The SAMARCH Project International Salmonid Coastal and Marine Telemetry Workshop

Edited by: Ken Whelan, Dylan Roberts and Janina Gray

Based on a workshop organised by Salmon & Trout Conservation and Game & Wildlife Conservation Trust on behalf of the SAMARCH Project and the Atlantic Salmon Trust in Southampton, UK, on the 5th and 6th November 2019.

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*SAMARCH is a €7.8m five-year project (2017-2022), part funded by the France England Interreg Channel VA Programme. The project will provide new transferable scientific evidence to inform the management of salmon and sea trout (salmonids) in the estuaries and coastal waters of both the French and English sides of the Channel.

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Foreword

In his presentation to the Workshop Martyn Lucas, of Durham University, reminded us that the past decade has seen a major step change in the ability of researchers to track migratory fish both in freshwater and in the ocean. Biotelemetry and bio-logging techniques have mushroomed into globally applied methods for fisheries science and management. Their use in marine environments has increased exponentially, especially with the availability of reliable, off-the-shelf telemetry products, particularly for acoustic tracking. The current underpinning electronic tracking technologies for marine salmonids, comprising acoustic telemetry, satellite telemetry and data storage tags (DSTs or archival tags) are all undergoing continued development, in particular through miniaturisation, reduced power consumption (extended life) and remote data transfer. Most acoustic telemetry, relies upon non-cabled arrays of passive hydrophone receiver-loggers from which data must be downloaded, increasingly combined with receiver units mounted on drifters and ocean gliders.

These technologies are being applied over a wide range of environments and with an equally diverse range of objectives. The ability of such new technology to amass and store information has obvious and long sought after advantages, but equally it poses major logistical and scientific challenges as terabyte after terabyte of information is stored from individual tracking projects. Tracking was originally confined to the use of static tags on or in the fish themselves. Increasingly, however, non-invasive techniques remote from the fish are being used to monitor their behaviour and the migration patterns of fish down rivers, through estuaries and across oceans. Chemical tracing techniques based around the science of genetics and the use of stable isotopes are opening up new tracking horizons which we could not even have dreamed of a generation ago.

The main objective of the SAMARCH Programme was to provide new, transferable scientific evidence to inform the management of salmon and sea trout in the estuaries and coastal waters of both the French and English sides of the Channel. Fundamental to achieving this goal was learning more about the migration and distribution patterns of migratory salmonids in this geographical area. In rolling out the programme it became clear that to optimise the scientific outputs it was important to compare and contrast results from SAMARCH with other major tracking initiatives across Europe and beyond. We are delighted with the outputs from the SAMARCH International Salmonid Coastal and Marine Telemetry Workshop, which has given us an inclusive and extensive overview of current and emerging tracking programmes and fish tracking technologies across Europe and in North America. The workshop has also provided us with a very clear and concise list of challenges that must be faced if we are to maximise the potential of modern fish tracking techniques in the marine environment.

Through the work of the Missing Salmon Alliance and the development of the Likely Suspects Framework, we are developing a novel approach whereby for the first time we can integrate results from the various tracking programmes to assess the causes of salmon mortality within clearly defined estuarine and open ocean domains. Work is under way to develop a series of clearly defined hypotheses around the factors influencing salmon mortality, which can be tested within these geographically discrete areas.

We are conscious that, collectively our organisations are very new to working with research into the lives of migratory salmonids in the ocean. However, we are convinced that if we combine forces with colleagues who are specialists in ocean processes and the changes which climate change is bringing about in the seas around us, that it will be possible to develop evidence-based management strategies to protect and enhance our valuable stocks of salmon and sea trout throughout their entire life cycles.

Finally we wish to sincerely thank all of authors who provided us with such excellent and very comprehensive summaries of their scientific findings and who helped us grow in our understanding of the exciting prospects which lie ahead for tracking salmonids across the full gambit of estuarine and marine environments.

We are also grateful to, Thelma Biotel, RS Aqua, Vemco, Cefas Technology, Biomark, Wildlife Computers and Lotek for part sponsoring the event.

Mark Bilsby, *CEO, Atlantic Salmon Trust*
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Overview: Tracking as a Contribution to the Likely Suspects Framework

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Despite extensive conservation measures involving constraints on fisheries and the restoration of freshwater habitat, many salmon populations in both the Atlantic and the Pacific basins, particularly at the southern extremes of their ranges, have experienced an ongoing decline in productivity since at least the early 1990s. While low marine survival is generally accepted as a cause of decline for many populations, the mechanisms involved, and the contributing factors, are poorly understood. Previous work on marine fisheries in Europe has shown that it is possible to identify a Strategic Framework that would place candidate mortality factors within an overall spatial and temporal framework, covering the full lives of salmon at sea.

In 2016 AST developed a concept that aimed to provide coherent guidance on how future research on salmon survival can be identified and prioritised. This has become known as the Likely Suspects Framework. To advance the Likely Suspects Framework concept the AST organised, in November 2017, a scoping workshop in Edinburgh, Scotland. The workshop included salmon scientists and modelers from both the Atlantic and Pacific areas and it marked the first scientific event held under the auspices of the International Year of the Salmon.

A key objective of the Framework is to stimulate the development of specific, testable scientific hypotheses about the factors influencing salmon survival. This will be achieved through the integration of various levels of data analysis and modelling approaches across a wide range of spatial (and temporal) scales and by refining estimates of the scale and variation in mortality, at each stage of the salmon's life cycle. Such an approach would help to quantify the potential of each factor to influence survival (i.e. the "likely suspects") and to link these dynamically in such a way that the cumulative effects of these factors could explain the variations in survival of different year classes of salmon. Such an approach can be used to identify the likely impacts, both individually and cumulatively, of the "likely suspects".

There is evidence for where Atlantic salmon migrate to and for the existence of numerous mortality candidates. Such evidence forms the starting point for the Framework. The intial step is to identify the main potential locations/times of mortality and to designate these as "ecosystem domains" in the Framework. Such domains can be placed at geographical locations that are judged to be significant, particularly in the marine phase of the life cycle. However, given the diadromous nature of the Atlantic salmon such domains are not all in the marine zone, as their life experiences as juveniles in rivers and the freshwater migration phase may also strongly influence subsequent survival at sea.

Population dynamics models, which are currently under development, are based on large geographical scales. They provide insights into responses shared by populations of Atlantic salmon. However, the scale and the data used in such models are not suitable for exploring precise mechanisms. By contrast, high demographic resolution data, at the scale of local populations in index rivers and in near shore areas, will allow a more precise examination of the key factors regulating survival. The Likely Suspects Framework approach would facilitate the collection of such data. Integral to such an approach is using a wide range of technologies to track the migration and distribution patterns of salmon populations across the various ecosystem domains – freshwater, estuarine, near shore and high seas. It will also be used to identify the pressures within those domains that may well be regulating the overall survival of individual salmon populations.

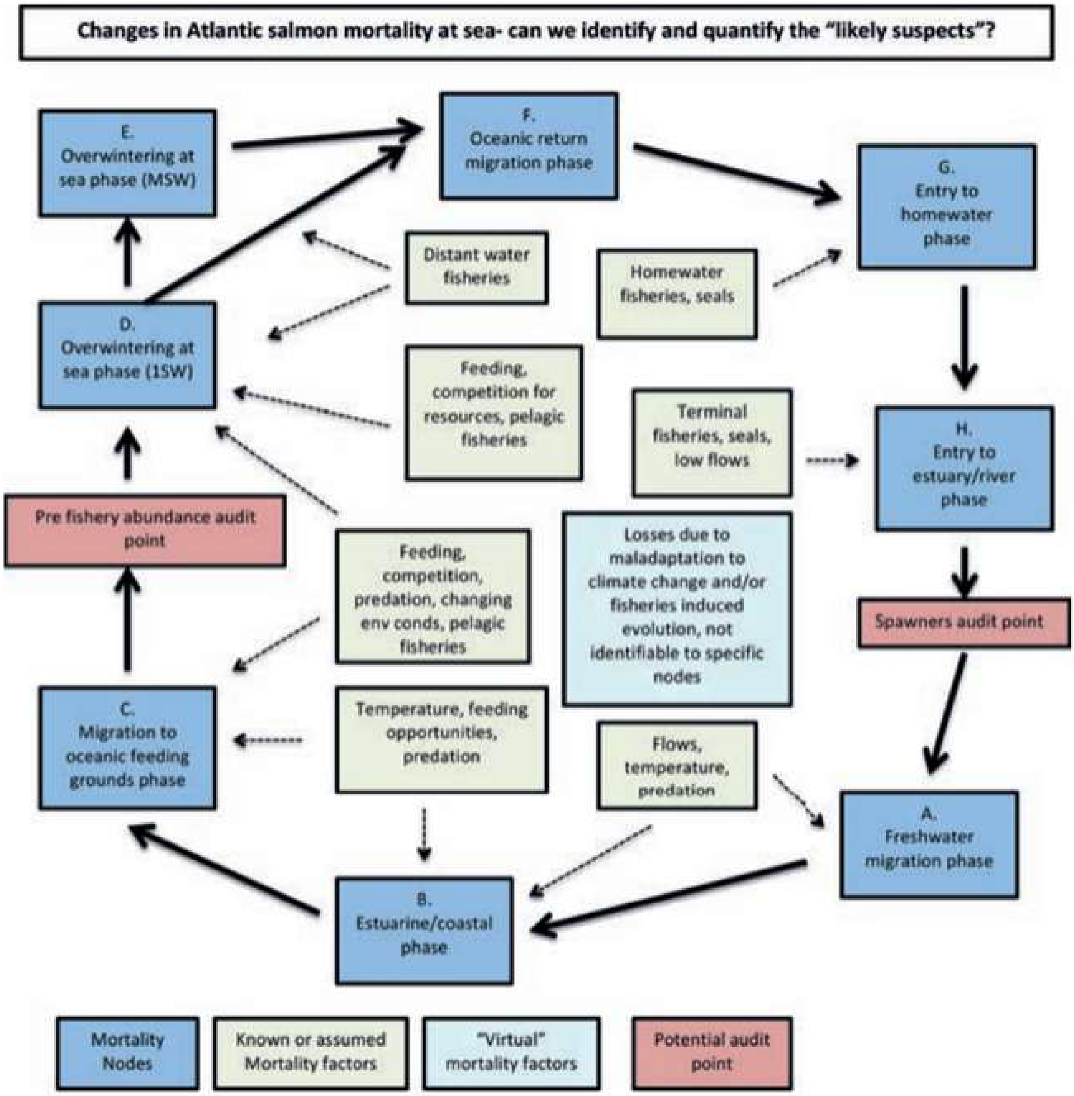

Figure 1: Changes in Atlantic salmon mortality at sea – can we identify and quantify the likely suspects?

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Crozier,W., Whelan,K. et al (2018) Testing Atlantic Salmon Mortality at Sea: Developing an Evidence-based Likely Suspects Framework. Atlantic Salmon Trust, Edinburgh, Scotland. 71 pp.

Current or recent fish tracking projects

Using Telemetry to Map Spatial and Temporal Distribution of Atlantic Salmon in the Ocean

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Atlantic salmon populations have precipitously declined since the 1980s and poor at-sea survival is thought to be the primary driver across its range. There is a need to better understand the distribution of multiple stocks at sea and at various stages during their migration to identify the causes for mortality. The development of marine tracking technologies has aided in determining when and where salmon are disappearing in the marine environment. Researchers have begun to identify key migration routes, behaviour, and mortality zones for Atlantic salmon through freshwater, estuaries and bays, and along the North American coast. Telemetry has emerged as an essential tool to partition and investigate migration timing, behaviour and survival throughout the different phases of the marine migration.

Since 2003 the Atlantic Salmon Federation and their partners have tracked more than 4,000 smolts (acoustic tags) and 580 kelts (acoustic and satellite tags) from several Gulf of St. Lawrence (GoSL) rivers through estuaries, bays, the gulf and into Labrador Sea (see Figure 1). Tagged smolt survival estimates through the freshwater zones have generally been high through the time series (Figure 2). The apparent survival for smolt populations transiting Chaleur Bay has been higher (median range from 67 - 95%) than the smolt populations crossing Miramichi Bay (median range from 8 - 82%; see Figure 2). Survival through the GoSL was variable but without trend among years and rivers, ranging from 96 - 99% per day. The Strait of Belle Isle (SoBI) is a major migration corridor for salmon smolts and kelts exiting the gulf. Although smolts were tagged up to a month apart in different river systems, their movements past the SoBI receiver arrays were synchronized, occurring over the 4-week period from late June to late July. More information on the GoSL smolt and early post smolt migration and survival can be found in Chaput et al (2018).

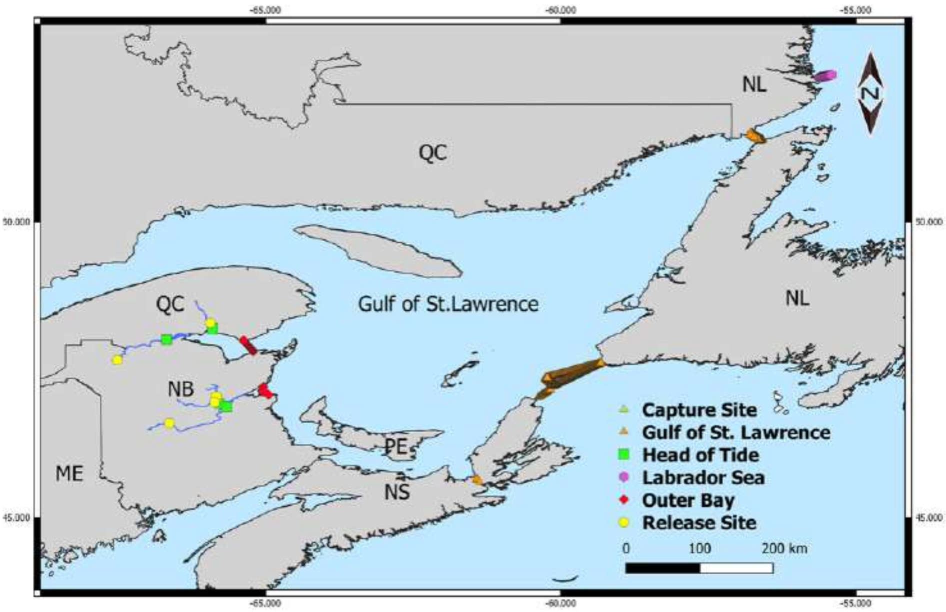

Figure 1: Map showing telemetry study area with release sites and receiver arrays.

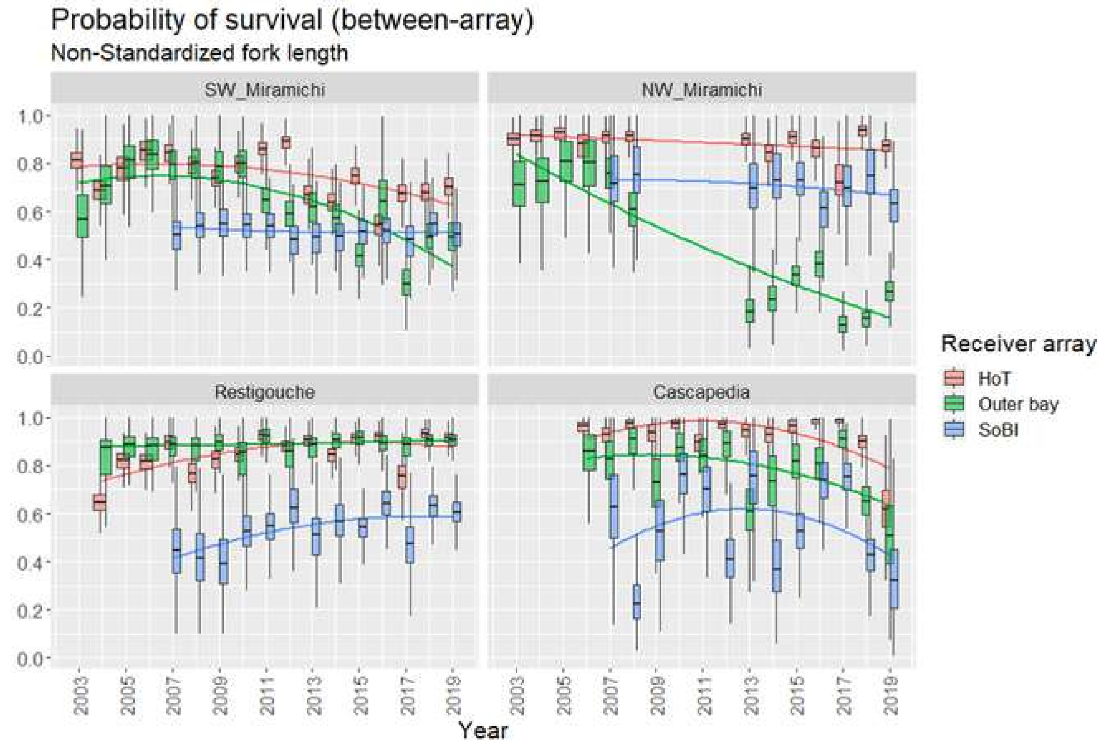

Figure 2: Probability of survival for acoustic tagged smolt between receiver arrays (freshwater river release to head of tide: HoT; Head of tide to outer bay; and from outer bay to Strait of Belle Isle), for four rivers, 2003-2018.

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Acoustic tagged kelt survival exceeds 80% through the estuaries and bays but decreases to about 50% in the GoSL. Kelts spend up to two months feeding in the GoSL. Some subsequently migrate back to spawn in their home rivers as consecutive year spawners. Others will continue their migration into Labrador Sea (via SoBI) with some fish travelling as far as Greenland. The latter fish are termed alternate year spawners and they generally return to spawn after spending one winter reconditioning at sea. When kelts return to the Gulf, their entry point of choice is through the Cabot Strait.

The application of PSAT tags on kelts has allowed us to obtain finer scale location and movement patterns, identify where fish are dying, and determine predation events. Our data has shown that reconditioning kelts generally remain near the surface, in the first 10-30m, during the day. Once these adults move into the Labrador Sea some move along the shelf near the coast of Labrador while others migrate into deeper waters diving to depths of more than 900m. More information on our PSAT research can be found in Strom et al. (2017).

There has been an alarming decline in acoustic tagged smolt survival through the Miramichi estuary and bay in recent years. At the same time the southern GoSL striped bass spawning population has greatly increased. The striped bass population was almost extirpated in the mid-1990s but with the implementation of management changes the population rebounded from fewer than 5,000 spawners to an estimated 1 million fish by 2017. All sexually mature striped bass within the southern GoSL congregate in the Miramichi Bay and estuary in October where they will overwinter. These fish spawn in a small section of the Northwest Miramichi estuary from late May to mid-June. After spawning, the bass disperse to coastal regions throughout the southern gulf. Acoustic tracking of both salmon smolt and striped bass has confirmed a spatial and temporal overlap between the two species during the spring smolt migration. Furthermore, models were developed to differentiate movement patterns between striped bass and smolt. These models were used to estimate the proportion of tagged smolt being eaten by striped bass. Annual consumption estimates have varied, ranging from 2-35% (2013 - 2019; see Figure 3). More details on this research can be found in Daniels et al (2018). Recent management measures have opened a commercial harvest for Aboriginal fishers along with loosening restrictions on the recreational sport fishery. Both smolt survival through Miramichi Bay and striped bass population levels will be closely monitored to assess the efficacy of these new management changes.

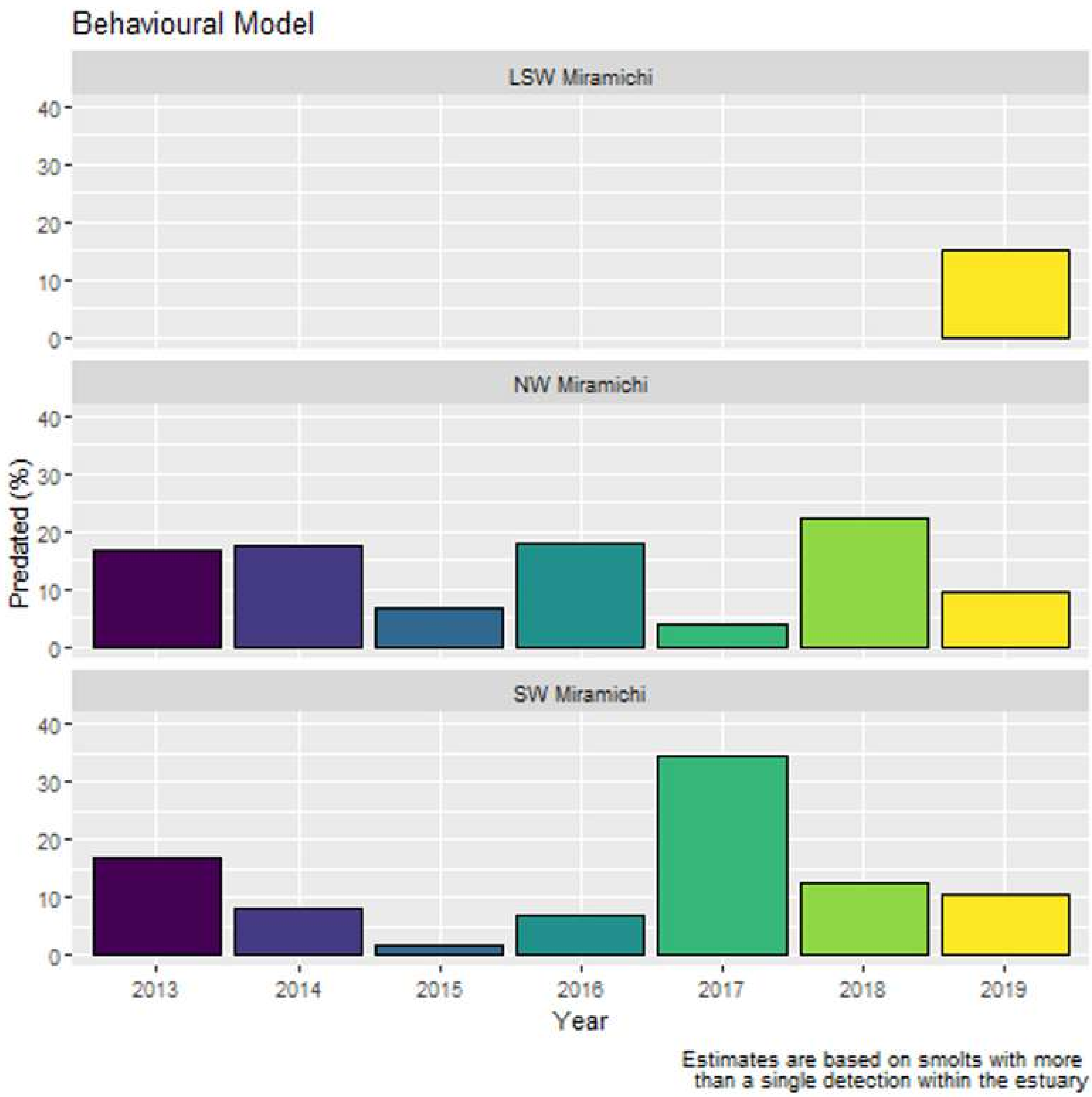

Figure 3: Annual estimated number of salmon smolts consumed by striped bass in various tributaries of the Miramichi River from 2013 to 2019. Models were developed to differentiate between movement patterns of smolts and striped bass.

We now have a better understanding of the migration routes and survival of smolts and post-smolts from freshwater to the exit of the GoSL, and on the behaviour of reconditioning kelts at sea. The next phase of tracking salmon will be focussed in the Labrador Sea where receiver infrastructure will be built. In 2017, a receiver array was started along the Labrador coast near Port Hope Simpson (about 130 km north of SoBI), extending about 32 km out from the coast. From 2017-2019 this line has detected 42 post-smolts and 31 reconditioning kelts from 13 different rivers, ranging from Maine to Labrador. This is the first time multiple acoustic tagged stocks from a wide geographic range has been detected crossing the same location over a relatively narrow time frame (5-13 days for post-smolt in late July/early August; 8-10 days for kelt in early to late July; see Figure 4). Many of these salmon had previously been detected at the SoBI. The plan is to continue to expand receiver infrastructure in the Labrador Sea.

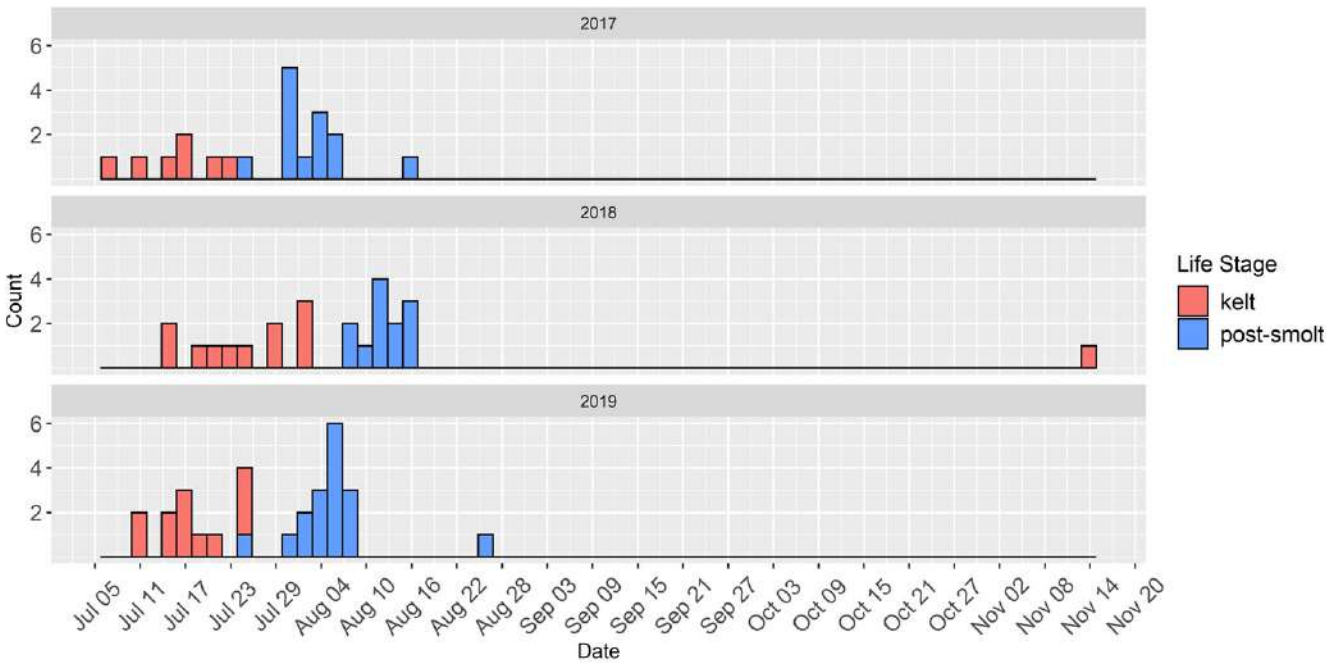

Figure 4: Detections and timing of individual acoustic tagged Atlantic salmon post-smolts and reconditioned kelts from multiple stocks originating from rivers in Maine to Labrador crossing the Port Hope Simpson receiver array, Labrador in 2017, 2018, and 2019.

While we strive to advance our understanding of mortality, dynamics, and ecology of Atlantic salmon during their first few months at sea, very little is known about salmon during the second year at sea. In the summer and early fall, fish are in close proximity to the West Greenlandic coast. The waters off the coast of west Greenland serve as an important summer feeding area for future maiden two sea-winter Atlantic salmon spawners (and post spawned adults) originating both from Southern Europe and North America. These two-sea winter maiden-spawners are a critical component of the spawning stock for many salmon populations across the broad range as they contribute a significant number of eggs given their larger size.

Pop-off Satellite Archival Tags (PSAT), in combination with genetic assignment methods, offer the ability to provide information on stock-specific migration routes, behaviour and mortality during the second year at sea. These studies can provide valuable information on mortality of adult salmon to inform the International Council for the Exploration of the Sea (ICES) assessment models (e.g. to improve confidence in the natural mortality values for adult salmon in the sea) and on migration dynamics which can be informative of larger ecological based questions and investigations. In 2018, a five-year tracking program was initiated in west Greenland. During the first two years of the program researchers captured and PSAT tagged 32 wild salmon (12 in 2018 and 20 in 2019) using trolling gear. At the time of this report genetic assignments were available from 2018 which determined that 50% of the salmon originated from Europe (UK and Scotland), and 50% from North America (Ungave Bay, Labrador, Gaspe, Maine). The objective is to PSAT tag as many salmon as possible over 5 years in coastal waters off west Greenland and map their marine distribution and migration patterns. The telemetry data will be compared with oceanographic (physical and biological) datasets to look for patterns between oceanographic features and marine distribution. It is important to run this project over multiple years to understand whether migration patterns vary among years and assess how inter-annual oceanographic variables (i.e. sea-surface temperatures, prey distribution and productivity, etc.) might be influencing the ocean distribution of Atlantic salmon.

There is no silver bullet when it comes to identifying a single tool that grants us a complete understanding of salmon mortality at sea, however progress continues to be made through technological innovation and diversification of telemetry programs. As partnerships grow and research and development tools advance, more information will come to the forefront as researchers strive to solve the mystery of salmon lost at sea.

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Acoustic Monitoring of Juvenile Salmonids in Transitional and Coastal Waters of the English Channel

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Introduction

For a long time, the only way to survey migratory salmonid populations was to count them on their way to and back from sea, in the river. In the late 80's and early 90's counter data from several rivers highlighted a decline in returning fish, emphasizing an increase in the "marine mortality". Some salmonid populations have been surveyed for decades and scientists point at a constant decline of most of the populations in Northern Europe (ICES 2019). In order to dig a little further, the EU part funded Interreg Channel VA SAlmonids MAnagement Round the CHannel (SAMARCH) project, is focusing on the transitioning of salmonids from freshwater through estuarine, coastal and marine environments. The objective of the SAMARCH project is to provide new information on the migration behaviour, survival and growth of salmonids to further improve the models assessing salmonid stocks but also to develop new policies for better management of sea trout and Atlantic salmon in the transitional and coastal waters of the English Channel.

With developments in acoustic telemetry technologies, it is possible not only to count individuals but also to track them during their migration. However, the weight and size of the tags has previously limited the length of fish which can be successfully tagged, as large, heavy tags have a potential impact on the swimming capacity of both sub-adult and adult salmonids (Richard et al. 1967, Lacroix et al. 2004, Collins et al. 2013). With the miniaturisation of batteries and tags, it is now possible to track small fish such as smolts, young salmonids ready to initiate their first migration to the sea, with limited if any impacts on their swimming behaviour and survival.

The SAMARCH smolt tracking project focused on the first downstream migration of sea trout and Atlantic salmon toward the sea. Smolts of both species were tracked in four estuaries flowing through into the English Channel in order. The project is designed to assess their use of estuarine and coastal waters, their migrating behaviour and mortality rates during their downstream migration. As the project is ongoing, this paper only presents descriptive observations on smolt downstream migration. Further more quantitative results will be published at the end of the project.

Material & Methods

Sea trout and Atlantic salmon smolts were tracked in four estuaries of the English Channel area, two in England (rivers Frome and Tamar) and two in France (rivers Bresle and Scorff, Figure 1).

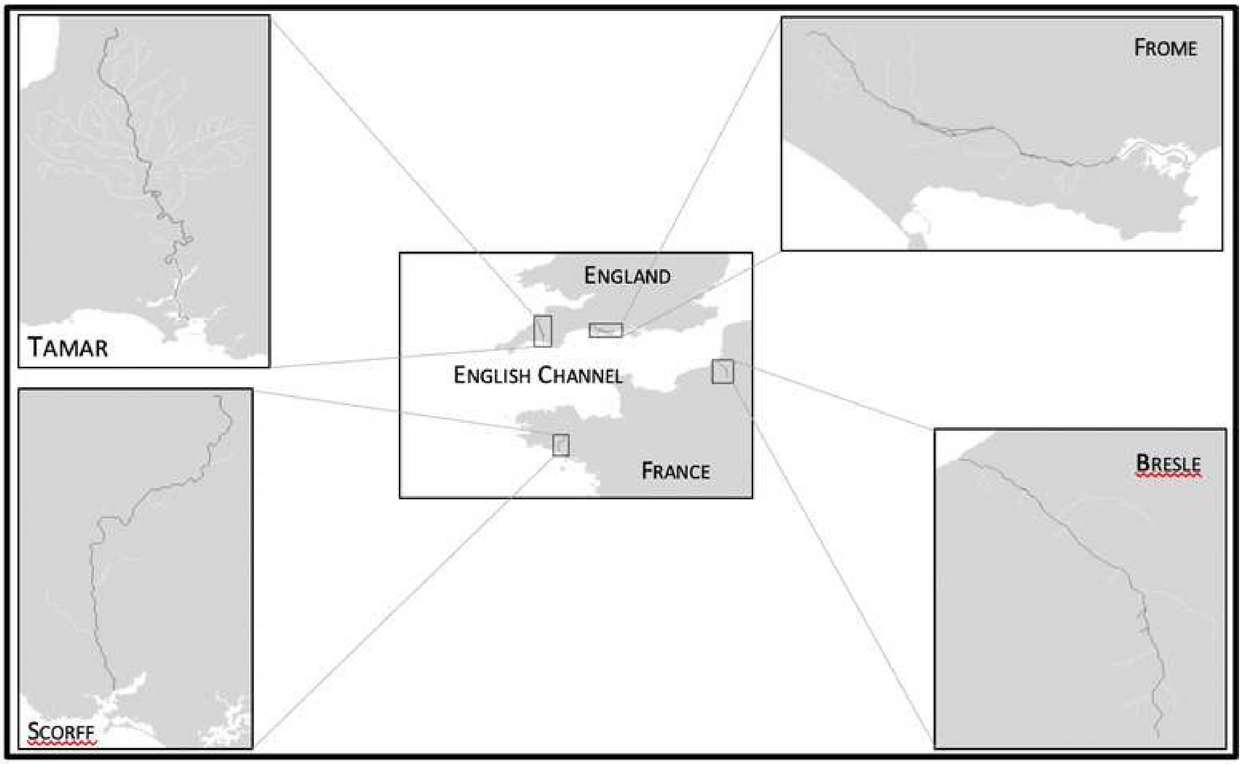

Figure 1: Location of the SAMARCH tracking project estuaries: rivers Tamar, Frome, Bresle & Scorff.

Between 10 and 15 VR2W 180 kHz (Vemco) acoustic receivers were deployed in each estuary from the salinity limit to the marine environment. These receivers have the capacity to detect the presence of a tagged fish in a 200m radius.

Tagging occurred 2 to 22 km upstream of the saline limit. In each river a V5 Vemco tag was surgically inserted into 60 sea trout and 60 Atlantic salmon smolts in 2018 and again in 2019. Only individuals larger than 13cm were tagged to keep the tag burden below 2% of the total fish mass.

A tagging experiment was undertaken prior to the sampling in order to study the impact of the tagging procedure on smolts survival. Thirty individuals were tagged following the above methodology and released in a 200 L tank along with 10 control individuals that were not tagged. All 40 individuals were in good condition after 10 days of observation and were released alive, highlighting that the tagging procedure did not impacted the survival of smolts.

Migration duration

Some smolts remained within the receiver network for up to 20 days but the estuarine migration lasted for 2 to 6 days and 1 to 3 days respectively for sea trout and Atlantic salmon smolts. The sea trout smolts remained within the immediate coastal areas after leaving the estuary and were detected in this area for an average of 3 to 10 days depending on the estuary and year whereas the Atlantic salmon migrated through this environment very quickly (0.1 to 0.2 day).

Migration speed

The overall migration speed of sea trout and Atlantic salmon during their downstream migration was about 1.2 km h^{-1}. However, this speed was not constant as the duration of detection around each receiver varied. Both species spent more time around receivers located at the salinity limit and before junctions and barriers. None of the biotic parameters explored (sex, age, length) appeared to influence the swimming speed of fish. A full investigation will be necessary to clearly state on the biotic or abiotic parameters influencing the migration speed of smolts.

Migration success

Individuals detected at the exit of the estuary were classified as “successful”. A higher migration success rate was observed for sea trout smolts than Atlantic salmon smolts with success rates of 59 to 97% and 47 to 87% respectively. The highest rate of migration success was recorded for smolts tracked on the Tamar (87 to 97%) and the lowest rate of migration success was recorded on the Frome (47 to 81%).

No influence of sex, age and length of the fish on the migration success rate was detected, but more analysis needs to be performed. In the same way, no areas with a higher detection loss were located, the loss of individuals appears to happen regularly throughout the estuaries. On average, the detection rate dropped by 1.6% for every kilometre travelled during the downstream migration of smolts.

Conclusion

The SAMARCH smolt tracking project started in 2017 and fieldwork finished in July 2019, after that batteries in the tags expired.

The results presented here represent a preliminary set of results, but a more comprehensive picture of smolts migration will be available after a full interrogation of the data has been completed.

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Sea trout in Norway and the Kerguelen Islands

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Conflicts between nature conservation and anthropogenic interactions such as urbanization, aquaculture, fisheries and recreation in coastal marine ecosystems are common and divisive for communities. In Europe, the increasing use of near-coastal areas for sea cage aquaculture may negatively influence anadromous brown trout (*Salmo trutta*; a.k.a. sea trout). Sea trout provide important social and ecosystem services in many countries, including Norway. However, during the last 10-20 years, the abundance of sea trout has declined markedly in many regions. For example, catches in Norwegian rivers have declined by 23%–70% during the last two decades, excluding the southern- and northernmost areas.

Knowledge about the biology, ecology and habitat use of sea trout is limited and insufficient for successfully planning sustainable coastal developments. "The secret life of sea trout" research program is using acoustic telemetry linked with physiology, stable isotopes and genomics to document marine migrations and habitat use of anadromous brown trout from several Norwegian fjords. The findings show that sea trout exhibits diverse marine behaviour in time and space depending on nutritional state, sex and morphology of the home watercourse. Thus, potential negative impacts from coastal developments may vary among individuals and watercourses.

Acoustic telemetry has been used in several estuaries and fjord systems in Norway to document potential conflicts with human influences such as different infrastructure and fish farming. At the same time, habitat use of sea trout has been studied in undisturbed and pristine estuaries at Kerguelen Island to serve as a reference point. Results show that estuaries are important transitional zones, especially for younger individuals, between the nursery areas in freshwater and feeding grounds at sea. Additionally, during certain times of the year, estuaries may act as an important longer-term habitat, with fish residing there for weeks to months, and sometimes for the whole duration of the summer feeding migration. A consequence of longer-term residency in estuaries is an increased risk of disturbance from boat traffic, industrial development, harbours, local pollution, gravel extraction, and other physical developments that are often located in estuaries.

As a part of our project, we are mapping physiologically differences between juvenile trout that become residents or migrate to sea and between short and long distance migratory sea trout. Seaward migration is a behaviour that can be expected when the gain for the individual fish is higher than the cost. Consequently, one can expect that this behaviour will be changed or disappear if sea conditions are so negative for sea trout that it loses reproductive potential by migrating to sea. Our findings so far suggest that morphology of the watercourse, condition before the seaward migration and sex influence the marine migratory behaviour. So far, we see that (i) body condition factor differs among fish adopting different migratory tactics, with outer fjord migrant being in poorer condition; and (ii) within migratory groups, plasma triglyceride concentration is negatively correlated with the duration of marine residency. The results support the idea of condition-dependent migration in veteran migrants, with individual variation in nutritional state influencing the spatiotemporal aspects of marine habitat use. Further, our data suggest that sea trout from watercourses with good conditions for over-wintering, such as lakes, stay shorter at sea than individuals from smaller rivers and streams.

The findings are used by stakeholders when decisions are made regarding locations of new fish farms and the development of new infrastructure in coastal areas. The participation of the public in the research project through community consultations has provided educational opportunities for the local communities, especially their youth, and has allowed for exchange of local and scientific knowledge, enriching both communities.

The Moray Firth Tracking Project – Marine Migrations of Atlantic Salmon (*Salmo Salar*) Smolts

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Juvenile Atlantic salmon (*Salmo salar*) migrating from nursery grounds in freshwater rivers to feeding areas at sea face a broad range of challenges. If they are to be successful, they need to adapt to: previously unknown habitats, very different ionic and osmotic conditions, unknown prey, novel predators and they need to do this whilst navigating through a set of unfamiliar environments to marine feeding sites that they have never visited before. There are thus good grounds for assuming that the earliest stages of seaward migration are likely to be a critical period in the life cycle of Atlantic salmon. Although migration during the riverine phase of seaward migration is relatively better studied, primarily as a result from the practical difficulties of studying salmon during transit from riverine to marine habitats, there is relatively little accumulated empirical knowledge on this stage of the life cycle of salmon. What evidence does exist, indicates that mortality in the early marine stages of migration can be high (Thorstad et al, 2012). A further component of the seaward migration of Atlantic salmon which is poorly understood is the coastal migration pathways used by smolts. Marine migration of smolts is effectively unconstrained with the ambiguity of potentially available navigational cues (e.g. current, temperature, salinity) increasing substantially on entering the coastal zone.

The use of electronic acoustic transmitters has enabled significant steps to be taken that begin to unravel the mysteries of juvenile salmon in the coastal zone. Acoustic telemetry composes a transmitter, attached to an individual animal, which transmits a coded sonic signal to a receiver comprising a hydrophone and a data logger. Acoustic transmitters are uniquely coded and are also able to determine and send information to the receiver on the environmental parameters (e.g. depth and temperature). Thus, by deploying receivers at various positions in the study system, it is possible to monitor the behaviour and survival of migrating tagged fish.

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 AST, comprises Glasgow University, the six District Salmon Fishery Boards / Fishery Trusts in the Moray Firth and Marine Scotland. The Moray Firth is a large expanse of water in the North East of Scotland, into which drain multiple river systems, many of which are home to significant salmon stocks. Over 340 acoustic receivers were deployed from the headwaters of the rivers out into the open sea within the Moray Firth (Figure 1). Fish were captured in seven river systems (Deveron, Spey, Findhorn, Ness, Conon, Oykel, Shin) which all flow into the Moray Firth. 800 salmon smolts and 50 sea trout smolts were tagged with acoustic transmitters. The core aim of the project was to 1) Identify how successfully smolts move down the main stem and into marine environments and 2) Identify the marine migration routes. The analysis for this work is currently being conducted (Early 2020) and thus outlined below are some early initial observations without any specific analysis.

Confirmed survival in freshwater (fish detected on receivers leaving freshwater) was approximately 50% across all river systems (Range: 80% – 10%) (Figure 2). This is somewhat surprising given the different river lengths tagged fish would have to travel from their release site down to the bottom of the river (Range of river lengths 10-80km). Confirmed survival rates differed significantly between river systems with no immediate obvious trends (statistical analysis yet to be completed) between river types. Following previous tracking data obtained in the River Deveron, losses recorded in 2019 appear to be in line with those recorded in previous years (Lothian et al, 2017).

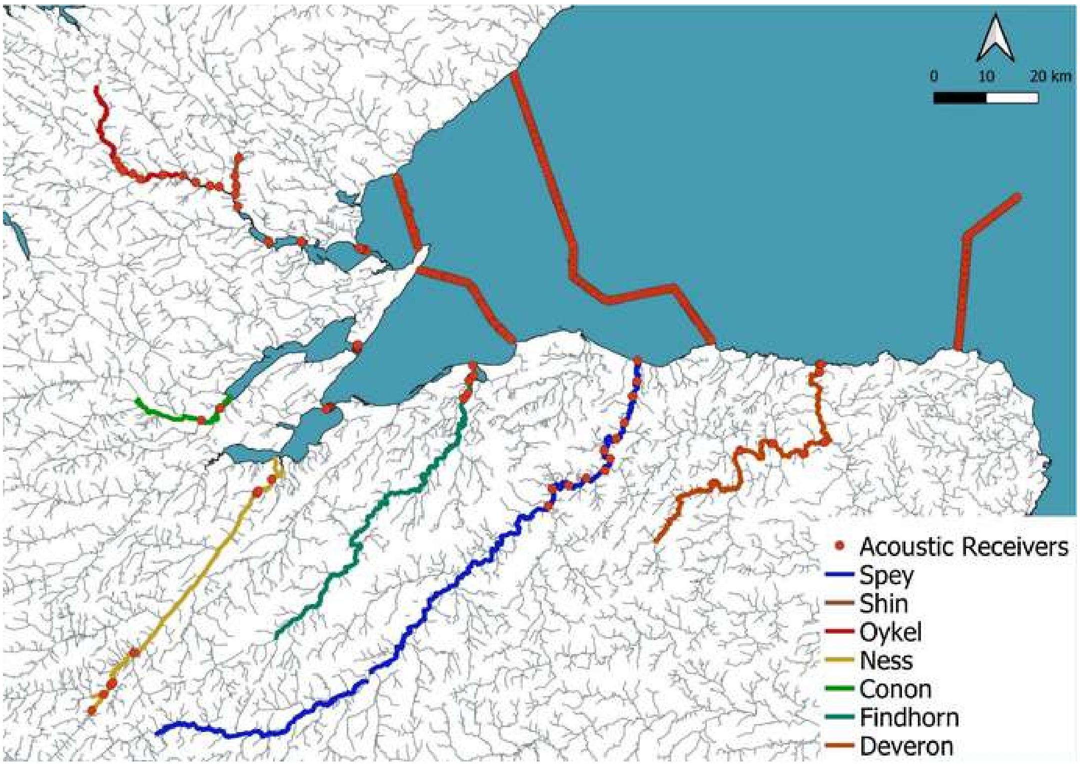

Figure 1: Locations of the acoustic receivers across the Moray firth and freshwater rivers.

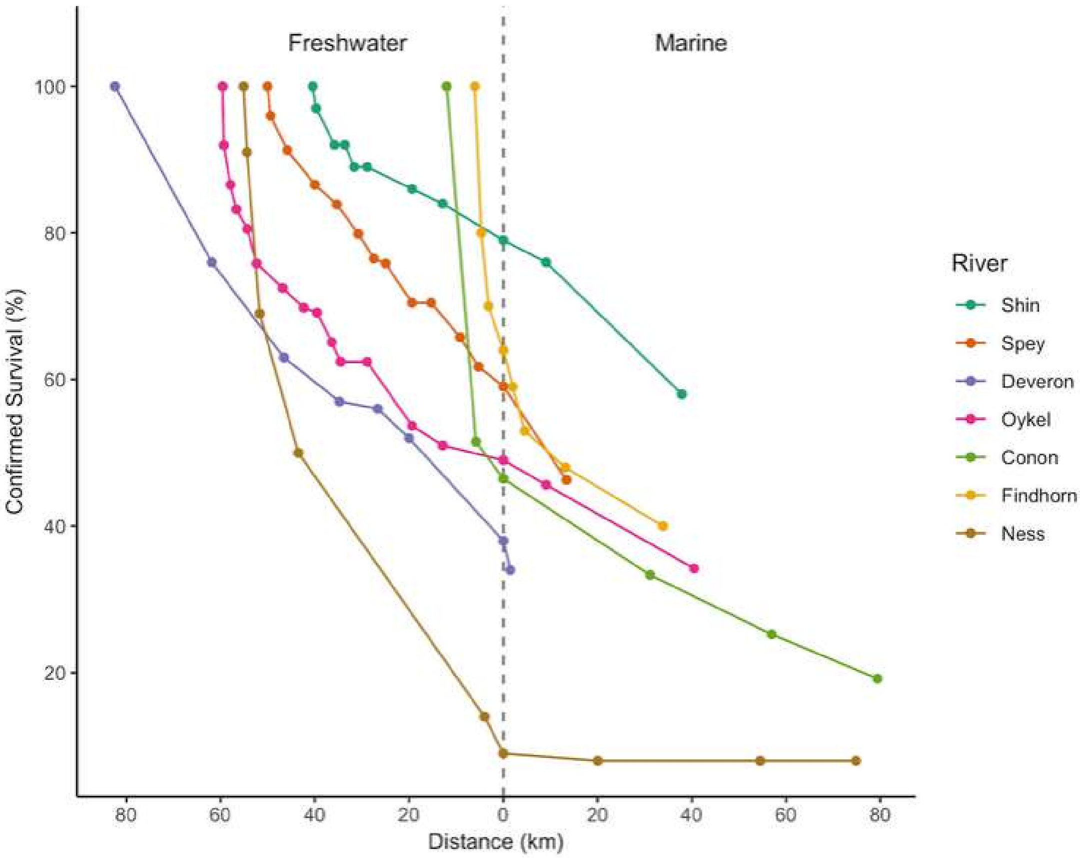

Figure 2: Confirmed survival (%) of salmon smolts for the seven rivers of the Moray Firth, with distance of smolt migration undertaken. Both freshwater and marine environments are included. The migration distance has been standardised so that the dotted line represents entry to marine water on each river system.

Upon entering the marine environment, migration was rapid with fish passing the most eastward curtain of receivers (Figure 1) within a few days of entering the marine environment. Fish were generally heading in an easterly/ north easterly heading but were well dispersed across the majority of the Moray Firth (Figure 3). Fish do not appear to be concentrated within narrow corridors, indeed fish were detected along the entire length of the most eastward curtain, it is likely fish were also present north of this line where there were no receivers. The eastward movement of fish is somewhat counter intuitive since the known salmon feeding ground (The Norwegian Sea) is directly north. The easterly movement of fish potentially indicates they are utilising the 'Dooly current' which flows from east Scotland to west Norway before heading north.

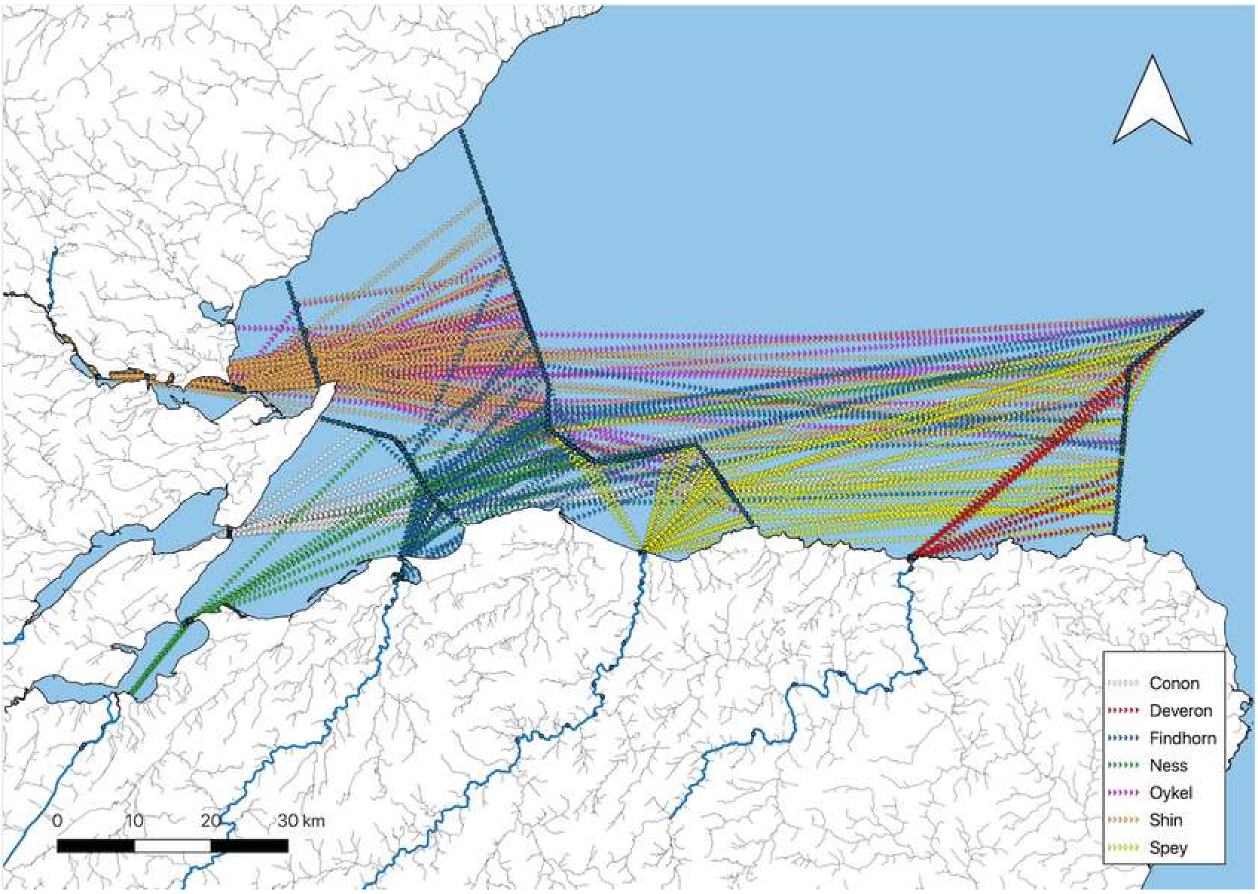

Figure 3: Marine migration direction of salmon smolts for the seven rivers of the Moray Firth, moving towards the east/north east.

There are in excess of 14 million acoustic detections within the data. Such substantial data will take time to digest and appropriately analyse. Outlined below are some questions which we will aim to answer within two key themes:

What is driving migration success:

- We aim to look both at the regional and reach scale at factors which may be driving successful migration in particular sections of a river and across rivers.
- Are river types driving different rates of successful migration?
- In collaboration with Hull University we will investigate if there is a genetic or morphometric element to migration success.

What is driving the migration routes:

- We aim to utilise particle tracking modelling to determine factors which may be influencing the routes taken by migrating fish (e.g. wind/currents).
- Determine the spatial distribution in migration paths, are all fish from the same river system utilising the same/similar pathways.
- Are there temporal aspects to the migration routes taken?

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The use of estuaries and marine migration of sea trout in the English Channel inferred from acoustic and data storage tags

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Introduction

Sea trout is the anadromous form of the brown trout (*Salmo trutta*), spending parts of its life in freshwater and parts in the marine environment. Its life starts in freshwater where spawning occurs during autumn and winter, the eggs hatch in spring and the juvenile trout will stay in freshwater for one to four years. Some individuals will initiate a physiological adaptation to saltwater called smoltification and will become anadromous individuals (sea trout), others will stay in freshwater all their life (brown trout) (Jonsson & Jonsson, 2011). When ready, in spring, smolts initiate the migration toward the sea where they have better access to food resulting in faster growth. The duration of their first marine phase varies from a few months to several years after which they return as adults to their natal river, to reproduce (Thorstad et al. 2016). Once sea trout have completed their first spawning migration, they will annually migrate between their marine feeding grounds and their freshwater spawning grounds for the remainder of their life.

In the past, researchers studying salmonids have mainly focused on salmon and less on trout hence the ecology of trout is not as well resolved as that of salmon. The sea trout's pattern of migration while at sea is still a mystery, but the few published studies available suggest that sea trout use coastal areas (Thorstad et al. 2016, Kristensen et al. 2019). When migrating between the river and coastal waters, sea trout encounter urbanised and industrialised areas. The fish may therefore be subject to significant human impacts in these transitional waters.

A tracking study aiming to map salmonid migration in transitional and coastal waters commences in October 2017 as part of the Salmonids Management Round English Channel (SAMARCH) project. One of the aims of the tracking study was to increase our knowledge of sea trout marine behaviour and migration patterns in the English Channel, to enable improved knowledge-based management of sea trout in this region.

This summary paper describes the preliminary findings of the ongoing SAMARCH tracking study of adult sea trout.

Material & methods

Adult sea trout were tracked in three estuaries in the English Channel area, rivers Frome and Tamar in England and River Bresle in France (Figure 1).

Between 10 and 15 Vemco VR2W 180 kHz acoustic receivers and one temperature logger were deployed in each estuary from the salinity limit to the marine environment. These acoustic receivers have the capacity to detect the presence of a tagged fish in a 200m radius.

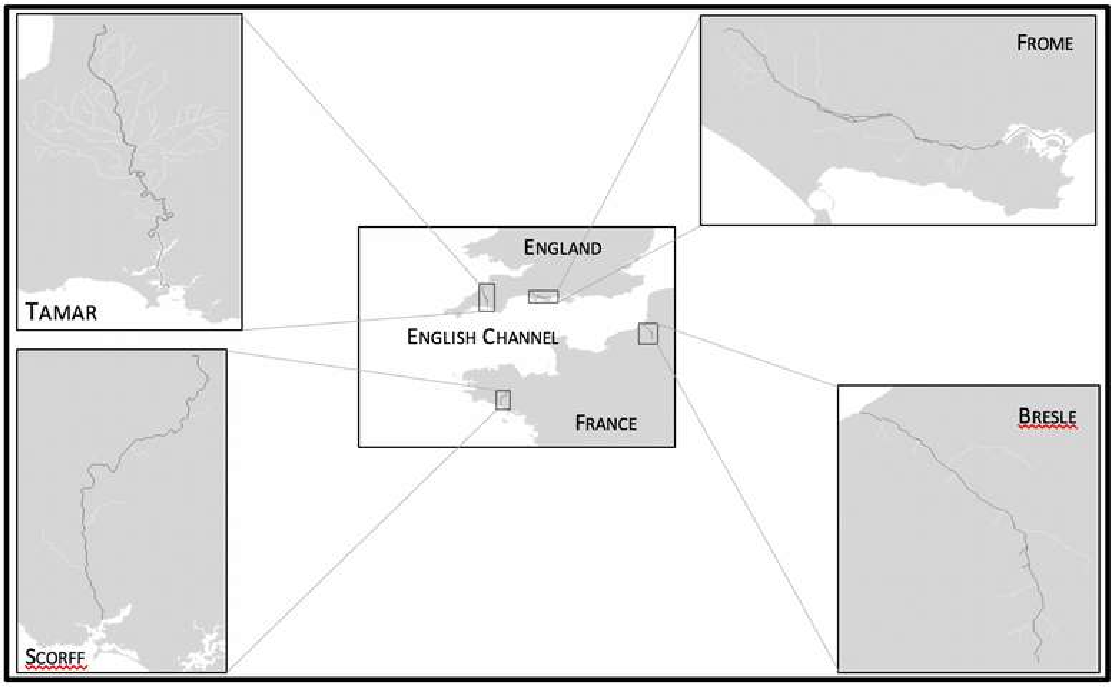

Figure 1: Location of the SAMARCH tracking study estuaries: rivers Tamar, Frome, Bresle & Scorff.

Post spawning individuals were captured by electrofishing in England and by trapping in France, 1 to 30 km upstream of the saline limit. Once captured, a Vemco V9 acoustic tag and a Cefas Technology G5 data storage tag (DST) were surgically inserted in the sea trout. Only individuals larger than 33 cm were tagged to keep the tag burden below 2% of the total fish mass. A total of 99 sea trout were tagged across the three rivers during the winter 2018/2019.

Data downloaded from the acoustic receivers provided information on the use of the estuarine environment and identified the time when the fish entered the English Channel and when they returned for repeat spawning. Temperature and depth recordings from the DSTs enabled reconstruction of individual migration routes while at sea, using a hidden Markov model (HMM). However, to recover the data from the DSTs the tagged individuals had to be recaptured. Recovery of returning fish was primarily achieved by in-river up-stream traps and electrofishing. However, to increase the chance of recovery, the tagged fish were fitted with two external marks: 1) a tattoo consisting of three blue dots on the belly; 2) a floy tag attached to the dorsal region. These external marks made the fish recognisable by anglers and commercial fishermen. To further increase the probability of recovering the data storage tags they were equipped with a bright orange floatation collar making them buoyant. Hence, mortalities at sea would result in the tag eventually floating to the surface and potentially being picked up on a beach. A reward offered of £50 for returned fish and/or tags was printed on the floy tags and the collar of the DSTs.

Live HR2 Vemco receivers, sending live detection information by satellite, were deployed at the saline limit of rivers Tamar and Frome to provide information of returning tagged fish enabling focussed trapping/electrofishing efforts.

Results

Of the 99 sea trout that were tagged in the winter 2018/2019, 68 were detected exiting the estuary. A total of 17 sea trout (25%) were detected returning to their natal rivers for repeat spawning and eight of these were recaptured. Furthermore, 16 DSTs from fish that died at sea were found on beaches increasing the number of recovered tags to 24 and counting.

Reason of marine mortality

Five individuals died in the river without reaching the sea but data from eleven of the DSTs recovered from beaches showed a mortality event happening at sea. The reason why 54% of the sample died is to date unexplained, 28% of fish were predated on by birds, 9% predated by unidentified marine animals and 9% of fish were caught in nets (information provided by the fisherman).

Marine swimming behaviour

The depth profile recorded by the DSTs indicated active vertical swimming behaviour with dives as soon as they exited the estuary up to 50 m.

Preliminary analysis was undertaken on data from four DSTs recovered from fish successfully returning for repeat spawning, one from River Tamar and three from River Bresle. The depth profile of these four fish differed between the two rivers. The Tamar sea trout was actively diving during the day and stayed close to the surface at night whereas all three individuals from River Bresle displayed vertical movement both during the day and at night. While at sea, all fish spent 60% of their time at a depth of 20m or deeper.

Marine migration route

The temperature profiles recorded, while at sea, indicated population differences, implying that the fish were not in the same area (Figure 2).

Preliminary results from the Hidden Markov Model indicate that two of the Bresle fish went into the North Sea, 250 km away from the mouth of the River Bresle, whereas the third sea trout from the River Bresle stayed in the English Channel. Data from the sea trout from the River Tamar indicated a more coastal migration route close to the Tamar estuary.

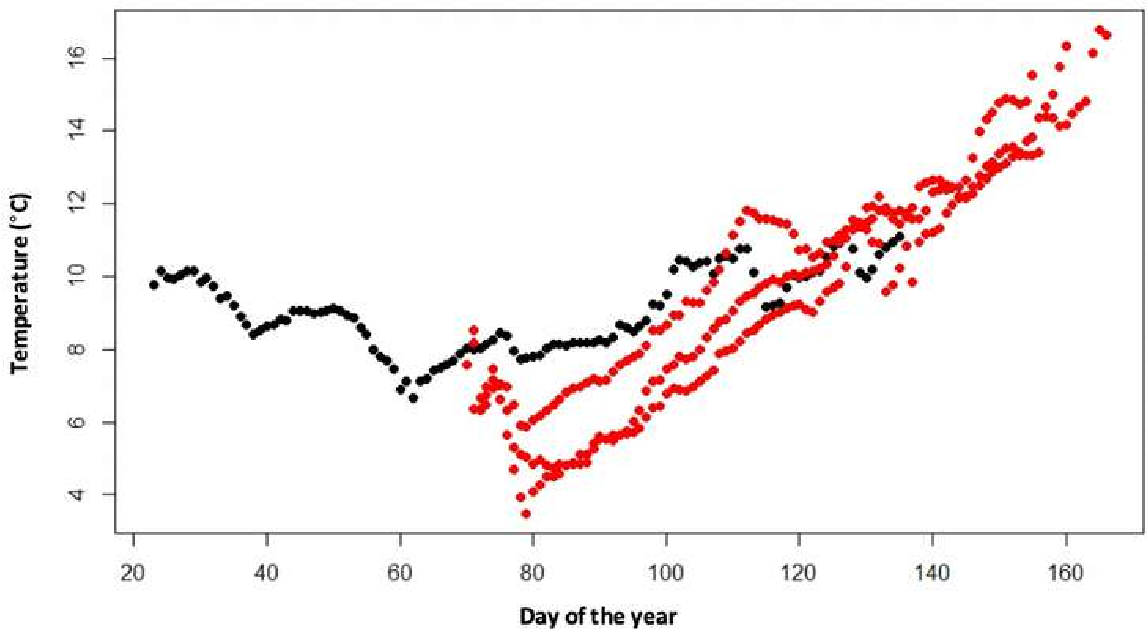

Figure 2: Temperature profiles of the four returning sea trout from rivers Bresle (red) and Tamar (black) during their marine migration.

Conclusion

These preliminary results highlighted a very active vertical swimming behaviour of adult sea trout while at sea reaching depths up to 50m. Variations in the recorded temperature profiles indicated between-population differences in migration routes for the Rivers Tamar and Bresle. The Hidden Markov Model is currently at an early stage of development and will need further refinement to confirm these preliminary results and to enable in-depth analysis of data from the growing number of DST tags recovered.

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Spatial and temporal patterns in the cost of migration and the evolutionary consequences of their long term change for Atlantic salmon

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Long distance migration is common amongst animal species (Baker, 1978). Billions of individuals, from thousands of species, from across the spectrum of animal phyla, migrate over significant distances each year (Bowlin et al., 2010). Migration behaviour has evolved repeatedly and in multiple discrete lineages (Cresswell, Satterthwaite, & Sword, 2011) and although the topic has fascinated for centuries (Linnaeus, 1757), the specifics of why this behaviour emerges and how it is maintained in wild populations remains poorly understood.

At the theoretical level, the multiple and convergent expression of long-distance migratory behaviour points towards significant net fitness benefit accruing from adopting a migration into their life cycle for a large number of species. For long distance migration to be expressed, there is thus a general assumption that the fitness benefits must be greater than the fitness costs (Mangel & Satterthwaite, 2008). Where such benefits have been examined in detail, they are mostly thought to include improved access to resources (Dingle & Drake, 2007) or avoidance of predators or parasites (see review in Alerstam, Anders, & Åkesson, 2003).

For the salmonids, migration to sea confers growth benefits that ultimately result in larger body size and consequential effects on reproductive output (Kinnison, Unwin, & Quinn, 2003) and that is also true for the Atlantic salmon *Salmo salar,* (see, for example, Sandlund et al., 2014).

Not surprisingly however, long-distance migrations are costly. There are the energetic costs of locomotion during the migration. Migration is frequently time consuming and thus interferes with other activities such as feeding (Dingle, 1996). There are probabilistic costs, such as the risk of finding suitable habitat and adequate resources at the end of the migration, as well as the risk of exposure to pathogens and predators not encountered previously in the habitats that they leave behind (Rankin & Burchsted, 1992; Cresswell, Satterthwaite, & Sword, 2011).

There is good reason to believe that during seaward migration, the Atlantic salmon in particular, incurs some very considerable costs and that these costs may be changing.

In the weeks prior to migration juvenile Atlantic salmon smolt. This is the complex of processes that prepare fish for entry to hyperosmotic seawater. It includes a number of physiological changes, they change colour, which is presumed to improve camouflage in the marine environment, and they change shape, thought to enhance midwater swimming ability (Hoar, 1988). As sea migration begins, they orientate with the current and actively swim down-stream through lower river reaches, often standing water, estuaries and near-shore coastal zones before entering the open sea. On entering sea water their diet changes; consuming prey items that they have never encountered and certainly not utilised in fresh water (Rikardsen & Dempson, 2011). Over the course of a very few weeks, these fish undergo a series of very rapid and fundamental changes in physiology, growth, diet, behaviour, colouration, body shape, feeding ecology and predation risk and are exposed to multiple habitat shifts from river to estuary to fjord/coastal zone to open ocean.

There is now emerging evidence that these dramatic changes are associated with relatively high mortality. In a meta-analysis of mortality rates of salmon during migration derived from telemetry studies, Thorstad and colleagues (Thorstad et al., 2012) showed migration loss rates to be habitat specific, frequently high but also very variable, during migration in lower river reaches, estuaries and the coastal marine zones.

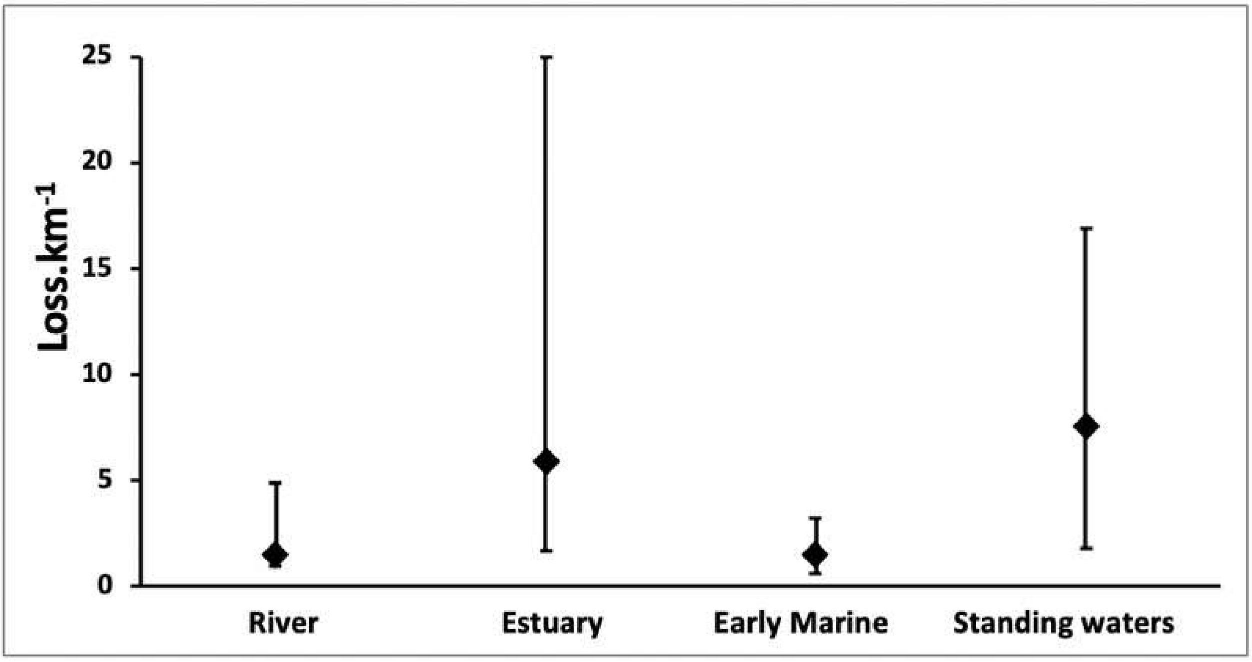

Figure 1: The habitat loss rate of tags in telemetry studies on Atlantic salmon in rivers, estuaries and the early marine environment, derived from a meta-analysis study (Thorstad et al. 2012) and for standing waters (original meta-analysis data, current authors).

A telemetry study of the patterns of migration success in seven adjacent rivers draining into the Moray Firth in north-east Scotland (Newton et al., 2020) (this volume) shows in more detail, the variation in success in the early stages of migration. Different rivers show contrasting patterns of migration success in the lower reaches of rivers, the very early marine and nearshore coastal zones. In addition, even within a single river, migration passage success varies between river reaches (Figure 2, Newton et al. 2020, this volume).

Thus, there is an emerging picture of very significant habitat related spatial variation in migration success in the very early stages of salmon migration to sea. This variation is apparently not consistent among rivers and even within a single habitat type, there is variation in migration success.

This raises a series of important questions around salmon migration success that are ultimately critical to the future management of the species. These are:

- How temporally stable are these migration success patterns?
- Can we predict the forces that are responsible for the spatial and temporal patterns of success?
- Are these forces changing over time?

A general aim of the research programme of the authors of this current piece is to attempt to quantify in more detail the emerging patterns of migration success in Atlantic salmon; to dig beneath these patterns, to find the driving forces influencing migration success or failure and to determine if and how, determinants of migration success are changing over time.

For one habitat type associated with low migration success we now have some partial answers.

Telemetry studies on salmon migrating through standing waters consistently show poor migration success (see e.g. Jepsen et al., 1998; Aarestrup et al., 1999). A meta-analysis of migration success through standing waters derived from published and unpublished studies (unpublished data, the current authors) shows average high loses but with considerable variability between studies and systems (Figure 1). In small scale study (Honkanen et al., 2018) we showed that although smolts were actively swimming during migration through a large lake, Loch Lomond, successful migrants took at least 30 times longer to migrate through standing water than an equivalent distance in the inflowing river. This was in part because smolts were swimming up to 10 times further than the minimum distance from the entry point to exit point in the lake. Further detail showed erratic directional movements frequently in a direction away from the lake outlet (Figure 2). In a second acoustic telemetry study in three lakes in north-west Scotland, two of which were impounded by dams that are passable by salmon (Loch Meig and Loch Achonachie) and one draining naturally (Loch Garve) 49% of all directional movements by salmon smolts were in the opposite direction from the lake outlet. Loss rates of tagged fish in this study was high, ranging from 16 to 53 %.km-1 across lakes and high compared with reported river migration loss rates (see Figure 1). Both impounded lakes (Meig and Achonachie) are lakes formed solely by impoundment, thus the low migration success rates at these sites represent a cost of migration that is relatively new. There was no evidence that loss rates were higher in impounded lakes compared with the naturally draining lake, but the lake transit time was at least 10 times slower for successful fish passing through impounded lakes compared with the natural lake.

A key conclusion from the above, is that the success rate of salmon migrating through standing waters is low and that this is at least in part because the cues that smolts use to navigate in standing waters are limiting direction determination.

Key questions for future research are:

- What are the navigation cues using in standing water? (the presumption is that water currents play a critical role)

- What is the magnitude of the directional cue needed to initiate directional swimming in smolts?

- Can these cues be manipulated to enhance migration success in environments where directional cues may have been lost (for example where impoundments or abstraction may result in cue modification)?

We are currently investigating these questions further.

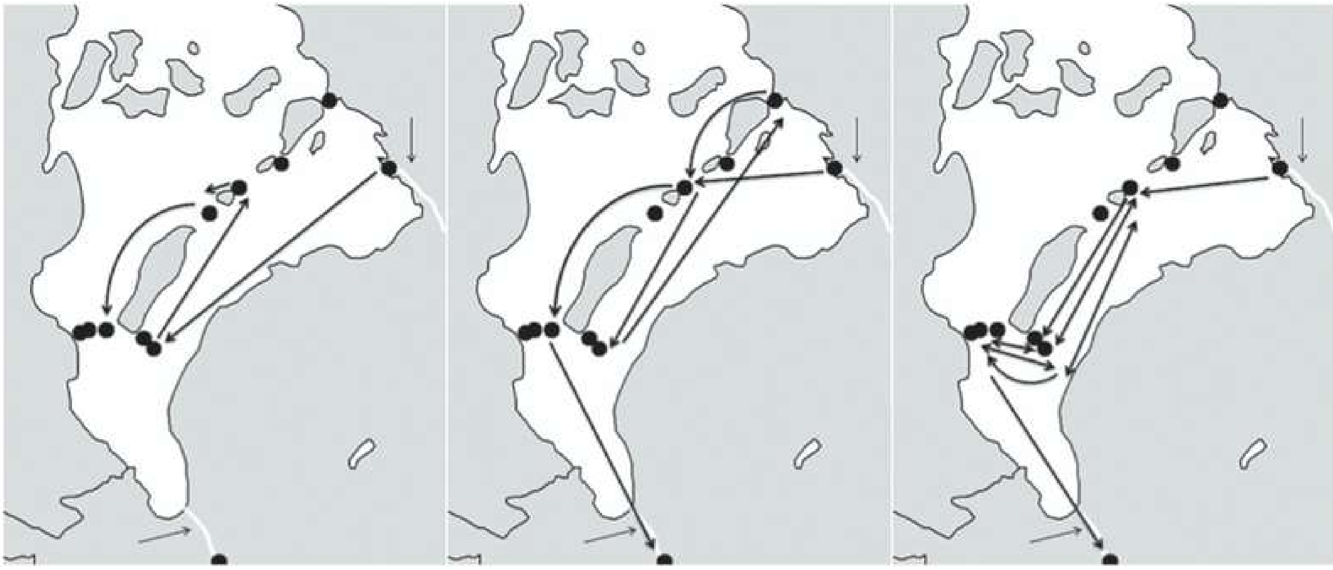

Figure 2: The migration tracks of three salmon migrating through Loch Lomond from the afferent River Endrick (arrow top right of image) to the efferent River Leven (arrow bottom left) derived from Honkanen et al. 2018.

Long-distance migration is an inherently risky strategy for any animal. For any individual undertaking long-distance migration neither the benefits nor the costs can be quantified in advance. At an individual level any net fitness gain resulting from migration is speculative, the biological equivalent of futures trading on a potential future reproductive fitness. The expression of long-distance migration behaviour is thus not driven primarily by the real-time cost-benefit assessment that shapes much other behaviour such as foraging, mate competition or predation avoidance (Abrams, 1993). In contrast, the net fitness gain that accrues to migrating individuals are accrued through the evolutionary processes that shape expressed traits over longer periods of generations.

There is some evidence that the costs associated with long-distance migration of Atlantic salmon has changed over the last few decades. It is clear that salmon populations have declined markedly across their range over the last 3 or 4 decades (depending on where and how it is measured) (Chaput, 2012; ICES, 2017). This change has largely been attributed to declines in marine migration success with a lower proportion of emigrating fish returning to freshwater rivers (Chaput, 2012 and references therein). If the costs of long-distance migration have increased, without an equivalent increase in migration benefits, as is suggested by the patterns of population change, then we might reasonably expect an evolutionary response from populations. Although speculative, a logical evolutionary response by Atlantic salmon to an increase in the costs of long-distance migration would be a shift in the sex ratio of sea migrants. The sex related disparity in the cost:benefit ratio of sea migration in the related brown/sea trout, Salmo trutta, where the reproductive advantage of large body size (and thus migration to high quality feeding areas at sea) is greater for females than for males (Hendry et al., 2004) underlies the female bias sex ratio of anadromous sea trout seen in many catchments (Ferguson et al., 2019). If, as there appears to be now, the costs of sea migration have increased then we might reasonably expect the changing selection pressures acting upon Atlantic salmon to favour a similar sex-based partial migration (Chapman et al., 2011) that is seen in brown/sea trout. Under this evolutionary scenario, the frequency of males becoming sexually mature as parr would increase and the probability of males migrating to sea decrease compared to females.

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Acoustic tracking of sea trout and salmon smolts using a grid arrangement of acoustic receivers in a Scottish sea loch system

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Background

Acoustic tracking studies of salmonid smolt migration in the marine environment have predominately relied on curtains of receivers placed across possible migration routes to identify tagged fish as they pass within range. These curtains are composed of autonomous receivers positioned in one or more lines that stretch between coastlines. The spacing of the receivers is usually close enough to attempt overlapping detection ranges. In practice however, receivers can never be guaranteed to detect a tagged fish as it passes. This restricts inferences that can be made regarding preferred migration routes and survival.

Here we describe the use of a grid arrangement of acoustic receivers to examine marine migrations within a loch system on the West coast of Scotland, UK and briefly discuss the advantages and disadvantages of this type of deployment when compared to curtains of receivers.

Method

For the last 20 years, the River Shieldaig in Wester Ross, Scotland has been used by Marine Scotland Science for the long-term monitoring of sea trout returns. This has been achieved by PIT tagging migrating sea trout captured via a two-way fish trap located 150m from the sea. The tagged fish leave the River Shieldaig to enter Loch Shieldaig, the central basin of a complex sea loch, comprising the additional basins of Outer Loch Torridon to the west and Upper Loch Torridon to the east.

In 2018, a two year tracking study was initiated using 79 acoustic receivers arranged in a regular grid pattern (~800m spacing) that extended across all three lochs (Fig. 1). Moorings were composed of a clump weight and anchor, with a riser and midwater buoy. A Thelma Biotel TBR700 acoustic receiver was cable tied onto the riser 12m below the surface and a line attached to a surface buoy for location. The time-clocks on all receivers were synched before deployment. The moorings were deployed in March prior to the smolt run in April/ May. Local fishermen and other Loch users were consulted and informed about mooring locations and the study prior to deployment.

Sea trout smolts were double-tagged during April-June 2018 with 69kHz acoustic transmitters (ID tags or temperature/ depth data tags, Thelma Biotel) and PIT tags, on the River Shieldaig (n=199). In addition, sea trout smolts were also captured and double-tagged on the rivers Balgy (n=30) and Torridon (n=30) which flow into Upper Loch Torridon. Migrating salmon smolts were also tagged from these two rivers (Balgy (n=30) and Torridon (n=6)).

The receivers were recovered during Autumn 2018 (September/October). Four receivers were lost during deployment and one failed due to water ingress. Data was downloaded, cleaned, and quality-checked prior to analysis. Additional checking for false detections could be achieved by identifying impossible and suspect movement patterns through the array (e.g. near-simultaneous tag detection at two distant receivers).

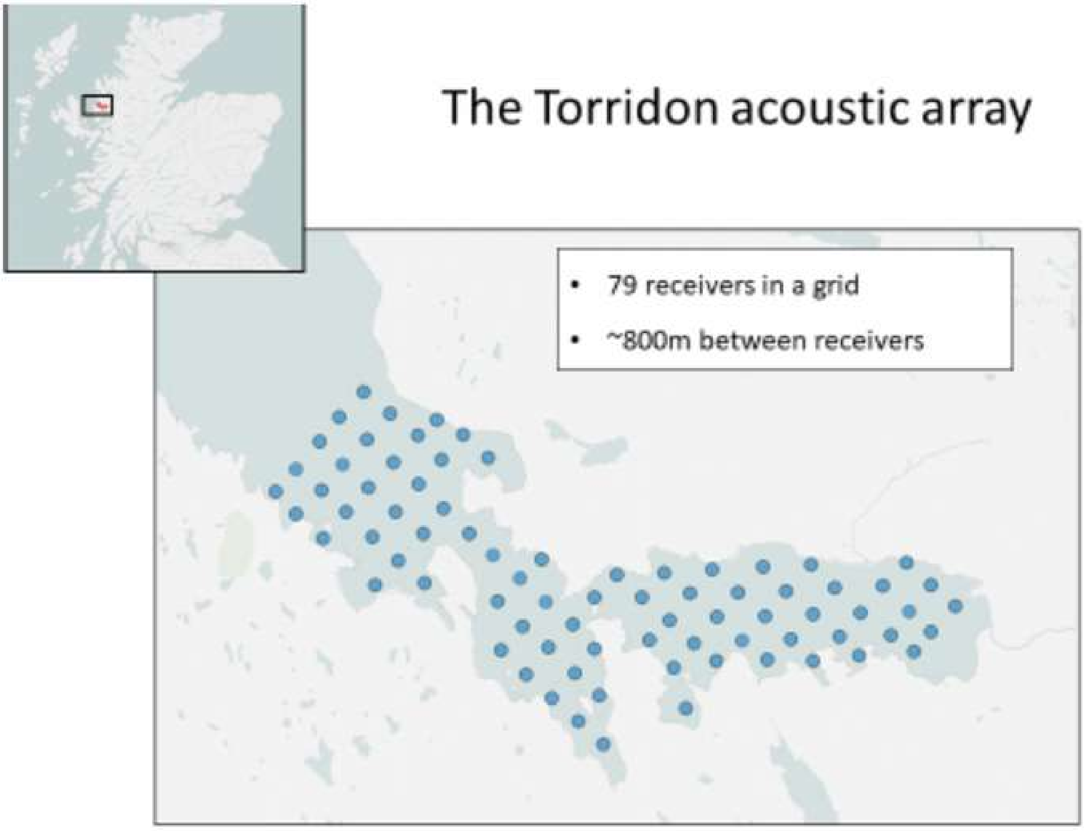

Figure 1: Grid arrangement of acoustic receivers in Loch Torridon, Wester Ross.

Results

The TBR 700 receivers record a measure of background noise during the deployment suggesting that receiver ability to detect a tag transmitter varied both spatially and temporally across the array.

Detections of tags provided evidence of non-lethal tag ejection events occurring during the deployment. This was determined by a tag being recorded as stationary on the sea bed, while the fish it had been inserted into was subsequently recaptured in the Shieldaig fish trap, recognised by its secondary tag. Recaptured fish allowed for visual evaluation of wound healing. It was noted that the return rates to the trap of acoustically tagged fish were comparable to PIT tagged only fish.

The coarse movement patterns of tags through the array could be determined. These demonstrated that there were pronounced differences in patterns between individual salmon and sea trout during their migrations. Predation events could be identified through pronounced changes of tag behaviour in the array, movement speed and for data tags, increases in reported temperature. Additional information regarding predator movements subsequent to eating a tag within the array could be ascertained until the predator left the study area or ejected the tag.

Discussion

When comparing an array based on acoustic receiver curtains and a grid arrangement the main advantage of the curtains is a reduction in expense in boat time and equipment. The dataset supplied by a receiver curtain also means that the analysis is relatively simple. However, curtains are spatially constrained and are often located at geographical pinch points and other areas of convenience rather than following any statistical sampling design. This means that the knowledge regarding migration using curtains is extremely limited other than indicating possible mark recapture end-points (Kraus et al. 2018). Inferences regarding 'survival' cannot easily be made as tags may fail, be ejected during migration, or local/temporal environmental factors prevent adequate decoding of the acoustic signal by receivers. Favoured migratory route choices by curtains are also difficult to ascertain if tag ingestion by a predator cannot be ruled out or a low proportion of tags are detected. In addition, due to the narrow window for detection available when detecting migrating salmon smolts, inferences from curtains are prone to be influenced by false detections. These can be reduced by statistical based filtering techniques, but at the risk of losing genuine detections.

The use of a grid arrangement of receivers makes fewer assumptions than a curtain design regarding smolt migration routes, tag retention and receiver detection efficiency. They are also more resilient to the impacts of receiver loss, low detection range through adverse environmental conditions or post-surgical tag ejection/ failure. While fish can pass through a grid without being detected, this is equally true of a curtain. However, the geographic coverage of a grid allows realistic migratory behaviours to be identified through detection of a fish at multiple points along its migratory path rather than reliance on single points.

The 800m spacing of receivers used in this study was adequate to capture facets of salmonid behaviour and migration. Wider spacing between receivers could be used to increase spatial coverage, while smaller spacing will increase resolution.

Salmonids are under multiple pressures within the marine environment while the use of acoustic tracking to understand their coastal migrations is expensive. Tracking studies should be designed with the aim of obtaining useful, robust data with a clear understanding of the limitations of the technologies. Therefore, when the opportunity for tracking arises, due to their inherent advantages, grid designs should be considered when contemplating receiver arrangements.

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Behaviour and mortality of sea trout at sea investigated with data storage tags

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This paper describes studies of Danish sea trout kelt behaviour using data storage tags. The temperature and depth records from the fish were examined in different ways and were used for geolocation of the fish with a Hidden Markov Model (HMM). The results revealed a characteristic diel behavioural pattern, a behavioural response to water temperatures and an apparent behavioural difference between fish that survived the marine period with fish that died at sea. Reconstructed migration tracks with the HMM suggested the fish had migrated from shallow, stratified and less saline areas that heat up fast during spring and into deeper, more heterogeneous areas, which heat up slower during summer.

The field work was carried out in 2012 - 2015 when a total of 125 kelts (460 – 925 mm) were tagged with positively buoyant DSTs, in seven different rivers. Fifty-three tags (42 %) were recovered by members of the public for a reward of 300 - 400 DKK (34 - £46). Twenty-five of the recovered tags were from fish that had died at sea, eight were from fish that had survived the entire marine period in the ocean and the remaining tags were either corrupted beyond repair or contained data suggesting mortality prior to sea entry. Mean tag-drifting time in the sea from mortality to the time the tags reached the shore was 24 days (range: 1-101 days). Tags were recovered from Danish, Swedish and Norwegian shorelines. One tag was recovered from the island of Dønna in central Norway, 1.300 km from the mouth of the river of origin.

Data suggested the initial three-week period after reaching the sea was dangerous for the kelts, as 19 of 21 natural marine mortalities had occurred within the first three weeks of entering the sea (Kristensen et al. 2019b). Mean survival time at sea was 14.3 days, and the mean survival time from the time of tagging was 40 days. The fish that survived the entire marine period spent a mean of 96.1 days at sea.

The fish initiated a characteristic diel behavioural pattern with repetitive dives down to 88 m during daytime and residency close to the surface at night once they reached the sea. The number of dives per day increased gradually after entering the sea and peaked in late June. All tagged fish had a characteristic diel behavioural pattern with repetitive dives down to 88m during daytime and residency at the surface during night time. The fish that survived the marine period were the most active divers while the fish that got caught by anglers from the coastline (n = 4) were the least active divers. The angler caught fish showed a preference for shallower depths than the other fish up to the point of their capture. Fish surviving the marine period had higher weight/length ratios than fish dying at sea (P = 0.005).

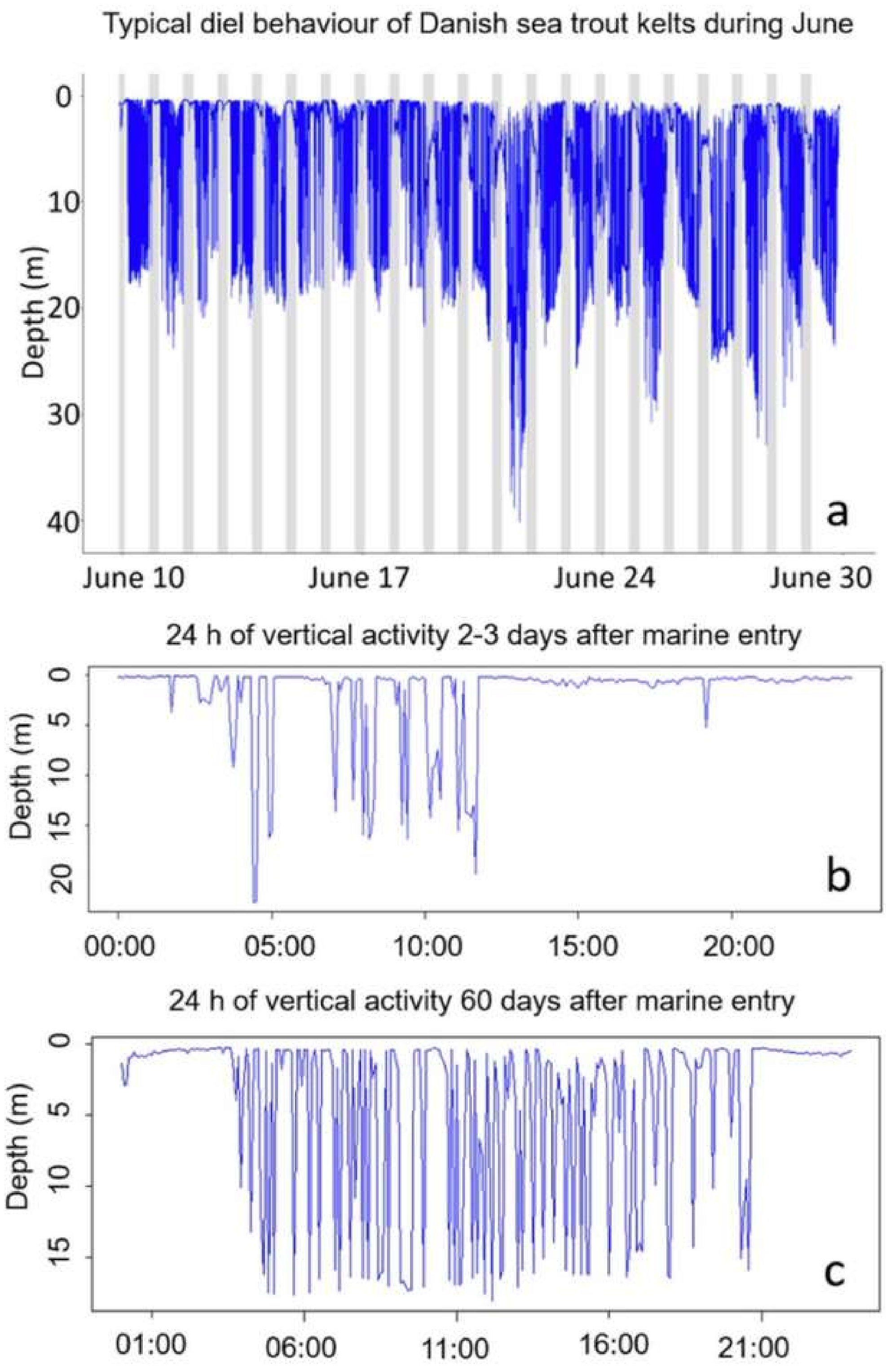

Figure 1: Diving behaviour of Danish sea trout for a three-week period (a), a single day in April (b) and a single day in June (c) when diving activity peaked.

The migration patterns and movements of the fish coincided with them residing in temperatures within the range reported as optimal for growth (12 - 17o C) during the majority of their marine period (Kristensen et al. 2018). There was considerable correlation between the depth and temperature use of the fish, and all fish gradually increased their residence depths when surface (0 – 2 m) water temperatures started to increase above 14 - 15o C. The fish generally avoided warm waters in a way that kept their internal temperatures below 17o C, for practically all of their period at sea. The percentage of measurements recorded at depths between 0-2 m ranged from 60 - 80 % in April-June to 3 - 8 % in late July. The mean residence depth increased from 1.95m at surface temperatures of 5 - 7oC to 10.1m at 17 - 19o C. The fish disrupted their characteristic diel behavioural pattern when sea surface temperatures surpassed 17oC and only made short excursions into depths shallower than 5 m under such circumstances.

Temperature profiles of the fish compared to mean sea surface temperatures in the seas surrounding Denmark revealed that the fish resided in waters 0 - 5o C warmer than the mean when mean temperatures were below 10oC and 0 - 5oC colder than the mean when mean temperatures were above 15oC. As a consequence of the combined vertical and horizontal movements, the fish managed to maintain body temperatures within the range reported as optimal for growth (12-17o C), during the majority of their marine residency period.

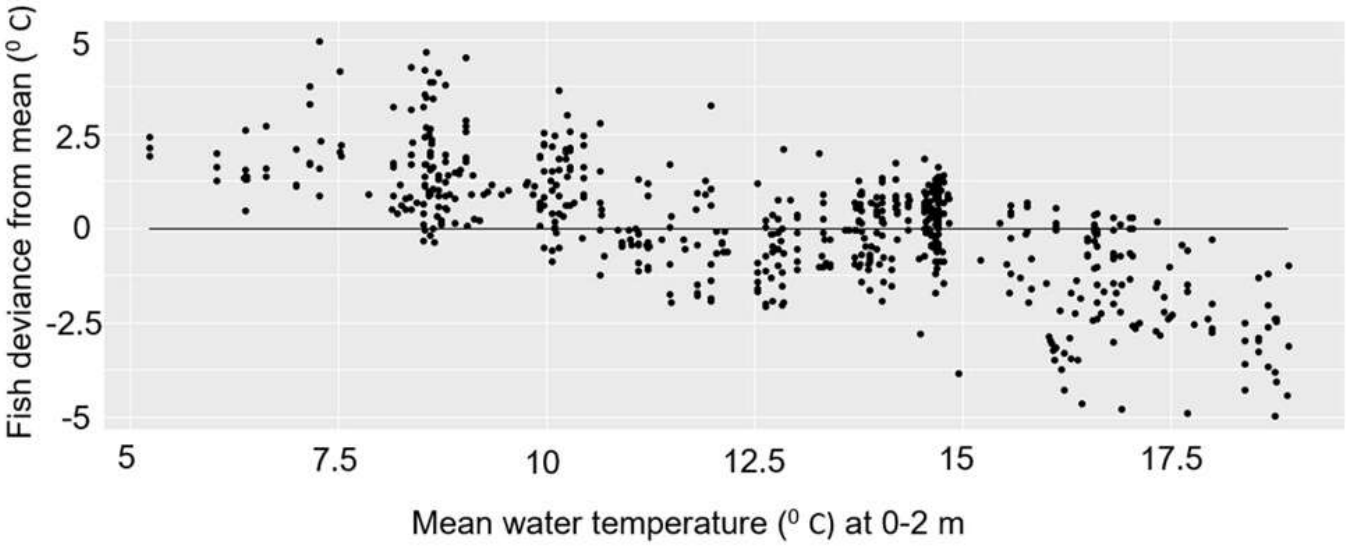

Figure 2: Deviance of mean fish temperature from mean sea surface (0-2 m) temperatures in the 53–59° N, 7–13.5° E area at 21-07 hours each day. The fish reside in areas 0-5 o C warmer when mean temperatures are below 10 o C and -1 – 5 o C colder than the mean when mean temperatures increase above 15 o C.

Migration routes of the fish were reconstructed with an HMM to investigate what areas of residency the fish were likely to prefer at different times of the season, considering their apparent movement from relatively warm areas during spring to relatively cold areas during summer. The model showed all of the fish staying relatively close to shore during the marine period. At times, however, considerable movements within the seas surrounding Denmark appeared to have occurred (Kristensen et al. 2019c). Specifically, all individuals migrated into the Kattegat Sea during spring, where temperatures are higher, and salinities lower at this time of the season. In June, the fish migrated into more open and well-mixed seas such as the North Sea, and some individuals went close to the S-SW coast of Norway or even migrated along it.

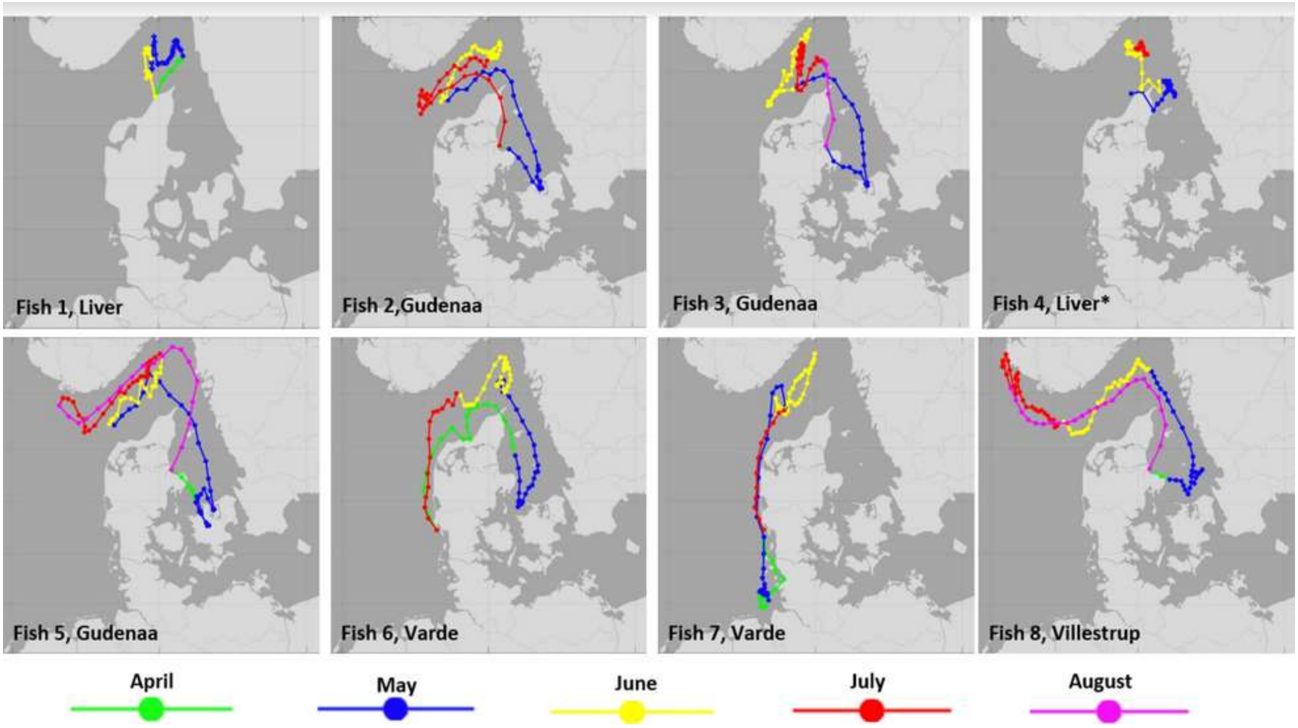

Figure 3: Reconstructed migration tracks of sea trout in the seas surrounding Denmark. The fish migrate into the shallow/stratified and less saline Kattegat-region during spring (blue/green) and out to the deeper and more well-mixed Skagerrak and North Sea during summer (yellow/red/pink).

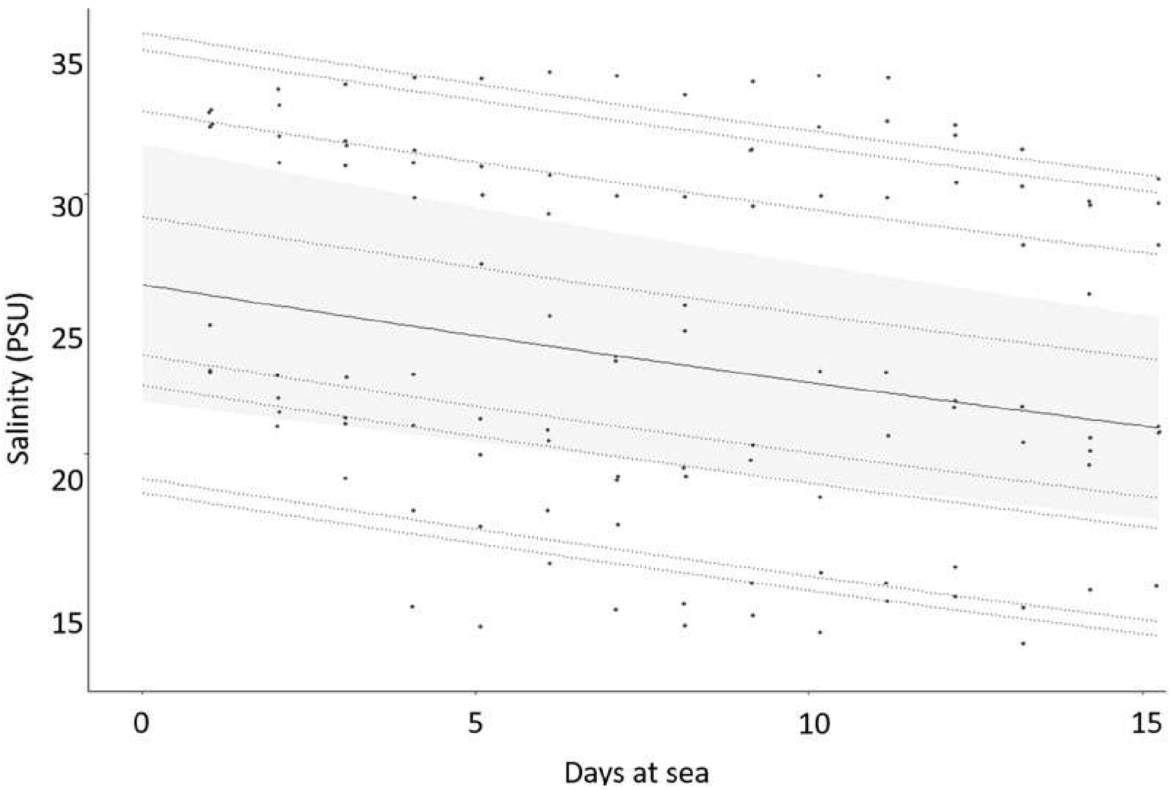

Figure 4: Salinity at modelled positions during the first 15 days of migration in the sea.

The migrations of the fish peaked at 130 - 580km from their natal river. Linear daily progression of the fish was 16 km (range: 0 – 58 km) which is within the values detected with acoustic telemetry on adult sea trout in the region (up to 59 km d-1; Kristensen et al. 2019a).

The results from DST-tagged Danish trout reveal that sea trout has a special behaviour in the seas surrounding Denmark. The results thus reveal that the marine behaviour of sea trout may vary considerably within its distribution area, possibly as a consequence of adaptations to local conditions (Kristensen et al. 2019d).

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New and Emerging Fish Tracking Technology

New and emerging technology for tracking salmonids at sea

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Scientists have tracked fish at sea with electronic tags for almost 50 years. Britain played a pioneering role, being among the first to use fixed hydrophone arrays with acoustic pingers (cod *Gadus morhua*, western Scotland, Tony Hawkins group); boat-mounted sonar tracking with acoustic transponders (cod and plaice *Pleuronectes platessa*, southern North Sea, Ron Mitson group); satellite tracking (basking shark *Cetorhinus maximus*, western Scotland, Monty Priede group). Decades on, biotelemetry and bio-logging have mushroomed into globally applied methods for fisheries science and management. Their use in marine environments has increased exponentially, especially with the availability of reliable, off-the-shelf telemetry products, particularly for acoustic tracking. While this has enabled researchers to get on with their work, assuming funding availability, the concentration of most commonly used marine biotelemetry products into production by a few commercial suppliers presents a risk to diversity of methodology and competitive pricing and is one that independent scientists should be wary of supporting excessively. This is despite the valuable role of platforms such as Ocean Tracking Network (OTN) in supporting projects such as marine tracking arrays such as SeaMonitor (between western Scotland and Northern Ireland) by the provision of expertise and loan of tracking infrastructure.

The current underpinning electronic tracking technologies for marine salmonids, comprising acoustic telemetry, satellite telemetry and data storage tags (DSTs = archival tags) are all undergoing continued development, in particular through miniaturisation, reduced power consumption (extended life) and remote data transfer. Most acoustic telemetry, which underwent a step-change in usability with the advent of tag-identity coding systems, relies upon non-cabled arrays of passive hydrophone receiver-loggers from which data must be downloaded, increasingly combined with receiver units mounted on drifters and ocean gliders. At sea, most of these operate at ~69KHz, reflecting a compromise for a tag frequency with limited noise attenuation and interference, and which can be produced at moderately high sound source levels using lead zirconate titanate transducers (smallest tags ~7 mm diameter). A significant challenge now is that for the multiple equipment and tag providers there is limited compatibility among systems at a time when research groups (especially in Europe) are trying to pool resources to track salmon over large areas at sea. The European Telemetry Network is calling for a common standard and developing a data centre (currently based at Flanders Marine Institute) to address these issues. Given the need for many receiver nodes and their expense, it is important that telemetry manufacturers do not force obsolescence on older functional equipment or seek market exclusivity through implementing incompatible code maps as some are doing.

The drive to acoustically track smaller fish (e.g. salmon smolts) has led to tag miniaturisation by increasing frequency (~180 - 416kHz) to enable smaller transducers (which have a higher resonant frequency) to be used. New battery technology and tag construction by the Pacific Northwest National Laboratory has enabled production of ‘injectable’ tags of just 3.4 mm diameter with good range and life >100 days. These, used with the Juvenile Salmonid Acoustic Telemetry System, have been widely used around large dams in the Columbia River system, but not widely in estuarine or marine environments. 416kHz tags of 12 x 2mm size, weighing just 0.08 g and with a life of 1 month have also been developed by PNNL. Although 416kHz JSATS claims to exploit ‘a low-noise window', in general sound attenuates more rapidly with increasing frequency and it remains to be seen if JSATS-type telemetry can be employed effectively in marine environments. JSATS tags and receivers are now manufactured by several commercial providers in North America under license to PNNL; there is debate within the user community as to how well equipment and consumables from those different users' functions. Tests of these JSATS-type systems are increasingly underway in the Atlantic region, including those planned in Scottish rivers and estuaries alongside conventional 69KHz systems.

One of the primary functions of acoustic tracking of wild salmon now and in the years ahead is to provide quantitative estimates of survival during smolt emigration (river and sea) and post-smolt migration at sea, due to observed reductions in return rates (i.e. higher mortality) in recent years. This can provide evidence of survival, and of likely mechanisms / locations of loss. However, it is dependent upon capture, handling, tagging and tag presence having no effect on survival or, more likely, the effects of these being known. Currently we still know too little about tag failure rates in the natural environment, expulsion rates of tags, and the effects of capture, handling, tagging and tag presence on fish 'performance' (acute and delayed mortality, growth and behaviour). Currently only the largest wild Atlantic salmon smolts can be tagged with 7mm 69kHz tags (most receivers used in estuaries and at sea are still 69kHz); generally, a minimum size of 13 cm fork length is used, but even in these the tag takes up a large proportion of the body cavity. Smaller tags result in a smaller tag burden, and 2 - 3mm JSATS tags will enable the smallest wild (~10 cm) smolts to be tagged with a low burden. However, low-power and/or high frequency tags may have smaller range (requiring more receivers) and lower detection. Large-scale and robust trials of the impacts of pre-smolt/smolt capture, tagging, and tag presence are urgently needed, as are 'blind' trials of tag failure rates in real-environment conditions, and range and detectability of different frequencies and power outputs of tags in estuaries and at sea. These are expensive and most "tracking projects" cannot afford them, but without them, survival data from tracked smolts and post-smolts will remain questionable or flawed.

Much fan-faring has accompanied the recent development of gastric predation acoustic tags, not least because high levels of predation represent a 'likely suspect' for marine smolt and post-smolt losses. Yet these predation tags are reliant on acoustic detection, so may be of little use if ingested by sedentary predators distant from passive receivers (unless wide-scale active tracking is employed to locate these), nor for avian predators. Currently the variable, sometimes high, rate of false-positives for live, tagged fish, and for dead, non-predated fish are further major confounding factors. Again, more independent laboratory and field trials are needed to determine their utility, especially since the sensors on these tags are still being fine-tuned and may vary between batches from the same supplier. Passive Integrated Transponder telemetry has a role to play in tracking the survival and distribution of smolts using trawls fitted with PIT antennas; tagging is cheap and can be applied across large numbers of rivers, though boat time is expensive and PIT trawls are technically tricky to optimise and maintain stable efficiency for. Automated PIT equipment at fish processing plants may be effective at detecting post-smolt bycatch, but eDNA may be a more effective means of determining this. PIT telemetry is already used widely for recording emigration and returns of wild fish at passage restricted sites (e.g. fish-ways). Although 8mm PITs are now commercially available it is unlikely they will alter how PIT telemetry is employed. Conventional VHF radio-telemetry, an increasingly "forgotten" telemetry technology remains the "go-to" technology to measure the rate of loss of salmonid juveniles to avian predators, particularly at roosts and breeding sites. PIT telemetry may be used in a similar way by manually scanning sites or deploying readers on All Terrain Vehicles. Increasingly smolts are double-tagged with PITs and acoustic or radio tags.

Pop-up satellite (PSAT) tags, miniaturised over the last two decades, are providing new insights concerning salmon kelt migrations and give the advantage of records of logged depth and thermal history, which can be used to reconstruct possible routes of movement, even when geolocation information from light-level data is suspect. Depth and thermal history also offer opportunities for identifying predation events by endothermic and ectothermic arge predators. Fish-borne cameras and receivers are increasingly likely to be used on adult salmonids. Provided DSTs can be recovered (ideal for repeat-spawning sea trout) they can enable coarse track reconstruction possibilities from environmental data. Application of Ranging And Fixing SOund (RAFOS) technology to hydrophone-carrying marine fishes, by detecting multiple fixed and identifiable sound sources, also has strong potential for tracking salmon over large areas of ocean. This technology is currently used for tracking ocean drifter buoys that carry hydrophones and record detections from known static sound sources. Pilot studies suggest that fish-borne RAFOS hydrophones and receivers could have a range exceeding 100km and a precision of 2km.

All fish telemetry methods can generate vast amounts of data and include the potential for misidentification or ‘ghost’ tags. Increasingly such data, especially at an ocean scale, need to held centrally and ‘open access’ provision be made once a project’s timescale has been completed. There will need to be greater cooperation and integration of projects, tag codes and data into data repositories and observation platforms such as the Integrated Ocean Observation Platform, Ocean Tracking Network, European Telemetry Network and Great Lakes Acoustic Telemetry Observation System. Inevitably, these need long-term and substantial operating budgets in order to function effectively and deliver the benefits for large-scale fish telemetry, including of Atlantic salmonids, in the decades to come.

RAFOS: Ocean Acoustic Monitoring (ROAM) Tag

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Abstract

Our ability to study and understand the marine dynamics of Atlantic salmon is constrained by our inability to accurately geolocate and track individuals over their entire marine migration. The application of various electronic tagging technologies has provided insights into the marine ecology of the species, but these approaches are biased. Acoustic tagging approaches are biased towards nearshore areas, are temporally limited due to tag size and battery life constraints and pose particular challenges when trying to monitor vast oceanic areas such as the North Atlantic. Pop-off satellite tagging (PSATs) approaches are restricted to the study of larger (pre) adults, which may or may not have similar migration dynamics as juvenile smolts. Further, current light-level, geolocation techniques have been shown to exhibit poor accuracy (±100-200 km; ~10,000 km2) even under best-case situations when movements are confined to surface waters (< 100 m) during daytime hours. To overcome these shortcomings, we are developing a new archival tag that will provide accurate geolocations of fish throughout the water column across ocean basins. The **R**AFOS **O**cean **A**coustic **M**onitoring (ROAM) tag miniaturizes and re-purposes a proven oceanographic technology used to track subsurface drifters into a small animal-borne tag. The ROAM tag promises ±5 km accuracy using an on-board hydrophone and an array of moored low-frequency sound sources. Archival and satellite-enabled tags are currently being designed and tested in collaboration with commercial tag companies. ROAM tags have the potential to become a tool for studying the entire marine migration of Atlantic salmon and will aid in our understanding of the links between open ocean features, salmon migration and marine productivity. Emerging technologies like ROAM can be complimentary to existing technologies (i.e. acoustic) and can be designed to answer different questions in different environments.

Background

RAFOS (SOFAR spelled backward: sound fixing and ranging) is a common oceanographic monitoring tool for tracking ocean currents by means of subsurface drifters capable of receiving sound. A RAFOS network relies on moored acoustic transmitting units that emit a unique acoustic signal which may carry upwards of a 1000 km, thereby providing a large monitoring area with minimal infrastructure and cost. A hydrophone on-board the RAFOS float detects the sounds from the network, and a triangulation algorithm uses the differential sound reception from multiple moorings to calculate position of tagged fish to within ± 5 km2.

The RAFOS technology has been evolved, modified, and miniaturized through the development of a new single board receiver. The receiver has been combined encased with a hydrophone outer shell to form the new RAFOS Ocean Acoustic Monitoring (ROAM) tag. The tag can be incorporated into an archive and pop-up satellite tag (PSAT) version. The archive tag version will be suitable for tracking fish as small as 180mm for up to two years, although the tag will need to be recovered to obtain the data. The PSAT tag will be larger (size to be determined) and therefore will be suitable for larger individuals. Tag recovery is not needed as data will be transmitted via satellite. This option will make the tag applicable to a number of species where tag physical recovery rates are typically very low.

There are many advantages of the ROAM tags compared to contemporary acoustic and PSAT tags. ROAM tags can provide accurate (±5 km2) location estimates. Acoustic tags can also as the detection radius of the monitoring equipment is ~1 km; however, data are available from monitored areas only. For PSATs, ongoing work in the NW Atlantic with light-based geolocation tags estimate location errors of 100-200km longitude (1-2°) and 200-400km latitude (2-4°). Archive ROAM tag life is estimated at approximately 2 years and therefore will allow for tracking smaller individuals over longer time periods than acoustic tags. The size of the ROAM PSAT tags has not been determined but will likely be approximate to or smaller than contemporary PSAT tags. For monitored area, a single sound source will transmit daily 'pongs' across an area of 785 km2 for 10 years. With relatively modest investment, very large areas of the ocean can be covered.

Engineering, fabrication, and field testing of the prototype archive ROAM tag has recently been completed. Negotiations with a commercial tag company to further test, develop, and refine the archive ROAM tag and to engineer and develop a PSAT version on ongoing. An archive ROAM tag and the PSAT ROAM tag are expected for field testing in 2020. A small number of sound sources are currently being fabricated to support field testing of the beta archive ROAM tag.

Using Environmental DNA for Atlantic Salmon Conservation

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There is an increasing concern that northeast Atlantic pelagic fisheries may inadvertently take a significant by-catch of juvenile Atlantic salmon, specifically in areas where salmon are migrating at particular times of the year. There is a need to identify, quantify and monitor the level of by-catch in order to develop mitigation measures. However, it is difficult and costly to visually inspect the catches from these pelagic fisheries as locating individual post-smolts, between 12cm and 20cm long, amongst the large catches of herring, mackerel and other pelagic species is almost impossible. New and innovative approaches are urgently required to resolve this.

To explore the potential of using environmental, eDNA, to screen the commercial catches of pelagic fishing vessels, the Atlantic Salmon Trust (AST) commissioned a pilot study by the Area52 Research Group at University College Dublin, Ireland. Environmental DNA is the collective term for DNA molecules that are released from living or dead organisms into the environment, which can come from sources as diverse as blood, skin, mucous, sperm, eggs and faeces. The eDNA can be extracted from an environmental sample such as water, air or soil using non-invasive techniques and confirm the presence of a species without direct observation. Further, modern metabarcoding methods can be used to sequence pooled DNA as a test to detect the presence of target organisms in a sample of interest. The Area52 Research Group has been developing eDNA probes and published them for a range of aquatic organisms in both freshwater (Gustavson et al. 2015; Carlsson et al. 2017; Atkinson et al. 2018, 2019; Bracken et al. 2018) and marine (Gargan et al. 2017) environments. Further unpublished probes are available for hydrothermal vent endemic shrimp (*Mirocaris fortunata*), tope, shad, blackbelly rose fish, orange roughy, pygmy hippo, slender snout crocodile, thornback ray, common stingray, ballan wrasse and pink salmon.

Through this joint UCD/AST programme a species-specific molecular probe for use in identifying Atlantic salmon eDNA was developed and tested both in the laboratory and in the field. The probe is currently being used within Workpackage 4 of NINA's SeaSalar Programme (www.seasalar.no) to test its efficacy in assessing the level of by- catch from pelagic vessels in the Norwegian Commercial fleet. The probe is also used in the Beyond 2020 (https://www.dkit.ie/beyond-2020) research project to assess the feasibility of detecting traces if Atlantic salmon in paleo lake cores.

The probe has also been used to track the presence of Atlantic salmon in headwater streams so as to assess whether or not natural or man-made barriers were in fact blocking salmonid access to these high water areas (Atkinson et al. 2017). Following the appearance of large concentrations of pink salmon (*Oncorhynchus gorbuscha*) in Irish rivers over the late summer of 2017 (Whelan 2017a &b) the approach taken when developing the Atlantic salmon eDNA probe was used to develop an equivalent probe for invasive pink salmon – Gargan et al. 2020.

The use of eDNA has many advantages over other tracking approaches and technologies as it is:

- non-invasive
- cost effective
- samples are relatively easy to take (e.g. taking water samples versus the use of receiver arrays)
- does not rely on taxonomic expertise to identify the species
- can be used at any life stage
- easy to replicate
- provides excellent geographical coverage

The emerging eDNA techniques have the potential to chemically track populations of salmonids in estuaries and in the surface layers of the ocean. In the case of Atlantic salmon it would be possible, using the panel of markers developed by the SALSEA Programme (Hansen et al, 2012 and Mork et al. 2012), to identify the regional origin of the Atlantic salmon migrating across the ocean. Using metbarcoding techniques and/or clade/population specific probes it should be possible, in the very near future, to detect populations of salmon trace them back to their rivers of origin.

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Using the stable isotope composition of archived scales to study marine migrations and responses of salmon populations to ocean warming

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Marine fish are influenced by changes in seawater temperatures through direct effects on their metabolism and indirect effects on prey distributions, phenology and potentially ocean currents. During the recent period of sustained ocean warming, many marine fish populations show evidence for widespread distribution range shifts, especially poleward extensions of the species' leading edge. Marine species show greater spatial responses to climate change than terrestrial species on average, because thermal gradients in marine systems are relatively shallow, with few opportunities for local refugia. Recent periods of warming in high latitude oceans are therefore expected to trigger responses in fish populations.

Locally resident fish populations may respond to climate warming through changes in the centres of distribution of population ranges. The response of migratory pelagic fish to climate change is less clear. Migratory fish may be relatively resilient to climate change as individuals have the capacity to move across wide spatial ranges to find more thermally optimal regions. However, phylogenetic (i.e. physiology, morphology and life history traits in general) and oceanographic factors may impose constraints on their capacity to adapt behaviourally to changing ocean conditions. Determining the response of migratory oceanic fish to climate change is especially challenging as they are typically dispersed across wide, inaccessible regions.

Salmon occupy a relatively wide thermal range in the open Atlantic Ocean, and salmon populations could therefore show resilience to climate change. However, salmon individuals and populations are also constrained in their ability to respond to climate change by their need to return to specific rivers to spawn. Salmon have experienced range-wide population declines in recent decades linked to conditions in the Atlantic Ocean, (ICES 2017). Recent stock assessment models outline that PFA (Pre Fisheries Abundance, corresponding to post-smolt stage) has halved over the last 40 years (Olmos et al. 2019). As there is no clear evidence of a generalized decline in juvenile production during freshwater stage (Crozier et al, 2003), decline in survival rates at sea is likely responsible for the estimated reductions in PFA (Chaput, 2012). However, despite intense research effort, locations of feeding grounds at sea remain uncertain, hampering attempts to connect population dynamics to environmental or ecological conditions. Atlantic salmon populations are believed to migrate to common feeding grounds located off the coast of West Greenland, in the Labrador Sea and Norwegian Sea, although evidence for common feeding areas is based on tag returns and biased by locations of commercial fisheries.

The development of electronic tagging technologies has enabled great progress in spatial ecology and conservation management (Hays et al. 2019) but tags are relatively large and expensive or require major ocean-based infrastructure (acoustic arrays). Identifying and quantifying plasticity in ocean in spatial behaviour of oceanic, pelagic fish populations in response to climate change across a species range requires data from large numbers of individual fish that are currently out of scope of tagging studies.

Static tag data give extremely valuable insights into distribution of known origin salmon over time and space, but despite millions of fish being tagged at great investment of time and resources, fewer than 7,500 individual high seas recaptures have been reported, spread over 50 years and across the N Atlantic (Ó Maoiléidigh et al 2018). Many questions remain about the distribution of salmon at sea, especially in the season prior to return.

As animals feed and grow tissues, the accreting tissues acquire chemical signals that reflect the local environmental and ecological conditions. If these conditions and their chemical expression vary systematically across potential foraging areas, then the chemical composition of animal tissues can be used as a natural tag, linking an animal with the location where tissues were grown. Atlantic salmon are largely aged using scale increment analyses, and consequently a great many salmon scales have been sampled and, frequently, archived. The resulting time series of salmon scales can be used to investigate ocean feeding among and between river stocks and cohorts of Atlantic salmon.

Stable isotopes of carbon and nitrogen are attractive targets for inferring aspects of marine ecology of Atlantic salmon. Scales are composed of a mineral (bioapatite) layer essentially superimposed on a bed of collagen-rich protein. This protein layer records the isotopic composition of carbon and nitrogen ingested by the fish during scale growth. The architecture of scale collagen growth essentially limits inferences to the last season of growth, so that scales from 1SW (1 sea winter) fish returning in summer reflect feeding in the months prior to return whereas scales from early-returning 2SW (2 sea winter) returning fish reflect feeding in the previous year.

A series of publications have described the use of stable isotopes of archived salmon scales to demonstrate separation in marine feeding grounds between river stocks and to propose relationships between ocean climate indices and salmon feeding ecology. Until now, however, these has been no systematic comparison of scale isotopes among rivers at a continent scale. Working in collaboration with a wide range of scale-holding organisations in the UK, Ireland, France, and Spain we have assembled a dataset of salmon scale isotope compositions from more than 5000 individual salmon returning as 1SW or 2SW fish to 16 rivers spanning the range of the ‘southern’ component of the Eastern Atlantic salmon population.

Work is underway to use this large dataset to address some fundamental questions in salmon ecology. In particular we will test whether salmon returning to rivers in the same geographic region return from similar marine feeding areas – and conversely whether salmon returning to rivers at the northern and southern extremes of the southern population range are separated during marine feeding. We will infer the most likely marine feeding areas for each sampled population based on models of the spatial distribution of stable isotopes in pelagic food webs across the North Atlantic.

Initial analyses suggest that there is a great deal of plasticity in marine feeding location both within and among river populations, implying that inferring feeding location or drivers of marine migratory behaviour will require large datasets. Nonetheless we observe consistent differences in inferred marine feeding locations between 1SW and 2SW returning salmon, and we see evidence for systematic differences in marine feeding area across the latitudinal range sampled in our dataset.

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Autonomous ocean observing platforms

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In recent decades, marine autonomous platforms have played an increasing role in ocean observing systems. They can potentially operate all day and all year long in any weather and location, allowing for safer, low-cost and more repeatable missions. Deployment and recovery can take place in a safe location during better weather conditions, the platforms being able to travel to and from their operational area. Two-way satellite communication with pilots onshore enables real-time data access and adjustments to the mission. In this talk, we discuss two types of non-propelled autonomous platforms: profiling gliders and autonomous surface vehicles, whose unusual propulsion methods offer months to year endurance at low speed with quiet operation and low environmental impact. Profiling gliders travel underwater, driven by buoyancy; autonomous surface vehicles travel at the surface, often harnessing wave or wind power for propulsion.

Profiling Gliders

The most common profiling gliders used for science are SeaExplorer (Alseamar), Seaglider (University of Washington/Hydroid), Slocum (Teledyne Webb) and Spray (Scripps Institute of Oceanography). They are driven by buoyancy changes, controlled by pumping oil into and out of a swim bladder, inducing a vertical motion in the water column from the surface down to 1000 m depth. Fixed wings convert the vertical velocity into forward velocity. Internal battery displacements enable pitch and roll management for direction changes. Performing successive V-shape dives up to 1000m deep along a predefined trajectory, they can travel ~20 km per day for up to 6 months covering thousands of kilometres. They carry various payloads to collect measurements of physical parameters (temperature, salinity, currents, turbulence, wind speed), biological parameters (phytoplankton, zooplankton) and chemical parameters (O2, CO2, irradiance, pH, NO3, hydrocarbon). The operational limitations to the use of profiling gliders are their reduced payload capabilities (weight, size, power), low speed (< 1 km h-1) and manoeuvrability. We do not recommend using profiling gliders in shallow water, strong currents, or high ship density areas.

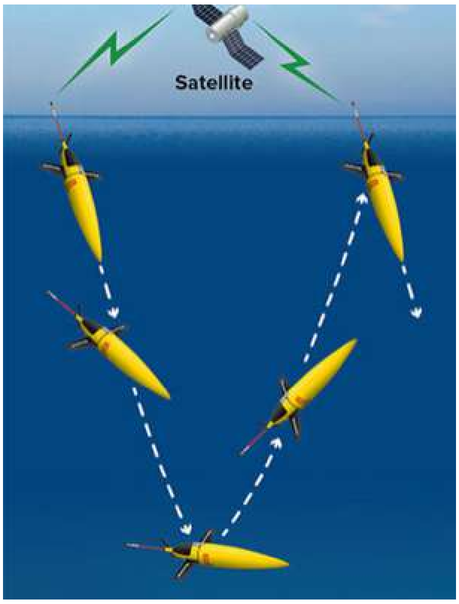

Figure 1: V-shape dive of a Seaglider (from www.hydroid.com).

Autonomous surface vehicles

Wave powered surface vehicles offer increased speed (up to 5 knots), larger and heavier payload capacity, 24/7 satellite communications, and access to solar power which can significantly increase mission durations. They can collect atmospheric and oceanographic data simultaneously, however the latter are typically limited to surface measurements only. The Wave Glider (Liquid Robotics) exploits the difference in vertical motion of waves at different depths. The surface float houses the electronics and most sensors, and is attached to the glider subunit below the surface by an 8 m long umbilical. The subunit converts the vertical oscillation of the float into forward motion. The AutoNaut (AutoNaut Ltd) uses foils to convert wave-induced pitch and roll oscillations into forward motion. Operational considerations for the use of wave powered autonomous surface vehicles are the risk of collision in high ship density areas or necessary navigational deviations, their relatively low speed in strong currents, and reliance on variable energy sources which can impact the consistency of vehicle speed.

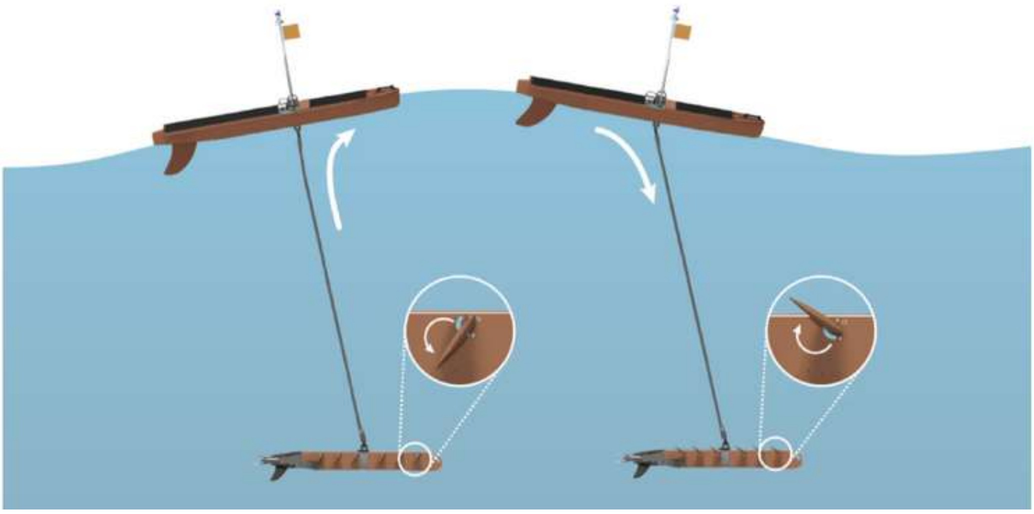

Figure 2: Schematic showing how the Wave Glider harnesses energy from the waves for forward propulsion (from https://www.liquid-robotics.com/wave-glider/how-it-works/).

Ocean Observing Systems

Marine autonomous platforms are now commonly used as components of ocean observing systems for physical oceanography purposes. In France and in the UK they have been successfully used for persistent monitoring of vast areas. Within the Mediterranean Ocean Observing System for the Environment (www.moose-network.org), profiling gliders have been deployed repeatedly for 15 years to monitor the ocean circulation in the Gulf of Lion on a large scale. Within the AlterEco framework (www.altereco.ac.uk), overlapping profiling glider and Wave Glider missions performed an 18 month continuous measurement campaign in the North Sea.

Sensors on autonomous platforms

Marine autonomous platforms can carry an ever-increasing list of sensors. Acoustic tag receivers for fish telemetry are now commercially available that can be fitted to any surface or underwater autonomous vehicle. Numerous examples can be found of studies of Snow Crabs, Atlantic Sturgeons, Sand Tiger Sharks, Red Groupers, Red Snappers (Oliver et al. 2013, 2017, Haulsee et al. 2015, Lembke et al. 2018, Breece et al. 2016), with detection ranges of about 500m. Marine autonomous platforms offer a low-cost solution for persistent monitoring when the use of moored receivers is not possible. In addition to carrying acoustic tag receivers, they provide a wide range of auxiliary observations relevant to fish behaviour and ecology, e.g. water masses, currents, primary production, prey availability, threats and predators, anthropic pressures, water quality, non-tagged fish.

Marine autonomous platforms are now commercially available with passive acoustic monitoring systems, allowing for detection of marine mammals (Cauchy et al. under review), soniferous fish species (Oliver et al. 2013, 2017) and anthropogenic noise pollution. Measurement of the ambient noise level can also provide information relevant to the expected detection range of acoustic tag receivers.

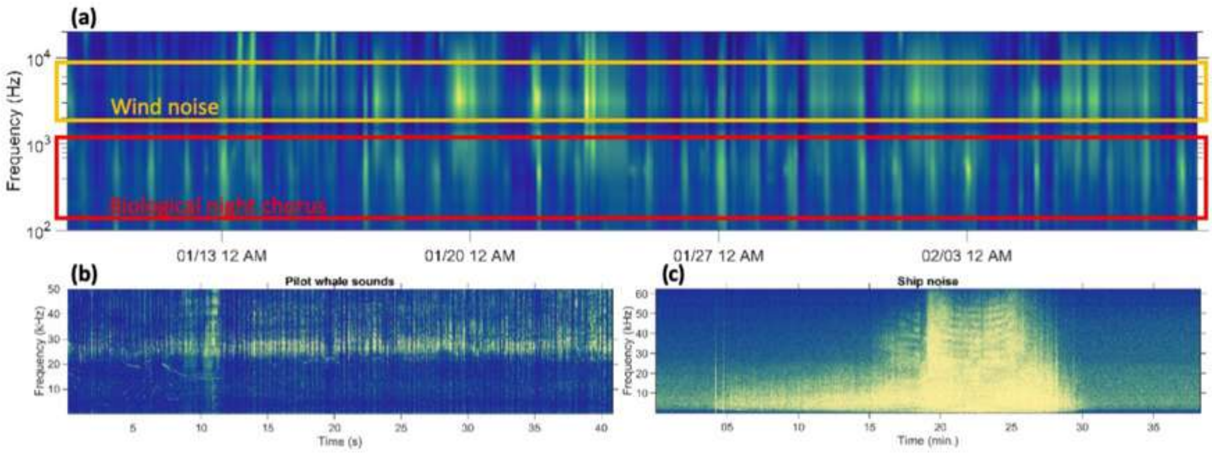

Figure 3: Spectrograms of underwater sounds recorded from a profiling glider. Wind noise and a daily biological chorus occurring at night (a), echolocation clicks and social whistle from long finned pilot whales (b), nearby ship noise (c).

Marine acoustic platforms can also carry active acoustic systems, such as echo-sounders commonly used in fisheries acoustics for biomass estimation, that can provide information on behaviour and abundance of target and non-target (e.g. predator or prey) species (Greene et al, 2016; Moline et al, 2016; Swart et al, 2016).

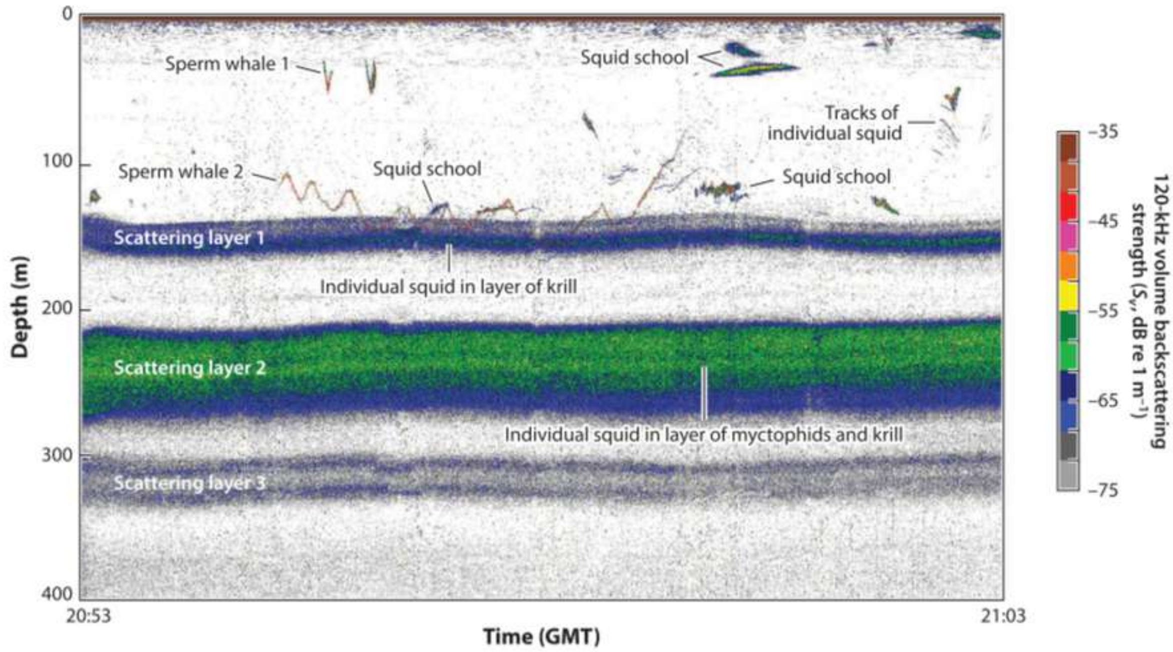

Figure 4: Echogram depicting interactions between multiple trophic levels simultaneously. Adapted from Benoit-Bird and Lawson (2016).

Autonomous platforms offer clear benefits for assessment of salmonid dispersal in the marine phase. They can considerably increase the acoustic tracking effort of tagged salmonids in key coastal areas, and cover locations where deploying traditional moored receivers is not logistically feasible. Opportunistic detections at sea can provide information about path and timing of migration. Data collected by oceanographic and acoustic sensors can provide valuable information to understand the wider context of salmonid movement behaviour and improve modelling of the most likely path of individuals.

Useful contacts and glider groups in France and in the UK:

UEA glider group (University of East Anglia, Norwich, UK)

Marine Autonomous and Robotic Systems (NOC, Southampton, UK)

Pôle national glider (DT INSU, La Seyne sur Mer, France)

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Using multi-beam sonar in open river channels to derive run estimates and assess fish passage

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Introduction

Salmon and sea trout monitoring on the River Teifi at Glanteifi was originally commissioned between 1997 and 1998 and funded by the Water Resources section of the Environment Agency with some initial funding from the Teifi Fishermen's Federation and the Countryside Council for Wales.

The overall aim of the project was to provide data that could be used to:
- Investigate the relationships between adult salmon migration and environmental factors such as river flow etc.
- Provide stock assessment data for fisheries management.

Historical Perspective and Site Selection

Between 1998 and 2007 a split-beam acoustic sonar was operational at the site and provided information on upstream fish movement passed the counter. This type of sonar collects information from acoustic echoes and uses sophisticated software to track the movement of fish and other objects passed a receiver in the river. It was operated continuously for twelve months of the year and attempts were made to provide daily upstream counts of salmon and sea trout. Differentiation (species apportionment) of the two species was done on the basis of echo signal strength which gave an estimate of fish size. This type of sonar was unable to monitor the entire water column and therefore video cameras were used to assess the proportion of fish that the counter actually detected (counter efficiency). This process was known as counter validation.

In 2007 the Environment Agency purchased a DIDSON Imaging sonar which was a new type of sonar which could provide near video-quality images of fish, even in turbid water. This was originally deployed at Glanteifi as an alternative to video cameras for counter validation, but ultimately revealed a number of issues at this and other monitoring sites. This led to a review of all split-beam monitoring sites in Wales and the decision was made to decommission all sites due to some fundamental limitations of the split beam technology.

Three factors were identified as key to preventing accurate fish counting at the site:
- The split-beam sonar was unable to provide a downstream count as it could not differentiate between floating debris and fish.
- The fish length information provided by the echo strength was inaccurate and this made species apportionment difficult.
- There was considerable fish movement near the bank during high flows which could not be easily monitored at the split beam site.

It was recommended following an initial trial in October 2009 that a DIDSON sonar could provide information on downstream moving fish and the accurate length information required for species apportionment. A DIDSON sonar was purchased to replace the split beam sonar at Glanteifi and a new monitoring location was selected to improve fish detection near the banks. The DIDSON has subsequently been replaced by the ARIS (also manufactured by Soundmetrics). ARIS offers several advantages including the ability to configure the number of down range samples, allowing the whole river width to be sampled simultaneously in one sample window, with high resolution (Figure 1). The increased number of sub-beams at low frequency also increases image quality and sizing accuracy at range: important species apportionment considerations.

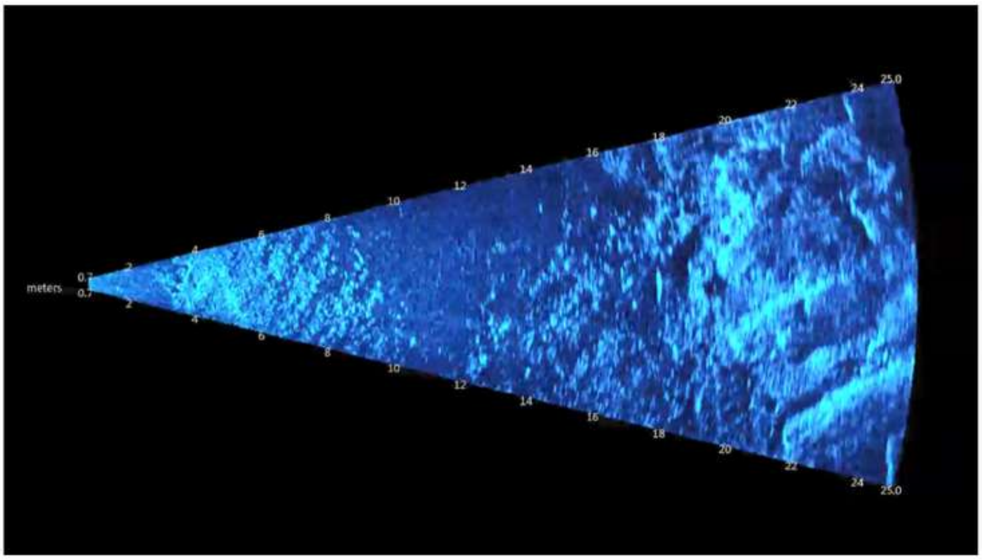

Figure 1: ARIS image of Teifi monitoring site, a fish is visible centre beam, 18m.

The new monitoring location is situated several hundred metres downstream of the original site. Although the cross-sectional profile is not as critical with an ARIS/DIDSON, it remains an important consideration. The profile should be wedge shaped, with depth increasing with range, so that beam fit is maximised.

Data Processing

All data is recorded on site on removable HDDs which are returned to the office, periodically, for processing. Motion detection algorithms are used to extract fish events from the surrounding data. We consider it important to collect all data as opposed to running motion detection live as part of on-site data collection. Collecting all the data allows subsequent data processing with different, more sensitive parameters, should it be necessary to extract for example different species or life stages from the data.

The resulting files, post motion detection, are then played back in the Soundmetrics software, in image mode. All fish >50cm in length are marked and measured. A log of the resulting information is written to a database for data QA and analysis. This process can take between 10 and 90 minutes per day, depending on fish behaviour and debris load. During spate conditions it can be necessary to watch all the data, due to reduced effectiveness of the motion detection algorithms, however this is generally short lived.

Species Apportionment, Counter Efficiency and Counter Leakage

Separation of false targets and species apportionment is another key consideration of data processing. The high image quality of the DIDSON/ARIS is crucial in separating non-target species and debris from salmonid targets. Non-fish events, such as otters, debris and birds are separated visually, as are non-target fish events, such as sea lamprey and eels. A modelling approach is used to separate salmon from sea trout, where there is often a size overlap and the targets are visually indistinguishable on the sonar. In this situation the proportion of salmon is estimated from logistic regression modelling of coracle net catch data using fish length and time of year. This modelling is carried out annually and considered preferable to the use of rod catch as it offers a more contemporaneous data set and has been shown to be more representative of the species composition at the monitoring site.

The proportion of fish targets detected within the monitored area is termed the detection efficiency. Direct assessment of this is difficult as the sampling power of the ARIS is so much greater than that of an independent assessment method; such as underwater cameras. Studies in North America have examined the detection efficiency of DIDSON by comparing DIDOSN counts with visual counts from counting towers. Such studies have indicated approximately 100% efficiencies at passage rates exceeding those ever likely to be encountered on the Teifi. Furthermore, it is usual to observe small trout targets across all the ranges on the Teifi, indicating that there should be no issues detecting larger salmon targets.

Counter leakage, fish moving in areas not routinely monitored, is more problematic on most multi-beam sites. On higher river flows migrating fish orientate themselves to either bank, taking advantage of turbulence and lower water velocities. On the Teifi this has been assessed using a secondary sonar unit. It is estimated that over 50% of the run can move in the first 3 metres of river on elevated flows. It is important that account is taken of this movement. On the Teifi the installation of a fish deflection fence and a pan and tilt unit to sequentially adjust the aim of the sonar is used to increase accuracy of fish counts on higher flows.

Run Estimates

Run estimates derived from the sonar have shown considerable decline since comparable data collection started in 2010. The decline is also evident from rod catch returns from the Teifi and is mirrored form other sites across Wales. Exploitation rate of the rod fishery was relatively stable up until 2014, after which rates became more variable. This is possibly due to changes in the rod catch reporting rate or changes in run timings of returning salmon.

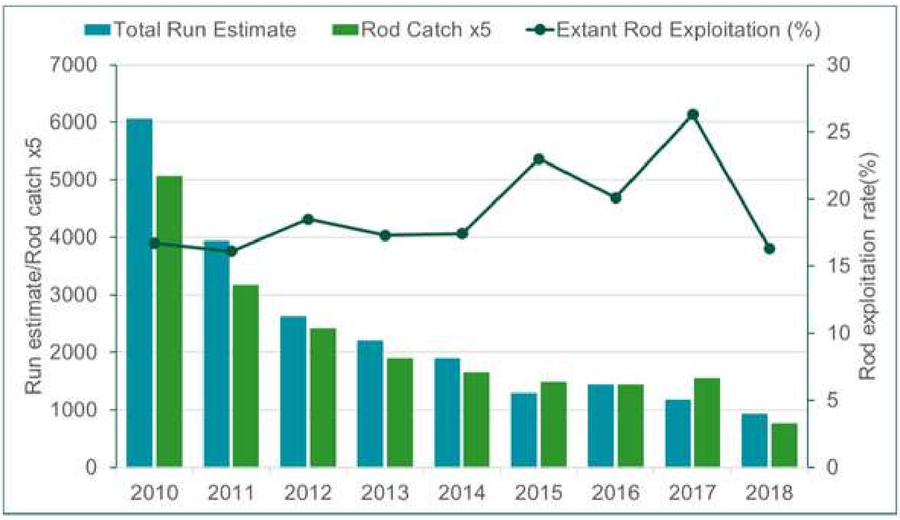

Figure 2: Sonar derived run estimates from the Teifi.

With changes in angler effort and the introduction of fishing byelaws, designed to protect vulnerable salmon stocks methods of fishery independent stock assessment are becoming ever more important. Multi-beam sonar, such as the ARIS, is one such method currently being employed in Wales.

Developments in acoustic telemetry from Innovasea (Vemco) and RS Aqua

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RS Aqua and the recent growth of acoustic fish telemetry in the UK and Ireland

RS Aqua are the UK's largest supplier of marine science instrumentation, and for the past 7 years have been the exclusive technical and scientific agents for Innovasea (formerly Vemco) in the UK and Ireland. Vemco are the world leader in the development and supply of acoustic telemetry fish tracking technology.

The first part of this paper focuses on the role RS Aqua have played in fish telemetry research in recent years and describes some of the support they have provided to the SAMARCH study. The latter part of the paper takes a look at the cutting-edge technological developments in acoustic telemetry that Vemco plan to roll out in the coming years.

RS Aqua supplies marine science technology and expertise into four main sectors: Environment & Fisheries, Marine Science Research, Offshore Resources, and Marine Survey and Inspection. The company has experienced sustained growth in recent years and has witnessed a marked increase in acoustic telemetry fish tracking in the UK & Ireland. As Vemco's exclusive agent RS Aqua have developed considerable expertise in this research field, working closely with fisheries researchers to specify the correct Vemco equipment for their work. For many studies RS Aqua not only oversee the logistics of equipment supply, but also provide technical expertise on the positioning, deployment and recovery of acoustic receivers, and in some cases help with the data analysis. RS Aqua have dedicated scientific staff responsible for this work in fisheries telemetry and have developed close relationships with many of the researchers in this field. They also provide lifetime product support for all the Vemco equipment supplied.

The engineering team at RS Aqua are the inventors of the ARC Acoustic Release Canister, which allows the safe recovery of the seabed anchor when using Vemco's VR2AR acoustic release fish tracking receiver. The development of this system was started in 2016 by Marine Scotland in response to a Scottish marine licensing requirement that all seabed anchors should be removed at the same time as any science equipment to which they are attached. With support from RS Aqua, Marine Scotland constructed a stainless steel rope canister with floatation that could be attached to the Vemco VR2AR receiver and which allowed the hauling up of the seabed anchor once the VR2AR had risen to the sea surface. This system worked well but was prone to extensive corrosion. RS Aqua came up with a Delrin version of the canister and field tested several prototypes throughout 2017 with the support of Marine Scotland. The ARC unit has been modified several times since then and it is now available in 4 different sizes and uses almost no metal parts whatsoever. Throughout its development and beta testing process the unit maintained a 100% successful recovery rate, and there have now been over 360 ARCs supplied to fisheries researchers in the UK, Ireland, Canada and the USA (including NASA!) The ARC has been a key part of several large acoustic telemetry fish monitoring projects e.g. COMPASS in Ireland and the Missing Salmon Project in the Moray Firth.

Figure 1: ARC systems with Vemco VR2AR receivers being prepared for deployment. Photo credit Rob Main, Marine Scotland.

Through their fish telemetry work RS Aqua have built up a fish tracking database which records all historical acoustic telemetry projects in the UK and Ireland. This resource allows researchers to see the location of multiple acoustic telemetry receiver arrays concurrently and judge whether these arrays could provide additional detections of tagged fish being released in other locations. The database has contributed to several research funding applications and is currently being built into an online and freely available geographical information system (GIS).

As demonstrated by the development of the ARC, RS Aqua's ability to work closely with fisheries researchers and understand the technical challenges they face can lead to the development of game changing technology. For the SAMARCH researchers this led to the provision of two real time detection receivers which operate on the Vemco 180 kHz telemetry system. These systems are the first of their kind in the world, and they allow the SAMARCH team to receive text message alerts as their tagged fish return to their home rivers. Some of these fish are carrying data storage tags (DSTs) which have recorded temperature and pressure data throughout the fish migration. Being alerted to the animal's return in real time means the SAMARCH team can get to fish's location quickly and safely electro-fish the animal and remove its DST tag, or activate traps on the river to hold the fish in particular zone until the team arrives.

The SAMARCH team had been talking to RS Aqua about this requirement for several years, whilst at the same time Vemco had developed various real time data transmission systems operating on at 69 kHz frequency. After input from RS Aqua, in early 2019 Vemco put together the first 180 kHz real time systems which were supplied to Celine Artero at SAMARCH. The systems have been successfully operating on the Frome and Tamar rivers since early summer 2019.

Future technologies from Vemco

The provision of these real time systems to the SAMARCH team is a good example of Vemco's enthusiasm to support researchers through the provision of new acoustic telemetry solutions. This can also be seen in a series of forthcoming hardware and software developments planned by Vemco as part of their Fathom range. Fathom is a suite of capabilities that will allow researchers to interact with both their Vemco acoustic telemetry equipment and their detection data for advanced study management and data analysis purposes. Five applications of Fathom are currently planned: Fathom Live, Fathom Mobile, Fathom Connect, Fathom Central, and Fathom Position.

Fathom Live provides users with real time detection, in a similar fashion to how SAMARCH's real time system works. It consists of a digital receiver cabled to a weatherproof surface telemetry unit with WiFi or Satellite communications. This system sends tag detection data in real time from the receiver to a secure online portal. This portal is intuitive and user friendly and allows the user to set up alert parameters and view basic statistics on their detection data.

Vemco's new wireless aquaMeasure environmental sensors can also be integrated into Fathom Live. AquaMeasures measure various underwater parameters, e.g. Temperature, Dissolved Oxygen, Salinity, Chlorophyll, and then transmit those measurements acoustically through the water column, in a similar fashion to a Vemco fish tag. When used as part of a Fathom Live system, aquaMeasures allow researchers to have a real time overview of animal detections and the environmental conditions in the detection zones.

Fathom Mobile is a smartphone app that allows researchers to offload animal detection data from their Vemco receivers directly to their phone in the field. Further, Fathom Mobile will immediately back that data up online, providing an enhanced level of data security should any data get lost or equipment damaged. The app will also display receiver health data and provide metadata management tools for receivers and tags.

Fathom Connect is a PC software interface that allows users to connect to their receivers, configure them and offload detection data. It is already being used with Vemco's 180 kHz High Resolution system, due to its ability to deal with the much higher amount of detections recorded by those receivers. Vemco's existing software platform (VUE) does not have the ability to process these larger datasets and Fathom Connect in conjunction with Fathom Central is set to replace VUE for all Vemco receiver types in future. It will allow researchers to work with much larger datasets across existing and forthcoming Vemco receivers and provide new data analysis and visualisation tools. Using Fathom Central researchers will be able to visualise arrays within a GIS, and the detection loads of each receiver in the array. It will also allow the easy conversion of detection datasets to formats such as CSV so further analysis can be carried out in other software.

Fathom Position will allow researchers to carry out their own fine-scale positioning analysis of their detection data, as an alternative to the in-house Vemco Positioning System (VPS) analysis service that has been successfully operating now for many years.

Vemco will soon be releasing a new 307 kHz telemetry system which will be capable of fish tracking in the vicinity of large anthropogenic noise sources e.g. around hydropower structures. The 307 kHz tags are much smaller than those currently used by the 69 and 180 kHz systems, and the first of these will measure 3 mm diameter by 15 mm length. This system will allow the detection of hundreds of tags at the same time and provide precise time of arrival data for the ultra-fine scale positioning of tags.

Vemco has recently developed and made available several new sensor tag types, including its smallest ever sensor tags at 7 mm diameter. Acoustic Data Storage Tags (ADSTs) which continually measure, and store temperature and depth data are already available from Vemco in 9 and 13 mm diameter form factors, and in positively and negatively buoyant versions. These tags will transmit environmental data when within range of Vemco receivers, but otherwise need to be recaptured to offload their complete dataset.

The Vemco patented Predation / Digestion tag is now available in 69 and 180 kHz transmission versions and will soon be incorporated into the 307 kHz system. These patented tags change their transmission protocol when in contact with the stomach acid of an animal predator, providing a direct measure of predation. The new transmission also includes the time that has elapsed since predation occurred. These tags are currently available in 5, 7 and 9mm form factors, and can be combined with temperature measurement in the 69 kHz 7 and 9mm versions.

In addition to the above technologies, Vemco is continuing to develop its online support service at www.support.vemco.com. Users of this support service have access to a wealth of technical support information and can contact the Vemco support team directly there as well.

The quick and helpful support of Vemco users is of primary importance to both Vemco and RS Aqua, and going that extra mile for researchers forms a central part of the philosophy of both companies.

A Flexible Approach to Acoustic Telemetry

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Fish telemetry has existed for more than 60 years, and while the exterior has looked similar most of the time, internal components are undergoing continuous development. The mind-boggling development of micro-electronics enables us to enhance the performance of our products and open new possibilities for research. The ultimate goal of making telemetry products microscopic, everlasting, and virtually free - presents an endless motivation to innovate and advance.

This summary paper gives an overview of the latest technology from Thelma Biotel, explaining what has been developed the past year, and what will be launched over the upcoming year(s).

New Technology

Tag specifications, both hardware, and software can be combined and programmed, creating nearly endless amounts of possibilities. An online tag builder was developed for the company website to give a better overview of all the tag sizes, sensor combinations, and power options. Additionally, specifications such as transmit interval can be set and adjusted for a quick estimate of the effects this will have on the operational lifetime. The tag builder is easy to use and gives a visual indication of what the tag will look like in size by using 3D drawings and listing the estimated weight both in air and in water, as seen in figure 1.

Figure 1: Tailor your tag and explore all the possibilities using the tag builder on the company website.

ComPort, Thelma Biotel's free software for data transfer and receiver configuration, got a major overhaul in 2019. In addition to having a brand-new design, new features were implemented, helping to make data overview and mining much more effective. The configuration window has a new and more visual interface, making it easier to see what changes are to be made, and how they differ from the current settings. Additionally, ComPort now supports multi-frequency, enabling the possibility to select how many frequencies the receiver should listen to, and which ones. In the configuration window, it is also possible to select which protocols or groups of protocols, the receiver should listen for. By only selecting the protocols needed, the receiver will use less power, prolonging its battery life and storage space. In collaborative projects and network deployments, the receivers must be set to operate on the shared protocols. Once the first receiver is configured, ComPort will remember the settings for the next receiver in the same project, so that all of the remaining receivers can be configured by the simple click of a button.

The most recent firmware for the TBR 700 is built into the ComPort software, and the user will be notified if the receiver is not up to date. When connected to the internet, ComPort will check to see if there are any further firmware updates, and give notice if the receiver needs to be updated. New versions are backward compatible, and we stress that no protocols or compatibility are changed with updating firmware. The user controls the data and the receiver compatibility by choosing the protocols and frequencies that should be used in that specific study. The TBR 700 also allows for custom firmware, for projects with specific needs not covered by the standard firmware. Thelma Biotel is always willing to adapt to the researcher's needs when it comes to special programming for both transmitters and receivers.

When downloading data from the receivers, auto-transfer is a new function. If auto-transfer is selected, all stored data will start downloading once a connection is established. The user will be notified once the data is safely transferred to your computer. With a single click to acknowledge the transfer, the receiver will be disconnected and ComPort will move on to the next receiver in line with Bluetooth enabled. The only action required from the user is to make sure the receivers are set in Bluetooth mode.

Together with the software upgrade Biotel has developed new and improved firmware for the receivers: v_3.0.0. The firmware supports all of the newest protocols and a multi-frequency upgrade. The new and more robust protocols have improved checksums, significantly reducing the number of false detections. The ID span for both ID and sensor tags has increased significantly. For sensor tags, there are now more than 64 000 unique IDs, and for ID tags there are more than one million unique IDs. For tropical areas with increased amounts of biological noise, a custom receiver firmware has been developed to filter out specific background noise, increasing the effective range and the number of available tag detections.

The advanced design of the TBR family receiver can currently listen to up to three frequency channels in true parallel processing. It also provides the signal intensity of every signal and accurate timestamp. Combined, these features allow for the PinPoint position service, which supports simultaneous tracking for high-density tag sites at a meter-level accuracy – all while keeping the range and robustness of the R-type, 69 kHz range transmit protocols. This technology is effective in large tanks, cages and in the open sea. Time synchronization is provided on the surface for the cabled units or by acoustic synchronization signals for the stand-alone submerged loggers. All timing data and tag transmit intervals are openly available for the user to perform their own positional analysis, such as YAPS.

Upcoming Technology

To meet the challenge of tagging ever-smaller animals and keeping the current receiver technology operative and compatible, Biotel is now working on a 69 kHz compatible tag with a diameter of only 6 mm, as seen in Figure 2. The upcoming tag platform employs the latest sensor and embedded technology, coupled with modern electronics production, testing procedures, and assembly. The launch is planned for spring 2020. Accurate temperature, acceleration, and pressure sensors will be available on the 6 mm platform, as will standard ID. The larger transmitters will also benefit from this upgrade, with prolonged battery life, increased shelf life and the added possibility of re- programming after delivery.

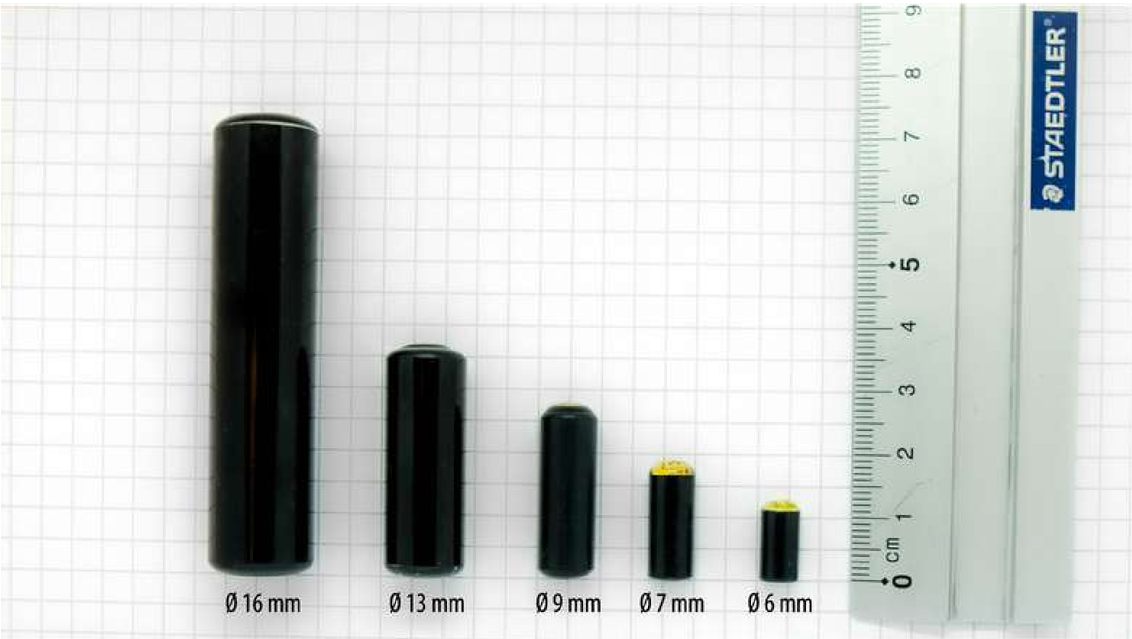

Figure 2: Overview of all tag sizes, including the new 6 mm tag.

Creating flexible designs allows for consecutive changes as new components emerge and smarter firmware is developed. The next generation Thelma Biotel Receivers (TBR), will keep the modular design where parts and features can be added or removed to suit the purpose of every deployment. An example is the acoustic release module, as a unit that can easily be added as an extension to the new generation TBR. Further, we develop sensor packages that are equally simple to install. This way the value of the investment is kept for many years to come.

Modular design is a cost-effective way of creating products. With fewer production lines and larger batches of main components, it makes the end product more affordable. Using the Tag Builder tool on our website, you can see how we can provide well over 200 different standard fish tags while keeping prices at a reasonable level.

Together with other manufacturers and the European Tracking Network (ETN), we have created new open protocols, making our tags and receivers compatible with the equipment from other manufacturers. The new protocols are efficient, robust, and have more than one million unique IDs. With an increasing amount of tagging projects and the continuous deployment of thousands of receivers around the world, it is important to cooperate to get the most out of the captured data. We believe in an open approach where groups that have invested in various equipment from different manufacturers, can share data and choose the best equipment to suit their needs at any given time.

After Dinner Presentation (5th November 2019)

Lessons Learned From Working On Large Scale Marine Tracking Arrays: Searching for Information in the 21st Century

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Initial optimism that decreasing survival of salmon in the Atlantic and Pacific Oceans could be managed through harvest restriction and restoring freshwater habitat has so far proven unfounded. This has resulted in the rather slow realisation that the marine survival issue needs to be addressed directly. This talk describes the authors perspective in designing and operating highly optimized marine acoustic telemetry arrays to address salmon conservation issues.

The most informative scientific results almost universally come from adopting “stretch goals” that refute current scientific hypotheses. In ocean salmon research, large scale marine telemetry arrays can be viewed as the equivalent of CERN’s Large Hadron Collider (but…on a more modest budget!) or various large-scale astronomical surveys. Success in these endeavours has been critically dependent upon getting the engineering right in order to answer big science questions. Equally important is the need to adopt the philosophical approach of testing an explicit experimental question, such as whether survival really is largely determined within some early life history period. Adopting this view then naturally transitions into thinking of properly designed telemetry arrays as “information machines”, that is measurement tools capable of making precise and accurate measurements of survival to test key theories. Within this framework other observational data on movement direction and speed (or depth of migration) naturally falls out. Unfortunately, the converse is not true, and arrays built in an ad hoc manner rarely will support sufficiently precise measurements of survival to be useful. This difference is important because the cost of marine telemetry studies will inevitably amount to several millions of dollars to be truly effective. However, current approaches will probably add up to far greater costs over time with little probability of ever yielding clear answers.

Over the past 15 years Kintama’s survival studies have shown that smolt freshwater survival is typically high. A more marked decline in survival is evident following ocean entry. However, it is also clear that much of the poor SARs (smolt to adult return rates) **could still be determined later in the marine phase**. Because Columbia River smolts, returning as precocious mini-jacks or jacks, do not migrate as far as the northern tip of Vancouver Island and (in common with all tagged Columbia River smolts) do not enter the Strait of Juan de Fuca, their migration routes at sea are thus quite precise. Although jack returns are frequently used for forecasting adult returns, jacks occupy a small marine area relative to smolts destined to return as adults, so they are not exposed to more distant ocean influences. Overall, our telemetry results found that downstream freshwater survival rates and survival rates during the first month of the marine phase contribute roughly equally to determining adult SARS. However, survival declines occurring later in the marine phase could determine why survival has fallen so drastically across the entire west coast of North America. This possibility may well hold more generally. For this reason, practitioners in the Atlantic should set up their telemetry studies to specifically test this possibility.

Analysis of tracking data

Researching Atlantic Salmon Marine Ecology – A 40 Year Perspective

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Fisheries historically provided evidence that Atlantic Salmon (*Salmo salar*) were found in the vicinity of coastal areas on their seaward migrations as smolts and early post-smolts, and on their return migrations as mature adults in all seasons. As marine fisheries for Atlantic Salmon developed at Greenland and Faroes and marine research expeditions were deployed, it became evident that salmon of various life stages were found in nearshore and offshore areas in essentially all seasons (Reddin 2006). Historic and contemporary samples and tagging programmes in combination with recaptures in fisheries, and new genetic technologies, have been highly informative of the migration phase of salmon at sea. These have shown that Atlantic Salmon is broadly distributed in the North Atlantic with some stocks from eastern North America migrating to the Northeast Atlantic and some stocks from Europe migrating to the Northwest Atlantic (Ó Maoiléidigh et al. 2018).

Observations from fisheries indicated that Atlantic Salmon were commonly distributed in the upper layers of the water column. It was not until the development and application of data storage tags with multiple sensors that log and retain data on temperatures, depths, and sequential locations of individual salmon at sea that the complex behaviour of salmon at sea was elucidated; collectively, data storage tag studies have shown the extent to which Atlantic Salmon spend a large portion of their time in the upper pelagic zone, with intermittent and generally very deep dives of short duration. Maiden salmon in their first year at sea (Gudjonsson et al. 2015) manifest similar behaviour to that shown by post-spawned salmon (kelts) at sea (Reddin et al. 2011; Strøm et al. 2017).

Monitoring of smolt migrations and subsequent adult returns from index rivers have documented the large inter-stock variation in return rates (adults per smolt; proxy for survival rates) of salmon across its distributional range in the North Atlantic, with returns rates in the Northeast Atlantic generally higher than in the Northwest Atlantic. Strikingly, there has been an important temporal decline in return rates to individual rivers from the 1970s and 1980s to the currently low return rates of the last two decades (ICES 2019; Figure 1). The return rates in the recent decades have plateaued or show increases but all remain low relative to the earlier period of higher abundance. Declines have also been more important for the salmon populations in the southern range than in the northern areas of the species distribution.

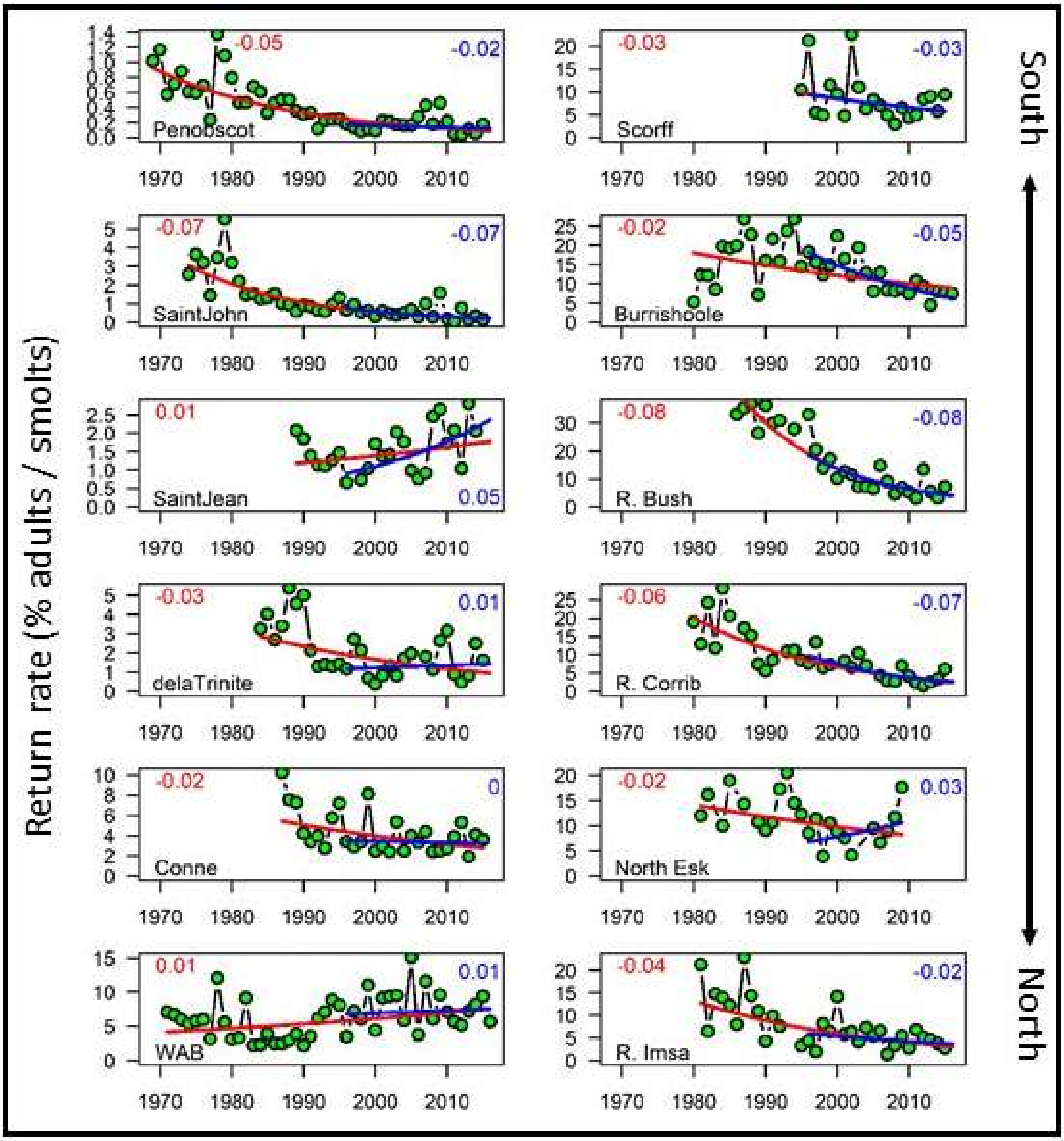

Figure 1: Reported return rates (‰; adult per smolt) of combined adult Atlantic Salmon sea ages by smolt cohort from monitored rivers in the western (North America, left column) and eastern (Europe, right column) North Atlantic. The instantaneous annual change over the time series for each river is shown in red and the instantaneous annual change since 1996 (smolt migration year) is shown in blue. Data are from the compilation by the ICES Working Group on North Atlantic Salmon (2019).

Survival at sea is not a random process; this is evident from monitoring programmes that show wild Atlantic Salmon smolt to adult return rates to be higher than hatchery return rates from the same river. Positive survival to smolt size dependence relationships (Gregory et al. 2019) suggest that mortality may not be expressed equally at all stages at sea.

The miniaturisation of transmitting tags that are subsequently detected by deployed acoustic receivers has provided new opportunities to learn about salmon ecology at sea, particularly for the smaller-bodied post-smolts in the initial migration period. Telemetry is good for learning about the timing and location of mortality events as you can get repeat observations of marked individuals, over time and in different locations, without having to catch them.

Just over 75 published studies, dating from 1975 to 2018, that used either acoustic or radio telemetry technologies to research various aspects of Atlantic Salmon smolt and post-smolt migratory phase were reviewed (Figure 2):

- Temporal coverage begins in the mid-1970s with most studies reported since the 2000s (Figure 2), hence the studies were conducted after the period of decline of salmon abundance and thus absent of the historical context for understanding the temporal changes in factors that have contributed to the declines in abundance of Atlantic Salmon.
- Temporal replication and spatial coverage is low; most studies are of one or two years duration, there is a handful of telemetry projects that have been replicated at the same location for more than five years, and the longest study at the same location was 14 years.
- Over all locations and years, 60% of individual studies had tagged and monitored less than 50 salmon smolts, with only 14% of studies using more than 100 smolts. The technology remains expensive. The small sample sizes constrain the ability to follow sufficient animals in time and space resulting in greater uncertainty in sequential estimates of survival.
- Smolts have been captured, tagged and released at various distances from the head of tide (<1 km to 187 km) and smolts and post-smolts have most often been tracked at sea over relatively short distances < 100 km; maximum distance monitored from head of tide to the last marine monitoring point is ~800 km for smolts from the Gulf of St. Lawrence (exit to the Labrador Sea) (Chaput et al. 2018).
- The size distributions of smolts used in individual marine monitoring studies are variable and stock specific; hatchery smolts are bigger than wild smolts and in many studies, wild smolts are quite small with mean lengths of 130 to 150 mm (Figure 2).

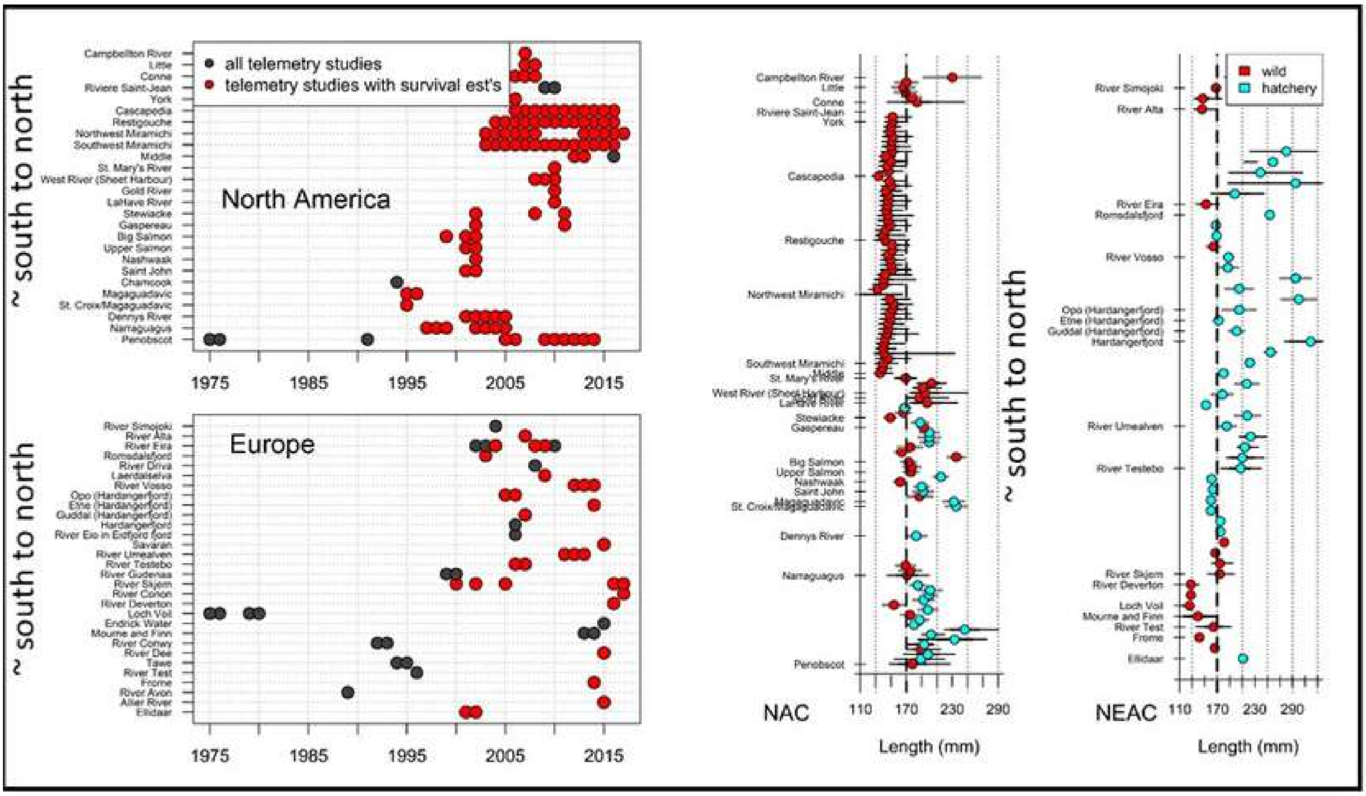

Figure 2: Summary of the location, timing, and size distribution of Atlantic Salmon smolts (wild, hatchery origin) in reviewed studies using telemetry technology to research the migration dynamics and survival of the smolt and post-smolt stages.

A number of studies provide estimates of "survival" rates during different phases of the smolt migration through freshwater and post-smolt migrations through estuaries and nearshore areas. For the freshwater phase, highly variable survival rates post-release are noted (Figure 3). In the North American studies (NAC), there is a general negative association between survival and migration distance, but with high variability. Survival declining with distance (or time) since release would be expected, particularly due to the initial tagging and handling effects. In Europe (NEAC), hatchery smolt survival rates through freshwater are generally lower than for wild smolts.

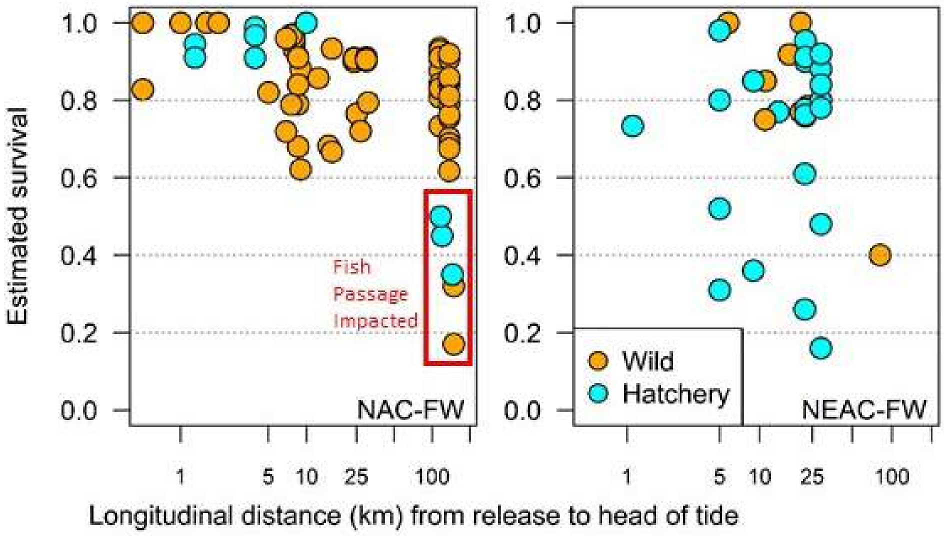

Figure 3: Summary of estimated cumulative survival by distance (log scale) from release to detection at the head of tide from studies of telemetry tagged Atlantic Salmon smolts in North America (left panel) and in Europe (NEAC; right panel). In the panel for North America, the highlighted low survival rates are from studies assessing the impacts of water regulation and hydro-electric generation on salmon smolt migration dynamics and timing in the Penobscot River (Maine, USA) (Holbrook 2007).

There is a general negative association between cumulative survival in the marine phase and distance to the monitoring point, with the maximum distance monitored ~ 900 km (Figure 4). Survival rate estimates are highly variable among locations of similar monitoring distances; these differences may in large part be related to differences in the bio-physical characteristics of the estuary, nearshore, and coastal environments transited by tagged salmon smolts as well as differences in experimental conditions among the studies.

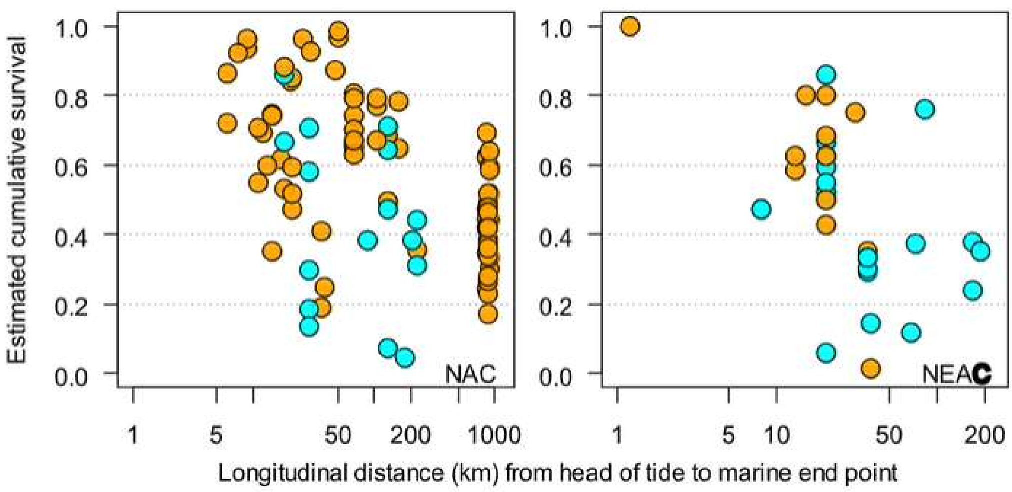

Figure 4: Estimated cumulative survival by distance (log scale) from the head of tide to the marine end point for detection of telemetry tagged Atlantic Salmon smolts in North America (NAC; left panel) and in Europe (NEAC; right panel).

An example of the annual and spatial variations of survival rates during different phases of the smolt and post-smolt migration through coastal bays and the Gulf of St. Lawrence is reported by Chaput et al. (2018; Figure 5). Over the 2003 to 2016 (smolt migration years) period of study, survival rates per km are lower through the coastal bays than during the offshore migration through the Gulf of St. Lawrence. Distance-scaled survivals through Miramichi Bay are lower and declined over time compared to those in the Chaleur Bay; a likely suspect is the high abundance of striped bass in the Miramichi area which are known to prey on salmon smolts and whose single spawning location and spawning period overlap with the smolt migration corridor and timing.

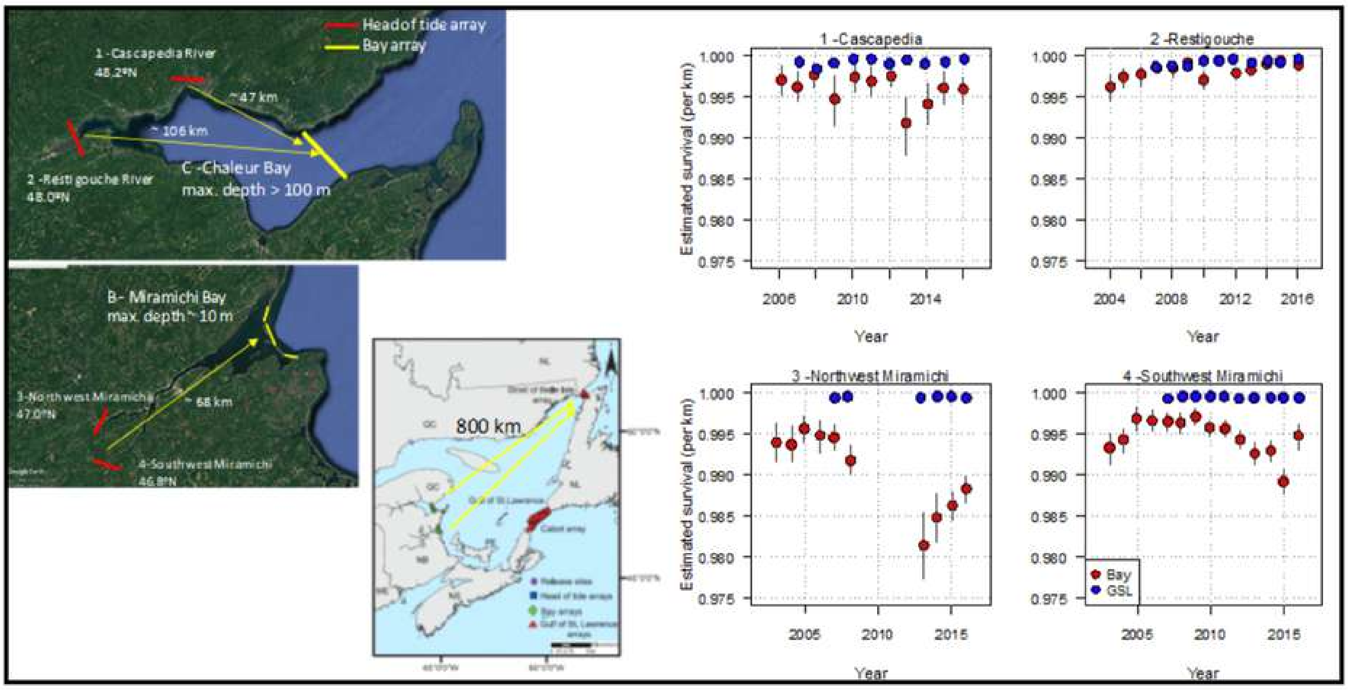

Figure 5: Estimated geographic area (bay; Gulf of St. Lawrence (GSL)) specific survival rates (per km) of telemetry tagged Atlantic Salmon smolts originating from four rivers, migrating through two bays (Chaleur Bay, Miramichi Bay) and collectively through the Gulf of St. Lawrence (Canada), 2003 to 2016 (Chaput et al. 2018).

The use of electronic technologies faces a number of challenges. In contrast to the historic annually supported marking and recovery programs undertaken by agencies for the purpose of fisheries management, there is substantially less domestic engagement in the establishment and maintenance of standardized annual tracking programmes. This stems in large part from the cost of the electronic technologies as well as the reduced information needs for managing the greatly reduced number of mixed stock marine salmon fisheries. Secondly, the biological limits of the experimental animals of interest may well be exceeded by the physical and physiological burden of transporting the current generation of electronic data loggers / transmitters. This is particularly important because the overall objective of these studies is to better understand wild fish dynamics and the assumption that empirical data from tagged animals are representative of un-manipulated animals is not certain.

Some additional points of consideration for researchers:

- For partitioning survival at sea, what are the relevant zones (estuary, bay, coastal), how are they characterized (depth, salinity, geo-physical features), and how should survival rates be calculated and reported (for ex. survival scaled by longitudinal length of the zone, survival scaled to mean/median time spent in the zone)?

- How to make each experiment useful and cumulative across years and studies. Are there minimum experimental details that should be reported, including a full description of the telemetry technology used (tag length, diameter, weight in air/water), of the experimental animals (length, weight, origin), of the manipulation protocols (recovery periods post-surgery, release type as single, by tag group, or with other smolts, and release locations (distance above head of tide, transport or not).

- Consider experimental designs that will facilitate replication and meta-analyses such as fixing positions of arrays at sea over several years.

- Understanding mark and recapture model requirements to optimize receiver deployments, as for example twinning the last receiver line to model detection probabilities.

With telemetry technologies, the challenge is to move away from the coast and later into the marine phase. It is reasonable to expect that technologies will continue to rapidly improve, removing many of the current constraints for studying the early phases of salmon post-smolts at sea.

Four decades plus of research and assessment have shown that older approaches, including sampling salmon at sea and re-analysis of historical marine samples using novel tools, in combination with anticipated further rapid developments in individual based electronic tags and technologies will be required to more fully understand the complex ecology of Atlantic Salmon at sea.

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Data management and analysis of tracking data

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Telemetry is a commonly applied method to investigate the ecology and movement behaviour of aquatic species in relation to their environment. It provides a scientific basis for management and conservation and has significantly improved our understanding of ecosystem functioning and dynamics. More specifically, telemetry provides valuable data that can be used in many policies and directives. To be able to do so, large-scale nationally and regionally managed networks are needed. With the European Tracking Network (ETN) (http://www.europeantrackingnetwork.org/) we want to ensure a transition from a loosely-coordinated set of existing regional telemetry initiatives to a sustainable, efficient and integrated Pan-European network embedded in the global arena of already existing initiatives outside Europe.

The backbone to achieve the goal of an integrated Pan-European tracking network is coordinated data management. This can be achieved using a central data portal (www.lifewatch.be/etn) storing all types of aquatic animal tracking. The requirements and policy should be mapped to the existing international biotelemetry data systems and adopt the FAIR Data Principles.

The portal, in its current form, stores all (meta) data related to acoustic telemetry. Different brands are supported. However, extension to be able to capture other types of aquatic animal tracking data (i.e. PIT, DST and satellite data), is needed to become all-inclusive in relation to the animal tracking.

ETN aims at implementing the FAIR Data Principles (see Figure 1). FAIR stands for Findable-Accessible-Interoperable-Reusable and the intent of the FAIR principles is that these may act as a guideline for those wishing to enhance the reusability of their data holdings. They put specific emphasis on enhancing the ability of machines to automatically find and use the data, in addition to supporting its reuse by individuals (Wilkinson et al. 2016).

Box 1 | The FAIR Guiding Principles

To be Findable:
F1. (meta)data are assigned a globally unique and persistent identifier
F2. data are described with rich metadata (defined by R1 below)
F3. metadata clearly and explicitly include the identifier of the data it describes
F4. (meta)data are registered or indexed in a searchable resource

To be Accessible:
A1. (meta)data are retrievable by their identifier using a standardized communications protocol
A1.1 the protocol is open, free, and universally implementable
A1.2 the protocol allows for an authentication and authorization procedure, where necessary
A2. metadata are accessible, even when the data are no longer available

To be Interoperable:
I1. (meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation.
I2. (meta)data use vocabularies that follow FAIR principles
I3. (meta)data include qualified references to other (meta)data

To be Reusable:
R1. meta(data) are richly described with a plurality of accurate and relevant attributes
R1.1. (meta)data are released with a clear and accessible data usage license
R1.2. (meta)data are associated with detailed provenance
R1.3. (meta)data meet domain-relevant community standards

Figure 1: The FAIR Data Principles

Good data management, taking care of the FAIR Principles, will lead to knowledge discovery and innovation, and to subsequent data and knowledge integration and reuse by the community after the data publication process. Thus, beyond proper collection, annotation, and archival, data stewardship includes the notion of 'long-term care' of valuable digital assets, with the goal that they should be discovered and re-used for downstream investigations, either alone, or in combination with newly generated data. The outcomes from good data management and stewardship, therefore, are high quality digital publications that facilitate and simplify this ongoing process of discovery, evaluation, and reuse in downstream studies.

FAIR data strives towards open access, and there are several advantages of doing this:

- It is (or will become) required by our funding agencies (e.g. Horizon 2020 and the Open Access Data Pilot).
- It aids in repeatability/validation of scientific results & greater (public) trust.
- There will be a wider use of your data, leading to greater visibility and more citations.
- You have more complete datasets, with information outside your own network.
- If you share, others share, and we all gain by having access to more data. As Nguyen et al. (2017) stated: Collaboration and engagement produce more actionable science.

However, data policies should be in place to protect data ownership. ETN also has a data policy (http://lifewatch.be/ETN/assets/docs/ETN-DataPolicy.pdf) with specific moratorium rules:

- Receiver moratorium: there is no moratorium for receiver information.
- Tag moratorium: there is no moratorium for tag information.
- Deployment moratorium: there is no moratorium for deployment information. All metadata is made publicly available immediately after installation. All open deployments (i.e. without an end date) will be visualised on a map on the ETN Data Portal. In exceptional cases, a deployment moratorium can be requested, with the ETN Data Committee reviewing requests.
- Animal moratorium: metadata related to tagged animals are placed under moratorium by default, in accordance with moratorium rule 5 of this policy.
- Detection data moratorium: detection data are placed under moratorium by default following a three-tier process:
    - i. Tag owner: has access to all detections of his/her tags (also from receivers that do not belong to the tag owner).
    - ii. Receiver owner: all detections on the device are shown with species information (also from tags than do not belong to the receiver owner)
    - iii. Others: no access to detection information from data under moratorium.
- Moratorium period is set at 4 years by default, starting from the moment a tag is attached to an animal. The moratorium period can be extended on request, but earlier release of data is highly desirable. Principal Investigators may request extension to this moratorium period by one-year increments, with the ETN Data Committee reviewing requests.
- Only detections from tags that are known by the database (i.e. tags that are linked to a specific project) will be listed.

ETN makes a distinction between Restricted and Unrestricted Data. Unrestricted Data is all data that is not under moratorium, outlined in the moratorium rules. Public access to Unrestricted Data is through the R-shiny data explorer (http://rshiny.lifewatch.be/ETN%20data/). Unrestricted Data is licensed as CC-By. This license lets others distribute, remix, tweak, and build upon the original Data Owner's work, even commercially, as long as they credit the Data Owner for the original creation (https://creativecommons.org/licenses/). Restricted Data is all data under

under moratorium. Access to that data is restricted to Data Owners and Data Collaborators granted access by the Data Owners and is in accordance with the moratorium rules as listed above.

Further, the scientific advancement in aquatic animal tracking also requires commitments from the industry to advance technologies and ensure compatibility between brands (Hussey et al. 2015). The European telemetry scene is highly diverse, using multiple telemetric approaches and equipment from several brands. However, the different brands don't have any agreements regarding transmit protocols, ID allocation and tag serial numbers. Tags from one brand might thus not be recognised by receivers of another brand. This is notably the case in acoustic telemetry. This leads to the potential loss of valuable data, tag code duplications and misinterpretations of results. To move forward towards a much-needed Pan-European collaborative network that could provide relevant information in support of decision making, compatibility between brands and agreements on transmit protocols and ID allocation is imperative. ETN has been in interaction with Vemco-Innovasea, Lotek, Sonotronics and Thelma Biotel to tackle this aspect. Lotek, Thelma-Biotel and Sonotronics have agreed on a common standard protocol which they would like to hand over to a third-party organization like for control. There are currently two open protocols; one for ID tags (OPi) and one for sensor tags (OPs). They have optimized for low level of transmit collisions, high amount of unique IDs as well as robustness against false IDs.

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Inferring fish survival from telemetry data: Promises, perils, and emerging methods

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This summary paper provides an overview of methods for estimating survival of fishes tagged with acoustic transmitters. While telemetry has revealed unprecedented information about animal movements and space use at scales not feasible with other technologies (Hussey et al. 2015), the ability to determine the location, timing, and cause of death of individual fish remains elusive. This paper outlines key design elements of mark-recapture models commonly used to estimate survival from telemetry data and key assumptions that have been difficult to address empirically.

A key challenge of using mark-recapture models to estimate survival is that models often require movement to be unidirectional in order to account for imperfect detectability. For models that estimate survival through time, this is implicit (time never moves backward) but studies that estimate survival through spatial regions (e.g., river reaches, embayments) must rely on carefully designed receiver networks for the behaviour of tagged individuals to ensure that the proportion of animals detected (or not detected) at each site can be inferred from detection later or farther "downstream". Perhaps the most ubiquitous implication of this requirement is the need for at least one "extra" sampling event beyond the time or location in which survival is desired. This is due to our inability to separately identify the detection probability at the last sampling location and survival through the last time interval or location. Similarly, in models that allow individuals to occupy discrete states at any given time or location (e.g., migration routes during smolt outmigration), receivers must often be arranged so that detection probabilities can be separately estimated within each state (i.e., two or more receiver stations that are exclusive to each route). For studies of migrating smolts in rivers, a receiver station may be easily added to achieve those goals, but for other life stages or in more open environments (coastal or open-ocean) these requirements may require more creative solutions.

As with any other inferential method, the usefulness of survival estimates from telemetry studies depends on the degree of uncertainty about parameter estimates (i.e., standard errors and confidence intervals). Mark-recapture models often assume that uncertainty arises from the binomial distribution and is thus, related to the sample size (n) at a given time/location and the specific values of each parameter at each location. For each parameter, n is effectively the number of fish "in play" at that time/location—not at release. Thus, for a single release of tagged individuals, uncertainty in survival estimates will increase as individuals are lost due to reductions in n at each subsequent sampling location. Similarly, for any given n, uncertainty under binomial distribution is greatest when s = 0.5 and smallest near 0 and 1. Studies that require a specific level of precision (or minimum detectable effect size) are often designed based on pilot study data and simulation to determine the number of tagged fish that would need to be released to achieve desired precision of estimates. The relatively high cost of telemetry transmitters may preclude the use of telemetry altogether for survival estimation if the required sample size is cost-prohibitive.

Accuracy and precision of survival estimates from telemetry data depend on many assumptions that may be particularly challenging to evaluate, though recent advancements that have made some elements tractable:

- Tagged individuals are assumed to be representative of the population of interest. Were the tagged fish randomly sampled from the target population, or could they merely represent a distinct segment of the population based on how, when, or where they were collected or released? For example, anomalous survival estimates have been attributed to differences in release timing between tagged and untagged smolts (Welch et al. 2009; Holbrook et al. 2011). Moreover, the number of fish tagged is often a very small fraction of the target population. True random sampling from a target population may be logistically daunting or simply impractical due to lack of information about the target population.

- Survival of tagged fish are assumed to be equal to untagged fish, and thus, tagged fish are not adversely affected by tagging or handling. This assumption is often acknowledged and has received much attention, but empirical evaluation may be needed whenever possible due to potential for study-specific circumstances to affect outcomes. For example, Holbrook et al. (2016) found that coded wire tagged adult sea lamprey (a notoriously resilient fish) were 1.26-2.74 times more likely to be caught in traps than acoustic-tagged individuals.

- All tags are assumed to be correctly identified and the status of tagged fish (alive or dead) is known without error. In survival studies, particularly of migrating smolts, “false positives” can arise from detection of dead fish drifting downstream or tags in live predators after a predation event (Romine et al. 2014; Gibson et al. 2015). Conversely, false negatives can arise if tags are expelled from live fish or fail prematurely (Townsend et al. 2006; Holbrook et al. 2013). Relatively new developments in tag technologies, such as predation sensors and accelerometers, may improve ability to evaluate these assumptions or explicitly account for these processes.

A study of out-migrating Atlantic salmon smolts in the Penobscot River, Maine (Holbrook et al. 2011) was an example of a common and widely used study design and modelling approach to estimate survival from telemetry data. In that study, data from acoustic receivers throughout the river were used to estimate the proportion of the smolt population that survived each discrete river reach and the proportion of smolts that used each route around an island where significant hydro-system changes were expected due operational changes among several hydroelectric dams. The model was a multi-state mark-recapture model fit using maximum likelihood estimation in Program MARK. A key result of that study was that the highest rates of mortality (proportion lost per river km) were observed in three reaches containing hydroelectric dams.

From a modelling standpoint, out-migrating smolts may present the most tractable study systems for estimating survival. For other life stages or more complex environments, significant challenges may be encountered. For example, in a study of walleye in Lake Huron (Hayden et al. 2014) tagged fish were tracked using a “coastal” receiver network comprised of a set of receiver lines arranged along one shore of the lake. A multi-state mark-recapture model was used to the probabilities of moving and surviving to each line (e.g., state-specific) during post-spawn migration (away from spawning tributary), but due to the openness of the system, a single parameter was used from each receiver line to represent the probability of returning to spawn the next year. That study showed that a larger-than-expected fraction of the population migrated to northern Lake Huron and returned to spawn in the same tributary the next year. As the number of receivers in the Great Lakes has increased in recent years, survival studies in open lakes have become popular.

In summary, some fundamental challenges will remain for the foreseeable future, including empirical evaluation of tag effects, representative samples, tag expulsion, and tag failure. Some research questions have become more tractable with recent advances such as tags and algorithms that detect predators and accelerometer and DST tags that can be used to confirm the state at detection (alive vs dead).

An appropriate sampling scheme (receiver arrangement) is critical to success (accurate and precise survival estimates) and will be especially challenging in marine and coastal environments. Networks and mobile platforms (gliders) may improve ability to collect observations in these environments, but careful planning and collaboration will be key to ensure that the location and timing and effort will be suitable for accurate and precise survival estimates.

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Maximising the benefits of multiple tracking projects

Electronic telemetry, networking and the possibilities for tracking salmon at sea

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Anyone with even a casual interest in the Atlantic salmon is aware that the abundances of our wild populations have fallen to the lowest levels on record. The pain is not evenly distributed across the species range: Europe seems to be faring better than North America, but southern populations on both continents have deeply declined and in North America the southern third of the species distribution is on the brink of biological extinction (ICES 2019).

There are many causes of salmon declines, most due to the historic impacts of humans. Dams have blocked spawning migrations, poor land-use practices have pumped sediment to rivers smothering spawning areas, harmful invasive species have been moved illegally into salmon waters, and the removal of riparian vegetation has warmed rivers to levels that are harmful to juvenile and/or adult salmon. On the positive side, we humans did learn from the environmental harms that we inflicted, which meant that for the Atlantic salmon by the mid-1990s we had instigated protections to safeguard the fish and their habitats and thought that we were now poised for a recovery. Instead, we entered into a new period of decline, driven primarily by falling survivals while the salmon is at sea (O'Neill et al 2000, ICES 2019).

The Atlantic salmon's ocean feeding migrations can cover vast distances, depending on whether the individual animal matures as a grilse or a multi-sea winter fish. Critically, the ocean of today is not the ocean of past decades. Industrial fishing has greatly reduced the biomass of valued species, altering species diversity, food webs and ecosystem stability and function (Pershing and Stamieszkin 2020). Perhaps the greatest change is the rapid warming of the ocean feeding areas inhabited by salmon, due to human-induced climate change (Saba et al. 2016). This too is having huge impacts on the North Atlantic Ocean, altering species compositions and distributions, and changing water circulation patterns and water column thermal regimes. These change in turn may be impacting the quantity and quality of food available for salmon. Such impacts may affect the species' energetics as warming water speeds up their cold-blooded metabolism. It may alter the disease organisms they encounter and have to cope with, and also change the numbers and kinds of predators they encounter. Some or all of these stressors may be contributing to our current salmon declines, but we do not have conclusive evidence about what is actually occurring, and which factors are the most important. This is a critical fault for our management regimes, as it is very difficult to provide a remedy if we do not know what the problem is.

We need to observe the salmon at sea to understand what is going on, however, the ocean feeding areas of the salmon span vast areas ranging from the Arctic to temperate regions, and salmon move through the water column from the surface to depths of hundreds of meters (Strøm et al. 2017). The only way to follow the salmon here for extended periods is with electronic tagging technology. The salmon is not the only valued migratory species in the North Atlantic Ocean that is under duress and for which we are seeking explanations of causes to guide management (e.g. Block et al. 2019, Iverson et al. 2019). Other species that share the same ocean regions with salmon, and are also highly valued, are also under duress.

There are three primary types of electronic telemetry: data storage tags, satellite tags, and acoustic tags. All have unique advantages and disadvantages. Data storage tags (a.k.a. data loggers) are small enough to fit on animals as small as smolts, have batteries that will last for years, and can store at short intervals an animal's geographic position (through light-based geolocation). They can also record the depths and temperatures the animal is experiencing. However, investigators must retrieve the tag to access the recorded information, which means we learn nothing about salmon that that die in the ocean sea with no tag recovery. By contrast, satellite tags will provide the same information as data storage tags with the added advantage that they can pop to the surface at a pre-programmed interval or after an animal dies and transmit stored data via satellite to the tagging teams. Their disadvantage is they are currently too large to fit on salmon smolts and most post-smolts, and their batteries typically last for only about a year. Acoustic tags come in a variety of sizes enabling investigators to tag both smolts and adult salmon. However, small tags have small batteries, and this limits smolt-sized tags to reporting over a few months whereas larger (adult) tags can last for years. Acoustic tags can carry sensors that report temperature, depth and whether or not the animal has been eaten by a predator (based on whether or not the tag is bathed in stomach acid), however, acoustic tags only provide instantaneous reports of what they are measuring when they are within range (≈ 1000 m) of acoustic receivers that have to be pre-positioned at known locations in the ocean.

All forms of electronic telemetry are expensive. In any given telemetry study, thousands of fish may need to be tagged to provide meaningful results, and the studies may need to be repeated in multiple years. A single satellite tags cost thousands of US dollars and each data logger or acoustic tag costs hundreds of dollars. In the case of acoustic telemetry, arrays of acoustic receivers (depending on model, each receiver can cost up to tens of thousands of dollars) need to be deployed in sufficient numbers and over large enough geographic areas to detect the salmon at sea.

The scale and cost of the work that needs to be done on salmon is beyond the scope of what can be afforded or accomplished by a single individual, or an isolated research group. To enable the sustained research covering the North Atlantic Ocean, we need to network. For salmon, the benefits of networking include:

- Bringing researchers together to develop testable hypotheses about stressors affecting salmon survival and distributions in the ocean, to build research plans, and to conduct the tests that will move our knowledge of salmon forward.

- Sharing resources and data amongst groups working on salmon and other valued species to make the work efficient and affordable.

- Stimulate and support the development of new technologies and sensors that will address important questions about salmon.

- Draw in the multidisciplinary capabilities (e.g., social scientists to address resource conflict issues; health scientists to address emerging disease issues, etc.).

- Creation of data systems for acoustic telemetry to share information about tag detections that occur on receivers maintained by individuals or groups other than the one that may have tagged the salmon in the first place. More broadly, the data system will curate and secure data from all types of tags and these data will provide us will baseline information against which future changes in salmon distributions and movements can be assessed.

- Provide the capability to react to a fast-changing ocean.

Researchers are now coalescing into networks to share infrastructure and data. Globally, the Ocean Tracking Network (OTN) is working to unite existing infrastructures and to create a global system that will enable the collection and exchange of data on a global scale (Cooke ta al. 2011). It is estimated that there are more than 20,000 mutually compatible acoustic receiver units currently deployed in the ocean, many in the North Atlantic region (Fig. 1). As these are linked together through the data system, they will enable watershed groups to benefit as they tag fish locally and receive back detections from widespread ocean receiver arrays. The local groups in turn provide valuable information to scientists on the river-specific movement and survival patterns that salmon exhibit, which will help us better understand the stressors on salmon.

Figure 1: Locations of individual acoustic receivers which are linked to exchange data among the North East Pacific (NEP-blue), Ocean Tracking Network (OTN-red) and South African (SAF-green) data nodes.

OTN is also working with multiple partners to create the necessary data system to curate, secure and exchange data on the detections of acoustically tracked animals across the globe (Fig. 2). In some cases, this involves the OTN providing a framework node to organize the partner's system to be fully interchangeable. In other cases, the OTN data team works with existing systems to cross-map them to enable data exchange. The OTN is internationally certified (Associate Data Unit of the UN's Intergovernmental Oceanographic Commission's' International Oceanographic Data and Information Exchange; Tier II node of the Ocean Biogeographic Information System) and is founded on FAIR (Findable, Accessible, Interoperable, Reusable) principles that meet the demands of public funders that data from public money spent on research must be publicly accessible. The system also uses open-source architecture, to make it affordable and because no organization will outpace/out-think/out-innovate the scale and energy of the open-source community.

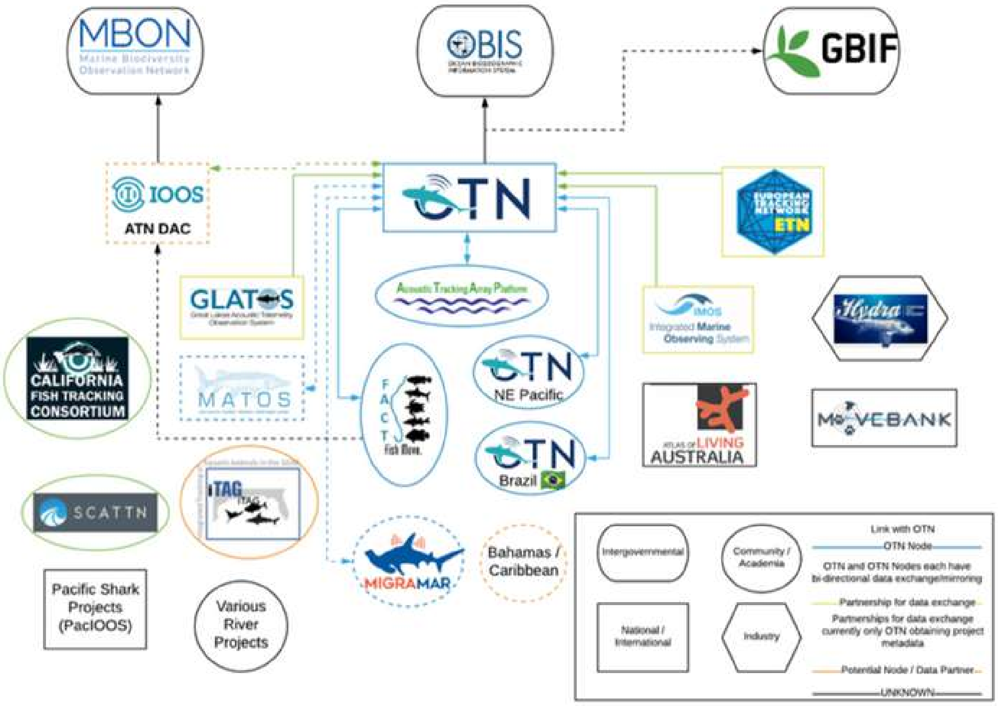

Figure 2: The various data systems and tracking nodes and their linkages to the OTN data systems.

Telemetry is enabling us to follow Atlantic salmon on their far-reaching ocean migrations and fostering multidisciplinary research that was not previously possible. The new knowledge being provided will transform our understanding of the biology and ecology of Atlantic salmon and help guide us as we try to restore stability and resilience to the species.

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Science for crafting policy: acoustic tracking of salmon smolts and post-smolts

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Introduction

Policy development generally follows a series of events including initiation, planning, options appraisal, decision, presentation, delivery, evaluation and review. Engagement with interested parties together with gathering of evidence occurs at each stage. In some cases, evaluation and review may lead to initiation of a revised policy and so a cycle of actions ensues until the process is complete. Hence, science is a key component of crafting policy since it provides evidence to inform decisions at each stage of the policy cycle.

The key characteristics of scientific evidence that lead to broad buy-in are that it should be robust, generalizable and understandable. The counteracting factor is cost effectiveness, since robust, generalizable science comes at a price and may need to be collected across a number of years. Hence, policy decisions may need to use best available scientific evidence while more robust information is obtained.

Acoustic tracking of salmon smolts and post-smolts (the life stages at which the fish migrate down river and through the coastal zone) is potentially useful in two important contexts that are considered here. First, monitoring losses of tagged fish within rivers may contribute to understanding of predation. Second, tracking of fish through the coastal zone may provide information on distribution of post-smolts in time and space to inform marine spatial planning.

Losses of smolts on downstream migration

Tracking smolts downstream has the potential to identify areas where losses occur and the proportion of the population lost to predation. It is important to recognise that losses during migration may result from a number of different factors. Usually, the most useful information that might be accrued is the loss due to predators that reflects mortality in untagged smolts, P. However, actual measurements can be expressed as:

Loss = P + H + (PH) + T + (PT) + E + F + M

where:

H = death due to handling (including capture) directly
(PH) = death due to additional predation caused by handling
T = death due to physical effect of a tag or result of tagging procedure
(PT) = death due to effect of the tag on escape ability
E = loss due to tag ejection
F = loss due to tag failure
M = loss due to missing passing tagged fish

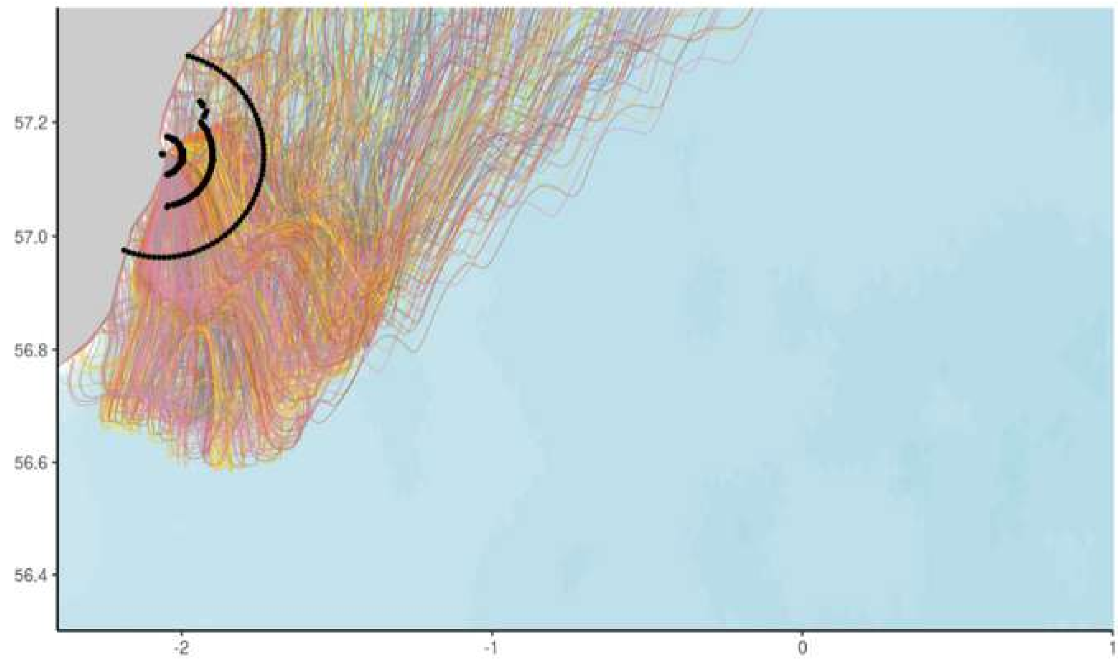
To move towards estimating P as robustly as possible, it is necessary to minimise those parameters apart from P on the right hand of the equation. In practice, this will involve using the smallest possible tags (or at least quantifying effects of tag size in the natural environment- not a tank where there are no predators and hence PT is not measured). It will also involve minimising effects of handling. Salmon and sea trout smolts are delicate animals that are easily damaged. Furthermore, capture and handling interfere with the normal downstream migration and change behaviours making fish more vulnerable to predators. Further work should tag fish before they commence their smolt migration to reduce impacts of handling. A further consideration is that fish can eject tags through the body wall or when suturing fails. It is important to quantify ejection rates and minimise them, probably by using small tags of specific design.

Distribution of post-smolts departing through the coastal zone

Smolt emigration can be considered to be a three-phase process. The first phase involves leaving the river and escaping in-shore features, such as islands. The second phase is a pause during which fish may drift on currents. The third phase is directed swimming, perhaps augmented by currents, to take the fish to high seas feeding grounds.

First phase dispersal is likely to be subject to local adaptation. For example, salmon smolts in Loch Linnhe, Scotland, head rapidly south-west as they leave the loch (Middlemas et al., 2016), exhibiting a behaviour that would clearly be mal-adaptive on the east coast of Scotland. The third phase dispersal may also be subject to local adaptation due to spatial variations in currents (Ounsley et al., 2019).

Little is known about the second dispersal phase, apart from the fact that it does exist at least in some cases. Preliminary data (Main et al., unpublished) suggest that many smolts from the Aberdeenshire River Dee drift to the south and south-east after leaving the river rather than immediately swimming actively to northerly feeding grounds. Such behaviour can rapidly spread fish over a wide geographic area depending on state of the tide (Fig. 1) and greatly increase difficulty of tracking subsequent directed movements.



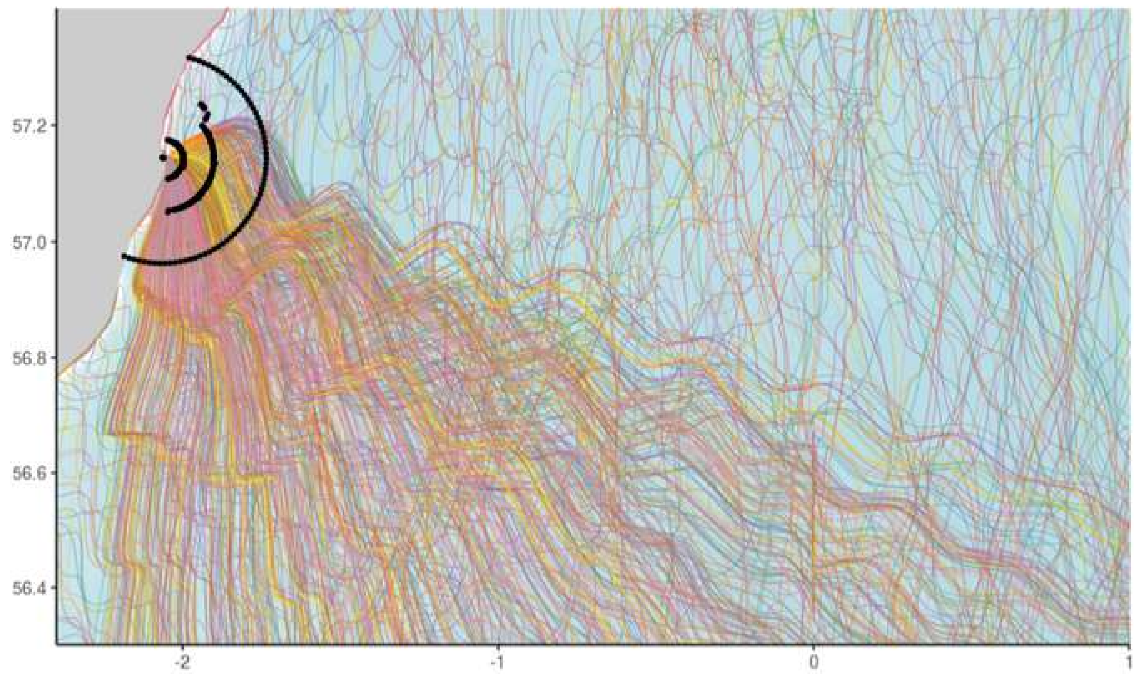


Figure 1: Particle tracking simulation of post-smolt migration from Aberdeenshire River Dee forced by a hydrodynamic model of the Scottish continental shelf. Lines show trajectories of simulated fish released over a 12-hour period with an initial trajectory reflecting the directional distribution and speed of receiver detections of tagged fish (black dots show receiver locations, outer receiver array = 20 km radius). Post-smolts drift on the current and then transition to a northward swimming trajectory after 1 (frame at bottom of previous page) and 5 (frame above) days.

It is difficult to verify mortality or survival of post-smolts at sea due to limited and variable range of moored receivers, false detections and in some cases the possible widespread dispersion of fish. However, acoustic tracking may be very useful for identifying general distributions of post-smolts in space and time. A recommended approach is to develop and test dispersion models that combine knowledge of local currents and notional fish swimming behaviour (Ounsley et al., 2019). Empirical testing may then identify actual swimming vectors and increase the applicability of models as generalizable predictive tools in spatial planning.

Deployment of acoustic receivers in leaky curtains between land masses has been widely applied to locate tagged fish. This approach at strategic locations could be useful for model testing and refinement of models. For example, considering Fig. 2, a deployment of receivers incorporating the string of Hebridean islands, could differentiate likely swimming vectors of post-smolts originating from south-west of Mull. More generally, deployment of receivers in grid arrays has significant merit (Morris et al., this volume) but may be constrained by cost and risk of obstructing fisheries.

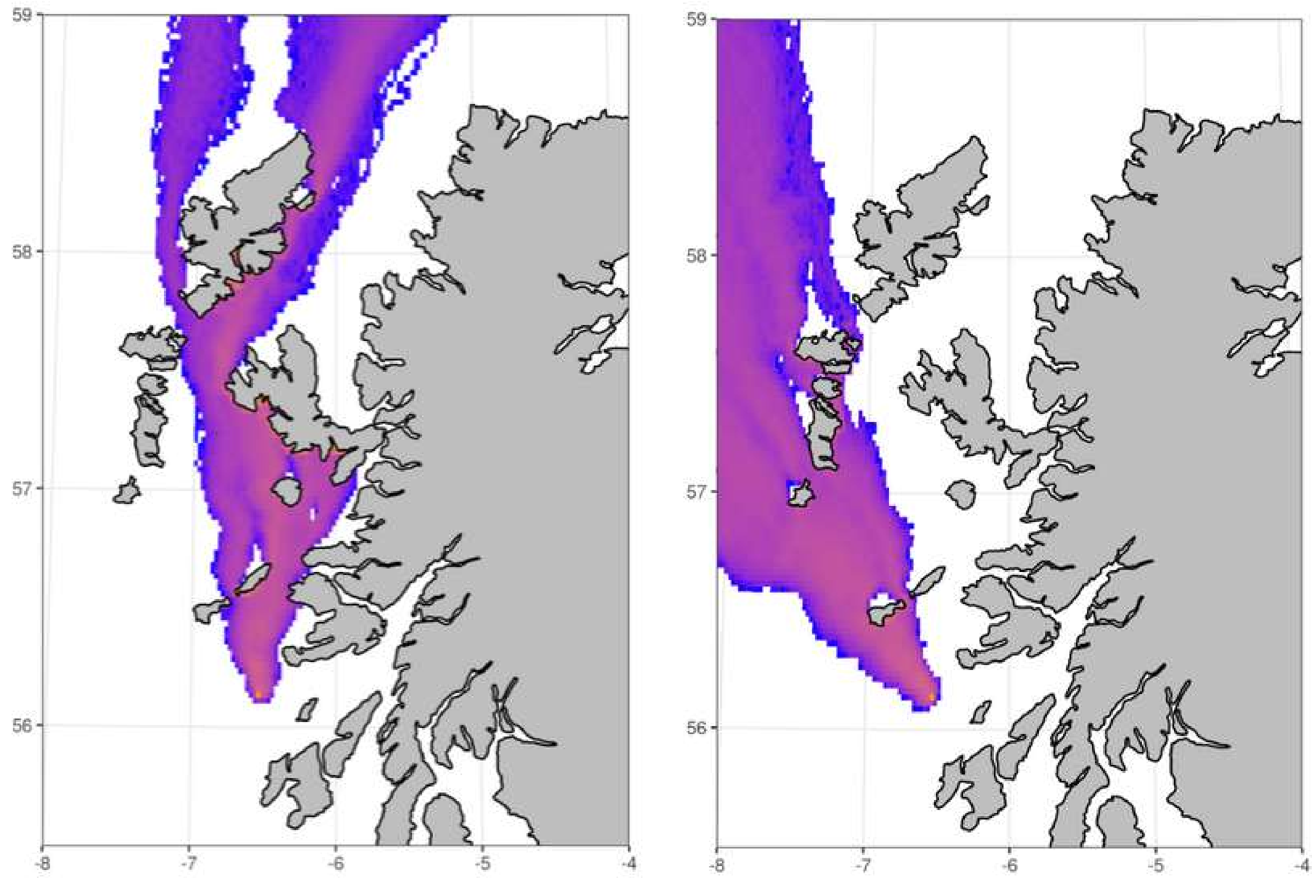


Figure 2: Particle tracking of post-smolt migration on the west coast of Scotland, originating south-west of the Isle of Mull, forced by a hydrodynamic model of the Scottish continental shelf. Heat maps show distribution of particles migrating along a north (left frame) and north-west (right frame) trajectory (+/- 15 degrees) with a swimming speed of 2 body lengths per second.

Conclusions

Tracking smolts and post-smolts has great potential for providing scientific information for policy development. At present there are significant challenges in securing data that are sufficiently robust to quantify losses to predators and survival at sea. However, there is good potential for assessing distribution patterns of fish and building generalizable models of migration behaviours. Future work should reduce transmitter size, tag salmon before they have started their smolt migration and consider application of grid arrays rather than curtains of receivers to determine migration vectors.

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The Way Forward: Future Research and Management Priorities

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Conclusions and Recommendations

Drawing from the foregoing summaries this final chapter provides conclusions and recommendations arising from the SAMARCH Tracking Workshop.

Despite conservation measures involving constraints on fisheries and on-going restoration of freshwater habitats, many migratory salmonid populations have experienced a continuing decline in productivity since at least the early 1990s, particularly at the southern extremes of their ranges. That's not to say more action is not required in the freshwater phase - past industrial gross pollution has now been replaced by more subtle, diffuse water quality pressures, such as excess fine sediments, phosphates and chemicals. Industrial rivers are now in many cases faring better than rural rivers, where these diffuse pollution pressures, mainly derived from agriculture, occur. The pressures facing salmonids are vast. The Likely Suspects Framework will provide important information to start to prioritise these pressures, so further work can be targeted to produce the greatest gains for populations of salmon and sea trout.

The Survival of Migratory Salmonids at Sea

Low marine survival is generally accepted as a major cause of decline for many populations, but the mechanisms involved, and the contributing factors, are poorly understood.
In the case of Atlantic salmon its ocean feeding migrations can cover vast distances, depending on whether the individual animal matures as a grilse or a multi-sea winter fish. We need to observe the salmon at sea to understand what is impacting on these populations. However, the ocean feeding areas of the salmon span vast areas ranging from the Arctic to temperate regions, and salmon move through the water column from the surface to depths of hundreds of meters, if not at times thousands of metres.

Fundamental to understanding the overall decline in stock abundance is assessing the migration and distribution patterns of salmonids across what are described as "domains" in the Likely Suspects Framework, to help identify the key factors affecting survival and fitness across the entire life cycles of both salmon and sea trout. Work to date indicates that out-migrating smolts may present the most tractable study systems for estimating survival. For other truly marine life stages or more complex environments, significant challenges remain.

Over the course of the discussion period at the workshop we were reminded that the demand for greater and great numbers of experimental wild smolts to be tagged is against a background of diminishing wild stocks, particularly in the case of salmon. If we wish to replicate the impressive but far longer duration tracking programmes (14 years) along the east coast Canada, we must be conscious of the very limited pool of natural experimental animals we have available to us.

We should re- evaluate the results from earlier tracking and tagging programmes such as the extensive use of coded wire tags across Europe and North America in late 80's and 90's and the genetic assignment work from

SALSEA which has provided us with some very powerful data sets. It was reported to the meeting that work on expanding the original SALSEA database is underway as part of the Norwegian SeaSalar Programme.

We were cautioned that we should not be deflected from a rigorous assessment of clearly defined hypotheses by the inventiveness and the cleverness of new and emerging tracking technologies. We are not tagging just to get the most out of a particular type of tag but testing core hypotheses within the marine environment.

One important research area not covered by the workshop was the survival of returning adults in nearshore areas and in estuaries when they are confined to these saline / semi-saline environments. With changes to the climate regime set to make periods of severe drought in our rivers and intertidal areas more common, this is an important area for further work in the future.

Tracking Tools

There are three primary types of electronic telemetry: data storage tags, satellite tags, and acoustic tags. All have unique advantages and disadvantages. Data storage tags are small enough to fit on animals as small as smolts, have batteries that will last for years, and can store at short intervals an animal's geographic position (through light-based geolocation). They can also record the depths and temperatures the animal is experiencing. However, investigators must retrieve the tag to access the recorded information, which means we learn nothing about salmon that that die in the ocean unless the tag is found by chance on a beach. By contrast, satellite tags will provide the same information as data storage tags with the added advantage that they can pop to the surface at a pre-programmed interval, or after an animal dies, and transmit stored data via satellite to the tagging teams. Their disadvantage is they are currently too large to fit on salmon smolts and most post-smolts, and their batteries typically last for only about a year. Acoustic tags come in a variety of sizes enabling investigators to tag both smolts and adult salmon. However, small tags have small batteries, and this limits smolt-sized tags to reporting over a few months whereas larger (adult) tags can last for years. Acoustic tags can, for example, carry sensors that report temperature, depth and whether or not the animal has been eaten by a predator, however, acoustic tags only provide instantaneous reports of what they are measuring when they are within range (≈ 1000 m) of acoustic receivers that have to be pre-positioned at known locations in the ocean.

Whilst telemetry is a powerful and useful method, in keeping with any technique that requires the capture and handling of fish, the process of fitting tags does have recognised limitations, and risks associated with it. These relate to the effects of the tagging procedure itself on the fish (the direct effects) and the effects that may result from altered behaviour in fish released and carrying the tags (the indirect effects). Effects are often grouped and referred to as "tagging effects" or "tagging mortality", and it is important to recognise that the direct and indirect effects can act together, or act separately on tagged individuals, and that they may also change in level of severity. The workshop concluded that some fundamental challenges remain, including empirical evaluation of tag effects, selecting truly representative samples, tag expulsion, and tag failure.

Detailed consideration must also be given to the type of acoustic array used in future tracking studies. Curtain arrays are spatially constrained and are often located at geographical pinch points rather than following any statistical sampling design. Therefore, the knowledge obtained regarding migration when using curtains is extremely limited other than indicating possible mark recapture endpoints. Using curtain arrays, it is also difficult to ascertain favoured migratory route choices, if tag ingestion by a predator cannot be ruled out or a low proportion of tags are detected.

The use of a grid arrangement of receivers makes fewer assumptions than a curtain design regarding smolt migration routes, tag retention and receiver detection efficiency. They are more resilient to the impacts of receiver loss, low detection range through adverse environmental conditions or post-surgical tag ejection/ failure. The geographic coverage of a grid allows realistic migratory behaviours to be identified through detection of a fish at multiple points along its migratory path rather than reliance on single points.

In summary, it was suggested that future acoustic tracking work should be focussed on reducing transmitter size, tagging salmon before they have started their smolt migration and closer consideration of the application of grid arrays rather than curtains of receivers, to determine migration vectors.

In addition to the more commonly used acoustic tracking technologies new and emerging refinements such as the development of the ROAM, open-ocean technology and the tracking of individual adult salmon using PSAT satellite tags were presented and discussed at the workshop.

Non-invasive chemical tracking technologies are developing fast and advances in the use of stable isotope and eDNA tracking techniques and the potential which they hold to monitor fish locations and migration pathways were described by a number of presenters. A discussion around these innovations clearly signalled the need to develop statistical and modelling approaches which could harness results from a broad range of tracking techniques to tackle the more untraceable questions relating to marine survival within open ocean and near shore domains.

Tracking Data

The ability of such new technology to amass and store information has obvious and long sought-after advantages but equally it poses major logistical and scientific challenges as terabyte after terabyte of information is stored from individual tracking projects. The integration and the analysis of such mountains of data poses great challenges for researchers. During the course of the workshop we heard of two open source data networks which are working towards achieving these goals.

The Ocean Tracking Network (OTN) is working with multiple partners to create the necessary data system to curate, secure and exchange data on the detections of acoustically tracked animals across the globe. In some cases, this involves OTN providing a framework node to organise the partner's system to be fully interchangeable. In other cases, the OTN data team works with existing systems to cross-map them to enable data exchange. The OTN is internationally certified (Associate Data Unit of the UN's Intergovernmental Oceanographic Commission's' International Oceanographic Data and Information Exchange; Tier II node of the Ocean Biogeographic Information System) and is founded on FAIR (Findable, Accessible, Interoperable, Reusable) principles that meet the demands of public funders that data from public money spent on research must be publicly accessible. The system also uses open-source architecture, to make it affordable and because no organization will outpace/out-think/out-innovate the scale and energy of the open-source community.

The main objective of the European Tracking Network (ETN) is to establish a sustainable, efficient and integrated Pan-European network, embedded in the global arena of already existing initiatives outside Europe. The backbone to achieve the goal of an integrated Pan-European tracking network is coordinated data management. This can be achieved using a central data portal storing all types of aquatic animal tracking.

The ETN portal, in its current form, stores all (meta) data related to acoustic telemetry. Different brands are supported. However, it needs to be extended to enable the capture of other types of aquatic animal tracking data (i.e. PIT, DST and satellite data) and in the future the capture of data from emerging techniques such as the use of isotopes and novel genetic techniques.

ETN also aspires to the FAIR, open access principles of Findable-Accessible-Interoperable-Reusable. Great emphasis is placed on enhancing the ability of machines to automatically find and use tracking data, in addition to supporting its reuse by individuals. The ETN goals reach beyond the appropriate collection, annotation, and archiving of data. Data stewardship within the ETN includes the notion of 'long-term care' of valuable digital assets, with the intention that they should be discovered and re-used for downstream investigations, either alone, or in combination with newly generated data.

In addition to the above emerging data networks it has become clear from work associated with the 2019 International Year of the Salmon that major private sector corporations in the US and in Europe are keen to explore how their Big Data skills and expertise might be used as corporate donation towards the conservation of migratory salmonids. Utilising such expertise to integrate and expand data storage and analysis could prove very beneficial over the years to come.

Networks

Researchers are now coalescing into networks to share infrastructure and data. Globally, OTN is working to unite existing infrastructures and to create a global system that will enable the collection and exchange of data on a global scale. It is estimated that there are more than 20,000 mutually compatible acoustic receiver units currently deployed in the ocean, many in the North Atlantic region. As these are linked together through the data system, they will enable catchment / watershed groups to benefit as they tag fish locally and receive back detections from widespread ocean receiver arrays. The local groups in turn provide valuable information to scientists on the river-specific movement and survival patterns that salmon exhibit, which will help us better understand the stressors on salmon. There are a large and growing number of researchers using biotelemetry to study aquatic animals and answer management-related questions, there is a stringent lack of in-field telemetry collaborations in Europe and as outlined above the ETN network has similar gaols and objectives to OTN, and has set itself clear objectives for a much improved integration of European tracking data.

Closer collaboration

The scale and cost of the work that needs to be done on salmonids is beyond the scope of what can be afforded or accomplished by a single individual laboratory, or an isolated research group. For salmonids, the benefits of networking and closer collaboration include:

- Bringing researchers together to develop testable hypotheses about pressure / stressors affecting salmon survival and distributions in the ocean, to build research plans, and to conduct the tests that will move our knowledge of salmon forward.
- Sharing resources and data amongst groups working on salmon and other valued species to make the work efficient and affordable.
- Stimulate and support the development of new technologies and sensors that will address important questions about salmon.
- Draw in the multidisciplinary capabilities required to assess the impacts of such stressors.
- Creation of data systems for telemetry programmes to share information about tag detections that occur on receivers maintained by individuals or groups other than the one that may have originally tagged the salmon.
- Such a data system could curate and secure data from all types of tags and such data could provide us with baseline information against which future changes in salmon distributions and movements can be assessed.
- Provide the capability to react to fast-changing oceans.

The value of the physical assets that teams are acquiring is far greater than any of the freshwater tracking programmes carried out to date. There is real risk that given the pace of change in the world of micro-electronics that such technology may have a relatively short shelf-life and, therefore, it is vitally important that such technology is shared so that it's use can be optimised in the short to medium term.

Ongoing work in designing the data acquisition and modelling formats required to move forward with the Likely Suspects Framework has clearly indicated the urgent need to integrate tracking data with other large oceanographic datasets available through, for example, the Global Ocean Observation Systems (GOOS) networks. To make the most of emerging partnerships with the ICES and EuroGoos networks it is vitally important that the tracking data is avail be in an integrate and standardised format.

Recommendations

Below is a summary of the recommendations arising from the Workshop:

- There was a clear need for the major tracking projects represented at the meeting to be better co-ordinated in a more cohesive fashion.

- The scale and cost of the marine tracking work required is beyond the scope of what can be afforded or accomplished by a single consortium or research group. Therefore, sister projects, such as SMOLTRACK, should also be invited to participate in efforts to better coordinate and streamline tracking research in the ocean.

- There is a clear need for agreed guidance on best practice for carrying out tracking studies and on data integration from all tracking methodologies, at an international level.

- It was agreed that the AST/GWCT & S&TC should organise a follow-up meeting of interested parties to:
    - Identify common issues and concerns which would be best tackled collectively.
    - Review the extent of physical assets associated with each participating programme and to see how best to ensure the full use of this equipment.
    - Review how the projects might be more closely linked with and support, existing networks such as the ETN and OTN, to develop a common repository for marine tracking data.
    - Review how best to format the tracking data so that it can be seamlessly integrated with oceanographic and other major biological data assets developed by ICES, The Global Ocean Observing System (GOOS), the Copernicus Marine Data Catalogue etc.
    - Review opportunities to seek collective funding to enhance the efficacy of the current and future marine tracking programmes.
    - Review the emerging, non-invasive chemical tracking techniques and to see how efforts to integrate analyses / results from these projects, with the more traditional tracking methods, might be improved and resourced.
    - Review what roles NASCO/ IASRB might play in supporting discussions and agreement on best practice for tracking studies and on data integration from all tracking methodologies at an international level.
    - Examine how private sector IT resources, such as Big Data analyses and access to supercomputers, might be mobilised in support of the above objectives.
    - Examine how to better coordinate physical and data assets so that these might better support research into key mortality factors within the Domains of Likely Suspects Framework.
    - Consider how a cooperative approach might be used to leverage funding from major national and international funding sources, such as the emerging Horizon Europe EU Framework Programme, making full use of the existing Galway Agreement on Marine Research between the EU, USA and Canada

- If considered beneficial, to formalise a Marine Tracking Coordination Group, to draw up Terms of Reference for the group and agree next steps in the process.

Summary of the aims and objectives of the SAMARCH Project

The SAMARCH project will:

- Provide novel information on the survival and migration of young salmon and sea trout in four estuaries of the Channel area.
- Provide novel information on the movements and swimming depths of adult sea trout in the Channel.
- Create a genetic data base for trout on both sides of the Channel.
- Create a map of areas that are important for sea trout in the Channel based on sea scape.
- Provide new information to further improve the models used in England and France to manage their salmonid stocks.
- Train students in the management of coastal and transitional waters.
- Engage with stakeholders throughout the project.
- Inform current and develop new policies for the better management of salmonid stocks in our coastal and transitional waters.

Although the project involves working on a number of rivers in the Channel area, the majority of the data collection and research will focus on the five salmon and sea trout "Index" rivers in the Channel area. These are the rivers Frome and Tamar in the south of England and the Scorff, Oir and Bresle in northern France.

The project includes 10 partners from France and England who are a blend of research and regulatory organisations, and the projects key stakeholders.

www.samarch.org

Summary of Work of Salmon & Trout Conservation

Salmon & Trout Conservation (S&TC) was established as the Salmon & Trout Association (S&TA) in 1903 to address the damage done to our rivers by the polluting effects of the Industrial Revolution. S&TC is the UK's leading campaigning wild fish charity. The work of the organisation is geared towards increasing awareness on the need to protect rivers, lakes and oceans and their dependent wild fish stocks and associated wildlife in the face of issues such as pollution from poor land management, excessive water abstraction and insensitive salmon farming. The S &TC aims to achieve better protection for fish, water life and the habitats on which they depend, by employing policies supported by sound scientific evidence.

Recently, S&TC has successfully employed a variety of influencing techniques to protect wild fish and the water environment. In Scotland, S &TC used a complaint to the EU, under the Habitats Directive, to force closure of all coastal salmon netting stations, thereby enabling tens of thousands of extra wild fish to reach their natal rivers and spawn. S&TC also submitted a petition to Scottish Government which directly led to two Parliamentary Committee Inquiries into the salmon farming industry and its impact on wild salmon and sea trout. In England and Wales, the S&TC Riverfly Census used species level invertebrate data to accurately identify that sediment, excess phosphate and pesticides are the posing the greatest dangers to our river water quality and, therefore, the health of wild fish and all other water life.

S&TC continues to work on such diverse issues as salmon farming, water quality and quantity; land management impact on rivers; aquatic habitat restoration; by-catch of salmon and sea trout in estuaries; and fisheries issues relating to the reintroduction of beavers.

www,salmon-trout.org

Salmon & Trout Conservation
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Summary of Work of the Game and Wildlife Conservation Trust

The Game and Wildlife Conservation Trust (GWCT) is a charity dedicated to the research of game species and their associated habitats. This includes game fish e.g. salmon, trout, sea trout and grayling. GWCT has been involved in fisheries research for 25 years and in 2009 set up our Salmon and Trout Research Centre at East Stoke, in Dorset. In doing so, we took over the running of the long-term salmon population monitoring on the River Frome in Dorset which has been on going since the mid 1970's. Our centre now includes some 14 permanent staff and PhD students. The salmon population monitoring on the Frome forms a core part of our work, where we estimate using a combination of automatic counters and traps the numbers of juvenile salmon in the river each year, the numbers of juveniles that leave the river each spring as smolts and the numbers of adults that return. This work forms part of a European network of salmon index rivers, that monitors salmon stocks in detail. The information from which is reported, locally, nationally and internationally to assess stocks and provide guidance on stock management to governments, through the International Council for the Exploration of the Seas. Given the fish counting infrastructure in place on the Frome, we use the facilities to bolt on applied research, for example, the effects of run of river low head hydro schemes on migrating salmon and trout smolts. The effect of managing aquatic plants on salmon and trout productivity. More recently, we have led large projects which are providing local and national bodies with evidence of the use of transitional and coastal waters by salmon and trout smolts and adult sea trout.

www.gwct.org.uk

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Summary of Work of the Atlantic Salmon Trust

Since 1967 the Atlantic Salmon Trust (AST) has supported research into key aspects of the lives of migratory salmonids. AST is the UK's only charity whose work is devoted exclusively to the conservation of wild Atlantic salmon and sea trout. The Trust facilitates research, partners research projects, organises scientific meetings, workshops and conferences. It communicates its findings to anglers, fishery managers, fishery owners and the public.

The role of the Trust is to demonstrate how both species can be conserved and managed to enable their value to society to be realised sustainably. The abundance of Atlantic salmon, prior to any fisheries exploitation, has declined over the last forty years; from 8 – 10 million fish in early 1980s to 3 – 4 million fish at present. At present AST's major concern is the dramatic decline in marine survival in the Atlantic which has fallen from over 15% in the 1980s to, at times, less than 5% over the past 10 years.

The Trust's research work concentrates on improving our scientific knowledge of wild salmon and sea trout, their habitats and their complex and fascinating life histories, and the threats to their survival. Until relatively recently this knowledge was confined mainly to the freshwater aspects of their life cycle. However, through the development of the Likely Suspects Framework, AST and its partners in the Missing Salmon Alliance, are also focusing on the estuarine, nearshore and marine phases of their life cycle. In recent years the Trust has embarked on a series of major smolt tracking projects to ensure that risks are significantly reduced for both salmon and sea trout smolts as they journey out into the ocean.

www.atlanticsalmontrust.org

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