River Shin 'Missing Salmon Project' 2019

Kyle of Sutherland Fisheries

SCENE Loch Lomond

ATLANTIC SALMON TRUST

Report compiled by the Scottish Centre for Ecology and the Natural Environment, University of Glasgow & Atlantic Salmon Trust

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Executive Summary

In the spring of 2019, the largest acoustic telemetry project in Europe, the Moray Firth "Missing Salmon Project", was initiated. The Moray Firth project partnership, led by the Atlantic Salmon Trust, comprises Glasgow University, the six District Salmon Fishery Boards / Fishery Trusts in the Moray Firth and Marine Scotland. Over 340 acoustic receivers were deployed from the headwaters of the rivers out into the open sea within the Moray Firth. Fish were captured in seven river systems (Deveron, Spey, Findhorn, Ness, Conon, Oykel, Shin) which all flow into the Moray Firth. Three tagging teams successfully captured and tagged 850 migrating smolts. The core aim of the project was to: 1) Identify how successfully smolts move down the main stem and into the transitional waters of the estuary and 2) Identify the marine migration routes.

All acoustic receivers were deployed prior to any fish being tagged and released. The majority of acoustic receivers were deployed in the marine environment by the MRV Alba Na Mara, funded by Marine Scotland Science. Fish were captured through close collaboration between tagging teams and local fishery boards who aided in the capture and pre-sorting of smolts ready for tagging. Smolts were tagged with Vemco V7 Acoustic Transmitters and were allowed to fully recover following tagging. The smolts were released a minimum of 45 minutes post- tagging. The tags used have a battery life in excess of 90 days.

Overall, year 1 of the project proved very successful. Recovery of acoustic receivers commenced in June and was completed in October 2019. A total of ~95 % of the receivers were recovered. Data downloaded from the receivers comprised of over 15million detections recorded throughout the study period, a significant amount of data. This report details the **initial analysis** of information so far gleaned from the data. Subsequent scientific reports will provide a detailed, quantitative analysis of the results. The aim of this report is to present descriptive data for the overall project but also focusing on river specific information.

The first year of the project has provided information on where fish losses in the seven rivers of the study occurred, during the first part of their ocean migration. From these initial analyses, it is clear that salmon migration through freshwater habitats during the migration of the salmon is risky. On average, across all seven river systems in 2019, confirmed escapement (fish detected leaving the river, including Oykel and Shin transitional environments), was only 49.2% (range 8-80%). For the Rivers Shin and Oykel, the freshwater environment in this report include freshwater and transitional environments to make it consistent among rivers comparison.

Future analysis in 2020 will aim to better understand the factors governing this part of the smolts migration, including variables, such as environment, genetics and morphology. Building on the 2019 results, the next two years of the project will focus on identifying the key factors involved in smolt losses in freshwater.

River Shin Highlights

- Throughout the smolt run, a total of 100 salmon smolts were tagged with acoustic tags (Vemco V7) over a 16-day period (11/4/19 to 27/4/19).

- The Atlantic salmon smolts had a mean fork length of 136.2 mm and a mean weight 24.2 g. The mean tag burden (% of body weight) was 6.6%.

- Of the 100 tagged salmon smolts, 79 smolts were estimated to have reached the receivers at the marine end of the transitional environment and 58 smolts reached the Spey Bay array. The confirmed survival rate were 79% and 58% respectively..

- Overall, losses rate in freshwater was 0.52 %/km. The loss rate varied between 0%/km (receiver 131694) and 4.0%/km (receiver 126845).

- Freshwater receiver efficiency averaged 88.0 %. Four receivers operated at over 98% efficiency.

- The median speed for confirmed migrant (e.g., smolts that were detected when crossing Fraserburgh array) was 0.04 m/s for river travel, and 0.03 m/s for the transitional environment travel. For the marine environment travel , median speeds were 0.37, 0.32 and 0.31 m/s to the Dornoch, Spey and Fraserburgh arrays.

- Confirmed successful migrant smolts took a median of 2.09 days to travel from the release site to the most downstream river receiver, and 10.83 days in the transitional environment. They took 0.29 days to travel to the marine Dornoch array, 1.06 days to travel to the marine Spey array, and 2.64 days to reach the marine Fraserburgh array.

- Once in the marine environment, the salmon smolts showed strong directional movement, heading east, north east.

Introduction

Smoltification and extensive migration characterise the anadromous Atlantic salmon (*Salmo salar*) and sea trout (*Salmon trutta*). Migration from a freshwater to saline environment is essential for individuals to rapidly grow in the richer feeding grounds offshore, optimising their growth rate and future reproductive output. When salmon parr reach a threshold size, they undergo physiological pre-adaptations to life in a saline environment through a process called smoltification (Kennedy and Crozier, 2010; Hvidsten *et al.,* 1995). The smolt run, occurring in spring, marks the mass migration of smolts to the sea. Smoltification and migration present numerous risks, which include an increased risk of predation, increased nutrient competition amongst smolts and osmotic pressures once they reach their new environment (Kennedy and Crozier, 2010). Numerous studies have reported these risks as having resulted in high mortality rates during the run. A review by Thorstad *et al.* (2012) reported the mortality rates started at 0.3%, and rose as high as 7.0%/km (averaging 2.3%/km). High variation in mortality rates occurs due to the differentiating river conditions (Thorstad *et al.,* 2012) and predatory hotspots (Jutila, Jokikokko and Julkunen, 2005).

There is increasing concern over the declining marine survival rates of Atlantic salmon being recorded from most North East and South East Atlantic monitored populations since 1980 (ICES, 2019). In recent years, wild salmon marine survival from Scottish rivers is generally believed to be below 5%, and this represents a notable decline in survival now compared to recorded return rates of over 10% in the 1990s. In a fitting setting under the 2019 'International Year of the Salmon', the Missing Salmon Project launched the largest acoustic tracking project in Europe. The project planned to tag 800 salmon smolts and 50 sea trout smolts, across 7 river catchments in the Moray Firth, so as to identify what is happening to salmon and to identify what management action could be taken to boost wild smolt survival.

This report provides an overview of the **initial analysis** of data for fish tagged in the River Shin and their downstream migration pattern to the Moray Firth. Currently detailed modelling, and investigations of other factors in the study are ongoing. These are outlined in the Next Steps section of the report. This report will refer to detection of fish as 'confirmed survival', hence the data here refers only to smolts which have been detected. A smolt that has not been detected may not necessarily have died. There are several other possible reasons for non-detection of the tagged fish, including non-detection by the acoustic receivers. Efficiency and range testing will be used to model potential missed detections of fish and thus provide more robust estimates of confirmed survival estimates. This is most likely to affect marine detections, where if any change occurs it would be a positive effect (i.e. an increase in survival)

Materials and Methods

Four receivers were placed at various intervals along the River Shin, and four in the Kyle to detect these tags as smolts migrate downstream (freshwater and transitional, see Figure 1a). River Shinn receivers were positioned in deep, slow moving pools, which provide the most suitable conditions for detecting tagged fish as they move downstream.

Smolts were captured via two rotary screw traps, located on the River Fiag (58.148359, -4.6065632) and the River Tirry (58.071093, -4.415040).Throughout the run a total of 100 salmon smolts were tagged. Smolts of suitable size (>130mm Fork Length [nose to 'V' of the tail]) were selected for tagging, thus limiting any tag burden effects. The acoustic tags emitted a 'ping' which is a unique ID, randomly every 15-35 seconds. Each tag was checked to confirm its activation. Fish were tagged over a 16-day period from 11/4/19 to 27/4/19. To mimic the natural smolt migration pattern as far as possible, the number of fish tagged each day was kept proportional to the total number sampled by the trap.

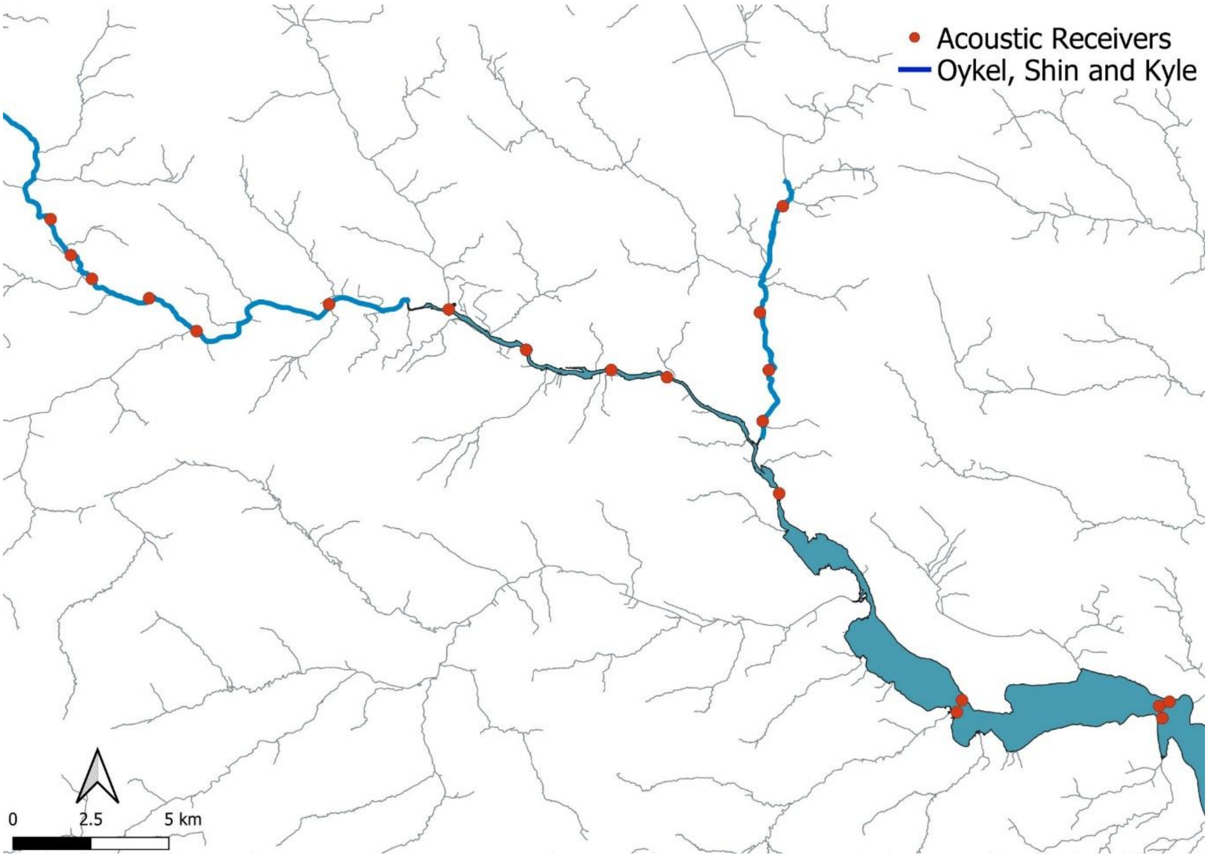

Figure 1a. Locations of the acoustic receivers along the River Shin.

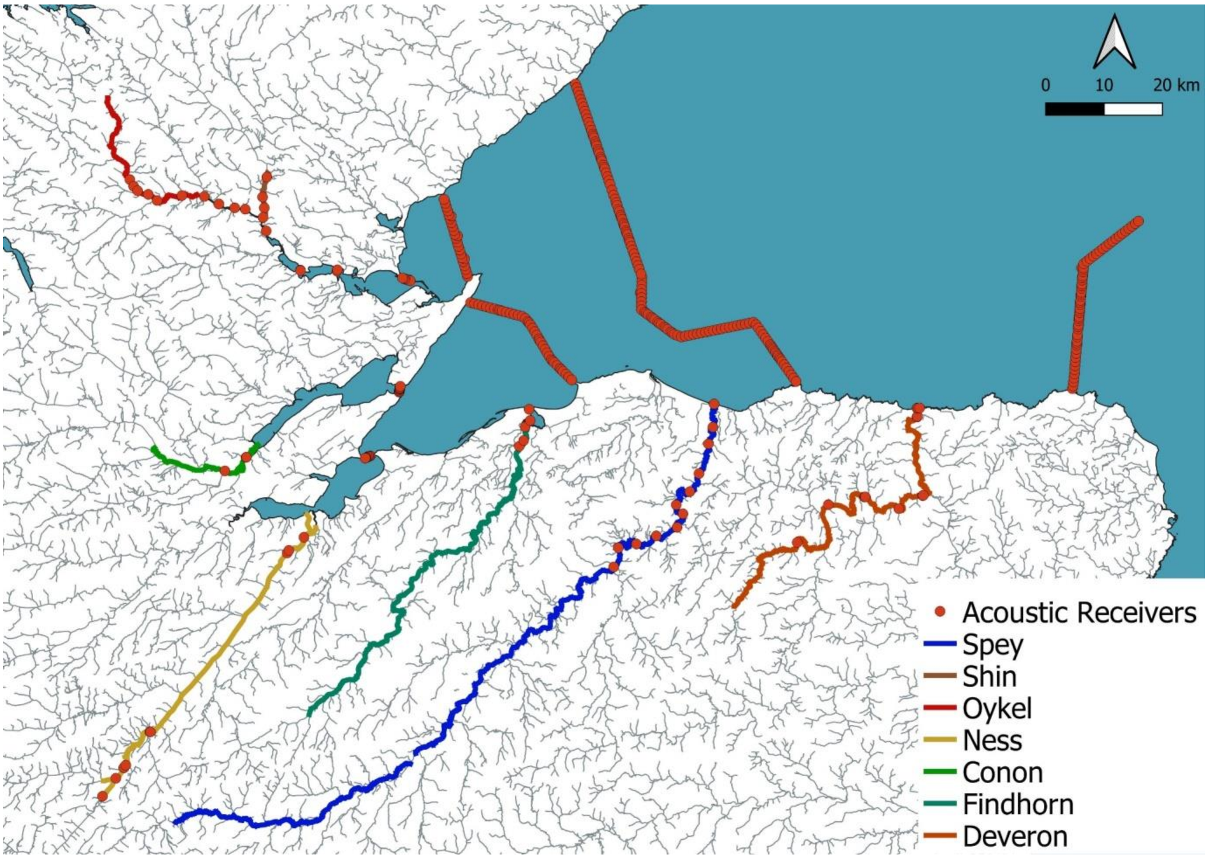

Figure 1b. Locations of the acoustic receivers across the Missing Salmon Project.

Prior to tagging, acoustic tags were sterilized in absolute ethanol and rinsed in distilled water. Fish were anesthetized (MS222: 0.1g to 1L of water). Their fork length (mm) and mass (g) were measured and a photograph recorded for later morphometric analysis (Figure 2). Fish were placed on a v-shaped surgical pillow with their abdomen side up. A small incision (10-13mm in length) was made anterior of the pelvic girdle where the tag was inserted. The incision was closed with two interrupted absorbable sutures (Ethicon VICRYL). All fish were oxygenated initially with 100% river water throughout the procedure, a 50% anesthetic dilution was used to maintain anesthesia if the fish showed signs of recovery. Finally, a fin clip (adipose fin) was collected from the fish and stored in absolute ethanol for later genetic analysis. The fish were then placed in a bucket containing aerated river water and allowed to fully recover (approx. 5 minutes), groups of tagged fish were then held within a recovery box (0.5m.sq perforated holes) and placed in the river, within an area of gentle flow and allowed to acclimatize for a minimum of 45 minutes prior to release. Fish were released downstream of the Shin diversion dam at 58.009568, -4.3994229.

Figure 2. A morphometric photograph was recorded for each tagged smolt.

Results and Discussion

Length and weight frequencies

The mean fork length of the tagged Atlantic salmon smolts encountered over the course of the study in the River Shin was 136.2 mm and the mean weight of the tagged smolts was 24.2 g. The tags weigh 1.6 g which results in an average tag burden (% of body weight) of 6.6%. The range of salmon smolt sizes and weights among rivers in the study varied from 133.6 mm (Deveron) to 140.3 mm (Ness) and from 23.5 g (Deveron) to 28.8 g (Ness).

A primary concern in migration behaviour studies that incorporate telemetry is that the implant of acoustic tags may impact fish behaviour and buoyancy compensation, impairing their swimming ability. The generally accepted '2% rule' states tag burden should not exceed 2% of dry body weight in salmonids. However, further studies have reported transmitters up to 7% (Smircich and Kelly, 2014) and as high as 12% body weight (Brown *et al.,* 2011) as having negligible impacts on swimming ability.

Survival

Of the 100 salmon smolts released, 89 (89%) individuals were detected leaving the River Shin for the tidal environment, 79 (79%) individuals were detected entering the marine environment and 58 (58%) individuals confirmed to survive at the Spey Bay array. Overall there was a decrease in the detection rates of smolts further downstream with an overall freshwater loss rate of 0.52% fish per km (Figure 3 and Table 1). This was at at the bottom of the range of rivers in the study, from 0.52% (Shin) to 5.95 % (Findhorn) (Figure 4; Appendix 1).

Receiver Efficiency

Receiver efficiency was calculated by determining the number of individuals which were detected on receivers downstream of the specific receiver that was being used. Freshwater receiver efficiency averaged 88.0%, with four receivers operating at over 98% efficiency (Figure 3 and Table 1).

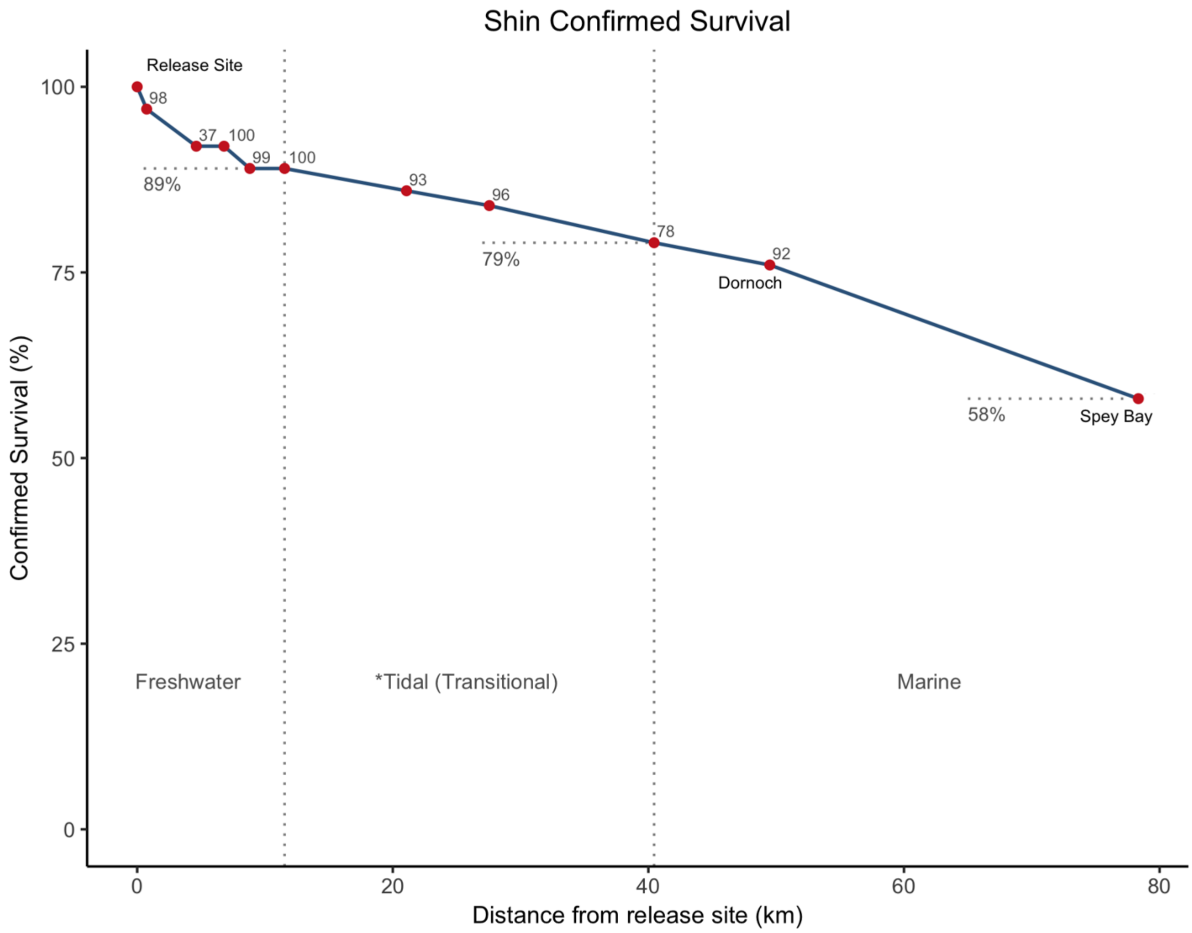

Figure 3. Confirmed survival (%) of smolts at increasing distance from the release site on the River Shin. Red dots represent receivers, and detection efficiency (%) of each freshwater receiver is provided. Receiver 5 is located just within the Transitional environment. *Please note that the marine array efficiencies are not complete as the Fraserburgh array was a partial array and not a fully closed array. The efficiencies of the marine arrays will be determined through modelling and simulations (see Next Step section).

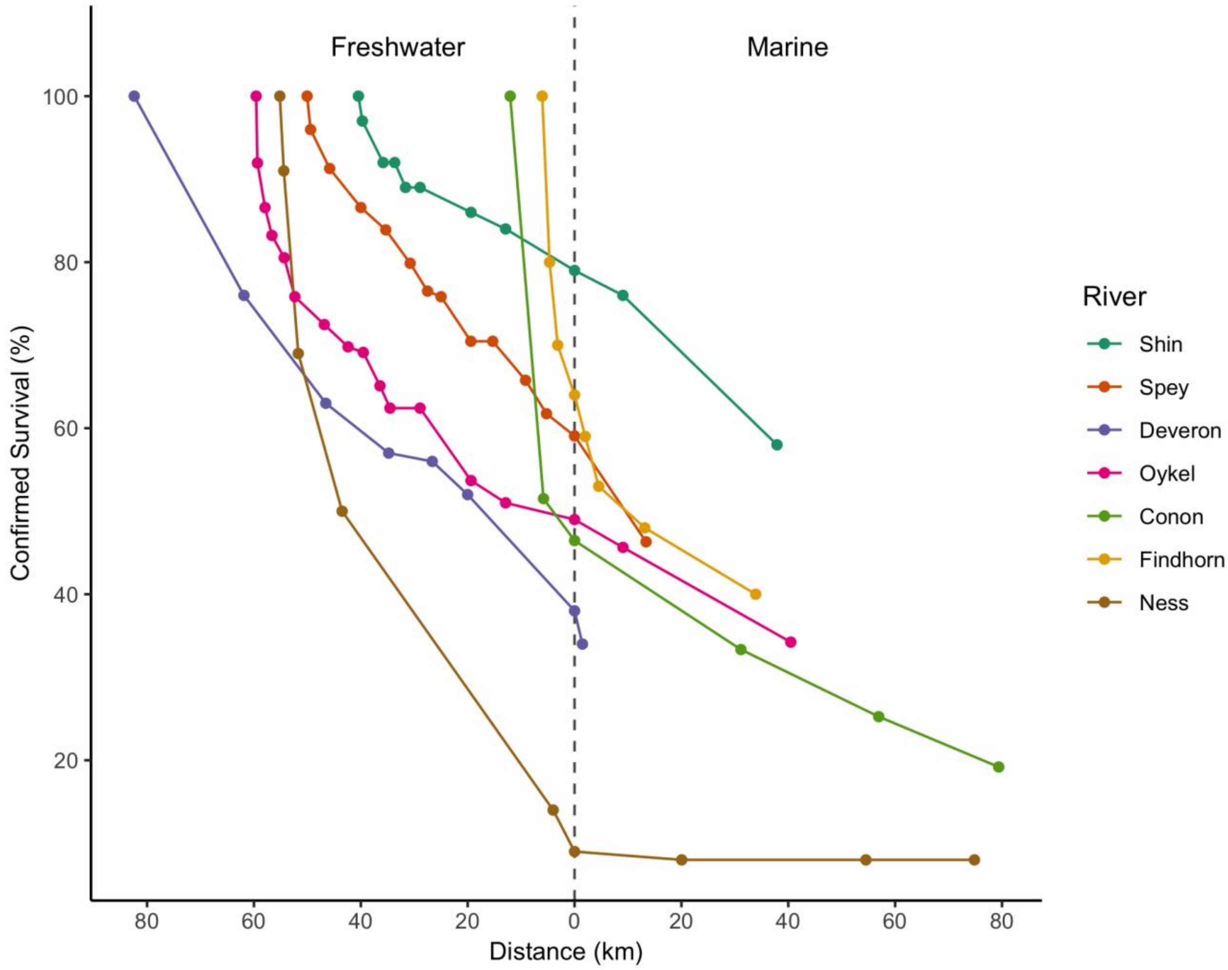

Figure 4. Confirmed survival (%) of salmon smolts for the seven rivers of the Moray Firth, with distance of smolt migration undertaken. Both freshwater and marine environments are included. The migration distance has been standardized so that the dotted line represents entry to marine water on each river system.

<u>Rate of Movement (ROM)</u>

To determine speed of migration, medians are given (in place of means) as due to the nature of the data, estimates of means can be skewed by the behavior of a small number of fish. Confirmed successful migrant smolts took a median of 2.09 days to travel downstream from the release site through the river habitats, 10.83 days to cross the transitional environment, 0.29 days to travel to the Dornoch array, 1.06 days to travel to the marine Spey array, and 2.64 days to reach the marine Fraserburgh array (Figure 5). This represents a median ground speed of 0.04 m/s for river travel, 0.03 m/s for the transitional travel, 0.37 m/s for the marine travel to Dornorch, 0.32 m/s marine travel to the Spey array, and 0.31 m/s for the marine travel to the Fraserburgh (Figure 6).

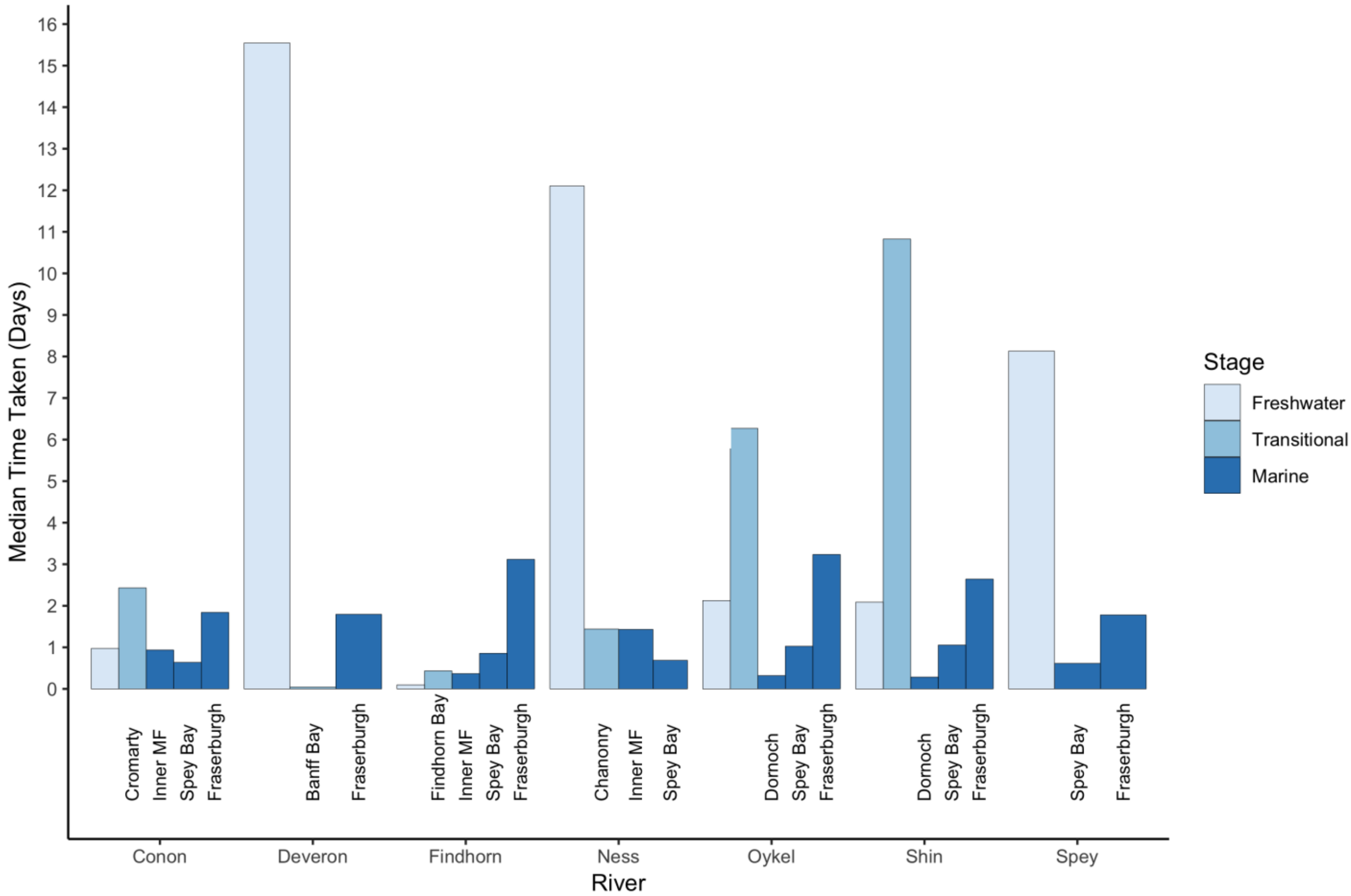

Figure 5. Median time taken by smolts to travel from the release site, to the mouth of the river, and then to each marine arrays. *Please note these values are only for fish that successfully migrated from release site to the Fraserburgh marine array. Distance travelled is not taken into consideration (see Figure 6 for standardised values among rivers).

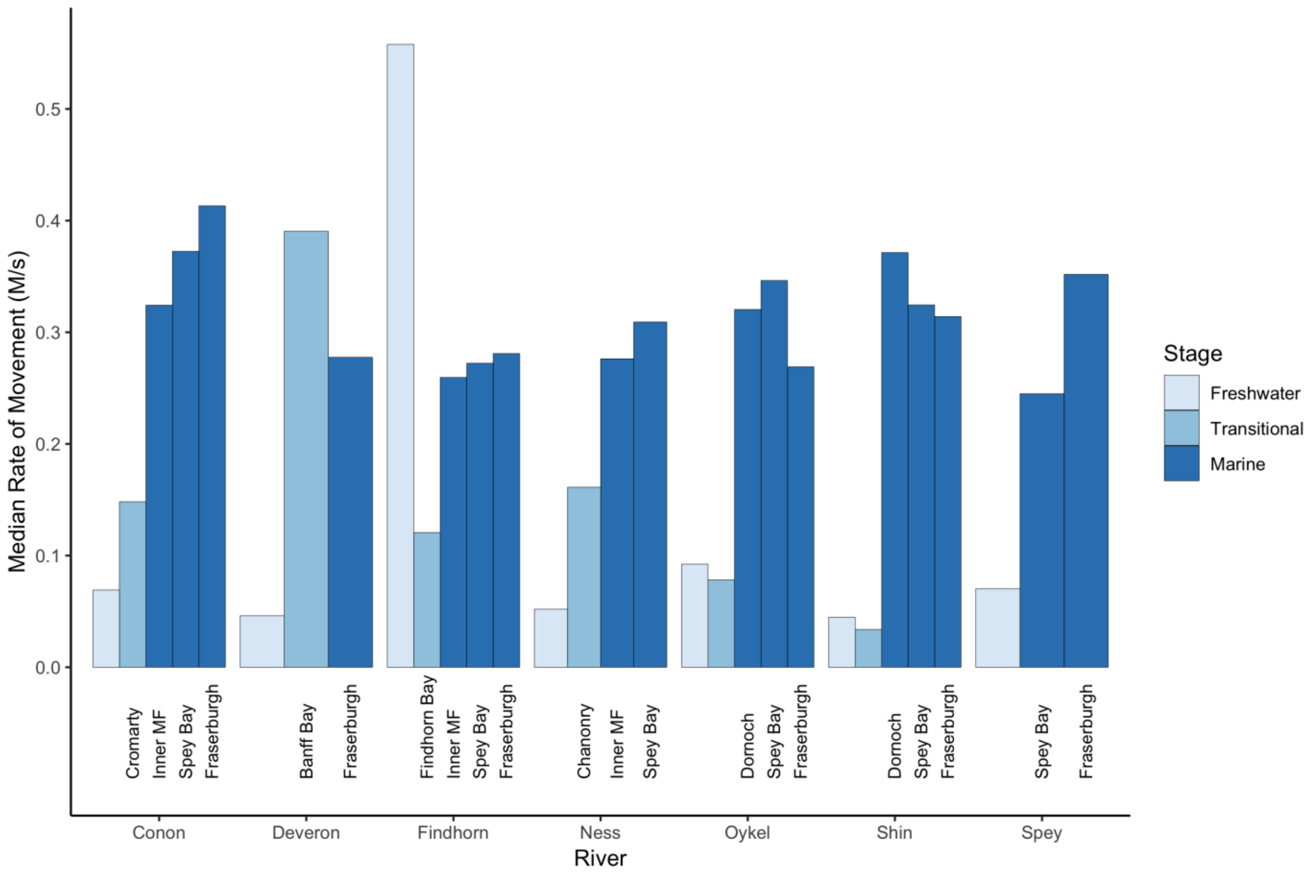

Figure 6. Median speed of smolts from all rivers travelling from the release site, to the mouth of the river, and then to each marine arrays. *Please note these values are only for fish that successfully migrated from release the release site to the sea.

Residency Times

For residency time, medians are given (in place of means) as due to the nature of the data, estimates of means can be skewed by the behavior of a small number of fish. The residency time, is the total time an individual fish spent at a single receiver. The durations are from the first river receiver and not the release site. The durations are calculated from the first river receiver and not the release site. This was to offset any residual surgery effects to provide a more accurate representation of a journey time under natural conditions. A new residency event was assigned if the fish went undetected for a period of 12 hours (e.g. to correspond with the day vs. night migrating timeline) thus fish could have multiple residency events at a single receiver (although this was rare). In general, residency times of tagged fish were low on the River Shin (Figure 7 and Table 1) and in the marine environment (Table 1). For the River Shin, the higher residencies were found at receivers 480408 and 481435.

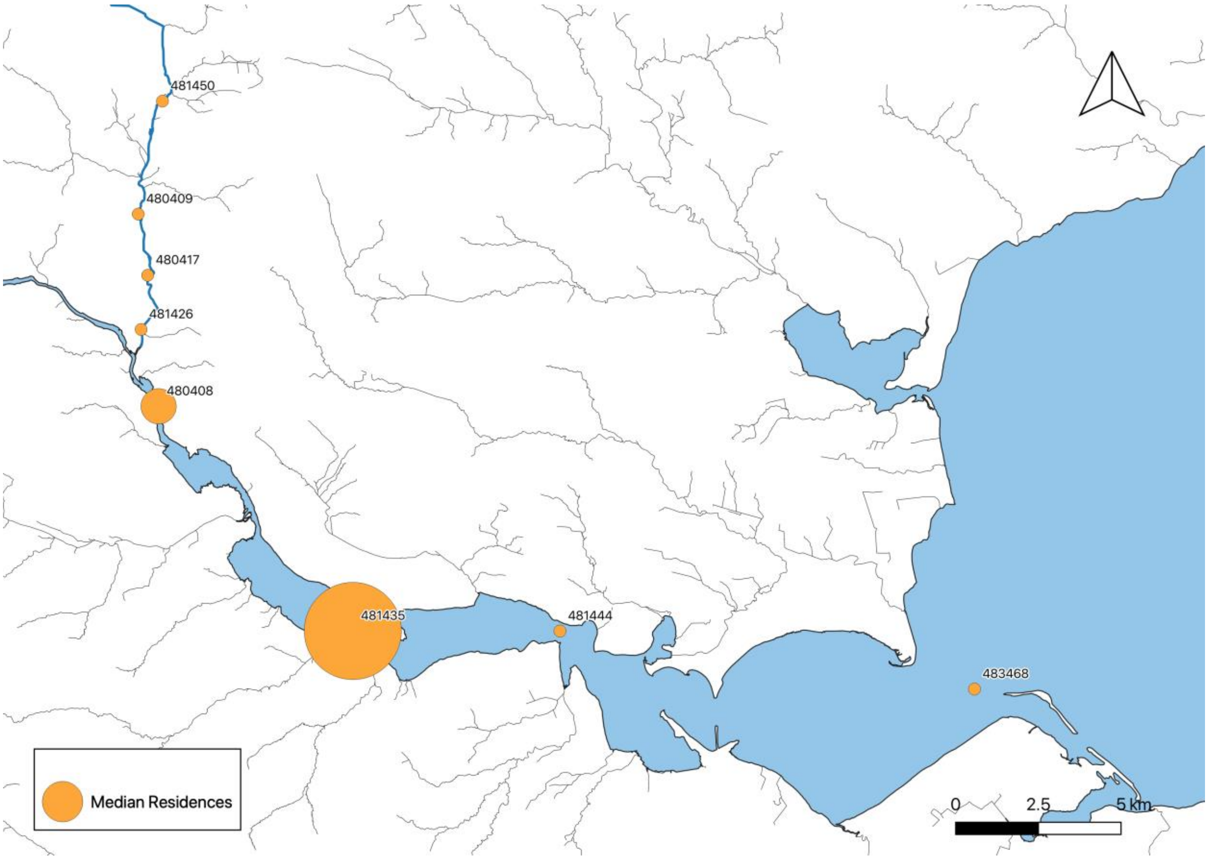

Figure 7. Median residency time of smolts on the River Shin.

Marine migration route/direction

Salmon smolt did not show shoaling behavior when exiting the mouth of the river for the marine environment. The migration pattern begins to be spread spatially at the Dornoch array, with smolts travelling in all direction along the Spey Bay and the Fraserbugh arrays. Overall, the salmon smolts showed strong directional movement, heading east, north east (Figure 8), whilst sea trout showed non-directional movement when exiting the mouth of the river for the marine environment (Figure 10). These patterns were generally reflected by tagged fish migrating out from other rivers in this study (Figure 9 and 10).

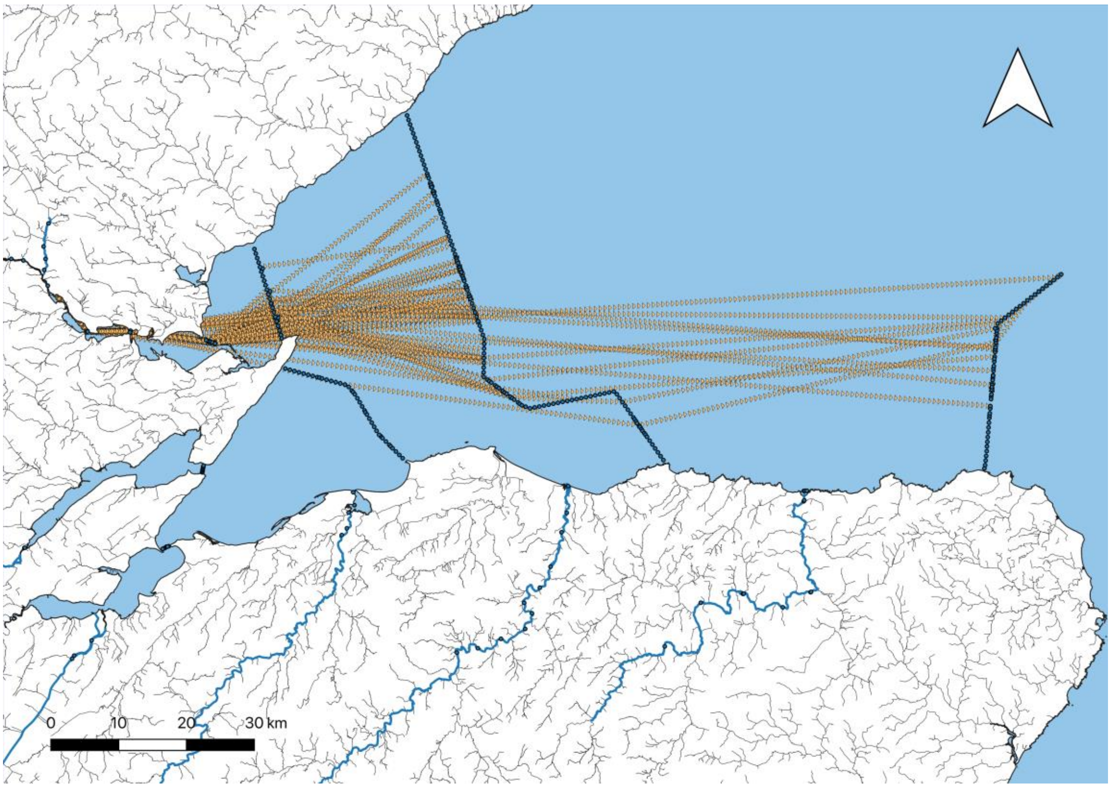

Figure 8. Marine migration direction of salmon smolts exiting the River Shin, moving towards the Dornoch, Spey Bay and Fraserburgh arrays.

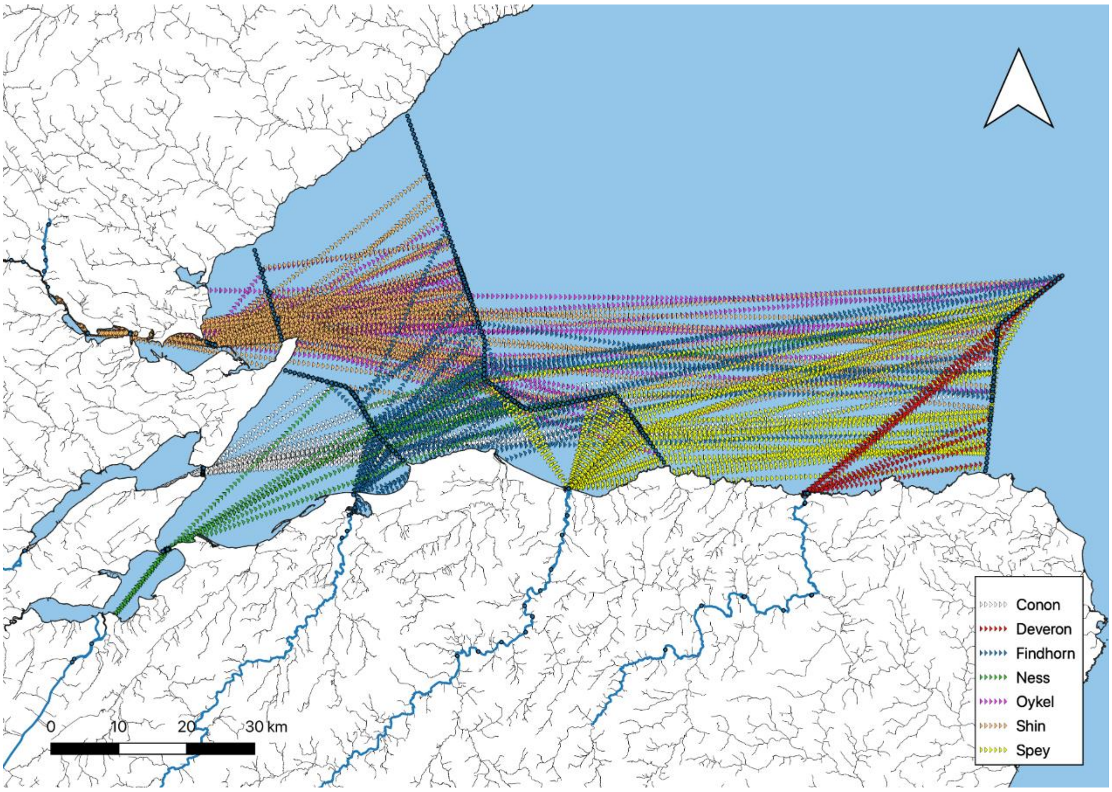

Figure 9. Marine migration direction of salmon smolts for the seven rivers of the Moray Firth, moving towards the Spey Bay and Fraserburgh arrays.

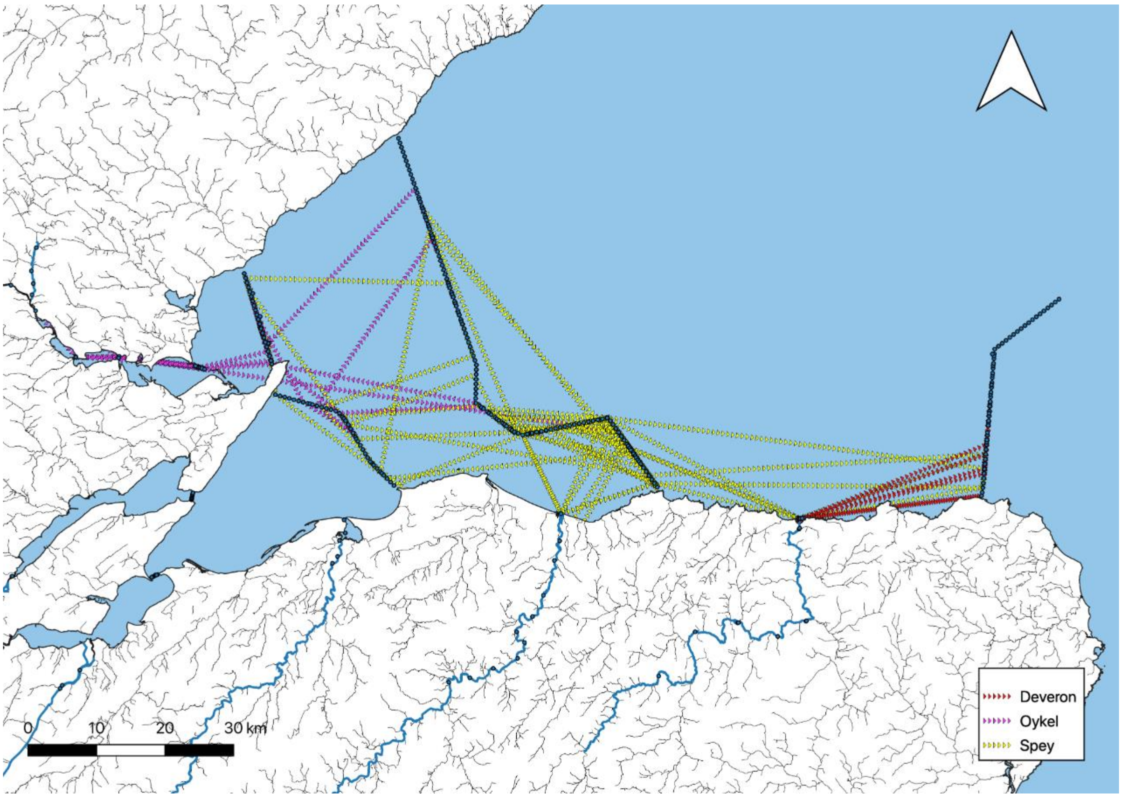

Figure 10. Marine migration direction of sea trout for three rivers of the Moray Firth, moving towards the Spey Bay and Fraserburgh arrays.

Table 1. Metrics of tagged fish that were detected at the reach scale (between two receivers) in the River Shin. Values are for all fish detected at least one time.

Receiver	Distance (km)	Distance Diff. (km)	Efficiency (%)	Confirmed Survival (%)	% losses per km	Median residences (mins)	Median ROM (m/s)	Median duration (secs)
Release Site	0	0	NA	100	NA	NA	NA	NA
481450	0.74	0.74	97.94	97	4.03	6.79	0.01	119326
480409	4.62	3.88	36.96	92	1.29	0.90	0.08	72141.5
480417	6.79	2.17	100	92	0	5.22	0.04	59004
481426	8.81	2.02	98.88	89	1.49	2.03	0.24	8426
480408	11.53	2.72	100	89	0	73.78	0.03	86385
481435	21.07	9.54	93.02	86	0.31	238.40	0.07	141907.5
481444	27.55	6.48	96.43	84	0.31	14.11	0.51	12590
483468	40.45	12.89	78.48	79	0.39	10.63	0.28	46759
Dornoch	49.50	9.05	92.11	76	0.33	11.76	0.37	24642
Spey Bay	78.34	28.84	NA*	58	0.62	5.99	0.32	91235
Fraserburgh	148.01	69.67	NA*	NA	NA	8.45	0.31	228432.5

*Please note that the marine array efficiencies are not fully tested because Fraserburgh array was a partial array and not a closed array. Efficiencies of marine arrays will be determined through modelling and simulation (see Next Step section).

River Shin Trap & Truck study

As part of the larger Missing Salmon Project, a sub-project investigating the so-called 'Trap & truck' method was completed on the River Shin. Two hydro-electric dams separate Loch Shin and the River Shin on the loch's lower section near the village of Lairg; Lairg Dam on the southern side of Loch Shin and the Shin Diversion Dam on the southern extent of Little Loch Shin which sits directly downstream of Loch Shin. In the Shin catchment, a 'Trap & truck' strategy is being currently implimentedin a bid to facilitate downstream smolt migration, which is impinged upon by the dams.. This includes transporting almost all of the smolts captured in the rotary screw traps from the inflowing rivers to the Loch Shin. While this methodology has been shown to lead to increases in returning adult numbers in some cases, there are also suggestions that the handling and transportation can lead to increased stress levels for the fish, possibly affecting behaviour or survival after release. The aim of this study thus was to test if and how release methodology after transportation may affect salmon smolt survival and behaviour. Two comparisons were investigated: day vs. night and immediate vs. delayed (24 hr) release. The study had three main questions and these are addressed individually below.

<u>Question 1: Does the release methodology affect the initiation of migration and initial survival (first 600 m) of transported smolts?</u>

Our hypothesis was that fish that were released at night would start migrating faster and have higher initial survival than those released at day time, however this was not the case. There was no significant difference in the time taken to move from the release site to the first receiver between the day and night time released smolts. There was no significant difference in survival either; 100% of the fish released during the day and 94% of the fish released during the night made it to the first receiver. Similarly, we expected that those fish that were allowed to recover for 24 hrs in a net pen would initiate migration faster and have lower initial mortality than those fish that were released after 30 minutes. The fish in the net pen did move down to the first receiver significantly faster than the 'immediate' release group (mean 18.6 hrs vs. 41.3 hrs), however when the 24-hour recovery period is added to that value it becomes almost identical to the other treatment group. Therefore, it seems that even if fish are not contained, they still spend time recovering after transporting before moving down. When comparing the initial mortality (release to the first receiver), there was no difference between the fish released almost immediately after transport and those that spend 24 hrs in a net pen (100% vs. 97% survival).

Question 2: Does the release methodology affect the overall survival of transported smolts?

During the freshwater and inner estuary migration, there was a small but not a statistically significant difference in the survival between the smolts released during the day and night ($X^2_{(1, N=67)}$=0.5, p=0.5). 88% of the fish released during the day made it to the final inner estuary array, whereas the value was 81% for the fish released at night. Interestingly this 7% difference grew to 16% when looking at the mortality at the outer marine array, approx. 80 km from the release point. From the day time release group, 65% of the fish made it to this point, compared to 49% of the night time release group. However this difference was still not statistically significant (likely due to the small sample size; $X^2_{(1, N=67)}$=1.8, p=0.2). When comparing fish released almost immediately after transport and those allowed to recover for 24 hrs, a higher percentage of the immediate release group fish made it to the final inner estuary array (88% vs. 76%), however this difference is not statistically significant ($X^2_{(1, N=67)}$=1.8, p=0.2). The difference between the groups evened out when mortality at the final marine array was compared; the survival estimates at this point were 65% for the immediate release group and 52% for the delayed release group (not significant: $X^2_{(1, N=67)}$=1.2, p=0.3).

Question 3: Does the release methodology affect the movement speed of transported smolts?

Speed of movement can act as an indicator of fish health, so this variable was also tested between the treatment comparisons. Speed was calculated for the freshwater and inner estuary section of the migration route (the first 28 km). There was no significant difference between the movement speed between the day and night time release groups or the immediate vs. delayed release groups.

In conclusion, this study did not find significant differences in behaviour or mortality for transported salmon smolts. However, it should be noted that the sample size was fairly small

(33-34 fish per group) and it may be that this could explain why differences were not found. Furthermore, this study presents data from one year only.

Next Steps

2019 Quantitative Data Analysis (University of Glasgow and AST)

For a more thorough understanding of the data, a variety of statistical models will be used to explore a potentially more complex set of questions. We will include all data from smolt migration across all rivers so as to provide a robust and thorough analysis of 2019 data. Some of the areas which will be investigated are:

-Determine efficiencies of marine arrays through modelling and simulation.

-Migration direction/success – How do smolts decide on their migration routes using the cues they have available?

A range of factors that could impact on the migration patterns will be examined in the analyses, including:

- Marine migration directionality; vector of travel (river and marine environments)
- Does marine migration directionality affect survivorship?
- Morphology (body shape / proportions) – what makes a successful migrating fish? Can we find characteristics that may affect confirmed survival (morphology is likely to vary among the rivers and may be among years)?
- Are there Sex differences in survival and behaviour? Genetics analysis, currently underway, will allow us to determine the sex of individual smolts. – is there a difference in survival between sexes; in river or marine migration?
- Timing – are fish arriving at the marine arrays at roughly the same time? Is there evidence of migration synchronicity? Are smolts from different rivers merging into groups in the marine environment?
- Do different river types show different patterns of migration passage from freshwater into the marine arrays, here we will compare rivers that open directly to the sea (e.g. Deveron) and rivers and that have sea loch type estuaries (e.g. Conon, Shin, and Oykel)?
- Are fish congregating before entering the marine environment?

- Do fish that migrate through the same areas compared with those fish that take alternative routes, show different migration success?
- Incorporate the temporal and environmental aspects into our analyses (e.g. day vs night, tidal events, precipitation, flow, temperature)?
- Looking at the migration patterns, grouping and temporal aspects we can try to visualise this by animating all the movement (e.g. day vs night, tidal events, precipitation, flow, temperature).

Freshwater Study 2020

As the rivers are the priority areas for understanding where fish are being lost the number of receivers in freshwater will be doubled in the second year of the study to increase the resolution at which the problem can be examined. A minimum of 700 salmon will be tagged across the seven rivers, as a repeat of the 2019 work. Alongside the tagging work, a predator pilot study will be conducted, as described below.

Marine Study 2020

The Spey Bay to Brora marine array will be reinstated in the 2020 study, as the work in 2019 indicated a very high efficiency in detecting tagged fish and acceptable losses of receivers from fishing activities. This configuration of the array for 2020 will allow for estuarine and coastal mortality information to be collected in a comparable way to 2019.

Buoyancy Ocean Glider

In addition to the above, there will be a trial of a buoyancy glider to track smolt migration outside of the Moray Firth. This will add to the limited knowledge on Scottish smolt migration routes beyond in near coast and will provide additional information to help validate the Marine Scotland smolt dispersal model. The exact route of the glider is currently being determined with the University of East Anglia and Marine Scotland. However, it is likely to be the offshore area to the north east of the Moray Firth.

The key deliverables of the 2020 programme will be:

1. Build on the success of the 2019 programme to ensure the results are valid between years.
2. Begin to understand the reasons for the high loss of salmon smolts in the freshwater environment (see predation study below).
3. Increase our understanding of smolt migration routes by locating them further out to sea and validating the smolt dispersal model.
4. Support the Likely Suspects Framework by providing key information on domains and associated pressures / mortality factors.

Genetics Study (AST, Hull University, and University of Glasgow)

The ability to tag and track individual salmon will uncover where and when salmon are being lost on their journey downstream. But understanding why they disappear is more difficult. By extracting the DNA from fin clips of fish with a known migration pattern, and success rate and by studying the genomes of the missing individuals compared to the successfully migrating ones, we may be able to identify why some fish and not others disappear.

Fish from two rivers will be used to:

- Compare immune response genes to understand the role parasite viral or bacterial burden, might play in migration success.
- Associate genetic types with migration success and body shape.
- Identify genomic signatures for different populations from different tributaries.
- DNA fingerprint successful individuals to track their eventual return as adults (after the battery in the tag has run out of power)

This will allow us to look for genomic associations between migratory traits, migration success and genetic regions, while also allowing us to demonstrate differences between populations from closely related tributaries, should there be any. It is possible that there are different processes affecting fish from different rivers, and this focussed strategy should give us the power to detect that. Ideally, given a successful outcome, we could then scale our study up across all rivers.

<u>Predator Study (AST and University College Dublin)</u>

Predation of smolts by birds, fish and mammalian predators has the potential to substantially impact juvenile and smolt survival. This reduced survival may, in turn, negatively affect adult returns to freshwater systems. However, both the scale and the timing of predation by these is little known, and largely subject to anecdotal claims. Indicative results from Moray Firth 2019 tracking project suggest higher than expected losses of smolts in-river and so there is a need to direct efforts to determine why this is happening. The following research questions are proposed as the guiding aims for a programme of predation studies in the Moray Firth in 2020 (and 2021).

1. Are predators responsible for the majority of smolt losses during in-river migration period?
2. If predation is responsible for the loss of a high proportion of the smolts in-river, what can be done about it?
3. If predation is responsible for losses of smolts during the in-river migration, does this actually lead to a correspondingly reduced adult return rate?
4. What groups of predators are responsible, and what proportions of the smolt run are lost to each group?
5. If predation is responsible for the loss of a high proportion of the smolts in-river then how does smolt tag burden influence the predation rate?
6. If predation is responsible for the loss of a high number of smolts in-river then how does smolt size, timing of migration and river conditions influence the severity of this pressure?

Clearly, advancing all of these in 2020 is not possible, and we acknowledge that Marine Scotland Science is planning a programme of predator research in 2020 and 2021. The research outlines presented here will compliment these plans and we aim to work collaboratively with MSS in this important area of research.

1. Avian predator abundance and distribution on rivers

In order to advance our knowledge about the distribution of avian predators within the Moray Firth rivers, one basic information requirement is a robust method for assessing population size and distribution at various times of the year. Canoe and ground based surveys have their limitations for counting birds but aerial survey methods may be possible and improve accuracy. Drone technology is advancing rapidly and missions in the UK can currently be flown 1km from an operator and up to 120m in height. Thermal imaging cameras can be carried and are coupled with regular cameras to provide a range of resolution options for warm-blooded targets, which will alter depending upon the height and also the width of the river corridor being surveyed.

2. Use of predator scat (faeces) and eDNA analysis as a quantitative tool to determine predation on salmon smolts

Molecular analysis of fresh avian and mammalian predator scat (faeces) can provide a non-invasive and accurate metric for estimating the composition of fish species that are consumed. Importantly, it may allow the estimation of the proportion of salmon and also the other fish in predator diets (otter, mink, heron, various gulls, cormorant and goosander / mergansers) throughout a season, or from particular locations (hotspots). The scat also contains genetic material from the predator that can be fingerprinted to identify species and potentially an individual. The suite of new techniques offer potential to use scat to investigate if the salmon predator population is made up of salmon specialists or mobile opportunists. The programme of work will focus on describing temporal and spatial changes in the pattern of salmon parr and smolt predation through the year.

3.Radio tracking of juvenile salmon to determine predation impacts

With the indications from tracking in 2019 suggesting considerable smolt losses in-river, there is now an urgent requirement to find out what is actually happening to the fish. Radio telemetry for fish is limited to use in freshwater systems, but can enable a higher level of spatial resolution for tag location than is possible using the current acoustic tagging system and static receivers. By using radio tags (or small acoustic tags and mobile receivers if tests prove them to be more suitable) the fate of individual fish can be determined more clearly during their in-river migration. An important refinement to this tracking study will be to differentiate if smolts lost from the migrating population are being removed from the water, or if they remain in the river. This will allow refinement of estimates of the proportion of smolts that are lost to avian or aquatic predators during in-river migration, and an assessment of factors that influence severity.

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Appendix 1.

Metrics of among the seven rivers of the Moray Firth 2019 tracking project. Values for tagged fish that were detected, at the reach scale (between two receivers). Values encompass all fish detected at least one time.

River	Receiver	Distance (km)	Distance Diff. (km)	Confirmed Survival %	Efficiency %	% losses per km	Median residences (mins)	Median ROM (m/s)	Median duration (sec)
Conon	Release Site	0.00	0.00	100.00	NA	NA	NA	NA	NA
Conon	481433	6.23	6.23	51.52	100.00	7.78	13.67	0.02	311034.0
Conon	480419	12.05	5.81	46.46	100.00	0.87	15.89	0.07	84119.0
Conon	Cromarty	43.19	31.14	33.33	100.00	0.42	10.88	0.15	210135.0
Conon	Inner MF	68.97	25.78	25.25	92.00	0.31	8.53	0.32	80902.0
Conon	Spey Bay	91.43	22.46	19.19	NA	0.27	4.03	0.37	55202.5
Conon	Fraserburgh	152.93	61.50	NA	NA	NA	2.43	0.41	159015.5
Shin	Release Site	0.00	0.00	100.00	NA	NA	NA	NA	NA
Shin	481450	0.74	0.74	97.00	100.00	4.03	6.79	0.01	119326.0
Shin	480409	4.62	3.88	92.00	36.96	1.29	0.90	0.08	72141.5
Shin	480417	6.79	2.17	92.00	100.00	0.00	5.22	0.04	59004.0
Shin	481426	8.81	2.02	89.00	98.88	1.49	2.03	0.24	8426.0
Shin	480408	11.53	2.72	89.00	100.00	0.00	73.78	0.03	86385.0
Shin	481435	21.07	9.54	86.00	93.02	0.31	238.40	0.07	141907.5
Shin	481444	27.55	6.48	84.00	96.43	0.31	14.11	0.51	12590.0
Shin	483468	40.45	12.89	79.00	78.48	0.39	10.63	0.28	46759.0
Shin	Dornoch	49.50	9.05	76.00	92.11	0.33	11.76	0.37	24642.0
Shin	Spey Bay	78.34	28.84	58.00	NA	0.62	5.99	0.32	91235.0
Shin	Fraserburgh	148.01	69.67	NA	NA	NA	8.45	0.31	228432.5
Deveron	Release Site	0.00	0.00	100.00	NA	NA	NA	NA	NA
Deveron	126853	20.54	20.54	76.00	100.00	1.17	1.72	0.06	335454.5
Deveron	126855	35.86	15.32	63.00	98.41	0.85	7.11	0.09	179627.0
Deveron	126851	47.63	11.77	57.00	98.25	0.51	5.15	0.12	94885.0
Deveron	126852	55.78	8.15	56.00	100.00	0.12	4.28	0.10	80289.5

Deveron	480423	62.40	6.62	52.00	100.00	0.60	4.29	0.04	161203.0
Deveron	480428	82.41	20.01	38.00	100.00	0.70	27.03	0.08	253730.0
Deveron	Banff Bay	83.88	1.47	34.00	NA	2.71	19.18	0.39	3775.5
Deveron	Fraserburgh	118.15	34.26	NA	NA	NA	6.20	0.28	155013.0
Spey	Release Site	0.00	0.00	100.00	NA	NA	NA	NA	NA
Spey	126845	0.65	0.65	95.97	98.60	6.20	3.17	0.02	34678.0
Spey	480407	4.22	3.57	91.28	98.53	1.32	1.33	0.75	4729.0
Spey	480410	10.07	5.85	86.58	99.22	0.80	3.62	0.07	86022.0
Spey	482008	14.72	4.65	83.89	61.60	0.58	3.43	0.06	83146.0
Spey	482012	19.29	4.57	79.87	97.48	0.88	3.98	0.05	87996.0
Spey	131694	22.54	3.25	76.51	98.25	1.03	3.68	0.82	3987.0
Spey	482007	25.07	2.53	75.84	93.81	0.27	1.72	0.66	3836.5
Spey	482006	30.65	5.58	70.47	88.57	0.96	1.02	0.07	74765.5
Spey	126849	34.73	4.08	70.47	98.10	0.00	9.01	1.16	3530.0
Spey	482010	40.88	6.15	65.77	70.41	0.76	0.88	0.75	8226.0
Spey	131693	44.80	3.92	61.74	96.74	1.03	0.81	0.26	17095.5
Spey	483473	50.05	5.25	59.06	98.86	0.51	6.43	1.02	5157.0
Spey	Spey Bay	63.44	13.39	46.31	NA	0.95	6.93	0.24	53113.0
Spey	Fraserburgh	118.03	54.60	NA	NA	NA	8.93	0.35	153771.5
Findhorn	Release Site	0.00	0.00	100.00	NA	NA	NA	NA	NA
Findhorn	131691	1.38	1.38	80.00	100.00	14.49	5.63	0.00	291313.0
Findhorn	480427	2.90	1.52	70.00	78.57	6.58	0.97	0.47	3240.0
Findhorn	483276	6.05	3.15	64.00	100.00	1.90	10.18	0.64	4953.0
Findhorn	126850	8.05	2.00	59.00	72.88	2.50	5.18	0.25	8104.0
Findhorn	480411	10.57	2.52	53.00	60.38	2.38	20.48	0.27	9166.0
Findhorn	Inner MF	19.20	8.63	48.00	85.42	0.58	11.40	0.26	31798.0
Findhorn	Spey Bay	39.95	20.75	40.00	NA	0.39	6.03	0.27	74000.0
Findhorn	Fraserburgh	115.43	75.49	NA	NA	NA	9.05	0.28	269472.0
Ness	Release Site	0.00	0.00	100.00	NA	NA	NA	NA	NA
Ness	480432	0.75	0.75	90.00	100.00	13.42	94.60	0.01	119760.0

Ness	483488	3.45	2.71	69.00	100.00	7.75	113.35	0.36	9662.0
Ness	483492	11.66	8.21	50.00	100.00	2.31	237.23	0.10	84935.0
Ness	483460	51.16	39.49	14.00	100.00	0.91	33.18	0.05	780018.0
Ness	483458	55.16	4.00	9.00	100.00	1.25	204.90	0.05	74611.0
Ness	Chanonry	75.21	20.05	8.00	100.00	0.05	10.98	0.16	124367.0
Ness	Inner MF	109.68	34.47	8.00	87.50	0.00	6.92	0.28	123733.0
Ness	Spey Bay	130.00	20.32	8.00	NA	0.00	7.10	0.31	59467.5
Ness	Fraserburgh	206.91	76.91	NA	NA	NA	8.33	0.25	308927.0
Oykel	Release Site	0.00	0.00	100.00	NA	NA	NA	NA	NA
Oykel	480422	0.25	0.25	91.95	100.00	32.47	4.25	0.00	183032.0
Oykel	131692	1.67	1.42	86.58	100.00	3.78	5.47	0.29	4913.0
Oykel	480415	2.96	1.29	83.22	100.00	2.60	11.40	0.30	4365.0
Oykel	480414	5.25	2.29	80.54	100.00	1.17	2.53	0.28	8260.0
Oykel	482009	7.25	2.00	75.84	100.00	2.35	15.45	0.03	60862.0
Oykel	480431	12.76	5.51	72.48	100.00	0.61	13.38	0.18	31042.0
Oykel	480413	17.21	4.45	69.80	100.00	0.60	26.05	0.34	13251.5
Oykel	481428	20.06	2.85	69.13	100.00	0.24	37.46	0.25	11281.5
Oykel	480424	23.18	3.12	65.10	100.00	1.29	69.80	0.43	7244.0
Oykel	480420	25.06	1.88	62.42	100.00	1.43	126.96	0.43	4348.0
Oykel	480408	30.68	5.62	62.42	100.00	0.00	37.63	0.04	137651.0
Oykel	481435	40.22	9.54	53.69	95.00	0.91	89.95	0.08	117823.0
Oykel	481444	46.70	6.48	51.01	93.42	0.41	11.82	0.58	11111.0
Oykel	483468	59.59	12.89	48.99	73.97	0.16	6.27	0.30	43680.0
Oykel	Dornoch	68.66	9.06	45.64	92.65	0.37	9.62	0.32	27706.0
Oykel	Spey Bay	100.06	31.41	34.23	NA	NA	9.07	0.35	88764.5
Oykel	Fraserburgh	177.96	77.90	NA	NA	NA	9.60	0.27	279448.5