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*Meeting report*

# New frontiers in biologging science

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**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-Coudert & 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.

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## 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); §2*a*), and is further enhanced through novel analysis tools (e.g. state-space models; §2*b*). To an increasing extent, however, researchers wish to know what animals do along those movement trajectories (table 1*c*)—how they pursue prey, interact with conspecifics and manage their energy budgets (body accelerometers, video cameras; §2*a*,*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 (§2*b*). Taken together, these advances enable researchers to study wild, free-ranging animals with exceptional detail, and across the full range of ecological scales (§2*c*).

### (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

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Table 1. Use of selected keywords in abstracts (talks and posters) submitted to the first three biologging conferences. (Where appropriate, keywords were searched for in all possible forms of spelling (e.g. behaviour/behavior) and grammatical usage (i.e. as verb, adjective, adverb and noun). Results are shown as the percentage of abstracts that contained a particular keyword at least once, and trends are indicated with symbols (new, new technology; ∼, no clear trend; +, increase; −, decrease). ODBA, overall dynamic body acceleration. For further details, see tables S1 and S2 in the electronic supplementary material.)

| | | conference | | |
|---|---|---|---|---|
| categories and keywords | trend | 2003 | 2005 | 2008 |
| (a) *tagging technology* | | | | |
| satellite (tracking, not remote sensing) | ∼ | 25.0 | 29.0 | 22.4 |
| Argos | ∼ | 8.0 | 14.0 | 10.5 |
| GPS | + | 6.0 | 9.7 | 14.7 |
| Fastloc | new | n.a. | n.a. | 6.3 |
| acceler* (as in accelerometer) | + | 14.0 | 16.1 | 20.3 |
| (b) *analysis and research approach* | | | | |
| state* (as in state-space model) | + | 0.0 | 2.2 | 5.6 |
| ODBA | new | n.a. | n.a. | 2.1 |
| hypoth* (as in hypothesis) | + | 4.0 | 9.7 | 10.5 |
| model* (as in theoretical model)[a] | + | 16.0 | 17.2 | 23.1 |
| experim* (as in experiment)[b] | ∼ | 10.0 | 9.7 | 9.1 |
| calibr* (as in calibration)[b] | + | 1.0 | 2.2 | 4.9 |
| (c) *research topics* | | | | |
| physiol* (as in physiology) | − | 17.0 | 12.9 | 10.5 |
| behav* (as in behaviour) | + | 52.0 | 64.5 | 66.4 |
| forag* (as in foraging) | + | 41.0 | 47.3 | 48.3 |
| habitat | + | 13.0 | 11.8 | 33.6 |
| conserv* (as in conservation biology) | + | 4.0 | 4.3 | 9.1 |
| climat* (as in climate change)[c] | + | 0.0 | 1.1 | 7.0 |

[a] This includes references to theoretical, mathematical and statistical models.

[b] The authors' own judgement is accepted of what constitutes an 'experiment' or a 'calibration', respectively.

[c] This only includes cases that explicitly mention 'change' or 'changing'; for results of a broader search, see table S2 in the electronic supplementary material.

Table 2. A comparison of the accuracy of conventional Argos satellite tracking versus Fastloc GPS tracking (http://www.wildtracker.com/performance.htm). (Accuracy refers to the standard deviation of positions around the actual location.)

| Argos | | Fastloc GPS | |
|---|---|---|---|
| Argos location class | accuracy (m) | Fastloc satellites detected | accuracy (m) |
| 0 | >1000 | 4 | 138 |
| 1 | 1000 | 5 | 64 |
| 2 | 350 | 6 | 40 |
| 3 | 150 | 7 | 27 |
| | | 8 | 22 |
| | | 9 | 19 |
| | | ≥10 | 17 |

generate GPS locations. Two solutions to this problem have now been devised, TrackTag and Fastloc, allowing rapid acquisition of GPS ephemeris (less than 60 ms); once fixes have been obtained, data are stored and can later be relayed remotely via satellite or mobile-phone networks. These novel, fast-tracking GPS technologies are opening up exciting possibilities to track marine animals for extended time periods and to assess micro-scale patterns of space use (§2*b*). With a first wave of field projects in progress (6.3% of abstracts mentioned Fastloc; table 1) and promising results from performance tests (table 2; Costa *et al.* p. 21; Goebel *et al.* p. 27), we anticipate much future work in this area.

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 1*a*): 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 (§2*b*). 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: neuro-loggers (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 assaying 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').

### (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.smru.st-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 (§2*a*) 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 1*c*) 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 1*b*). 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 (§2*c*; 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 interpreting correlational evidence, it will often be sufficient for a well-planned experiment. The success of such work (§2*c*) illustrates how researchers can maximize the biological insight gained per tag deployed in the field. Second, existing datasets could be used for robust meta-analytical work. Taken together, small-scale projects have deployed thousands of tags over the last few decades, across species and continents, creating a 'data gold mine' that has remained largely untapped. Notwithstanding first studies (e.g. Sims *et al.* 2008) and some excellent attempts to facilitate data sharing (e.g. with the new data repository 'Movebank'; see table S3 in the electronic supplementary material), we believe that the potential of meta-analyses, of either published results or collated original datasets, is currently underexploited by the biologging community.

We wish to conclude by encouraging those biologists, who have not yet used biologging in their studies, to explore the rich tool kit that is now available, as 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.).

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Electronic supplementary material

# New frontiers in biologging science

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## SUPPLEMENTARY TABLES

Table S1. Summary statistics for the third international conference on biologging science (Biologging III), and two earlier meetings. Three (non-independent) measures indicate that collaborative projects in this field have been increasing in size. The focus of the meetings remained on marine applications (*cf.* §1 and §3). Note that all information was extracted from the conferences' abstract booklets, i.e., late changes could not be considered (e.g., for Biologging III, 100 talks are included in the booklet, but only 96 were delivered).

| | Biologging I | Biologging II | Biologging III[a] |
|---|---|---|---|
| year | 2003 | 2005 | 2008 |
| location | Tokyo, Japan | St. Andrews, UK | Pacific Grove, USA |
| sessions (talks only) | 7 | 6 | 8[b] |
| abstracts (talks/posters) | 100 (52/48) | 93 (53/40) | 143 (100/43) |
| authors per abstract (median, mean ± SE)[c] | 3.0, 3.4 ± 0.2 | 4.0, 4.2 ± 0.3 | 5.0, 5.1 ± 0.3 |
| affiliations per abstract (median, mean ± SE)[d] | 2.0, 2.1 ± 0.1 | 2.0, 2.5 ± 0.2 | 3.0, 2.8 ± 0.1 |
| authors per affiliation (median, mean ± SE)[e] | 1.5, 1.7 ± 0.1 | 1.5, 1.9 ± 0.1 | 2.0, 2.0 ± 0.1 |
| abstracts mentioning study system | 92 | 89 | 137 |
| of which aquatic[f] | 75% | 85% | 85% |
| of which flying sea birds | 20% | 13%[h] | 9%[h] |
| of which terrestrial[g] | 5% | 1% | 6% |

[a] The conference was attended by 209 delegates from 20 different nations (D. Kohrs, pers. comm.).

[b] Session topics: (1) biologging and climate change; (2) monitoring organismal physiology; (3) linking ecology and oceanography; (4) new frontiers in biologging data analysis and visualization; (5) new frontiers in electronic tag technology; (6) conservation and management applications of biologging science; (7) at sea observation and laboratory modelling of animal behaviour; (8) marine life and ocean observatory networks.

[c] Kruskal-Wallis test, $H_2 = 23.16$, $p < 0.0001$; *post-hoc* Mann-Whitney *U*-tests are significant, at a Bonferroni-corrected $\alpha = 0.017$, for I *vs.* III and II *vs.* III.

[d] This count includes multiple, and new, affiliations of authors. Kruskal-Wallis test, $H_2 = 13.17$, $p = 0.001$; a *post-hoc* Mann-Whitney *U*-test is significant, at a Bonferroni-corrected $\alpha = 0.017$, for I *vs.* III.

[e] This statistic is based on dividing, for each abstract, the number of authors by the number of affiliations. Kruskal-Wallis test, $H_2 = 7.72$, $p = 0.021$; a *post-hoc* Mann-Whitney *U*-test is significant, at a Bonferroni-corrected $\alpha = 0.017$, for I *vs.* III.

[f] Abstracts are only considered if they make unambiguous reference to aquatic study systems (species mentioned; empirical data mentioned; broader discussion/review); this category combines marine and freshwater systems and includes penguins.

[g] Abstracts are only considered if they make unambiguous reference to terrestrial study systems; this category includes one abstract on polar bears.

[h] If abstracts are added here that mention both aquatic and sea-bird systems, the values increase to 16% (II) and 11% (III), respectively.

Table S2. Full results of a keyword search conducted with the abstract booklets of the first three biologging conferences (2003, Toyko, Japan, $n$ = 100 abstracts; 2005, St. Andrews, UK, $n$ = 93 abstracts; 2008, Pacific Grove, USA, $n$ = 143 abstracts). For further details on methodology, see caption and footnotes of table 1. Each table cell contains three values: (i) percentage of titles that contained a particular keyword at least once; (ii) percentage of abstracts that contained a particular keyword at least once; and (iii) number of times a keyword was mentioned in abstracts that contained that keyword.

| categories and keywords | conference | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2003 | | | 2005 | | | 2008 | | |
| | i | ii | iii | i | ii | iii | i | ii | iii |
| (*a*) tagging technology | | | | | | | | | |
| *satellite* (tracking, not remote sensing) | 10.0 | 25.0 | 1.6 | 7.5 | 29.0 | 1.4 | 2.8 | 22.4 | 1.6 |
| *Argos* | 1.0 | 8.0 | 1.4 | 3.2 | 14.0 | 1.2 | 4.9 | 10.5 | 2.8 |
| *GPS* | 4.0 | 6.0 | 2.3 | 2.2 | 9.7 | 2.0 | 7.7 | 14.7 | 2.8 |
| *Fastloc* | n/a | n/a | n/a | n/a | n/a | n/a | 1.4 | 6.3 | 1.6 |
| *acceler** (as in accelerometer) | 4.0 | 14.0 | 1.9 | 3.2 | 16.1 | 1.6 | 8.4 | 20.3 | 2.7 |
| *video* (animal-borne imaging) | 2.0 | 5.0 | 2.4 | 1.1 | 3.2 | 2.0 | 1.4 | 2.1 | 4.3 |
| *camera* (animal-borne imaging) | 1.0 | 7.0 | 1.4 | 0.0 | 3.2 | 1.7 | 2.1 | 2.8 | 2.0 |
| *imag** (animal-borne imaging) | 1.0 | 2.0 | 5.0 | 2.2 | 2.2 | 3.5 | 0.0 | 1.4 | 2.5 |
| *CTD* | 0.0 | 2.0 | 1.5 | 1.1 | 2.2 | 2.5 | 2.8 | 6.3 | 1.9 |
| *SRDL* | 0.0 | 2.0 | 1.5 | 0.0 | 2.2 | 1.0 | 0.7 | 3.5 | 2.4 |
| (*b*) analysis and research approach | | | | | | | | | |
| *state** (as in state-space model) | 0.0 | 0.0 | n/a | 0.0 | 2.2 | 1.0 | 0.7 | 5.6 | 1.1 |
| *ODBA* | n/a | n/a | n/a | n/a | n/a | n/a | 0.0 | 2.1 | 4.3 |
| *hypoth** (as in hypothesis) | 0.0 | 4.0 | 1.5 | 0.0 | 9.7 | 1.1 | 0.0 | 10.5 | 1.3 |
| *model** (as in theoretical model) | 2.0 | 16.0 | 1.8 | 1.1 | 17.2 | 1.6 | 4.2 | 23.1 | 2.2 |
| *experim** (as in experiment) | 0.0 | 10.0 | 1.5 | 0.0 | 9.7 | 1.0 | 1.4 | 9.1 | 1.5 |
| *calibr** (as in calibration) | 0.0 | 1.0 | 1.0 | 0.0 | 2.2 | 1.0 | 0.0 | 4.9 | 1.6 |
| *automat** (as in automated analysis) | 0.0 | 3.0 | 1.3 | 0.0 | 4.3 | 1.0 | 0.7 | 2.8 | 1.8 |
| (*c*) research topics | | | | | | | | | |
| *physiol** (as in physiology) | 2.0 | 17.0 | 1.4 | 4.3 | 12.9 | 1.3 | 2.8 | 10.5 | 1.3 |
| *behav** (as in behaviour) | 23.0 | 52.0 | 2.1 | 20.4 | 64.5 | 2.2 | 14.7 | 66.4 | 2.2 |
| *forag** (as in foraging) | 18.0 | 41.0 | 2.9 | 17.2 | 47.3 | 3.8 | 12.6 | 48.3 | 3.2 |
| *habitat* | 4.0 | 13.0 | 2.2 | 1.1 | 11.8 | 1.5 | 9.8 | 33.6 | 2.3 |
| *conserv** (as in conservation biology) | 0.0 | 4.0 | 1.3 | 1.1 | 4.3 | 1.5 | 2.1 | 9.1 | 1.2 |
| *climat** (as in climate change) | 0.0 | 0.0 | n/a | 0.0 | 1.1 | 2.0 | 0.0 | 7.0 | 1.2 |
| *climat** (as in macro climate) | 0.0 | 2.0 | 1.0 | 1.1 | 2.2 | 2.5 | 0.0 | 11.2 | 1.4 |
| *predat** (as in predation) | 2.0 | 12.0 | 1.4 | 0.0 | 16.1 | 1.6 | 5.6 | 18.9 | 2.1 |
| *ecol** (as in ecology) | 5.0 | 16.0 | 1.2 | 3.2 | 9.7 | 1.2 | 4.2 | 24.5 | 1.3 |
| *welfare* | 1.0 | 1.0 | 4.0 | 0.0 | 0.0 | n/a | 0.0 | 0.0 | n/a |
| *ethic** (as in ethical issues) | 0.0 | 1.0 | 1.0 | 0.0 | 1.1 | 1.0 | 0.0 | 0.0 | n/a |

Table S3. A selection of large-scale collaborative biologging projects (listed in alphabetical order).

| project acronym | project name | abstract (page) | website (www) |
|---|---|---|---|
| AATAMS | Australian Acoustic Tracking and Monitoring System | 35 | n/a |
| ACT | Atlantic Cooperative Telemetry | 24 | n/a |
| ARTS | Automated Radio Telemetry System | n/a | princeton.edu/~wikelski/research |
| CFTC | California Fish Tracking Consortium | n/a | n/a |
|  | Codyssey | 6 | codyssey.co.uk |
| EELIAD | European Eels in the Atlantic: Assessment of Their Decline | 6 | eeliad.com |
| FACT | Florida Atlantic Coast Telemetry Project | n/a | n/a |
| ICARUS | International Cooperation for Animal Research Using Space | n/a | IcarusInitiative.org |
|  | Movebank | n/a | movebank.org |
| OTN | Ocean Tracking Network | 24, 37, 57 | oceantrackingnetwork.org |
| POST | Pacific Ocean Shelf Tracking Project | 37, 57 | postcoml.org |
| TAG | Tag-A-Giant Foundation | 1 | tagagiant.org |
| TOPP | Tagging of Pacific Pelagics | e.g., 1, 16 | topp.org |