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Considering cost alongside the effectiveness of management in evidence-based conservation: a systematic reporting protocol

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Supplementary material:

Table S1. Example of conservation intervention cost data collection and reporting sheet using an ingredients approach, adapted from the WHO-CHOICE tool CostIt.

Table S2. An application the reporting protocols developed by the WHO, as applied to a case study of Pacific leatherback turtle (*Dermochelys coriacea*) conservation.

Abstract

Given the limited resources available to address conservation problems, decision-makers are increasingly seeking management solutions that provide value for money. Despite an increasing number of studies that generate estimates of the return-on-investment from conservation management interventions, the ways in which costs are reported are highly variable and generally aggregated. This prevents comparison between studies and the application of systematic tools to synthesize conservation evidence and evaluate the factors that modify costs and benefits. A standardized consensus on the type of cost data to collect and report in conservation science would help build a body of evidence to support decision makers. In efforts to improve evidence-informed decision-making, conservation has looked to health care for tools to support the integration of evidence into management decisions. Increasingly, health care uses economic evaluations of treatment options to estimate the return on investment from medical interventions. Here, we describe economic evaluations as a tool for evidence-informed decision-making in health care and draw parallels for how these evaluations could be integrated into conservation. We also suggest tools to help systematically report economic costs of conservation interventions, and illustrate this approach with a case study of turtle conservation. We describe the important elements of economic evaluations, and how these data can be used to greatest effect through tools for evidence synthesis, such as systematic reviews or synopses, to enable decision-makers to identify cost-effective interventions. We believe that a routine commitment from researchers to capture the costs of management interventions would help support evidence-informed decision-making by facilitating the economic evaluations that support cost-effective management decisions. However, this will require clear guidelines for how to capture these data and incentives for conducting the necessary economic evaluations. Being able to present results systematically as return-on-investment could be an important step in encouraging greater use of science by those making management decisions.

1. Introduction

The value of testing the effectiveness of potential conservation interventions is now widely acknowledged. Efforts to synthesize the best available evidence and disseminate it to environmental managers have grown significantly with the support of tools, such as systematic reviews (Pullin and Stewart 2006), evidence synopses (Dicks et al. 2014), causal criteria analysis (Norris et al. 2012) and stand-alone meta-analyses (e.g., Cadotte et al. 2012). Providing decision-makers with the evidence for the effectiveness of potential management interventions is important, but by itself may not be sufficient (Cook et al. 2013). Constraints on decision-makers, including resource shortages (James et al. 2001; Murdoch et al. 2007) and competing priorities (Sheil 2001), mean they must seek the most cost-effective strategies to achieve their management objectives. The distinction between the most effective and the most cost-effective management intervention is important because it may lead to different actions. For example, the most effective weed management option for *Rhododendron ponticum* (physical removal followed by herbicide application) is twice as effective as the alternative (e.g., herbicide application alone) (Tyler et al. 2006). However, the cost of labour means that physical removal is three times as expensive as herbicide application alone (Tyler et al. 2006) resulting in the less effective alternative providing a greater return-on-investment. Documenting the costs and outcomes of common conservation interventions can also reveal where widely used interventions are wasting resources (e.g., Walsh et al. 2012), with significant implications for policy and practice.

More efficient conservation outcomes are forecast when the costs of management alternatives are explicitly considered (e.g., Moore et al. 2004; Naidoo et al. 2006; Polasky et al. 2001). These benefits hold whether considering the heterogeneity of costs to prioritise different actions (e.g., priority threat management; Chadès et al. 2015, Carwardine et al. 2012) or the spatial heterogeneity of costs (e.g., systematic conservation planning; Balmford et al. 2000). These and other studies have increased the emphasis on economic considerations in conservation and translated into more studies attempting robust cost-effectiveness analysis of conservation interventions (e.g., Gjertsen et al. 2014; Murdoch et al. 2007; Kubasiewicz et al. 2016), albeit from a very low base (Fig. 1). Many studies must base cost estimates on coarse proxies (e.g., Armsworth 2014) or use estimates from managers because data on actual cost and benefits are not available (e.g., Chadès et al. 2015; Carwardine et al. 2012). Where actual costs are reported, the details and level of aggregation vary dramatically. This large heterogeneity prevents comparisons between studies and precludes the use of methods for evidence synthesis (e.g., systematic reviews or meta-analyses), which could draw conclusions from the evidence base as a whole. A widespread, systematic reporting of conservation intervention costs would enable a significant advance in conservation evidence, providing decision-makers with a critical piece of the puzzle for determining how to act.

For more than a decade, conservation has been looking to health care for guidance on how to improve evidence-informed decision-making (Pullin and Knight 2001; Sutherland et al. 2004). Pressure from governments to be accountable for the cost-effective use of public funds and the strategic allocation of finite resources has led to 'evidence-based medicine' identifying techniques to measure the return-on-investment from medical interventions (Brunetti et al. 2013). Despite adopting many lessons from health care (Dicks et al. 2014; Pullin and Stewart 2006), at present, conservation lags well behind health care in reporting economic data and incorporating it into the evaluation of potential management interventions (Cook et al. 2013).

In this article we introduce economic evaluations as an underutilised and a critical tool for evidence-informed decision-making. We highlight the important features of rigorous economic evaluations by drawing parallels between conservation and health care, and describe the critical metadata studies must report to ensure they can be interpreted by others. Reporting standards for costs that assist conservation scientists and practitioners to systematically capture the economic costs of conservation interventions are currently lacking in conservation. Therefore, we adapt a reporting protocol used by the World Health Organisation and illustrate its use with a published case study of Pacific leatherback turtle (*Dermochelys coriacea*) conservation (Gjertsen et al. 2014). This is, to our knowledge, the first available cost reporting protocol for conservation interventions to support cost-effectiveness estimation. We also illustrate how evidence-informed conservation can take the critical step of integrating economics evaluations into evidence synthesis, a current omission from conservation evidence, to build a robust evidence base for decision makers. Through more consistent reporting of costs, conservation science can build an evidence base that enables conservation decision-makers to identify interventions that provide the greatest return-on-investment.

2. Economic evaluations

2.1. Types of economic evaluations

Methods for collecting data on the costs and outcomes of interventions are termed economic evaluations (Drummond et al. 2005). Economic evaluations determine the return-on-investment for different interventions (Shemilt et al. 2008). There are several forms of economic evaluations that use different approaches to help assess return-on-investment (Samuelson and Nordhaus 2005), including cost-benefit analysis (CBA) and cost-effectiveness analysis (CEA).

Cost-benefit analysis (CBA) is an approach to economic evaluation that uses monetary units to compare both the costs of an intervention and its outcomes (Hughey et al. 2003). Using monetary units to represent both costs and outcomes allows different interventions to be compared regardless of the types of benefits they provide. Estimating the monetary value of the outcomes of medical treatments can be highly subjective (e.g. measuring reduction in pain; Robinson-Papp et al. 2015) and it can be similarly challenging to monetise conservation outcomes (Laycock et al. 2009). The growing fields of environmental accounting and ecosystem services valuation continue to grapple with processes to place a dollar value on biodiversity and ecosystem services (Häyhä and Franzese 2014). Estimates are often based on asking people what they would be willing to pay (a type of contingent valuation) to conserve a conservation target (e.g., a hectare of Amazon rainforest;

Horton et al. 2003). Even when there are quantifiable, monetary benefits from natural systems, such as in the case of ecosystem services (e.g., carbon sequestration), there is still no consensus on how to estimate the monetary value of biodiversity (Häyhä and Franzese 2014).

CEA considers the costs of an intervention in monetary units and the outcomes in relation to the objective for the intervention (i.e., natural units; Hughey et al. 2003). This allows an assessment of whether the desired outcomes can be achieved given a particular level of investment. Traditionally, CEA uses a single measure of outcomes. For example, in health care, CEA might use a single clinical outcome measure, such as the number of heart-attacks avoided (Brunetti et al. 2013). However, a more sophisticated type of CEA (sometimes called cost-utility analysis) uses a composite measure of outcomes. In health care, the composite measures for the value of an intervention are Quality Adjusted Life Years (QALYs), which measure the increase in patient survival (number of additional years) along with a measure of their quality of life (Shemilt et al. 2008) and Disability Adjusted Life Years (DALYs), which measure the number of years lived with disability and years lost due to premature death (Murray 1994).

A key difference between health care and conservation is that conservation lacks a universally agreed outcome metric that would provide an equivalent to QALYs and DALYs. Conservation studies generally use single outcome measures in CEA, such as the number of species or the area of habitat protected. There have been some attempts to use multiple outcome measures for priority threat management (Chadès et al. 2015). Where the measures of observed outcomes are in the same units (e.g., numbers of Pacific leatherback turtle, *Dermochelys coriacea*), CEA can be used to compare the return-on-investment provided by different interventions. However, where the outcomes of interventions are measured using different units (e.g., numbers of Pacific leatherback turtle, *D. coriacea*, versus golden eagles, *Aquila chrysaetos*) CEA cannot meaningfully evaluate different alternatives (Hockley 2010; Kubasiewicz et al. 2016). A great strength of using agreed, composite measures of outcomes is that this facilitates a fair comparison of the return-on-investment from different interventions that might yield different ecological outcomes. Although, the fact that social values for different species vary can still complicate comparisons. CEA using a common metric has occasionally been applied in conservation (Cullen et al. 2001; Cullen et al. 2005; Gjertsen et al. 2014). Where a common metric is available, it is possible to avoid the challenge of estimating the monetary value of conservation outcomes (Hockley 2010).

While conservation studies often simplify cost-effectiveness to benefits (conservation gains) divided by costs (e.g., Carwardine et al. 2012), CEAs are typically conducted by calculating cost-effectiveness ratios (CER): the intervention costs (IC) minus the avoided costs (AC) divided by the change in outcomes as the result of the intervention (the “benefits” in the conservation literature ΔO). An example from public health would be the cost of implementing insecticide-treated bednets to prevent malaria (e.g., Goodman et al. 2001) where IC would be the costs of buying the bednets and training the households, AC would be the reduction of costs due to fewer hospital visits and less work absenteeism and ΔO would be the net reduction in number of malaria cases, deaths or equivalent health metrics like DALYs. If CER is lower than a threshold, typically associated with the gross national income per capita or gross domestic product per capita in the country where the intervention occurs, the project is deemed cost-effective (Sachs 2001).

Estimating AC (i.e., benefits) of an intervention together with the intervention costs at different scales is an important part of calculating the CER because AC can be larger than IC (i.e. CER<0), meaning the project is cost-saving (e.g. tackling unhealthy diets by increasing population awareness is a cost-saving health intervention (Cecchini et al. 2010). For example, the benefits obtained at the national and global level through the Ranomafana National Park in Madagascar were greater than the opportunity cost for local communities (Ferraro 2002). Avoided costs, however, are rarely estimated in CEA in conservation because these costs can be hard to judge accurately. Accurately estimating avoided costs requires good data on the effectiveness of an intervention, which can be lacking in conservation projects (Ferraro and Pattanayak 2006). The type of costs and avoided costs (i.e., economic benefits) to be collected will also vary depending on the type of conservation intervention (see case study; Section 3.1).

2.2. Elements of a robust economic evaluation

Despite differences in the types of economic evaluation, there are certain things that all economic evaluations should consider and report. We discuss these in turn, providing examples from health care and conservation. First, a well-designed economic evaluation should clearly set out the context for the economic evaluation (Table 1; Questions 1-3) by stating the research question, and justifying the economic importance of the issue and rationale for the type of evaluation used in relation to the question being addressed (Drummond et al. 2005). The context for the evaluation describes the importance of the problem in terms of the economic burden it creates for society, which drives the need for the intervention (Table 1), such as illness reducing the productivity of the workforce, or deforestation causing landslides. Part of the economic context is also considering how investing in an intervention might influence future costs, both through avoided costs and indirectly creating additional costs (Table 1). The complex nature of indirect costs that can create perverse outcomes is a challenge in both conservation (e.g., impacts of pollution created by herbicide use), and medicine (e.g., river contamination by estrogenic compounds) as it requires a detailed understanding of system dynamics in conservation and close monitoring of side-effects in medicine. Finally, the economic context must also consider who will bear the costs and who will receive the benefits (Table 1). This is important for understanding equity issues surrounding interventions because the costs and benefits are often inequitably distributed across different stakeholders and locations (Guerrero et al. 2013), generally disproportionately impacting local communities (e.g., as in our case study; Gjertsen et al. 2014).

Authors must also determine the appropriate spatial and temporal scale for the economic evaluation (Table 1; Questions 4, 5, 8, 9, 14, 15), because this has implications for the scale at which costs and benefits need to be measured. For example, there can be economies of scale in implementing an intervention such that cost-effectiveness is greater at larger scales (Armsworth et al. 2011). Benefits can also vary spatially, sometimes occurring beyond the intervention site (Guerrero et al. 2016), such that small scale actions can have large scale benefits. Avoided costs generally occur on a different time horizon to the intervention costs; costs occurring early in the time horizon and benefits (or avoided costs) accruing later in the time horizon, thus making project evaluation very sensitive to the discount rate used (Cook et al. 2011). The appropriate scale of the economic evaluation depends on the context for the intervention (see section 2.3) and the purpose of the evaluation. For example, if the evaluation is being conducted by government they may not be interested in long-term outcomes, and so set the time horizon for costs and benefits at a political term. With an ecological outcome in mind, the time horizon could be decades (e.g., habitat restoration).

Economic evaluations should consider a range of factors relating to the costs associated with an intervention (Table 1). Using broad categories of costs, including personnel (e.g., person-hours), equipment, materials, transportation, and capital costs (e.g., depreciation of machinery used) (Brunetti et al. 2013; Table 1; see template for costs in Table S1) can guide decisions about which costs to include. It is important that costs be disaggregated when they are reported (see Section 2.4). Using disaggregated values, an estimate of the total cost can be made along with a measure of the uncertainty associated with that estimate (Brunetti et al. 2013). However, economic evaluation is also trying to assess questions about which costs will be most influential in deciding to conduct an intervention (Table 1). For example, there may be relatively high fixed costs related to travel to a site, which will make any intervention costly (e.g., in our case study; Gjertsen et al. 2014). Similarly, it is important to consider whether the intervention was conducted in different ways that might influence the costs (Table 1). This might relate to the intensity (e.g., shooting pest animals from a helicopter versus a vehicle) or the approach (e.g., home care versus hospital treatment) to the intervention. These metadata about the intervention (see Section 2.3) are critical to interpreting the costs of the intervention and should be discussed in relation to the evaluation outcomes.

The quality of the outcome measures are critical to robust economic evaluations (Table 1). The source of effectiveness estimates should be detailed, describing the primary outcome measure and justifying the methods used to value benefits (Table 1; Shemilt et al. 2008). Studies should also provide details of any analyses or statistical tests conducted (Brunetti et al. 2013) such as effect sizes and their associated confidence intervals, and at a minimum report summary statistics (mean, sample size, variability) that enable effect sizes to be calculated (Haddaway 2015).

When interpreting the findings of the study, there should be a discussion of what level of cost is likely to be meaningful to a decision maker when selecting an intervention. In the context of budget constraints, the cost of an intervention may be negligible or may make the intervention unaffordable. Likewise, some elements of the intervention may be responsible for the majority of the cost, such as for labour intensive methods (Table 1, Question 7), and highlighting the important components of the overall cost of an intervention allows decision makers to consider variants that may reduce costs (Table 1, Question 11). Wherever possible, there should be a consideration of the additional benefit needed to justify a more costly version of the intervention. This involves considering the relationship between the costs and the benefits of the intervention. Where there is a linear relationship between costs and benefits, it may be simple to determine how much to spend to achieve the desired outcome (Fig. 2). Alternatively, there may be a minimum level of investment to achieve any outcome at all, or small investments may generate large positive outcomes (Fig. 2). For instance, large nonlinearities occur in the case of invasive pest eradication by which only certified eradication would allow the cessation of control efforts, creating a spike in economic benefits (Fraser et al. 2006). Estimates of the uncertainty in the costs-benefit relationship are also critical to determining how reliable outcomes will be under different levels of investment (Table 2), and the probability that they will be fully realised over time. In our case study, uncertainty in parameter estimates for turtle population models are addressed through the use of probability distributions (Gjertsen et al. 2014). This is all valuable information for decision-makers trying to decide which intervention to adopt.

2.3. Metadata for an economic evaluation

A challenge for economic evaluations is that costs can vary widely in different context. Therefore, metadata should be included that provide critical context for the evaluation (Table 2), facilitate the transfer of cost information among conservation interventions and enable evidence synthesis (see Section 3). The context for the intervention (e.g., starting conditions) and how it was conducted (i.e., details of the methodology for the intervention) yields valuable information about the intensity and approach used (Table 2) that can help interpret both the cost information and the outcome information. This should include the spatial and temporal scale for the intervention (Table 1, Question 4-5; Table 2). Interpreting the results of an economic evaluation also requires information about the time horizon over which the costs and outcomes were calculated (Table 2). For example, cost estimates may be substantially lower if only the cost of the initial treatment is included, rather than including on-going maintenance costs. Likewise, the outcomes could differ significantly if measured directly after the treatment, rather than one or two years later. This is typical of the economic evaluation of invasive species, where avoided costs can outweigh intervention costs as longer time horizons are considered (Cook et al. 2011). This may over-estimate benefits if outcomes are short-lived or under-estimate benefits if outcomes take decades to accrue (e.g. habitat restoration). Measuring short term outcomes provides no indication of whether outcomes continue to accrue over time. This is also true in health care, where studies rarely measure the longevity of outcomes (e.g., do subjects maintain weight loss?).

While detailed reporting of the resources used is desirable through a standardised protocol such as that in Table S1, if resource use is recorded as the monetary cost, it is important to report the currency and the year of expenditure in the metadata (Table 2, Table S1). This will ensure figures can be translated into a common currency and price year through the use of conversion factors, such as purchasing power parity and gross domestic product deflators (Shemilt et al. 2008). The source of any cost estimates should also be included, describing any cost calculations or comparators used.

This information enables the findings of the economic evaluation to be interpreted in other jurisdictions.

3. A tool for transparent reporting of intervention costs

To facilitate robust and transparent recording and reporting of costs, we suggest the use of a standardised protocol that sets out the elements involved in the intervention and the opportunity costs (Table S1). This protocol is based on CostIt, a cost reporting tool for health interventions from the WHO (WHO 2015). An alternative specialized cost reporting tool for REDD+ projects is the REDD+ Cost Model (CIFOR 2016).

This protocol not only prompts the evaluator to consider the important cost categories (see Section 2.2; Table 1) and to disaggregate costs data, but also to include the generic units and unit costs. This is defined as the “ingredients approach” in the recommendations for CEA by the WHO (Edejer et al. 2003). For instance, reporting the number of person hours and the salary per person hour, or litres of fuel and the unit cost per litre, rather than the aggregated monetary costs incurred during the study (Brunetti et al. 2013). This is important because reporting total costs, rather than the ingredients used to calculate those costs, prevents practitioners from transferring this information to other settings, or even evaluating how useful it is for their own case (Edejer et al. 2003). Similarly, it prevents understanding how costs will vary if the intervention effort is increased or decreased.

3.1. Case study

In Table S2, we illustrate the use of this tool based on a case study of an intervention to conserve Pacific turtle (*Dermochelys coricea*) in Hawaii, California and Indonesia (Gjertsen et al. 2014), which provided unusually detailed cost information. The intervention in Indonesia involved easily quantified capital costs (on-site camps to house personnel), transport costs to and from the camps and administration costs (IC in CER). Also included in the IC were the costs to compensate the community for impacts on their livelihoods (i.e., the opportunity costs of stopping egg collection in Indonesia). The Hawaiian and Californian interventions involved fisheries closures and regulation and was costed based on the opportunity costs of changing equipment, and fisheries closure. The change in outcomes corresponded to the improvements in the turtle population (ΔO), estimated through biological models which capture uncertainty in the estimated ecological benefits (Gjertsen et al. 2014; Table S2 in Supplementary material). The cost per turtle saved (CER) was then estimated.

Unfortunately, the case study used to illustrate the protocol reported aggregated costs, making it difficult to determine how complete the costings were or how they would transfer to different regions or contexts (see Section 2.2). Nevertheless, it provides a useful example of the different types of costs, including the opportunity costs of an intervention (see Section 2.1), and the challenge for those wishing to interpreting the findings of economic evaluations that do not provide detailed metadata (Table 2) or disaggregated cost data and generic units. In addition, the authors acknowledged that the opportunity costs to local communities are not fully compensated in the program (Gjertsen et al. 2014), which highlights the need for studies to take note of any inequality in the distribution of costs and benefits among different stakeholders in a conservation intervention. Transparent reporting of costs, and who bears them, can help identify these inequities.

4. Synthesizing data from economic evaluations

Understanding the relationship between the costs and benefits of an intervention requires measuring both across the range of conditions in which the intervention is implemented, providing an understanding of the socioeconomic and environmental context. This is beyond the scope of most economic evaluations but can be established through meta-analysis where there are multiple economic evaluations addressing the application of the intervention under different conditions (e.g., Carrasco et al. 2014). While far from ubiquitous, economic evaluations of medical interventions are considerably more widespread than for conservation interventions; although, it is still rare for meta-analyses of CEA studies to account for the context of the intervention. Nevertheless, in health care economic evaluations are incorporated into evidence synthesis tools like systematic reviews, to determine which interventions provide the greatest return-on-investment under different circumstances (Drummond et al. 2005).

4.1. Integrating economic data into systematic reviews

The Cochrane Handbook for authors of systematic reviews of medical evidence provides explicit guidance for how to integrate the available data from existing economic evaluations into systematic reviews (Shemilt et al. 2008). These guidelines ensure that authors consider the relevant issues *a priori* and extract the necessary information from studies (Table 2) to properly consider the different factors that can influence the return-on-investment.

One key lesson that can be learnt from systematic reviews of medical interventions is that integrating economic evaluations has implications for every step in the evidence synthesis process. While meta-analysis can be used to synthesize the results of multiple economic evaluations as part of a systematic review (Shemilt et al. 2008), costs should be fully integrated into the review process. That is, in the *a priori* protocol the objectives for how the cost data will be used within the review should be clear, there should be explicit reference to economic evaluations in the inclusion criteria for studies, the outcome measures to be used should be clear (and consistent to facilitate comparisons among studies) and there should be specific mention of the return-on-investment within the recommendations for management and further research (Shemilt et al. 2008). Providing guidelines for how costs should be discussed in relation to the implications for management and further research has enabled medical systematic reviews to be more consistent in the interpretation of review findings.

Just as with other studies included in systematic reviews, it is important to assess the quality of economic evaluations. Economic evaluations should always include the relevant information about how the study was conducted (e.g., the type of valuation method, the time horizon; Table 2) to enable this quality assessment (Section 2.3). However, it is important to note that inconsistent results between economic evaluations do not necessarily indicate poor quality studies. There can be legitimate reasons why costs vary between studies and this variability, once environmental and socioeconomic factors are accounted for, can provide valuable insight into different applications of the treatment. Therefore, it is worthwhile exploring the reasons behind any differences. If plausible reasons cannot be found for variation in cost estimates, then the confidence in those estimates should be reduced (Brunetti et al. 2013).

Where multiple estimates of costs are available, any variation in cost estimates between economic evaluations should be explored. Some variation will be explained by how the intervention was conducted, which can help reveal the most cost-effective way to achieve the desired outcomes. For example, it would be possible to examine whether shooting feral goats from a helicopter versus doing it from a car provides sufficient benefits to justify the additional cost. Similarly, it is worth investigating which costs are most variable and why, and the relevant implication for the way interventions should be conducted. Where there is concern about the quality of some economic evaluations, sensitivity analysis can be used to determine the impact of potentially spurious studies on the overall findings. Sensitivity analyses can also be used to explore the stability of results, testing assumptions by including different components of costs, or altering which pieces of data are used in the analysis using alternative data and assumptions (Chee 2004).

Sensitivity analyses can be valuable for exploring which costs are most influential in determining the overall cost of the intervention (Brunetti et al. 2013). Differences in cost will often be explained by variation in the location, timing and spatial and temporal scale of the study, which helps estimate how much costs differ for the same intervention. Therefore, information about the context for the intervention that might influence the heterogeneity of costs should be recorded (Table 2). The relevant contextual factors are often the same as those that influence the heterogeneity in effectiveness of interventions. Highlighting large, unexplained discrepancies between studies can suggest areas for further research, and draw attention to the decision context where such knowledge gaps are most relevant.

5. Recommendations for improving the use of economic evaluations in conservation

For conservation, a significant challenge for integrating economic evidence into management recommendations is finding primary evidence on the costs of interventions. To evaluate the variability in costs and outcomes of interventions across the range of relevant management contexts, it is necessary to conduct economic evaluations under a range of conditions. Therefore, economic evaluations should be given an important place in the conservation literature, building a routine commitment to primary conservation research recording the costs associated with an intervention when effectiveness is being tested. A strong incentive for researchers to make this change would be a requirement by academic journals to report costs and associated metadata as supplementary material. To be most effective, agreed standards should be adopted for how to capture and report the costs of conservation projects. Without standards, the availability and quality of estimates of resource use are likely to remain poor, limiting the ability to conduct economic evaluations. While there may be sensitivities to transparently reporting costs (e.g., concerns about perceived competitiveness when tendering for grants), the reporting of raw units without the actual dollar figure would still provide valuable information for others, and granting bodies could require this in project outcomes reporting.

Despite the challenges, capturing cost data should not be an all or nothing proposition, and it is important that tools for evidence synthesis, such as systematic reviews and evidence synopses, attempt to capture cost estimates wherever they are available. This may mean that initially cost estimates are simple, presented as relative figures (e.g., one intervention requires 3 to 5 times more resources than the alternative), and discussed broadly in terms of how and when the costs of an intervention might alter the choices of decision-makers. In these cases, costs would not be incorporated into the critical review, but could be discussed qualitatively. Where this is done, it will be critical to include an analysis of why costs were difficult to estimate and the important sources of uncertainty in the available information. While far from the ideal evidence for decision-makers, such presentations may encourage discussion about how to improve estimates or the important factors to consider.

6. Conclusions

Economic evaluations that compare alternative interventions provide decision-makers with critical information about cost-effectiveness. Conservation is not the only discipline to face challenges in capturing and integrating information about intervention and opportunity costs into decisions-making, enabling us to leverage progress made elsewhere. Examples from health care illustrate the value of developing universally agreed outcome measures that enable comparison between interventions targeted at different outcomes, and the benefit of including avoided costs when calculating cost-effectiveness ratios. Moving forward as a discipline requires widespread recognition of the benefits of considering the costs of management, a commitment from researchers to capture economic information, clear guidelines and standards for how to capture and report these data in a standardized manner, and real incentives for conducting economic evaluations of management interventions. We acknowledge however that systematically collecting cost and effectiveness data is challenging and even simple qualitative accounts would prove very valuable to advance the field. Practitioners should not be discouraged from collecting cost data if a full detailed report is not feasible. We attempt to advance the systematic reporting of costs by developing several cost reporting tools for conservation interventions (Tables 1, 2, S1). As the knowledge base grows, economic evaluations should be routinely integrated into methods for evidence synthesis and used to help practitioners make rational decisions about resource allocation. While the necessary changes will require effort, researchers may find that their science gets greater traction with decision-makers if research findings can be communicated in terms of the greatest return on investment.

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Tables and Figure Legends

Table 1. Important elements of economic evaluations of interventions and questions to facilitate the economic analysis and reporting for health care versus conservation interventions [adapted from Shemilt et al. 2008].

Examples from health care	Examples from conservation
Economic Context	
Question 1. What is the economic burden to society of the problem the intervention is seeking to affect and what proportion of that burden can be reduced by the intervention?	
Smoking cessation would reduce the economic burden on the public health system of the health problems associated with smoking.	Environmental weeds have costs to landholders and governments in terms of lost productivity and management costs.
Illness leads to reduction in productivity due to patients requiring time out of the work force.	Weeds can disrupt ecological processes leading to additional management costs (e.g., fire management due to gamba grass infestations in Northern Australia increasing the frequency of wildfires; Settlerfield et al. 2014).
Question 2. How might investing in the intervention influence future resource use?	
Intervening may lead to indirect costs associated with the treatment (e.g., the need to manage side-effects from a treatment).	Intervening may lead to indirect costs associated with the action (e.g., costs of managing changes in water quality caused by herbicide application or soil disturbance caused by mechanical removal).
Early intervention programs can reduce the cost of co-morbidity (e.g., reducing childhood obesity can reduce the incidence of type 2 diabetes).	Intervening may lead to changes in recurrent costs (e.g., reduction in cost of on-going management due to local eradication of a weed versus the increased cost of management if inaction allows the weed to spread into new areas).

Question 3. How equitably will the costs and benefits of the intervention be distributed?

Government (therefore society) often pay for health care interventions while benefits primarily accrue to treated individuals and employers (through increased productivity).	The costs of interventions such as fisheries closures can be incurred by conservation agencies but also cost local communities their livelihoods. Unless compensation is paid to local communities, benefits will accrue to society generally at the expense of local communities.

Intervention Context

Question 4. What is the spatial scale of the intervention?

The spatial scale of an intervention can have impact costs in two ways. First the overall scale could be local (e.g., bednets for a village), regional (e.g., health care education program), national or international (e.g., immunization program).	The spatial scale of an intervention can have impact costs in two ways. First the overall scale could be local (e.g., protect a single population of threatened species), regional (e.g., landscape scale restoration), national or international (e.g., illegal wildlife trade)
Second, how dispersed the treatment locations are could reduce economies of scale due to extra travel time between sites. For example, treating several villages in a region that is sparsely populated.	Second, how dispersed the treatment locations are could reduce economies of scale due to extra travel time between sites. For example, treating 5 ha in a single plot versus 5, 1 ha plots.

Question 5. What is the temporal scale of the intervention?

Costs can vary significantly with the temporal scale of an intervention. A treatment could be short term over days (e.g., contraceptive implant), multiple treatments over months (e.g., chemotherapy) or long-term treatment program over years (e.g., major surgery and rehabilitation).	Costs can vary significantly with the temporal scale of an intervention. A treatment could be short term over days (e.g., fishery closure), multiple treatments over months (e.g., weed management) or long-term treatment program (e.g., rat eradication from island with on-going surveillance).

Question 6. What is the starting condition (state) for the intervention?

	The cost of an intervention for individuals with a chronic illness that has caused organ damage could be significantly higher than an early intervention program before illness becomes chronic.	Cost will be significantly higher at a site where weeds are established and at high densities versus a site where the native vegetation is largely intact and weeds are localised.
Costs		
Question 7. *What resources are required to implement and sustain the intervention?*		
	Categories of resources include personnel (e.g., specialists, clinicians, nurses, laboratory technicians), intervention costs (e.g., drugs, surgery, physical therapy), laboratory tests, transportation costs (e.g., patient transport, home visits), capital costs (e.g., constructing a temporary clinic)	Categories of resources include personnel (e.g., field workers, laboratory technicians, training), equipment (e.g., tools, safety gear), consumables (e.g., herbicide), transportation costs (e.g., travel to and from the site), capital costs (e.g., building camps) (Table S1).
Question 8. *What is the time horizon over which costs are likely to accrue?*		
	Costs may be immediate and one off (e.g., surgery) or interventions may continue over a number of years (e.g., physical therapy to recover from stroke).	Costs may be accrued once or over several years depending on the treatment. For example, a single herbicide application may be used or repeated applications may be required followed by revegetation.
Question 9. *What is the spatial scale over which costs are likely to occur?*		
	The costs may be incurred at multiple scales, including a broad scale for government funded programs (e.g., by society as a whole), or local scale for user pays schemes (e.g., by the patient) or combination of scales when costs are shared among a range of stakeholders (e.g., community run education programs, combined with government treatment programs).	The costs may be incurred at multiple scales, including broad scale for government funded programs (e.g., by society as a whole), intermediate scale (e.g., donors to NGOs) or local scale (e.g., regulation affecting private landholders) or a mixture of all of these.
Question 10. *Who will incur the costs of the intervention?*		
	The costs may be incurred by society as a whole (e.g., government funded programs), the patient (e.g., user pays) or a mixture of both.	Costs can be incurred by society as a whole (e.g., government programs), stakeholders (e.g., landholders, NGOs), communities (e.g.,

	Examples from health care	Examples from conservation
		livelihood impacts of opportunity costs) or a combination of these.
Question 11. Which costs are likely to be most important in deciding to carry out the intervention?		
	Generally there are some elements of medical interventions that are always costly and will influence whether the intervention is affordable (e.g., surgery, hospital stays, the need for on-going care).	Labour costs are often significant and may influence the practicality of some interventions. Project may require specialist skills not available in-house adding costs for contractors or staff training. Likewise, opportunity costs may be large if the project affects land use.
Question 12. *What are the costs of different variants of the intervention?*		
	Different ways of administering the intervention might include a lower dose of medication or fewer applications. These variants might have different objectives, such as managing chronic illness rather than providing a cure.	Different intensities of an intervention (e.g., single versus multiple applications of herbicide, increased concentrations of the herbicide). These variants might represent different management objectives of containment versus eradication.
Outcomes		
Question 13. What is the best measure of the outcomes of the intervention?		
	The primary outcome measure for an intervention aimed at reducing blood pressure may be the number of heart attacks avoided. Complex outcomes might be measured as Quality Adjusted Life Years or Disability Adjusted Life Years.	The primary outcome measure for a weed management intervention could be the restoration of native vegetation. Other outcomes might be the number of threatened species that have been protected from extinction.
Question 14. What is the time horizon over which outcomes are likely to accrue?		
	Outcomes might be rapid (e.g., patients who would have died survive) but may only accrue over long time periods (e.g., rehabilitation from a	Outcomes may be accrued rapidly (e.g., increased survival and reproduction) or may take decades to accrue (e.g., habitat restoration).

	Examples from health care	Examples from conservation
	traumatic brain injury).	
Question 15. What is the spatial scale over which outcomes are likely to accrue?		
	Outcomes might be rapid (e.g., patients who would have died survive) but may only accrue over long time periods (e.g., rehabilitation from a traumatic brain injury).	Outcomes may be accrued rapidly (e.g., increased survival and reproduction) or may take decades to accrue (e.g., habitat restoration).
Question 16. Who will benefit from the intervention?		
	Benefits can be local (e.g., the individual treated), regional (e.g., state government programs benefiting taxpayers and employers in the state) or broad scale accrued by society as a whole (e.g., laws preventing passive smoking).	Benefits can be accrued locally (e.g., human-wildlife conflict interventions), regionally (e.g., restoration of ecosystem services) or more broadly for species conservation (e.g., accounting for intrinsic value of threatened species).
	Benefits may also accrue in a different location to where costs are incurred (e.g., immunization programs that prevent the spread of disease to surrounding areas)	Benefits may also accrue in a different location to where costs are incurred (e.g., for migratory species that move across borders).

[a] *Can be viewed as avoided costs if an intervention is successful*

Table 2. The metadata that should be reported in studies to facilitate evidence synthesis.

Item	Description	Relevance
Context		
Date	The year the study was conducted and dates when the costs were incurred if different.	Used to convert monetary figures to common price year
Study location	The geographical location of the study	Used to examine whether geographic location influences the cost of the intervention
Context for the intervention	Description of the starting conditions for an intervention (e.g., initial population size or area affected, environmental conditions, histories of human disturbance etc)	Provides critical detail for understanding both the expected benefits for an intervention and the resource required to achieve the desired outcome.
Methodological information		
Study design	Detail about how the study was conducted	Used to determine whether the findings of the study are sufficiently reliable to be included in the review
Details of the interventions	Specific details about how each intervention was carried out	Used to determine whether all resources used have been accounted for and to examine variability in costs and outcomes
Estimates of effectiveness	The measure of the outcomes derived from the intervention	Allows the outcomes of different interventions and different studies to be compared alongside the data on costs
Time horizon for outcomes	The total period of time over which outcomes will accrue	This is relevant when outcomes are uncertain or may accrue over a long period of time (e.g., restoration projects).
Benefits or avoided costs	Benefits derived from the intervention (e.g. ecosystem services provided)	Needed to deduct from the intervention and opportunity costs. They may offset a large fraction of the costs of the intervention.

Item	Description	Relevance
Time horizon for benefits or avoided costs.	The flow of benefits across the time horizon.	Needed to understand how the time horizon affects the CEA.
Economic information		
Resources used	The amount of natural units and unit cost of resources used under different categories (Table S1)	Used to estimate the overall cost of the intervention. Reporting the units or values for each resource used allows the variability in costs between interventions and between studies to be compared, and facilitates sensitivity analysis to determine which costs are most influential.
Currency	The currency in which monetary costs were paid	Used to convert monetary figures to common price year
Source of data for resources used	A description of how each of the resources were measured and any cost calculations or comparators used to derive these values	Assists in converting different cost estimates into the same price year, and facilitates exploration of variation between cost estimates.
Time horizon for costs	The total period of time over which costs were incurred	This information is needed to compare the cost and outcomes of interventions over time (e.g., when not all costs are incurred up front or where effectiveness is related to the number of repeated applications of an intervention).
Uncertainty in cost estimates	A description of any sources of uncertainty in the estimates of resource use provided by authors	Provides guidance about how complete estimates are likely to be, and can be used to develop confidence intervals around cost estimates.

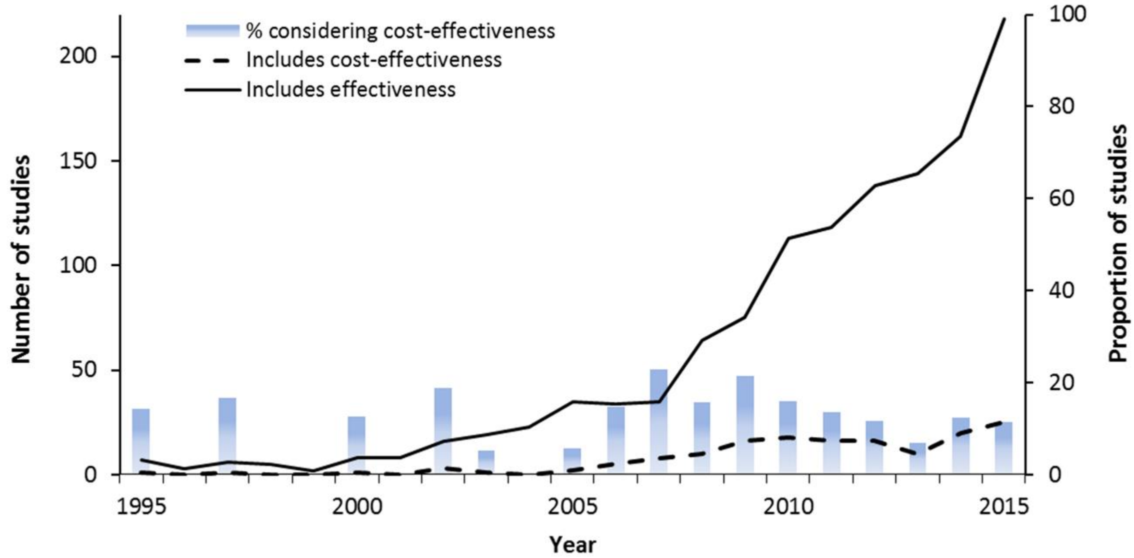

Figure 1. The number of studies in the conservation literature that include the keywords "effectiveness" (solid line) and "cost-effectiveness" (broken line) over the past 20 years. Blue bars indicate the proportion of studies considering cost-effectiveness relative to the overall number considering effectiveness, demonstrating that any increase in number is likely a product of increasing number of papers published in conservation, rather than a net increase.

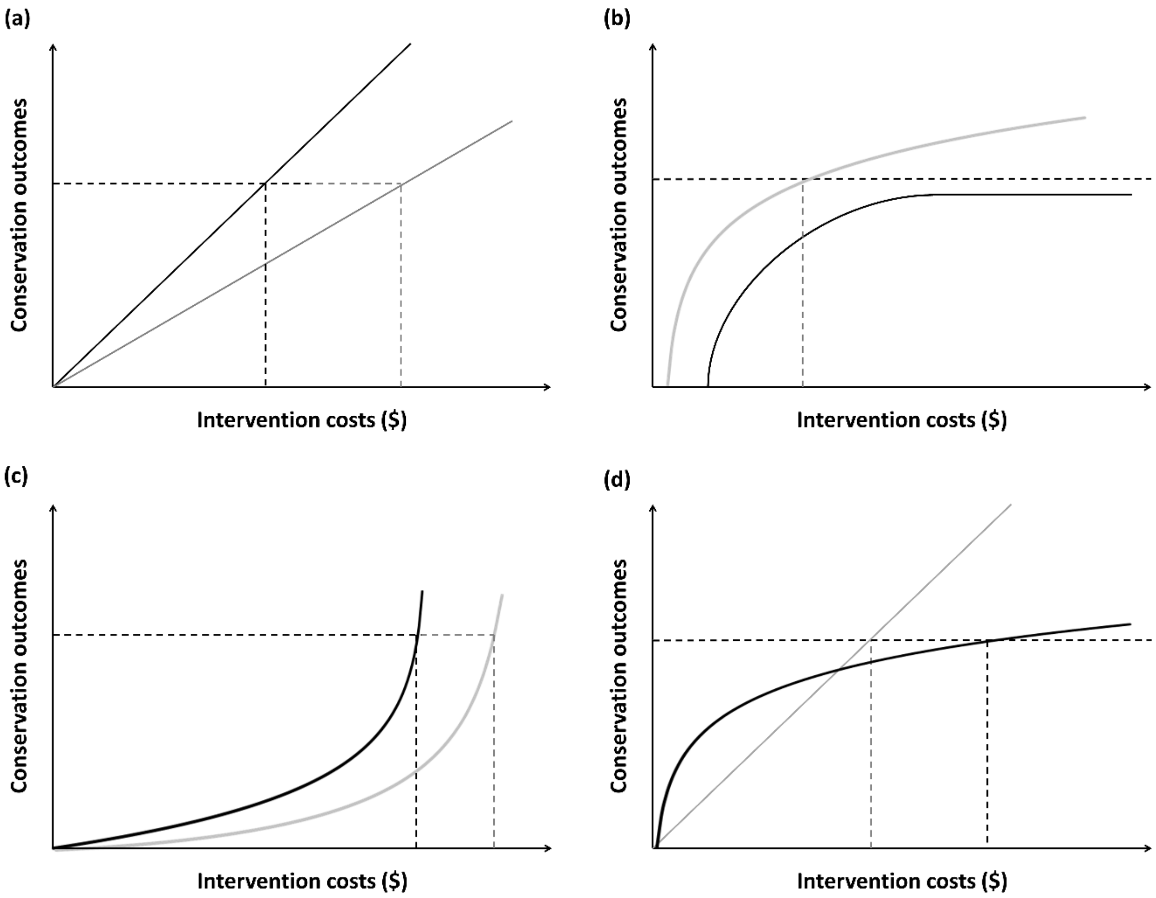

Figure 2. Four examples of the relationships between intervention costs and conservation outcomes for alternative interventions (solid black line = intervention 1; solid grey line = intervention 2). The broken lines represent the cost of implementing each alternative intervention to achieve the desired conservation outcomes. (a) Both relationships are linear but the gradient determines the best alternative. (b) While conservation outcomes are acquired rapidly for relatively little cost, marginal decreasing returns occur and, as a result, intervention 1 never achieves the desired conservation outcomes. (c) Both interventions require a significant investment to accrue conservation outcomes. (d) The best intervention changes beyond a certain level of investment.