Networked Animal Telemetry in the Northwest Atlantic and Caribbean Waters

Charles W. Bangley* 
*Corresponding author: bangleyc@si.edu

Frederick G. Whoriskey

Joy M. Young

Matthew B. Ogburn

Abstract

Acoustic telemetry, in which transmitters projecting ultrasonic signals carrying unique identification codes are deployed on marine and aquatic animals and detected and logged by acoustic receivers, is becoming a common tool in fisheries science. Collaboration among researchers using this technology has led to the development of telemetry networks that are capable of detecting transmitters at coastwide and even continental scales through the combined coverage of all members’ receivers. Two grassroots telemetry networks in the northwest Atlantic and Caribbean, the Atlantic Cooperative Telemetry (ACT) Network and the FACT Network, began as small-scale efforts among neighboring researchers and have expanded to include shared databases of tagged animals along entire coastlines. A third telemetry network, the Ocean Tracking Network (OTN), has brought additional capacity to the ACT and FACT networks and has provided a focus for telemetry activities in Canadian waters. It has also improved the power and efficiency of telemetry research globally through collaborative, standardized methods for storing, sharing, and processing data. When used in combination with other data collected by traditional fishery research methods and emerging technologies, such as remote sensing and autonomous vehicles, data collected through acoustic telemetry networks can address fundamental but previously unanswered questions about key habitat areas and data-poor species and can yield new insights into the ecology of species that are thought to be well known. Here, we provide an overview of acoustic telemetry networks, including a history of the ACT Network, FACT Network, and OTN and a review of recent and current research that has been made possible through the connections enabled by these networks.

*Corresponding author: bangleyc@si.edu
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Acoustic telemetry, involving an acoustic transmitter that is attached to or implanted in an animal and produces signals that are then recorded by separately deployed receivers, is becoming a ubiquitous tool in fisheries management. This method of tracking aquatic animals has been used in a wide variety of marine and freshwater environments (Cooke et al. 2013; Hussey et al. 2015). Early use of acoustic telemetry was limited to individuals or small networks of people with small numbers of receivers maintained in a specific area (e.g., Heupel and Heuter 2001). More recently, collaborative networks involving participation across multiple institutions have given researchers the ability to gather transmitter detection data at coastal and even continental spatial scales (e.g., Donaldson et al. 2014; Abecasis et al. 2018). These advances are leading to the development of standardized analytical methods for telemetry data (Udyawer et al. 2018) and have greatly increased the ability of researchers using acoustic telemetry to answer “big questions” in aquatic animal migration and habitat use (Brodie et al. 2018; Boucek and Morley 2019). The use of large-scale acoustic telemetry networks has the potential to solve long-standing issues in fisheries management (Crossin et al. 2017; Ogburn et al. 2017), particularly for species with wide distributions covering multiple jurisdictions and species for which data on habitat use and migration pathways are currently lacking.

As an introduction to telemetry studies, we review the development and organization of large-scale acoustic telemetry networks, demonstrate the ability of these networks to both gather broad ecological data and answer individual management questions, and show the power of combining large-scale telemetry data with other environmental and fisheries data sets. Although our review focuses on North American and Caribbean waters in the northwestern Atlantic Ocean, similar methods have been successfully employed elsewhere (e.g., Brodie et al. 2018).

RECEIVER NETWORKS

Regional Networks

The northwest Atlantic and Caribbean are representative of basin-scale regions with many researchers using acoustic telemetry technology. Several cooperative telemetry networks have emerged in the region in the last two decades to facilitate data sharing and management, including the Atlantic Cooperative Telemetry (ACT) Network, the FACT Network, the Great Lakes Acoustic Telemetry Observation System, Integrated Tracking of Aquatic Animals in the Gulf of Mexico, the U.S. Caribbean Acoustic Network, and the Ocean Tracking Network (OTN; Table 1). The Animal Telemetry Network was also established to bring together U.S. data on aquatic animal behavior and movement on a national level (Block et al. 2016). Each network has had its own successes, but member investigators have increasingly recognized the need for enhanced interactions and maturation of networks to facilitate efficient, cost-effective telemetry research. Brief histories of the networks operating along the U.S. Atlantic coast, including the ACT Network, FACT Network, and OTN, are provided below. Network histories are followed by a description of efforts to increase cross-network collaboration.

The ACT Network was initiated in 2006 as a grassroots effort among researchers (largely focused on Atlantic Sturgeon Acipenser oxyrinchus oxyrinchus) to facilitate data sharing and collaboration along the U.S. Atlantic coast. By 2020, it had grown to a network of 176 researchers studying 97 species with active transmitters, and a total of over 120 researchers from Canada to the Caribbean studied 85 species over the course of the first decade (ACT Network 2020). The growth and continued operation of the ACT Network and the cohesiveness of ACT members were enabled by significant investments of time and effort by researchers at Delaware State University. In recent years, the Mid-Atlantic Acoustic Telemetry Observation System (MATOS) was developed for the ACT Network as a regional acoustic telemetry database (now the ACT_MATOS database) supported by the Mid-Atlantic Regional Association Coastal Ocean Observing System and the Animal Telemetry Network. The ACT_MATOS database is designed as a database tool for streamlining data sharing and providing data management, quality control, and archiving services through a Web-based data portal and cloud-based data-sharing platform following the OTN database structure. In April 2020, administration of the ACT Network transitioned to the Smithsonian Environmental Research Center and a steering group of regional partners.

The FACT Network is a grassroots collaboration among scientists using acoustic telemetry to study the movements, ecology, and life history of aquatic animals (Young et al. 2020, this themed issue). The FACT Network was founded in 2007 by seven partner groups on the east coast of Florida in an effort to increase spatial coverage of individual studies by sharing tag and detection data and to provide a platform for communication among members. Without dedicated funding, support from partner groups—specifically the Florida Fish and Wildlife Conservation Commission—was vital for the early successes of the FACT Network. Since its inception, the FACT Network has grown to include over 283 members with telemetry assets throughout the southeastern United States, the Bahamas, and the Caribbean. To ease the burden of sharing data amongst the growing network of scientists as well as to provide quality control measures on data and archival services, the FACT Network adopted a
cloud-based data-sharing platform in 2018 that was created by the OTN and supported by the Animal Telemetry Network and the Southeast Coastal Ocean Observing Regional Association. By aggregating telemetry data while maintaining privacy (i.e., data are password protected and are only accessible by project principal investigators), concerns over data sharing among scientists have been reduced. The reduction of these concerns has encouraged participation in the network. As important as data services is the FACT Network’s sense of community, which promotes collaborative partnerships between or among members, improves communication, increases the exchange of ideas, and supports scientists and students who are new to acoustic telemetry technology (Young et al. 2020).

The OTN began its operations in 2008 and has been dedicated to using electronic telemetry—and, in particular, acoustic telemetry—to document the movements and survival of aquatic animals and linking these to environmental variables (Cooke et al. 2011; Iverson et al. 2019). Its infrastructure was funded (Can$35 million) as an International Joint Ventures Fund project by the Canada Foundation for Innovation, while Canada’s Natural Sciences and Engineering Research Council provided $10 million to support Canadian researchers working with the infrastructure. The Social Sciences and Humanities Research Council of Canada also supported a modest social science component. The OTN was intended from the start to be a global enabler, and much of its early funding was dedicated to establishing infrastructure in places other than Canada. The OTN has provided equipment for acoustic telemetry installations in North America, South America, Australia, Europe, Africa, and the Middle East. More than half of OTN’s staff is dedicated to developing a data system that will support international exchange of telemetry information. This system has been accredited as an Associate Data Unit of the Intergovernmental Oceanographic Commission’s International Oceanographic Data and Information Exchange. It is also a Tier II node for the Ocean Biogeographic Information Service. Ocean Tracking Network data scientists are working to link the global telemetry community together through timely and efficient data-sharing mechanisms. In some cases, OTN has provided data system templates so that regional organizations can create their own nodes that are fully interchangeable with other OTN collaborators. For cases in which organizations have already built data systems, OTN works to cross-map them to enable information exchange. For researchers that are not affiliated with a regional network, the OTN data system will securely store and curate their data. In 2017, the Canada Foundation for Innovation renewed OTN as a National Research Facility (Major Sciences Initiative), which is now enabling long-term planning.

### Scaling Up with Networks of Networks

As regional networks grew, spatial coverage and membership began to overlap. This created greater opportunities for data sharing and collaboration but also increased the challenges involved in organizing and maintaining shared data and resources. In the northwest Atlantic, the FACT and ACT_MATOS database efforts have benefited from collaborations with OTN to develop standardized data-sharing and management tools that enable data sharing between their respective databases. Previously, researchers based in the ACT Network relied on membership in both the ACT Network and either the FACT Network or OTN to ensure that they obtained tag detection data from southeastern U.S. waters (FACT Network) or

| Network                                         | Year established | Region                        | Reference                  |
|-------------------------------------------------|------------------|-------------------------------|----------------------------|
| Atlantic Cooperative Telemetry (ACT) Network*   | 2006             | U.S. mid-Atlantic and North Atlantic | ACT Network 2020           |
| FACT Network*                                   | 2007             | U.S. South Atlantic and Caribbean | Young et al. 2020          |
| Ocean Tracking Network (OTN)*                   | 2008             | Global                        | O’Dor and Stokesbury 2009  |
| Animal Tracking Network (ATN)*                  | 2011             | National                      | Block et al. 2016          |
| U.S. Caribbean Acoustic Network (USCAN)*        | 2011             | U.S. Caribbean                | Pittman et al. 2014        |
| Great Lakes Acoustic Telemetry Observation System (GLATOS) | 2012 | Laurentian Great Lakes        | Krueger et al. 2018        |
| Integrated Tracking of Animals in the Gulf of Mexico (iTAG) | 2014 | U.S. portion of the Gulf of Mexico | Currier et al. 2015        |
Canadian waters (OTN). With both the ACT_MATOS and FACT database nodes linked to the OTN database as of early 2020, detection data are now searchable across the ACT Network, FACT Network, and OTN, removing the need for researchers to carry multiple memberships. In this way, the receiver coverage of the ACT Network, FACT Network, and OTN is now combined, allowing participating researchers to access tag detections across an area spanning from Atlantic Canada to the Caribbean from their local network database (Figure 1). Such coastal- and continental-scale coverage allows for large-scale collaborative projects that would not be possible through a single institution or regional network. The ability of Australian researchers to coordinate acoustic telemetry data through the Integrated Marine Observing System to compare movement behavior among 92 marine taxa (Brodie et al. 2018) is an example of what can be accomplished through continental-scale networks. With OTN coordinating regional networks based on six continents, the potential for global-scale telemetry analysis is developing.

**FISHERIES APPLICATIONS OF ACOUSTIC TELEMETRY**

**Identifying and Monitoring Important Habitats**

Identification and protection of essential fish habitat, defined as those habitats required to complete a species’ life cycle (Langton et al. 1996), are key components of sustainable fishery management. This is true even of highly migratory and wide-ranging species, which often have defined essential habitat areas that may be of particular importance in maintaining their populations (Chapman et al. 2015). Degradation of these habitats through development or pollution and interactions with human activities, such as fisheries or shipping, can have a disproportionate impact on aquatic species populations when they occur within essential habitat areas (Sadovy and Domeier 2005). Protection of these areas is the rationale behind spatial fishery management and conservation measures, such as seasonal time-area closures, gear-restricted areas, and the establishment of marine protected areas (MPAs). Movement and habitat use behaviors vary among individuals in many marine species, but receiver networks enable sufficient data collection to account for individual variability (e.g., Ogburn et al. 2018). Perhaps the most direct practical applications of large-scale telemetry networks are to support planning, siting, and assessment of proposed or implemented spatial management measures.

Coastal-scale networks of receivers provide the opportunity for acoustic telemetry to collect data at spatial scales previously only attainable through satellite-based telemetry, with the advantage that acoustic telemetry can be used with species that are smaller in size and/or do not surface often. Receiver networks can potentially cover the entire migratory range of a tracked species, which can reveal the full extent of the species’ distribution, the timing with which the species occurs at various geographic locations, whether or not the species crosses national borders, and differences in the amount of time spent at some locations in comparison to the rest of the species’ range. This approach is useful in identifying habitat areas that may be worth further assessment as essential habitat. For example, Ogburn et al. (2018) tracked Cownose Rays *Rhinoptera bonasus* migrating from summer habitats in the Chesapeake Bay and Savannah River to a shared overwintering habitat off Cape Canaveral, Florida, and they noted that the bay and river were the only locations along the migratory route within which tagged rays would slow their movements and spend extended periods of time. Although
summer habitats have long been identified as or suspected to be nursery habitats for Cownose Rays (e.g., Smith and Merriner 1987), the aggregation site revealed off Cape Canaveral may also be worthy of further assessment as essential habitat (Ogburn et al. 2018). Coastal-scale tracking using receiver networks also allowed Bangley et al. (2020, this themed issue) to identify potential associations between juvenile Dusky Sharks *Carcharhinus obscurus* and areas where oceanographic features created seasonal temperature stratification. By utilizing receiver networks covering areas both within and outside of estuaries, Myers et al. (2020, this themed issue) and Krause et al. (2020, this themed issue) were able to identify areas of transition between estuarine and oceanic habitats for Striped Mullet *Mugil cephalus* and Weakfish *Cynoscion regalis*, respectively.

Telemetry networks are also useful in habitat studies that are area based rather than species based, assessing the use of specific areas that are either confirmed or potential essential habitat or areas of particular interest for multiple species due to potential interactions with human activities. Such areas are often in distinct habitats, such as the entrances to estuaries, coral reefs, and anthropogenic structures, and can be known or suspected aggregation sites for many species. For example, lower Delaware Bay and surrounding coastal areas are important migratory routes between oceanic and estuarine nursery habitats for Sand Tigers *Carcharias taurus* and Atlantic Sturgeon, and aggregations of these animals may make them more vulnerable to fishery interactions and vessel strikes (Breece et al. 2016; Haulsee et al. 2018). Breece et al. (2016) and Haulsee et al. (2018) used acoustic telemetry to identify patterns of seasonal presence for both sharks and sturgeon in this area and to assess the potential for overlap with these possible sources of mortality. Many grouper species aggregate in reef habitats, particularly spawning locations, and can be extremely vulnerable to overfishing if these areas are heavily targeted (Robinson et al. 2015). Keller et al. (2020, this themed issue) employed acoustic telemetry to assess the use of a potential aggregation site for multiple grouper species in the Florida Keys. Such sites are frequently considered as locations for MPAs, but the effectiveness of MPAs in protecting species may depend on the extent of movement outside of their boundaries (Pittman et al. 2014). Telemetry networks can be effective in determining how much time a species spends within and outside of MPA boundaries, as demonstrated by Novak et al. (2020, this themed issue) in their study of Yellowtail Snapper *Ocyurus chrysurus* movements in an MPA in the U.S. Virgin Islands. Acoustic receivers deployed along important migratory corridors can also be used to identify the timing and extent of coastal and anadromous migrations off Cape Hatteras, North Carolina (Rulifson et al. 2020, this themed issue), and in the Charles River, Massachusetts (Gahagan and Bailey 2020, this themed issue).

One of the greatest strengths of telemetry networks is their ability to reveal connections among habitats and regions. An extensive acoustic array covering most of the coastal waters of South Carolina and Georgia was initially deployed to monitor Atlantic Sturgeon movements but also detected 37 other highly migratory species, including sharks, marine reptiles, and a variety of finfish species that were originally tagged in locations from Canada to the Gulf of Mexico (Arendt et al. 2017). A long-term acoustic telemetry study that focused on Gray’s Reef National Marine Sanctuary detected 11 elasmobranch species, 6 teleost species, and 1 sea turtle species originating from areas both north and south of the array (Williams et al. 2019). The acoustic array deployed off Cape Hatteras, North Carolina, by Rulifson et al. (2020) was situated in an important migratory corridor between temperate and boreal waters to the north and subtropical waters to the south, and the array detected Atlantic Sturgeon that were originally tagged in locations ranging from Connecticut to Georgia. Dusky Sharks tagged by Bangley et al. (2020) were detected from the New York Bight to Cape Lookout, North Carolina. Networked telemetry can also reveal connections among freshwater, estuarine, and oceanic environments for anadromous (Gahagan and Bailey 2020) and estuarine-spawning species (Krause et al. 2020; Myers et al. 2020). Networks covering areas within and outside of MPA boundaries can provide information on connectivity between animals protected by the MPA for at least part of their life cycle or annual migration and other, possibly unprotected habitats (Novak et al. 2020). Many of these connections will be surprises, but they can reveal crucial information about the life cycle, movement ecology, and habitat needs of aquatic species, and such connections might have remained completely unknown without the use of telemetry networks.

**New Information on Data-Poor Species**

Many marine and aquatic species, particularly highly migratory and anadromous species, are still considered too data deficient to permit accurate assessment of their conservation or management status (Arthington et al. 2016). Even some species for which life history, essential habitat, and other aspects of successful management are well understood could benefit from updated or new data given the rapid pace at which global ocean environments are changing. The ability of telemetry networks to fill in knowledge gaps in habitat use and movement patterns is well known (and covered in the section above), but this approach can also provide data on other management-relevant topics, such as life history, mortality, and stock structure.
Stock structure is often defined spatially based on site fidelity to essential habitats and the degree of overlap between migration routes (Cadrin and Secor 2009). Telemetry methods have long been used to establish site fidelity to certain areas and to define the full migratory extent of stocks. Often, factors affecting population dynamics, such as fishing pressure and predation mortality, differ between spatially discrete stocks, and telemetry is a great tool with which to conduct place-based studies on these factors focused in particular core areas. For example, Krause et al. (2020) assessed the relative importance of predation and fishery mortality on the Weakfish stock that reproduces in Bogue Sound, North Carolina, an area where the numbers of adult-sized Weakfish have been in serious decline.

Some species are so familiar to anglers and fishery managers that they are the focus of extensive management effort, but basic knowledge on aspects of their migratory behavior and movements can still be lacking. This can be especially true for species (e.g., Striped Mullet) that move between estuarine and oceanic environments and where one side of this transition may be better covered by fishery management effort and infrastructure than the other. Myers et al. (2020) were able to use network analysis of Striped Mullet tag detections to describe the timing and conditions related to passage in and out of the Indian River Lagoon, Florida. Gahagan and Bailey (2020) similarly used telemetry approaches to identify movement patterns of anadromous American Shad Alosa sapidissima within the Charles River, Massachusetts, a highly urbanized nursery habitat with improving water quality. However, new data may sometimes provide more questions than answers for data-poor species, as was noted by Bangley et al. (2020), who found that tagged juvenile Dusky Sharks did not migrate as far south as their range and historical data would suggest.

COMBINING TELEMETRY WITH OTHER DATA AND TECHNOLOGIES

Telemetry by itself can reveal much about movement and distribution, but combinations of telemetry data with other data sources and technologies can be extremely powerful for answering pressing but unaddressed fisheries questions. A recent example matched satellite telemetry positions from large migratory sharks with Automatic Identification System positions from fishing vessels and showed that nearly a quarter of the space used by these species overlapped with pelagic longline fishing activity (Queiroz et al. 2019). Such combinations can involve historical data, traditional fishery-dependent or fishery-independent survey data, remote sensing technology, and emerging technologies, such as autonomous underwater vehicles (AUVs; Côté et al. 2019).

Telemetry data used in synergy with existing or concurrently collected fisheries management data can fill gaps in knowledge that have perplexed fishery managers. For example, Braun et al. (2019) combined telemetry data with oceanographic and fisheries catch data to fill in management-relevant knowledge gaps for Swordfish Xiphias gladius in the Atlantic Ocean. Krause et al. (2020) used a similar approach, bringing together a variety of methods, including acoustic telemetry, traditional mark-recapture, landings, and feeding habits data, to identify the sources of mortality in Weakfish. Combining all of these methods allowed Krause et al. (2020) to determine that natural mortality likely had a stronger influence than fishing mortality on North Carolina Weakfish stocks and also allowed for possible identification of their major predators.

As telemetry networks increasingly enable data collection at large spatial scales, the availability of large-scale remote sensing data from satellites enables those telemetry positions to be matched with physical environmental data. This in turn allows telemetry data to be used in habitat modeling at a variety of spatial scales (Braccini and Taylor 2016; Breece et al. 2016; Calich et al. 2018; Haulsee et al. 2018). Bangley et al. (2020) used this approach to identify seasonal distributions and areas of potentially important habitat for Dusky Sharks in the northwest Atlantic Ocean. For that study, acoustic tag detections were overlaid with publicly available satellite-based environmental data (Bangley et al. 2020), which demonstrated both the utility of combining telemetry and remote sensing data and the importance of allowing open access to public environmental data.

In addition to remote sensing, telemetry technology is increasingly integrated with AUVs, which show great promise as mobile receiver platforms and other forms of support for acoustic telemetry efforts. The use of AUVs to actively track tagged animals stands to dramatically increase the duration of the tracking period by avoiding the need to keep human researchers continuously on the water for days at a time, and field trials have shown that AUVs can track tagged animal locations more accurately than humans (White et al. 2016; Lowe et al. 2019). Autonomous underwater vehicles can also aid in passive acoustic telemetry by detecting tagged animals along transects within areas of interest (Oliver et al. 2013). In addition to tracking tagged animals, AUVs can record concurrent environmental data, which can be used to define habitat preferences (Haulsee et al. 2015; Lowe et al. 2019). Autonomous vehicles do not need to directly track or detect tagged animals in order to be useful in telemetry studies: in areas where acoustic receivers are deployed beyond the capability of vessel- or diver-based retrieval, AUVs are used to remotely download detection data (Davis et al. 2018).
CONCLUSIONS

The future of telemetry research in fisheries science will likely involve expanding spatial coverage and further integration with other technologies, among other developments (e.g., new data types and analyses, new tag technologies, and new applications). The ability to combine telemetry detections, environmental data, and oceanographic models simultaneously at large scales will enable researchers to answer questions about the basic environmental and behavioral drivers of migration and habitat use. These methods could allow for precise spatial and temporal delineation of essential habitats as well as areas of particularly high natural and fishery mortality. Telemetry networks will undoubtedly play a key role in the siting of future spatial management and conservation measures and in predicting the consequences of climate change on species distributions. Strengthening cross-network collaboration, increasing the interoperability of data management systems, and integrating diverse data streams will be critical for the field of animal telemetry to realize its potential to resolve the challenges inherent in monitoring species that are usually out of sight under water.

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ORCID

Charles W. Bangley https://orcid.org/0000-0002-6044-7694

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