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Fishing-focused marine conservation planning underestimates losses of other ecosystem benefits to local communities

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Incorporating meaningful social and economic information into conservation planning is challenging but critical to minimizing impacts of conservation actions on livelihoods and increasing the likelihood of compliance with restrictions on resource use. The social impacts of conservation reserves are generally included in planning mostly through opportunity costs. For marine systems, these opportunity costs tend to be measured only for fishers. However, the services and associated benefits people gain from their marine environments go beyond food and income from fishing. People also benefit from recreation, aesthetic enjoyment, spiritual connections, medicine, and culture. We explored how conservation planning can be informed and optimized with data on how people value coral-reef ecosystem benefits. We identified and mapped important places, including for fishing, to households of the Riwo (*Ziwo*) community of the Madang Lagoon, Papua New Guinea, using interviews from heads of households ($n = 52$). Then, we incorporated data on the multiple benefits of the Madang Lagoon into spatial prioritization with novel cost functions. We found that different places in the Madang Lagoon were important for different reasons, and that designing reserves only to minimise forgone fishing can have incidental impacts on other benefits. We also found that incorporating information on all benefits was the most effective way to minimize the loss of the full suite of benefits, should their access be limited by reserves. We demonstrated how planners can develop approaches that consider all the various costs of conservation that matter to local people.

Successful conservation requires planners to understand and account for the needs and aspirations of people[1,2]. Conservation planners aim to protect areas with the highest benefit for biodiversity, and typically with the least impact on people's use of natural resources[3]. Reserves (a type of protected area where extractive activities are restricted) can have numerous long-term benefits for local communities and other stakeholders e.g.[4–8]. However, restrictions on human activities can also compromise access to ecosystem services, affecting benefits to people such as livelihoods and well-being[9–12], compromising acceptance and therefore ecological benefits of the reserves[13]. It is now widely recognised by economists and social scientists that, to be effective, conservation planning should consider entire social-ecological systems. Consequently, effective approaches to assess and incorporate relevant social and economic data into ecosystem-based systematic planning are being continually developed[14–16].

Planners attempt to place reserves where they will minimize negative effects on people in the hope of improving social acceptance and compliance, thereby potentially improving the effectiveness of reserves[17]. Typically, planners consider the negative impacts of reserving significant areas for biodiversity in the form of "costs" of conservation actions to affected stakeholders[18,19]. Potentially affected stakeholders include people who depend on the resources within reserves for commercial or non-commercial uses. The most straightforward way

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to assess these costs is by estimating opportunity costs or forgone access to resources[14]. These costs are usually measured through proxies of the economic value of candidate areas for reservation, and are assumed to reflect broader socioeconomic impacts on people.

In marine environments, intended conservation actions can conflict with fishing activities that are important for economies and livelihoods, leading conservation planners to focus on the opportunity costs of conservation decisions to fishers e.g.[18,20–22]. However, most coastal communities gain more from their marine environments than just fish for food or income (benefits). People often access and consider the marine realm beneficial for a range of other ecosystem services and derived benefits. For example, Hicks and Cinner[23] identified nine important services from coral reefs: two provisioning (fishery, materials), two regulating (coastal protection, sanitation), one supporting (habitat control), and four cultural (culture, education, recreation, and bequest). These services were considered important by fishers from 28 coral reef fishing communities across four countries. Here, we focus on the benefits such as food, medicine, or spirituality people gain from accessing the marine environment and associated goods and services[24]. We use the terms 'ecosystem benefits' to follow Hicks and Cinner's framework used at the time of the study.

Minimising opportunity costs to fishers by implementing conservation actions away from the most important fishing areas is a first step towards incorporating people's needs into conservation plans[25]. However, this approach can incidentally displace restrictions on access or resource extraction to areas or activities that are important for other benefits. Considering only opportunity costs to fishing could therefore create a false sense of achievement, hiding unexpected negative impacts on the wider community and undermining acceptance and compliance, thus compromising conservation effectiveness. Key research gaps here are therefore assessing and understanding how communities, not just fishers, perceive and value different areas they access for the full range of benefits they gain, in a way that can be incorporated into conservation planning. Addressing those gaps would help minimise potential broader impacts of proposed conservation plans, identify opportunities to maximise both conservation and socioeconomic benefits, foster stakeholder engagement, and help make decision-making more transparent.

Following the publication of the Millennium Ecosystem Assessment[26], there was a rapid growth in the number of studies assessing economic, social, and cultural services and associated benefits of marine ecosystems to people e.g.[27,28], with many studies recommending their incorporation into conservation planning. Despite calls from both the social sciences and the conservation planning community to explicitly assess and incorporate such information into conservation plans[29], only a few published studies have done so with tools for systematic conservation planning. These studies are primarily terrestrial, undertaken over large extents (tens of thousands of square kilometres), in developed regions, and use biophysical proxies to value ecosystem goods and services e.g.[30–33] with no link to people's perception of benefits.

Approaches are available for collecting spatial information on how ecosystem benefits are perceived by people and at local scales. Brown[34] reviewed and proposed methods to incorporate into natural resource management what he called "perceived landscape values", or the perceived benefits provided by landscapes. To do this, he adapted a typology of ten landscape values (life support, economic, scientific, recreation, aesthetic, wildlife, biotic diversity, natural history, spiritual, intrinsic) initially developed by Rolston and Coufal[35]. Brown[34] then used participatory GIS techniques to map and measure the importance to people of areas for their landscape values. Although he recommended the use of such participatory mapping methods to derive data for conservation planning, the study did not provide further indication on, for instance, how this might be incorporated into spatial decisions with systematic planning tools. Raymond and Brown[36] revised Brown's method to map what they called "community values" for natural capital and ecosystem services. Although the results were accounted for in the local conservation plan, by including "people" as an asset al.ongside land, water, biodiversity, and atmosphere, the spatial dataset created was not used explicitly to inform systematic conservation planning scenarios. Whitehead et al.[37] incorporated spatial data on "social values", collected with the approach of Raymond and Brown[38], into systematic conservation planning to find optimal places for conservation. At the time of the study, it was the only published study, to our knowledge, to do so (but see[25] on the "fishing importance" of places and a handful of more recent studies in[39]. The study areas for all these approaches were in developed countries for which mail or online surveys were relevant, and often covering large areas. One challenge was to further adapt this work to tropical marine contexts for local-scale conservation planning, recognising that communities in developing countries rely strongly on natural resources, not only for subsistence or commerce, but for a wide variety of benefits that are less well understood by conservation planners.

Our goal in this paper was two-fold: (1) to explore ways to collect spatial information on the perceived importance of ecosystem benefits in a marine environment and to use it for local conservation planning with a spatial prioritisation tool; and (2) to assess the potential impact of considering only fisheries benefits to people when designing conservation plans, when compared to considering a suite of ecosystem benefits relevant to the whole community. We discuss advantages and limitations of our approach in a conservation planning context, propose possible improvements and further research directions to develop the method, and present practical recommendations for planners who wish to use this approach in the field. We use the Madang Lagoon in Papua New Guinea, a tropical coral reef social-ecological system, as a case study. While conservation planners may be familiar with some aspects of the workflow, detailed descriptions are provided to support reproducibility and to ensure that readers from broader disciplines can apply and improve the methods.

Materials and methods

Ethics statement

The study did not involve manipulation of animals or protected species. This study included research involving human subjects and was specifically approved by James Cook University's Human Research Ethics Committee with approval number H4766. Because of the low level of literacy observed in our study site, asking for written informed consent was inappropriate. Therefore, a verbal outline of the project was provided to participants, with oral consent audio recorded before the start of all interviews, a procedure also approved by James Cook University's Human Research Ethics Committee for this study. Participants were fully informed about the study's purpose, procedures, potential risks, and their right to withdraw at any time. This research was performed in accordance with guidelines/regulations relevant at the time. All field work in the Madang Lagoon, Papua New Guinea was undertaken under research permit 10,350,012,063. Access to all coastal villages constituting the Riwo (*Ziwo*) community was granted by the Riwo community chief prior to the field study. Relevant landowners were informed of the study by the chief and principal investigator during a community meeting prior to the study.

Overview of the method

The implementation of protected areas in the form of reserves where restrictions on extractive activities apply can affect people by revoking access or use in areas they visit to derive benefits from ecosystem services other than and including fishing (hereafter 'benefits'). The systematic conservation planning approach employed here helps to design reserves that meet conservation objectives while accounting for the perceived importance of areas for the benefits they provide to people (Fig. 1). We present our method within the general framework for landscape- and seascape-scale conservation planning developed by Pressey and Bottrill[3]. Their widely used framework consists of 11 stages ranging from scoping and costing the planning process through selecting protected areas, to maintaining and monitoring them. It should be noted that, although Pressey and Bottrill presented the 11 stages as a linear sequence, in practice, they will likely be followed in a different order depending on the context. This paper focuses on stage 5 in their framework ("collecting data on socio-economic variables and threats") by detailing a novel approach with field methods, data processing, and spatial analyses related to the collection and compilation of local data on a range of ecosystem benefits, including but not limited to fishing, as "socio-economic variables". In the following text, we adapted and simplified Pressey and Bottrill's framework into 6 steps (from A to F, Fig. 1) for clarity and conciseness and to help readers visualize where lies our contribution to Systematic Conservation Planning.

Step A: identify the study area and understand the context

Step A involves identifying the study area, the stakeholders, and understanding its social and ecological context (stages 1 to 3 in[3]. Madang Lagoon, the largest and most ecologically diverse lagoon on the north coast of Papua New Guinea[40–42], is located in the Coral Triangle region, 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 (Fig. 2). We selected this study area for two reasons. First, our socioeconomic work was combined with an extensive biological survey (Papua-Niugini 2012–2014 expedition), providing extensive spatial data on habitats for our planning exercise (details in[25]. Second, similar to most coral reef countries[43], coastal communities of the Madang Lagoon rely on threatened coral reef resources and habitats for their day-to-day life, subsistence, and income[44–46], presenting the challenge of incorporating into conservation plans spatial information on the perceived importance of coral reef ecosystem benefits.

We focused on Riwo (*Ziwo* in the local *Bel* language), the largest coastal community in the Madang Lagoon, because of its central location (Fig. 2), with over 2000 inhabitants[48], and a history of involvement in conservation and resource management. Good interactions with the Riwo community during engagement visits done at early stages of the expedition also reinforced this choice. Three of the four Wildlife Management Areas (WMAs) in the lagoon were established by clans of Riwo (Tabad in 2002 and Sinub and Laugum in 2006), with the support of local and international NGOs[41,49]. We engaged with the local coastal community of Riwo as stakeholders with marine tenure[46] who could potentially be affected by hypothetical natural resource management actions.

Step B: define broad planning goals

Step B requires a clear definition of the broad planning goal(s) (stage 4 in[3], allowing planners to scope the type of data required. Broad goals are typically refined into quantitative conservation objectives later in the process. Here, our goal was to simulate the design of hypothetical reserves that would protect marine habitat types within the Riwo waters, while minimizing loss of access by the community to important ecosystem benefits. Therefore, spatial data on habitat types present in the region were necessary, as well as maps of the benefits provided by the Madang Lagoon as perceived by the community.

We planned for two types of hypothetical reserves. The first, no-take areas, prohibiting extraction of live and dead material. This restricted, for example, artisanal fisheries, collection of seaweed and shellfish for therapeutic purposes, and collection of coral or shellfish to make lime to chew with betel nut (less restrictive than the "fully protected areas" that are part of the Wildlife Management Areas). The second type, no-go areas, prohibited access to everyone, regardless of the activity involved, including recreation, aesthetic enjoyment, and visits for spiritual purposes (more restrictive than the "fully protected areas"). The no-go areas (corresponding to IUCN protected areas category Ia) ensure the natural integrity and values of areas. They are less common than other reserve types, but have been implemented elsewhere in Oceania[50–52]. Restriction on access is a topic that emerged from discussions with Riwo residents, who identified the need to limit access to some areas in the Lagoon to protect their natural values. Using this category allowed us to demonstrate in a simple, albeit extreme, way what could happen with restrictions on access for activities other than resource harvesting, including recreation and tourism.

Step C: delineate planning region and planning units

Pressey and Bottrill[3] recommended an initial broad definition of the planning region, followed by refinement of boundaries as data are compiled. Here, in step C, the planning region was first broadly defined as the extent of marine habitats and islands within the section of the Madang Lagoon used by the Riwo community (roughly the

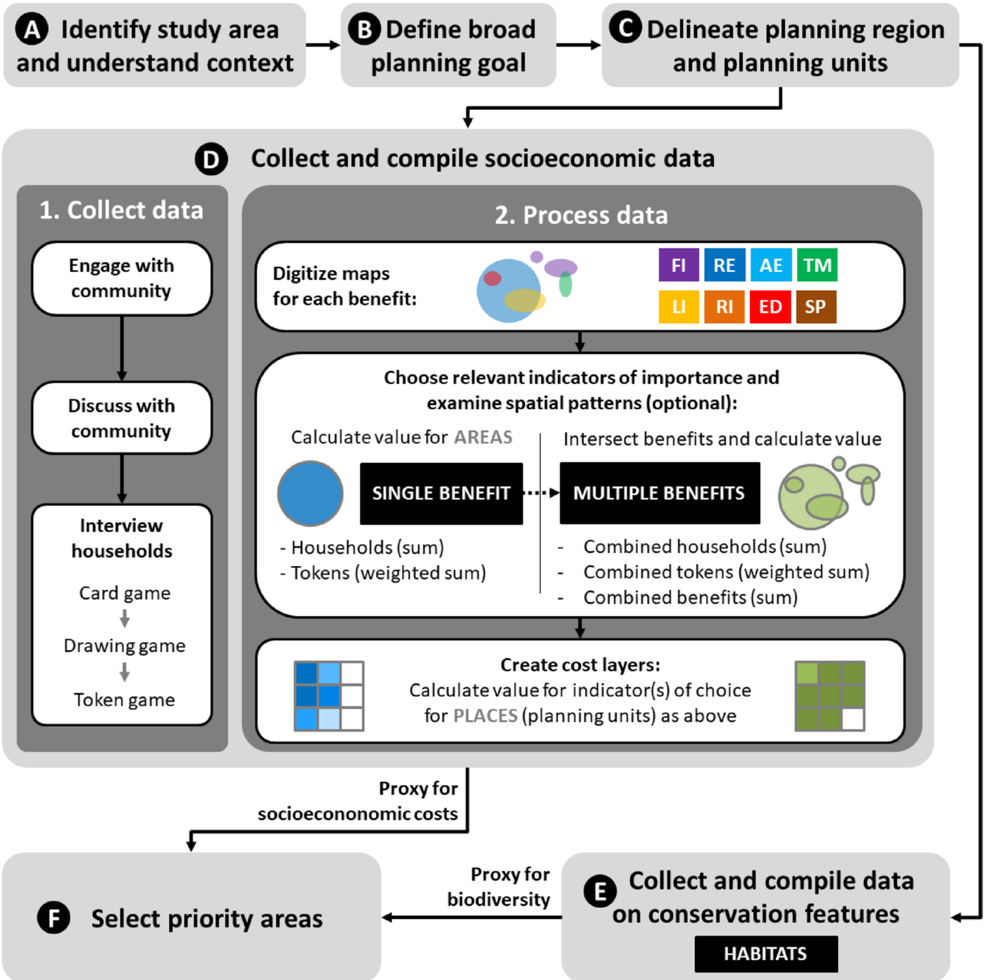

Fig. 1. Overview of the method used to incorporate information on perceived ecosystem benefits into systematic conservation planning. The method described in this paper corresponds to step D "Collect and compile socioeconomic data" of the simplified version of Pressey and Bottrill's framework depicted in this diagram. Each step (from A to F) is detailed in the main text. Benefits identified and investigated in this case study include fishing (FI), recreation (RE), aesthetics (AE), traditional medicine (TM), lime for betel nut chewing (LI), perceived biological richness (RI), education (ED), and spirituality (SP). Details on benefits are included in Supplementary Table S2. In step D2, after digitizing maps for each benefit, we strongly recommend an examination of spatial patterns within and between different indicators using raw data before computing cost layers, but this step is optional. This step involves using relevant indicator(s) to quantify the importance of each "area" for a given benefit or a combination of benefits. An "area" can be only one mapped polygon for a given benefit, or the overlap between two or more polygons (when areas of importance for the same benefit delineated by different households overlapped). Planners can focus on incorporating individual benefits only (SINGLE BENEFIT) in the spatial prioritisation, and/or a combination of benefits (MULTIPLE BENEFITS). To quantify the importance of a given area for a given benefit, two indicators can be used: based on the number of households perceiving the area as important for this benefit, or based on the number of "importance" tokens assigned to the area by all households. If planners choose to focus on a combination of benefits, the importance of areas must be calculated for individual benefits first, then combined. A third indicator can also be used: the total number of perceived benefits found in a given area, based on the spatial footprint for each benefit of interest. Creating cost layers used in spatial prioritisation is done by calculating the importance of each "place" (planning unit) instead of each area, for the indicator(s) of choice. Details on calculation methods and equations can be found in the Supplementary Information 2.

combined customary tenure of all clans making up the Riwo community). We later refined the boundaries of our planning region by overlaying a grid of planning units (hereafter "places") on both a map of marine habitats and islands in the study area (step E) and the spatial footprint of our benefits dataset (step D).

Two criteria determined the size of places. First, single or grouped places needed to be small enough to facilitate local management while allowing use of alternative areas. We used the smallest zone of the Wildlife Management Areas (17 ha) as a reference. Second, places needed to be large enough to account for possible errors in mapping, particularly in the information collected during the interviews. Indeed, fishers were able to

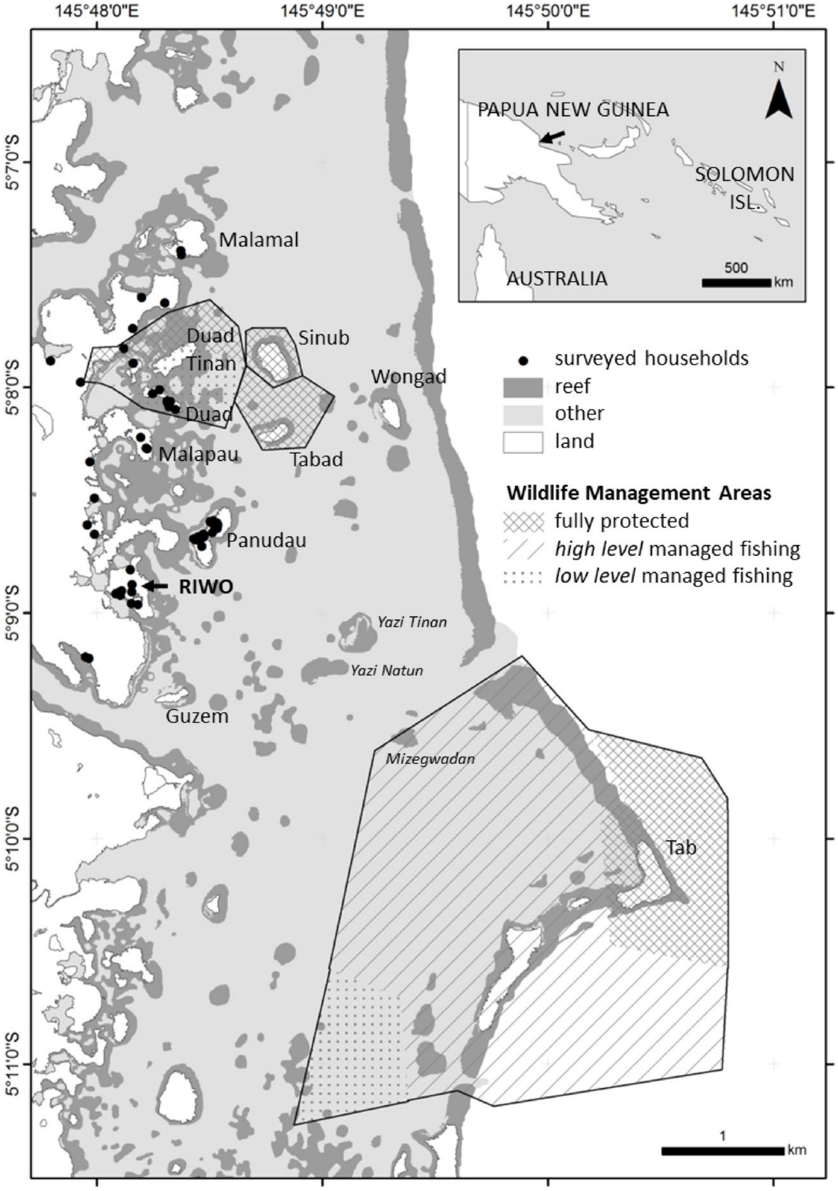

Fig. 2. Study area. Inset shows the location of the Madang Lagoon in Papua New Guinea. Large map shows detail, including names of main islands (romans) and reefs (italics). Of the four Wildlife Management Areas in the study area, three (Sinub, Tabad and Laugum in the northern section) are managed by the Riwo community. In "fully protected areas", all forms of resource extraction as well as anchoring and rubbish disposal are prohibited, and access by visitors from commercial tours is limited. In "high level managed fishing areas", only line fishing is allowed. In "low level managed fishing areas", subsistence fishing without destructive methods is allowed. The base map was created using the geomorphic habitat data collected in Step E. The Wildlife Management Areas boundaries were republished from the World Data Base on Protected Areas under a CC BY license, with permission from UNEP-WCMC, original copyright 2023[47]. Base maps and spatial layers were compiled and visualised using ArcGIS Desktop version 10.0 (ESRI, Redlands, CA, USA; https://www.esri.com), and the final map layout was produced by the authors.

map specific features such as wrecked ships and planes with an accuracy of between 5 m and 200 m[25]. Therefore, we defined places with planning units of 300 m by 300 m (or 9 ha). We used square planning units. Marginal ones were trimmed to the Madang Lagoon boundaries. The final planning region consisted of 319 places, each 300 m x 300 m, intersecting both marine habitats and benefits.

Step D: collect and compile socioeconomic data

Step D here corresponds to stage 5 in[3], and is the main focus of our paper.

Step D1: collect Spatial data on perceived ecosystem benefits

Here the aim was to collect the information to create accurate maps of the importance of social, economic, and cultural benefits derived from the Madang Lagoon's ecosystem services. We assumed that losing use or access to a place equates to losing the associated benefits. Participatory GIS methods[36] were adapted to the local context of the Madang Lagoon to collect this information.

In November 2012, we held open meetings with the Riwo community to explain the project, refine data collection methods, and obtain approval from the chief and residents. Four preliminary focus groups were conducted to identify the range of perceived benefits provided by the Madang Lagoon to the Riwo community, capturing perspectives across gender and fishing/non-fishing roles. We asked participants, with open questions, to identify and discuss the different reasons why people access their marine environment in the community. Picture cards illustrating different benefits (Supplementary Table S2) adapted from the list of "landscape values" in[34] were prepared a priori to help with the discussions. Cards were used only at the end of the open discussion to refine the list and ensure that no benefits were missing. Cards deemed irrelevant by respondents were discarded. The compiled list of benefits (Table 1) was used to assist in the survey described below. All focus groups were facilitated in English by the lead author, ensuring that at least one community member present in each group was bilingual in English and Tok Pisin (one of the national languages of Papua New Guinea) or English and Bel (Riwo's local language) to minimize possible language bias. Summary notes from focus group discussions were documented on paper and digitally recorded with participant's consent.

To map how and where Riwo people value different areas they visit in the Madang Lagoon, we conducted interviews with 52 heads of households (17% of Riwo households[48] opportunistic sampling across all main villages, hamlets, and islands making up the Riwo community over a 20-day period, from 14 November to 3 December 2012 (Fig. 2). We targeted heads of households whose main occupation was fishing (males and females) for their good spatial knowledge of the marine environment, but often whole households were present during the interviews.

Each interview followed a three-part, game-based survey (Supplementary Information 1) designed to identify benefits, map spatial use to derive those benefits, and quantify the importance of accessing mapped areas for these benefits.

1. **Card game**: Participants identified the benefits important to their household, first unprompted and then with picture cards, and ranked them in order of importance. This ranking determined the order in which benefits were mapped.

2. **Drawing game**: Using a high-resolution satellite image, participants drew polygons showing where they regularly accessed each selected benefit.

Code	Benefits	Details (from focus groups and surveys)	Use category
FI	Fishing (food and income)	Riwo people harvest reef resources such as fish, octopus, shellfish, and squid for income and food. Within the Madang Lagoon, fishers mainly use nets of varying mesh sizes, spear guns, small handlines (reef fishing) and larger trolling lines (lagoon fishing). Main means of transport include kayaks, traditional dugout canoes, motorboats, swimming, walking, diving, and snorkeling. Octopuses are fished by both males and females. Younger males often catch them with a wire rod or a spear gun. Mostly women collect shellfish. The largest reef fish are sold at local community markets and at the Madang markets, but also sometimes to local resorts. Smaller fish are consumed by households, traded within the community (sold, exchanged for garden food), or given away.	extractive
RE	Recreation	Riwo people often visit islands for picnicking or swimming. They light fires on the beach to grill freshly caught fish or shellfish while children and adults swim and play in the shallows.	non-extractive
AE	Aesthetic enjoyment	Some places such as islands, the Madang Lagoon coastline, and coral reefs are valued by Riwo people for their appearance.	non-extractive
TM	Traditional medicine	Riwo people use the Madang Lagoon and its marine resources for traditional medicine. Traditional sore throat remedies include consumption of shellfish soup, or fresh "bubble" *Caulerpa spp*. (*Ninaz*) algae. Sponges, very abundant in the area, are used to cure asthma and other respiratory infections. Seawater is also drunk to cure various illnesses. Swimming in seawater is used to heal skin infections, and to clean newborn babies. Swimming near healing stones is a traditional healing practice for various illnesses. The traditional medicine benefit (TM) corresponds to both non-extractive and extractive activities. Therefore, it was separated into two distinct benefits for analyses: TM (non-extractive) and TM (extractive).	extractive and non-extractive
LI	Lime material to chew with betel nuts (and income)	Riwo people chew betel nut. The practice, common in Papua New Guinea, involves chewing three ingredients: the betel nut, mustard stick, and lime powder. Betel and mustard are often locally grown in villages. Lime powder is obtained from harvested, dried, burned, sieved, and crushed corals or shells from shellfish. Corals (staghorn) and shellfish are therefore collected from nearshore reefs. Lime is used either directly or traded within and outside the community.	extractive
RI	Perceived biological richness	Riwo people value rich areas for their existence value, as well as for the material goods they provide, and perceive rich marine areas as areas with many fish and many coral types. They also value terrestrial coastal areas and islands for their biological richness, which they perceive from the abundance and diversity of plant types, and the presence of mangrove.	non-extractive
ED	Education and knowledge	Riwo people visit the reefs to share fishing knowledge (mostly done by fathers), and educate the youth about marine hazards. Mothers will educate about the history of places and ancestors in the region.	virtually non-extractive
SP	Spirituality	Riwo people assign a spiritual importance to churches or cemeteries on islands in the region. Spirits of ancestors are also believed to inhabit different parts of the region, and spiritual stories are shared to remember the history of ancestors.	non-extractive
WR	Wrecks (food, income, recreation)	There are several sunken ships and planes in the Riwo tenure. Those are mostly used for fishing (as fish aggregating devices), and for diving (tourism and recreation). The wrecks are also used to teach history to children.	extractive and non-extractive
TO	Tourism (income)	Tourism is not common in Riwo. However, some community members take rare tourists on guided tours, and clan leaders collect diving fees when tourists dive in their tenure. One respondent was renting out a house for tourists on Wongad Island.	non-extractive

Table 1. Main reasons for Riwo people to visit places in the Madang lagoon in 2012, with associated types of benefits and use categories.

3. **Token game**: Participants distributed tokens (shells or stones) among the polygons drawn for each benefit to indicate their relative importance. More tokens reflected higher importance. Token totals were standardised to a 0–100 scale per benefit per household to ensure comparability.

Surveys lasted about one hour and produced one map for each household, with a different colour for each benefit. Full procedural details, token rules, and survey materials are provided in Supplementary Information 1.

Step D2: process data to measure the importance of places

All polygons drawn by households during the drawing game were digitized manually in ArcGIS Desktop 10.0 (ESRI 2010), creating one layer per benefit. In this study, we tested multiple indicators to assess how different ways of quantifying importance influence spatial patterns of cost and, ultimately, prioritisation outcomes.

To assess the importance of areas for each benefit, we created two indicators (Fig. 1):

- HOUSEHOLDS: number of households identifying an area as important.
- TOKENS: total number of tokens assigned to the area.

Differences in spatial patterns between benefits were explored visually using difference maps (Supplementary Fig. S3).

To assess the importance of areas across all benefits, we created three indicators (Fig. 1):

- COMB BENEFITS: number of benefits assigned to each area.
- COMB HOUSEHOLDS: the number of households valuing any benefit in each area.
- COMB TOKENS: the total number of tokens across all benefits.

Indicators were calculated for all benefits combined, as well as separately for extractive versus non-extractive benefits (Table 1).

We assumed that reserving a place incurs a "cost" in terms of lost access or harvest rights. The cost of restricting access or harvest was defined by the value of the place for a particular benefit: the more important the place as perceived by the local community, the higher the cost. TOKENS was used as the primary cost indicator for individual benefits because it gave the most detail on how people valued access to areas. COMB TOKENS was used for the combined-benefit cost layer ('ALL' in Fig. 3). A uniform cost layer ('UNIFORM' in Fig. 3), with all places assigned a cost of 100, was also created for comparison. The uniform cost layer allows for a scenario where no cost to the local community are considered. All spatial cost layers were created using a combination of ArcGIS and R (R Development Core Team 2008). Details on data processing and calculation of cost layers, including standardization methods and spatial analyses, are provided in Supplementary Information 2.

Step E: collect and compile data on conservation features

This step corresponds to stage 6 in[3]. We created a habitat map of the Madang Lagoon from a high-resolution (2 m) Worldview satellite image[25]. The map was created following the steps in the "user approach" described in[53]: a priori manual delineation of habitats, ground truthing data collected separately from this project during the Coral-Triangle cruise on board R/V ALIS[54], contextual editing, classification and merging of habitat segments. The resulting hierarchical habitat typology for the Madang Lagoon describes 28 geomorphic types (Supplementary Information 3), including 22 within the planning region. We computed the extent of each habitat type in each of the 319 places.

Step F: select priority areas for conservation

The compiled data on habitats and socioeconomic costs were used in systematic conservation planning scenarios. With the Marxan software[55], the scenarios proposed cost-effective reserve systems that limited activities posing a threat to coral reef ecosystems in the form of no-go or no-take areas, achieving representation objectives for habitats at minimum cost. 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). Our analyses addressed three questions: (1) what are the incidental costs incurred by the reservation of places valued for the full range of services and benefits when only cost to fishing is minimised? (2) what are the incidental costs incurred by the reservation of places when other costs are minimised separately? and; (3) what are the potential advantages and limitations of incorporating all benefits in a single prioritisation exercise, by minimising the cost related to all benefits combined?

Multiple scenarios were run to answer each question (Table 2). We refined conservation goals defined earlier (designing hypothetical reserves that would protect marine habitat types within the Riwo waters, while minimizing loss of access by the community to important ecosystem services and benefits, step B) by setting a quantitative objective for habitat protection while minimizing the incurred 'cost' to Riwo people. In all scenarios, proposed reserve systems had to include at least 20% of the total extent of each habitat in the study area, following a precautionary interpretation of Aichi target #11[56] as in[57], the international conservation target in effect at the time of the study. The cost of reserving places was calculated differently in each scenario, using the cost layers from step D (Table 2; Fig. 3). Marxan was run 1000 times for each scenario.

For question 1 (Table 2: "What are the incidental costs of reducing impact on fishing only?"), the FISHING scenario minimized costs only in terms of fishing. We looked at how implementing the candidate reserve systems as either all no-go or all no-take would likely affect access to places providing benefits, including fishing, to the Riwo community. For the same scenario, incurred costs for no-go areas were assessed for all benefits, whereas incurred costs for no-take areas were only assessed for benefits with an extractive component.

For Question 2 (Table 2: "What are the incidental costs of reducing impact on each separate benefit?") As well as the FISHING scenario, we ran scenarios that aimed to minimize loss of each non-fishing benefit separately (RECREATION, AESTHETICS, TRADITIONAL MEDICINE (all), TRADITIONAL MEDICINE (ext.), TRADITIONAL MEDICINE (non-ext.), LIME, BIOLOGICAL RICHNESS, EDUCATION, SPIRITUAL). For comparison, we ran a scenario (UNIFORM) with a uniform cost of 100 for all places, simulating a situation

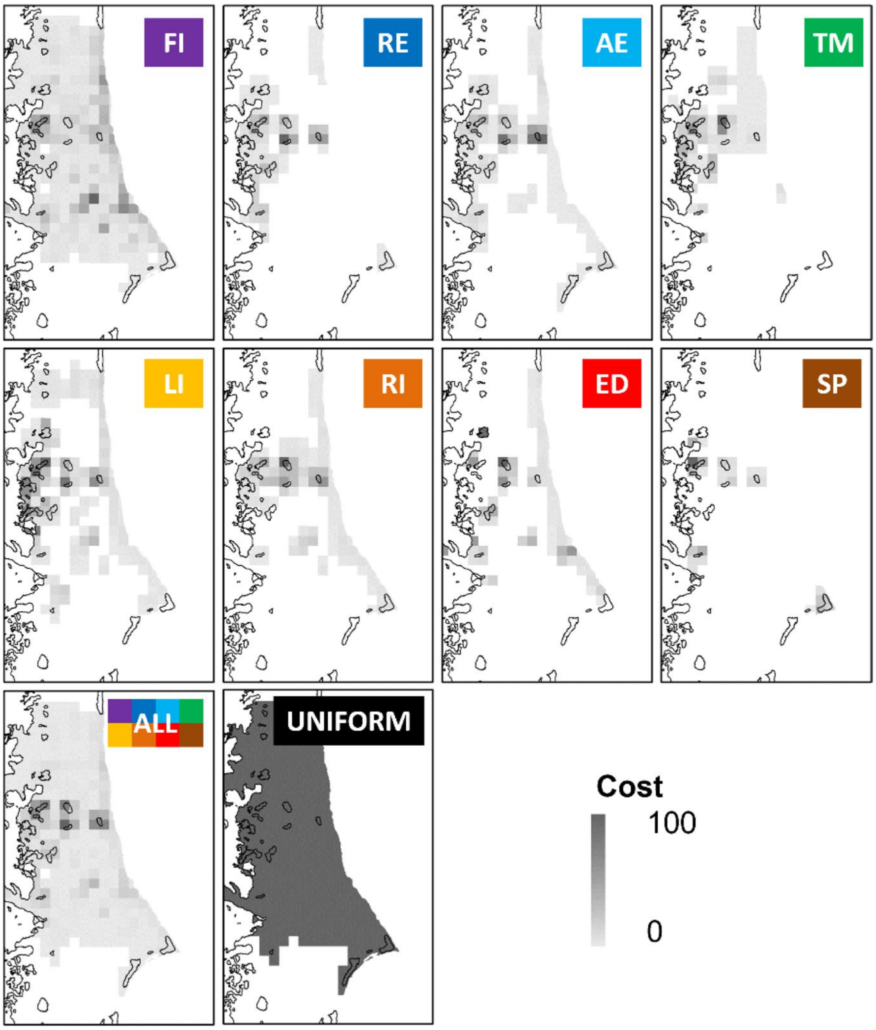

Fig. 3. Standardised cost layers used in spatial prioritisation of the Madang Lagoon. Cost layers show the relative importance of places for Riwo people across eight benefit categories: fishing (FI), recreation (RE), aesthetic enjoyment (AE), traditional medicine (TM), collecting material to make lime used in betel nut chewing (LI), perceived biological richness (RI), education and knowledge sharing (ED), and spiritual value (SP). For each benefit, a cost layer was generated using the TOKENS indicator, which reflects the importance assigned to each polygon in providing access to that benefit. The combined cost layer (ALL) was created using the COMB TOKENS indicator, summing TOKENS across all benefits, and weighting each benefit by their importance as assigned by the community. A uniform cost layer (UNIFORM) is used in a scenario where no cost is considered. Some areas are consistently important across many benefits (visible in ALL), whereas others are important for only one benefit. Fishing-important areas differ clearly from areas valued for other benefits. Base maps and spatial layers were compiled and visualised using ArcGIS Desktop version 10.0 (ESRI, Redlands, CA, USA; https://www.esri.com), and final map layouts were produced by the authors.

where no social impacts are considered. For each scenario, we measured two things: (1) the proportion of places, valued for each benefit other than fishing, where access (no-go reserves) or harvest (no-take reserves) would be lost with implementation of candidate reserves; and (2) the percentage incidental cost, for each benefit including fishing, of the best candidate reserve systems in relation to the maximum possible cost for each benefit (i.e. if all 319 places were reserved).

For Question 3 (Table 2: "What are the advantages and limitations of combined benefits?"), scenarios were set to design systems of no-go areas that also achieved the conservation objectives above, but this time with minimal impact on all benefits combined. We planned only for hypothetical no-go areas here (an extreme management solution) to show the potential cost of not accessing areas for the full range of extractive and non-extractive benefits. To do this, we tested two different scenarios, both using the same combined cost layer created in step D. In the "ecological" scenario (ECOLOGICAL), we designed reserves using the conservation objective while minimizing costs for all benefits combined, including fishing. In the "social-ecological" scenario (SOCIAL-ECOLOGICAL), we excluded a priori the most valued places from the pool of possible reserves (i.e. all places with a cost for combined benefits above the upper quartile), as a way to consider the reduction of

SCENARIOS What are the incidental costs of reducing costs to:			COST MINIMIZED	SOCIOECONOMIC OBJECTIVE	CONSERVATION OBJECTIVE
Q1. fishing only?	Q2. separate benefits?	Q3. combined benefits?			
FISHING	FISHING		Fishing (FI)*	None. Socioeconomic objective is seen as a constraint (cost minimised) to meeting the conservation objective.	Reservation of 20% of the extent of each habitat type (rationale in main text)
	RECREATION		Recreation (RE)		
	AESTHETICS		Aesthetics (AE)		
	TRADITIONALMEDICINE (all)		Traditional medicine, all (TM)		
	TRADITIONAL MEDICINE (ext.)		Traditional medicine, ext. (TM ext.)*		
	TRADITIONAL MEDICINE (ext.)		Traditional medicine, non-ext. (TM non-ext.)		
	LIME		Lime (LI)*		
	BIOLOGICAL RICHNESS		Biological richness (RI)		
	EDUCATION		Education (ED)		
	SPIRITUALITY		Spirituality (SP)		
	UNIFORM		None, all costs = 100.		
		ECOLOGICAL	All benefits combined (ALL)		
		SOCIAL-ECOLOGICAL	All benefits combined (ALL)	No reservation possible a priori for places the most highly valued for all benefits combined.	

Table 2. Scenarios used for Spatial prioritization. The paper investigated three questions (see main text). Scenario names are indicated under each question and capitalised. The cost minimised in each scenario is indicated, as well as the conservation objective used to select reserves. Indicators used to measure the costs of reserving each planning unit according to each benefit were TOKEN and COMB TOKEN for separate and combined benefits, respectively. Asterisks in the COST MINIMIZED column indicate that the cost has a major extractive component, and will be incurred both in the context of no-go and no-take areas. The conservation objective was the same for all scenarios: reservation of 20% of the extent of each habitat type (see rationale in main text).

socioeconomic impact as an objective rather than as a constraint only. Then we designed reserves, excluding these places, with the same objectives as in the ECOLOGICAL scenario. We measured all incidental costs for each benefit individually, and the number of planning units reserved in both scenarios.

Results

Identifying and mapping benefits to Riwo people derived from accessing the Madang lagoon

The card game identified the ways in which Riwo households benefit from the Madang Lagoon and provided a ranking of the relative importance of these benefits. All benefits listed in the cards were mentioned by at least three of the four focus groups, except education, which was mentioned only by non-fishers. Households visited and valued their marine environment (marine habitats and islands) for fishing (98% of all interviewed households), followed by recreation (79%), aesthetics (65%), traditional medicine (60%), lime material for betel nut chewing (56%), perceived biological richness (50%), education (33%), and spirituality (21%). Wrecks (10%) was excluded from analyses because all 4 respondents who benefited from wrecks did so for recreation and/or fishing, making it redundant. Tourism (6%) and two benefits not in the cards (transportation and friendship), were identified by only four or fewer households so were excluded from analyses.

The drawing game identified the areas of the Madang Lagoon that Riwo households access to derive each benefit. Many of the areas people valued for fishing, recreation, aesthetics, and biological richness overlapped between households, indicating some consensus on important areas (Supplementary Fig. S4). In contrast, areas valued for therapeutic, lime, education, and spiritual benefits differed more strongly between households. Overlaps of areas delineated for each benefit showed ten distinct geomorphologic entities of importance for the Riwo community: six islands (*Guzem*, *Duad*, *Duad Tinan*, *Tabad*, *Sinub* and *Wongad)*; three patch reefs (*Yazi Tinan*, *Yazi Natun* and *Mitzegwadan)*; and the barrier reef (Supplementary Fig. S5 and Table S6). In general, reefs were mostly valued for fishing, while islands and associated reefs were appreciated for a greater range of uses and benefits, including fishing. In particular, *Tabad* and *Wongad* islands were identified as having great recreation and aesthetic benefit. *Tabad*, *Sinub* and *Wongad* islands had the greatest number of benefits. The barrier reef had the highest fishing benefit.

The token game quantified how important each mapped area was to households for accessing a specific benefit. Using data from the token game, we created a range of indicators to explore how different ways of quantifying importance influence spatial patterns of cost and, ultimately, prioritisation outcomes. For individual benefits, we used two indicators: TOKENS, and HOUSEHOLDS. We found small differences between the importance of areas according to the frequency of households valuing them (HOUSEHOLDS) and their relative importance according to their weighting, or number of tokens associated with them during the surveys (TOKENS). Compared to TOKENS, HOUSEHOLDS tended to emphasise the importance of very specific areas relatively far from the coast for fishing, aesthetics, and lime, but reduced the apparent importance of some areas closer to shore for recreation (Supplementary Fig. S6). HOUSEHOLDS tended to slightly emphasise the therapeutic and educational benefits of all areas compared to TOKENS. Both indicators were very similar for biological richness and spiritual benefit.

Combining all benefits showed the overall importance of areas of the lagoon for the Riwo community according to different indicators of importance. The three measures (COMB BENEFITS, COMB HOUSEHOLDS and COMB TOKENS) showed similar spatial patterns with some differences (Supplementary Fig. S3). In general, higher numbers of different benefits (COMB BENEFITS) were assigned to islands, mainly because of the wide range of uses they support. More people (COMB HOUSEHOLDS) valued *Wongad* and *Tabad* Islands, especially for non-extractive uses. The reefs around *Wongad* Island provided all eight types of benefits. Areas valued for extractive uses (fishing, collecting material for lime, therapeutic uses) were mainly the barrier reef, *Yazi Tinan*, and *Yazi Natun*. Accounting for the way people weighted each area for a given benefit, and the benefits themselves (COMB TOKENS) altered the importance of some areas when compared to COMB HOUSEHOLDS. For example, many households valued *Wongad* and *Tabad* for non-extractive uses but placed a relatively low importance on these islands in terms of the level of benefits they provided. Fewer people valued *Duad* and *Duad Tinan* overall but these islands and surrounding reefs were very important to these people in terms of the benefits they provided.

Question 1: what are the incidental costs of reducing impact on fishing only?

Designing reserves that aimed only to minimize costs to fishing (FISHING scenario) meant that some no-take and no-go closures would still be placed in areas with high social, cultural, and economic benefits, generating substantial incidental costs. In particular, with this scenario, a high proportion of places valued for other extractive uses tended to be candidates for reservation. In the best solution that achieved conservation objectives at the smallest possible cost and for the smallest reserve system out of 1000 runs, candidate reserves included 19% of places valued for fishing, but also incidentally included 25% of places for extractive aspects of traditional medicine and 19% for lime material. The cost of this scenario to fishing was relatively low at 3% of maximum possible cost (Fig. 4). Major incidental costs were for spirituality (19% of maximum possible cost), extractive uses for traditional medicine (18%) and lime material (10%). Overall, higher incidental costs of the FISHING scenario were incurred when we simulated restrictions on access (no-go reserves) rather than only on harvest (no-take reserves) as more benefits would be affected by the loss of access to places than by the loss in harvest rights. Although the implementation of proposed reserves as no-take had a strong impact on extractive benefits other than fishing, implementing these reserves as no-go not only incurred costs to all extractive uses, but also particularly affected benefits related to Riwo people's culture and traditions (e.g. spirituality, traditional medicine, lime for betel nut chewing). In contrast, there were minor incidental costs for non-extractive traditional medicine (1% of valued places in candidate reserves). Interestingly, only 10% of places valued for their biological richness by the Riwo community were candidate reserves in this scenario.

Question 2: what are the incidental costs of reducing impact on each separate benefit?

Designing reserves to minimize costs to each benefit separately highlighted how accounting for one benefit (including fishing) can incur significant incidental costs to others (Fig. 4). Notably, the best solution for the FISHING scenario incurred incidental costs to all benefits (average of all incidental costs of 7%) but these costs were lower than best solutions for scenarios focused on other individual benefits (between 9 and 34%). Not including spatially explicit socioeconomic costs in the reserve design (UNIFORM scenario) incurred the second highest average incidental cost (best solution: 25%).

Question 3 : what are the advantages and limitations of combined benefits?

The two combined benefits scenarios (ECOLOGICAL and SOCIAL-ECOLOGICAL) yielded very similar results, regardless of the way we treated costs to benefits (Fig. 5). The best no-go reserve system proposed for the ECOLOGICAL scenario required 67 places to be protected, while the SOCIAL-ECOLOGICAL scenario required 72 places (aside from those locked out as candidates because of their social benefits). The two resulting reserve systems were very similar spatially, sharing 51 candidate no-go reserves. The ECOLOGICAL scenario selected only two places that were locked out in the SOCIAL-ECOLOGICAL scenario. Both the best ECOLOGICAL and SOCIAL-ECOLOGICAL reserve systems were successful at lowering incidental costs for all benefits with an average incidental cost of only 3% each, with individual costs ranging from 0 to 4%, except for spiritual benefit with a cost of 15% and 12% respectively (Fig. 4). In the scenarios minimizing combined costs, only two of the eight benefits had lower costs than incidental costs in scenarios focused on other individual benefits: traditional medicine (extractive uses only) had the lowest incidental cost with the LIME scenario (1% against 2% for both the ECOLOGICAL and SOCIAL-ECOLOGICAL scenarios); and spirituality had the lowest incidental cost with the AESTHETICS scenario (8% against 12% and 15% for the SOCIAL-ECOLOGICAL and ECOLOGICAL scenarios, respectively). The combined benefits scenarios also required fewer planning units than other scenarios to achieve conservation objectives. Considering a scenario for no-take reserves would imply creating a combined benefit layer for benefits with an extractive component only: FISHING, LIME, and TRADITIONAL MEDICINE, and measuring incidental costs to these benefits.

Discussion

Despite long-standing calls from both the social and conservation sciences to more fully incorporate social, cultural and economic dimensions into systematic conservation planning, practical examples remain scarce, particularly those that consider the full breadth of benefits people derive from a given landscape or seascape. This gap is especially pronounced in Oceania, where strong cultural, livelihood, and identity-based connections to marine ecosystems mean that management actions can have far-reaching social implications. At the time

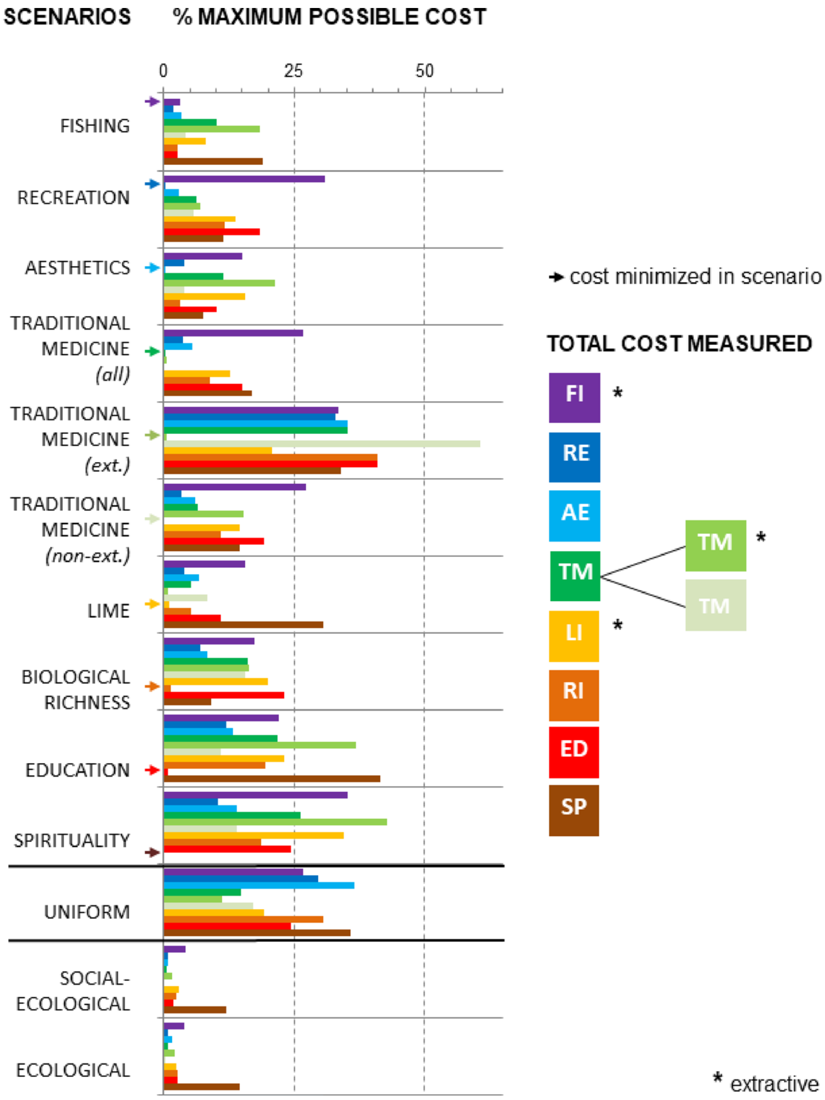

Fig. 4. Incidental costs to Riwo people's access to benefits under all planning scenarios. Each scenario produces a portfolio of theoretical marine reserves that represent 20% of every marine habitat type while minimizing (or not) loss of access to particular benefits. Scenarios are listed on the y-axis. For each, a different benefit or combination of benefits is used as the 'cost' to minimize. Scenarios minimizing costs to individual benefits are capitalized, labelled with the full benefit name, and arrows identify the corresponding bar. For example, the FISHING scenario selects reserves that best prevent loss of access to FISHING benefits. (ext.) and (non-ext.) denote extractive and non-extractive components of traditional medicine; (all) refers to both combined. The UNIFORM scenario uses a cost layer in which all places have a value of 100, simulating a situation where no cost is explicitly considered. The SOCIAL-ECOLOGICAL and ECOLOGICAL scenarios both minimise combined benefit costs, but differ in how such costs are treated (constraint vs. objective). Incidental cost (x-axis) is expressed as the percentage of the maximum possible cost for each benefit (i.e. the total cost when all places are selected as reserves). Each measured cost to a benefit is shown in a different colour; asterisks next indicate benefits with a strong extractive component. When cost is minimised for a single benefit, that benefit has the lowest incidental cost (arrows), but incidental costs to other benefits vary highly. Data for this figure are in Supplementary Table S8.

this study was conducted, only a few Australian examples[58,59] were available to guide the integration of socio-spatial data into marine spatial planning (MSP), a framework which sometimes uses systematic reserve design tools. More than a decade later, such applications remain limited, especially on the use of community-based participatory mapping methods (but see[60,61] for recent advances in incorporating social and cultural values in MSP). In a recent review on integrating social factors into spatially-explicit marine conservation planning[62], most costs used in the 89 studies were related to recreational/commercial fisheries and other tangible uses such as tourism, shipping and transportation. In this study, we (1) developed a method to map and quantify multiple ways in which people value their reef and lagoon environments, and (2) demonstrate how these locally derived value layers can be incorporated directly into conservation-planning scenarios. Together, these advances show

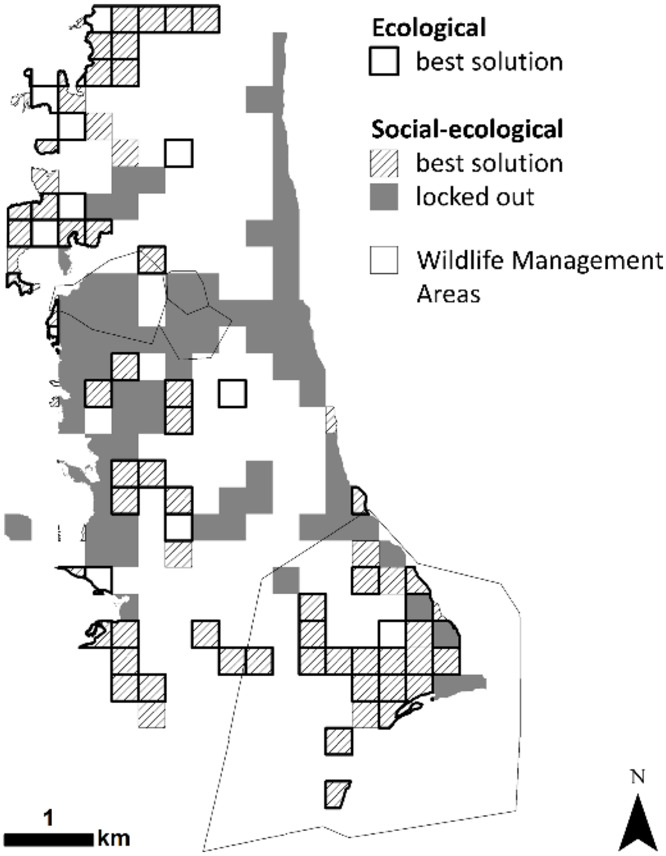

Fig. 5. Best reserve designs under the ECOLOGICAL and the SOCIAL-ECOLOGICAL approaches. Both approaches aimed to represent 20% of each habitat type, while reducing social, economic, and cultural costs to the Riwo community, but they differ in how these costs are treated. The ECOLOGICAL approach minimizes the total cost of the hypothetical reserve system to all benefits combined, treating socioeconomic considerations as a constraint. The SOCIAL-ECOLOGICAL approach treats socioeconomic costs as an objective: places with high aggregated benefits (above the third quartile), are locked out (grey areas), and reserves are selected only from locations of relatively low benefit. Actual Wildlife Management Areas are shown with thin black outlines. The two approaches produce different planning solutions, reflecting the different ways that socioeconomic costs can be incorporated into reserve design. Base maps and spatial layers were compiled and visualised using ArcGIS Desktop version 10.0 (ESRI, Redlands, CA, USA; https://www.esri.com), and final map layouts was produced by the authors.

how recognising places that are important for a diversity of benefits can substantially reduce the potential social impacts of proposed reserves.

We found that many places in the Madang Lagoon hold value for the Riwo community across multiple types of benefits. Designing reserves with consideration only of fishing impacts, as is commonly done, risks shifting protection to areas whose closure would inadvertently restrict access to other important extractive and non-extractive benefits (depending on the type of closure), thereby likely increasing social costs (question 1). We also showed that planning separately for individual benefits can lead to unnecessarily high incidental costs to other benefits (question 2). By contrast, incorporating the full suite of benefits simultaneously provided the most efficient strategy for designing reserve systems that minimise the total loss of opportunities to access valued places (question 3).

Key caveats and solutions to improve the approach

Working in Riwo was an important first step toward integrating ecosystem services and culturally grounded values into local-scale systematic conservation planning. As such, several aspects of the approach could be improved, both practically and conceptually, in future applications.

First, marine social-ecological systems are inherently dynamic, including in the period following reserve implementation. Different conservation actions may influence each benefit in positive or negative ways[63,64], whether through no-take or no-go reserves, activity-specific restrictions (e.g., gear limits, species or size limits), or non-regulatory measures such as education and communication programs. Over time, new reserves and surrounding areas may themselves become valued for attributes such as enhanced biodiversity, improved aesthetics of restored habitats, strengthened spiritual significance (see[65] for a terrestrial example) or new recreational opportunities[65]. A community may also wish to incorporate important areas such as culturally significant features as part of the reserve rather than being avoided as done in this study[66]. Anticipating these dynamics, either a priori or through an adaptive, iterative planning process, could help incorporate projected spatial shifts in perceived benefits into future scenarios.

Second, our classification of benefits relied on a typology defined prior to the surveys, but future applications could refine this classification, or develop it collaboratively with the community, to ensure that all locally relevant values are adequately described and incorporated[67] provide a practical example from a fjord in British Columbia, USA, in a MSP context). Using our a priori typology resulted in some overlaps among benefits. For example, biological richness and fishing were often conflated as people tended to value fishing areas for their abundant biodiversity. Similarly, benefits associated with shipwrecks were entangled with fishing, recreation and tourism, because people visited wrecks primarily for these uses and not for other benefits. Places valued for spiritual purposes were frequently linked to traditional medicine and learning. Simply merging overlapping benefits is not a satisfactory solution, however, because overlaps were not uniform across the lagoon (some were highly location-specific) so spatial patterns of individual benefits could be obscured if aggregated indiscriminately.

Third, we treated the Riwo community as a single, homogeneous stakeholder group, but in reality it is organized into clans, each holding specific customary tenure rights over land and sea, as is common throughout Melanesia. Spatial planning could affect these rights differentially, with some clans experiencing greater restrictions than others, potentially generating tensions within the community[20,68,69]. Stratifying surveys and responses by clan would allow planners to assess the importance of areas to each group separately and, for each scenario, quantify inter-clan incidental costs. An additional optimization constraint could then be introduced to minimize disparities in these costs across clans. Beyond clans, other stratification criteria may be relevant depending on the social structure and heterogeneity of the community, including age, gender, or religious affiliation, which could provide further insights into how conservation actions differentially affect stakeholders.

Relevance to broader conservation planning practice

We acknowledge that systematic conservation planning, like other formal conservation approaches, has a colonial history: it has often prioritized Western scientific knowledge and external decision-makers over Indigenous and local perspectives. ‘Planners’ in this context may include academic researchers, NGOs, government agencies, or community committees, each with different levels of authority and influence. While many SCP applications remain Western-driven, there is growing potential for genuinely community-led planning, in which local groups or committees define priorities, identify valued places, and guide trade-offs, while technical experts provide support in mapping, scenario analysis, and visualization. Recognizing this legacy and these possibilities is essential for designing processes that avoid tokenistic participation, meaningfully incorporate local knowledge and values, and foster co-ownership of conservation outcomes. In this context, we also acknowledge that this case study could be strengthened in various ways. Although our study focused on the Riwo community on the coast of the Madang Lagoon, Papua New Guinea, in 2012, the approach remains relevant and timely for systematic conservation planning theory and practice. Below, we highlight several key insights from this exercise that may be applicable in other contexts.

We showed that reducing the social impacts of conservation actions should not focus solely on fishing, because avoiding closures in areas valued for fishing can inadvertently restrict access to other benefits important to communities. We expect similar outcomes in most socio-ecological systems, particularly rural and coastal areas, where both subsistence and commercial fishing play a role and may bias planning approaches if considered in isolation. More broadly, our findings suggest that planners should not concentrate solely on minimizing opportunity costs for the most visible or economically engaged stakeholders in the hope of facilitating implementation and compliance (e.g.[18,19,65,69]. As in Riwo, such stakeholders are not necessarily representative of the values and interests of the entire community, and overlooking broader preferences can produce planning scenarios with substantial incidental costs, potentially leading to inequity and frustration for local people in any context.

We acknowledge that diversifying the range of stakeholders and integrating multiple benefits across a community before running systematic conservation planning scenarios can be more complex than focusing on a single aspect of the socio-ecosystem, such as fisheries. For Riwo, the time spent with the community (one month, by a single investigator) was short but longer than the average duration of previous surveyors in the region according to community members. It was comparable, for example, to efforts in French Polynesia to quantitatively characterize and map fishers’ habits, catch types, and strategies to avoid ciguatera poisoning (three investigators in the field for one week)[70,71], although those studies did not map other types of benefits as in Riwo. All investigations were carefully prepared in advance; while some improvisation and adaptability were necessary, objectives and survey questions were clearly defined, as the work required cards, maps, tokens, and questionnaires. The surveys themselves were intensive, but importantly, they did not seek to understand *why* different places were valued for different benefits. Fish abundance and distribution can explain why fishers frequent certain areas, but it is not the only factor. The assignment of a given benefit to a place is often multifactorial and complex. Investigating these reasons requires slower, anthropological methods, which were beyond the scope of our primary SCP objectives. Nevertheless, reserve design, as demonstrated here, is only one step in the broader and complex conservation planning process[3]. Complementary anthropological work on why people value particular areas would provide additional insight for other stages of planning, for example to anticipate which options may be supported or criticized by stakeholders.

While the role of stakeholder involvement in mitigating inequalities and improving social and ecological outcomes of protected areas is still unclear[72], support for conservation is strengthened when stakeholders’ preferences and perceptions are explicitly considered[73]. While the Riwo case study did not proceed to the implementation of reserves identified in our scenarios, which would require following all steps of the Pressey and Botrill methodology[3], our approach highlights several lessons for planners in other contexts. This is particularly relevant in regions such as Madang with evident research fatigue. First, careful attention to engagement methods helps ensure approaches are well received. In this study, interviews were structured as interactive "games" and used participatory GIS, which facilitated household-level engagement. Second, quantifying benefits and incorporating them transparently into planning scenarios allows for clearer communication of trade-offs. Third, although we could not complete this step, returning to communities to review spatial analyses and scenario outcomes is important to capture feedback on acceptable trade-offs and incidental costs. Our own ability to engage with Riwo residents was limited at the time of the study but was facilitated by the history of collaborations with environment and development NGOs. Engagement approaches will vary with context but need to be integrated into the design and budgeting of conservation planning programs to avoid perceptions of tokenism[74], or not be limited to only one survey[68]. When stakeholders' views are adequately incorporated, a sense of co-ownership is fostered, reducing the likelihood of perceived value alteration. Finally, while no-go or no-take reserves designed using systematic conservation planning frameworks may not always be the most suitable approach, the structured mapping of habitats (or other ecological entities to be managed), resource uses, and places valued for the benefits people can access can prompt and stimulate discussions among scientists, managers, and communities on local ecosystems.

Conclusion

Ultimately, our study illustrates that systematically incorporating the full range of community-valued benefits into conservation planning, not just the most visible or economically productive uses, could help reduce social costs, foster equitable outcomes, and support meaningful local engagement, providing a pathway for more inclusive and context-sensitive systematic conservation planning.

Data availability

Most of relevant data are within the manuscript and its Supporting Information files. Protected area data is available from the World Data Base on Protected Areas (WDPA, www.protectedplanet.net). Spatial habitat data are available from https://doi.org/10.25903/v7pp-7e51. Spatial socioeconomic data cannot be shared publicly because it contains sensitive and confidential information. De-identified data can be available upon request from the main author.

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Author contributions

M.H. wrote the main manuscript text. S.A., B.P. and C.H. supervised the work and contributed to the manuscript. All authors reviewed the manuscript.

Declarations

Competing interests

The authors declare no competing interests.

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