The Ocean Tracking Network: A Global Partnership Uses Electronic Tagging Technologies to Track the Movements of Aquatic Animals, Answer Science Questions, Stimulate New Technology Development and Assist with Sustainable Development of the Ocean

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***Abstract*— The Ocean Tracking Network (OTN) is a global research and technology development platform headquartered at Dalhousie University, in Halifax, Nova Scotia. OTN uses electronic telemetry to document the local-to-global movements and survival of aquatic animals, and to link them to environmental correlates. OTN works with various tracking methods including satellite and data storage tag systems, but its dominant focus is acoustic telemetry. Results from OTN studies inform conservation, management and policy for aquatic biological resources. OTN is built on global partnerships for the sharing of equipment and data. The OTN has stimulated technological development in telemetry by bringing researchers with needs for new capabilities together with manufacturers to generate, test, and operationalize new technologies. This has included pioneering work into the use of marine autonomous vehicles (Slocum electric gliders, and a Liquid Robotics Wave Glider) in animal telemetry research. Similarly, OTN scientists worked with the Sea Mammal Research Unit to pioneer the placement of mobile acoustic receiver units on grey seals, linked via Bluetooth to a satellite transmitter/receiver. This provided receiver coverage in areas occupied by the seals during their typically extensive migrations, reported any detections the seal-borne receivers had in near-real time, and allowed for the examination of behavioral interactions among the seals as well as between seals and other tagged species. OTN and its researchers have also partnered with industry to use OTN's infrastructure to help provide answers to questions posed to industry by regulators prior to authorizing their proposed developments of the ocean. These studies have included documenting how animals are affected by underwater electrical transmission lines, or aquaculture infrastructure.**

***Keywords*—** *Ocean Tracking Network, OTN, acoustic telemetry, animal movements, autonomous vehicles, global partnership*

I. INTRODUCTION

Many aquatic species, including those that support the most important fisheries for human populations, move during their lives. Depending on the species, the movements can range in scale from local to inter-oceanic, and can place animals into a succession of different ecosystems [1]. For example, diadromous species move between freshwater and marine habitats and in the case of salmonids can undertake large scale migrations across multiple ecosystems with important impacts on those ecosystems and for the evolution of these species life histories [2, 3]. Aquatic animals move among habitats to acquire the resources they need for growth, shelter and reproduction. Where resource availability is predictable in time and space, predictable movements often occur. Movement's role in maintaining this connectivity between animals and their different resources/places is critical for the health and well-being of populations and ecosystems.

The ability of researchers to document and study aquatic animal movements has historically been restricted by our ability to monitor what happens in water. Much of the early work involved marking animals with external tags, and inferring movement timing and pathways by comparing release locations to the points where the tagged fish were recovered in fisheries. This approach suffered from a number of limitations, notably it generally provided a guess (extrapolation) of an animal's locations in the intervening period between release and recapture, and it was biased toward documenting movements between places where fisheries were prosecuted, which at best is a subset of the habitats that the animals use.

Human exploration and use of the oceans has historically been limited by the capacity of our technologies. These technologies have now advanced sufficiently that there is no point in the ocean that is unreachable (e.g., James Cameron recently built a "personal" submersible that permitted him to film the deepest point of the ocean (Challenger Deep) in the Marianas trench; http://www.deepseachallenge.com/). This has poised humanity for a massive industrial development of the ocean, frequently termed Blue Growth (a.k.a., the Blue Economy). However, the terrestrial industrial revolution 150 years ago was characterized by a big loss of terrestrial biodiversity and ecosystem services, and the associated socioeconomic benefits that humans drew from these biological resources [4]. If we are to properly manage the Blue Growth agenda by sustainably developing new ocean activities while maintaining the benefits that accrue from traditional ocean biological resources, it will be essential that we not put structures or activities into aquatic environments that create blockages across the migratory pathways that animals use to meet their needs. To manage this, we need a much better understanding of the timing and pathways of aquatic animal movements.

II. ELECTRONIC ANIMAL TRACKING AND TELEMETRY

Advances in technology (Fig. 1) have also ushered in a new era of animal tracking [1,5]. A variety of electronic tags have been developed that can document the positions of free-ranging animals, most without their having to be recaptured, and in some cases the tags also carry sensors that provide

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Fig. 1: Top (left to right), Maritime Biologgers accelerometer archival tag, an American eel fitted with a pop-up satellite tag, a grey seal bioprobe with a head mounted Argos satellite tag and a mobile acoustic receiver that transmits its data through the Argos tag via a Bluetooth connection. Middle (left to right): VEMCO acoustic tags, OTN researchers surgically implant an acoustic tag in the body cavity of a blue shark, deployment of a VR4 acoustic receiver unit equipped with an acoustic modem. Bottom, left-VEMCO VMT receiver mounted below the tail of a Slocum Glider; middle (upper),- Slocum glider; middle (lower)-surface float of the OTN Wave Glider; right-Wave Glider towfish containing the hydrophones to download VR4 receivers attached to the propulsion sled that converts wave energy to propulsion which in turn is tethered to the surface float

information about the environment (e.g., water temperature, conductivity) or an animal's behavior (pressure sensors for depth preferences; swimming speeds and energetics from accelerometer tags). However, no single tagging technology is fit-for-purpose for all animals and tasks. The new tagging technologies include:

A. *Archival tags*

Archival tags are data loggers equipped with a variety of sensors that are attached to an animal and store records from the sensors for as long as long as their batteries are operational and their internal memories have room. The tags typically record dates, time, temperature, depth, and position of the animal (geolocation) determined via light sensors. Some models have been miniaturized so that they can be placed on fish down to sizes of about 18 cm length. They are relatively inexpensive, making it feasible to tag large numbers of animals, however, their major disadvantage is that the tags must be recovered so that their data can be retrieved; hence their prime utility has been to follow species subjected to heavy fishery pressure [6, http://www.coml.org/comlfiles/scor/SCOR-tagging.pdf].

B. *Satellite tags*

Satellite tags are externally mounted on animals and use global satellite coverage and telemetry to retrieve information from the tags. The antenna of a satellite tag must be out of the water to make contact with a satellite. For animals that come regularly to the surface, such as seals (heads and backs out of water) or sharks (dorsal fins protruding into air), the tags are glued to the heads (seals and sea lions) or fixed onto the dorsal fins (sharks). These tags can provide real time or near-real time locations and data transmission [1, http://www.coml.org/comlfiles/scor/SCOR-tagging.pdf].
Certain satellite tags primarily give the position of an animal (e.g., Smart Positioning and Temperature, or SPOT tags). Others have an archival capability and store information from a suite of sensors similar to those on archival tags on board the tag until the animal comes to the surface and can transmit it. For animals that do not come to the surface regularly, a "pop-up" satellite tag is available. Typically these slightly buoyant tags are attached to a short tether anchored on the dorsal surface of the animal and trails behind it as it swims. The tag can sever the tether either at a predetermined time, or when the animal dies. The tag then floats to the surface and transmits a summary of the data that it contains through the Argos satellite network. Should the tag be recovered, a much more detailed data record can be retrieved. In addition to documenting the migration pathways of animals, the oceanographic sampling carried out by satellite tags is proving to be very valuable. Tagged marine mammals (a.k.a. "animal oceanographers") especially sea lions and seals penetrate into areas such as under ice that we currently have great difficulty sampling. The data being obtained from these animals are making large contributions to our understanding of global oceanography [7, 8], as well as permitting biologist to analyze the behavior of animals in relation to environmental variability [1]. The primary disadvantages to satellite tags are their large size which limits their use to big animals, and high cost that has restricted the number of animals that can be tagged.

C. *Acoustic tags*

Acoustic telemetry involves fitting an animal with an ultrasonic tag which regularly emits a signal encoding the animal's unique identification, and then recording the date and time a tagged animal passes by an acoustic receiver capable of detecting it. Acoustic signals transmit in both fresh and salt water, making acoustic telemetry a valuable tool to follow the transition of diadromous species between fresh water and the sea. Radio telemetry is another powerful tagging method to follow animals in fresh water, however, the salt in saline waters blocks radio signals. In sonic telemetry, movement pathways for individual animals are determined by tracing the passage of the animal from one receiver to the next. Acoustic tags are relatively inexpensive, and can be mounted either internally or externally on an animal. Tags come in different sizes, which is primarily related to their battery size which in turn determines tag life. The smallest tags currently weigh <0.3 g (in water) and have a life span of about 20 d. These are proving very useful for the study of juvenile Pacific salmonids during their early migration to sea. The larger tags weigh < 10 g (in water) and have life spans of 10 years or more. These permit investigators to document ontogenetic shifts in the behavior of long lived animals such as sharks and tunas. Acoustic tags can also be fitted with environmental sensors (depth, temperature, others are currently in development). The

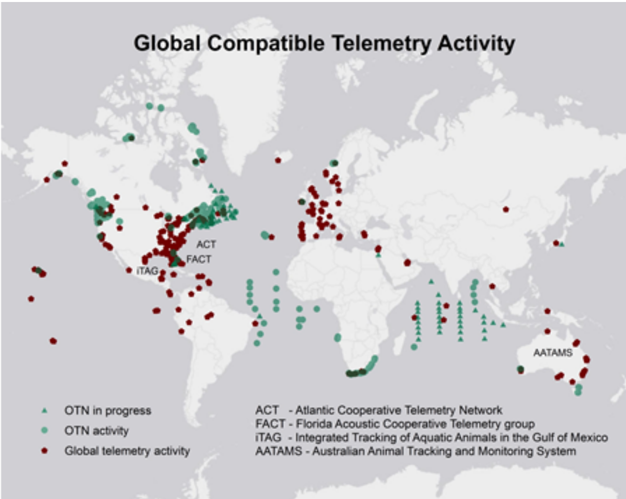

Fig. 2: Global existing receiver deployments (red), current OTN deployments (blue circles), and in-progress (blue triangles) OTN deployments of compatible acoustic telemetry equipment

prime disadvantage of acoustic telemetry is that tagged animals must pass within range of an acoustic receiver for an animal to be recorded. Detection distances for individual receivers will vary from site to site depending on tag power and environmental conditions (temperature, depth, wind entrained bubbles in the water column, other factors). Under good conditions the detection range of a receiver will be about 800-1000m. In a large ocean, there is a need for a large number of receivers to reliably detect tagged animals. Nevertheless, the popularity of acoustic telemetry has been growing in the science community [1], and researchers using compatible acoustic telemetry technology are now active in most parts of the globe. While the Ocean Tracking Network will deploy about 2000 receiver units in its first seven years of its operation, providing a significant boost to acoustic telemetry globally [9], there are an additional approximately 20,000 compatible receivers that are already active but generally not coordinated (Figure 2). The potential to unite the independent global activity into a new global network was the genesis for the Ocean Tracking Network.

III. THE OCEAN TRACKING NETWORK

The Ocean Tracking Network (OTN) is a research and technology development platform headquartered at Dalhousie University, in Halifax, Nova Scotia, but built on global partnerships. While the OTN tracks the movements and survival of 80 species with a variety of electronic tagging systems, a key focus of its activity is the use of acoustic telemetry. The OTN recognized that through a combination of equipment and data-sharing partnerships among existing users of compatible acoustic telemetry equipment, and the addition of new, strategically deployed equipment (Figure 2), a global telemetry network could be created. By coordinating studies and sharing data, telemetry researchers are capable of documenting the local-to-inter-ocean movements and survival of tagged aquatic and exploring how both are influenced by oceanographic conditions. Currently there are > 400 scientists from 19 countries working within the OTN. Their studies typically address pressing science questions related to animal movements and survival that have implications for policy and management.

The creation of a global network is being aided by the fact that in some ocean regions, the telemetry community was already organizing itself into networks. This has included a continental scale network in Australia (Australian Animal Telemetry and Monitoring System-AATAMS), and localized networks in North America (Atlantic Cooperative Telemetry Network-ACT; Florida Atlantic Coast Telemetry array-FACT; and the Integrated Tracking of Aquatic Animals in the Gulf of Mexico-iTAG; Figure 2). A network has also been established in the Laurentian Great Lakes of North America (Great Lakes Acoustic Telemetry Observation System- GLATOS).

IV. OTN DATA MANAGEMENT

To create an efficient and functional global animal tracking network, a first-class data system is required. Half of the personnel of the OTN are devoted to data management. Data from OTN receivers flow into the OTN data warehouse, where it is quality controlled and made available to investigators as per OTN data policies. OTN intends for all of its data to become public. However, our policies provide lag periods in making data public in order to protect researchers while they publish their work, to protect endangered species, and for other reasons. The OTN data system has now been named the first Canadian Associate Data Unit of the International Oceanographic Data and Information Exchange (and one of only 11 globally), showing that it meets global standards for data curation and management. Templates for the OTN data system are being made available to members of the international science community who wish to establish regional nodes for their data. The OTN data team provides assistance to these groups as they implement their new data node, and the adoption of the templates facilitates compatibility with the OTN data system. Where regional networks have already developed their own data systems and are interested in fostering broader compatibility, the OTN data team has worked to cross map its system with these other databases. OTN also has an international data community that is working with OTN data to provide analysis, visualization and modeling tools.

V. OTN AND TECHNOLOGICAL INNOVATION

While the benefits that could accrue from having a global acoustic telemetry animal movement monitoring network are substantial, the costs associated with creating a supporting infrastructure are an issue. Tagging the animals is relatively inexpensive and can frequently be piggybacked at low cost on existing commercial or sportfishing activities. Receivers are long-lived, making their capital costs reasonable. However, operations and maintenance costs for the servicing of moorings and receivers (some models require new batteries on a yearly basis), and to retrieve data, can require expensive ship time. To manage these costs, OTN where possible co-deploys its receivers on existing mooring systems established for other purposes and whose maintenance costs are already funded. For example, the OTN has receivers on the PIRATA (Prediction and Research Moored Array in the Atlantic) buoy array in the tropical South Atlantic Ocean, and is presently deploying receivers on the RAMA (Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction) buoy network in the Indian Ocean. Where stand-alone acoustic receiver lines need to be deployed, OTN has been working with equipment manufacturers to find technological solutions to reduce operations and maintenance costs.

Some models of acoustic receivers have to be brought to the surface to retrieve their data, a time-consuming and expensive procedure. Models exist that can be cabled into buoys with sufficient electrical power to permit them to transmit data in real time via satellite or cellular phone networks, but these are also expensive and are mostly used for special purposes such as providing warnings of tagged sharks off of beaches (www.sharksmart.com.au). Working with VEMCO, the major supplier of acoustic telemetry equipment, a new model of receiver (the VR4) was developed for the OTN that incorporated an acoustic modem, a long-lived battery, and the software to transmit detection records to a surface vessel equipped with a hydrophone. The VR4 receiver can be left in position for up to six years, and interrogated as frequently as data is needed. This reduces ship time substantially. A further reduction in ship-time costs was achieved by the purchase of an autonomous vehicle, a Liquid Robotics Wave Glider, and a towed array hydrophone. The Wave Glider generates its electrical power from solar panels and harnesses wave energy for its propulsion, hence its deployment times can be long. The Wave Glider can be piloted remotely via satellite from almost anywhere by a trained pilot equipped with a laptop and a reliable internet connection. VEMCO and Liquid Robotics worked together to integrate the VEMCO technology into the Wave Glider. This advance in some instances has reduced OTN costs of tending receivers by a factor of 80.

Autonomous vehicles also offer an attractive platform on which to deploy receivers into areas where it is not feasible to moor equipment (for example, areas of heavy fishing pressure) and to expand acoustic receiver coverage in the ocean in general. Wave Gliders, and Slocum Electric Gliders have both been fitted with acoustic receiver units. In most instances, investigators have used a VEMCO VMT receiver which is smaller than other models and self-contained with its own batteries and data storage capabilities. Data is retrieved when the autonomous vehicle is retrieved and detections are matched to the estimated positions of the glider at the time the tagged animal was in range. Various mounting strategies have been developed to attach the receiver to the glider (Fig 1). By contrast, the OTN Wave Glider has integrated the receiver into its tow body, and can report detections in real time, and the University of Delaware has worked with VEMCO to fully integrate a hydrophone into a Slocum Glider [10].

OTN scientists worked with the Sea Mammal Research Unit to pioneer the placement of mobile acoustic receiver units on grey seals, linked via Bluetooth to a satellite transmitter/receiver. This advance provided receiver coverage in areas occupied by the seals during their typically extensive migrations, reported any detections the seal-borne receivers had in near-real time, and allowed for the examination of behavioral interactions among the seals as well as between seals and other tagged species.

The OTN has stimulated technological development in telemetry by bringing researchers with needs for new capabilities together with manufacturers to generate, test, and operationalize new technologies. A company (Maritime Biologgers) with a new accelerometer archival tag (Fig. 1) to measure three dimensional movements of aquatic animals has spun out of OTN and is now selling their equipment internationally. OTN has also supported its researchers to work with industry (Lotek Wireless) to develop a new version of a geo-locating tag that has now been miniaturized to the point that fish as small as Atlantic salmon smolts can carry them.

The OTN is a system and project of the UN's Intergovernmental Ocean Commission's (IOC) Global Ocean Observing System

VI. CONCLUSION

Animal telemetry is making an important contribution to the conservation and management of valued aquatic species, to oceanographic sampling, and in the formulation of ocean policy. Rapid technological advances, deployment of telemetry equipment on existing mooring systems and global partnerships are cost-effectively promoting the use of electronic tagging, and a global scientific network built on the technology and science needs telemetry can address is becoming established.

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