Northeast Fisheries Science Center Reference Document 19-15

Workshop Report:
Introduction and Overview of the ROAM (RAFOS Ocean Acoustic Monitoring) Approach to Marine Tracking

by Kristen Bronger and Timothy F Sheehan

October 2019

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US DEPARTMENT OF COMMERCE
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National Marine Fisheries Service
Northeast Fisheries Science Center
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EXECUTIVE SUMMARY

Poor marine survival is a primary factor limiting Atlantic salmon (*Salmo salar*) productivity across much of the species North Atlantic range. Increasing our understanding of survival in the marine environment has been identified as a priority action in numerous international and domestic forums. Historically, knowledge about marine distribution of many fish species has come from mark-recapture studies or genetic sampling associated with fisheries and/or surveys. Recently, telemetry methods (i.e., ultrasonic acoustic monitoring and archive telemetry) have been used to study individual fish movements in the ocean. These 2 methods offer both benefits and disadvantages, but neither is wholly suitable for tracking a relatively small marine species, which undergo extensive marine migration into Arctic water over an extensive time period. RAFOS is a common oceanographic monitoring tool used to track ocean currents and relies on moored acoustic transmitting units that emit an acoustic signal that can be detected by a hydrophone on a RAFOS float. The RAFOS technology has recently been modified and miniaturized through the development of a new single board receiver and may be suitable for tracking relatively small marine species across large areas of the ocean. A workshop was held on June 7-8, 2018 in Woods Hole, MA, USA to facilitate a detailed technical discussion on the RAFOS Ocean Acoustic Monitoring (ROAM) approach to tracking. Participants from both North America and European attended as did representatives from the Pacific salmon (*Oncorhynchus* spp) community from the west coast of North America. Workshop objectives were to: (1) provide an in-depth overview of the ROAM approach to marine tracking; (2) provide an overview of field testing to date; (3) discuss pros and cons of the ROAM approach compared to contemporary methods; (4) discuss limitations and solutions of ROAM approach; (5) discuss West Greenland ROAM satellite tracking project; (6) discuss other potential projects tracking juveniles, subadult, or adult stage Atlantic salmon; and (7) discuss the potential for a North Atlantic-wide monitoring project and applicability to the International Year of the Salmon (IYS). This report provides and overview of the workshop, discussions, and conclusions.

BACKGROUND

Poor marine survival is a primary factor limiting Atlantic salmon (*Salmo salar*) productivity across much of the species North Atlantic range. Within the United States, remnant populations are listed as endangered under the Endangered Species Act, and a poor marine survival was identified as a primary constraint to recovery. Atlantic salmon is also a NOAA Species in the Spotlight (www.fisheries.noaa.gov/topic/endangered-species-conservation#species-in-the-spotlight), and increasing our understanding of survival in the marine environment is an identified key action.

The North Atlantic Salmon Conservation Organization (NASCO) is a regional fishery management organization, to which the United States is a party. Its International Atlantic Salmon Research Board (IASRB) has identified the need to understand salmon mortality at sea as a priority. In response, the IASRB developed a cooperative research on salmon at sea, SALSEA – Track (www.nasco.int/sas/salsea.htm), a collaborative marine telemetry program that aims to track salmon along their marine migration routes. SALSEA – Track consists of 12 independent telemetry-based research projects that together would track Atlantic salmon through much of its marine residency across much of the species range. SALSEA – Track is an ambitious program, which if fully implemented may still not provide the detailed understanding of Atlantic salmon marine migration necessary to identify where and when salmon are dying at sea. It is a fragmented approach and even though major advancements have been made in the field of marine tracking, the technology today is still not wholly suitable for tracking a relatively small marine species which undergoes extensive marine migration into Arctic water over an extensive time period, such as Atlantic salmon.

Historically, knowledge about marine distribution of many fish species has come from mark-recapture studies or genetic sampling associated with fisheries and or surveys. More recently, detailed understanding of individual fish movements have come via 2 methods: ultrasonic acoustic monitoring and archive telemetry methods. Ultrasonic acoustic monitoring involves tagging fish with acoustic pingers that emit an acoustic signal that can be detected by deployed hydrophone receivers. There are many challenges associated with ultrasonic acoustic monitoring. One major challenge is with deploying and maintaining large monitoring networks across large spatial scales. Archive telemetry methods involve archiving collected environmental information while a tagged animal is at large. Archive telemetry methods can be lumped into 2 general types: Data storage tags where the tag must be recaptured to obtain the collected data and pop-off satellite tags (PSATs) where archived data are transferred to passing satellites once detached. Beyond data retrieval differences, archival monitoring is also limited by the tag size, accuracy of light-based geolocation, and species behavior as species that inhabit northern areas or species that exhibit frequent diving activity will further reduce the accuracy of light-based geolocation.

RAFOS (SOFAR spelled backwards: SOund Fixing And Ranging) is a common oceanographic monitoring tool for tracking ocean currents by means of subsurface drifters capable of receiving sound. A RAFOS network relies on moored acoustic transmitting units that emit an acoustic signal which may carry upwards of 1000 km under optimal conditions. Given this capability, strategically placed sound sources have the potential to cover a large monitoring area with relatively minimal infrastructure and cost. A hydrophone onboard the RAFOS float detects the sounds from the sound source network, and a triangulation algorithm uses the differential sound reception from multiple moorings to calculate position. In its original form, RAFOS technology was not suitable for tracking marine organisms because of size limitations.

Recently, the RAFOS technology has been modified and miniaturized through the development of a new single board receiver. The receiver has been encased within a hydrophone outer shell to form the new RAFOS Ocean Acoustic Monitoring (ROAM) tag. The ROAM tag can now be used in a similar fashion as an archival tag (e.g., data storage tag [DST]) and may be suitable for tracking fish as small as 180mm for up to 2 years, although the tag will need to be recovered to obtain the data. The ROAM tag can also be integrated into conventional PSAT. Since these PSAT tags will be larger (exact size yet to be determined), they will be suitable for larger individuals, but tag recovery is not needed since data will be transmitted via satellite.

In June 2017, a presentation was given to NASCO describing the ROAM approach to marine tracking and outlining a proposed pilot project to track subadult Atlantic salmon captured and released off the coast of west Greenland enroute to natal rivers during their second year at sea. The presentation was favorably received, and many of the participants of that meeting felt that the ROAM approach held promise for a basin-wide tracking program for Atlantic salmon in the North Atlantic. As NASCO is also involved in the upcoming International Year of the Salmon, there was also a discussion about the applicability of ROAM approach for a large scale marine tacking program in the Pacific Basin.

Project collaborators committed to hosting a ROAM workshop prior to the 2018 NASCO Annual Meeting. The overall goal of the workshop was to facilitate a detailed technical explanation of the ROAM approach to tracking, to review the progress to date and field trial results, and to discuss the potential development of a large scale monitoring and tracking program for both Atlantic and Pacific salmon.

Specific workshop objectives were to:

- Provide an in-depth overview of the ROAM approach to marine tracking
    - Including overview of current production status for sound sources, archive ROAM tags, and ROAM satellite tags;
- Provide an overview of field testing to date;
- Discuss pros and cons of ROAM approach compared to contemporary methods;
- Discuss limitations and solutions of ROAM approach;
- Discuss West Greenland ROAM satellite tracking project: study plan, timeline, and progress to date;
- Discuss other potential projects tracking juveniles, sub-adult, or adult stage Atlantic salmon; and
- Discuss the potential for a North Atlantic-wide monitoring project and applicability to the International Year of the Salmon (IYS)

The workshop was held on June 7-8, 2018 in Woods Hole, MA. The workshop agenda (ANNEX 1) was organized to address each of the specific objectives by providing an overview of marine tracking and an introduction to ROAM on Day 1 with a more in-depth look at the ROAM technology and discussion on Day 2. It was noted that the agenda was not "set in stone" and could be adapted depending on participant feedback. This report provides an overview of the workshop presentations and discussions.

A total of 27 participants from both the Atlantic and Pacific Ocean basins attended the workshop (ANNEX 2). Attendees from federal agencies, universities, private companies, and nongovernmental groups participated.

At the beginning of the workshop, Tim Sheehan provided an overview of North Atlantic salmon population dynamics, the need and the development of SALSEA – Track, and how the

ROAM Workshop came to be developed (ANNEX 3). Tim also reviewed the workshop agenda, identified how the organizers feel that this workshop represents a first conversation, and also stressed the desire for substantive engagement of all workshop participants to maximize the information exchange over the course of the 2 days.

STATUS OF TRACKING IN THE OCEAN: OVERVIEW OF ACOUSTIC TRACKING WITH PARTICULAR FOCUS ON ATLANTIC SALMON

Jon Carr provided an overview of acoustic marine tracking and the Ocean Tracking Network with particular focus on Atlantic salmon related research (ANNEX 4) which generated further discussion. These discussions are summarized by topic below.

- <u>Ocean Tracking Network</u>
    - The Ocean Tracking Network (OTN) (http://oceantrackingnetwork.org/) builds infrastructure and a network of assets for acoustic tracking. Multiple organizations worldwide utilize this network and tie into OTN's larger database which exceeds 10 million detection records. The OTN system allows organizations to obtain their data fast. The OTN works in partnership with other companies, such as oil companies, and thus is able to facilitate the deployment of receivers of opportunity.
- <u>Using gliders to track fish</u>
    - The question was asked if it was possible to use gliders to track fish. The short answer was no. Gliders are too slow to keep up with most fish species, and multiple hydrophones would need to be installed on each glider to calculate tag position. Adding engines to a glider would cause additional problems.

STATUS OF TRACKING IN THE OCEAN: OVERVIEW OF SATELLITE TAGGING WITH PARTICULAR FOCUS ON ATLANTIC SALMON

Camrin Braun provided an overview of satellite tracking efforts in the ocean (ANNEX 5). He described the benefits and challenges of obtaining accurate location data via PSATs. The presentation generated a number of discussions which are summarized by topic below.

- <u>Archive tag options:</u>
    - There are 2 archive tag options for salmon:
        - Data Storage Tags (DST), which requires retrieving the tag to obtain the data.
        - Pop-off Satellite Archival Tags (PSAT), which does not require retrieving the tag to obtain the data since the data are transmitted to satellites once the tag is released and floats to the surface. The transmission hardware can make the tag relatively big compared to a DST.
    - These 2 types of tags gather light-level data to generate geolocation position estimates. Although the technology is 20 years old, seasonal and behavioral issues associated with light-based geolocation still persist. Preliminary location estimates can be wildly inaccurate, and ancillary data (e.g., temperature and depth) and a

priori assumptions can be used to minimize location errors to within ±200km. Despite these limitations in our ability to estimate accurate light-based geolocations, the collected temperature and depth data can be very informative.

- Pelagic fish
    - Satellite tags were developed for larger pelagic fish. Technological advancements are making possible the development of special purpose tags that could be smaller with fewer features. It was also noted that there are specific applications where either PSATs or DSTs are the preferred option.
- Pacific Basin tracking overview
    - Since the previous presentations were focused primarily on the Atlantic Basin, participants from the Pacific Basin were asked to provide an "on the spot" overview of tagging in the region.
    - Similar to the Atlantic, the Ocean Tracking Network is managing arrays in the Salish Sea, and Kintama Research Services (http://kintama.com) is also managing assets on the West Coast Continental Shelf. There is a lot of radio tracking on early marine survival happening in the rivers and coastal locations such as Puget Sound and the Columbia River, but not in the ocean because of incapability of radio tags and saline water.
    - There was a brief discussion on the funding sources that are used to support these tagging projects.
- Smolts v. Predators
    - Many participants noted that when interpreting the data, it can be difficult to identify if a predation event has occurred, as it is sometime difficult to distinguish between smolt tracking and predator tracking. In some instances behavioral patterns and temperature differences may be used to distinguish between the 2 types of data sets. There are Vemco acoustic tags with additional sensors that can help determine a predation event, but these are double the price and increase the size of the tag, factors which limit both the number and size range of fish that can be tagged for a particular study.
- Basin specific issues
    - It was noted that researchers from both the Atlantic and Pacific basins require more information to truly understand the causal mechanisms driving marine survival of their various salmon stocks. Participants from the Pacific Basin were of the opinion that although the exact mechanisms driving Atlantic salmon productivity have not been identified, there appears to be a stronger consensus within the Atlantic participants as to what the major productivity drivers are.

ATLANTIC SALMON TELEMETRY PLANNING MEETING: EXPANDING THE TRACKING NETWORK IN THE NORTH ATLANTIC

Jon Carr provided an overview of the Atlantic Salmon Telemetry Planning Meeting held on December 5-6, 2018 in Halifax, Nova Scotia, Canada (ANNEX 6). The meeting was supported by the Atlantic Salmon Research Joint Venture and was a follow-up to the 2014 NASCO workshop which lead to the development of SALSEA – Track. The workshop reviewed past and ongoing studies in the North Atlantic and aimed to develop a research program for North Atlantic, which builds on SALSEA – Track by focusing on estimating and partitioning marine mortality of Atlantic salmon and improving our understanding of marine migration and distribution patterns.

- Jon noted that the final report was expected to be available in early fall of 2018; the report will be forwarded to the participants of this workshop when finalized. Workshop recommendations were:
  - Expand coastal tracking of Atlantic salmon;
  - Undertake a modelling exercise to better quantify the feasibility of high seas acoustic tracking;
  - Endorse further development of emerging technologies that facilitate open ocean research;
  - Pursue tagging efforts on adult salmon at Greenland; and
  - Consider standardization of methodologies across the North Atlantic.

TRACKING SUBSURFACE FLOATS WITH SOUND

Simon Thorrold provided an overview of the of the RAFOS technology. RAFOS technology is not new; it is currently used in the physical oceanography field to track subsurface currents in the ocean. Sound sources are moored in the ocean's sound channel. These sound sources emit a "pong" that is detected by a 2m long cylindrical glass float, which also houses various oceanographic monitoring equipment. The longevity of the sound source is 3,000 transmissions and can be programed to pong as many times a day as desired. The sound source would last approximately 10 years if a single pong per day is generated, but it would last for approximately 5 years if 2 pongs per day are generated. A single RAFOS pong transmission is 80 seconds, but for ROAM tags the transmission is reduced to 30 seconds and is approximately 260Hz (180 db at 1 m). The current RAFOS sound sources are not compatible with the ROAM tags. The sound sources for ROAM tags have slightly different specifications, but moving forward the sound sources for RAFOS and ROAM will be compatible. The presentation generated a number of discussions which are summarized by topic below.

- <u>Sounds sources</u>
  - All the sound sources pong at the same time. It was noted that the sound sources do not have individual IDs and instead are identified by taking into account the previous day's estimated locations. The pongs could be staggered to help with individual identification, but the tag would need to have a longer listening window, and therefore, the battery life would be reduced. Having a single listening window helps to conserve battery life.
  - Increasing the number of sounds sources may increase positions accuracy, but there is a point where having too many sound sources might decrease accuracy. The primary reason for adding more sound sources is to increase coverage range, and it is good to find the balance between "more is better" and "'more is too much."
  - The cost for a full oceanographic sound source and mooring at 100 km depth is approximately $60k USD.
  - Sound travels further with off-shelf sound sources. Permitting for on-shelf sound sources would need to be addressed. However, the pong is only 30 seconds in duration, it may only occur once a day, and a cargo ship is also measured at

approximately 180 db, so sound sources may not be contributing significant additional noise in the ocean. There is also a good cost/benefit argument (i.e., low environmental cost/risk with high benefit of increased and improved ability to track marine organisms) that can be made for this approach, especially given all the other sounds present in the ocean.

- Current RAFOS sound arrays
    - There is currently no overall management of RAFOS. Sound sources are deployed on a project by project basis. Currently, there are 4 sound sources supporting research in the Gulf of Mexico, and the Overturning in the Subpolar North Atlantic Program (OSNAP; http://www.o-snap.org/) has 10 sound sources deployed in the North Atlantic.
    - In the past, some RAFOS monitoring was conducted in the Pacific along the West coast of the United States. Further information on these efforts would be beneficial.
    - The ROAM tags are not able to be used in all environments.
- Tracking software
    - The RAFOS tracking software can be used immediately for any ROAM application.

TRACKING ATLANTIC SALMON IN THE LABRADOR SEA

Jon Carr provided an overview of the Labrador Sea Project, which is a multiyear study tracking subadult Atlantic salmon from Greenland back to coastal areas and natal rivers (ANNEX 7). The plan is to rely on PSAT tagging for the first year (Fall 2018) and to gradually incorporate the ROAM approach in years 2 and 3. It is estimated that 6 sound sources will be needed to cover the range of Atlantic salmon in the Labrador Sea.

SmolTrack I and II (additional agenda item)

Kim Aarestrup provided an overview of SMOLTRACK I and II (ANNEX 8; http://www.smoltrack.eu/). SMOLTRACK I and II are EU funded projects. Partners include Ireland, Northern Ireland, United Kingdom, Spain, Sweden, and Denmark. The project's aims are to estimate lower river and early marine survival of Atlantic salmon and to monitor the marine migration of previously spawned Atlantic salmon from a few European rivers.

RAFOS OCEAN ACOUSTIC MONITORING (ROAM)

Simon Thorrold provided an overview of RAFOS Ocean Acoustic Monitoring. The presentation noted that tracking small fish in the ocean remains very difficult but that the ROAM approach may hopefully overcome many limitations. ROAM tags have the ability to track horizontal and vertical movements on a scale that will allow for the investigation of the importance of mesoscale features of the ocean on the productivity and survival of the tracked animals. The presentation generated a number of discussions which are summarized by topic below.

- ROAM Testing
    - Field testing will occur in late 2018/early 2019 off the coast of Bermuda with a glider mimicking the behavior of different species (e.g., salmon, swordfish

[*Tetrapturus audax*], and bigeye tuna [*Thunnus obesus*]). This proposed field test will provide a much clearer understanding of ability of the ROAM approach to track Atlantic salmon throughout the North Atlantic.

  - Testing will occur in Bermuda because it is easy to access and to extrapolate data from there. Results will be applicable to any acoustic modeling in any study area.
  - Field testing is also scheduled for late 2018. Field tests will occur in the relatively shallow waters of Long Island Sound and will involve tracking American lobsters (*Homarus americanus*). Long Island Sound was selected because of its convenient location for work and accessibility. Since most fish occupy shallow water, it will be a good evaluation of the ROAM approach, especially since RAFOS has already been shown to work in deep water.
  - Testing has previously occurred in Long Island Sound and the Gulf of Mexico. The sound source detection range was only ~60 km (only sound source travel times were estimated, not locations, since only one sound source was employed), but the test conditions were not optimal. Further testing as noted above will be critical for evaluating expected performance.
- <u>Network of sound systems</u>
  - Sounds systems are deployed on a study-by-study basis, and there is no central oversight for the approach. Given the life span of the sound systems, a network of infrastructure could be built over time.
- <u>Potential for other species</u>
  - There are likely other researchers working on a variety of other species that would be willing to use any infrastructure available.
- <u>Sound Source identifier</u>
  - A sound source identifier could be added, but it would most likely limit some range and battery life.
- <u>Frequency and duration</u>
  - The ideal frequency for the sound source pong is between 250-400Hz for distance and environmental reasons. A higher frequency would limit the sound range, and ambient noise would interfere with a lower frequency.
  - The optimal time duration for the pong is 30 seconds. The chip memory is limited, so if the duration were any shorter there would be a loss of correlation strength. A longer duration would take up battery life.
  - 260Hz for a 32 second sweep was used for testing the ROAM technology to date.

Survive the Sound (additional agenda item)

Michael Schmidt, from Long Live the Kings, provided an overview of the online game "Survive the Sound" (www.survivethesound.org) which the general public and schools can adopt salmon to see how far they migrate each year. The online game uses Pacific salmon telemetry data and was presented as an example of what can be done with these types of migration data for outreach, given the general public's interest.

ROAM TECHNOLOGY OVERVIEW

Godi Fischer provided an in-depth overview of how the ROAM technology works (ANNEX 9). Details on the tag structure, design, and specification as well as the power allocation/map were provided. It was noted that the primary cost for the monitoring system is related to the sound sources. However, once a sound source is constructed and deployed, it can operate for up to 10 years. Acoustic releases can be incorporated into the mooring device which would allow for retrieval, repowering, and redeployment of the sound sources. The tags are 11 mm in diameter and 25 mm in length. They weigh ~9 g in air and ~3 g in water. However, for ocean application, the plastic hydrophone will need to be replaced with a ceramic hydrophone, and the resulting tags will be slightly heavier (~6 g in water). It was noted that accurate tracking and recording of time is essential, and a number of options for minimizing the impacts of time drift in the tag or sound source were noted. The presentation generated a number of detailed discussions related to the specifications and performance of the tags and sound sources, measurement errors, issues and corrections for clock deviations, etc., which have not been captured within this report.

After the discussion about the previous presentation concluded, the 2 tag manufacturing companies that attended the workshop were asked to provide some comments on their initial view of the technology and how feasible it would be for the ROAM technology to be further developed for salmon studies.

- <u>Vemco, Inc.</u>
    - The ROAM workshop has facilitated Vemco seeing what the limitations are of their current technology for tracking Atlantic salmon.
    - Vemco wondered if there is an option for acoustically transmitting the data off of the tag to avoid the recapture requirement.
    - The requirement of retrieving the archive tag does pose some significant challenges; the application of ROAM into a satellite tag version is promising.
    - ROAM is promising, but the size of the tags is an issue for smolts.
    - There are still a lot of questions, but this is definitely a promising new tool that Vemco wants to be a part of and help develop.
    - Next steps are for further discussions within Vemco.
- <u>Wildlife Computers, Inc.</u>
    - Wildlife Computers is experienced at casting and molding tags. The first step would be to place the ROAM technology in an existing PSAT tag.
    - They are also interested in further developing this new tool.
    - Some questions were raised to Wildlife Computers about the feasibility of developing a smaller pop off tag with no additional sensors or developing a nontransmitting floating tag. The quick response was that removing the sensors from a traditional PSAT tag would not save much space, but a floating tag which would require retrieval, may be an option.
    - Suggestion was that for a first step, the ROAM tag may be able to be incorporated into a traditional PSAT tag as well as a floating archival tag.
    - It was also noted that even with some positive advances with Argos, there are still some concerns and uncertainty given the lack of dedicated government funding to maintain the program.

The remainder of the workshop was spent discussing and revisiting various topics from the previous day and a half. Short summaries of these discussions are provided below:

- Testing
    - Workshop participants are keen to see the results of the upcoming lobster and Bermuda field trials. Workshop participants were curious as to how the field trial results would be disseminated? There are no concrete plans for dissemination at this point, but workshop participants are encouraged to contact Simon Thorrold or Gobi Fischer directly.
    - It was suggested that for the lobster study, it might be a good idea to place a hydrophone at a fixed location as a reference/control point.
- Use with other data sets
    - It is important to have good fish tracks but also critical to have the appropriate concurrent environmental data available or plans to collect these data. These additional data will ensure that we can better answer questions about salmon movements.
- Atlantic basin draft proposal
    - The draft proposal for an international Atlantic basin collaboration was presented. The proposal was developed to take advantage of any potential future opportunities that may arise via NASCO or the International Year of the Salmon. The proposal outlined a gradual incorporation of 3 projects: the Labrador Sea, SmolTrack and SeaSalar (a new Norwegian-funded Atlantic salmon marine research initiative). The proposal outlined a plan to facilitate the (1) testing of the ROAM approach in the North Sea, (2) tagging of marine phase Atlantic salmon via conventional methods with a transition to ROAM, and (3) the development of a floating archival ROAM tag. Proposal collaborators will continue to advance this initiative as able.
- Future ROAM
    - As the ROAM approach continues to be developed, it will be important for standardized protocols to be developed for sound source deployment, tag deployment and data management. It will also be important that realistic expectations be developed and shared with managers and potential funders. A future workshop to further develop these ideas should be considered if appropriate. Such an effort could be possibly funded by national governments (e.g., NASCO parties).
- Permitting concerns
    - Permitting of sound sources is a concern. Potential funders and participating parties will be asked questions about potential effects of the sound sources on marine mammals, including Right whales. It will be important to address the permitting question. Preliminary inquiries on this issue have been initiated within the United States.
- Pacific basin
    - The Pacific needs an effective tag return strategy, more than just recapturing salmon. Tag returns are not guaranteed, but given the density of people living on the coast in the Northwest United States, tag recovery rates may be high for a floating archival tag. By eliminating the satellite technology from the tag, the expected price could drop to 25%, which would enable researchers to put out 4x as many tags.

- Given the varied size distribution of juvenile Pacific salmon, the proposed ROAM approach would not work for all Pacific salmonid species. One option would be to capture and tag subadult salmon at sea. As such, researchers on the west coast may consider building a ROAM network with researchers working on other species (e.g., blue shark [*Prionace glauca*]) to enable a proof of concept. This collaboration would allow the technology to continually develop and to provide time to devise sampling approaches to maximize the utility of using this technology on Pacific salmonids.
- To help move this process along in the Pacific, there was support for undertaking field testing, similar to the glider study off Bermuda, in the near future within the Pacific.

The workshop ended with a reminder that the ROAM approach to marine tracking is still in its infancy. The RAFOS approach to tracking is well established, but the migration of this approach to tracking marine animals is still being refined. The beta tag construction is currently done on a small scale, sound source construction schedules are still being developed, and additional field trials are still needed to provide real world performance metrics. As such, expectation of what ROAM can deliver at this stage needs to be adjusted accordingly. However, given the proven track record of the RAFOS approach and the work that has been done to date, expectations for success are high. This workshop provided an early view of the ROAM approach to marine tracking and provided an opportunity for people to evaluate the approach and to decide if they would like to contribute early on in the process.

CONCLUSIONS

General conclusions from the workshop were:

- Participants appreciated the in-depth, early view of the detailed specifications of the approach.
- Workshop participants felt that the approach held high promise for tracking salmon further out to sea and for longer periods than previously possible, although significant challenges and unknowns remain.
- Participants would like to be kept abreast of ongoing efforts and developments and are keen to see the results of the planned field trials.
- Participants recognize that the technology is in its infancy but are willing to pursue projects and funding that may help further test and develop the technology (e.g., field trials in the Pacific, Salmo Quest, and follow-on workshop(s) as appropriate) given its potential.
- Permitting issues and concerns over marine mammal interactions remains of high concern and should be addressed as soon as possible.

ADDITIONAL READING

Fischer G, Rossby T. 2017. An acoustic archival tag for long-range tracking of small fishes. Oceanography and Fisheries 7(1):555707.

Fischer G, Rossby T, Moonan D. 2017. A miniature acoustic device for tracking small marine animals or submerged drifters. Journal of Atmospheric and Oceanic Technology 34(12) 2601-2612.

Rossby T, Dorson D, Fontaine J. 1986. The RAFOS System. Journal of Atmospheric and Oceanic Technology 3:672-679.

Rossby T, Fischer G, Omand MM. 2017. A new technology for continuous long-range tracking of fish and lobster. Oceanography 30(2):36–37.

APPENDIX A: ROAM WORKSHOP AGENDA

Thursday June 7, 2018

Time	Topic	Lead(s)
10:00	Logistics Introductions, etc. Workshop overview	Simon Thorrold All Tim Sheehan
10:45	Status of tracking in the ocean: Overview of acoustic tracking with particular focus on Atlantic salmon	Fred Whoiskey
11:15	Status of tracking in the ocean: Overview of satellite tagging with particular focus on Atlantic salmon	Camrin Braun
11:45	Atlantic Salmon Telemetry Planning Meeting: Expanding the tracking network into the North Atlantic	Jon Carr
12:00	Lunch (coordinated and in-house)	
13:00	Tracking Subsurface Floats with Sound	Simon Thorrold
14:30	Break	
15:00	Tracking Atlantic Salmon in the Labrador Sea	Jon Carr
15:45	ROAM (RAFOS Ocean Acoustic Monitoring)	Simon Thorrold
~17:00	Adjourn for the day	

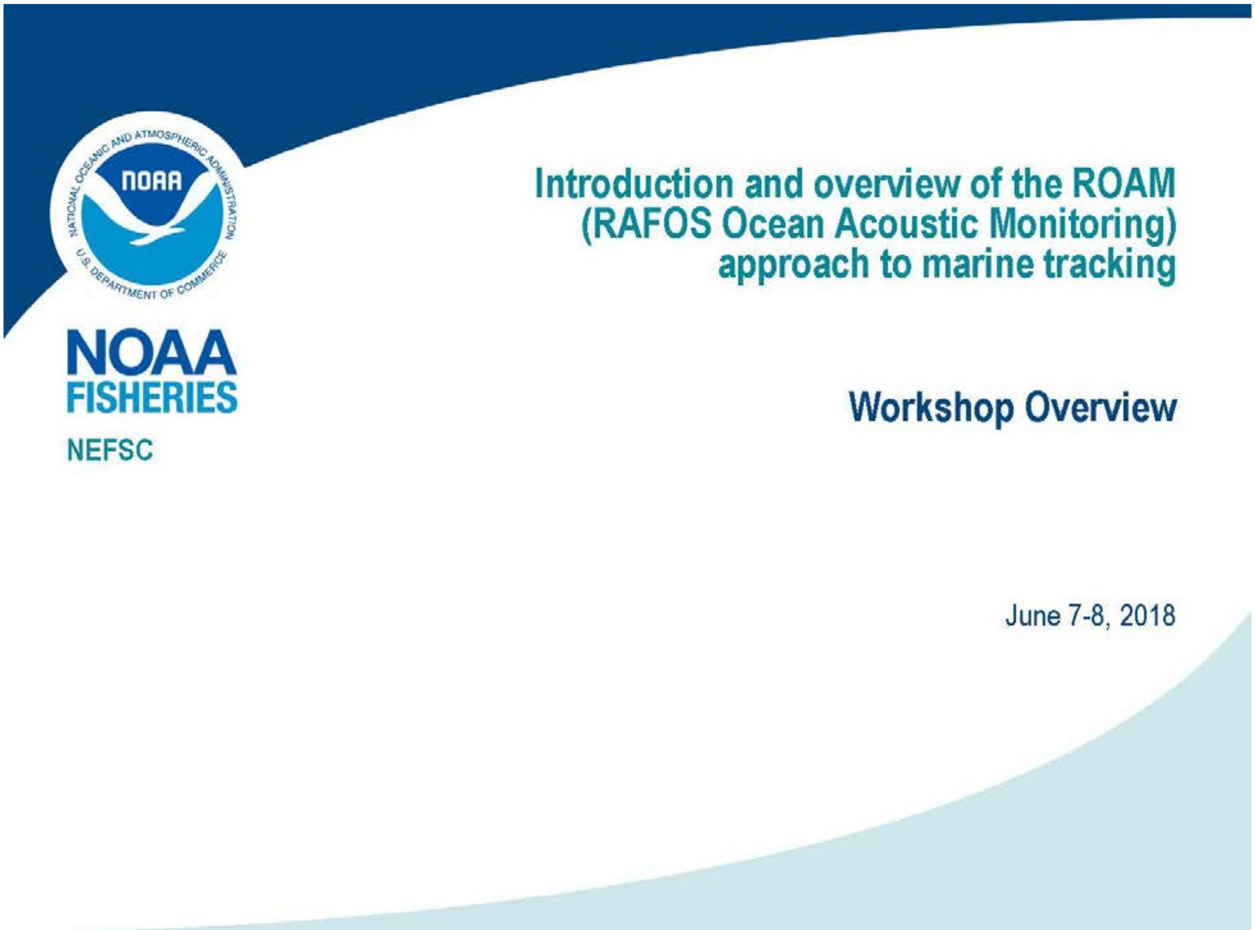
Friday June 8, 2018

Time	Topic	Lead(s)
8:30	Coffee provided	
9:00	ROAM technology overview	Godi Fisher
10:00	Discussion: Pros/Cons of ROAM	All
10:30	Break	
11:00	Discussion: Limitations/solutions of ROAM	All
12:00	Lunch (coordinated and in-house)	
13:00	Discussion: North Atlantic ROAM (including West Greenland ROAM)	All
14:30	Break	
15:00	Discussion: Pacific ROAM	All
16:30	Next Steps	All
~17:00	Adjourn for the day	

APPENDIX B: ROAM WORKSHOP ATTENDEES

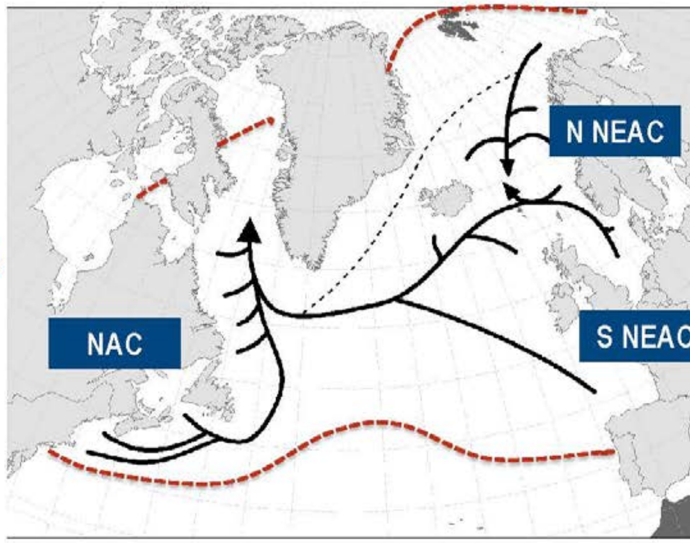
Name	Organization
Kim Aarestrup	DTU Aqua – National Institute of Aquatic Resources
Camrin Braun	Woods Hole Oceanographic Institute
Jon Carr	Atlantic Salmon Federation
Kristen Bronger	NOAA Fisheries
Jan Grimsrud Davidsen	NTNU University Museum
Richard Dewey	Ocean Networks Canada
Dennis Ensing	Agri-food and Biosciences Institute
Bengt Finstad	Norwegian Institute for Nature Research
Godi Fischer	University of Rhode Island
Cathal Gallagher	Inland Fisheries Ireland
Sean Hayes	NOAA Fisheries
Melinda Holland	Wildlife Computers
Isaac Heizer	Wildlife Computers
Niels Jepsen	DTU Aqua – National Institute of Aquatic Resources
Jeremy Kuehner	Vemco
David Meerburg	Atlantic Salmon Federation
Jean Quirion	Vemco
Erin Rechisky	Kintama Research Services
Mark Renkawitz	NOAA Fisheries
Michelle Rub	NOAA Fisheries
Michael Schmidt	Long Live the Kings
Tim Sheehan	NOAA Fisheries
Simon Thorrold	Woods Hole Oceanographic Institute
Amie Vo	Wildlife Computers
Danny Vo	Wildlife Computers
Dale Webber	Vemco
Hannah Whitaker	NOAA Fisheries (Hollings Intern)

APPENDIX C: INTRODUCTION AND OVERVIEW OF ROAM (RAFOS OCEAN ACOUSTIC MONITORING) APPROACH TO MARINE TRACKING



Atlantic salmon life history

- Broad range
- Extensive feeding migrations
- Common marine areas (e.g. Greenland)
- Marine maturation
  - 1SW mat. (1SW)
  - 1SW non-mat. (2SW, MSW)

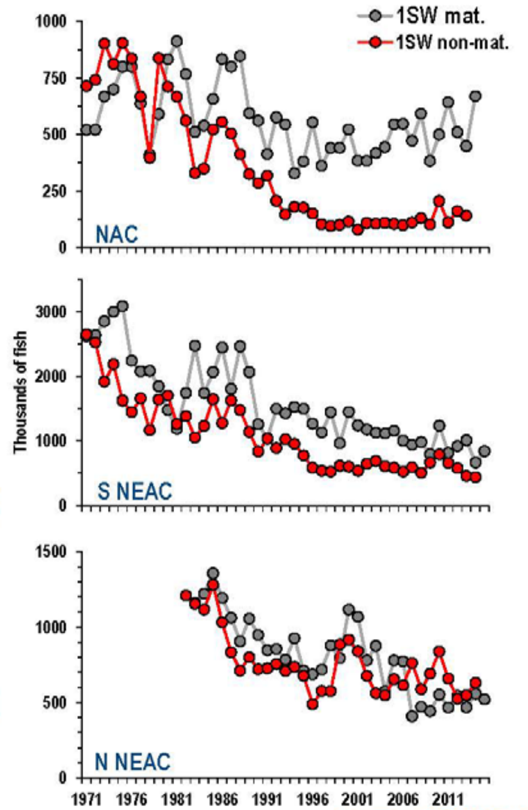


Abundance trends

- 1SW non-mat. declines
  - NAC ~86%
  - S NEAC ~78%
  - N NEAC ~49%

- Declines more severe for 1SW non mat.

- Stronger declines for NAC and S NEAC



Source: ICES 2015/16

NOAA FISHERIES

U.S. Department of Commerce | National Oceanic and Atmospheric Administration | NOAA Fisheries | Page 3

ICES WGNAS (2018)

- The continued low abundance of salmon stocks across North America, despite significant fishery reductions, strengthens the conclusions that **factors acting on survival in the first and second years at sea**, at both local and broad ocean scales are constraining abundance of Atlantic salmon.

NASCO, SALSEA, and SALSEA - Track

- Motivated by need to understand marine mortality
- Second phase of SALSEA
- Utilize advances in telemetry technology to track salmon along their migration routes
  - Individual projects (12) all tracking salmon in the North Atlantic (acoustic and PSATs)
  - One project outlined adult satellite/acoustic tagging at Greenland

Greenland tracking

- Re-initiate PSAT'ing at Greenland and develop nearshore acoustic telemetry arrays
- Discussions at WHOI on stable isotope analysis lead to ROAM introduction
- Continued exploration of ROAM potential caused NASCO SALSEA – Track plans to be modified

NASCO (2017)

- Update to NASCO on Greenland tracking project, included ROAM overview
- Researchers and managers interested in technology and saw potential regional/global applications at a *reasonable* cost
  - Offered a *chance* at the Holy Grail
  - IYS connections noted
- Agreed to host a workshop (2018) to provide an in-depth overview of the ROAM approach to marine tracking

NOAA FISHERIES

U.S. Department of Commerce | National Oceanic and Atmospheric Administration | NOAA Fisheries | Page 7

Objectives

1. Provide an in-depth **overview** of the ROAM approach to marine tracking
   - Including overview of current production status for sound sources, archive ROAM tags, and ROAM satellite tags
2. Provide an overview of **field testing** to date
3. Discuss **pros and cons** of ROAM approach compared to contemporary methods
4. Discuss **limitations and solutions** of ROAM approach
5. Discuss **West Greenland** ROAM satellite tracking project: study plan, timeline, and progress to date
6. Discuss **other potential projects** tracking juvenile, sub-adult, or adult stage Atlantic salmon
7. Discuss the potential for a **North Atlantic-wide** monitoring project and applicability to the **International Year of the Salmon** (IYS)

Day 1

Time	Topic	Lead(s)
10:00	- Logistics overview - Introductions, etc. - Workshop overview	- Simon Thorrold - All - Tim Sheehan
10:45	- Status of tracking in the ocean: Overview of acoustic tracking with particular focus on Atlantic salmon	- Fred Whoriskey - **Jon Carr**
11:15	- Status of tracking in the ocean: Overview of Satellite tagging with particular focus on Atlantic salmon	- Camrin Braun
11:45	- Atlantic Salmon Telemetry Planning Meeting: Expanding the tracking network into the North Atlantic	- Jon Carr
12:00	Lunch (coordinated and in-house)	
13:00	- Tracking Subsurface Floats with Sound	- Simon Thorrold
14:30	BREAK	
15:00	- Tracking Atlantic Salmon in the Labrador Sea	- Jon Carr
15:45	- ROAM (RAFOS Ocean Acoustic Monitoring)	- Simon Thorrold
~17:00	Adjourn for the day	

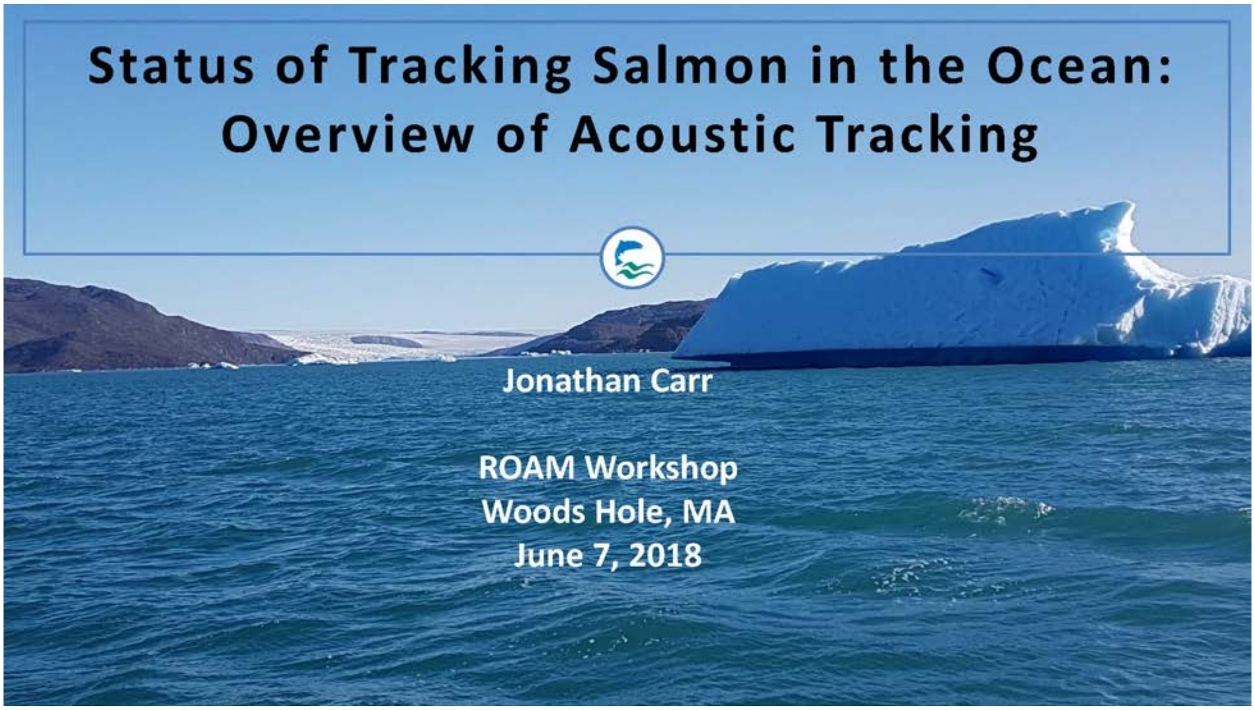
Day 2

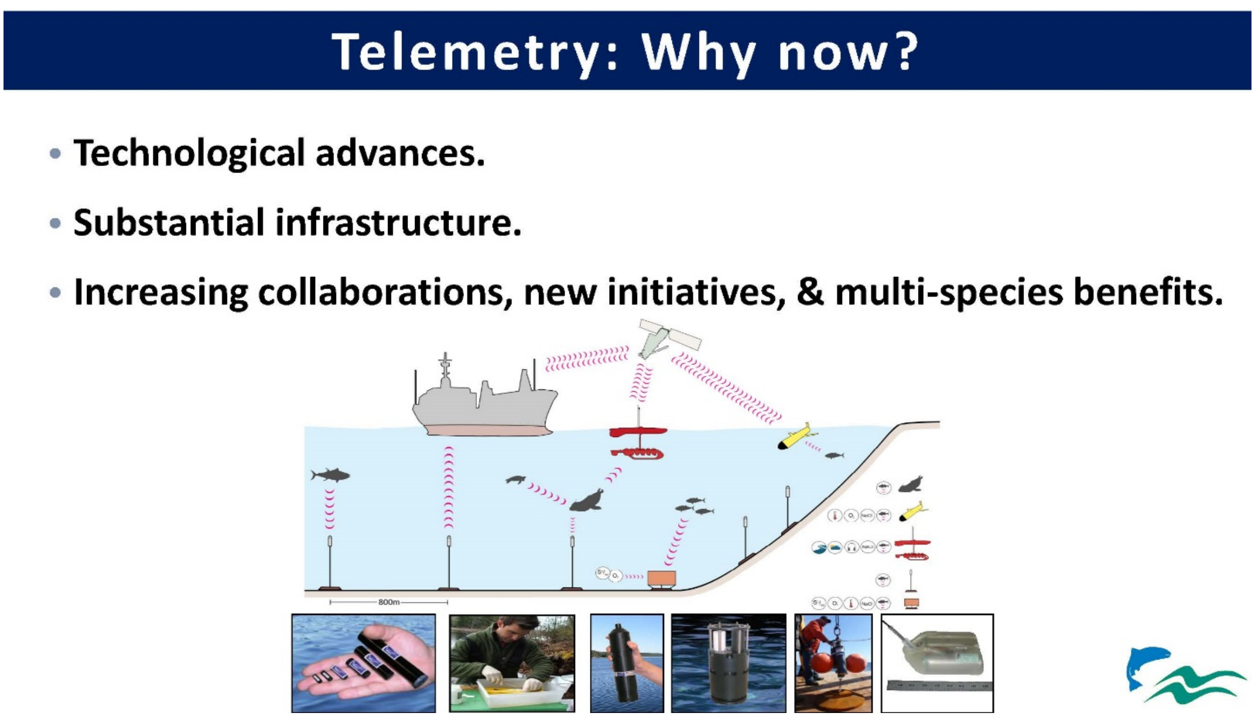
Time	Topic	Lead(s)
8:30	Coffee provided	
9:00	- ROAM technology overview	- Godi Fisher
10:00	- Discussion: Pros/cons of ROAM	- All
10:30	BREAK	
11:00	- Discussion: Limitations/solutions of ROAM	- All
12:00	Lunch (coordinated and in-house)	
	- Discussion: North Atlantic ROAM (including West Greenland ROAM)	- All
14:30	BREAK	
15:00	- Discussion: Pacific ROAM	- All
16:30	- Next Steps	- All
~17:00	Adjourn for the day	

Finally

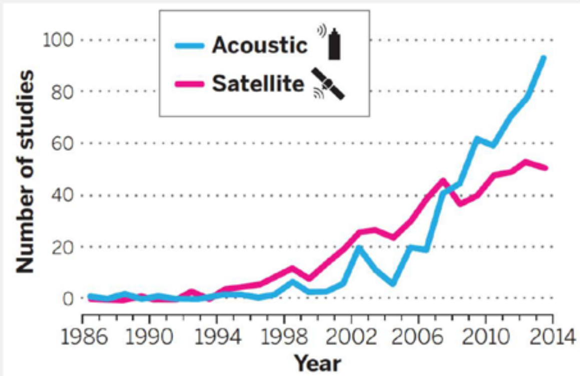
- Apologies for all the back and forth and confusion
- Thanks you for you interest and effort
- This is meant to be an introduction and 'first' conversation
- This is also meant to be informal, so please feel free to:
  - Chime in
  - Ask questions
  - Provide additional information/points
  - Presentations, etc.

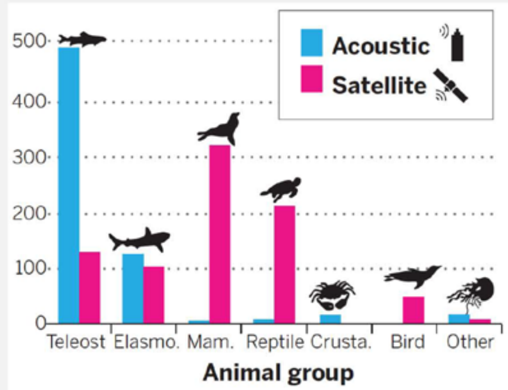
APPENDIX D: STATUS OF TRACKING IN THE OCEAN: OVERVIEW OF ACOUSTIC TRACKING WITH PARTICULAR FOCUS ON ATLANTIC SALMON





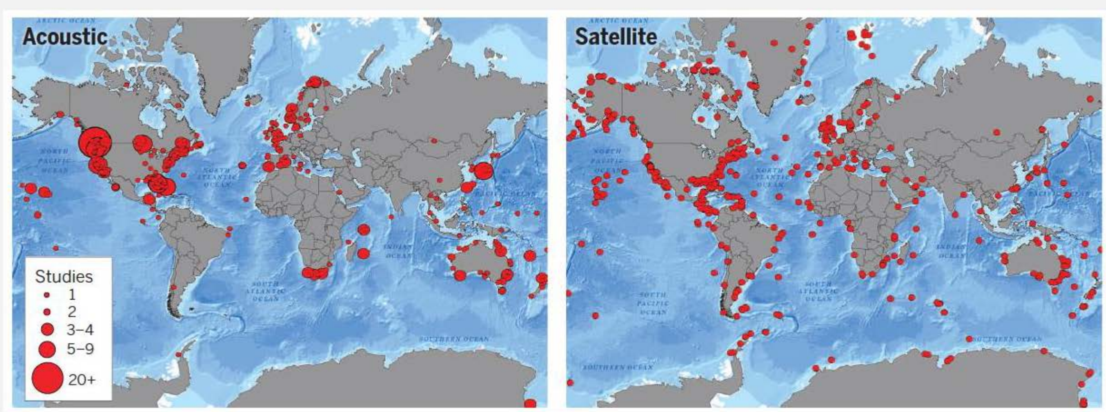
Global Telemetry Inventory





Hussey et al. (2015) Aquatic animal telemetry: a panoramic window into the underwater world. Science

Global Telemetry Inventory



Hussey et al. (2015) Aquatic animal telemetry: a panoramic window into the underwater world. Science

Acoustic vs Satellite Tags

	Acoustic	Satellite
Sizes of animals tagged	> 5 cm	> 50 cm
Tag life	up to 10 Y	1 y
Cost	400$/unit	5000$ unit
Real time data?	Sometimes	Sometimes
Archival capability	No	Yes
Environmental sensors	Yes	Yes

Ocean Tracking Network (OTN)

OCEAN TRACKING NETWORK

Global monitoring network:

– Builds infrastructure to track local-to-global movements and survival of aquatic animals with acoustic/satellite telemetry; environmental correlates

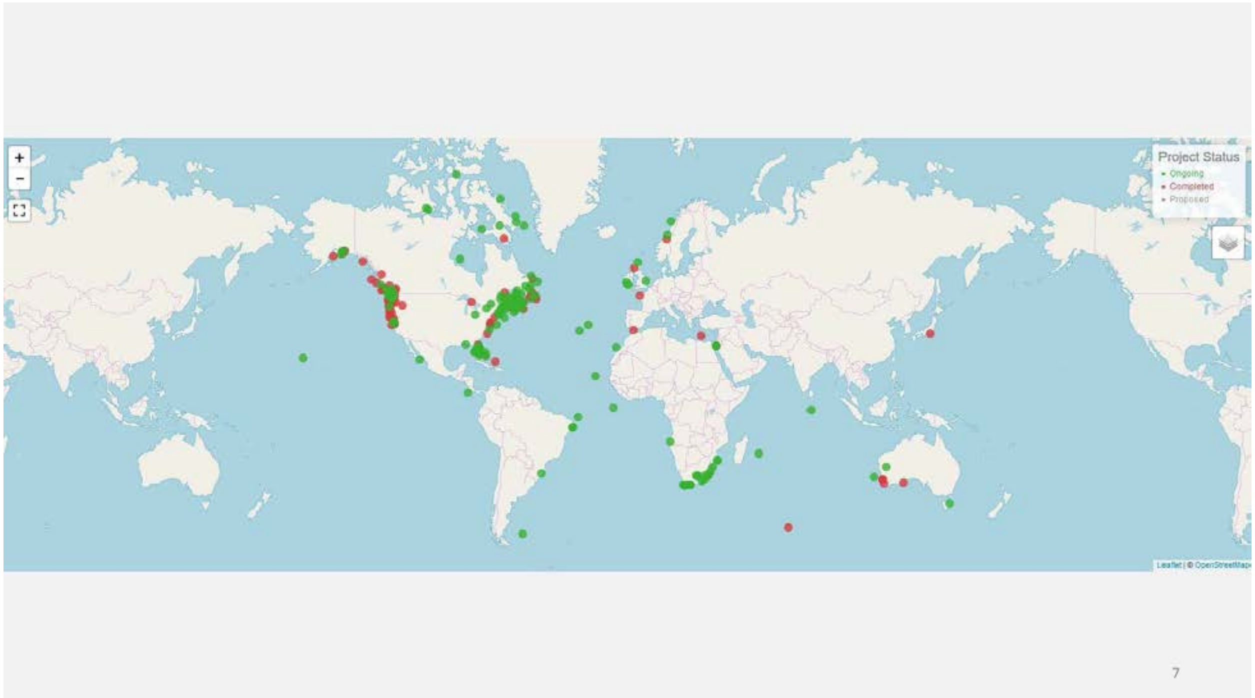
– Existing networks (i.e. Atlantic Salmon Federation).

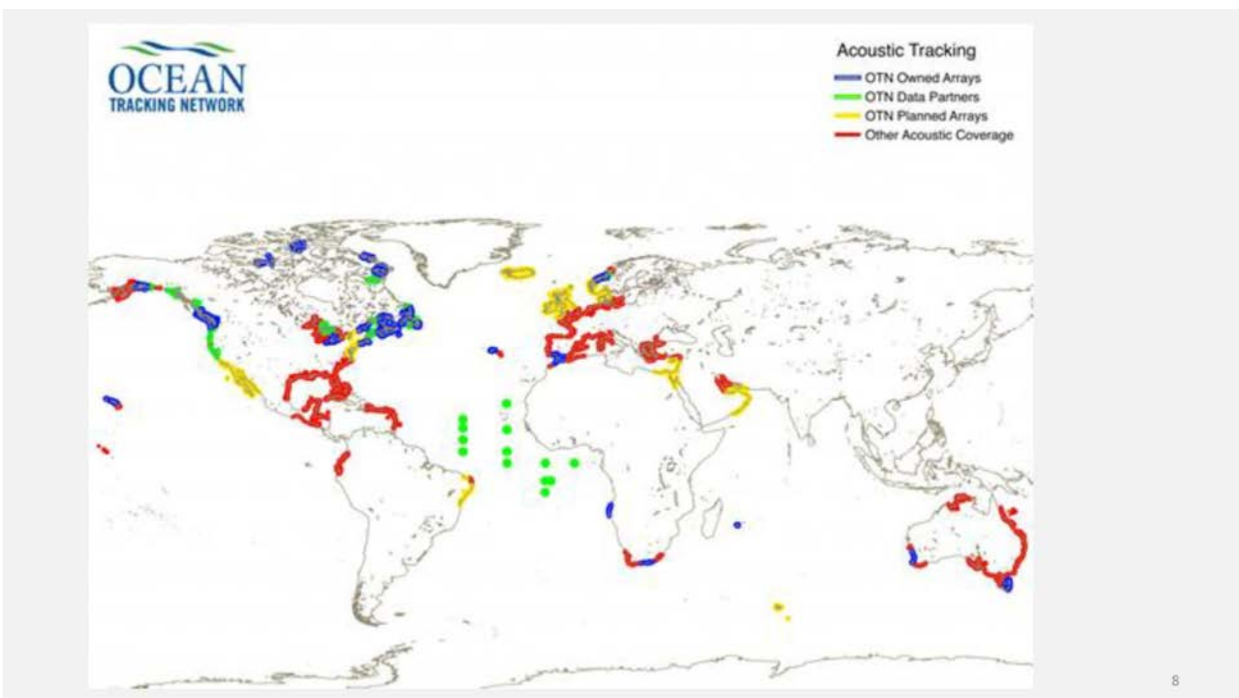
– Universities, Government, NGO sector, Industry (e.g., offshore oil and gas).

– Data warehousing and infrastructure provisions.

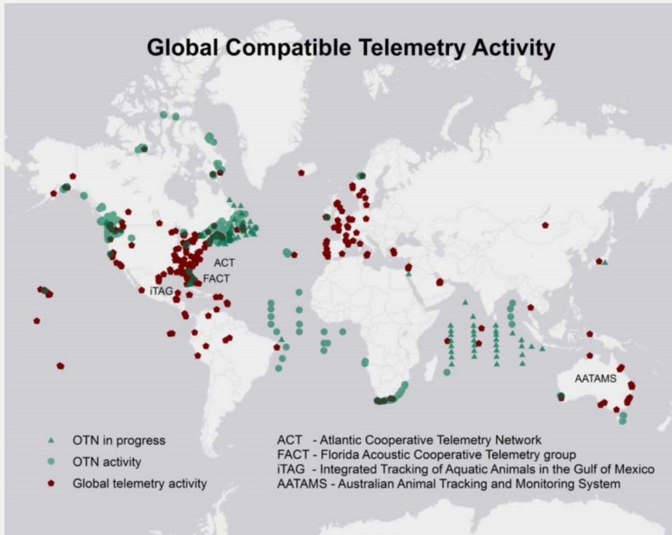
– Increasing opportunities for deployment, tagging and data collaborators.

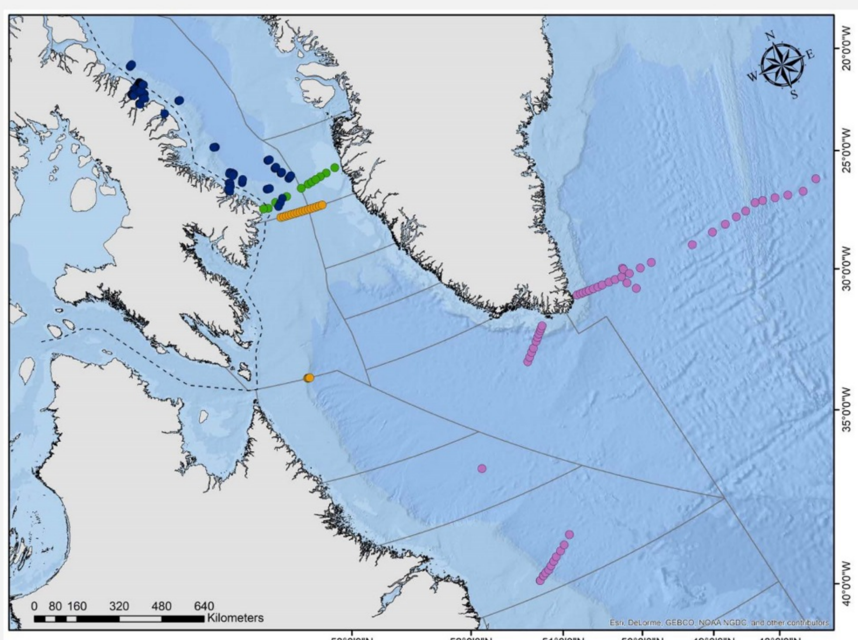
– >10 million detection records, historic and current .


Project Status
Ongoing
Completed
Proposed
Leaflet | © OpenStreetMap
7

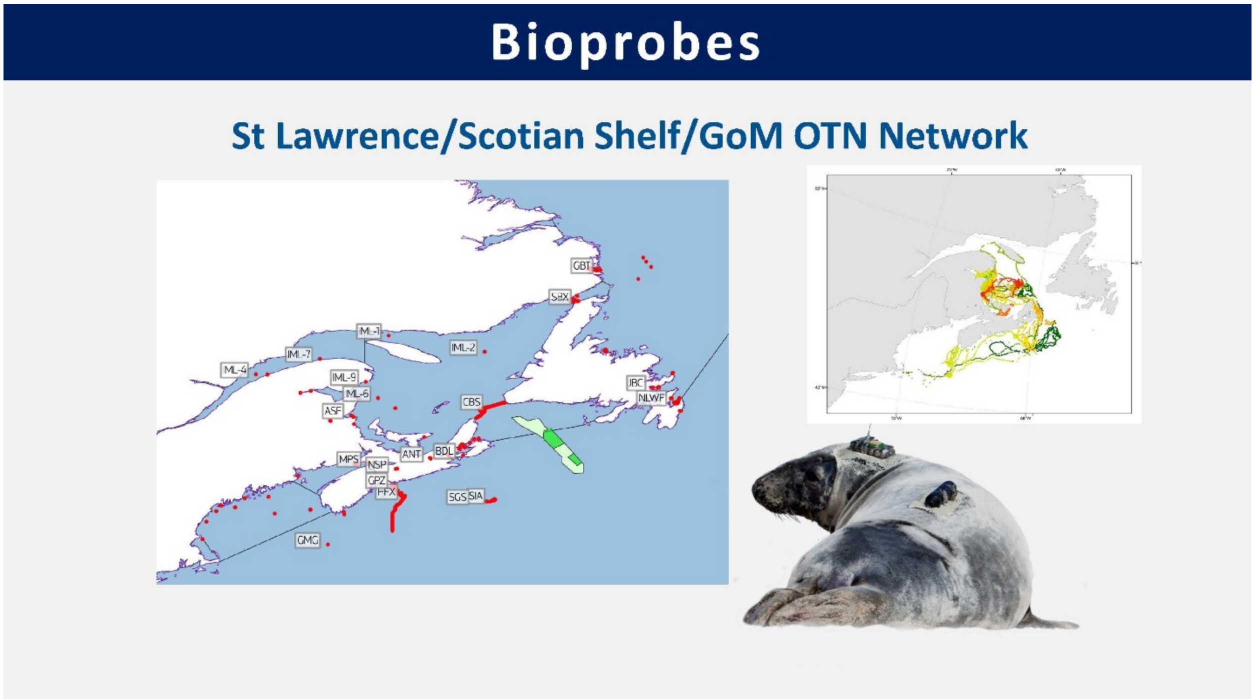

OCEAN
TRACKING NETWORK
Acoustic Tracking
OTN Owned Arrays
OTN Data Partners
OTN Planned Arrays
Other Acoustic Coverage
8

Global Compatible Telemetry Activity



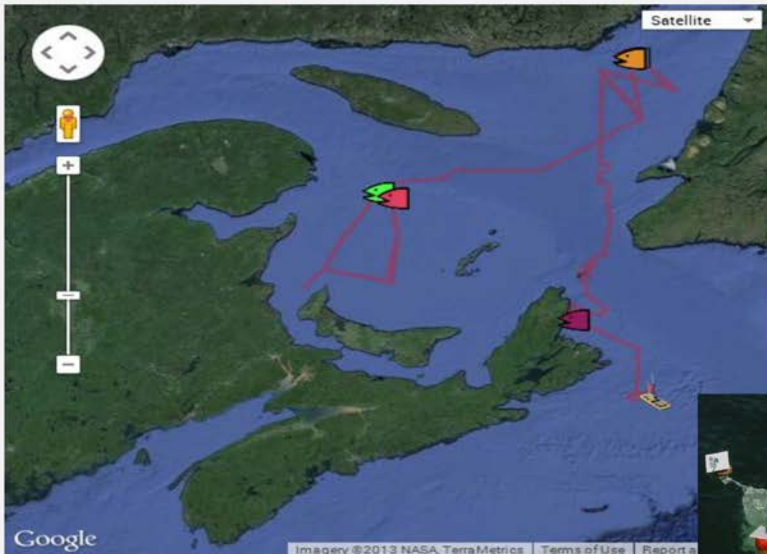


10

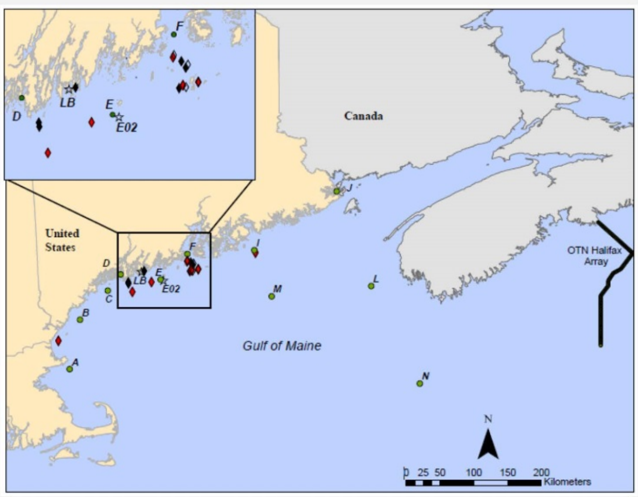


ATLANTIC SALMON DETECTED BY SABLE ISLAND GREY SEALS

Gliders and Drifters



Platforms of Opportunity



FEATURE

Opportunistic Acoustic Telemetry Platforms: Benefits of Collaboration in the Gulf of Maine

Graham S. Goulette, James P. Hawkes, and John F. Kocik

NOAA's National Marine Fisheries Service, Northeast Fisheries Science Center, 17 Godfrey Drive, Suite 1, Orono, Maine 04473. E-mail: John.Kocik@noaa.gov

James P. Manning

NOAA's National Marine Fisheries Service, Northeast Fisheries Science Center, Woods Hole, MA

Paul A. Music

Integrated Statistics, Orono, ME

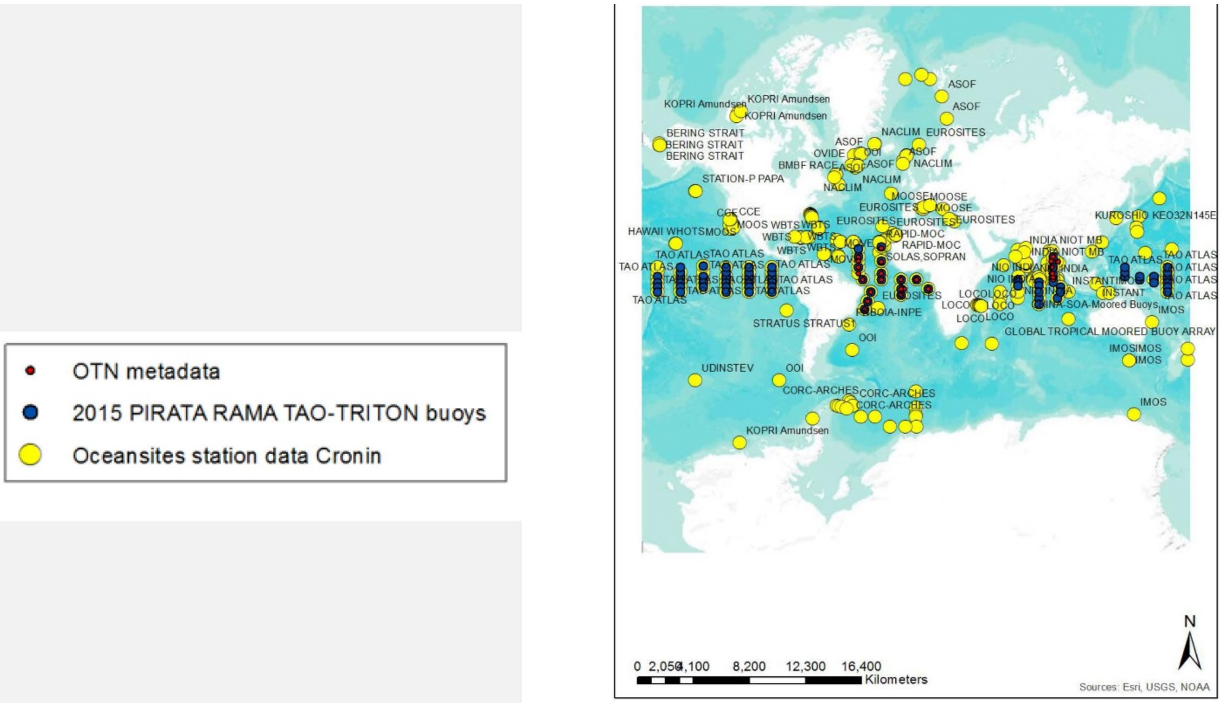
John P. Wallinga and Gayle Barbin Zydlewski

University of Maine, School of Marine Sciences, Orono, ME

ABSTRACT: *Biologists monitor animal behavior, habitat use, and survival through local telemetry projects. Migratory species cross these lines, connecting projects. Biologists can further these connections by expanding the area monitored, but this step is expensive. We evaluated three opportunistic platforms: (1) oceanographic buoys, (2) commercial fishing gear, and (3) drifters to test the feasibility of expanding coverage while minimizing costs. All Gulf of Maine platforms provided novel data, generating over 15,000 detections from animals released by 18 organizations. Performance was strong for buoys and commercial gear but low recovery hampered drifter utility, although advances in real-time drifter communication should improve future efficacy. Opportunistic platforms proved to be a low-cost method that can benefit researchers across aquatic systems. Animals from other studies connected us with researchers, fostered dialogue, and highlighted information gains from data sharing. Working with fishers and oceanographers also strengthens interdisciplinary and stakeholder communication and can increase overall public understanding and support.*

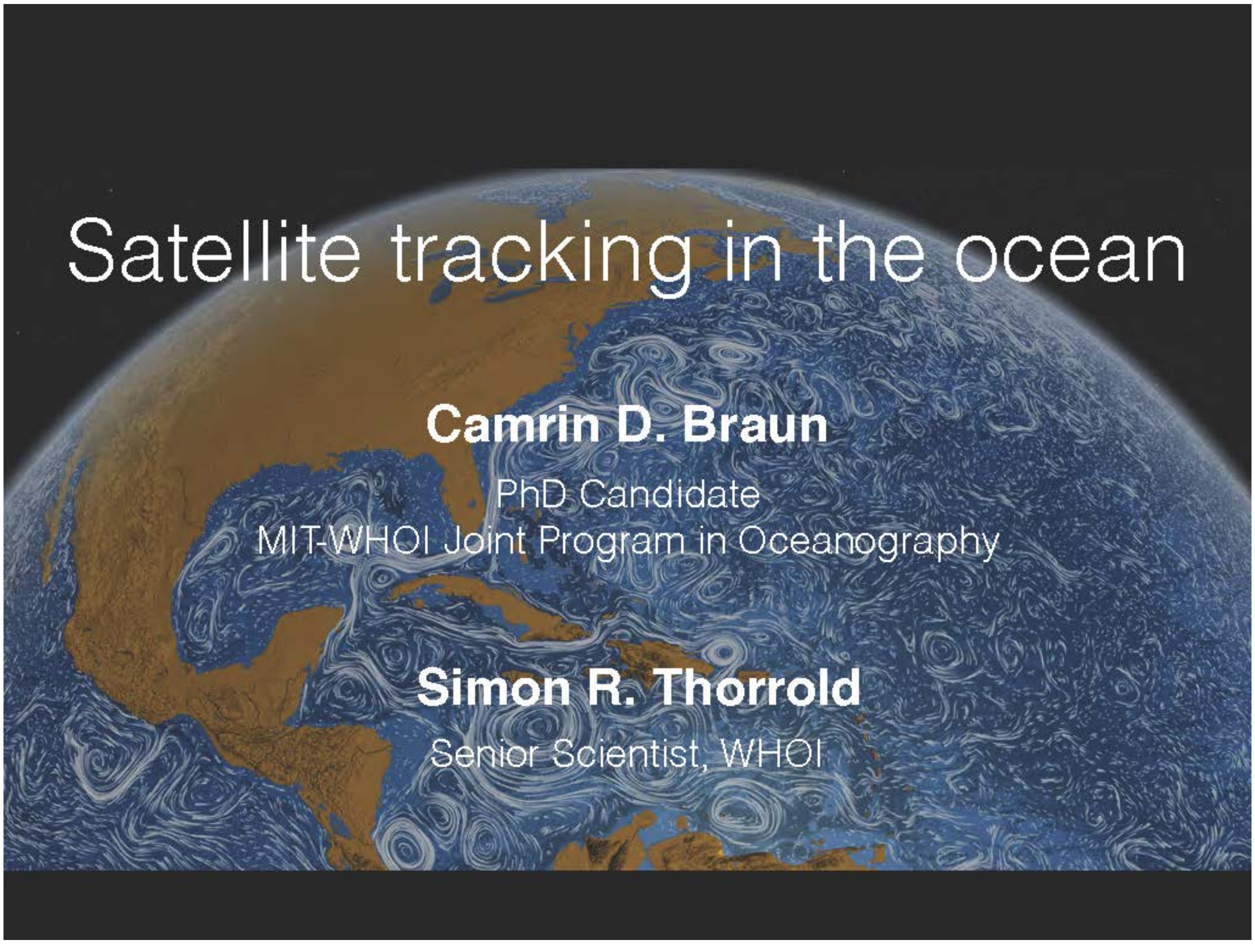
Plataformas de oportunidad de telemetría acústica: beneficios de colaboración del Golfo de Maine

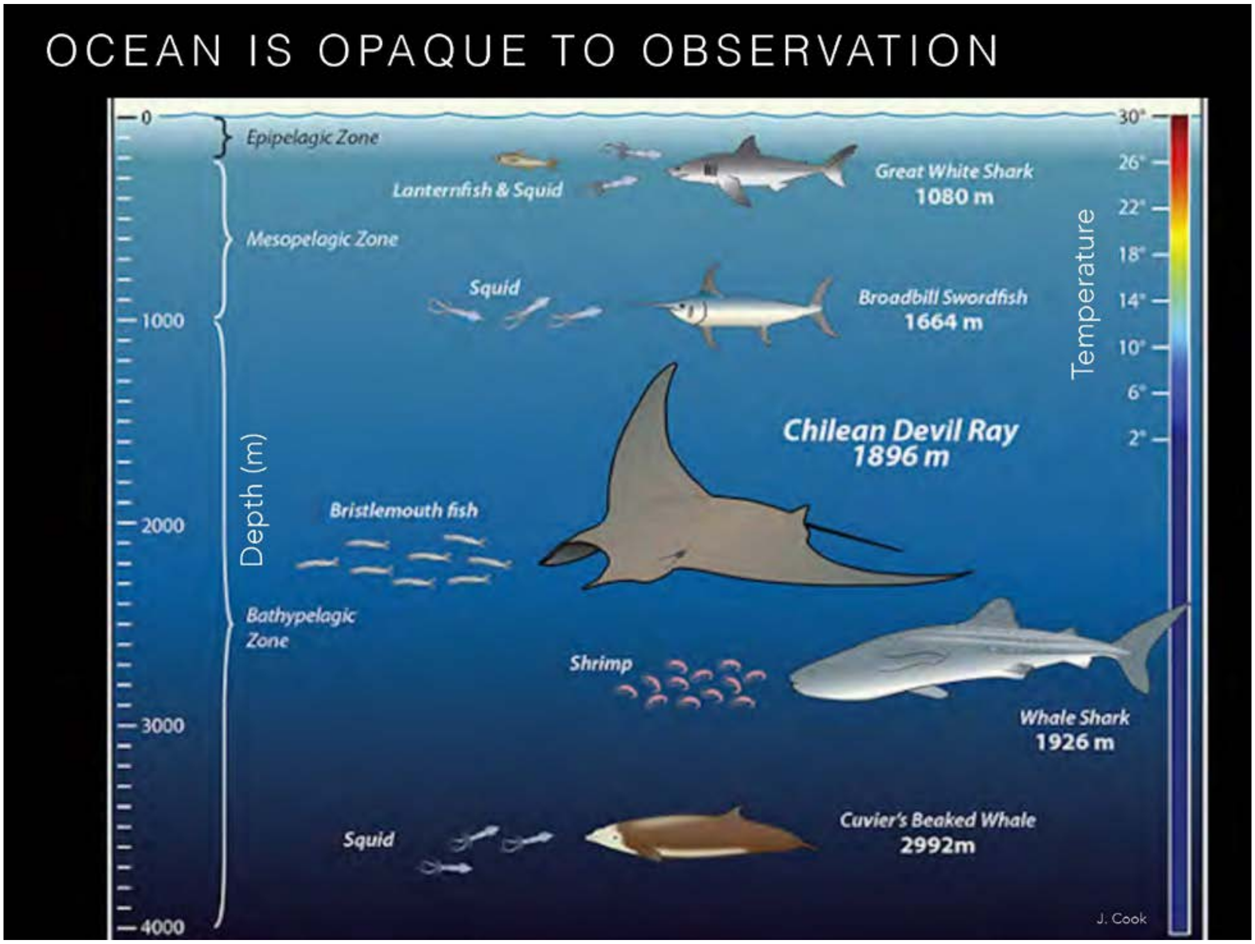
RESUMEN: *los biólogos monitorean el comportamiento, uso de hábitat y supervivencia de los animales a través de proyectos locales de telemetría. Las especies migratorias traspasan estos límites y, por consecuencia, representan una oportunidad para conectar los proyectos. Los biólogos pueden llevar aún más allá estos proyectos, expandiendo las áreas monitoreadas, sin embargo dar este paso resulta costoso. En este trabajo, se evalúan tres plataformas de oportunidad: (1) boyas oceanográficas, (2) equipos de pesca comercial y (3) cuerpos de deriva para probar la viabilidad de expandir la cobertura de los proyectos, al mismo tiempo que se minimizan los costos. Todas estas las plataformas en el Golfo de Maine proveen datos nuevos, generando más de 15,000 detecciones de animales liberados por 18 organizaciones. El desempeño fue bueno en el caso de las boyas y del equipo de pesca comercial, pero los cuerpos de deriva redujeron las utilidades debido a su lenta recuperación; no obstante, los avances alcanzados en la comunicación en tiempo real con estos artefactos debieran mejorar su efectividad en el futuro. Las plataformas de oportunidad probaron ser un método de bajo costo que puede beneficiar a los investigadores que trabajan en distintos sistemas acuáticos. Los animales estudiados en otros trabajos, permitieron conectar a los investigadores entre sí, lo que propicia el diálogo y pone en relieve la ganancia de información e intercambio de datos. El trabajo conjunto entre pescadores y oceanógrafos fortalece la interdisciplinariedad y la comunicación con los interesados y, asimismo, puede incrementar el entendimiento y el soporte del público en general.*

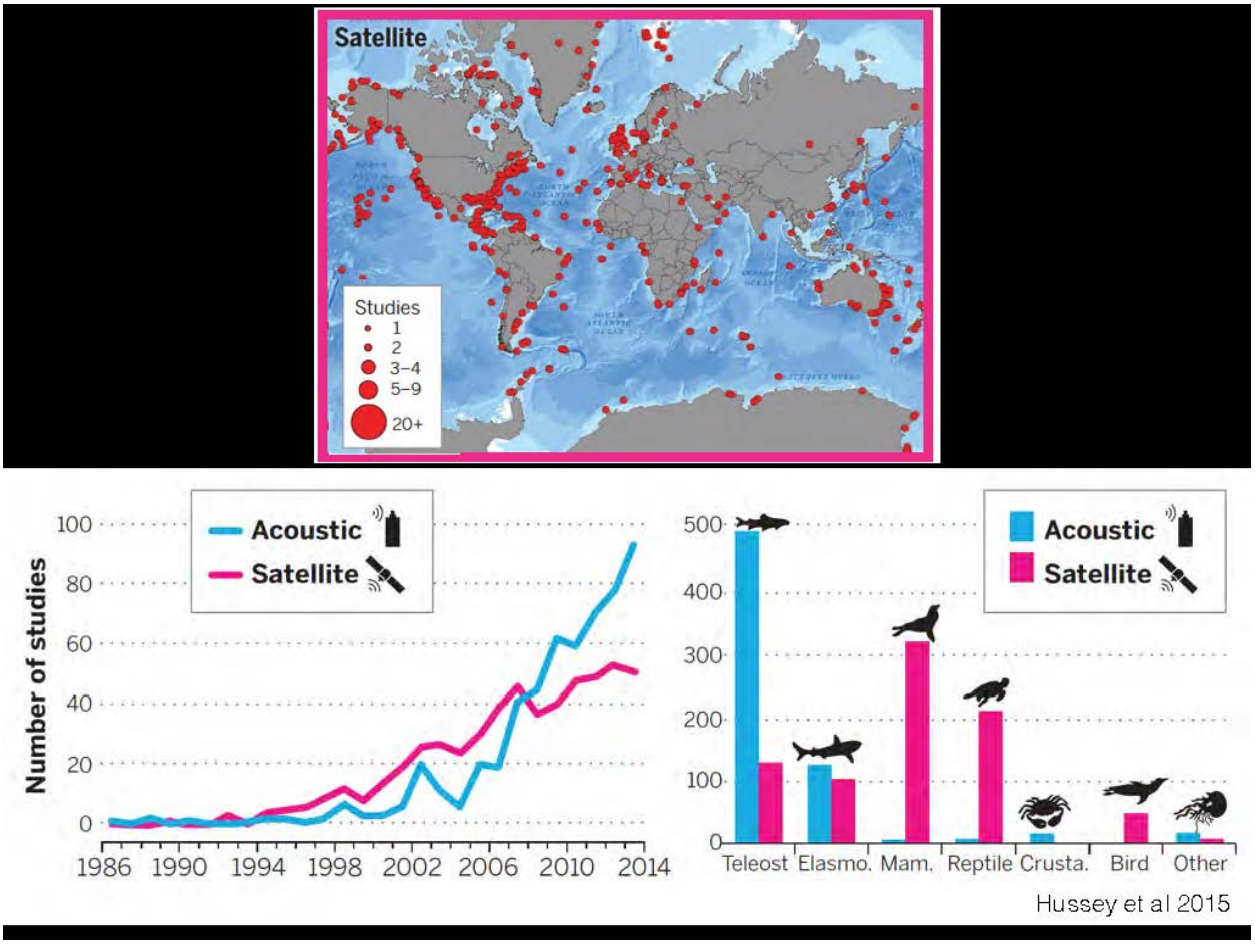


OTN metadata
2015 PIRATA RAMA TAO-TRITON buoys
Oceansites station data Cronin
N
0 2,050 4,100 8,200 12,300 16,400
Kilometers
Sources: Esri, USGS, NOAA

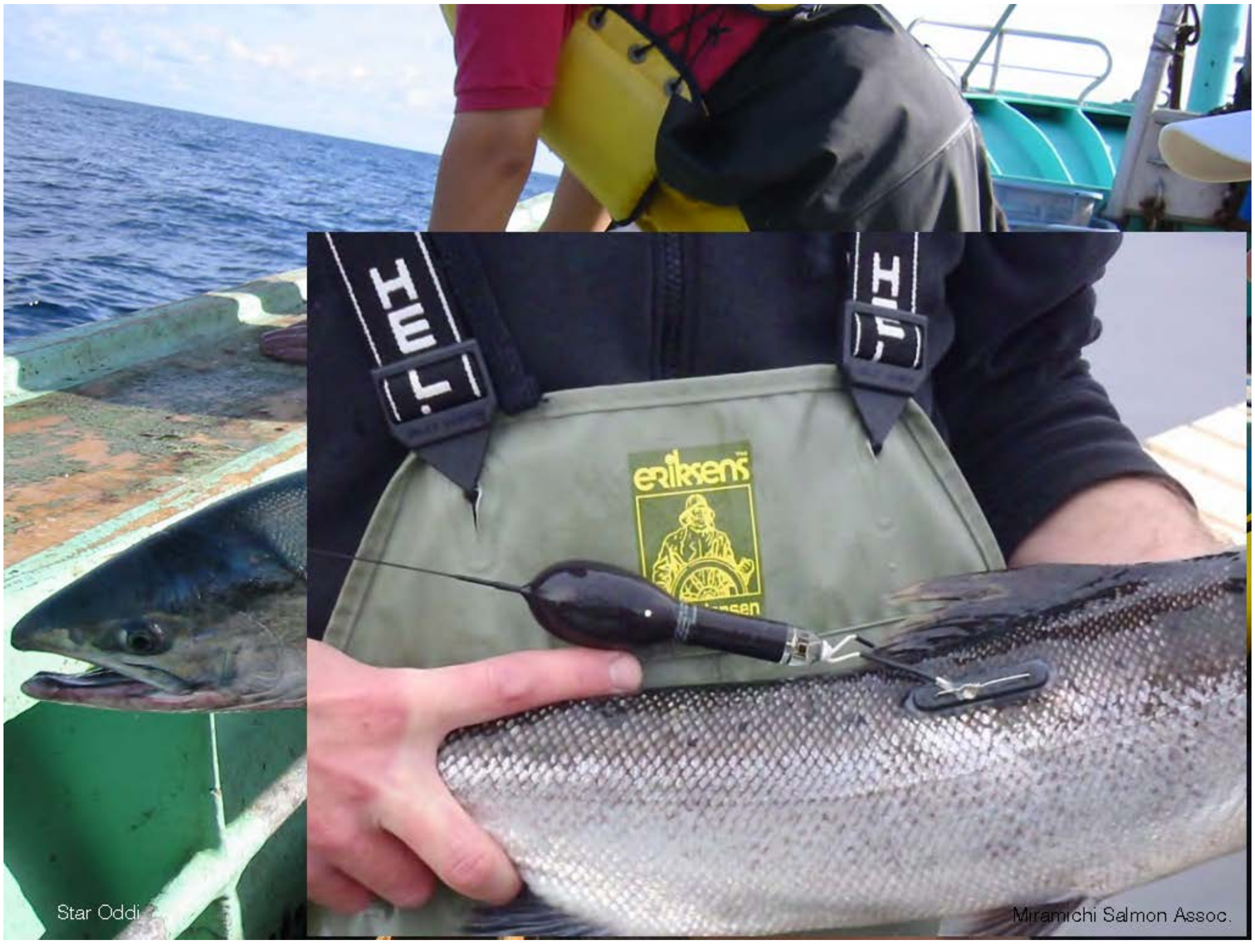
APPENDIX E: STATUS OF TRACKING IN THE OCEAN: OVERVIEW OF SATELLITE TAGGING WITH PARTICULAR FOCUS ON ATLANTIC SALMON

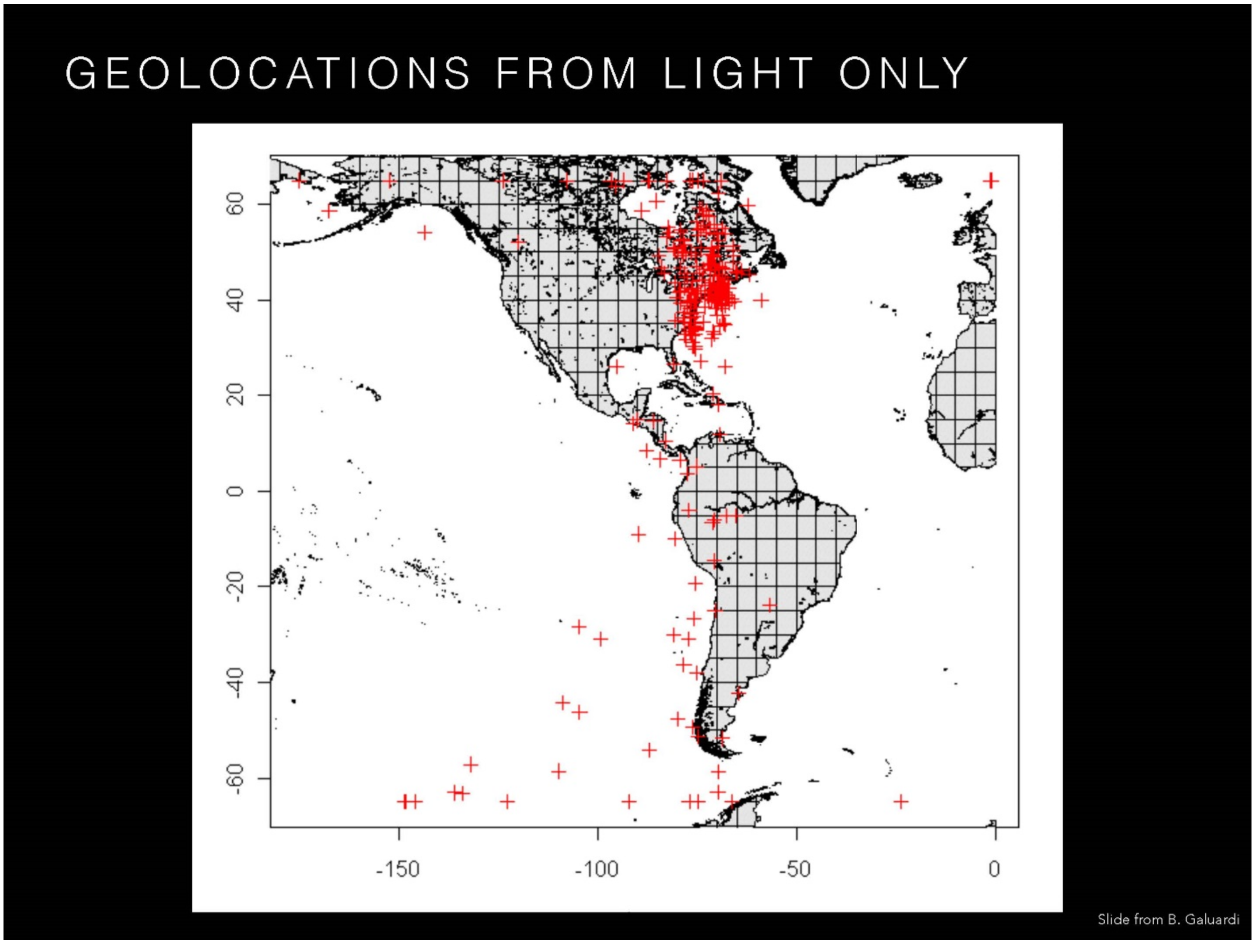


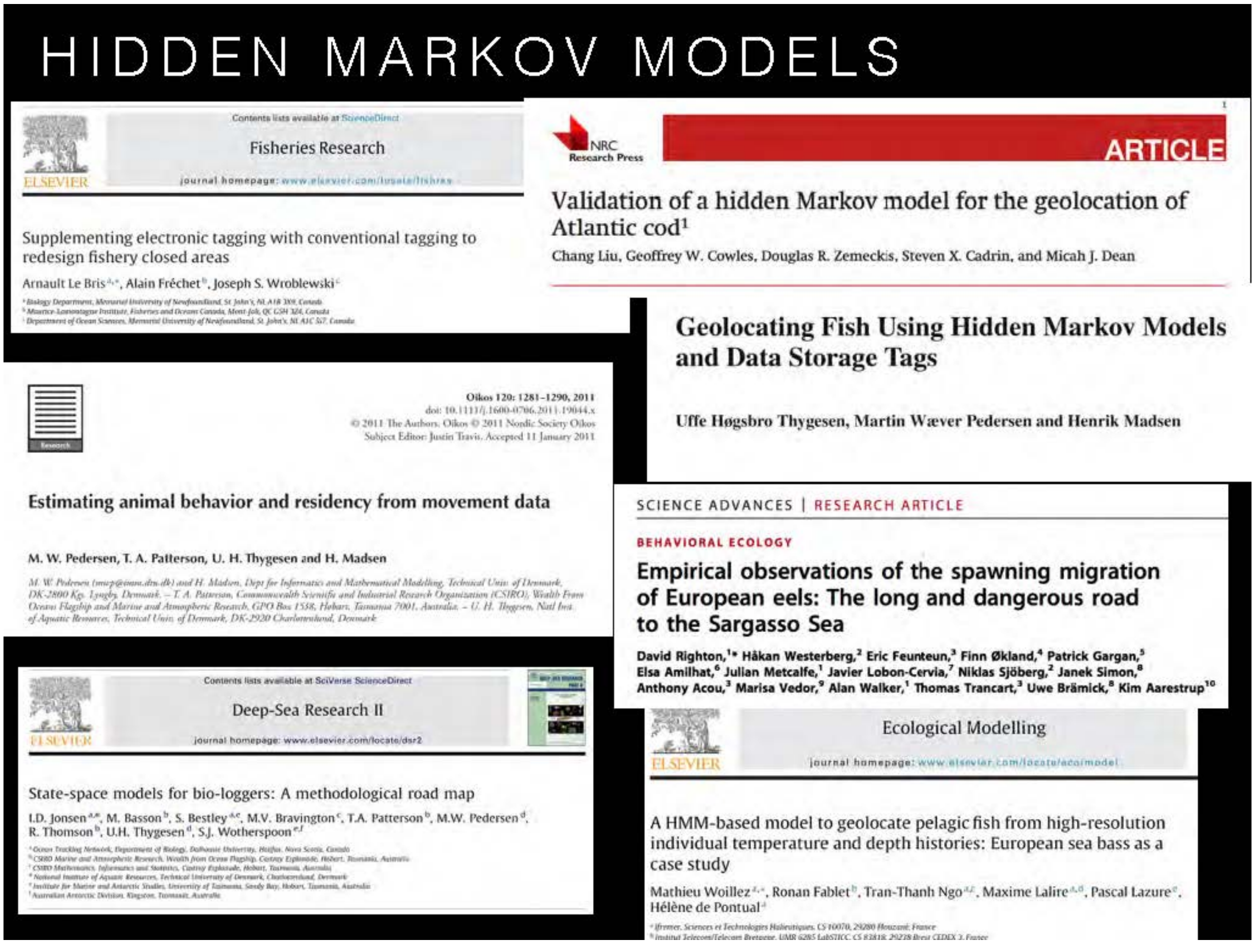

OCEAN IS OPAQUE TO OBSERVATION
Epipelagic Zone
Mesopelagic Zone
Bathypelagic Zone
Depth (m)
0
1000
2000
3000
4000
Lanternfish & Squid
Great White Shark
1080 m
Squid
Broadbill Swordfish
1664 m
Chilean Devil Ray
1896 m
Bristlemouth fish
Shrimp
Whale Shark
1926 m
Squid
Cuvier's Beaked Whale
2992m
Temperature
30°
26°
22°
18°
14°
10°
6°
2°
J. Cook

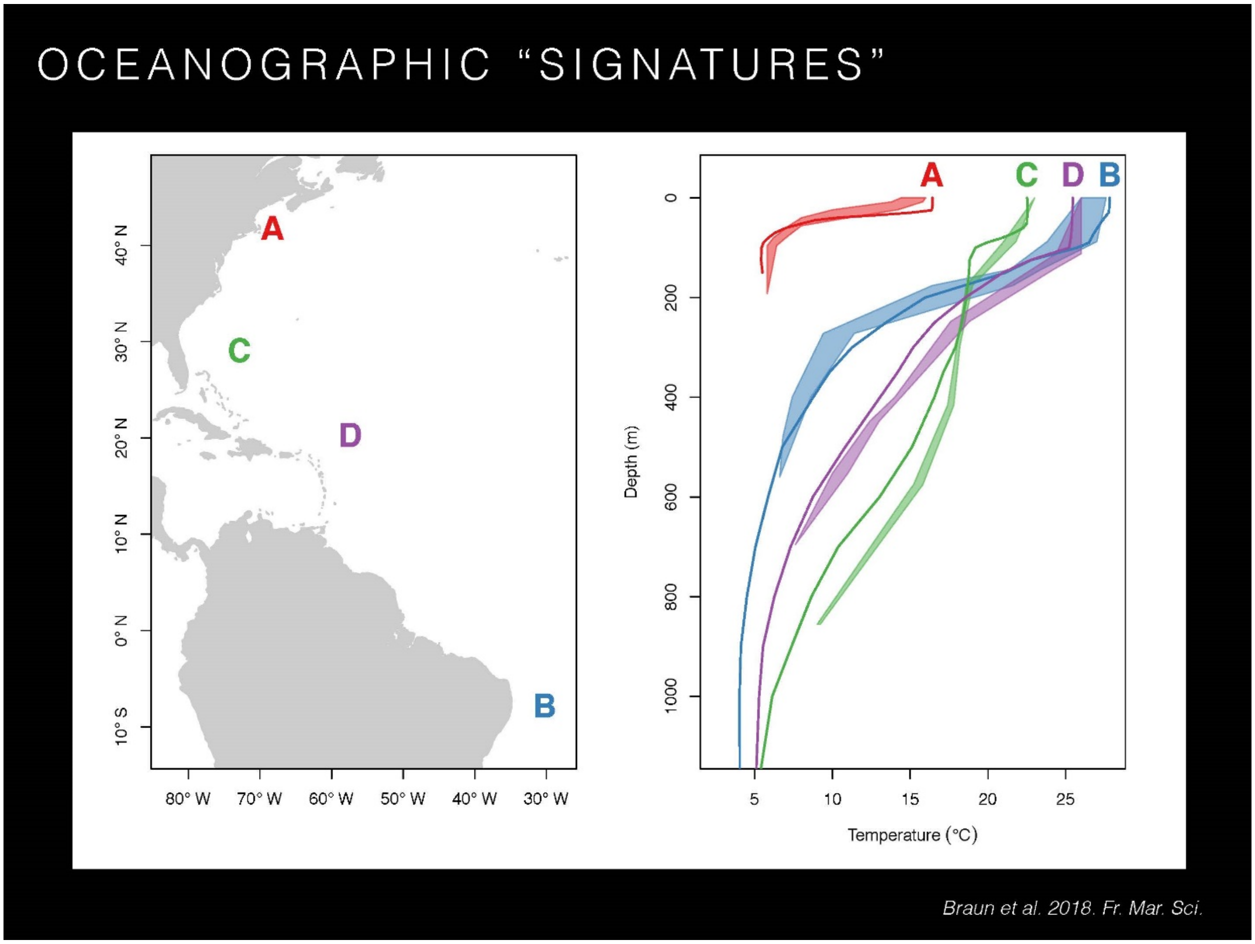

Satellite
Studies
1
2
3–4
5–9
20+
Number of studies
Acoustic
Satellite
Teleost
Elasmo.
Mam.
Reptile
Crusta.
Bird
Other
Hussey et al 2015

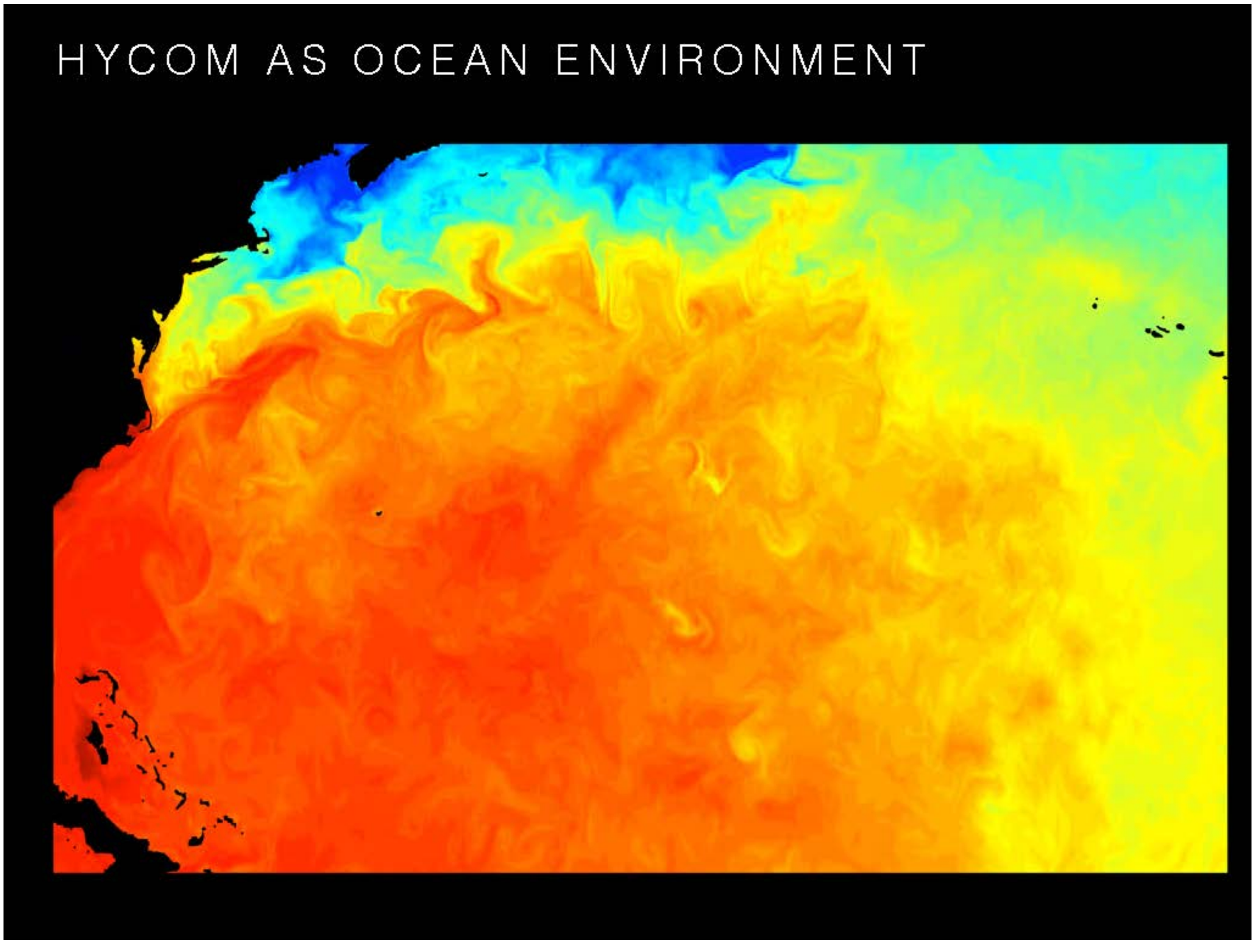

Dan Costa

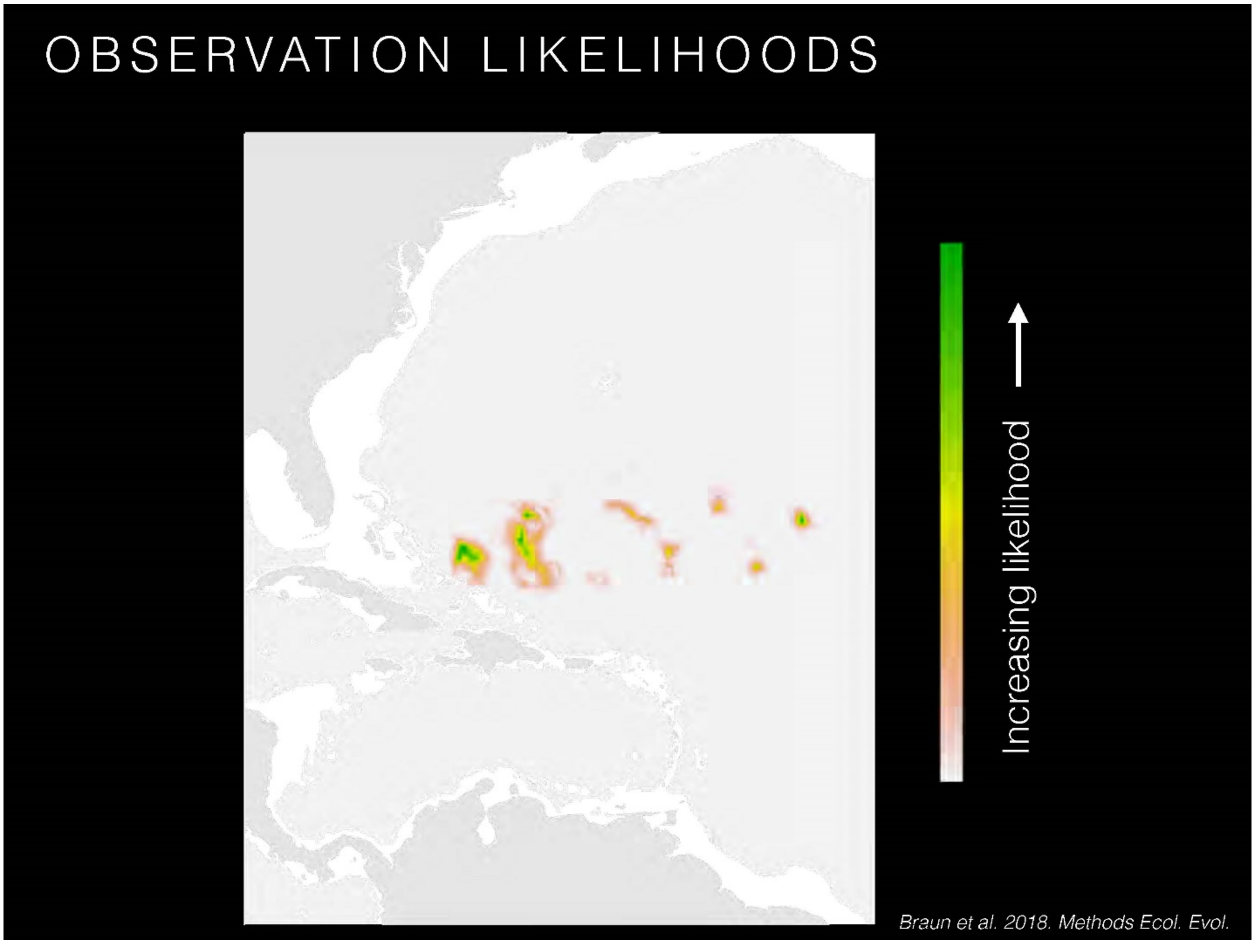

HELLY HANSEN
eriksens
Star Oddi
Miramichi Salmon Assoc.

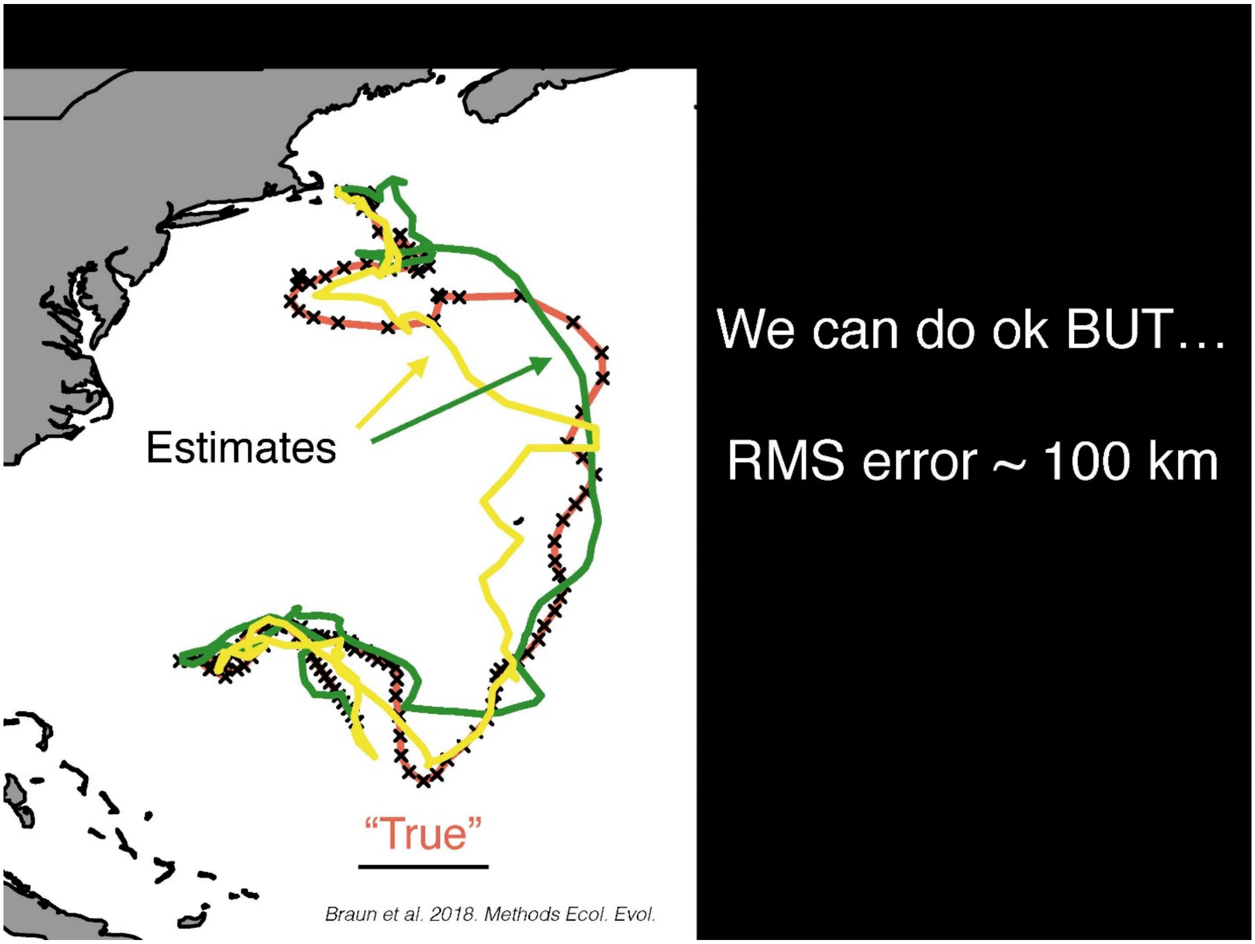

GEOLOCATIONS FROM LIGHT ONLY
60
40
20
0
-20
-40
-60
-150
-100
-50
0
Slide from B. Galuardi

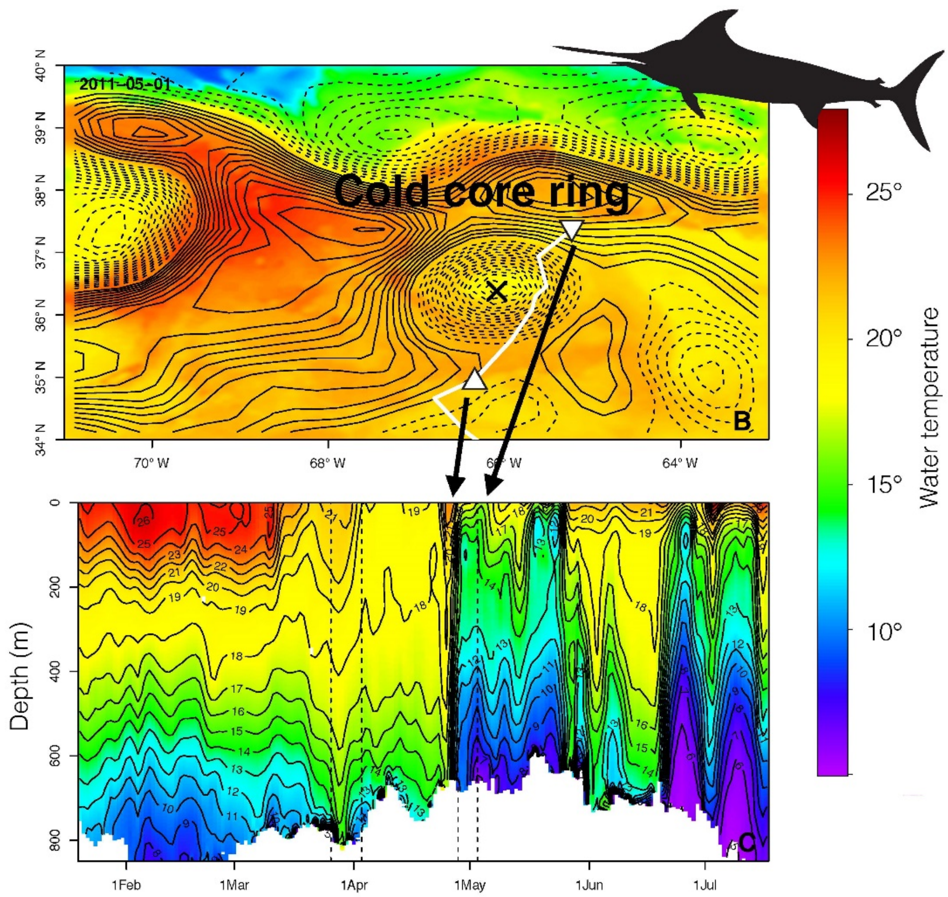

HIDDEN MARKOV MODELS
Contents lists available at ScienceDirect
Fisheries Research
journal homepage: www.elsevier.com/locate/fishres
Supplementing electronic tagging with conventional tagging to redesign fishery closed areas
Arnault Le Bris, Alain Fréchet, Joseph S. Wroblewski
NRC Research Press
ARTICLE
Validation of a hidden Markov model for the geolocation of Atlantic cod
Chang Liu, Geoffrey W. Cowles, Douglas R. Zemeckis, Steven X. Cadrin, and Micah J. Dean
Geolocating Fish Using Hidden Markov Models and Data Storage Tags
Uffe Høgsbro Thygesen, Martin Wæver Pedersen and Henrik Madsen
Oikos 120: 1281–1290, 2011
Estimating animal behavior and residency from movement data
M. W. Pedersen, T. A. Patterson, U. H. Thygesen and H. Madsen
SCIENCE ADVANCES | RESEARCH ARTICLE
BEHAVIORAL ECOLOGY
Empirical observations of the spawning migration of European eels: The long and dangerous road to the Sargasso Sea
David Righton, Håkan Westerberg, Eric Feunteun, Finn Økland, Patrick Gargan, Elsa Amilhat, Julian Metcalfe, Javier Lobon-Cervia, Niklas Sjöberg, Janek Simon, Anthony Acou, Marisa Vedor, Alan Walker, Thomas Trancart, Uwe Brämick, Kim Aarestrup
Contents lists available at SciVerse ScienceDirect
Deep-Sea Research II
journal homepage: www.elsevier.com/locate/dsr2
State-space models for bio-loggers: A methodological road map
I.D. Jonsen, M. Basson, S. Bestley, M.V. Bravington, T.A. Patterson, M.W. Pedersen, R. Thomson, U.H. Thygesen, S.J. Wotherspoon
Ecological Modelling
journal homepage: www.elsevier.com/locate/ecolmodel
A HMM-based model to geolocate pelagic fish from high-resolution individual temperature and depth histories: European sea bass as a case study
Mathieu Woillez, Ronan Fablet, Tran-Thanh Ngo, Maxime Lalire, Pascal Lazure, Hélène de Pontual


OCEANOGRAPHIC "SIGNATURES"
A
B
C
D
40° N
30° N
20° N
10° N
0° N
10° S
80° W
70° W
60° W
50° W
40° W
30° W
Depth (m)
0
200
400
600
800
1000
5
10
15
20
25
Temperature (°C)
Braun et al. 2018. Fr. Mar. Sci.

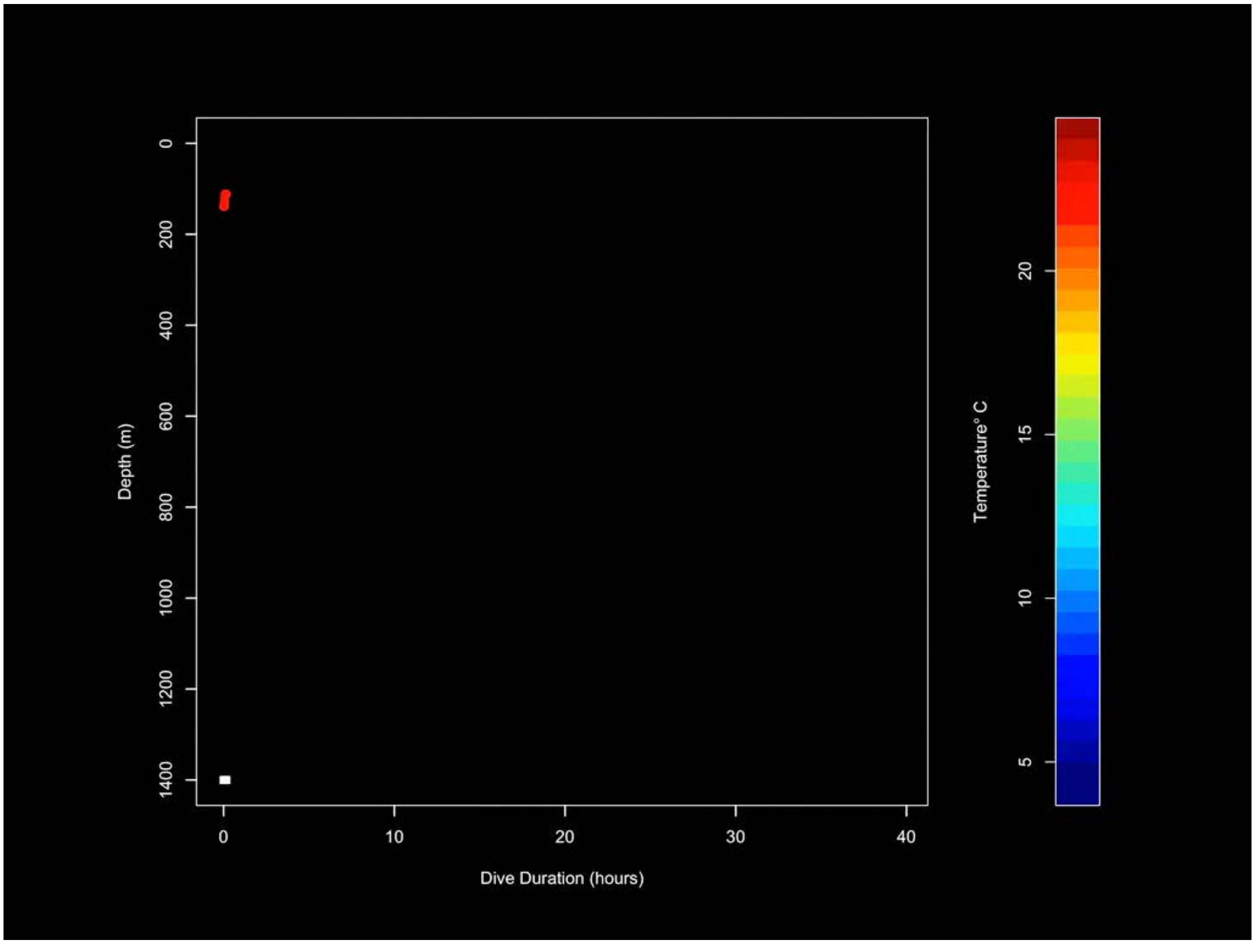

HYCOM AS OCEAN ENVIRONMENT


OBSERVATION LIKELIHOODS
Increasing likelihood
Braun et al. 2018. Methods Ecol. Evol.

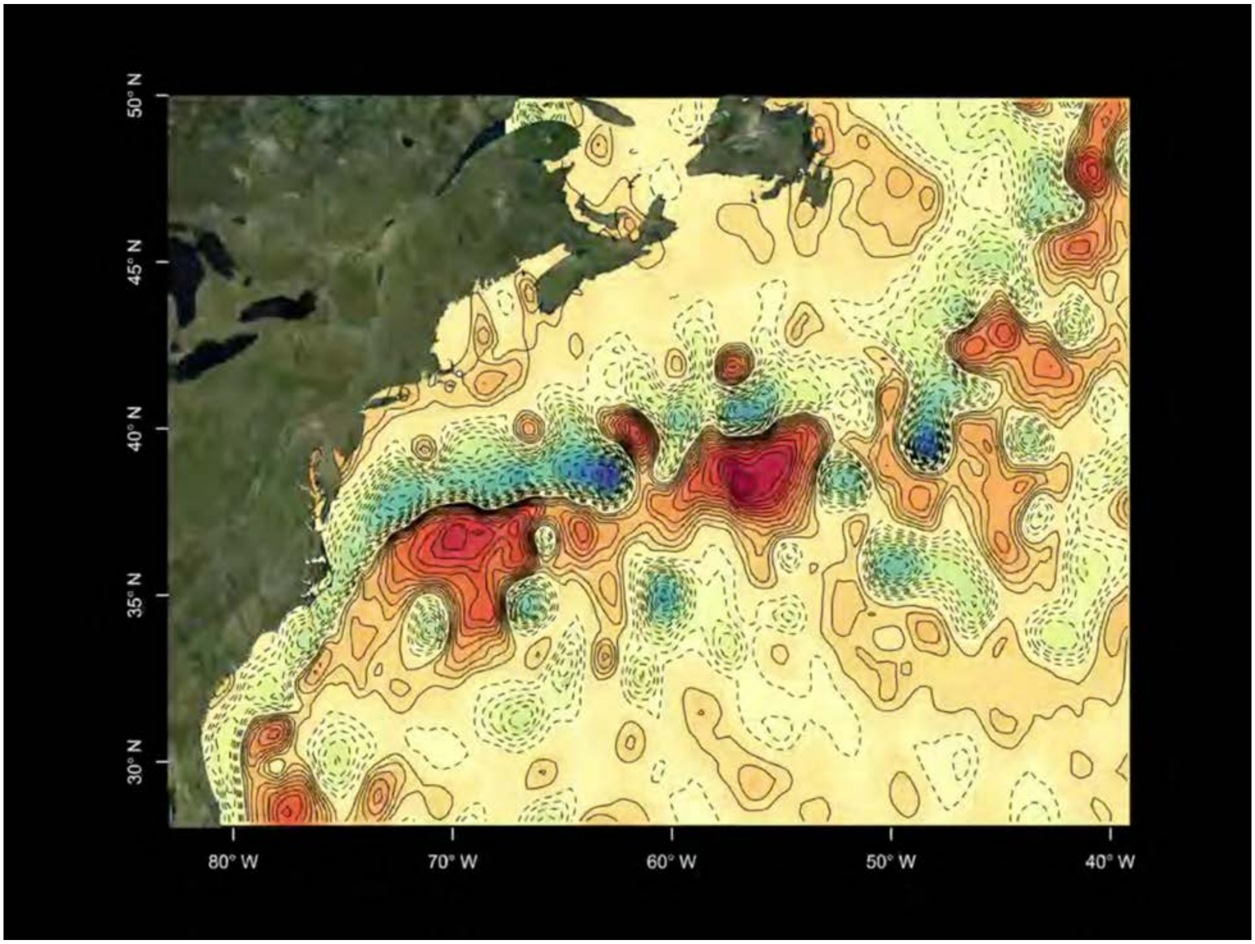

Estimates
"True"
Braun et al. 2018. Methods Ecol. Evol.
We can do ok BUT…
RMS error ~ 100 km



2011-05-01
Cold core ring
B
40° N
39° N
38° N
37° N
36° N
35° N
34° N
70° W
68° W
64° W
C
Depth (m)
0
200
400
600
800
1Feb
1Mar
1Apr
1May
1Jun
1Jul
Water temperature
25°
20°
15°
10°

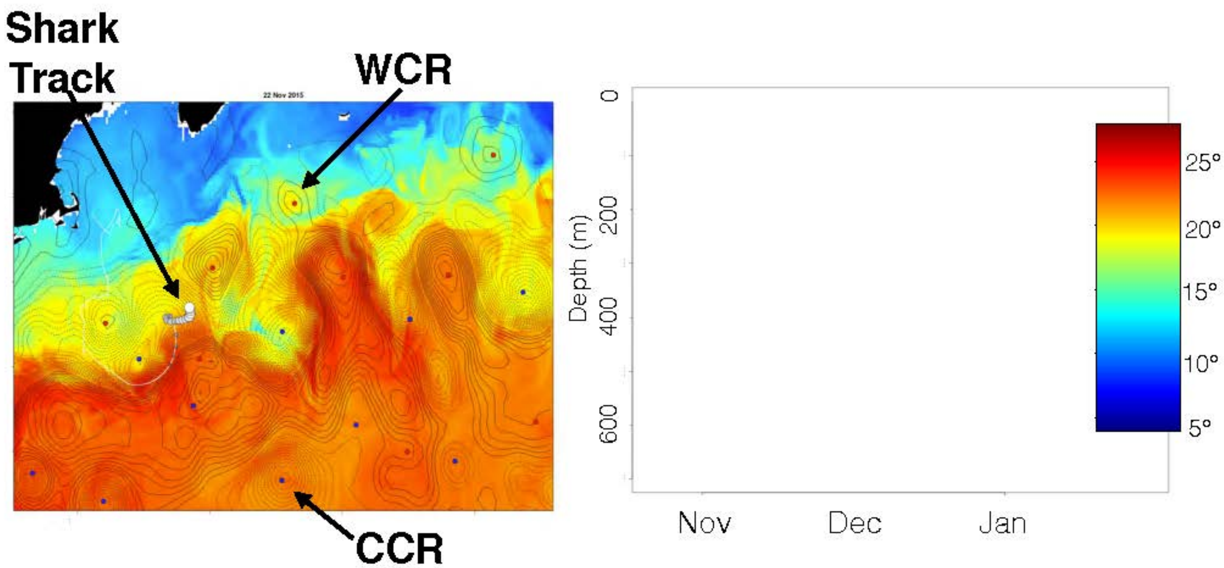


0
200
400
600
800
1000
1200
1400
Depth (m)
0
10
20
30
40
Dive Duration (hours)
20
15
10
5
Temperature° C

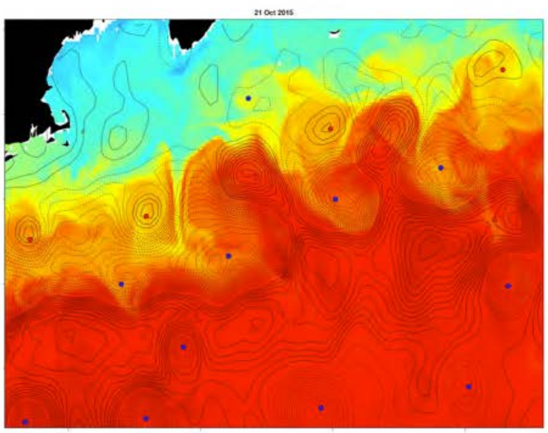


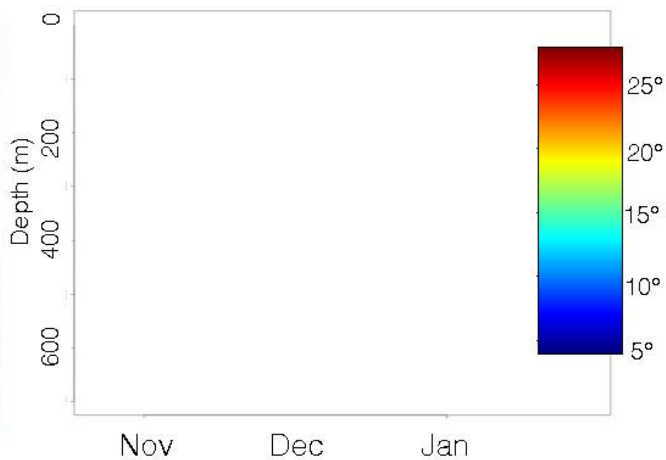
50° N
45° N
40° N
35° N
30° N
80° W
70° W
60° W
50° W
40° W

DIVING IN EDDIES



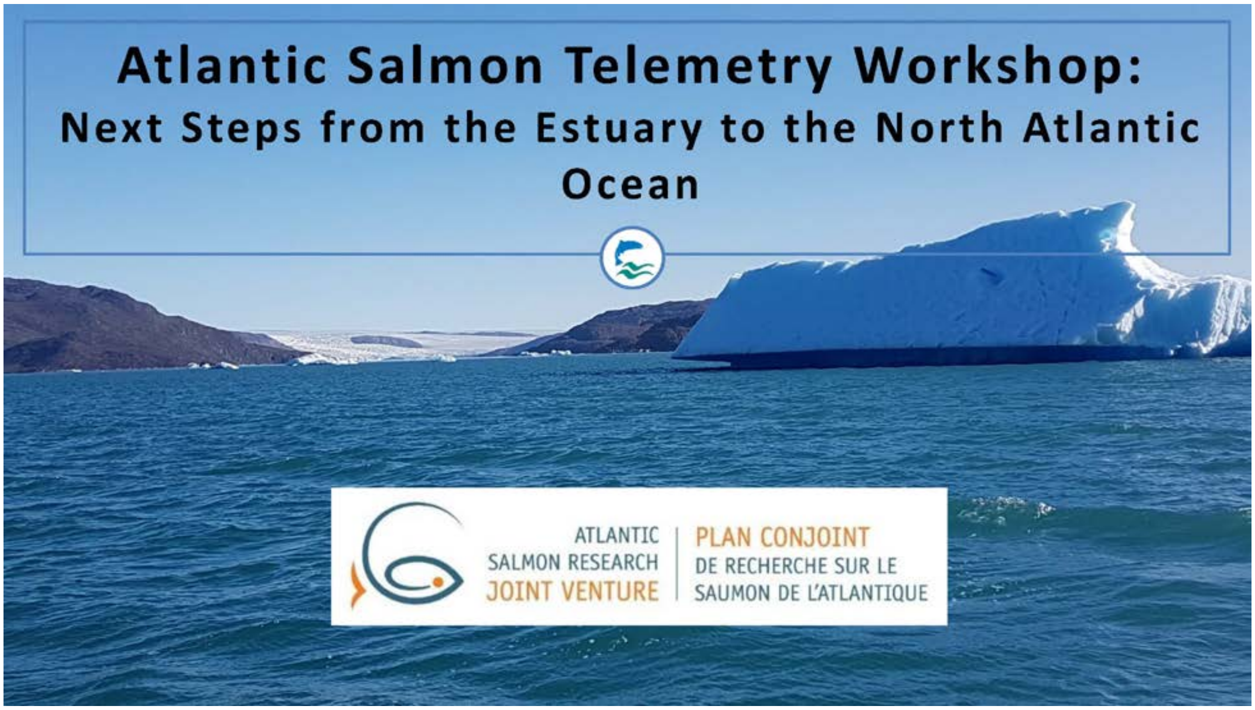
DIVING IN EDDIES






QUESTIONS?
camrinbraun.com
cbraun@whoi.edu
WOODS HOLE OCEANOGRAPHIC INSTITUTION
1930
NASA
NATIONAL GEOGRAPHIC
amazon web services™
Photo by T. Sinclair-Taylor

ANNEX F: ATLANTIC SALMON TELEMETRY PLANNING MEETING: EXPANDING THE TRACKING NETWORK INTO THE NORTH ATLANTIC



ATLANTIC SALMON RESEARCH JOINT VENTURE | PLAN CONJOINT DE RECHERCHE SUR LE SAUMON DE L'ATLANTIQUE

VISION

Organizations working together to improve the conservation of wild North American Atlantic salmon.

MISSION

Scientists working together to advance knowledge on wild Atlantic salmon by identifying common scientific objectives; sharing expertise and resources; and generating knowledge that improves conservation and management for the sustainability of the resource in North America.

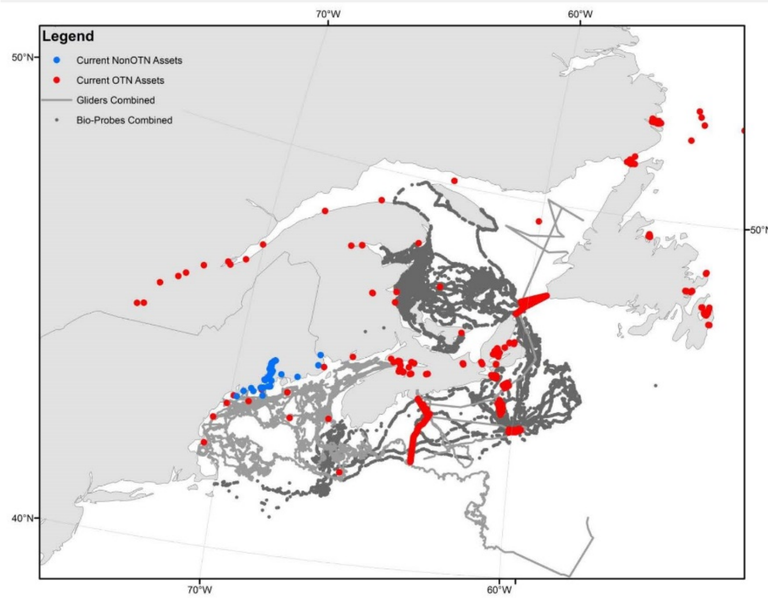
Telemetry Workshop Scope

- **Review past and ongoing studies in the North Atlantic**
- **Develop research program for North Atlantic that builds on SALSEA TRACK and focuses on:**
  - **Estimate and partition marine mortality of Atlantic salmon**
  - **Improve knowledge of migration and distribution patterns**

NASCO's International Atlantic Salmon Research Board (IASRB)

- **Promote collaboration/cooperation on research into marine mortality of Atlantic salmon and the opportunities to counteract this mortality.**
- **SALSEA (Salmon at Sea) Programme:**
  - Coordinated marine sampling initiatives across the North Atlantic (2008-2010).
- **SALSEA – Track:**
  - To encourage the development of large international collaborative telemetry projects that together build upon and expand local efforts.
  - Involve collaboration with scientists undertaking telemetry studies on a variety of other marine species.

North American Overview



Challenges:

- Big ocean
- Limited transmitter/receiver ranges
- Tag size/battery life
- Equipment cost and labor
- Data compilation/storage
- Correlating animal movements with environmental variables

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Executive Summary

1. Poor at sea survival is the primary driver for the Atlantic salmon's decline .
2. Acoustic telemetry work had led to essential information gains over the last few decades by partitioning survival from headlands to coastal regions.
3. Need to address knowledge gaps further offshore to map the spatial and temporal distribution of mixed salmon populations.
4. Moving telemetry programs further offshore is a challenge due to current limitations in the technology and the size of the area of interest.
5. Need a balance of low risk projects with a high likelihood of success with projects that are more high risk.
6. Deploying receivers on platforms of opportunity can be a cost-effective way to collect baseline acoustic monitoring data, supplemental to fixed arrays.

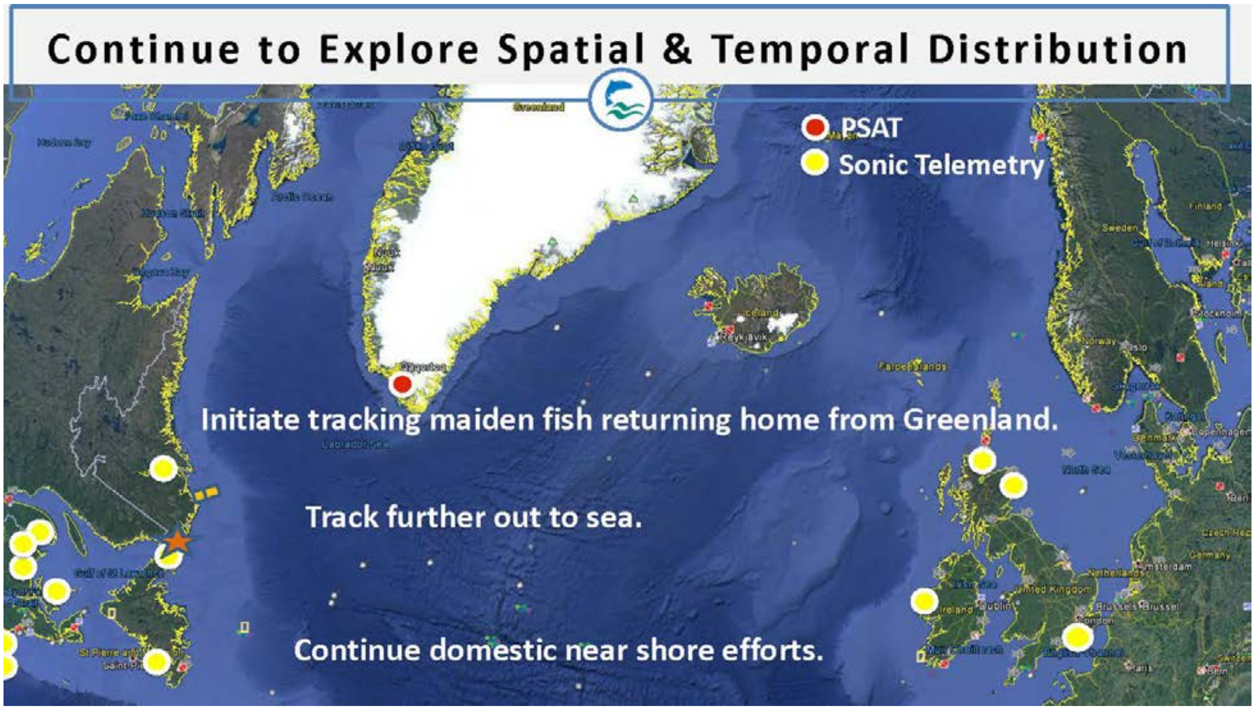
Executive Summary

7. 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.
8. Important to exchange information with oceanographers to gain insight into the environmental factors in the ocean that are driving biotic and abiotic interactions.
9. PSATS, in combination with genetic assignment methods, offer the ability to partition mortality daily during their final months of ocean residency (i.e. West Greenland) before returning to spawn in freshwater.
10. It is critical to support research and development of innovative technologies (i.e. ROAM).
11. It is important to assess the quality of smolts not just quantity.
12. 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 so that data can be used together.

Recommendations

1. **Expand capacity to track the coastal movement of wild Atlantic salmon, where possible using existing infrastructure.**
2. **Undertake a modelling exercise (particle tracking model including drivers) to better understand detection probability of wild Atlantic salmon across seascapes.**
3. **Endorse further development of emerging technologies that facilitate Open Ocean research.**
4. **Further develop tagging research (satellite/acoustic/emerging) on adult salmon at Greenland.**
5. **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.**

APPENDIX G: TRACKING ATLANTIC SALMON IN THE LABRADOR SEA



West Greenland Tracking Objectives

1. Map the marine distribution and migration patterns for maiden Atlantic salmon and post spawned adults tagged in coastal waters off the west coast of Greenland.
2. Test and implement novel technological telemetry advancements using ROAM.
3. Examine the oceanographic (physical and biological) features occurring in the salmon's distribution and migratory routes and assess how they could be linked to survival and growth.

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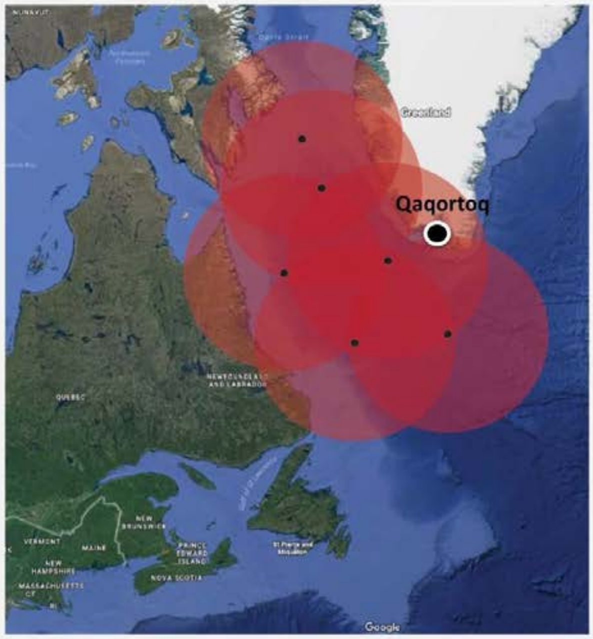

28

West Greenland Project Outputs

- Map the marine distribution and migration patterns for maiden Atlantic salmon and post spawned adults tagged in coastal waters off the west coast of Greenland.
- Fill knowledge gaps on the marine distribution and migration routes for maiden and post spawned Atlantic salmon and determine annual variation.
  - Learn where, and for how long, salmon spend foraging along the coast of Greenland;
  - Extent of population mixing in the ocean;
  - Stock-specific and population structure (spatial and age) homeward migration strategies;
  - Mortality in relation to habitat occupation in feeding areas
  - Predation rates and likely suspects;
  - Migration dynamic linkages with oceanographic conditions.

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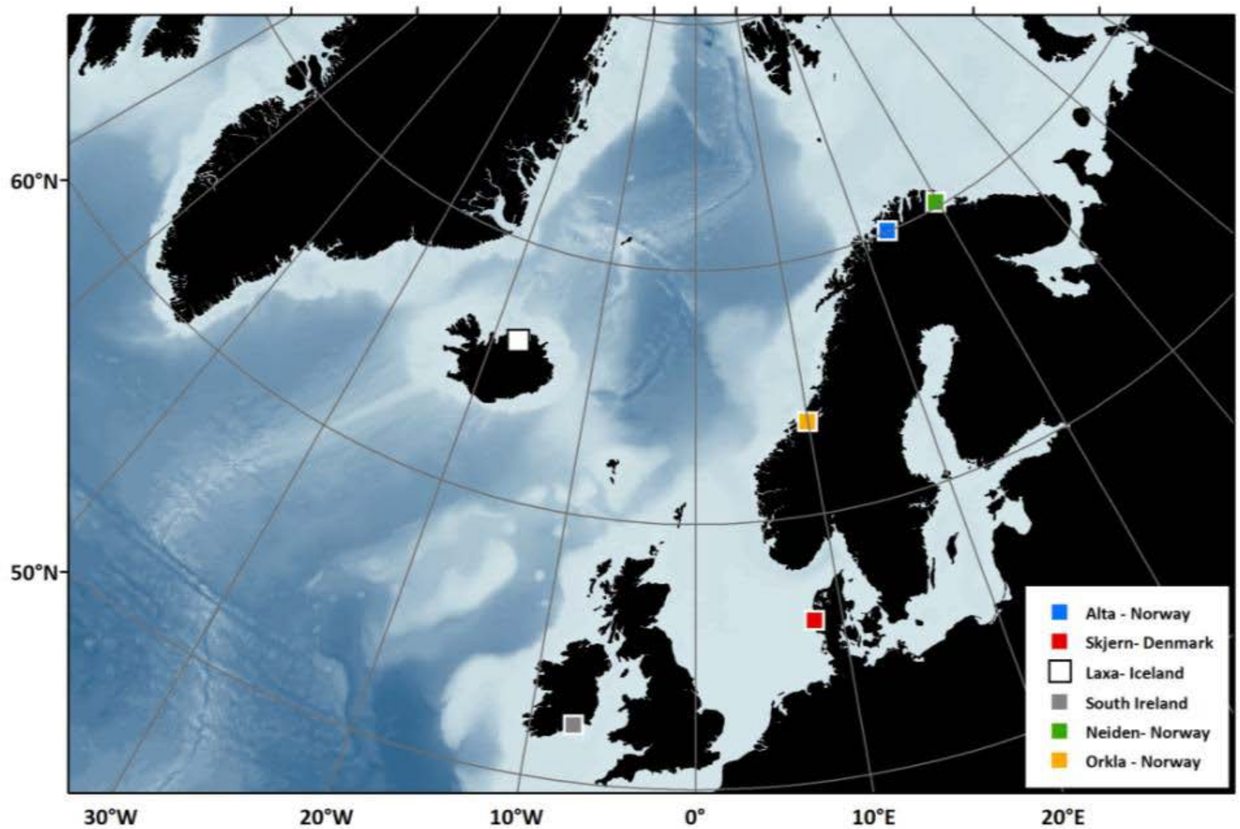
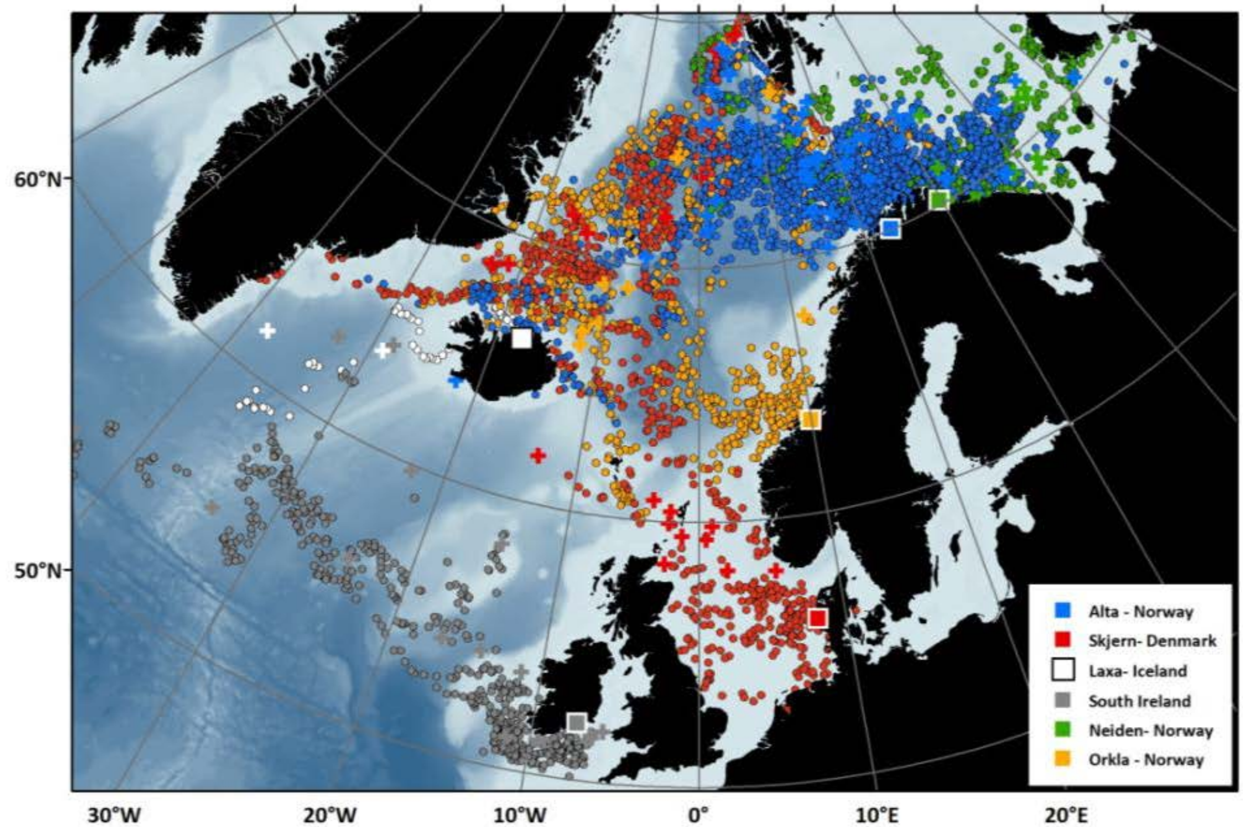
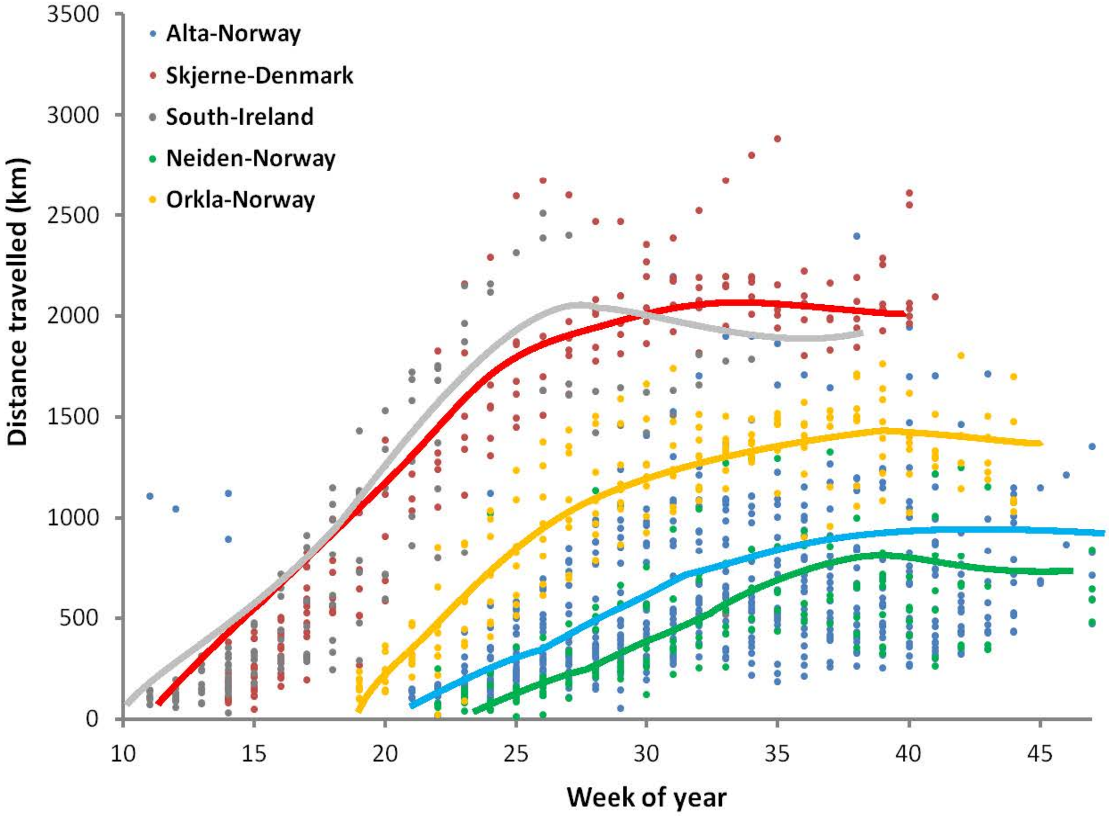
APPENDIX H: SMOLTRACK I AND II



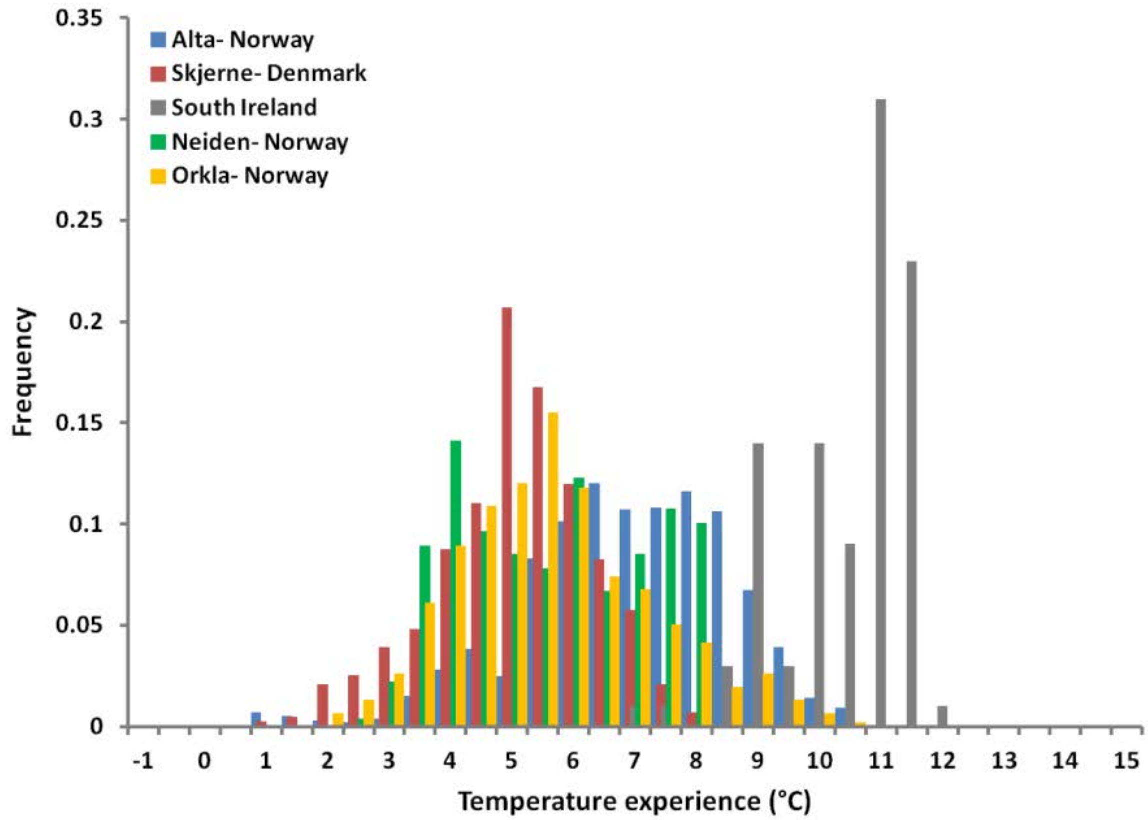
170 kelts from six rivers were tagged between 2008 and 2011



Mixing of eastern stocks in north-east Atlantic



Migration phase, then ‘residence’ in presumed feeding areas



Occupation of low temperatures for fish of eastern populations

Smoltrack I and II

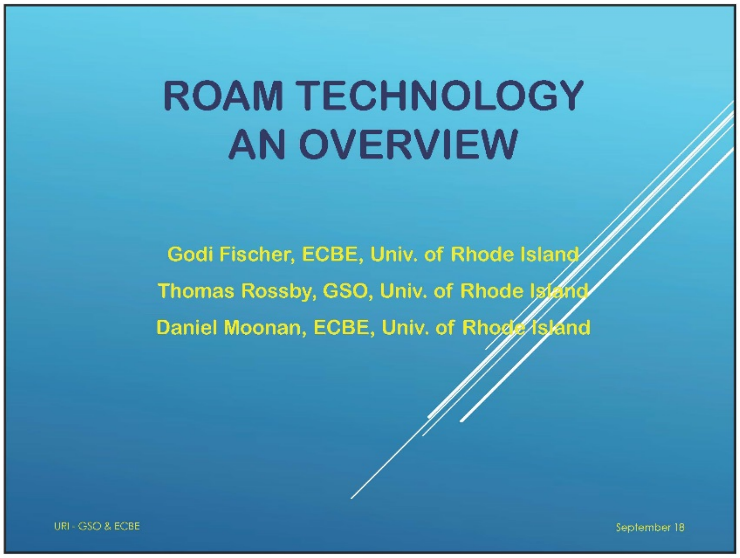
EU funded, EU partners, Index catchments

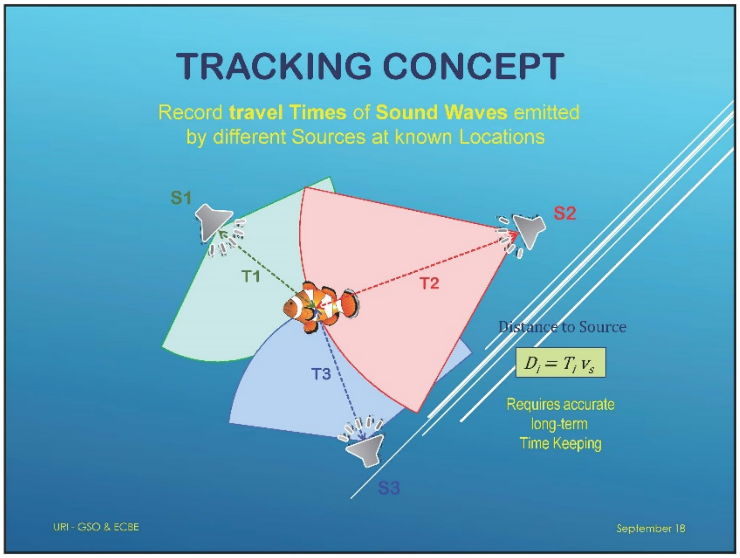
- Estimate lower river and early marine survival of European Rivers
- Identify potential mortality causes
- Hatchery vs Wild
- Quality
- Sop
- Technology evaluation
- Pilot project on genetically assigned and tag salmon at sea

Smoltrack I and II - Partners

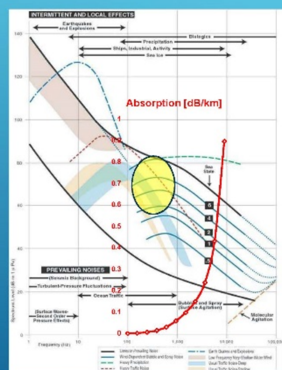
- Ireland
- Northern Ireland
- England/UK
- Spain, two rivers
- Sweden, two rivers
- Denmark

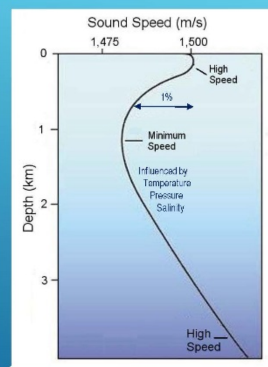
APPENDIX I: ROAM TECHNOLOGY OVERVIEW





SOUND IN THE OCEAN





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HIGH-Q SOUND SOURCE

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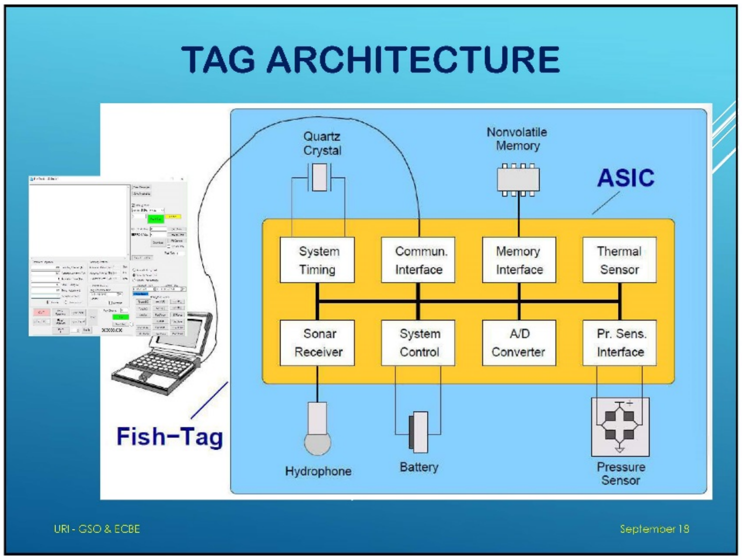
TAG ARCHITECTURE
Quartz Crystal
Nonvolatile Memory
ASIC
System Timing
Commun. Interface
Memory Interface
Thermal Sensor
Sonar Receiver
System Control
A/D Converter
Pr. Sens. Interface
Fish−Tag
Hydrophone
Battery
Pressure Sensor
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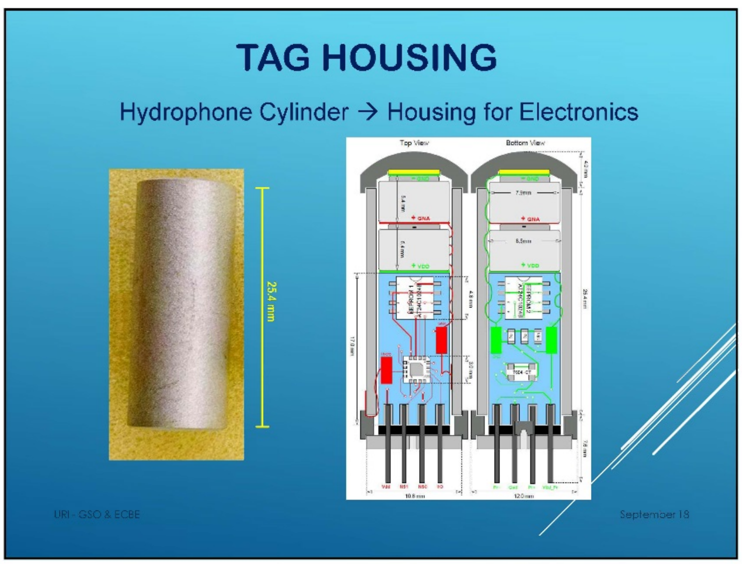
TAG HOUSING
Hydrophone Cylinder → Housing for Electronics
25.4 mm
Top View
Bottom View
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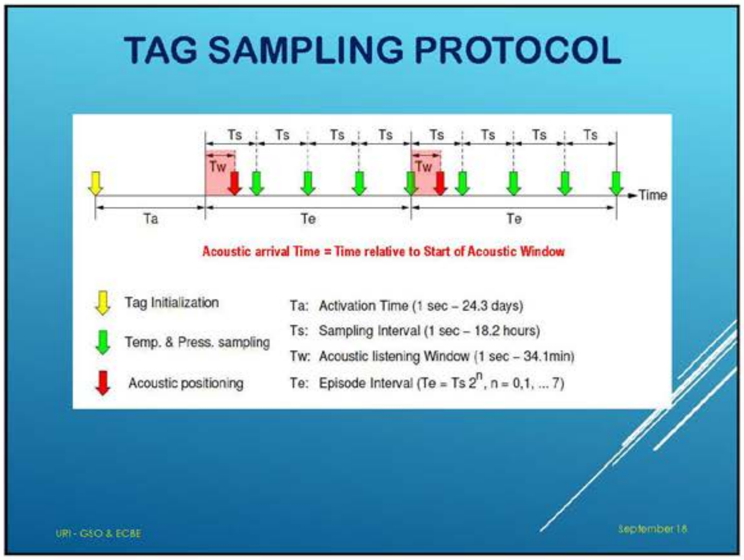
TAG SAMPLING PROTOCOL
Ts Ts Ts Ts Ts Ts Ts Ts
Tw
Tw
Time
Ta
Te
Te
Acoustic arrival Time = Time relative to Start of Acoustic Window
Tag Initialization
Temp. & Press. sampling
Acoustic positioning
Ta: Activation Time (1 sec – 24.3 days)
Ts: Sampling Interval (1 sec – 18.2 hours)
Tw: Acoustic listening Window (1 sec – 34.1min)
Te: Episode Interval (Te = Ts 2^n, n = 0,1, ... 7)
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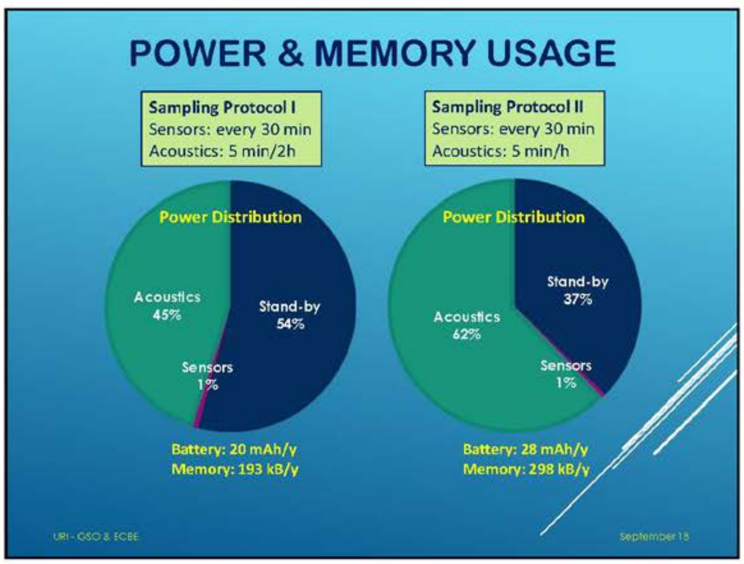
POWER & MEMORY USAGE
Sampling Protocol I
Sensors: every 30 min
Acoustics: 5 min/2h
Sampling Protocol II
Sensors: every 30 min
Acoustics: 5 min/h
Power Distribution
Acoustics 45%
Stand-by 54%
Sensors 1%
Battery: 20 mAh/y
Memory: 193 kB/y
Power Distribution
Stand-by 37%
Acoustics 62%
Sensors 1%
Battery: 28 mAh/y
Memory: 298 kB/y
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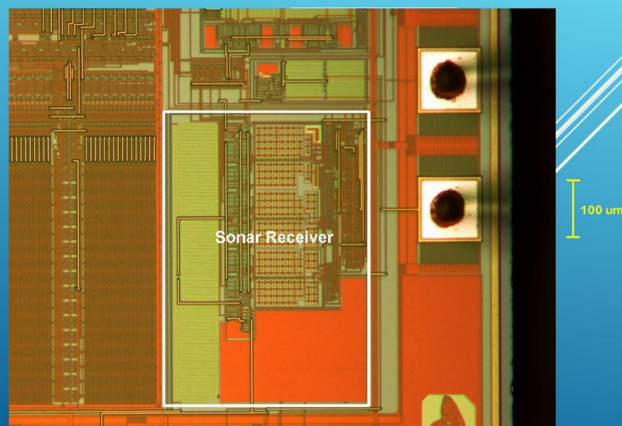
SONAR RECEIVER ANALOG



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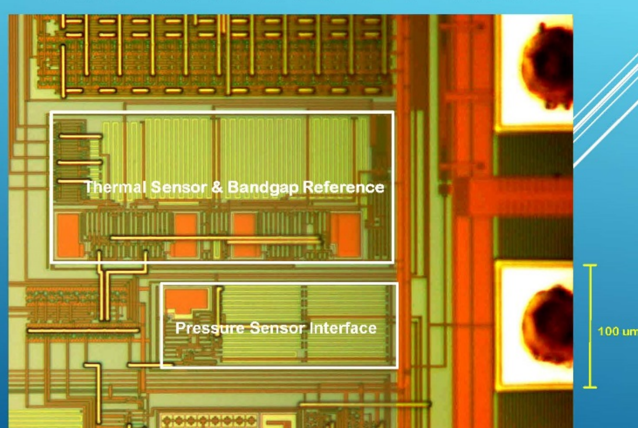
TEMP. & PRESSURE SENSING



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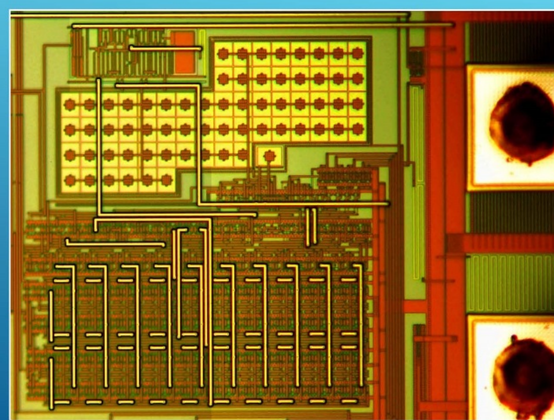
10 BIT ADC



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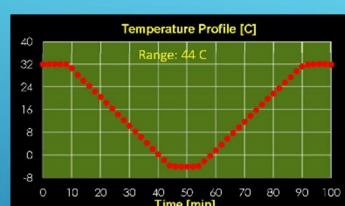
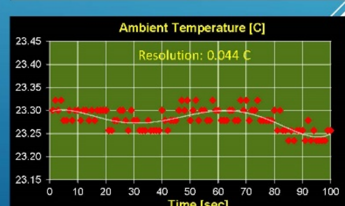
THERMAL SENSOR CHARACTERISTICS





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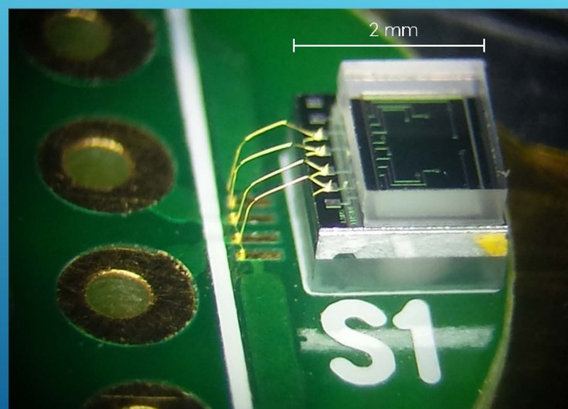
PRESSURE SENSOR



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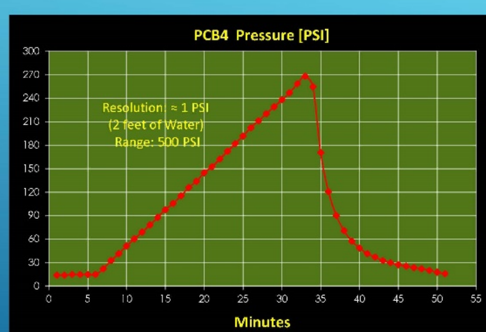
PRESSURE SENSOR CHARACTERISTICS



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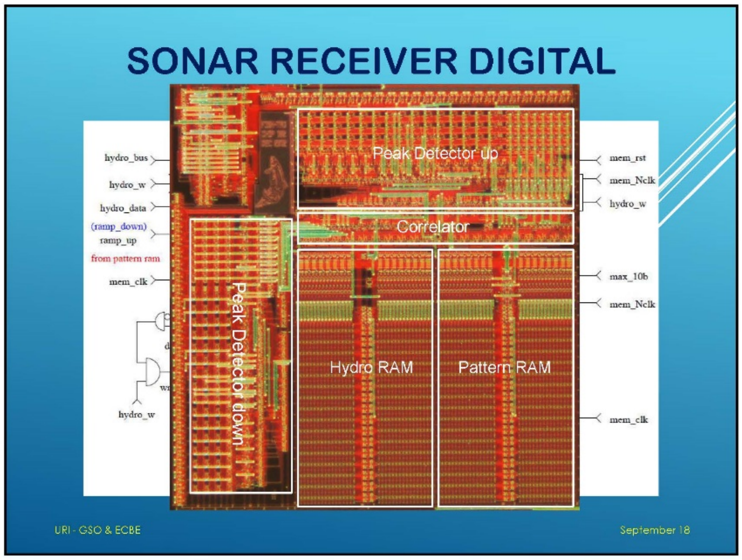
SONAR RECEIVER DIGITAL
Peak Detector up
Correlator
Peak Detector down
Hydro RAM
Pattern RAM
hydro_bus
hydro_w
hydro_data
(ramp_down)
ramp_up
from pattern ram
mem_clk
hydro_w
mem_rst
mem_Nclk
hydro_w
max_10b
mem_Nclk
mem_clk
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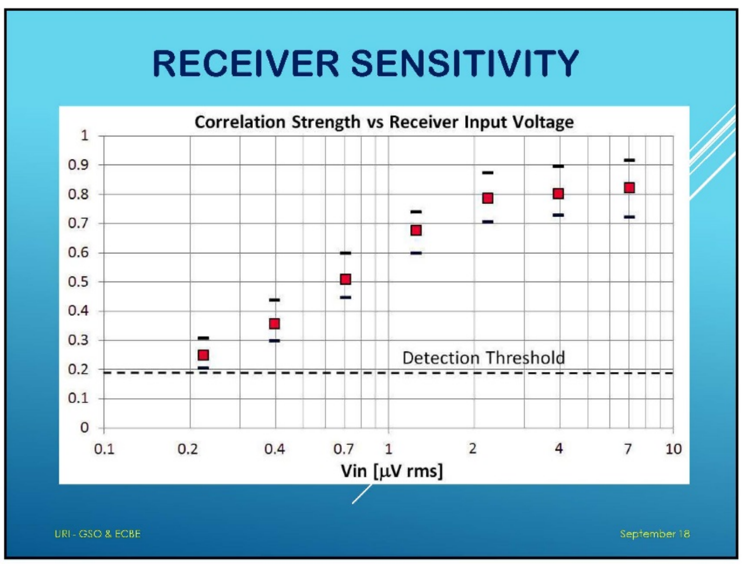
RECEIVER SENSITIVITY
Correlation Strength vs Receiver Input Voltage
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Detection Threshold
0.1
0.2
0.4
0.7
1
2
4
7
10
Vin [μV rms]
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ACOUSTIC SIGNATURE

Length:	1024 samples @ $f_{clk}/1024$
Duration:	T_d = $1{,}048{,}576/f_{clk}$
Mid-Band:	f_{mid} = $f_{clk}/125.07$
Bandwidth:	BW = $f_{clk}/10{,}922.7$
Shape:	Arbitrary

System Clk:	f_{clk} = 32,768 Hz
Clk In:	f_{in} = 8,192 Hz
Clk Out:	f_{out} = 32 Hz
Duration:	T_d = 32 sec
Mid-Band:	f_{mid} = 262 Hz
Bandwidth:	BW = 3 Hz
Shape:	Linear Sweep

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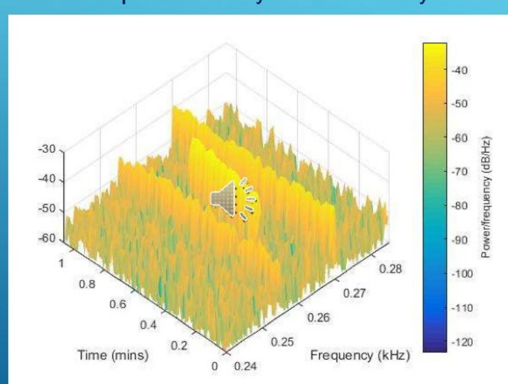
STRONG ACOUSTIC SIGNAL

Linear Sweep with nearby Tones → Easy Detection



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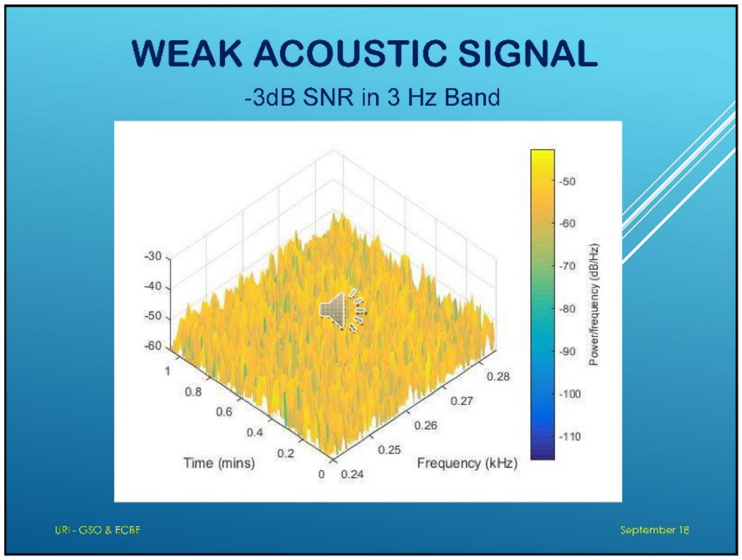
WEAK ACOUSTIC SIGNAL
-3dB SNR in 3 Hz Band
-30
-40
-50
-60
1
0.8
0.6
0.4
0.2
0
Time (mins)
0.24
0.25
0.26
0.27
0.28
Frequency (kHz)
-50
-60
-70
-80
-90
-100
-110
Power/frequency (dB/Hz)
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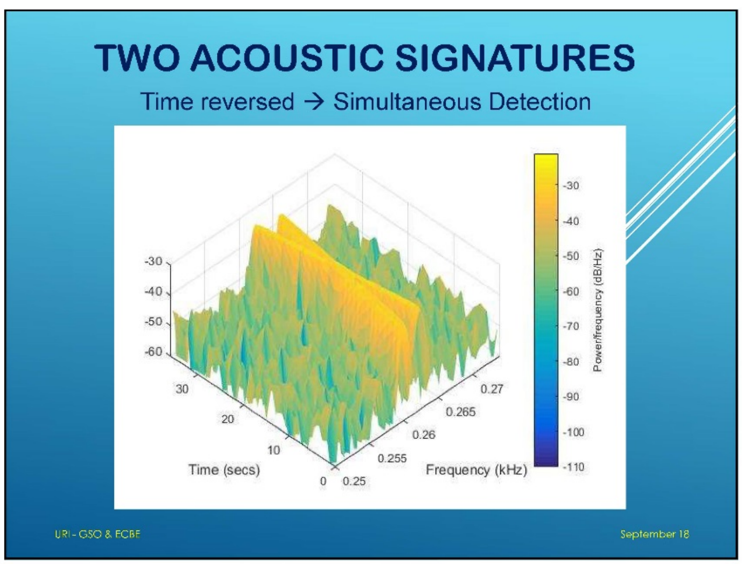
TWO ACOUSTIC SIGNATURES
Time reversed → Simultaneous Detection
-30
-40
-50
-60
30
20
10
0
Time (secs)
0.25
0.255
0.26
0.265
0.27
Frequency (kHz)
-30
-40
-50
-60
-70
-80
-90
-100
-110
Power/frequency (dB/Hz)
URI - GSO & ECBE
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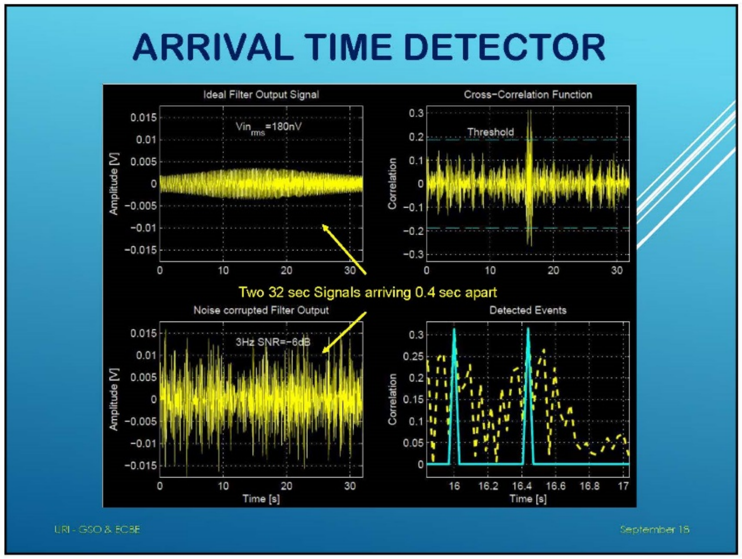
ARRIVAL TIME DETECTOR
Ideal Filter Output Signal
Vin_rms=180nV
Amplitude [V]
Cross-Correlation Function
Threshold
Correlation
Two 32 sec Signals arriving 0.4 sec apart
Noise corrupted Filter Output
3Hz SNR=-6dB
Detected Events
Time [s]
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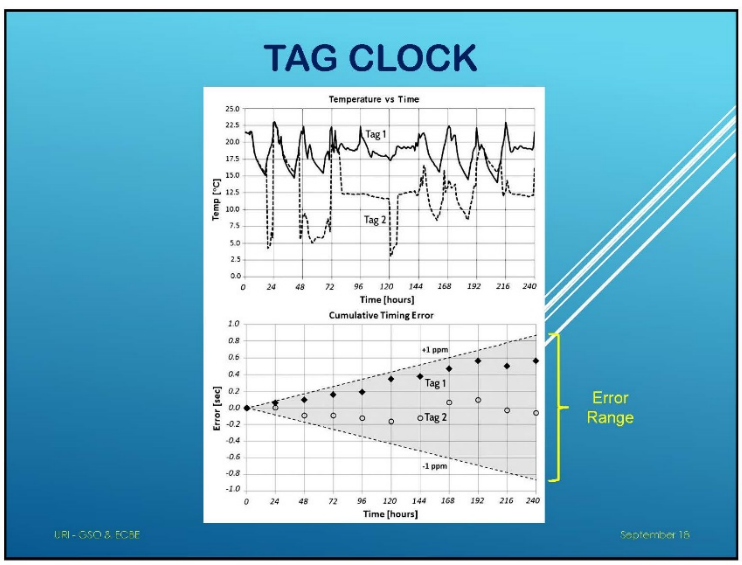
TAG CLOCK
Temperature vs Time
Temp [°C]
Tag 1
Tag 2
Time [hours]
Cumulative Timing Error
Error [sec]
+1 ppm
-1 ppm
Error
Range
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POSITIONING ERRORS

- **Transmitter-Receiver Clock Deviations** accumulates over time → significant, but can be removed retrospectively
- **Multiple Sound Paths**
- **Sound Speed Variations**
- **Doppler Frequency Shifts**
  For Saw Tooth Sweep:
  $\Delta d = v_r f_{mid}/BW\ T_{sw}$
  (can be avoided by employing Triangular Frequency Sweep)

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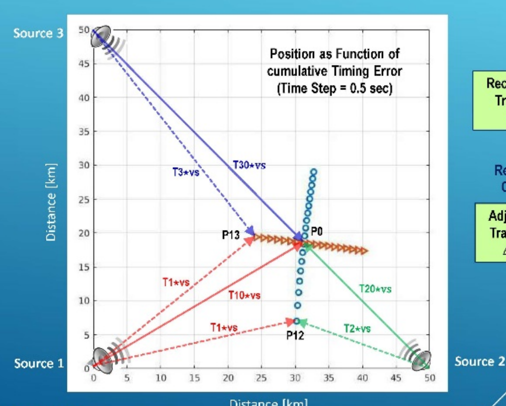
CLOCK ERROR CORRECTION

Requires Detection of 3 Source Signals



Recorded Signal Travel Times: T_1, T_2, T_3

Retrospective Correction:

Adjust recorded Travel Times by $\Delta T = T_{i0} - T_i$

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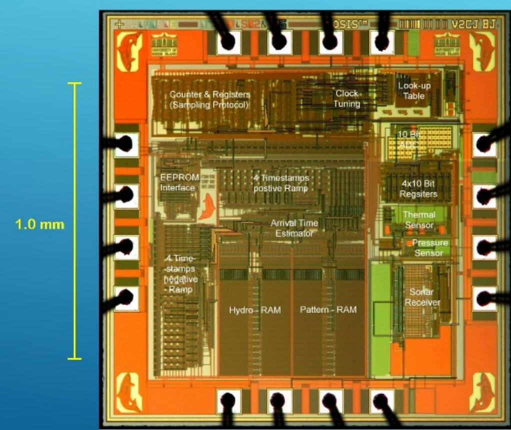
FISH CHIP MICROGRAPH



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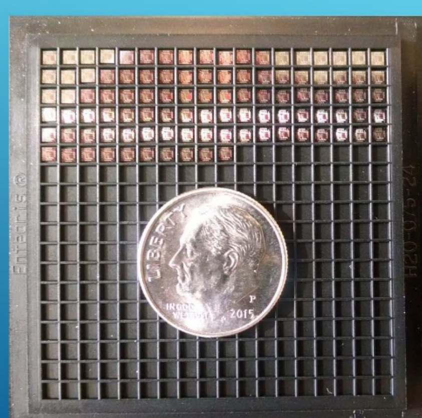
FISH CHIP DIES



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TAG COMPONENTS
Memory
Fish Chip
CN1
S1
Pressure Sensor
Batteries
Hydrophone
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TAG ASSEMBLY
Memory
Fish Chip
LIBERTY
2014
Hydrophone
Assembled Tag
Batteries
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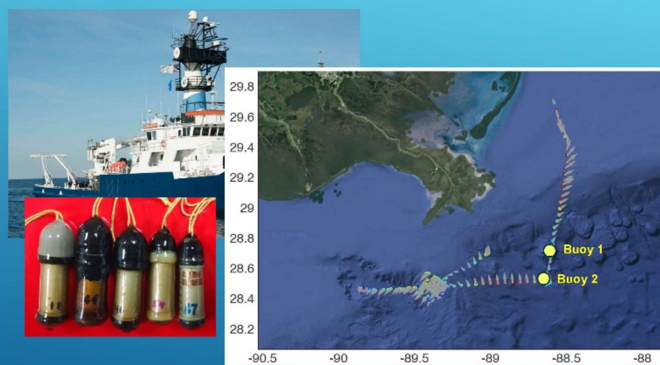
RV ENDEAVOR CRUISE 7/17



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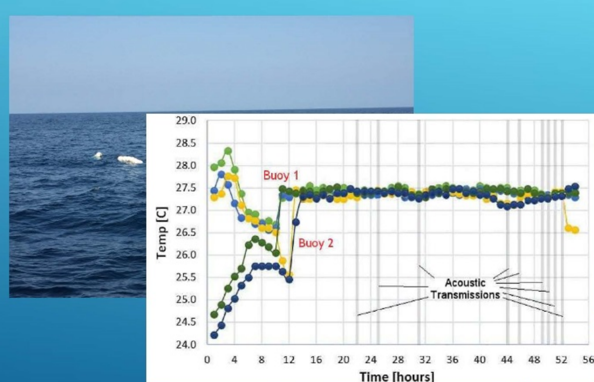
TEMPERATURE RECORD



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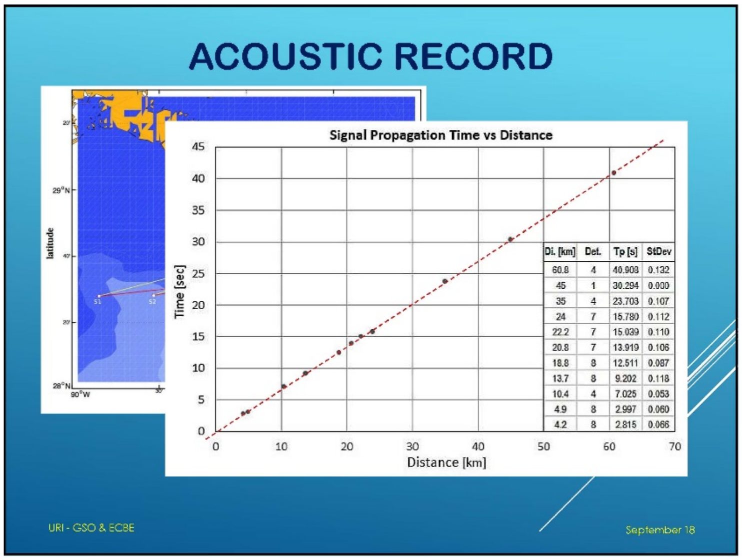
15



Di. [km]	Det.	Tp [s]	StDev
60.8	4	40.908	0.132
45	1	30.294	0.000
35	4	23.703	0.107
24	7	15.780	0.112
22.2	7	15.039	0.110
20.8	7	13.919	0.106
18.8	8	12.511	0.087
13.7	8	9.202	0.118
10.4	4	7.025	0.053
4.9	8	2.997	0.060
4.2	8	2.815	0.066

ADJUSTMENTS FOR ROAM TAG

Operating Depth up to 800 m

- More robust Housing to withstand 80 bar (1200 PSI) → use Ceramic Hydrophone → more Weight
- 1200 PSI Pressure Sensor Possible with MEMS Device, but will yield less resolution (2-3 PSI → 1.4-2.1 m Depth)

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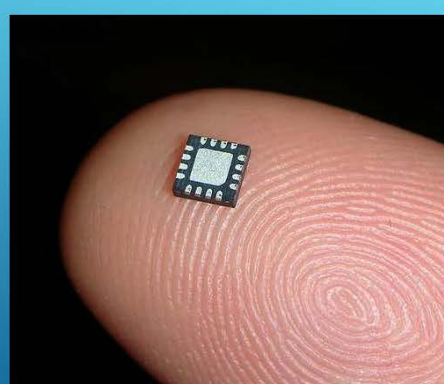
PACKAGED DIE



URI - GSO & ECBE

September18

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All manuscripts submitted for issuance as CRDs must have cleared the NEFSC's manuscript/abstract/ webpage review process. If any author is not a federal employee, he/she will be required to sign an "NEFSC Release-of-Copyright Form." If your manuscript includes material from another work which has been copyrighted, then you will need to work with the NEFSC's Editorial Office to arrange for permission to use that material by securing release signatures on the "NEFSC Use-of-Copyrighted-Work Permission Form."

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Manuscripts must have an abstract and table of contents, and (if applicable) lists of figures and tables. As much as possible, use traditional scientific manuscript organization for sections: "Introduction," "Study Area" and/or "Experimental Apparatus," "Methods," "Results," "Discussion," "Conclusions," "Acknowledgments," and "Literature/References Cited."

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The CRD series is obligated to conform with the style contained in the current edition of the United States Government Printing Office Style Manual. That style manual is silent on many aspects of scientific manuscripts. The CRD series relies more on the CSE Style Manual. Manuscripts should be prepared to conform with these style manuals.

The CRD series uses the American Fisheries Society's guides to names of fishes, mollusks, and decapod crustaceans, the Society for Marine Mammalogy's guide to names of marine mammals, the Biosciences Information Service's guide to serial title abbreviations, and the ISO's (International Standardization Organization) guide to statistical terms.

For in-text citation, use the name-date system. A special effort should be made to ensure that all necessary bibliographic information is included in the list of cited works. Personal communications must include date, full name, and full mailing address of the con- tact.

Preparation

Once your document has cleared the review process, the Editorial Office will contact you with publication needs – for example, revised text (if necessary) and separate digital figures and tables if they are embedded in the document. Materials may be submitted to the Editorial Office as email attachments or intranet down- loads. Text files should be in Microsoft Word, tables may be in Word or Excel, and graphics files may be in a variety of formats (JPG, GIF, Excel, PowerPoint, etc.).

Production and Distribution

The Editorial Office will perform a copyedit of the document and may request further revisions. The Editorial Office will develop the inside and outside front covers, the inside and outside back covers, and the title and bibliographic control pages of the document.

Once the CRD is ready, the Editorial Office will contact you to review it and submit corrections or changes before the document is posted online.

A number of organizations and individuals in the Northeast Region will be notified by e-mail of the availability of the document online.

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Northeast Fisheries Science Center
National Marine Fisheries Service, NOAA
166 Water St.
Woods Hole, MA 02543-1026

MEDIA MAIL

Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "conducting ecosystem-based research and assessments of living marine resources, with a focus on the Northeast Shelf, to promote the recovery and long-term sustainability of these resources and to generate social and economic opportunities and benefits from their use." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific journals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Currently, there are three such media:

NOAA Technical Memorandum NMFS-NE -- This series is issued irregularly. The series typically includes: data reports of long-term field or lab studies of important species or habitats; synthesis reports for important species or habitats; annual reports of overall assessment or monitoring programs; manuals describing program-wide surveying or experimental techniques; literature surveys of important species or habitat topics; proceedings and collected papers of scientific meetings; and indexed and/or annotated bibliographies. All issues receive internal scientific review and most issues receive technical and copy editing.

Northeast Fisheries Science Center Reference Document -- This series is issued irregularly. The series typically includes: data reports on field and lab studies; progress reports on experiments, monitoring, and assessments; background papers for, collected abstracts of, and/or summary reports of scientific meetings; and simple bibliographies. Issues receive internal scientific review and most issues receive copy editing.

Resource Survey Report (formerly *Fishermen's Report*) -- This information report is a regularly-issued, quick-turnaround report on the distribution and relative abundance of selected living marine resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. This report undergoes internal review, but receives no technical or copy editing.

TO OBTAIN A COPY of a *NOAA Technical Memorandum NMFS-NE* or a *Northeast Fisheries Science Center Reference Document*, either contact the NEFSC Editorial Office (166 Water St., Woods Hole, MA 02543-1026; 508-495-2350) or consult the NEFSC webpage on "Reports and Publications" (http://www.nefsc.noaa.gov/nefsc/publications/). To access *Resource Survey Report*, consult the Ecosystem Surveys Branch webpage (http://www.nefsc.noaa.gov/femad/ecosurvey/mainpage/).