The Changing Ocean and the Impact of Technology: The Role of the Ocean Tracking Network

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It’s Personal

The historic but false vision of the ocean as being so vast and inexhaustible that it would benefit humankind forever has been destroyed during my lifetime. I lived this change, and watched in dismay as it was documented in scholarly publications. The personal experience started in early childhood where summers were spent on the coast in Scituate, Massachusetts. I passed more time in the water with a mask than I did on land. My earliest ocean memories (I was born in 1954 and by 8 years old was a devoted snorkeler) are of a nearshore zone full of life, and of being able to catch cod (Gadus morhua), flounder (Pseudopleuronectes americanus), striped bass (Morone saxatilis), cunner (Tautogolabrus adspersus), American lobster (Homarus americanus; duly licensed as a Massachusetts recreational harvester), and dogfish (Squalus acanthias) within a few meters of shore. Within ten years, most of these species were gone, and the few that remained were greatly reduced in numbers, most probably falling victim to overharvesting. This left the American lobster as the major resource for the coastal fisheries.¹

Concomitant with the fish declines, other stressors were also rearing their head. Repeated small-scale oil spills occurred,² fouling beaches and having undocumented consequences for the area’s ecology. Plastic waste began to pile up on the shore, and the ocean began warming. As temperatures rose, southern

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¹ “Living Marine Resources,” Government of Massachusetts, last accessed 2 February 2018, http://www.mass.gov/eea/docs/czm/oceans/waves-of-change/tech-lmr.pdf.

² See, for example, Nuka Research and Planning Group, Evaluation of Marine Oil Spill Threat to Massachusetts Coastal Communities, Report prepared for the Commonwealth of Massachusetts, Department of Environmental Protection, December 2009, http://www.mass.gov/eea/docs/dep/cleanup/laws/osthrt.pdf.
species like the lady crab (*Ovalipes ocellatus*) began to make their appearance\(^3\) in what used to be a cold-ocean bastion. The warming of waters immediately adjacent to the coast resulted in the lobsters withdrawing to deeper, colder water.\(^4\) The familiar nearshore lines of buoys marking lobster traps are now gone, reducing the socio-economic benefits that flowed from this dominant commercial species and changing the social nature of the coastal community. New invasive species arrived, displacing the existing, common invasive species that in my ignorance I had assumed were our native fauna. In particular, the green crab (*Carcinus maenas*) that probably made its way to North America from Europe on the bottom of colonial sailing ships and so enjoyed the area that it took over the intertidal and nearshore,\(^5\) has now been displaced by the Asian shore crab (*Hemigrapsus sanguineus*),\(^6\) which most probably arrived as larvae in ballast water of a cargo ship\(^7\) from the massive transport network that keeps the global economy chugging along.

However, the ocean story is not one of total gloom and loss. The environmental movement that developed in the wake of large-scale environmental damage changed public policy and regulatory regimes. Globally, requirements were phased in requiring the conduct of environmental impact assessments to mitigate or eliminate impacts of proposed projects that could harm the environment. The concept of sustainable development, so eloquently expressed in the Brundtland Report,\(^8\) has taken deep international root, and with the arrival of the United Nation’s newly crafted Sustainable Development Goals (SDG),\(^9\) the health of the ocean for the first time has been specifically and

\(^3\) J.C.A. Burchsted and F. Burchsted, “Lady Crabs, *Ovalipes ocellatus*, in the Gulf of Maine,” *Canadian Field-Naturalist* 120, no. 1 (2006): 106–108.

\(^4\) E. Greenhalgh, “Climate & Lobsters,” US National Oceanographic and Atmospheric Agency (NOAA) (6 October 2016), https://www.climate.gov/news-features/climate-and/climate-lobsters.

\(^5\) E.D. Grosholz and G.M. Ruiz, “Predicting the Impact of Introduced Marine Species: Lessons from the Multiple Invasions of the European Green Crab, *Carcinus maenas*,” *Biological Conservation* 78, no. 1–2 (1996): 59–66.

\(^6\) C.E. Epifanio, “Invasion Biology of the Asian Shore Crab *Hemigrapsus sanguineus*: A Review,” *Journal of Experimental Marine Biology and Ecology* 44 (2013): 33–49.

\(^7\) For a review of ballast water transfers, see J.T. Carlton, “The Scale and Ecological Consequences of Biological Invasions in the World’s Oceans,” in *Invasive Species and Biodiversity Management*, eds., O.T. Sandlund, P.J. Schei and Á. Viken (Dordrecht: Kluwer Academic Publishers, 1999), 195–212.

\(^8\) World Commission on Environment and Development, *Our Common Future* (Oxford: Oxford University Press, 1987), http://www.un-documents.net/our-common-future.pdf.

\(^9\) “Sustainable Development Goals,” United Nations Development Programme, http://www.undp.org/content/undp/en/home/sustainable-development-goals.html.
unquestionably recognized by the international community as critical to humanity’s future (SDG 14).

Looming Challenges: The Impacts and Benefits of Technology

There still are huge challenges looming for the ocean, stemming from its ‘open access’. An astonishingly rapid development of technology is totally changing the nature of humanity’s relationship with the ocean. There is now no location in the sea that is not accessible should we want to pay a visit (note, for example, film director James Cameron’s ability to construct a personal submersible to access the deepest portion of the ocean in the Challenger Deep of the Mariana Trench), or to initiate economic activities. The economic drivers will be the most formidable. The ocean economy is currently estimated to be worth at least US$24 trillion worldwide, and systematic attention is now being focused on developing much more ocean economic activity. ‘Blue growth’, or the ‘Blue Economy’, are becoming staples of the economic development plans of ocean nations, and we are poised on the brink of a technology driven ‘ocean industrial revolution’. If this economic development is not handled carefully, we stand to lose much of the critical ocean biodiversity on which a great deal of our current ocean economy (fisheries, nature tourism), food security, and valued ecosystem services depend. We also face the possibility of a major extinction pulse, similar to the one that was observed for land animals when the terrestrial industrial revolution occurred in the eighteenth and nineteenth centuries.

The impacts of technology can swing both ways. While next generation technologies may create new problems, they can also help to mitigate or eliminate existing or future problems by providing the information and knowledge needed to plan development that will be truly stable. The latter is the world in which Dalhousie University’s Ocean Tracking Network (OTN) operates.

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10 L. Klimas, “What Exactly Did James Cameron Find in the Deepest Ocean Trench?,” The Blaze (26 March 2012), http://www.theblaze.com/news/2012/03/26/what-exactly-did-james-cameron-find-in-the-deepest-ocean-trench.

11 O. Hoegh-Guldberg et al., Reviving the Ocean Economy: The Case for Action—2015 (Gland: WWF International, 2015), http://wwfintcampaigns.s3.amazonaws.com/ocean/media/RevivingOceanEconomy-REPORT-lowres.pdf.

12 D.J. McCauley et al., “Marine Defaunation: Animal Loss in the Global Ocean,” Science 347, no. 6219 (2015): 1–7. doi.org/10.1126/science.1255641.

13 Id.
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Many animals are unable to meet all of their life-history needs at a single geographic location. Habitat needs and prey types change as animals grow, requiring changes in geographic location. Seasonal variation in habitat productivity may alter the locations where food is available. The habitats and environmental conditions necessary for successful reproduction may be different from those needed for feeding or sheltering. Any of these may trigger predictable and extensive movements in highly valued species. Should something occur to block these movements, populations can decline, and in the worst cases the species can be extirpated locally or go extinct.14

As the future Blue Economy develops, the potential for single or multiple projects (cumulative impacts) to fall across the migration routes of these species is increasingly of concern. If we know what the animal's needs are, and the movement pathways that they follow to meet them, policy and management decisions can be taken to locate projects or conduct operations in ways that minimize the potential impacts. Our problem has been that until relatively recently, we were unable to document the movements and habitat use of aquatic animals. Ocean areas are vast; they cover three dimensions; they include extreme temperatures, depths, pressures and other environmental conditions; and humans are badly adapted to personally follow aquatic animals that are at home in the water. Until recently, all of this made it extremely difficult for scientists to document movements and the preferred habitats of animals in the ocean.

The advent of electronic telemetry since the late 1970s has enabled the observation of local and long distance migrations of aquatic species and their use of particular habitat types.15 A variety of electronic telemetry systems are available. Some, like radio telemetry or passive integrated transponders (PIT tags), are used primarily in fresh water because they depend on transmission of radio signals, which will not penetrate long distances in salt water. However, data loggers, satellite tags, and acoustic telemetry are available and are widely used to track animals in marine systems.16

14 H. Dingle, Migration: The Biology of Life on the Move (New York: Oxford University Press, 1996); R. Nathan et al., “A Movement Ecology Paradigm for Unifying Organismal Movement Research,” Proceedings of the National Academy of Sciences of the United States of America 105, no. 49 (2008): 10952–10959, doi.org/10.1073/pnas.0800375105.
15 N.E. Hussey et al., "Aquatic Animal Telemetry: A Panoramic Window into the Underwater World," Science 348, no. 6240 (2015): 1255642, doi.org/10.1126/science.1255642.
16 M.B. Ogburn et al., “Addressing Challenges in the Application of Animal Movement Ecology to Aquatic Conservation and Management,” Frontiers in Marine Science 4 (2017): 70, doi.org/10.3389/fmars.2017.00070.
There are common elements to the marine telemetry technology systems, but also big differences among them. Common elements include the need to capture animals, humanely attach the tags, and at some point retrieve detections of the animals from the tags that document the animal’s geographic locations over time. Data loggers and satellite tags both incorporate environmental sensors (e.g., light sensors for light-based geolocation, depth, and temperature sensors), allowing scientists to link animal movements to environmental conditions. These tag types store their data on board the tag; however, the way the information is retrieved differs. In the case of the data logger, the tag must be recovered from the animal, which can occur, for example, when the tagged animal is captured in a fishery. By contrast, satellite tags report some or all of their data to orbiting satellites whenever the antenna of the tag pops out at the water surface. This can occur, for example, when the tag is fitted on the dorsal fin of a shark and the shark is swimming at the surface with the fin out of the water, or when the tag is a ‘pop-up’ model, designed to release itself from the animal on a predetermined set date after the animal was tagged. It then floats to the surface where it broadcasts some or all of the contained data, depending on the model of the tag and its settings. Satellite tags are large and very expensive; hence they tend to be used on big, high-value species such as tuna. Data loggers, whose utility is determined by the probability of the tagged fish being captured in fisheries, tend to be used on species where there is a high exploitation rate, increasing the probability of return of the tag.

The third electronic tagging system, acoustic telemetry, uses sound transmission. Animals are tagged with an acoustic tag (also known as a ‘ping’er’) that has a unique identification signal (ID) assigned to each individual, letting all subsequent detections of that tag be attributed to the original animal. These tags can also carry additional sensors such as depth and temperature. However, to detect the acoustic tags, a network of acoustic receivers needs to be deployed in the ocean at known locations. These typically have omnidirectional detection ranges of about 800 m, record the signals from the tags whenever they are within range, and store detections until the data can be retrieved. Course tracks and residency of animals are determined by linking sequential detections on the various receivers in the network. Data retrieval is done in one of three ways: by bringing the receiver to the surface and connecting it to a computer; in more expensive receiver models, by uploading the data from a moored receiver through an acoustic modem to a surface platform or marine autonomous vehicle; or in the most expensive model, by cabling the receiver

17 F. Whoriskey and M. Hindell, “Developments in Tagging Technology and their Contributions to the Protection of Marine Species at Risk,” Ocean Development & International Law 47, no. 3 (2016): 221–232, doi.org/10.1080/00908320.2016.1194090.
to a surface buoy or mobile marine autonomous vehicles that have satellite or cellular phone links and can transmit detections in real time. Acoustic telemetry has become the most used form of marine electronic telemetry, due to its relatively inexpensive tag costs, and the availability of a variety of tag sizes that let investigators tag animals as small as 4.5 cm in length or which can last for ten years or more. This makes acoustic telemetry a flexible system that can address many questions and species (or their life stages) of interest.

Canada’s Ocean Tracking Network (www.oceantrackingnetwork.com) has become a world leader in the field of acoustic telemetry. OTN is a project and system of the United Nations Intergovernmental Oceanographic Commissions’ Global Ocean Observing System. Starting in 2008, the OTN began deploying Canadian state-of-the-art acoustic receivers and oceanographic monitoring equipment in key global ocean locations. These are being used to document the movements and survival of acoustically tagged marine animals and to link both to oceanographic conditions. OTN deployments have occurred in all of the world’s five oceans, and frequently complement/enhance existing deployments maintained by OTN partners. The >160 species tracked include marine mammals, sea turtles, squid, and fish, including sharks, sturgeon, eels, tuna, salmon, and cod. Over 400 international researchers from 19 countries are currently participating in the global network. Innovative use of autonomous vehicles and platforms of opportunities (e.g., meteorological buoys and offshore oil infrastructure) to position new receivers is greatly enabling OTN’s ability to monitor acoustically tagged animals and to retrieve data from moored receivers via acoustic modems.

A particularly unique element of the OTN is its systematic focus on international networking through its data system. OTN maintains a sophisticated data warehouse and is creating networked international nodes to house regional telemetry data. Half of the OTN staff is devoted to the task of seeing that the data from OTN’s 1,600+ acoustic receivers are linked to the data flowing from >20,000 additional acoustic receivers deployed by individuals and telemetry networks throughout the global ocean.18 OTN has been recognized as an Associate Data Unit of the International Oceanographic Data and Information Exchange. The sharing of data in this manner is technically challenging; there is a need for common or at least exchangeable metadata and data standards, and for QA/QC of large volumes of data. A major challenge has been getting

18 S.J. Cooke et al., “Ocean Tracking Network Canada: A Network Approach to Addressing Critical Issues in Fisheries and Resource Management with Implications for Ocean Governance,” Fisheries 36, no. 12 (2011): 583–592.
individual investigators to buy into the process of data sharing and making their data available for use by the current and future scientific community. Some investigators who are reluctant to network are concerned about data theft or misuse; however, those investigators who are networking are increasing their productivity.19

The Future of Electronic Telemetry

Given the need for the information that electronic telemetry provides, the science community believes that its use for tracking aquatic animals will only grow in the future.20 Continuing technological development (e.g., addition of oxygen, pH, and other sensors to tags) and expansion of its use will reduce costs and increase its utility by letting it help address the key management and policy questions. As the data grow in volume and especially in complexity, with varied environmental and animal movement variables measured at different time and geographic scales, much of the action in the field will shift to data analytics and visualization. There is a bright future for those with strong skills in data analytics and visualization, and with the communication skills to work with animal telemetrists.

Implications for Ocean Governance

Since coastal communities of ocean nations depend on their fisheries/biological resources for their socio-economic well-being, there is a critical need to inform policy and management systems with the best information possible on the impacts of our management decisions and on the potential consequences of future ocean development. We know that many valued species must move at predictable times to meet their life-history needs. If we want these species to prosper and continue to provide benefits to humans, it is imperative that we not block these movements. OTN researchers are informing policy and management decisions about fisheries, endangered species, the effectiveness of

19 V.M. Nguyen et al., “To Share or Not to Share in the Emerging Era of Big Data: Perspectives from Fish Telemetry Researchers on Data Sharing,” Canadian Journal of Fisheries and Aquatic Sciences 74, no. 8 (2017): 1260–1274, doi.org/10.1139/cjfas-2016-0261.

20 R.J. Lennox et al., “Envisioning the Future of Aquatic Animal Tracking: Technology, Science, and Application,” BioScience 67, no. 10 (2017): 884–896, doi.org/10.1093/biosci/bix098.
marine protected areas, and the potential environmental impacts of proposed industrial development in the ocean. They are also linking animal distributions to environmental conditions, which will provide a predictive capacity for changed animal distributions in the face of a changing ocean. As such, the OTN has an important role to play in the quest to maintain the health of the oceans.