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Editorial

Bio-logging science: Logging and relaying physical and biological data using animal-attached tags

Bio-logging can be defined as the theory and practice of logging and relaying of physical and biological data using animal-attached tags. Bio-logging technologies have become available relatively recently (i.e. within the last couple of decades) and continue to advance rapidly. Animal-attached tags are being applied to an increasingly wide range of study animals. In the marine environment, where it is almost impossible to directly observe individual animals over extended periods, the attachment of archival dataloggers and/or data relay devices is crucial to monitoring animal behaviour beneath the water surface or in the open ocean. An understanding of such behaviour is in turn imperative for the assessment and understanding of the role of these animals within the wider biophysical systems in which they operate, and for an appreciation of their sensitivity to environmental change.

The papers in this volume were contributed following presentation at the Second International Conference on Bio-logging Science that took place at the University of St Andrews, UK during 13–16 June 2005. This symposium followed the inaugural meeting held at the Japanese Institute of Polar Research in Tokyo in March 2003, which brought together approximately 150 scientists and engineers from around the world (Naito et al., 2004). At that time it was decided to continue this meeting regularly, and, in the spirit of the first meeting, it was believed that attendance from researchers working on a diversity of taxa (fish, amphibians, birds and mammals) would help promote the exchange of ideas and new developments that otherwise can be lost at more specific meetings. Although these meetings are not exclusive to marine taxa, the majority of presentations have concerned marine animals. For the past 15 years, the Sea Mammal Research Unit (SMRU) has been at the forefront of the development of technologies and scientific methods for studying these aspects of marine mammal biology, and it was therefore natural for SMRU to host the second symposium. The 2005 symposium was attended by 172 scientists and engineers from all over the world, and 94 papers were presented.

As a science, bio-logging lies at the interface between scientific enquiry and technological feasibility. As was evident at the symposium, instrumentation continues to be improved in terms of the sophistication of the loggers themselves, with increasing data capacity and longevity, and with the availability of new sensors, methods of data recovery, and new frameworks and techniques for data analysis. We outline some of these improvements here.

The aim of Bio-logging 2005 was to provide a stimulating forum for the exchange of ideas and information among biological, engineering and computational fields. This collection of papers reflects a sample of the topics discussed at the symposium. As an introduction to this volume, we briefly summarise the overarching issues presented during the symposium and discuss in particular some of the new techniques that were presented in order that this information be included with this collection of papers. Some of this work has not yet been published but is nevertheless mentioned here to provide a flavour of the current state of bio-logging science.

1. Collection of data

The mainstay of bio-logging efforts has been the collection of data related to animal movements since this is crucial to the study of many aspects of behaviour and ecology (e.g., diving behaviour, flight

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patterns, foraging strategies, migration, attendance patterns, and distribution). Terrestrial studies, almost by definition, concentrate on movements in two dimensions. In aquatic studies the additional third dimension of depth is fundamental to the study of behaviour and ecology.

At a finer scale of movement, the incorporation of swim-speed sensors can provide information on dive geometry and swimming effort (Hassrick et al., 2007). The determination of buoyancy (at depth) based on dive geometry allows the estimation of animal condition (fat to lean ratio). Investigation of variation in buoyancy over time can then enable the determination of where and when animals actually gain energy at sea (Biuw et al., 2003). The development of accelerometers, which detect the rate of change of movement and can even record the acceleration due to individual flipper movements, has provided further increased resolution of movement data and allowed remarkable insights into locomotion and animal condition. Accelerometers have permitted the effects of buoyancy on swimming and gliding behaviour to be explored (Sato et al., 2003). These fine-scale studies can even infer the degree of lung inflation and how this varies with different behaviours (Sato et al., 2002). In flying animals, acceleration loggers can be used to investigate flying and gliding behaviours and thus variation in energy expenditure according to behavioural budgets.

A major difficulty in the interpretation of information obtained by biologging is the allocation of function to observed behaviour. This is particularly true for the inference of feeding—knowing where and when animals feed at a fine scale is often one of the primary reasons for embarking on telemetry studies (e.g., Garthe et al., 2007). If possible, researchers often wish to determine food types (Tinker et al., 2007). Stomach or oesophageal temperature probes can be used to record the passage of a cold food item, and thus infer feeding events (Bost et al., 2007). New techniques such as the use of magnetic sensors to record jaw angle show promise for demonstrating when, where and how much an animal consumes at each feeding event (Liebsch et al., 2007). Sensors to record stomach pH and acidity are being tested for large fish and also show promise for the study of feeding events (Papastamtiou et al., 2005).

Information about an animal's geographic location can be achieved via a range of methods. Tracks can be monitored in real time using VHF tags, estimated post hoc from stored sunset/sunrise times, or calculated in near real time using the Argos satellite system. Global positioning system (GPS) tags can also provide archived locations, and the recent development of fast acquisition GPS fixes (Fastloc) now even permits accurate location determination in animals that surface for only short periods.

Information about an animal's movements and behaviour are best interpreted in the context of its environment (see Weimerskirch, 2007). This aids the interpretation of behavioural data, in terms of understanding what features of the environment are important to animals, how they locate these features, and what happens when these features move. For marine animals, their immediate physical environment is well described by the collection of temperature and salinity data (Bailleul et al., 2007). Temperature, water salinity and depth information can be used to characterise the water masses animals encounter, and to derive measures of water flow and eddy activity. Such information is generally not available from remote ocean regions and seasons (such as polar waters in winter) due to a paucity of traditional ship-borne oceanographic surveys. Similarly, even in more accessible regions, oceanographic survey data may be collected at divergent scales, locations and times to that of bio-logging studies. The fact that such data can be collected from animals rather than needing large ship-based surveys, particularly in areas inaccessible to vessels, is also of increasing interest to the oceanographic community for inclusion into operational and forecasting models of ocean circulation and heat distribution (Fedak, 2005).

Our methods of perceiving an animal's environment may be different from the way that the animal actually perceives it. Efforts to obtain an animal's eye view of its environment have included the development of acoustic and video imaging tags to record what an animal hears and sees in conjunction with its movements (Akamatsu et al., 2007; Fuiman et al., 2007). Combining sensors in this way allows a virtual view of an animal's world, and we can record the sounds that an animal hears, a partial view of what it sees, the sounds it produces and movements that it makes in relation to prey capture, or movement in relation to conspecifics (Johnson and Tyack, 2003; Miller et al., 2004). Tags placed on multiple animals are furthermore providing an unprecedented view of the coordination of behaviour within animal groups. With the recent reduction in size of tags available, researchers can now instrument younger animals and look at the ontogeny of diving behaviour (e.g., Yoda et al., 2007).

The diving abilities and underwater performance of animals that have been observed have further led researchers to investigate the mechanisms underlying such performance, i.e. how it is achieved in terms of energetics, thermoregulation and physiological abilities (Ponganis, 2007). Increasingly sophisticated sensors are being developed to record aspects of animal physiology. Temperature probes are used at different internal locations in penguins to record the temperature differential across the body during diving (Schmidt et al., 2006). Heart-rate loggers are used to infer the oxygen consumption and metabolic rate during different behaviours, even year-round (Green et al., 2005). An oxygen probe inserted into the posterior airsac of diving penguins has even allowed monitoring of compression hypoxia and oxygen store depletion during dives (Stockard et al., 2005).

2. Data recovery

Whether the data collected by a tag are simply stored in memory or are relayed ashore has large consequences for the resolution of data that can be recovered. If there is a good chance of recovering a tag then data may simply be stored in memory for future retrieval. Improvements in memory storage capacity and battery life are now reducing the need to trade-off data resolution with study duration, and allowing the collection of relatively higher-resolution data over longer time intervals.

If data must be relayed ashore, it is usual to incorporate onboard compression. The Argos System is the usual data relay choice, primarily due to its in-built location determination system and its global coverage. The Argos satellite system is both a relay and positioning system, attempting the calculation of location of transmitters during the satellite uplinks. However, the demand for higher-resolution data has strained the current bandwidth capabilities of Argos. Although the Argos bandwidth will improve in the future, the GSM mobile phone system provides an alternative data 'store and forward' relay strategy for animals that, at least occasionally, come within coastal GSM coverage. GSM data relay is energy efficient and thus, for a fixed battery size, increases longevity (McConnell et al., 2004).

Using these systems, the critical factors driving study duration have been the longevity of the tag (optimised by low-power operation and high energy density batteries) and the longevity of the tag attachment. For pinnipeds the latter is usually governed by how long a tag will remain glued to the animal's fur. There is therefore also interest in the development of implantable tags with sufficient transmission potential to allow monitoring over periods of years, rather than the single field-season that externally glued devices allow. Among whale studies, the study duration has been related to how long a satellite tag will remain implanted (see Mate et al., 2007). A new approach under investigation is the development of a life-history transmitter that collects data during the life of an animal but upon the animal's death, becomes extruded and transmits the collected data to satellite (Horning and Hill, 2005). This pop-up approach is currently used in fish studies for which transmitters are implanted for a period of time and then released to float to the surface and transmit to satellite (Block et al., 2005).

3. Data analysis

Analysis of large and complex data sets collected using bio-logging techniques is a significant challenge to the field. There are several problems inherent to the collection of data from biological tags on individual animals and this received some attention during the symposium. Problems with data are primarily due to uncertainties in position estimates, and the inherent autocorrelation of collected data. State space approaches, such as Hidden Markov models, were suggested as a potential statistical tool to address some or all of these issues.

Further problems are generated by the scale at which data are collected and analysed. Among studies of location, scales range from the daily and imprecise locations obtained from geolocation tags (see Ekstrom, 2007), to the varying accuracy of positions obtained at intervals of several hours from the Argos System, to the potential high accuracy and high-resolution detailed tracks available from GPS tags. In the past, the acquisition time needed for GPS systems has prohibited their use for studies of diving animals, but recently developed rapid acquisition GPS tags are now making high accuracy position information available for species that surface for only short intervals. Different methods can be used to analyse the tracklines resulting from these positioning methods in terms of preferred foraging areas (Robinson et al., 2007; Bailleul et al., 2007). In addition, these positioning systems relate only to positions calculated for animals while at the water surface. While animals are underwater, surface positions can be supplemented by knowledge of speed, heading and change in depth such that underwater positions can be estimated by dead-reckoning (Wilson et al., 2007).

Satellite-derived oceanographic data allow us to characterise areas of high-usage and interpret animal movements. For instance, by analysing animal trajectories together with ocean currents estimated from satellite-derived sea level anomaly data, it is possible to examine in greater detail how animals allow for these currents when making navigational decisions.

4. Application to conservation

The identification of important foraging areas or high-usage areas can be crucial for identifying regions that may warrant special protection status. Increasingly, multi-species bio-logging studies are being used to identify 'hot-spots' of high-use within a region across species (e.g., Frydman and Gales, 2007). Similarly, the Tagging of Pacific Pelagics (TOPP) study simultaneously maps sharks, tuna, albatrosses, seals and whales across the North Pacific Ocean Basin (Block et al., 2002). By integrating predator movements with satellite remote sensing technologies the oceanographic features driving these biological hotspots can be identified. Such areas are increasingly of interest as potential reserves (Hooker and Gerber, 2004). Furthermore, such information, in coordination with proposed fishery effort can be used to identify areas of likely by-catch and to plan appropriate mitigation measures. Bio-logging information can also be used to link behavioural differences to population dynamics, which is of particular concern when a population is at risk (e.g., Call et al., 2007).

5. Ethical concerns

A concern among all bio-logging studies, whether explicit or implicit, is the effect of logger attachment on the behaviour of the study animal. It is pointless to conduct any study of behaviour if the collection process itself causes aberrant behaviour. Size and position of any logger may affect the hydrodynamic drag or the thermal consequences for the study animal (Ropert-Coudert et al., 2007; McCafferty et al., 2007). The hydrodynamic shape and mechanical properties of a tag will also have an effect and consideration of these particularly with reference to the anatomical structure to which they are attached will be important (Pavlov et al., 2007). Analysis of the recorded behaviour may also demonstrate aberrant behaviour during the short interval immediately following tag deployment.

During the symposium, participants discussed the need for an informal code of practice for Bio-logging Science, but several such recommendations already exist for other societies and it was pointed out that additional recommendations were not needed within this group. However, participants agreed that in the interests of best practice, the sharing of techniques (particularly those that did not work and so were unlikely to be published!) should be encouraged, so that researchers were not continually 'reinventing the wheel.'

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