Atlantic salmon smolts in the Irish Sea: first evidence of a northerly migration trajectory

RUNNING HEAD: SALMON SMOLT MIGRATION ROUTE IN THE IRISH SEA

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Abstract

Results from an acoustic telemetry study have revealed for the first time a northerly migration route for Atlantic salmon (*Salmo salar* L.) smolts leaving the east coast of Ireland. Atlantic salmon smolts were tagged in Spring 2019 in the Castletown and Boyne rivers. Three tagged smolts registered on disparate deep-water offshore marine receivers as they travelled northwards out of the Irish Sea through the North Channel. One fish had migrated an estimated 250 kilometres in a period of 32 days. The remaining two individuals were detected on receivers located off the Northern Ireland coast, further corroborating the northward migration of salmon smolts through the Irish Sea.

Introduction

Migration trajectory and timing have been identified as critical factors for fish species to arrive at their destination at the right time and play an important role in survival rates (Cooke et al., 2006). The vast majority of Atlantic salmon (*Salmo salar* L. 1758) populations in the North East Atlantic area are currently recording record low numbers of returning adult salmon to their rivers (ICES, 2019). In recent years there has been a significant decline in marine survival and thus increased research focus on the salmon smolt life stage and migration trajectories at sea. Data on marine distribution of salmon smolts and post-smolts is limited although a number of possible feeding and migration routes have been inferred through recaptures at sea and modelling swimming behaviour (Went, 1973; Mork, Gilbey, Hansen, Jensen, Jacobsen, Holm, & Melle, 2012; Ounsley, Gallego, Morris, &Armstrong, 2019).

Marine survival can vary between years and regions. The trends in return rates of smolts to one sea winter salmon for populations in the North East Atlantic area (of which Irish salmon rivers are a significant contributor) are declining and currently at record low levels ranging between 2.9-5.7% over past 6 years in comparison to 14% in the 1980's (ICES, 2019). Atlantic salmon smolts enter the marine environment during late spring and the post-smolt stage is probably the most vulnerable and least understood period of their life history (Thorstad, Whoriskey, Uglem, Moore, Rikardsen & Finstad, 2012; Flávio, Kennedy, Ensing, Jepsen, & Aarestrup 2020.) In general, progression through rivers and estuaries is fast with timing and speed of movement into coastal waters varying only marginally between regions (Thorpe, Ross, Struthers, & Watts, 1981; Svendsen, Eskesen, Aarestrup, Koed, & Jordan, 2007; Martin, Hedger, Dodson, Fernandes, Hatin, Caron, & Whoriskey 2009; Thorstad et al., 2012; Lothian, Newton, Barry, Walters, Miller, & Adams 2018; Newton, Barry, Dodd, Lucas, Boylan, & Adams 2019). Subsequent movements away from inshore coastal regions to the open ocean are poorly understood with limited empirical research data available, due in part to the difficulty of tracking small fish in extensive and deep oceanic waters. The current literature suggests that post-smolts travel in small groups and remain close to the surface where they are strongly influenced by environmental conditions such as wind and tidal streams (Dutil & Coutu 1988; Lacroix & McCurdy 1996, NASCO, 2011; Mork et al., 2012).

There are very few empirical studies of salmon post-smolt migration and processes (e.g tidal currents) underlying trajectories or routes taken by fish (NASCO, 2011; Chaput, Carr, Daniels, Tinker, Jonsen, & Whoriskey 2018). At present the only data available for migration routes of smolts around the island of Ireland have been the limited information on smolt distribution at sea from the recapture in surface trawls in the western Atlantic Ocean and then their assignment to river of origin using genetic techniques (NASCO, 2011). Studies investigating the marine migration in Atlantic salmon smolt to date have focused on deep estuaries and coastal fjords (Økland, Thorstad, Finstad, Sivertsgard, Plantalech, Jepsen & McKinley 2006; Hedger, Martin, Hatin, Caron, Whoriskey & Dodson 2008; Dempson, Robertson, Pennell, Furey, Bloom, Shears & Robertson 2011) and there are very limited data on open ocean swimming, routes and migration distance covered over time.

The current poor understanding of this critical life stage of salmon limits the advice that can inform marine and coastal management strategies directed at the protection and conservation of salmon during their early marine migration. There is a pressing need to improve the understanding of the factors influencing marine migration and also to identify any issues or potential survival bottlenecks which may be negatively impacting this critical life stage. In an Irish context a long-term research question has been to determine the direction of salmon smolt migrations out of Irish waters on the east coast. Among the objectives of this study was an investigation of the migration routes, directionality and timing of salmon smolts as they entered and navigated through the Irish Sea.

Methods

Atlantic salmon smolts were captured in a single 1.2 metre rotary screw trap (Key Mill Construction Ltd, Ladysmith, BC, Canada), deployed for discrete periods, on the Castletown river (54.026°, -6.429°) 6.93 km above sea entry and subsequently on the River Boyne (53.721°, -6.427°) 13.2 km above sea entry (Figure. 2.), in April-May 2019, Salmon smolts were tagged with V7-2L acoustic transmitters (VEMCO Ltd, www. vemco.com; 7mm diameter, 1.7g in air). This research was undertaken in accordance with the ethical standards of the Health Products Regulatory Authority of Ireland (HPRA) under the project number AE19118/P011. The acoustic array comprised of acoustic listening stations (VR2W & VR2AR; www.vemco.com) deployed in both inshore (extensive array n=29) and offshore locations (n=2) (Figure. 1). Minimum migration distances were obtained by calculating straight line distance between sea entry points and marine detection site, accounting for coastal boundary effects. All analyses were conducted using Google Earth "Ruler" tool. These estimated distances between detection points were then converted to body lengths (BLs^{-1}) to standardise for body length effect (Table 1). To investigate selective tidal stream transport, time of detections when fish passed within range of the receiver were cross checked with known tidal stream patterns through the North Channel (www. eoceanic.com). Tidal state was obtained from South Rock and Portrush tide stations (https://www.tidetimes.org.uk/).

Results

In total 100 salmon smolts were tagged; River Boyne (n=70) & Castletown River (n=30). The mean total length and mass of tagged salmon smolts was 14.76 ± 2.2 cm and 31 ± 7.4 g (range: 18.2–12.6 cm, 24–54 g). Tag burden varied between 3.1% and 8.5% (mean 5.61% ± 1.2%). In total 80 salmon smolts were detected exiting their river into sea water (n=57 Boyne, n=23 Castletown) with river mortality (% loss per km being 0.89% and 3.37% respectively. Progression rates for salmon smolts from tagging site in freshwater to sea entry averaged 1.61 km / day (Castletown smolts) and 9.42 km /day (Boyne smolts).

Three salmon smolts (3.7% of total entering marine waters) were detected on receivers in offshore waters within the Irish Sea and North Channel (St. Johns Point, Copelands and Middle Bank). The offshore receivers provided limited coverage and it is probable that many more smolts passed undetected. Smolt 13956 was detected entering Dundalk Bay on 27/04/2019 at 19:00 hr. This fish was re-detected passing St. Johns Point on 06/05/2019 at 01:26 hr, some 8.26 days later having travelled an estimated distance of 60 km at a mean speed of 7.2 km/d. Smolt 13971 was detected entering Dundalk Bay on the 22/04/2019 at 14:00 hr and then re-detected passing the Copelands marine receiver on 13/05/2019 at 07:18 hr, some 20.7 days later having migrated some 140 km, mean speed 6.7 km/d. Smolt 13948 was detected leaving the Boyne estuary on the 10/05/2019 at 20:50 hr and was re-detected passing the Middle Bank marine receiver on 12/06/2019 at 13:29 hr. This 250 km migration took 32.7 days at an estimated mean speed of 7.6 km per day (Figure 2). All three smolts were detected by receivers during periods when currents were flowing in a northerly direction which suggests that smolts from these systems are likely to use favourable tidal conditions (i.e. northerly discharging) to progress along this particular migration pathway (Table 2). Only one salmon smolt of the 80 which entered the sea was detected on the extensive inshore receiver array (deepest inshore receiver). In contrast, high detection rates were recorded on this inshore array for many of the 160 contemporaneously tagged sea trout smolts from 5 rivers on the same coast. (Figure 1 & Supporting Information Figure 1).

Discussion

Despite the relatively small sample size, these results provide strong evidence that smolts progress quickly from the coast (as evidenced by the lack of salmon smolt detections on the extensive inshore coastal array; 1 smolt detection from 80 marine entrants) into deeper offshore waters. Given the sequential recordings of tagged fish and consistent swim speeds, the results presented here provide the first evidence for northerly migration through the Irish Sea. The three individual smolts detected on the marine receivers exhibited remarkably similar migration speeds over the varying distances travelled / days at sea. The speeds recorded for smolts in this study (~7km/day; Table 1) are in contrast to speeds of 17–22km day recorded for Atlantic salmon smolts in the Gulf of St. Lawrence (Chaput et al., 2019); this highlights that the localised dynamics of the marine environment which smolts are swimming through may dictate progression rate. It is assumed that tag detections on marine receivers were from independently swimming live smolts rather than tags from predated smolts being retained in the stomach of a predator. The similar swim speeds observed for the separately detected individuals support this assumption. Findings from this study are consistent with observations from Chaput et al. (2019) and provide preliminary evidence that Atlantic salmon smolts may be using coastal currents to aid navigation in the Irish Sea. Within the Irish Sea the semi-diurnal tides are the dominant physical process in the region, propagating into the Irish Sea from the Atlantic Ocean through both the North Channel and the St. George’s Channel (Howarth, 2005). Currents of 1–1.5 m/s are observed during mid-ebbs and mid-floods in the North Channel (MacDowell, 1997) (Supporting Information Figure 2). The three smolts were detected passing receivers when tidal currents were favourable (i.e. moving in a northerly direction). Other studies have also have aligned active swimming direction with the surface currents (Mork et al., 2012). The annually averaged flow through the Irish Sea is in a northward direction (2.50 km^3/day) however, under certain conditions is reversed to southward (Dabrowski, Hartnett, & Olbert, 2010). Hydrodynamic models used to investigate the transport pathways of scallop larvae in the Irish Sea (Hartnett, Berry, Tully, & Dabrowski, 2007) suggest a slack area and a light southerly flow pattern in close proximity to where the Castletown and Boyne rivers where they enter the Irish Sea. These localised currents may encourage smolts seeking to move north to move offshore quickly and potentially explain the lack of detections on the inshore receiver array in this study.

At present very little is known about coastal migration pathways for Atlantic salmon smolts and data provided from telemetry, although sparse, is important to consider in a management context. For example post-smolts have been recorded in catches in pelagic fisheries (herring & mackerel), hence it is critical to understand these migration routes in order to establish potential threats from this and similar activities. The data presented here will contribute to informing models (with empirical swim speed observations) which aim to build "predicted migration routes" for this important life stage.

Lennox et al., (2019) reviewed the pressing questions facing global fish migration, and highlighted the need for better understanding of the mechanisms used by species which allow them to navigate to the correct place. Knowledge of the migratory trajectories and behaviour in relation to ocean currents during the early marine phase of the Atlantic salmon life cycle is needed to ensure effective conservation and protection management in a time when coastal marine development is continuing apace (Ohashi & Sheng 2018; Ounsley et al., 2019). Mork et al. (2012) found that faster swimming speed gave better overlap between modelled and observed distributions and a value between 1.5 and 2.0 body length s^{-1} provided the best overlap in that case. These values were considerably higher than the values observed in this study (average of 0.50 body length s^{-1}) which may suggest varying swimming speed depending on river of origin and/or challenging environmental conditions experienced by individual fish.

This study? presents findings on the first record of salmon smolts taking a northern migration trajectory from east coast rivers in Ireland and empirical data on migration behaviour in the open ocean environment. It also provides some of the first long distance tracking of individual salmon smolts at sea using acoustic telemetry. Given that routes and pathways are beginning to be understood, the migration metrics presented here will aid in refining placement of further detection equipment within this region and enable future research on migration pathways, survival rates and regional differences in migration success. A key aim of the ICES working group for Atlantic salmon (ICES, 2019) is to continue, expand and develop tracking programmes because information from such work will inform and develop the assessment of marine survival and modelling of oceanic movements of salmon post-smolts. Initial research results like those presented here offer insights which will allow policy makers to consider the issues which will need to be considered to direct management actions aimed at the protection and conservation of important salmon stocks, and consider the complexities of managing a moving target migrating through international waters. These findings will also contribute to the understanding of environmental conditions that smolts may be experiencing and to investigate potential climate change impacts if this environment were to change. Collaborative research efforts, nationally and internationally are needed to support the conservation of salmon stocks which are threatened by current and increasing threats posed by a changing environment.

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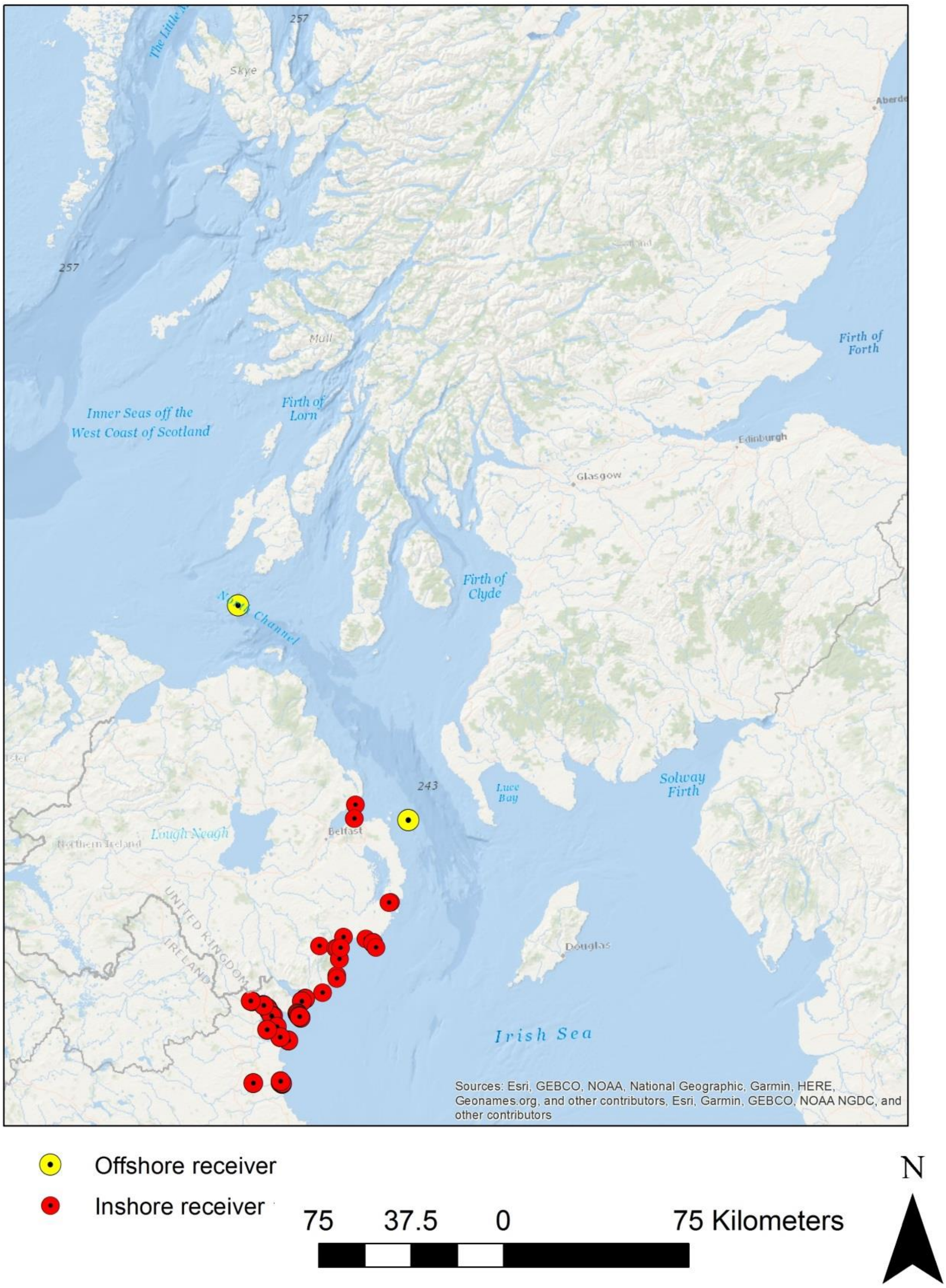

Figure 1: Locations of Acoustic Listening Stations :Inshore coastal array (n=29) and offshore locations (n=2)

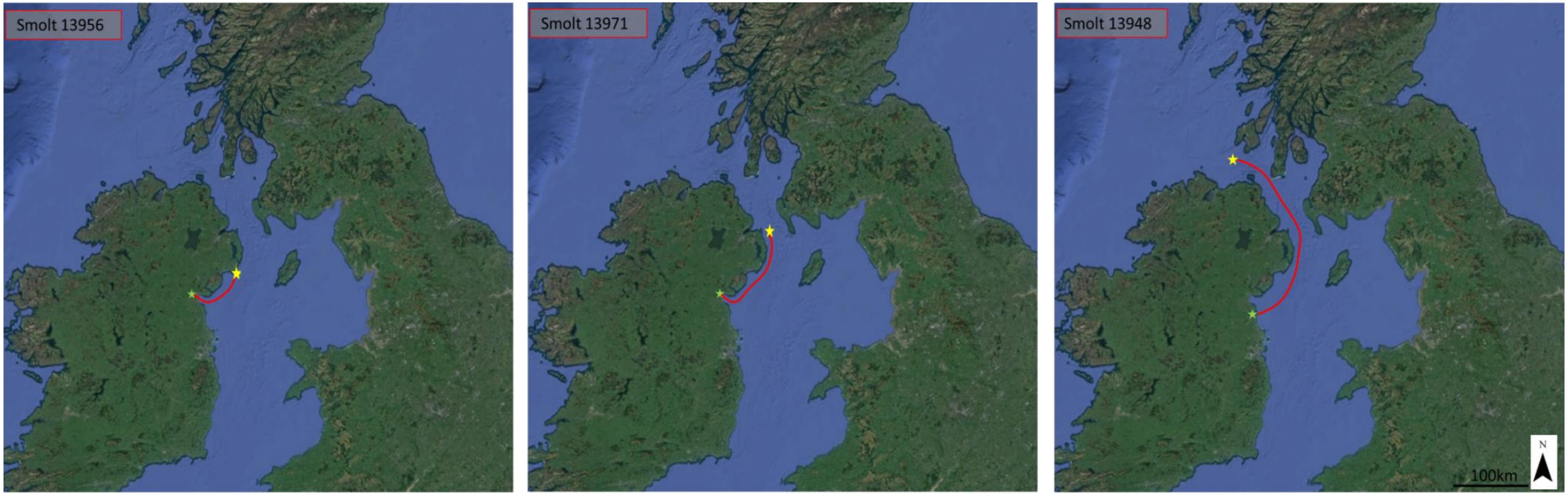

Figure 2: Minimum distance travelled between sea entry (green star) and marine detection site (yellow star) for the 3 salmon smolts detected on marine receivers.

Table 1 : Smolt characteristics and migration speed metrics for individuals detected at marine receivers.

Smolt tag number	Date tagged	Lt (mm)	W (g)	River	Estimated distance travelled before marine detection	km/day	m/s	Body lengths s-1	Days at sea
13956	22/04/2019	177	52	Castletown	60 km	7.2	0.083	0.469	8.26
13971	19/04/2019	164	39	Castletown	140 km	6.7	0.077	0.470	20.7
13948	07/05/2019	152	40	Boyne	250 km	7.6	0.087	0.572	32.7

Table 2: Tidal stream characteristics at detection time on marine receivers.

Detection location	**Time of detection**	**No. of detections (minutes)**	**Tidal stream direction**	**Tidal state**
St. John's Point (passing)	06/05/2019 01:35	43 (20 minutes)	North	Ebb (start)
Copelands (arrival)	13/05/2019 01:14	2 (4 minutes)	Slack – south	Low / Slack
Copelands (departure)	13/05/2019 07:14	11 (7 minutes)	North	Ebb (start)
Middle Bank (passing)	12/06/2019 13:35	3 (8 minutes)	North west	Flood

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SUPPORTING INFORMATION

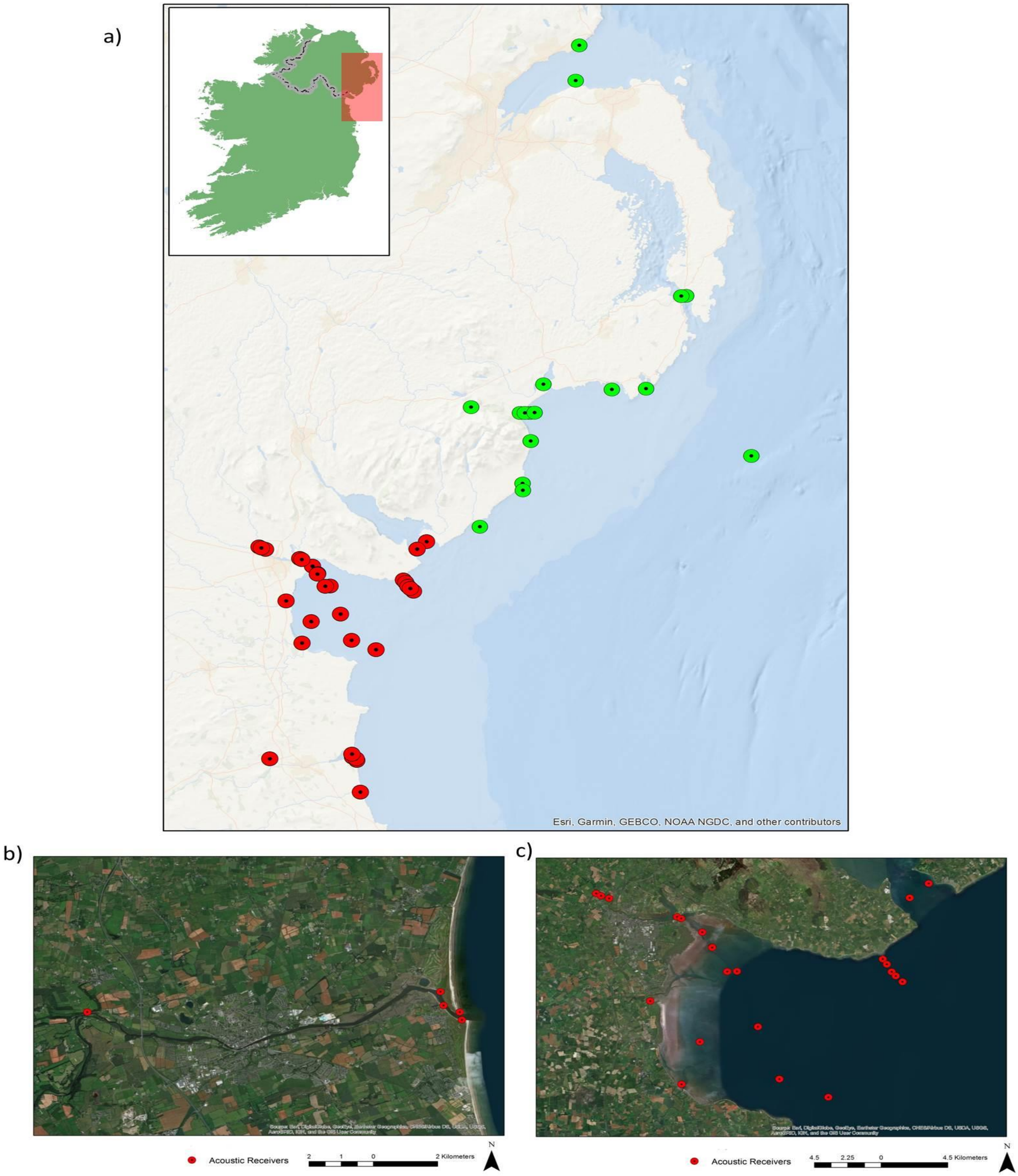

Figure 1 :a) Inshore array off north east coast of Ireland b) receiver array in Boyne estuary c) receiver array in Castletown river and Dundalk bay.

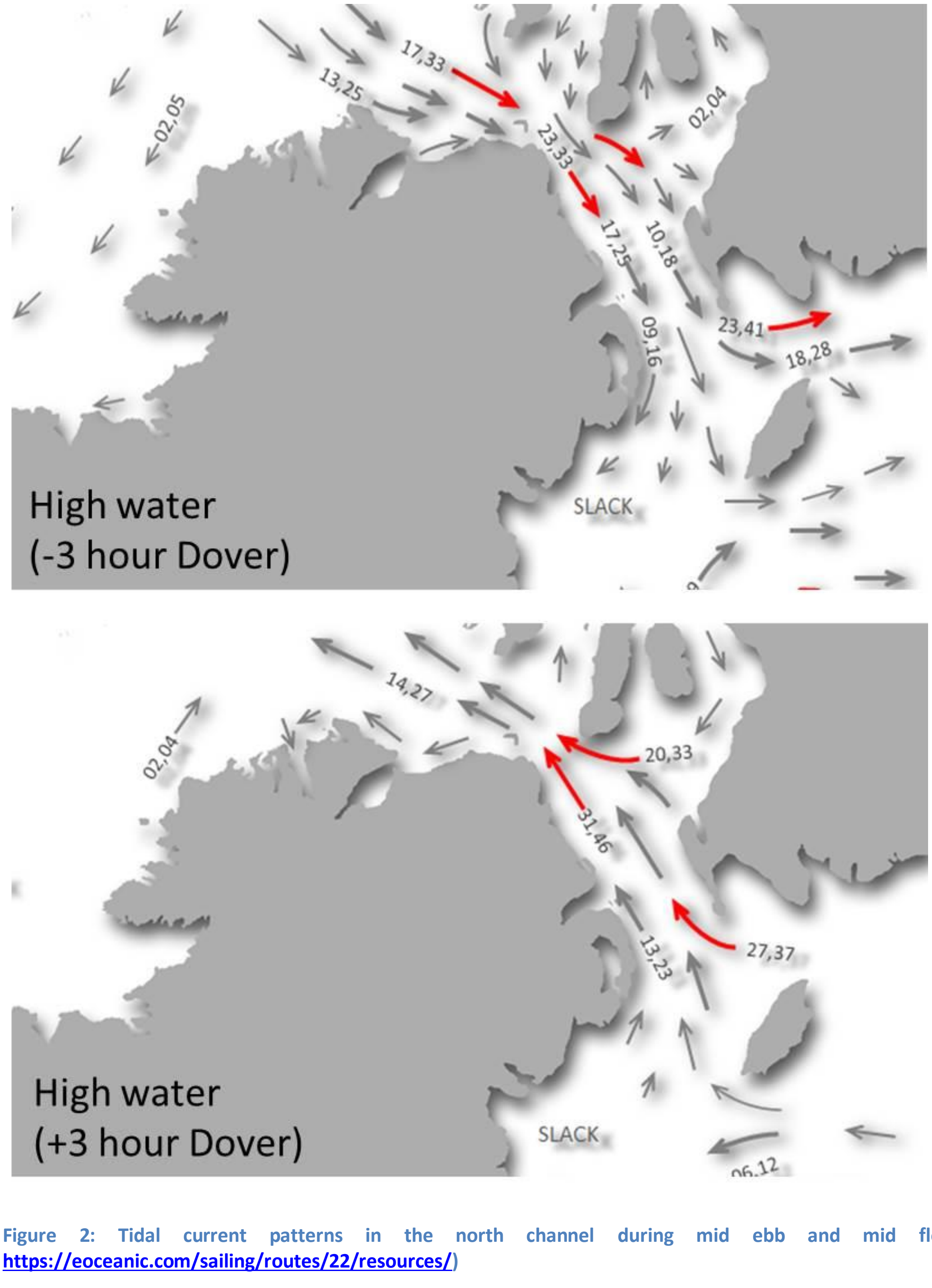

Figure 2: Tidal current patterns in the north channel during mid ebb and mid flood (source https://eoceanic.com/sailing/routes/22/resources/)