



Essays and Perspectives

Functionally connecting collaring and conservation to create more actionable telemetry research



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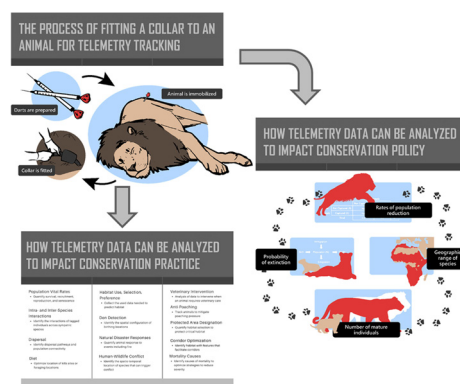
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HIGHLIGHTS

- Telemetry technology has revolutionized ecological research.
- Comparable impacts to conservation science, however, are presently unclear.
- Conservation is an applied discipline where impacts drive new policies and practices.
- Frameworks to functionally connect collaring and conservation are presented.
- The ways in which these frameworks can yield conservation gains are discussed.

GRAPHICAL ABSTRACT



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ABSTRACT

While telemetry technology has undoubtedly revolutionized ecological research, the impacts to conservation remain in question. Conservation is, after all, an applied discipline with research that is intentionally designed to inform policies and practices that can demonstrably protect biodiversity. Though telemetry is a tool that is commonly used to raise conservation funding, the technology itself cannot generate these policies and practices. Rather, it is the outputs of the analytical processes interrogating the data deriving from telemetry systems that can do so. This distinction is not semantic but rather fundamental to creating more actionable research. We developed conceptual frameworks to delineate the pathways by which telemetry research can be structured to inform conservation policies, practices, and the decisions of funders motivated to support conservation. We demonstrate how the application of these frameworks can

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reduce the research-implementation gap so as to make biodiversity conservation more effective. While our assessment uses collaring as a case study, our conceptual frameworks are applicable to all research using animal-borne technology seeking to promote the recovery of species of conservation concern.

The impacts of telemetry on ecological research

Ecologists have long held an interest in monitoring the behavior and movement of animals across space and time. Such pursuits historically involved prolonged periods in the field habituating animals to human presence to facilitate close observation (see Grinnell, 1917; Altmann, 1974). In the mid-20th century, the advent of telemetry technology, originally engineered for wireless communication, allowed animals to be tracked remotely via very high frequency (VHF) radio equipment (LeMunyan et al., 1959; Benson, 2010). Devices could be fit to animal subjects with subsequent triangulation of the radio frequencies pinpointing, with reasonable precision, an animal's location in time and space (Montgomery et al., 2010). While VHF transmitters have largely been superseded by more robust Global Positioning System (GPS) units offering more frequent and resolute location information, the general design of data collection has changed little. Animal subjects are immobilized so that they can be fit with telemetry tracking devices which can take a diversity of forms, including collars and tags, positioned on the animal research subjects (Fig. 1). Following recovery from immobilization, the animal research subjects are then released where their movement and behavior are monitored via the animal-borne technology. Although telemetry systems have made substantial contributions to ecological research (Hebblewhite and Haydon 2010; Kays et al., 2015), the extent to which they have made, or can make, comparable contributions to conservation remains unclear. Though previously noted tendencies to misrepresent ecological outputs of telemetry research as conservation impacts persist (Jeffers and Godley, 2016; McGowan et al., 2017). Here, we articulate how telemetry-based research can be structured in specific ways to generate actionable conservation outputs. While we focus on the use of collars in telemetry research, which are typically attached to large animal research subjects, the principles presented here are applicable to wildlife across taxa for which animal-borne technology is implemented.

Collaring and conservation

While ecological research can be motivated by basic, fundamental, or theoretical pursuits, conservation biology has always been depicted as an applied field of study (Soulé, 1985). Developed into an independent discipline in the late 1970s, conservation biology was established with two specific goals. The first goal was to document the mechanisms associated with biodiversity loss, while the second goal was to translate that research into policies and practices that could evidentially conserve biodiversity (Soulé, 1986). Noticeably, the root of the word conservation is a verb (i.e., to conserve) and the entire field of study is motivated by timely action (e.g., the primacy of action; Soulé and Kohm, 1989). Importantly, however, verbs can exhibit considerable variation in their task, action, and achievement connotations (Vendler, 1957). Thus, someone can call themselves a conservation biologist without any demonstrable success at conserving biodiversity. Further, the research of many conservationists has been found to be surprisingly disconnected from any practical efforts to conserve species (Nature, 2007). Correspondingly, since the establishment of conservation biology there has been near-exponential growth in research outputs while the world has lost in excess of 60% of its biodiversity (Montgomery et al., 2022). Thus, a large gap exists between research and implementation and while evident across disciplines,

it is particularly costly to conservation science given the speed with which biodiversity is being lost (Knight et al., 2008; Gray et al., 2019; Leclère et al., 2020). At the heart of this problem is that conservation science tends not to be conducted in ways that are actionable (Artelle et al., 2018; Gray et al., 2019) and the disconnections between collaring and conservation are demonstrative of this point.

Neither collars nor the physical act of collaring can inform conservation. Rather, it is the process of applying outputs emerging from the analysis of data deriving from telemetry systems that can do so. One of the reasons why there is confusion herein is because collars continue to be used as a convenient tool to raise conservation funding. Collars are appealing because they are often fit to large animals, which tend to be species that are charismatic and comparatively rare (Courchamp et al., 2018), and the technology exhibits a certain degree of tangibility (i.e., physical tools that can be directly attached to animal subjects), both of which are important components of funder decision-making (Sitas et al., 2009). Consequently, there is a need to clarify the ways in which collaring can generate conservation impacts via the design, data collection, analysis, interpretation, and application of data deriving from these telemetry systems. Here, we pursue this objective via the presentation of conceptual frameworks outlining how actionable telemetry research can inform conservation policies and practices. We also discuss the need for transparency in the relationships between funders and conservation scientists and present a conceptual framework linking the types of information that funders should consider when making funding appropriations to meet their desired conservation outcomes.

How collaring can inform conservation policies

We present four ways in which the findings deriving from collaring efforts can be structured to directly inform conservation policies by assessing the conditions necessary to provide a species with protected status on The International Union for the Conservation of Nature (IUCN) Red List. We use language from the IUCN because; (i) they are “the global authority on the status of the natural world and the measures needed to safeguard” nature and (ii) that language is comparable with that used among several other conservation policies globally (e.g., the US Endangered Species Act, Canada's Species at Risk Act, or Australia's Environment Protection and Biodiversity Conservation Act). Within the IUCN Red List, protected species status at vulnerable, endangered, or critically endangered levels requires *quantitative distinction* of the: (i) rates of population reduction, (ii) geographic range (measured either as the extent of occurrence of area or occupancy) dynamics including fragmentation, (iii) number of mature individuals, and (iv) probability of extinction in the wild (IUCN, 2012). The exact categorization is considerably more complex and depends upon a combination of these conditions at various levels (Collen et al., 2016). Regardless, to establish protected species status, resolute data describing these criteria are needed and here we describe how collaring data can be used to collect such information.

Rates of population reduction

To detect rates of population reduction, abundance estimates at time T must be produced and then compared to estimates produced at time $T + 1$ (i.e., at some later point). Methods leading to

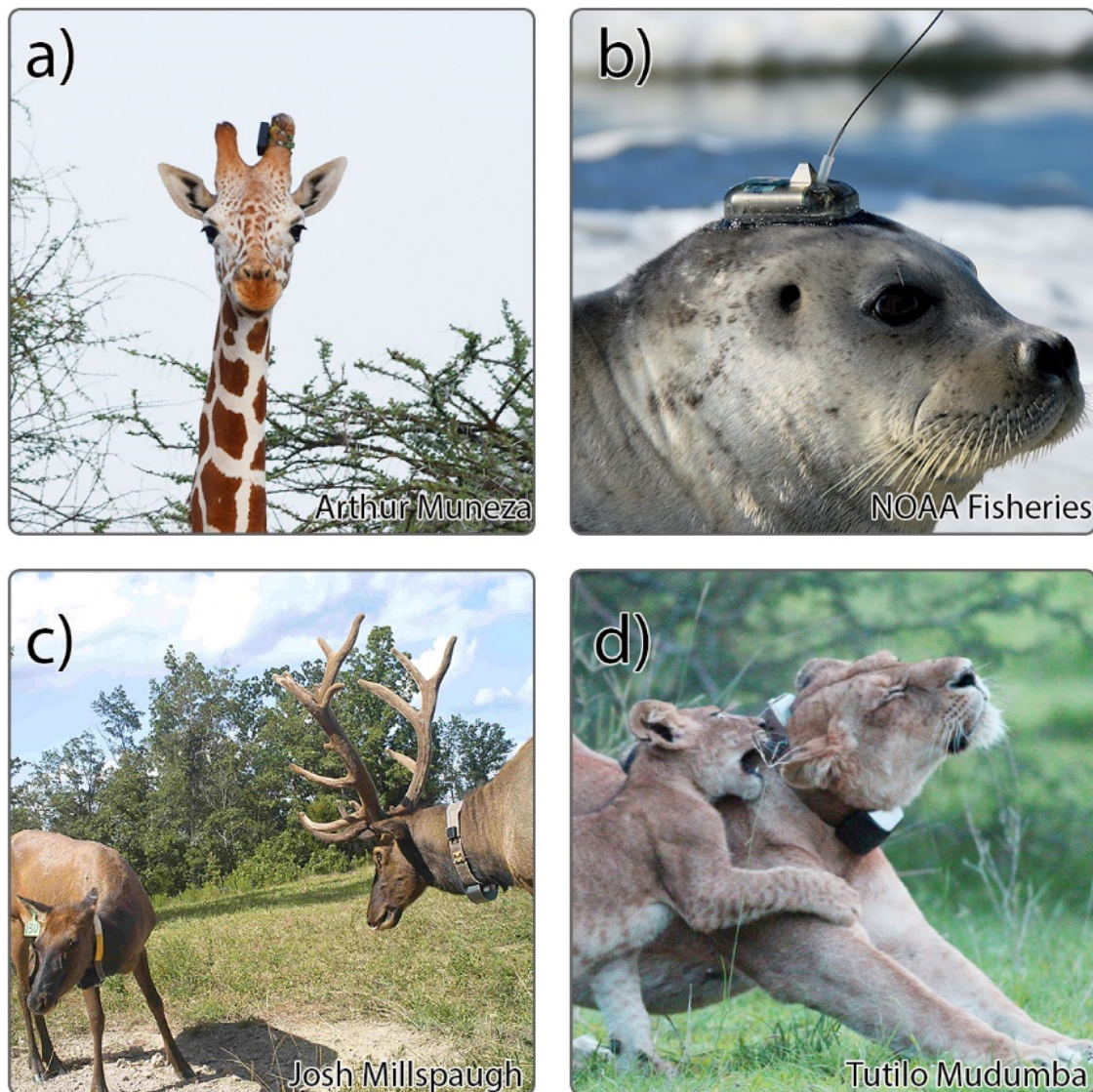


Fig. 1. Telemetry collars fit to large animal research subjects come in a variety of different types. Panel a) depicts an ossicone-mounted telemetry tag on a giraffe (*Giraffa camelopardalis*). Panel b) shows a head-mounted telemetry tag on a harbor seal (*Phoca vitulina*). Panel c) illustrates telemetry collars on a female and male elk (*Cervus elaphus*). Panel d) depicts a telemetry collar on a female lion (*Panthera leo*).

the highest precision, and thus the highest power to detect trends in abundance, include individual animal identification of all, or part, of the population, and re-sighting of those individuals regularly increases this precision. Telemetry collars can facilitate the marking and re-sighting of individual research subjects over time (Carter et al., 2019). Subsequent analysis of telemetry data can be used to quantify recapture rates as part of mark-recapture models, observation rates integral to mark-resight models, or probability of sightings profiles as part of sight ability models (White and Shenk, 2001). Despite this utility, efforts to develop precise population estimates often depend upon marking a reasonable proportion of the population of interest while minimizing the potential for pseudoreplication. Estimates of that minimum number are variable and contingent upon the local abundance of the animal population of interest. However, as many as 25 conspecific individuals may need to be simultaneously collared per geographic study area to reliably produce such estimates (Powell et al., 2000). Sample sizes such as these may be infeasible given various considerations (e.g., cost, efficiency, species rarity, and ability to capture the focal species) inherent to the collaring of animal subjects, particularly among large animals. Nevertheless, via these processes, telemetry data can

be effectively analyzed to quantify the rates of population reduction for species of conservation concern and identify causes of reduction (Carter et al., 2022; Cozzi et al., 2020; Johnson et al., 2019).

Geographic range dynamics

Evaluating geographic range dynamics is perhaps the most obvious way in which collaring can inform conservation practice. Geographic range dynamics can be informed by estimates of home range size and configuration quantified from telemetry data using a variety of different methods (e.g., minimum convex polygons, fixed kernel density estimates, or utilization distributions; Kenward et al., 2001; Kie et al., 2010; Hooten et al., 2017). Furthermore, habitat use models, such as resource selection functions (RSFs), also tend to be built from telemetry data and can be fit to predict habitat types that are more likely to be selected by species of interest (Boyce and McDonald, 1999; Millsaugh and Marzluff, 2001; Hooten et al., 2017). Here, field observations, home ranges, and habitat use estimates, in combination with predictive modeling, can be used to describe the geographic range of a species. It is important to note however, that a weakness of telemetry is that, in

its current form, the technology will only return data on the individual animal subject, not on the number of conspecifics that are accompanying that animal in space and time. Despite historic progression in video collars (see Moll et al., 2007) the technology has yet to be widely adopted. Thus, additional collar modifications and new technological designs in telemetry will be required to return spatially-explicit estimates at the sub-population level. Emergent research is also demonstrating that individual variation among animals, even those that are highly social, can be high, challenging the notion that data on individual animals is actually representative of the sub-population or population (Montgomery et al., 2018; Carlson et al., 2021). Thus, to describe the extent of occurrence, the area of occupancy, or geographic range fragmentation at the population or species level, multiple animal subjects across those extents would need to be telemetered. This is, in part, captured by the IUCN in what they describe as the ‘problem of scale’ (IUCN, 2012). Thus, even in this most obvious way in which collaring can inform conservation, the pathway to doing so involves considerable effort, time, monetary support, and research complexities.

Number of mature individuals

Telemetry data can also be used to calculate the number of mature individuals (i.e., those capable of reproduction; IUCN, 2012) via modeling of *marked* animal subjects. Population demography has been an area of intense inquiry among telemetry research historically (Millspaugh and Marzluff, 2001). At the time of collaring, animal subjects are often aged and sexed with a number of different pieces of biometric data that also tend to be collected (Farine et al., 2017; Heit et al., 2023). Via the application of that telemetry technology, the individual animal subjects can be tracked, observed directly, and monitored over time to record specific life history stages (i.e., birth, breeding age, and senescence age). Combined with the population abundance modeling approaches described above, estimates of the number of mature individuals can then be produced. Once again, however, synthesis of comparable information across populations would then be needed to quantify the number of mature individuals at the species level. Thus, while collars can be used to calculate the number of mature individuals in a population or area, other non-invasive techniques, such as camera traps, can often be more effective.

Probability of extinction

Population viability analyses predicting the probability of extinction are dependent upon data describing not only the number of mature individuals but also the vital rates of the species of interest. Telemetry systems have been capably deployed to quantify these vital rates including estimates of survival, fecundity, mortality, immigration, emigration, and senescence (Millspaugh and Marzluff, 2001; Hooten et al., 2017). Telemetry technology enables these animal subjects to be tracked over time so as to estimate these rates.

Thus, the four criteria needed to inform the quantitative distinctions of protected species status can be readily predicted as a function of data recorded by telemetry collars.

How collaring can inform conservation practices

Concurrent to the potential policy impacts, telemetry can also inform a variety of practices, management strategies, and on-the-ground decisions to protect species of conservation concern (Table 1). Collars, for instance, can be used to generate data with implications for animal survival and reproduction such as the spatio-temporal configuration of breeding locations (*sensu* den sites), the nature and strength of animal social interactions,

Table 1

A non-exhaustive list of the data analyses, aligning to specific conservation practices, that can be made possible by telemetry. Such analyses can yield novel scientific information that can inform management actions and other outcomes.

Conservation practices	Data analyses
Population vital rates	Quantify survival, recruitment, and senescence
Intra- and Inter-species Interactions	Identify the interactions of tagged individuals across sympatric species
Dispersal	Identify dispersal pathways and population connectivity
Diet	Optimize location of habitat where foraging and/or hunting is pursued
Habitat use, selection, and preference	Collect the used data needed to predict habitat use, selection, and preference
Den detection	Identify the spatial configuration of locations for resting, sleeping, and birthing
Natural disaster responses	Quantify animal response to events including fire
Human-wildlife conflict	Identify the spatio-temporal location of species that can trigger conflict
Veterinary intervention	Analysis of data to intervene when an animal requires veterinary care
Anti-poaching	Track animals to mitigate poaching pressure
Protected area designation	Quantify habitat selection to protect critical habitat
Corridor optimization	Identify habitat with features that facilitate corridors
Mortality causes	Identify causes of mortality to optimize strategies to reduce severity

responses to natural disasters, as well as population vital rates, and quantification of specific causes of mortality. Telemetry can also be used to directly inform management practices to reduce human-wildlife conflict, optimize veterinary interventions, to detect and intervene to reduce poaching pressure, or to inform protected area designations or animal movement corridor optimization (Table 1). Despite this diversity, however, we once again emphasize that it is the analysis of these data and the application of the outputs to solving conservation challenges that is vital. For instance, research assessing the habitat selection of quokkas (*Setonix brachyurus*) provided novel insights on animal responses to fire and specific causes of mortality (Hayward et al., 2005a, b) which were then directly incorporated into the national recovery plan for this species (De Tores and Williams, 2008). This type of applied integration was made possible by the collaring research being structured in action-able ways.

Telemetry can also produce data on population vital rates, including the number of reproductively-viable individuals (Kotze et al., 2020), which is vital for decision-makers to implement practices promoting the persistence of species of conservation concern (Table 1). Data from collared individuals can be used to quantify interspecific interactions which can provide improved understandings of ecological processes such as the transmission of disease (Broekhuis et al., 2019). With respect to management interventions, recent advances in telemetry technology have informed real-time monitoring of animal populations to reduce human-wildlife conflict. Virtual fences, for example, can alert managers or local human communities to the movement of collared animals detected within some specified user-defined distance of a remote telemetry base station (Jachowski et al., 2014; Weise et al., 2019). Such approaches can help to reduce the likelihood that collared animals raid crops or predate livestock where they may, subsequently, be subject to human retaliation. Data collected from collaring can also be used to guide veterinary interventions for animals vulnerable to injury from a diversity of mechanisms, including poaching pressure (Table 1). Wire snaring, for instance, is an important threat to a variety of species of conservation concern (Mudumba et al.,

2020). Telemetry can be used to identify when collared animals are caught in a snare so as to optimize veterinary interventions and promote animal survival. Thus, the outputs of data collected from telemetry systems can be structured in actionable ways to inform conservation practices.

The risks inherent to telemetry collaring

The process of making telemetry research more actionable is particularly important given that the act of collaring is inherently risky for animal subjects. To facilitate collar attachment, animals need to be immobilized, often with the aid of chemical suppressants. Capture myopathy deriving from such animal handling activities can in some circumstances be lethal, subverting the entire purpose of conservation (Breed et al., 2019). As well as the stress associated with the capture and handling process, mistakes made in the administration of drugs and poor collar attachment can also decrease the fecundity of animal research subjects. Ethical approval has often been lacking in studies with these risks (Hayward et al., 2012). The means by which collars and tags are attached to animal research subjects (Fig. 1) also present important concerns with respect to animal welfare. The attachment location, weight, and fit of the collar or tag can impact individual animal movement, ranging, and reproduction (Kenward, 2001; Rasiulis et al., 2014) and these effects have been detected across a broad range of species (Calvo and Furness, 1992; Moorhouse and MacDonald, 2005; Brooks et al., 2010; Coughlin and Van Heezik, 2015; Wilson et al., 2021). Unfortunately, such negative impacts that can derive from collaring are rarely documented in the literature (see McIntyre, 2015) nor openly discussed within the scientific community or shared with funders.

It is also important to note that telemetry collars are subject to failure and malfunction leading to the loss of data negating any ability to generate conservation impacts. Even when collars function well, vast amounts of telemetry data are never been analyzed, much less developed into actionable research informing conservation policies and practices (Hebblewhite and Haydon 2010; Jeffers and Godley, 2016). The data that is collected is also subject to misuse and data breaches that can put the welfare of individual collared animals, and the recovery of species more broadly, at risk (see Lennox et al., 2020). Furthermore, many of the studies that do emerge are missing critical hallmarks of the scientific process. In the United States and Canada, for example, just 6% of 667 documents informing agency practices on wildlife management and conservation had been submitted for external review (Artelle et al., 2018). And even among those studies that have been published via peer-review, many fail to be structured in ways that enable their results to be actionable, as has been demonstrated for human-carnivore studies in East Africa (Gray et al., 2019). Thus, to close the research-implementation gap for the benefit of conservation, it is vital that collaring be implemented in ways to eliminate risk to the animal subjects, the data emerging from the telemetry systems be rigorously analyzed, and that the subsequent results be structured in ways that enable that research to be actionable.

Considerations for funders supporting collaring activities

Conservationist scientists must recognize that adhering to the expectations of the agencies, organizations, and individuals that fund their work requires analysis of the resultant telemetry data from basic descriptive statistics to sophisticated quantitative modeling. Potential funders should be aware of the degree of data analysis proposed and inquire as to the overall conservation impacts that the proposed research could generate. These points are particularly important given the wise use of conservation

resources. Disparities between conservation needs and conservation funding have been widely studied with important voids that are evident globally and, most especially, in the world's most biodiverse regions (Balmford et al., 2003; McCarthy et al., 2012). The importance of private funding in addressing these funding disparities has been highlighted (Verissimo et al., 2011). However, the allocation of conservation funding is often biased toward highly charismatic species and may offer comparatively narrow conservation impacts (Bennett et al., 2015). Consequently, it is imperative that those seeking support for collaring articulate, in detail, how their study will be structured so as to inform specific conservation practices and policies. A fit-for-purpose tool such as collars is not a substitute for wise judgement in conservation (Can and Macdonald, 2017).

Here, we provide a set of criteria and questions that funders can raise with applicants when making funding allocation decisions (see Fig. 2). To start, applicants should be requested to provide a detailed cost-benefit analysis of their projects (Fig. 2). Importantly, telemetry is not the only way to collect data to inform conservation practices and policies. A number of comparatively non-invasive techniques, including environmental DNA (Rees et al., 2014), drone-based tracking (Schad and Fischer, 2022), camera traps (Caravaggi et al., 2017), and satellite monitoring (LaRue et al., 2021), can generate comparable, or even more sophisticated, data depending on the precise research questions being assessed. Further, several of these techniques can be superior in that they carry less risk for animal subjects and typically return data at the population level whereas telemetry technology, at present, can only return data at the individual-animal level. Additionally, swift progress has recently been made in the non-invasive tracking of animal subjects without the advent of telemetry. Instead, pattern analysis of imagery returned from unmanned aerial vehicles or satellite technology can now distinguish among species with progress being made in the tracking of individual animal research subjects (Duporge et al., 2020) or the estimation of species population size (LaRue et al., 2021). Thus, the speed of technological advancements in remote sensing might diminish the utility of collaring moving forward.

We also advocate for transparent description of the data that the collaring projects are seeking to collect, the risks inherent to that process, and how the data collection will directly inform conservation policies or practice (Fig. 2). Accurately and precisely describing experimental designs is not only an integral component of the scientific method (i.e., necessary to promote replicability), but should also be considered to be a vital element of funder engagement. When researchers clearly articulate a pathway by which collaring can generate conservation outcomes, funders can appreciate and evaluate how their support will benefit biodiversity recovery. From that point, funders will be able to set realistic expectations and require accountability from all grantees, which will begin closing the gap between conservation needs and conservation funding (see Fig. 2). Finally, the importance of diverse and interdisciplinary collaborations including members of local communities, agencies, authorities, NGOs, universities, and governing bodies responsible for developing and enacting on-the-ground practices and the implementation of conservation policy (see Montgomery et al., 2020) should be forged. Such collaborative partnerships making research actionable are more effective if they occur early in the scientific process when research questions are being proposed and experimental designs are being established.

Closing the research-implementation gap

It is clear that technologies, such as telemetry, have huge potential to address many of the world's most pressing problems and will

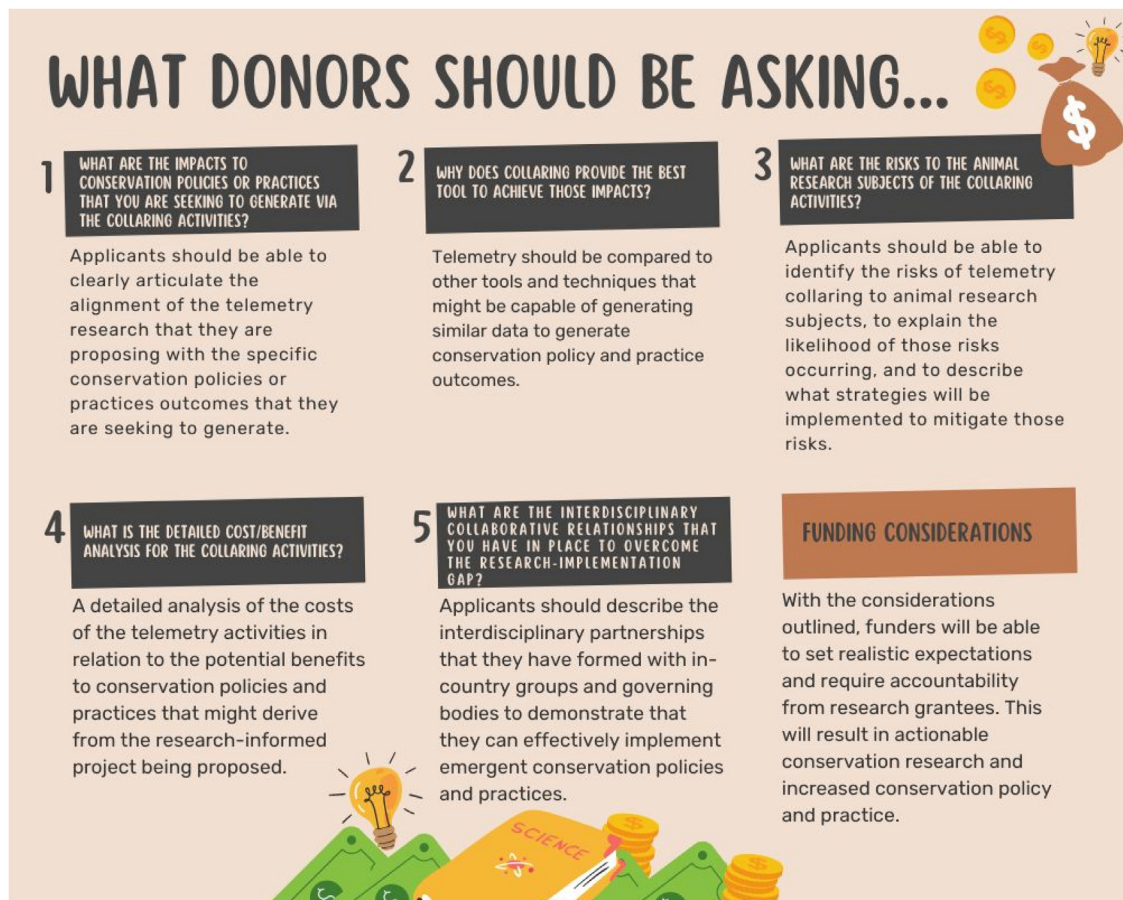


Fig. 2. A conceptual framework describing the factors that funders should consider when providing monetary support for a collaring-based research project.

continue to be integral components of the future of conservation science (Can and Macdonald, 2017; Berger-Tal and Lahoz-Monfort, 2018). It is not the act of collaring, itself, but rather the wise analysis, interpretation, and qualification of the data deriving from telemetry systems that can generate conservation impacts. This emphasizes the point that a revolution in data collection, including tools such as telemetry, doesn't guarantee comparable impacts on conservation (Can and Macdonald, 2017). For that research seeking to produce conservation outcomes, the power of telemetry lies in its ability to inform both practice and policies via rigorous and focused actionable research designs. This is particularly important given that one of every six species on the IUCN Red List is data deficient (IUCN, 2019), meaning that there is not enough quantitative information, where telemetry is one of the primary research techniques used to generate such data, across the rates of population reduction, geographic range dynamics, number of mature individuals, or probability of extinction necessary to adequately provide these species with aligned protected status. In the event that such deficiencies cannot be addressed, society risks the continual, and perhaps even accelerated, loss of biodiversity. We have illustrated how telemetry research can be structured to be more actionable so as to inform conservation policies and practices while maximizing the impact of scarce funding resources. Interdisciplinary research teams promoting clarity, authenticity, and accountability are needed to align collaring and conservation so as to positively contribute to the protection of biodiversity.

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