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Title: Integrating research using animal-borne telemetry with the needs of conservation management

Short title: Linking animal telemetry to conservation actions

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Summary:

1. Animal telemetry has revolutionized our understanding of animal movement, species physiology, demography and social structures, changing environments and the threats that animals are experiencing. Yet applications of this information to guide conservation actions have been scarce.

2. Here we argue that telemetry data is of limited practical use for conservation unless it enables us to choose between management actions. To bridge this gap, we define a framework that directly links telemetry data to conservation management decisions.

3. Policy Implications: We argue that ecologists and managers have a joint responsibility to use telemetry data to inform management questions, and suggest the use of "value of information analysis" to quantitatively assess the return-on-investment from telemetry data.

Key Words: movement ecology, adaptive management; conservation science; demography; telemetry; threat mitigation; value of information;

The rapid ascent of animal telemetry reflects the ability of these approaches to improve our understanding of fundamental ecology, enhance monitoring of the planet's natural resources and inform conservation practices (Hussey et al. 2015; Kays et al. 2015). What is remarkable about telemetry research is its ability to illustrate how animals, ranging from bees to whales, interact with each other and the natural environment and reveal information about species habitat use, movement patterns, behavior, physiology and the environment they inhabit (Cooke et al. 2004). These studies have documented ocean-wide dispersal events (Block et al. 2011), identified the use of unexpected habitats (Raymond et al. 2014), fundamentally changed our understanding of physical processes in the natural environment (Roquet et al. 2013), and revealed unknown life history characteristics of threatened and cryptic species (Davidson-Watts et al. 2006). It is indisputable that animal telemetry research has altered our understanding of the natural world and the animals that inhabit it.

With these advances there comes an opportunity to use animal telemetry to combat global species declines (Ceballos et al. 2015), yet the link from many animal tracking studies to direct conservation actions remains tenuous. A recent review of over 500 published studies on animal telemetry in the Australasia region reported that while over half of these studies were purportedly in support of management outcomes (i.e. claimed to have conservation implications), less than a third of the subsampled studies were actually designed to directly inform management applications (Campbell et al. 2015). Here, we challenge the assumption by many scientists that more telemetry data will invariably lead to better management and suggest an evaluation of the return-on-investment from such research (Runge et al. 2011; Maxwell et al. 2014).

Given the potential of animal telemetry to inform resource management and conservation and the various costs involved in collecting telemetry-derived data (e.g. financial costs of equipment and salaries, impact on mortality and reproduction of animals involved (Cooke et al. 2004; McMahon et al. 2012)), it is essential to evaluate the conservation benefit of this growing field of research. As conservation science is an explicitly applied field, our aim is to differentiate between telemetry research that broadly influences a larger conservation agenda versus telemetry research that has direct short-term impact on conservation decision-making. Our objective is to encourage researchers utilizing telemetry technology with an underlying conservation rationale to target their research towards gathering information that is more likely to change actions and maximize species persistence.

Differentiating conservation impacts

Telemetry science can impact species conservation in many ways; to differentiate these according to conservation specificity and time-scale of impact, we draw from a mental model developed for ecological monitoring activities (Possingham et al. 2012). We present this framework to distinguish how animal telemetry studies, specifically, can influence conservation. We frame this discussion around the distinctions made among fives types of impact - from long-term and diffuse impacts to short-term and direct impacts (Fig 1).

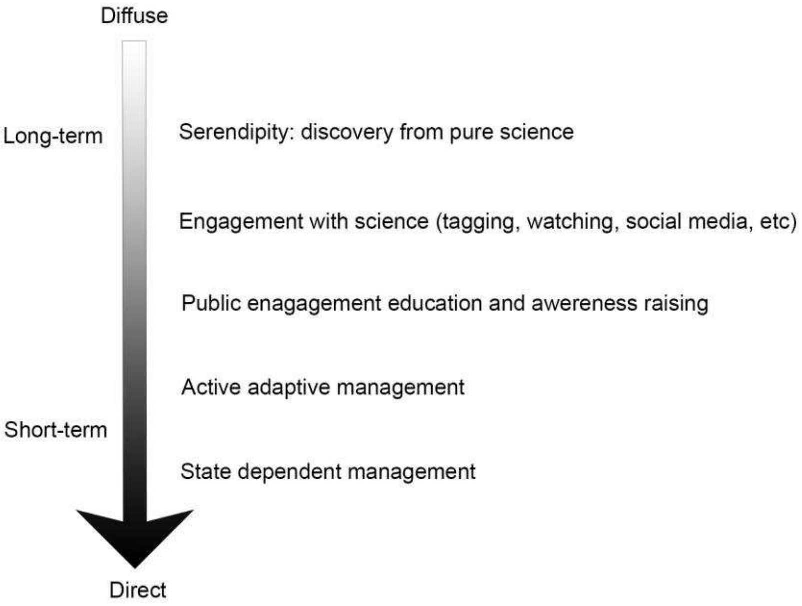

Figure 1. A framework to evaluate scientific research as a function of its impact on conservation (based on Possingham et al. 2012). Within this framework, there are five types of conservation impact ranging from diffuse and long-term, through to directly informing management actions in the short-term.

Serendipitous discovery

Discovering new facets of life history, biology or ecology motivates many scientists conducting animal telemetry. The driver of this work is often pure ecological enquiry (Hart & Hyrenbach 2009; Donaldson et al. 2014). Through exploratory science, telemetry can generate novel findings or improve existing knowledge. It is possible that this knowledge will indeed influence conservation actions at some point. For example, radio-tracking studies in the UK revealed that protected species of *Pipistrelle* bats, which cannot be distinguished through observational studies, actually exploit distinct species-specific habitats and thus require distinct conservation measures (Davidson-Watts et al. 2006). New insights of this nature will certainly change conservation goals and thinking.

Engaging the public and leveraging effort

Unlike other forms of monitoring, where members of the public can easily participate and volunteer in the data collection process (i.e. citizen science), the tagging and tracking of individuals requires special expertise, which can limit the role of the public to be intimately involved in the acquisition of telemetry data. Public engagement would rarely be the sole purpose of a telemetry study, however, the application is exciting and often engages and captivates a broad public audience through social media campaigns (http://www.ocearch.org) and cultural events (Fig 2.)

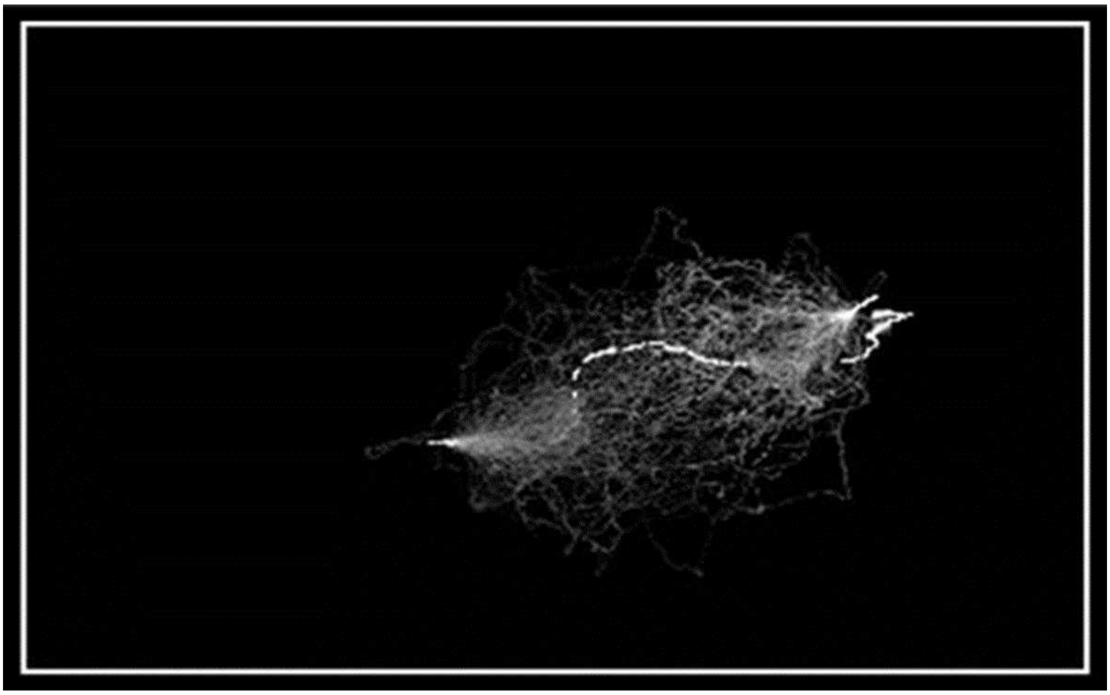

Fig 2: Art derived from tracking studies for a public gallery event during the 2016 International Penguin conference. Image courtesy of Jonathan Handley, Nelson Mandela Metropolitan University, South Africa.

The astonishing behaviors revealed through tracking individuals, such as the recent discovery of the 1,500 mile long-distance American eel migration (Beguer-Pon et al. 2015), can raise species profiles and promote public awareness of species conservation issues.

Raising awareness of an issue for the public and policy makers

Visual aids, such as maps, can be vital knowledge brokering tools for issues of conservation concern (Hebblewhite & Haydon 2010). Maps of animal movements provide evidence of both the ecological and social connectivity between disparate geographies. These findings provide visual support to unify politically diverse regions or groups towards a common conservation goal, encouraging cross-boundary collaboration. For example, telemetry studies have revealed pathways of long-distance migrants that connect countries, continents and hemispheres. These studies underpin multi-lateral initiatives such as the East Asian Australasian Flyway (http://www.eaaflyway.net/), the Convention for Migratory Species (www.cms.int), as well as species focused initiatives such as sea turtle conservation under the Coral Triangle Initiative for Coral Reefs, Fisheries, and Food Security (Beger et al. 2015).

Active adaptive management:

Telemetry data can also identify which conservation actions to take -or not take- within the adaptive management framework (Holling 1978; McFadden et al. 2011). Adaptive management capitalizes on opportunities to improve the effectiveness of management strategies as new knowledge is gained (McCarthy & Possingham 2007; Grantham et al. 2009). This may be a "passive" process, which involves reviewing the performance of past or current actions to alter future actions, or "active", where there is a conscious effort to balance knowledge acquisition and conservation action. Active adaptive management programs maintain well-established monitoring programs and are capable of responding to observed changes in populations. For example, biotelemetry research on anadromous salmon have led to a better understanding of mortality events from catch and release fishing interactions, and physiological factors influencing spawning failure, which in turn justify restrictions on fished populations (Cooke et al. 2012).

State-dependent management:

State-dependent management requires monitoring the state of a system or population to determine how best to manage it. State-dependent management, such as quota setting for sustainably harvesting a species is the most direct pathway for telemetry to influence species conservation. Animal telemetry is already powering new approaches that integrate individual-based movement information and decision theory. For instance, Dynamic Ocean Management is an approach that changes in space and time in response to the shifting nature of the ocean, the animals in it, and its users. It is based on the integration of current biological, oceanographic, social and/or economic data (Maxwell et al. 2015). Some of these applications use telemetry-derived data to alter spatial management over short timeframes (Lewison et al. 2015). This has benefits for mitigating dynamic threats such as bycatch from seasonal tuna fishing effort (Hobday et al. 2010).

The value of information to decision making

A common justification for many animal tracking studies is the potential to inform species conservation. We have discussed several classes of impacts delivering important benefits to society and species from telemetry, but in each case we would ideally quantify both the costs and expected benefit of those actions. If that effort could have been placed directly into management actions, would the species be better off?

The benefits of serendipitous discovery on conservation science is difficult to quantify. Corresponding conservation outcomes may happen only in the long-term. Although changing perceptions and improving commitment to nature is an important component of a society's willingness to commit resources to species conservation, the role that telemetry has on this process can be unpredictable and diffuse.

We focus the remaining discussion of how to improve the conservation return-on-investment in telemetry science and argue that to do so, the ecological knowledge derived from telemetry studies needs to inform and guide actions (McDonald-Madden et al. 2010). Most published research falls short of links to implementation but several excellent reviews discuss the potential of telemetry research for species management (Cooke 2008; Godley et al. 2008; Metcalfe et al. 2012) and policy (Barton et al. 2015). Yet, these underemphasize the importance of defining clear links from research to actions. Similarly, Allen and Singh (2016) recently developed the Movement Management Framework - a first attempt to formally integrate information derived from movement ecology into a decision-making process. However, the authors overlooked critical aspects of modern decision science, namely the importance of setting explicit quantitative objectives, and how movement data can help screen and select actions at the forefront of the planning process based on their associated costs, social and economic acceptability and likelihood of success (McGowan & Possingham 2016). Figure 3 highlights two questions that serve to directly connect telemetry research to applied conservation decision-making: 1) Would my choice of action change if I had more data? and 2) Is the expected gain in objective/s worth the money and time required to collect the data?

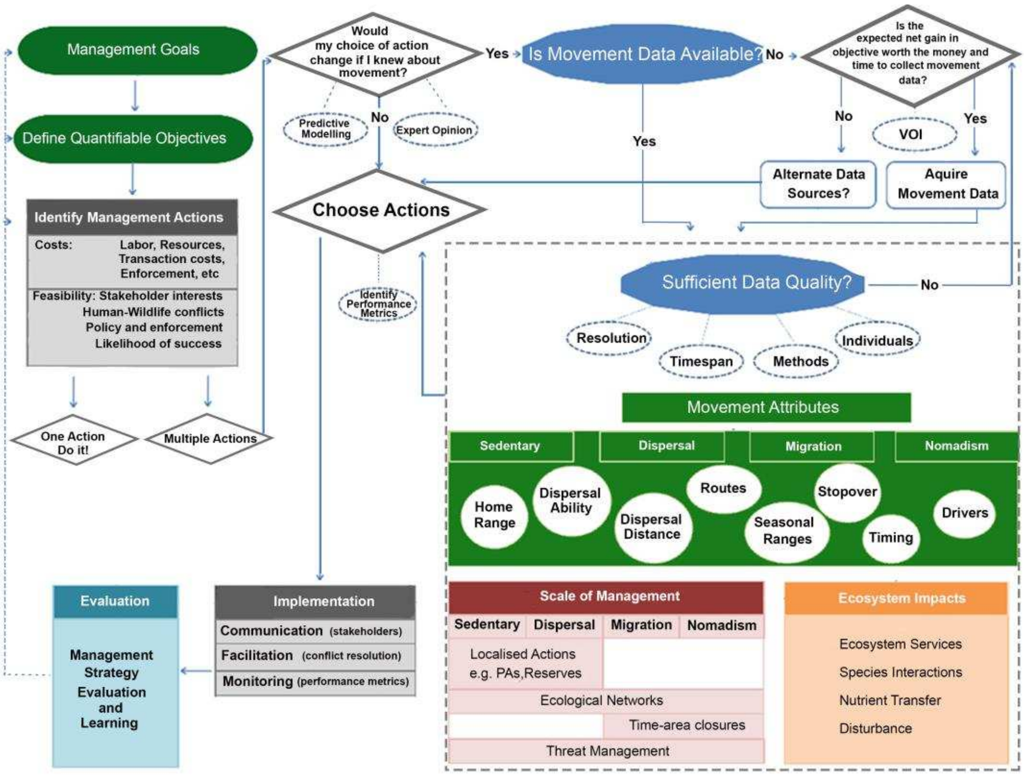

Fig 3. The updated Movement Management Framework (McGowan and Possingham 2016) places movement information within a decision-science framework. Adapted from Allen and Singh (2016).

Would my choice of action change if I had more data?

To know this, quantifiable objectives must first be established so that actions can be evaluated based on their ability to improve the overall benefit of the conservation intervention (Tear et al. 2005). Table 1 provides some examples of how the results from telemetry research enable managers to choose between conservation actions that abate threats to population growth rate, habitats amount and quality, and connectivity, and deliver outcomes for specific objectives. We also note that telemetry studies can play a major role in reducing uncertainty about threats themselves, which may be a necessary step before mitigating actions can be prescribed. However, we stress that just because there is uncertainty in an ecological variable, parameter or threatening process, it does not mean that reducing that uncertainty facilitates better decisions or leads to better management (Runge et al. 2011).

We draw from a trend in the movement ecology literature to track individual occupancy within and around established protected areas to illustrate this point. The rationale underlying these studies is often to inform protected area design, as the data reveal that changes are needed to better capture the movements and habitat-use of the species being tracked. A fundamental yet often ignored aspect of these studies is that once established, protected area boundaries are very slow to change. Given that planning horizons can be decades long (Grantham et al. 2009), these findings likely fall within the diffuse impact category of raising public concern and awareness about protection deficiencies, rather than delivering direct benefits.

While telemetry-derived data may reveal major gaps in contemporary conservation practices, an explicit mechanism from which to enact upon this knowledge is also required to achieve direct influence over conservation. For example, if the objective is to maximize the population size of the species, money spent on tracking individuals around an MPA could be more optimally spent on threat mitigation, such as fisheries regulations outside the boundaries, nesting/breeding site patrols, or bycatch reduction strategies. From a decision science perspective, we don’t necessarily need to know the movements of individuals to best achieve the objective.

Table 1. Examples illustrating the linkages between classes of threats, conservation objectives and actions informed by animal telemetry data.

Threat	Class	Objective	Actions	Telemetry-derived data tell us
Linear infrastructure e.g. road and rail	a) Demographic, animals are killed by vehicles b) Connectivity, animals avoid crossing roads	a) Reduce road kills b) Improve colonization or genetic exchange	a) Fence entire road segments b) Build crossing structures	a) which road segments are most frequently crossed b) where animals are more likely to cross
Anthropogenic barriers in rivers e.g. dams, and weirs	a) Connectivity, animals need to move from feeding to annual breeding grounds b) Habitat, altered flow means breeding habitat becomes less suitable	a) Increase the fraction of individuals able to reach their breeding grounds b) Increase the area of suitable breeding habitat	a) Prioritise the location of fish ladders b) Regulate flow regime at upstream barriers to increase habitat availability	a) the barriers that are stopping the most fish b) which habitats are being most used for breeding
Point infrastructure e.g. wind farms	a) Demographic, wind farms kill threatened birds and bats (vultures, orange-bellied parrot, migratory microbats)	a) Not cause unacceptable harm to any species	a) Approve, or otherwise, a windfarm	a) the number of individuals passing through a site and their residency time at a site for key species
Mortality from industry (fisheries, wind farm)	a) Demographic, interactions result in harm or death	a) Restore seabird population viability	a) Gear restrictions or spatial closures	a) when and where the birds are foraging
Human-wildlife conflict	a) Demographic; interactions result in harm or death	a) decrease poaching	a) Optimize patrol routes	a) where human-animal conflict co-occur
Disease	a) Demographic;	a) understand how disease spreads through population	a) Restrict the movement of disease vectors	a) where and when carrier individuals move

Is the expected gain in knowledge worth the cost?

Our imperfect knowledge of natural systems often leads to the assertion that a greater understanding of ecological processes, spatial data and/or detailed parameters will always improve decisions. However, from a conservation decision-making perspective, investments in advancing basic ecological science to aid conservation can redirect resources away from management, undermining the very purpose of a study.

This trade-off between investing in management versus knowledge advancement is inherent to many conservation frameworks, such as the active adaptive management approach, but management trade-offs are often resolved non-quantitatively based on intuition. We propose to instead use Value of Information analysis (VoI), a quantitative tool for incorporating uncertainty into decision making (Canessa et al. 2015; Williams & Johnson 2015). VoI can evaluate the trade-off between the ability of new information to reduce decision uncertainty and the costs of collecting the data; which uncertainties may be most important to reduce in order to improve gains in management outcomes (Runge et al. 2011); or what the financial value of gaining new information is worth to management (Maxwell et al. 2014).

For example, Maxwell et al. (2014) considered several possible actions that can be taken to maximize the growth rate of a declining koala population. These include building wildlife passages to avoid vehicle collisions, allocating resources to dog owners to prevent attacks, and securing koala habitat. The best decision relied on uncertain information about demography and movement so one could easily argue for a tracking study to inform the decision. However, investing in telemetry research *a priori* would have been misguided as the VoI analysis showed optimal management decisions were not sensitive to these uncertainties, but were primarily driven by the cost-efficiency of the actions and the management budget (Maxwell et al. 2014).

Improving the return on investment of animal telemetry for decision science

To date, there are few examples of using VoI to inform management decisions, and even fewer using telemetry information. The potential to use the valuable insights gained from telemetry in conservation decision making and spatial prioritization is rarely being realized (Mazor et al. 2016). While there will always be a need for basic ecological research and discovery, the conservation crisis demands we look more closely at the data required to make decisions. Given the global investment in telemetry for threatened species, we have an ethical and practical obligation to maximise its benefit to conservation. To avoid another decade of limited progress, we need new tools and frameworks to effectively link the growing catalog of animal telemetry data to conservation and management. VoI and other approaches, that explicitly evaluate the value of science, should play an increasingly important role.

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