Spiorad na Mara Offshore Wind Farm

Offshore Project

Environmental Impact Assessment Report

Appendix 12.1.3: Fish Tracking Study (Atlantic Salmon Fish Tagging Survey)

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Tracking juvenile salmonids to determine migration routes in relation to the Spiorad na Mara development

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EXECUTIVE SUMMARY

Offshore Wind Developments (OWDs) are set to expand substantially around Scotland over the next decade to meet ambitious carbon reduction targets. A robust evidence base is needed to inform the spatial planning of OWDs to ensure minimal negative impacts on marine biota, including diadromous salmonids.

Spiorad na Mara (SNM) is a proposed OWD being developed between Northland Power and ESB Energy in an area extending to 161 km^2 located off the west coast of the Isle of Lewis, Scotland.

A fish tracking study was undertaken in 2024 to aid the environmental impact assessment of the proposed SNM development on juvenile Atlantic salmon (*Salmo salar*) migrating from the River Grimersta and Loch Roag, Isle of Lewis.

A total of 100 salmon smolts captured in the lower River Grimersta were fitted with acoustic transmitters and tracked through an array of fixed detection stations positioned within East Loch Roag (13 receivers) and the SNM site (20 receivers).

A total of 78 tagged fish commenced migration through Loch Roag, of which 15 individuals (19%) subsequently entered the SNM site.

The time fish spent within the SNM detection array ranged from 31 seconds to 2 hours (median 16 minutes). The time difference between the first and last detection of an individual by the SNM array ranged from 7 minutes to 27 h (median 29 minutes), suggesting that some individuals remained in the region of the SNM site for extended periods.

Most (60%) of the reconstructed fish movement paths within the SNM site were relatively direct, with detections on just one or two receivers. However, some individuals exhibited more complex paths including doubling back and looping movements.

Whole site detection coverage was not possible given the budgetary constraints of the study, therefore the configuration of the receiver array within the SNM site was designed to maximise the likelihood of intercepting post-smolts travelling north and east on their seaward migration to assumed feeding grounds in the Norwegian Sea. As such, the presented post-smolt encounter rates and durations within the SNM site should be interpreted as minimum values for the purposes of environment impact assessment.

INTRODUCTION

Background

The Scottish Government has set a range of ambitious targets to cut greenhouse gas emissions and generate more renewable energy. Renewables will be a key part of commitments to decarbonise the UK power sector by 2035 and for Scotland to be net zero by 2045. There is an intention to generate 50% of Scotland's overall energy consumption from renewable sources by 2030 (Scottish Government, 2023). Offshore renewable energy derived from wind will play a fundamental role in meeting these targets and is set to expand substantially around Scotland over the next decade. Developments that have potential for a significant adverse effect on the environment are required by law to conduct an Environment Impact Assessment (EIA) as part of the consenting process. Diadromous fish are one component of the marine biota that may be susceptible to impacts from offshore wind development (OWD) and, accordingly, must be considered within the EIA.

Salmon populations are declining globally and in 2023 the International Union for the Conservation of Nature (IUCN) classification for Atlantic salmon (*Salmo salar*) moved from Least Concern to Near Threatened globally, and to Endangered in Great Britain. The drivers of these declines are complex and most likely result from a combination of pressures, particularly habitat fragmentation in freshwaters and exploitation and aquaculture impacts in the marine environment (Dadswell et al., 2022). Similarly, these pressures have contributed to local collapses of the anadromous component of many brown trout (*Salmo trutta*) populations (sea trout hereafter) (Butler & Walker, 2007; Gargan et al., 2007; Skaala et al., 2014). When juvenile salmon and sea trout emigrate from freshwater to undertake their marine feeding migration, and when the adult component of the population returns to freshwater to spawn, there is potential for migration routes to intersect with marine development sites including offshore wind generation arrays. The potential impacts of OWD on these species may include physical, acoustic, and electromagnetic effects (Gill et al., 2012; Harding et al., 2016; Malcolm et al., 2015). Determining how the spatial and temporal distribution of anadromous salmonids overlaps with future OWDs is crucial for accurate assessment of the potential impacts. Currently, the routes taken and local factors driving decision making for salmonids migrating through marine environments are only partially understood (Ounsley et al., 2020). Predicting encounter rates and understanding the underlying mechanisms of effects from wind turbines on salmonids as they undertake their juvenile and adult migrations, as well as the wider impacts on their populations, is fundamental for informing EIAs and contributing to the conservation of these imperilled species.

Spiorad na Mara (SNM) is a proposed offshore wind energy project being developed between owners Northland Power (75.5%) and ESB Energy (24.5%), with Northland Power leading on the development, construction, and operation. The project aims to install an array of up to 65 fixed bottom turbines located 5-13 kilometres off the west coast of the Isle of Lewis, Scotland, in an area extending to 161 km^2 with a water depth of 40–75 m. The potential expected capacity of the proposed development would be around 900 MW and could meet the average annual electricity needs of around 1.2 million Scottish homes.

The proposed SNM development site is located a minimum of 5.5 km north-east of the seaward opening of East Loch Roag. The wider Loch Roag system, its associated rivers and extensive network of freshwater lochs represent a significant area of production and growing habitat for salmonids. The Langavat catchment covers an area of approximately 105 km^2 and is the most extensive freshwater catchment in the Outer Hebrides. The system begins in the hills of North Harris and flows in a

northerly direction through a network of freshwater lochs and connecting channels before entering the Grimersta River which flows into Loch Roag. In 2005, the Loch Langavat catchment was designated as a Special Area of Conservation (SAC) for Atlantic salmon under the EU Habitats Directive. In Scotland, Atlantic salmon SACs extend to the tidal limit of rivers only. However, the Langavat SAC conservation advice package highlights the importance of recognising that marine mortality is one of the key issues facing Atlantic salmon in Scotland and elsewhere (NatureScot, 2020).

There is general uncertainty regarding the marine migration route(s) taken by juvenile salmon once they leave the rivers of the Outer Hebrides; a life phase generally termed 'post-smolts'. Recent tracking studies around Scotland have identified out-migration routes that differ from the shortest routes to their assumed feeding grounds in the Norwegian Sea. For example, post-smolts from rivers entering the Moray Firth (Deveron, Spey, Findhorn, Ness, Conon, Oykel, Shin) indicated substantial individual variation among migration routes, but a general pattern of fish not heading directly north but instead following a more easterly route, even when this conflicted with the direction of dominant tidal currents (Newton et al., 2021; Scottish Centre for Ecology and the Natural Environment & Atlantic Salmon Trust, 2019). Tracking passive particles within modelled hydrodynamic simulations of the study area provided strong evidence that tracked fish were unlikely to be passively carried but instead showed a clear active swimming component (Newton et al., 2021). In 2023, an array of 21 receivers was deployed forming a 120 km "leaky" line (i.e. fish can potentially pass between receivers undetected) running parallel with the north coast of Scotland. This array detected salmon post-smolts from the Isle of Lewis, from the rivers Laxay (9 fish detected of 120 tagged) and Grimersta (6 fish detected of 120 tagged) (Newton, 2024), as part of the West Coast Tracking Project (Atlantic Salmon Trust, 2024). There is, therefore, evidence that a component of salmon post-smolts migrating out of the Grimersta and through Loch Roag have a propensity to swim east. Depending on the exact route taken, this behaviour could increase the likelihood of fish intersecting with the proposed SNM site.

Study aims & objectives

The overall study aim was to provide an evidence base to aid the environmental impact assessment of the Spiorad na Mara offshore wind development on juvenile salmonids migrating from the River Grimersta and Loch Roag, Isle of Lewis.

There were four objectives:

1. Design and deploy an acoustic receiver array to detect tagged fish entering the proposed Spiorad na Mara development site
2. Capture, tag and release juvenile salmonids on their seaward migration from the Grimersta River
3. Retrieve and analyse the detection data to determine encounter rate and the durations of fish residencies within the array
4. Provide a summary report of fish movement data to feed into the Environmental Impact Assessment

METHODS

Study area

The current study was conducted during the period from 20th April to 6th September 2024 in Loch Roag, Isle of Lewis (58.2061° N, 6.7654° W) and the proposed development site of the Spiorad na Mara (SNM) wind farm located northeast of the seaward opening of Loch Roag (58.4081°N, 6.7879°W) (Figure 1).

Telemetry array

An acoustic telemetry array was deployed to track tagged out-migrating salmon post-smolts through East Loch Roag and within the SNM site.

Loch Roag

The array in Loch Roag comprised 13 receiver stations (Model VR2Tx or VR2AR, Innovasea, Nova Scotia, Canada) and was designed to create a series of four detection zones leading out from the fish release site in the lower River Grimersta to the seaward limit of East Loch Roag. This configuration enabled determination of the minimum number of fish to reach the detection zone, thereby allowed estimation of the loss rate for various sections of the loch (Figure 1). In open water marine sites, the maximum detection range of receivers of the type used, with tags of the types used, is typically 400 m. In shallower sites, such as for the receivers forming the first two zones in Loch Roag, the typical maximum detection range is 300 m. Seaward migrating post-smolts may take one of two routes through Loch Roag, either through East Loch Roag or through West Loch Roag. The westernmost receiver in detection Zone 2 was place in the channel leading to West Loch Roag to provide indication of migration through that route.

The configuration and spacings between receivers were based on the results of pre-study range testing. As such, the setup aimed to provide detection zones through which tagged fish were theoretically unable to pass undetected. However, due to inherent variability in receiver efficiency caused by numerous unpredictable human and environmental factors (e.g. boat traffic, wave action and bubble entrainment, fouling and debris), there is always a low possibility that tagged fish could pass a zone undetected. To accommodate for this, multiple zones were deployed to strengthen inference.

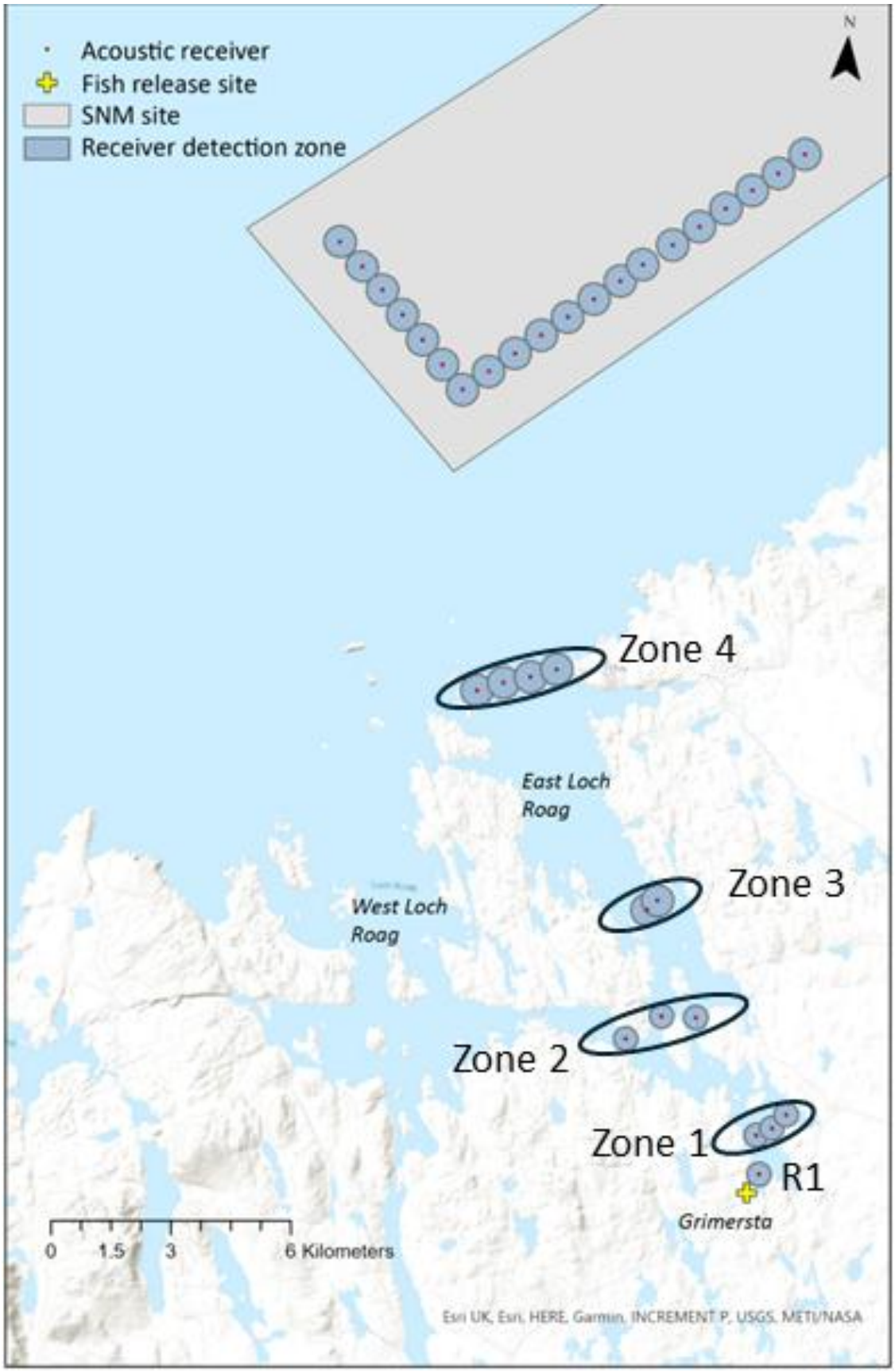

Figure 1 The study area, fish release site and acoustic receiver array within Loch Roag and the proposed Spiorad na Mara (SNM) wind farm site. The array design within East Loch Roag enabled the delineation of detection zones (1 to 4) which were applied during data analysis. R1 denotes the first receiver beyond the outlet of the River Grimersta.

With the exception of three receiver stations located in relatively shallow sites, the receiver units in Loch Roag were of 'acoustic release' (AR) type with mooring retrieval canister. They were deployed by boat following well-established methods developed in previous similar deployments. This approach enabled anchoring (70 kg per station consisting of 2x35 kg steel chain links) of the receiver with no part projecting >3 m from the seabed (Figure 2). The lack of a full water depth rope and surface buoy reduces obstruction in deep or more sensitive locations. For retrieval, a release pin was remotely activated by an acoustic signal to bring the receiver to the surface, while leaving a trailing rope attached to the anchor enabling the recovery of all equipment.

The three shallow site receivers were of VR2Tx type and anchored to the seabed using one 35 kg steel chain link attached to which was a 3 m riser rope and submerged trawl float. These receivers were manually deployed and retrieved.

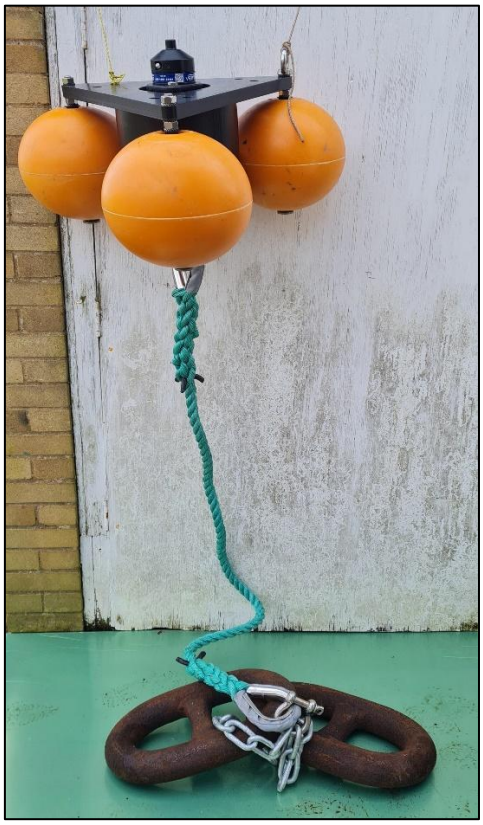

Figure 2 Configuration of an Acoustic Receiver (AR) fixed within the top plate of the Acoustic Retrieval Canister (ARC) with 3 x 11" orange trawl floats on each corner. The AR and ARC are attached to a 70 kg anchor (consisting of 2 x 35kg chain lings) via a polysteel rope strop (3 m) and connection chain. Marine grade high load stainless steel shackles are used on all connections.

Appropriate consent for the deployment of acoustic receivers and their associated moorings onto the seabed in Loch Roag was obtained from The Crown Estate Scotland by ZSL.

Spiorad na Mara site

The acoustic array in the SNM site comprised 20 receiver stations (Model VR2AR, Innovasea). The configuration, in two perpendicular lines, was designed to provide the greatest likelihood of

intersecting the migration routes of fish travelling north and east after emerging from Loch Roag (Figure 1). Given the 400 m maximum typical detection range, receivers in the SNM site were spaced at 800 m to provide maximum linear coverage and were inset from the site boundary by 1500 m to detect only those fish that entered the SNM site; it was not desirable to detect fish that passed close to the site but did not enter. Based on the typical maximum detection range, 0.35% of the 161 km^2 SNM site was covered by the combined detection ranges of all 20 receivers. Assuming no directionality preference was exhibited by post-smolts migrating out of East Loch Roag, nor any tidal current effects, the receiver array in the SNM site would be expected to intercept 34% of possible straight-line swim trajectories by chance. This is based on the detection area intercepting 54° of the 159° of possible bearings for straight-line swim trajectories (Figure 3).

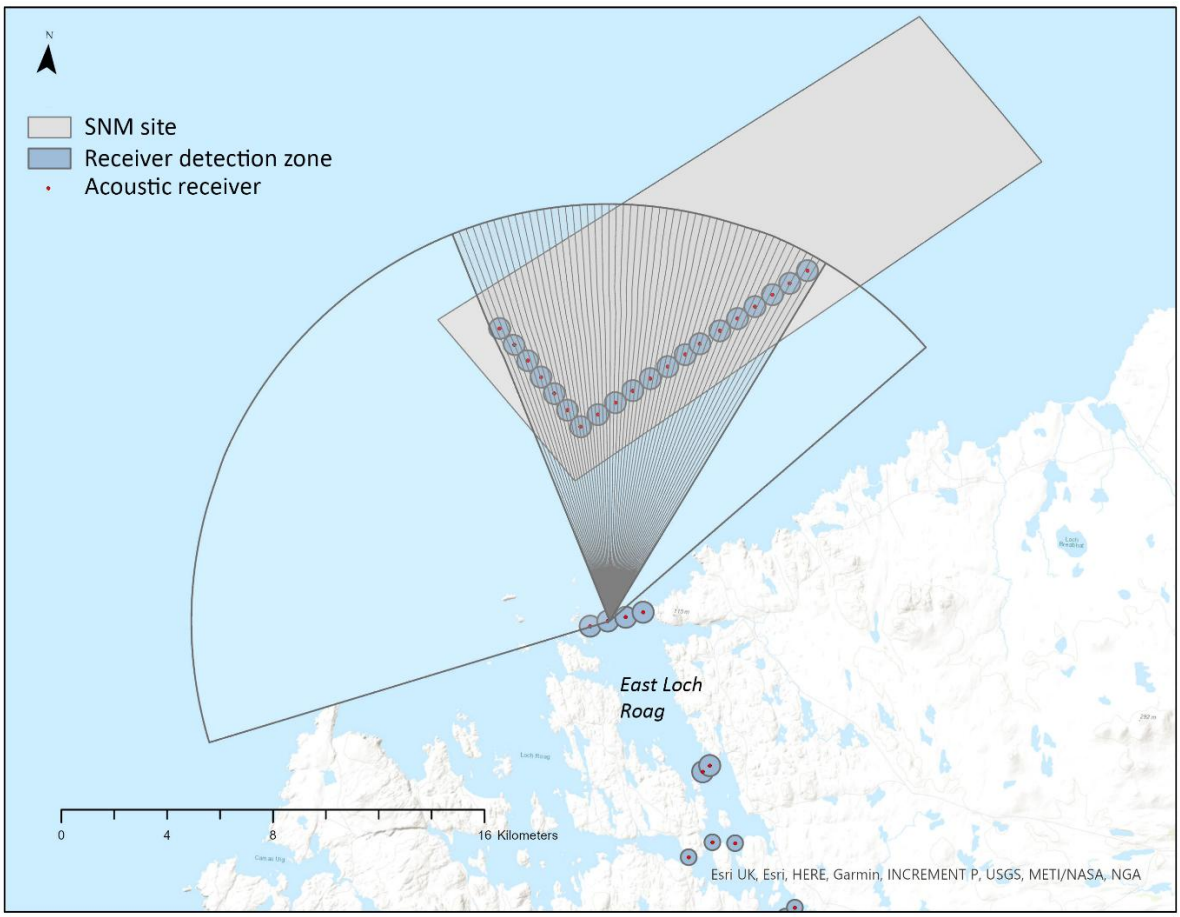

Figure 3 The receiver array in the Spiorad na Mara (SNM) site showing the bearings of potential straight-line swim trajectories of salmon migrating out of East Loch Roag that would intercept the detection zone, a total of 54° (indicated by hatched area), out of 159° of possible bearings (indicated by light blue circle section).

The receiver units in the SNM site were all of 'acoustic release' (AR) type with mooring retrieval canister. They were deployed by boat following well-established methods developed in previous similar deployments. As above, this approach enabled anchoring (70 kg per station consisting of 2x35 kg steel chain links) of the receiver with no part projecting >3m from the seabed (Figure 2). For retrieval, a release pin was remotely activated by acoustic signal to bring the receiver to the surface, while leaving a trailing rope attached to the anchor enabling the recovery of all equipment.

The appropriate consent for deployment within the Spiorad na Mara development site was obtained by Northland Power.

Fish capture and tagging

Salmon smolts were captured during the period from 1st to 8th May 2024 using a rotary screw trap deployed in the lower River Grimersta (58.167452° N; 6.737948° W) (Figure 4). Captured fish were visually assessed and selected for tagging (n = 100) if they were clearly smolts (principally determined by silver colouration), of sufficient size for tagging (≥ 120 mm fork length) and exhibited no notable external indicators of damage or disease. Selected individuals were anaesthetised (0.1 g/L MS222 1:1 buffered with $NaHCO_3$), measured (fork length, mm) and placed on a V-shaped sponge saturated with river water. An incision of approximately 10 mm in length was made in the ventral abdominal wall, anterior to the pelvic girdle, and a coded acoustic transmitter (Model V6-2x, 6.3 mm diameter, 13 mm length, 0.5 g mass in air or Model V7TP-2x, 7 mm diameter, 21 mm length, 1.7 g mass in air, Innovasea, dependent on fish size) inserted into the peritoneal cavity. The Model V7TP-2x tags (n = 20) incorporated additional temperature and pressure sensors, enabling the collection of water temperature (°C) and swim depth (m) data along with fish ID. All tags were programmed with a nominal transmission rate of 30 s (range 15–45 s), yielding an expected battery life of 52 and 57 days for the V6-2x and V7TP-2x models, respectively. After tag implantation, the incision was closed using two independent sterile sutures (coated Vicryl 5/0 absorbable, Ethicon). The gills were continuously irrigated with river water throughout tag implantation. Once recovered, fish were transferred to an in-river perforated holding box close to the point of capture with a timed released system set to open and release fish during darkness (23:15–00:00 h). Fish were held for a minimum of 6 h post-recovery before release.

Figure 4 Rotary screw trap deployed to catch out-migrating smolts for tagging in the lower River Grimersta

Fish capture was conducted under licence from Marine Scotland. Fish tagging was conducted under a Home Office Project Licence held by Adam Piper. Regulated Procedures were conducted by Adam Piper of ZSL and Paul Hopper of the Outer Hebrides Fisheries Trust, both of whom hold Home Office Personal Licences to conduct Regulated Procedures on fish.

Data filtering and analysis

The receiver array was successfully retrieved during the period from 31st July to 6th August 2024. Time-stamped detection data were downloaded, filtered to remove spurious records linked to false IDs, then analysed to generate metrics on the following: 1) timing and duration of river emigration; 2) loss rate and transit time through Loch Roag, 3) point of entry into the SnM site, 4) duration spent within the SnM site, 5) movement pattern within the SNM site, 6) point of exit from the SNM site. Data from receivers which formed the same detection zone within Loch Roag were grouped, yielding four separate zones (Zone 1 to Zone 4). The first receiver beyond the outlet of the River Grimersta (R1) and all the receivers in the SNM site formed two additional detection zones (Figure 1).

To minimise the impact of erroneous detections caused by tag collision, single detections of an ID within a zone were excluded from the dataset (6 instances out of 23,053 detections; 6 individual IDs). The time of the last detection of each individual within Zone 4 was used to denote the time of successful emigration from East Loch Roag. To calculate the duration (minutes) spent within the SnM site, the time fish spent in the vicinity of SNM receivers was quantified using residence events. Each residence event was defined as a period of detection at the same receiver, during which consecutive detections were separated by time intervals of less than three minutes. Detection of the fish at a different receiver started a new residence event, irrespective of the detection interval. If a fish was not detected for 3 minutes at any receiver it was deemed to have either moved out of the SNM site or still been within the SNM site but not within the detection range of the receivers. It was not possible to differentiate between these two possible non-detection scenarios, therefore the durations derived represent *minimum* estimates. The cut-off was informed by interval analysis which identified that 90% of detection intervals were of 3 minutes or less. Given that the tag transmission rate ranged from 15 to 45 s, the 3 minute cut-off represents a minimum of four and a maximum of 12 transmissions without detection. The chronological order of residence events within the SNM site was used to estimate individual swim paths, assuming straight-line movements between receivers with consecutive residence events.

RESULTS

Morphometrics of tagged smolts

Captured and tagged salmon smolts ranged in length from 132 to 178 mm fork length. Only fish exceeding 150 mm fork length were tagged with V7TP-2x tags (Table 1) (Figure 5).

Table 1 Summary of salmon smolts from the River Grimersta tagged during May 2024

Tag model	No. smolts	Fork length (mm) median (min–max)	Mass (g) median (min–max)
V6-2x	80	144 (132–173)	32 (21–51)
V7TP-2x	20	166 (158–178)	45 (38–56)

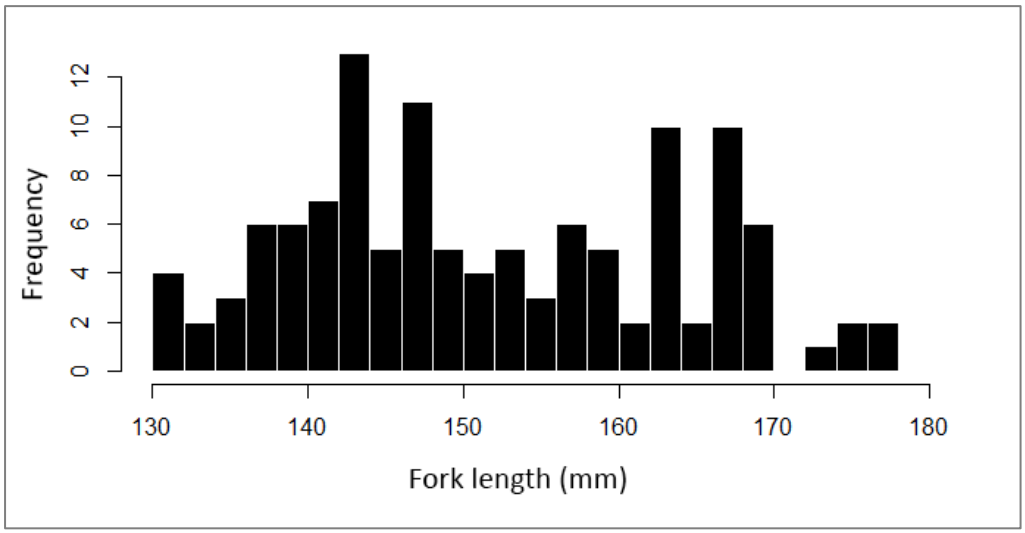

Figure 5 Frequency distribution of fork lengths (mm) of tagged salmon smolts (n = 100) from the River Grimersta.

Migration through Loch Roag

Number of smolts that migrated

Of the 100 smolts tagged, 78 were detected at least twice by the whole acoustic receiver array (Loch Roag and SNM). R1, the receiver located close to the outlet of the River Grimersta and which confirmed the entry of tagged fish into the marine environment, detected all 78 of the out-migrating individuals, with detection numbers falling with increasing distance from the release site (Table 2). Of the 78 individuals that successfully reached the R1 receiver, a total of 38 (49%) reached Zone 4, the outermost zone in East Loch Roag (Figure 1), and were thus deemed to have successfully emigrated from East Loag Roag. A total of 15 individuals were detected within the SNM site, these comprised 12 fish that were last detected in Zone 4 in East Loch Roag and three fish that passed Zone 4 without detection.

Table 2 Number of tagged salmon post-smolts detected in each of the detection zones in Loch Roag and SNM site, and minimum straight-line distances between consecutive zones and the release location.

Zone	Minimum distance from release location (km)	Minimum distance from previous zone (km)	No. post-smolts detected
R1 (outlet of River Grimersta)	0.56	-	78
Zone 1	1.53	0.97	66
Zone 2	4.86	3.33	52
Zone 3	7.54	2.68	41
Zone 4	14.03	6.49	38
SNM site	21.33	7.30	15

Migration routes

There are two possible migration routes for fish migrating seaward from Zone 2, either continuing northwards through East Loch Roag or taking the westward channel towards West Loch Roag. Of the 52 fish that reached Zone 2, 10 individuals were last detected on the receiver within the channel leading to West Loch Roag and were therefore assumed to have taken the westerly migration route (Figure 6). None of these fish were subsequently detected within the SNM site.

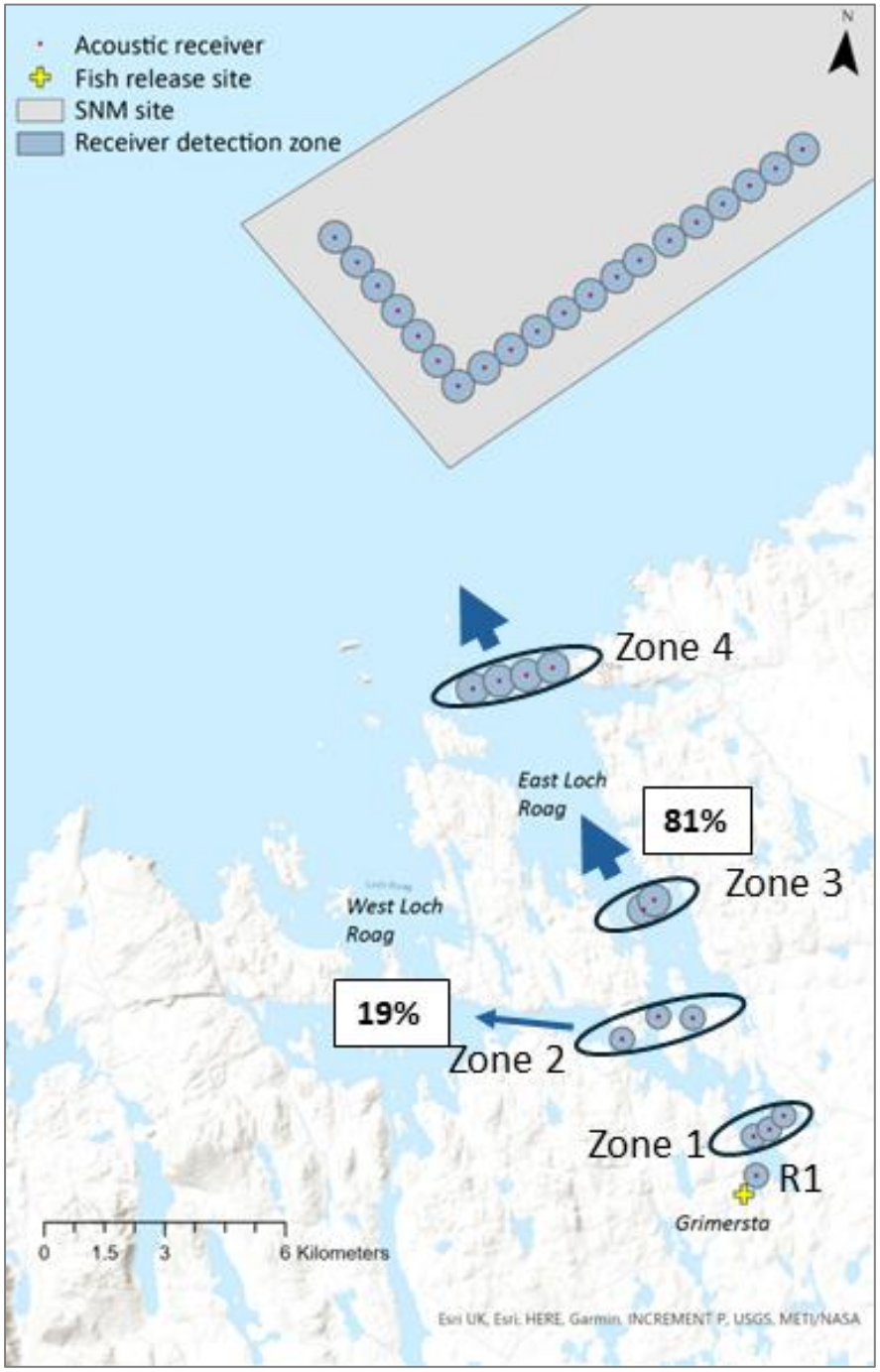

Figure 6 Map showing the two migration routes that post-smolts may take after leaving detection Zone 2 in Loch Roag. Percentages in boxes denote the proportion of post-smolts detected in Zone 2 which subsequently migrated though the two routes.

Duration of migration

The time between fish release and first detection on R1, denoting certain entry into Loch Roag from the river Grimersta, ranged from 0.25 h to 4.86 days (median 26.5 h). Subsequent seaward movement through East Loch Roag occurred fairly rapidly with 97% of the 38 individuals that reached the outermost zone doing so within 3 days of leaving the detection zone of R1. Total migration duration through Loch Roag, from first detection on R1 to last detection in Zone 4, ranged from 13.30 h to 6.15 days (median 1.82 days) (Figure 7)

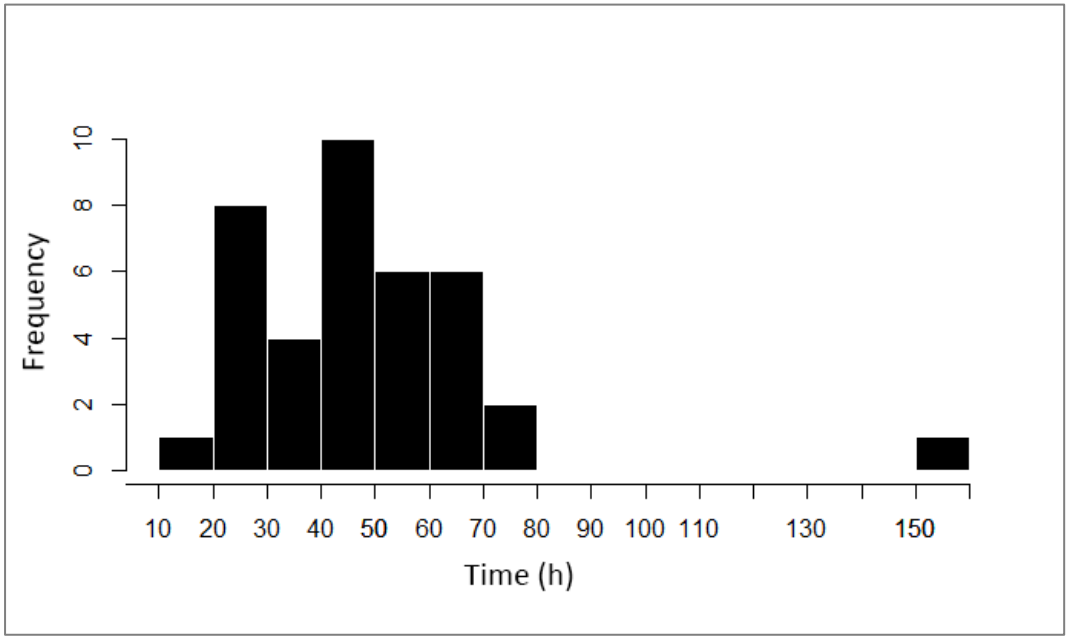

Figure 7 Histogram of time (h) to reach the outermost region in East Loch Roag after leaving R1 (i.e. time to travel through the sea loch)

After leaving Loch Roag (Zone 4), the fish that were subsequently detected in the SNM site took between 4.92 h and 3.10 days (median 11.11 h) to reach it (Figure 8).

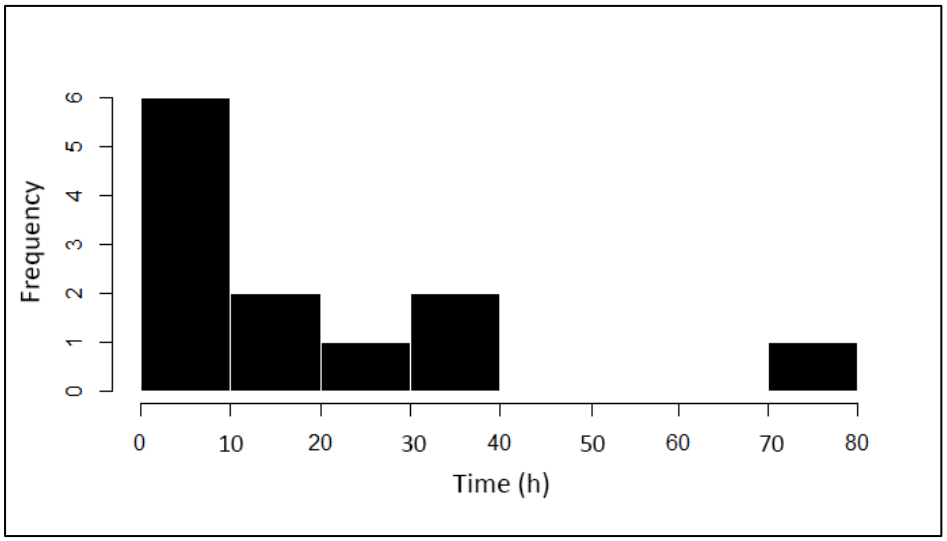

Figure 8 Histogram of time (h) between last detection in the outermost region in East Loch Roag (Zone 4) and first detection within the SNM site.

Movements within the SNM site

A total of 793 raw detections of 15 tagged post-smolts were recorded by the 20 receivers within the SNM site. All 20 receivers detected at least one fish. Raw detections were condensed during analysis to form 86 residence events. Fish exhibited between 1 and 22 residence events in the SNM array (median = 3). Receivers associated with the highest numbers of residence events were located towards the south-west corner of the site and along the western edge (Figure 9).

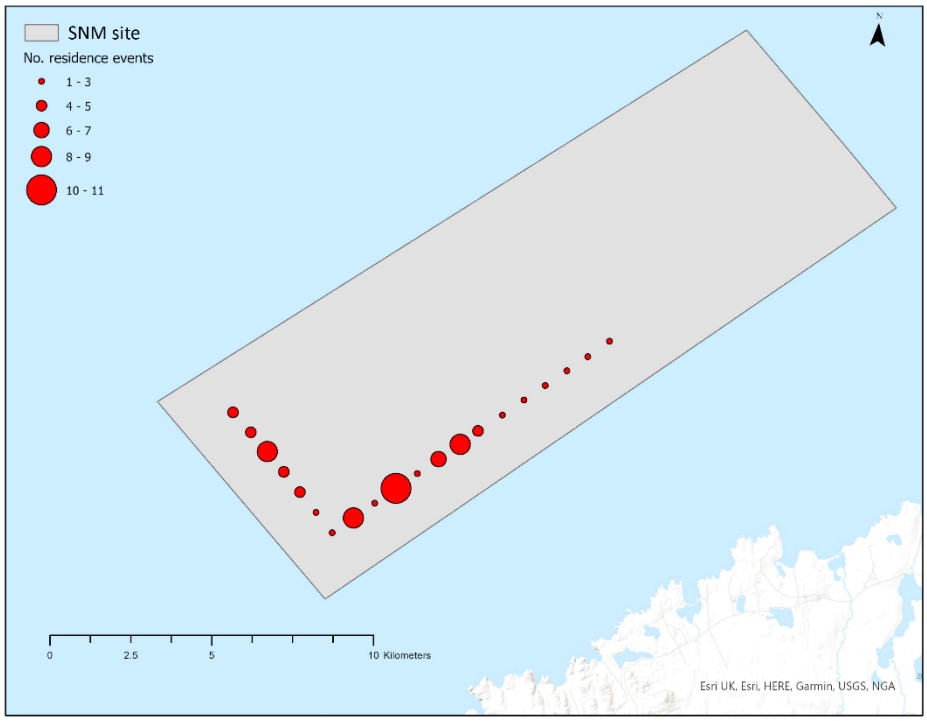

Figure 9 Number of residence events recorded at each receiver within the Spiorad na Mara (SNM) array.

Extraction of the locations of first and last detections of the 15 post-smolts indicated a propensity for fish to enter at the south-west corner of the array (Figure 10).

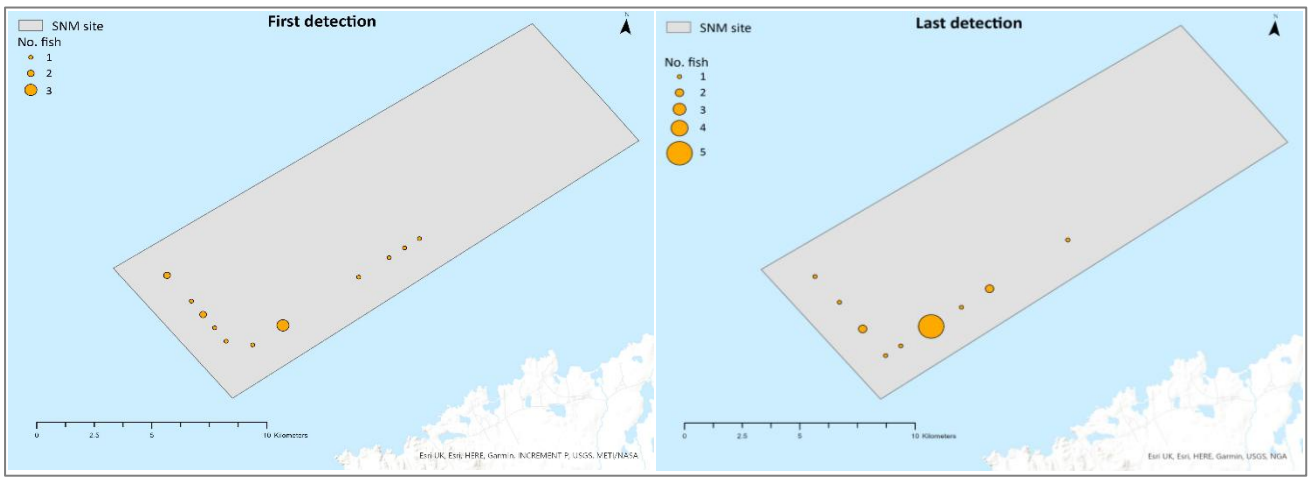

Figure 10 Locations of first (left image) and last (right image) detections within the Spiorad na Mara (SNM) array of the 15 post-smolts that entered it.

Duration within the SNM array

Total minimum duration within the SNM site, calculated by summing the durations of all the residence events attributed to each fish, ranged from 31.0 seconds to 2.0 h (median 15.9 minutes) (Figure 11). The shortest and longest individual residence events recorded were <1 s and 61 minutes, respectively. However, the time difference between the first and last detection of an individual by the SNM array ranged from 6.58 minutes to 26.82 h (median 28.8 minutes).

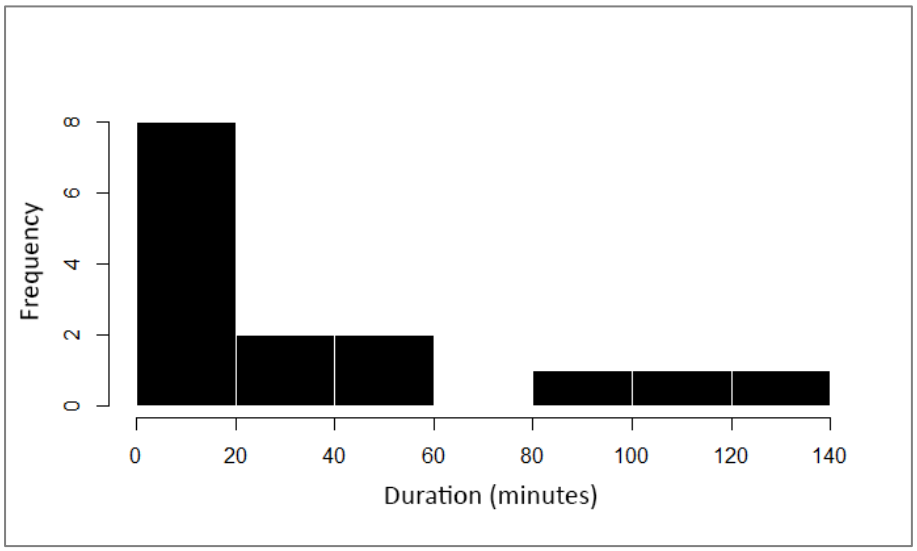

Figure 11 Frequency distribution of total duration of residence events (minutes) per fish within the Spiorad na Mara (SNM) array.

The total residence event durations (all 15 fish) calculated for each receiver provides indication of the areas within the SNM array that fish most associated with. Longest durations of association were recorded in the far eastern extent of the array and the south-west corner. The latter reflects the activity pattern of just one fish moving in and out of the detection zone of one receiver for just over 1 h (Figure 12).

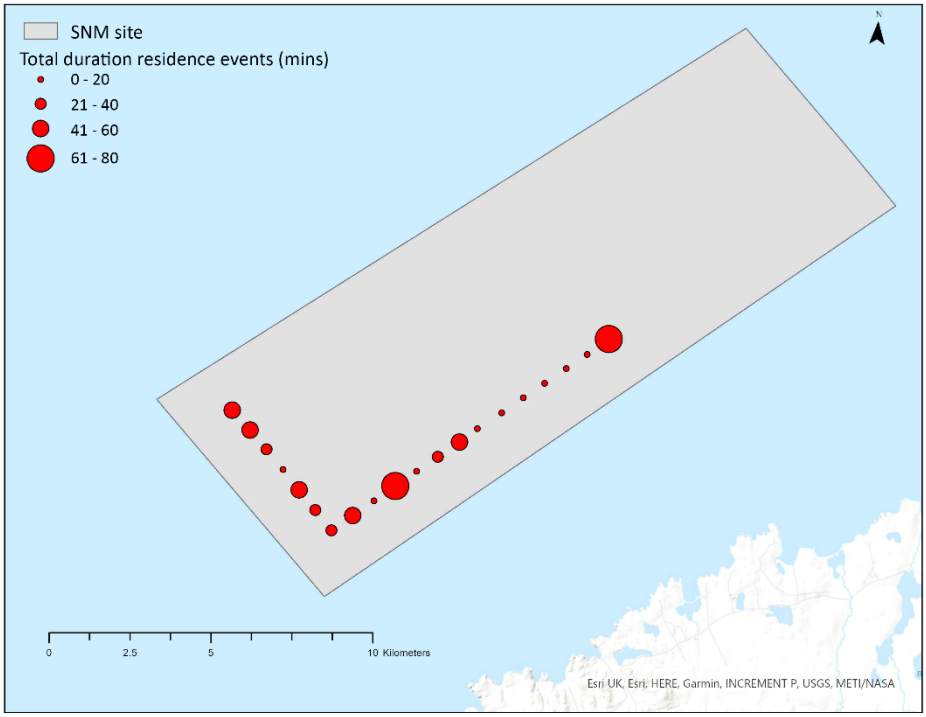

Figure 12 Total duration of residence events (minutes) recorded by individual receivers within the Spiorad na Mara (SNM) array.

Temporal activity

Activity patterns derived from the number of last detections in outer East Loch Roag (Zone 4) per hour indicated that while some individuals emigrated from Loch Roag during daylight hours, the majority left during periods of darkness. In contrast, activity within the SNM array occurred during both the day and night, with a peak between 07:30 and 09:00 (Figure 13).

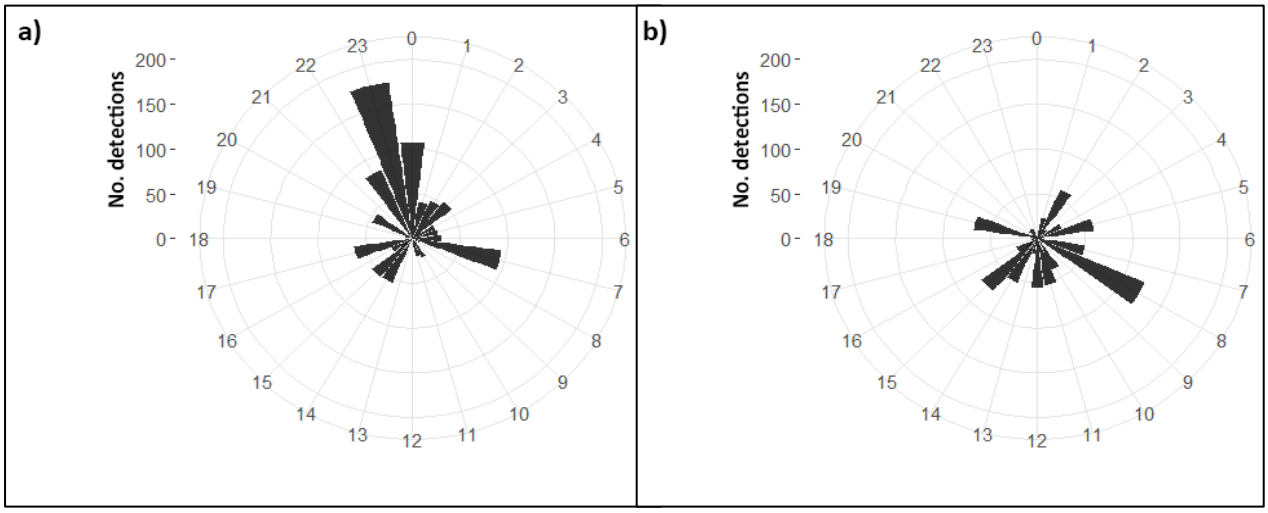

Figure 13 Number of detections per hour of tagged salmon post-smolts in a) outer East Loch Roag, and b) the Spiorad na Mara (SNM) array, as a surrogate of activity.

Individual fish swim paths

Nine of the 15 fish detected with the SNM array were detected on only one or two receivers. Of those fish detected at three or more receivers, there was wide variation in movement patterns, with individuals observed moving in east to west, west to east, and south to north directions. Four individuals doubled back and made looping paths within the array (Figure 14, Figure 15). Due to the inherent limitations of the telemetry method employed, it was not possible to characterise the shape of swim paths between residence events at receiver stations, hence the actual trajectories may be more tortuous than the lines imposed to illustrate minimum straight-line routes only. All 15 individual swim paths are presented in Appendix 1.

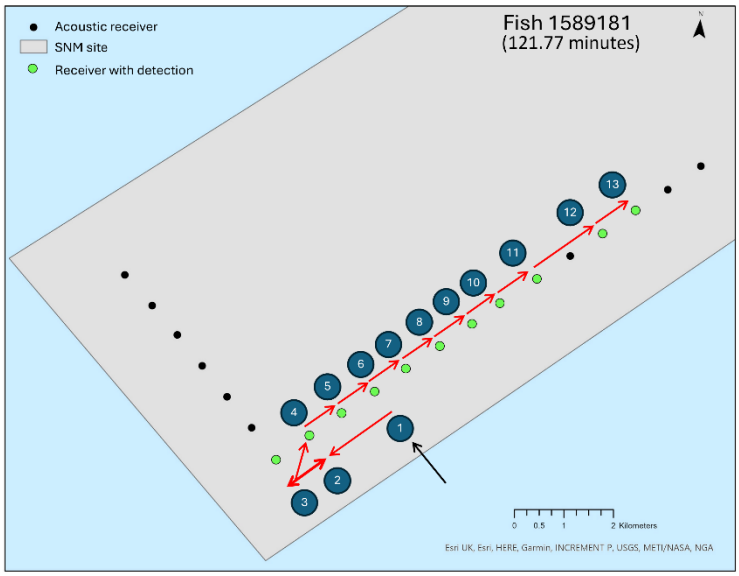

Figure 14 Estimated swim path of salmon post-smolt ID1589181 within the SNM array. Steps are derived from residence events and numbered in chronological order. The total duration of all residence events is presented in brackets. The black arrow denotes entry into the site, an assumed path perpendicular to the receiver where first detected. The red arrows denote imposed straight-line path between receivers with detections. Double sided red arrows indicate multiple back and forth movements between adjacent receivers.

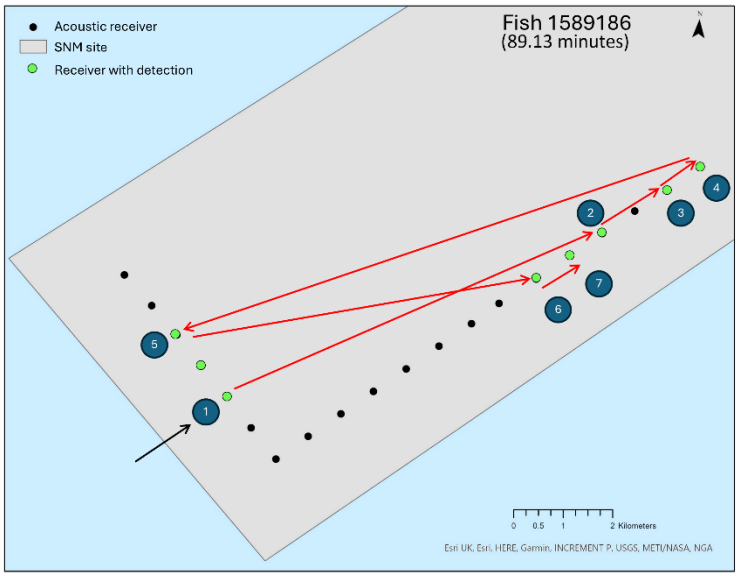

Figure 15 Estimated swim path of salmon post-smolt ID1589186 within the SNM array. Steps are derived from residence events and numbered in chronological order. The total duration of all residence events is presented in brackets. The black

arrow denotes entry into the site, an assumed path perpendicular to the receiver where first detected. The red arrows denote imposed straight-line path between receivers with detections.

Temperature and swim depth

Of the 20 fish tagged with temperature and pressure (depth) sensor tags, 7 were detected within the SNM array. Recorded temperatures within the SNM site ranged from 9.57 to 10.98°C (median 9.88°C), and swim depth from 0.0001 to 4.51 m (median 0.3 m). In one of the more extensive datasets, fish ID 1589171 was present within the SNM site for 1.72 h during the period from 01:12 to 08:53 and utilised the surface layers, predominantly within a zone ~1 to 2.5 m depth, undertaking a single deeper dive to 4.51 m.

DISCUSSION

Encounter rate with SNM site

Results from the current salmon post-smolt tracking study which focussed on Loch Roag and the proposed SNM wind farm site demonstrated that of the 78 post-smolts that commenced migration, 15 (19%) subsequently entered the SNM. Of the 38 post-smolts detected in Zone 4, and thus assumed to have successfully left East Loch Roag, 12 (32%) were subsequently detected in the SNM site between 4.92 h and 3.1 days afterwards. None of the post-smolts that were assumed to have migrated through West Loch Roag (10 fish) were subsequently detected within the SNM site. The 32% encounter rate is similar to the 34% rate expected by chance based on the estimated total detection area of receivers in the SNM array (Figure 3).

Duration and movements within SNM site

The median time fish spent within the detection area of the SNM site was 16 minutes and estimated swim paths demonstrated that the majority of individuals passed through in a relatively direct manner. However, large variation between individuals was observed, with three individuals spending over 80 minutes in the site. Further, from the observed repeated movements into and out of the detection zone among a small number of individuals, it may be inferred that they were in the region of the SNM site for longer periods (up to 27 h). The observed doubling-back, looping and east to west trajectories highlighted non-direct migration routes among a few individuals, which sometimes included extended periods spent in the vicinity of a single receiver.

Loss rate within Lower Grimersta and Loch Roag

Of the 100 smolts tagged, 22 were not detected by any receiver within the array. They either did not successfully reach the marine environment from the freshwater reach of lower river Grimersta or entered Loch Roag and were lost before reaching R1. It is not possible to determine the fate of these individuals from telemetry data, however, the detection rate at R1 was similar to that observed in two previous smolt tracking studies in 2022 and 2023 in the same location using similar methods (AST, pers. comm.). The estimated loss rate during migration through Loch Roag was 35%, equating to 2.5% km^{-1}, based on the assumption that all 10 post-smolts that selected the western migration route successfully emigrated through West Loch Roag. Estuaries and river mouths are associated

with the highest mortalities of post-smolts during their migration, primarily due to predation, and the loss rate observed is within the range reported by other studies (Thorstad et al., 2012).

Limitations

As discussed previously, the acoustic tracking methods used have inherent limitations which mean it is not possible to ensure 100% detection efficiency throughout a study of this type due to the influence of dynamic environmental and human-induced parameters. Further, the array design, location and resulting detection area within the SNM site was deemed to represent an appropriate balance between the limited resources available to conduct the study, which precluded whole site detection coverage, while still providing high likelihood of detecting post-smolts emigrating from East Loch Roag if their migration paths intersected with the leading edges of the SNM site closest to the Loch Roag outlet. Accordingly, quantification of post-smolt association with the SNM proposed site was constrained to a detection zone that encompassed approximately 28% of the boundary and 0.35% of the whole site. Nevertheless, within these limitations, the location and coverage of the receiver array successfully detected 15 tagged post-smolts, with the majority detected at multiple receiver locations over extended periods, thus providing additional information about movement behaviour within the southeastern and southwestern edge of the SNM site perimeter closest to the outlet of Loch Roag.

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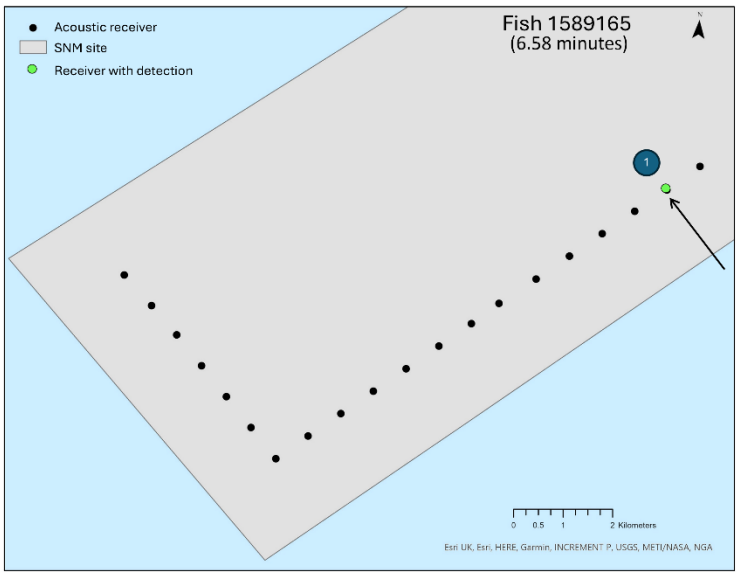
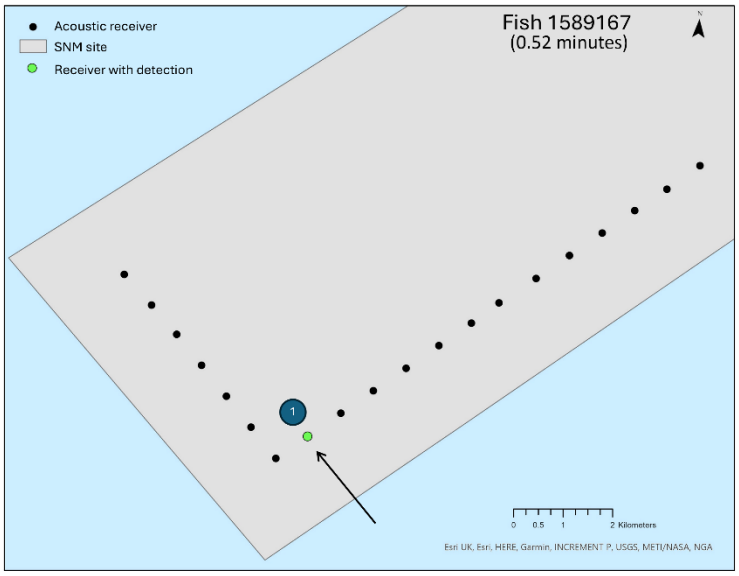
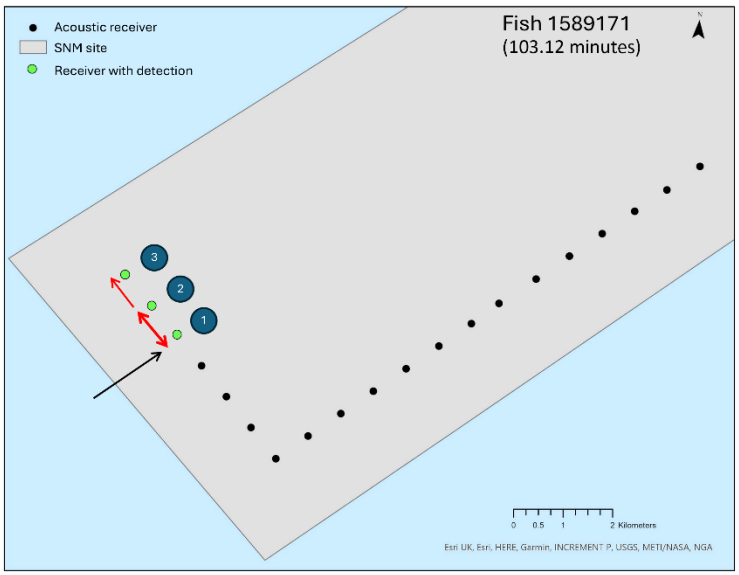
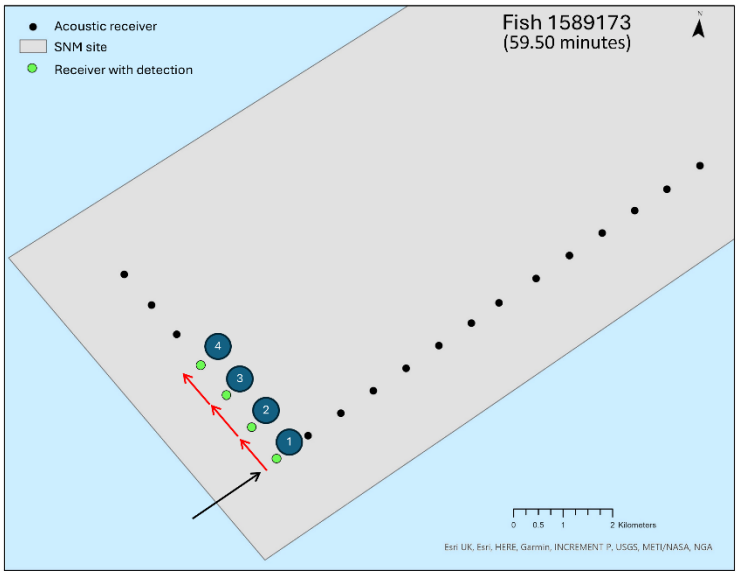
Appendix 1

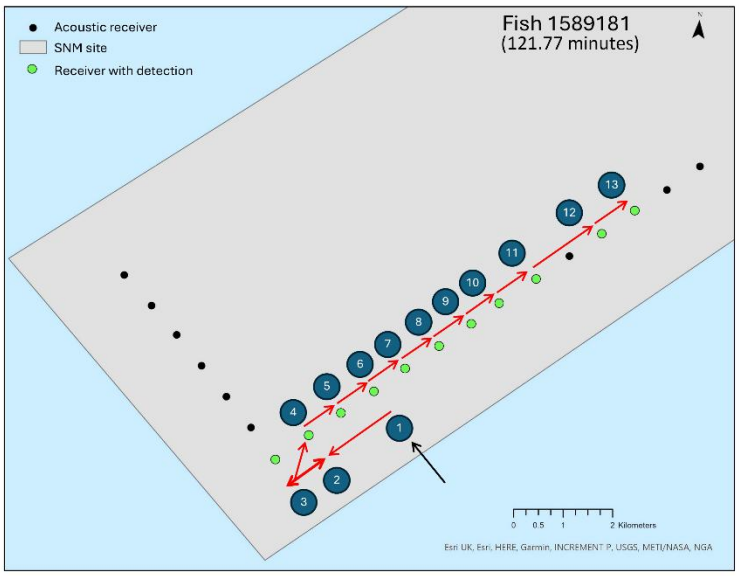
Summaries of swim path steps for individual salmon post-smolts within the SNM array. Steps are derived from residence events and numbered in chronological order. The total duration of all residence events is presented in brackets. The black arrow denotes entry into the site, an assumed path perpendicular to the receiver where first detected. The red arrows denote imposed straight-line path between receivers with detections. Double sided red arrows indicate multiple back and forth movements between adjacent receivers.

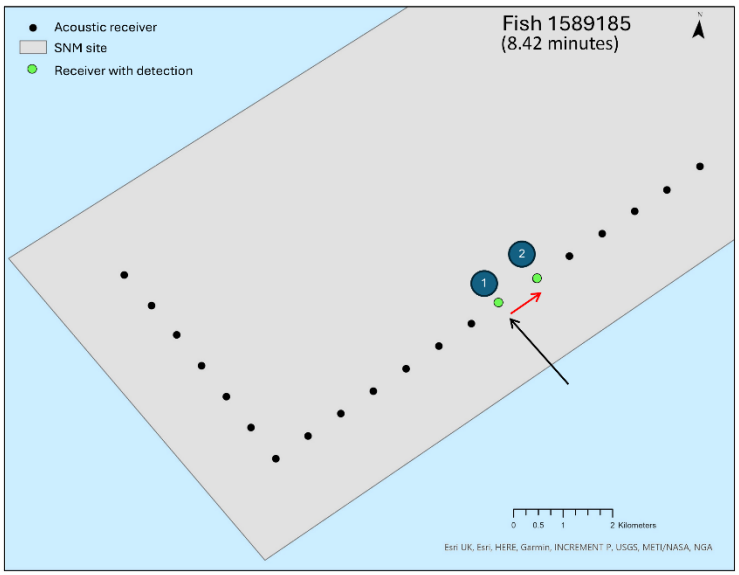


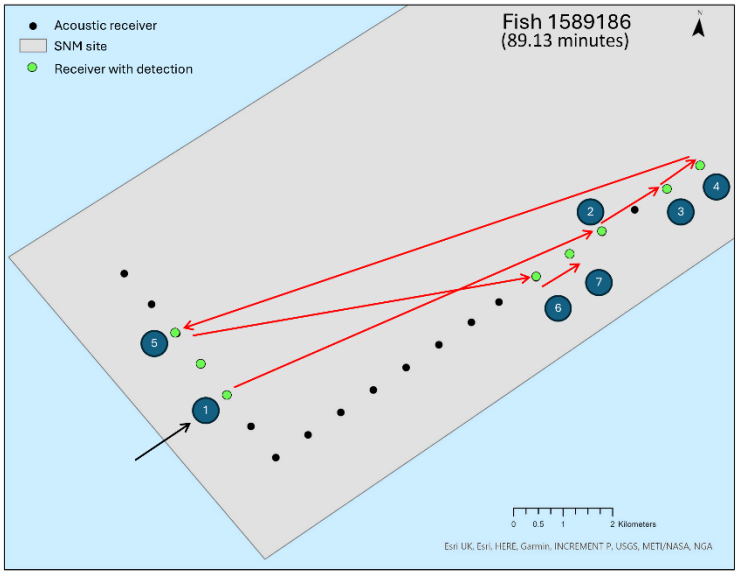


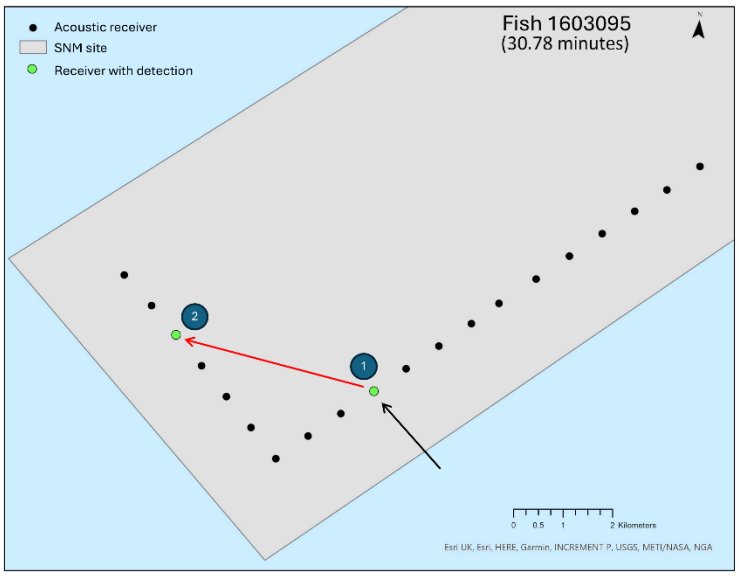

Acoustic receiver
SNM site
Receiver with detection
Fish 1589171
(103.12 minutes)
3
2
1
0 0.5 1 2 Kilometers
Esri UK, Esri, HERE, Garmin, INCREMENT P, USGS, METI/NASA, NGA

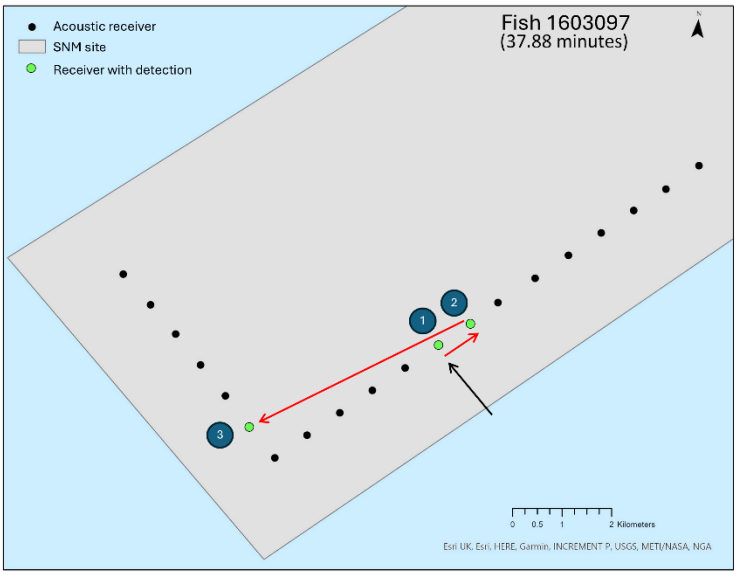

Acoustic receiver
SNM site
Receiver with detection
Fish 1589173
(59.50 minutes)
4
3
2
1
0 0.5 1 2 Kilometers
Esri UK, Esri, HERE, Garmin, INCREMENT P, USGS, METI/NASA, NGA

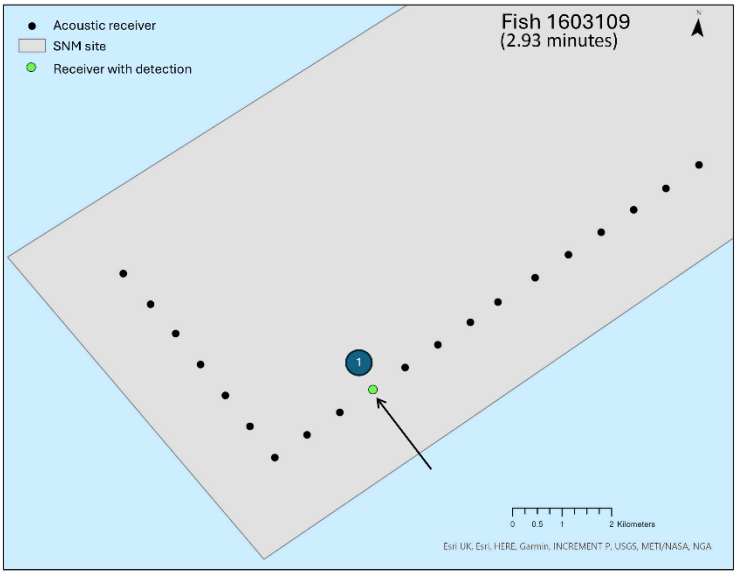

Acoustic receiver
SNM site
Receiver with detection
Fish 1589181
(121.77 minutes)
13
12
11
10
9
8
7
6
5
4
1
2
3
0 0.5 1 2 Kilometers
Esri UK, Esri, HERE, Garmin, INCREMENT P, USGS, METI/NASA, NGA

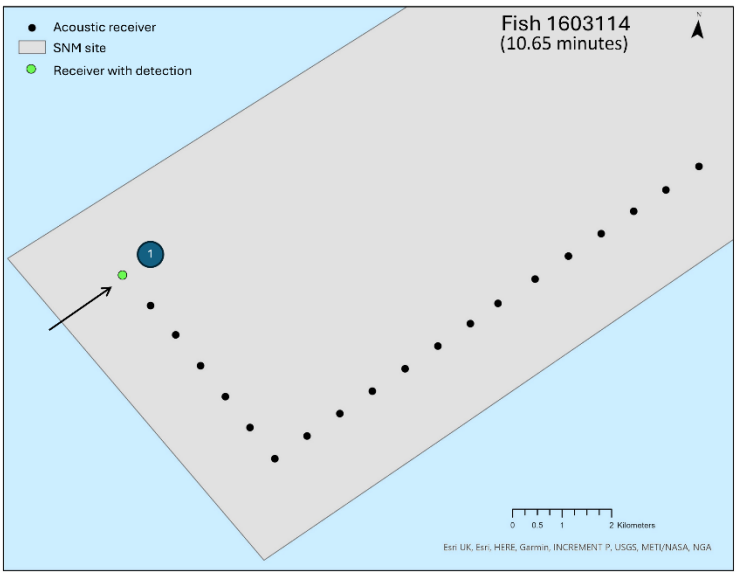

Acoustic receiver
SNM site
Receiver with detection
Fish 1589185
(8.42 minutes)
1
2
0 0.5 1 2 Kilometers
Esri UK, Esri, HERE, Garmin, INCREMENT P, USGS, METI/NASA, NGA

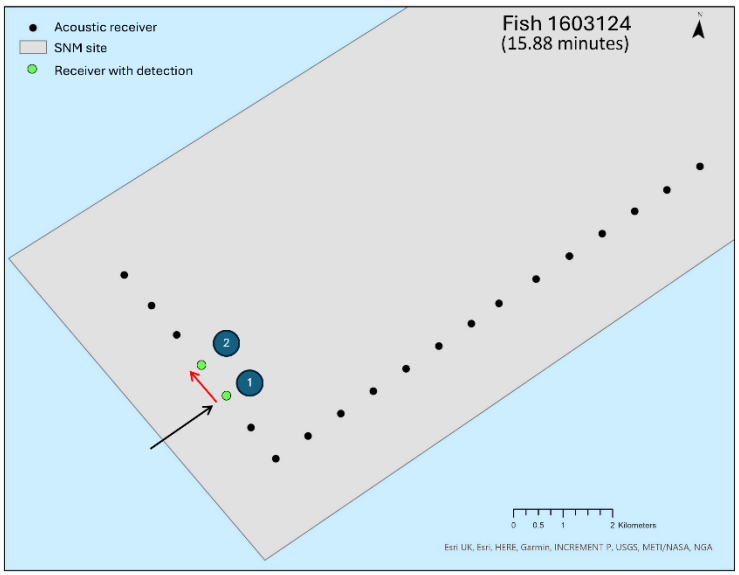

Acoustic receiver
SNM site
Receiver with detection
Fish 1589186
(89.13 minutes)
1
2
3
4
5
6
7
0 0.5 1 2 Kilometers
Esri UK, Esri, HERE, Garmin, INCREMENT P, USGS, METI/NASA, NGA

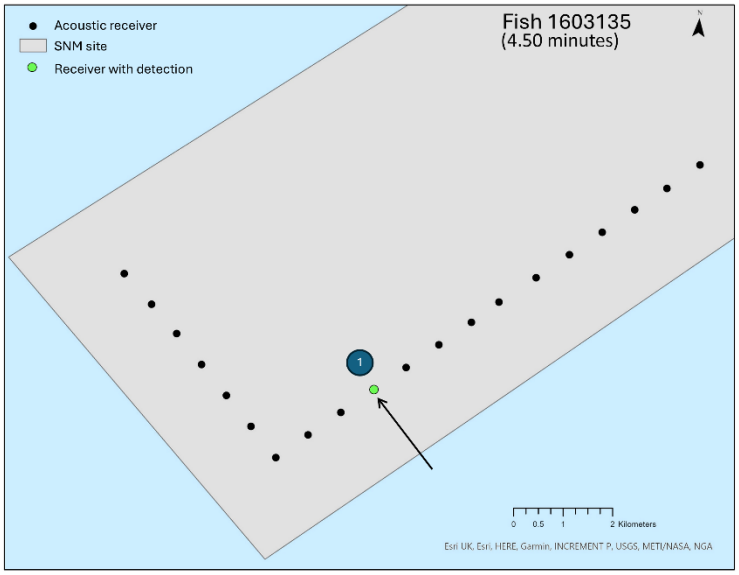

Acoustic receiver
SNM site
Receiver with detection
Fish 1603095
(30.78 minutes)
1
2
0 0.5 1 2 Kilometers
Esri UK, Esri, HERE, Garmin, INCREMENT P, USGS, METI/NASA, NGA


Acoustic receiver
SNM site
Receiver with detection
Fish 1603097
(37.88 minutes)
1
2
3
0 0.5 1 2 Kilometers
Esri UK, Esri, HERE, Garmin, INCREMENT P, USGS, METI/NASA, NGA


Acoustic receiver
SNM site
Receiver with detection
Fish 1603109
(2.93 minutes)
1
0 0.5 1 2 Kilometers
Esri UK, Esri, HERE, Garmin, INCREMENT P, USGS, METI/NASA, NGA


Acoustic receiver
SNM site
Receiver with detection
Fish 1603114
(10.65 minutes)
1
0 0.5 1 2 Kilometers
Esri UK, Esri, HERE, Garmin, INCREMENT P, USGS, METI/NASA, NGA


Acoustic receiver
SNM site
Receiver with detection
Fish 1603124
(15.88 minutes)
2
1
0 0.5 1 2 Kilometers
Esri UK, Esri, HERE, Garmin, INCREMENT P, USGS, METI/NASA, NGA


Acoustic receiver
SNM site
Receiver with detection
Fish 1603135
(4.50 minutes)
1
0 0.5 1 2 Kilometers
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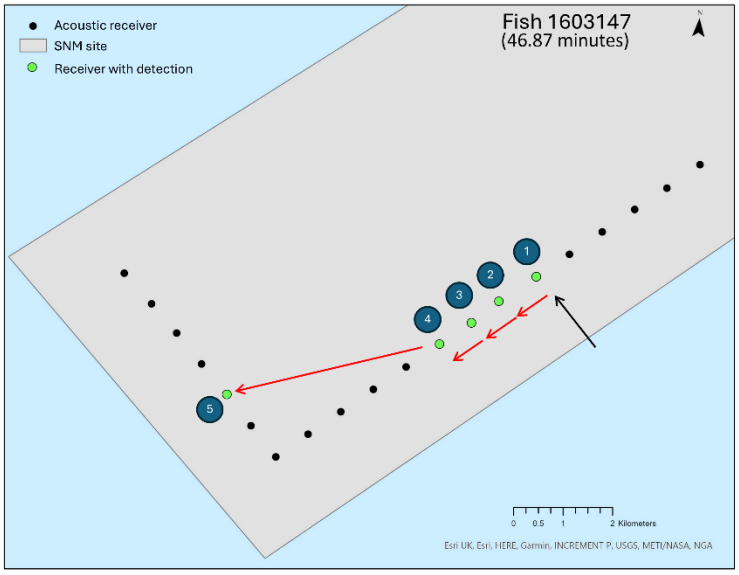
Acoustic receiver
SNM site
Receiver with detection
Fish 1603147
(46.87 minutes)
1
2
3
4
5
0 0.5 1 2 Kilometers
Esri UK, Esri, HERE, Garmin, INCREMENT P, USGS, METI/NASA, NGA