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Biologging technologies: new tools for conservation. Introduction

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ABSTRACT: Biologging technology allows researchers to take measurements from free-ranging animals as they move undisturbed through their environment. Recent advances in biologging technology, including electronic tag miniaturization and improved animal movement models, have revolutionized our understanding of the ecology of top predators and have permitted observations well beyond the reach of standard measurement techniques. Engineering has provided the biologging community with ever more sophisticated tags, and advances in the application of statistical methods to interpret these data have yielded powerful new tools for understanding animal behavior. The technology has also reached sufficient sophistication and reliability such that the data collected is often equivalent to industry standards for environmental sampling, which has led to profound advancements in the marine realm, where the sheer vastness, in 3 dimensions, limits our ability to observe. Biologging data is now being increasingly applied to marine management and conservation policy. In this introduction, we highlight a few of the research themes presented at the Third International Conference on Biologging Science, and comment on the future challenges of biologging science.

KEY WORDS: Biologging · Telemetry · Tagging technologies · Animal movement · Environmental sensors · Oceanography · Conservation

INTRODUCTION

Biologging can be defined as 'the use of miniaturized animal-attached tags for logging and/or relaying data about an animal's movements, behaviour, physiology, and/or environment' (Rutz & Hays, 2009). Biologging technology allows researchers to take measurements from free-ranging animals as they move undisturbed through their environment. Recent advances in biologging technology, including electronic tag miniaturization and improved animal movement models, have revolutionized our understanding of the ecology of top predators and have permitted observations well beyond the reach of standard measurement techniques. This has led to particularly rapid advancements in the marine realm, where extended observations of undersea animals are rare and often logistically difficult. Biologging observations are used for basic ecological research, controlled experimental studies, physiological studies, and observations of the *in situ* environment surrounding the animal. Long-term biologging observations are also used to understand the influence of climate variations, and to predict the potential impacts of climate change, on megavertebrate distributions (Costa et al. 2010b).

The majority of papers in this Theme Section were contributed following the Third International Conference on Biologging Science that took place at the Asilomar Conference Grounds in Pacific Grove, California, from 1 to 5 September 2008 (http://biologging.

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wordpress.com). A total of 235 attendees representing 20 nations delivered 103 oral and 45 poster presentations, describing a wide variety of biologging applications on 89 different species (see Rutz & Hays 2009, supplementary material). This conference followed the inaugural symposium held at the Japanese Institute of Polar Research in Tokyo in March 2003 (Naito 2004), and the second symposium hosted by the Sea Mammal Research Unit at the University of St. Andrews, UK, from 13 to 16 June 2005 (Hooker et al. 2007). Symposium sessions focused on advancement of biologging technology, models of animal movements, monitoring physiology, climate change, habitat preferences and utilization, and new multi-species observatory networks that take a snapshot of an entire ecosystem. A special session was convened on the application of biologging to the conservation and management of wildlife and ecosystems (see Rutz & Hays 2009 for summary statistics of research themes presented at the symposium). The papers in the present volume represent the breadth and novelty of the research conveyed at the symposium.

The third symposium was hosted by the Tagging of Pacific Predators (TOPP; www.topp.org) and Tag-a-Giant (TAG; www.tagagiant.org) programs, 2 of the world's largest marine biologging programs. TOPP, a component of the Census of Marine Life (www.coml.org), is a multi-institutional, multi-year large-scale biologging program that has deployed over 4000 tags on 23 marine species throughout the Pacific Ocean in a series of studies providing essential input into the effective management of marine ecosystems and conservation of top predator populations (Block et al. 2002, Block et al. 2010, Costa et al. 2010a). TOPP has contributed over 100 publications on multi-taxa tagging and has synoptically examined how animals are using the North Pacific ecosystem. TAG is a long-term electronic tag study of Atlantic bluefin tuna that has led to new insights into the distribution, movements and population structure of this overexploited species (Block et al. 1998, 2001, Block 2005, Teo et al. 2007, Walli et al. 2009). The program has deployed over 1000 electonic tags on Atlantic bluefin tuna, with the data providing management-relevant information on their foraging and breeding grounds, levels of population mixing, and ontogenetic movements.

Two papers in this Theme Section provide reviews of the development and current state of marine biologging science: Hart & Hyrenbach (2009) review the satellite telemetry literature of air-breathing marine taxa for the period 1987 to 2006, and evaluate progress in satellite tracking of marine megavertebrates. Ropert-Coudert et al. (2009) provide a retrospective study of the use of biologging technology to study diving activity of marine taxa. Rutz & Hays (2009) provide an overview of the research themes presented at the Third International Conference on Biologging Science, and summarize the progress of biologging science between the first and third conferences. The program and abstract book of the third symposium are available as a supplement to Rutz & Hays (2009). In this introduction, we highlight a few of the research themes presented at the symposium, and comment on the future challenges of biologging science.

SYMPOSIUM HIGHLIGHTS

New tag technologies and animal movement models

There has been a tremendous improvement over the last 20 yr in the number and quality of locations recorded by animal tags. This is now leading to questions about animal behavior underwater and consequently in the development of new sensors and tagging technologies. For example, the use of tri-axial accelerometer tags (Wilson et al. 2006, 2008) has begun to resolve details of the 3-dimensional movement of tagged animals. Shepard et al. (2008) provide a general framework for interpreting data from tri-axial accelerometers across a range of species with varying body sizes and patterns and life history traits, allowing the identification of a wide range of behavioral patterns. Gómez Laich et al. (2008) identify several behavioral patterns of free-living imperial cormorants using tri-axial accelerometers, and Whitney et al. (2010) used the same technology to identify mating events in free-living nurse sharks, which were validated through direct observations. Okuyama et al. (2009) examined the breathing and feeding behavior of captive loggerhead turtles by attaching acceleration dataloggers to their lower beaks. Skinner et al. (2009) attached accelerometers to the head and torso of Steller sea lions to differentiate head and body acceleration and, thus, estimate foraging effort.

Other biologging advances involve the novel use of existing technologies. Cronin et al. (2009) demonstrate the novel use of mobile phone telemetry to investigate the haulout behavior of harbor seals. Holland et al. (2009) describe results from the deployment of a prototype acoustic 'business card' tag on Galapagos sharks, which allow for 'mobile peer-to-peer' transmission of information between tagged animals during at-sea encounters. These tags provide the capacity for ecosystem-level experiments.

While engineering has provided the biologging community with ever more sophisticated tags to acquire high-quality animal movement data, advances in the application of statistical methods to interpret these data have yielded powerful new tools for understanding animal behavior (Fauchald & Tveraa 2003, Jonsen et al. 2003, 2005, 2007, Tremblay et al. 2006, 2009, Bradshaw et al. 2007, Patterson et al. 2008, Schick et al. 2008). A major development has been the inclusion of error within statistical models to better discriminate biological signals from observation noise, for example using state-space models. Bailey et al. (2009) applied a switching state-space model to satellite tracks of blue whales to identify seasonal and interannual variability in the location of migratory pathways and foraging hot spots. Thiebot & Pinaud (2010) extend the use of a spatial template fitting method, using Markov chain Monte Carlo and state-space modeling, to include a sea surface temperature matching procedure and land mask, thus improving the quality and potential use of light-based geolocation data.

Physiology, behavioral ecology and population structure

Biologging has long been an important tool for studying the behavior and physiology of free-ranging animals (Gentry & Kooyman 1986, Priede & Swift 1992, Costa 1993, Metcalfe & Arnold 1997, Kooyman & Ponganis 1998, Wilson et al. 2002, Costa & Sinervo 2004, Block 2005, Ropert-Coudert & Wilson 2005, Ponganis 2007). The ability to instrument animals and actively record physiological parameters such as body temperature, oxygen utilization or heart rate has provided important new knowledge about how animals function (Meir et al. 2008, Ponganis et al. 2009).

Papers in this volume include descriptions of the physiology and/or behavior of a broad array of marine top predators. Andrews-Goff et al. (2010) used satellite-linked data loggers to describe haulout behavior of female Weddell seals in eastern Antarctica over 3 winters, and found haulouts to be more frequent at night and in conditions of low winds and high temperatures. Mazzaro & Dunn (2009) performed a pilot study to determine the effects of satellite tag attachment and detachment on captive harbor seals, and found no significant adverse physiological effects or behavioral changes. This is a particularly important aspect of biologging since all tagging studies aim to minimize any short or long-term effects of tagging on the animal whilst maximizing the amount of information that can be collected. In another study of potential observer-instigated effects on haulout behaviors, Gucu (2009) compared the responses of Mediterranean monk seals exposed to photo traps within their cave haulouts, finding a potentially negative reaction to visible flashes. Horning & Mellish (2009) deployed Life History Transmitters (Horning & Hill 2005), which are capable of post-mortem data transmissions via satellite, on juvenile Steller sea lions in the northern Gulf of Alaska, and detected 5 acute mortality events which they attributed to at-sea predation.

In the first satellite-tagging of beaked whales, Schorr et al. (2009) monitored the island-associated movements of 8 Blainville's beaked whales around Hawaii, including within naval training areas where they are particularly vulnerable to naval sonar. Biologging is likely to play an increasingly important role in determining human impacts on marine species and developing mitigation plans. Baird et al. (2010) compared the movements of 2 stocks of false killer whales near Hawaii, finding habitat overlap between the the offshore population and the smaller, insular population. Green et al. (2009) used implanted data loggers on Australasian gannets to estimate the energetic costs of plunge diving, using heart rate as a proxy for metabolic rate.

Animals as environmental sensors

Biologging tools have reached sufficient sophistication and reliability that the data collected is often equivalent to industry standards for environmental sampling (Costa et al. 2010a,b). This has led to profound advancements in the marine realm, where the sheer vastness, in 3 dimensions, limits our ability to observe. The feasibility of marine animals to record oceanographic data and be utilized as autonomous ocean profilers has been proven by deployments of conductivity-temperature-depth (CTD) tags on a variety of marine species (Block et al. 2002, Charrassin et al. 2002, 2008, Lydersen et al. 2002, Hooker & Boyd 2003, McMahon et al. 2005, Campagna et al. 2006, Biuw et al. 2007, Costa 2007, Boehme et al. 2008a,b). Elephant seals, for example, can sample the water column 60 times a day, reaching depths of 1000 m under their own power across broad expanses of the ocean that are difficult to reach by ship or other conventional means (Boehlert et al. 2001, Simmons et al. 2009). Thus, the research subjects become research tools that can provide oceanographic data for a fraction of the costs and in remote regions where conventional methods are not practical (Shaffer et al. 2006, Costa et al. 2010a,b). A significant advantage of tag-collected data is that they are collected at a scale and resolution that matches the animals' behavior. Large field programs like TOPP have built the capacity for, and have demonstrated the efficacy of, an ocean-scale biologging program that is essential for monitoring and sustaining the health of marine ecosystems (Block et al. 2010, Costa et al. 2010a,b). Data from TOPP and other biologging programs are now being incorporated into global ocean databases (e.g. Boehlert et al. 2001) and assimilated into ocean general circulation models.

Many of the papers presented at the symposium described the environmental characteristics of the habitats utilized by their study animals. Four examples in this Theme Section, from pinnipeds, a reptile, and a fish, demonstrate the utility of biologging to characterize ocean habitat and obtain critical subsurface ocean data. Simmons et al. (2010) describe habitat selection and foraging behavior in satellite-tracked northern elephant seals over a vast region of the North Pacific transition zone, while Lander et al. (2010) characterize the small-scale thermal variability associated with foraging effort of satellite-tagged juvenile Steller sea lions. Swimmer et al. (2009) used pop-up satellite archival tags, with light-based and SST-corrected geolocation, to define the preferred thermal range and identify hot spots for olive ridley turtles in the eastern tropical Pacific. Finally, Wilson & Block (2009) describe the oceanographic characteristics of foraging hot spots for Atlantic bluefin tuna equipped with conventional and pop-up satellite archival tags.

Applications to conservation

In addition to providing critical information on the movements and behaviors of a variety of animals, biologging data are increasingly being applied to management and conservation policy (Peckham et al. 2007, Burger & Shaffer 2008, Shillinger et al. 2008, Witt et al. 2008, Greene et al. 2009, McClellan et al. 2009). The use of biologging tools for the conservation of threatened and endangered species was, in fact, a principal theme of the symposium. Many of the papers in this volume discuss the implications of biologging data to the conservation of their tagged species, including several papers that focus on sea turtles. Cuevas et al. (2008) characterize the migratory patterns and feeding grounds of post-nesting female hawksbill turtles tagged on the Yucatan Peninsula, Mexico, while McClellan & Read (2009) used sonic and satellite telemetry to determine the vulnerability of juvenile green turtles to incidental capture in an artisanal gill net fishery off the coast of North Carolina, USA. Schofield et al. (2009) used GPS loggers and conventional ARGOS transmitters on loggerhead turtles within the National Marine Park of Zakynthos, Greece, in the eastern Mediterranean, to advise conservation measures, policies and legislation on both a local and regional scale. Shillinger et al. (2010) characterize interannual variability of the high-use internesting habitats of female leatherback turtles tagged at Playa Grande, Costa Rica, and evaluate the efficacy of a local marine protected area in protecting these turtles. Okuyama et al. (2010) compared the movements and foraging behaviors of wild vs. head-started (a type of reintroduction program) hawksbill turtles using ultrasonic telemetry and found that the head-started animals did not undergo homing migrations or seek adequate shelter for resting, suggesting the need for pre-release training in reintroduction programs.

In a marine conservation application to a cetacean species, Rayment et al. (2009) applied passive acoustic monitoring with a T-POD to determine the distributions of 4 dolphin species in the genus *Cephalorhynchus* in the Banks Peninsula Marine Mammal Sanctuary, New Zealand. Each of these species have small populations and restricted coastal distributions and are therefore vulnerable to fisheries bycatch.

Not all manuscripts focus on the marine realm. Pillans et al. (2009) used acoustic tags to record the short-term movements and distribution of critically endangered river sharks *Glyphis* spp. in northern Australia, and discuss the need for national recovery plans for these species. In a terrestrial biologging application, Peters et al. (2009) used radio tracking to determine the home ranges of European minks that have been reintroduced in a nature reserve in Saarland, Germany. Finally, Inman et al. (2009) used radio-transimitters and miniature dataloggers to track the distribution and nanoclimate surrounding threatened Mohave desert tortoises, and use this information to provide improved population estimates for recovery plans.

THE FUTURE OF BIOLOGGING SCIENCE

Although biologging science is advancing rapidly, particularly in the marine realm (Rutz & Hays 2009, Hart & Hyrenbach 2009), there are many challenges remaining. As Hooker et al. (2007) state, biologging 'lies at the interface between scientific enquiry and technological feasibility'. Technological limitations include the ability to increase battery life, miniaturize electronics, develop inexpensive silicone-based technologies (ASIC), increase the rate of data transmission to satellites, reduce the error associated with geolocations, develop alternate data recovery methods, and improve methods to infer animal behavior from tag data. Increased sensor capabilities on electronic tags (e.g. dissolved oxygen, pH, or chlorophyll on marine tags) would greatly improve our ability to characterize critical habitats. In addition, we are only beginning to contemplate the impacts of climate change on the distribution and survival of apex predators, and the vulnerability or resilience of ecosystems impacted by natural and anthropogenic forces. As evident in this collection of papers, the biologging community is pushing hard against these boundaries, and offers the most sophisticated tools for assessing the function and stability of ecosystems on a dynamic planet. In the future, data from biologging studies should play a strong role in conservation management, for example in marine spatial planning, and assessing and reducing human impacts on marine species. We look forward to the exciting new advances that will be presented at the Fourth International Conference on Biologging Science, to be hosted by Commonwealth Scientific and Industrial Research Organization (CSIRO) in Hobart, Tasmania, Australia, March 14–18, 2011 (www.cmar.csiro.au/biologging4).

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