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Prioritizing management strategies to achieve multiple outcomes in a globally significant Indonesian protected area

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Abstract

The multiple values delivered by protected areas around the world are threatened and in decline. We propose a structured decision science prioritization approach for justifying and guiding increased investments in protected area management to improve outcomes for a suite of important values. Using Bali's only national park, Taman Nasional Bali Barat (TNBB) as a case study, we draw from existing park documentation and 80 participating experts in TNBB's ecology, society and management to define goals that describe a successful outcome for nine core values of the park: threatened species, ecosystem function, ecosystem habitats, scientific research, food and health, spiritual values, traditional fishing, community prosperity, and ecotourism. Participants estimated that without increased investment, the extent of goal achievement is likely to be below 30% for all values at the end of the 15-year planning time frame. However, implementing nine strategies, at an increased annual investment of 5.5 billion Indonesian rupiah (US$385,666) per year, would achieve the goals for all values. The most cost-effective strategies were predicted to be collaboration and planning, monitoring and managing invasive species, followed by establishing and using a research and management fund, adapting to climate change, managing illegal resource use, waste and human impacts, as well as improving the captive breeding program for the iconic and critically endangered bird, curik Bali. Our approach may be useful for systematically comparing costed sets of management investments in other conservation areas worldwide.

KEYWORDS
biodiversity, conservation planning, cost-effectiveness analysis, expert elicitation, livelihoods, Priority Threat Management, structured decision making

1 | INTRODUCTION

Conservation areas are often focal areas for biodiversity and human cultures (Chape, Spalding, & Jenkins, 2008), being not about social exclusion but inclusion. In a single location a protected area can provide many values for nature and people (Oldekop, Holmes, Harris, & Evans, 2016; Pascual et al., 2017), where values may include essential habitat for threatened species, regulatory ecosystem services like climate and soil protection, as well as important cultural, spiritual, recreational and economic and subsistence values (Pascual et al., 2017). Some protected area values are also of growing importance, such as carbon storage to counter the effects of growing global carbon emissions (Melillo et al., 2016) and opportunities to alleviate poverty (Balmford et al., 2015). In many of the world's protected areas, conservation is tightly balanced with often competing objectives such as continued and in some cases accelerating traditional natural resource-use objectives (Ellis, 2013).

The maintenance of multiple values across Earth's land and seascapes is paramount to human wellbeing and survival (Maron, Simmonds, & Watson, 2018; Pascual et al., 2017). For example, as economies and human populations grow across much of South East Asia, protected areas provide important combinations of values that are increasingly rare, including endangered species and spiritual connections to ancient traditions and essential natural resources for human subsistence (Chape et al., 2008; Juffe-Bignoli et al., 2014). South East Asian protected areas also provide ecosystem services of major global significance, including some of the world's highest carbon storage forests (Saatchi et al., 2011), important medicinal resources and unique ecotourism experiences (Juffe-Bignoli et al., 2014). However, without effective management of protected areas, biodiversity and its associated values have been shown to decline (Leverington, Costa, Pavese, Lisle, & Hockings, 2010). The effective management of protected areas in South East Asia is therefore essential for conserving, restoring and utilizing protected area values from local to global scales (Juffe-Bignoli et al., 2014; Sodhi, Koh, Brook, & Ng, 2004).

Making management decisions for multi-value protected areas is complex and challenging. Managers of protected areas typically have inadequate resources and information for managing all important values and threats (Bruner, Gullison, & Balmford, 2004; McCarthy et al., 2012; Watson et al., 2016). Values in protected areas can conflict, such as where wildlife threatens agriculture (Karanth, Gopalaswamy, Prasad, & Dasgupta, 2013), or complement, where management actions can simultaneously improve biodiversity and reduce poverty (Austin et al., 2016; den Braber, Evans, & Oldekop, 2018). Good management outcomes therefore rely upon understanding which management strategies will generate the greatest improvements across multiple values, using the limited resources available, while taking account of different objectives, trade-offs, synergies and opportunities. Methodologies for prioritizing locations for protected or conservation areas that cost-effectively co-locate multiple values have been demonstrated (Egoh et al., 2010; Whitehead et al., 2014). However, analyses of the threats to multiple values in these conservation areas and the management strategies required to manage those threats tend to focus on biodiversity values (Jones et al., 2018; Schulze et al., 2018), despite the well-understood linkages between the values of protected areas for both nature and people (Brockington & Wilkie, 2015; Oldekop et al., 2016; Salafsky & Wollenberg, 2000).

Emerging conservation action prioritization approaches use structured decision making and expert elicitation (Hemming, Burgman, Hanea, McBride, & Wintle, 2018; Martin et al., 2012) to identify the management strategies that are likely to provide the greatest return on investment for improving biodiversity values (Carwardine et al., 2012; Cullen, 2013; Joseph, Maloney, & Possingham, 2009). These approaches assess the cost-effectiveness (calculated by the nonfinancial benefits divided by cost) (Levin & McEwan, 2001) for improving species outcomes through implementing a range of strategies or actions, in contrast to spatial conservation prioritization tools, like Marxan or Zonation, which require spatial data to provide optimal locations for protection and management (Ball, Possingham, & Watts, 2009; Moilanen et al., 2005). For example, the Priority Threat Management (PTM) approach brings together key stakeholders and experts to define and assess threat abatement strategies that improve multiple threatened species across landscapes (Carwardine et al., 2019), while the Project Prioritization Protocol defines and prioritizes recovery projects for each species that abates its key threats and ensures its persistence (Joseph et al., 2009). In some cases, conservation action or spatial prioritization approaches consider additional objectives for specific projects (Pannell, Roberts, Park, & Alexander, 2013), or priorities, such as minimizing impacts on fisheries profitability (Adams, Mills, Jupiter, & Pressey, 2011). However, none of these approaches have been applied to assess strategies for improving a comprehensive set of values in a multifunctional protected area. An action prioritization approach that can address multiple values in protected areas may help to develop science-based, agreed-upon protected area management programs that effectively deliver multiples outcomes.

In this study we develop an approach to define and prioritize threat management strategies for maximizing benefits to a diverse range of values. We adapt the PTM tool, which has thus far been used for prioritizing strategies that mitigate threats to flora and fauna species. We demonstrate our approach by prioritizing the management of threats to the multiple values in the *Taman Nasional Bali Barat* (TNBB) in Bali, Indonesia. Indonesia has the highest species endemism in Asia, with many species threatened with extinction. As is typical of protected areas in Indonesia, TNBB is critically important for a broad set of values, many of which are threatened by a range of processes that require management.

In consideration of the complexity of essential values and threats to TNBB, in this study we aimed to: (a) build an approach capable of assessing the cost, relative benefits and cost-effectiveness of implementing threat management strategies that improve a broad range of values in multifunctional areas; (b) bring together and build key information to help managers and stakeholders understand the values, goals, threats, total management costs and opportunities for achieving goals for values, using the TNBB as a case study; and (c) deliver a set of costed, prioritized strategies for achieving goals across multiple important values of the TNBB. We envisage our approach will assist with decision making and generating opportunities for increased investment in effective management of the park.

2 | METHODS

2.1 | Case study

The TNBB (Figure 1) is the only national park in Bali and delivers a range of significant cultural, provisioning and economic values to Balinese people and visitors. TNBB includes the last wild habitat of the critically endangered curik Bali (*Leucopsar rotschildi*, also known as the Jaluk Bali). Several communities are dependent on the park and its surrounding area for agricultural production (e.g., rice fields, dry land agriculture, and forestry) and animal husbandry (e.g., cattle and pigs) (Taman Nasional Bali Barat, 2019).

Historically, TNBB land was used for timber production and other non-timber forest products. TNBB's path to protection began in 1911 with the discovery of the rare endemic species of curik Bali in Bubunan Village. The home range of the curik Bali is approximately 32,000 ha starting from Bubunan Village near Singaraja to Gilimanuk (Taman Nasional Bali Barat, 1997). The Council of Kings in Bali issued a Decree in 1947, establishing what would become today's TNBB, by designating the Banyuwedang forest area (19,366 ha) as a natural protected park to protect the critically endangered curik Bali as well as the (now extinct) Bali Tiger (*Panthera tigris sondaica*). In 1978, West Bali animal sanctuary, Menjangan Island, Bird Island, Kalong Island and

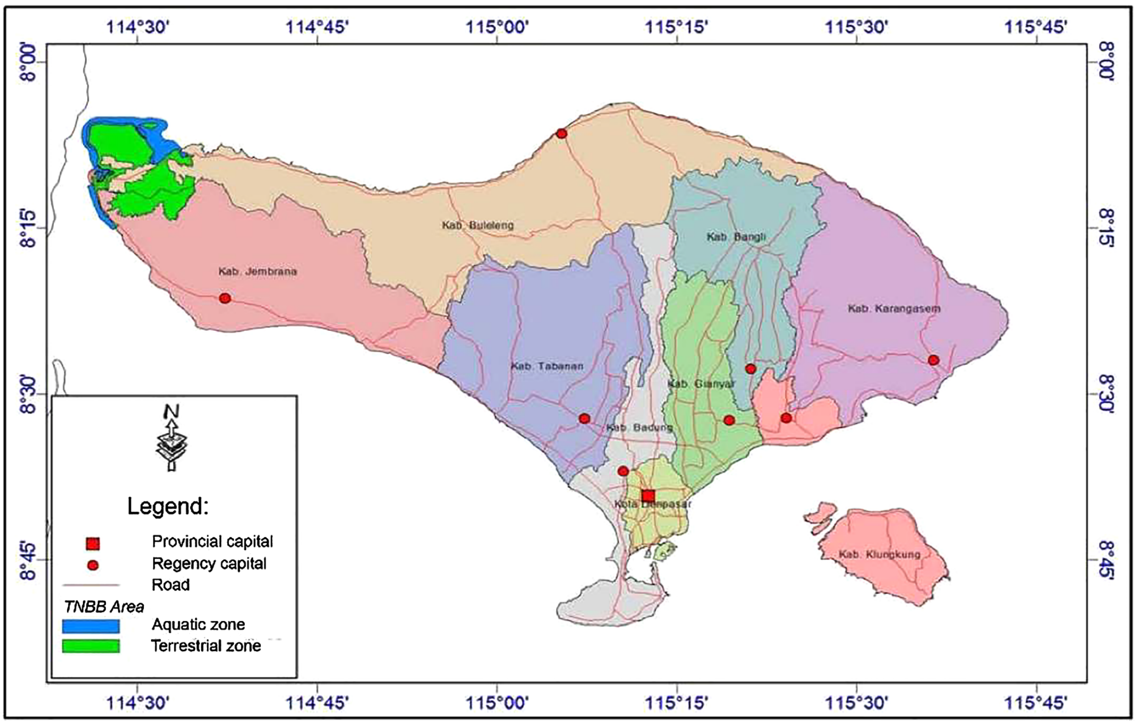

FIGURE 1 Site location and zones of Taman Nasional Bali Barat (TNBB) in Bali, Indonesia (Taman Nasional Bali Barat, 2019)

Gading Island were all designated as additional conservation areas. Due to changes in delineation of the buffer zone, by 1995 the total area of TNBB was 19,003 ha and consisted of 15,588 ha land and 3,415 ha of ocean. Of this, the management of 3,980 ha as "*Hutan Produksi Terbatas*," limited production forest/forests allocated for low intensity timber production, was granted to the Bali Provincial Forestry Agency. TNBB today is separated into seven management zones consisting of the core zone (±8,023 ha), jungle zone (±6,175 ha), marine protection zone (±222 ha), utilization zone (±4,294 ha), cultural, religion and historical zone (±50.5 ha), special zone (±3.9 ha), and traditional zone (±311 ha) (Taman Nasional Bali Barat, 1997).

2.2 | Building a multi-value, threat management prioritization approach

We used a collaborative process to develop an approach for prioritizing management strategies for a range of values, using the existing PTM approach as a basis (Carwardine et al., 2019). The PTM approach was initially developed to prioritize the management of threats to imperiled species across broad regions in Australia and Canada (Carwardine et al., 2012; Chades et al., 2015; Firn, Maggini, et al., 2015; Firn, Martin, et al., 2015; Ponce Reyes et al., 2016; Ponce Reyes et al., 2019). The approach brings together knowledge from key experts and stakeholders in each region to estimate the likely cost-effectiveness of possible threat management strategies. The cost-effectiveness metric is derived from estimates of the likely benefit of the strategy and the costs of its management. In all previous case studies, strategies were focused on improving the outlook for threatened species or a similar biodiversity surrogate. The key adaptation of the PTM approach made for the current study is threat management strategies to improve a broader set of values held by park managers and stakeholders. This involved broadening the benefit metric to encapsulate values beyond biodiversity, making this a multi-objective decision approach (Adem Esmail & Geneletti, 2018; Dujardin & Chadès, 2018).

Like previous PTM applications, the approach we developed uses structured elicitation to define the set of values of importance in the park, the threats to these values and the possible management strategies to abate them. Participants should be prompted to include specific values that fall within ecological, cultural, provisional and economic values. In order to adapt the benefit metric to capture a range of different values, participants need to define one or more achievable goals, or measures of success, for each value, following the globally established principles for goal setting (The Nature Conservancy, 2007) Participants are then asked to define threats to each value and the set of management strategies that would collectively abate these threats and meet the goals for each of the values. In the current study participants were most comfortable to assume equal weights on each value, however, in future applications variable weights could be assigned using approaches from multiple criteria decision analysis or non-market valuation techniques.

The adapted PTM approach requires participants to estimate the future extent that each goal will be met as a percentage from 0 to 100%. A goal achievement of less than 100% indicates that the goal is partially met by a strategy. The benefit of each management strategy for a value is estimated by the expected change or improvement in goal achievement when the strategy is implemented, compared with a baseline scenario where no strategies are implemented. Strategies may have a different feasibility, which is the likelihood that the strategy can be implemented successfully, given social and technical constraints, assuming funding was available. If feasibility is considered to vary significantly, this could be estimated for each strategy as a separate parameter, or if it is reasonably uniform, participants can account for the feasibility of each strategy when estimating the expected change in goal achievement for each of the values (Firn, Martin, et al., 2015). Each strategy needs to be financially costed annually, over the time frame of interest for the study. Strategies can then be compared by their cost-effectiveness ranking, which is their total benefit divided by their cost. Cost-effectiveness rankings enable a comparison of the relative return on investment of an option, decision or strategy; however, these ranks assume a level of independence among the benefits of each strategy, hence should be interpreted with caution.

2.3 | Information collection and analysis

This study combined existing information with expert and stakeholder-held knowledge, applying and adapting best practice and protocols from the literature to conduct the expert elicitation process (Hemming et al., 2018; Martin et al., 2012). We gathered existing information on the values, threats and management of the park from the existing grey and published literature, including TNBB park management documents, to help inform the project. We engaged with a total of 80 experts and stakeholders (hereafter participants) by phone, email and at workshops, describing the purpose and processes involved with the project. These participants had important knowledge, interest and/or decision-making roles relating to the park and included academic experts in

TABLE 1 Description of the multiple values of TNBB, with goals and threats for each value

Value		Categories/examples	Goal(s)	Major threats
Ecological values	1. Species	Threatened fauna and flora; curik Bali; Rusa; Banteng; Black monkey; turtle	Targeted species (curik Bali) is persisting in the wild and maintain or improve their conservation status, through the creation of ideal habitat and threat management	Hunting, fishing, logging, predators, competition, open access, forest fires, habitat changes
	2. Ecosystem function	Fertility—nutrient cycling; air quality; carbon storage; hydrological flow	All ecosystem functions are maintained to at least the same quality as today and are able to sustainably provide benefits to science, social, economic, ecotourism, and culture	Waste, clearing, agriculture, pollution
	3. Ecosystem habitat	Quality, complexity, integrity of trophic level interactions; coral reef and sacred island; Savanna; tropical forest; coastal areas; mangroves; monsoon forest	Trophic level interactions are intact to at least the same level as today + at least 30% of each ecosystems is in high quality reference condition quality + the remaining extents of ecosystems are maintained at least as high quality as today	Climate change, invasive species, diseases, damage from recreational activities
Cultural and provisioning values	4. Scientific research	Genetic diversity; biocontrol; medicinal; species bank	Sufficient knowledge is created for the best practice biocontrol, genetics and species bank to ensure no species becomes extinct + medicinal research resources are protected and available for medical advances	Theft, illegal experiments, over-exploitation
	5. Food and health	Health, for example, hot springs; plants; other food resources	The park continues to provide food and health benefits, at least as functional high quality as today	Over-exploitation
	6. Spiritual	Meditation; special sites, for example, temples	Spiritual sites are restored to and maintained in a pristine condition	Expanding temples, fires from incense, waste
	7. Traditional fishing	Traditional fishing	Current practice and knowledge of traditional fishing is sustainable into the future	Species declines, waste management
	8. Community prosperity	Livelihoods and wellbeing	Current community prosperity is maintained and/or improved from today's levels	Waste management, climate change, landscape changes
Economic values	9. Ecotourism	Tourism: marine; tourism: land/forest	Ecotourism is the dominant/only type of tourism in TBBN + tourism has negligible negative impacts on TBBN	Hotels, mass tourism, vandalism

biological and socio-economic sciences, high level government staff and park management directors. We collated most of the required information from participants using a structured elicitation approach over two workshops held at Udayana University. The elicitation methodology was approved by CSIRO and QUT Human Research Ethics.

In September 2016 we held the first workshop with a subset of 50 participants with expertise in the values, threats and decision-making processes of the park. At this workshop we defined the process, and elicited the values, goals for each value, the threats and the management strategies to address the threats in the park (Table 1). Values were defined as the key assets, functions or uses that arise from the TNBB, and included ecological, cultural and provisional and economic values (Hicks, Cinner, Stoeckl, & McClanahan, 2015). Nine core values of the park, a description and examples of each value, as well as key threats and goals were drawn from existing park literature, discussed and refined by the expert group (Table 1). Participants are then divided into smaller groups of 4–5 people to define management actions to address each threat. Management actions were synthesized post workshop and aligned into nine strategies that collectively abate threats to values in TNBB (Tables 2 and S1). Goals for each value were set to be achievable, and strategies were designed to meet the goals for all values.

In July 2018 we held a second workshop with 30 additional participants to define the costs and likely benefits of each strategy. Participants suggested that costs were best estimated annually, and we did not apply a discount rate due to the relatively short time frame of this study. Here were reviewed the strategies, defining actions for each strategy in more detail. In small groups of 4–5 people, we asked participants to estimate the annual cost of the actions and resources required to implement each strategy in present day Indonesian rupiah per annum over 15 years, in alignment with current planning timelines. Participants were asked to consider the kinds of costs that might be involved, including human resources (i.e., number of Full Time Equivalent staff), materials and equipment, travel and planning workshops. At the workshop, 22 experts with the time and management expertise independently estimated the extent of goal achievement for each value if management strategies were put into practice in the next 15 years, which is the time schedule used in current management plans. Goal achievement was estimated as a score from 0 to 10, where 10 is completely achieved and 0 is completely failed. Experts first made estimates of goal achievement for a baseline scenario (i.e., a "minimal management" scenario which does not include the implementation of the strategies outlined in this analysis) and then with the implementation of each strategy. For the baseline scenario and each strategy, these estimates were averaged across experts and converted to a percentage out of 100, to provide an overall estimate of the likely goal achievement for each value with the baseline scenario (denoted I_{0j} for value j), and with the implementation of each strategy (denoted I_{ij} for strategy i and value j). We used a single best guess estimate rather than a four point estimate due to time and communication constraints, and for this reason we conducted an extensive sensitivity analysis around the best guess values of benefit and cost. Participants considered the feasibility of strategies to be high assuming funding was available, hence the feasibility of each strategy was not estimated as a separate parameter.

Post workshop, the authors determined the annual cost of achieving the best possible improved outcomes for values of TNBB through threat management, by summing the annual costs across all strategies. We provided these total costs to participants who were given the opportunity to refine the cost estimates for each strategy, creating a final total annual cost for each strategy (C_i for strategy i). For each value, we calculated the average benefit of each management strategy, measured as the gain in improvement relative to the baseline scenario where no strategies were implemented. This was calculated by taking the average overall benefit of each strategy, which was the summed difference in the percentage of goal achieved G under each value j, divided by the number of values included in the analysis (for this study, $J = 9$, see results):

$$B_i = \frac{\sum_j^J (Gij - Goj)}{J}.$$

We identified the strategy that was most important for each of the values. Finally, we compared and ranked strategies by their overall cost-effectiveness (CE), by dividing the total benefit (B) of each strategy by the total cost (C_i) of the strategy i:

$$\mathrm{CE}_i = \frac{B_i}{C_i}.$$

As per previous PTM applications, this analytical approach makes two assumptions: (a) that the values considered are weighted equally (a goal improvement of 20% in one value is equal in importance to the same magnitude of goal improvement of another value) and (b) that there is a linear relationship between the benefit of a strategy and the improvement in it generates (i.e., an improvement of 40–60% was an equal benefit to an improvement of 70–90%). For the TNBB case study, it was neither culturally appropriate nor readily communicable to vary weights or the benefit linearity among the agreed upon set of values. However, the results generated by the approach can be interpreted to understand which strategies achieve a minimum threshold for each value. Future case studies may build in weights and vary the linearity of benefit metrics if appropriate, applying analytical approaches from multi-criteria analysis, non-market valuation and

TABLE 2 Description, costs, benefit, and cost-effectiveness of threat management strategies

Strategy name	Details of strategy	Annual cost (Indonesian rupiah)	Benefit (% goal improvement)	Cost-effectiveness rank[a]	Annual cost (USD)
1. Collaboration and planning	Collaborate, plan and regulate park land use + support and work with communities to achieve on ground outcomes	Rp 50 million	44.0	1 (1.926)	$3,487
2. Invasive species management	Monitor, research and manage invasive animals and plants + eradicate top three weed species + collaborate with university	Rp 111 million	43.8	2 (0.875)	$7,706
3. Research and management fund	Establish and use an ongoing research and management fund for emerging projects and threats	Rp 200 million	49.8	3 (0.548)	$13,947
4. Religious practices management	Maintain cultural and religious practices + monitor and manage increasing religious temple and other site use + prevent vandalism	Rp 500 million	47.5	4 (0.209)	$34,867
5. Direct human impact management	Monitor and manage impacts of tourism and unauthorized road access + increase opportunities for low impact access	Rp 550 million	48.7	5 (0.195)	$38,354
6. Climate change adaptation	Develop and implement plans that are adaptive to climate change + scientific research on climate change impacts	Rp 600 million	49.5	6 (0.182)	$41,841
7. Waste management	Campaigns to reduce tourism waste + collect and recycle plastic waste + volunteer tourism to collect park and beach rubbish	Rp 670 million	50.5	7 (0.166)	$46,722
8. Endangered species management	Expand curik Bali captive breeding program + maintain species inventories	Rp 1,300 million	50.1	8 (0.085)	$90,655
9. Illegal harvesting management	Monitor and control extraction of medicinal species, illegal logging, hunting and fishing	Rp 1,550 million	44.3	9 (0.063)	$108,088
Total		Rp 5,531 million			$385,666

[a]Cost-effectiveness score is the average improvement in goal achievement (%) across all values per million rupiah spent.

optimization (Adem Esmail & Geneletti, 2018; Dujardin & Chadès, 2018).

Due to the uncertainty in both the cost and benefit estimates for each strategy, an analysis was conducted to investigate the sensitivity of the priority rankings to cost and benefit estimates. To do this we tested the potential change in cost-effectiveness ranking of each strategy under a range of possible different values for the benefits and costs of each of the strategies that are all within 0–100% of the confidence intervals for each parameter. To generate possible variations in cost and benefit estimates, we used the R function runif, which produces a random number (weighting) for each cost and benefit estimate, based on a uniform distribution between the

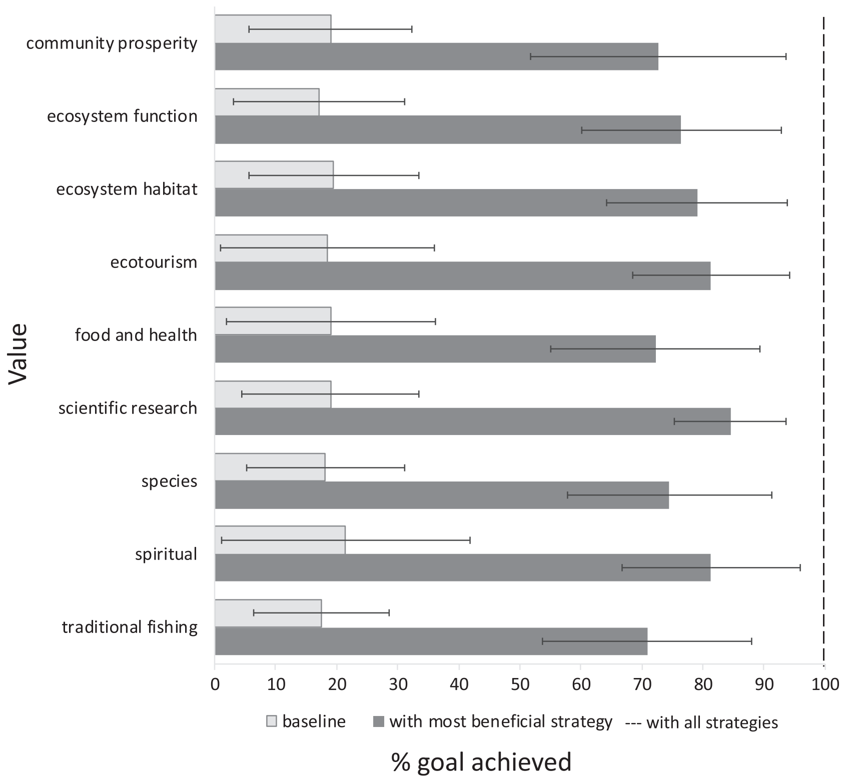

FIGURE 2 The expected goal achievement (%) of each value in 15 years under the baseline scenario (no additional strategies, light grey bars), with effective implementation of the strategy that provided the greatest benefit to each value (dark grey bars) and with all strategies implemented (dashed line). Error bars show standard deviations of estimates across all experts

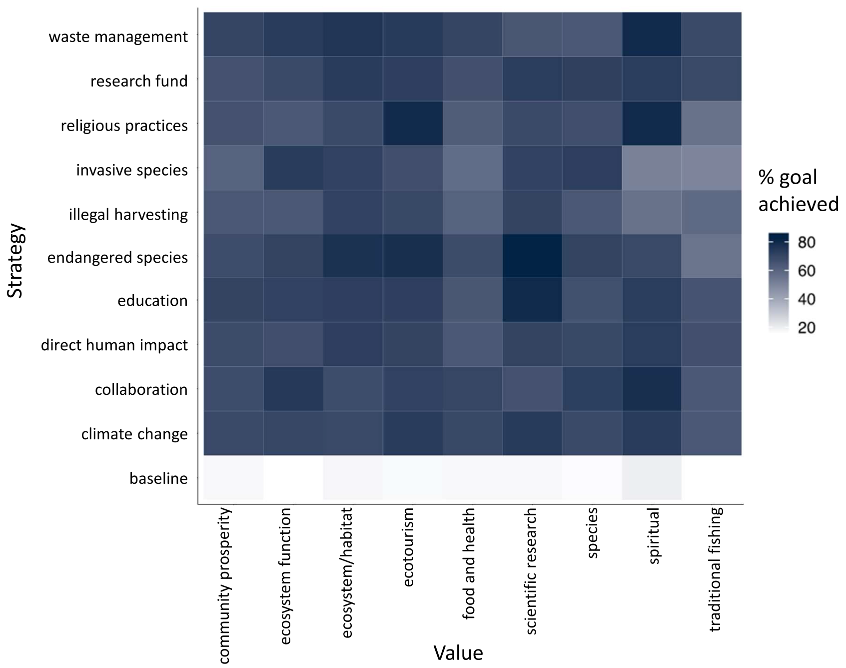

FIGURE 3 The estimated goal achievement (%) of each value in 15 years under the implementation of each strategy compared with the baseline scenario (no additional strategies implemented). Darker hues indicate a greater estimated goal achievement by the end of 15 years

minimum and maximum values. The random weightings were assigned to each cost and benefit estimate independently for each of the nine strategies, resulting in the cost being given a different weighting than the benefit for the same strategy type. Using this combination of weighted estimates for costs and benefits, a new cost effectiveness score was calculated for each of the nine strategies. This was considered one random trial which resulted in a new set of CE rankings for the nine strategies. The process of randomly weighting the expected benefit and costs and then producing a new set of CE rankings was repeated 100 times, with different weightings for all estimates for each new trial. The average rank number for each strategy was plotted along with the standard deviation for each of strategies, shown in Figure S1.

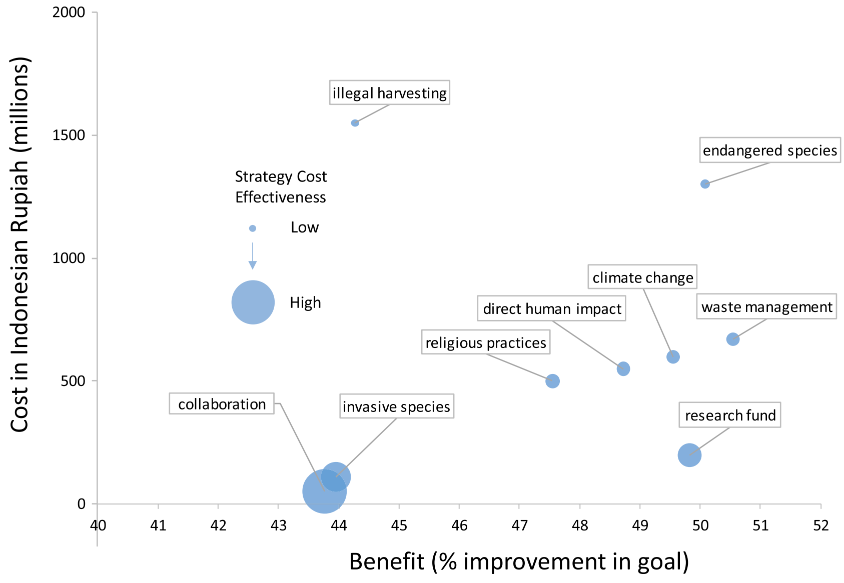

FIGURE 4 The estimated cost, benefit (average % improvement across all values) and cost-effectiveness of each strategy. Larger circles indicate a higher expected benefit to cost ratio of the strategies

3 | RESULTS

Participants defined nine core values for the TNBB, within three broad categories: ecological values (threatened species, ecosystem function, ecosystems/habitats), cultural and provisioning values (scientific research, food and health, traditional fishing, spiritual, community prosperity), and economic values (ecotourism) (Table 1). The process of specifying goals for each value helped participants refine which aspects of the value were most important, for example, for threatened species the focus was predominantly on curik Bali. Many of the same threats impact multiple values across the park. Strategies to abate these threats were to manage endangered species, invasive species, illegal harvesting, waste, human impacts, religious practices and climate change adaptation; and establish and use a research and management fund and improve collaboration and planning approaches (Tables 2 and S1).

According to expert participants in this study, core values of the TNBB are likely to be significantly degraded in 15 years without effective management: participants estimated that the extent of goal achievement without additional investment was between 17 and 22% across all values at the end of the 15-year time frame (Figure 2). Achieving 100% of the extent of the goal for all values would involve implementing all strategies, at a cost of 5.53 billion rupiah (or US$386,000) each year (Table 2). However, implementing only the most beneficial management strategy for each value increased its likely goal achievement to between 71 and 85% (Figure 2). Due to time limitations we were unable to assess scenarios involving the implementation of other combinations of strategies.

According to our analysis, strategies varied in terms of the benefits provided to each of TNBB's core values (Figure 3). For example, to achieve the goals for spiritual values, the most beneficial strategies are to manage waste and religious practices. Managing invasive species generates the greatest benefits to threatened species and ecosystem function values. The analysis indicates interdependencies between many strategies and values—for example, the endangered species strategy involves a research element, and hence generates a high benefit for the scientific research value. No net negative impacts of strategies on values were suggested by participants—each of the strategies was predicted to have a positive impact on each of the values.

Strategies varied in terms of their estimated cost-effectiveness for collectively achieving goals across all values (Table 2; Figure 4). The benefit of strategies varied only slightly, with the least beneficial strategy (invasive species management) improving goal achievement for the parks core values by 43.8% and the most beneficial strategy, waste management, improving goal achievement by −50.5%, compared with the baseline scenario (Table 2). The strategy costs for TNBB varied more significantly between the cheapest (collaboration, 50 million rupiah annually) and the most expensive strategy (managing illegal harvesting, 1.55 billion rupiah annually). In US dollars, these strategies are expected to cost from just under US$4,000 and US$108,000 each year. Hence the cost-effectiveness of strategies was driven primarily by the strategy costs, with the cheaper strategies (collaboration, invasive species and research fund) being ranked as the most cost-effective (Table 2; Figure 4).

The cost-effectiveness rank of the top three strategies, that is, collaboration, invasive species and research fund, and the lowest two strategies, that is, endangered species and illegal resources, did not change when we tested the sensitivity of the rankings to benefit and cost estimates (Figure S1). The standard deviations of the cost-effectiveness scores of the remaining four strategies did overlap when benefits and costs were varied across ±100% of the original estimate, indicating that it would be possible to mis-rank strategies due to errors within this range. However, this occurs because the cost-effectiveness scores of these strategies are very similar initially, hence such a mis-rank would not have significant negative impacts on an investment decision.

4 | DISCUSSION

Our analysis indicates that goals for the core values of Bali's only national park are unlikely to be achieved within the next 15 years without increased investment in effective management. Experts participating in this study believed that each of the important values is impacted by multiple threats. Our analysis represents the best available knowledge from participants about the costs and benefits of conserving a range of key values in Bali's national park. Using a structured, participatory approach, we show that with an investment of approximately 5.5 billion rupiah (US$385,666) each year for 15 years, decision makers and managers of the park have the potential to achieve the goals for all values defined by participating stakeholders. This would require effective investment of resources to minimize threats through a combination of collaboration and planning, establishing and using a fund for research and management, adapting to climate change, on-ground monitoring and management for invasive species, managing illegal resource use, waste, human impacts, as well as improving the curik Bali captive breeding program.

Effective implementation of the strategies outlined in this analysis is expected to achieve high benefits for the nine important values of the park, ensuring that goals for each value are met over the next 15 years. To achieve this, the most cost-effective strategies are collaboration, followed by invasive species management and the establishment and use of a research and management fund (research fund). At just over US$20/ha combined, the cost of implementing all strategies identified in this analysis is within the range of global estimates of protected area management costs (McCarthy et al., 2012), although this varies spatially with many factors (Bruner et al., 2004). The information generated by the PTM process is designed to help guide higher level investment opportunities in abating threats to values that stakeholders (managers, decision makers, and investors) are concerned about. For example, an investor who is concerned with spiritual values may wish to focus on the strategies involving collaboration, waste management and religious practices management.

The strategies presented in this analysis complement existing National Park documentation and include some additional strategies identified by participants in this study. In particular, the need for adapting management strategies to climate change and investment in research programs to assist with current and future directions was identified but not currently explicitly described in the TNBB plans, including in the newly produced but yet to be ratified park plan (Taman Nasional Bali Barat, 2019). The information provided by our multiple value approach may be useful to help build upon existing planning work to design a management program with costed strategies to achieve a comprehensive set of outcomes across these values. However, further efforts would be required to incorporate the preferences of local communities and in defining the details of the actions and their schedule of their implementation.

The set of values and strategies used in this PTM assessment are described from the perspective of park directors, government staff and academic experts, and may be refined through engagement with local communities. The cost-effectiveness analysis we ran assumed all values are of equal importance, due to constraints on complexity, time and cultural considerations. In reality, the importance of each value is likely to vary among individual stakeholders and investors, depending on their preferences. The cost-effectiveness rank of strategies is reasonably robust to ±100% of benefit and cost values, hence weight changes and variable weightings within this range are unlikely to change recommendations. The similarities among the overall benefits of strategies across values may indicate co-dependencies between values and strategies that are important to consider for decision making. Our process did not highlight any conflicting strategies that were important for one value and had an overall negative impact on another value, however, trade-offs may occur at a finer resolution, making the implementation of strategies more challenging than recorded here. A PTM analysis could potentially be re-run with additional information and weights to explore these trade-offs.

The magnitude of the threats impacting upon important values in TNBB are likely to be similar in other protected areas across the region, and indeed the world (Oldekop et al., 2016; Schulze et al., 2018; Sodhi et al., 2004). Global biodiversity is declining at an alarming rate both within and outside of protected areas (Jones et al., 2018), due to anthropogenic threats like habitat loss and climate change (Maxwell, Fuller, Brooks, & Watson, 2016). While it is important to tell the story of biodiversity declines, protected areas hold many values which cannot easily or ethically be separated from biodiversity (Brockington & Wilkie, 2015; den Braber et al., 2018; Gruber, Mbatu, Johns, & Dixon, 2018; Oldekop et al., 2016). Our analysis complements previous work, by showing that many of the same processes that threaten biodiversity, such as invasive species and unsustainable waste practices (Leverington et al., 2010), are also threatening many other important values held in protected areas, such as spiritual values and sustainable ecotourism. This highlights the potential for implementing strategies that address threats across these sets of multiple values, and for including processes for monitoring the status of values aside from biodiversity.

Investors and protected area directors are required to make decisions about how to use limited funding to improve multiple values. However, in many cases they do not have a consolidated set of knowledge to estimate how much resources are needed to achieve a good outcome, or which management strategies will collectively create the greatest improvements to all values. In multifunctional areas, the consideration of a single value such as biodiversity is likely to miss opportunities to improve other values of essential importance to people (Austin et al., 2016; Brockington & Wilkie, 2015; Salafsky & Wollenberg, 2000). A single value approach may also be unable to achieve conservation outcomes, due to a lack of support and failure to address critical human needs (Dressler, de Koning, Montefrio, & Firn, 2016; Salafsky & Wollenberg, 2000). Therefore, while challenging, it is essential to synthesize the costs and benefits of management strategies across many different values in multi-value areas. The approach we present can help to meet this challenge by defining goals for each value, enabling management priorities to be assessed and compared across all values.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

All authors contributed to the collation of information and writing the manuscript. N.W.F.U., J.F. and J.C. led the analysis.

DATA ACCESSIBILITY STATEMENT

All data are included in the manuscript and appendices.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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