Projects of Interest to the Board and its Work

Purpose

The purpose of this paper is to provide an update on projects of interest to the Board and its work, namely the Likely Suspects Framework, the ROAM Programme, SAL-MOVE, smolt migration studies being conducted in England, the SMOLTrack Projects and PINKTrack.

Decisions

- no decisions are required.

Background

At the 2020 Annual Meeting of the International Atlantic Salmon Research Board (the Board), ICR(20)16, it was agreed that an Agenda item would be retained in future years which focused on projects of interest to the Board and its work. This would include information on projects where NASCO has some ownership (such as EU-funded projects, the SALSEA-Track successor, when agreed, and the Likely Suspects Framework) and other relevant projects; those researchers could be invited to contribute information. The Board asked the Secretary to provide updates on projects where NASCO has some ownership and, through the Board and SAG members, to seek information on projects that would be of interest to the Board and its work.

This paper contains the information provided in response to the Secretariat's request for information in relation to projects of interest to the Board.

LIKELY SUSPECTS FRAMEWORK PROGRAMME

Background

At its 16th Annual Meeting (2017) the Board agreed to part-fund a workshop on The Likely Suspects Framework (LSF) concept. An Atlantic Salmon Trust (AST) workshop in 2017 developed the concept and the proceedings were published in the AST Blue Book series.

The 35th Annual Meeting of NASCO (2018) endorsed the LSF concept and agreed to request the Secretary to explore with ICES how best to integrate Atlantic salmon marine survival and population data with relevant ICES marine databases, and to suggest that a number of joint workshops might be convened. The first of these workshops (WKSalmon) was held in June 2019 with the second completed in 2022.

The LSF project has been developed by the UK's Missing Salmon Alliance[1] since 2019, with an agreed 5-yr implementation plan to:

- provide and mobilise new knowledge on the drivers of salmon mortality from across the full life-cycle in sea and freshwater; and

[1] [The Missing Salmon Alliance brings together leading salmon conservation organisations across the UK -the Atlantic Salmon Trust, Game & Wildlife Conservation Trust, Fisheries Management Scotland, The Rivers Trust and the Angling Trust. It aims to reverse the devastating collapse in wild salmon populations around the UK. By combining expertise, co-ordinating activities and advocating effective management solutions MSA is focused on ensuring that wild Atlantic salmon populations survive and thrive in rivers, lochs and seas for the next generation.]

- generate new stock forecasting and scenario-testing capacities to support salmon managers' appraisal of options and guide their activities.

Over the last three years, reports were delivered to the Board outlining project progress. The current report provides an update on LSF project progress over the past 12 months.

Progress in 2023

Supporting co-operative research and the ecosystems-based approach for Atlantic salmon was assisted in 2023 by the acceptance for publication of primary scientific articles on salmon risk assessment frameworks (Bull & Luedke (*in press*)), the challenges for data mobilisation in salmon management (Diack *et al.,* (*in press*) and links between salmon marine return rates and zooplankton community dynamics (Tyldesley *et al*., (*in press*)). The modelling of post-smolt marine migration routes has been advanced by Ailsinn Borland in her NERC-funded PhD and preparation of a first project manuscript (Borland *et al*., (*in prep*)). In 2023 the international database for sharing salmonid PIT tagging records recorded a second PIT-tagged smolt from a French river detected as a capture in July by an Icelandic mackerel-fishing vessel.

During 2023 progress was made by the LSF team towards analysing the data emerging from the NASCO-ICES WKSalmon2 workshop on commercial pelagic fish landings. Funding has been secured to advance this in 2024 under the guidance of an expert steering group to evaluate trends in fishing activity and possible variation in salmon bycatch risks. Presentations by members of the LSF team were made at the Fisheries Society of the British Isles Annual Conference, the ICES-PICES joint science conference, the Association for the Sciences of Limnology and Oceanography annual meeting and the Marine Alliance for Science and Technology for Scotland Annual Science Meeting.

Development of an underlying salmon mortality framework has advanced in 2023 in the provision of a stage and state responsive population model that has undergone sensitivity testing and tuning. Built primarily to reflect expected population dynamics of the River Bush (NI) salmon population, the base model is being developed to address the need to represent multiple life-history strategies and undergo tuning and parameterisation application at wider regional scales. In early 2024 a new post-doctoral research modeller (Elliot Sivel) joined the LSF team in a 2-yr position to lead on the development and completion of the underlying model.

Provision of a Salmon Management Decision Support Tool has advanced considerably in 2023 based largely upon feedback obtained from two focus group workshops in summer 2023. Considerable development steps were made to reflect users' desires for accommodating specific utilities, priority scenarios and comprehensive reporting options. The online tool will keep track of modelling developments and become available for wider use later in 2024. Together, the model and tool development will form the basis of at least two primary scientific articles.

Researching the drivers of salmon mortality at sea has advanced in 2023 with the discovery of possible explanatory factors acting during the initial marine migration period that explain patterns of regionally varying marine return rates in NEACs populations (Tyldesley et al., (*in press*)). Coupled with the development of individual-based models for the initial months of post-smolt migration from a range of UK and Irish populations (Borland et al., *in prep*), this will enable more focused understanding and evaluation of regionally appropriate conditions and pressures facing migrating salmon at sea.

Developing science outputs that contribute to the evidence base has been achieved by the LSF programme in 2023 with significant contributions to the following outputs:

Borland, A., Banas, N., Gallego, A., Spiers, D and C. Bull. In prep. Modelling the migration of Atlantic salmon post-smolts from Irish and Scottish rivers: interannual variation in relation to environmental conditions.

Bull, C. & Luedke, W. In press. Building salmon life cycle and risk assessment frameworks to address future management challenges. Salmon Data Mobilization, NPAFC Bulletin

Diack, G., Bird, T., Knight, A., de Eyto, E., Bayer, J., Walker, A., Johnson, B.T., van der Stap, T., Nevoux, M., Bull, C., Hanson, N., Brophy, D., Jones, M., Akenhead, S.A. In press. Salmon Data Mobilization, *NPAFC Bulletin* https://doi.org/10.31219/osf.io/hk4gu

Tyldesley, Banas, Diack, Johns, Kennedy & Bull In press. Declining feeding conditions for forage fish larvae in the Northeast Atlantic: an indicator for Atlantic salmon marine survival.

Tyldesley et al. In prep. Assessing the influence of spatial and temporal scales on using water temperature data as an indicator of ecosystem change for Atlantic salmon.

ROAM APPROACH TO MARINE TRACKING

RAFOS Ocean Acoustic Monitoring (ROAM) is an acoustic tracking system where low frequency long ranging sound wave 'pongs' are emitted from ocean moored sound sources and received by a tag equipped with a hydrophone attached to the study animal. A primary advantage of the ROAM approach is the long range of the 'pongs', which could result in more accurate geolocation over a wider spatial and temporal range compared to traditional light-based methods. The development of the ROAM approach to marine tracking is being led by researchers at the Woods Hole Oceanographic Institute (WHOI) and the University of Rhode Island, USA.

ROAM was first brought to the attention of the Board in 2017 (CNL(17)09) and annual updates have been provided to the Board since (ICR(18)06; CNL(19)09; ICR(20)16; CNL(21)12; CNL(22)10, CNL(23)10). In addition, a workshop involving researchers from the North Atlantic and Pacific oceans was held in 2018, which provided a detailed overview of the ROAM approach (https://repository.library.noaa.gov/view/noaa/22044). ROAM is a redesign and repurposing of a common oceanographic monitoring technique. As such, efforts have been focused on evolving the monitoring approach to be suitable for tracking marine animals in the ocean and on conducting field trials to verify that the equipment performs as expected. Unfortunately, the project has experienced numerous delays associated and caused by the COVID-19 pandemic, equipment / supply shortages, equipment failure and a lack of dedicated funding. However, in spite of these setbacks all collaborators remained keen on the project and progress continues.

In early summer 2021, two ROAM sound sources were deployed off the coast of the Northeast United States and a series of field trials involving both opportunistic (in 2021) and dedicated glider missions and a concurrent tagging effort (in 2022) were conducted. The opportunistic glider missions obtained encouraging results, but the dedicated glider mission and tagging effort produced minimal result due to a fatal chip malfunction traced back to the manufacturing process. Some shipboard data was collected however, which measured the efficacy of the sound source 'pongs'.

The chip issue has been remedied, but unfortunately, there is an absence of cost-effective chip manufacturing options. As a result, researchers have begun producing custom-made processors. The custom-made processors are unfortunately too large for a ROAM tag, but are

being incorporated into a larger vessel, which is designed for different marine monitoring purpose. The ROAM portion of these larger units will operate along the same principles as the envisioned ROAM tag and therefore will be used for ROAM field trials in summer 2024. Results from these field trials should provide an evaluation of the performance of the ROAM approach and if successful could provide the justification for the large financial expenditure necessary for the large-scale chip manufacturing.

On a positive note, the setbacks experienced to date have not been associated with the functionality of the ROAM approach, but rather with an array of associated issues. As such, interest remains high and researchers continue to pursue the field-testing of the approach so that informed decisions can be made on the next step for the proposed ROAM approach to marine tracking.

MIGRATION TIMING GENOTYPE AS A PREDICTOR OF SALMON VULNERABILITY TO ENVIRONMENTAL CHANGE (SAL-MOVE)

Coordinated by: The University of the Highlands and Islands, UK
Project value: €258,498.24

The genetic basis underlying the timing of salmon migration

The migrations of Atlantic salmon (*Salmo salar*) from the river of their birth to their marine feeding grounds and back again are an iconic example of seasonally timed movements in a species. The EU-funded SAL-MOVE project will collate existing datasets and apply state-of-the-art genomic analysis to determine the environmental effects and genetic basis of Atlantic salmon migration timing. The findings will be combined with future climate scenarios in an eco-evolutionary modelling framework to predict how Atlantic salmon populations will be impacted by anthropogenic change via their migration phenotypes and genotypes. Results from SAL-MOVE will directly inform management actions aimed at improving the security of wild Atlantic salmon.

The Rivers Tamar and Frome are contributing samples to feed into the research programme.

SMOLT MIGRATION STUDIES BEING CONDUCTED IN ENGLAND

River Teme

This is a PhD study led by Bournemouth University in collaboration with The Severn Rivers Trust. The study will track migrating smolts using acoustic transmitters located in the upper River Teme down to its confluence with the main River Severn below Worcester, and then downstream through to the estuary and into the Bristol Channel. The principal objective is to identify key barriers to downstream migration and other pressure which may impact fitness, lethal and sublethal impacts on emigrating smolts and also identify abiotic conditions which influence smolt movements (primarily flow and temperature). The study will use an existing acoustic receiver array which is part of a separate tracking study led by Swansea University. Approximately 100 salmon smolts will be tagged in the study. The PhD runs from 2023 – 2026.

River Teign

This is a PhD study led by Bournemouth University in collaboration with the Teign Conservation and Angling Association (TACA). The study will track migrating smolts using both PIT tags and acoustic transmitters located in the upper River Teign down to the Teign estuary. Both salmon and trout parr have been captured and tagged with PIT tags in 2022 – 2023 and in 2024 a proportion of smolts will be tagged with acoustic tags to track movements at a finer spatial resolution. The principal objective is to identify key barriers to downstream migration and other pressure which may impact fitness, lethal and sublethal impacts on emigrating smolts and also identify abiotic conditions which influence smolt movements (primarily flow and temperature). Approximately 60 salmon smolts will be tagged with

acoustic tags in the study, with sea trout smolts used as a proxy if salmon smolts can not be obtained. The PhD runs from 2022 – 2025

SMOLTRACK PROJECTS

The EU has provided funding to the Board to support the following SMOLTrack projects:

- Understanding and comparing early mortality of European salmon populations at sea (SMOLTrack I – completed);
- Comparing mortality of European salmon populations at sea using multiple -method telemetry studies (SMOLTrack II – completed);
- Quantifying smolt survival from source to sea: informing management to optimise returns(SMOLTrack III – completed);
- Quantifying salmon survival from river exit to return as adult: Collecting thermal and behavioural data to refine smolt to adult survival indices (SMOLTrack IV – completed. Update below); and
- Studies of behaviour and survival of salmon during their migration – development of tagging programmes to follow the marine migration of salmon to oceanic feeding areas and back (SMOLTrack V – ongoing. Update below).

The website for the projects is: SMOLTRACK. There is also information on the Board website.

SMOLTrack IV: Quantifying salmon survival from river exit to return as adult. Collecting thermal and behavioural data to refine smolt to adult survival indices.

Climate change is a major threat to the survival of Atlantic salmon, where increasing temperatures have contributed to the decline of several populations. It is recognised that marine temperatures are likely to influence survival and behaviours of smolts at sea, thereby influencing adult survival back to river. Yet, data on the thermal environment experienced by migrants, initially in freshwater, and subsequently in transitional and marine waters are limited. SMOLTrack IV aims to fill these knowledge gaps, namely (1) temperature preferences of salmon during its outward and return migrations, and (2) tracking and temperature data for immature fish as they return to their natal rivers. The following section summarises this project's objectives and its main findings.

Objective 1. OceanTemp-smolt – Describing temperature experience of postsmolt migration towards and returning from their oceanic feeding grounds (WP1)

Background

The goal of this WP was to record the range of temperatures that migrating salmon, from smolt stage to adult river return, experience over their full oceanic migration. Few data are available due to the small size of salmon smolts which, to date, could not accommodate internal implantation of temperature logger tags which typically exceed the tag burden smolts can tolerate. Recent advances in logger technology have resulted in increased miniaturisation and this presented a unique opportunity for SMOLTrack IV to collect a key dataset (thermal data for migrating salmon smolt and returning adults).

Methods

Outgoing smolts (minimum > 12.5 cm FL) were implanted with miniature Data Storage Tags (DST; Star-Oddi nano-T tags) at two river sites which have full trapping facilities for adult returnees (River Bush in Northern Ireland, and River Erriff in Ireland). This allowed for removal and processing of returned tagged fish. Smolts were also implanted with a PIT tag to

trigger DST tagged fish removal at each trap site. Smolts were captured with a Wolf trap in River Bush and with a screw trap in River Erriff.

Key findings

A total of 599 smolts were tagged with DSTs in River Bush (Northern Ireland) and River Erriff (Ireland) between 2021 and 2023 (Table 1). The upstream adult traps were monitored daily at both sites from the start to the end of 1 SW adult salmon run in 2022 and 2023. One tagged adult salmon returned in 2022 to the River Bush from the entire 2021 tagging group for both sites; this fish was a 1 SW female which was 54.5 cm L_F, 1460 g and had a Condition Factor 0.90 (Fulton's Index).

Conclusion

The recovery of one tagged adult fish was a key achievement for this WP, demonstrating proof of concept and demonstrating the feasibility of tracking the thermal experience from smolt to adult stage. Greater returns were anticipated, based on historical smolt to adult returns averaging 5%, but return rates across much of the range of 1 SW salmon was very low in 2022 and 2023, indicating poor smolt to adult survival. Nonetheless, the single adult return has provided a wealth of data that is currently being analysed. Monitoring of adult traps for further tag recoveries is ongoing in 2024 as it is possible that a small number of tagged 2 SW fish could return from the batch of tagged smolts in 2022. Returns are expected in 2024 from smolts tagged in 2023. The initial outcome of this study has presented a realistic expectation that this relatively low-cost WP will provide more comprehensive data on thermal preferences in the marine phase of the life cycle. Tagging activity will continue in 2024 through SMOLTrack V, with refined methods (e.g. release timing / location) being employed with a view to enhancing returns.

Table 1. *Summary data for salmon smolts implanted with nanotags and PIT tags in the Erriff and Bush catchments from 2021 to 2023.*

Year	n	Mean Fork Length (cm)	Mean Weight (g)	Tagging Dates	Location
2021	100	13.6 (±0.7)	25.0 (±4.5)	15 April – 7 May	River Erriff, Ireland
2022	100	13.1 (±0.6)	23.2 (±3.7)	7- 28 April	River Erriff, Ireland
2023	84*	13.0 (±0.6)	21.9 (±3.4)	14 April – 5 May	River Erriff, Ireland
2021	99	16.2 (±1.1)	42.9 (±9.2)	13 – 21 April	River Bush, N. Ireland
2022	100	16.5 (±0.9)	47.6 (±7.5)	5 – 20 April	River Bush, N. Ireland
2023	116	16.1(±1.1)	45.5 (±7.7)	14 Apr – 15 May	River Bush, N. Ireland
* Run ended early – remaining 16 tags deployed on River Bush, N. Ireland					

Objective 2: FFPT – Fit for purpose tagging of adult salmon to understand feeding behaviour and backtrack return migration in the north Atlantic (WP2)

Background

Adult Atlantic salmon have been shown to migrate to eastern Greenland and its fjords to forage, especially from European rivers (Rikardsen et al. 2021). However, there is limited information on Atlantic salmon behaviour and survival in their ocean phase and scant knowledge on the Atlantic salmon frequenting the area, including origin, size and feeding. Generating data on individual survival and behaviour requires tagging with electronic tags, which necessities catching live salmon in good condition. One cost-efficient way to achieve this is to capture Atlantic salmon in fjords of Greenland, where salmon can be captured, sampled, and tagged

from smaller boats by trolling. The fjords are more sheltered from weather and trolling can provide salmon in good condition for tagging with electronic or traditional tags. Additionally, by sampling via netting provided by local fishers, it is possible to increase the samples taken for population assignment and feeding habits. The goal of this WP was to (1) test the feasibility of different sampling methods to capture immature Atlantic salmon outside eastern Greenland, (2) sample and tag Atlantic salmon to determine population origin, localised feeding habits and behaviour and (3) investigate the feasibility of live fish holding in the area, with the future goal of being able to tag individual salmon after rapid genetic assignment (fish fit for tagging purpose).

Methods

The pilot studies took place in 2021 where the area was visited over two weeks from 7-23 September, and in 2023 from 6-22 September. Atlantic salmon were targeted via fishing with longlining, monofilament nets, and by rod and line trolling from boat. Captured salmon were sampled for length, weight and fin clips, otoliths and food items were retained. Salmon caught by trolling were measured, weighed, and tagged, before being released shortly after tagging. Based on length and weight data, Fulton's condition factor was calculated. In 2023, the same procedure was followed, except longlining was dropped because of poor catch results. The livewell option was tested in 2023. The first few salmon caught by trolling in 2023 were used to test the utility of the live holding facilities (which may enable collecting, sampling, assignment and tagging salmon in the future). The initial test was performed in a 1.5 x 1.5 x 0.7 metre hard plastic bin. The bin was equipped with a wooden lid of similar surface area to the bin. The lid was attached to the corners of the bin with rope, so the fish was unable to escape or jump. The bin was then weighted down by attaching ropes to the four bottom corners, and the entire structure was placed subsurface outside the harbour in a weather-protected area. The rock weight was adjusted so the lid was a few cm above the water surface.

Stomach contents were analysed onsite for sacrificed salmon. The stomach was opened, and all material was dissected. Content was divided into functional groups (fish, crustaceans and squid) and furthermore divided to species, where possible. After this division, the number of prey items were counted and noted for each stomach.

Key findings

The study confirmed the presence of Atlantic salmon in East Greenland waters. Long-lining proved to be an ineffective method to catch salmon, whereas the use of gillnets and (rod and line) trolling were successful capture methods. Two and nine salmon captured by trolling were anaesthetised, tagged with floating DST-tags, and released on site in 2021 and 2023, respectively. In 2021, 41 salmon were sampled, with 39 caught in nets and two caught by trolling. The total Atlantic salmon sampled in 2023 was 159 of which 138 were caught in gillnets (set by the survey team and by local fishers), and 21 were caught by trolling. In total, samples (tissue, stomach content and scales) from 39 and 62 salmon were collected in 2021 and 2023, respectively (Table 2). The test of the holding facilities showed it is possible to hold salmon for 3-4 days without severe adverse effect, when a large hard-wall container with substantial flow-through of seawater was used. In both years, salmon checked for maturity status were immature. All females had very small egg sacs and males had slim, hardly visible semen strings. The proportion of females was 0.76 (of 38 checked) and 0.72 (of 47 checked) in 2021 and 2023 respectively. For the stomach content analysis, the dominant food item was sand eel (Table 3). In both years pink salmon (*Oncorhynchus gorbuscha*) were caught in the nets along with Atlantic salmon, and spawning activity was observed in local streams, suggesting that there is active pink salmon spawning in East Greenland streams. Salmon origins are currently being determined by genetic assignment, but initial tests on salmon from 2021

have shown the salmon had primarily originated from NW Europe, including countries like Denmark, Norway, Ireland, Scotland and England.

Conclusion

The trips have shown that it is possible to study, sample and work on Atlantic salmon on their feeding grounds for a fraction of the price required for a large research vessel (we spent €30K for two weeks, DTU Aqua's research vessel Dana would cost at least €500K for two weeks). This study demonstrated that Atlantic salmon are present in good numbers, and that it is possible to capture salmon in good condition by trolling, obtain biopsy samples, and retain them alive in livewells for several days. This opens the possibility for holding salmon until their origin can be identified through rapid genetic testing. By specifically tagging salmon from rivers equipped with the necessary recapture facilities, we increase the likelihood of recovering key thermal data on their return migration. A larger livewell is recommended though, as the shallow depth in the used tank makes the entire set-up more susceptible to waves. Initial preparation for a much larger livewell was begun on site in September 2023 in case of future expeditions. In both years, troll caught salmon were tagged and released successfully, showing the potential for electronic tagging in the area.

Table 2. *Mean Length (+ / - SD), weight (+ / - SD) and condition factor (+ / - SD) of sampled salmon in 2021 and 2023. N = numbers measured. Only 62 of the 159 salmon where tissue samples and length were obtained were also weighed.*

Year	N	Females/males	Length (cm)	Weight (g)	Condition Factor (F)
2021	39	29/38	68.9 (+/- 3.3)	3477 (+/- 650)	1.05 (+/- 0.11)
2023	62	36/54	64.8 (+/- 4.8)	2974 (+/- 755)	1.08 (+/- 0.11)

Table 3. *Observation of food items in examined salmon content divided on functional groups (fish, crustacean and squids). Fractions in percentage. N=number of stomachs examined.*

Year	N	Fish	Crustacean	Squid
2021	39	100	10	10
2023	50	90	38	6

Moreover, the expedition demonstrated that it is possible to obtain biopsy samples and to catch salmon – in good condition – by angling, and to retain them alive in wells for several days. In both years, salmon captured by trolling were tagged and released, showing the potential for electronic tagging in the area.

Overall Conclusions and Impacts

The SMOLTrack IV project has significantly advanced our understanding of the oceanic migrations of Atlantic salmon. The project's success in tracking the thermal range from smolt to adult returns provides a substantial contribution to the literature and is crucial to improve our understanding of the thermal preferences that influence salmon survival during their marine phase. Furthermore, the development and application of capture methods and of livewell holding in eastern Greenland opens the possibility for future studies on the marine migrations of salmon. These insights are essential for developing informed conservation strategies in the face of changing marine environments.

Manuscripts published / to be published in scientific peer-reviewed journals

Alexandre, C.M., Silva, S., Mateus, C.S., Lança, M.J., Quintella, B.R., Belo, A.F., Domingues, A., Rato, A.S., Oliveira, R., Moreira, A. *et al.* 2022. Living on the Edge: Management and Conservation of Atlantic Salmon at the Southern Limit of the Species Distribution. Biology and Life Sciences Forum, 13, 107. https://doi.org/10.3390/blsf2022013107

Flavio, H., Aislabie, L., Birnie-Gauvin, K., Caballero, P., Ensing, D., Gallagher, C., Höjesjö, J., Ives, M., Jepsen, N., Kennedy, R., Moore, A., Roche, W., Wightman, G., and Aarestrup, K. Submitted. The Atlantic salmon smolts that never reached the sea. Lessons learnt from a pan-European project.

Flavio, H., Birnie-Gauvin, K., Koed, A., Larsen, S. and Aarestrup, K. Submitted. Insights on the seaward and return migration of repeat spawning Atlantic salmon: unusually high straying rate and implications.

Sortland, L.K, Aarestrup, K. and Birnie-Gauvin, K. In Press. Comparing the migration behaviour and survival of Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) smolts.

Sortland, L.K, and Jepsen, N.T. Submitted. The effects of trapping on behaviour and survival of salmon smolts. River Research and Applications.

Eastern Greenland Expeditions 2021 and 2023

Summary

Scientists from the National Institute of Aquatic Resources, Denmark (DTU Aqua) and Inland Fisheries Ireland (IFI) visited Eastern Greenland in September 2021 and September 2023. The purpose was to document the presence of Atlantic salmon in inshore marine waters and determine their relative abundance and catchability. It is hypothesised that these fish emanate from European salmon rivers. This new programme in this area was designed to allow for sampling for potential genetic, age and growth analysis, and to establish procedures for future electronic tagging programs. A total of 200 individual immature adult salmon were sampled for genetic analysis. In both years, a subsample was sacrificed and examined further for a general health assessment, and for stomach content analysis, and otoliths were extracted. Most salmon were caught in floating monofilament gillnets, but trolling was also successfully used to catch and tag a number of salmon with electronic tags. Fork length ranged from 51 cm to 88 cm and condition factor was generally high in all fish. The sex ratio was in favour of females. All examined salmon were sexually immature, indicating that they will all be two-sea-winter (2SW) or older when returning to spawn.

Introduction

Adult Atlantic salmon have been shown to migrate to Eastern Greenland for foraging, especially from European rivers (Rikardsen *et al.* 2021). Older expeditions to eastern Greenland have also shown the salmon migrate to the fjords in the area and catches are also documented by local fishers today. There is very limited information on Atlantic salmon behaviour and survival in their ocean phase and scant knowledge on the Atlantic salmon frequenting the area, including origin, size and feeding. The typical marine surveys involving expeditions at sea in research ships are very costly and generally will not be able to provide detailed knowledge on behaviour.

Individual survival and behaviour require tagging with electronic tags, which again necessitates catching live salmon in good condition. One way to generate key knowledge in a cost-efficient way is to target Atlantic salmon in such fjords. Here, the salmon can be caught, sampled and tagged from smaller boats by trolling. The fjords are more sheltered from weather and trolling can provide salmon in good condition for tagging with electronic or traditional tags.

Additionally, by sampling via netting provided by local fishers, it is possible to increase the samples taken for population assignment and feeding habits. This approach has proven successful in western Greenland (Sheehan *et al.* 2019, 2021a, 2021b).

Eastern Greenland is a vast area and very sparsely populated. Approximately 3000 people live on the entire east coast of Greenland, with 2 / 3 living in Tassilaq and the remainder dispersed in few small communities across the fjords in the area. This constrains the choice of locations where such an expedition can take place, because local support and knowledge is often essential for such projects. The current expeditions were centred around the village of Kuummiut (65°51′55″N 37°00′30″W), where the necessary infrastructure, local knowledge and support was available (Figure 1). The expeditions took place over two weeks in September 2021 and September 2023. The purpose of the expeditions was to:

- test whether a sampling and tagging approach was possible and what would be the most successful sampling methods;
- to sample and tag Atlantic salmon captured in the area with the aim to determine population origin, localised feeding habits and behaviour; and
- to investigate the feasibility of live fish holding in the area, with the future goal of being able to tag individual salmon after rapid genetic assignment (fish fit for tagging purpose).

Figure 1. *Map over the study area. Fishing took place from Kuummiut to Kulusuk.*

Methods

The pilot studies took place in 2021 where the area was visited over two weeks from 7-23 September, and in 2023 from 6-22 September. Atlantic salmon were targeted via fishing with longlining, monofilament nets and by rod and line trolling from boat. Captured salmon were sampled for length, weight and fin clips, otoliths and food items were retained. Salmon caught by trolling were measured,

weighed and tagged, before being released shortly after tagging (Flotsam G5 DST, Cefas Technology, Lowestoft, UK) on an experimental basis. Based on length and weight data, Fulton's condition factor was calculated. In 2023, the same procedure was followed, except longlining was dropped because of poor catch results.

The livewell option was tested in 2023. The first few salmon caught by trolling in 2023 were used to test the utility of the live holding facilities (which may enable collecting, sampling, assignment and tagging salmon in the future). The initial test was performed in a 1.5 x 1.5 x 0.7 metre hard plastic bin. The bin was equipped with a wooden lid of similar surface area to the bin. The lid was attached to the corners of the bin with rope, so the fish were unable to escape or jump. The bin was then weighted down by attaching ropes to the four bottom corners, and the entire structure was placed subsurface outside the harbour in a weather-protected area. The rock weight was adjusted so the lid was a few centimetres above the water surface.

Results

The pilot study in eastern Greenland undertaken in September 2021 tested various possibilities of catching adult salmon in the area with the overarching project goal of collecting data on their return migration. Use of long-lines was difficult and time-consuming and failed to catch any salmon, despite several trials in different depths, areas and with a variety of baits. Setting of short gillnets (30-60 m) perpendicular from the coast, consistently produced catches of salmon, confirming abundance of salmon in the area. For logistical reasons, rod and line trolling could only be tested during the last three days of the 2021 trip. After some adjusting of techniques, two salmon were caught on surface lures in relatively few hours of fishing. The fish were in great condition and were anaesthetized and tagged with floating DST-tags and released on site. Figure 2 shows the first tagged salmon.

Figure 2. *First salmon caught, tagged and released in eastern Greenland by SMOLTrack-IV project in 2021.*

In total, samples (tissue, stomach content and scales) from 41 salmon were collected. Length distribution is shown in Figure 3. Mean weight and condition factor can be seen in Table 1.

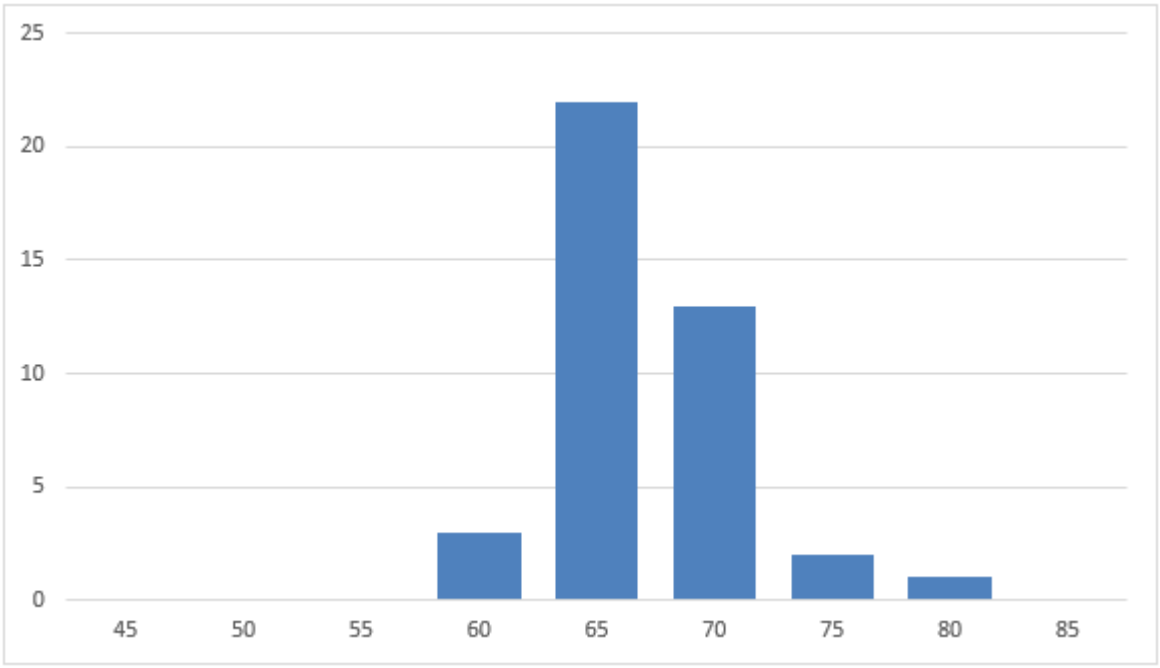

Figure 3. *Number and length of Atlantic salmon caught during the expedition in September 2021. Mean length was 68.9 cm (n=41).*

In 2023, longlining was abandoned, and focus was on increasing sample size through net fishing and trolling from two small open boats. The total Atlantic salmon sampled in 2023 was 159 of which 138 were caught in gillnets (set by the survey team and by local fishers), and 21 were caught by trolling. Length distribution is shown in Figure 4. Additional salmon were sampled from local commercial fishers' nets and were not weighed. Length, weight and condition factor of weighed salmon can be seen in Table 1. Nine of the trolling-caught salmon were anaesthetized and tagged with floating DST-tags and released on site. The test of the holding facilities showed it is possible to hold salmon for 3-4 days without severe adverse effect, when a large hard-wall container with substantial flow-through of seawater was used.

Table 1. *Mean Length (+ / - SD), weight (+ / - SD) and condition factor (+ /- SD) of sampled salmon in 2021 and 2023. N = numbers measured. Only 62 of the 159 salmon where tissue samples and length were obtained, also got weighed.*

Year	N	Females/males	Length (cm)	Weight (g)	Condition Factor (F)
2021	39	29/38	68.9 (+/- 3.3)	3477 (+/- 650)	1.05 (+/- 0.11)
2023	62	36/54	64.8 (+/- 4.8)	2974 (+/- 755)	1.08 (+/- 0.11)

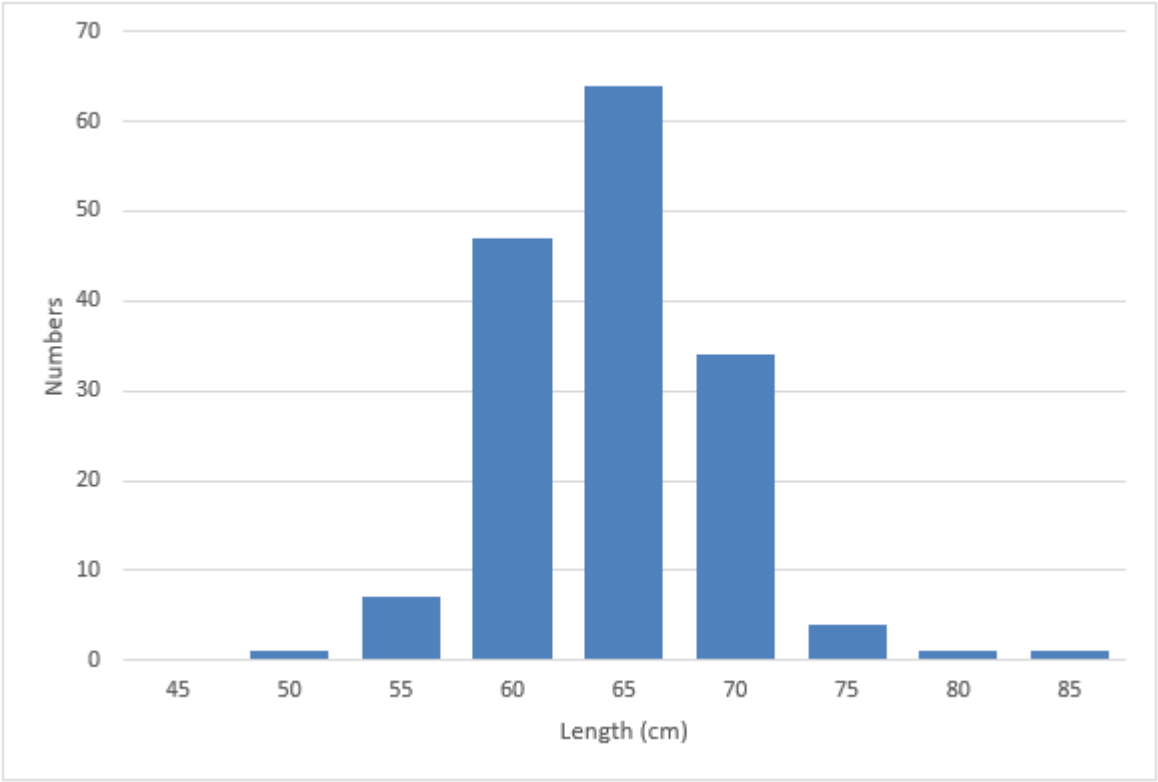

Figure 4. *Number and length of Atlantic salmon caught during the expedition in September 2023. Mean length was 66.6 cm (n=159).*

In both years, salmon checked for maturity status were immature. All females had very small egg sacs and males had slim, hardly visible semen strings. The proportion of females was 0.76 (of 38 checked) and 0.72 (of 47 checked) in 2021 and 2023 respectively.

Stomach content

Stomach content was analysed onsite for sacrificed salmon. The stomach was opened and all material were dissected. Content was divided into functional groups (fish, crustaceans and squid) and furthermore divided to species, where possible. After this division, the number of prey items were counted and noted for each stomach. Two types of fish species were identified (sand eel (*Ammodytes* spp) and capelin, (*Mallotus villosus*)) and two types of crustacean (shrimp (*Palaemon* spp) and isopod (*Themisto* spp)). Only one type of squid was observed (Atlantic cranch squid (*Teuthowenia megalops*)). The dominant food item was sand eel, which was found in the majority of stomachs (Table 2) and often with three or more specimens. Sand eel length ranged from 10-15 cm in 2021 and from 4-5 cm in 2023. Crustaceans were the second most common food item, but with varying numbers observed. Typically, both shrimps and isopods were from 1-5 cm. The observed squids were relatively uniform in size, around 10 cm total length.

Table 2. Observation *of food items in examined salmon content divided on functional groups (Fish, crustacean and squids). Fractions in percentage. N=number of stomachs examined.*

Year	N	Fish	Crustacean	Squid
2021	39	100	10	10
2023	50	90	38	6

Pink salmon

In both years pink salmon (*Oncorhynchus gorbuscha*) were also caught in the nets along with Atlantic salmon. Despite the late time (September), pink salmon were still recorded at sea and notably one mature specimen with food in the stomach was captured. Spawning activity of pink salmon was observed in local streams in both years and it seems likely that there is active pink salmon spawning in many of the East Greenland streams.

Discussion

The catches demonstrated that Atlantic salmon are present in good numbers. Importantly the survey demonstrated, for the first time in this part of Greenland, that it is possible to obtain biopsy samples and furthermore to catch salmon in good condition by angling and to retain them alive in livewells for several days. In both years, troll caught salmon were tagged and released successfully, showing the potential for electronic tagging in the area.

The length of the observed salmon were in the same general range in both years, probably reflecting the majority of salmon present. However, a difference in mean size of caught salmon was observed depending on mesh size, with increasing mean length with increasing mesh size in 2023. This is a general phenomenon in net fishing for salmonids, whereby mesh size selects for a for a certain size range of fish. It maybe be beneficial to use different mesh sizes in a more consistent manner to test if smaller and larger salmon are also present.

Length and maturity status indicated that all salmon caught were one-sea-winter (1SW) or older. The capture period in September makes it highly unlikely that the salmon would spawn in the season they are caught. In effect this meant that any salmon returning to their natal system will be 2SW or older. Salmon in both years had a mean condition factor > 1 and in general, they were in very good condition.

The livewell test in 2023 was successful after some adjustments and tests of different set-ups. This opens the possibility for holding salmon until a rapid test genetic assignment can be made and hence a chance to specifically tag fish from particular areas / populations of interest, which enhances the opportunity to recover key data relating to their return migration. A larger livewell is recommended though, as the shallow depth in the used tank makes the entire set-up more susceptible to waves. Initial preparation for a much larger livewell was begun on site in September 2023 in case of future expeditions.

Stomach content analysis, although not exhaustive, showed a relatively narrow range of food items, with sandeel as the predominant food item in most fish. Hence, we suggest that sandeel is a major food source for salmon in eastern Greenland. However, caution is advised as the potential foraging range of salmon is extensive (around 1500 km of coastline and fjords) and because sampling was limited to September. It may be beneficial to visit other areas in eastern Greenland, like the Scoresbysund / Ittoqqortoormiit area and also in other months (local fishers indicate they start catching salmon from August through October).

Salmon origins are currently being determined by genetic assignment, but initial tests on salmon from 2021 have shown the salmon had primarily originated from NW Europe, including countries like Denmark, Norway, Ireland, Scotland and England.

Conclusion

The experiences from the two sampling expeditions have been overly positive, despite major challenges in logistics by working in such a remote location. The trips have shown that it is possible to study, sample and work on Atlantic salmon in their feeding grounds for a fraction of the price required for a large research vessel (we spent €30,000 for two weeks, DTU Aqua's research vessel Dana would cost at least €500,000 for two weeks). This short-term study provided valuable insights collected over a short period indicating the efficiency and value of

such an approach. Thus, the density and reliability of salmon being available at Kummiut, is a very persuasive justification for a number of very relevant research avenues which could be based there.

The site provides access to a mixed pool of pre-adult salmon from most geographical areas of its distribution range in the middle of their feeding period, a part of the life cycle least studied. Specifically, an acoustic telemetry project could widen the understanding of survival, timing and behaviour within the fjords. Stable isotope studies would also inform previous feeding patterns of these fish and further study is merited.

With the development of a rapid genetic assignment test with high accuracy, various types of tagging could lead to genuine breakthroughs in the understanding of a key element of Atlantic salmon ecology and population development. In addition, anecdotal evidence (from direct local observations) of spawning Atlantic salmon in some of the local rivers in East Greenland was reported to the survey team. This phenomenon should be investigated, not least because of the warming climate, possibly facilitating a build-up of local East Greenland salmon populations. Equally, the occurrence of spawning pink salmon in Greenland streams and to what extent juveniles are being produced, should be studied because of their potential impact on the local biota and ecosystems (freshwater and marine waters).

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SMOLTRACK V: Studies of behaviour and survival of salmon during their migration – development of tagging programmes to follow the marine migration of salmon to oceanic feeding areas and back.

Recent marine survival estimates for Atlantic salmon are amongst the lowest recorded in decades and indicate that as little as 3% of wild smolts now survive to return as adults. In recent decades, survival at sea has widely been accepted as the key determinant of river stock abundance. However, recent research conducted in Denmark, England, Ireland, Spain, Sweden and Northern Ireland through the EU-funded SMOLTrack and related initiatives, have indicated that smolt mortality during the early outward migratory phase from 'source to sea' is much higher than previously assumed. Thus, early smolt mortality may be more important than marine mortality. To support this hypothesis, various studies have demonstrated that a

reduction in negative pressures (e.g. predation, aquaculture) on smolts in the relevant zone of influence can ultimately boost associated numbers of adult returns.

Therefore, it has become apparent that significant knowledge gaps remain to understand, quantify and partition the principal cumulative factors responsible for Atlantic salmon smolt survival during this critical life stage. In addition to the high mortality for smolts and post-smolts, there is also a significant mortality in the oceanic phase of Atlantic salmon.

It is important to investigate if any part of this mortality may be managed. The SMOLTrack V project will build on the ongoing and published work of the previous SMOLTrack projects, enabling studies of behaviour and survival rates of salmon during their migration through the lower parts of rivers, estuaries and coastal areas. Thus, the project will provide data on smolt run timing and migration behaviour, as well as generate ocean migration data through nano-DST tagging of smolt. SMOLTrack V will further expand on the development of a 'fit for purpose tagging programme' to be able to follow the return migration of salmon from feeding areas in the Arctic Sea (East Greenland).

WP1: Tagging in East Greenland

Objectives

WP1 will test a 'fit for purpose tagging program' developed in SMOLTrack-IV, to be able to follow the return migration of salmon from the feeding areas in the North Atlantic and Arctic Sea.

The WP will target salmon in East Greenland, catching live salmon and establishing holding facilities to enable genetic assignment before subsequent tagging and release. This requires a quick genetic assignment and the project aims to establish ways to accomplish this. Such a setup could be of great value for many salmon studies.

A third 'expedition' to East Greenland will be planned for summer of 2024 and potentially 2025. The aim is to catch (in nets) 50 salmon for genetic assignment (to population) and catch (with rod and line) and tag 20 salmon with either acoustic, radio tags, DST and/or PSAT tag, with the tag types depending on the assignment.

NASCO staff will be involved in the administration and co-ordination of this WP. However, as this project is the latest in the SMOLTrack series (there have been four previous projects), efficiencies are available, since the scientists understand what they need to deliver. Therefore, NASCO's staff allocation for the management of the action can be kept to a minimum, whilst retaining the quality of the project.

WP2: Full marine migration temperature of salmon smolts, gender dependant behaviour, smolt-runs in River Minho and test of impacts of handling, tagging

Objectives

The first objective of WP2 is to continue the effort to obtain several full marine migration temperature data-sets from salmon. This will be accomplished by tagging outgoing smolts with miniature Data Storage Tags (DST). The aim is to tag 200 smolts with DST tags in Erriff and Bush Rivers with the goal of getting as many adult returns as possible (rendering full-datasets upon retrieval).

WP2 will increase knowledge of smolt run size and behaviour data for the most Southern salmon populations. This will be accomplished with smolt-trapping and PIT (Passive Integrated Transponders) tagging.

To investigate if there is sex-based differences in smolt outmigration survival and / or in return rates of 1SW and MSW, outmigrating smolts will be captured and tagged. Their sex will be determined by genetic analyses of a tissue sample. The WP aims at 100 smolts gender-

determined and tagged in River Bush or River Erriff and a (much) higher number sex assigned and PIT-tagged to evaluate return rates.

The effect of nano tags on survival and growth of smolts / post smolts will be analysed. A significant part of the SMT-V budget will be allocated to analyse large datasets collected and publish the results and conclusions.

NASCO staff will be involved in the administration and co-ordination of this WP. As this project is the latest in the SMOLTrack series (there have been four previous projects), efficiencies are available. The scientists work builds on similar work conducted under previous projects. This allows comparable data to be collected efficiently and effectively. Therefore, NASCO's staff allocation for the management of the action can be kept to a minimum, whilst retaining the quality of the project.

WP3: Project Workshop

Objectives

WP3 is the organisation of a physical 2-3 days project workshop, where partners will meet and discuss the execution of the plans, enhancing methodologies and the dissemination of results. NASCO staff will be encouraged to participate to discuss how NASCO can implement novel scientific information discovered in the SMOLTrack research.

The existing SMOLTrack partnership, which has been operating since 2017, together with its new partners, has extensive experience in migratory fish research and particularly telemetry studies, often **using** their existing telemetry arrays. The distribution of experienced project partners, across the wide latitudinal distribution of salmon in Europe, will allow the project to investigate salmon under varying climatic ranges. It ensures a fast and wide international uptake of the results produced by the studies. SMOLTrack I, II, III and IV have already produced important research outputs (peer reviewed papers) and SMOLTrack V aims to further advance understanding.

PINKTRACK: CO-ORDINATED eDNA SURVEILLANCE FOR PINK SALMON IN THE EU.

The EU has provided funding to the Board to support the PINKTrack project.

At the 2022 and 2023 meetings of the North Atlantic Salmon Conservation Organisation (NASCO) serious concerns were raised about the ongoing and future threat of non-native pink salmon to native wild Atlantic salmon stocks in the Convention areas. There has been an unprecedented occurrence of pink salmon over a wide geographical scale in all Convention areas since 2017, predominately in odd-years. Of particular concern is that self-sustaining pink salmon populations have become established in northern Norwegian rivers in recent years and in some rivers there they have been reported to out-number co-existing Atlantic salmon stocks. Since 2019, an explosive population growth in pink salmon stocks has been observed both in northern Norway and in the adjacent White Sea basin of northwestern Russia, where this non-native species was originally introduced. This has raised additional concern, that as a consequence, pink salmon may more commonly be encountered and have the potential to establish populations in adjacent and more southerly EU member states. This project intends to address these concerns under the beneficiary of NASCO, through a consortium comprised of state agencies and research institutes based in EU jurisdictions which is supported by technical expertise from Norway. The project will undertake work to better understand the extent of occurrence of pink salmon in EU waters through the use of environmental DNA (eDNA), which will enable it to elucidate temporal and geographic patterns of spread and provide an 'early warning system' of their presence to inform appropriate management responses.

WP 1: eDNATrack – Development of standardised protocols for eDNA

Objectives

Standardised protocols for eDNA sampling and standardised approaches for the analyses of eDNA samples for the detection of pink salmon in EU member states will be developed with the intention that such methods can continue to be utilised in routine national monitoring programmes after the project concludes. This WP includes preparatory work to evaluate different approaches to sampling and analyses and their effect on the results for detection. In addition it includes the establishment of a repository of eDNA samples collected during the project and in subsequent years to provide valuable material for future assessments as analytical technologies develop.

WP 2: SurveillTrack – Establishment and undertaking of an eDNA sampling programme for detection of pink salmon in EU member states

Objectives

An eDNA sampling programme for detection of pink salmon in EU member states will be established and undertaken in order to elucidate temporal and geographic patterns of spread and provide an 'early warning system' of their presence to inform appropriate management responses. The intention for this programme of work is to provide a basis for continued routine national programmes after the project concludes. The work also includes the analyses of any samples taken by the project partners in 2023.

WP 3: ProjectTrack: Organisation and hosting of a two day virtual project workshop after project commencement

Objectives

A virtual project workshop was held in January 2024, where partners met and discussed the development and execution of the sampling programme, protocols and methodologies for sampling and analyses and the dissemination of results. A project wrap-up virtual workshop will also be held as the project concludes to review outputs and inform their further adoption by EU member states.

Secretariat
Edinburgh
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