditions, which will reduce the total survival of young salmon (Fraser et al., 2010). These consequences can cause a severe decline in salmon populations, and therefore also reduce the total economic value of sportfishing in regions with salmon rivers (Kjelden et al., 2012). Hybridization between farmed and wild salmon is recorded in almost all regions where salmon aquaculture and wild populations co-occur (Wringe et al., 2018). Wild salmon are physically more fit and have a higher reproductive success than farmed escapees and hatchery-reared salmon (Fleming & Einum, 1997; Fleming et al., 1996). The first generation of hybrids could be able to pass physical obstacles such as waterfalls due to higher fitness than pure farmed individuals, and therefore expand introgression in the river (Diserud et al., 2022). The first-generation hybrids have also shown higher rates of straying, and thus spreading introgression to other rivers as well (Jonsson & Jonsson, 2017).

Migrating salmon can be monitored both in the ocean and in the river, where the caught farmed salmon can be euthanized to prevent competition and hybridization (Aronsen et al., 2019). Surveillance fishing in the ocean is conducted by setting up traps along key migration points (Hvidsten et al., 2004). Monitoring of the mature migrating salmon in the river can be done in several ways, but a widely used method is to perform designated fishing surveys after the recreational fishing period (Lennox, et al., 2017b). Anglers who fish in the regular period during the summer will also to some extent be able to identify caught escaped farmed salmon, but in many cases, genetic analysis or scale reading are necessary to determine the origin of the salmon (Fiske et al., 2005; Lund & Hansen, 1991). This is a consequence of hybrids or smolt-escapees, which are especially difficult to distinguish from wild salmon. The catches of farmed salmon in the regular fishing period can also be underrepresented because the farmed salmon often enters the river later than the wild salmon (Moe et al., 2016; Svenning et al., 2017).

The designated fishing surveys after the recreational fishing period should be done two weeks after the recreational fishing period and end two weeks before the presumed spawning period (Aronsen et al., 2016). These surveys are conducted using a traditional rod and line, with the intention of performing catch and release (C&R) on presumed wild salmon and the presumed farmed salmon are killed. All caught salmon are sampled for scales, which will be analysed to determine the origin of the salmon and verify the field assessment. From these data, the percentage of farmed salmon represented in the spawning stock can be calculated and it can then be assed if any further actions are required to reduce the number of farmed fish in the river.

During surveillance fishing, there will be a large proportion of wild salmon caught close to the spawning period. These salmon will often have completed their upriver migration (Økland et al., 2001), unlike the salmon caught in the summer that are often caught while migrating upstream. The effects of being C&R have been shown to alter the behaviour of salmon caught in the recreational period (Havn et al., 2015; Mäkinen et al., 2000; Thorstad et al., 2003), but survival of the released salmon is high (Lennox, et al., 2017a), especially if the water temperature is below 18^{o} C (Keefe et al., 2022). The C&R practice is widely used in Norwegian rivers, but to work properly it is reliant upon the salmon surviving and contributing with offspring to their native river after release (Tufts et al., 2000). Along with C&R, there is potential risks that are hard to avoid such as physical injury (caused by hooking, landing, and handling), air exposure (oxygen deprivation during handling), and generalized primary and secondary stress (fear response and exhausting exercise) (Arlinghaus et al., 2007). The C&R may end in death or sublethal effects such as reduced reproductive success, increased susceptibility for diseases, reduced growth, and behavioural impairments (Cooke et al., 2013).

The aim of the present study was to evaluate if surveillance fishing caused behavioural differences in migrated distance of wild salmon, using a control group caught in the summer as an indicator of normal behaviour. Based on earlier knowledge from Lennox, et al. (2017b) that indicated no prolonged effects of surveillance fishing, the objectives were to investigate migrated distances in the Orkla river in terms of; (1) relative migrated distance per day in the period 11 October – 31 October 2021, and (2) total migrated distance in the period 11 October – 31 October 2021. All salmon that were caught and released in this study were tagged with a radio transmitter and tracked intensively in the three weeks between 11 October and 31 October 2021.

2 Methods

2.1 Study site

The study site of this project was the Orkla river, which is in central Norway. The river has a catchment area of 3092 km^2 and drains into the sea via Trondheimsfjorden (Hvidsten et al., 2015). The river has several tributaries that provide habitat to both anadromous salmon and anadromous brown trout (*Salmo trutta* L.). The wild salmon have a natural travelling route in the main river up to Ulsberg, which is about 90 kilometres upstream of the total 170km of the river (Harby et al., 2010). There is a hydropower facility at Bjørsetdammen that is the only large artificial obstacle along the migration route. The salmon can pass this obstacle and access the spawning grounds further upstream. The recreational fishing season in the river is 01 June – 31 August and the average catch of salmon from the year 2000 to 2021 was 22531kg (Statistics Norway, 2022).

2.2 Map

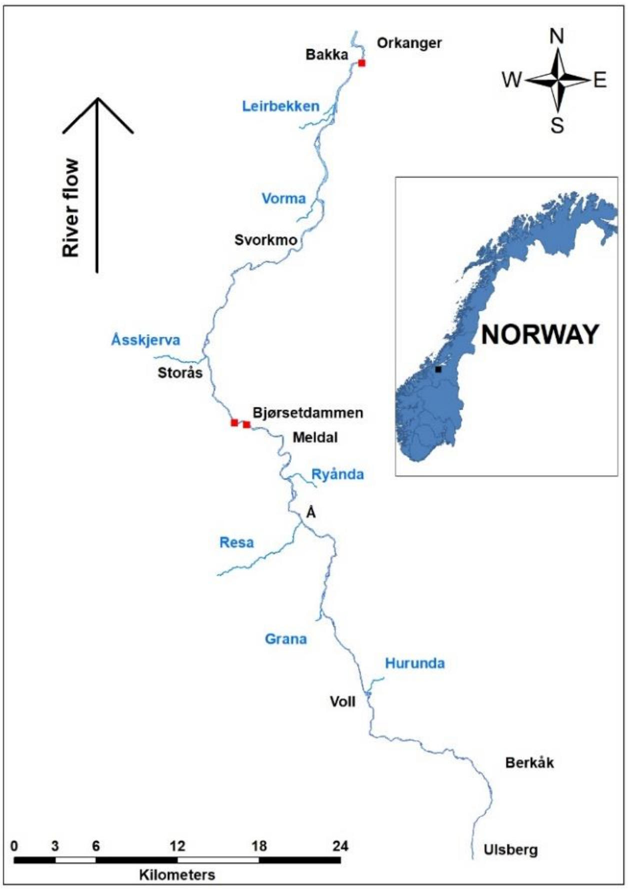

Figure 1: Map of the study area which is the anadromous part of Orkla river (Credit: NINA). Red dots are stationary listening stations, blue text marks the tributaries to Orkla river visited by tagged salmon and black text gives some of the local urban areas along the river are marked with. Note that the river flows south to north and that Bjørsetdammen is a hydropower facility which is the only large artificial obstacle along the migration route of the salmon. The salmon can pass this obstacle and access the spawning grounds further upriver. The map is produced in ArcGIS (version 10.8.1).

2.3 Experimental design

2.3.1 Tagging

Two groups of Atlantic salmon were caught and tagged with radio transmitters in the period 26 June – 04 October 2021. The first group (summer group) consisted of 34 salmon that were caught between 26 June – 20 July 2021 (Figure 2), by various anglers in the Orkla river. The second group (autumn group) was caught between 07 September – 04 October 2021 (Figure 2) by many of the same anglers as the first group.

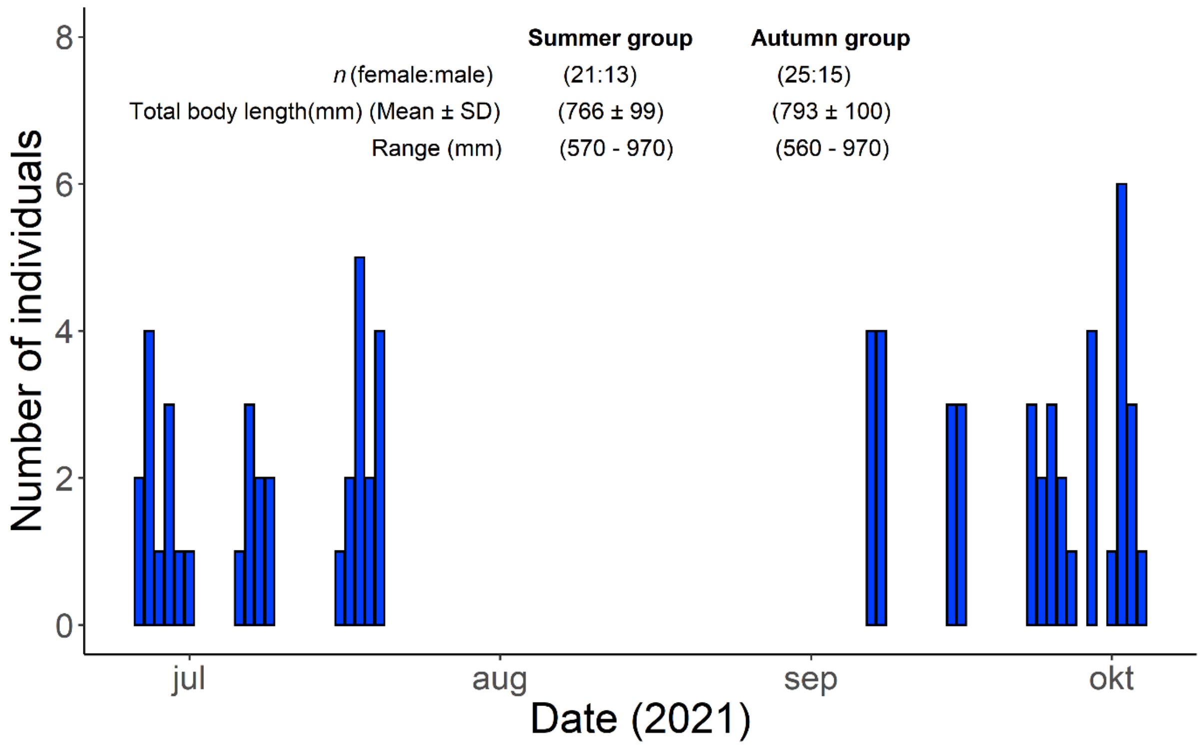

Figure 2: Tagging dates for both the summer and autumn group of salmon in Orkla river 2021. The bars indicate the number of tagged salmon for each date in the period 26 June – 04 October 2021. The summer group were tagged between 26 June and 20 July 2021 and the autumn group were tagged between 07 September and 04 October 2021. The sex-ratio and length data of the tagged salmon are also presented for the two groups.

Both groups were caught using rod and line, baited with flies *(n* = 32), metal spoons *(n* = 19), spinners *(n* = 14) or worm *(n* = 9). All fish caught on worm was in the summer group and carefully checked for injuries before release, since there is a tendency of deep hooking with this method, increasing the mortality of released salmon (Havn et al., 2016). All fish caught on spinners was in the autumn group. The fish tagged in the summer were caught by local anglers, and the person tagging the fish was not able to be always present. To account for this problem the anglers were equipped with a submergible tube that could hold the salmon until the tagger arrived the location. The salmon were on average held in the submerged tubes for 157 minutes (range 15- 664 minutes). The autumn group did not include this submergible tube, since the anglers always were accompanied by a tagger.

Atlantic salmon in both groups were tagged externally with a radiotag model F2120 (Advanced Telemetry Systems, Minnesota, USA) (https://atstrack.com/tracking-products/transmitters/product-transmitters.aspx?serie=F2100). The tag itself is flat and square, measuring 21 x 52 x 11 mm and 16 g in air. The effect the radiotag has on swimming performance in adult salmon has earlier been tested in laboratory trials, and was considered to be insignificant (Thorstad et al., 2000). Estimated battery life was 299-535 days for each radiotag, depending on the battery used and how often it is asked to transmit a signal. Each radiotag used in the study transmitted a signal with a frequency in the range 142.113-142.342 MHz along with a unique code that was used for identification.

Prior to radiotagging, the fish in the summer group were anesthetized with Benzoak vet. (ACD Pharmaceuticals AS) with a concentration of 0,125 – 0,250 mlL^{-1}. The concentration was adjusted based on water temperature and condition of the fish. The summer group were anesthetized due to requirements from the Norwegian Food Safety Authority (Mattilsynet). The fish in the autumn group were tagged without anaesthesia to most accurately replicate the methods used in surveillance fishing and to avoid bias of the pharmokinetic effects. After capture, the salmon was transferred to a tagging tube where the transmitter was externally attached just below the dorsal fin. This was done by using two hollow needles that were pushed through the salmon’s dorsum 2 cm below the dorsal fin. The transmitter was then attached by pulling metal wires through the needles and joining the two wires on the opposite side. The reduced distance between the wires on the opposite side reduces the angle, and therefore also reduces the erosion of the flesh (Økland et al., 2001). During this procedure the salmon had a wet cloth over its eyes, which reduced stress in the fish. After the procedure, the salmon were monitored while recovering. When the fish showed significant effort to swim on its own, it was released back into the river. During the procedure, the fish were also scale-sampled, measured, sexed, and assessed for any scars or damages. Further, the handling time as well as the recovery time were noted. The average handling time was 10 minutes (SD = 2 minutes; range 7 – 15 minutes) and the average recovery time was 5 minutes (SD = 16 minutes; range 1 – 110 minutes) where the majority of the recovery times were between 1-5 minutes. Only 4 out of 74 salmon had a recovery time longer than 10 minutes and all of these were in the summer group which included anaesthesia. Out of 74 tagged fish, one transmitter was never detected after release.

Mortality from catch and release was calculated as the percentage of fish that died prior to, or after tagging based on tracking data. The fish had to perform an upriver movement more than two days after release, to be considered a survivor. Fish that did not meet these requirements were verified to be survivors or dead by snorkel surveys.

2.3.2 Tracking

The tagged salmon were tracked using two methods. In May 2021, four automatic radio listening stations were set up in the Orkla river at three locations (figure 1). One listening station was located at the mouth of the river, by the outlet of Orkla river down in the centre of the town of Orkanger. Listening station number two was located further up the river, 400m below the Bjørsetdammen power plant. The last two listening stations were located at Bjørsetdammen power plant. These stations consisted of a stationary radio instrument (ATS model R4500c) that detected the signals from the tagged salmon as they travel near the station. The detection range of the stationary listening stations was not measured, but they confirmed to pick up every fish that migrated past it by manual tracking.

Manual tracking was conducted by vehicle using a magnetic dipole antenna (Laird Technologies) on its roof and the radio instrument (ATS model R4500c) connected inside. This was used to roughly position the salmon, while a hand-held 4-element yagi antenna was used to position the salmon in the river with highest possible accuracy (± 5-100m, depending on the width of the river).

The tracking regimes from 20 June – 31 October 2021 is presented in (table 1). In addition to these tracking regimes, Gaula river and Stjørdal river were manually tracked by car to investigate if any of the tagged salmon who left Orkla river had migrated up these nearby rivers. This was done three times in both rivers as personnel from the study drove along these rivers. The two days with non-stop 24hours tracking were conducted on ten selected salmons. The salmon selected were relatively close to each other in the river to make the tracking more efficient and convenient. The salmon were tracked in the following days after release in the effort to ensure survival.

Table 1: Period of tracking, frequency of tracking and accuracy of tracking. The accuracy of tracking was split into three categories, low, medium and high. Low indicates using only the car with the magnetic dipole antenna. Medium indicates using the car with the magnetic dipole antenna combined with using a four-element yagi antenna to roughly position the salmon either up- or downstream. High indicates using the car with the magnetic dipole antenna combined with using a four-element yagi antenna to position the salmon with high accuracy in the river. This includes using multiple angles to get a good cross-section of the salmon in the river.

Period of tracking	Frequency of tracking	Accuracy of tracking
20.06.2021 - 07.09.2021	Every ten days	Low/Medium
07.09.2021 - 15.10.2021	Every Monday	Medium
15.10.2021 - 01.11.2021	Every second day	High
9 a.m. 18.10.2021 - 9 a.m. 19.10.2021	Every 4 hours	High
9 a.m. 28.10.2021 - 9 a.m. 29.10.2021	Every 4 hours	High
One, two and four days after release	One point per day	High

2.4 Data filtering

The initial number of radiotagged fish was 74, but several individuals were excluded from the analysis due to various reasons. Eight salmon from the summer group migrated out of the river after tagging. Among these, six salmon were confirmed migrating up a different river. Three salmon were confirmed in Gaula river, two were confirmed in Stjørdal river and one were confirmed in Mossa river, the last two individuals were not located after migrating out of Orkla river (figure 3). The individual in Mossa river was confirmed by capture by a local angler. One salmon from the summer group was not located after tagging, possible due to transmitter malfunction or recapture. Two salmon from the summer group were captured and killed by anglers after tagging. The transmitters of two salmon were found on land, one from the summer group and one from the autumn group, indicating that the fish were dead. There were not detected any remains from the two dead salmon on land. This resulted in 22 salmon from the summer group and 39 salmon from the autumn group that were included in the analysis.

The data were filtered by date of tracking. The data included in the analysis were from the period 11 October – 31 October 2021, but with some exclusions. The data from the intensive tracking periods from 9 a.m. 18 October – 9 a.m. 19 October 2021 and 9 a.m. 28 October – 9 a.m. 29 October 2021 were excluded, except the last registration of each fish that were kept due to the tracking interval of every second day, which included both 19 October and 29 October 2021. All data filtering were conducted with R version 4.1.1 (www.r-project.org) and the R-package dplyr (Wickham & Wickham, 2020). The reason to use these data was that by 11 October the autumn group would likely not display any immediate tagging response, since the last salmon was tagged a week prior.

Two fish left the river between 11 October – 31 October 2021, where one left 13 October and the other left 29 October. The fish that left 13 October later re-entered the river 29 October. The data from these fish are included in the analysis, but only when they were present in the river.

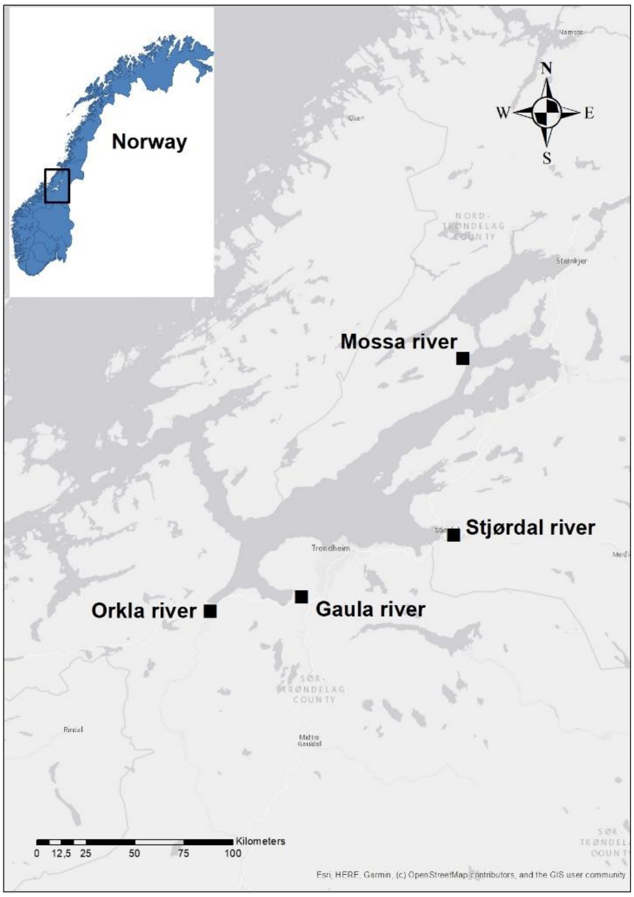

Figure 3: Map over the Trondheimsfjord with the rivers that tagged salmon from Orkla river entered after leaving Orkla river. The black boxes show where the different river mouths are located along the fjord. Three salmon entered Gaula river, two salmon entered Stjørdal river, and one salmon entered Mossa river. The map is produced in ArcGIS (version 10.8.1).

2.5 Calculation of absolute migrated distance

For calculation of distances, the least cost path principle was used and calculated in R. This is a measure of the minimum linear distance between two points around a boundary. The least cost path was calculated by establishing a transition matrix using the raster package (Hijmans et al., 2015). To account for positional errors, a 100-meter buffer zone was drawn around the river polygon. The Orkla river polygon was rasterized at a resolution of 10 meters and a transition matrix was established with eight possible directions. The least cost distances from the river mouth were calculated using the shortestPath function from the gdistance package (van Etten, 2017). The distances moved for an individual salmon between tracking intervals were calculated for each least cost path using the gLength function from the rgeos package (Bivand et al., 2017). To calculate the accumulated distances moved, the function summarise from the package dplyr was used (Wickham & Wickham, 2020).

2.6 Statistical analysis

After filtering the data, the statistical analysis in this study were conducted with R. The statistical level of significance was set to $P < 0.05$. Statistical tests were performed on length data, distance data, and positional data for analysis of variance between the summer and the autumn group. Due to non-normality of the data the Mann-Whitney U test was implemented. The normality of the data were tested with the functions shapiro.test and ggqqplot from the package ggpubr (Kassambara, 2018). For analysis of variance between three or more groups, Tukey ANOVA was applied from the R package "base".

For analysis of accumulated absolute migrated distance, a generalized negative binominal linear model (glm.nb) was used from the package MASS (Ripley et al., 2013). The data did not meet the assumptions of a Poisson model (glm) due to overdispersion and had to be fitted with a negative binominal distribution. In order to compare the variables (distance from river mouth and total body length) with each other, the function "scale" from the R "base" package was used. The regression model included group (summer/autumn), sex (female/male), total body length, tackle (fly/spoon/spinner/worm) and relative distance to the river mouth on 11 October. The best fitting model(s) were identified with AICc (Akaike's information criterion) with the function aictab from the package AICcmodavg (Mazerolle & Mazerolle, 2017). The model selection provided two alternative models ($\Delta AICc < 2$) (Anderson et al., 2001). The model that contained the most parameters was chosen as the best model to predict the estimated accumulated absolute migrated distance.

To test for possible differences in the relative absolute migrated distance, a generalized negative binominal linear mixed-effect model (glmer.nb) from the package MASS was used with random effect of each individual salmon. The data did not meet the assumptions of a Poisson mixed effect model (glmer) and had to be fitted to a negative binominal distribution due to overdispersion. In order to compare the variables (day of the year, distance to river mouth and total body length) with each other, the function "scale" from the R "base" package was used. The regression model included group (summer/autumn), sex (female/male), total body length, tackle (fly/spoon/spinner/worm), day of the year, relative distance to the river mouth on 11 October 2021 and the random effect of each individual salmon. The best fitting model(s) were identified with AICc (Akaike's information criterion) with the function aictab from the package AICcmodavg (Mazerolle & Mazerolle, 2017). The model selection provided multiple alternative models (ΔAICc < 2) (Anderson et al., 2001). Therefore, conditional model averaging was applied to calculate the model estimates with the function mod.avg from the package AICcmodavg (Mazerolle & Mazerolle, 2017).

3 Results

3.1 Biological characteristics and mortality

All the 74 Atlantic salmon tagged were confirmed by scale analysis and DNA testing to not be of farmed origin. One salmon from the summer group and one salmon from the autumn group were confirmed dead after tagging, respectively 67 days and 49 days after tagging. The autumn salmon that died was tracked at the same location from day 32 after tagging, which could indicate that it died prior to day 49. All other salmon were confirmed to have survived the catch, tagging, and release. In addition to these two salmon, three wild salmon were killed prior to tagging due to bleedings from the gills during the surveillance fishing period. The immediate mortality of wild salmon caught during surveillance fishing was 7% and the total mortality of wild salmon caught during the surveillance fishing was 9.3%. One salmon was considered too small for tagging and was released back into the river. The number of confirmed farmed salmon captured and killed were 4 out of 48 captured individuals, which provides an estimate of 8.3% farmed salmon in the spawning stock.

There was no significant difference in total body length between the summer and autumn group at capture (Mann-Whitney U test: $W = 784$, $P = 0.258$), nor were there any significant difference in total body length between the summer and autumn group included in the analysis (Mann-Whitney U test: $W = 489$, $P = 0.366$).

3.2 Accumulated absolute migrated distance

There was no significant difference between the summer and autumn group in accumulated absolute migrated distance (Mann-Whitney U test, $W = 424$, $P = 0.946$). The summer and autumn group moved on average respectively 11,9 km (SD 13,7 km, range 0,6 – 47,1 km) and 12,6 km (SD 14,6 km, range 0,4 – 66,3 km) in accumulated absolute migrated distance in the period 11 October – 31 October 2021 (figure 4). The median accumulated absolute migrated distance however was 6,5 km and 7,8 km for the summer and autumn group respectively.

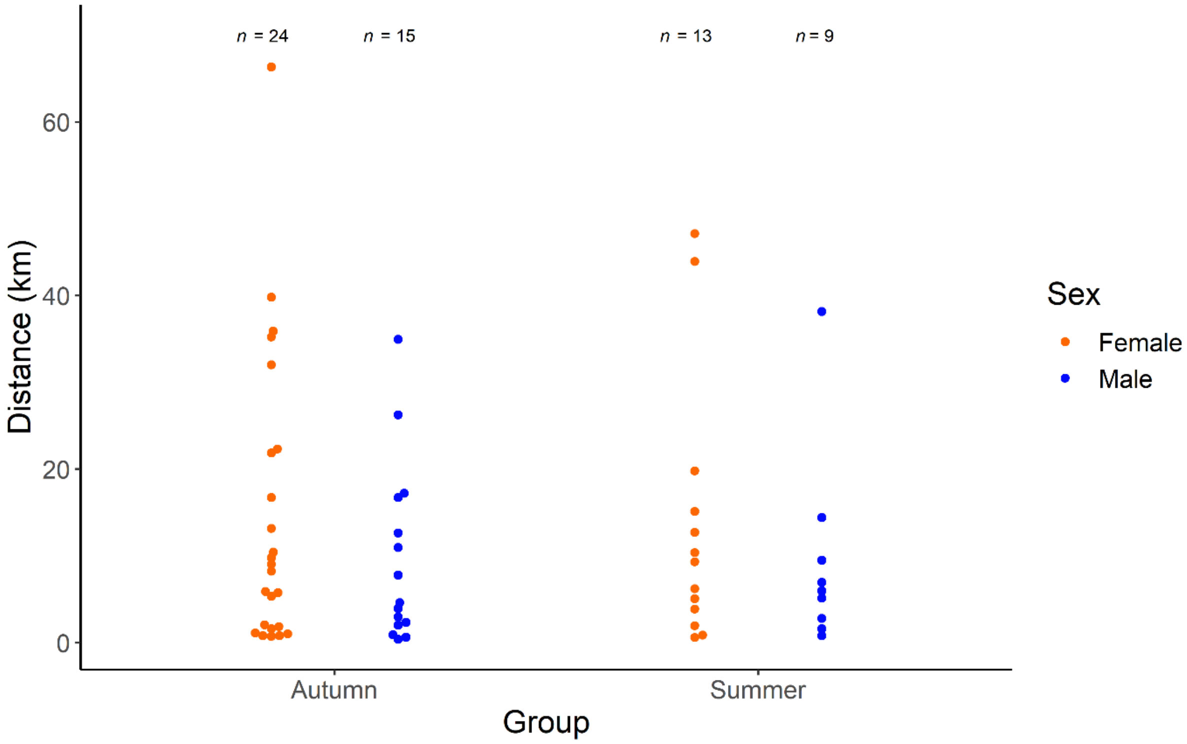

Figure 4: Beeswarm plot of accumulated absolute migrated distance for the autumn and summer group for male (blue) and female (orange) salmon in the period 11 October – 31 October 2021. Each point represents an individual salmons accumulated absolute migrated distance. The text over the beeswarm plots shows the number of individuals in each group.

3.3 Regression model for accumulated absolute migrated distance

Model selection indicated the factors relative distance to river mouth on 11 October 2021 and sex as the best predictors for accumulated absolute migrated distance in the period 11 October – 31 October 2021 (ΔAIC < 2, table 2). The model predicted that the accumulated absolute migrated distance for salmon increases with distance from river mouth at the start of the tracking period, 11 October 2021 (Table 3; $Z = 2.534$, $n = 61$, $p = 0.01$). The model indicated that the sex of the salmon was not significant but was relatively close to significant ($Z = -1.45$, $n = 61$, $p = 0.09$). In the model selection process several factors were excluded such as group (summer/autumn), tackle used to catch and total body length of the salmon.

Table 2: Model selection for the estimation of determinants of accumulated absolute migrated distance. The model estimates the relative contribution to accumulated absolute migrated distance of the parameters sex and the relative distance to river mouth on 11 October 2021. AICc is the score based on Akaike's information criterion.

Model	AICc	Δ AICc	AICc weights	DF
[Sex, Relative distance to river mouth]	1270.4	0.00	0.46	4
[Relative distance to river mouth]	1270.8	0.45	0.37	3

Table 3: Summary of the model including both sex and relative distance to river mouth on 11 October 2021. The table shows intercept and independent variables from generalized negative binominal linear models on accumulated absolute migrated distance in the period 11 October – 31 October 2021. The asterisk mark shows significant values, and the punctum shows nearly significant values.

Effect	Estimate	Std. Error	z Value	*P*
(Intercept)	9.5297	0.1727	55.176	< 0.05
Sex Male	-0.4700	0.2756	-1.705	0.09 .
Distance from River mouth	0.3441	0.1358	2.534	0.01*

3.4 Relative distance moved per day

In the period 11 October – 31 October 2021 the summer group moved on average 0.75 ± 1.90 km per day (median 0.19, range 0 – 17.00 km). The autumn group moved on average 0.70 ± 1.90 km per day (median: 0.17, range 0 – 17.55 km). Salmon tended to move longer distances between tracking intervals at the end of the period 11 October – 31 October 2021 (Figure 5). All movements in the tracking interval of two days that exceeded 10 kilometres were downward movements and conducted by ten different salmon. There was no significant difference between the summer and autumn group in distance moved exceeding 10 kilometres between the tracking interval of 2 days (Mann-Whitney U test, $W = 9$, $p = 0.459$).

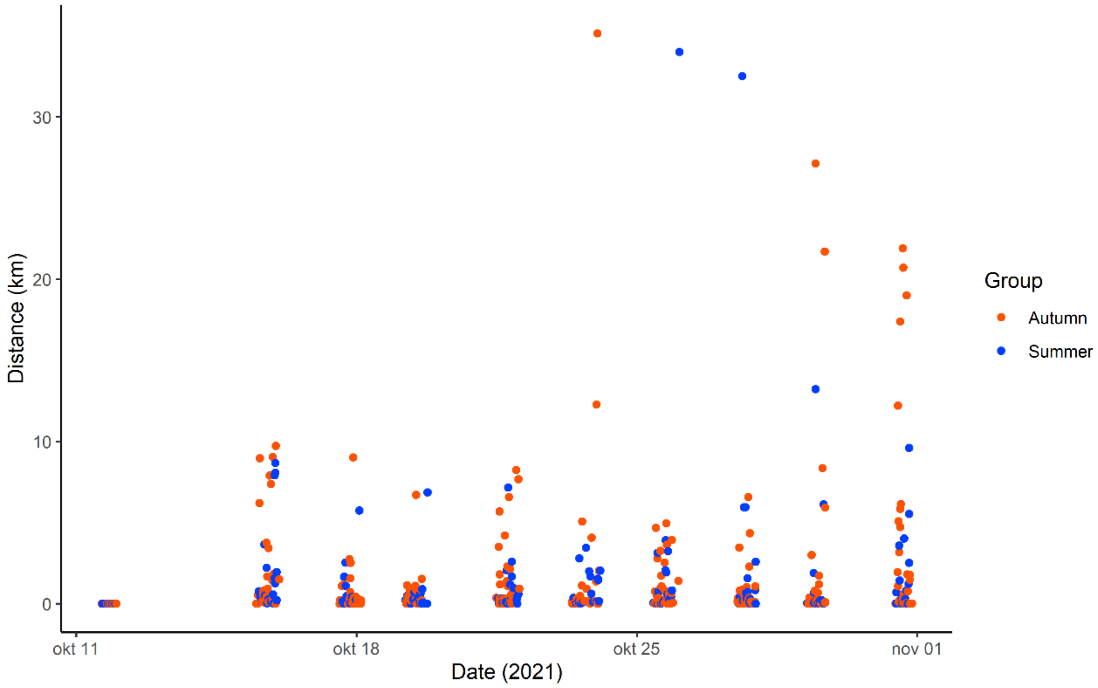

Figure 5: Absolute migrated distance for each individual salmon between tracking days in the period 11 October – 31 October 2021. The orange dots represent salmon from the autumn group and the blue dots represent salmon from the summer group.

The geographical position on 11 October 2021 for the summer and autumn groups in relative distance to the river mouth were not significantly different (Mann-Whitney U test: $W = 369$, $P = 0.371$). The ending position on 31 October 2021 for the summer and autumn groups in relative distance to the river mouth were not significantly different (Mann-Whitney U test, $W = 320$, $P = 0.170$).

Variation in relative distance to the river mouth on 11 October 2021 for the different tackle used to catch salmon was tested. Salmon caught on spinners was located significantly longer upstream than the salmon caught on spoons (Tukey ANOVA, $n = 61$, $P = 0.01$). This type of variation was not observed between the other groups of tackle (Tukey ANOVA, $n = 61$, $P > 0.05$). The relative distance from the river mouth on 11 October for the four different groups of tackle used is presented in (figure 6).

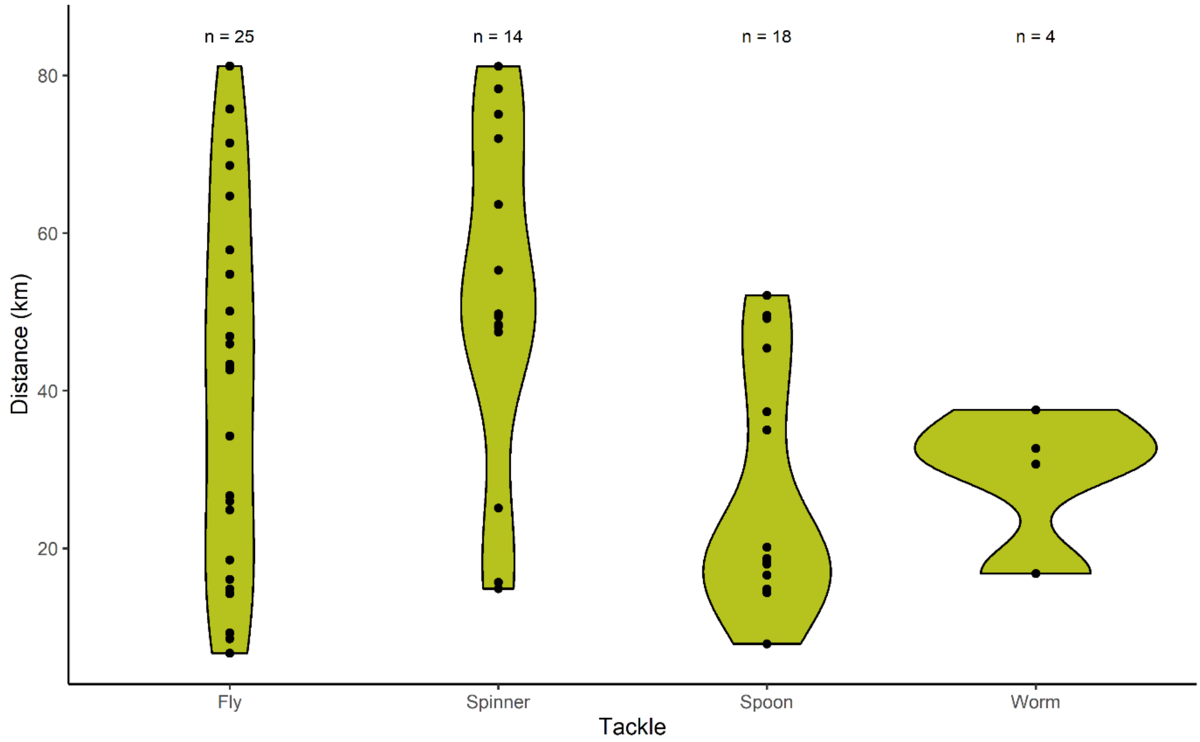

Figure 6: Violin plot showing distance from river mouth on the 11 October 2021 for the four different tackles used to catch salmon. Each point is an individual registration of a manually tracked salmon. The points are overlaid within the violin plot to show the positions of individual salmon. The figure widens if there are many points in the same location and is narrow if there are few points in the same location.

3.5 Relative absolute migrated distance per day

Model selection indicated the factors day of year and tackle as the best predictors of relative absolute migrated distance in the period 11 October – 31 October 2021 and were included in four out of five equally well fitted regression models ($\Delta AIC < 2$, table 4). The factors relative distance to river mouth on 11 October 2021 and group (autumn/summer) had limited effect on the relative absolute migrated distance and were only included in one out of five equally well fitted regression models. Total body length and sex were also initially included in the models but based on model selection they were found not significant and hence removed in the final models

Table 4: Model selection for the estimation of determinants of relative absolute migrated distance. The model estimates the relative contribution to relative absolute migrated distance of the parameters tackle, day of year, group and the relative distance to river mouth on 11 October 2021. AICc is the score based on Akaike's information criterion.

Model	AICc	Δ AICc	AICc weights	DF
[Day of year, Tackle]	8057.6	0.00	0.22	7
[Day of year]	8057.9	0.30	0.19	4
[Day of year, Tackle, Relative distance to river mouth]	8058.6	1.01	0.13	8
[Tackle]	8058.8	1.19	0.12	6
[Group, Day of year, Tackle]	8059.4	1.82	0.09	8

Table 5: Summary of the model conditional averaging of intercept and independent variables from generalized mixed effect negative binominal linear models on relative absolute migrated distance in the period 11 October – 31 October 2021. The asterisk mark shows significant values, and the punctum shows nearly significant values.

Effect	Estimate	Std. Error	z Value	*P*
(Intercept)	6.6730	0.2646	25.168	< 0.05
Day of year	0.1300	0.0721	1.799	0.07 .
Tackle Spinner	0.2411	0.0431	0.558	0.57
Tackle Spoon	-0.7425	0.4019	1.843	0.06 .
Tackle Worm	0.1971	0.6608	0.298	0.76
Group Summer	-0.2195	0.4488	0.488	0.62
Distance from River mouth	0.1793	0.1744	1.026	0.30

The predicted distance from the model average output is presented in (figure 7). The relative absolute migrated distance increased with the day of the year for all four tackles used to catch the salmon and was almost significant ($P = 0.07$). The spoon captured treatment showed a shorter distance moved throughout the period compared to the three other tackles used and was almost significant ($P = 0.06$). The summer and autumn group did not move significantly different from each other ($P = 0.62$).

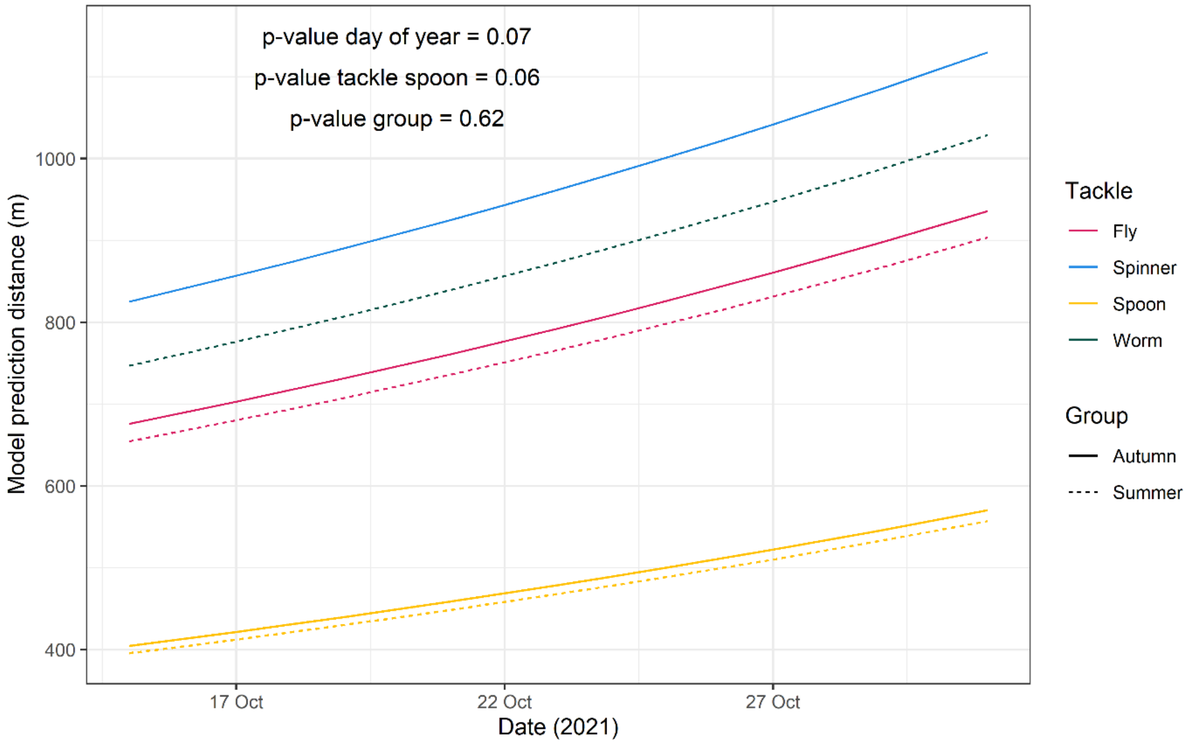

Figure 7: The predicted distance for an individual salmon by the model average output in the period 15 October – 31 October 2021. The model is split according to tackle, fly (red), spinner (blue), spoon (yellow) and worm (green). The summer and autumn group are also indicated with dotted line for summer and solid line for autumn. The tackle spinner was only used for the autumn group and the tackle worm was only used for the summer group. The p-value from the model is also provided for tackle spoon, day of the year and the group (summer/autumn).

4 Discussion

4.1 Migrated distance between 11 October and 31 October 2021

There was no observed difference in accumulated absolute migrated distance between the summer and autumn groups. There was also no difference in the relative absolute migrated distance per day, which is the distance each individual salmon moved in one day, for the summer and autumn group. The distances moved per day were slightly longer than found in river Namsen (Moe et al., 2016; 0,5 km day^{-1}) and in river Alta (Økland et al., 1995; 0.6 km day^{-1}). The distances moved per day were, however, volatile, and will often depend on environmental variables such as temperature or water flow and also the phase of the upriver migration (Økland et al., 2001).

Salmon located in the upper parts of the river on 11 October 2021 tended to move more than salmon further downriver. These results could be due to the calculation of absolute distance, which did not separate up- and downstream movements, and hence be influenced by that fish located in the upper parts of the river had more potential to move downstream.

4.2 Downstream movements

All movements between the tracking interval of two days that exceeded 10 kilometres were downstream movements and were conducted by ten different salmon. The salmon tended to move more at the end of the period 11 October – 31 October 2021, possibly due to completion of spawning. The long downriver movements were conducted by both female and male salmon from the summer and autumn group. If the surveillance fishing caused any long-term effects, it could be expected that the autumn group would move downstream earlier and faster than the summer group due to the stressors from angling closer upon the spawning period. However, there was no evidence for this as both groups moved downstream in an equal fashion. Earlier studies such as Lennox, et al. (2017b) did not observe these long downstream movements, but this could be due to ending the tracking period three weeks earlier than the present study. Moe et al. (2016) did record some downstream movements in wild salmon during the spawning period, but never more than one kilometre per day. When comparing the results from the current study with these previous studies, it seems like the salmon caught in surveillance fishing experienced some long-term exhaustion from C&R, and consequently must abandon spawning grounds earlier than non-angled individuals.

The individual salmon who moved the longest total distance was the last caught salmon (hereafter referred to as number 74), caught 04 October 2021. Number 74 was caught furthest upstream the river among the 61 individuals included in the analysis and was the first to perform a downriver movement of more than 10 kilometres between two consecutive tracking days. It can hence be speculated if number 74 displayed some long-term effects from C&R, which happened 18 days earlier, and perhaps did not contribute to the spawning. Another possible cause for the long downstream movement could be that number 74 was foul hooked in the adipose fin, which increased the playing time. Although playing time in general has not been shown to influence the post-release mortality of salmon (Lennox, et al., 2017a), it can influence the reproductive success (Richard et al., 2013).

Of the ten salmon that performed a downstream movement of more than 10 kilometres between two consecutive tracking days in the period 11 October – 31 October 2021, four salmon were tagged in the four last days of the surveillance period. A conclusion from these observations is hard to state, but it is worth noting that the small sample size would make it unlikely to detect a significant effect. Based on these observations, surveillance fishing may have continued for too long and affected the tagged salmon too close to spawning. Future studies should therefore take extra precaution setting the deadline for surveillance fishing in consideration of these observations. The estimate of ending surveillance fishing two weeks before the presumed spawning period could be considered extended, to make sure the effects from C&R are manageable for the fish. Another important point is that the date of the spawning period is volatile from year to year, so it is important to end in time, to be sure the salmon has a sufficient recovery time.

The results from a study in Lakselva in 2016 (Lennox, et al., 2017b) showed immediate effects from C&R in surveillance fishing but concluded that long-term effects were not apparent from the data. The present study showed the same pattern of no long-term effects detected. However, it should be noted that some long downstream movements from late-tagged fish, suggest having a non-angling period of minimum two weeks between the end of the surveillance fishing and the spawning period. The inclusion of a control group in this study provided a positive refinement on the previous study on surveillance fishing (Lennox, et al., 2017b), since the present study indicates no difference between the summer and autumn group in total and relative distance moved.

4.3 Spawning behaviour

That 40% of the salmon were relatively stationary during the period 11 October – 31 October 2021 (never moving over 2 km between two consecutive tracking days), indicate that most of the fish were in their holding phase prior to spawning (Økland et al., 2001). The holding phase itself gives no guarantee for successful spawning but could be used as an indicator of normal spawning behaviour of an individual salmon. Stationary behaviour close upon spawning has similarly been observed in other studies (Moe et al., 2016; Økland et al., 2001; Økland et al., 1995).

It cannot be confirmed that all salmon present in Orkla river during the spawning period participated in the spawning, as the methodology used in this study could not detect actual spawning. A map of known spawning grounds for the entire river does not exist, which would be useful to evaluate if expected spawning fish actually were present at spawning grounds during the spawning season. Earlier studies have however documented indirect positive population effects following C&R, by an increased number of spawning redds (Thorstad et al., 2003) and by higher densities of juvenile salmon (Whoriskey et al., 2000). There is also evidence of that salmon from C&R may play an important role in the population reproductive output and have the same probability of spawning as non-angled salmon, albeit salmon in the actual study were captured early in the season (Richard et al., 2013). Hence, the fact that the salmon in the present study were alive and presumably present on spawning grounds, indicate that the fish from the C&R surveillance fishing participated in the spawning.

For future studies, a more direct approach on reproductive output from the salmon caught in surveillance fisheries could be done in the same way as Richard et al. (2013), where they estimate reproductive success by matching genetical analysis of young salmon found in the river with mature salmon caught in the previous year. This setup is however hard to achieve in larger rivers such as Orkla, due to the amount of water and width of the river challenging efforts to capture a large percentage of the juveniles for genotyping.

4.4 The effect of tackle and capture site

The tackle used to catch the salmon seemed to have some relation to the relative distance moved per day. Especially the salmon caught on spoons were moving less per day than the salmon caught by one of the three other groups of tackle. The majority of the salmon caught on spoons were located about 20 kilometres from the river mouth on 11 October 2021, while the salmon caught on flies and spinners were more equally distributed in the river from 5 – 80 kilometres from the river mouth on 11 October 2021. It is nevertheless surprising that the spoon should induce a shorter moved distance since Lennox, et al. (2017b) did not record this effect. A theory could be that the tackle triggered different phenotypes of salmon into biting, and that the salmon were divided into different behavioural groups before being angled. Some move less and are more stationary, while others move more and swims up- and downriver in search of the perfect spawning ground. The spoon often has a more triggering effect with sharp colours, lots of movement, and flashes. The more stationary salmon could have been triggered by this effect and bite more often compared to other fishing tackle.

The farmed salmon caught in this study tended to be caught far downstream in the river (1-20 km from the river mouth; three individuals) while only one were captured about 45 kilometres from the river mouth. The finding that most of the farmed salmon were captured in the lower part of the river did not correspond with earlier studies indicating that farmed salmon migrate further upstream than wild fish (Moe et al., 2016). If the farmed salmon do migrate further upriver than wild fish, the surveillance fishing should be conducted higher upriver than performed in this study. However, the number of farmed salmon in this study reflects that the lower parts of the river also is a good place to fish for farmed individuals during surveillance fishing. Hence, it must be concluded that the whole river should be covered to get the most representative estimation of the proportion of farmed salmon.

4.5 Mortality in surveillance period

Salmon that are angled with rod and line will always have a risk of mortality due to physical and physiological impacts from capture and handling (Arlinghaus et al., 2007; Lennox, et al., 2017a). Some mortality can therefore be expected among the salmon caught in the surveillance fishery, both immediately after capture and delayed following release. The amount of mortality will not be a fixed value but will be volatile from season to season due to different factors such as knowledge among the anglers involved (Lennox, et al., 2017a). Earlier studies have concluded that high water temperature can cause mortality in C&R salmon (Havn et al., 2015; Keefe et al., 2022; Lennox, et al., 2017a), however the water temperature in the autumn is colder than in the summer, and seldom over 18^{o}C. The mortality is therefore not expected to be influenced by high water temperatures in surveillance fisheries. The immediate mortality caused by injury from the hook was in the same range as previous studies (3–10 %) (Havn et al., 2015; Lennox et al., 2016; Lennox, et al., 2017b). The only potential delayed mortality was from a salmon caught on a spoon equipped with a treble hook that had penetrated one of the eye cavities. The reduced eyesight and open wound could therefore be the proximate cause of death. The fact that the transmitter was found on land, 100 meters from the river, indicated that it was transported by a predator or scavenger after the time of death.

The total mortality of wild salmon in the surveillance fishing was found to be 9,3%. In comparison 8,3% of the caught salmon was identified as farmed salmon, which is considered to be moderate (Wennevik et al., 2021). Castellani et al. (2018) showed that this intrusion level of farmed salmon will not necessarily have a huge impact on the wild population, since the proportion of farmed salmon must be close to 30% before phenotypic and demographic changes are to be expected in a time scale of 50 years. This was possible due to reduced spawning success in farmed salmon and natural selection purging maladapted genotypes from the wild population (Castellani et al., 2018). All the farmed salmon caught during the surveillance fishing in this study was correctly identified and euthanized, and the fact that no farmed salmon were released back into the river strengthens the cause of surveillance fisheries. Experience is a key factor in the evaluation of a caught salmon is of farmed or wild origin. Anglers involved in surveillance fishing who lack experience should therefore always be accompanied by an experienced companion to ensure correct identification (Svenning et al., 2015).

Every wild salmon removed from the river during surveillance fishing results in a decreased genetic potential, since the salmon is likely to participate in the spawning. The genetic introgression from farmed salmon for larger rivers like Orkla will have a smaller impact than in rivers with smaller populations (Hindar et al., 2018), but if the use of surveillance fishery increases, the impacts could become larger than the benefits due to increased mortality among the wild salmon. For smaller rivers, surveillance fishing may be more damaging due to smaller number of spawning salmon, and a higher relative loss of genetic potential from foul hooking and long-term effects of C&R. In these smaller rivers a less invasive capture method like fish traps could be more efficient and less damaging to the fish involved.

4.6 Salmon using the tributaries

Out of the 61 salmon included in the analysis, eleven salmon migrated up seven different tributaries to Orkla river (Leirbekken, Vorma, Åsskjerva, Ryånda, Resa, Grana and Hurunda). This means that nearly 20% of the tagged salmon used the tributaries prior or during spawning and could indicate that the tributaries of Orkla river is not only important to brown trout, but to the salmon as well. Solem et al. (2018) found that in some tributaries to Orkla river, salmon are more frequent than brown trout, indicating the importance of reproduction in these creeks. Future studies can also consider performing surveillance fishing in these tributaries, as a significant amount of the wild salmon use these areas. Since the wild salmon uses these smaller watercourses, it is likely to assume some presence of farmed salmon as well. This could be a shortcoming of the surveillance fishing program, which does not focus on surveillance in tributaries. Establishing knowledge of the usage of these, in terms of farmed salmon, could therefore be recommended for future studies.

4.7 Conclusions

The total migrated distance and relative distance per day were equal for the summer and autumn group in the period 11 October – 31 October 2021, which indicated no long-term effects from the surveillance fishing. Some large downriver movements from salmon angled late in the surveillance fishing period indicated that the surveillance fishing should be stopped in time to let the salmon recover properly before spawning. The mortality of this study was on the same level as previous studies (3-10%) and could be refined by developing less harmful capture methods in the future. Some mortality from C&R is nevertheless almost impossible to avoid and must be considered before conducting the study. This is especially important in smaller populations, since the survey could cause larger negative consequences than benefits.

Further studies on surveillance fishing should focus on the reproductive output from the salmon C&R from surveillance, since this ultimately is the most important effect to the wild salmon population. The tributaries of the rivers could also be a potential area of focus, since it is unknown to what extent the farmed salmon use these smaller watercourses.

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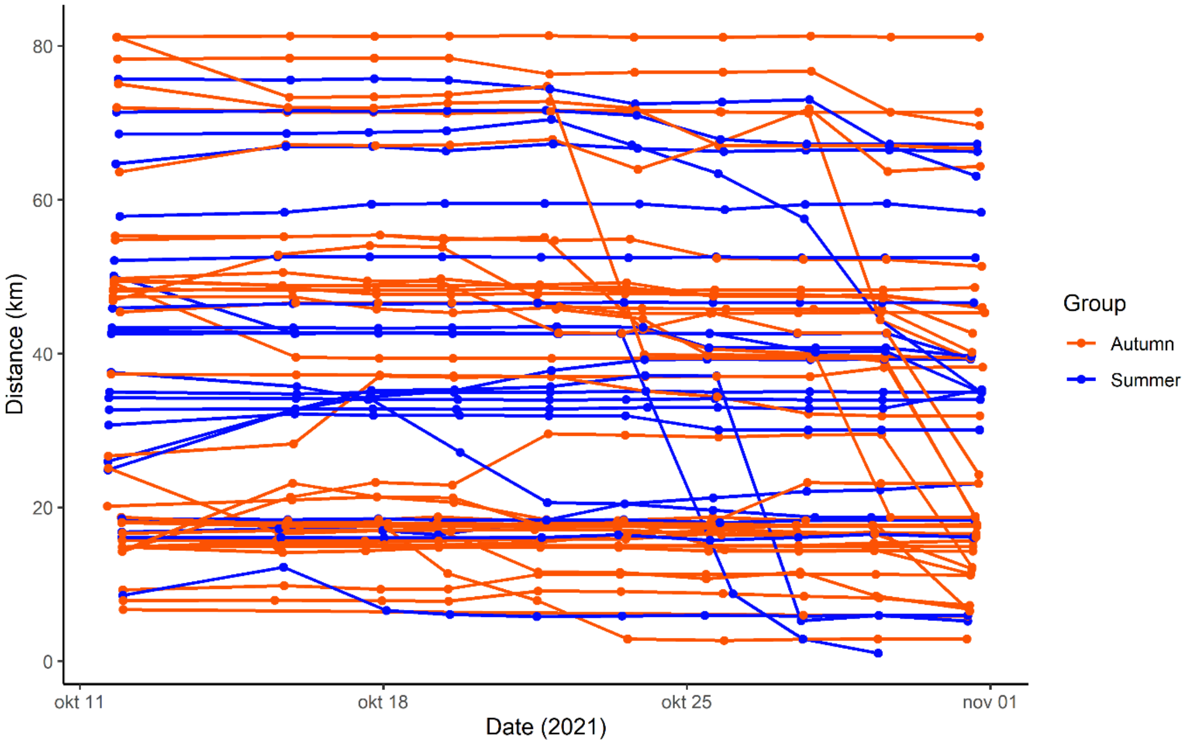
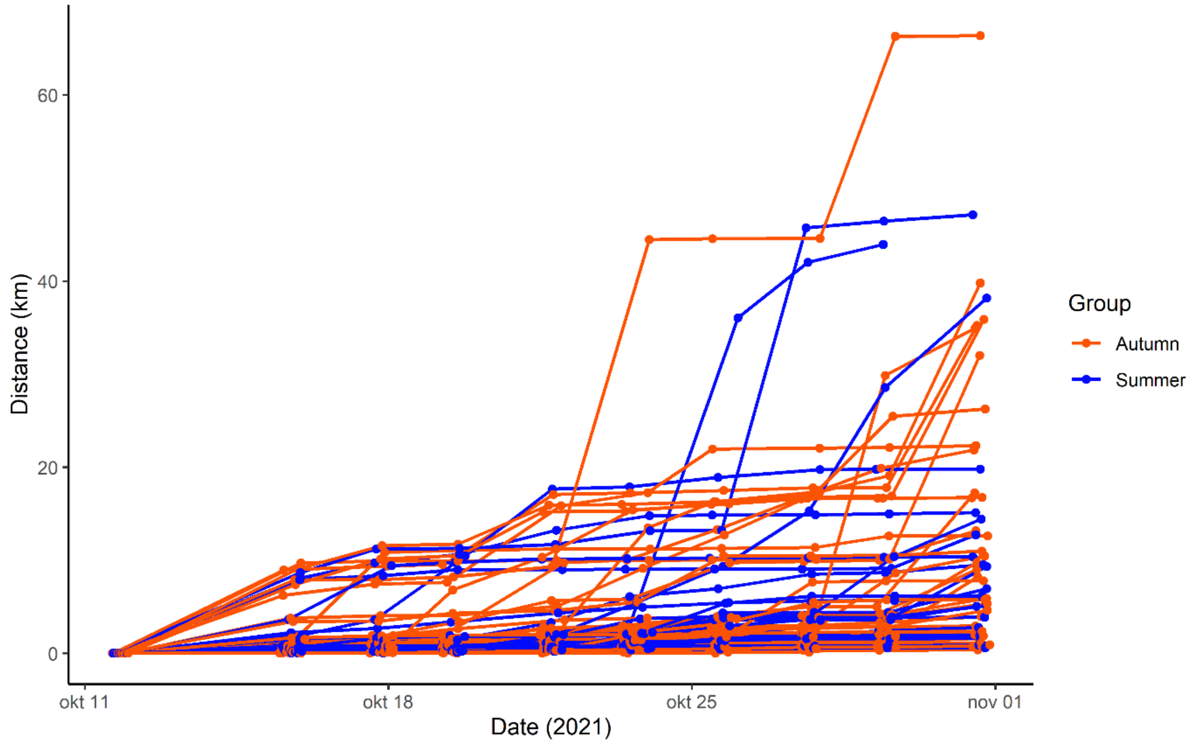
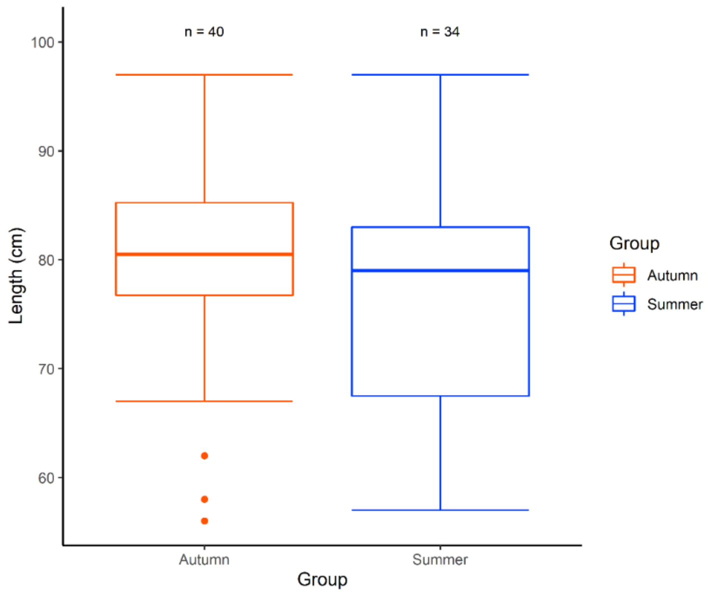
Appendix



Appendix 1: Relative distance from river mouth for each individual salmon in the period 11 October – 31 October 2021. The line between each point represents if the salmon moved up- or downriver where the autumn group is orange and the summer group is blue.



Appendix 2: Absolute total migrated distance for each individual salmon in the period 11 October – 31 October 2021. The line between each point increases if the salmon moved up- or downriver where the autumn group is orange and the summer group is blue.



Appendix 3: Total body length (cm) of tagged fish in Orkla river. The summer group were tagged between 26 June – 20 July 2021 and the autumn group were tagged between 07 September – 04 October 2021. The box-and-whisker plots show mean values (line inside the box), the interquartile range (box) and the 5th and 95th percentiles (whiskers). Dots indicate outliners.

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