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Managers consider multiple lines of evidence important for biodiversity management decisions

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ABSTRACT

Protected area managers often fail to use empirical evidence for their management decisions, yet it is unclear whether this arises from a lack of available data, difficulty in interpreting scientific information for management application, or because managers do not value science for their decisions. To better understand the use of evidence for management decisions, we asked protected area managers in Australia what information is important when making decisions, the types of evidence they find most valuable, and the types of evidence they have for their protected areas. Managers described a complex array of information needed for management decisions, with nine different factors representing decisions about individual management issues and how to prioritize management actions. While managers reported less access to empirical evidence than other sources, this is not because they do not value it, reporting it to be the most valuable source of evidence. Instead, they make up the shortfall in empirical evidence with experience and information synthesized from multiple lines of evidence, which can provide important context for their decisions. We conclude that managers value a diversity of evidence because they face complex conservation decisions. Therefore, while empirical evidence can play an important role, alone this cannot provide all the knowledge managers need.

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1. Introduction

With escalating pressure on natural areas from human populations, protected areas are an increasingly important conservation tool. Safeguarding this investment requires understanding the pressures on natural systems and which management strategies will be effective (Ervin, 2003; Pullin and Knight, 2001; Sutherland et al., 2004). There is evidence to suggest that conservation managers (i.e., those responsible for the day-to-day decisions about management, and those responsible for strategic decisions about management priorities and resource allocation) rarely use empirical data to select management actions (Pullin and Knight, 2005; Sutherland et al., 2004; Young and Van Aarde, 2011) or to judge the outcomes of their management (Cook et al., 2010). However, it remains unclear how managers apply evidence to decisions and why they so often fail to use empirical data. Explanations for the poor use of science in conservation management include that managers cannot access or interpret the peer-review literature (Arlettaz et al., 2010; Chapple et al., 2011; Fazey et al., 2005b), and that timeframes for providing clear answers are incompatible with urgent conservation problems (Kareiva et al., 2002; Young and Van Aarde, 2011). Alternatively, managers are said not to value empirical evidence because it often fails to address the issues most relevant to managers (Fazey et al., 2005b; Whitten et al., 2001), or they are more comfortable with experience-based evidence (Pullin et al., 2004; Sutherland, 2005). To improve the use of empirical evidence within conservation management it is important to distinguish between these competing hypotheses. Should conservation science focus on improving access to management-relevant science, as some suggest (Pullin and Knight, 2009), or on demonstrating the value of science to managers and how to integrate it into their decisions (Arlettaz et al., 2010)?

The poor use of science in conservation management also raises the question of which types of evidence managers use to inform their decisions and whether this is due to necessity or an active choice to use particular sources of evidence, such as personal experience (Pullin and Knight, 2005), or expert opinion

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(Sutherland, 2005). While empirical evidence has many advantages, it can also be challenging to collect (Ferraro and Pattanayak, 2006), and the information provided may not always justify the cost (Grantham et al., 2008, 2009; McDonald-Madden et al., 2010). Collecting empirical information can be time consuming, which is incompatible with urgent decisions and can result in data that does not reflect a rapidly changing environment. Conversely, other types of evidence, such as expert opinion, can be a readily available alternative, are comparatively inexpensive to collect (Lele and Allen, 2006), can provide vital context for empirical data, and make a valuable contribution to conservation decisions (Baird and Flaherty, 2005; Fazey et al., 2005a, 2006; Martin et al., 2005; Runge et al., 2011). Yet, expert opinion can be subject to bias (Martin et al., 2010), and acting on the prevailing wisdom can lead to negative outcomes (Sutherland et al., 2004). Understanding the nature of the evidence managers use to make decisions can provide valuable insight into whether managers are accessing the knowledge they require to manage protected areas effectively.

Given the conflicting costs and benefits of different types of evidence for decision-making, it is unlikely that conservation outcomes will be best served by uniformly requiring the highest standard of empirical evidence for decisions or by simply using readily available evidence regardless of its uncertainty. Instead, the most appropriate type of evidence is likely to depend on factors such as the nature of the decision, with empirical evidence being given higher priority for decisions with more severe consequences (Hockings et al., 2009). If this is the case, those making management decisions may be well placed to inform the evidence debate, even though their perspectives are rarely sought (Young and Van Aarde, 2011).

Our objective was to understand whether managers have the knowledge they need to manage protected areas effectively. Therefore, we asked managers: (i) what information they need to make management decisions, (ii) which evidence they find useful to support their conclusions, and (iii) which evidence they actually have to inform their decisions.

2. Methods

We targeted protected area managers within two Australian conservation management agencies (New South Wales Office of Environment and Heritage (NSW OEH) and Parks Victoria (PV)); both are state-level government agencies charged with protecting biodiversity and cultural heritage and facilitating and managing visitation. Parks Victoria has almost 3000 parks and reserves in the state of Victoria, totalling 18% of the State (>3.96 million ha), while NSW OEH is responsible for over 800 protected areas in the state of NSW, totalling over 7 million ha (9% of the State). Both agencies are relatively well funded and have shown leadership in attempting to integrate more science into management decisions and evaluating management success.

We surveyed on-ground and regional managers (Table 1). On-ground and regional managers were asked the same questions so are collectively referred to as managers, unless there were specific differences in the views of these two groups.

2.1. Questionnaire development

We elicited managers' views on the evidence for decisions about three biodiversity management issues: the conservation of threatened species (i.e., flora, fauna and ecosystems), non-threatened fauna, and non-threatened ecosystems.

The use of closed-format questionnaires has many advantages. By standardizing questions, all respondents are prompted to make the same considerations and data can be analyzed using quantitative statistical techniques (Bryman, 2004). However, predefined responses increase the potential for the researcher's personal views to constrain possible answers (Patton, 2008). Therefore, we initially used open-format questions, such as "what type of information do you think is important when making decisions about managing threatened species", to elicit the components of a management decision for which they need information, and the types of evidence that managers value when making decisions about managing biodiversity. The open-format questionnaire was piloted with 30 managers who coordinate monitoring and evaluation activities for a region of the state. These managers listed up to nine different components of management decisions (Table 2) and up to eight classes of evidence that are useful for decision-making (Table 3).

The responses from the open-format questionnaire were used to define the closed-format questionnaire, where managers rated the importance of information for each component of a management decision (Table 2), and the utility of each type of evidence (Table 3), using a four-point ordinal scale with an additional option to indicate if they were unsure (Table 4). To understand whether managers have the information they value for decision-making, we asked respondents to indicate if they had access to each type of evidence, regardless of how they rated its utility.

Table 1
Description of sample population.

Sample population	Responsibilities	Number of reserves managed	Proportion of management agency
On-ground managers	Make decisions about day-to-day reserve management such as, which threats to manage, where to focus management activities, and which management actions are most appropriate	1–5	80%
Regional managers	Responsible for strategic decisions, such as which weed species should be given priority, and for allocating resources to reserves for particular activities	10–15	20%

Table 2
The different components of management decisions protected area managers reported to be important when making decisions about biodiversity. An open-format questionnaire was used to elicit information from managers, asking, "which information is important to support your management decisions?". These categories were then used in the closed-format questionnaire.

Components of decisions	Description
Information about managing individual species or ecosystems	
Occurrence	Which species or ecosystems occur in the protected area
Threats	The threatening process impacting on species or ecosystems in the protected area
Management	The appropriate management actions to mitigate the threats to species or ecosystems
Ecology	An understanding of the ecology of biodiversity relevant to their management
Effectiveness	An understanding of whether conservation targets are responding to management actions
Information about management priorities	
Distribution	Where species or ecosystems are found within the protected area
Significance	The legislative (or local) significance or status of species or ecosystems in the protected area
Condition	The condition of species or ecosystems (e.g., population status)
Resources	The funding and/or personnel available to conduct management activities

Table 3
A description of the types of evidence used for decisions about the management of biodiversity, as described through an open-format questionnaire where respondents were asked, "which types of evidence are useful for decision-making". These evidence categories were subsequently used in the closed-format questionnaire.

Types of evidence	Description
Empirical evidence	
Research	Published studies, consultant reports, masters and doctoral theses, etc.
Population monitoring	Regular population monitoring data
Condition assessments	Quantitative assessments of population status or vegetation condition
Experience-based evidence	
Anecdotal evidence	Information derived from the personal experience of protected area managers, experts and community members
Syntheses of multiple evidence sources	
Databases	Point location data (e.g., species sighting recorded in the wildlife atlas) and vegetation mapping (e.g., geographic information system layers)
Management plans	General management plans for the protected area (e.g., synthesizing multiple sources of evidence and setting out management priorities)
Specific management plans	Plans that address specific management issues (e.g., recovery plans, fire management plans etc.)
Legislation	State and Federal legislation and international agreements that influence management priorities (e.g., Environmental Protection and Biodiversity Conservation Act, Ramsar agreement etc.)

The closed-format questionnaire was piloted with a further ten randomly selected respondents to confirm the face validity (an indication of whether the meaning of the questions is clear to respondents – Wainer and Braun, 1988), and all respondents responded positively. The final questionnaire was distributed to all of the 460 on-ground (192 in NSW OEH; 167 in PV) and regional managers (53 in NSW OEH; 48 in PV) within the two agencies (245 from NSW OEH and 215 from PV) in May 2007.

2.2. Data analyses

2.2.1. Information managers need for management decisions

We coded responses (Table 4) and used Kruskal–Wallis nonparametric tests to determine if some components of decisions were considered more important to understand than others (importance score was an ordinal response variable; components of decisions was a categorical explanatory variable). For each test, we first assessed whether there were any differences in the responses provided by on-ground versus regional managers. If no differences were found then responses were combined.

We also compared whether there were any relative differences in how respondents scored information for decisions about different taxa. To do this we calculated the mean importance score for each type of biodiversity management issue (the average of the importance scores for the different components of a management decision). We used the mean importance score as an ordinal response variable in the Kruskal–Wallis test, with the type of biodiversity management issue as a categorical explanatory variable.

Table 4
The ordinal rating scale used to elicit the value protected area managers place on different types of information and different types of evidence to support decisions about biodiversity management.

Value of information	Utility of evidence	Coding
Information neither essential nor desirable for decision-making	Not at all useful	1
Information desirable, but not essential for decision-making	Moderately useful	2
Information essential for high priority species/sites but only desirable for everything else	Useful	3
Information essential for all (including high priority) species/sites	Extremely useful	4
Unsure	Unsure	Missing value

2.2.2. Evidence valued by managers for management decisions

To examine the utility of different types of evidence for management decisions, we grouped the classes of evidence (Table 3) into (i) empirical, (ii) experience, and (iii) syntheses of multiple lines of evidence. We calculated the mean usefulness score for each group based on the coded data (Table 4) and used a Kruskal–Wallis test to examine differences in usefulness scores across the groups of evidence (mean usefulness score was an ordinal response variable; group of evidence was a categorical explanatory variable).

To examine whether respondents had the evidence they find useful for decision-making, we calculated the proportion of evidence individuals reported to be both useful (coded 3 or 4, Table 4) and available for the protected area. To avoid overestimating the knowledge gap in protected areas, we were only interested in 'useful' evidence, deliberately excluding evidence that respondents did not value because they were unlikely to use it for their decisions (e.g., poor quality or outdated information).

3. Results

In total, 99 questionnaires were returned (51 from PV and 48 from NSW OEH), a response rate of 22%. When a reason was supplied for not participating in the study, lack of time was always cited. This response is consistent with many other studies (Sivo et al., 2006), particularly those targeting conservation managers (Sutherland et al., 2011; Winter and Bigler-Cole, 2010), for whom time constraints often limit participation. To identify potential non-response bias, we used paired sample t-tests to compare the distribution of respondents and non-respondents according to the types of protected areas managed (national park versus nature reserve; $t = 0.17$; d.f. $= 98$; $p = 0.083$) and management roles (on-ground versus regional manager; $t = 0.14$; d.f. $= 98$; $p = 0.158$), and found no significant differences between the two populations. Our sample reflected a cross section of educational backgrounds (high school through doctorate) and years of management experience (1–32). Therefore, while our sample likely reflects the broader populations of managers within these two agencies, the low response rate, along with the potential for the level of interest or existing personal knowledge to differ among managers, suggests that results should be interpreted with caution.

3.1. Information managers need for management decisions

Managers indicated that they need a broad understanding of biodiversity management when making decisions, reporting all nine components of decisions (Table 2) to be important (mean scores of 3 or above; Fig. 1). These components of decisions can be grouped into (Table 2): (i) understanding information relevant to the management of individual species and ecosystems (e.g., which threats need to be managed, and which actions are appropriate to mitigate threats); and (ii) information to help prioritize potential management actions (e.g., which species occur within the protected area, their relative significance and condition, and the resources available for management).

Managers placed the highest priority on understanding which species and ecosystems occur within their protected areas (occurrence), the best management strategies (management), which

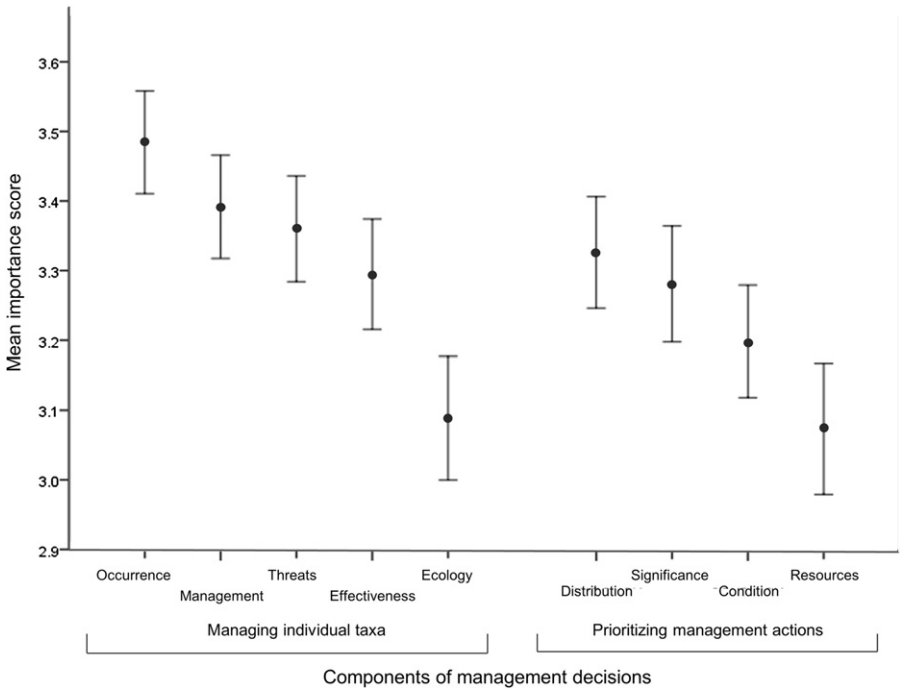

Fig. 1. The value of information (mean importance score ± SE) for the different components of a management decision, as reported by protected area managers. Importance scores of ≥3 indicate managers consider this information important to make management decisions about biodiversity conservation.

threats need to be managed (threats), and where things occur within the protected area (distribution) (H statistic = 78.54; $p < 0.001$; d.f. = 8; Fig. 1). This suggests that while managers are mainly focused on what they need to know to manage individual species and ecosystems, they also highly value information that will help them prioritize management actions. Despite the potential to heavily influence their management decisions, managers did not prioritize an understanding of the financial resources available for management or the ecology of managed populations (Fig. 1).

Overall, managers were more likely to value information for decisions about managing threatened species and non-threatened ecosystems, rather than managing non-threatened fauna (H statistic = 14.63; $p = 0.001$; d.f. = 2; Fig. 2).

3.2. Evidence valued by managers for management decisions

We found that managers use a broad spectrum of evidence to inform their management decisions (Fig. 3). While valuing empirical evidence most highly for their decisions (H statistic = 54.81; $p < 0.001$; d.f. = 2; Fig. 3), they reported having poorer access to these data than other evidence (Table 5). Conversely, evidence they reported to be most readily available (experience and information syntheses, Table 5), were viewed as less useful (Fig. 3). Despite the lower availability of empirical evidence within protected areas, managers still reported having two-thirds (68%) of the evidence they value when making management decisions (Table 5). Including all the evidence that managers consider useful, they appear to have greater support for their decisions than previously thought (Cook et al., 2010; Sutherland, 2005).

4. Discussion

4.1. Information needed for management decisions

We found that managers face complex decisions when trying to conserve biodiversity, describing nine different components as

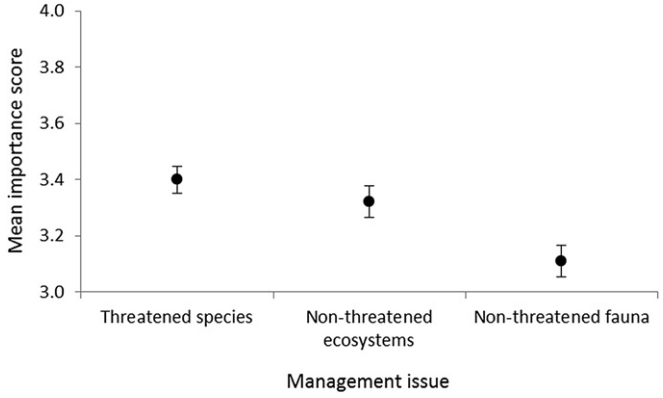

Fig. 2. The value of information (mean importance score ± SE) to inform decisions about biodiversity management issues, as reported by protected area managers. Importance scores of ≥3 indicate managers consider this information important for making decisions.

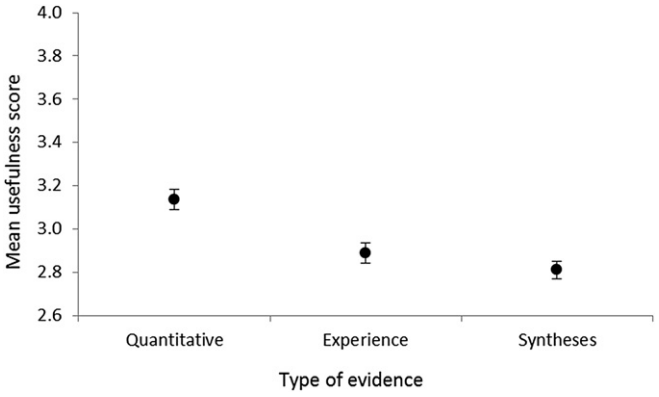

Fig. 3. The utility of different types of evidence (mean usefulness score ± SE) to inform management decisions, as reported by protected area managers. Usefulness scores of ≥3 indicate managers consider this evidence valuable for making management decisions about biodiversity conservation.

Table 5
The proportion of each type of evidence that managers reported to be both valuable (scores of 3 or 4; Table 4), and have available, to inform their decisions about managing biodiversity.

Proportion of 'useful' evidence available to managers	Threatened species	Non-threatened fauna	Non-threatened ecosystems
Empirical evidence (%)	53	59	59
Experience (%)	68	65	69
Syntheses (%)	82	77	75
Total (%)	68	67	68

important to consider (Table 2; Fig. 1). Conservation management decisions are often simplified to selecting the most effective intervention (Roberts et al., 2006). However, the managers we surveyed reported that they include a much broader suite of considerations (Table 2), reflecting the practical restrictions on their activities, such as limited resources (James et al., 2001), the need to direct resources where they will provide the greatest benefits (Bottrill et al., 2009), and the socio-political and ethical context of the decision (Arlettaz et al., 2010). These considerations are likely to be even more important in developing countries where resource shortages are often far greater (James et al., 2001) and management contexts can vary greatly.

While the managers in our study described nine different components of management decisions, they did view some as more important to consider than others (Fig. 1). Managers gave priority to information addressing the what, where, how, and why aspects of their management decisions, relating mostly to the day-to-day management of individual species and ecosystems (Fig. 1). Conversely, they placed less value on the components of decisions that related to how to prioritize management activities (Fig. 1). In Australia, decisions about resource allocation and management priorities are often determined by those higher in the management hierarchy such as regional managers, leaving on-ground managers to work within these constraints. Therefore, the tendency to take a more simplistic view of information needs, focused on the day-to-day aspects of management, rather than a holistic view, may reflect that on-ground managers made up the bulk of our sample and that these managers focus on the elements they can most influence. Despite the lack of control on-ground managers have over the funds available for management, this information is crucial when allocating effort to competing management priorities (Joseph et al., 2009). It is therefore surprising that they did not give greater value to this aspect of their decisions. However, this result may differ in other parts of the world where resources are less abundant, and where training and experience differ.

The managers sampled reported that they prioritize information about protecting threatened species and non-threatened ecosystems over non-threatened fauna (Fig. 2). Given the legislative requirement to protect threatened species and the risk that poor decisions may lead to catastrophic consequences, it is pragmatic for managers to prioritize information about threatened species. Likewise, prioritizing information about the condition of ecosystems demonstrates that managers understand the importance of conserving processes and habitats, not just species (Franklin, 1993). Given that habitat condition is thought to be indicative of the condition of fauna populations (Gibbons et al., 2008a), it is efficient for managers to give priority to information at the scale of ecosystems.

Managers will never have all the information they desire to inform their management decisions, but this study demonstrates that they make pragmatic assumptions about how to make the most of limited resources. Understanding how managers use information to make robust management decisions is a field of research that requires more attention. Information use will likely differ according to the context for management and the background and training of managers, especially in developing countries. However, our data suggest conservation decisions are more complex than is often acknowledged in the literature.

4.2. Evidence valued by managers for management decisions

Our findings do not support the view that managers undervalue empirical evidence for their decisions. Instead, empirical sources, such as research, population monitoring data, and condition assessments, were reported to be the most useful evidence for management decisions across all biodiversity management issues (Fig. 3). However, managers in our study reported a wide range of other evidence types to be valuable when making decisions (values of 3 or greater in Fig. 3), likely reflecting the complexity of their management decisions and the diversity of their information needs. This is in keeping with Seavy and Howell (2010), who found that restoration practitioners, and land managers of riparian ecosystems in California value peer-reviewed publications and synthetic reviews similarly to one-on-one interactions with ecologists. The need for a diversity of evidence may arise from the fact that the broader socio-political context for management decisions is rarely considered or understood by conservation scientists (Ascough et al., 2008; Esler et al., 2010). Therefore, managers must use other sources of knowledge to support crucial aspects of their management decisions. For example, cattle grazing can be a serious threat to alpine environments in Australia (Williams et al., 2003); yet alpine grazing is entrenched in Australian folklore and there is vocal opposition to the removal of cattle from protected areas (Williams et al., 2006). While this may be a simple decision ecologically, the social and political aspects of this management decision have greatly increased its complexity.

Our results confirm that managers were less likely to report having empirical data available than other sources of evidence (Table 5). While this may reflect a lack of access to data, the managers in our study reported much higher rates of empirical evidence than previously reported for Australia or the United Kingdom (Cook et al., 2010; Sutherland et al., 2004); levels more in keeping with figures for the USA (Seavy and Howell, 2010). Nevertheless, managers do have access to a range of other evidence, with up to two thirds of the evidence they want being available to them. Therefore, the knowledge gap in protected areas may not be as severe as first thought, at least in relatively well resourced protected area networks. In countries where managers have less scientific training, they may be less confident using empirical evidence. Undoubtedly, managers would like and would benefit from more empirical evidence for their decisions. There may be opportunities to make more of existing empirical data through better engagement between managers and scientists (Chapple et al., 2011; Gibbons et al., 2008b; Lauber et al., 2011), through the use of adaptive management approaches (Fazey et al., 2005a; McCarthy and Possingham, 2007), by improving processes that funnel research findings to managers and by ensuring research is presented in a form that is accessible and can be readily understood by managers. However, empirical data alone is likely to be insufficient to guide decisions because of the complexity of natural systems, the varied management contexts (Arlettaz et al., 2010) and the lag in providing evidence from research (Meffe, 2001). Therefore, managers benefit from multiple lines of evidence to adapt to the continually changing management context.

5. Conclusions

This study sought the views of protected area managers about the information needed to inform their decisions about biodiversity

conservation, revealing a different perspective on the evidence for conservation decisions. Managers in our study describe complex and multifaceted decisions that require multiple lines of evidence. They highly value empirical evidence for their decisions and would like more data, but use several types of evidence for their decisions. This study provides insight into the evidence used for conservation management in Australia; elsewhere the use of evidence in management decisions is poorly understood. More attention should be focused on how best to integrate science into decision-making processes and how the evidence needed for decisions is influenced by the availability of resources, different management contexts, and the values, skills and experience of managers.

Equipping managers to make robust decisions requires a better understanding of when empirical evidence is most important, such as for decisions with severe consequences, and when experience and other evidence are a crucial overlay to account for the management context. Management agencies would benefit from a closer working relationship with scientists to identify and fill vital knowledge gaps, to improve the accessibility of research findings and to ensure science can be interpreted by managers and used to inform management decisions. While these changes should increase the rate of evidence-based conservation, the complexity of management decisions means that multiple lines of evidence will still be required to capture all the information managers need.

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References

Arlettaz, R., Schaub, M., Fournier, J., Reichlin, T.S., Sierro, A., Watson, J.E.M., Braunisch, V., 2010. From publications to public actions: when conservation biologists bridge the gap between research and implementation. BioScience 60, 835–842.

Ascough, J.C., Maier, H.R., Ravalico, J.K., Strudley, M.W., 2008. Future research challenges for incorporation of uncertainty in environmental and ecological decision-making. Ecol. Model. 219, 383–399.

Baird, I.G., Flaherty, M.S., 2005. Mekong River fish conservation zones in southern Laos: assessing effectiveness using local ecological knowledge. Environ. Manage. 36, 439–454.

Bottrill, M.C., Joseph, L.N., Carwardine, J., Bode, M., Cook, C.N., Game, E.T., Grantham, H., Kark, S., Linke, S., McDonald-Madden, E., Pressey, R.L., Walker, S., Wilson, K.A., Possingham, H.P., 2009. Finite conservation funds mean triage is unavoidable. Trends Ecol. Evol. 24, 183–184.

Bryman, A., 2004. Social Research Methods, second ed. Oxford University Press, Oxford, New York.

Chapple, R.S., Ramp, D., Bradstock, R.A., Kingsford, R.T., Merson, J.A., Auld, T.D., Fleming, P.J.S., Mulley, R.C., 2011. Integrating science into management of ecosystems in the Greater Blue Mountains. Environ. Manage. 48, 659–674.

Cook, C.N., Hockings, M., Carter, R.W., 2010. Conservation in the dark? The information used to support management decisions. Front. Ecol. Environ. 8, 181–186.

Ervin, J., 2003. Protected area assessments in perspective. BioScience 53, 819–822.

Esler, K.J., Prozesky, H., Sharma, G.P., McGeoch, M., 2010. How wide is the "knowing-doing" gap in invasion biology? Biol. Invasions 12, 4065–4075.

Fazey, I., Fazey, J.A., Fazey, D.M.A., 2005a. Learning more effectively from experience. Ecol. Soc. 10, 4–25.

Fazey, I., Fischer, J., Lindenmayer, D.B., 2005b. What do conservation biologists publish? Biol. Conserv. 124, 63–73.

Fazey, I., Fazey, J.A., Salisbury, J.G., Lindenmayer, D.B., Dovers, S., 2006. The nature and role of experiential knowledge for environmental conservation. Environ. Conserv. 33, 1–10.

Ferraro, P.J., Pattanayak, S.K., 2006. Money for nothing? A call for empirical evaluation of biodiversity conservation investments. PLoS Biol. 4, 482–488.

Franklin, J.F., 1993. Preserving biodiversity – species, ecosystems, or landscapes. Ecol. Appl. 3, 202–205.

Gibbons, P., Briggs, S.V., Ayers, D.A., Doyle, S., Seddon, J., McElhinny, C., Jones, N., Sims, R., Doody, J.S., 2008a. Rapidly quantifying reference conditions in modified landscapes. Biol. Conserv. 141, 2483–2493.

Gibbons, P., Zammit, C., Youngentob, K., Possingham, H.P., Lindenmayer, D.B., Bekessy, S., Burgman, M., Colyvan, M., Considine, M., Felton, A., Hobbs, R.J., Hurley, K., McAlpine, C., McCarthy, M.A., Moore, J., Robinson, D., Salt, D., Wintle, B., 2008b. Some practical suggestions for improving engagement between researchers and policy-makers in natural resource management. Ecol. Manage. Restor. 9, 182–186.

Grantham, H.S., Moilanen, A., Wilson, K.A., Pressey, R.L., Rebelo, T.G., Possingham, H.P., 2008. Diminishing return on investment for biodiversity data in conservation planning. Conserv. Lett. 1, 190–198.

Grantham, H.S., Wilson, K.A., Moilanen, A., Rebelo, T., Possingham, H.P., 2009. Delaying conservation actions for improved knowledge: how long should we wait? Ecol. Lett. 12, 293–301.

Hockings, M., Stolton, S., Dudley, N., James, R., 2009. Data credibility: what are the "right" data for evaluating management effectiveness of protected areas? New Dir. Eval. 122, 53–63.

James, A., Gaston, K.J., Balmford, A., 2001. Can we afford to conserve biodiversity? BioScience 51, 43–52.

Joseph, L.N., Maloney, R.F., Possingham, H.P., 2009. Optimal allocation of resources among threatened species: a project prioritization protocol. Conserv. Biol. 23, 328–338.

Kareiva, P., Marvier, M., West, S., Hornisher, J., 2002. Slow-moving journals hinder conservation efforts. Nature 420, 15.

Lauber, T.B., Stedman, R.C., Decker, D.J., Knuth, B.A., 2011. Linking knowledge to action in collaborative conservation. Conserv. Biol. 25, 1186–1194.

Lele, S.R., Allen, K.L., 2006. On using expert opinion in ecological analyses: a frequentist approach. Environmetrics 17, 683–704.

Martin, T.G., Burgman, M.A., Fidler, F., Kuhnert, P.M., Low-Choy, S., McBride, M., Mengersen, K., 2010. Eliciting expert knowledge in conservation biology. Conserv. Biol. 26, 29–38.

Martin, T.G., Kuhnert, P.M., Mengersen, K., Possingham, H.P., 2005. The power of expert opinion in ecological models using Bayesian methods: impact of grazing on birds. Ecol. Appl. 15, 266–280.

McCarthy, M.A., Possingham, H.P., 2007. Active adaptive management for conservation. Conserv. Biol. 21, 956–963.

McDonald-Madden, E., Baxter, P.W.J., Fuller, R.A., Martin, T.G., Game, E.T., Montambault, J., Possingham, H.P., 2010. Monitoring does not always count. Trends Ecol. Evol. 25, 547–550.

Meffe, G.K., 2001. Crisis in a crisis discipline. Conserv. Biol. 15, 303–304.

Patton, M.Q., 2008. Utilization-focused Evaluation, fourth ed. Sage Publications, Thousand Oaks, California.

Pullin, A.S., Knight, T.M., 2001. Effectiveness in conservation practice: pointers from medicine and public health. Conserv. Biol. 15, 50–54.

Pullin, A.S., Knight, T.M., 2005. Assessing conservation management's evidence base: a survey of management-plan compilers in the United Kingdom and Australia. Conserv. Biol. 19, 1989–1996.

Pullin, A.S., Knight, T.M., 2009. Doing more good than harm – building an evidence-base for conservation and environmental management. Biol. Conserv. 142, 931–934.

Pullin, A.S., Knight, T.M., Stone, D.A., Charman, K., 2004. Do conservation managers use scientific evidence to support their decision-making? Biol. Conserv. 119, 245–252.

Roberts, P.D., Stewart, G.B., Pullin, A.S., 2006. Are review articles a reliable source of evidence to support conservation and environmental management? A comparison with medicine. Biol. Conserv. 132, 409–423.

Runge, M.C., Converse, S.J., Lyons, J.E., 2011. Which uncertainty? Using expert elicitation and expected value of information to design an adaptive program. Biol. Conserv. 144, 1214–1223.

Seavy, N.E., Howell, C.A., 2010. How can we improve information delivery to support conservation and restoration decisions? Biodivers. Conserv. 19, 1261–1267.

Sivo, S.A., Saunders, C., Chang, Q., Jiang, J.J., 2006. How low should you go? Low response rates and the validity of inference in IS questionnaire research. J. Assoc. Inf. Syst. 7, 351–414.

Sutherland, W.J., 2005. How can we make conservation more effective? Oryx 39, 1–2.

Sutherland, W.J., Goulson, D., Potts, S.G., Dicks, L.V., 2011. Quantifying the impact and relevance of scientific research. PLoS One 6.

Sutherland, W.J., Pullin, A.S., Dolman, P.M., Knight, T.M., 2004. The need for evidence-based conservation. Trends Ecol. Evol. 19, 305–308.

Wainer, H., Braun, H.I. (Eds.), 1988. Test Validity. Lawrence Erlbaum Associates, Hillsdale, New Jersey.

Whitten, T., Holmes, D., MacKinnon, K., 2001. Conservation biology: a displacement behavior for academia? Conserv. Biol. 15, 1–3.

Williams, R.J., Mansergh, I.M., Wahren, C.H.A., Rosengren, N.J., Papst, W.A., 2003. Alpine landscapes. In: Attiwill, P.M., Wilson, B. (Eds.), Ecology: an Australian Perspective. Oxford University Press, Oxford, pp. 352–369.

Williams, R.J., Wahren, C.H., Bradstock, R.A., Muller, W.J., 2006. Does alpine grazing reduce blazing? A landscape test of a widely-held hypothesis. Austral Ecol. 31, 925–936.

Winter, P.L., Bigler-Cole, H., 2010. Information needs, acceptability of risk, trust, and reliance: the case of National Predictive Services customers. U S Forest Service Pacific Northwest Research Station General Technical Report PNW-GTR, pp. 397–407.

Young, K.D., Van Aarde, R.J., 2011. Science and elephant management decisions in South Africa. Biol. Conserv. 144, 876–885.