Prioritizing threat management for biodiversity conservation

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Abstract

Calls for threat management actions to protect biodiversity and restore ecosystem function are rarely coupled with costed and prioritized sets of management actions for use in decision making. We present a cost-effectiveness approach for prioritizing threat management to maximize the *in situ* protection of biodiversity per dollar spent. The approach draws on empirical data and expert knowledge of major threats to biodiversity, feasible threat management actions, and likely responses of biodiversity to a set of costed management scenarios. An application assessing 637 vertebrate wildlife species in the Kimberley region of north-western Australia suggests that the likely functional loss of 45 mammals, birds, and reptiles over the next 20 years can be averted by effectively managing fire, grazing, and invasive species for approximately AU$40 million per year. Our approach is flexible and may be useful for delivering transparent guidance for conserving species and ecosystems in other regions, including those where data is limited.

Introduction

Conservation efforts have not yet achieved "a significant reduction in the rate of global biodiversity loss" as agreed by many at the Convention on Biological Diversity 2002 (Butchart *et al.* 2010). Declines in threatened and common species are accelerating within and outside protected areas (Leverington *et al.* 2010; Woinarski *et al.* 2011), because of an array of pervasive threats such as invasive species and changed fire and grazing regimes (Rands *et al.* 2010). To restore and maintain functioning ecosystems with ecologically effective populations of native species, pervasive threats need to be managed across land tenure types (Woinarski *et al.* 2007). In developing and implementing threat management plans for a region, governments and other investors must be able to discern between alternative threat management actions using transparent information on the likely costs,

risks, and benefits of taking action compared to inaction (Possingham *et al.* 2001).

Cost-effectiveness analysis, where a nonfinancial measure of the likely "benefit" of an option is divided by its cost (Levin & McEwan 2001) has emerged as a useful tool in conservation for enabling more informed and justifiable investments. Briggs (2009) and Joseph *et al.* (2009) offer cost-effectiveness approaches for prioritizing species recovery projects, although Cullen *et al.* (2005) and Laycock *et al.* (2011) offer retrospective evaluation tools for such projects. At the landscape scale, Pannell *et al.*'s (2012) approach can be used for natural asset restoration, although large-scale multiple conservation actions can be evaluated at both coarse and finer resolutions (Possingham *et al.* 2000; Possingham *et al.* 2002; Murdoch *et al.* 2007; Carwardine *et al.* 2008). As yet, no landscape-scale threat management approaches assess individual persistence responses of large numbers of biodiversity

features to multiple actions simultaneously, which can be imperative for the efficient targeting of investments to avoid declines and extinctions (Joseph *et al.* 2009).

We present a cost-effectiveness approach for threat management prioritization where the benefits of alternative management actions are estimated by improvements in species persistence (1–probability of extinction) across a number of conservation features. Our approach is undertaken in a simple spreadsheet. It relies on the availability of empirical data and/or expert scientific information including traditional ecological knowledge (Martin *et al.* 2012) of the biodiversity features targeted, as well as their likely responses to threats and feasible management actions for the region. Features may be any number of species, ecosystems, and ecosystem processes or services provided the relevant knowledge exists.

Our approach estimates critical information for prioritizing threat management, such as the relative cost-effectiveness of different management actions for improving the probability of persistence of biodiversity features; the likely biodiversity outcomes under specific management scenarios including a "do nothing" scenario; and the suite of actions and funds required to achieve prespecified thresholds of persistence, or conversely, the best use of a limited budget to maximize expected ecological benefit. We demonstrate our approach by prioritizing threat management actions to protect and restore wildlife populations in the Kimberley of north-western Australia. The expert elicitation approach, including study design, is summarized in the supporting information.

Methods

The Kimberley is an ecologically rich region of north-western Australia covering an area of 30 million ha (Figure 1). Recent records of native wildlife declines across Northern Australia indicate that the relative intactness and high ecological significance of this region is under threat (Start *et al.* 2007; Burbidge *et al.* 2008; Woinarski *et al.* 2011).

The objectives of the Kimberley case study were to (1) identify and assess the cost-effectiveness threat management actions for improving the persistence of wildlife in the Kimberley over 20 years, (2) estimate the likely outcomes for wildlife of a no management scenario and the minimum level of funding required to support management actions to avoid likely wildlife losses and secure species over 20 years, assuming thresholds of <50% persistence probability indicates a species is likely to be lost and ≥90% indicates a species is likely to be secure [thresholds for vulnerable and critically endangered species on the International Union for Conservation of Nature (IUCN) red list (IUCN 2001)], and (3) estimate

the maximum number of wildlife species that can be improved to above each of these thresholds if only part of the budget required to avoid wildlife losses were available. We focused on vertebrate wildlife as these were considered of most immediate priority for the region and expert knowledge on other features is more limited hence would have taken significantly more time and resources to gather. However, our results can be updated with information on other features such as plants, invertebrates, ecosystems, or ecological processes. A checklist of general components for threat management prioritization is provided in Table 1; these should be discussed and defined by the group of expert participants under the guidance of the decision analyst.

The Kimberley study was parameterized by drawing upon the most useful empirical data and knowledge from 27 experts on the Kimberley region. The expert elicitation process was carried out using a modified Delphi approach (Kuhnert *et al.* 2010) over two workshops and follow up consultations. See supporting information for more details on the elicitation process, including dealing with uncertainties in experts' estimates.

The experts defined the study area by the Western Australian extent of the Kimberley's five bioregions, which were used as evaluation units. Experts identified, as a group, the following set of key management actions for abating threats to Kimberley wildlife: (1) management of fire and introduced herbivores (these actions were combined because it was not possible to disentangle their individual benefits to wildlife), including fine-scale early dry season burns to create a mosaic of burnt and unburnt areas, fencing and focal burning around key assets, managing domestic stock densities, and culling feral stock (Woinarski *et al.* 2007; Legge *et al.* 2008; Legge *et al.* 2011); (2) management of weeds, including control and containment, eradication and quarantine, particularly at road and port entries; and (3) management of feral cats, including ceasing the poison-baiting of dingoes on pastoral land (intact populations of *Canis lupis dingo*, a naturalized canid and Australia's top terrestrial predator, regulate cat activity (Glen *et al.* 2007; Kennedy *et al.* 2011), education on the role of dingoes in trophic regulation, and cat spaying programs. For more details see Carwardine *et al.* (2011).

Ecological experts provided information to estimate the potential benefits of implementing each action, and all actions together, in each evaluation unit, or bioregion. The potential benefit parameter was defined as the summed improvement in persistence of wildlife species resulting from the action. Because of time and information constraints, experts assessed persistence probabilities for species in groups with similar expected ecological responses to threats and actions. A total of 637 vertebrate
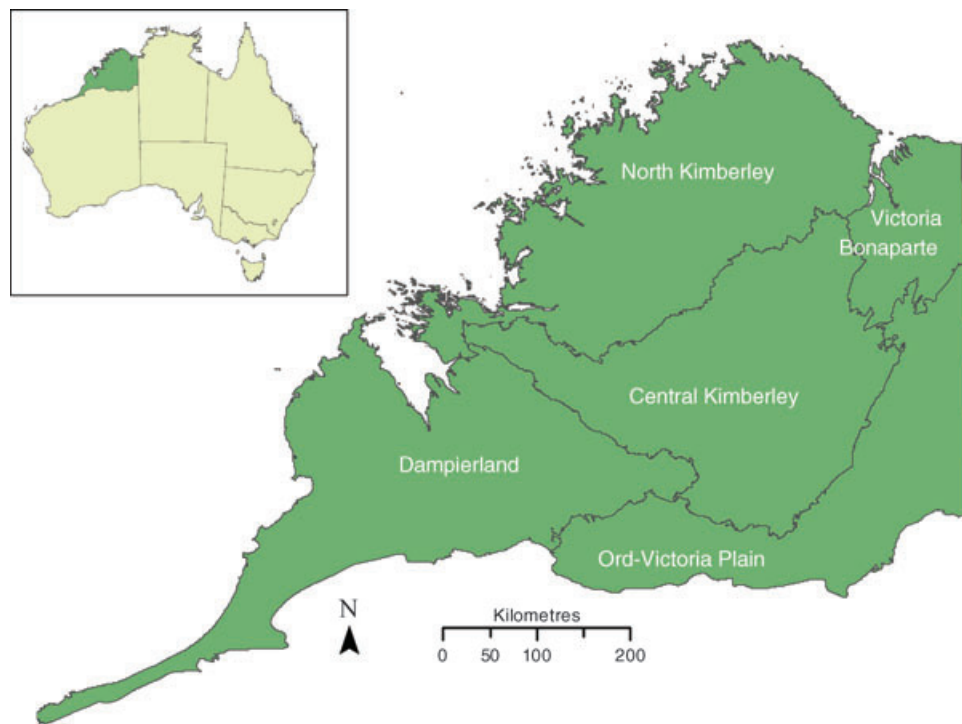
Figure 1 The five bioregions of the Kimberley in north-western Australia.

wildlife species were considered, including known freshwater species but excluding sharks, rays, and any species that are predominantly marine based. Species were allocated to groups using information from field guides and checked by experts.

Experts estimated, for each species group in each bioregion, the probability of persistence over 20 years with and without implementation of each action, noting species with persistence estimates that deviated from the average of the group. The potential benefit, B_{ij}, of action i (which may be a package of management activities) in bioregion j, was then defined by,

$$B_{ij} = \sum_x (P_{xi} - P_{xo}),$$

where x identifies the biodiversity features (here species), P_{xi} is the benefit parameter (probability of persistence) of species x under action i in bioregion j over the time period (20 years), and P_{xo} is the benefit parameter of species x without action i in bioregion j over the time period. Experts allocated persistence improvements for each species such that they could be added for multiple actions, although in reality interactions between actions are likely to be more complex.

Land management experts estimated the feasibility and costs of undertaking each action in each bioregion, con-

sidering their experience of previous and existing management activities and spatial variants such as land tenure and remoteness. The feasibility F_{ij} is the probability that action i can be implemented successfully in bioregion j estimated as a probability between 0 and 1 (McBride *et al.* 2007). The economic cost C_{ij} is the cost in present day Australian dollars of activities associated with action i in bioregion j over 20 years. Once off costs, such as building a fence, were counted once, although annual costs, such as maintaining the fence, were summed over 20 years using a discount rate of 2% per year.

The cost-effectiveness, CE, in ecological terms, of each action i in each bioregion j was then defined by:

$$CE_{ij} = \frac{B_{ij} \cdot F_{ij}}{C_{ij}}.$$

We carried out a sensitivity analysis on the ranked order of actions by altering the cost-effectiveness by 20% and 30% and recording changes in rank (see the supporting information for more details).

We created an Excel spreadsheet comprising a species list and persistence estimates under each action, and combination of actions, in each bioregion. Actions were ranked by the number of new species brought above each of the 50% and 90% persistence thresholds if the action was implemented, taking account of species

Table 1 Checklist of components for threat management prioritization

Study design	
Expert participants	Experts should be engaged on the basis of knowledge of species, ecosystems, threats, and/or management options for the region. See supporting information for more details.
Spatial extent	The study region may be defined by ecological, tenure, and political and administrative boundaries, as these factors often relate to current and potential management efforts, limits to information and expert knowledge, funding, and feasibility.
Spatial resolution	The region is divided into evaluation units for mapping and reporting results. The scale of analysis should reflect the resolution of the available data and information, the time available for information collection and analysis, and what are considered practical management units. Within management units, the major landscape ecosystem types may be identified for considering spatial variability in threatening processes, management actions, costs, and benefits.
Setting objectives	One or more measurable objectives are set up front. Scores and ranks should be avoided in favor of numbers that represent physical quantities suitable for rational addition or multiplication (Wolman 2006). Objectives can either maximize a benefit subject to a budget constraint or minimize the cost of achieving a target level of benefit (Carwardine *et al.* 2009).
Features	Features are the species, ecosystems, or ecological processes of concern, or groups or subsets of these for which adequate data is available. Features may be grouped based on similarity in resource use and responses to threats or actions, to overcome time and information constraints.
Elicitation approach	There are a number of options for eliciting expert information (we used a modified Delphi approach). For more details see supporting information.
Existing funds and activities	Existing funds and initiatives in the region assist in understanding the potential reallocation and increase of budgets and efforts and estimates of benefits, costs, and feasibility of actions.
Parameters and analysis Threats	Start by generating a list of threatening processes and their impact pathways to the biodiversity features. Identify those for which feasible management actions can be defined.
Identifying management actions	Identify actions that abate specific threats to the biodiversity features. Avoid actions that are completely infeasible because of legislative, technological, economic, social, or knowledge constraints. The socioeconomics, politics, and culture of a region have a profound impact on the effectiveness and appropriateness of management actions.
Measuring biodiversity benefit	Define a parameter to measure improvement to the biodiversity features created by the implementation of each action. If the objective is to maximize improvement in the persistence of species, measure the improvement in persistence probability of each species/group. Other measures may include: quality or extent of critical habitats, increase in growth rate or size of a population, quality or extent of ecosystems, and presence/absence of ecological processes.
Measuring cost	This is the cost of all activities required to carry out an action, accounting for factors such as land tenure, terrain, remoteness, and changes in cost over time if applicable. Many costs are higher in the first year for setting up compared with ongoing maintenance. Decide whether to measure the total cost of carrying out the action over the time period or an annual average cost; this will not change the ranks but it does change how the results might be interpreted.
Measuring feasibility	The feasibility is a probability of success from 0 to 1, with 0 being an action that is impossible to achieve and 1 being an action that is certain to be achieved, taking account of social, knowledge, economic, and logistical constraints. Feasibility may vary with land tenure, land use, time, and funds available to overcome existing constraints, but must be averaged or summarized to give one feasibility estimate per action per evaluation unit.
Cobenefits and costs other than biodiversity	Benefits in addition to biodiversity, such as ecosystem services, cultural benefits and employment, and costs other than the financial costs of the action, such as opportunity costs can be assessed qualitatively or quantitatively using information provided by the experts as the scope and time of the project allows. All benefits should be scaled between 0 and 1 and can then be included as per biodiversity benefits, or weights can be used if some are considered more important. Costs should be converted to dollars where possible, but if not appropriate, costs can be combined using a multiple criteria approach (Hajkowicz *et al.* 2008).
Complexities	Temporal changes in conditions, such as climate change, can theoretically be included by modifying persistence estimates, feasibility, or the costs of management in response to changed conditions. Interactions between actions can also be included by asking experts to consider the costs and benefits of combinations of actions, if time and knowledge permits.

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Table 1 Continued

Study design	
Sensitivity analysis	The analyst should test the sensitivity of the cost-effectiveness ranks to possible errors in any one or all of the above parameters. This can be useful for determining the impact of each parameter on the ranks and for describing the overall robustness of the approach.
Knowledge brokering, stakeholders, and implementation Reporting and disseminating Reporting and disseminating	Report format and dissemination should be targeted to the audience relevant to the study. State key messages, e.g., the most cost-effective actions, the predicted outcomes of various management scenarios, and the investment required to achieve particular objectives.
Stakeholder engagement	Threat management prioritization can be a standalone tool, or used within a comprehensive planning process which includes the priorities and preferences of stakeholders. The study scope and purpose defines when and how stakeholder preferences are considered.
Implementation	Implementation is context specific and may be undertaken as a separate phase which is informed by threat management prioritization information. Regardless, the characteristics of stakeholders and potential implementing agents should be considered when estimating costs, benefits, and feasibility of actions.

persistence values that deviated from the average of the group. By selecting from the top of the list until all persistence probabilities reached the threshold or the budget was expended (and updating ranks after each selection), we estimated: (1) how many species were likely to be lost (persistence <50%) and how many were likely to be secured (persistence ≥90%) in one or more bioregions without effective conservation action, (2) the actions and minimum costs required to avoid all likely losses of wildlife species and then to secure wildlife species, first in all bioregions in which they occur and then in a minimum of one bioregion, and (3) how many species could be brought above 50% persistence probability under budget constraints of $18 million and $9 million per year (two-thirds and one-third of the funds required to meet 50% persistence threshold, respectively).

The results of the Kimberley study were presented in a report targeted at decision makers within governments, nongovernment organizations, and corporations with the potential to invest in threat management in the region (Carwardine *et al.* 2011). Akin to a prospectus, the report provides investors in threat management with a list of investment options and projected returns on these investments with respect to conserving wildlife in the Kimberley. The report was made available online as well as mailed to the target audience. Knowledge brokering, stakeholder engagement, and implementation of this project are ongoing through discussions with the state and federal government and via nongovernment conservation organizations.

Results

Actions varied in terms of their estimated cost-effectiveness across the Kimberley (Table 2) and among bioregions within the region (Table 3). Despite its relatively low feasibility, implementing the available management option for the control of feral cats (including ceasing poison-baiting of dingoes) was projected to be the most cost-effective action because of low costs and high potential benefits, particularly in Victoria Bonaparte, North Kimberley, and Central Kimberley. The management of fire and introduced herbivores was the next most cost-effective action, particularly in Victoria Bonaparte and North Kimberley. These combined actions are more expensive but highly attractive because of existing

Table 2 Costs, feasibility, benefits, and cost-effectiveness ranks of threat management actions across the Kimberley

Action	Examples of activities required	Cost (average p.a.)	Feasibility	Benefit	Cost-effectiveness rank
Feral cats	Education, reduction of dingo baiting, free spaying service, and culling	$3.5 million	25%	243.15	1
Fire and introduced herbivores	Controlled burning, removing feral stock, fencing sensitive areas, and education	$25.2 million	90%	391.10	2
Weeds	Control, eradication, and quarantine programs	$2.8 million	50%	34.0	3

Table 3 Costs, feasibility, benefits, and cost-effectiveness ranks of top five bioregional threat management actions in the Kimberley

Action	Bioregion	Cost (average p.a.)	Feasibility	Benefit	Cost-effectiveness rank
Feral cats	Victoria Bonaparte	$0.3 million	25%	41.35	1
Feral cats	North Kimberley	$0.4 million	25%	50.75	2
Fire and introduced herbivores	Victoria Bonaparte	$2.2 million	90%	61.75	3
Feral cats	Central Kimberley	$0.9 million	25%	55.5	4
Fire and introduced herbivores	North Kimberley	$6.0 million	85%	101.45	5

projects and partnerships and provide the largest wildlife benefit. The next most cost-effective action was the control, eradication, and quarantine of weeds. Some funds are currently spent on all of these actions in the Kimberley but our analyses suggest that they are inadequate to prevent species losses. The sensitivity analysis indicates that the bioregional ranks were quite robust to changes in estimates of costs, benefits, and feasibility, with only minor changes in ranks (see the supporting information for more details).

The assessment projects that without effective threat management, 45 of the species considered may be functionally lost from the Kimberley in 20 years (Figure 2). Approximately one-third of these would be global extinctions. Species most at risk are small to medium sized mammals and seed-eating birds, including regional endemics and species that have declined over the rest of their Australian ranges. The analysis suggests that these and other species may be secured with an initial investment of $95 million and $40 million per year ongoing

spent effectively on adaptively managing fire, introduced herbivores, feral cats, and weeds across the Kimberley, including $5 million for monitoring and $3.5 million for establishing two cat-proof sanctuaries on the mainland and island sanctuaries. If only $27 million were available per year, and spent efficiently and effectively on fire, herbivore, and cat management, persistence probabilities for all species may be improved to 50% (Figure 2), which is not secure but indicates a lower risk of loss. If only two-thirds of this budget were available ($18 million per year) up to 31 species are projected to be lost from parts of the region and five lost altogether. At one-third of this budget ($9 million per year), up to 33 species are projected to be lost from parts of the region, and 10 lost from the region altogether, including three global extinctions.

Implementation will require further efforts for designing adaptive management and monitoring programs, stakeholder engagement processes, building partnerships and capacity, coordinating and supporting initiatives such as the Indigenous Protected Areas program, pastoral
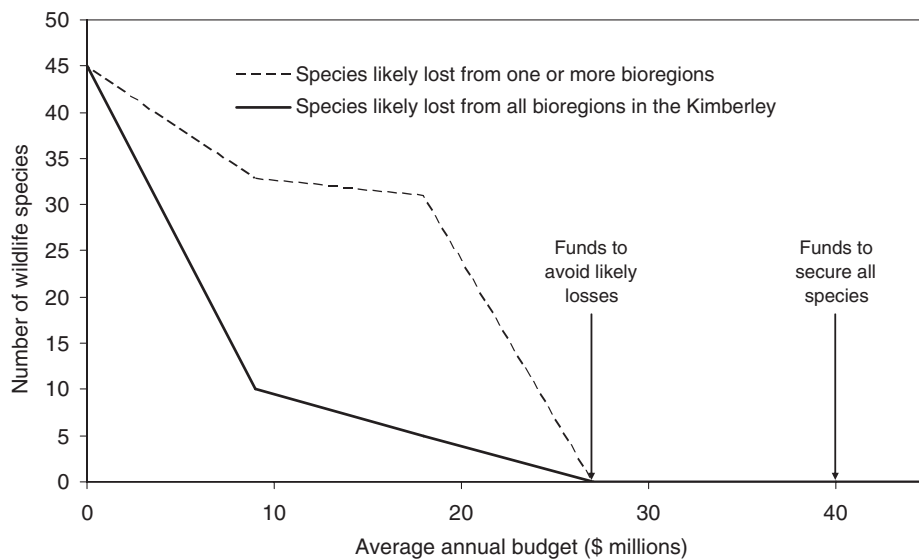

Figure 2 The number of wildlife species that are projected to be lost (persistence <50%) from at least one bioregion (dashed line) and from the entire region (solid line), at various levels of optimal investment in conservation management of the region. The projections are that $27 million per year avoids likely losses whereas $40 million per year secures all species (persistence ≥90%).

stewardship, private conservation, and cross-tenure threat management programs. Strategic implementation would generate cobenefits such as job creation, carbon sequestration, improved pastoral productivity, and the conservation of Indigenous knowledge (Carwardine *et al.* 2011).

Discussion

Decision makers responsible for directing conservation investments face growing pressure to protect biodiversity, but are rarely provided with the information required to justify conservation management investments (Wilhelm-Rechmann & Cowling 2011). This can lead to inefficient spending of conservation funds, unnecessary biodiversity losses, and avoidable degradation of ecosystem function (Briggs 2009; Joseph *et al.* 2009; Underwood *et al.* 2009). Investors frequently prefer ventures with quantitative information on the likely costs and outcomes and on the risks of not making the investment (Levin & McEwan 2001). The risks of not investing in landscape-scale threat management are high, particularly for the many species that do not occur in protected areas (Rodrigues *et al.* 2004; Watson *et al.* 2011) or are declining within protected areas (Leverington *et al.* 2010; Woinarski *et al.* 2011). Our approach provides information for generating a "business plan" for assisting governments and organizations to direct funds toward actions that are most cost-effective and meet stated goals and policy objectives. This would involve accounting for stakeholders and existing management activities, broader ecological, social, cultural, and economic cobenefits and priorities of people in the region, many of which were noted but not quantified in our analyses.

We identify clear and costed pathways for threat mitigation in the Kimberley region, which expert estimates suggest can mitigate species declines at a cost of approximately $1 million per species saved per year (assuming effective management delivery). Following the release of our prospectus in early 2011 (Carwardine *et al.* 2011), the Premier of Western Australia announced a $63 million investment in Kimberley conservation targeting, among other things, the management actions identified therein (Department of Environment and Conservation 2011).

We made many simplifying assumptions because of time, resource, and information constraints, which may have affected the accuracy of the results. We did not address all threats or all biodiversity features; hence estimates of persistence and extinctions may be considered a best-case scenario. We did not have sufficient information or time to include regional climate predictions. Nevertheless, addressing manageable threats on regional scales is likely to be the best way to increase the resilience of ecological systems to cope with other threats such as climate change. Priorities for plants, invertebrates, marine systems, ecological processes, and ecosystem services are likely to be different from those for vertebrate wildlife. Further efforts are required to examine the most useful ways to use our approach in other locations, at different scales, and with other types of information, objectives, criteria, and analytical methods (see Table 1 for a summary). The expert elicitation process would need to be tailored to the requirements of the types of experts who are engaged. Threat management prioritization can be used within a comprehensive stakeholder engagement and implementation process, but this is as yet untested.

Our recommendations for budgets required to achieve 50% and 90% persistence probabilities in the Kimberley are estimates only. Uncertainty and incomplete information on species distributions, their responses to threats and management, and the costs of actions challenge almost all conservation prioritization tasks (Carwardine *et al.* 2009). However, thresholds of data adequacy often mean that a decision is not improved by more information and the time taken to collect information can result in fewer conservation options (Grantham *et al.* 2008; McDonald-Madden *et al.* 2010). Not taking action to conserve biodiversity is the most common response to lack of data. Decision makers should be accountable for not investing in conservation management because of limited data, just as they are accountable for acting on information. Data collection should be undertaken when it can cost-effectively improve decisions; adaptive threat management and monitoring approaches should be developed to allow strategic learning and management of ecological systems (Possingham *et al.* 2001; Conroy *et al.* 2011).

Conclusion

We present a generic approach for prioritizing threat management actions to improve biodiversity persistence. We demonstrate our approach to assess the conservation of vertebrate wildlife species subject to pervasive threats across an extensive region with a range of land tenure types. The approach can be applied to other biodiversity features and in a range of social and biogeographic contexts. Importantly, it allows urgent and accountable decision making even where formal systematic data is lacking. In a world of increasing biodiversity declines, limited funds and trade-offs between conservation and other priorities, such rapid and defensible decision support can make a decisive difference to conservation outcomes.

Acknowledgments

Supporting Information

Additional Supporting Information may be found in the online version of this article, including Supplementary References and Sensitivity analysis.

Table S1. Sensitivity of ranks in the five highest ranked actions

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