Report of the Telemetry and Atlantic Salmon Workshop: Next Steps from Estuary to the North Atlantic Ocean

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2020

Canadian Manuscript Report of
Fisheries and Aquatic Sciences 3208

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Cat. No. Fs 97-4/3208E-PDF ISBN 978-0-660-36945-7 ISSN 1488-5387

Correct citation for this publication:

Carr, J., Kocik, J., and Edwards, P. 2020. Report of the Telemetry and Atlantic Salmon Workshop: Next Steps from Estuary to the North Atlantic Ocean. Can. Manuscr. Rep. Fish. Aquat. Sci. 3208: vi + 25 p.

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ABSTRACT

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Marine survival is a primary challenge to sustainable Atlantic Salmon fisheries and conservation of endangered populations. Telemetry has emerged as an essential tool to study fish at sea and technological developments and innovative study designs are advancing this technology beyond descriptive work. A workshop of research partners and experts was convened in Halifax (NS) on December 5 – 6, 2017 to review ongoing telemetry initiatives and to develop a vision for a collaborative and coordinated telemetry program for Atlantic Salmon, leveraging the scoping efforts of the North Atlantic Salmon Conservation Organization's (NASCO) International Atlantic Salmon Research Board (IASRB) SALSEA-Track initiative. The workshop was focused on research efforts for North American Atlantic Salmon populations throughout their migratory range. The workshop participants concluded that emerging technologies would change the way Atlantic Salmon populations are monitored at sea. These data combined with informed and complex models will help researchers understand habitat use at sea and start to identify areas/regions of importance. Survival studies using telemetry beyond embayments and straits will not be practical in the immediate future. However, integrated approaches can be developed that will greatly refine our understanding of ocean occupancy, timing, and population-specific migratory routes. This information will begin to narrow down the when and where of marine mortality to finer levels of resolution. As technology advances, acoustic telemetry will remain an important tool on continental shelves, satellite telemetry will uncover migration routes from the Greenland feeding area to the open ocean, and emerging technologies are expected to offer a more detailed look at open ocean movements at finer spatial and temporal resolution and more importantly for longer periods of time. This report summarizes the discussions from the workshop for the purpose of creating a framework for integrating future research efforts to maximize information gains. The workshop was financially supported by a project contribution to the Atlantic Salmon Federation from Fisheries and Oceans Canada through the Atlantic Salmon Research Joint Venture.

RÉSUMÉ

Carr, J., Kocik, J. and Edwards, P. 2020. Report of the Telemetry and Atlantic Salmon Workshop: Next Steps from Estuary to the North Atlantic Ocean. Can. Manuscr. Rep. Fish. Aquat. Sci. 3208: vi + 25 p.

La survie en mer du saumon atlantique est un défi principal pour la durabilité des pêcheries et pour la conservation des populations menacées de disparition. La télémétrie est devenue un outil essentiel dans les études des poissons en mer et les développements continus de ces technologies, en association avec des conceptions d'études innovateurs, ont permis d'aller au-delà de travaux descriptifs. Un atelier regroupant des collaborateurs et des experts en recherche s'est tenu à Halifax (N-É) les 5 et 6 décembre, 2017 dans le but de passer en revue les activités courantes et de fournir une vision de programme coordonné et collaboratif utilisant la télémétrie pour étudier le saumon atlantique. Ces discussions ont été alimentées par le travail déjà entrepris dans l'initiative « SALSEA-Track » coordonnée par le « International Atlantic Salmon Research Board » de l'Organisation pour la Conservation du Saumon Atlantique Nord (OCSAN). L'accent durant l'atelier était sur les activités de recherche portant sur l'étendue de la migration des populations de saumon atlantique de l'Amérique du Nord. Les participants à cet atelier ont conclu que les technologies émergentes vont changer la façon d'étudier les populations de saumon atlantique en mer. Les données provenant de telles études en combinaison avec des modèles complexes et informés vont alimenter nos connaissances sur l'utilisation de l'habitat en mer et ceci permettra d'identifier des endroits et des régions d'importances pour le saumon. À court terme, les recherches au sujet de la survie en mer utilisant la télémétrie ne seront pas pratiques au-delà des zones côtières ou des détroits marins. Le recours aux approches intégrées permettra de grandement améliorer nos connaissances des endroits d'occurrences en océan, de la synchronisation, et des routes migratoires spécifiques aux populations. Avec ces connaissances, il sera possible d'identifier à meilleur précision les périodes et les endroits de mortalités en mer. Avec les progrès technologiques anticipés, la télémétrie acoustique sera davantage un important outil pour des études s'étendant sur les plateaux continentaux, tandis que la télémétrie utilisant les satellites permettra de mieux connaître les trajets migratoires partant des lieux d'alimentation au Groenland jusqu'en haute mer. Les nouvelles technologies offrent le potentiel d'obtenir de plus amples détails sur les déplacements en haute mer, à des niveaux temporels et spatiaux plus précis et pour une plus longue durée de temps en mer. Ce rapport est un sommaire des discussions durant l'atelier dans le but de construire un cadre de recherche intégrée qui permettra de maximiser les apports d'information. L'organisation de l'atelier a été appuyée par une contribution financière de projet à la Fédération du saumon atlantique par l'intermédiaire du Plan conjoint de recherche sur le saumon atlantique de Pêches et Océans Canada.

INTRODUCTION

This workshop, held December 5-6, 2017 in Halifax (NS), was convened for the purpose of reviewing and developing a strategic approach for telemetry studies on Atlantic Salmon in the Northwest Atlantic. The workshop logistics were provided through a contribution agreement to the Atlantic Salmon Federation by Fisheries and Oceans Canada through the Atlantic Salmon Research Joint Venture (ASRJV). The ASRJV is a collaborative partnership of Federal and Provincial agencies, Indigenous organizations and governments, non-government organizations and academia actively engaged in carrying out or supporting research on wild Atlantic Salmon. The mission of the ASRJV is to advance the knowledge on wild Atlantic Salmon by engaging the scientific community in the identification of common scientific objectives; in the sharing of expertise and resources, leading to improved conservation and management practices for the sustainability of the resource in eastern North America.

The workshop was chaired and facilitated by Jon Carr (Atlantic Salmon Federation) and Patricia Edwards (Fisheries and Oceans Canada, ASRJV Coordinator). The workshop objectives and agenda (Appendix 1) were developed to build upon a workshop convened in December 2014 by the North Atlantic Salmon Conservation Organization's (NASCO) International Atlantic Salmon Research Board (IASRB). The outcome of that workshop was the SALSEA-Track initiative. Currently there are 12 priority projects in that sphere, of which five are connected to North American populations and one is based in West Greenland. However, our focus was to support the ASRJV and we worked to keep their priorities of practical conservation advice in mind as discussions occurred and approaches were outlined. As in the previous workshop, the ASRJV partners and invited experts were assembled to develop a collaborative and coordinated telemetry program in North America within which would be nested individual telemetry projects occurring across the species range in North America and the western North Atlantic. Because several of the participants were at the IASRB meeting this provided some continuity among the two efforts. However, several additional experts and partners helped provide fresh ideas and perspectives (Appendix 2).

Our target goals are outlined below. However, we approached the workshop as a structured decision-making exercise. As such, the three goals framed our approach but did not constrain our brainstorming sessions, discussions, or resulting outputs. We reviewed historical studies of salmon at sea (Appendix 3) and ongoing telemetry work organized by geographic region (NAFO zones) through syntheses by presenters (Appendix 4), followed by an overview of SALSEA-track. These presentations and associated questions and answers formed an excellent baseline of existing knowledge.

During subsequent discussions of a research plan, we tried to integrate the five ongoing US-Canada based SALSEA-Track projects into the discussion and project plan development. Through discussion, we determined that four of them were important at an ASRJV level and appropriate to 5-year management needs (drifters/bioprobes; expanded receiver arrays; platforms of opportunity; and West Greenland tracking). While of scientific interest, kelt tracking was felt to be less important at the ASRJV priority-level since this stage was less important to overall North American population productivity. Given the state of both spatial coverage and analytical methods, the group concluded that estimating and partitioning marine mortality was

still best accomplished at a local level of resolution (bays, headlands, and straits). As such, for a larger spatial scale of interest, the focus over the next 5 years would be on understanding distribution, timing, and habitat characteristics important to marine salmon further out on the coastal shelf, open ocean, and West Greenland coastline.

Telemetry is in a transition period between descriptive work and more directed science questions to identify and determine the scope of marine threats. This is a natural and necessary step in marine research as tools and technology emerge to allow more quantitative data to be collected at much larger spatial scales. Currently, more direct questions are being investigated at a local level (e.g. timing of hatchery releases in Maine; predation in New Brunswick estuaries) while assets and methods in the open ocean are quickly advancing from R&D to operational products and models. Given this transitional phase and the desire of the group to engage a larger research community in problem solving, we developed recommendations of priority work rather than a more specific project list or list of testable hypotheses. Lists would have been too narrow in geographic scope and not fully representative across North American estuaries, coastal waters, and ocean migration area. The recommendations we made are designed to provide critical focal areas that will advance information gains in an integrated fashion. Advanced collectively and with continued communications across the five topic areas, this information will provide the tools to better scope research questions and to move forward with studies approaching 1,000 km^2 and eventually the scale of the Northwest Atlantic. Time scales will also shift from 90-120-day studies to 12-20 months providing a composite picture of salmon ecology and survival at sea.

Scope of the Workshop

The specific goals of the workshop were:

- Review past and ongoing studies in the North Atlantic to inform future research based on data needs/gaps;
- Frame discussions within SALSEA-Track North American and Greenland Components;
- Develop 5-year research program for the North Atlantic that builds on SALSEA-Track and focuses on:
    - estimating and partitioning of marine mortality of wild Atlantic Salmon; and
    - improving our knowledge of salmon migration and distribution patterns.

Specific Objectives of the Workshop

The specific objectives of the workshop were:

- Review historical/current state of knowledge of Atlantic Salmon migration and distribution patterns in the North Atlantic;
- Review current research efforts on Atlantic Salmon migration and distribution at sea;
- Review inventory of existing or potential tag release locations and telemetry platforms (“of opportunity”) in the Northwest Atlantic, relative to NAFO Zones (1-5) and identify prime areas that require coverage;

- Review and discuss up and coming research and development innovations that might advance and improve telemetry studies in the North Atlantic;
- Identify and define a series of testable hypotheses to address knowledge gaps in Atlantic Salmon migration and distribution patterns in the North Atlantic;
- Develop a concise list of research themes/projects to address future data needs and gaps.
- Identify projects to be nested within a multi-year research program designed to improve our understanding of Atlantic Salmon migration and distribution patterns in the North Atlantic including: project lead(s), regional collaborators, number of tagged fish required, life-stages, in-kind and monetary commitments, resource needs; and (time permitting)
- Review and discuss protocols for Atlantic Salmon tag and tracking methodologies (surgery protocols, appropriate tag-body ratios, requirements from regulators and/or animal care committees, deployment strategies, etc.).

PRE-ACOUSTIC STUDIES

Atlantic Salmon in the Northwest Atlantic: A Summary of Eight Studies.

Historically, knowledge about marine distribution of many fish species has come from mark-recapture studies or genetic sampling associated with fisheries and or surveys. Earlier research on Atlantic Salmon post smolt and adult migration and distribution in the Northwest Atlantic relied heavily on trawls and gillnets (Templeman 1967, 1968; Lear 1972; Reddin 1985; Reddin and Shearer 1987; Reddin and Short 1991; Reddin and Friedland 1993; Sheehan et al. 2012). In addition to counts, CPUE, basic measurements, gut-content and sea surface temperature were all measured by most researchers. The areas covered ranged from the Grand Banks to Davis Strait off West Greenland. Studies are summarised in Appendix 3.

NORTHWEST ATLANTIC FISHERIES ORGANIZATION (NAFO) ZONE UPDATES

Prior to this workshop, participants were requested to provide one-page summaries related to the history and known telemetry or tracking activities of wild Atlantic Salmon in the North American Commission (NAC) NAFO Zone. These summaries included the study goals; seasonality of coverage; location and description of related receiver arrays; mobile monitoring; and lessons learned. The detailed NAFO Zone and European program updates are summarised in Appendix 4.

SALSEA-Track

The North Atlantic Salmon Conservation Organization's (NASCO) International Atlantic Salmon Research Board (IASRB) has identified the need to understand salmon mortality at sea as a priority, and promotes the collaboration and cooperation on research into marine mortality of Atlantic Salmon and the opportunities to counteract this mortality. NASCO's IASRB implemented SALSEA-Track to encourage the development of large international collaborative telemetry projects that together build upon and expand local efforts. They hosted a telemetry workshop in December 2014 where international scientists formulated and/or built upon 12

independent telemetry-based research projects aimed to investigate much of the Atlantic Salmon's marine migration patterns, and to identify where and when salmon are dying at sea. Six of the SALSEA-Track projects (five in the NAC, and one associated with the North-East Atlantic Commission) are reviewed below in the context of this workshop.

Drifters and Bioprobes: Options for detecting acoustically tagged fish in large geographic areas for North American Commission SRBTW (14)3

Line arrays for detecting the movement of acoustically tagged animals and to estimate survival rates have been used in many locations with relatively narrow passage points and in locations in which the movement of animals is assumed to be generally unidirectional. Using line arrays in areas in which animals can disperse over much broader areas is a challenge because of the narrow spatial coverage afforded by these arrays and the short time period which acoustically tagged animals may be in the vicinity of any of the receivers in the array. The use of bioprobes or drifter arrays may be informative in these areas. (from ICR (15)3: Report of NASCO's International Atlantic Salmon Research Board's Telemetry Workshop, 2014).

Participants at the workshop discussed the challenges and opportunities of equipping drifters, bioprobes and gliders with receivers and concluded that if we could determine how to strategically utilize existing programs and infrastructure, information from these tools could fill gaps in existing knowledge.

Further R&D work is required for equipping drifters/bioprobes/gliders with acoustic telemetry capabilities to facilitate the spatial coverage for acoustically tagged animals in the open ocean.

New Receiver Lines/ARRAYS/Grids in North Commission Area SRBTW (14)4

Additional receiver detection points would greatly advance our understanding of the marine phase of Atlantic Salmon. Additional receiver arrays at key locations would provide more robust stock-specific estimates of mortality, migration routes and dynamics during the first year at sea. (from ICR(15)3: Report of NASCO's International Atlantic Salmon Research Board's Telemetry Workshop, 2014).

Participants at the workshop agreed that very little is known about the distribution of salmon after their first month at sea. Questions were raised as to where receivers should be deployed. While tracking studies have shown that salmon post smolt appear to be following the shelf it is not known if there are alternate strategies. Are post smolts captured in trawls off the shelf following similar migratory patterns to post smolts on the shelf closer to shore? Are there subpopulations? An exploration of these questions would help guide the appropriate deployment of receivers. It was determined by the participants that while these methods were appropriate for post smolts, capture and satellite tagging was a better method for tracking adult salmon.

Trawl surveys conducted by DFO (1965-1991) captured too few salmon near the end of this time period (<100 fish) to warrant the cost of vessel time thus, re-starting a North Atlantic trawl focused on Atlantic Salmon is not a viable option. Another question of this earlier survey information is whether the salmon caught in the gillnet trawls were a mix of various populations of fish that were not as successful at competing in the coastal zone and were thus forced off the

shelf. Salmon and tags continue to be found in coastal Labrador drift net fisheries. The participants agreed that until more is known about the spatial and temporal migration patterns of salmon after their first month at sea (i.e. predictions through simulation modelling), receiver arrays should be concentrated in nearshore areas.

As a first step, receiver lines along the coast of Labrador and Newfoundland, extending 10-30 km from shore, could be established to determine the extent to which salmon migrate in proximity to the coast in that area.

Platforms of Opportunity in the North American Commission Area: Stationary Platforms of Opportunity Receiver Exchange (SPORE) SRBTW (14)5

Receivers deployed on existing buoys and platforms associated with collection of environmental monitoring (oceanography and weather buoys) and offshore commercial enterprises (fishing, aquaculture, offshore energy etc.) can be a cost-effective way to obtain baseline acoustic monitoring data. These associations of fish location data with environmental data provide an opportunity to exchange information and expertise with oceanographers and others to better understand seasonal salmon distributions in changing oceans. (from ICR(15)3: Report of NASCO's International Atlantic Salmon Research Board's Telemetry Workshop, 2014).

Information that could be derived from platforms of opportunity in the North American Commission area or SPORE (Stationary Platforms of Opportunity Receiver Exchange) were seen by participants to be useful supplemental information but perhaps would not play a central role in deployments until migration modelling was undertaken and collaborations between salmon researchers and biological oceanographers could identify on which SPORE it would be strategic to deploy receivers.

North American Commission Kelt Satellite Tagging SRBTW (14)6

Atlantic Salmon kelts from different rivers migrate in spring to feeding areas before returning after one or more years. Kelts from different rivers use separate feeding areas that are defined by oceanographic processes which vary from year to year. The use of satellite tags will allow researchers to address: the extent of fine-scale population mixing/segregation in the ocean; stock-specific and population structure (spatial and age) migration strategies; mortality/success in relation to habitat occupation in feeding area; return/predation rates and type; migration dynamic linkages with oceanographic conditions. (from ICR(15)3: Report of NASCO's International Atlantic Salmon Research Board's Telemetry Workshop, 2014).

Although kelt tracking programs have increased our knowledge of marine distribution and habitat use of this life stage, the larger knowledge gap is on the maiden life stages and further kelt tracking studies would not be a priority in the immediate future.

Adult Satellite/Acoustic Tagging at Greenland SRBTW (14)13

This technology, in combination with genetic assignment methods, offers the ability to provide information on stock-specific migration routes, behaviour and mortality during the second year at sea. (from ICR(15)3: Report of NASCO's International Atlantic Salmon Research Board's Telemetry Workshop, 2014).

The waters off the coast of West Greenland serve as an important mixed stock summer feeding area for future maiden two sea-winter Atlantic Salmon spawners (and post spawned adults) originating both from Southern Europe and North America. Given the constraints of poor marine survival on stocks from North America and Southern Europe, and the importance of this life history type to the overall productivity of these stocks, a tracking program provides an excellent opportunity to conduct studies that further our understanding of this critical life stage.

The ASF, NOAA, Woods Hole Oceanographic Institute (WHOI) and DFO are in the planning stages for a PSAT tagging program at West Greenland to begin in September 2018. The area of coverage will encompass a substantial portion of the marine feeding areas for mixed stocks of maiden and post spawned Atlantic Salmon from both sides of the Atlantic. Genetic analysis will determine continent of origin. The program will also incorporate research and development of ROAM technology (see next section in this report). The objectives are to gain a better understanding of where, and for how long, salmon spend foraging along the coast of Greenland; the extent of population mixing in the ocean; stock-specific and population structure; homeward migration strategies; mortality and predation rates; and migration dynamic linkages with oceanographic conditions.

The application of satellite tags on the non-maturing salmon life stage at West Greenland provides a unique and timely opportunity to address knowledge gaps on the marine distribution, stock specific migration routes and behaviour and mortality for maiden and post spawned Atlantic Salmon during the second year at sea.

Migration Modelling

Workshop participants discussed the value in formulating simulation models to predict salmon migration patterns at sea. These models could help identify how and where receivers are eventually deployed in the Labrador Sea. A similar approach was undertaken by researchers in the North-East Atlantic Commission (NEAC) termed ‘particle drift model’. This was discussed at the SALSEA-Track workshop and is summarised below.

Particle Drift Model

A particle drift model, developed as an output from the SALSEA-Merge project (2009 to 2011), indicated a strong likelihood that most southern European post smolts (Spain, France, Ireland and UK) use the European shelf edge current as a marine ‘highway’, following currents to summer/autumn feeding grounds in the Norwegian Sea. The SALSEA-Merge model assumed that much of the movement of post smolts was a result of passive transport. This model and the associated hypotheses surrounding the migration paths of southern European post smolts should be tested to see if it accurately portrays smolt migration, particularly in areas where smolts leaving freshwater have to migrate significant distances against the residual coastal and oceanic currents. The utility of using smolt migration models for designing large-scale telemetry monitoring projects should be considered further. (from ICR(15)3: Report of NASCO’s International Atlantic Salmon Research Board’s Telemetry Workshop, 2014).

Workshop participants discussed the importance of understanding Atlantic Salmon movements in the Labrador Sea and the challenges (logistics and costs) associated with receiver deployments in such a large area. Simulation modelling to predict Atlantic Salmon (primarily

post smolt) migration pathways in the Labrador Sea would help with the design of telemetry arrays to test model predictions. Such models will also be useful for the design of grid arrays, for planning wave glider missions, SPORE deployments, etc.

A subgroup from workshop participants was formed to discuss and formulate the development of a simulation model for the Labrador Sea.

ADDITIONAL PROJECTS AND FUTURE NEEDS

In addition to SALSEA-Track, the workshop participants identified a number of other research gaps. These are discussed in the sections below.

Partitioning Marine Mortality

Telemetry with fixed acoustic arrays provides us with more power to examine early weeks of marine survival and questions of detectability. But telemetry and fixed arrays are only one set of tools in our toolkit. We should also consider nesting a smolt pit tag study within an existing telemetry system to partition mortality further i.e. which smolts to adults proved to be most successful at sea and examine this between years in different NAFO zones.

Oceanography

Workshop participants discussed the importance of understanding the oceanographic conditions associated with salmon migrations. We need to understand the physical and biological oceanographic processes that drive observed salmon migration patterns (i.e. sea-surface temperatures, prey distribution and productivity, etc). It is important to examine how the spatial distribution of salmon corresponds with the temporal occurrence of abiotic (temperatures, currents, etc.) and biotic (prey and predators) features and assess how they could be linked to survival and growth.

The participants highlighted the importance of forming collaborative partnerships with oceanographers in parallel with telemetry programs.

Research & Development

Our understanding of fish movements is largely derived via two methods: ultrasonic acoustic monitoring and light-level geolocation via PSAT tags. Acoustic and archival telemetry programs have undergone major advancements in recent years; however, we are still limited in our ability to accurately geolocate and track individual salmon throughout their complete marine migration. Acoustic tagging approaches are biased towards nearshore areas and currently limited due to tag size and battery life constraints. PSAT monitoring is currently limited by tag size, accuracy of light geolocation, and species behaviour (species in northern areas or that exhibit frequent diving activity reduces the efficacy of light-based geolocation).

To overcome some of these shortcomings, the Woods Hole Oceanographic Institute (WHOI) is developing a new archival tag that will provide accurate geolocations of fish throughout the water column across ocean basins. These tags (called ROAM) have the potential to become a tool (used in concert with other telemetry methods) for studying the entire marine migration of Atlantic Salmon.

ROAM

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. The RAFOS Ocean Acoustic Monitoring (ROAM) tag miniaturizes and re-purposes a proven oceanographic technology used to track subsurface drifters into a small animal-borne tag. A RAFOS network relies on moored acoustic transmitting units that emit a unique acoustic signal which may carry upwards of 1000 km, thereby providing a large monitoring area with minimal infrastructure and cost. A hydrophone onboard the RAFOS float detects the sounds from the network, and a triangulation algorithm uses the differential sound reception from multiple moorings to calculate the position of instrument or fish to within ± 5 km^2. It is estimated that a minimum of six sound sources would be sufficient to provide detection coverage from western Newfoundland to Disko Bay, Greenland.

An archive ROAM tag has been produced in prototype form and preliminary field tests (led by the WHOI) have been conducted and performance met expectations. The archive tag is suitable for tagging fish as small as 180 mm for tracking up to two years, although the tag will need to be recovered to obtain the data. Discussions are ongoing with a commercial tag company to incorporate the archive ROAM tag into a PSAT version. Expectation is for a prototype tag to be available for testing in late 2018 or early 2019. The PSAT tag will be an equivalent size as a contemporary PSAT tag, with the objective of making them up to 50% smaller; for these tags, tag recovery is not needed as data will be transmitted via satellite. A workshop is planned at the Woods Hole Oceanographic Institute June 7-8, 2018 to discuss the ROAM approach and technology.

Participants agreed that ROAM tags may have the potential to overcome many of the limitations of current geolocation tag technology by providing accurate geolocation at depth over large spatial scales in the open ocean. Emerging technologies like ROAM can be complimentary to existing technologies (i.e. acoustic) and can be designed to answer different questions in different environments.

CONCLUSIONS

Over the course of the two-day workshop, discussions from the participants led to a number of general conclusions:

- Poor at sea survival is the primary driver for the Atlantic Salmon's decline across its entire range.
- Acoustic telemetry work had led to essential information gains over the last few decades by partitioning survival from headlands to coastal regions. There is now a need to address knowledge gaps further offshore and to map the spatial and temporal distribution of salmon.
- Understanding the distribution of different populations at sea and at various points in migration will be key to better understanding the causes of mortality.
- Moving telemetry programs to the next level (Labrador Sea and Atlantic Ocean) is a challenge due to current limitations in the technology and the size of the area of interest.

- Our knowledge base can be expanded through a balance of low risk projects with a high likelihood of success (i.e. linear arrays of proven performance at new locations along the Labrador coast) with projects that are more adventurous (i.e. supporting R & D of new technologies at an Atlantic Ocean scale). A similar (successful) approach was taken in the early years of telemetry with the headlands to coastal programs.
- Deploying receivers on platforms of opportunity (i.e. oceanographic buoys, wave gliders, bioprobes, commercial enterprises, etc.) can be a cost-effective way to collect baseline acoustic monitoring data, supplemental to fixed arrays.
- Strategic placement of receivers in Labrador Sea and Atlantic Ocean should be driven by specific questions. Simulation models offer a tool to refine research questions and explore receiver density and placement needed to answer each question. Receivers should also be deployed to test the validity of the models and constantly refine efficiency measures.
- It is important to exchange information and expertise with oceanographers to gain insight into the environmental factors in the ocean that are driving biotic interactions and life histories of salmon. There is a need to undertake a hypothesis-driven approach and focus on specific questions rather than a 'collect everything approach' and having big data processing sort it out.
- PSATs, in combination with genetic assignment methods, offers the ability to provide information on life stage and stock-specific migration routes, behaviour and mortality during the second year at sea. The West Greenland Atlantic Salmon stock complex is comprised of Atlantic Salmon originating from both Europe and North America. PSATs offer the ability to partition mortality daily during their final months of ocean residency before returning to spawn in freshwater.
- It is critical to encourage and support the research and development of innovative technologies. A promising technology called ROAM (RAFOS Ocean Acoustic Monitoring) was discussed at the workshop. ROAM tags have the potential to overcome many of the limitations of current tag technology by providing accurate geolocation (+ 5 km) at depth over large spatial scales in the open ocean.
- It is important to assess the quality of smolts not just quantity migrating to sea; this applies to differences between hatchery and wild fish and fish under new thermal regimes (early/late run fish). More work is needed here.
- Further research needs to be undertaken to assess the potential for tag related impacts on survival and consideration should be given to the development of standardized operating procedures for all tagging studies (International level).

RECOMMENDATIONS

- Expand capacity to track the coastal movement of wild Atlantic Salmon, where possible using existing infrastructure.
    - Expand northward - extend the existing Labrador 'line' at Port Hope Simpson, NL and add another line further north at Rigolet, NL to assess the use of this area along the Labrador Shelf by salmon.
    - Partners should take advantage of existing stationary (buoys, moorings, off-shore energy) and mobile (drifters, autonomous underwater vehicle (AUV), gliders) assets to deploy acoustic receivers. We need capacity to communicate across groups and to combine data.

- Undertake a modelling exercise (particle tracking model including drivers) to better understand detection probability of wild Atlantic Salmon across seascapes.

A structured migration model will help develop the most cost-effective methods to sample broad geographic areas by instructing the positioning of future receiver lines/grids, etc. or which vessels or AUV search patterns would be most effective. The tool will also help develop hypotheses by looking at ocean features (currents, depth, etc.) not just X-Y coordinates.

- Endorse further development of emerging technologies that facilitate open ocean research.

Current tracking technologies (acoustic and satellite) are not the only solutions to answering our questions in the open ocean. Innovations like ROAM [RAFOS Ocean Acoustic Monitoring] could overcome current limitations of tracking 'small' fish due to current tag, battery, and receiver technology.

- Further develop tagging research (satellite/acoustic/emerging) on adult salmon at Greenland.

West Greenland is a key feeding area for multi-sea spawners from multiple North American and European populations, and understanding habitat use there is important to a more complete understanding of drivers of marine productivity. Information would also aide the development of predictive models of marine productivity and provide a better understanding of factors contributing to differential marine survival between stocks.

- Standardize the methodology used for all tagging studies, both nationally and internationally, so that data from all studies might be used in concert with one another.
    - Information sharing across groups and with other fields of expertise (e.g. veterinarians, physiologists) is essential to minimizing tag effects and allowing study animals to better represent the population at large.
    - Further tag retention study(ies) and accompanying Research and Development to improve tag retention are needed. Next generation tags will need to be retained for years not months.

ACKNOWLEDGEMENTS

The workshop logistics were provided through a contribution agreement to the Atlantic Salmon Federation by Fisheries and Oceans Canada through the Atlantic Salmon Research Joint Venture (ASRJV). The ASRJV is a collaborative partnership of Federal and Provincial agencies, Indigenous organizations and governments, non-government organizations and academia actively engaged in carrying out or supporting research on wild Atlantic Salmon. The mission of the ASRJV is to advance the knowledge on wild Atlantic Salmon by engaging the scientific community in the identification of common scientific objectives; in the sharing of expertise and resources, leading to improved conservation and management practices for the sustainability of the resource in eastern North America. The secondary publications editor for this report was Dr. Stephanie Boudreau, Fisheries and Oceans Canada, Gulf Region, Moncton, NB.

APPENDICES

Appendix 1: Agenda

Time	*Item*	*Lead(s)*
Tuesday December 5		
09:00	**Introduction** – to ASRJV, of Participants, and Overview of objectives of Meeting	Trish Edwards Jon Carr
09:30	**Review of SALSEA Track** – 2014 workshop and progress to-date 2014-2016	Tim Sheehan
10:00	**Intro to Working Paper:** Brief Summary of Pre-Acoustic Work in the Labrador Sea and NW Atlantic - *What we know and how we know it*	ASF – Eric Brunsdon
10:10	**Discuss History and Known Activities Zone by NAFO Zone by Zone (goal of study and what did we learn)** – focus on fish, past studies, seasonality of coverage, where are there arrays, mobile monitoring (Using 1-page summaries as a foundation) ● 5Y - Gulf of Maine (Kocik & Sheehan) ● 4X - Bay of Fundy - Scotian Shelf to Halifax (Halfyard, Hardie, Trudel, Levy)	TBD
10:30	***BREAK (refreshments provided)***	
	Zone by Zone Activities (cont.) ● 4W - Scotian Shelf to Sable Island (Halfyard, Levy) ● 4R,S,T - Gulf of St. Lawrence, Cabot, SOBI (Carr, Castonguay, April) ● 3 - Saint Pierre and Miquelon Grand Banks - Newfoundland Coast (Robertson) ● 2 - Labrador Coast to Baffin Island (Robertson) ● 1 - Greenland By Zone 1A - 1F (Sheehan, Carr, Robertson) ● 0 - Baffin Coast - (TBD: possible Nunavut contact)	TBD
12:00	***LUNCH (provided)***	
13:00	***Lessons learned from European Studies***	Matt Newton, Kim Aarestrup, Andy Moore, Cathal Gallagher
14:00	***Where are our Ocean Assets –*** *Large printed Map will available indicating OTN known as a Visual Guide – intent to identify others from group* Review **2017 SALSEA Track** accomplishments: seasonality of coverage, location of existing arrays, mobile monitoring, and *What's on Tap*... ● Drifters and BioProbes: Options for detecting acoustically tagged fish in large geographic areas (North American and/or North-East Atlantic Commissions), SRBTW(14)3 ○ Updates ○ Ideas for synthesis - km per month by NAFO Zone ○ Salmon Detections per km and time ● New Receiver Lines/Arrays/Grids (North American Commission area), SRBTW(14)4	TBD

	• Platforms of Opportunity in the North American Commission area: Stationary Platforms of Opportunity Receiver Exchange (SPORE), SRBTW(14)5
	• North American Commission kelt satellite tagging, SRBTW(14)6
	• Adult satellite/acoustic tagging at Greenland, SRBTW(14)13
	• Other Fish Arrays - on OTN map - so who should Salmon JV connect with other programs to ID cross-cutting ecosystem studies
	  ○ Data sharing for arrays
	  ○ OTN - shared
	  ○ non-networked data	

15:00	***BREAK (Refreshments provided)***	
15:30	**Define testable hypotheses** to identify knowledge needs and gaps and generalized approaches Index Rivers • High Tag Output Areas & Sustaining High Numbers of Tags • Focus Areas	
17:00	***Adjourn Day 1***	
18:30	***Group Dinner - Location TBD*** *(optional)*	

Tuesday December 6		
08:30	Review Status and Progress	
09:00	Review R&D projects & future needs Tech Talk • VEMCO • OTN • ROAM	VEMCO– TBD Fred Whoriskey Simon Thorrold
10:00	***BREAK (refreshments provided)***	
10:30	Define testable hypotheses to identify knowledge needs and gaps and generalized approaches • Index Rivers • High Tag Output Areas & Sustaining High Numbers of Tags • Focus Areas	
12:00	***LUNCH (provided)***	
13:00	**Develop list of research themes nested in SALSEA-Track North American and Greenland** Goal: develop a 5-year research program for the North Atlantic that builds on SALSEA-Track and focusing on: • Estimation and partitioning of marine mortality of wild Atlantic salmon; and • Improving our knowledge of salmon migration and distribution patterns. • Identifying impacts of emerging marine threats climate (oceanographers, etc) and human activity (development, fisheries, etc) and management actions	
15:00	***BREAK (refreshments provided)***	
15:30	**Outcomes, Next steps and Recommendations** (e.g. public access to data; projects to undertake; Foster Partnerships - Ecosystem Studies (Turbot, striped bass, grey seals, cod)	
17:00	***Adjourn***	

Appendix 2: List of Participants

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Appendix 3: Pre-Acoustic Work – A Summary of Eight Studies

- Templeman, W. 1967. Atlantic Salmon from the Labrador Sea and Off West Greenland, Taken During A.T. Cameron Cruise, July-August 1965. ICNAF Research Bulletin, volume 4: 4-40, 1967.

During a cruise of the A.T. Cameron to investigate ground-fish stocks, 18 gillnet sets were made for Atlantic Salmon during July of 1965. Sets were made over oceanic depths at the mouth of the Labrador Sea, in shallower waters off West Greenland and again in deeper waters west of Cape Desolation and Farewell on southern Greenland. Only adult fish were caught, likely due to the mesh size used (as small as 70mm, but mostly larger). A total of 39 Atlantic Salmon were caught in the 18 sets. All were caught near the surface, with 97% in the upper 2.4m. River ages of the caught salmon ranged from 2 to 6 with 61% being aged at two river years. This suggests the salmon caught originated over the range of salmon in North America. Stomach content analysis revealed that in the Labrador Sea, arctic squid was a major component. Off West Greenland, sand lance and capelin dominated. Paralepids (barracudina) and Greenland halibut fry were also found. Temperatures were taken during the gill net sets at the foot line of the net. Off West Greenland, temperatures ranged from 3.2°C - 5.3°C and 2.3°C off Cape Desolation. The highest catches were made in the Labrador Sea and west of Cape Farewell in temperatures of 8.5°C.

- Templeman, W. 1968. Distribution and Characteristics of Atlantic Salmon Over Oceanic Depths and on the Bank and Shelf Slope Areas off Newfoundland, March – May, 1966. ICNAF Research Bulletin Number 5, 1968.

Drifting gillnets were deployed from March 21 to May 1, 1966. Areas sampled were North-East of Labrador in the Labrador Sea down along the Southern edge of Newfoundland. A total of 45 salmon were caught in temperatures ranging from 3.7 to 6.1°C. Only one gillnet set did not catch any salmon and was within temperatures of 9.2°C within the Labrador Sea northeast of Newfoundland. 84% of salmon were 2 SW fish, 9% were 1SW and 7% were 3 SW. Of maiden fish, 68% were females, and of fish older than 1 SW, 73% were females. Gut contents mainly consisted of paralepid and lantern fish.

- Lear, W.H. 1972. Food and Feeding of Atlantic Salmon in Coastal Areas and Over Oceanic Depths. ICNAF Research Bulletin Number 9, 1972.

An investigation of stomach contents from 2,350 salmon caught in research cruises, commercial catches in West Greenland and Newfoundland and Labrador coastal areas and in the Saint John and Miramichi Rivers in New Brunswick. Findings indicate that salmon eat at differing intensities and on different organisms in different habitats. In the Labrador Sea in May, barracudina species were the main prey item, while between August and November, Arctic squid was also found frequently. Salmon off West Greenland were feeding more continuously but less intensively than coastal Newfoundland and Labrador with capelin, sand lance, amphipods, euphasids making up more of their diet than other species, though variety existed. In Newfoundland coastal waters in May through July, sand lance, capelin and herring were found to be the most frequent prey item.

- Reddin, D.G. 1985. Atlantic Salmon (*Salmo salar*) On and East of the Grand Bank. Journal of Northwest Atlantic Fishery Science. Vol 6:157-164, 1985.

In 1979 and 1980, gillnets were set during May within the Grand Banks and just east of Grand Banks. A total of 14 and 327 salmon were caught in 1979 and 1980, respectively. The majority of sampled areas within temperatures ranging from 3.8 - 7°C were successful at capturing adult salmon, and the highest catch rates were in areas of 5.8 to 7.5°C. Of all fish sampled in 1979 and 1980, river age ranged from 1-5, sea age ranged from 1-3. Overall, 46% of fish were female, however, in multi sea winter fish, females consisted of 63% of the population, whereas in maiden fish, females consisted of 28% of the population. Gut content analyses showed that 93% of their diet consisted of Sand lance and Capelin.

- Reddin D. and Shearer W. 1987. Sea-Surface Temperature and Distribution of Atlantic Salmon in the Northwest Atlantic Ocean. American Fisheries Symposium 1:262-275, 1987.

Survey and commercial fisheries data was taken from 1969-1985 off West Greenland, Grand Bank (southern Newfoundland), Labrador Sea and the Irminger Sea. Catch data was compared to the latitude of the 4°C isotherm within January and August, and the relative rate of spring heating (area covered by 4°C isotherm) within the areas. Overall, catches were higher within areas within the 4°C isotherm and salmon movements were influenced by water temperatures. Years where catches were low (1983 and 1984) off the west coast of Greenland were related to colder water temperatures. Abundance of Atlantic Salmon off western Greenland was highly influenced by the extent of the 4°C isotherm in August. Catches were highest at temperatures above 3°C and declined at temperatures above 8°C.

- Reddin D. and Short P. 1991. Postsmolt Atlantic Salmon (*Salmo salar*) in the Labrador Sea. Can. J. Fish. Aquat. Sci., Vol. 48:2-6, 1991.

During the autumns of 1987 and 1988, surface gill-nets were set in the Labrador Sea. Over 400 salmon were caught including 207 post-smolts that originated from Maine to Labrador, as judged by river-age from scale analysis and Carlin tags. They conclude that since post-smolts are found in the Labrador Sea approximately 4 months after leaving freshwater, the area is an important nursery ground for salmon. Additionally, they note that since post-smolts are caught in the Labrador Sea in autumn as well as spring, they may use they area for over-wintering as well. The highest catches of post-smolts occurred between 56°N and 58°N.

- Reddin D. and Friedland K. 1993. Marine Environmental Factors Influencing the Movement and Survival of Atlantic Salmon. In Salmon in the Sea and New Enhancement Strategies – pp79-103. Ed. By D. Mills. Fishing News Books.

A summary of previous work detailing catches of Atlantic Salmon in the Labrador Sea, off West Greenland, the Irminger Sea and the Grand Bank off Newfoundland and Labrador. Research vessel catches of the period from 1965 – 1991 indicate that salmon of all sea-ages occurred seasonally over most of the Northwest Atlantic. They are concentrated throughout the year in the Labrador Gyre, in summer and fall off West Greenland and in the spring near the eastern slope of the Grand Bank. Post-smolts are found in the Labrador Sea, mostly between 56° and 58° during the fall. The areas sampled had recorded sea surface temperatures (SST) generally between 4°C and 10°C. Adults appeared to range over a wider area than post-smolts. Scale analysis of river-age showed that captured post-smolts likely originated from the entire range of Atlantic Salmon in North America.

Catch rates are significantly related to SST and peak at 7°C and 8.5°C. No sets had been made

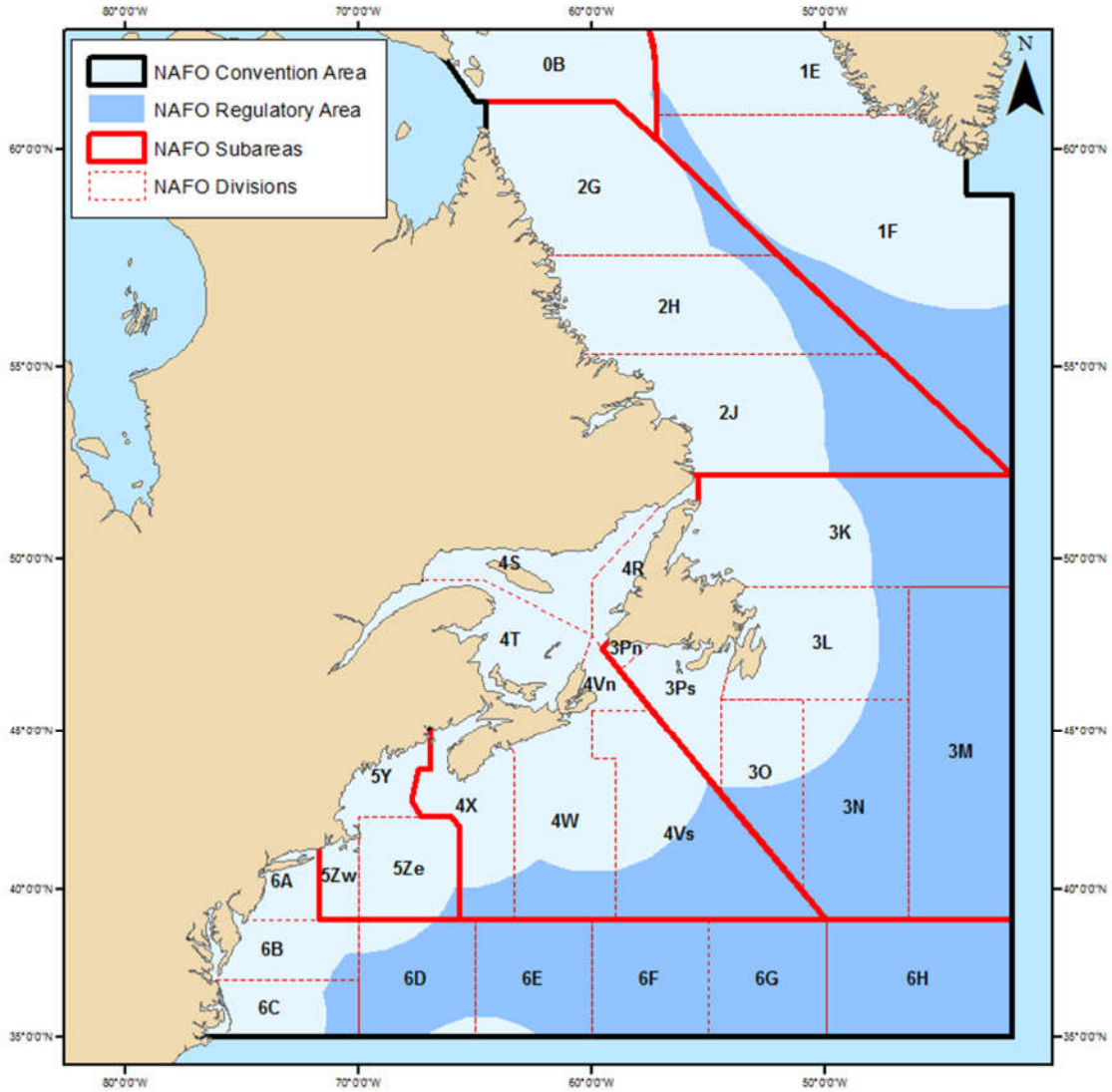
above 13.5°C. The range from 4°C to 10°C included 80% of the catch. It was postulated that salmon modify behaviour based on SST. Included in this behaviour would be ice avoidance as when ice cover was higher in more northerly waters, catches increased in southerly waters. The area of 4°C to 10°C water varies annually in size and thus affects MSW and post-smolt salmon survival and migration.

- Sheehan T., Reddin D., Chaput G., Renkawitz M. 2012. SALSEA North America: a pelagic ecosystem survey targeting Atlantic salmon in the Northwest Atlantic. ICES Journal of Marine Science (2012), Vol.69 (9), 1580-1588.

In 2008 and 2009, pelagic surveys were undertaken in the Labrador Sea for Atlantic Salmon during August and September. Using both surface trawl and surface gillnets, 107 Atlantic Salmon were caught. The gillnet proved to be more effective for salmon, catching 84 versus 23 fish. Salmon from different cohorts were caught together suggesting that the Labrador Sea is a common habitat across different life stages. Stomach content analysis revealed *Themisto compressa* to be a very important food item.

Appendix 4: NAFO Zone Updates

Prior to this Workshop, participants were requested to provide one-page summaries related to the history and known telemetry or tracking activities of wild Atlantic Salmon by NAFO Zone (Appendix 4 Figure 1). These summaries included the goal of the study(ies); seasonality of coverage; location and description of related receiver arrays; mobile monitoring; and lessons learned. The detailed NAFO Zone and European program updates are summarised in the sections below.



Appendix 4 Figure 1. Map of North Atlantic Fisheries Organization (NAFO) Zones.

Gulf of Maine (5Y)

- John Kocik, Tim Sheehan, Jim Hawkes, Graham Goulette, Mark Renkawitz

NOAA initiated ultrasonic tracking of Atlantic Salmon smolts in 1997 to obtain information on emigration dynamics and identify survival bottlenecks in lower river, estuary, and coastal habitats. Initial efforts focused on a single drainage and tracked a small group (100) of tagged smolts with a small number of fixed receivers through riverine, estuarine and nearshore marine habitats. The tracking program has expanded to include five populations and migration information from over 3,500 individuals. Unique to each system, tracking array resolution and distance has generally increased over time. In some systems, salmon are tracked for 90 km, from their release point 45 km up-river through their migration to headlands 45 - 60 km offshore. These studies have shown that migration is generally surface oriented (< 5 m), rapid (~1 km·h-1), and that survival is highly variable among systems, but losses are great in the 4-week estuary transition period. Our findings suggest that annual variation is likely depended on a host of factors including migration timing, predator suites, prey fields, foraging behaviours, and physiological factors influenced by salinity and thermal regimes. NOAA telemetry data has revealed insights into the complexities of behaviour, survival, and post smolt dynamics during the early marine migration.

NOAA efforts led to new partnerships with a variety of entities, including the Ocean Tracking Network (OTN). US post smolts are now tracked during their migration through the Gulf of Maine (GOM) via platforms of opportunity (PlatOpus- i.e., oceanographic buoys, commercial fishing gear, and ocean drifters). These PlatOpus provide significant infrastructure to other researchers- over 270,000 detections of 15 species released by 28 organizations have been recorded (2005-2016). NOAA efforts have demonstrated that these opportunistic platforms are a low-cost approach, provide benefits to a wide array of researchers and species, and foster dialogue and research sharing to strengthen interdisciplinary and stakeholder communication. Further out to sea, US post smolts have been detected at OTN telemetry arrays cross the Scotian Shelf, mobile units at Cabot Strait, arrays for other species off Newfoundland, and Sable Island seals with VMTs. These data have allowed for the development of Gulf of Maine and Scotian Shelf migration models that have identified potential trajectories and refined likely ocean migration paths used by post smolts. These pieces of information are critical to determine if implementation of management actions to improve survival to the Labrador Sea can be undertaken.

Recommendation: require a dedicated person to communicate with NOAA, Coast Guard, and other agencies or organizations to devise and implement a strategy to use already existing platforms of opportunity to detect marked fish.

Bay of Fundy – Scotian Shelf to Halifax (4X)

- Current research efforts: David Hardie (DFO Maritime Region)

<u>Smolt predation</u>

In 2017, I initiated the first of three years of planned smolt tagging using VEMCO predation tags on the Stewiacke River. These tags emit a different tag ID when proteinaceous glue covering an electrode on the outside of the tag has been digested by a predator. These tags operate at

180 kHz frequency, for which there is currently little or no active receiver infrastructure beyond my receivers at the mouth of the estuary of the Shubenacadie River (Maitland, Nova Scotia). I maintained 18 stationary receivers as well and employed mobile tracking (boat) in the tidal portions of the Stewiacke and Shubenacadie Rivers to track the migration of 50 Stewiacke River smolts tagged and released above the head of tide. The smolt migration in the Stewiacke River occurs during the spawning migration of striped bass. Of the 50 smolts tagged and released over a 9 day period in May and June 2017, 45 were detected resuming a normal downstream migration. Five tagged fish appear to have either died or lost their tags near the release site (2) or were never detected again after release (2, possible avian predation). Nineteen of the 45 remaining tags were detected as having experienced predation on the striped bass spawning grounds. Twenty tags were detected unpredated at the estuary mouth. The remaining 4 tags were detected as not having been predated in the Stewiacke river but not detected thereafter (possible avian predation or tag loss). In future years the smolt tagging and release will be staggered over a month-long period (the full length of the smolt run) to better represent the range of predator- (striped bass) and alternate prey- (gaspereau) fields.

Nashwaak River smolt estuarine and early-marine survival and migration

Results of previous tracking projects and population viability analyses suggested that a higher proportion of total marine mortality occurred during the riverine migration for Nashwaak (Saint John) River smolts than for other rivers in Maritimes Region. Given that improving riverine survival presents a more tractable problem than resolving marine mortality issues I undertook a tagging project of Nashwaak River smolts using conventional 69 kHz tags (detectable on all VEMCO marine acoustic infrastructure as well as on my own deployments, Canadian Rivers Institute etc.). Unfortunately, spring river flow conditions resulted in a failure to capture the wild smolt run in the Nashwaak River for the first time in 15 years, so only 6 wild smolts were tagged. As a result, a further 69 hatchery smolts (Mactaquac Biodiversity Facility) of Nashwaak River origin were tagged and released at the smolt-wheel site. Preliminary results suggest that 70% of the tagged hatchery smolts survived to reach Saint John Harbour, as did all 6 of the tagged wild smolts. This high survival rate is higher than expected based on past research by DFO as well as contemporary research by the Canadian Rivers Institute on Tobique River smolts. These other research projects suggested that high mortality was experienced in the Long Reach area of the Saint John River above Reversing Falls.

Stewiacke River Live Gene Bank non-target adult salmon tracking.
With Jeff Reader – Mi'kmaw Conservation Group.

A total of 50 fish were tagged and released at head of tide. Tracking is ongoing. Half dropped quickly down the estuary. Of the remaining half about 15 stayed in river fairly close to release site while 7 went upriver to deep pools. Mobile and stationary tracking is ongoing.

Question: Can the Ocean Tracking Network be convinced to maintain both the 180 and 69kHz receiver capability? There is potential that we may be missing many fish if we were to only utilize the 69kHz capability.

Assessing the interactions between wild and farmed salmon

- Marc Trudel – DFO Maritime Region

Background

Salmon aquaculture has been identified as a potential threat limiting the recovery of endangered populations of Atlantic Salmon in eastern Canada and the United States. In the marine environment, wild salmon may be exposed to parasites and pathogens originating from farmed salmon or to predators that may be attracted to aquaculture facilities. As a result of these interactions, mortality may increase either in the proximity of the farms (i.e. predators) or distantly from the farms (i.e. disease). Despite growing concerns on the potential impacts of salmon aquaculture on wild salmon, a literature review on Atlantic Salmon migration revealed that little is actually known on the interactions between wild salmon and aquaculture in marine ecosystems.

Objectives

One of the objectives of the aquaculture ecosystems interaction program located at the St Andrews Biological Station in St Andrews, NB, is to better characterize the extent of the interactions between wild and farmed salmon.

Methods

We plan to use acoustic telemetry to estimate the residence time of Atlantic Salmon post smolts in the vicinity of active and fallowed salmon aquaculture facilities in Passamaquoddy Bay and the Bay of Fundy, the primary areas where salmon aquaculture occurs in New Brunswick. For Passamaquoddy Bay, we plan to deploy receivers in 2018 at all the choke points (Lacroix et al. 2004) and on all active salmon aquaculture sites to determine the migration routes used by Atlantic Salmon post smolts, the proportion of post smolts migrating near aquaculture sites, and their residence time near these sites. Hatchery fish will be implanted with acoustics tags and released below the dam in the Magaguadavic River at two periods. Manual tracking will also be performed in the Bay. In addition, drifters will be released to determine to what extent salmon post smolts are passively using currents during their marine migrations.

For the Bay of Fundy, our long-term plan is to deploy receivers in the outer Bay of Fundy along a transect from the coast of New Brunswick to the coast of Nova Scotia similar to the array deployed by Lacroix (2008, 2012) in 2001 and 2002 in collaboration with the Ocean Tracking Network and at active and fallowed salmon aquaculture sites. The proportion of post smolts migrating near aquaculture sites and their residence time near these sites will be determined for selected populations located in the outer and inner Bay of Fundy.

Gulf of St. Lawrence, Cabot Strait, Strait of Belle Isle (4RST)

- Atlantic Salmon Federation (Jonathan Carr)

Since 2003, the Atlantic Salmon Federation (ASF) has been using acoustic telemetry to study the movement and behaviour of Atlantic Salmon post smolts from four rivers draining to the Gulf of St. Lawrence (Southwest Miramichi River, Northwest Miramichi River, Restigouche River, Cascapedia River). ASF carries out this research through collaboration with government, universities/research institutions, First Nations, and other NGOs. This multi-year and multi-population sonic telemetry study has quantified proxies of survival rates of Atlantic Salmon (post) smolts at pre-defined geographic locations in freshwater, in the estuarine and open ocean migratory phases up to almost two months at sea.

Over 3,100 individual smolt have been tracked remotely, via a series of individual, and lines of, receivers that monitor their movements from rivers to the outer reaches of the Gulf of St Lawrence (Strait of Belle Isle and Cabot Strait), covering more than 800 km from their home rivers. More than 400 kelt have been acoustically tagged and tracked from the Miramichi and Restigouche Rivers. Many kelt (N=53) have also been fitted with pop off satellite archival tags (PSATs) allowing us to more definitively identify migratory routes of fish.

Receiver arrays have been strategically positioned at the head of tide for each river, outer Miramichi and Chaleur Bays, and at the two Gulf of St. Lawrence (GoSL) exits: north via the Strait of Belle Isle (SoBI) to the Labrador Sea, and east via Cabot Strait (operated by Ocean Tracking Network) to northwest Atlantic Ocean.

The (median) survival through freshwater has ranged from 80% (Southwest Miramichi) to 96% (Cascapedia River). Survival through freshwater is negatively related to migration duration. Median survival of tagged smolts exiting Chaleur Bay ranged from 80-97% in all years except in 2013 when Cascapedia River post smolts had 64% survival. Median smolt survival through Miramichi Bay has shown a declining trend in recent years. Northwest Miramichi smolt survival decreased from a range of 54-73% (2003-2008) to 29-46% (2013-2016). Southwest Miramichi smolt declines have not been as dramatic, ranging from 60-80% (2003-2010) to 47-68% (2011-2016). Estimated survival rates through the GoSL were the most uncertain with annual CVs ranging from 13-38%. With the exception of the Northwest Miramichi, the estimated survival rates through the gulf ranged from 40-90%. Only 2 smolts were detected at the Cabot Strait line which indicates that the SoBI is the primary exit route for smolts (and kelt) through the gulf. There is an annual synchronization of post smolt migration through SoBI with peak migration occurring over a period of about 7-10 days in early July.

ASF and DFO have used acoustic telemetry to study smolt and striped bass interactions in Miramichi Bay from 2013 -2016. Our data has shown that the percentage of tagged smolts exhibiting striped bass behaviour ranged from 9-20% (Northwest Miramichi) and from 3-17% (Southwest Miramichi).

DFO Québec Region

- Research plan for improved understanding of the marine ecology and survival at sea of Atlantic Salmon: the Québec component (Pedro Nilo – DFO Québec Region)

Three potential directions have recently been proposed by DFO for studying the marine ecology of Atlantic Salmon and testing hypotheses contributing to increased mortality at sea: (1) modelling using available ecosystem data, (2) genomics and other opportunistic sampling, and (3) the use of telemetry to characterize salmon distribution at sea while estimating survival rates at different locations and times.

Québec is one of the most important regions for Atlantic Salmon production in North America. While the Federal Government (DFO) has the mandate for diadromous fish in Atlantic Canada, diadromous fish are a Provincial jurisdiction in Québec (Ministère Forêts, Faune et Parcs, MFFP) and Ontario (Ontario Ministry of Natural Resources, OMNR).

Survival rates

In 2017, DFO Québec and MFFP started a research program that addresses research avenues

(2) and (3) above. Tagging with Vemco V8 transmitters was performed in June 2017 on ca. 75 smolts in each of two Québec rivers where smolts were large enough to meet criteria of the Animal Care Committee: Rivière Jacques-Cartier (50 km upstream of Québec) and Rivière de Vieux Fort (Lower North Shore). Smolt migrations out of these two rivers were monitored by MFFP. Lines of acoustic receivers with thermographs were installed across the two estuaries. Estuarine receivers were close to each other to ensure total coverage of the smolt migration.

Post-smolts from Rivière Vieux-Fort leave the Gulf of St. Lawrence through Strait of Belle Isle on their way to the Labrador Sea and Western Greenland feeding grounds. The route chosen by Rivière Jacques Cartier post-smolts is not yet known (i.e., Cabot or Belle Isles Strait). Although the data are not yet fully compiled, some of the smolts were detected at the Belle Isle receiver array operated by the Atlantic Salmon Federation. Twinning of this acoustic line allows estimating its detection efficiency. This should provide in due course survival estimates of Québec post smolts as they leave the Gulf of St. Lawrence. This acoustic line was equipped with thermographs and mini CTDs to allow monitoring physical oceanographic conditions for the purpose of eventually modelling the post-smolt migration.

Opportunistic sampling

The DFO Atlantic Zonal Monitoring Program (AZMP) installs each year a number of moorings throughout the northern and southern Gulf of St. Lawrence. These moorings are being equipped with Vemco VR2W receivers as opportunistic listening devices to increase overall probability of detecting smolts and returning adults equipped with transmitters.

Predation by seals has been suggested as an important component of mortality of Atlantic Salmon at sea. Providing evidence of prey presence in the diet of key predators is the first step in evaluating the potential impact of predation. Analysis of stomach contents of harbour seals sampled strategic locations and times (in rivers or estuaries) will allow us to start examining this potential impact. We plan to start the harbour seal predation work in 2018.

Question1: Were there, or should there be, receivers placed around Anticosti Island and an array in freshwater at the junction of the St. Lawrence River?

Saint Pierre and Miquelon – Grand Banks – Newfoundland Coast (3) and Labrador Coast to Baffin Island (2)

The following table summarizes the various research activities conducted in the Newfoundland and Labrador areas using telemetry technologies over the period 1996 to 2017.

Year	Life Stage	Season	Location	Habitat	Tag
1996-1997	Adult	Summer	South Coast Newfoundland (Conne River)	River	Radio
1998	Kelt	Summer	Newfoundland (Western Arm Brook, Humber, Campbellton and Highlands Rivers)	Marine	Data Storage
1998-2002	Parr	Winter	South Coast Newfoundland (Northeast Trepassey, Stoney Brook and West Salmon River)	River	Radio
2001-2002	Smolt	Spring	Northeast Coast Newfoundland (Exploits River)	River	Radio
2001-2002	Adult	Summer	Northern Labrador (English River)	River	Radio
2000-2017 (various yrs)	Adult	Summer/ Fall	Northeast Coast Newfoundland (Exploits River and Rattling Brook)	River	Radio
2006-2008	Smolt/ Kelt	Spring/ Summer	South Coast Newfoundland (Conne and Little Rivers)	Estuary (50 km)	Acoustic
2007	Kelt	Summer	Northeast Coast Newfoundland (Campbellton River)	Marine	Data Storage (Geolocation)
2009	Adult	Summer/ Winter	South Coast Newfoundland (Conne River)	River	Radio
2011	Kelt	Spring/ Summer	Northeast Coast Newfoundland (Campbellton River)	Marine	Data Storage (Geolocation)
2014	Smolt/ Kelt	Spring	Northeast Coast Newfoundland (Campbellton River)	Estuary (32 km)	Acoustic/ Data Storage (geolocation)
2014-2017	Adult	All Year	Labrador (St. Lewis River and Hunt River)	River/Estuary	Radio/ Acoustic
2015	Smolt/ Kelt	Spring	Southern Labrador (Muddy Bay Brook)	Estuary (20 km)	Acoustic
2016	Smolt	Spring	Northeast Coast Newfoundland (Campbellton River)	Marine	Data Storage (geolocation) (dummy tags)
2017	Adult	All Year	Labrador (Lake Melville)	All Habitats (140 km Estuary)	Radio/ Acoustic

European Studies

- Centre for Environment, Fisheries and Aquaculture Science (Cefas) - Andy Moore

Current Research Programmes include:

- Understanding and comparing early marine mortality of European salmon populations. (NASCO/EU).
- Telemetry research programme to determine the mortality of salmon smolts and post-smolts during their migration through the lower parts of rivers, estuaries/fjords and near-shore areas in selected river systems in Denmark, England, Ireland, Northern Ireland and Spain.
- Influence of freshwater environment on marine survival of Atlantic Salmon (Defra - SA001K).
- Interdisciplinary research programme using physiological, behavioural and telemetry methodologies to examine how conditions in the freshwater environment regulate survival of juvenile salmon/smolts after the transition to the marine environment. Focus on diffuse contaminants, effluents from fish farms, intensive agriculture and renewable energy.
- Impact of in-river hydropower on smolt migration and marine survival (Defra - SF0267).

- Interdisciplinary research programme using physiological, behavioural and telemetry methodologies to examine the impact of small hydropower schemes on the migratory behaviour of salmon smolts and their adaptation to the marine environment.

Previous Research Programmes include:

- Influence of freshwater contaminants on smolt migration and marine survival (1994 – 2015: Defra SF0218, SF0228, SF0244, SF0256).
- Impact of estradiol, atrazine, brominated flame retardants and effluents from intensive in-river aquaculture on smolt migration within transitional waters and physiological adaptation to the marine environment.
- The environmental and physiological control of smolt migration in freshwater, transitional waters and the coastal zone (1989 – 2017: Defra SF0219, SF0230, SF0244, SF0256).
- Development of tracking methodologies to examine the physiological and behavioural basis of migration in wild Atlantic smolts in UK rivers. Focus on migration patterns and behaviour in estuaries and coastal waters. Development of manual tracking methods for investigating the movements of wild smolts in the immediate coastal zone.
- Movement of salmonid smolts in relation to estuarine barrages (1993 – 1996: Defra SF0219, SF0230).
- Migratory behaviour of salmon and sea trout smolts in the lower estuary of impounded river systems. Subsequent manual tracking of salmon smolts in the coastal zone.
- The development of an intraperitoneal tagging technique for wild Atlantic Salmon smolts. (1989 – 1991: Defra SF0219).
- Physiological and behavioural study to determine the impact of surgically implanting acoustic transmitters into juvenile salmon and smolts.

Telemetry based salmon research undertaken by Inland Fisheries Ireland

Inland Fisheries Ireland (IFI) is the state agency responsible for the protection, management and conservation of Ireland's inland fisheries and sea angling resources. IFI is the competent authority for freshwater fish (including salmon) in Ireland. IFI carries out applied fisheries research for national management and has used telemetry on various species in fresh and marine waters for over 15 years.

Telemetry based salmon research undertaken by DTU (and Partners)

- Kim Aarestrup

DTU-Aqua is the institution responsible for management and ministerial advice on fish and fisheries related matters in Denmark, including Atlantic Salmon. We are leading the conservation activities of Atlantic Salmon and have for decades performed multiple studies aiming at understanding bottlenecks in Atlantic Salmon, including many with telemetry.

Atlantic Salmon Trust (AST)

- Matt Newton

The Atlantic Salmon Trust (AST) has not previously undertaken acoustic telemetry projects however they do realise its value in advancing our knowledge in migratory salmonids. The AST

recently employed Dr. Matt Newton as their acoustic tracking coordinator to provide advice to other acoustic tracking projects and roll out a programme of acoustic tracking within the AST.

Matt works in close collaboration with Glasgow University who are one of the lead groups undertaking work in Scotland. Previous projects have tracked smolts through freshwater, impounded water bodies, estuaries and the marine environment. One project installed an acoustic array 30km from shore and is the furthest yet a smolt has been tracked from shore in UK waters with acoustic telemetry.

The vision of the AST is to develop further these projects with arrays extending deeper into the marine environment than previously achieved. The AST is embarking on a fundraising campaign to raise approximately £1.2million to facilitate a tracking programme in 2019. In brief the project will track smolts from multiple river systems through freshwater, estuaries, near shore environment and out to 100km from shore. Details outlined below

The broad aims of the project are:

- Where does mortality occur in the early marine migration of smolts?
- What migration routes are used by migrating smolts once they leave the river?
- What cues do they use to determine this migration pathway?
- What are the roles of tide and currents in aiding smolt migration?
- Which coastal activities might be impacting upon smolt migration success?
- Do fish from all rivers behave in similar ways once they reach the sea?
- What is the importance of smolt shoaling on marine survival?