New frontiers in biologging science

Christian Rutz1,* and Graeme C. Hays2

1Department of Zoology, University of Oxford, South Parks Road, Oxford OX1 3PS, UK
2Department of Biological Sciences, Institute of Environmental Sustainability, Swansea University, Singleton Park, Swansea SA2 8PP, UK
*Author for correspondence (christian.rutz@zoo.ox.ac.uk).

The term ‘biologging’ refers to the use of miniaturized animal-attached tags for logging and/or relaying of data about an animal’s movements, behaviour, physiology and/or environment. Biologging technology substantially extends our abilities to observe, and take measurements from, free-ranging, undisturbed subjects, providing much scope for advancing both basic and applied biological research. Here, we review highlights from the third international conference on biologging science, which was held in California, USA, from 1 to 5 September 2008. Over the last few years, considerable progress has been made with a range of recording technologies as well as with the management, visualization, integration and analysis of increasingly large and complex biologging datasets. Researchers use these techniques to study animal biology with an unprecedented level of detail and across the full range of ecological scales—from the split-second decision making of individuals to the long-term dynamics of populations, and even entire communities. We conclude our report by suggesting some directions for future research.

Keywords: animal tracking and telemetry; climate change; fastloc GPS; meta-analysis; overall dynamic body acceleration (ODBA); state space model

1. INTRODUCTION

Studying wild animals in their natural environments often presents major challenges to field biologists. Many species are shy and avoid humans, while others live in habitats where direct observation is difficult or impossible. Biologging technology seeks to overcome these problems by enabling the remote measurement of data for free-ranging, undisturbed subjects (Cooke et al. 2004; Ropert-Couzet & Wilson 2005). Over the past five decades, miniaturized animal-borne tags have been developed to record spatio-temporal movements of wild animals, aspects of their behaviour and physiology or properties of their environments. Data are relayed to receivers (ground-operated or satellites) and/or stored on-board the device for future transmission or download (so-called dataloggers).

Biologging applications have permitted important, and often surprising, insights into the lives of many species, including mammals, birds, fishes and even invertebrates, substantially advancing both basic and applied research.

Here, we present a brief meeting report for the third international conference on biologging science, which was held from 1 to 5 September 2008 in Pacific Grove, California (USA), co-hosted by Tagging of Pacific Pelagics (TOPP) and Tag-A-Giant Foundation. The conference showcased the discipline’s latest technological and conceptual advances, and their field application, focusing (for historical reasons; §3) on marine study systems (see table S1 in the electronic supplementary material). We review some of the highlights, provide essential context by discussing recent developments in terrestrial biologging science, and provide directions for future research.

2. MAJOR THEMES

We attempted to identify topics that are currently perceived as important and exciting by a large proportion of the community, and quantified trends by conducting systematic keyword searches in abstracts submitted to the first three biologging conferences (table 1; see table S2 in the electronic supplementary material). Throughout the report, we quote conference papers by citing authors’ names and the respective page numbers from the abstract booklet (see 3rd International Biologging Science Symposium in the electronic supplementary material).

One of the field’s key interests remains quantitative movement analysis (Nathan 2008). Knowing where an animal is, in space and time, can provide important indirect information about its behaviour, ecology and social interactions. The ability to map movements has increased dramatically over the last few years (fast-tracking global positioning system (GPS); §2a), and is further enhanced through novel analysis tools (e.g. state-space models; §2b). To an increasing extent, however, researchers wish to know what animals do along those movement trajectories (table 1c)—how they pursue prey, interact with conspecifics and manage their energy budgets (body accelerometers, video cameras; §2a,b). With improving tagging technologies, biologging datasets become increasingly large and complex, but much progress has been made with data management, visualization, integration and analysis (§2b). Taken together, these advances enable researchers to study wild, free-ranging animals with exceptional detail, and across the full range of ecological scales (§2c).

(a) Tagging technology

Thirty years ago, direct tracking of marine species was still achieved by visually following balloons towed by animals (Hays p. 33). We have come a long way since. Following first applications of very-high-frequency radio technology in the 1970s, satellite tracking of animals became routine in the 1980s using the Argos system, which provided animal locations to within a few hundred metres (table 2). However, a long-standing Achilles heel for marine studies was that, for animals that surface only briefly (e.g. seals or turtles), there was insufficient time to
For some applications—for example, where high sensor sampling rates create large amounts of data—storing of information on-board the tag may be preferable to its transmission. One such data logging technology is currently attracting a lot of interest (table 1a): accelerometers for recording energy expenditure, activity budgets (ethograms) and/or rare behavioural events (such as prey captures). State-of-the-art tags can measure body acceleration in up to three dimensions, yielding datasets with high information content for subsequent decoding (§2b). Accelerometers are often integrated with other technologies to obtain complementary data (video, Davis et al. p. 23; audio, Tyack p. 77). A remarkable breakthrough is the construction of matchbox-sized ‘daily diary’ tags, which offer, in addition to a triaxial accelerometer, sensor readings on 11 other channels (Wilson et al. 2008). Geolocator tags and heart-rate loggers remain important, well-tested research tools, and considerable miniaturization has now been achieved with two emerging technologies: neurologgers (Vyssotski et al. 2006) and video/still-image loggers (Rutz & Bluff p. 65; Takahashi et al. p. 73). Finally, novel ‘business card’ tags exchange information with other nearby tags and base stations (Holland et al. p. 34; Rutishauser et al. p. 65), and could facilitate assigning physical proximity of tagged subjects, e.g. for analyses of social networks or predator–prey interactions (for a terrestrial application, see Princeton University’s ‘ZebraNet’).

For further details, see tables S1 and S2 in the electronic supplementary material.)
(b) Data management and analysis
With an increasing number and sophistication of sensors, and growing battery life and memory capacity, biologging tags create large datasets that require customized software for management and analysis. A daily diary tag, for example, will accumulate approximately 650 million data points per deployment (Wilson et al. 2008). A string of presentations introduced innovative ways of managing (e.g. Hartog et al. p. 32) and visualizing such large data volumes (e.g. Blight & Fedak p. 15; freeware Mamvisad, http://www.smrast-andrews.ac.uk/Software/MamVisAD/). Recurring issues were also the necessity for data compatibility to facilitate collaborative projects, and the question of whether future tags could incorporate (enhanced) processing capabilities that would allow them to pre-analyse data, discarding erroneous or unwanted records.

Interpretation of animal movement patterns remains a fast-moving area. Simple descriptions of movements can be highly informative, but embedding analyses into a more quantitative framework is preferable, as it enables objective comparison across individuals and species. For example, first passage-time analysis identifies areas of focused use by animals (Guinet et al. p. 30; Kappes et al. p. 40; Weng et al. p. 80), state-space models (e.g. Johnson & Kuhn p. 37; Patterson et al. p. 58; Schick et al. p. 68) delineate different behaviours occurring within tracks, and analyses of step lengths and turn angles can help uncover the search strategies employed by foraging animals (Sims et al. 2008).

While the basic rationale of most biologging applications is simple, interpretation of raw data can prove challenging. It was our impression that the current interest in accelerometer applications (§2a) is primarily due to the recent development of analytical tools, which promise major advances in: (i) the calculation of (activity-specific) energy expenditure (using overall dynamic body acceleration; Gleiss et al. p. 27; Halsey et al. p. 30; Kabat & Butler p. 39), and (ii) the automated construction of ethograms (using wavelet transformations; Naito et al. p. 56; Sakamoto et al. p. 66; Sato et al. p. 67; Suzuki et al. p. 72; Watanabe & Sato p. 80; cf. Gadenne et al. p. 25; freeware Ethographer, http://bre.soc.i.kyoto-u.ac.jp/bls/). Critical calibration experiments are underway, and we anticipate a surge of field studies, once these new analysis techniques are firmly established.

(c) Research themes and conceptual approaches
Numerous presentations highlighted the scientific value of large-scale biologging programmes (see table S3 in the electronic supplementary material). One of the meeting’s co-hosts (TOPP, Block et al. p. 16), for example, has accumulated some 4000 tag deployments on 23 species, producing exceptional insights into the ecology of an ocean’s predator community. Another initiative (not represented at this conference) has the ambitious goal to launch a dedicated satellite for tracking small animals globally (ICARUS; see table S3 in the electronic supplementary material). At the same time, however, this conference reminded us that biological research demands enquiry across scales—from the deployment of a few tags for detailed behavioural studies to continental-scale collaborations that are capable of examining population-level phenomena (§3).

Global climate change and its potential implications for animal conservation receive considerable attention from the biologging community (table 1c) and were treated in a dedicated session. Apart from studying the animals’ response to changing climatic conditions, important work is underway, which uses marine animals as ‘oceanographers’ to sample environmental data in areas that are currently not covered by survey networks, or in habitats where conventional measurement techniques fail (Block et al. p. 16; Boehme et al. p. 16; Charrassin et al. p. 20; Roquet et al. p. 64).

Biologging is increasingly used for controlled experimentation with free-ranging animals (but see table 1b). While there is a strong tradition of such work in the field of animal physiology (Kooyman p. 43; Ponganis p. 61), it is only fairly recently that researchers have started using tagged subjects to examine experimentally their navigational abilities (through translocation experiments; Hays p. 33; Robinson et al. p. 63) or their response to anthropogenic stressors (e.g. response of whales to naval sonar; Mate p. 49; Tyack p. 77). It is also encouraging to see that a growing number of studies use high-quality biologging data for building predictive models (Boustany et al. p. 17) or for comparing life-history traits across species (Gadenne et al. p. 25; Sato et al. p. 67). We return to these approaches below, as we believe they hold much promise for future work.

3. SYNTHESIS AND OUTLOOK
It is not too difficult to predict the future of biologging science. Curious minds will produce new hypotheses, which will drive the development of increasingly sophisticated technology. Continued miniaturization of tags will require new battery technologies and increased memory capacity, and the accumulation of large, complex datasets will foster the development of powerful analytical techniques, similar to those employed in bioinformatics and computational biology (Davis 2008). We are confident that these challenges will be met as they arise—if not by biologging engineers, then by the large industries that cater for expanding global markets of communication and entertainment products. But these technological aspects aside, how could the field advance conceptually? We offer a few ideas below.

While this conference encouraged the participation of terrestrial biologists, there was nevertheless a strong bias towards marine studies (see table S1 in the electronic supplementary material). This is not surprising, given the field’s historical roots: it was marine biologists, after all, who pioneered many biologging technologies in their attempts to collect data from submerged study subjects. But the field has moved on since, and terrestrial ecologists have started embracing opportunities of collecting data remotely for species that are difficult, or impossible, to study
with conventional observation techniques (Cooke et al. 2004). In fact, the challenges presented by marine and terrestrial systems are very similar, and researchers in both fields have followed similar paths in developing efficient data-collection and analysis technologies. We encourage both communities to be more proactive in exchanging expertise, and believe that the forthcoming conference (to be hosted by CSIRO in Tasmania, Australia) could be an excellent starting point for future collaborations.

There is no doubt that biologging can provide precious insights into otherwise largely inaccessible biological systems, but we think it is at its best when integrated carefully into a holistic research programme that uses a suite of other methodologies. While this may be easier to achieve in most terrestrial studies, excellent recent examples have come from marine biology, where studies have used biologging technology to complement results from DNA analysis (Jorgensen et al. p. 38; Reeb et al. p. 62) or stable-isotope profiling (Henry-III et al. p. 33; Madigan et al. p. 47; Suryan et al. p. 72).

Biologging projects are often expensive and logistically challenging, limiting the number of tags that can be deployed by any given project. As illustrated by this conference, one of the common findings of biologging studies is that there is a staggering amount of variation—between animals, seasons and populations. This presents opportunities as well as challenges. The constraint of small sample sizes can be overcome elegantly by organizing large collaborative projects (§2c; see table S3 in the electronic supplementary material), but research efficiency can be enhanced further by exploring two main avenues. First, tagged subjects could be used for experimental work, either in dedicated projects or opportunistically after observational data have been collected for the undisturbed system. While a sample size of 6–12 subjects is small for a study that relies entirely on undisturbed system. While a sample size of 6–12 subjects is small for a study that relies entirely on observational data, it may help answer some of their most pressing research questions.

Special thanks to the conference organizers—Barbara Block, Dan Costa and Steven Bograd—and their team for preparing this meeting, and to the delegates for making it such a success. We thank S. Bograd, D. Costa, S. Hooker, G. Kooyman, Y. Naito and M. Wikelski for commenting on draft manuscripts, and the Cogito Foundation for funding (C.R.).


