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Prioritisation of conservation research and monitoring for Western Australian protected areas and threatened species

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ABSTRACT

Prioritisation of natural assets for monitoring and research activities facilitates equitable allocation of finite conservation resources. We present a framework that identifies broad monitoring and research priorities for conservation areas, such as marine parks, and threatened species. Criteria within the framework are used to assess: the value (V) of assets; anthropogenic pressures (P) that affect assets; and the current state of asset knowledge (K). A panel of experts score criteria and the relative importance of each asset is calculated for monitoring (V * P), fundamental research (V * K) and applied research (V * P * K). The framework allows prioritisation of assets in an initial evaluation that agrees with institutional mandates, and facilitates future assessment of the feasibility and cost of monitoring or research in the implementation phase. The utility of the framework is that it can be easily applied by conservation practitioners and can concurrently prioritise monitoring and research of species, habitats and communities in marine and terrestrial environments.

Keywords: prioritisation framework, condition–pressure–response monitoring, marine protected area, Ningaloo

INTRODUCTION

Robust conservation and natural resource management decisions must be founded on sound scientific knowledge (Roux et al. 2006). However, there is often a mismatch between research effort and conservation needs (Fisher et al. 2010). For this reason, it is imperative that management for protected areas and threatened species identify and prioritise knowledge gaps that constrain effective management, and that these gaps be addressed by targeted research and monitoring activities (Field et al. 2005; Fancy et al. 2009). Given the number and diversity of possible research and monitoring actions, managers must also prioritise activities to ensure the effective use of limited resources (Wilson et al. 2006). Employing a structured and consistent quantitative approach to prioritising research and monitoring activities enables managers to make decisions that are transparent, reviewable and adaptive (Day 2008). This provides a structured and informed decision-making process that avoids personal bias and is scientifically defendable.

A structured and consistent framework to prioritise research and monitoring for biodiversity conservation and natural resource management should incorporate a broad range of environmental, social, cultural and economic parameters (Given & Norton 1993; Suter 2006; Bryan et al. 2010a). Such a framework should be founded on robust conceptual models and where possible, be supported by quantitative information (Possingham et al. 2001; Lindenmayer & Likens 2009). The process should, however, be flexible enough to use the informed consensus of experts in the absence of quantitative data to provide robust outcomes (Feary et al. 2014; Ward 2014a). The broad utility of such a framework is enhanced through the use of simple assessment metrics and computations that avoid the need for complex computer software or particular staff expertise (Cullen et al. 2013; Pannell et al. 2013). This increases the potential for engagement and participation in the process whilst maximising transparency of the prioritisation decisions and avoiding delays in progressing research and monitoring activities.

Prioritisation frameworks have previously been developed to assess conservation priorities spatially (Groves et al. 2002; Margules & Pressey 2000; Margules et al. 2002), by species (Coates & Atkins 2001; Arponen 2012; Hiscock et al. 2013) and using simplified links to pressures (Moorcroft et al. 2012). There has, however, been less emphasis on prioritizing research and monitoring activities for the suite of biophysical assets within established protected areas or for species already under conservation management (but see Grech & Marsh 2008; Ward 2014a). Management plans for protected areas or species typically identify important assets and the human pressures that influence asset condition (e.g. CALM 2005). Assets are identified on the basis that they have special conservation value, are unique to the area, are key structural components of the system, or have commercial and/or other social value (Groves et al. 2000; Wilson et al. 2005; Natural Resource Management Ministerial Council 2010). Management plans, however, contain multiple assets and associated pressures, generally with no indication of their relative importance, making it difficult to assess where research and monitoring is most warranted (Knight et al. 2009). Identifying research and monitoring priorities may be further hindered by limited information on assets or the probability and consequences of threatening processes, making it difficult to determine their relative impact upon the suite of biophysical assets within the protected area or threatened species (Brooks et al. 2006; Arponen 2012). For this reason, any framework should consider the current state of knowledge, both of assets and threatening processes, as a mechanism to highlight information gaps and direct research and monitoring towards clear areas of need.

Previous research has also emphasised the importance of project costs (Possingham & Wilson 2005; Wilson et al. 2006) and effectiveness (Cullen 2013), which may be used to undertake cost benefit analyses when prioritising actions (Joseph et al. 2009). However, our objective is not to evaluate and compare specific projects or actions, but to identify assets or species that warrant research and monitoring attention. This is akin to a filtering stage that is undertaken before comprehensive cost–benefit analysis (Pannell et al. 2013) and allows a broad prioritisation prior to the development of specific projects. Moreover, calculating the economic benefit of environmental research and monitoring is often difficult and time consuming, particularly when these values are not easily quantified or tangible. It is therefore prudent to only undertake cost–benefit analyses on projects that address topics of most concern.

Accordingly, we present a semi-quantitative assessment framework to prioritise research and monitoring for the conservation of protected areas and threatened species. The framework considers the relative conservation 'value' (based on ecological and social criteria) of each asset and links this with measures of current management-related knowledge and the relative significance of relevant threatening processes (i.e. pressures). Based on this premise, we describe the framework and the associated equations and then apply these to the assets of Ningaloo Marine Park (NMP) in Western Australia to demonstrate how the framework could be used to identify research and monitoring topics of high priority.

THE PRIORITISATION FRAMEWORK

The prioritisation framework is based on the construction of a matrix of the assets of interest (e.g. assets identified within a marine protected area, or suite of threatened species), and a series of criteria used to assess the relative value of assets (V), the pressures (P) acting on the assets and the adequacy of management-related knowledge (K) relating to each asset. Research and monitoring priorities are determined based on rankings of these criteria (e.g. using scores from 1 = low to 3 = high). When criteria listed are independent of each other, the scores are added but when criteria are clearly related, a geometric mean is calculated. Combined this provides a systematic attempt to set research and monitoring priorities.

Ranking the relative significance of asset value (V)

Ecological and social values of an environmental asset are often disparate and it is important to consider criteria that relate to both these aspects when assessing asset value (Marsh et al. 2007; Bryan et al. 2010a). Moreover, assets within marine parks may be of a physical nature (e.g. geomorphology), and biological characteristics of species are often important when prioritising threatened species (Williams et al. 2008). Consequently, the relative value of assets is determined from ten criteria (Table 1) that relate to ecological role (V_{1-3}) social importance (V_{4-7}) and ecological robustness (V_{8-10}). The relative value of each asset can then be determined by summing the geometric means (Π) of similar criteria:

$$V = ((\Pi\ V_{1-3})^{1/3} + (\Pi\ V_{4-7})^{1/4} + (\Pi\ V_{8-10})^{1/3}).$$

Ranking the relative significance of pressures (P)

For conservation purposes, pressures can be defined as human activities that potentially or actually impact on assets at a scale that is receptive to the influence of management. It is therefore imperative that prioritisation frameworks consider the relative importance of different pressures (Evans et al. 2011; Murray et al. 2011). Here, the consequences of a pressure are assessed as the geometric mean of four criteria (P_{1-4}), whilst the likelihood of that pressure occurring is measured by P_5 (Table 2). Consistent with the concept of risk-ranking assessment (AS/NZS 2009; Burgman 2005), the overall significance of a pressure is then expressed as a function of consequences and likelihood of occurring:

$$P = ((\Pi\ P_{1-4})^{1/4}) * P_5.$$

Table 1

Criteria used to assess the ecological, biological, physical and social value of assets. Numerical values in parentheses are indicative of appropriate scores for each criterion.

Criteria	Intent of the criteria
Foundation habitat or habitat forming biota (V1)	To identify physical characteristics, communities or species that create key habitats (Dayton 1972). Those assets that form the basis of the habitat (e.g. corals and sediment) score high (3) against this criterion, whilst assets that modify the habitat (e.g. herbivores) will score moderately (2) and those that only use the habitat for food or shelter will score lower (1).
Ecosystem processes (V2)	To recognise that some assets support a broader array of key ecosystem processes than others (Daily 1997, 2000). Seagrass, for example, is a primary producer, provides refugia, stabilises sediments (Orth et al. 2006) and would score high for this criterion (3), as would keystone species (2), which exert a disproportionally high influence on their surrounding environment relative to their abundance (Marsh et al. 2007).
Uniqueness (V3)	To recognise local physical assets or species that are exceptional relative to other areas. Assets with a relatively limited distribution (e.g. endemic species or distinctive geological formations) or assets with exceptional quality, abundance or composition in relation to other areas will score higher (3) than those assets that are relatively well represented elsewhere (2), or those that have no outstanding local characteristics (1).
Cultural (V4)	To take account of the cultural significance of an asset in relation to its physical or spiritual heritage and iconic status (Navrud & Ready 2002; Speed et al. 2012). Some assets have significance because they are an integral component of one culture or they are valued by several cultures for multiple reasons and will score high (3) against this criterion (e.g. whales). Other assets have limited (2) or no apparent cultural value (1).
Recreational (V5)	To recognise that some assets are valued as they support recreational activities which have an inherent value or worth for the community (Brander et al. 2007). Assets that have extensive existing (3) or potential (2) importance for recreational activity (e.g. diving locations, wildlife watching or recreational fishing) will score high against this criterion.
Economic (V6)	To recognise the economic value associated with an asset (Daily 1997). Assets that directly contribute to an economic activity (e.g. fish for artisanal or commercial fisheries, aquaculture or nature-based tourism) will score high (3) against this criterion. Assets that support economically important species or services (e.g. seagrass for prawn fisheries) or have potential economic importance (e.g. seaweed as biofuels) would rate moderately (2) and assets with no apparent economic value will score low (1).
Scientific (V7)	To recognise that some assets attract high levels of scientific interest because of their intrinsic value (e.g. rare marine stromatolites) and/or because the scientific community values a unique or extensive data resource relating to the asset (Reynard et al. 2007). Assets that are recognised for their broad scientific significance and attract interest from multiple, independent research groups will score high (3) against this criterion. Assets that have some interest from at least one research group will score moderately (2) and assets with no ongoing research interest will score low (1).
Historical perspective (V8)	To recognise that some assets may have had a higher value in the past but have been subjected to significant pressures resulting in a current condition that is highly modified. For example, although cetaceans are no longer hunted in Australia, their populations remain depleted and are still recovering (Alter et al. 2012). Assets that are in a degraded or depleted condition irrespective of current pressures will score highly (3) under this criterion, while those that are recovering will score moderately (2) and those with no evidence of historic degradation will score low (1).
Vulnerability (V9)	To recognise that some assets are highly susceptible to degradation by natural and/or anthropogenic pressures, whilst others are resistant (Burgman 2005). Assets susceptible to a variety of common pressures will score higher (3) against this criterion compared to those that are susceptible to few pressures (2) or those with a higher resistance to disturbance that are rarely affected (1).
Recovery potential (V10)	To place greater emphasis on assets that have a limited capacity to respond to disturbance and recover to their prior state (Pimm 1984; Brand & Jax 2007) Thus, those assets with traits that confer low rates of recovery (e.g. coastal geomorphology following development) will score higher (3) against this criterion than assets with moderate (2) or rapid (1) recovery trajectories.

Ranking the adequacy of existing knowledge (K)

Research priorities for conservation should be guided by gaps in the current state of fundamental knowledge and the information requirements of conservation practitioners (Jennings 2000). The adequacy of knowledge relating to assets, and the pressures acting on them, is determined from four criteria (Table 3). Two of these criteria, inventory (K_1) and baseline (K_2), are spatially explicit and require knowledge that is relevant to the area of interest. However, knowledge of ecological and physical processes (K_3) and modelling to identify management targets (K_4) may be relevant even when it is not drawn directly from the area or species of interest. The lack of knowledge can be assessed by:

$K = (4 - (\Pi\ K_{1\text{–}4})^{1/4}) * 3.$

The lack of knowledge value is multiplied by 3 so the potential range of 1–9 is the same as V and P values, ensuring V, P and K have equal weighting when calculating research and monitoring scores.

Fundamental Research

Fundamental (or strategic) research provides knowledge of natural systems that is required for effective ecosystem-based management without directly addressing the management of pressures. As such, fundamental research may characterise the ecological and cultural values of an area, investigate key ecological and social processes or determine natural patterns of spatial and temporal variability, thus providing information on the background patterns of natural dynamics for estimating the scale and significance of human-induced change. The importance of undertaking fundamental research (FR) on a particular asset will therefore be a function of its relative ecological value (V) and the extent of existing knowledge (K):

$FR = V * K.$

Applied Research

Applied research seeks to understand how natural systems respond to anthropogenic pressures and the mitigation strategies that might be used to ameliorate them. Studies that investigate human usage patterns and attitudes, and interactions between human pressures and values are examples of applied research that aim to address foreseeable or immediate management issues. The relative importance of undertaking applied research (AR) on a particular asset is a function of its value (V), the pressures acting on it (P) and the current knowledge of the interaction between the asset and that specific pressure (Kp). The criteria and scoring scale used to calculate Kp are the same as those used when calculating K, although Kp explicitly assesses knowledge on how a particular pressure influences an asset's condition:

$AR = V * P * Kp.$

Monitoring

Monitoring provides time-series data to help understand inherent variability and manage human activities that place pressure on the environment. Importantly, monitoring programs should reconcile the spatial and temporal scales of assets under threat relative to identified pressures (Chapman 2012). This approach applies to both short-term compliance-type monitoring programs with very specific management targets, and longer-term surveillance-type monitoring programs that assess the nature, extent and frequency of natural and human pressures. Moreover, condition–pressure–response monitoring requires periodic measurements of asset condition, the significance of pressures acting on the asset and the resources invested in management, with the overall aim of assessing the effectiveness of management (Ward 2000; Burgman 2005; Thomas 2005). Should, for example, asset condition deteriorate with a linked increase in a particular pressure, management settings or resourcing can be altered to counter such a trend (Lindenmayer et al. 2013). The priorities for monitoring relate to the value (V) of the asset and the significance of the pressures (P) acting on it. As such, monitoring (M) should be a clearly linked function of a specific pressure–asset interaction:

$M = V * P.$

Project development

This framework identifies assets that warrant research and monitoring attention, but does not identify or prioritise specific projects. Nonetheless, the development of research projects can be guided by the criteria that promoted high research scores. For fundamental research, this will reflect the extent and type of knowledge currently available, whilst applied research projects should relate to knowledge relevant to the pressure–asset/species interaction. The spatial and temporal extent of high priority monitoring projects will be informed by the distribution of key pressures in space and time. Detailed assessment of the costs, benefits, feasibility and uptake of projects can then be used to identify those of highest priority (Pannell et al. 2013).

NINGALOO MARINE PARK: AN EXAMPLE OF HOW THE FRAMEWORK COULD BE USED

To demonstrate how the framework could be applied, monitoring and research priorities were identified for the NMP. Assets were restricted to ecological key performance indicators of management effectiveness in the 2005–2015 NMP Management Plan (CALM 2005). These assets were scored using criteria in Tables 1 and 3 to assess their relative values and current extent of knowledge. The main pressures acting on each asset were also drawn from the management plan and were scored for the ensuing 10-year period using criteria in Table 2. Climate change was also recognised as an important driver of prioritising conservation activities (Hodgson et al. 2009; Natural Resource Management Ministerial Council 2010; Iwamura et al. 2013); and although this is not listed in the management plan, it is included as a pressure that

Table 2

Criteria used to assess pressures. Values in parentheses are indicative of appropriate scores for each criterion.

Criteria	Intent of the criteria
Spatial scale (P1)	This criterion assumes that the greater the spatial extent of a pressure in relation to the spatial distribution of the asset, the greater the management concern (Thrush et al. 1998; Clavero et al. 2010). Pressures resulting in widespread impacts across an entire region would be given a higher score (3) than those that cause multiple (2) or isolated (1) localised impacts.
Temporal scale (P2)	This criterion acknowledges that sustained pressures are generally of greater management concern than short-lived pressures (Hughes et al. 2003). Sustained pressures will score higher (3) than occasional but short-lived (2) or rare (1) pressures.
Biological severity (P3)	The ramifications of some perturbations can have greater biological consequences than others for an asset. For example, fishing is expected to have a greater effect on the abundance and long-term survival of targeted fish species than climate change (Graham et al. 2011). Pressures that have a severe impact on an asset and have consequences over ensuing years to decades will score highly against this criteria (3) relative to pressures that have consequences that last months to years (2) or are negligible (1) (Fletcher 2005).
Socio-political implication (P4)	This criterion acknowledges that pressures have different social, economic, cultural and political consequences (Suter 2006). A pressure that creates a high social/political consequence, inducing immediate management or stakeholder response, will score highly (3) for this criterion whilst pressures that attract social attention but no response will score moderately (2) and those that attract no attention will score low (1).
Likelihood (P5)	This criterion addresses the probability of a pressure occurring within a specified timeframe (Burgman 2005). Pressures that exist or are expected to occur within the timeframe established for the prioritisation matrix will score higher (3) than those with possible (2) or a remote (1) probability of occurring (adapted from Fletcher 2005).

Table 3

Criteria used to assess scientific knowledge related to an asset. Values in parentheses are indicative of appropriate scores for each criterion.

Criteria	Intent of criteria
Inventory (K1)	This criterion assesses the existing level of descriptive, qualitative or quantitative information on the asset (e.g. initial surveys of seagrass biomass and distribution, or species lists). Scores are high (3) if a comprehensive and verified inventory is available and moderate (2) if only limited data exists and low (1) if no data exists.
Baseline (K2)	This criterion assesses whether there is adequate quantitative spatial and temporal information to express the 'natural' state of an asset and distinguish between natural variability and human influences. Adequacy of baseline data is measured in both temporal and spatial terms. The presence of long-term, spatially representative datasets would score high (3) for this criterion whilst spatially extensive short-term, or long-term localised data sets would score moderately (2) and data with no temporal or spatial replication would score low (1).
Processes (K3)	This criterion assesses whether adequate information exists to identify and quantitatively assess processes that influence the condition of the asset (e.g. growth and reproduction). Regional-scale knowledge of relevant processes may be applicable even when knowledge was not collected locally. If current knowledge allows multiple key process parameters to be readily identified and quantified a high score (3) would be recorded. When key processes are identified but not quantified a moderate (2) score will be recorded and no reliable process information warrants low score (1).
Management targets (K4)	This criterion assesses whether the level of knowledge is adequate to be used to model the consequences of changing pressures and set ecologically sustainable management targets (Ferrier 2012). Regional scale knowledge of relevant modelling parameters may be applicable even when knowledge was not collected locally. The score increases as the level of understanding of the cause-effect pathways becomes clearer. When knowledge is sufficient to set robust management targets for asset condition, associated pressures and management actions, the score against this criterion will be higher (3), than when uncertainty around these targets is unacceptable (2) or there is insufficient data to calculate targets (1).

impinges upon all the considered assets. The final scores for each value, knowledge and pressure criteria were based on average values from independent assessments by four of the co-authors, all of whom possess significant (5+ years) research and/or management knowledge of NMP. Average scores, with 95% confidence intervals, were then used to assess variance among participants and identify research and monitoring activities of similar priority. A more comprehensive assessment of assets should incorporate independent scores from a broader array of scientists, managers and stakeholders to capture all levels of relevant expertise and experience.

Coral reefs, finfish and turtles had the highest relative value among the assets; however, knowledge relating to management of these NMP assets is extensive, and they were not considered a high priority for fundamental research. Conversely, knowledge on water quality is low for NMP, especially baseline information. Therefore, fundamental research is required on this topic (Table 4).

The most significant pressure acting across all key performance assets for NMP was climate change, whilst fishing was also a major pressure on finfish (Table 5). Accordingly, applied research projects should focus on the effects of climate change on corals, finfish, mangroves and turtles, with emphasis on developing predictive models. In addition, high scores were achieved by the effects of fishing and habitat loss on finfish, as well as the effects of groundwater removal on mangroves. Applied research projects on finfish might focus on better understanding key processes and modelling impacts of fishing and habitat loss, whilst inventory and baseline information is required to better understand interactions between groundwater levels and mangrove persistence. Monitoring priorities should focus on assets and associated pressures with high scores. At Ningaloo, this includes projects that monitor the effects of climate change on coral, finfish and turtles, as well the impacts of fishing on finfish.

DISCUSSION

The framework presented here provides a clear process for identifying research and monitoring priorities for protected areas and threatened species by concurrently assessing asset values, pressures and the current extent of knowledge. The utility of this framework enables the criteria to be easily evaluated in a manner that provides a consistent, transparent and defensible set of research and monitoring priorities for managers. Such outcomes are important because conservation resources are often inadequate and managers must be able to demonstrate that their limited research and monitoring capacity is directed to areas of greatest strategic need (Hughey et al. 2003; Marsh et al. 2007). Conservation science competes for funding with other societal priorities, severely constraining the availability of resources for research and monitoring (Wilson et al. 2009). Despite limited resources, we contend that monitoring, fundamental and applied research are complementary and equally important aspects of building knowledge to ensure that management decisions are based on sound science.

By using this framework to prioritise research and monitoring activities in NMP, we have shown that fundamental research on water quality is a high priority, whilst applied research and monitoring should focus on the effects of climate change on corals and turtles and the influence of fishing on finfish. The emphasis on climate change and fishing acknowledges the direct impact that these pressures can have on assets of high ecological and social value (Jennings & Kaiser 1998; Hughes et al. 2003), and the importance of research and monitoring to understand the impacts of these pressures (Fisher et al. 2011). Findings are also consistent with a recent assessment of the Great Barrier Reef that found climate change, water quality and extractive activities pose the greatest threat to ecosystem health (Ward 2014b). The primary objective here was, however, to demonstrate how

Table 4

Fundamental research (FR) priorities for key performance assets at NMP. Criterion scores, mean and 95% confidence intervals (CI) for FR calculated from four independent scores. Based on 95% CI, the values in red are the highest.

	Value											Knowledge							
Asset	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}	V	K_1	K_2	K_3	K_4	K	FR mean	FR lower 95% CI	FR upper 97% CI
Coral reefs	3.0	2.0	1.8	2.0	3.0	2.0	2.0	2.3	3.0	2.0	6.7	3.0	3.0	3.0	2.0	3.9	26.0	24.7	27.3
Finfish	1.8	2.0	1.0	3.0	3.0	3.0	2.0	3.0	2.0	1.0	6.0	3.0	3.0	2.0	2.0	4.7	28.1	27.3	28.8
Mangroves	3.0	1.8	1.0	1.0	2.0	2.0	1.0	1.0	2.0	2.0	4.7	3.0	2.0	2.0	2.0	5.4	25.3	24.3	26.3
Turtles	1.3	1.3	1.3	3.0	2.0	2.0	3.0	3.0	3.0	2.0	6.3	3.0	3.0	2.0	2.0	4.7	29.2	28.0	30.5
Water quality	2.5	3.0	2.0	2.0	2.0	2.0	1.0	1.0	2.0	1.0	5.4	2.0	1.0	2.0	2.0	7.0	37.3	34.5	40.0

V1 Foundation habitat
V2 Ecosystem processes
V3 Distribtion
V4 Cultural
V5 Recreational
V6 Economic
V7 Scientific
V8 Historical perspective
V9 Vulnerability
V10 Resilience
K1 Inventory
K2 Baseline
K3 Model parameters
K4 Predictive models

Table 5

Applied research (AR) and monitoring (M) priorities for key performance assets at NMP. Criterion scores, mean and 95% confidence intervals (CI) for AR and M calculated from four independent scores. Based on 95% CI, the values in red are the highest.

		Pressure						Knowledge										
	V	P_1	P_2	P_3	P_4	P_5	P	K_1	K_2	K_3	K_4	Kp	AR mean	AR lower 95% CI	AR upper 95% CI	M mean	M lower 95% CI	M upper 95% CI
Coral reefs–																		
Visitor	6.7	1.0	1.8	2.8	1.0	3.0	4.4	3.0	2.3	2.8	2.0	4.6	137.5	124.2	150.7	29.6	26.7	32.4
Oil spill	6.7	2.8	1.0	1.8	3.0	1.0	1.9	3.0	1.8	2.0	1.0	6.6	86.3	73.9	98.7	13.0	11.7	14.2
Climate change	6.7	2.8	2.8	3.0	3.0	2.8	7.9	2.8	2.0	2.8	1.8	5.2	267.5	249.4	285.7	53.2	41.1	65.3
Finfish–																		
Fishing	6.0	2.3	2.8	2.8	2.0	2.8	6.6	3.0	2.3	2.0	2.0	5.2	210.4	150.8	270.1	40.1	30.6	49.6
Fish feeding	6.0	1.0	2.0	1.3	1.8	2.3	3.3	2.8	1.8	1.8	1.3	6.6	126.9	100.9	152.9	19.4	14.4	24.3
Loss of habitat	6.0	2.0	2.3	2.3	1.5	2.3	4.4	2.8	2.5	1.8	1.5	5.8	164.4	75.4	253.3	26.6	18.6	34.5
Climate change	6.0	2.5	2.0	2.3	1.8	2.5	5.3	2.3	2.0	1.8	1.0	7.0	220.7	159.6	281.8	32.0	21.1	42.9
Mangroves–																		
Trampling	4.7	1.0	1.8	1.3	1.0	3.0	3.6	2.8	1.8	1.8	1.0	6.9	116.8	98.0	135.6	16.9	16.2	17.5
Oil spill	4.7	2.5	1.3	2.5	2.5	1.0	2.1	1.8	1.3	1.3	1.3	7.9	78.4	70.1	86.7	9.7	8.9	10.4
Water extraction	4.7	2.5	2.8	1.5	1.8	2.0	4.1	1.3	1.3	1.3	1.0	8.5	161.1	131.3	191.0	18.9	16.9	20.9
Climate change	4.7	2.3	2.5	1.8	1.5	2.3	4.4	2.3	1.8	1.8	1.8	6.4	138.5	65.1	211.8	21.3	10.9	31.7
Turtles–																		
Invasive predators	6.3	2.8	2.8	1.0	1.3	2.3	3.9	3.0	3.0	3.0	2.0	3.9	93.4	76.8	110.1	24.2	19.9	28.5
Visitor	6.3	1.0	2.0	2.8	1.3	3.0	4.9	2.0	2.0	2.8	2.8	5.0	150.0	127.3	172.6	30.0	28.9	31.2
Climate change	6.3	3.0	2.8	2.3	2.3	2.5	6.4	2.3	1.8	2.3	1.0	6.8	274.9	188.7	361.2	40.1	28.1	52.0
Water quality–																		
Sewage input	5.4	1.0	1.8	3.0	1.3	1.0	1.6	2.3	2.0	2.5	1.8	5.7	47.9	45.4	50.5	8.4	7.8	9.0
Oil spill	5.4	2.3	1.5	3.0	3.0	1.0	2.3	2.3	1.3	1.5	1.3	7.5	93.9	73.6	114.2	12.4	11.4	13.3
Litter	5.4	1.3	1.8	1.3	1.8	2.3	3.3	2.5	2.3	1.8	1.8	5.9	102.5	65.4	139.7	18.4	8.5	28.3
Climate change	5.4	3.0	2.3	1.5	2.3	1.5	3.3	2.3	1.5	1.8	1.5	6.8	120.7	67.8	173.6	17.8	9.3	26.3

P1 Spatial scale
P2 Temporal scale
P3 Biological severity
P4 Social/political implications
P5 Likelihood
K1 Inventory
K2 Baseline
K3 Model parameters
K4 Predictive models

the framework could be applied. An assessment of all assets in the NMP Management Plan by a broader suite of participants is warranted.

The framework has potentially broader application in both marine and terrestrial systems, and may be used to prioritise research and monitoring for a range of conservation management scenarios where one or more assets are subject to different pressures, and the state of knowledge of each asset varies. When using the framework for alternative scenarios it may be necessary to modify criteria to ensure they are appropriate for the range of assets in question. If, for example, the framework were used to prioritise research and monitoring for marine mammals, the criteria could be customised to ensure that variation among species is recognised. In particular, marine mammals are typically long-lived, slow breeders, and have inherently similar levels of vulnerability when this criterion is based solely on life history traits (Marsh et al. 2003). Consequently, variation in the vulnerability criterion (V_9) could be driven by availability of suitable habitat and current population size (Simmonds & Isaac 2007). Such flexibility enables management agencies to use a consistent and defendable method of determining research and monitoring priorities across what are commonly broad-ranging conservation responsibilities.

The framework is also flexible in relation to the relative importance of the criteria, and can be modified by removing, adding or weighting criteria. Weighting of criteria can be undertaken using an Analytical Hierarchy Process, AHP (Saaty 1980), which is based on pairwise comparisons of criteria importance by experts, an approach that has been used in other frameworks (e.g. Bryan et al. 2010b; Graham et al. 2011).

A major limitation of many prioritisation processes is that scoring may be biased by the prejudices of the experts involved (Master 1991; Drescher et al. 2013). This subjectivity may be overcome by having a diverse group of people score criteria. For example, Fleishman et al. (2010) used an open participation process that encouraged hundreds of scientists and managers to identify conservation priorities. Incorporating opinions from a large and diverse number of participants should reduce personal bias, although any inherent prejudices of participants may be assessed by asking each about their background and determining if they place higher prioritization on areas that reflect their interests (Wilson et al. 2010). Importantly, the mechanism by which participants are identified and selected must be transparent and repeatable (Burgman et al. 2011; Drescher et al 2013). Magos Brehm et al. (2010) ranked the conservation importance of plant species using four different assessment computations of the same prioritisation criteria. The order in which species were ranked differed among the computations, although some species consistently ranked above others and were appropriately identified as high conservation value. These results indicate that there is considerable variance among prioritisation frameworks, but high priority projects, species or areas may be identified from congruent patterns among a composite of processes.

Determining threshold scores for high, medium or low priority research and monitoring activities is another potentially subjective process associated with the framework. However, treating the prioritisation criteria as a multivariate data set allows research and monitoring activities to be plotted in multidimensional space and clusters of activities of similar priority to be identified (Given & Norton 1993).

Establishing research and monitoring priorities provides a more structured basis for the equitable allocation of conservation resources. The framework presented here identifies biophysical assets and species that warrant the greatest monitoring, fundamental or applied research. The framework incorporates information on asset value, the anthropogenic pressures that impinge upon those assets and the current knowledge relating to the asset or asset–pressure interaction. As priority-informed research and monitoring programs are implemented and completed the accrued information will, however, fill knowledge gaps and as K approaches zero, the emphasis for further research will be reduced. Moreover, evolving knowledge may alter perceptions of pressures and values. To maintain relevant research and monitoring priorities and the efficient use of resources new information should therefore be regularly collated and the prioritisation process repeated.

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