


## ARTICLE

# The effect of surveillance fishing on migration distance of Atlantic Salmon during the spawning period

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## Abstract

**Objective:** Surveillance fishing surveys can be performed to estimate the proportion of farmed salmon represented in the spawning stock of native Atlantic Salmon *Salmo salar* populations. These surveys take place after the recreational fishing period and therefore closer to the spawning period than the open recreational fishing season. Although catch-and-release angling has been demonstrated to affect salmon migration during the summer months, surveillance fishing that is conducted close to the spawning time could have more severe effects.

**Methods:** To test this, the migration distance of Atlantic Salmon ( $n=74$ ) caught in the Orkla River, Norway, was tracked by use of radiotelemetry. One group was tagged during the regular fishing season in the summer (control group), whereas another group was tagged in autumn during surveillance fishing (surveillance group).

**Result:** Sixty-one salmon remained for analysis after we excluded fish that were recaptured, died, or migrated to other rivers. Relocation of the salmon during autumn (October 11–31) was used to compare movements and test for differences in migration using negative binomial regression because distances were nonnegative integers. During the tracking period, the surveillance group moved  $12 \pm 14$  km (mean  $\pm$  standard deviation) and the control group moved  $13 \pm 15$  km; both groups moved  $1 \pm 2$  km/day on average. There was no evidence that surveillance fishing impacted movement of the salmon compared to controls. However, one salmon died after tagging and three were not released due to injuries; total mortality of 9% during surveillance fishing could be unsustainable for smaller populations. Consequently, factors such as surveillance sample size, the status of the salmon population, and the population size should be assessed for each river individually when deciding the necessity of and approach to surveillance fishing.

**Conclusion:** The results support existing recommendations to use careful handling and to end surveillance at least 2 weeks prior to the expected onset of spawning, thus providing a sufficiently long period for recovery after surveillance fishing.

## KEYWORDS

fish farming, movement ecology, radiotelemetry, recreational fishing, river

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## INTRODUCTION

The farming of Atlantic Salmon *Salmo salar* L. represents one of the most urgent threats to the viability of wild salmon populations. Farmed salmon that escape from aquaculture facilities in Canada, Scotland, Norway, or other nations where farming is common can aggregate with local wild salmon at marine feeding areas and join the migration into freshwater or migrate directly from coastal waters (Hansen and Jacobsen 2003). The abundances of farmed salmon in Norwegian rivers are typically 0–9% during the summer or 1.6–14.0% during the autumn spawning period (Thorstad et al. 2021). In some parts of Canada, the percentage of farmed fish in the river can be substantial—up to about 43% (Stokesbury et al. 2001). Because of open net-pen farming in fjords, escaped farmed salmon are now present at the spawning grounds of wild salmon (Forseth et al. 2017; Wringe et al. 2018; Bolstad et al. 2021). Interbreeding with farmed salmon has been shown to alter the 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; Wacker et al. 2021). These consequences can cause severe declines 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 observed in almost all regions where salmon farming overlaps with areas used by native wild populations of Atlantic Salmon (Wringe et al. 2018). Wild salmon are adapted to their home river, and the native fish have a higher reproductive success than farmed escapees and hatchery-reared salmon in experimental trials (Fleming et al. 1996; Fleming and Einum 1997). 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 could expand introgression in the river, spreading the nonnative genes (Diserud et al. 2022). First-generation hybrids have also shown higher rates of straying, thus spreading introgression to other rivers as well (Jonsson and Jonsson 2017). Methods for identifying escaped farmed salmon are needed to track the impacts of open net-pen fish farming on wild populations and to remove as many farmed fish as possible before they can spawn with the wild fish.

Surveillance fishing for salmon is the practice of surveying fish in the river before the reproductive period (Lennox et al. 2017a). Surveillance fishing begins approximately 2 weeks after the recreational fishing period to let the river “rest,” and surveillance ends 2 weeks before the presumed spawning period (Aronsen et al. 2016).

### Impact statement

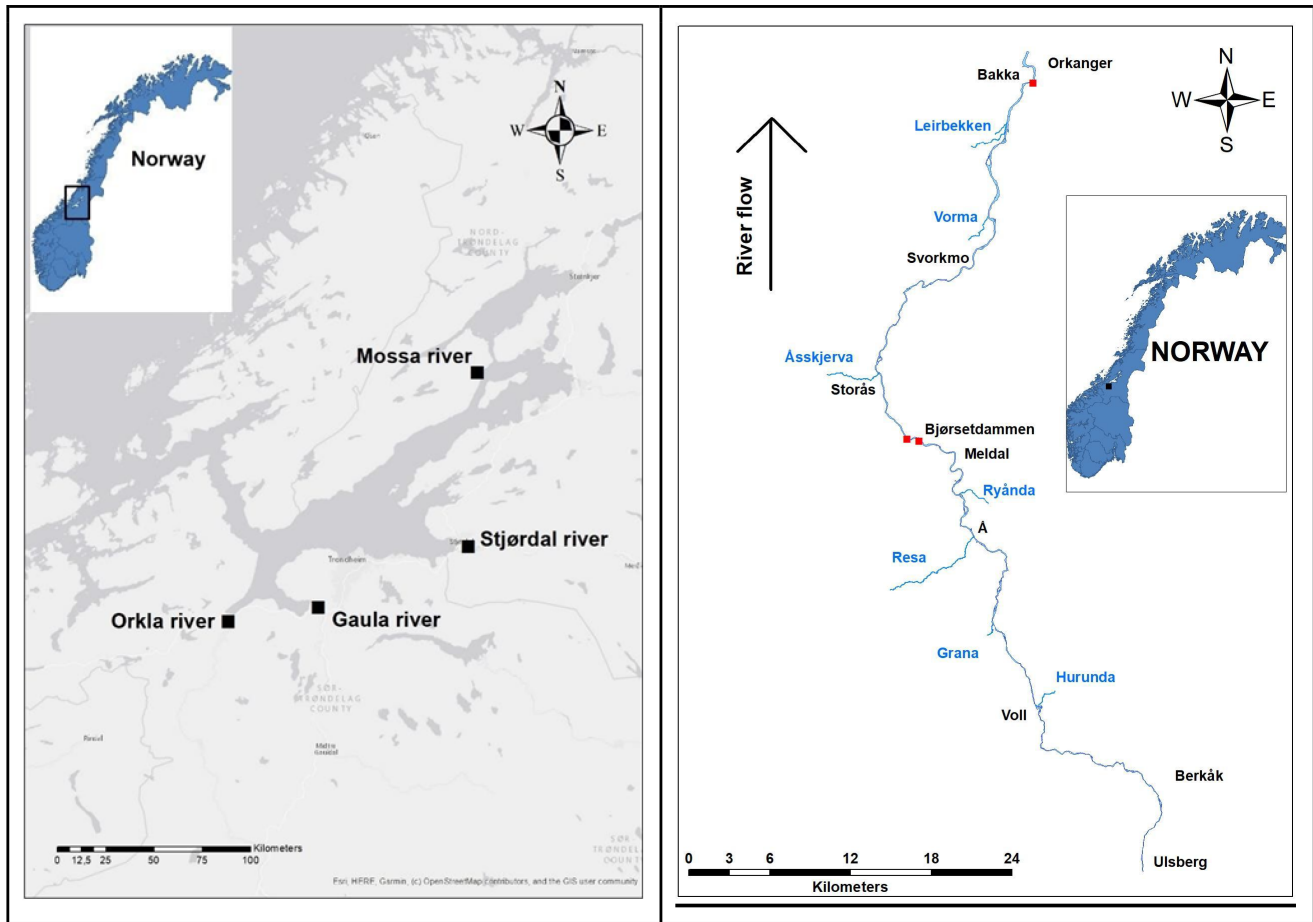
Surveillance fishing is a method to determine the number of farmed salmon in a river. Capture and release of wild salmon during an autumn surveillance period may negatively impact these important spawners, but we found that movement of surveillance-captured fish was not different from a control group.

Surveillance angling is not open to the public, but experts are asked to volunteer to catch salmon. Fishers must use gear that will limit damage, and they must retrieve the salmon quickly, minimize air exposure, and release the fish promptly after scales are removed for later visual analysis. The fisher is expected to kill any fish that is suspected to be farmed based on external characteristics (e.g., fin erosion, facial deformities, and spot patterns). Because surveillance fishing occurs in close temporal proximity to the spawning of the salmon, the potential for negative impacts on the fitness of wild fish is elevated compared to the impacts of catch and release during the angling season, which occurs several weeks before the spawning period. Given the lack of knowledge about how wild salmon respond to the stresses associated with surveillance fishing, the aim of the present study was to evaluate whether surveillance fishing of wild Atlantic Salmon caused behavioral differences in migration distance compared to a control group. The objectives were to investigate migration distances in the Orkla River, Norway, in terms of (1) relative migration distance per day during the spawning period (October 11–31, 2021) and (2) total migration distance during the spawning period.

## METHODS

### Study site

The study took place in the Orkla River in central Norway. The river has a catchment area of 3092 km<sup>2</sup> and drains into the sea at the Trondheimsfjord (Hvidsten et al. 2015). The river has several tributaries that provide habitats to both Atlantic Salmon and sea-run Brown Trout *S. trutta* L. The wild salmon have a migration distance of 90 km in the main river, with a total of 170 km of accessible river (Harby et al. 2010; Figure 1). A hydropower facility at Bjørsetdammen (37 km upriver) is the only large, artificial obstacle along the migration route. The salmon can pass this obstacle via a ladder and access the spawning grounds further upstream. The recreational fishing season in the



**FIGURE 1** Map of the study area, which encompasses the anadromous part of the Orkla River, Norway. The left panel shows the location of the Orkla River relative to other rivers in the fjord where tagged Atlantic Salmon were detected. The right panel shows the part of the Orkla River accessible to anadromous fish; red dots indicate where the stationary listening stations were located, blue text represents the Orkla River tributaries that were visited by tagged salmon, and black text indicates some of the local urban areas along the river. Note that the river flows south to north and that Bjørsetdammen is a hydropower facility, which is the only large, artificial obstacle along the salmon migration route. The salmon can pass Bjørsetdammen and access the spawning grounds further upriver. The map was produced in ArcGIS version 10.8.1.

river is June 1–August 31, and the average catch of salmon from 2000 to 2021 was 22,531 kg (Statistics Norway 2022). Surveillance fishing starts on approximately September 15 and ends about 2 weeks before the presumed spawning period, which may vary among years depending on environmental conditions (October 10–25).

## Experimental design

### Tagging

Two groups of Atlantic Salmon were caught and tagged with radio transmitters. The first group (control) consisted of 34 salmon that were caught between June 26 and July 20, 2021, by recreational anglers. The second group (surveillance) was caught between September 7 and October 4, 2021, during autumn surveillance fishing and

consisted of 40 salmon. During autumn surveillance fishing, angling of salmon by using spoons on heavy rods with a thick line is recommended to reduce fight time, and the use of lures with two barbless hooks is recommended to avoid injury. To avoid air exposure, fish that are captured in surveillance fishing are not generally handled out of water or photographed; therefore, this fishing method is usually distinct from the typical catch and release by anglers during summer and should have a lower impact on the fish and a lower probability of negative physiological or behavioral responses. Both the control and surveillance groups were caught using rod and line, with flies ( $n=32$ ), metal spoons ( $n=19$ ), spinners ( $n=14$ ), or worms ( $n=9$ ) as bait. All fish that were caught on worms belonged to the control group, and those individuals were carefully checked for injuries before release, as there is a tendency of deep hooking with this method (Bartholomew and Bohnsack 2005) that could increase the mortality of

released salmon. All fish that were caught on spinners were in the surveillance group.

The control group was established from fish tagged during the summer that were caught by recreational anglers. Anglers were equipped with a submersible tube that could hold the salmon until the tagger arrived at the capture location. The salmon were held in the submerged tubes for 157 min on average (range = 15–664 min). Submersible tubes were not used for the surveillance group since the anglers were always accompanied by a tagger.

Atlantic Salmon in both the control and surveillance groups were radio-tagged externally with a Model F2120 transmitter (Advanced Telemetry Systems [ATS]; <https://atstrack.com/tracking-products/transmitters/product-transmitters.aspx?serie=F2100>). The tag was flat and square, measuring 21 × 42 × 11 mm, and was 12 g in air, with a ping rate of 0.40–0.52 pulses/s. The effect of the radio tag on swimming performance in adult Atlantic Salmon was previously tested in laboratory trials, and the tag was not found to be a significant impediment (Thorstad et al. 2000). Estimated battery life for each radio tag was 207–264 days. The radio tags used in the study transmitted a signal with a frequency in the range of 142.113–142.342 MHz along with a unique code that was used for individual identification.

Prior to radio tagging, the fish in the control group were anesthetized by using Benzoak Vet (ACD Pharmaceuticals AS) with a concentration of approximately 200 mL/100 L. The concentration was adjusted based on water temperature and the condition of the fish. Control fish were anesthetized due to requirements from the Norwegian Food Safety Authority (Mattilsynet). An exemption was applied to the surveillance group: to most accurately replicate the methods used in surveillance fishing and to avoid bias from pharmacokinetic effects, anesthesia was not provided to this group. After capture, each 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 dorsum of the fish about 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. A reduced distance between the wires on the opposite side of the tag reduces the angle and therefore also reduces the erosion of the flesh compared to wires that are inserted in parallel (Økland et al. 2001). During this procedure, each salmon had a wet cloth over its head to cover the eyes, which reduces 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, each salmon was sexed, assessed for any scars or injuries, and

measured for total length. Scale samples were taken from salmon in the surveillance group. The handling time and the recovery time were noted. Mortality from catch and release for the surveillance group was calculated as the percentage of fish that died prior to or after tagging based on tracking data. Mortality prior to tagging for the control group was unknown, as the person tagging the fish was not always able to be present to assess the condition of fish that recreational anglers had harvested or deemed unsuitable for tagging. To be considered a survivor, the fish had to exhibit upriver movement for more than 2 days after release. For fish that did not meet these requirements, snorkel surveys were used to verify whether the fish survived or died.

## 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 in the center of the town of Orkanger. The second listening station was located further upriver and was 400 m below the Bjørsetdammen power plant. The last two listening stations were located at the Bjørsetdammen power plant. All four stations consisted of a stationary radio receiver (ATS Model R4500c) that detected the signals from the tagged salmon as they traveled near the station. The detection range of the stationary listening stations was not measured, but each station was confirmed (via manual tracking) as detecting every fish that migrated past it. Because the automated stations were widely spaced, we used manual tracking along the Orkla River by vehicle using a magnetic dipole antenna (Laird Technologies) on the vehicle's roof and a radio receiver (ATS Model R4500c) to obtain the positions of the fish. The manual tracking regime, which was conducted from June 20 to October 31, 2021, was scheduled to provide information about fish movements at fixed intervals. This was used to locate the salmon, while a handheld, four-element Yagi antenna was used to determine the position of the salmon in the river with highest possible accuracy (within ±5 to ±100 m, depending on the width of the river). Manual tracking surveys were conducted every 10th day from June 20 to September 7, weekly from September 7 to October 15, and every second day from October 15 to November 1. On each tracking day, a single location (i.e., detection) was recorded for each individual. Additionally, intensive tracking of 10 salmon, with their positions determined every fourth hour, took place on two occasions: October 18–19 and October 28–29, 2021 (i.e., tracking from 0900 hours on the first day to 0900 hours



on the second day). Opportunistic tracking (i.e., not at fixed intervals) was performed in other local rivers (Gaula, Mossa, and Stjørdal rivers) to identify fish that left the Orkla River for other systems, but this tracking was not conducted systematically.

## Data filtering

The initial number of radio-tagged fish was 74, but several individuals were excluded from the analysis. Eight salmon from the control group migrated out of the river after tagging. Among these, six salmon were confirmed as migrating up a different river. Three salmon were confirmed in the Gaula River, two were confirmed in the Stjørdal River, and one was confirmed in the Mossa River (Figure 1). The other two individuals were not located after migrating out of the Orkla River. The individual in the Mossa River was confirmed via capture by a local angler. One salmon from the control group was not located after tagging, possibly due to transmitter malfunction or recapture. Two salmon from the control group were captured and killed by anglers after tagging. The transmitters of two salmon—one from the control group and one from the surveillance group—were found on land, indicating that the fish were dead. No salmon remains were detected at the locations where the two transmitters were found. Overall, 22 salmon from the control group and 39 salmon from the surveillance group were ultimately included in the analysis ( $N=61$ ).

The data were filtered by date of tracking. We included data from the period October 11–31, 2021, in the analysis but with some exclusions. The data from the two intensive tracking periods (October 18–19 and October 28–29, 2021) were excluded except for the last observation of each fish, which was kept due to the tracking interval of every second day, which included both October 19 and 29. All data filtering was conducted with R version 4.1.1 ([www.r-project.org](http://www.r-project.org)) and the R package `dplyr` (Wickham and Wickham 2020). The reason for using these data was that by October 11, the surveillance group would likely not display any immediate tagging response, as the last salmon was tagged 1 week prior. Two fish left the river between October 11 and 31, 2021; one individual left on October 13, and the other left on October 29. The fish that left on October 13 later re-entered the river on October 29. The data from these two fish are included in the analysis but only when they were present in the river.

## Calculation of absolute migration distance

The least cost path principle was used for calculation of distances in R to ensure that the movements were

restricted to within the river boundary. The least cost path is a measure of the minimum linear distance between two points around a boundary; it was calculated by establishing a transition matrix using the raster package (Hijmans et al. 2015). To account for positional errors, a 100-m buffer zone was drawn around the river polygon. The Orkla River polygon was rasterized at a resolution of 10 m, and a transition matrix was established with eight possible directions. The least cost distances from the river mouth were calculated using the “shortestPath” function in the `gdistance` package (van Etten 2017). The distances moved for an individual salmon between tracking intervals were calculated for each least cost path by using the “gLength” function in the `rgeos` package (Bivand et al. 2017). To calculate the accumulated distances moved, the “summarize” function from the `dplyr` package was used (Wickham and Wickham 2020). Absolute distance was the relative distance from the starting point, whereas accumulated distance was the total distance moved.

## Statistical analysis

After filtering the data, we conducted the statistical analysis with R. Statistical significance was designated at  $p$ -values less than 0.05. To establish whether the control and surveillance groups were comparable, the lengths of fish from the two groups were compared by a Mann–Whitney  $U$ -test.

For analysis of total migration distance, a generalized negative binomial linear model was fitted using the `mgcv` package (Wood 2017). The negative binomial family was used because total distance was composed of nonnegative integer values (Ripley et al. 2013). The data did not meet the assumptions of a Poisson model (general linear model) due to overdispersion. We had a relatively small number of fish for modeling, so we aimed to avoid overparameterizing the model with too many different factors. Migration distance was hypothesized to differ between the surveillance group and the control group, and there could be differences between sizes or sexes; because females tend to be larger (i.e., collinear), we included only length.

To test for possible differences in the absolute migration distance, we used a generalized negative binomial linear mixed-effect model in the `mgcv` package (Wood 2017). Group and fish length were again included in the model, but because relocations were made many times for the same individual, we included individual identity as a random intercept. Day of tracking was also included to test whether the distances moved changed from the beginning to the end of tracking.

## RESULTS

### Biological characteristics and mortality

All 40 Atlantic Salmon that were tagged during surveillance fishing were confirmed by scale analysis and DNA testing to be of wild origin. The 34 salmon in the control group were not tested for origin, but anglers and the tagger were very experienced and would most likely be able to identify any fish of farmed origin based on external characteristics. The average handling time was 10 min (standard deviation [SD]=2; range=7–15 min), and the average recovery time was 5 min (SD=16; range=1–110 min); most of the recovery times were between 1 and 5 min. Only 4 out of 74 salmon had a recovery time longer than 10 min, and all of those fish were in the control group, which had undergone anesthesia. Out of the 74 tagged fish, one individual had a transmitter that was never detected after release. One salmon from the control group and one salmon from the surveillance group were confirmed dead (~3%) at 67 and 49 days after tagging, respectively. The mortality from the surveillance group was tracked at the same location beginning at day 32 after tagging, which could indicate that the fish died prior to day 49. The three salmon (i.e., the individual with the undetected transmitter and the two fish whose mortality was confirmed) were excluded from further analysis.

In addition to one postrelease mortality, three salmon died prior to tagging during surveillance fishing, yielding a total mortality of 9% (4 of 43) for the surveillance

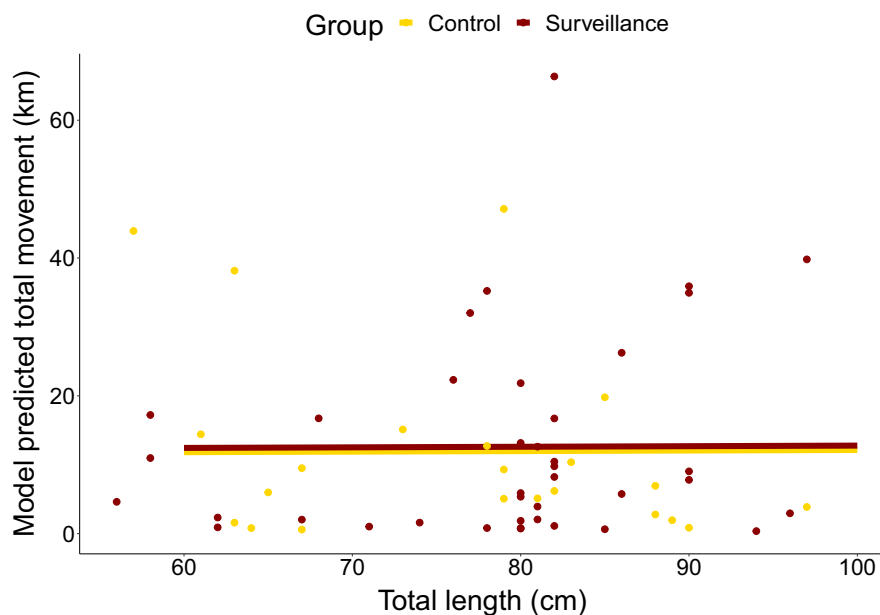
group. Total mortality for control fish caught and released during the summer is unknown because mortality prior to tagging was not documented for that group. All other salmon were confirmed to have survived catch, tagging, and release. There was no significant difference in total body length between the control and surveillance groups at capture (Mann–Whitney  $U$ -test:  $W=784$ ,  $p=0.258$ ).

### Total migration distance

Accumulated absolute migration distances for the control and surveillance groups during October 11–31, 2021, were on average 12 km (SD=14; range=1–47 km) and 13 km (SD=15; range=0–66 km), respectively, based on least cost distances. However, the median accumulated absolute migration distances were 7 and 8 km for the control and surveillance groups, respectively. The model indicated no difference in the total in-river movements between the control and surveillance salmon ( $z=-0.09$ ,  $p=0.93$ ). There was also no effect of length ( $z=0.16$ ,  $p=0.87$ ; Figure 2).

### Relative distance moved per day

During October 11–31, 2021, the control group moved on average  $1 \pm 2$  km/day (mean  $\pm$  SD; median=0.2 km/day; range=0–17 km/day). The surveillance group also moved on average  $1 \pm 2$  km/day (median=0.2 km/day;



**FIGURE 2** Accumulated distance moved by Atlantic Salmon from the control and surveillance groups in the Orkla River, Norway, during October 11–31, 2021. Model-predicted movement for both groups is presented as solid-colored lines, and raw data are presented as points.

range = 0–18 km/day). Salmon tended to move longer distances between tracking intervals at the end of the study period. Most of these movements were downriver, suggesting activities related to the completion of spawning. The model suggested that the distances moved per day increased later in the tracking period ( $z = 1.99$ ,  $p = 0.04$ ) and did not differ between control and surveillance salmon ( $z = 0.19$ ,  $p = 0.85$ ; Figure 3).

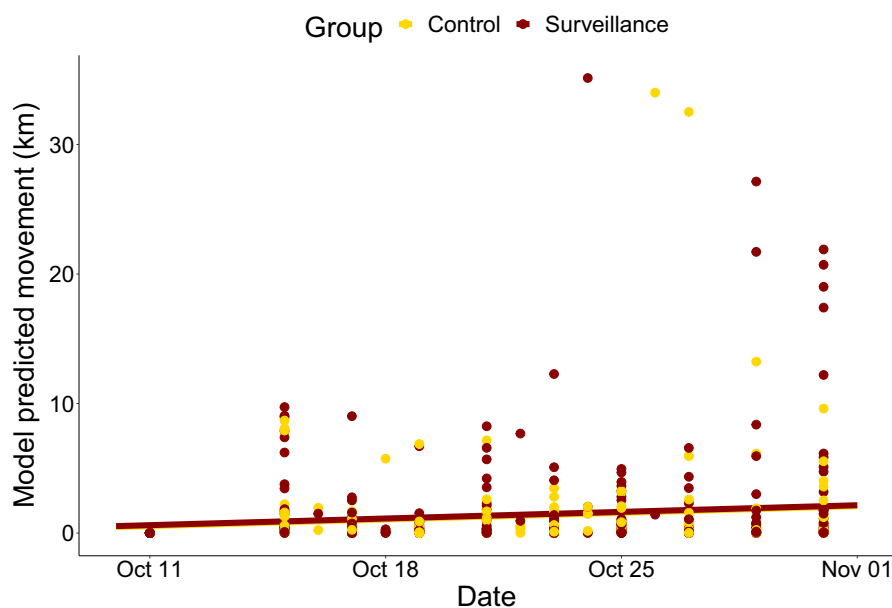
## DISCUSSION

This study compared the movement of Atlantic Salmon that were captured by recreational fishing during the summer with the movement of salmon that were captured during surveillance fishing in the autumn. Movements during the spawning period revealed no significant differences, and statistical modeling did not reject the null hypothesis that the two groups had similar behavior. Migration distance was not different between the groups, and total migration distance during the 20-day tracking period (October 11–31, 2021) also did not differ.

The Orkla River salmon moved more per day than Atlantic Salmon whose movements were monitored in the Namsen River (Moe et al. 2016; 0.5 km/day) and the Alta River, Norway (Økland et al. 1995; 0.6 km/day). However, the distances moved per day were variable and can be expected to depend on environmental variables, such as temperature or water flow. At this time, it is anticipated that

all salmon would be finished with their upriver migration and would be holding or actively searching for spawning sites (Økland et al. 2001). Movements will also depend on various factors, including the habitat and distance between spawning grounds, but further analysis was beyond the scope of our study.

The salmon tended to move more at the end of the tracking period, possibly due to the completion of spawning at the end of October. Some long downriver movements were conducted by both female and male salmon from the control group (captured during summer) and the surveillance group during the autumn tracking period, indicating that such movements were not unique to the autumn-captured group and were not symptomatic of negative behavioral effects from the surveillance fishing. We predicted that if the surveillance fishing caused any long-term effects to salmon, then the surveillance group would have moved downstream earlier and faster than the control group due to the stressors from angling and tagging closer to the spawning period. However, there was no evidence for this. An earlier study (Lennox et al. 2017b) did not observe long downstream movements of salmon (except one fish that appeared to exit the river), but those findings could be due to the tracking period ending 3 weeks earlier than that in the present study, thereby missing the postspawn movements that we were able to document. Moe et al. (2016) and Heggberget et al. (1996) did record some downstream movements in tagged wild female Atlantic Salmon during the spawning period. Moe (2014) suggested that these females were spent fish moving to postspawn resting places.



**FIGURE 3** Distance moved per tracking day for control and surveillance groups of Atlantic Salmon in the Orkla River, Norway, during October 11–31, 2021. Model-predicted movement per day for both groups is illustrated as solid lines (note: the lines for the two groups are overlapping). Raw data are presented as points.

It cannot be confirmed that all salmon present in the Orkla River during the spawning period participated in spawning because the methodology used in this study could not detect actual spawning. However, Moe (2014) documented that radio-tagged salmon in the Namsen River did stay on known spawning grounds during the spawning period. Furthermore, it is reasonably well established that fish engage in spawning after their release from angling based on observations of an increased number of spawning redds (Thorstad et al. 2003) and higher densities of juvenile salmon (Whoriskey et al. 2000). There is also evidence that salmon subjected to catch-and-release angling may play an important role in the population reproductive output and have the same probability of spawning as nonangled 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, which were exposed to additional handling (i.e., tagging) compared to salmon normally captured in surveillance fishing, were alive and presumably present on spawning grounds suggests that most of the salmon released back into the river during surveillance fishing participate in spawning.

Our study used recreational fishing data from summer and autumn, relying on cooperation with fishers to provide fish for tagging. Two potential biases arise from this approach. First, tagging may affect the behavior of fish in a way that is not representative of their typical movements. External radio tagging is believed to be the lowest impact method of electronically tagging salmon because it does not require invasive surgical implantation. The tags that we used were shown not to affect swimming performance in experiments (Thorstad et al. 2000). The control group received an anesthetic for tag attachment, which may have affected swimming, but we expected that the effects would have worn off after several months, yielding a suitable control group. Lennox et al. (2017a) used radio-tracking data from a group of Atlantic Salmon tagged during summer in a different year as a control group for surveillance angling, and those authors came to similar conclusions about the effects of surveillance fishing. A second potential source of bias is the small sample size that we ultimately had for modeling. Relying on individual data from recreational salmon angling for analysis provides a relatively small sample size; therefore, we emphasize that our models could not detect small differences between the treatment and control groups. We did not identify large effects of surveillance fishing, but our results should be interpreted while considering that there may have been small effects that were beyond our ability to detect at these sample sizes.

Surveillance fishing is established to quantify the impacts of escaped farmed salmon on rivers and to remove as many as possible before spawning starts. Surveillance

anglers are expected to follow strict guidelines to reduce stress on the salmon; therefore, surveillance fishing is not the same as recreational angling due to the more professional way in which it is conducted. Although the process could affect salmon, this study failed to reject the hypothesis that the behavior of salmon released by surveillance anglers did not differ from the behavior of control fish. Collateral damage associated with surveillance fishing, such as infrequent mortality or impacts on spawning, would be challenging to identify if those effects are sufficiently rare. Such impacts would be negligible in rivers that are not below their conservation limit. Surveillance fishing is an important method used in the management program for monitoring escaped farmed salmon in rivers. Our results show that the effects of surveillance angling are minor or even null for salmon populations that attain the spawning target if surveillance is used with caution and if only a small proportion of the population is sampled. However, in small and vulnerable salmon populations, a total mortality rate like that observed in the present study (9%) would have larger impacts on the population. Consequently, factors such as sample sizes, the state of the salmon population, and the population size should be assessed for each river individually when deciding the necessity of and approach to surveillance fishing.

Surveillance fishing is commonly implemented in Norway, where escaped farmed salmon and their impacts on wild fish are prevalent (Diserud et al. 2019, 2022). This paper strengthens the evidence base for the recommendations used to regulate surveillance fishing in Norway—specifically to use careful handling of salmon and to cease sampling at least 2 weeks prior to the expected onset of the spawning period, thus providing a conservative recuperation period. Therefore, surveillance fishing could be a useful method for assessing the influence of escaped farmed salmon in other countries that experience this conservation challenge. However, the effectiveness of surveillance fishing depends greatly on the ability of fishers to accurately differentiate the farmed salmon from their wild counterparts. Visual assessment is the standard method for field identification of farm-origin fish, and it is accepted that salmon that escaped early in life and have spent most of their lives in the wild may be difficult to differentiate from wild fish (Glover et al. 2019). Because we did not have a systematic overview of each fish that was released, we cannot estimate the anglers' success rate in identifying farmed fish, but a future analysis would be an important part of the evaluation of surveillance fishing. The use of telemetry to compare the movements of control and surveillance groups of salmon provided an ideal methodology to investigate the impacts of surveillance fishing. There is evidence that this practice can be a sustainable management tool for as long as escaped farmed



salmon continue to plague Atlantic Salmon spawning rivers (Diserud et al. 2019).

## ACKNOWLEDGMENTS

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## CONFLICT OF INTEREST STATEMENT

The authors are not aware of any conflict of interest.

## DATA AVAILABILITY STATEMENT

Raw data are available on github in the BTN R package: <https://github.com/robertlennox/BTN/tree/main/data>.

## ETHICS STATEMENT

Experiments were conducted according to a scientific license from the Norwegian Food Safety Authority (Mattilsynet).

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## REFERENCES

- Aronsen, T., Bakke, G., Barlaup, B., Fiske, P., Florø-Larsen, B., Glover, K. A., Hindar, K., Næsje, T., Otterå, H., & Skaala, Ø. (2016). *Felthåndbok for overvåking av rømt oppdrettslaks* (Rapport Nr. 16-2016). Havforskningsinstituttet.
- Bartholomew, A., & Bohnsack, J. A. (2005). A review of catch-and-release angling mortality with implications for no-take reserves. *Reviews in Fish Biology and Fisheries*, 15, 129–154. <https://doi.org/10.1007/s11160-005-2175-1>
- Bivand, R., Rundel, C., Pebesma, E., Stuetz, R., Hufthammer, K. O., & Bivand, M. R. (2017). Package 'rgeos'. <https://cran.r-project.org/package=rgeos>
- Bolstad, G. H., Karlsson, S., Hagen, I. J., Fiske, P., Urdal, K., Sægrov, H., Florø-Larsen, B., Sollien, V. P., Østborg, G., & Diserud, O. H. (2021). Introgression from farmed escapees affects the full life cycle of wild Atlantic Salmon. *Science Advances*, 7, Article eabj3397. <https://doi.org/10.1126/sciadv.abj3397>
- Diserud, O. H., Fiske, P., Karlsson, S., Glover, K. A., Naesje, T., Aronsen, T., Bakke, G., Barlaup, B. T., Erkinaro, J., Florø-Larsen, B., Foldvik, A., Heino, M., Kanstad-Hanssen, O., Lo, H., Lund, R. A., Muladal, R., Niemela, E., Okland, F., Ostborg, G. M., ... Hindar, K. (2022). Natural and anthropogenic drivers of escaped farmed salmon occurrence and introgression into wild Norwegian Atlantic Salmon populations. *ICES Journal of Marine Science*, 79, 1363–1379. <https://doi.org/10.1093/icesjms/fsac060>
- Diserud, O. H., Fiske, P., Sægrov, H., Urdal, K., Aronsen, T., Lo, H., Barlaup, B. T., Niemelä, E., Orell, P., Erkinaro, J., Lund, R. A., Økland, F., Østborg, G. M., Hansen, L. P., & Hindar, K. (2019). Escaped farmed Atlantic Salmon in Norwegian rivers during 1989–2013. *ICES Journal of Marine Science*, 76(4), 1140–1150. <https://doi.org/10.1093/icesjms/fsy202>
- Fleming, I., & Einum, S. (1997). Experimental tests of genetic divergence of farmed from wild Atlantic Salmon due to domestication. *ICES Journal of Marine Science*, 54, 1051–1063. [https://doi.org/10.1016/S1054-3139\(97\)80009-4](https://doi.org/10.1016/S1054-3139(97)80009-4)
- Fleming, I., Jonsson, B., Gross, M., & Lamberg, A. (1996). An experimental study of the reproductive behaviour and success of farmed and wild Atlantic Salmon (*Salmo salar*). *Journal of Applied Ecology*, 33, 893–905. <https://doi.org/10.2307/2404960>
- Forseth, T., Barlaup, B. T., Finstad, B., Fiske, P., Gjosæter, H., Falkegård, M., Hindar, A., Mo, T. A., Rikardsen, A. H., & Thorstad, E. B. (2017). The major threats to Atlantic Salmon in Norway. *ICES Journal of Marine Science*, 74, 1496–1513. <https://doi.org/10.1093/icesjms/fsx020>
- Fraser, D. J., Minto, C., Calvert, A. M., Eddington, J. D., & Hutchings, J. A. (2010). Potential for domesticated–wild interbreeding to induce maladaptive phenology across multiple populations of wild Atlantic Salmon (*Salmo salar*). *Canadian Journal of Fisheries and Aquatic Sciences*, 67, 1768–1775. <https://doi.org/10.1139/F10-094>
- Glover, K. A., Urdal, K., Næsje, T., Skoglund, H., Florø-Larsen, B., Otterå, H., ... Wennevik, V. (2019). Domesticated escapees on the run: The second-generation monitoring programme reports the numbers and proportions of farmed Atlantic Salmon in >200 Norwegian rivers annually. *ICES Journal of Marine Science*, 76(4), 1151–1161. <https://doi.org/10.1093/icesjms/fsy207>
- Hansen, L. P., & Jacobsen, J. A. (2003). Origin and migration of wild and escaped farmed Atlantic Salmon, *Salmo salar* L., in oceanic areas north of the Faroe Islands. *ICES Journal of Marine Science*, 60, 110–119. <https://doi.org/10.1006/jmsc.2002.1324>
- Harby, A., Tøfte, L. S., Alfredsen, K., Finstad, A. G., Fiske, P., Forseth, T., Hvidsten, N. A., Jensen, A. J., Nester, M., & Sælthun, N. R. (2010). *Climate change effects on discharge, hydropower production, water temperature, ice conditions and their impact on Atlantic Salmon in the regulated Orkla River in Norway*. Presented at the 6th International Symposium on Ecohydraulics, Christchurch, New Zealand.
- Heggberget, T. G., Økland, F., & Ugedal, O. (1996). Prespawning migratory behaviour of wild and farmed Atlantic Salmon, *Salmo salar* L., in a north Norwegian River. *Aquaculture Research*, 27(5), 313–322. <https://doi.org/10.1111/j.1365-2109.1996.tb01258.x>
- Hijmans, R. J., Van Etten, J., Cheng, J., Mattiuzzi, M., Sumner, M., Greenberg, J. A., Lamigueiro, O. P., Bevan, A., Racine, E. B., & Shortridge, A. (2015). Package 'raster'. R package 734. <https://cran.r-project.org/package=raster>
- Hvidsten, N., Diserud, O., Jensen, A., Jensås, J., Johnsen, B., & Ugedal, O. (2015). Water discharge affects Atlantic Salmon *Salmo salar* smolt production: A 27 year study in the River Orkla, Norway. *Journal of Fish Biology*, 86, 92–104. <https://doi.org/10.1111/jfb.12542>
- Jonsson, B., & Jonsson, N. (2017). Maternal inheritance influences homing and growth of hybrid offspring between wild and

- farmed Atlantic Salmon. *Aquaculture Environment Interactions*, 9, 231–238. <https://doi.org/10.3354/aei00232>
- Kjeldsen, J., Krogdahl, R., Heggem, V., Fiske, P., Hvidsten, N. A., Baardsen, S., Stensland, S., & Aas, Ø. (2012). *Elvene rundt Trondheimsfjorden. Laks og verdiskaping. Oppsummeringsrapport-korrigert versjon* (Temahefte 48). NINA.
- Lennox, R. J., Cooke, S. J., Davis, C. R., Gargan, P., Hawkins, L. A., Havn, T. B., Johansen, M. R., Kennedy, R. J., Richard, A., & Svenning, M.-A. (2017a). Pan-Holarctic assessment of post-release mortality of angled Atlantic Salmon *Salmo salar*. *Biological Conservation*, 209, 150–158. <https://doi.org/10.1016/j.biocon.2017.01.022>
- Lennox, R. J., Havn, T. B., Thorstad, E. B., Liberg, E., Cooke, S. J., & Uglem, I. (2017b). Behaviour and survival of wild Atlantic Salmon *Salmo salar* captured and released while surveillance angling for escaped farmed salmon. *Aquaculture Environment Interactions*, 9, 311–319. <https://doi.org/10.3354/aei00235>
- Moe, K. (2014). *Comparison of area use and movement behavior in wild and escaped farmed Atlantic Salmon (Salmo salar L.) before and during spawning in the River Namsen* [Master thesis, Norwegian University of Life Science]. NMBU. <http://hdl.handle.net/11250/199050>
- Moe, K., Næsje, T. F., Haugen, T. O., Ulvan, E. M., Aronsen, T., Sandnes, T., & Thorstad, E. B. (2016). Area use and movement patterns of wild and escaped farmed Atlantic Salmon before and during spawning in a large Norwegian river. *Aquaculture Environment Interactions*, 8, 77–88. <https://doi.org/10.3354/aei00165>
- Økland, F., Erkinaro, J., Moen, K., Niemelä, E., Fiske, P., McKinley, R., & Thorstad, E. (2001). Return migration of Atlantic Salmon in the River Tana: Phases of migratory behaviour. *Journal of Fish Biology*, 59, 862–874. <https://doi.org/10.1111/j.1095-8649.2001.tb00157.x>
- Økland, F., Heggberget, T. G., & Jonsson, B. (1995). Migratory behaviour of wild and farmed Atlantic Salmon (*Salmo salar*) during spawning. *Journal of Fish Biology*, 46, 1–7. <https://doi.org/10.1111/j.1095-8649.1995.tb05942.x>
- Richard, A., Dionne, M., Wang, J. L., & Bernatchez, L. (2013). Does catch and release affect the mating system and individual reproductive success of wild Atlantic Salmon (*Salmo salar* L.)? *Molecular Ecology*, 22, 187–200. <https://doi.org/10.1111/mec.12102>
- Ripley, B., Venables, B., Bates, D. M., Hornik, K., Gebhardt, A., & Firth, D. (2013). *Package 'MASS'*. <https://cran.r-project.org/package=MASS>.
- Statistics Norway. (2022). 07670: Elvefiske. Fangst, etter elv/delvassdrag, fiskeslag og bruken av fangsten 1993 - 2023. Statbank Norway [Online database]. <https://www.ssb.no/statbank/table/07670/tableViewLayout1/>
- Stokesbury, M. J., Lacroix, G. L., Price, E. L., Knox, D., & Dadswell, M. J. (2001). Identification by scale analysis of farmed Atlantic Salmon juveniles in southwestern New Brunswick rivers. *Transactions of the American Fisheries Society*, 130(5), 815–822. [https://doi.org/10.1577/1548-8659\(2001\)130<0815:IBSAOF>2.0.CO;2](https://doi.org/10.1577/1548-8659(2001)130<0815:IBSAOF>2.0.CO;2)
- Thorstad, E., Økland, F., & Finstad, B. (2000). Effects of telemetry transmitters on swimming performance of adult Atlantic Salmon. *Journal of Fish Biology*, 57, 531–535. <https://doi.org/10.1111/j.1095-8649.2000.tb02192.x>
- Thorstad, E. B., Forseth, T., & Fiske, P. (2021). *Status for norske laksebestander i 2021* (Rapport Nr. 16). Enskapelig råd for lakseforvaltning.
- Thorstad, E. B., Næsje, T. F., Fiske, P., & Finstad, B. (2003). Effects of hook and release on Atlantic Salmon in the River Alta, northern Norway. *Fisheries Research*, 60, 293–307. [https://doi.org/10.1016/S0165-7836\(02\)00176-5](https://doi.org/10.1016/S0165-7836(02)00176-5)
- van Etten, J. (2017). R package gdistance: Distances and routes on geographical grids. *Journal of Statistical Software*, 76(13), 1–21. <https://doi.org/10.18637/jss.v076.i13>
- Wacker, S., Aronsen, T., Karlsson, S., Ugedal, O., Diserud, O. H., Ulvan, E. M., Hindar, K., & Næsje, T. F. (2021). Selection against individuals from genetic introgression of escaped farmed salmon in a natural population of Atlantic Salmon. *Evolutionary Applications*, 14, 1450–1460. <https://doi.org/10.1111/eva.13213>
- Whoriskey, F. G., Prusov, S., & Crabbe, S. (2000). Evaluation of the effects of catch-and-release angling on the Atlantic Salmon (*Salmo salar*) of the Ponoï River, Kola Peninsula, Russian Federation. *Ecology of Freshwater Fish*, 9, 118–125. <https://doi.org/10.1034/j.1600-0633.2000.90114.x>
- Wickham, H., & Wickham, M. H. (2020). *plyr: Tools for splitting, applying and combining data*. R package version 1.8.5. <https://cran.r-project.org/web/packages/plyr/index.html>
- Wood, S. N. (2017). *Generalized additive models: An introduction with R* (2nd ed.). Chapman and Hall/CRC. <https://doi.org/10.1201/9781315370279>
- Wringe, B. F., Jeffery, N. W., Stanley, R. R. E., Hamilton, L. C., Anderson, E. C., Fleming, I. A., Grant, C., Dempson, J. B., Veinott, G., Duffy, S. J., & Bradbury, I. R. (2018). Extensive hybridization following a large escape of domesticated Atlantic Salmon in the northwest Atlantic. *Communications Biology*, 1(1), Article 108. <https://doi.org/10.1038/s42003-018-0112-9>