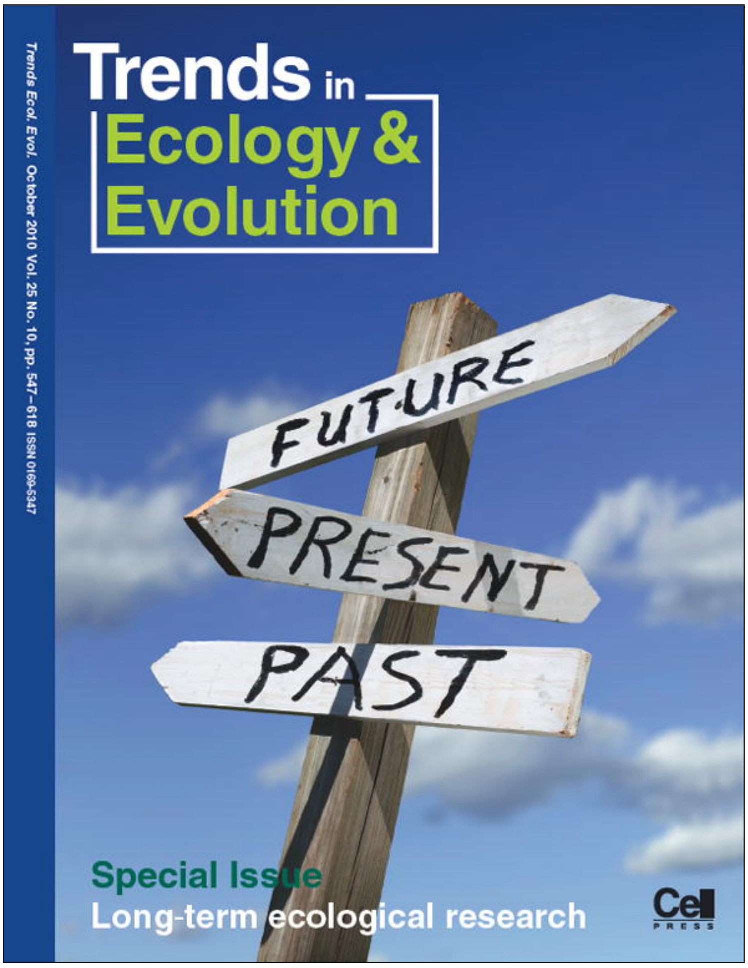
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Monitoring does not always count

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The gross under-resourcing of conservation endeavours has placed an increasing emphasis on spending accountability. Increased accountability has led to monitoring forming a central element of conservation programs. Although there is little doubt that information obtained from monitoring can improve management of biodiversity, the cost (in time and/or money) of gaining this knowledge is rarely considered when making decisions about allocation of resources to monitoring. We present a simple framework allowing managers and policy advisors to make decisions about when to invest in monitoring to improve management.

Knowing how to monitor is not enough

There has been a dramatic increase in conservation monitoring over recent years, with investment in monitoring often consuming 10% or more of the multimillion dollar budgets of agencies charged with managing our planet's biodiversity [1,2]. This increase has led to considerable critical examination of monitoring design issues such as implementation and statistical power [e.g. 3]. However, good monitoring should rest more fundamentally on a clear justification for acquiring information in the first place: what we strive to know should be driven by what we need to know [4,5, and references therein]. Two of the main reasons for conservation monitoring focus on acquiring information needed to improve management decisions [5]: adaptive management (which systematically integrates results of management interventions to iteratively improve management), and monitoring to inform state-dependent management (which implements actions based on the current state of the system; Box 1). Despite potentially improving conservation decisions, the benefits of the information gained do not always outweigh the costs of acquiring it [4]. Understanding the nature of these costs and benefits is vital to evaluating them rationally in the context of financial limitations and the urgency of conservation issues [6].

A decision tree to decide when monitoring counts

Decision theory [7] allows explicit consideration of the value of information and thus provides a useful framework to resolve questions of monitoring investment. Complex procedures for evaluating the trade-off between monitoring and management have been explored for specific conservation problems [e.g. 8]. However, the complexity and specificity of these procedures limit their utility for most conservation managers and policy makers. We present a decision tree which, through a series of simple questions, guides decision makers towards an explicit and transparent decision regarding whether or not to monitor, and what type of monitoring to undertake (Box 2). We focus solely on monitoring that directly improves management; that is, monitoring to guide state-dependent management and monitoring to learn the best management action (Box 1). We ignore all the other potential reasons for monitoring (e.g. legislative obligations); our decision tree is not designed for making decisions regarding investment in these monitoring endeavours.

Using the decision tree

We illustrate the utility of the decision tree (Box 2) using three contemporary conservation problems: managing populations of killer whales *Orcinus orca*, Florida scrub jays *Aphelocoma coerulescens*, and Tasmanian devils *Sarcophilus harrisii*. We highlight particular components of these conservation problems simply to illustrate our approach, and we do not attempt to definitively answer the question of whether, or how much, to invest in monitoring these species.

Threats to killer whales in the Georgia basin

Killer whales in the Georgia Basin on Canada's west coast declined significantly between 1995 and 2001 prompting listing under the Species at Risk Act and the development of a recovery strategy (**Q1**)[9]. Causes of the decline are poorly understood (**Q2– No**)[9], so it is difficult to derive management options and evaluate the benefits of these alternative actions. As such, it is prudent to implement research (e.g. through scientific research or an expert elicitation process) to identify threats and uncover management options (**Decision 3**). Once this is achieved, managers can return to the decision tree to decide whether monitoring is needed to improve management. Whereas it might seem alarming to postpone monitoring of a threatened population, it is often more important to identify threats and appropriate management actions than to expend resources on merely

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Box 1. Definition of adaptive management and limitations to its implementation

'Adaptive management' is a process by which we manage a system and learn as we go: learning while doing [13]. There are two key forms of adaptive management: passive and active. A *passive adaptive* manager will assess the probable outcome of each strategy and implement the one most likely to maximise the objective based on current knowledge. Under a passive adaptive scenario, the consequences of management are repeatedly evaluated but, as the name suggests, no attempt is made to impose a management action specifically with the intention of learning. In contrast, an *active adaptive* manager anticipates the knowledge to be gained from particular management actions and evaluates that knowledge in terms of its probable contribution to future outcomes. In active adaptive management, managers assess the likely outcome of, and learning from, each strategy, choosing the one most likely to achieve their objectives overall.

For adaptive management to progress successfully, appropriate financial and human resources need to be made available. Institutions must strive to ensure necessary resources are in place before embarking on adaptive management [14].

Temporal constraints must also be considered. Conservation science is often a crisis discipline [6] and the urgency of the problem in hand affects decision-making in regard to learning. A key question is do we have enough time before our species is lost to implement adaptive management? If the answer is yes, we must check whether the response of the system relative to the objective of the conservation program can be observed within the project timeframe. Adaptive management requires iterations of management to be implemented allowing knowledge to accrue, so an adequate funding period is essential for adaptive management to be successful.

For further information see [13] and [14].

confirming an ongoing decline. Similarly, even if multiple threats are suspected, management actions on potentially misleading targets risk wasting resources.

State-dependent prescribed burning

The Florida scrub jay is listed as threatened under the US Endangered Species Act. Florida scrub jays require specific scrub-oak habitat conditions to persist [10]. Prescribed burning is needed to reach the management objective of maintaining the shrub layer between 1 to 2 metres (**Q1**). Note that there is also a wider suite of relevant objectives, for example scrub jay population targets; we focus on this habitat-specific objective here by way of illustration. The major threat to Florida scrub jays is scrub oak habitat degeneration due to fire suppression (**Q2-Yes**)[10]. Management is dependent on the state of the system, namely the height of the shrub layer (**Q4-Yes**). In this case, monitoring for adaptive management does not need to be considered (**Q9-15**) as the conservation activity for each state is known (**Q5-Yes**); that is if the shrub layer is below the threshold no action is required and, if above, prescribed burning is required (**Q5-Yes**). After deciding that monitoring is required for optimal management, managers must resolve how to monitor the vegetation and thus the state of the scrub oak habitat (**Decision 6**). To make this choice, a manager should employ decision analysis based on the adequacy of habitat information delivered by different monitoring techniques and the cost of each monitoring technique (Box 3).

Learning how to manage Tasmanian devils

The Tasmanian devil has declined rapidly in the last decade due to a fatal facial tumour disease, and a vigorous response has been launched [11]. There are many potential objectives for this initiative; as an example, we specify an objective to minimise disease prevalence (**Q1**). Here the cause of decline is known and potential actions have been described [11] (**Q2-Yes**). The state of the system (e.g. total devil population or number of infected animals) does not affect the management decision (**Q4-No**) but the novelty of the disease has led to multiple hypotheses about disease behaviour and so the best management options is not clear [11] (**Q7-No**). Thus the reason for monitoring in this case is for adaptive management. Funding is committed over the next five years, so several iterations of removing individuals and tracking disease prevalence could occur during the conservation program (**Q9-Yes**). The decline of this iconic Australian species has drawn over A$13 million from state and federal government bodies [1,12] (**Q11-Yes**). Given this high level of resourcing, active adaptive management (Box 1) is a feasible option for understanding how to manage the impact of the facial tumour disease (**Decision 12**). However if sufficient resources (both financial and institutional) were not committed to an active adaptive strategy (**Q11-No**), then it is essential to decide if an effective monitoring strategy for observing change in disease prevalence is possible (**Q13**). If there is a cost effective monitoring strategy, passive adaptive management might be implemented (**Q13-Yes**), but if no cost-effective monitoring strategy exists (**Q13-No**), then the benefits of monitoring to inform management are negligible and monitoring should not be implemented. Managers should instead make an informed decision (Box 3) regarding the best management action and proceed with implementation (**Decision 15**). Managers of threatened species often have very limited funds, and as such, many will face this final suite of questions (**Q13-15**; Box 1).

Monitoring for reasons other than improving management

There are of course other reasons to monitor including legislative obligations or precautions, auditing or publicity purposes. The limitation of time and money, however, often plays a lesser part in such monitoring endeavours. Here, the key requirement is that the information required be obtained for the least cost, or is at least traded-off against the benefits of other actions. If a decision to monitor based on our decision tree suggests no monitoring is required to improve management outcomes, managers must then assess whether it is necessary to monitor for any other purpose, ideally by implementing a formal decision analysis (Box 3). Similarly, if monitoring is required to improve management (Box 2), managers should assess if the monitoring strategy implemented is satisfactory to fulfil these other reporting requirements and thus avoid unnecessary expenditure. In the case of long-term monitoring programmes, where they are experimental or intended to inform management action directly (Silvertown *et al.* this volume), the decision tree we provide can be used to ask whether effective monitoring is possible given the resource limitations. However, long-term monitoring often delivers unforeseen outcomes that might have a broader conservation impact. We are not aware of any rigorous decision-making frameworks for evaluating long-term monitoring

Box 2. Making decisions about monitoring

The first step in the monitoring decision tree (Fig. I) is to state clearly the objective(s) of the conservation program (Q1). Objectives must be realistic, explicit, measurable, and relevant to management. The second step is a review of existing information on threats and possible management options to address those threats (Q2). Where threats and management actions are well understood (the certainty attached to the term 'well' will be a case specific quantity), the next step is to assess whether monitoring can usefully inform management (Q4, 5, 7). However, it is also important not to delay management simply because of imperfect knowledge about management actions. See main text for examples of these assessments in practice. The fourth step is to consider constraints (most notably time (Q9) and resources (Q11)) on our ability to implement the type of monitoring or research that is needed. Even if considerable financial or human resources are available, there may not be sufficient time to correctly identify trends or incorporate monitoring results into future management. Where insufficient resources exist for active adaptive management, an assessment of other monitoring options might identify alternate cost-effective strategies (Q13). Working through this decision tree yields recommendations on whether and how to implement monitoring for management (Recommendations 3, 6, 8, 10, 12, 14, 15). In some cases monitoring might not be possible or justified, given for example the urgency of the conservation issue or where only one clear management option exists. In all cases, monitoring for reasons other than improving management must be considered after progressing through this decision tree.

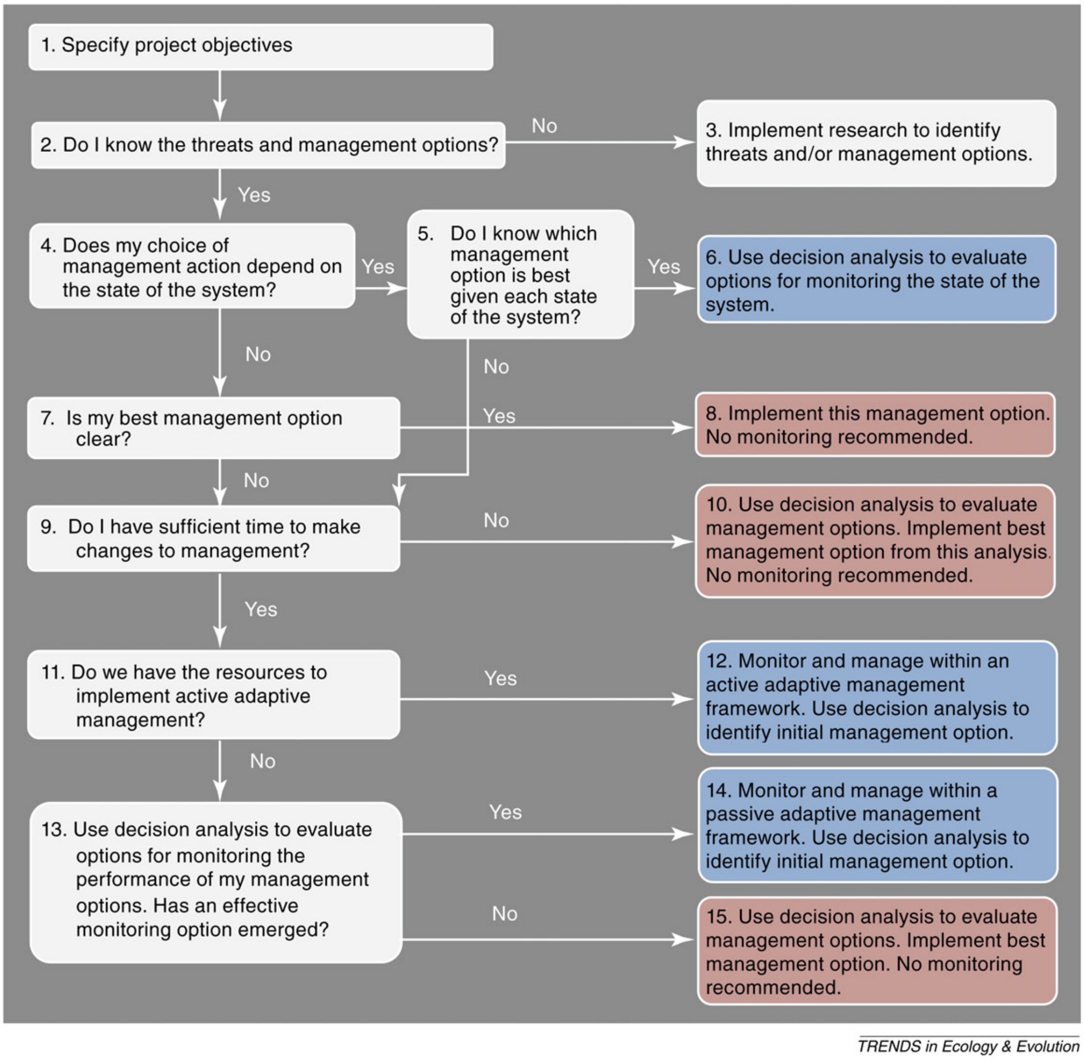

Figure I. Decision tree for deciding when to implement monitoring to improve conservation management.

proposals of a more serendipitous nature (i.e. where threats and management options are not known a priori). We suspect that long-term monitoring programmes are typically terminated for reasons other than a rational assessment of cost and benefit (e.g. loss of the main instigator).

Information gain is not necessarily conservation gain

Monitoring is generally perceived as a rational and defensible activity in the pursuit of improved conservation outcomes. Rarely, however, do we critically assess the relative value of gaining information. We must be prepared to forego monitoring in some cases by explicitly asking the question: is spending money on monitoring justified relative to funding other actions, including strategic research? Importantly, within the framework presented here, a decision to direct resources away from monitoring is not driven by reluctance to evaluate our conservation investments. Instead, this decision is driven by a desire to maximise expected conservation outcomes given limited resources. We believe there are a large number

Box 3. Implementation of decision analysis

Decision analysis is a procedure for discriminating between suitable courses of action; in our case, to select the most appropriate regime for monitoring (Decision 6, Question 13 in Box 2) or management (Decisions 10, 14, 15 in Box 2). Decision analysis involves a structured enquiry into the different actions available, along with their costs, benefits and constraints [15]. One must consider the benefit of each possible activity, e.g. learning, monitoring or management action in terms of reaching the overall conservation objective, the probability of success of that activity, and of course the cost of implementing it. Options for implementing decision analysis range from a simple calculation of the combined benefits relative to the total costs incurred (e.g. *Benefit x Probability of success / Cost*) to a more complex optimization (e.g. stochastic dynamic programming).

For further information on decision analysis see [15].

of conservation projects where information gain might not maximise conservation gain.

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Letters

Uniting marine and terrestrial modelling of biodiversity under climate change

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Well-documented differences between marine and terrestrial environments [1] have resulted in limited interaction between ecologists working in each of these realms [2], which has reduced our capacity to address shared research priorities such as predicting effects of climate change on biodiversity. Efforts to model impacts of climate change on compositional biodiversity are important for planning ameliorative conservation and management actions [3],

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