

TELEMETRY CASE REPORT

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# Evidence of long-distance coastal sea migration of Atlantic salmon, *Salmo salar*, smolts from northwest England (River Derwent)

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## Abstract

**Background:** Combining data from multiple acoustic telemetry studies has revealed that west coast England Atlantic salmon (*Salmo salar* L.) smolts used a northward migration pathway through the Irish Sea to reach their feeding grounds. Hundred Atlantic salmon smolts were captured and tagged in May 2020 in the River Derwent, northwest England as part of an Environment Agency/Natural England funded project.

**Results:** Three tagged smolts were detected on marine acoustic receivers distributed across two separate arrays from different projects in the Irish Sea. One fish had migrated approximately 262 km in 10 days from the river mouth at Workington Harbour, Cumbria to the northernmost receiver array operated by the SeaMonitor project; this is the longest tracked marine migration of an Atlantic salmon smolt migrating from the United Kingdom. This migrating fish displayed behaviours which resulted in fast northward migration. The remaining two fish were detected on a receiver array operated by a third project: the Collaborative Oceanography and Monitoring for Protected Areas and Species (COMPASS).

**Conclusion:** These detections further provide evidence that migration to reach marine feeding grounds of at least a proportion of salmon smolts from rivers draining into the Irish Sea is northerly, though without a southern marine array it is impossible to conclude that this is the only route. The pattern of these detections would not have been possible without the collaborative efforts of three distinct and separately funded projects to share data. Further work is required to fully understand migration trajectories in this species on the west coast of the British Isles.

**Keywords:** *Salmo salar*, Smolt, Acoustic telemetry, Migration, Irish Sea

## Background

For diadromous fish species, that migrate between marine and freshwater habitats, there is commonly very considerable disparity in knowledge about their ecology in different habitats [1, 2]. For the anadromous Atlantic salmon (*Salmo salar*) there is a relatively good

understanding of the ecology of the freshwater phase of the life cycle in published literature; this is in marked contrast to that of the marine phase (post-smolt) [3–5]. In particular, we have only a limited comprehension of their marine habitat use and the migration pathways they use to migrate between their natal river and their marine foraging areas in both directions [6]. The limited knowledge gathered for Atlantic salmon making their outwards marine migrations and the environments through which they migrate comes principally from two approaches: the capture of salmon at sea from either targeted [7–9]

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or opportunistic [3] capture by fisheries vessels and from telemetry studies tracking fish tagged in freshwater to marine habitats [4, 10–16].

The former study approach can provide important, spatially explicit, but point source data on the presence of migrating salmon [17–19]. This approach has shown us that salmon emanating from rivers in southern Europe migrate north to marine feeding grounds in the Norwegian Sea and/or to the north-west Atlantic, to the seas off west Greenland [1, 3, 20]. Using this approach however, it is difficult to reconstruct migration pathways and passage speeds, in part because it requires fish collection over an enormous spatial area from which pathways need to be inferred.

The telemetry approach applied to seaward migrating smolts has until now, mostly centred around tracking using acoustic technology. Acoustic telemetry studies, typically using fixed position, continuous monitoring acoustic receivers and fish tagged with acoustic transmitters, have rapidly become a common method to investigate fish migration patterns (large and small), site fidelity and diel and seasonal movements [17–19] through both freshwater and marine environments. This technique has the advantage that it can provide highly precise spatial information and thus more precise migration pathways. The disadvantage, when this approach is used to track anadromous species migrating into marine systems, is that the financial and logistical costs of maintaining suitably positioned receivers increases exponentially with distance from the river from which individuals are being tracked. Collaboration amongst global and regional projects, often with differing primary aims, allow for fish migration information in the spatially extensive marine environments to be obtained in a more cost-effective way [21, 22].

In one of the few studies to have looked at migration pathways of anadromous Atlantic salmon in the Irish Sea using acoustic telemetry, Barry and colleagues [4] analysed fish migrating from Castletown River and the River Boyne, both of which discharge into the west of the Irish Sea (on the east of Ireland). They found three Atlantic salmon smolts tagged in these tributaries were detected in the north Irish Sea, suggesting a northern trajectory after leaving the river mouth, taking them towards the North Channel, giving them access to the North Atlantic. Of these, one fish was detected on one of only two marine receivers, 250 km to the north, approximately 30 days after leaving its natal river. This finding provided the first evidence of a northerly marine migration trajectory for Atlantic salmon migrating into the Irish Sea. However, because there was no southern marine receiver array, it was not possible to completely exclude the possibility of some southern migration occurring [4].

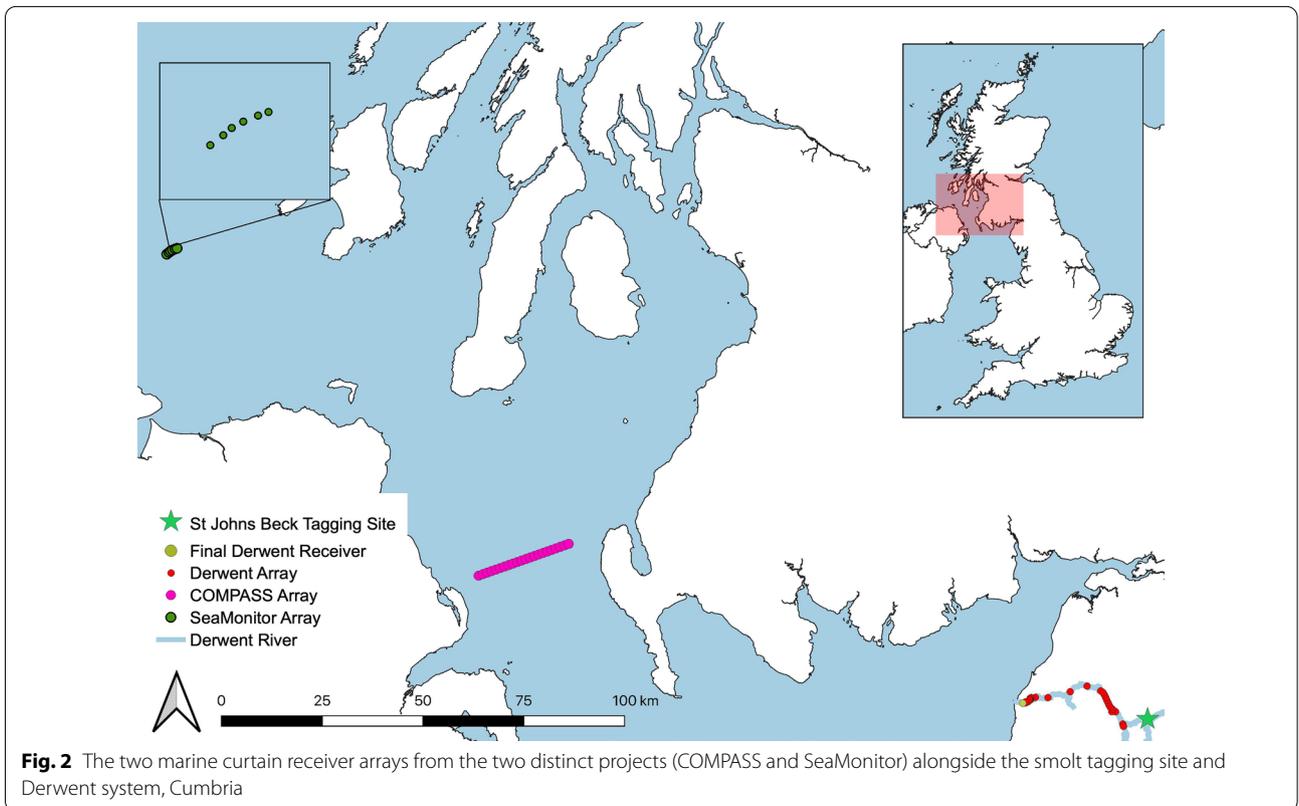
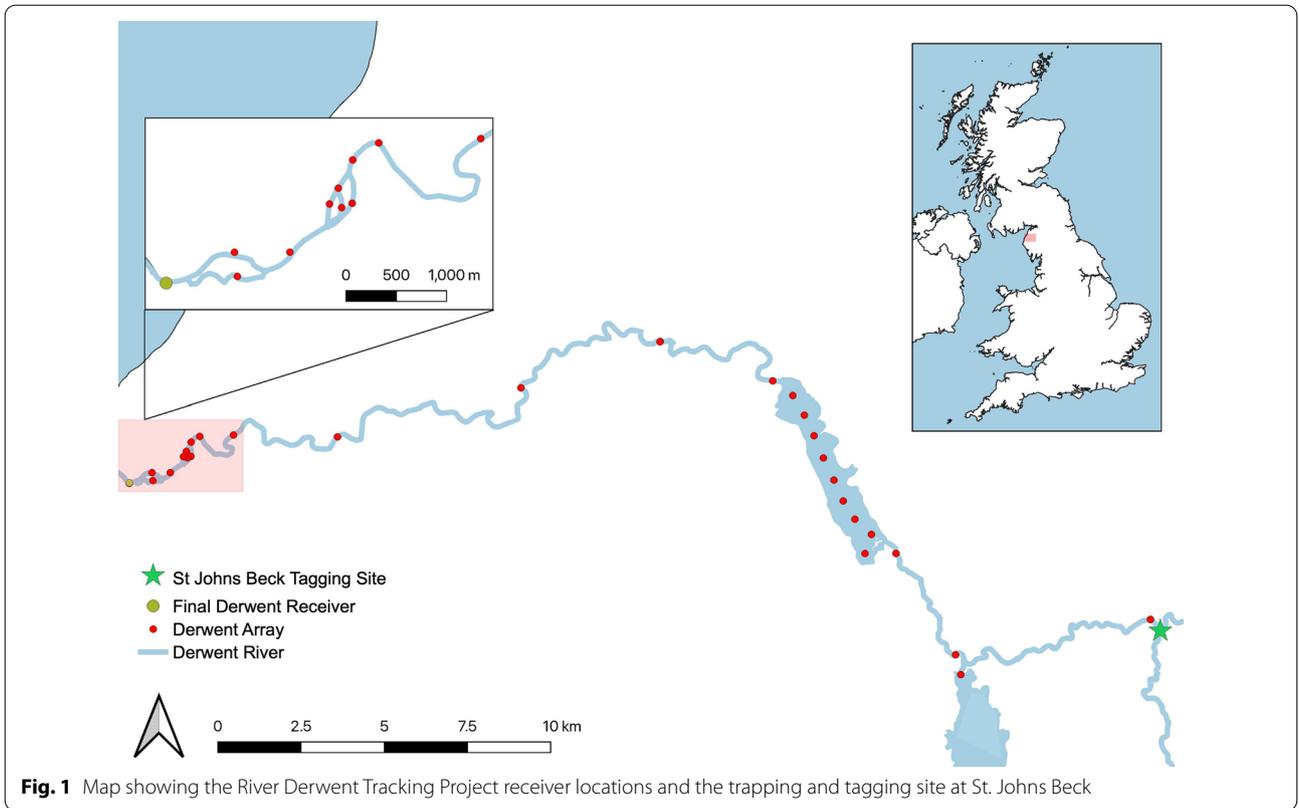
Here we provide a Telemetry Case Report on sea migrating Atlantic salmon from a river in north-west England discharging into the eastern Irish Sea. We show that Atlantic salmon smolts once entering the Irish Sea took a northern pathway suggesting a northern trajectory towards the North Channel, giving them access to the more open North Atlantic. We extend the maximum distance that a post-smolt Atlantic salmon has been tracked in acoustic studies in Europe to date. This study also demonstrates the need for both collaboration and data sharing between telemetry projects with alternative funding sources and project aims and for cross project detection compatibility to obtain maximum benefit from highly expensive, logistically demanding marine telemetry studies.

## Methods

The River Derwent, Cumbria, North-West England, (catchment: 679 km<sup>2</sup>) supports a population of wild Atlantic salmon. As part of a multi-partner project, led by the University of Glasgow, 100 Atlantic salmon smolts were captured in May 2020 by rotary screw trap and fyke net in St. Johns Beck, Threkheld (54.61058°, – 3.06168°), a tributary in the River Derwent which flows through Bassenthwaite Lake, before draining west into the outer Solway Firth at the Port of Workington (54.649487°, – 3.568865°) 50 km from the trapping site. The smolts were tagged at the capture location under licence (UK Home Office PPL 70/8794) with V7-2L (69 kHz) coded acoustic transmitters (VEMCO Ltd., 7 mm diameter, 1.7 g in air, average transmission delay of 45 s) and released during daylight hours. Acoustic receivers [VR2W and VR2Tx (Vemco Ltd.)] were deployed throughout the Derwent system ( $n = 29$ ) from the tagging site to where the river discharges to the open sea (see Fig. 1). Two marine arrays were deployed. One, part of the Collaborative Oceanography and Monitoring for Protected Areas and Species (COMPASS) project, in the Irish Sea, comprised 22 Vemco VR2ARs receivers, deployed as a curtain over 24 km from Northern Ireland (54.8885002°, – 5.6567001°) to Scotland (54.9700012°, – 5.3150501°). The other, deployed by a different project, the SeaMonitor project, comprised of six Vemco VR2ARs, deployed as a curtain over a distance of 2 km from 55.340280°, – 6.568360° to 55.349130°, – 6.545230° (see Fig. 2).

## Results

In total, 100 Atlantic salmon smolts were captured using in the upper reaches of the River Derwent, northwest England. The mean ( $\pm$  SD) fork length and mass of tagged salmon smolts was 139.36  $\pm$  0.65 mm and 27.89  $\pm$  0.42 g (range: 157–130 mm, 21.4–41.4 g) respectively. The



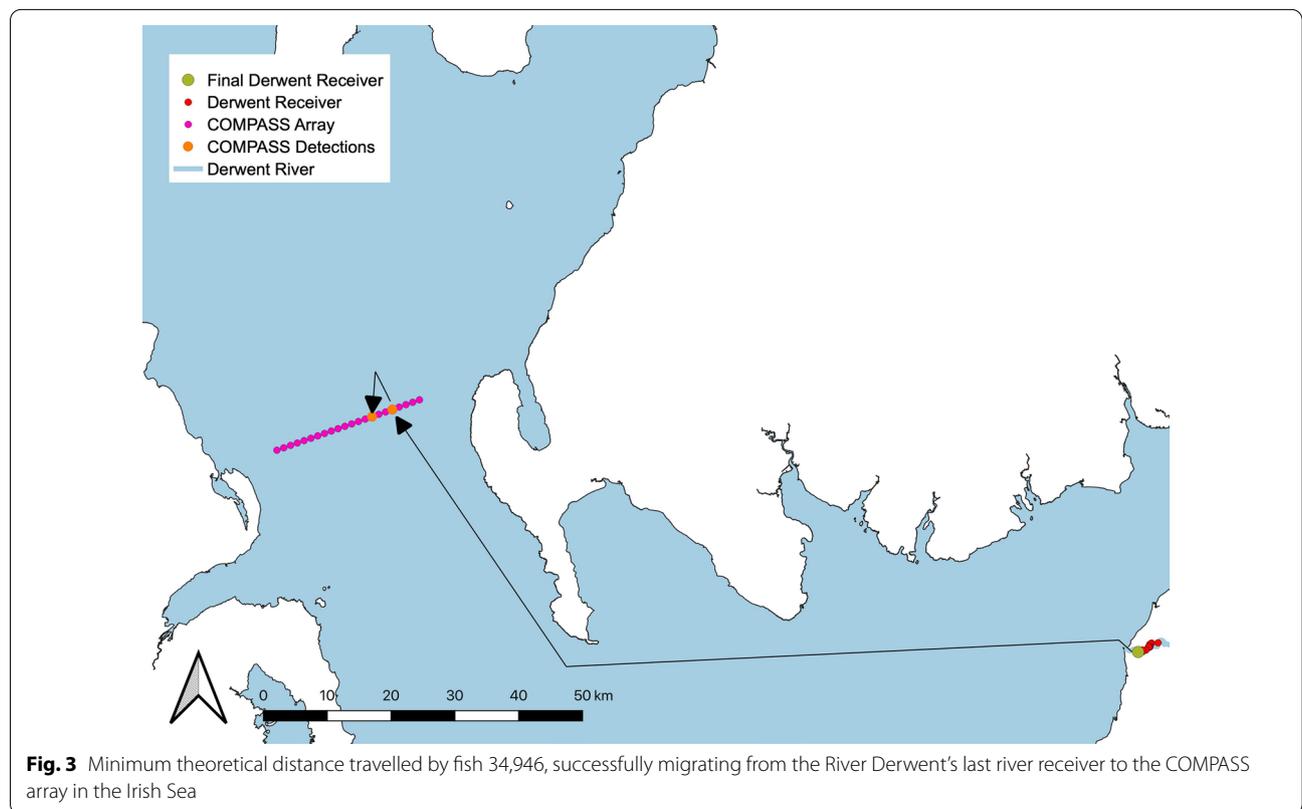
mean ( $\pm$  SD) tag burden was  $5.1 \pm 0.07\%$  (range: 3.5–6.7%). Eight smolts (8% of those tagged) were detected at the last River Derwent receiver at the river mouth before Workington port (see Fig. 1), equating to a river loss rate of 1.84%/km. The mean migration speed of the eight successful migrants from the release site to the final receiver before sea entry was  $0.4 \text{ km day}^{-1}$ . The eight successful fish had a mean ( $\pm$ SD) fork length and mass of  $141.38 \pm 5.10 \text{ mm}$  and  $28.84 \pm 3.11 \text{ g}$  compared to the unsuccessful salmon smolts ( $n = 92$ )  $139 \pm 6.33 \text{ mm}$  and  $27.48 \pm 4.11 \text{ g}$ , respectively.

Thirty seven point five percent of the salmon smolts that entered the marine environment were detected on receivers deployed across the Irish Sea. Two smolts (34,946 and 34,988) were detected on the COMPASS array and another smolt (34,920) was detected on the SeaMonitor array. Unfortunately, the distances between receivers (ca.1 km) exceed the presumptive detection ranges (ca.400 m) [23] for both marine arrays, therefore, it is plausible that more smolts may have passed both arrays undetected.

Tag 34946 was last detected entering Workington harbour from the river on 18th May 2020 at 16:34 pm (UTC) and subsequently detected at both marine arrays. After approximately 6 days at sea, travelling a distance of approximately 138 km, this fish was detected on the

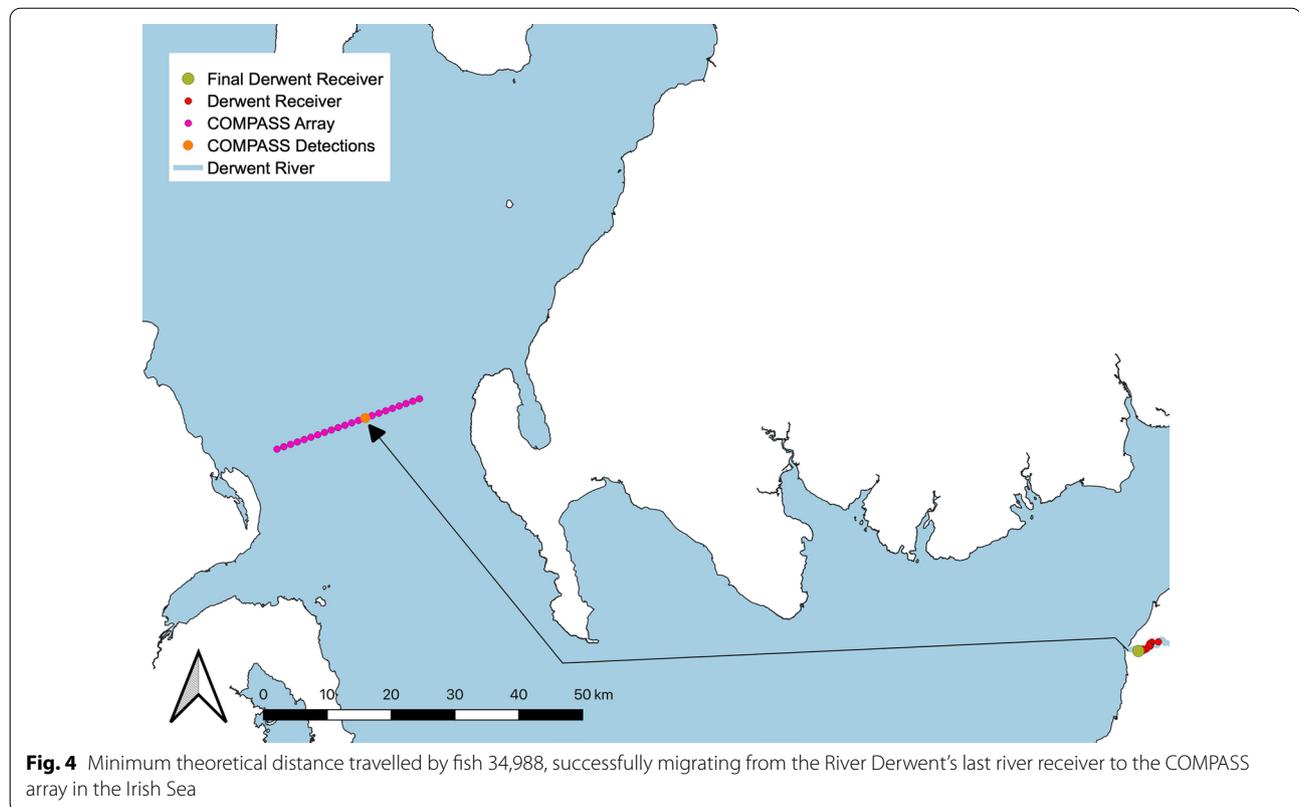
COMPASS array ( $54.9544983^\circ$ ,  $- 5.3801298^\circ$ ) on 31st May 2020 at 1:38 am. This equates to a movement speed of  $23 \text{ km day}^{-1}$  or 1.72 body lengths per second (BL/s). Seven detections were made of this fish at this site, providing confidence that this was not a false detection. This fish left this receiver location on 31st May 2020 at 1:46 am and travelled in a westerly direction to be re-detected again on the COMPASS array ( $54.9429016^\circ$ ,  $- 5.4289398^\circ$ ) on 31st May 2020 at 4:29 am, after travelling a further 3.37 km at 2.41 BL/s ( $29.77 \text{ km day}^{-1}$ ). There was only one detection on this receiver at this site (Fig. 3, Table 1). Tag 34988 was last detected at Workington on 24th May 2020 at 15:58 pm. After approximately 9 days at sea, travelling a minimum distance of 137.8 km, this smolt was detected on the COMPASS array ( $54.9389992^\circ$ ,  $- 5.44521^\circ$ ) on the 3rd June 2020 at 12:49 pm, having travelled at a speed of  $15.3 \text{ km day}^{-1}$  or 1.08 BL/s. Tag 34988 was detected six times on this receiver (Fig. 4, Table 1).

Tag 34920 was last detected entering the marine environment on the 18th May 2020 at 16:34 pm. Taking 10 days to travel at sea, this smolt covered a distance of 262 km ( $26.2 \text{ km day}^{-1}$ ) at a speed of 1.97 BL/s. This smolt was the only smolt from the River Derwent tracking project to be detected only on the SeaMonitor array ( $55.567250^\circ$ ,  $- 6.947361^\circ$ ). This smolt must have passed



**Table 1** 2020 tagged Atlantic salmon smolt characteristics and migration speed metrics for individuals detected at the COMPASS and SeaMonitor marine receivers

Smolt tag number	Date tagged	FL (mm)	W (g)	Tag burden	Estimated distance travelled before marine detection (km)	Migration speed		Body lengths/s	Days at sea	Array detection
						km day <sup>-1</sup>	ms <sup>-1</sup>			
34920	2020-05-01	146	31.4	4.5	261.88	26.2	0.2876	1.9701	10	SeaMonitor
34946	2020-05-02	143	30.7	4.6	138.01	23	0.2457	1.7184	6	COMPASS
34988	2020-05-03	149	32.3	4.3	137.75	15.3	0.1616	1.0843	9	COMPASS



the area of the COMPASS array without being detected. This fish was detected twice on the SeaMonitor array (Fig. 5, Table 1).

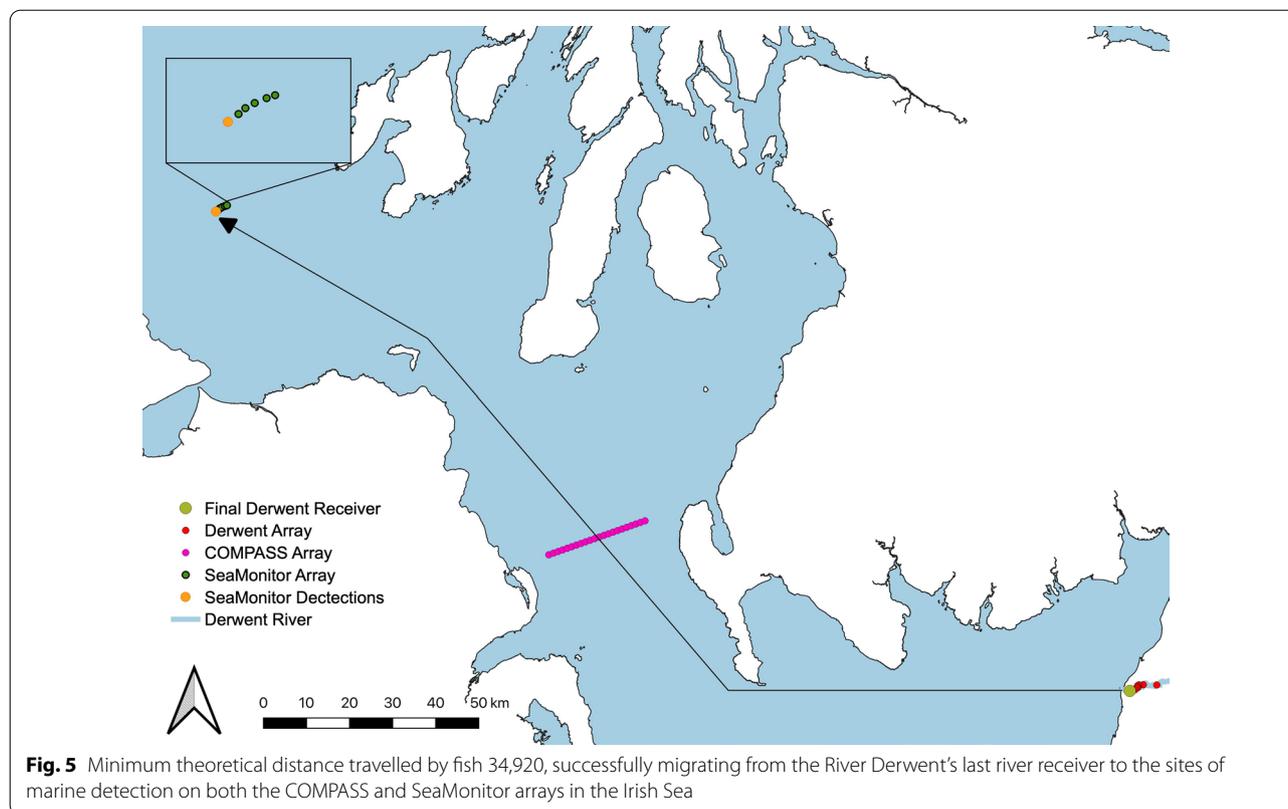
The overall net movement of all three River Derwent salmon smolts was northwards as registered in the marine receiver arrays. Thus, fish effectively must have taken an initially westerly trajectory towards the Irish coast once they left the riverine environment, followed by a northerly trajectory towards the North Channel (Figs. 3, 4, 5, Table 1). Without a southern receiver array, we cannot completely exclude the possibility of southern migration occurring initially for these fish or others that were not detected.

## Discussion

The results presented here provide consistent evidence of northerly movements by smolts after entering the marine environment of the Irish Sea. Despite a small sample size, the three individuals detected had relatively similar migration speeds over varying distances. The average speed recorded for all three salmon smolts ( $0.23 \text{ ms}^{-1}$  or  $21.5 \text{ km day}^{-1}$ ) is similar to the findings of Chaput et al. [15] of  $17\text{--}22 \text{ km day}^{-1}$  during Atlantic salmon smolt migration in the Gulf of St. Lawrence (North America). However, the travel speeds found in the study reported here are considerably higher than those reported in the

Barry et al. [4] study, which indicated migration speeds of  $\text{ca.}7 \text{ km day}^{-1}$ . In their study, Barry et al. [4] tagged smolts in two rivers in Ireland, Castletown River ( $54.026^\circ$ ,  $-6.429^\circ$ ) and the River Boyne ( $53.721^\circ$ ,  $-6.427^\circ$ ), which is at the same latitude as the River Derwent. The three river systems which all flow into the Irish Sea are separated by a channel of  $\text{ca.}200 \text{ km}$ , although the channel narrows to  $\text{ca.}35 \text{ km}$  further north creating a substantially narrower route for migration to the north. Due to a gradually narrowing channel, individuals are more likely to migrate through similar marine habitats and theoretically should experience similar environmental conditions. One explanation for the difference in the travel speeds noted above, is that migration progression rates are influenced by a combination of regional environmental differences and population specific features.

The Irish Sea is a semi-enclosed body of water characterised by concurrent action tides entering from both the north and the south [24, 25], creating semi-diurnal tides with areas of both high and low energy mixing [26]. However, intra-annual variability has been found there and it is known that current direction can change under specific environmental conditions such as wind, causing a greater southerly water flow [4, 24]. SALSEA-Merge [7] showed that post-smolt salmon use such currents during migration in marine environments and based on captures of



smolts in northern Scotland, concluded that post-smolts moved northwards along with the shelf edge currents [27]. Previous modelling by Mork et al. [11] indicated that the empirical data from the study by SALSEA-Merge [7] is to be consistent with fish following water currents and actively swimming in the direction of those currents. Dabrowski, et al. [24] analysed seasonal circulation and flushing of the Irish Sea and found that net flow through the Irish Sea varied significantly throughout the year, but that annually average flow ( $2.50 \text{ km}^3/\text{d}$ ) was northward, though southward flows were possible under certain meteorological conditions. The results of the study presented here and those of Barry et al. [4] imply that sea migrating post-smolts may well be navigating with the predominant current in this area, however, these movements may well be considerably more complex and much more detailed study is required. In contrast however, Newton et al. [23] used particle tracking to show that post-smolt Atlantic salmon were actively migrating in a direction that was not following the prevailing currents. The importance of using marine currents by migrating post-smolt Atlantic salmon thus requires further investigation.

Alternative possibilities for migratory pathway choice in post-smolts in marine environments could include that: (i) post-smolts disperse in random directions once

the open coast is reached, (ii) post-smolts take the most direct migratory pathway to reach their feeding grounds in the northern hemisphere, (iii) post-smolts use coastlines as geographical markers during their migration to their northerly destination. None of the three alternative scenarios here can be resolved from the study presented here without marine current data, a higher receiver density of detections from more receivers located throughout the Irish Sea. For example, marine array in the southern Irish Sea would also be required to test if some fish exhibit a southerly migration trajectory or that there is random direction dispersal removing all assumptions that only a northern migration trajectory is chosen. Additionally, greater receiver density along the coastline and on existing marine arrays would be required to analyse if post-smolts are using coastlines as geographic markers for initial marine migration. This would provide increased detection efficiency and lead to greater accurate analysis and future understanding of post smolt migrating behaviour.

Receiver detections not only provide timestamps for individual migration trajectories but may also indicate if predation of a tagged fish has occurred. Based on the detections in this study, we have presumed that all River Derwent fish detected on the marine receivers were post-smolt Atlantic salmon and not a tag retained

by a predator. Although this scenario cannot be completely ruled out, the assumption that detections are those of live post-smolts is supported by the similarity of the swimming speeds of detected smolts in this study, compared to other similar studies of Barry et al. [4] and Chaput et al. [15].

Currently literature on the coastal migration pathways of Atlantic salmon smolts is considerably limited. What information does exist particularly that from telemetry technology, is important to inform management strategy [4, 16, 28] and could be used in conjunction with behavioural studies on current use and environmental pressures. Thus, this information can contribute to assessing overlap with potential threats, such as pelagic fisheries, and inform modelling, which can in turn predict future migration routes of a population during this important life stage. The findings from this study have also provided, along with the results from Barry et al. [4], insight into future receiver array placements within the region, enabling future research on smolt migration pathways within the Irish Sea.

## Conclusion

This paper provides the first empirical evidence that west coast England Atlantic salmon smolts, adapting to the new marine environment, utilise the broad existing hydrodynamic conditions and display a northern migration trajectory in the Irish Sea, up to 262 km away from their natal river. Future work into understanding Irish Sea migration salmon pathways will require tracking a greater number of successful migrating individuals from rivers in both the east and west of the Irish Sea and a southern marine array is required to test for the potential of southern migration routes.

Gathering the results of this study has only been possible through cross jurisdictional and between research group collaboration. Meaningful and successful long distance migration telemetry studies are only possible when such collaborations are in place. The results of this study only emerged through the collaboration of three distinct jurisdictions and three separate research programmes: The Environment Agency/Natural England/University of Glasgow's River Derwent Tracking Project and the EU INTERREG VA funded COMPASS and SeaMonitor projects. Data sharing between projects has allowed a much greater insight into the northern migration of Atlantic salmon smolts through the Irish Sea from a river on the west coast of England. Further collaboration by the research community in this field is required to ensure marine migration trajectories are explored further.

## Authors' contributions

This study was planned by RR, PR, BS, MF, HMH, SW, CEA and AG; executed by AG, HMH, CEA, DD, RK, NOM, JB, FW and PK. All authors have contributed intellectually and to the writing of this manuscript. All authors have read and approved the final manuscript.

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## Availability of data and materials

The datasets generated and/or analysed during the current study are available on reasonable request from Amy Green, Scottish Centre for Ecology and the Natural Environment, Glasgow, G63 0AW, UK.

## Declarations

### Ethics approval and consent to participate

All tagging was conducted under UK Home Office License Number PPL 70/8794.

### Consent for publication

All authors have given their consent to the final manuscript being published.

### Competing interests

The authors declare that they have no competing interests.

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