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FORUM

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

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Summary

1. Animal-borne telemetry has revolutionized our ability to study animal movement, species physiology, demography and social structures, changing environments and the threats that animals are experiencing. While there will always be a need for basic ecological research and discovery, the current conservation crisis demands we look more pragmatically at the data required to make informed management decisions.

2. Here, we define a framework that distinguishes how research using animal telemetry devices can influence conservation. We then discuss two critical questions which aim to directly connect telemetry-derived data to applied conservation decision-making: (i) Would my choice of action change if I had more data? (ii) Is the expected gain worth the money and time required to collect more data?

3. *Policy implications*. To answer questions about integrating telemetry-derived data with applied conservation, we suggest the use of value of information analysis to quantitatively assess the return-on-investment of animal telemetry-derived data for conservation decision-making.

Key-words: adaptive management, animal behaviour, animal-borne telemetry, biotelemetry, conservation science, demography, movement ecology, species physiology, threat mitigation, value of information

Introduction

The rapid ascent of animal-borne telemetry research reflects the ability of this approach 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 animal-borne telemetry is its ability to illustrate how individuals, ranging from bees to whales, interact with each other and the natural environment and reveal information about species habitat use, movement patterns, behaviour, physiology and the environment they inhabit (Cooke *et al*. 2004). These studies have documented oceanwide 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, Walls & Jones 2006). It is indisputable that animal-borne telemetry has enriched our understanding of the natural world and the animals that inhabit it.

With these advances there comes an opportunity to use animal telemetry-derived data to combat global species declines (Ceballos *et al*. 2015). Much of the published literature using telemetry technologies claims conservation

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implications, yet the link between many of these studies to direct conservation actions remains tenuous (Campbell *et al.* 2015; Jeffers & Godley 2016). Here, we challenge the assumption by many scientists that more data will invariably lead to better management and suggest an evaluation of the return-on-investment from research using animal-borne telemetry devices (Runge, Converse & Lyons 2011; Maxwell *et al.* 2014).

Given the potential of telemetry-derived data to inform resource management and conservation, and the various costs involved in collecting these 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 these research techniques. As conservation science is an explicitly applied field, our aim is to differentiate between telemetry-derived data that improve ecological knowledge with implications for broad conservation efforts vs. data that have direct 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

The use of telemetry devices to monitor free-ranging animals can affect species conservation in many ways. To differentiate these impacts according to conservation specificity and time-scale of impact, we draw from a conceptual model developed for ecological monitoring activities (Possingham *et al.* 2012). We present this framework to distinguish how animal-borne telemetry studies, specifically, can influence conservation. We frame this discussion around the distinctions made among six types of graduated impact, ranging from long-term and diffuse to short-term and direct (Fig. 1).

Pure scientific research

Discovering new facets of life history, biology or ecology motivates many scientists conducting animal-borne telemetry research. The driver of this work is often pure ecological enquiry (Hart & Hyrenbach 2009; Donaldson *et al.* 2014). Through exploratory science, telemetry-derived data 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 *Pipistrellus* bats, which cannot be distinguished through observational studies, actually exploit distinct species-specific habitats and thus require individually tailored conservation measures (Davidson-Watts, Walls & Jones 2006). New insights of this nature will certainly change conservation goals and thinking, yet the impact is often serendipitous, diffuse and over long time-scales.

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 and can limit the role of the public to be intimately involved in data acquisition. Although public engagement would rarely be the sole purpose of a telemetry-based animal study, the application is exciting and often engages and captivates a broad public audience through social media campaigns (www.ocearch.org) and cultural events (Fig. 2). The astonishing behaviours revealed through tracking individuals, such as the recent discovery of the near 2500-km long-distance American eel *Anguilla rostrata* migration (Beguer-Pon *et al.* 2015), can raise species profiles and promote public awareness of conservation issues. Although changing perceptions and improving

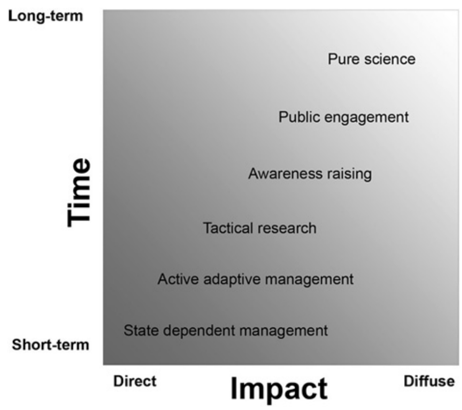

Fig. 1. A categorization of research and monitoring activities in terms of their ability to deliver conservation outcomes. The impacts can be visualized along a gradient from direct to diffuse and occurring in the near- or long-term time-scales.

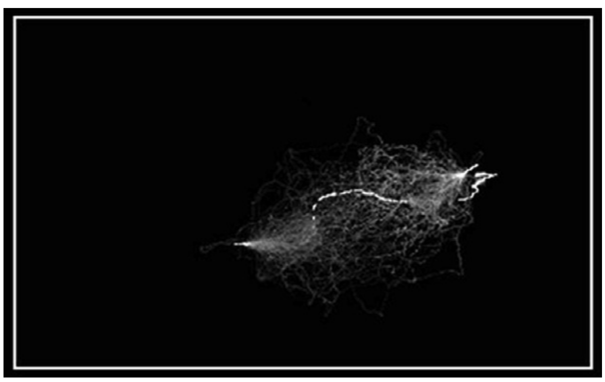

Fig. 2. Art derived from animal tracks for a public gallery event during the 2016 International Penguin conference. Image courtesy of Jonathan Handley, Gentoo penguin project with NMMU, South Africa, and Falklands Conservation and SAERI, Falkland Islands.

commitment to nature is an important component of a society's willingness to commit resources to species conservation, the process can be unpredictable.

Raising awareness for the public and policymakers

Visual aids, such as maps, can be vital knowledge brokering tools for issues of conservation concern (Hebblewhite & Haydon 2010). Maps of animal movements and habitat use provide evidence of the ecological connectivity between disparate geographies. These findings provide visual support to unify politically diverse regions or groups towards a common conservation goal and encourage cross-boundary collaboration. For example, telemetry-derived data reveal the movements of long-distance migrants that connect countries, continents and hemispheres. These studies underpin multilateral initiatives such as the East Asian Australasian Flyway (www.eaaflyway.net) and 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).

Tactical research

Tactical research is research that is not of immediate use to solve a management problem, but is prioritized because a researcher uses their experience to determine that it is likely to be important in the near future. For example, we know that many animals experience different and varied magnitudes of threats across migration routes. Therefore, the success of an action taken in a breeding or nesting may prove futile if threats at important stopover, bottleneck or refugia sites are not identified and mitigated. Committing resources to monitor and learn about unknown spatial processes using telemetry technologies, such as identifying migratory pathways, can determine what state- and time-dependent actions will deliver the greatest benefit to the population's viability (Runge *et al*. 2014; Cooke *et al*. 2016). However, there is a point where investing in tactical research returns marginal benefits to conservation decision-making relative to solving urgent problems (Possingham *et al*. 2012).

Active adaptive management

Telemetry-derived data can also identify which conservation actions to take – or not take – within the adaptive management framework (Holling 1978; McFadden, Hiller & Tyre 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. These management programmes maintain well-established monitoring protocols and are capable of responding to observed changes in populations. For example, biotelemetry research on anadromous salmon has led to an improved 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 harvestable species is the most direct way for telemetry-derived data to influence species conservation. These research techniques are 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 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 time frames (Lewison *et al*. 2015). This has benefits for mitigating dynamic threats such as bycatch from seasonal fishing effort (Hobday *et al*. 2010).

The value of information to decision-making

It is clear that many studies using animal-borne telemetry have the potential to inform conservation. We have discussed several classes of impacts delivering important benefits to society and species. As with all research efforts, one would want to know both the quantifiable costs and expected benefits from the research. Here, we present a framework that can allow researchers to ask: 'If that effort could have been placed directly into management and implementation, would the species be better off?'

We focus the remaining discussion on how to improve the conservation return-on-investment in research using animal-borne telemetry and argue that to do so, the ecological knowledge derived from these studies needs to inform and guide management actions (McDonald-Madden *et al*. 2010). Several excellent reviews discuss the potential of using telemetry technology for species management (Cooke 2008; Godley *et al*. 2008; Metcalfe *et al*. 2012; Hays *et al*. 2016) and policy (Barton *et al*. 2015). Yet, these reviews underemphasize the importance of defining clear links from research to actions. Similarly, Allen & Singh (2016) recently developed the Movement Management Framework – a first attempt to formally integrate movement information 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 beginning of the planning process based on their associated costs, social and economic acceptability and likelihood of success (McGowan & Possingham 2016). Figure 3 highlights two key questions that serve to directly connect research using animal-borne telemetry to applied conservation decision-making.

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 animal research using telemetry technology enable managers to choose between conservation actions that abate threats to population growth rates, habitat quantity, quality and connectivity, and deliver outcomes for specific objectives. We also note that telemetry techniques 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, Converse & Lyons 2011).

We draw from a trend in the movement ecology literature to track individual occupancy within and around

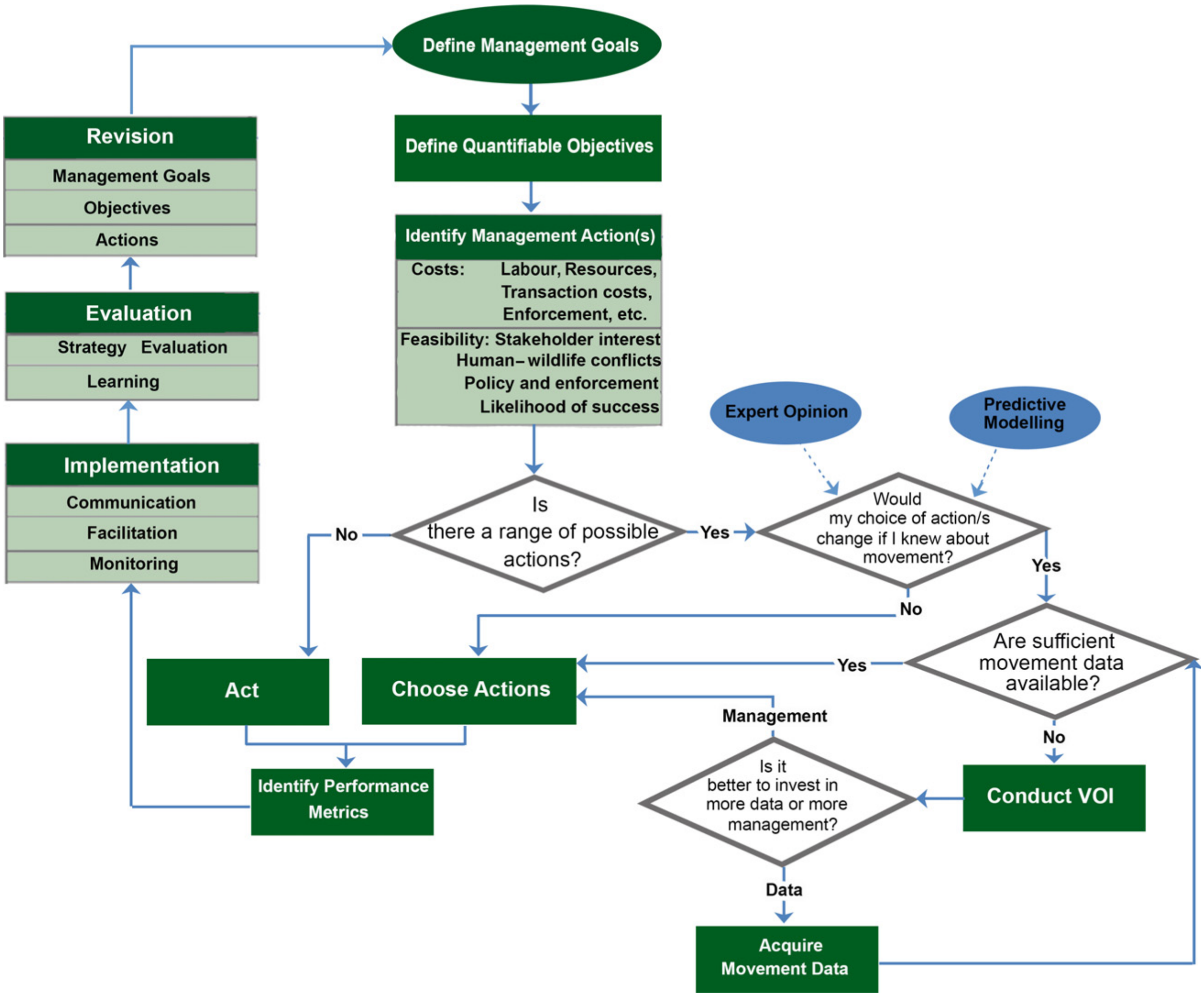

Fig. 3. A decision tree to assist with evaluating the conservation return-on-investment from acquiring telemetry-derived data for decision-making. After conservation goals, objectives and possible actions are defined, one must ask if certain types of data, such as animal movement, will affect the selection of management action(s). If yes, then one should evaluate existing data for quality and new data should only be pursued after a value of information (VOI) analysis reveals that the benefit of that new data (e.g. reducing uncertainty) outweighs the benefit relative to more management. Adapted from previous versions of the Movement Management Framework of Allen and Singh (2016) and McGowan & Possingham (2016).

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

Threat	Class	Objective	Actions	Animal telemetry-derived data tell us:
Linear infrastructure (e.g. road, rail and power lines)	a) Demographic, animals are killed by collisions	a) Reduce collisions	a) Fence entire road segments or increase visibility	a) Which linear feature segments are most frequently crossed
	b) Connectivity, animals avoid crossing linear features	b) Improve colonization or genetic exchange	b) Build crossing structures	b) Where animals are more likely to cross
Anthropogenic barriers in rivers (e.g. dams and weirs)	a) Connectivity, animals need to move between feeding and breeding grounds	a) Increase the fraction of individuals able to reach their breeding grounds	a) Prioritize the location of fish passage options	a) Which barriers prevent the most fish from passing
	b) Habitat, altered flow decreases suitable breeding habitat	b) Increase the area of suitable breeding habitat	b) Regulate flow regime upstream of barriers to increase habitat availability and quality	b) Which habitats are most used for breeding
Point infrastructure (e.g. electricity pylons, communication towers or wind farms)	Demographic, structures kill threatened species (e.g. vultures, orange-bellied parrot, migratory microbats)	a) Not cause unacceptable harm to a population	a) Approve location of point infrastructure	a) The number of individuals passing through and residency time at a site for key species
		b) Reduce the likelihood of threats at an existing site	b) Modify timing of operations (e.g. wind turbines)	b) The time at which individuals pass through a site
Mortality from extractive industry (e.g. fisheries)	Demographic, interactions result in harm or death	Reduce incidental mortality (e.g. bycatch rates)	Gear restrictions or spatial closures	When and where non-target individuals forage
Human–wildlife conflict	a) Demographic, persecution and culling impact on survival	a) Reduce frequency of negative interactions with humans	a) Install barriers to protect communities	a) Frequency of wildlife encroachments
	b) Habitat, exclusion from key breeding or foraging areas	b) Maximize area of important habitats which species can access	b) Introduce compensatory schemes to encourage coexistence	b) When and where important breeding and feeding areas are
Disease	Demographic, mortality from pathogen transfer	Understand how disease spreads through population	Restrict the movement of disease vectors	When and where carrier individuals move
Illegal harvest or poaching	Demographic, interactions result in harm or death	Decrease poaching rates	Optimize patrol routes	Spatial and temporal distribution of poaching-related mortality
Invasive species	a) Demographic, mortality from invasive predators	a) Increase probability of persistence of prey species	a) Control of invasive predator population	a) Location and timing for culling operations to have greatest impact
	b) Habitat, exclusion by introduced competitor	b) Reduce area of occupancy of competitor	b) Control of invasive competitor	b) Home range and encounter probability of traps or bait

established protected areas to illustrate this point. The rationale underlying these studies is often to inform protected area design, as data reveal that changes are needed to better capture the movements and habitat use of the tracked population. 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 benefits in the near-term.

While telemetry-derived data may reveal major gaps in contemporary conservation practices, a mechanism to take the recommended action is also required to achieve direct influence over conservation. For example, if the objective is to maximize the population size of a marine species, money spent on tracking individuals around a protected area 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 do not necessarily need to know the movements of individuals to best achieve the objective.

Is it better to invest in more data or more management?

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. Given this quandary, how does one decide whether or not to invest in more data collection? We can resolve this using an approach relatively new to ecology and conservation – value of information (VoI) analysis, a quantitative tool for incorporating uncertainty into decision-making (Canessa *et al.* 2015; Williams & Johnson 2015). Value of information analysis can be used to examine the trade-off between the ability of new information to reduce decision uncertainty and the costs of collecting more data; which uncertainties may be most important to reduce in order to improve gains in management outcomes (Runge, Converse & Lyons 2011); or what the financial value of gaining new information is worth to management (Maxwell *et al.* 2014).

Maxwell *et al.* (2014) provide an excellent example of using value of information analysis for wildlife conservation. In this study, the authors considered several possible actions that can be taken to maximize the growth rate of a declining koala *Phascolarctos cinereus* population. These include building wildlife passages to avoid vehicle collisions, allocating resources to dog owners to prevent attacks, and securing koala habitat. The management decision relied on uncertain information about demography and movement, so one could easily have argued for a tracking study to inform the decision. However, investing in telemetry devices for research *a priori* would have been misguided as the value of information 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-borne telemetry for conservation decision-making

To date, there are only a few examples of using value of information analysis to inform management decisions, and even fewer using telemetry-derived data. The potential benefits from this field are rarely being systematically incorporated into conservation decision-making or spatial prioritization (Mazor *et al.* 2016). While there will always be a need for basic ecological research and discovery, the extent of the current conservation crisis demands we look more pragmatically at the data required to make decisions. Given the global investment in telemetry devices for threatened species, we have an ethical and practical obligation to maximize this investment's benefit to conservation. To improve the conservation return-on-investment in these techniques, we need new tools and frameworks to effectively link the growing catalogue of animal telemetry-derived data to conservation and management. Value of information and other approaches that explicitly evaluate the value of science should play an increasingly important role.

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Data accessibility

Data have not been archived because this article does not contain data.

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