Efficient and equitable design of marine protected areas in Fiji through inclusion of stakeholder-specific objectives in conservation planning

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ABSTRACT

The efficacy of protected areas varies, partly because socioeconomic factors are not sufficiently considered in planning and management. Although integrating socioeconomic factors into systematic conservation planning is increasingly advocated, research is needed to progress from recognition of these factors to incorporating them effectively in spatial prioritization of protected areas. We evaluated 2 key aspects of incorporating socioeconomic factors into spatial prioritization: treatment of socioeconomic factors as costs or objectives and treatment of stakeholders as a single group or multiple groups. Using as a case study the design of a system of no-take marine protected areas (MPAs) in Kubulau, Fiji, we assessed how these aspects affected the configuration of no-take MPAs in terms of trade-offs between biodiversity objectives, fisheries objectives, and equity in catch losses among fisher stakeholder groups. The achievement of fisheries objectives and equity tended to trade-off concavely with increasing biodiversity objectives, indicating that it is possible to achieve low to mid-range biodiversity objectives with relatively small losses to fisheries and equity. Importantly, the extent of trade-offs depended on the method used to incorporate socioeconomic data and was least severe when objectives were set for each fisher stakeholder group explicitly. We found that using different methods to incorporate socioeconomic factors that require similar data and expertise can result in plans with very different impacts on local stakeholders.

INTRODUCTION

Protected areas are a principal tool employed globally to help mitigate the current biodiversity crisis and accelerating environmental degradation. Extensive establishment of protected areas is mandated under several international agreements (e.g., UNEP/CBD 2010), which are reflected in government policy at national (Douvere et al. 2007) and local scales (Lipsett-Moore et al. 2010). However, the efficacy of protected areas is variable (Green et al. 2011). A key factor suggested to contribute to this lack of success is insufficient consideration of socioeconomic factors in planning and management (Christie 2004; Ban et al. 2013). Consideration of socioeconomic factors is critical for achieving social benefits from conservation and engendering stakeholders' support for management.

The importance of including socioeconomic factors in systematic conservation planning (SCP; Margules & Pressey 2000), the foremost paradigm under which protected areas are designed (Kukkala and Moilanen 2013), is increasingly advocated (e.g., Polasky 2008; Ban et al. 2013). Consequently the original biocentric framework of SCP has been modified to better recognize socioeconomic factors to aid implementation of plans (Pressey & Bottrill 2009). However, this theoretical evolution has not been mirrored in practice, and socioeconomic factors continue to be considered as secondary to biological factors in SCP, particularly in spatial prioritization of protected areas using optimization algorithms. Thus, development and assessment of techniques for explicitly incorporating socioeconomic considerations into prioritization are still limited (Ban et al. 2013). Two key aspects of how socioeconomic data can be incorporated are whether socioeconomic factors are treated as costs or objectives, and whether stakeholders are treated as a single group or multiple groups.

Whether socioeconomic factors are treated as costs or objectives is important for determining how human factors are considered in spatial prioritization. In the field of SCP, socioeconomic factors were originally conceived as costs to conservation organisations focused solely on achieving biodiversity benefits. Thus the predominant approach has been to treat socioeconomic factors as costs (hereafter ‘costs approach’) in spatial prioritization tools (e.g. Marxan, C-Plan, Zonation), whereby a single index of cost is minimized whilst meeting biological objectives (Ban & Klein 2009). The assumption underpinning this approach is that minimizing total costs to stakeholders will generate the most socially acceptable plans (e.g. Fernandes et al. 2005). Given that only a single index of cost can be minimized, approaches to dealing with multiple costs include post-hoc analysis of solutions from prioritizations using different types of costs (e.g., Cameron et al. 2008), and combining costs to form a single index (e.g., Green et al. 2009). A disadvantage of post-hoc analyses is that no solutions consider all costs simultaneously. Single-index approaches amalgamate disparate socioeconomic data which often have different measurement units (e.g., dollars and area), thus adding subjectivity when determining the relative importance of different costs (Naidoo et al. 2006). An alternative, recent approach is to treat socioeconomic considerations as objectives in spatial prioritization (hereafter ‘objectives approach’), facilitating design of plans based simultaneously on biological objectives (e.g., Klein et al. 2010; Grantham et al. 2013). Multiple socioeconomic objectives can be set under this approach (e.g., for different stakeholder groups). An objectives approach is not underpinned by the assumption that minimizing total socioeconomic cost provides the most socially acceptable plans. Rather it can facilitate more nuanced treatment of socioeconomic data, allowing consideration of more complex and realistic determinants of social acceptability of plans. Further, this approach allows planning for multiple competing objectives simultaneously, potentially increasing the likelihood of achieving win-win outcomes. Importantly, engaging stakeholders through requesting them to identify their objectives for human uses, rather than which areas should remain available (i.e. positioning stakeholders as antagonists to conservation) is likely to result in more positive participatory decision making. However, existing studies do not provide a rigorous comparison of treating socioeconomic data as costs or objectives. The few studies that have used an objectives approach have focused on its utility to include multiple management zones (but see Weeks et al. 2010).

Regardless of whether socioeconomic data are analysed as costs or objectives, stakeholders can be considered as a single group or multiple groups. Typically, stakeholders are treated as a single group either by using a surrogate measure to represent impacts on all stakeholder groups collectively (e.g., population density; Ban et al. 2009), or by considering only one stakeholder group (e.g., commercial fishers; Richardson et al. 2006). However, the assumption underpinning these approaches – that there is no spatial variation between costs to different stakeholder groups – is rarely met; consequently such plans are likely to have inequitable impacts (Adams et al. 2010). A handful of studies have considered costs to multiple stakeholder groups under a costs approach (e.g., Klein et al. 2008; Adams et al. 2010) or an objectives approach (e.g., Klein et al. 2010; Weeks et al. 2010). Studies that used a costs approach aggregated costs to each stakeholder group in the prioritization analysis and assessed impacts to each group post hoc, whereas studies that used an objectives approach optimised costs to each stakeholder group explicitly in prioritization. However, treating stakeholders as a single group or multiple groups using both a costs and objectives approach has yet to be examined. Further, those studies that assessed amalgamating costs into a single index (i.e. Klein et al. 2008; Adams et al. 2010) did not compare alternative methods for integrating costs, instead comparing plans using cost data based on a single stakeholder group to those produced using the normalized sum of costs (Klein et al. 2008) or the sum of raw costs (Adams et al. 2010) across groups.

Research in incorporating socioeconomic factors into spatial prioritization is limited (Ban et al. 2013) partly because of SCP's focus on efficiency, motivated by the assumption that minimizing cost will generate the most socially acceptable plans. However, it is increasingly recognized that such simplification of the determinants of social acceptability is often inadequate (Adams et al. 2010), and other important determinants of social acceptability, such as equity, have begun to be incorporated in SCP (e.g., Klein et al. 2010). Although inequitable impacts of conservation can cause conflict between stakeholders and thus impede management (Gurney et al. 2014), there is little theory to guide incorporation of equity into SCP (Halpern et al. 2013). Halpern et al.'s (2013) simulation analysis of the relationship between efficiency, equity, and conservation provides the most rigorous assessment of equity in an SCP framework to date. However, research has yet to address how different techniques for incorporating socioeconomic data into prioritization tools that are commonly employed by managers affect prioritization outputs in terms of the relationship between equity, biodiversity conservation, and efficiency.

SCP is increasingly being employed globally to design marine protected areas (e.g. Álvarez-Romero et al. 2011), including in areas where people rely heavily on marine resources for subsistence and income, such as the Coral Triangle and South Pacific (Weeks et al. 2014). It is in these areas that the need for more nuanced incorporation of socioeconomic factors into spatial prioritisation is particularly acute. To this end, we evaluated alternative approaches for integrating socioeconomic factors into spatial prioritization of marine protected areas, using as a case study the design of a system of no-take marine protected areas (hereafter 'MPAs') in the Kubulau District, Fiji. Specifically we addressed two key research gaps regarding how socioeconomic factors are addressed in SCP, and thus asked 'How does treating socioeconomic considerations as costs or objectives, and treating fisher stakeholders as a single group or multiple groups affect the resulting MPAs in terms of spatial configuration, and trade-offs between biodiversity objectives, fisheries objectives, and equity in catch losses among fisher stakeholder groups?'

METHODS

Planning region

We used Kubulau District on the island of Vanua Levu in the Republic of Fiji (Fig. 1) as a case study because detailed spatial data on fisheries and habitats were available. Our planning region covered Kubulau's 260 km^2

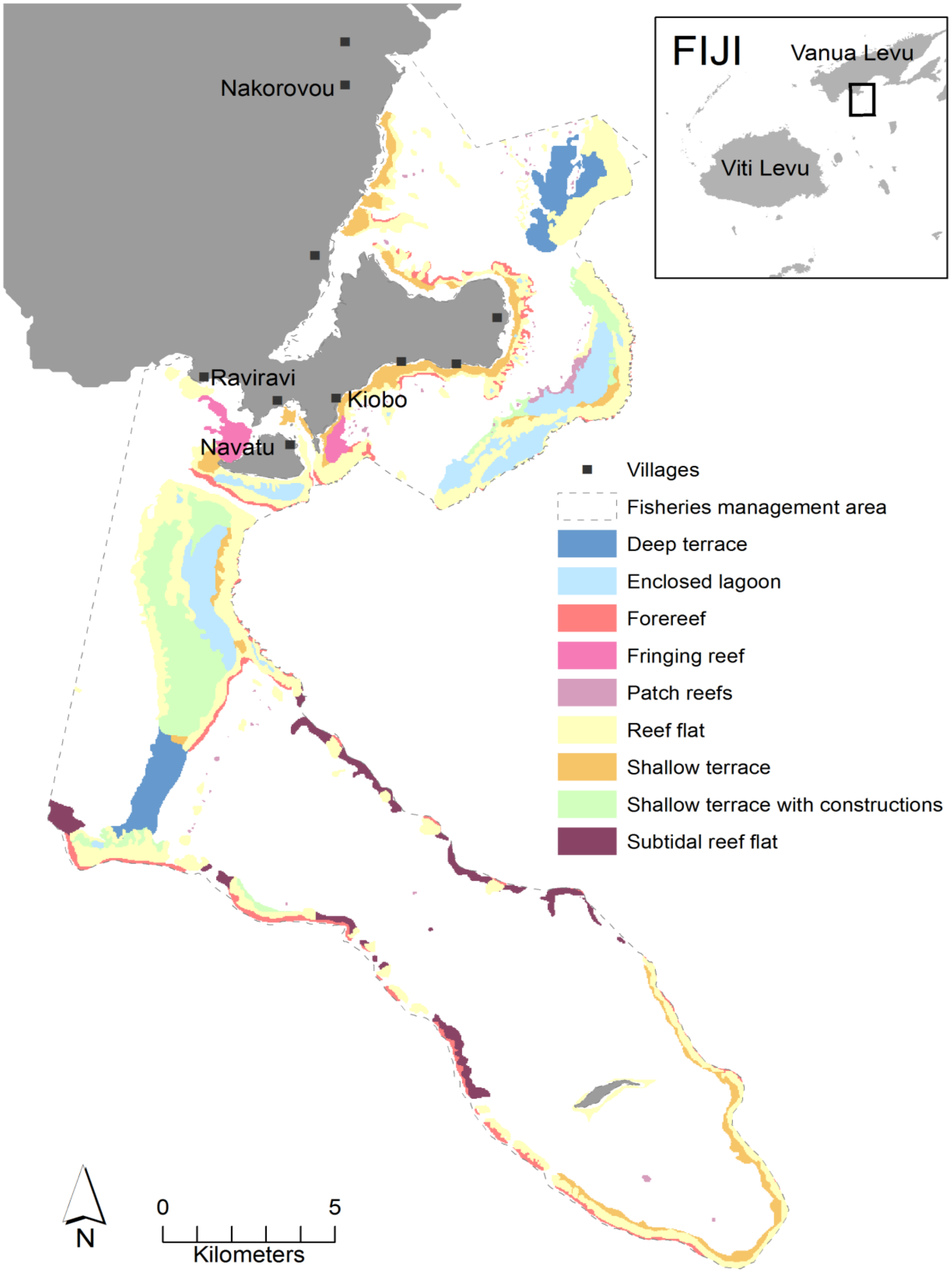

Fig. 1. Kubulau District, located in Vanua Levu, Fiji (inset). The traditional fisheries management area used as our planning region is demarcated (dashed line). Villages from which CPUE data were collected are labelled. Habitat geomorphic classes are from the Millennium Coral Reef Mapping Project (Andréfouët et al. 2006).

traditional fisheries management area (Jupiter & Egli 2011). The ten villages within Kubulau are highly dependent on fisheries for subsistence and income, and the main types of fishing gear (hereafter 'gear') employed are speargun, hand line, gill net, Hawaiian sling, and trolling (Cakacaka et al. 2010). In 2005, the district's villages established a system of marine reserves and adapted its design in 2012 (Weeks & Jupiter 2013). The existence of these reserves did not influence our analysis because our intention was not to modify current management in the region; rather we aimed to further understanding of the use of socioeconomic data in spatial prioritization tools in the design of protected areas more generally. We used uniform hexagonal planning units of 0.06 km^2; this size matched the resolution of our data, and was comparable to the smallest marine reserve in the district (Weeks & Jupiter 2013).

Data

A habitat map of Kubulau's marine area was derived from the Millennium Coral Reef Mapping Project (Andréfouët et al. 2006), which identified nine geomorphic habitat classes (Fig. 1). Species-specific data were not available across the study region. Spatially-explicit catch data, recorded from 180 fishing trips from fishers in four of the ten villages in Kubulau between May 2008 and June 2009, were used to calculate catch per unit effort (CPUE; in kilograms $person^{-1}$ $hour^{-1}$; Cakacaka et al. 2010). Fishers were asked to indicate the locations of their fishing areas on a map by drawing polygons or points, which were digitized (Adams et al. 2011). Locations identified as points were converted to polygons with an area equivalent to the mean of the area of hand-drawn polygons reported for the same combination of transport and gear. Where polygons overlapped for the same gear type, we calculated the mean CPUE value to create a single layer for each gear. CPUE data were not available for the remaining six villages, and too many assumptions would have been required for extrapolation. However, to explore the potential effect of incomplete CPUE data we assessed spatial similarity between the original CPUE data layer (that included the four villages) and four CPUE layers that excluded CPUE data from one village at a time. We calculated Pearson correlation coefficients, and found that CPUE layers for which data from one village were excluded were highly correlated to the original CPUE layer (Appendix S1).

Design of MPAs

We examined four scenarios for integrating socioeconomic considerations into spatial prioritization of MPAs. These were combinations of treating socioeconomic data as costs or objectives, and considering fisher stakeholders as a single group or multiple groups according to gear employed (Fig. 2). To allow comparisons between scenarios, all analyses had two zones: MPAs and an open zone where fishing with all gears was possible. The biodiversity objectives for all four scenarios were to ensure minimum levels of representation of the nine habitats in the MPA zone. We used equal-representation objectives so that we could vary the biodiversity objectives of each of the habitats equally in increments of 10% (between 10% and 90%), allowing us to examine trade-offs between biodiversity and fisheries objectives.

For the two scenarios where socioeconomic data were treated as costs (i.e. Cost_single, Cost_multiple; Fig. 2), we used Marxan (Ball et al. 2009) to identify potential configurations of MPAs that achieved biodiversity objectives. Marxan uses a simulated annealing algorithm to generate multiple solutions of MPAs that minimize the total cost of selected planning units subject to the constraint that all biodiversity objectives are met (Appendix S2).

For the two scenarios where socioeconomic data were treated as objectives (i.e. Objective_single, Objective_multiple; Fig.2), we used Marxan with Zones (Watts et al. 2009), to identify potential MPAs. Marxan with Zones solves essentially the same problem as Marxan, to achieve objectives for a minimum cost, but multiple management zones can be employed, and users can specify the costs and contributions of each zone to alternative objectives (Appendix S2). Although we specified only two zones (MPAs and open), Marxan with Zones allowed us to set objectives for CPUE in the open zone (i.e. fisheries objectives). Thus design of MPAs was based on achieving biodiversity and fisheries objectives simultaneously. For both Objectives scenarios, the cost associated with achieving the biodiversity objectives in the no-take zone was the total area of planning units, and no cost was associated with achieving the fisheries objectives.

The fisheries objective for Objective_single was to maintain a minimum of 90% of total CPUE in the open zone. Based on our experience, we considered this objective was realistic and potentially socially acceptable, and would ensure that fishers retained access to their most productive fishing grounds. However, defining this objective in real-world planning requires thorough socioeconomic analyses and consultation with fishers. The fisheries objective for Objective_multiple was to retain a minimum of 90% of each gear's CPUE in the open zone. The feature penalty factor (fpf) was first set to ensure that the 90% fisheries objectives were achieved (with the same fpf for each gear in Objective_multiple). If this objective was achievable without compromising the biodiversity objectives, it was

		TREATMENT OF SOCIOECONOMIC DATA	
		COSTS	OBJECTIVES
TREATMENT OF STAKEHOLDERS	SINGLE GROUP	Cost_single: CPUE of all six gears summed to obtain a single value of CPUE per planning unit. Summed CPUE data used in prioritization analyses as a cost to be minimized whilst achieving biodiversity objectives.	Objective_single: CPUE of all six gears summed to obtain a single value of CPUE per planning unit. Prioritization analyses set to maintain a minimum of 90% of summed CPUE outside of MPAs whilst simultaneously achieving biodiversity objectives.
	MULTIPLE GROUPS	Cost_multiple: The relative importance of each planning unit for each gear was calculated by normalising to the maximum CPUE value for that gear; these values were summed to obtain a single value of CPUE for each planning unit, effectively weighting gears equally. Summed CPUE were treated as a cost to be minimized whilst achieving biodiversity objectives.	Objective_multiple: CPUE of each of the six gears was treated separately. Prioritization analyses set to maintain a minimum of 90% of each gear's CPUE outside of MPAs whilst simultaneously achieving biodiversity objectives.

Fig. 2. The four scenarios investigated for integrating socioeconomic considerations into spatial prioritization.

increased as far as possible without affecting biodiversity objectives to ensure the maximum percentage of CPUE remained in the open zone. All gears had the same fisheries objective in the Objective_multiple scenario. If the 90% fisheries objective compromised the biodiversity objectives, the fpf for each biodiversity objective was increased to ensure all habitats were represented at the required level. Thus if both the biodiversity and fisheries objectives could not be met, the fisheries objectives suffered the shortfall.

Analysis of configurations of MPAs

We compared scenarios in terms of raw CPUE retained outside MPAs, either in terms of CPUE by gear type or total CPUE. To assess equity we used the inverse of the Gini coefficient of inequality (Gini 1921), calculated as (1-Gini), which ranges from 0 (maximal inequity) to 1 (perfect equity). We assessed equity in terms of the percentage of retained CPUE (CPUE outside MPAs) per gear. To compare the spatial configuration of solutions between scenarios we assessed the selection frequency of planning units under each objective level for each scenario using two methods: Spearman rank correlations and non-parametric multidimensional scaling (MDS). Spearman rank correlations were calculated between all combinations of biodiversity objectives and scenarios. To visualize the differences between scenarios we created an MDS ordination based on a Bray-Curtis similarity matrix of selection frequencies.

RESULTS

Although biodiversity objectives tended to trade-off nonlinearly (concavely) with the extent to which CPUE could be retained outside MPAs for all scenarios, the level of the biodiversity objective at which fisheries objectives were compromised differed between scenarios (Fig. 3). Concave trade-off curves indicate that low and moderate biodiversity objectives can be achieved with relatively small losses of CPUE, and that the loss of CPUE accelerates as biodiversity objectives increase. Trade-offs between biodiversity and fisheries objectives were most direct (linear) under Cost_single (Fig. 3a), and least so under Objective_multiple (Fig. 3d). Thus, the fisheries objective of maintaining a minimum of 90% of each gear's CPUE in the open zone was achieved under Objective_multiple for biodiversity objectives up to 60% (Fig. 3d). However, under all other scenarios, the maximum biodiversity objective at which CPUE for any of the gears fell below 90% in the open zone was 20%, 30% and 40% under Cost_single, Objective_single, and Cost_multiple, respectively.

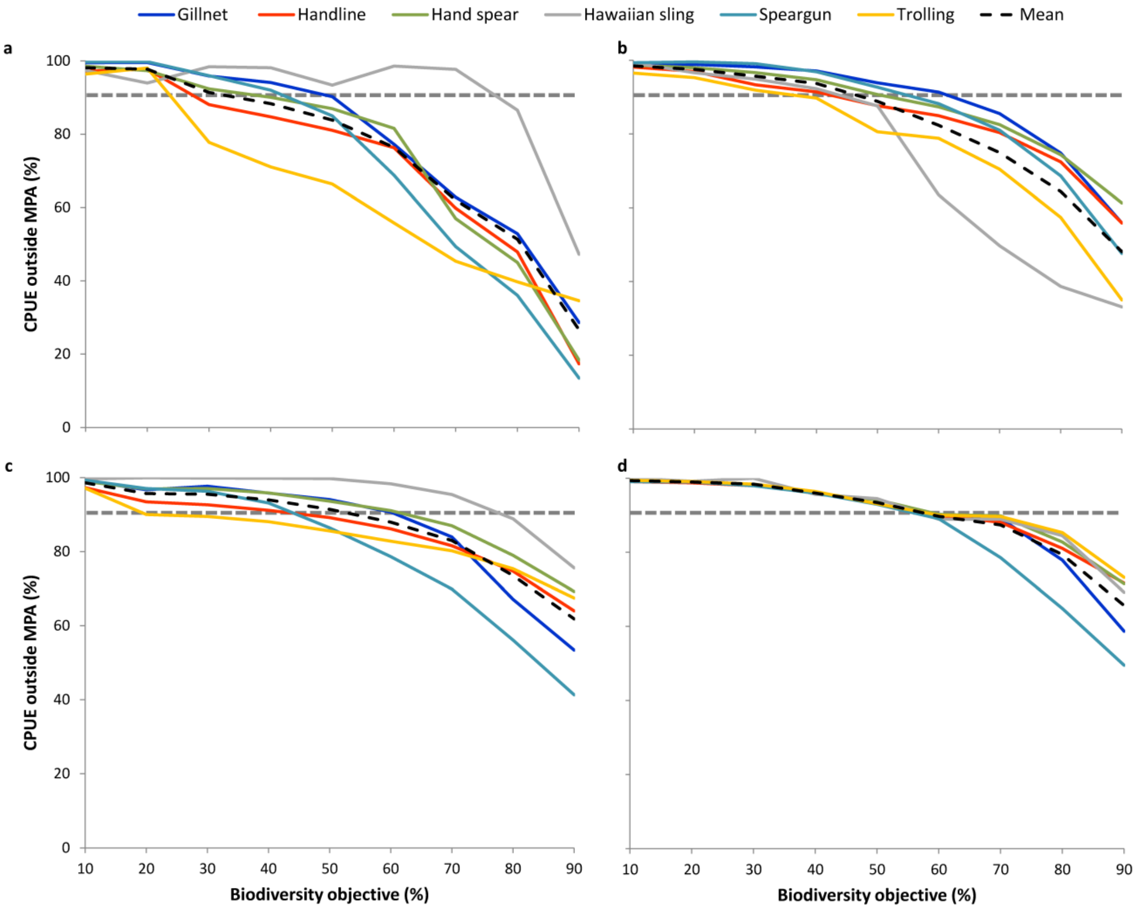

Fig. 3. Trade-offs between achieving biodiversity and fisheries objectives for each gear for the four scenarios: Cost_single (a); Objective_single (b); Cost_multiple (c); and Objective_multiple (d). The results presented are means of solutions from 100 replicate runs of each biodiversity objective under each scenario. The horizontal grey dotted line marks the fisheries objective of maintaining 90% of CPUE in the open zone.

Although trade-offs between biodiversity and fisheries objectives for all gears were roughly concave, the shape of the curves differed between gears within scenarios, particularly when stakeholders were treated as a single group. For example, under Cost_single, the percentage of CPUE retained in the open zone for Hawaiian sling did not drop below 90% until the biodiversity objective exceeded 70%, in contrast to trolling, for which the 90% objective was achieved only for biodiversity objectives less than 30% (Fig. 3a).

Equity among gear stakeholder groups in terms of retained CPUE also tended to trade-off concavely with biodiversity objectives in all scenarios (Fig. 4). The impact of MPAs on fisheries was most equitable under the Objective_multiple scenario, in which fisheries objectives were set explicitly for each gear, followed by Cost_multiple. The impact was least equitable under Cost_single. Importantly, increases in equity under scenarios in which stakeholders were considered as multiple groups were not accompanied by decreases in relative efficiency, in terms of area or CPUE retained outside MPAs (Fig. 5).

Under all scenarios, as expected, the area and total CPUE retained outside MPAs decreased as biodiversity objectives increased. Retained area traded-off approximately linearly with biodiversity under all scenarios (Fig. 5a).

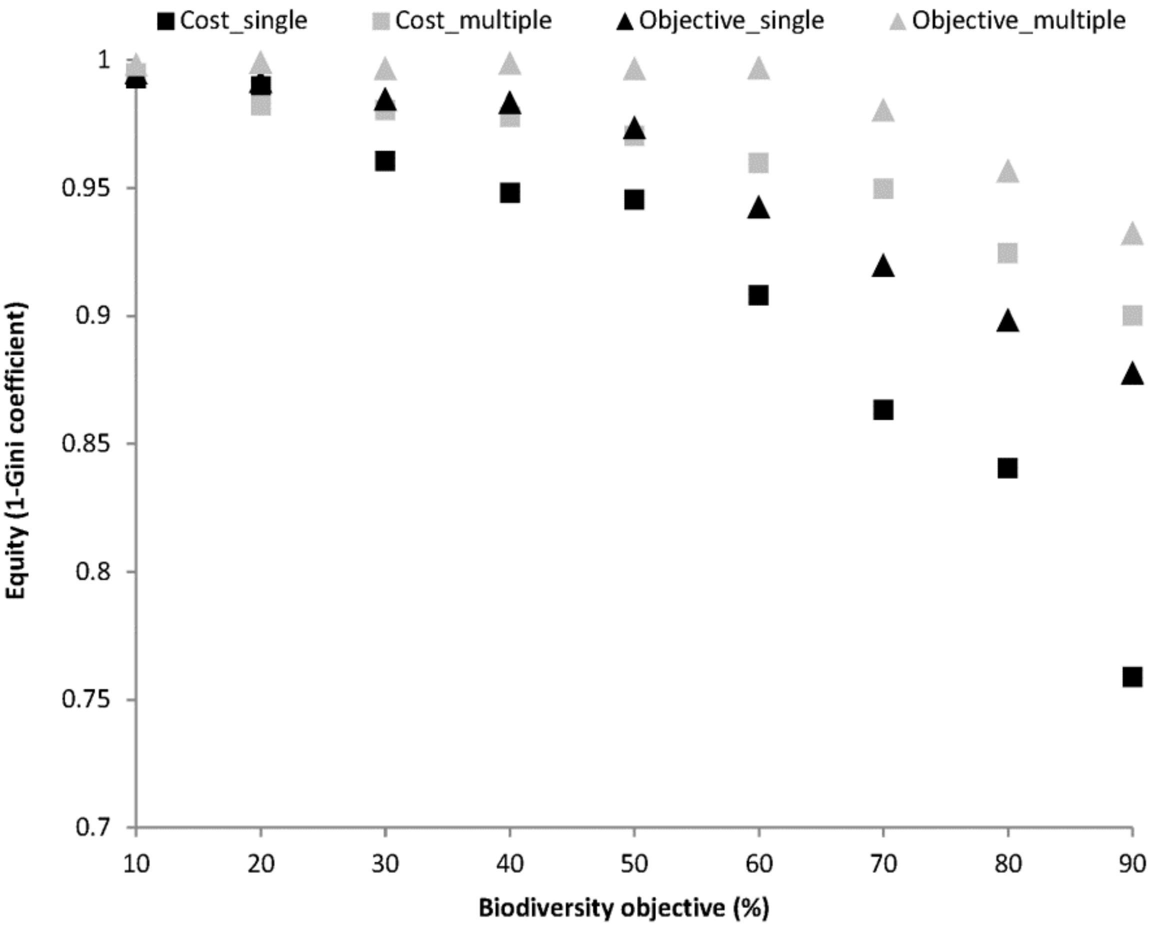

Fig. 4. Trade-offs between achieving biodiversity objectives and equity of retained CPUE (i.e. CPUE outside MPAs) between gears for the four scenarios. Equity is measured using the inverse of the Gini coefficient, which ranges from a value of 0 (maximum inequality) to 1(perfect equality). The results presented are means of solutions from 100 replicate runs of each biodiversity objective under each scenario.

In contrast, trade-off curves between retained total CPUE and biodiversity were concave, and differed between the costs and objectives approaches (Fig. 5b). When socioeconomic data were treated as costs, considering stakeholders as multiple groups by gear type resulted in more efficient MPAs, but when data were treated as objectives the difference was negligible. Further, MPAs were more efficient when data were treated as objectives rather than costs, particularly at biodiversity objectives greater than 50%; above this objective level, retained total CPUE under Cost_single was 20-67% less than under Objective_single and Objective multiple, and 12-64% less than under Cost_multiple.

There was clear similarity in spatial configurations of MPAs, represented by selection frequencies, between the two objectives scenarios and between the two costs scenarios (Appendix S3, Appendix S4). However, as biodiversity objectives increased, MPAs under the Cost_single scenario diverged from those under the Cost_multiple scenario, and were more similar to those in the objectives scenarios.

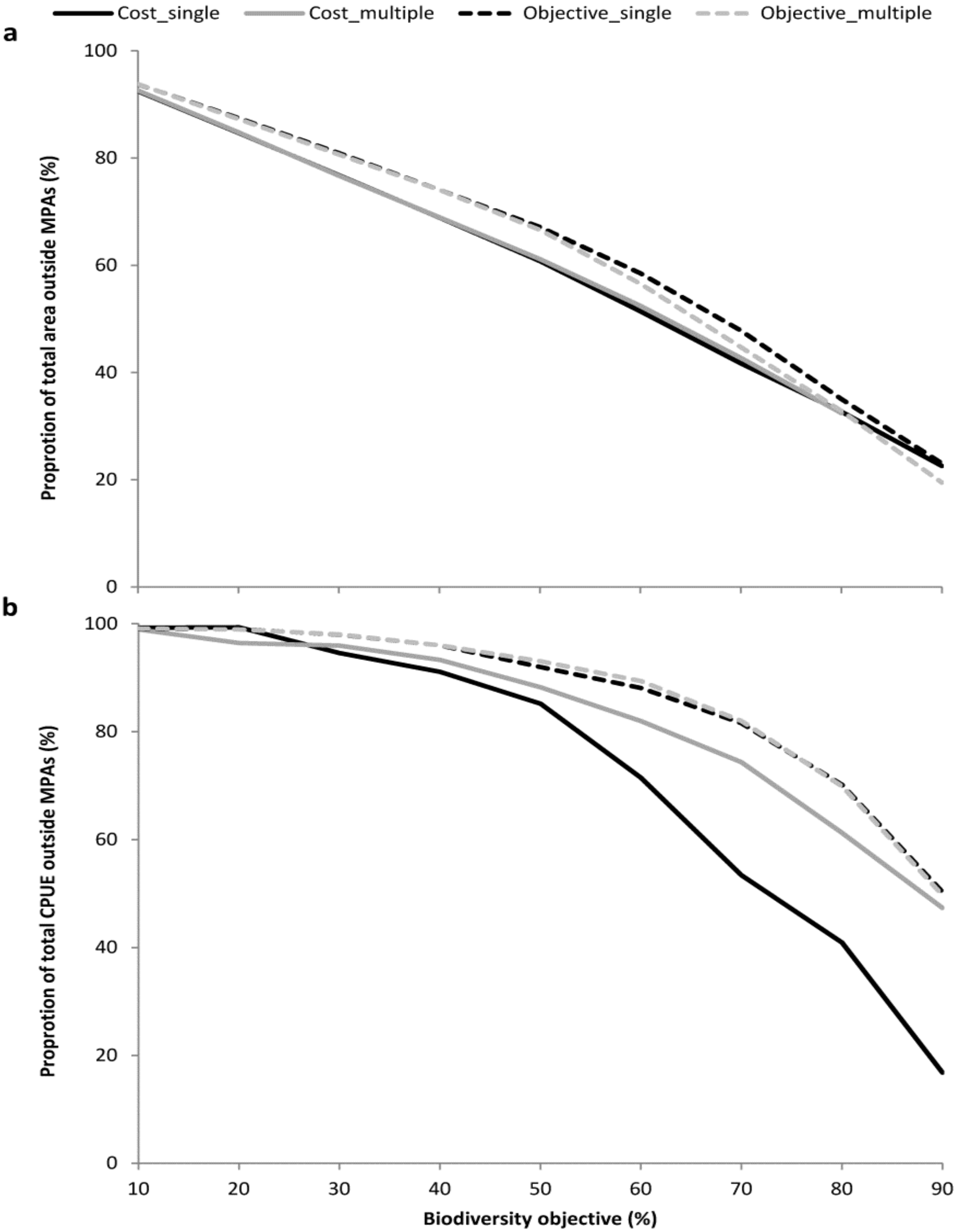

Fig. 5. Proportion of total area of planning region (a) and CPUE for all gears (b) retained outside MPAs for different biodiversity objectives for each of the four scenarios. The results presented are means of solutions from 100 replicate runs of each scenario.

DISCUSSION

Given that an important factor contributing to the lack of success of protected areas is insufficient consideration of socioeconomic factors in planning and management (Ban et al. 2013), there is a pressing need to advance techniques for integrating these into SCP. Our analysis of key methods for integrating socioeconomic factors into prioritization found major differences in MPAs produced by alternative methods in terms of trade-offs between biodiversity objectives, fisheries objectives, and social equity. For our case-study in Fiji, setting stakeholder-specific objectives produced MPAs with the least severe trade-off between biodiversity and fisheries objectives, and that were most equitable in terms of lost catch potential between gears.

Trade-offs between fisheries and biodiversity objectives

Biodiversity objectives tended to trade-off concavely with retention of CPUE outside MPAs. Concave trade-off curves between biodiversity and socioeconomic objectives have been found in studies that have used a costs approach to spatial prioritization (Hamel et al. 2013), and those that have set stakeholder-specific objectives in a framework of multiple-zone management (e.g., Klein et al. 2010; Grantham et al. 2013). Concave trade-off curves indicate that it is possible to achieve low to mid-range biodiversity objectives with relatively small losses of CPUE.

Concave trade-off curves occur when: (1) biodiversity and socioeconomic features are poorly correlated (Naidoo et al. 2006); (2) socioeconomic variables are skewed toward low values; or (3) higher socioeconomic values are spatially concentrated. In these cases, low biodiversity objectives can be achieved by selecting planning units with little or no socioeconomic value but, as biodiversity objectives increase, areas of high socioeconomic value must be selected. All three data characteristics applied to our case study. Contributing factors were the concentration of CPUE in inshore waters (Adams et al. 2011) and the presence of MPAs in 45% of Kubulau's traditional fisheries management area which tended to displace fishing to unprotected areas. Another contributing factor is underestimation of CPUE because data were collected from only four of the ten villages in Kubulau. Obtaining data from the remaining six villages in the region would be critically important if the approach outlined in this paper was undertaken to inform marine spatial planning in Kubulau. Plans produced using data from a subset of the ten villages, such as ours, could result in inequitable loss of fishing grounds, particularly for those villages for which no CPUE data is available.

Trade-offs between biodiversity and fisheries objectives were most severe under the common approach of considering socioeconomic data as costs and stakeholders a single group. Thus it is important to consider alternative methods to integrating socioeconomic data into spatial prioritisation to avoid unnecessarily hard trade-offs between competing objectives, thereby reducing conflicts that often arise from protected areas impinging on human uses (Redpath et al. 2013). Our results suggest that treating socioeconomic data as objectives rather than costs, and stakeholders as multiple groups rather than a single group, could ease such trade-offs. In cases where information is available only for one socioeconomic value, an objectives rather than a costs approach could facilitate win-win outcomes.

Equity of MPAs

Treating all gear users as a single group produced MPAs with inequitable loss of CPUE because gears that had CPUE values of the highest magnitude dominated the prioritization, displacing MPAs to areas important to other gears. Similarly, Adams et al. (2010) found that summing the economic value of multiple land uses to form a single cost layer resulted in protected areas that least impacted uses with highest economic value, displacing opportunity costs toward stakeholders involved in lower-value uses. Conversely, treating stakeholders as multiple groups, either by summing normalized CPUE values across gears or by setting gear-specific objectives, resulted in more equitable MPAs. Normalizing CPUE values ensured that CPUE per gear type was more equally weighted in the prioritization than under the scenarios when stakeholders were considered a single group. However, given the variation in raw CPUE values between gears, normalizing did not result in exact equal weighting of gears. Gears that had a smaller range in raw CPUE values (e.g., Hawaiian sling) lost a lower proportion of CPUE than other gears because the magnitude of most of their normalized values was higher. Thus setting gear-specific objectives produced the most equitable solution. This finding is consistent with previous studies (i.e. Klein et al. 2010; Weeks et al. 2010), who found that setting stakeholders-specific objectives led to more equitable MPAs than under the typical approach of treating stakeholders as a single group.

While it has been assumed that increased equity will result in less efficient conservation plans (Pascual et al. 2010), we found that increased equity in retained CPUE between gears did not come at a cost to efficiency in terms of total area of MPAs or CPUE available for extractive use. For a given biodiversity objective, MPAs produced using gear-specific objectives were most equitable and, compared to other scenarios, tended to be equally efficient in terms of area and more efficient in terms of retained CPUE. Previous results have been inconsistent in this regard. Klein et al. (2010) found that MPAs produced under an objectives approach were both more equitable and efficient than those produced under a costs approach, while Weeks et al. (2010) found that more equitable MPAs under an objectives approach were less efficient. Differences in findings are likely due to factors such as spatial variability and correlation between different socioeconomic objectives, resolution of data and/or whether multiple management zones are employed. Given the range of factors that can affect the relationship between equity, efficiency and biodiversity, a scenario-analysis approach can be useful in determining how the relationship manifests in a given planning context, rather than assuming that incorporating equity will necessarily compromise achievement of other planning objectives (Pascual et al. 2010). Such assumptions are likely to have been barriers to incorporating equity in past planning.

Practical applications

Recognizing the diversity of stakeholders and setting objectives for human uses in parallel with those for biodiversity is likely to be well received by stakeholders. Given that most land- and sea-scapes are subject to multiple human uses (Sanderson et al. 2002), an objectives approach to prioritization in which multiple competing objectives can be planned for simultaneously increases the relevance of plans to a wider variety of people. Coupled with trade-off analysis, an objectives approach provides transparency through making the losses and gains to different uses and planning objectives explicit. Although trade-off analyses are uncommon in SCP (Ban & Klein 2009), and in conservation in general (White et al. 2012), such an approach is useful for identifying multiple potential locations for protected areas. It thus provides the flexibility required to produce outcomes likely to be acceptable to the stakeholders involved. Importantly, as we have shown, the expertise and data required to undertake an objectives approach are not substantially different from the typical costs approach.

Increasing emphasis on generating socioeconomic benefits from conservation, and on the critical importance of gaining stakeholder support for achieving conservation (Gurney et al. 2014), has recently catalyzed more nuanced incorporation of socioeconomic considerations in SCP. It is clear that the prevailing preoccupation with efficiency (Kukkala and Moilanen 2013) is insufficient in many contexts. Stakeholders' preferences for management will be determined by their socioeconomic, biophysical, and cultural context (Ban et al. 2013). For our comparative evaluation of approaches to prioritization, we assumed that equity in retained CPUE (as a proxy for equity in impact) between gears was a desirable management outcome for local fishers. However, given that most Kubulau households use multiple gears and share catch within and among households (S. Jupiter, pers. comm.), maximizing the total village catch as a whole might take priority over equitable impact. Alternatively, if fish are sold rather than consumed, equity in retained economic value could be more appropriate. Given that plans produced using different metrics of equity could vary (Halpern et al 2013), it is important to identify the metric of equity that is most relevant to stakeholders to ensure plans are most likely to reflect their preferences. Further, we did not consider that equity in retained CPUE does not necessarily translate to equity in impact. The impact to fishers of losing fishing ground is mediated by factors that dictate their response, such as spatial and occupational mobility (Cinner et al. 2009). For example, fishers using motorized boats have the most spatial mobility and thus are least vulnerable to implementation of MPAs. Therefore, achieving equal impact amongst gears may require different objectives for each fisher gear group, reflecting the constraints of their response to lost fishing grounds.

Further, while we only considered equity in terms of lost CPUE by gear type, achieving socially equitable solutions requires consideration of other factors that demarcate fishers into different stakeholder groups. For example, real-world planning in this context should consider which villages fishers reside in to avoid inequitable impacts among villages. Indeed a case study of marine planning in the Philippines found that not considering local tenure in prioritisation produced plans that were infeasible because some villages' entire inshore fishing grounds were designated as no-take areas (Weeks et al. 2010). Given the complexity of deciphering the potential socioeconomic impacts of management actions, it is critical to engage with stakeholders throughout the planning process, including identifying stakeholders' objectives and potential responses to management actions. If stakeholders' preferences are misrepresented, subsequent protected areas might not win support and might not be effective. Further, given detailed socioeconomic data tend to be limited and their collection requires large investments of time and money, involving stakeholders in the design of data-collection strategies and instruments may allow for more targeted data collection.

CONCLUSION

Our analysis of key methods for integrating socioeconomic factors into prioritization found major differences in MPAs produced by alternative methods in terms of trade-offs between biodiversity objectives, fisheries objectives, and social equity. While the type and extent of trade-offs between competing objectives will vary with context, our results suggests that treating socioeconomic data as objectives and stakeholders as multiple groups could minimise impacts to local stakeholders, at least in regions with similar data characteristics to our case study. In our case study, employing stakeholder-specific objectives, an approach that requires similar data and expertise to typical methods of treating socioeconomic data as costs and stakeholders as a single group, facilitated more nuanced approaches to integrating socioeconomic considerations into spatial prioritization. Although plans produced through spatial prioritization will always need modifying prior to implementation, the more detailed the incorporation of socioeconomic factors, the less likely plans will need to be significantly altered and biodiversity objectives potentially compromised (Weeks et al. 2010). Further, better incorporation of socioeconomic factors will increase the likelihood of achieving social benefits from protected areas and gaining stakeholders' support, on which conservation success is predicated. Given the planned expansion of protected areas globally, better approaches to incorporating human dimensions into spatial prioritization are of critical importance.

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SUPPORTING INFORMATION

Further details are available online for: (1) Pearson correlation coefficients between CPUE data layers that included data from four villages and data layers that excluded data from one of the four villages at a time; (2) the spatial prioritization analysis undertaken using Marxan and Marxan with Zones (Appendix S2); (3) the results from the MDS ordination (Appendix S3); and (4) the results of the spearman rank correlations (Appendix S4). The authors are solely responsible for the content and functionality of these materials. Queries (other than the absence of the material) should be directed to the corresponding author.

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