Conservation Letters
A journal of the Society for Conservation Biology
Open Access

LETTER

The Importance of Fishing Grounds as Perceived by Local Communities Can be Undervalued by Measures of Socioeconomic Cost Used in Conservation Planning

Mélanie A. Hamel[1,3], Robert L. Pressey[1], Louisa S. Evans[2], & Serge Andréfouët[3]

[1] Australian Research Council Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, Queensland 4811, Australia
[2] Geography, College of Life and Environmental Sciences, University of Exeter, Exeter, EX4 4RJ, United Kingdom
[3] Unité Mixte de Recherche 250 ENTROPIE (Institut de Recherche pour le Développement, Université de La Réunion, Centre National Recherche Scientifique) 101 Promenade Roger Laroque, Anse Vata, BP A5 - 98848 Nouméa, New Caledonia

Keywords
Coral Triangle; small-scale fisheries; socioeconomic costs; systematic conservation planning; Madang Lagoon; opportunity costs; values.

Correspondence Mélanie A. Hamel, Australian Research Council Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, Queensland 4811, Australia. Tel: +61(0) 7478 14000; fax: +61(0) 7472 55043.
E-mail: melanie.hamel@my.jcu.edu.au

Received
16 September 2016
Accepted
3 February 2017

doi: 10.1111/conl.12352

Abstract

Marine reserve placement must account for the importance of places for resource use to minimize negative socioeconomic impacts and improve compliance. It is often assumed that placing marine reserves in locations that minimize lost fishing opportunities will reduce impacts on coastal communities, but the influence of the fishing data used on this outcome remains poorly understood. In the Madang Lagoon (Papua New Guinea), we compared three types of proxies for conservation costs to local fishing communities. We developed two types of proxies of opportunity costs commonly used in marine conservation planning: current fishing activity with fisher surveys ($n = 68$) and proximity from shore. We also developed proxies based on areas of importance for fishing as perceived by surveyed households ($n = 52$). Although all proxies led to different configurations of potential marine reserves, the three types of cost data reflect different aspects of importance for fishing and should be used as complementary measures.

Introduction

Applications of systematic conservation planning to marine ecosystems are now widespread (e.g., Leslie 2005; Álvarez-Romero *et al.* 2013). Increasingly, these approaches recognize that successful conservation and management of natural resources rely on a good understanding of the social-ecological system of interest (e.g., Lundquist & Granek 2005; Klein *et al.* 2008; Ban *et al.* 2013; Kittinger *et al.* 2014; Le Cornu *et al.* 2014). Socioeconomic assessments at the beginning of a project can help to engage stakeholders, understand opportunities for and constraints on implementation, and reduce the risk that conservation plans will not be accepted by local communities.

Systematic conservation planning attempts to minimize negative impacts of conservation actions on stakeholders by considering social and economic "costs" in the design of protected areas (Naidoo *et al.* 2006; Ban & Klein 2009). In marine social-ecological systems, the most common method to estimate costs has been through opportunity costs to fishers, often estimated with empirical catch data (Deas *et al.* 2014), models of catch (e.g., amount of resource caught, monetary value of catch), effort (e.g., number of boats or fishers, distance to ports, population density), or catch per unit of effort (e.g., Ban & Klein 2009; Weeks *et al.* 2010; Adams *et al.* 2011).

More broadly, ecosystems provide a diversity of tangible and intangible services (and disservices) to people (Millennium Ecosystem Assessment 2003). These services benefit different people in different ways (Daw *et al.* 2011; Fisher *et al.* 2014), leading to diverse perceptions of importance (or subjective "value") of services and associated places (Lele *et al.* 2013). This article focuses on fisheries as a provisioning service. Here, we first define the importance of a fishing place using fishing catch, effort, and other common proxies of fishing opportunities such as proximity to shore. Then, we quantify and compare this depiction of fishing importance (hereafter current "fishing activity") with the importance of fishing areas as perceived by households (hereafter "perceived fishing value"). We assess whether these two depictions of fishing importance and the different cost layers derived from both data sets provide convergent conservation solutions. Specifically, we aim to answer the following questions:

(1) Is fishing importance based on catch data and proximity from shore (commonly used proxies in conservation planning) congruent with the perceived value of fishing grounds?
(2) How do marine reserves designed to minimize impacts on fishing activity affect the fishing community based on the perceived fishing value of areas, and vice versa?
(3) If fishing activity and perceived fishing value are poorly aligned spatially, how should they be used in conservation planning?

In answering these questions, our results have implications for marine conservation planning in parts of the world where local communities perceive fisheries resources, and lost opportunities to fishing, in ways that are more diverse than just the amount of catch.

Methods

Study area

Madang Lagoon (Figure 1) is the largest and most ecologically diverse lagoon on the north coast of Papua New Guinea, in the Coral Triangle region (Jebb & Lowry 1995; Jenkins 2002a; Miller & Sweatman 2004). Similar to most developing coral-reef countries (Bell *et al.* 2009; Burke *et al.* 2011), coastal communities of the Madang Lagoon rely on coral-reef resources for their day-to-day life (Marnane *et al.* 2002; Kinch *et al.* 2005; Jenkins 2011). However, in those regions, unregulated fishing practices coupled with rapid population growth make small-scale fisheries unsustainable and threaten whole social-ecological systems (Cinner & McClanahan 2006). Building approaches that achieve objectives for ecosystem conservation while maintaining livelihoods is therefore critical. We focused on Riwo (*Ziwo*, in local Bel language), the largest coastal community in the lagoon, because of its central location (Figure 1), large population with over 350 households (National Statistical Office of Papua New Guinea 2002), and history of involvement in conservation and resource management (Jenkins 2002a, b).

Mapping fishing activity (fisher surveys)

To map fishing activity, we conducted fisher surveys (Appendix S1). We interviewed one fisher per boat returning to the main landing sites (Figure 1). All gears, transport methods, and targeted resources were included. Demographic information (e.g., age, gender), catch weight, trip duration, and number of fishers contributing to the catch were recorded. Respondents were asked to draw the area where their fishing took place on a high-resolution satellite image (1:15,000). Surveys lasted 5 minutes on average, and produced one map for each fishing trip. Information was recorded over 20 days from 68 fishing trips, covering an estimated 17% of Riwo fishers (Marnane *et al.* 2002; National Statistical Office of Papua New Guinea 2002, 2009).

Mapping perceived fishing value (household surveys)

To map the value of places to Riwo people for fishing, we conducted household surveys (Appendix S1). The heads of households were surveyed through opportunistic sampling in all main villages, hamlets, and islands making up the Riwo community (Figure 1). Ninety percent of participants fished as a main cash activity. Sample compositions in terms of genders, gears, and transport were comparable for the fisher and household surveys (Appendix S1). The survey included participatory mapping of important fishing places and other questions not detailed here. First, participants were asked to identify and draw the fishing grounds where household members usually collected reef fish, octopus, and/or shellfish on a high-resolution satellite image (1:15,000). Participants were then asked to distribute a set of tokens (shells or stones) among these fishing grounds to show their relative importance to the household. More tokens on a fishing ground indicated higher importance. Since the number of fishing grounds drawn per household was highly variable (from 1 to 18), smaller sets of tokens were offered when fewer places were identified (details in Appendix S2). Surveys lasted 1hour on average, with one map produced for each household. Over 20 days, 52 households were surveyed, corresponding to an estimated 14% of Riwo households.

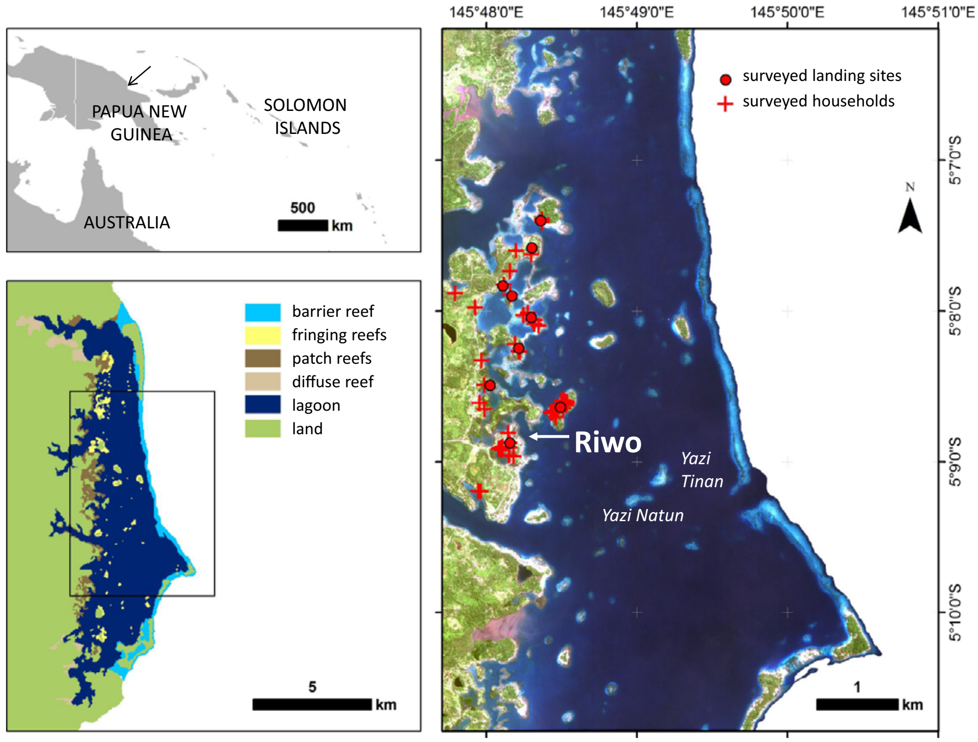

Figure 1 The Madang Lagoon, Papua New Guinea, extending 16 km north to south and 4 km west to east, with a surface of 40 km^2 and a maximum depth of 54 m.
Top left panel: location within Papua New Guinea. The black arrow shows the location of the Madang Lagoon. Bottom left panel: geomorphological setting. The black rectangle covers the extent of the study area. Right panel: Study area, all within the Riwo village customary tenure. Yazi Tinan and Yazi Natun are the two largest patch reefs in the area. Surveyed landing sites (fisher survey, on current fishing activity) are shown with red dots, and surveyed households (household survey, on perceived importance for fishing) are shown with red crosses. Worldview image © 2010 DigitalGlobe, Inc.

Planning region and "places" (planning units)

The planning region was defined as the extent of marine habitats used by the Riwo community. We deliberately did not use a map of the customary tenure of Riwo as the planning region because of the disputed and fuzzy nature of boundaries reflected during focus groups held at the start of the broader project. To delimit this region, we created a grid of square planning units, 300 m by 300 m or 9 ha (hereafter "places," Appendix S2) over a map of coral-reef and lagoon habitats (details below). The 312 places mapped for fishing activity and perceived fishing value constituted the final planning region, corresponding roughly to the customary tenure of Riwo.

Habitats as proxies of biodiversity

We created a habitat map of the Madang Lagoon from a high spatial resolution (2 m) Worldview satellite image. The map was created following the "user approach" described in Andréfouët (2008). Steps included a priori manual delineation of habitats, ground truth following the Medium Scale Approach (Clua *et al.* 2004), contextual editing, classification, and merging of habitat polygons. The resulting hierarchical habitat typology for the Madang Lagoon describes 28 geomorphic types (Appendix S3). For spatial prioritization, we recorded the type and extent of all habitats contained in each of the 312 places. We used these fine-resolution geomorphologic habitats as the conservation features to protect because they were defined consistently across the lagoon.

Importance of areas for fishing as a proxy for conservation cost

We assumed that restricting fishing activities in places deemed more important for fishing will incur a higher direct cost of protected areas to fishers. We derived various proxy measures of the fishing importance of places (details in Appendix S2), combining data on all gears, transport methods, and targeted resources. Proxies based on fishing activity in each place were:

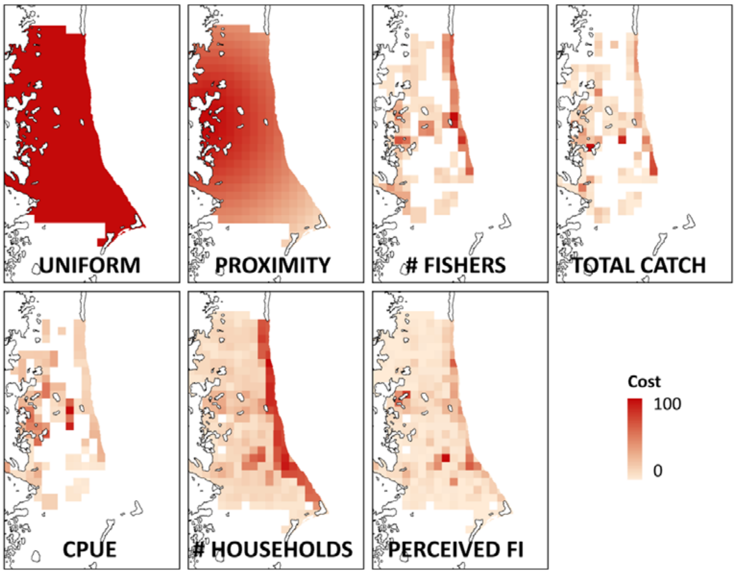

Figure 2 Proxies for the conservation cost of reserving each place, derived from measures of the importance of each place for fishing (normalized as percentages of maximum).
The top row shows uniform importance (UNIFORM), proximity to landing sites (PROXIMITY), and two proxies derived from data on current fishing activity: # FISHERS (the number of fishers visiting each place) and TOTAL CATCH (the total weight of catch). The bottom row shows the averaged CPUE (catch per unit effort, derived from data on current fishing activity) and two cost proxies derived from perceived value: # HOUSEHOLDS (the number of households valuing each place) and PERCEIVED FI (the value of each place for fishing measured with the summed number of tokens).

number of fishers (# FISHERS); total catch in kilograms (TOTAL CATCH); and the average catch per unit effort in kilograms/person/hour (CPUE). Proxies derived from the perceived fishing importance of each place were: number of households valuing the place for fishing (# HOUSEHOLDS); and the total number of tokens allocated (PERCEIVED FI). We also derived other proxies used in previous studies for comparison. For each place, PROXIMITY was the inverse distance to landing sites as a rough proxy for opportunity costs (e.g., Green *et al.* 2009; Weeks *et al.* 2010; Giakoumi *et al.* 2013; Mazor *et al.* 2014). UNIFORM was a reference layer in which all places were given the same cost. All spatial layers for the seven proxies were normalized as percentage of maximum (Figure 2) to allow for comparisons.

Spatial prioritization

We used Marxan (Ball *et al.* 2009), a conservation planning tool, to select cost-effective reserve systems that achieved conservation objectives while minimizing conservation costs. Marxan feeds a simulated annealing algorithm with spatial data on the features to protect (habitats as a proxy for marine biodiversity), and on the cost of protecting each area (our five fishing proxies and our two fishery-independent proxies).

We defined one optimization scenario for each cost layer to compare the configuration of candidate reserves. All scenarios aimed to meet the same conservation objective: 20% of the total extent of each habitat, following a precautionary interpretation (as in Hamel *et al.*, 2013) of Aichi target #11 (UNEP/CBD/COP/10/X/2 2010). Marxan's species penalty factor was adjusted to ensure habitat objectives were always met. Default values were used for all other parameters. We ran each scenario 1,000 times, recording the selection frequency of each place and the best (lowest-cost) solution. For each of the best solutions, we recorded: the number of places selected, their total extent, the total cost for the proxy being minimized, and the total costs incurred incidentally for all other proxies. For comparison with the costs of each scenario, we randomly selected 1,000 times the same number of places identified in the best solution.

Results

Comparison of proxies before reserve design

Information on the cost of places based on fishing activity and perceived fishing value can be found in Appendix S4.

Proxies of fishing importance based on fishing activity and perceived fishing value had distinct spatial patterns. Areas of fishing activity were smaller and patchier than areas of perceived fishing value (Appendix S3), reflected in more strongly right-skewed distributions and higher proportions of zero cost (Figure 3).

Costs based on proximity to landing sites differed spatially from those based on fishing activity and perceived fishing value (Figures 2 and 3). The barrier reef, fringing reefs, and the main islands were valued and fished by more people than other parts of the study area. Noteworthy was the high perceived fishing value of two large patch reefs, *Yazi Tinan* and *Yazi Natun* (Figure 1) that were not prominent for fishing activity or other proxies.

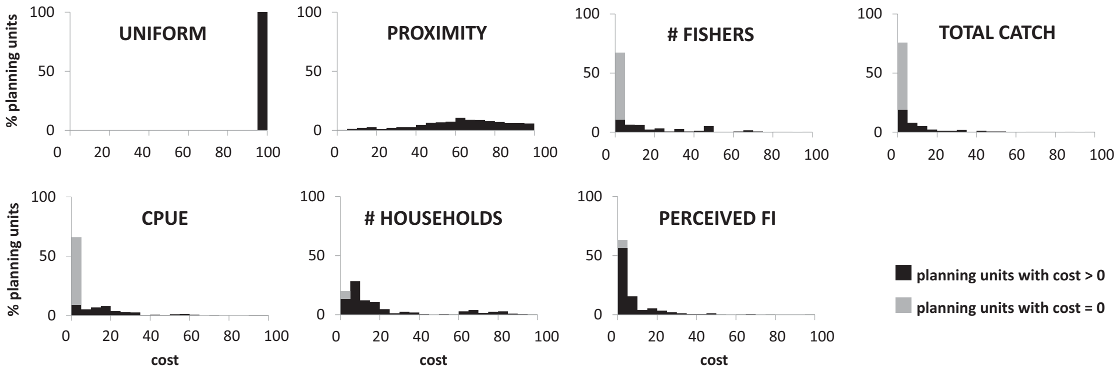

Figure 3 Distribution of cost values among places (planning units) for each type of cost. Abbreviations for cost variables are the same as in Figure 2. The grey parts of bars for catch and value indicate the percentages of places unfished or unvalued and having zero cost.

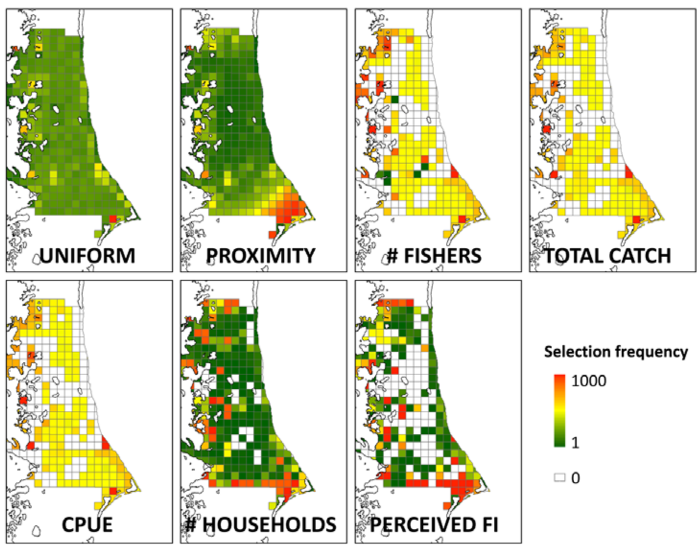

Figure 4 Selection frequencies, across 1,000 runs, of places (planning units) for all scenarios. Scenario names are indicated in capital letters, corresponding to respective cost layers in Figure 2. Places left white were never selected.

Spatial prioritization

Selection frequencies (Figure 4) for the UNIFORM scenario varied slightly between places, except for one always-selected place in the southeast because it contained a habitat type rarely found in other places. Smaller places at the margins of the planning region were selected less frequently because they contained smaller habitat extents at the same cost. Predictably, selection frequencies in the PROXIMITY scenario were higher in places more remote from landing sites.

Patterns of selection frequencies using proxies based on fishing activity were similar to each other, but distinct from those based on perceived fishing value (Figure 4). Priorities based on fishing activity reflected the preference of fishers for some fringing reefs and the barrier reef, with places containing these formations never selected. Costs derived from fishing activity were small for the widespread "deep lagoon" habitat, leading to selection of associated places with equal frequencies. Overall, selection frequencies of places for scenarios that minimized costs based on fishing activity were dominantly intermediate or zero. This is because many different combinations of places with little apparent importance for fishing could achieve conservation objectives while leaving places of high apparent importance (cost) unreserved.

Places overlapping *Yazi Tinan* and *Yazi Natun* reefs were not selected frequently in the scenario using measures of perceived fishing importance because of their high cost (Figure 4). Conversely, places at the northern and southern margins of Riwo's waters were selected frequently due to their low perceived importance.

Selection frequencies for PERCEIVED FI resembled those for scenarios based on fishing activity (Figure 4). Small differences reflected fewer places with zero cost for PERCEIVED FI, and places with both a high perceived fishing value and a high contribution to meeting habitat conservation objectives. The difference between selection frequencies based on fishing activity and perceived fishing value was more pronounced for # HOUSEHOLDS, with this aspect of perceived fishing value having very few low-cost places (Figure 3).

Best solutions for scenarios based on measures of fishing activity achieved conservation objectives with larger total extents (Appendix S4), but with lower costs compared to perceived fishing value scenarios (Figure 5A). Scenarios based on TOTAL CATCH gave the largest reduction in total cost compared to random selections (Figure 5A). As expected, the best solution for UNIFORM was not better than random. PROXIMITY was moderately better. Across all scenarios, percentage cost reductions from random were larger for proxies with more strongly right-skewed distributions (Figure 4), indicating greater potential for achievement of objectives at low cost.

The UNIFORM and PROXIMITY scenarios incurred high incidental costs to current fishing activity and perceived fishing value (Figure 5B), much larger than when elicited fishing costs were minimized (Figure 5A). Scenarios based on fishing activity had incidental costs for perceived fishing value substantially larger (from 10.5% to 21.7% of the maximum possible cost) than what was found with scenarios that specifically accounted for perceived fishing value (4.8-7.7%). Scenarios based on perceived fishing value had incidental costs for fishing activity much larger (4.5%-14.4%) than when specifically minimizing costs derived from fishing activity (0.1-0.2%).

Discussion

Our article addresses two important aspects of socioeconomic cost data in conservation planning. We tested commonly used proxies for opportunity cost (proximity to landing sites and current fishing activity) against perceived fishing value elicited from local people. Furthermore, for the first time, we compared the implications of using the actual fishing activity or the perceptions of fishing value in conservation planning. We found potential conflicts between the different types of proxies, and demonstrated that their use in marine reserves design leads to high incidental costs for the proxies that were not considered directly.

Different proxies imply different purposes

Opportunity costs based on fishing activity, perceived fishing value, and proximity provide different types of information. All three data sets are useful for conservation planning but their relevance depends on what planners hope to achieve.

Proximity data are easily derived without surveys and assumed to indicate ease of access or preference for fishing close to settlements, although this assumption is not always reliable (Weeks *et al.* 2010). The complexity, small-scale, growing access to new equipment, and variable nature of reef fisheries limits the value of such coarse proxies (Deas *et al.* 2014). More sophisticated proximity variables, perhaps based on accessibility of specific areas within the lagoon, could be derived and tested, but the transferability of such methods is limited (Deas *et al.* 2014).

Using data on fishing activity would explicitly attempt to maintain short-term food or income security. In contrast, minimizing loss of access to places of high perceived fishing value could keep open fishing places important to people for emotional or spiritual attachment, aesthetics, safety, or ease of access, and could contribute to improving social acceptance, compliance, and engagement in planning (West *et al.* 2006; Mascia *et al.* 2010). Intuitively, costs based on both fishing activity and perceived fishing value would likely maximize the acceptability of additional marine reserves.

Recommendations

Designing reserves with an inadequate cost layer (not reflecting the whole breadth of actual negative impact) has potentially serious implications both in terms of biodiversity protection and impacts of conservation on people. In our study area, proximity to landing sites was unrelated to fine-resolution patterns of resource use and had high incidental costs both in terms of fishing activity and perceived importance. These findings reinforce the risks of using such crude proxies in similar coastal contexts.

Our work shows the potential implications of using fine-resolution data collected under typical constraints of time and logistics in planning exercises (fisher surveys) for the long-term achievement of socioeconomic goals. The fisher surveys yielded smaller, patchier fishing grounds compared to household surveys. This resulted in discrepancies in reserve selection frequencies which led to different interpretations of the contribution of each place to meeting objectives, but also in high incidental perceived fishing costs when minimizing cost to proxies of fishing activity.

Combining costs based on fishing activity and perceived fishing value would have the benefit of maintaining food and income while minimizing the broader social impacts of conservation. Analytically, recent software developments can accommodate multiple costs (Pauly *et al.* 2000; Watts *et al.* 2009) but this remains a

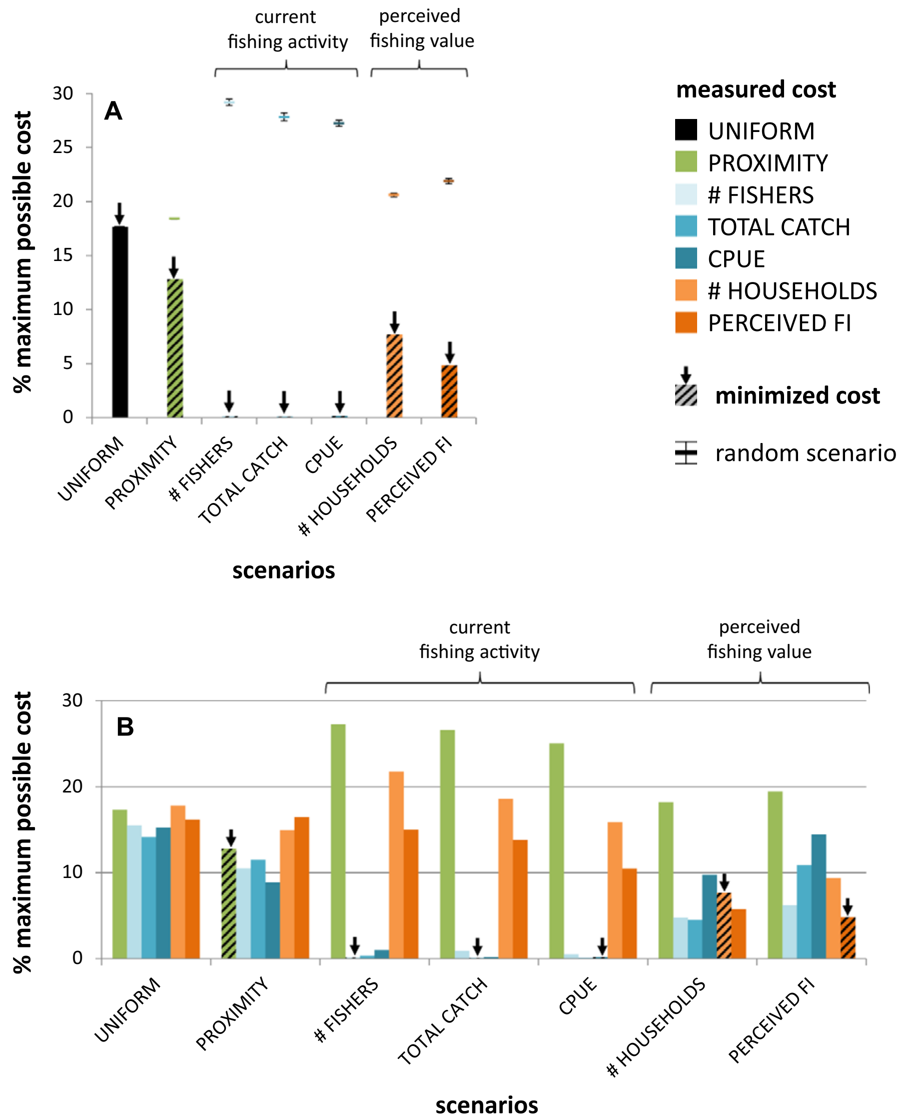

Figure 5 Costs of scenarios in terms of the measure used in each scenario and incidental costs in relation to other measures. (A) Lowest-cost (best) reserve systems obtained for each scenario, compared to random selections of the same number of places. Hatched colored bars with arrows indicate the cost of the best solution across 1,000 runs for each scenario. Colored lines and error bars indicate mean cost from 1,000 random selections and 95% confidence intervals, respectively. The greater the difference between a best solution and a random selection, the better the scenario is at minimizing the given cost compared to random. (B) Incidental costs of the lowest-cost (best) solution for each scenario. For each scenario, colored bars indicate the total cost of the solution for the cost being minimized (hatched, with arrows) and for other costs incurred incidentally. Maximum possible cost, for a given cost layer, is the sum of costs for all places. The UNIFORM scenario is shown for comparison.

frontier in the field. The main challenges lie in integrating costs in different units (e.g., subjective value and catch-per-unit-effort, in our case), and objectively estimating the relative importance of each cost layer (Ban & Klein 2009; Gurney *et al.* 2015). A practical approach would be to return to affected communities after data collection and preliminary reserve design, consult with them about the different types of costs, and produce alternative designs to determine the best strategy.

Possible shortcomings

While survey duration and sample size could be considered limited, our data are not unusual for use in natural resource management. We expect that data on perceived fishing value reflect long experience with the Lagoon, and are unlikely to be sensitive to the timing of surveys. A more extensive survey on fishing activities (greater number of trips over a longer timeframe) might, however, have yielded different results. Perhaps extensive data would be more aligned with perceived fishing importance data (Turner *et al.* 2015), and better reflect the highly dynamic nature of coastal fisheries due to variation in biology (e.g., spawning aggregations at certain times, movement of small pelagic species into the lagoon), environment (e.g., weather), and social factors (e.g., personal preferences). Such survey would be needed to thoroughly investigate the differences between both types of data collection methods. Nonetheless, the initial goal here was to investigate whether data on fishing activity, perceived fishing value, and proximity produced different pictures of opportunity cost. Some places (e.g., barrier reef) had high value for both activity and perceived importance, but there were notable differences including high activity in places with little perceived value. We did not investigate the reasons why fishers perceived places of varying fishing value, but this information would help in interpretation of similar research in the future.

Acknowledgments

The authors are grateful to the Riwo community for their interest, assistance, and participation. We thank the Muséum National d'Histoire Naturelle (France) and the Institut de Recherche pour le Développement (New Caledonia) for organizing the expedition "Papua New Guinea 2012–2014". Particular thanks go to expedition leader Prof. Philippe Bouchet for his support during fieldwork. MAH thanks Natalie Stoeckl, Christina Hicks, and Philippa Cohen for useful advice early in the study. Ethics for research projects involving human participants was approved by James Cook University. MAH and RLP acknowledge support from the Australian Research Council.

Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web site:

Appendix S1. Fisher and household surveys.
Appendix S2. Details on methods.
Appendix S3. Details of raw data.
Appendix S4. Details on results.
http://www.blackwell-synergy.com/doi/ful/10.1111/j.1755–263X.2008.00002.x

References

Adams, V.M., Mills, M., Jupiter, S.D. & Pressey, R.L. (2011). Improving social acceptability of marine protected area networks: a method for estimating opportunity costs to multiple gear types in both fished and currently unfished areas. *Biol. Conserv.*, **144**, 350-361.

Álvarez-Romero, J.G., Pressey, R.L., Ban, N.C., Torre-Cosío, J. & Aburto-Oropeza, O. (2013). Marine conservation planning in practice: lessons learned from the Gulf of California. *Aquat. Conserv.*, **23**, 483-505.

Andréfouët, S. (2008). Coral reef habitat mapping using remote sensing: a user vs producer perspective. Implications for research, management and capacity building. *J. Spat. Sci.*, **53**, 113-129.

Ball, I.R., Possingham, H.P. & Watts, M. (2009). Marxan and relatives: software for spatial conservation prioritisation. in A. Moilanen, K.A. Wilson, H.P. Possingham editors. *Spatial conservation prioritisation: quantitative methods and computational tools*. Oxford University Press, Oxford, UK, 185-195.

Ban, N.C. & Klein, C.J. (2009). Spatial socioeconomic data as a cost in systematic marine conservation planning. *Conserv. Lett.*, **2**, 206-215.

Ban, N.C., Mills, M., Tam, J., *et al.* (2013). A social–ecological approach to conservation planning: embedding social considerations. *Front. Ecol. Environ.*, **11**, 194-202.

Bell, J.D., Kronen, M., Vunisea, A., *et al.* (2009). Planning the use of fish for food security in the Pacific. *Mar. Policy*, **33**, 64-76.

Burke, L., Reytar, K., Spalding, M. & Perry, A. (2011). *Reefs at risk revisited*. World Resources Institute, Washington, DC.

Cinner, J.E. & McClanahan, T.R. (2006). Socioeconomic factors that lead to overfishing in small-scale coral reef fisheries of Papua New Guinea. *Environ. Conserv.*, **33**, 73-80.

Clua, E., Legendre, P., Vigliola, L., *et al.* (2004). Medium scale approach (MSA) for improved assessment of coral reef fish habitat. *J. Exp. Mar. Biol. Ecol.*, **333**, 219-230.

Daw, T., Brown, K., Rosendo, S. & Pomeroy, R. (2011). Applying the ecosystem services concept to poverty alleviation: the need to disaggregate human well-being. *Environ. Conserv.*, **38**, 370-379.

Deas, M., Andréfouët, S., Léopold, M. & Guillemot, N. (2014). Modulation of habitat-based conservation plans by fishery opportunity costs: a New Caledonia case study using fine-scale Catch data. *PLoS ONE*, **9**, e97409.

Fisher, J.A., Patenaude, G., Giri, K., *et al.* (2014). Understanding the relationships between ecosystem services and poverty alleviation: a conceptual framework. *Ecosyst. Serv.*, **7**, 34-45.

Giakoumi, S., Sini, M., Gerovasileiou, V., *et al.* (2013). Ecoregion-based conservation planning in the Mediterranean: dealing with large-scale heterogeneity. *PLoS ONE*, **8**, e76449.

Green, A., Smith, S.E., Lipsett-Moore, G., *et al.* (2009). Designing a resilient network of marine protected areas for Kimbe Bay, Papua New Guinea. *Oryx*, **43**, 488-498.

Gurney, G.G., Pressey, R.L., Ban, N.C., Álvarez-Romero, J.G., Jupiter, S. & Adams, V.M. (2015). Efficient and equitable design of marine protected areas in Fiji through inclusion of stakeholder-specific objectives in conservation planning. *Conserv. Biol.*, **29**, 1378-1389. https://doi.org/10.1111/cobi.12514.

Hamel, M.A., Andréfouët, S. & Pressey, R.L. (2013). Compromises between international habitat conservation guidelines and small-scale fisheries in Pacific island countries. *Conserv. Lett.*, **6**, 46-57.

Jebb, M.H.P. & Lowry, J.K. (1995). Natural history of Madang Lagoon with an appendix to collecting localities. Pages 1-24 in J.K. Lowry editor. *The Amphipoda (Crustacea) of Madang Lagoon, Papua New Guinea, Part 1*. Records of the Australian Museum, Supplement, **22**.

Jenkins, A.P. (2002a). *Madang locally managed marine area network*. Wetlands International - Oceania, Canberra, Australia.

Jenkins, A.P. (2002b). *Sinub Island marine wildlife management area: plan of management*. Wetlands International - Oceania, Canberra, Australia.

Jenkins, A.P. (2011). *Natural history & ecological status of coral reefs in Madang Lagoon, Papua New Guinea (1997-2009): food fish security & biodiversity conservation implications*. Wetlands International - Oceania, Canberra, Australia.

Kinch, J., Baine, M., Mungkaje, A., Dako, C., Bagi, T. & Aranka, M. (2005). *Moving towards management: an analysis of the socio-economic conditions and catch data of the European Union's rural coastal fisheries development programme's fisher groups, Madang Province, Papua New Guinea*. Motupure Island Research Centre, University of Papua New Guinea, Port Moresby.

Kittinger, J.N., Koehn, J.Z., Le Cornu, E., Ban, N.C., Gopnik, M., Armsby, M., Brooks, C., Carr, M.H., Cinner, J.E., Cravens, A., D'Iorio, M., Erickson, A., Finkbeiner, E.M., Foley, M.M., Fujita, R., Gelcich, S., Martin, K.S., Prahler, E., Reineman, D.R., Shackeroff, J., White, C., Caldwell, M.R. & Crowder, L.B. (2014). A practical approach for putting people in ecosystem-based ocean planning. *Front. Ecol. Environ.*, **12**, 448-456. https://doi.org/10.1890/130267.

Klein, C.J., Chan, A., Kircher, L., *et al.* (2008). Striking a balance between biodiversity conservation and socioeconomic viability in the design of marine protected areas. *Conserv. Biol.*, **22**, 691-700.

Le Cornu, E., Kittinger, J.N., Koehn, J.Z., Finkbeiner, E.M. & Crowder, L.B. (2014). Current practice and future prospects for social data in coastal and ocean planning. *Conserv. Biol.*, **28**, 902-911.

Lele, S., Springate-Baginski, O., Lakerveld, R., Deb, D. & Dash, P. (2013). Ecosystem services: origins, contributions, pitfalls, and alternatives. *Conserv. Soc.*, **11**, 343-358.

Leslie, H.M. (2005). A synthesis of marine conservation planning approaches. *Conserv. Biol.*, **19**, 1701-1713.

Lundquist, C.J. & Granek, E.F. (2005). Strategies for successful marine conservation: integrating socioeconomic, political, and scientific factors. *Conserv. Biol.*, **19**, 1771-1778.

Marnane, M., Cinner, J., Clark, T., *et al.* (2002). *A socio-economic and coral reef ecosystem assessment of Kranket and Riwo Villages, Madang Province, Papua New Guinea*. Working Papers. The Wildlife Conservation Society's Asia-Pacific Coral Reef Program.

Mascia, M.B., Claus, C.A. & Naidoo, R. (2010). Impacts of marine protected areas on fishing communities. *Conserv. Biol.*, **24**, 1424-1429.

Mazor, T., Possingham, H.P., Edelist, D., Brokovich, E. & Kark, S. (2014). The crowded sea: incorporating multiple marine activities in conservation plans can significantly alter spatial priorities. *PLoS ONE*, **9**, e104489.

Millennium Ecosystem Assessment. (2003). *Ecosystems and human well-being: a framework for assessment*. World Resources Institute, Washington, DC.

Miller, I.R. & Sweatman, H.P.A. (2004). Status of coral reefs in Australia and Papua New Guinea in 2004. Pages 303-335 in C.R. Wilkinson editor. *Status of coral reefs of the world*. Australian Institute of Marine Science (AIMS).

Naidoo, R., Balmford, A., Ferraro, P.J., Polasky, S., Ricketts, T.H. & Rouget, M. (2006). Integrating economic costs into conservation planning. *Trends Ecol. Evol.* **21**, 681-687.

National Statistical Office of Papua New Guinea. (2002). *Papua New Guinea 2000 census: final figures*. Port Moresby, Papua New Guinea.

National Statistical Office of Papua New Guinea. (2009). *Papua New Guinea demographic and health survey. 2006 National Report.*, Port Moresby, Papua New Guinea.

Pauly, D., Christensen, V. & Walters, C. (2000). Ecopath, Ecosim, and Ecospace as tools for evaluating ecosystem impact of fisheries. *ICES J. Mar. Sci.: Journal du Conseil*, **57**, 697-706.

Turner, R.A., Polunin, N.V.C. & Stead, S.M. (2015). Mapping inshore fisheries: comparing observed and perceived distributions of pot fishing activity in Northumberland. *Mar. Policy*, **51**, 173-181.

UNEP/CBD/COP/10/X/2. (2010). *Strategic plan for biodiversity 2011-2020*. Conference of the parties to the Convention on Biological Diversity (Tenth Meeting). Nagoya, Japan, 18–29 October 2010.

Watts, M.E., Ball, I.R., Stewart, R.S., *et al.* (2009). Marxan with zones: software for optimal conservation based land- and sea-use zoning. *Environ. Modell. Softw.*, **24**, 1513-1521.

Weeks, R., Russ, G.R., Bucol, A.A. & Alcala, A.C. (2010). Shortcuts for marine conservation planning: the effectiveness of socioeconomic data surrogates. *Biol. Conserv.*, **143**, 1236-1244.

West, P., Igoe, J. & Brockington, D. (2006). Parks and peoples: the social impact of protected areas. *Annu. Rev. Anthropol.*, **35**, 251-277.

