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Finding our way: On the sharing and reuse of animal telemetry data in Australasia

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HIGHLIGHTS

- Details the breadth and depth of animal telemetry research in Australasia
- Less than half of all telemetry research has been published
- Less then 8 % of telemetry data is discoverable
- Provides direction to enhance data sharing across the discipline

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ABSTRACT

The presence and movements of organisms both reflect and influence the distribution of ecological resources in space and time. The monitoring of animal movement by telemetry devices is being increasingly used to inform management of marine, freshwater and terrestrial ecosystems. Here, we brought together academics, and environmental managers to determine the extent of animal movement research in the Australasian region, and assess the opportunities and challenges in the sharing and reuse of these data. This working group was formed under the Australian Centre for Ecological Analysis and Synthesis (ACEAS), whose overall aim was to facilitate trans-organisational and transdisciplinary synthesis. We discovered that between 2000 and 2012 at least 501 peer-reviewed scientific papers were published that report animal location data collected by telemetry devices from within the Australasian region. Collectively, this involved the capture and electronic tagging of 12 656 animals. The majority of studies were undertaken to address specific management questions; rarely were these data used beyond their original intent. We estimate that approximately half (~500) of all animal telemetry projects undertaken remained unpublished, a similar proportion were not discoverable via online resources, and less than 8.8% of all animals tagged and tracked had their data stored in a discoverable and accessible manner. Animal telemetry data contain a wealth of information about how animals and species interact with each other and the landscapes they inhabit. These data are expensive and difficult to collect and can reduce survivorship of the tagged individuals, which implies an ethical obligation to make the data available to the scientific community. This is the first study to quantify the gap between telemetry devices placed on animals and findings/data published,

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and presents methods for improvement. Instigation of these strategies will enhance the cost-effectiveness of the research and maximise its impact on the management of natural resources.

1. Introduction

Animal movement reflects and influences the distribution of ecological resources in space and time (Brown et al., 2013). Understanding movement assists in assessing how animal populations and ecosystems may respond to natural (e.g. climatological, geomorphological) and anthropogenic (e.g. habitat loss and disturbance) changes, and as a consequence, there is a growing body of research investigating the causes, mechanisms, patterns and impacts of animal movement (Nathan et al., 2008). The advent of satellite-based animal telemetry, combined with advances in receiver technology, battery-life, and miniaturisation, has dramatically increased the duration, frequency, and accuracy by which researchers and resource managers can record observations from free-ranging animals (Tomkiewicz et al., 2010). This has resulted in a proliferation of studies utilising animal-borne devices, and throughout Australasia many species have had their movements recorded.

National collaborative cyber-research infrastructures (e.g. DataONE (USA), Dryad (UK), Terrestrial Ecosystem Resource Network (Australia)) are enhancing scientific innovation in the environmental and ecological sciences through the discovery, sharing and reuse of environmental data (Hampton et al., 2012, 2013). A search of these national data repositories however, reveals that collections of animal telemetry data are poorly represented, and the current number of projects using collaborative infrastructure framework does not reflect the high usage of animal-borne devices by the ecological community. A working group, sponsored by the Australian Centre for Ecological Analysis and Synthesis (ACEAS), was convened in 2012 to bring together field biologists, resource managers, statisticians, modellers and policy makers to discuss this issue and assess the opportunities and challenges for the sharing and reuse of animal telemetry data via national collaborative cyber-infrastructures.

Our first objective was to characterise the variety and frequency of animal telemetry research throughout Australasia and quantify research output. Although we were primarily interested in ecosystem science and management in Australia, we included the wider Australasian region because many marine and avian species move throughout this region. Our study was limited to research projects that began after 1999 because after this period was really when animal telemetry research exploded onto the animal ecology scene. This was due to technological development, miniaturisation, improvements in power consumption and reduction in costs, and because of the removal of 'selective availability' from GPS satellites (i.e., the accuracy of the satellites was no longer intentionally degraded; Tomkiewicz et al., 2010). Our second objective was to determine the number of animal telemetry research projects that were discoverable via online ecological data-repositories for the same temporal and spatial extent, thereby allowing us to determine the proportion of telemetry datasets that are shared with the wider ecological community. Finally, we assessed the opportunities and challenges associated with sharing and reusing animal telemetry data, for purposes for which they were not originally collected. Based on the findings from these studies, we discuss the current state of collaborative use of animal telemetry data across Australasia and suggest how trans-disciplinary collaboration may assist us to enhance the emerging discipline of movement ecology into the future.

2. Methods

The ISI Web of Science (WoS) online was used to search for peer-reviewed publications containing one of 30 different keywords commonly used to describe animal telemetry studies (Supplementary data). These publications were further refined within the WoS to include only papers published between and including 2000 to 2012, and undertaken in the Australasian region (Australia, New Zealand, Papua New Guinea, Solomon Islands and New Caledonia). The following information was extracted for each publication where possible, publication year, scientific journal, study time frame, corresponding author contact details, primary institute responsible for the study, funding agency, study purpose, number of citations, longitude and latitude of study site, study species, telemetry technology employed, total number of tagged individuals and total tracking days. Only one publication was counted for each research project.

To estimate the proportion of publications that are missed by the WoS search we communicated directly with 10 of the authors in the database to obtain comprehensive lists of relevant publications. The difference between the number of papers in the WoS database and the actual number of papers provided by the authors is a measure of the proportion of missed publications.

We hypothesised that approved permit applications could be used as a proxy for the total number of animal telemetry projects (both published and unpublished) undertaken in the region. Local authorities in Australia and New Zealand were approached and requested to provide details on approved ethics applications. Unfortunately, permit applications could not be acquired for all areas in the Australasian region because different countries and states stored this information in different formats, and many were stored in paper format in decentralised archives. Therefore, for efficiency, we focused on only those animal telemetry studies conducted in New Zealand, where all permit applications had been submitted, authorised, and stored electronically through a central authority (i.e. the Department of Conservation). Researchers with approved permits were then asked to provide further details relating to the number of tags actually deployed and what technology was used.

Comparisons were then made between the animal telemetry projects undertaken and those reported in the scientific peer-reviewed publications. The proportion of the total number of research projects that were actually published was extrapolated throughout the Australasian region under the assumption that the proportion of unpublished animal telemetry studies did not vary among countries. We base this on the fact that; 1/ the majority of the research throughout the region is undertaken by researchers based at New Zealand or Australian institutes, 2/ both countries have a similar socio-economic index, 3/ the academic and research outputs of the universities within the two countries are similar, and 4 /both are English speaking.

Finally, a search of on-line facilities that store ecological data within the Australasian region (Movebank.org, OzTrack.org, OBIS-SEAMAP, Seaturtle.org, Terrestrial Ecosystem Resource Network, Australia National Data-service, Integrative Marine Observing System, The Atlas of Living Australia) was undertaken. This was then used to assess the proportion of completed animal-telemetry projects that were discoverable online, as well as collections of animal telemetry data that were open-access and available for download by a third-party.

3. Results

Based on the literature keyword searches, 501 papers that used animal-borne telemetry devices in the Australasian region had been published in 116 different journals between 2000 and 2012. These papers had been cited 5593 times (April 2013), and averaged 11.00 ± 0.59 (mean ± S.D.) citations per publication. This body of scientific research involved the capture and tagging of 12,656 animals, and amassed 81,546 tracking days. Comparing our database with a selected subgroup of authors, the database contained 81% of the total number of

published papers that had used animal-borne in Australasian region and were published between 2000 and 2012. Application of this correction factor (1/81%) to the database increased the estimated total number of scientific papers to 596 and the number of tagged individuals to 14,807.

The geographic distribution of the telemetry studies reflected the location of major urban centres throughout the region (Fig. 1), which also reflects the location of many academic research institutions. The majority of published manuscripts were focused on mammal species; however, fish, reptile, and bird species were also well-represented. Taxa that were less represented in the published literature included amphibians, cephalopods, crustaceans, insects and jellyfish (Fig. 2). Most studies were conducted for purposes of wildlife management, with non-applied research questions less frequently addressed (Fig. 3). There was a 3-fold increase in the annual number of published manuscripts of studies that used animal telemetry devices between 2000 and 2012 (Fig. 4), and the average time required for an animal telemetry project to be published in the scientific literature, after the last telemetry device had been removed, was three years.

Comparison of the literature database with the submitted and approved animal ethics applications for New Zealand revealed that 49.2% of all permit applications made between 2000 and 2012 remained unpublished in the peer-reviewed scientific literature. If these findings were representative for the entire Australasian region, we estimate that approximately 600 animal telemetry studies, consisting of approximately 15,000 tagged animals, remain unreported in the peer-reviewed literature. Based on the average time taken to publish a study after completion of the field work and the annual increase in animal telemetry studies, we estimate that approximately 50% of projects undertaken in 2010, 2011, and 2012 may yet to be published.

A search of animal telemetry data-repositories available online and other Web-based metadata-directories revealed that approximately half of all Australasian telemetry projects undertaken between 2000 and 2012 were not discoverable via on-line resources (Table 1). A much smaller proportion of animal location data (8.8%) recorded during the same period were accessible for viewing or downloading.

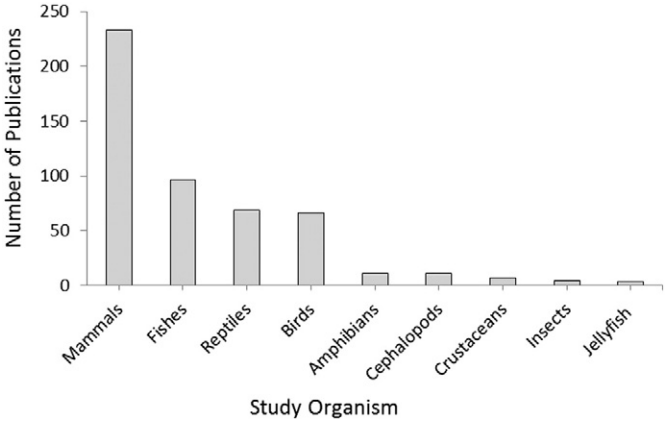

Fig. 2. The number of peer-reviewed animal telemetry papers within each of the major taxonomic classes.

The process of attempting to use animal telemetry data for a purpose beyond which it was originally intended implies numerous issues that should be accounted for by online data-repositories. Firstly, detailed information describing the telemetry data itself must be supplied in the project's metadata. These include: i) the datum and coordinate system of the locations recorded by the collar (e.g. geographic coordinates based on the WGS84 datum), and the time zone of the dates and times associated with each record (e.g. universal time); ii) the date and time of release of the animal, and the date and time of collar recovery (with the time zone specified); and iii) detailed descriptions of any filtering or pre-processing that has occurred, or any other modifications or manipulations of the data (if none has occurred, explicitly stating this is useful). Second, important methodological information includes: i) the type of capture and tracking technology used (including model numbers where possible); ii) the attachment technique; iii) the method of capture and release; iv) the weight of the tag; and v) descriptions of

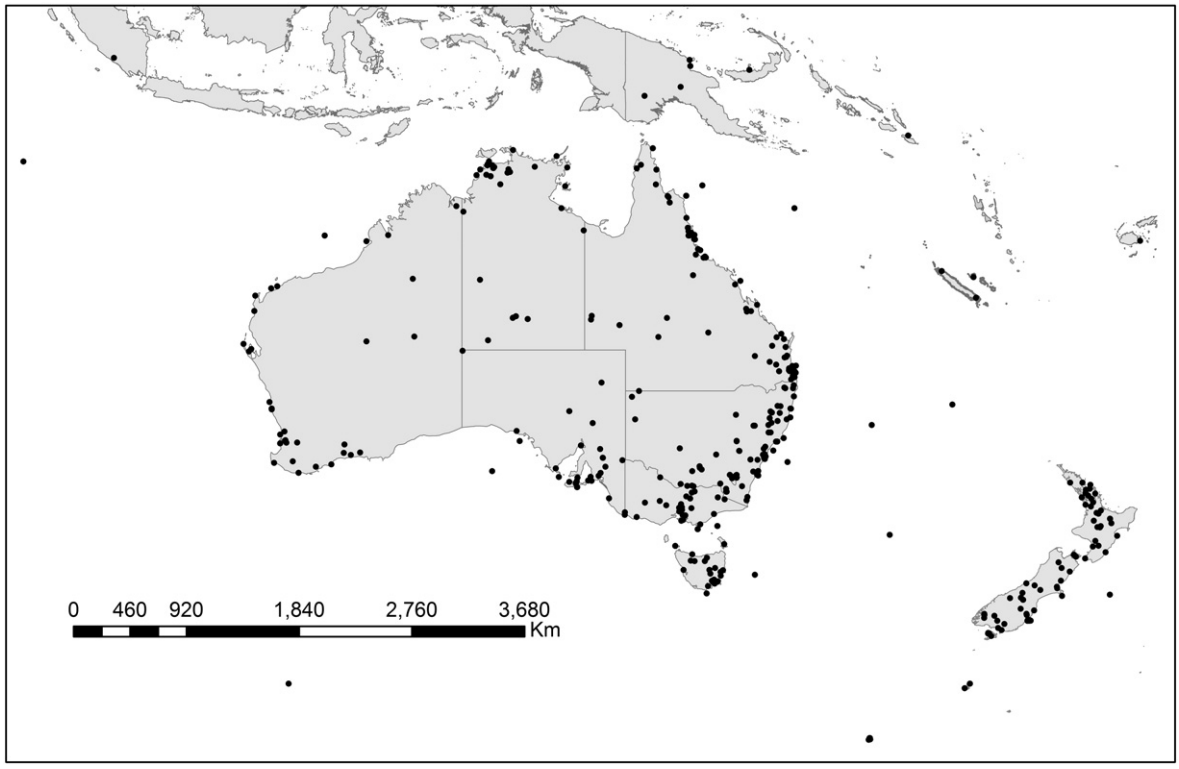

Fig. 1. The spatial distribution of the 501 animal telemetry studies found in the peer-reviewed literature between 2000 and 2012 within Australasia. The spatially referenced database containing project details and content can be viewed and queried at http://aceas-data.science.uq.edu.au/portal/.

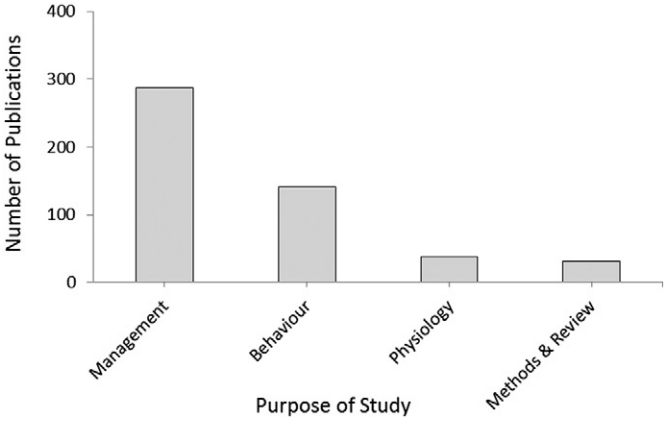

Fig. 3. The frequency of study motivations reported in the telemetry paper for the use of collecting geographical location animal-borne devices.

any licensing or ethics approvals that were obtained. Finally, important information relating to the tagged individual includes i) any physiological measurements that were taken, such as mass, size, sex, estimated age, reproductive status, population size and social group membership; ii) any experimental manipulations such as translocation or reintroduction; and iii) the environmental context in which the animal was captured or released (habitat and weather descriptions). Some of these meta-data are already included in current animal telemetry online repositories. It is difficult to find a good balance between standardization of information across species, completeness of information, and turning users off.

4. Discussion

4.1. The current state of the science

We found that there was considerable extensive use of animal-borne tracking devices throughout Australasia that tracked a variety of terrestrial, freshwater, avian, and marine species. The findings from some of these studies had been published across a broad range of scientific journals (116); however, the findings from approximately half of the research remained unpublished in peer-reviewed scientific literature. Further, a similar proportion of projects could not be discovered via online facilitates, and were thus invisible to the wider scientific community. This represents a large and lamentable knowledge gap and it is imperative that this situation be remedied. Further, in the last 10 years

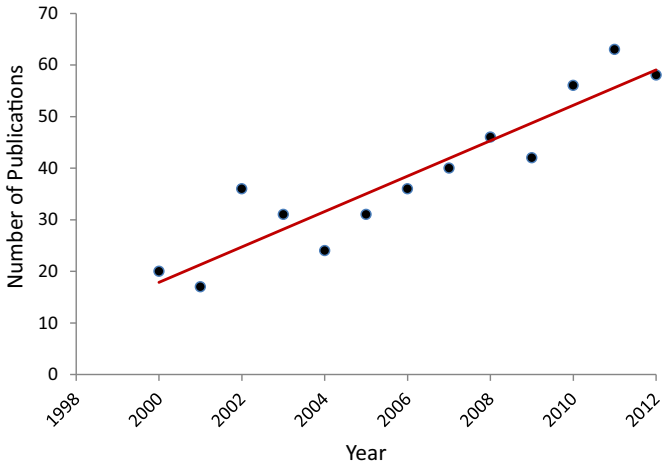

Fig. 4. The annual number of peer-reviewed publications that have utilised telemetry devices to monitor free-ranging animals ($y = 3.07x + 18.6$; $r^2 = 0.84$).

there has been significant growth in studies that have used animal-borne devices throughout Australasia. As this rate of growth appears to be continuing improvements in the reporting and documentation of telemetry research need to be made if the usage of animal-telemetry devices for ecosystem research and management is to advance in a coordinated and efficient manner.

To explain why a significant proportion of completed animal telemetry research projects between 2000 and 2012 remained unpublished in peer-reviewed scientific journals at the time of the analysis (2013), we hypothesise that (i) a significant lag-time exists between field work completion and publication of the manuscript; (ii) collected data were not of sufficient value, robustness, or extensiveness to warrant scientific publication; (iii) the project leaders had inadequate motivation, experience, time, or funding to publish study results in a peer-reviewed scientific journal; (iv) the study was undertaken to address a specific management question and publication was not an intended end product.

A limitation of the data was our inability to access electronic records of animal ethic permit records from most of the regions in Australasia except New Zealand. We recommend the electronic storage of meta-data for animal ethic permit applications into the future. This would certainly have improved the robustness of this project, and would enable a more coordinated approach to wildlife and fisheries research.

In an attempt to address the issue of data availability a number of online facilities with data-storage and discovery capabilities for telemetry-derived animal location data have become available in recent years. These include OzTrack.org (Dwyer et al., 2015), Movebank (Kranstauber et al., 2011), OBIS-SEAMAP (Ocean Biogeographic Information System Spatial Ecological Analysis of Megavertebrate Populations) (Hartog et al., 2009), Wildlife Tracking (Coyne and Godley, 2005) (formerly Seaturtle.org), WRAM-Wireless Remote Animal Monitoring (Dettki et al, 2014), and EURODEER (Cagnacci and Urbano, 2008). Searches of these data-bases for Australasian-based data-collections revealed that only a fraction (<50%) of completed animal telemetry projects were discoverable and a much lesser proportion (<8%) accessible.

4.2. The value of sharing and reusing animal telemetry data

There are three levels by which animal telemetry data can be shared to the benefit of the wider community of ecosystem researchers: 1) synopses of data through presentations and publications; 2) storage and discovery of project meta-data; and 3) storage and discovery of the raw animal location data with appropriate meta-data. Clearly, the peer-reviewed publication process is the cornerstone of modern science and facilitates knowledge transfer and development of theory. As discussed however, publication is not always possible, and therefore it would be beneficial if the project meta-data were discoverable to the wider scientific community. If cataloguing at this level was inclusive of all animal telemetry projects undertaken within a specific region, this would help to reduce study replication, identify knowledge gaps, increase sample sizes and study duration, enhance collaboration, and link data custodians with those best placed to synthesise the data (i.e. those who are efficient at the capture and tagging of animals in the field are not always the best placed to synthesise and analyse the data). In the long term however, it has been demonstrated empirically that research data cannot be reliably preserved by individual researchers (Vines et al., 2014). Moreover, the likelihood that a researcher can be located from an email listed in a paper or from meta-data listings diminishes with time (Vines et al., 2014). To ensure that animal telemetry data-collections are secure, consistent, managed efficiently, effectively disseminated, and not lost over time, we argue that the third level (storage and open-access of the raw animal location data) is the most appropriate action.

Long-term storage of animal telemetry data has the potential to enhance opportunities for novel research, which often emerge after data are subjected to complex, multistep processes of aggregation, modelling, and analysis (Reichman et al., 2011). Interpretation of the detailed

Table 1
The current degree of access to animal telemetry data-collections across Australasia (data accessed July 2014).

Data-repository	No of animal telemetry projects	No of individual animal tracks	No of viewable animal tracks	No of downloadable animal tracks
Movebank	48	693	0	0
Oztrack	54	1480	144	144
Australian National Data Service	80	Unobtainable	0	0
Wildlife tracking/Seaturtle.org	64	574	574	0
OBIS-SEAMAP	121	367	367	367
IMOS/AATAMS	91	3882	0	1722

information embedded in time-series data requires analytically complex methods not readily accessible to most wildlife managers and applied ecologists (Urbano and Cagnacci, 2010). Consequently, much of the highly accurate and detailed location data collected by modern GPS/satellite telemetry is still analysed using descriptive models of movement and space use (Kie et al., 2010). These types of synthesis may be adequate for some immediate conservation and management applications but we argue that the permanent archiving of these datasets under licensing that allows widespread access to the data will provide long-term and unpredictable benefits to the ecosystem research and management community when new and more advanced analytical approach will be developed and used. For example, recent advances in movement modelling provide robust approaches for developing a more mechanistic understanding of animal movement and the processes that drive it. Examples of this include understanding how habitat preference varies among behavioural states (Morales et al., 2004; Beyer et al., 2013a; Roever et al., 2014), how anthropogenic features influence movement and space use (Beyer et al., 2013b, 2014), and the link between movement and population processes (Morales et al., 2010). Although these techniques are often not straightforward to implement, they provide more robust inferences about species–habitat relationships by explicitly accounting for the time-series nature of telemetry data and the lack of independence between movement and habitat preference (Beyer et al., 2010).

A number of studies have now shown that tracking devices can have a detrimental effect on the tagged individuals (Barron et al., 2010; Campbell et al., 2005), and even seemingly innocuous tags such as bird bands have been shown to cause long-term injuries (Moore, 2003) and affect survival (Gauthier–Clerc et al., 2004). We therefore argue for an ethical obligation for researchers to make telemetry data available to the wider scientific community, in order that we maximise the utility of these data. One of the most effective ways of doing this is to archive the data appropriately so that it may be used in future analyses.

4.3. Improvements upon the current situation

The case-study undertaken during this investigation revealed that it was possible to derive information about animal distribution and probability of occurrence through the synthesis of animal location data and environmental information – that were collected by a third party, discovered and downloaded via an open-access on-line data-repository. Nevertheless, there are technological and societal challenges that must be overcome if the ecological research and management community are to improve upon the sharing and reuse of telemetry data. The technological challenges to achieving this are similar to those faced by other fields of ecology and may be grouped into data dispersion, data heterogeneity and data provenance (Michener, 2006; Jones et al., 2006). The challenges for each are explained below.

Throughout Australasia animal telemetry datasets are dispersed across a broad range of researchers and natural-resource managers based in governmental and non-governmental organisations, and academic institutions. There is no professional society or organisation in the region whose purpose is the study of animal movement, but results of our study suggest that the user community across Australasia is sufficiently large that such a society or association would be viable. A professional society (or working group within a professional society) could help to facilitate data sharing and information exchange across political boundaries.

Animal telemetry data are highly heterogeneous in that they encompass a broad assortment of species from a variety of environments over a wide range of spatial and temporal scales. Moreover, animal-location data are collected using different technologies that have varying levels of accuracy, precision and sampling frequency. One method used to address heterogeneity of the data in other fields (i.e. genetics), is to create communal on-line data-repositories with formal data-standards and metadata specifications. Repositories of animal telemetry data have been created that focus on single groups of animals (e.g. European Roe Deer project and Seaturtle.org), single telemetry methodologies (e.g. Australian Animal Tracking and Monitoring System), or particular environments (e.g. Ocean Biogeographic Information System Spatial Ecological Analysis of Megavertebrate Populations). A 'one-size-fits-all' storage facility of animal telemetry data on a global scale (e.g. MoveBank.org) is extremely useful, but difficult to manage on the long run. It would be almost impossible to support and maintain a direct link with all the scientific and regional communities that produced the data. A region specific initiative may be less challenging to implement than a global initiative and the introduction of top-down (stick) and bottom-up (carrot) incentives to encourage user participation are more likely to succeed as they could be directed at both funding agencies and the researchers that are funded by them at a national scale. Then linkages for data discovery across regionally managed databases could be initiated at a later date.

The societal barriers for sharing animal telemetry data may be greater than the technical ones. Animal telemetry researchers are often uncomfortable with losing control over how their data will be used in the future and are concerned their data may be used without permission or attribution. These concerns are particularly prevalent for animal telemetry researchers because of the financial costs and effort involved in collecting the data. Further, the traditional collection of animal location data has not required shared infrastructure and there have been few incentives for data-sharing in the past. This is changing, however, with shared hard-ware and software infrastructures becoming more common for tracking animal movements, and meta-analysis and multi-species studies producing high-impact publications (Block et al., 2011; Hazen et al., 2013; Sims et al., 2008). Tracking the provenance of data collections from storage to reuse in policy and management or scientific publication would certainly encourage sharing by data custodians. It also would provide a record of how the data were collected and transformed, supporting reproducibility and confidence in results. Repositories such as DataONE and DRYAD provide a digital object identifier to data collections, providing provenance for data-reuse and citation. The animal telemetry repository Movebank.org has recently introduced this aspect into their site. The ability to place a moratorium on the release of data (while still allowing the metadata to be searchable) should allay many concerns by data providers that they will not have the opportunity to publish their research before other researchers use their data. In addition to providing incentives through enhanced recognition and publication, data sharing should be made an expectation of funding bodies and animal ethic committees with rewards to those who meet these expectations (Reichman et al., 2011).

Finally, we encourage collaborative trans-organisational and trans-disciplinary synthesis of animal movement information. Through this

process the gap between those collecting and analysing the data and those best placed to use the resulting information may be bridged.

4.4. The future state of play

The field of ecology is changing and practitioners are improving how they collaborate, share and reuse data (Hampton et al., 2013). Animal movement and connectivity between important habitat fragments are fundamental components of ecological processes, and as such, the animal telemetry research community has an important role to play in the future of ecosystem science and management. The animal telemetry community can learn from disciplines such as genetics, which have demonstrated that it is possible to make data collections open-access and discoverable while giving credit to the data contributors (Piwowar et al., 2007). We argue that such a cultural and technological shift would assist scientific innovation and discovery, and enhance ecosystem research and management.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.scitotenv.2015.01.089.

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