TOWARD A US ANIMAL TELEMETRY OBSERVING NETWORK (US ATN) FOR OUR OCEANS, COASTS AND GREAT LAKES

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Abstract

Aquatic animal tracking is the science of elucidating the behavior of animals as they move through the world's oceans and lakes. Tracking devices ("tags") yield detailed data regarding the physical environment through which the animals are moving. Sometimes this can be done in near-real time - true telemetry - and in other tags the data are stored for later acquisition. Animal species tagged range from 20-gram salmon smolts to 150-ton whales. Detailed observations of animal movements and their aquatic environment, have significantly improved our understanding of ecosystem function and the evolutionary constraints of species. These data are critical for preventing extinctions, preserving biodiversity and implementing ecosystem-based management of living resources. Animal-borne sensors have come of age and deliver high resolution physical oceanographic data at a relatively low cost. Animals are particularly adept at finding areas of interest to oceanographers (fronts, upwelling areas) and they provide important insights into regions of the oceans that are difficult and expensive to monitor (e.g. Polar Regions). Animal telemetry technology is operational and the community is starting to incorporate this capability into a US Integrated Ocean Observing System. This community white paper focuses on how to integrate an operational Animal Telemetry Network into the US IOOS.

Key words: observing, operational oceanography, Animal Telemetry Network, Animal Borne Sensors

1. BACKGROUND

The development of the Integrated Ocean Observing System (IOOS) initially focused on the acquisition and integration of physical and chemical oceanographic data. With this system now operational, it is important for IOOS to add the acquisition of relevant biological data, and to enhance the acquisition of physical and chemical oceanographic data with Animal Borne Sensors (ABS) or Animal Oceanographic Platforms. Animal telemetry is a mature technology, provides essential information on marine resources and environmental data and is ready to be integrated within IOOS. Animal telemetry is the process of obtaining data remotely (via a tag secured to the animal) and can be conducted in real time with radio and acoustic telemetry, or in 'archival mode' where tracks and ocean profiles are reconstructed from time-series data that are either transmitted on a time-delayed basis to satellites, or analyzed when the animal is recaptured and the tag physically returned[1-6]. Passive acoustic systems are also operational, detecting whales and dolphins based on their natural vocalizations.

Over the past two decades thousands of animals have been tagged and released in North American waters. The tags animals carry record data at rates that may exceed 1 measurement per second including location, depth, temperature, light, salinity, acceleration, acoustics, and physiological parameters (heart rate, oxygen, and body temperature). Animals are sensitive indicators of environmental trends and current oceanic conditions. Animal telemetry provides the opportunity to monitor these sentinels to assess current conditions and predict climate trends. These valuable data are useful for multiple purposes.

Federal, state, academic and commercial organizations routinely collect animal telemetry data. Current projects range in scale from neritic to ocean basins. In the past decade, regional networks collecting data in US waters have emerged Atlantic Coastal Telemetry Network (ACTN), Florida Atlantic Coast Telemetry (FACT) Pelagic Fisheries Research Program in Hawaii (PFRP), Ocean Biogeographic Information System- SeaMap (OBIS SeaMap), Pacific Ocean Shelf Tracking (POST) and Tagging of Pelagic Predators (TOPP). Inclusion of biological resources in ocean observation is critical to advancing National Ocean Policy priority objectives, particularly Ecosystem-Based Management and Coastal and Marine Spatial Planning. Many of the existing programs already have the capability to provide live updates on animal movements, behavior, and oceanographic environment data. Importantly, demonstration projects have indicated animal-borne sensors are reliable, inexpensive platforms for delivering high quality oceanographic data. National and international programs have succeeded in delivering these oceanographic data to IOOS and Global Ocean Observing System and biological data to OBIS. The biologging community is internationally recognized and organized, and large scale global animal telemetry programs have emerged (Australian Animal Tagging and Monitoring System (AATAMS), Global TOPP (GTOPP), Ocean Tracking Network (OTN), Southern Elephant Seals as Oceanographic Samplers (SEaOS), Southern Ocean Observing System (SOOS)

Autonomous platforms are the backbone of the global *in situ* ocean observing system. In the last 25 years, technological advances have made it possible to use animals as ocean observing platforms to carry remote-sensing devices (i.e. Animal Borne Sensors)[3,7-9]. ABS are mobile autonomous platforms that are relatively inexpensive to deploy (compared to ocean gliders or AUVs) and provide important insights into US coastal and EEZ areas, and are particularly useful in the open oceans that are difficult and expensive to monitor (e.g. Arctic and Antarctic regions). Animals are adept at finding areas of particular interest to oceanographers, including surface and sub-surface fronts, eddies, and confluences that aggregate prey. Data collected by ABS include: oceanographic-quality water column profiles (temperature, conductivity, light level, O_2, and tag derived variables such as chlorophyll proxies from light extinction) as well as behaviors in foraging “hotspots,” ecological interactions, migration routes and habitat utilization patterns. ABS complements gliders and other autonomous vehicle products to provide unique and cost-effective data from poorly sampled ocean regions, and are rapidly becoming an integral component of the GOOS, especially at high latitudes.

2. TECHNICAL AND USER REQUIREMENTS

Major “customers” of animal telemetry include: 1) Federal and state agencies; 2) fisheries, marine mammal, sea turtle and bird conservation and management communities; 3) tribal communities; 4) the energy sector; 5) the tourism sector; 6) the general public; 7) educational institutions; 8) private industry and 9) the research community. The animal telemetry community anticipates numerous benefits to having a permanent ATN as a part of IOOS. Potential benefits are listed below:

a. Provide the scientific basis for ecosystem-based management (EBM).
b. Provide long term biological monitoring of animals for improvements of population census and habitat shifts associated with climate change.
c. Investigate regional connectivity of marine biological resources and integrate ocean observation systems across large marine ecosystems, sanctuaries, and marine protected areas. Such integration is vital to successful marine spatial planning, which aims to minimize the impact of multiple overlapping human activities.
d. Provide large volumes of ocean data that improve oceanographic models. This will provide increased understanding of ecosystem processes and improve predictions of future ecosystem conditions including storms, floods, drought, climatic variation and other weather.
e. Provide near real-time geospatial data that are integral to realistic parameterization of spatially explicit population and fishery assessment models, to assist with conservation of species and the maintenance of biodiversity.
f. Provide real-time monitoring capabilities that permit management of marine protected areas, operational windows for construction/dredging, or enforcement of fisheries regulations, to avoid harming sensitive stocks and to improve fisheries harvests.
g. Define essential or critical habitat. This is relevant to many aspects of fisheries and protected species management and the design and evaluation of MPAs. On a larger scale, these studies can inform managers about the geographical range and seasonality of the stocks they are charged with managing.
h. Evaluate how marine species use potential sites of future anthropogenic disturbance (e.g. aquaculture sites, OTEC and wind farm energy development, military activities, shipping, sewage treatment facilities, and

marina development), to aid developers who are trying to comply with environmental regulations.

i. Develop maps of sensitive “hot spot” areas and high-value ecosystems, which are necessary to identify regions that may warrant special protection status and creation of marine protected areas, and to identify transit corridors where impacts must be regulated.

j. Monitor the effectiveness of protected areas (MPAs) and Special Management Zones (SMZs) in buffering human impacts

3. STATE OF THE ANIMAL TELEMETRY OBSERVING SYSTEM AND TECHNOLOGY

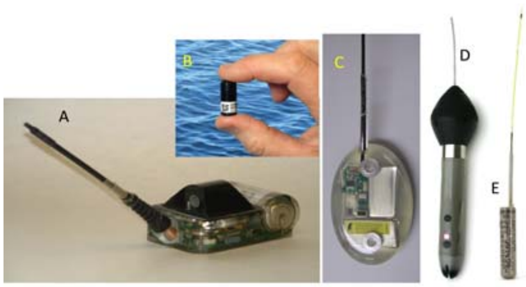

Figure 1. Examples of electronic tags used on marine animals. A Sea Mammal Research unit CTD tag, B. Vemco acoustic tag, C. Wildlife Computers SPOT tag, D, Wildlife Computers PSAT, E Lotek archival TDR

In the past two decades, rapid advances in animal transmitters and data storage tags have made it possible to use animals to collect high quality biological and oceanographic observations as they cruise through ocean habitats[1-11]. Currently about 10 standard tag types exist with distinct position and sensor capabilities. Sharks, tunas, salmon, sturgeon, marine mammals, reptiles and seabirds have been tagged routinely with sophisticated instruments that sample biological behaviors (diving), oceanographic variables (pressure, light, temperature, salinity), position (GPS, ARGOS, Geolocation) and biology/physiology (body temperature, heart rate, blood or tissue oxygen saturation, tail-beat, sound) (Figure 1). Some electronic tags report profiles of the water column to satellites in near-real time. In cases where animals return to predictable haul-out sites, where exploitation rates are high (tunas), or where aggregation occurs around buoys (FADS), the tags are recovered and the entire archived time series can be downloaded. Together, these technologies provide the means to track animals for multiple years, providing seasonal, annual and climatological data. In addition, the collection of high quality oceanographic data by animals has created new and productive partnerships between physical oceanographers and biologists[7-11]. These collaborations have substantially increased our capacity to sample and understand the oceanography along our coastal waters as well as in remote locations. Animal telemetry provides unique datasets for resource management and ocean modellers and enables IOOS to conduct analyses that address the Interagency Ocean Policy Task Force’s National Ocean Policy Priority Objectives.

In addition to electronic tags that record data from environmental sensors, some tags transmit acoustic data to underwater receivers. This results in a cable-free underwater network for recording animal movements and is particularly useful for studying small species, and aquatic species that do not surface often, making radio telemetry difficult to employ[5]. The decreasing size, longer life spans of batteries and increasing sophistication of acoustic transmitters[6] provides a mechanism for monitoring the behavior of a wide range of species across great distances, using networks of underwater receivers that span multi-national boundaries. Complementing these networks are the emerging use of satellite-enabled acoustic receivers and unmanned mobile gliders or mobile marine mammals fitted with acoustic receivers. For cetaceans that vocalize, passive receivers on moorings use hydrophones to listen for whales. By investing and maintaining fixed underwater receiver networks (passive and active), and mobile receiver platforms that uplink to Iridium satellite receivers or cell networks, the opportunity for long-term monitoring of North American waters has emerged. Monitoring marine species is valuable not only in terms of increasing the perceived value of protected and exploited resources and minimizing human impacts, but also for the data those species deliver as roving reporters about the oceans, our changing climate and by extension our terrestrial weather. Several nations have increased the priority of using these operational technologies with substantial government and private investments (Australia: ATAMS, Canada: OTN).

Significant infrastructure costs are required for large-scale acoustic telemetry. Other Nations have recognized the need for National investment in ocean infrastructure for biological monitoring and have incorporated these infrastructure costs into their growing IOOS equivalent capacities (Australia, Canada). We envision that the ATN efforts in the US will require a combination of acoustic, satellite and archival technologies deployed simultaneously that will assure complete monitoring of coastal and pelagic marine ecosystems within and beyond the EEZ. Importantly, US scientists are proven leaders in ATN and have organized and carried out some of the largest telemetry programs in global ocean waters.[5.,12,.13]

3.1 Challenges:

The challenges lie in defining what biological ocean observing data will best meet the needs of multiple users, and discerning the most economical acquisition and delivery of ATN data to IOOS. Importantly, the technical achievements of the past decade make biological ocean observation of animals a reality, and a US operational capacity only requires stable investments in existing technology across American waters. We envision national IOOS and regional association coordination and investments are required to make an ATN operational in US waters. Due to the existence of a large number of animal telemetry regional projects, in US waters, and the coordination exemplified by ATN members at workshops to date, we believe that the rapid assembly of a unified US network is possible. However, we recognize this will require national IOOS investment in infrastructure, tags, and data management

3.2 Examples of animal telemetry applications

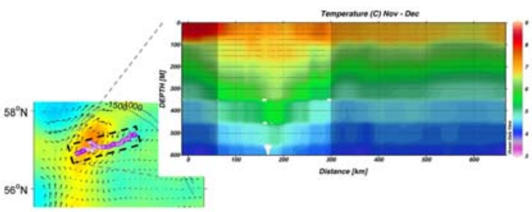

Figure 2. Lower left shows an AVHRR image of a Sitka Eddy shedding off of Southeastern Alaska. The dots show the track of an elephant seal and the top right box shows a temperature profile of that eddy detected by a temperature tag on the seal.

Using animal telemetry, it is now possible to record the ocean environment and fine-scale behavior of individuals even in the most remote regions of the world's oceans. Tagged animals routinely provide vertical oceanographic profiles throughout the upper 1500 m of the water column and in some cases deeper (2000m) (Figure 2). Animals travel to regions that are relatively inaccessible to other ocean observing technologies, such as the polar oceans beneath seasonal or permanent sea ice[3,7-9] or remote atolls such as those in the Northwest Hawaiian Islands. Additionally animals move into locations and sample where ARGOS floats are often pushed away (upwelling zones) and across political boundaries. This technology allows researchers to investigate how animals use their three-dimensional world and to quantify important physical and biological aspects of their environments while in transit. These data can be used to improve ocean forecasting systems by reducing ocean model initial condition errors. Simultaneously they inform federal and state fisheries management, conservation and sustainable use management policies[10-11]. For example, tag-derived movement data helped to improve management of Atlantic bluefin tuna through delineation of stock structure[14] and satellite and acoustic data from white sharks[13], combined with photo ID, are being used in models to provide estimates of California white shark populations. Patterns of habitat utilization revealed from animal telemetry have helped to identify and avoid or mitigate conflicts with oil, gas and wind development, dredging, military activities, fisheries interactions, shipping and research activities[15-24] and defining critical habitats for protected species.

New technology makes it possible for tags on free-ranging animals to exchange data among themselves, which can provide information on social dynamics and predator/prey interactions[5]. Large marine mammals can carry mobile acoustic receivers to track smaller tagged animals[25]. Additional distribution and migration data from other taxa have been overlaid on oceanographic data to develop predictive mapping tools that help the US Navy avoid endangered whales, and Central Pacific longline fishers minimize bycatch of protected loggerhead sea turtles[15]. On the West Coast of North America, discoveries about the unexpectedly large extent of green sturgeon movements were used to designate federally-mandated critical habitat for the ESA listed (threatened) southern stock[16]. Similarly, animal telemetry has revealed information critical to salmon conservation in West Coast river systems, e.g., that out-migrant smolt survival through the Columbia River hydropower system was better than previously believed, and that survival through the Sacramento River Basin was uniformly poor throughout the river as opposed to concentrated in the river delta[12]; in both regions, federal and state agencies spend millions of dollars per year to increase salmon survival so these are not merely academic exercises. Information acquired through acoustic tracking has been used by government agencies to guide FAD deployment strategies and formulate public policy regarding responses to shark attacks and tourist activities in areas of high shark utilization[21,24]. Tracking data are essential to understanding how diseases are spread and how disease networks might change as animals change their migration patterns. The impact of climate change on seals in the Antarctic and albatrosses in the Southern Ocean have been revealed using animal tracking. Tracking data were important in the decision to list black-footed albatross as an endangered species by the US Fish and Wildlife Service and by BirdLife International. Such data were also essential for the development of a management plan for endangered Australian and New Zealand sea lions[26,27]. Laysan albatross tagged at Guadalupe Island, Mexico are found within the California Current System and within exclusive economic zones of at least three countries. Leatherback sea turtles have been observed to use corridors shaped by persistent oceanographic features such as the southern edge of the Costa Rica Dome and the highly energetic currents of the equatorial Pacific[28]. These findings have led to an International Union for Conservation of Nature resolution to conserve leatherback sea turtles in the open seas. Similarly, tracking data were used to develop an MPA off the coast of Baja California to protect loggerhead sea turtles and to assess the efficacy of an implemented MPA to protect olive Ridley sea turtles off the coast of Gabon[20,29].

4. INTEGRATION WITHIN US IOOS, MODELING, AND DMAC

The ATN is currently a grassroots organization at a national level and IOOS is poised to take a leadership role nationally and internationally. Similar telemetry organizations already exist in several National Ocean observing program. By developing, maintaining and disseminating an integrated data display and storage of animal and telemetry data gathered by private, academic, local, state and federal institutions, IOOS has the capacity to lead and strengthen our national ocean observing capabilities in this area. Stronger ATN ocean observing capabilities will augment our knowledge and understanding of ocean ecosystems and our ability to engage in science-based decision-making and ecosystem-based management.

The following are recommendations on how IOOS can integrate ATN efforts into a national and international system for delivering critical information on biological resources and ecosystem function, and deliver oceanographic data that can compliment and enhance existing observing capability:

We envision the role for organizing ATN would be as follows:

1. Invest, deploy and maintain key assets (tags, underwater receivers and data management systems) required for building a national ATN across the nation's waters.
2. Improve the national ATN data management capacity by establishing standards and infrastructure for facilitating this IOOS activity.
3. Synthesize and make animal telemetry products available to advance the NOP Priority Objectives (i.e. Ecosystem-based Management, Coastal and Marine Spatial Planning)
4. Advance the National capacity for making animal oceanographic telemetry data accessible in near-real-time via Global Telecommunications System (GTS).
5. Establish the capacity to assimilate ATN data daily to the ocean modeling community (HYCOM, ROMS).
6. Establish pathways for rapid sharing and maintaining data at National and International levels. This will help avoid duplication of ATN efforts and ensure data are compatible and accessible for analyses and assimilation by computer models. Increased access to animal telemetry information will improve our ability to provide accurate forecasts and inform ecosystem based coastal and marine spatial planning.
7. Promote development of new and lower cost tag technology.
8. Promote investment in new sensors (e.g. oxygen and pH sensors) in response to growing concerns about the potential impacts of ocean acidification and hypoxia on marine biological resources and the health of marine ecosystems.
9. Bring permanence and sustainability to a national network. ATN will only be successful with a sustained long-term support for maintenance of infrastructure for receiving data (such as acoustic receiver arrays), regional support at RAs for tag deployment (e.g. animal borne sensors on all three coasts), and for advancement of technology to continue providing continuous biological and geophysical observations.
10. Discern how best to reduce costs of deployments (e.g. by coordinating deployments on existing monitoring missions by federal or state vessels).
11. Document and coordinate priority deployment of animal telemetry assets. Currently, there is a diverse set of animal telemetry projects taking place throughout the country with different Federal, state, academic or regional objectives.
12. Expand animal telemetry outreach and education programs. Animals are a way to foster a public understanding of the value of the ocean, coasts and the ocean observing systems. Resources and funding should be given to support building products for grades K-12 with animal and telemetry data. Aquariums offer great opportunities to expose the public to this initiative through education programs and by exhibiting tracks of tagged animals in near-real time.
13. Plan and execute demonstration projects in 2013 that demonstrate one or more of the above recommendations.

5. LOOKING FORWARD IN THE NEXT DECADE

The US IOOS could immediately take the lead to capture ATN data into our national ocean observing system. To date, IOOS has conducted two workshops in which a dialogue with telemetry teams from all North American regions was initiated. Outcomes from the meeting currently include plans to integrate data and infrastructure. Discussions of data quality standards, interoperability, portability and scalability have been initiated and demonstrations projects have been funded. Importantly, however, a clear outcome from these workshops is the recognition that a US National commitment to establish and improve the ATN infrastructure must exist to be successful. We envision this would occur if IOOS committed annual funds for ATN activities to the Regional Associations (RAs). We recommend that IOOS RAs utilize funds regionally to initiate and support tagging/telemetry activities, and acoustic infrastructure development that would be coordinated into an IOOS ATN system. These investments would immediately be used to conduct projects that address resource management observing (i.e. Ecosystem-based Management and seventh goal of US IOOS- Sustain Marine Living Resources), sanctuary or marine protected area monitoring, spatial planning issues pertinent to their regions or complement current direct ocean observations in the region. Using RAs to initiate the ATN will assure regional development. Coordination would occur at the National IOOS level with allocation of resources for this activity. Immediate steps that would facilitate National organization under IOOS are:

- IOOS could take the lead in facilitating the organization of local animal telemetry arrays into confederated regional arrays. Establishment of current and future animal telemetry assets into a super-region in collaboration with U.S IOOS RAs would only occur if RA financial assets are utilized to leverage this collaborative activity. RAs would contribute observations to the National IOOS repository.
- IOOS should engage government agencies as the lead on an interagency effort to support funding for some of the assets of the ATN (acoustic receivers, tags, data management activities). Potential partners include the U.S. Navy, Bureau of Ocean Energy Management, and the Department of Energy and NSF.
- Organize regional and national meetings to establish and implement the ATN.
- Promote funding for development of new ATN tags and sensors (the animal community sees a need for O_2 and pH sensor development).
- Establish national data management infrastructure in ATN technologies and leverage existing resource knowledge in data management to advance all regions.
- Facilitate communications among regional telemetry efforts, and hold regular meetings of the ATN community. This will help in many ways, including identification of shared problems and solutions.
- Facilitate delivery/access of animal telemetry data (geo-physical data) through GTS.
- Collect and display telemetry products including publications, data visualization or decision-support tools and other software that may have wide applications.
- Invest in and coordinate deployment and maintenance of coastal and ocean arrays
- Support maintenance of infrastructure (possibly including in-kind support of ship time by participating agencies)
- Conduct and develop education and outreach programs including Web-based learning
- Underwrite sessions at various symposia to foster exchange between biologists and physical oceanographers and biologists and regional planners.
- Establish ATN representation on the Data Management and Communication (DMAC) steering committee and DMAC Regional Association Data management workshops.

6. CONCLUSIONS AND RECOMMENDATIONS

Animal telemetry has matured and the Nation should launch a US ATN observing system that monitors marine life on a range of temporal and spatial scales that will yield both short and long-term benefits, fill oceanographic observing and knowledge gaps and advance many of the NOP Priority Objectives identified by the Interagency Ocean Policy Task Force. ATN has the potential to create a huge impact for the ocean observing activities undertaken by IOOS.

We recommend incorporation of ATN and its subsequent data products within IOOS to advance National Ocean Policy Priority Objectives as follows:

1. Establish a permanent and sustainable ATN in the national IOOS framework
2. Support biological monitoring assets (receivers) and deployments of electronic tags on animals in America’s oceans and Great Lakes ecosystems.
3. Collect and integrate routine ATN oceanic data observations delivery into US oceanographic models.
4. Improve data standards, management, and sharing capability among ATN users.
5. Improve our ability to acquire and redistribute or display data that will improve management of our fisheries, enhance our ability to plan for an expanding human population and changing climate
6. Improve our ability to predict weather that affects our nation’s productivity.
7. Work with industry to improve requirements for tag specifications including coding management, and manufacturing standards that will make data more reliable and cheaper to obtain.
8. Document and help in the coordination of deployments of animal telemetry assets.
9. Use regional associations to initiate local telemetry projects by region.

10. Expand animal telemetry outreach and education programs. Connecting people and animals in their blue ocean habitat will increase investments in IOOS.

11. Plan and execute a collaborative national project to demonstrate the utility of the ATN to the fisheries, habitat management and/or oceanographic communities.

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